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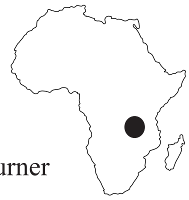
Excavations at Site C North, Kalambo Falls, Zambia: New Insights into the Mode 2/3 Transition in South-Central Africa



Lawrence Barham, Stephen Tooth, Geoff A.T. Duller, Andrew J. Plater & Simon Turner

Abstract

We report on the results of small-scale excavations at the archaeological site of Kalambo Falls, northern Zambia. The site has long been known for its stratified succession of Stone Age horizons, in particular those representing the late Acheulean (Mode 2) and early Middle Stone Age (Mode 3). Previous efforts to date these horizons have provided, at best, minimum radiometric ages. The absence of a firm chronology for the site has limited its potential contribution to our understanding of the process of technological change in the Middle Pleistocene of south-central Africa. The aim of the excavations was to collect samples for luminescence dating that bracketed archaeological horizons, and to establish the sedimentary and palaeoenvironmental contexts of the deposits. Four sedimentary packages were identified with the oldest containing Mode 2 and Mode 3 horizons. In this paper we consider the implications of the luminescence ages for the archaeological record at Kalambo Falls, and place them in a regional context. The reworking and preservation of the archaeological horizons is interpreted as the result of successive phases of meander migration and aggradation. Limited pollen evidence suggests a persistent floodplain palaeoenvironment with intermittent swamp forest and adjacent valley woodland, while mineral magnetic susceptibility data support an interpretation of river flow variability without any significant change in sediment provenance. The dynamics of the fluvial system cannot as yet be linked directly with regional climate change. The age range of ~500–300 ka for the oldest sedimentary package places the Mode 2/3 succession firmly in the Middle Pleistocene, and contributes to an expanding African record of technological innovation before the evolution of Homo sapiens.

Résumé

Nous présentons ici les résultats de fouilles réduites du site de Kalambo Falls, en Zambie du nord. Le site est connu depuis longtemps pour sa stratigraphie paléolithique, surtout pour ses niveaux attribués à l'Acheuléen supérieur (Mode 2) et au Paléolithique moyen (Mode 3). Les démarches entreprises précédemment pour dater ces niveaux n'ont livré que des âges radiométriques minimums. L'absence d'une bonne chronologie a limité la contribution de ce site à notre compréhension des processus de changement technologique au cours du Pléistocène moyen en Afrique australe. L'objectif des dernières fouilles était de collecter des échantillons pour la datation par luminescence qui encadrent les horizons archéologiques et pour établir les contextes sédimentaire et paléo-environnemental des dépôts. Nous avons identifié quatre ensembles sédimentaires, le plus ancien contenant des niveaux du Mode 2 et du Mode 3. Cet article considère les implications des datations obtenues par luminescence pour le gisement de Kalambo Falls et son contexte régional. Les pédoturbations et la préservation des horizons archéologiques sont interprétées comme le résultat de phases successives de migration de méandres et d'alluvionnement. Les données palynologiques limitées suggèrent que le paléo-environnement était composé d'une plaine d'inondation persistante avec des forêts marécageuses intermittentes et des forêts en vallée contigües, tandis que les données de susceptibilité magnétique viennent appuyer l'hypothèse d'un débit fluvial variable, sans modification significative dans la provenance des sédiments. La dynamique du système fluvial ne peut pas encore être directement mis en rapport avec le changement climatique régional. L'âge des ensembles sédimentaires, entre 500 et 300 ka, place clairement la succession Mode 2/3 dans le Pléistocène moyen. Cette étude renforce le corpus des données archéologiques africaines qui montre des innovations technologiques avant l'émergence de Homo sapiens.

Keywords: South-central Africa, Acheulean, Middle Stone Age, luminescence dating, sedimentology, palaeoenvironment

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Introduction

After its discovery in 1953, the archaeological site of Kalambo Falls, northern Zambia, became the focus of extensive excavations between 1956 and 1966. The archaeological deposits were preserved in the small (4 km x 1.5 km) Kalambo basin (Haldemann 1969), located a few hundred metres upstream of the main waterfall (***Fig. 1a***). The resulting culture-stratigraphic succession extended from the late Holocene (Iron Age) to beyond the range of radiocarbon dating, perhaps as far back as the Middle Pleistocene (Haldemann 1969: 45; Clark 2001: 28). Of particular interest both then and now were the earliest Middle Stone Age (Mode 3) occurrences (Sangoan, Lupemban) which unconformably overlie Upper and Final Acheulean (Mode 2) horizons. Previous large-scale excavations at Kalambo Falls have provided numerically large lithic collections for characterising the process of technological change, but the succession essentially remains poorly constrained chronologically. As a result, the site does not feature in current discussions about behavioural change in Middle Pleistocene Africa (*e.g*., McBrearty & Tryon 2006; Porat *et al.* 2010).

The shift from Mode 2 to Mode 3 tools has been recognised as a significant technological and cognitive development in hominin evolution (Clark 1989; Wynn 2009; Barham 2010, 2013; Ambrose 2010). Recent developments in the dating of the Mode 2/3 transition in southern Africa place it as early as ~500–400 ka (Porat *et al*. 2010; Wilkins *et al*. 2012). In south-central Africa, it may date to at least 265 ka but the evidence is based on a single U-series date from the collapsed cave site of Twin Rivers with a complex stratigraphic record (Barham 2000, 2012; *cf.* Herries 2011).

In view of this poor regional chronological framework for the Mode 2/3 transition, test excavations were carried out at Kalambo Falls in August 2006. A six-day long re-investigation of the site was undertaken with the objective of locating stratified deposits containing Mode 2 artefacts overlain by Mode 3 artefacts in contexts that could potentially be dated. Samples were collected for luminescence dating and for sedimentological, artefact and palaeoenvironmental analyses, and a supporting survey was undertaken of the wider area to provide the broader geomorphological context for the reconstruction and interpretation of the depositional history of the archaeological succession. Luminescence dating methods and analyses are presented in detail elsewhere (Duller *et al*. 2015). This paper integrates the luminescence ages with the sedimentological, artefact and palaeoenvironmental analyses and assesses the implications for our understanding of the archaeological record at Kalambo Falls. An overview of the regional setting and previous investigations in the basin precedes the description and analysis of the 2006 excavations and survey data. The sedimentology and luminescence ages for each excavation unit are

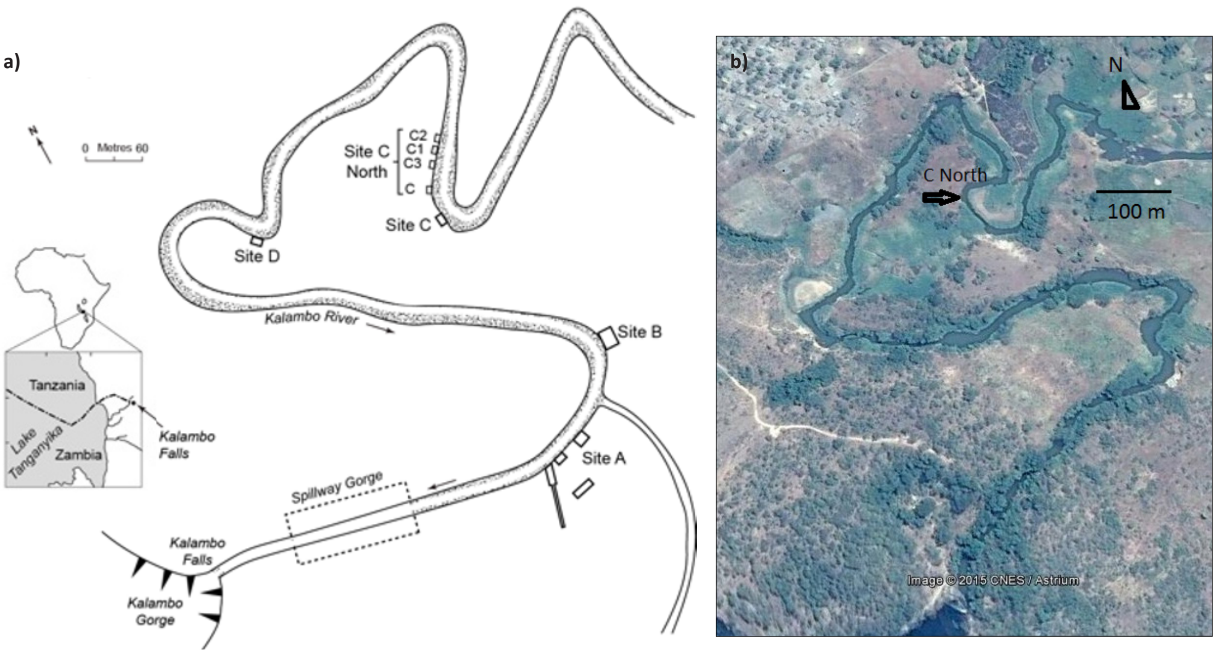

Figure 1. a) Location map of the archaeological site of Kalambo Falls based on J.D. Clark (1969: fig. 2) showing the meanders of the Kalambo River in the Kalambo basin, the spillway gorge, the location of previous excavation areas and the location of Site C North; b) Google Earth (July 2013) image showing how the course of the Kalambo River has changed since 1969 and the location of Site C North. Note the erosion and expansion of the meander in the area of Site C North.

described, the archaeological content summarised, and associated palaeoenvironmental data (pollen and magnetic susceptibility analyses) outlined. The combined dataset is used to interpret the formation of the sedimentary packages and to reassess existing models that link punctuated sedimentation in the basin to climatically- or tectonically-induced blockage events (*e.g.*, Kleindienst 1969). In the oldest sedimentary package, the small archaeological sample provides evidence of what appears to be a Mode 2/3 shift and we discuss the wider regional significance of the new luminescence ages for these sediments. Throughout the paper we equate Mode 2 with the Acheulean and Mode 3 with the Middle Stone Age. The fit between Modes and industrial developmental stages is imperfect, but given the small sample of artefacts recovered in parts of the 2006 excavations we cannot be confident in making attributions to specific industries or to stages.

Regional setting and sedimentary record

The Kalambo River arises in the Ufipa Highlands in south-central Tanzania (Clark 2001: 3) and flows in a general southerly and then westerly direction towards the southern end of Lake Tanganyika, the largest lake in the western arm of the East African Rift systems (***Fig. 1a***). The discharge regime is strongly seasonal with higher flows and overbank flooding occurring mostly during the wet season (late October through early April) (Clark 1969: 4). In its lowermost third, the river forms the border between Tanzania and Zambia, and is characterised by a straight to moderately sinuous channel that is confined mostly by bedrock or colluvial sediments. The archaeological site of Kalambo Falls is located centrally in the Kalambo basin where there is a marked increase in channel sinuosity within a locally widened section of the valley (***Fig. 1a***). The local bedrock geology comprises sedimentary, metasedimentary and igneous lithologies (*e.g.*, sandstones, quartzite, siliceous mudstone, and dolerite), but outcrop is limited, with alluvial deposits being widespread in the basin centre and along several small tributary valleys, and extensive colluvium mantling the gently to moderately sloping basin margins (typically <0.02 m/m). The modern channel is incised ~10–20 m below higher elevation abandoned alluvial surfaces (terraces) and steep faces of eroded colluvium but is flanked by a narrow, discontinuous floodplain (***Fig. 1b***).

Although there are suggestions that the Kalambo River originally may have followed a course to the northwest along a now infilled valley (Bond 1969; Schick 2001), the river today exits the basin in the southwest through a narrow valley cut into a quartzite ridge (***Fig. 1a, b***). Within this narrow valley, known informally as the 'spillway gorge' (Haldemann 1969: 38), floodplain development is limited and the river follows a straighter course for ~200 m before plunging abruptly ~220–235 m in a single drop over a nearly vertical cliff of quartzite. Below the falls, the river flows for ~10 km in a narrow, steep-sided valley that broadens downstream towards Lake Tanganyika (***Fig. 1a***).

Previous descriptions of the basin's sedimentary geology focussed on the alluvial and colluvial sediments that contain the stratified but discontinuous archaeological successions (Bond 1969; Haldemann 1969; Clark 2001). Extensive excavations were undertaken between 1956 and 1966 in four sites located at the western end of the basin and upstream from the spillway gorge (Sites A–D; ***Fig. 1***). Near the spillway, excavations reached a depth of 2.7 m below river level, but intact bedrock outcrop was not encountered and the total thickness of the basin fill remains unknown (Clark 2001: 4). Site A provided the type section for the Kalambo Formation with its succession of three members (Mkamba, Mbwilo and Chiungu) that have been described in detail by Kleindienst (1969: 46–56) and summarised by Clark (2001).

Based on this work, the Kalambo Formation as a whole can be characterised as a largely fluvial record of successive aggradational fining-up packages that are separated by unconformities. Around the basin margins, colluvial sediments locally interfinger with the fluvial sediments. The unconformities typically contain 'rubble lines' (aggregates of clasts), some of which represent lag deposits with concentrations of artefacts. We refer to these and all other sedimentary deposits in Site C North containing artefacts as 'horizons' to avoid descriptive labels from the outset. Each horizon is described by excavation unit and given a level number.

In the oldest sediments investigated previously (lower Mkamba Member), 'Rubble II' and other aggregates once interpreted as Acheulean 'living floors' (Clark 1974: 73) have since been shown to be in secondary, fluvially disturbed contexts (Sheppard & Kleindienst 1996; Schick 2001). Just as claims for intact living floors cannot be supported, neither can the associations of stone tools with modified wooden objects nor with charred nuts and wood be assumed to be intentional or evidence of activity areas (Clark 2001: 24). Small debitage (<30 mm) indicative of intact primary knapping areas has been preferentially removed by fluvial winnowing in the Mkamba Member aggregates (Sheppard & Kleindienst 1996; Schick 2001), leaving artefact horizons dominated by larger flakes and cores. In the Ochreous Sands Bed of the upper Mkamba Member at Sites A and B, the sands contain separate Mode 3 horizons in secondary contexts, namely Sangoan ('Chipeta Industry') overlain unconformably by 'earlier' Lupemban ('Nakisasa Industry') (Clark & Kleindienst 1974: 75–76). The attribution of the Sangoan to Mode 3 remains uncertain (see Gowlett *et al.* 2001), however, and this issue is discussed in more detail below. Also reconsidered is Clark's (2001) separation of the Lupemban into two phases. Previous efforts to date waterlogged wood from archaeological horizons in the Mkamba Member have produced inconsistent ages for the Acheulean and what is probably a minimum age for the Sangoan (Clark 2001: 662) [>110 ka by amino-acid racemisation (Lee *et al.* 1976) and 182 ± 10 ka based on U-series on wood from the Acheulean, and ~76 ± 10 ka by U-series on wood from the Sangoan (McKinney 2001: 665–667)].

At the base of the overlying Mbwilo Member, Mode 3 'later' Lupemban material ('Siszya Industry') occurs in a widespread aggregate labelled 'Rubble I', which is found as a marker horizon with sub-divisions (Clark & Kleindienst 1974: 76). At Sites A and B, the Lupemban aggregates lie unconformably over the eroded surface of the Ochreous Sands Bed of the upper Mkamba Member. The Rubble I aggregates are considered to be general stratigraphic equivalents, but are too discontinuous and dissected by channel cut and fill events to enable direct correlations to be drawn between archaeological horizons at different sites (Clark 2001: 24). These aggregates remain essentially undated. Other archaeological horizons occur in the upper Mbwilo Member including another Mode 3 industry ('Polungu') and a Mode 5 (Later Stone Age) industry (Clark 1974).

The Chiungu Member lies unconformably on the Mbwilo Member and is often found as a channel fill containing Iron Age ceramics. Radiocarbon ages associated with the fill indicate that this member formed in the late Holocene [1400 ± 150 BP, L-395C, 10 feet (3 m) below surface; 370 ± 50 BP, GrN-3189, 2–3 feet (<1 m) below surface (Clark 1969: appendix J)].

Despite the evident secondary, discontinuous nature of the archaeological horizons, the Kalambo basin deposits preserve an archaeological record with a coherent stratigraphic order. The August 2006 pilot study had as its underlying aim the development of a reliable chronology for the Kalambo Formation, combined with an improved understanding of the depositional processes that generated and preserved the archaeological and palaeoenvironmental records. Geomorphological surveys of the basin were combined with small-scale excavations targeted at archaeological exposures in fluvial sediments with quartz sand-rich horizons (*e.g.*, upper Mkamba and basal Mbwilo Members). The sands bracketing archaeological horizons could potentially be dated by luminescence techniques, namely optically stimulated luminescence (OSL, Duller 2004) and thermally transferred optically stimulated luminescence (TT-OSL, Duller & Wintle 2012).

Materials and methods

Re-examining the Site C area

Sites A, B and D of Clark's original excavations were relocated and examined, but the trenches were too degraded or overgrown to be workable in the limited time available. Instead, the broad area of Site C, located the farthest upstream (***Fig. 1a***), was selected for further investigations. Previous excavations at Site C in 1959, 1963, 1966 (Clark & Cole 1969: 181–186), and 1988 (Clark 2001: 20) had demonstrated the presence of Mbwilo Member sands containing early Mode 3 artefacts. In 1959, Keller reported a rubble line near the base of the 9 m tall cliff, which was 10–13 cm thick, dipping gradually northward and lying unconformably over the Ochreous Sands Bed of the Mkamba Member (Clark 1969: 181). This aggregate, later identified as Rubble I, contained 350 artefacts, including discoidal, prepared and blade cores, flakes with facetted and plain butts, and blades attributed to the later Lupemban. Among the 18 retouched pieces, morphologically-distinctive core-axes were found and considered to be early Lupemban or Sangoan. On the basis of the core-axes and limited evidence for the use of prepared cores, Clark (1969: 181) concluded that this horizon was attributable to the earlier Lupemban or Sangoan. A section of Site C, drawn by Haldemann in 1959 (Clark 1969: fig. 11), places this rubble layer at a height of 2.4 m above modern river level. Subsequent excavations along the bank face identified a more complex succession of rubble lines in the Mbwilo sands containing larger unabraded artefacts of Sangoan and Lupemban affinity in the lower lines and smaller Lupemban and later MSA artefacts (Polungu Industry: Clark 1974) in the upper lines (Clark 1969: 184–185). A brief re-investigation of Site C in 1988, described by Clark, exposed two rubble lines attributed to the later Lupemban and at the very northern edge of the bank face a "compact rubble layer 10–12 cm thick, in a grey gritty matrix" essentially containing MSA artefacts comparable to those from Rubble I, Site D (Clark 2001: 120). The small number of artefacts recovered from this layer along with those from the other Site C excavations has not been described in detail.

Adding to the potential importance of Site C for our study was the recovery in 1988 of Mode 2 tools (a handaxe and a cleaver) in fresh condition at water level lying on the surface of a black clay bed that passes beneath the Ochreous Sand Bed and below river level (Clark 2001: 20, 118). This observation, combined with the previous investigations at Site C, provided the stratigraphic framework that guided the 2006 sampling of the upper part of the Mkamba Member and basal Mbwilo Member with their known Mode 2 and

Figure 2. Overview of the central part of the Kalambo basin showing the location of excavation Units C, C1, C2 and C3 at Site C North. Unit C3 is located between Unit C and Unit C1 and samples a palaeochannel and underlying (Mkamba) sediments.

Mode 3 succession. The quartz-rich sands bracketing the horizons also offered the prospect of developing a luminescence chronology for this portion of the Kalambo Formation.

Field and laboratory methods

The original Site C trenches could not be located and are presumed lost to erosion. A comparison of ***Figure 1a*** with ***Figure 1b*** shows the extent of changes in the course of the river since the 1960s. The general area of Site C could, however, be identified by a ~9 m high cliff of pale-coloured, predominantly sandy sediments exposed in a sharp river bend. Some 20.5 m downstream (north) from this bend, erosion had provided a more accessible exposure of Mbwilo Member sands. The exposure included a 10–13 cm thick layer of concentrated flakes, blades, cores, and picks set in a coarse sandy matrix that formed a shelf ~2.29–2.42 m above modern river level. Although the height of the exposures along this cliff section is lower than at Site C, reaching only up to ~5–7 m above river level, we focussed our investigation on these opportune exposures of fluvial sediments before they could erode further and because of the limited time available for this pilot study.

Along a ~60 m stretch of the river cliff, termed Site C North (S8º35'31.01"; E31º14'33.37"), four step trench units were excavated and labelled C, C3, C1, and C2 (in spatial order) (***Fig. 2***). Excavations were undertaken down to, and in some cases, slightly below river water level, but bedrock was not encountered. Three trenches were 3 m x 1 m rectangles, C2 was narrower (2 m x 1 m). The uppermost artefact horizon in Unit C (Level 3, below) was initially sub-divided into three 100 cm x 50 cm sub-units, with artefacts larger than 2 cm piece plotted and the dip and orientation recorded of clasts with an A-axis of >10 cm. This informative but time-consuming procedure was abandoned because of time constraints. The six days available for the project meant this level of detailed recording could not be sustained and the excavations proceeded without piece plotting.

The archaeological analyses are based on techno-typological approaches previously applied to the Kalambo Stone Age sequence (Clark & Kleindienst 1974: 71–106) and to assemblages elsewhere in Zambia (Barham 2001: appendix 3). A further modification was made, in light of time and logistical constraints (the analysis was undertaken in the field), with a batch analysis (by size-range, raw material, butt preparation) applied to flakes, blades, broken flakes, and blades in

Class	Level 3 N (%)	Level 2 N (%)	Level 1 N (%)
Manuports	4 (0.6)	0	0
Cores	49 (7.8)	22 (16.9)	8 (12.1)
Whole flakes	312 (49.4)	77 (59.2)	35 (53.0)
Broken flakes	128 (20.3)	9 (6.9)	12 (18.2)
Whole blades	35 (5.5)	0	0
Broken blades	12 (1.9)	0	0
Chunks/shatter	60 (9.5)	6 (4.6)	5 (7.6)
Retouched/ utilised	31 (4.9)	16 (12.3)	6 (9.1)
Total	**631**	**130**	**66**
<20 mm	*52 (8.2)*	*0*	*0*

Table 1. Unit C artefact summaries by level.

Unit C. The very low artefact numbers in Units C1 and C2 made it necessary to combine data from excavation levels within each unit to identify technological trends at the Mode level. The mud layer in these units served as the stratigraphic divide for grouping data above and below. The artefact content from Unit C3 is also described below.

Given the general rarity of retouched tools in Site C North (***Table 1***), Mode attribution relied in part on the typology of core forms, with prepared cores considered indicative of Mode 3 status (J.G.D. Clark 1969). The frequency of faceting on flake butts was recorded as a proxy for core preparation. Faceting, however, can occur unintentionally during core reduction, particularly among centripetal approaches to flake removal (*e.g.*, discoidal cores) (van Peer 1992), and the process of core platform rejuvenation can mimic intentional faceting. The simplified analysis conducted in the field did not distinguish between blank types. A basic distinction was made between multiple and minimally faceted butts and the frequency of faceted flakes as an indicator of intentional use of prepared cores to produce specialised flakes. Prepared cores do not occur in the Kalambo Falls Acheulean and appear in low frequencies in the Sangoan and early Lupemban (Sheppard & Kleindienst 1996: fig. 6). Radial and prismatic cores (flake and blade) also feature in Mode 3 assemblages in the region (Barham 2000); at Kalambo Falls they are more common in Mode 3 (Sangoan, early Lupemban) than in Mode 2 horizons (Sheppard & Kleindienst 1996). Their presence is noted here as a supporting indicator of Mode 3 status. Prepared and blade cores (after Inizan *et al.* 1999) (Mode 4) co-occur in the region (Barham 2000). The Mode concept as used here allows for the co-existence of multiple modes within an archaeological horizon (*e.g.*, Shea 2011).

A Mode 2 attribution was made on the presence of large cutting tools (LCTs) (McNabb *et al.* 2004), in particular handaxes and cleavers, and the absence or rarity of markers of Mode 3 and Mode 4 technologies. Industry labels were avoided because of the small sample sizes and the rarity of diagnostic retouched forms in all the archaeological horizons as detailed below.

The raw materials used in Site C North are the same as those reported elsewhere at Kalambo Falls, including soft (feldspathic) and hard (non-feldspathic) quartzite along with siliceous mudstone (Clark & Kleindienst 1974). The quartzites are available today on the margins of the basin and as large cobbles and boulders approximately 250 m upstream of Site C North (see Haldemann 1969: fig. 1.2). Mudstone deposits also occur on the basin margins; knapping experiments in the field have shown that the blocky (angular) form of this material simplifies the production of blades by providing a natural ridge for initiating laminar removals (Taylor, *pers. comm.*). Sheppard & Kleindienst (1996: 180–181) observed subtle shifts in raw material preference through the succession and noted a gradual increase in the use of mudstone and decrease in use of feldspathic quartzite. Raw material percentage frequencies are presented here only for whole flakes because of the small sample sizes for retouched artefacts and cores. Attempts were made at refitting flakes to cores but were unsuccessful, as can be expected of artefacts in secondary contexts. Small debitage (<30 mm) was uncommon, and its occurrence is noted on each summary table as an indicator of possible variation in fluvial winnowing (Sheppard & Kleindienst 1996; Schick 2001). Qualitative observations were made on the extent of weathering (surface alteration) based on criteria previously applied at Kalambo Falls (Clark 1974: 103). Relative elevations were calculated from a survey benchmark located at an old river gauging station near the spillway gorge. Field descriptions of exposed sediments were undertaken using grain-size analysis cards and the textural terminology of Gale & Hoare (1992). All sediments were sieved using a 2.5 mm mesh to ensure recovery of small lithic debris.

A total of 18 samples for luminescence dating was collected from the four excavation units. Sampling locations were selected to bracket archaeological horizons and therefore to provide maximum and minimum age ranges. A portable gamma spectrometer was used to collect in-situ dosimetry data. The details of the sampling and dosimetry measurements are outlined elsewhere along with the justification for the selection of luminescence analytical approaches (Duller *et al* 2015). In brief, single grain optically stimulated luminescence (OSL) measurements on quartz were used for many of the younger samples, but the OSL signal was saturated in many older samples, so multiple grain measurements were undertaken using thermally-transferred OSL (TT-OSL).

Units C and C2 were chosen for pollen sampling because of their distinctive sedimentological profiles (below). A total of 24 sediment samples was recovered and prepared for analysis with the aim of identifying evidence of past vegetation dynamics that may be the result of climatic or anthropogenic changes in the surrounding area. The analysis did not include examination for non-pollen palynomorphs. *Lycopodium* tablets were first added to the samples to track any losses through the preparation procedure. Samples were digested in NaOH to remove organic matter and in HCl to ensure carbonate removal. A HF digest was then employed to remove the high proportions of mineral matter. Counting was undertaken at x400–x480 magnification. Each sample was counted until a minimum of 1000 *Lycopodium* grains had been obtained. A pollen dictionary was created based on previous work from the Kalambo Falls site (van Zinderen Bakker 1969; Taylor *et al.* 2001), reference work on the ecology of Zambian vegetation (Lawton 1978), and online pollen databases (including Gosling *et al.* 2013). This linked the taxa identified to those from broadly similar habitats in the region with varying combinations of forest, scrub, swamp, and woodland taxa.

To investigate any changes in sediment provenance, post-depositional diagenesis, and subtle variations in sediment composition or grain size not visible in the lithostratigraphy of the deposits, field measurements were also made of low frequency magnetic susceptibility, χ, using a Bartington MS2E sensor and MS2 susceptibility meter. In Units C1, C2 and C3, continuous measurements were made every 2 cm down-profile relative to established benchmarks or steps cut into the excavations. Repeat measurements were also made on some sections to investigate any spatial variability. Care was taken to avoid exposing the MS2 susceptibility meter to direct heating by sunlight during the measurements.

Results

Sedimentology and luminescence ages

This section outlines the sedimentological features and associated luminescence ages in each excavation unit. Kleindienst's description of the Kalambo Formation members (in Clark 1969) provides the basis for making preliminary correlations between the Site C North deposits and those deposits described from earlier excavations (Clark 2001). The 2006 results are presented in numerical order (Units C, C1, C2, and C3), but note that Unit C3 is located between Unit C and Unit C1 (see ***Fig. 2***). The associated archaeological data are summarised in terms of generic Mode attribution at this stage and described in detail in subsequent sections as are associated palaeoenvironmental data. ***Figures 3–6*** show the sedimentological context of each archaeological horizon (labelled by Mode) and its relationship with the luminescence ages.

Unit C (***Fig. 3***)

Unit C was the first to be excavated and was chosen for an apparent exposure of Rubble I, as reported upstream at the original Site C (Clark 1969). This horizon proved to be laterally discontinuous, disappearing over the distance of 29 m between Unit C and Unit C3 (***Fig. 2***), probably owing to erosion or bank slumping.

From the base of the excavation upwards, key sedimentological features include basal layers of interbedded fine-medium sand and sandy mud and a layer of slightly gravelly sand with mud patches. These basal sediments contain Mode 2 artefacts and are overlain by a 1.6 m thick layer of slightly gravelly sand and sand, the latter with a TT-OSL age of 386 ± 94 ka (KB17). These sediments are overlain by 1.3 m of slightly gravelly sand and sand, incorporating a diffuse Mode 3 horizon. An overlying sand layer has a TT-OSL age of 455 ± 103 ka (KB16). All these sediments are largely 'white' in colour, albeit with local iron/manganese-oxide staining, and are interpreted as upper Mkamba Member sediments. The sediments are truncated by a consolidated 10–20 cm thick layer of sand with local granules and pebbles that contains Mode 3 artefacts. This layer is interpreted as the base of the Mbwilo Member that rests unconformably on the Mkamba Member. Overlying sediments consist of gravelly sand and sand, the latter with OSL ages of 39.4 ± 2.0 ka (KB15) and 38.5 ± 1.7 ka (KB19: sampled just to the left of the excavated section and not illustrated in ***Fig. 3***), and are also attributed to the Mbwilo Member.

Unit C1 (***Fig. 4***)

Unit C1 was located 44 m downstream of Unit C and exposed the upstream end of a distinctive, roughly horizontal, cohesive mud layer 15–43 cm thick at approximately 0.91–1.16 m above modern river level.

From the base of the excavation upwards, key sedimentological features include basal layers of gravelly sand with mud patches, slightly gravelly sand, and sand. Mode 2 artefacts occur in the gravelly sands which have a TT-OSL age of 384 ± 72 ka (KB6), while the overlying sand has a TT-OSL age of 416 ± 91 ka (KB5). These basal sediments are attributed to the Mkamba Member, as is the overlying distinctive mud layer that also contains Mode 2 artefacts. Root casts and a distinctive near-circular depression (possibly a large animal footprint) on the surface of this mud layer suggest a period of subaerial exposure. Gravelly sand overlying the mud layer contains a diffuse horizon of

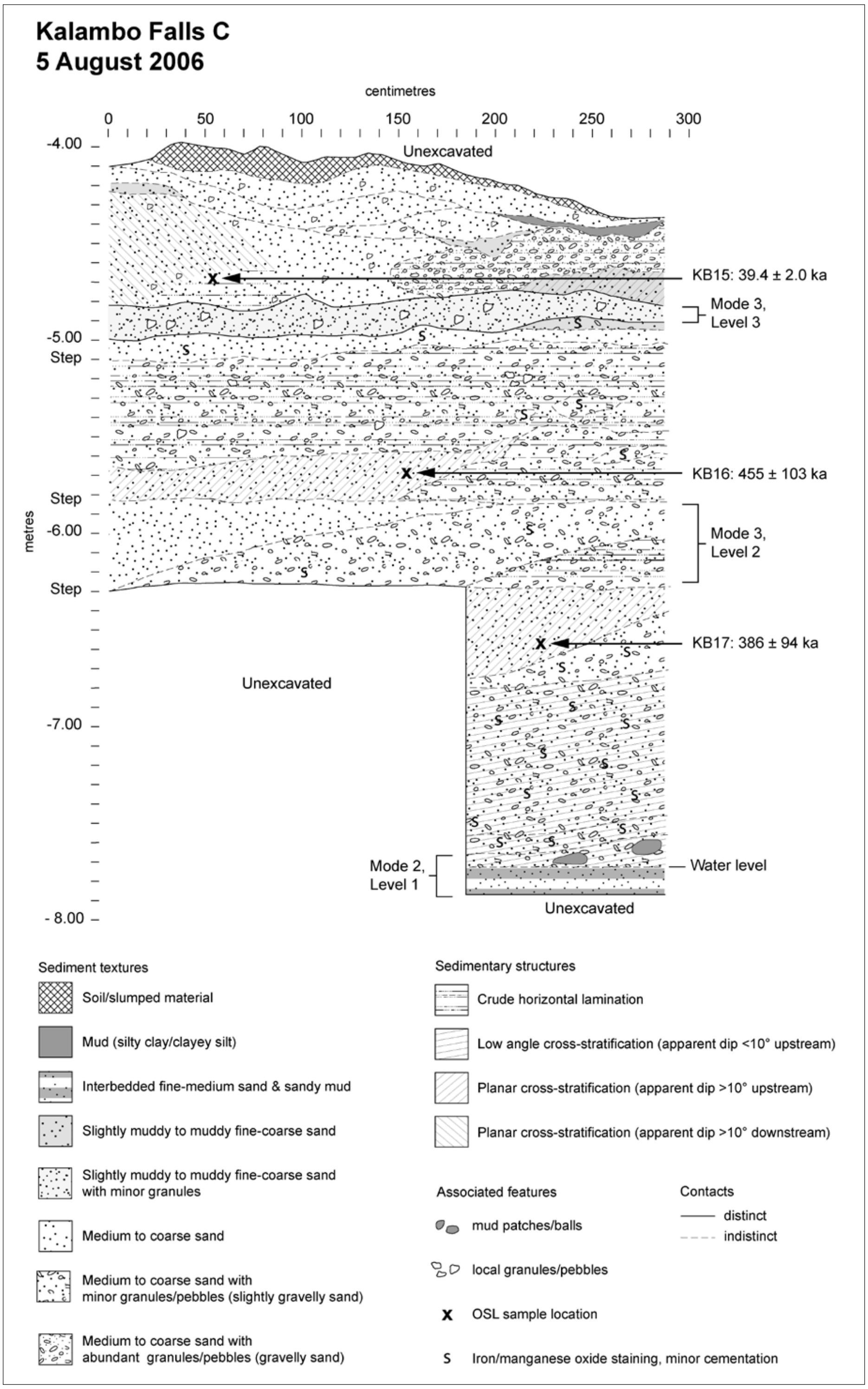

Figure 3. Unit C section showing artefact levels (horizons) 1, 2 and 3, key sedimentological features, and the location of luminescence samples.

Mode 3 artefacts and has a TT-OSL age of 159 ± 17 ka (KB4). This gravelly sand layer and an overlying layer of slightly muddy to muddy sand is separated by a distinct, inclined contact from a 0.7–1.7 m thick layer of fine-medium sand with local coarse sand layers. The fine-medium sand layer has an OSL age of 33.4 ± 1.6 ka (KB3). All the sediments above the distinctive mud layer are also attributed to the Mbwilo Member.

Unit C2 (***Fig. 5***)

Unit C2 was located 58 m downstream of Unit C and exposed the downstream end of the distinctive, roughly horizontal, cohesive mud layer.

From the base of the excavation upwards, key sedimentological features include basal layers of slightly gravelly sand and sand, the latter with a TT-OSL age of

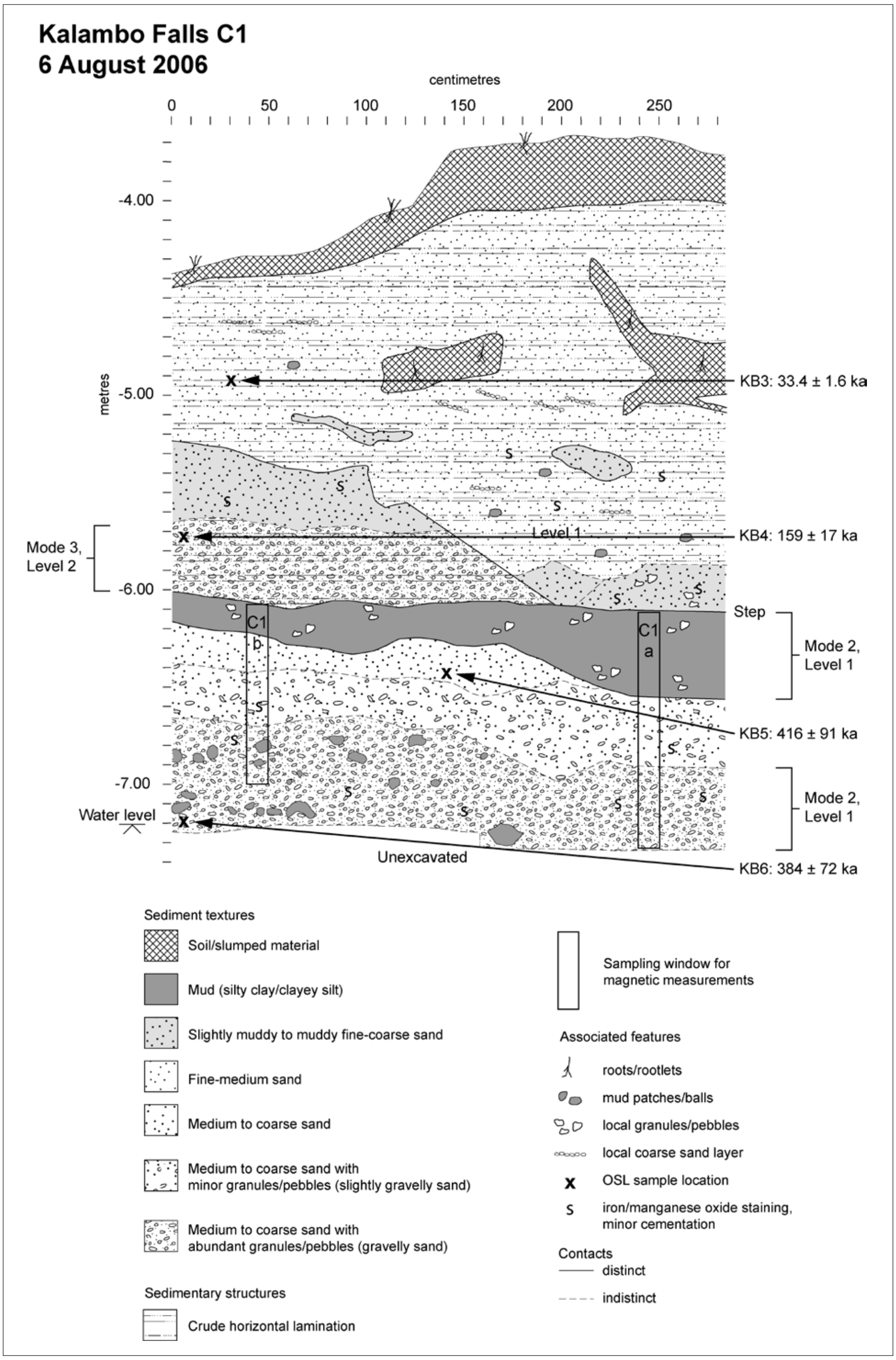

Figure 4. Unit C1 section showing artefacts levels (horizons), key sedimentological features, and the location of luminescence and mineral magnetic susceptibility samples.

339 ± 49 ka (KB7). These basal layers are dominantly 'white' in colour but display iron/manganese staining and are attributed to the Mkamba Member. Mode 2 artefacts occur in the sand layers and in the overlying distinctive mud layer. Overlying the mud layer is 1.0–1.3 m of sand, which contains a basal scatter of Mode 3 artefacts, and has OSL ages of 43.7 ± 2.0 ka (KB9) and 35.8 ± 1.7 ka (KB10). These sediments are attributed to the Mbwilo Member. The middle metre of the excavation is characterised mainly by interbedded fine-medium sand and sandy mud, with an OSL age of 24.1 ± 1.2 ka (KB12). These sediments are truncated by a distinct contact and overlain by up to 0.5 m of sand, gravelly sand, and slightly muddy to muddy sand. The sand layer immediately above the distinct contact has an OSL age of 31 ± 1.5 ka (KB13). These

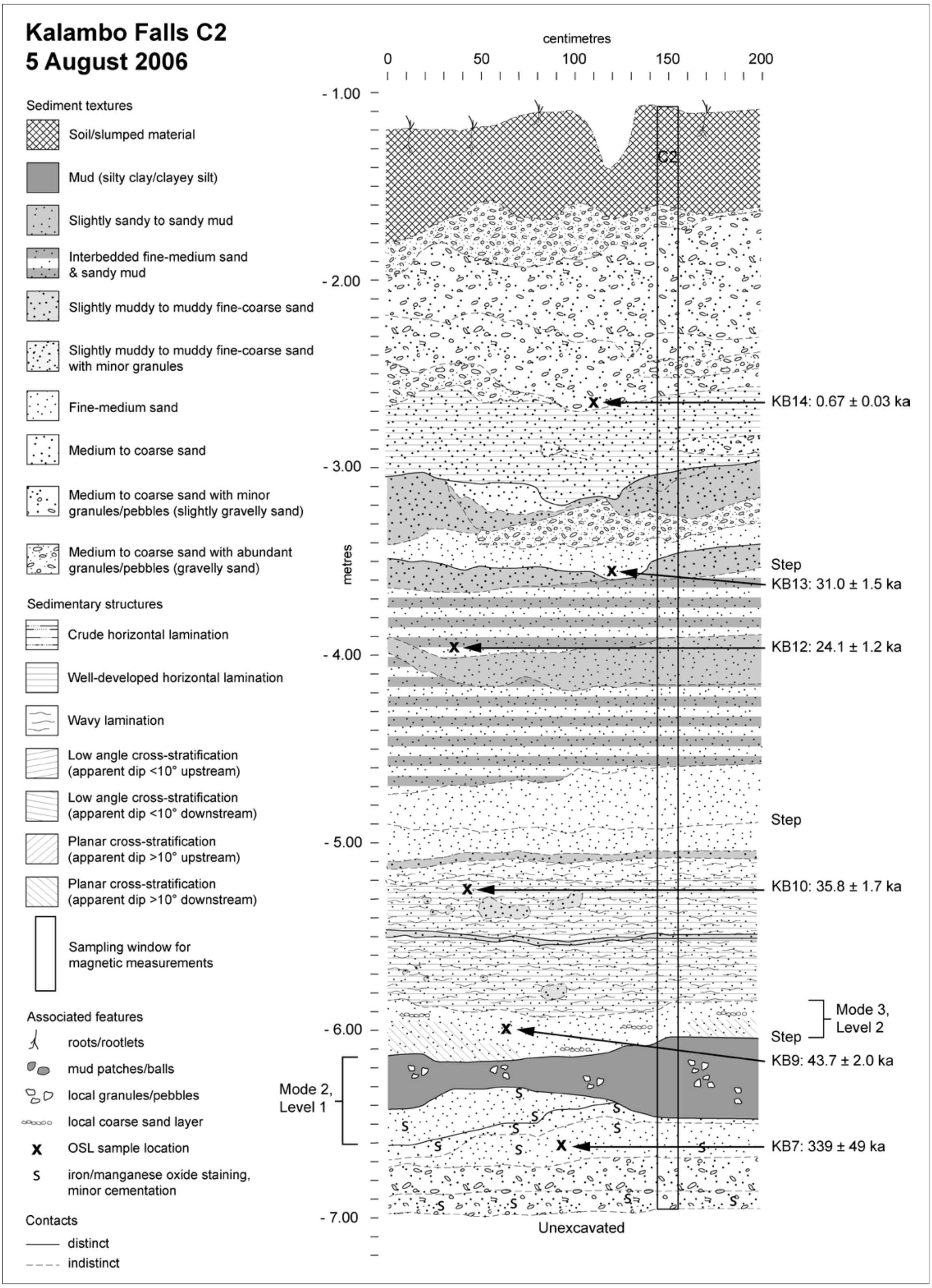

Figure 5. Unit C2 section showing artefact levels (horizons), key sedimentological features, and the location of luminescence and mineral magnetic susceptibility samples.

sediments are also attributed to the Mbwilo Member and are truncated by another distinct contact, which is overlain by sand and slightly gravelly to gravelly sand. The slightly gravelly sand has an OSL age of 0.67 ± 0.03 ka (KB14). These uppermost sediments are attributed to the Chiungu Member.

Figure 6. Photograph of Unit C3 showing the location of luminescence and mineral magnetic susceptibility samples. The pale sediment at the base of the section contains Mode 2 artefacts, and TT-OSL sample KB 11 (532 ± 133 ka) was collected from this deposit (to the left of the shovel). OSL sample KB8 (1.42 ± 0.10 ka) was collected in the step above and near the base of the paleochannel fill. OSL sample KB2 (0.73 ± 0.03 ka) and KB1 (0.49 ± 0.02 ka) were collected near the top of the fill and the locations are obscured by the standing figure.

Unit C3 (***Fig. 2***)

A characteristic feature of Site C North is a broad, trough-shaped palaeochannel (***Fig. 2***) that appears to have eroded into older sediments and been infilled with up to 4 m of younger sediments. This feature could be traced over a distance of ~28 m between Unit C and Unit C1, with the right-hand margin being the steepest (locally 65º). Unit C3 was excavated primarily to document the sedimentological character of the thickest part of the fill, as this formed a key part of reconstructing the recent depositional history of the Kalambo basin (no section was drawn for this geomorphological feature). The palaeochannel truncates at its base distinctive layers of slightly muddy sand that are dominantly 'white' in colour and contain Mode 2 artefacts. These underlying sediments have a TT-OSL age of 532 ± 133 ka (KB11) and are attributed to the Mkamba Member. Above the distinct basal contact, the browner, sand, silt and minor gravel is much younger, with stratigraphically-consistent OSL ages of 1.42 ± 0.1 ka (KB8), 0.73 ± 0.03 ka (KB2) and 0.49 ± 0.02 ka (KB1). These younger sediments are attributed to the Chiungu Member, and the OSL age range for the upper part of the fill matches closely the age range of the radiocarbon dates for this Member reported by Clark (1969: Appendix J).

Summary of sedimentology and luminescence ages

The sedimentological succession at Site C North exposes the three main members of the Kalambo Formation as defined by Kleindienst (1969). Mkamba Member deposits are overlain unconformably by Mbwilo Member sediments, and locally by Chiungu Member sediments. Mode 2 horizons occur at the base of each excavation unit in association with Mkamba Member sediments which have TT-OSL ages in the broad 500–300 ka range. A single Mode 3 horizon in Unit C is attributed to the Mkamba Member and bracketed by TT-OSL ages of 386 ± 94 ka below and 455 ± 103 ka above. These two ages appear to be in reverse chronological order, but they overlap within their large statistical uncertainties (1σ). If all the Mkamba Member luminescence samples from Site C North relate to the same depositional event, then the six ages combined (KB16, KB17, KB5, KB6, KB7, KB11) give a best estimate for the depositional age. The result is an age of 419 ka with a standard deviation of 68 ka and a standard error ($n = 6$) of 28 ka. Given the sampling context, however, it is more likely that the samples do not relate to the same depositional event but instead are from sediments that have been deposited over a long period of meander migration (see below). Hence, we prefer to be more cautious, especially given the large uncertainties on individual luminescence ages, and to retain a broad age range for the Mkamba Member.

Other than the single Mode 3 horizon in Unit C, Mode 3 horizons are otherwise associated with the Mbwilo Member. The Mbwilo deposits are discontinuous across Site C North, with TT-OSL and OSL ages ranging from 159 ± 17 ka in Unit C1 to 31 ± 1.5 ka in Unit C2, restricting our ability to make firm correlations with the wider sedimentological record at Kalambo Falls.

Artefact analyses

For each excavation unit, the data are presented starting with summary statistics by basic reduction categories for each artefact level. Core, flake and retouched tool data are then examined separately for evidence of Mode markers. The results are presented for each unit from the basal deposits upwards.

Unit C

A total of 827 artefacts were recovered from three levels in Unit C (***Table 1; Fig. 3***). Level 1 artefacts (n = 66) were found in interbedded sand and sandy mud and slightly gravelly sand with mud patches at the base of a 1 m^2 pit, at and just below river level (7.68–7.88 m below datum). Level 1 has a minimum TT-OSL age of 386 ± 94 ka (KB17). Level 2 artefacts (n = 130) were dispersed in a matrix of sand and slightly gravelly sand (5.95–6.21 m below datum) and bracketed by TT-OSL ages of 386 ± 94 ka below (KB17) and 455 ± 103 ka above (KB16). Level 3 artefacts (n = 631) were concentrated in a narrow layer of sand with local granules/pebbles (4.78–5.00 m below datum), with smaller flakes and cores wedged tightly between larger clasts (tools and manuports). This layer is bracketed by a TT-OSL age of 455 ± 103 ka below (KB16) and an OSL age of 39.4 ± 2 ka above (KB15).

The archaeological data are summarised in ***Table 2*** (cores), ***Tables 3–5*** (flakes) and ***Table 6*** (retouched artefacts). The small size of the Level 1 assemblage

	Level 3		Level 2		Level 1	
	N	**%**	**N**	**%**	**N**	**%**
chunk	6	(12.2)	2	(9.1)		
2 platforms right angle	8	(16.3)	2	(9.1)		
single platform	12	(24.5)	6	(27.3)	3	(37.5)
multiple platforms	4	(8.2)	2	(9.1)	1	(12.5)
prepared core	5	(10.2)	1	(4.5)		
prepared recurrent	2	(4.1)				
blade	2	(4.1)	1	(4.5)		
pyramidal/radial flake			1	(4.5)		
flake as core	4	(8.2)	2	(9.1)		
change of form	1	(2.0)			1	(12.5)
opposed platforms	1	(2.0)				
disc	2	(4.1)	1	(4.5)		
disc core one bifacial edge			2	(9.1)		
split cobble centripetal flaking	1	(2.0)				
split cobble, peripheral flaking					1	(12.5)
disc, split					2	(25.0)
core fragment	1	(2.0)	2	(9.1)		
Total	**49**		**22**		**8**	

Table 2. Unit C core and core fragment frequencies by type and level.

Size range	Raw material	N (%)	Faceted
21–30 mm	quartzite	2 (5.7)	0
	mudstone	1 (2.9)	0
31–40 mm	quartzite	4 (11.3)	0
	mudstone	4 (11.3)	0
41–50 mm	quartzite	9 (25.7)	0
51–60 mm	quartzite	3 (8.6)	0
	mudstone	2 (5.7)	1
61–70 mm	quartzite	5 (14.3)	0
71–80 mm	quartzite	1 (2.9)	0
>81 mm	quartzite	3 (8.6)	0
	mudstone	1 (2.9)	0
Summary	**quartzite**	**27 (77.1)**	**0**
	mudstone	**8 (22.9)**	**1**
Total		**35**	**1 (2.86%)**

Table 3. Unit C, Level 1 whole flake frequencies by size range, raw material and faceting on butt.

Size range	Raw material	N (%)	Faceted
21–30 mm	quartzite	1 (1.3)	0
	mudstone	2 (2.6)	0
31–40 mm	quartzite	5 (6.5)	1
	mudstone	5 (6.5)	1
41–50 mm	quartzite	13 (16.8)	7
	mudstone	12 (15.6)	0
51–60 mm	mudstone	8 (10.4)	0
61–70 mm	quartzite	12 (15.6)	0
	mudstone	5 (6.5)	0
71–80 mm	quartzite	12 (15.6)	2
>81 mm	quartzite	1 (1.3)	0
	mudstone	1 (1.3)	0
Summary	**quartzite**	**44 (57.1)**	**10**
	mudstone	**33 (42.9)**	**1**
Total		**77**	**11 (14.29%)**

Table 4. Unit C, Level 2 whole flake frequencies by size range, raw material and faceting on butt.

Size range	Raw material	N (%)	Faceted (%)
1–10 mm	mudstone	1 (0.3)	
11–20 mm	quartzite	4 (1.3)	
	mudstone	5 (1.6)	1 (2.2)
21–30 mm	quartzite	8 (2.6)	
	mudstone	8 (2.6)	2 (4.3)
31–40 mm	quartzite	24 (7.7)	1 (2.2)
	mudstone	30 (9.6)	9 (19.6)
	Total	54 (17.3)	10 (21.7)
41–50 mm	quartz	1 (0.3)	
	quartzite	31 (9.9)	3 (6.5)
	mudstone	35 (11.2)	11 (23.9)
	Total	67 (21.5)	14 (30.4)
51–60 mm	quartz	1 (0.3)	
	quartzite	39 (12.5)	4 (8.7)
	mudstone	28 (9.0)	11 (23.9)
	Total	68 (21.8)	15 (32.6)
61–70 mm	quartzite	34 (10.9)	
	mudstone	21 (6.7)	3 (6.5)
	Total	55 (17.6)	3 (6.5)
>71 mm	quartzite	32 (10.3)	
	mudstone	10 (3.2)	1 (2.2)
	Total	42 (13.5)	1 (2.2)
Summary	**quartz**	**2 (0.6)**	
	quartzite	**172 (55.1)**	**8 (17.4)**
	mudstone	**138 (44.2)**	**38 (82.6)**
	Total	**312**	**46 (14.74)**

Table 5. Unit C, Level 3 whole flake frequencies by size range, raw material and faceting on butt.

Artefact type	Level 3	Level 2	Level 1
	N	N	N
anvil, pitted	1	0	0
hammerstone	3	1	0
hammerstone, split	0	1	1
upper grindstone	1	0	0
utilised flake quadrilateral	2	0	0
blade, use/edge damage	0	1	0
utilised flake, notched edges	1	1	0
scraper, end	1	0	0
scraper, side	3	1	0
scraper, concave	0	0	1
segment	1	0	0
trapezoid	2	0	0
denticulate	1	2	1
awl/bec	3	0	0
adze, one side retouched	2	2	0
pick	5	3	0
core-axe	1	1	0
point, bifacial retouch	1	0	0
point, partly bifacial	1	0	0
LCT, bilateral retouch	0	0	1
LCT, knife	0	0	1
LCT, bifacial cleaver	0	0	1
misc. retouch, flat invasive	1	2	0
misc. retouch, steep	0	1	0
misc. retouch, notched	1	0	0
Total	**31**	**16**	**6**

Table 6. Unit C retouched and utilised artefact by type and level.

limits the techno-typological inferences drawn, but it does contain LCTs which are key Mode 2 markers. These include a bifacially retouched quartzite cleaver on a side-struck flake (***Table 2; Fig. 7.1a***). By contrast, Level 2 contains no LCTs and its Mode 3 indicators take the form of core types represented (prepared, prismatic/radial, blade) (***Table 2; Fig. 8***). Blade and prepared cores also occur in Level 3 (***Fig. 7.2d***), and blades (whole and broken) feature in Level 3 which is attributed to Mode 3 (***Table 1; Fig. 7.2e***). The percentage frequency of faceted flakes among total whole flakes is similar in Level 2 (14.3% of 77) and Level 3 (14.7% of 312), but they differ in raw material patterns. Quartzite is the primary material faceted in Level 2 (10 of 11 flakes), while siliceous mudstone predominates in Level 3 (38 of 46 flakes). One simple faceted flake was found in Level 1 (2.8%) and is presumed to be an unintended by-product of knapping. Picks and core-axes occur in Levels 2 and 3 (***Fig. 7.1b, c***); retouched points and backed pieces occur in Level 3 only (***Fig. 7.2f, g***).

Visible abrasion or weathering occurs on the majority of Level 2 and Level 3 artefacts (*e.g.*, ***Fig. 8***). Indicators of chemical weathering (see Burroni *et al.* 2002) are also evident in the Level 3 aggregate in the form of the loss of feldspar from quartzite artefacts, variable patination (especially of mudstone), and traces of iron staining. Level 1 artefacts are less visibly abraded or weathered with no signs of patination.

Eight pieces of soft limonite (iron hydroxide) and one piece of haematite (iron oxide) were found in Level 3, and limonite staining was observed on four flakes. No signs of use or modification were visible macroscopically. Limonite patches and yellow staining are local pedogenic features of the Ochreous Sands of the Mkamba Member (***Figs. 3–5***). The identification was made in the field based on colour streaks (Munsell 2.5Y 7/8-8/8) and subsequently verified qualitatively by ED-XRF analysis. The deposition of the iron minerals is interpreted as the result of chemical weathering of either iron carbonates or iron sulphides (T. Young, *pers. comm.*).

Unit C1

Given the small number of artefacts recovered from this unit (n = 85, ***Table 7***), their analysis is based on combined samples and qualitative comparisons.

The most distinctive sedimentological feature in this excavation unit was a consolidated mud layer (~6.03–6.40 m below datum) with artefacts found below, within and immediately overlying. The mud itself was not excavated beyond a depth of 30 cm across the

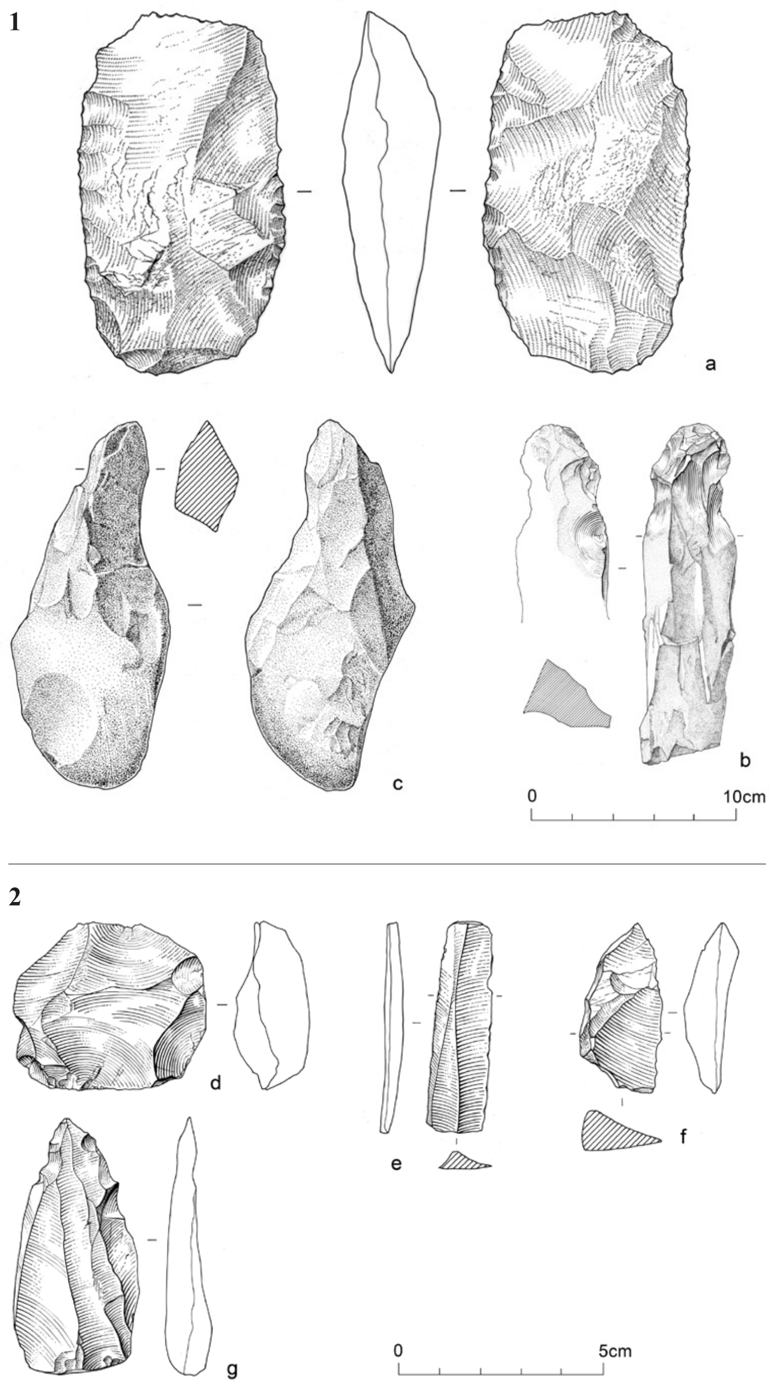

Figure 7. 1 – Unit C artefacts: a) quartzite bifacial cleaver on side struck flake, Level 1 (Mkamba Member); b) parallel-sided mudstone core-axe, Level 2 (Mkamba Member); and c) quartzite core-axe, heavily weathered, Level 3 (Mbwilo Member). 2 – Unit C, Level 3 artefacts (Mbwilo Member): d) mudstone prepared core; e) mudstone blade with edge damage; f) mudstone backed flake; and g) mudstone unifacial point.

Figure 8. Left – Top view of pyramidal/radial flake core (mudstone) from Level 2 (Mkamba Member) showing final large flake removal across the platform (centimetre scale). Right – Basal view of pyramidal/radial flake core (mudstone) from Level 2 (Mkamba Member) showing patinated and worn surface as well as accumulation of hinge fractures at the termination of intersecting flake scars forming a knot (centimetre scale).

Class	Level 2	Level 1
	N	N
Manuports	0	0
Cores	9	1
Whole flakes	26	21
Broken flakes	1	5
Whole blades	0	0
Broken blades	1	0
Chunks/shatter	6	1
Retouched/ utilised	9	5
Total	**52**	**33**
<20mm	*7*	*7*

Table 7. Unit C1 numerical summary of artefacts by type and level.

Core type	Level 2	Level 1
	N	N
disc	1	0
polyhedral	1	0
2 platforms right angle	2	0
single platform	2	0
multiple platforms	0	1
chunk core	2	0
flake as core	1	0
Total	**9**	**1**

Table 8. Unit C1 core frequencies by type and level.

Level	Size range	Raw material	N	Faceted
Level 2	11–20 mm	mudstone	1	
	21–30 mm	mudstone	3	
		quartzite	1	
	31–40 mm	quartzite	2	
		mudstone	3	
	41–50 mm	quartzite	1	
		mudstone	3	1
	51–60 mm	quartzite	1	
		mudstone	3	1
	61–70 mm	quartzite	2	
		mudstone	3	1
	>71 mm	quartzite	3	
	Summary	**quartzite**	**10**	
		mudstone	**16**	**3**
	Total		**26**	**3**
Level 1	0–10 mm	quartzite	8	
	11–20 mm	quartzite	1	
	21–30 mm	quartzite	1	
	31–40 mm	quartzite	1	
		mudstone	1	
	41–50 mm	quartzite	2	
		mudstone	3	
	51–60 mm	mudstone	1	
	>71 mm	quartzite	3	
	Summary	**quartzite**	**16**	
		mudstone	**5**	
	Total		**21**	

Table 9. Unit C1 whole flake frequencies by raw material and faceting by level.

section face to sample the artefact content and expose underlying sediments. All other artefacts in this unit were found in diffuse and discontinuous scatters. The scatters were grouped into two levels for analysis. Level 1, encompassing the mud layer and underlying sand and slightly gravelly to gravelly sand, incorporates four scatters (n = 33), including one embedded in the base of the mud layer and the remainder found in the underlying sediments down to the modern river level (***Fig. 4***). Level 2 incorporates three scatters (n = 52) found in a truncated gravelly sand overlying the mud layer (***Fig. 4***).

Level 1 below the mud layer is bracketed by two TT-OSL ages of 384 ± 72 ka (KB6) and 416 ± 91 ka (KB5). The dating of Level 2 is considered problematical (see Duller *et al.* 2015), but has a TT-OSL age of 159 ± 17 ka (KB4). The upper section of Unit C1 has an OSL age of 33.4 ± 1.6 ka (KB3), with no artefacts recovered from these sediments. The archaeological data are summarised in ***Table 8*** (cores), ***Table 9*** (flakes) and ***Table 10*** (retouched artefacts). Level 1 is distinguished by the presence of Mode 2 LCTs (1 cleaver, 3 bifacially flaked handaxes; all quartzite and in comparatively fresh condition). There are no specialised core types in either level, but faceted flakes (n = 3) occur only in Level 2 and are suggestive of a Mode 3 attribution. Quartzite flakes are more prevalent in Level 1 and siliceous mudstone flakes are more prevalent in Level 2. One pick was found in Level 2 as well as one heavily abraded cleaver which is assumed to have been re-deposited given the unabraded condition of the Level 1 LCTs.

Type	Level 2	Level 1
heavy edge flaked	2	0
utilised convergent plain butt	1	0
scraper, end	1	0
scraper, side	1	0
denticulate	1	1
awl/bec	1	0
pick	1	0
cleaver	1	1
biface	0	3
Total	**8**	**6**

Table 10. Unit C1 retouched artefact totals by level.

Unit C2

Only 58 artefacts were found in this unit (***Tables 11–13***), and as in Unit C1 they occurred in diffuse, discontinuous scatters. The distinctive mud layer separates one scatter below (Level 1, n = 13) from two scatters above, which are incorporated into one analytical unit (Level 2, n = 45) (***Fig. 5***). Level 1 has a TT-OSL age of 339 ± 49 ka (KB7), and Level 2 has an OSL age of 43.7 ± 2 ka (KB9) with an overlying OSL age of 35.8 ± 1.7 ka (KB10). Data on flake raw material and size is not presented because the sample is too small to be meaningful (n = 17). No faceted flakes were found in either level. The diagnostic Mode 2 markers in Level 1 are LCTs (two quartzite handaxes and one large flake with retouch on one lateral or 'knife' after Roe 2001) and one siliceous mudstone biface thinning flake plus a bifacially retouched flake with pick-like tip (***Table 13***). The diagnostic Mode 3 markers in Level 2 are two siliceous mudstone prepared cores (***Table 12***). Quartzite picks (n = 3) and core-axes (n = 2) occur in Level 2.

Unit C3

The artefacts found in the palaeochannel fill were not analysed beyond describing their mix. A plain pot sherd was found near the base of the fill which also contained Mode 5 and Mode 3 artefacts. The OSL ages for the fill sediments (1.42 ± 0.10 ka [KB8], 0.73 ± 0.03 ka [KB2], and 0.49 ± 0.02 ka [KB1]) indicate deposition during the late Holocene and confirm our interpretation that artefacts in the fill are a product of fluvial mixing. The palaeochannel is eroded into slightly muddy sand of the Mkamba Member, which has a TT-OSL age of 532 ± 133 ka (KB11). Two quartzite bifaces (Mode 2) were found below the palaeochannel basal contact.

Class	**Level 2**	**Level 1**
	N	**N**
manuports	4	1
cores	10	0
whole flakes	15	2
broken flakes	2	4
whole blades	0	0
broken blades	1	0
chunks/shatter	1	1
retouched/ utilised	12	5
Total	**45**	**13**
<20mm	*0*	*1*

Table 11. Unit C2 artefact frequencies by type and level.

Core type	**N**
2 platforms right angle	2
single platform	1
multiple platforms	4
prepared core	2
flake as core	1
Total	**10**

Table 12. Unit C2 core frequencies by type.

Artefact type	**Level 2**	**Level 1**
upper grindstone	1	0
upper grindstone/hammerstone	1	0
sub-spheroid	1	0
heavy edge flaked piece	0	1
scraper, end	1	0
denticulate	1	0
awl/bec	1	0
pick	3	1
pick/core-axe	2	0
chisel	1	0
biface (handaxe)	0	2
'knife'	0	1
Total	**12**	**5**

Table 13. Unit C2 retouched and utilised artefact frequencies by type and level.

Summary of the artefact analyses

The above data are interpreted as a sample of a discontinuous technological succession from Mode 2 (Acheulean) at the base of each unit to Mode 3 (Middle Stone Age) above, with possible variants of Mode 3 that cannot be linked spatially or chronologically. With its densely packed and variously weathered artefacts, Level 3 in Unit C constitutes an aggregate that formed in a manner different to the loose scatters of artefacts seen in the other Mode 3 horizons. This aggregate probably experienced significant time-averaging (temporal mixing); without tighter dating controls we cannot be confident that the contents reflect a meaningful behavioural or culture-stratigraphic entity (*e.g.*, Premo 2014).

Unit C, Level 2 is constrained chronologically to the Middle Pleistocene (~500–300 ka), unlike the other Mode 3 horizons which are later or of uncertain age. The attribution of Level 2 to Mode 3 is of particular importance as a result, but no further distinction (Sangoan or early Lupemban) can be made without a larger sample.

The mud layer that extends across Units C1 and C2 provides a localised chronological and techno-typological marker with Mode 2 material below and within the mud and post-Mode 2 horizons above. The overlying succession of archaeological horizons is temporally discontinuous between the units.

An attribution of the C3 palaeochannel fill to the Chiungu Member is supported by the associated mixture of artefacts, including pottery, and the late Holocene OSL ages.

Pollen and mineral magnetic analyses

The results of the pollen analysis and their categorisation according to Zambian ecological species groups (*cf.* Lawton 1978) are given in ***Table 14***. The sediment samples were mineral rich with variable but always low organic matter content (<2%). Pollen numbers are low and sparsely distributed throughout the units. The limited species identified are predominantly grasses (Poaceae) and sedges (Cyperaceae), which in most cases are badly preserved, broken or crumpled. The only other significant species (albeit in low numbers) is *Myrica*. Sparse and inconsistent numbers of Meliaceae, *Alchornea* and *Combretum* are observed, but again preservation is poor.

The overall limited numbers of pollen counts are to be expected given the typically poor preservation in river and floodplain sands and silts with low organic content. No trend is observed in the pollen data, neither in terms of improved counts in relation to the organic content or grain size of the sediment analysed nor with depth through the units investigated. Units C and C2 have grasses and sedges indicative of floodplain habitats with some evidence of swamp forest. The local occurrence of woodland and forest taxa in the pollen counts is interpreted as reflecting input from vegetation on the valley margins. These observations aside, the pollen sample as a whole is too small and irregularly distributed to make accurate palaeoenvironmental interpretations about the vegetation history at Site C North. The pollen data are also too limited to be correlated with the revised pollen zones developed by Taylor *et al.* (2001) based on their re-analysis of the published pollen data from Clark's (1969) excavations.

Mineral magnetic susceptibility analyses from Units C1, C2 and C3 (***Figs. 9, 10***) provided additional

				Broad ecology		**Swamp forest**		**Forest**	**Woodland**	**Unknown**
PollenTube Id	**Unit**	**Datum**		*Poaceae*	*Cyperaceae*	*Myrica*	*Alchornea*	*Meliaceae*	*Combretum*	*Unidentifiable*
13	C2	- 4.16		10	5	5				
14	C2	-4.22		9	37	7				21
15	C2	-4.33		8	16	3	2	1		12
16	C2	-4.42			3			1		4
17	C2	-4.67		3	5	1				3
18	C2	-4.61	Barren							
19	C2	-5.07		1						
20	C2	-5.18			1	2				8
21	C2	-5.54		12	10	9		4		11
22	C2	-6.24		2	2					1
23	C2	-6.32		2						
24	C	-4.43-4.45		2	7	3		1		
1	C	-5.20		1						2
2	C	-5.78	Barren							
3	C	-7.30	Barren							
4	C	-7.40		2	2	3		1		
5	C	-7.69		2		3				3
6	C	-7.70		5	1	3				
7	C	-7.71			1	1			2	
8	C	-7.72		3	4	6				
9	C	-7.73		4	1					
10	C	-7.74		1		2				3
11	C	-7.50 Upper		1	5	3	2	2		
12	C	-7.50 Lower		2	1	3		3		

Table 14. Pollen data for Units C and C2 (sample depths correspond to section depths shown in ***Figure 3*** and ***Figure 5*** respectively. Pollen Analysts: Tim Shaw and Jason Kirby).

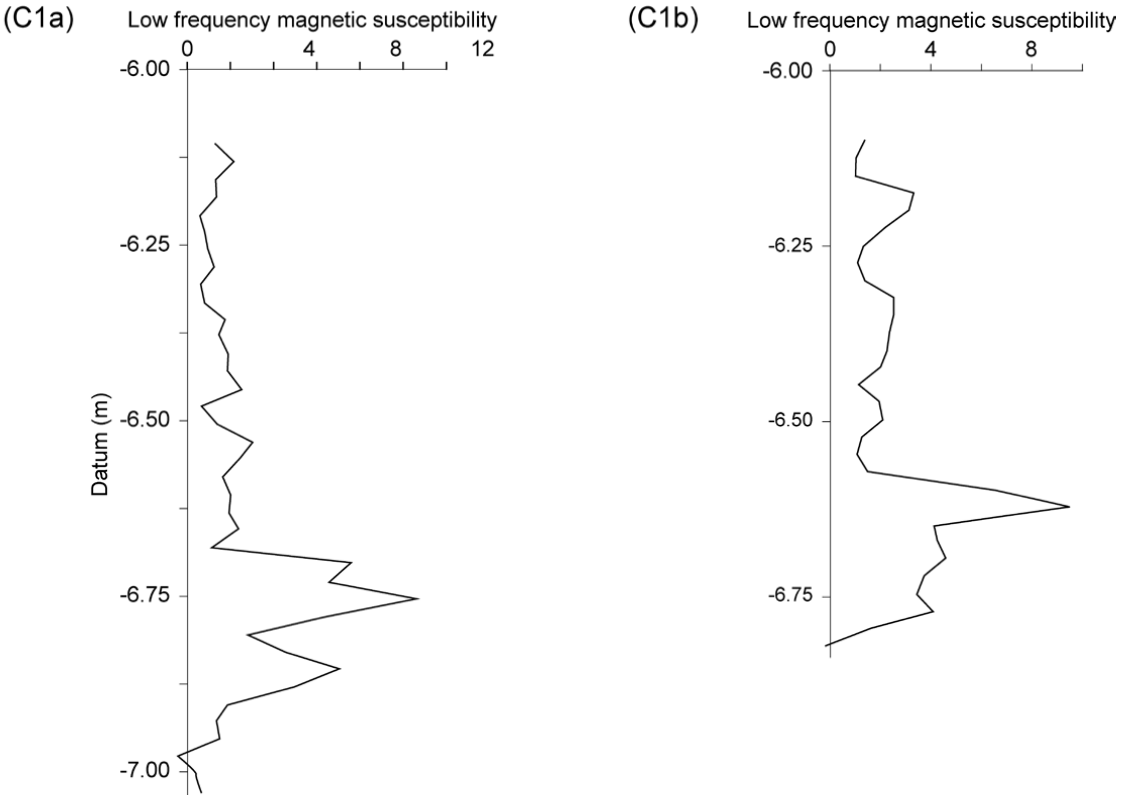

Figure 9. Plot of low-frequency magnetic susceptibility (χ) against depth (cm) for the lower part of Unit C1 (see ***Fig. 4*** for sampling context): a) left-hand side of the lower section; b) corresponding right-hand side.

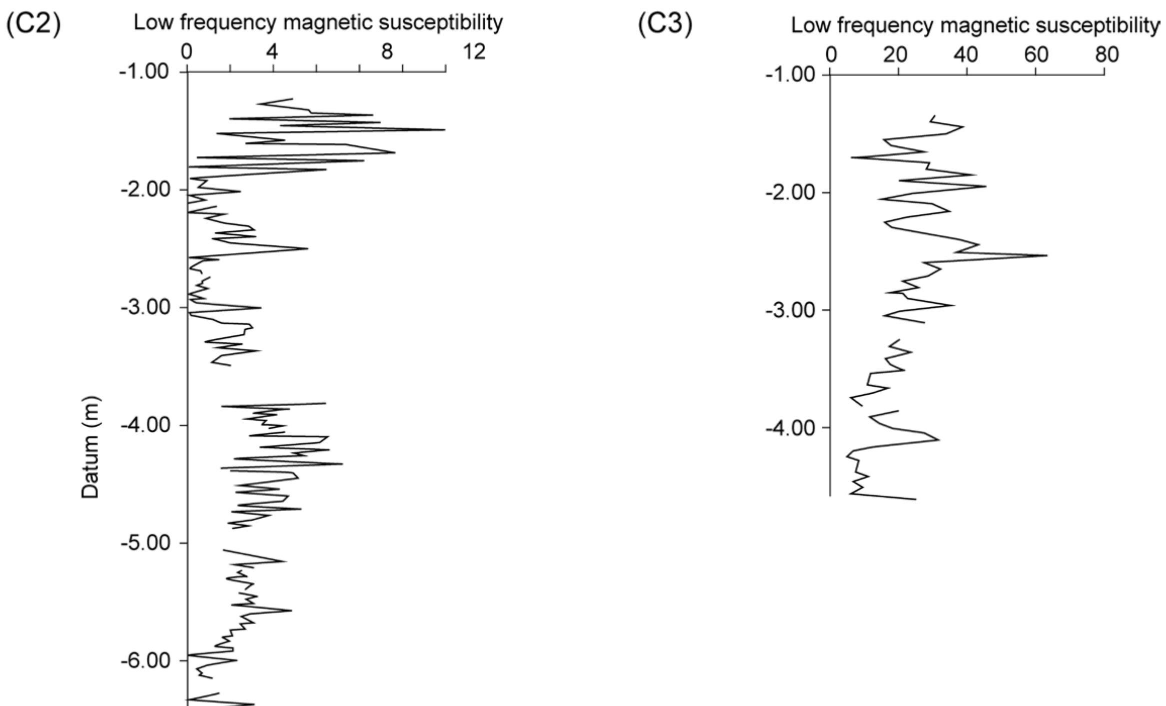

Figure 10. C2: Plot of low-frequency magnetic susceptibility (χ) against depth (cm) for Unit C2 (see ***Fig. 5*** for sampling context). C3: Plot of low-frequency magnetic susceptibility (χ) against depth (cm) for the Unit C3 (see ***Fig. 6*** for sampling context).

information on palaeoenvironmental conditions in the Kalambo basin. In the following interpretation of the data, higher values of χ reflect the presence of magnetic minerals that may be of primary and/or secondary origin. In contrast, quartz-dominated sediment possesses low χ, and both organic matter and carbonate minerals may exhibit negative values of χ (diamagnetism).

Unit C1

Measurements were made in the lower part of Unit C1 beneath the step at ~6 m below datum down to the water level (***Fig. 4***). This part of the unit is characterised by basal layers of gravelly sand with mud patches, locally with iron/manganese staining, which are overlain by slightly gravelly sand and sand, and capped by a roughly horizontal cohesive mud layer. Measurements were taken on both the left- and right-hand sides of the exposed sediments (***Fig. 9a, b***); they reveal that the basal gravelly sand consistently exhibits χ values in the region of 4–10 SI units, values which are higher than those in the overlying sediments (~1–2 SI units). The broad distinction is interpreted as a function of the iron oxide cement and grain coatings increasing the concentration of magnetic minerals in sediments that otherwise are largely dominated by quartz, feldspars and some pedogenic carbonate. The increased clay content in the mud layer leads to a subtle increase in χ (2–4 SI units).

Unit C2

Measurements were made starting from the basal layers of slightly gravelly sand and sand, and continuing up through the distinctive mud layer and overlying coarser layers to the modern surface (***Fig. 5***). χ values are generally 1–3 SI units but have a high degree of variability, with values locally reaching 10–12 SI units (***Fig. 10***). This is not interpreted as being due to significant changes in sediment composition but rather as the inherent variability in data where the signal is only marginally above that of the background. Elevated values of χ (4–8 SI units) are particularly notable above the lower step (~6 m below datum) to immediately below the uppermost step (~3.6 m below datum). This may represent a subtle change in the proportion of silt- and clay-sized particles that increases upward through the succession of interbedded sand and sandy mud. The upper 2.2 m of Unit C2 are characterised by sand and gravelly to slightly gravelly sand with low but variable χ (0–4 SI units), which are overlain by a more magnetic sediment (4–12 SI units) in the soil immediately beneath the modern surface. This increase in χ can be attributed to a combination of fine-grained primary minerals and secondary minerals arising from pedogenetic and diagenetic processes in the uppermost layers.

Unit C3

A general upward increase in χ can be observed through the sand, silt and minor gravel that characterise the palaeochannel fill, with values increasing from about 5–10 SI units at the base to 20–30 SI units nearer the surface (***Figs. 6, 10***). Magnetic susceptibility peaks at ~65 SI units around 1.30 m depth where there is no obvious change in the lithostratigraphy. Again, the magnetic susceptibility seems to reflect the increasing proportion of primary and secondary fine-grained mineral matter and local iron staining up through Unit C3, potentially accentuated by a reduction in the presence of secondary carbonate cement.

Summary of pollen and mineral magnetic analyses

The limited pollen evidence suggests a persistent floodplain palaeoenvironment with intermittent swamp forest and adjacent valley woodland. The mineral magnetic susceptibility data support an interpretation of river flow variability without any significant change in sediment provenance, as shown by the absence of any significant or consistent co-variance between the magnetic properties and the different sedimentary layers. Indeed, the magnetic data are interpreted as reflecting the relative significance of coarse-grained mineral matter dominated by quartz and siliceous mudstone and minor contributions from both primary and secondary clay minerals. Post-depositional overprinting of the magnetic properties arises from pedogenetic and/or diagenetic formation of iron oxide and carbonate coatings and cements. Sediments that are darker and/or redder in colour or finer grained tend to exhibit higher χ values. In the upper parts of the sections investigated, this magnetic enhancement is likely to be the result of pedogenesis. In contrast, diagenesis at lower depths in the sections is probably linked to either the downward percolation of water causing carbonate and iron oxide dissolution and re-precipitation (reduced χ) or limitations to free drainage or periodic waterlogging (by mud layers or seasonal variations in the water table) leading to iron reduction and oxidation (increased χ).

Discussion

Interpretation of the Site C North succession

The combined data from the excavations at Site C North provide evidence of extensive but temporally discontinuous mid to late Quaternary fluvial deposition in the central part of the Kalambo basin. This section offers an interpretation of the fluvial processes responsible for the formation of the succession, including the implications for generation and preservation of the archaeological record. This interpretation may be applied more generally to the archaeological record recovered from fluvial contexts in the Kalambo basin and leads to the consideration of the broader-scale controls on fluvial deposition and erosion.

To recap, there are sedimentological differences between each of the excavation units, but broad similarities are evident (***Figs. 3–6***), including:

1) pronounced vertical and lateral variations in grain size, sedimentary structures, and colour, with both fining-up and local coarsening-up successions being present;
2) distinct, typically irregular or wavy contacts between some sedimentary layers that indicate periods of erosion and/or non-deposition. Localised, irregular, rounded to subrounded mud patches within some gravelly sand layers can be interpreted as mud balls derived from localised reworking of more extensive mud layers;
3) many horizons that are not laterally continuous over more than a few metres. A distinct palaeochannel in the upper part of the succession provides evidence for a major cut-and-fill event in the recent site history and may have contributed to lateral discontinuities between Units C and C1, but correlation is difficult even between the closely adjacent Units C1 and C2 (the distinctive mud layer is an exception but sediments above and below this layer cannot be matched precisely);
4) sedimentological evidence for erosion and/or non-deposition that is supported by significant differences in the luminescence ages across distinct contacts;
5) recent channel incision that has occurred into the fluvial succession, with subsequent lateral migration of the incised channel providing the sedimentary exposures along outer (cut) banks (***Fig. 2***).

Genesis of the Site C North succession

Together, these observations are broadly consistent with the earlier descriptions of Kalambo Formation sediments (Clark 1969) and support an interpretation that the exposures at Site C North are the product of deposition by a laterally migrating and vertically aggrading meandering river subject to seasonal flow fluctuations (Duller *et al.* 2015). The limited pollen evidence suggests a persistent floodplain palaeoenvironment and the mineral magnetic analyses support an interpretation of river flow variability without any significant temporal changes in sediment provenance.

In detail, the processes of deposition and erosion along meandering rivers such as the Kalambo are complex. Previous studies of meandering rivers transporting mixed sediment loads of minor gravel, sand and mud (*e.g.*, Miall 1996; Bridge 2003; Marren *et al.* 2006) have shown how lateral bend migration is accomplished by erosion of the outer bank and concomitant deposition on the inner bank in the form of a point bar. On this inner bank, coarser-grained sediments (gravel, sand) carried in the lower part of the water column are preferentially deposited (***Fig. 11***), but where there are marked seasonal flow fluctuations, cohesive mud drapes can form on the surface of the point bar during the waning stage of wet season floods. If these mud drapes survive reworking during subsequent floods and are buried by more coarse-grained sediments, ultimately they form part of the developing point bar stratigraphy, although they may be partially reworked to form mud balls that are deposited along with coarser sediments. As bend migration continues, older point bar sediments that become located farther from the channel margins are gradually capped by finer-grained sediments (finer sand, silt, clay) that tend to be carried higher in the water column and are therefore dispersed overbank during floods. These overbank sediments are deposited on levees or more distal parts of the floodplain (***Fig. 11***) and become incorporated in the developing sedimentary package. This set of processes during the 'initial migration sweep' of a meander produces a characteristic overall fining-upwards succession in floodplain-levee sediments, ranging from relatively coarse basal sediments to finer-grained overlying sediments.

The relative balance between the river's lateral movement (meander bend migration) and vertical movement (incision or aggradation) influences the preservation of older river deposits during later phases of river activity. For instance, where lateral migration occurs but there is little or no net aggradation and little or no incision, older river deposits are progressively reworked ('cannibalised') by later 'return migration sweeps' as a meander moves back across the floodplain (***Fig. 11***). By contrast, where lateral migration occurs in association with a component of net vertical aggradation, the deeper part of older river deposits can be preserved as an 'aggradation increment' during the return migration sweep (***Fig. 11***). This aggradation increment selectively preserves the coarser basal sediments of the characteristic fining-upwards succession, and crucially, through selective winnowing of the finer-grained host sediments, may concentrate large archaeological artefacts as lags (***Fig. 11***).

This understanding of fluvial sedimentological processes informs our interpretation of the stratigraphy and sedimentary architecture at Site C North. The sedimentology and luminescence chronology demonstrates that older river deposits have partially survived later phases of river activity, consistent with a depositional

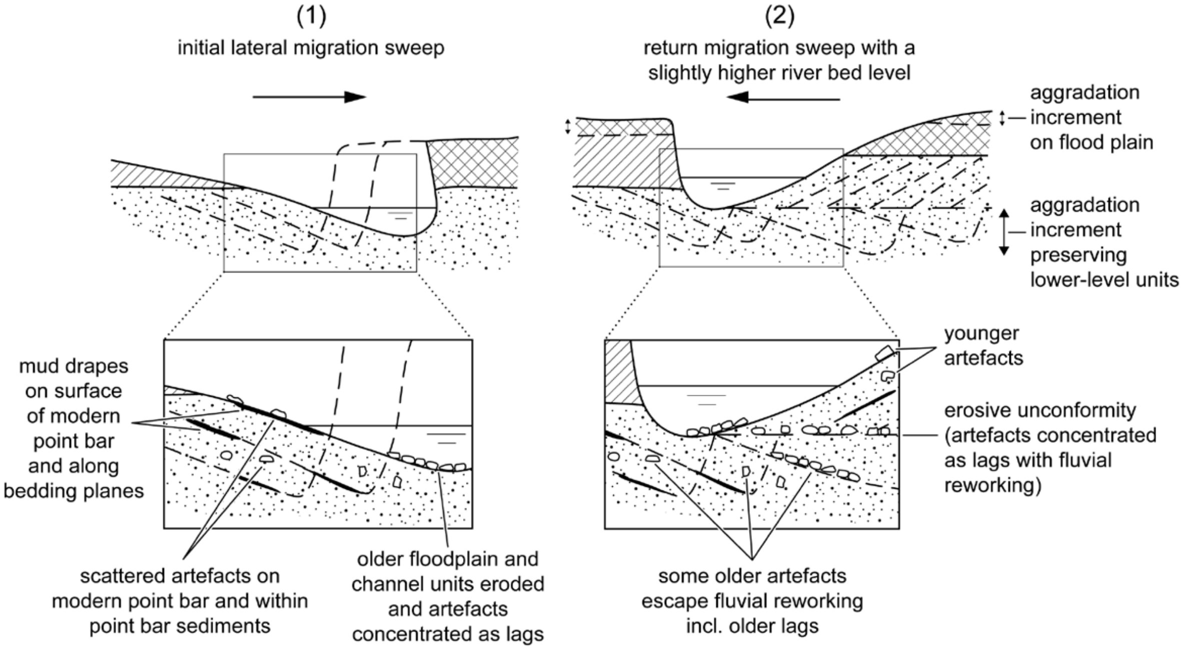

Figure 11. Schematic diagram illustrating formation of the Kalambo archaeological record by meandering river processes (adapted from Lewin & Macklin 2003). The record is characterised by scattered artefacts and lags that nonetheless retain a gross chronological order in vertical succession.

scenario involving lateral migration and a component of net vertical aggradation. These older, partially preserved deposits are dominated by sand and minor gravel, but also incorporate finer-grained layers consistent with fluvial deposition in a seasonal flow regime. Layers of interbedded fine-medium sand and sandy mud are a prominent component of the lowermost part of Unit C, possibly indicating the successive deposition and preservation of thin sandy mud drapes on point bars, but locally thicker mud deposition is indicated by the distinctive layers evident in the lower parts of Units C1 and C2. At least seasonal exposure of these mud-draped point bars is suggested by the possible evidence for bioturbation and by the magnetic evidence for diagenesis. Survival of many of these mud drapes, thicker mud layers and the limited gravel component in the underlying and overlying river deposits points to an overall low energy flood flow regime consistent with a small meandering river in a local basin (*cf.* Clark 2001).

Implications for generation and preservation of the archaeological record

At Site C North the concentrations of large stone artefacts as horizons seem to be consistent with their interpretation as aggregates derived from selective winnowing of surrounding finer-grained fluvial deposits. Sheppard & Kleindienst (1996) and Schick (2001) reached similar conclusions from their research in the Kalambo basin. ***Figure 11*** suggests that during return migration sweeps artefacts can become incorporated at the base of the sediments that overlie the aggradation increment preserved from the previous phase of meandering river deposition, which itself may contain artefact horizons developed along bedding planes. The limited evidence for abrasion on most Mode 2 artefacts suggests that while they are not in primary context, they have not been transported far, a conclusion also reached by Sheppard & Kleindienst (1996). These early archaeological horizons do not contain temporally mixed assemblages and remain in stratigraphic order, which is consistent with their derivation from reworking of only the top part of a previously accumulated fluvial deposit of broadly similar age. The notable exception to this process of artefact horizon formation is the Level 3 lag in Unit C with its dense concentration of artefacts. This material has been subjected to fluvial action as well as chemical weathering based on the range of patination colours and presence of iron-oxide staining (Burroni *et al.* 2002). The bracketing luminescence ages of 455 ± 103 ka (KB16) and 39.4 ± 2.0 ka (KB15) indicate a considerable hiatus separating the formation of the sand and local gravel with its capping horizon of artefacts and the deposition of the overlying sediments. Level 3 appears to contain temporally unrelated material in contrast to the other horizons at Site C North. Such a hiatus and process of time-averaging may characterise other Rubble I aggregates at Kalambo Falls.

In the case of Units C1 and C2, the main artefact-bearing levels tend to be overlain locally by finer-grained sediments with lower archaeological content, an observation that is consistent with channel margin or overbank deposition. This local decrease in grain size is also evident in the χ data from Unit C1, but less so in Unit C2 where post-depositional overprinting of the primary magnetic properties is perhaps more developed.

Unit C3 provides evidence for palaeochannel cut and fill, a process that also concentrated limited artefacts as a lag in the basal part of the fill. Compared with fluvial sediments lower in the succession that are dominantly medium-coarse sand and minor gravel, this infill is significantly finer, consisting mainly of sand and silt. This may reflect a decrease in flow competence along the Kalambo River or suggest that this palaeochannel represents a side branch (*e.g.*, a floodplain chute channel) of the main Kalambo River that may have been active only during flood flows.

These older channel and floodplain sediments have been exposed by erosion associated with meander bend development along the modern channel (***Fig. 1a,b***), which is now incised up to ~9 m into the fluvial sediments in the centre of the Kalambo basin (***Fig. 2***). Sediment exposure has promoted the post-depositional dissolution and re-precipitation of both iron and calcium carbonate that is evident in the magnetic data (***Figs. 9–10***). In addition, erosion provides increased visibility of the archaeological record and potentially is leading to formation of new lags. Indeed, bank surveys reveal how present-day erosional winnowing is concentrating Mode 2 artefacts on the modern channel bed and point bars. With ongoing bend development, ultimately these lags will become incorporated into the base of the modern floodplain that is currently aggrading to a level up to several metres above the modern channel (***Fig. 2***).

Controls on deposition and erosion

The product of this suite of fluvial processes is a complex but interpretable set of sedimentary packages. Based on luminescence age ranges, four main sedimentary packages can be identified: (1) ~500 ka to ~300 ka; (2) ~300 ka to ~50 ka; (3) ~50 ka to ~30 ka; and (4) ~1.5 ka to 0.49 ka (Duller *et al*. 2015). These packages correspond to the Mkambo (1), Mbwilo (2, 3) and Chiungu (4) Members of the Kalambo Formation. In the older part of the record, successive phases of meander migration and aggradation have generated local fining-upwards successions of sand, minor gravel and mud that have been deposited in channel and near-channel (levee and floodplain) settings. Although the successions are discontinuous, with evidence of partial reworking and preservation of older sediments and generation of artefact-rich horizons as lags, net aggradation over at least the last 500–300 ka means that the associated archaeological succession has been preserved in stratigraphic order (***Fig. 11***). During the very late Holocene, however, this trend of net valley aggradation has ceased and been supplanted by a greater tendency for incision. Evidence for cutting and filling of a palaeochannel in the top part of the succession has been followed by a phase of deep channel incision, with meander migration and floodplain formation now taking place at a level up to ~9 m below the surface of the older fluvial sediments.

Outstanding questions concern the controls on deposition and erosion at Site C North and in the Kalambo basin more generally. Previous interpretations of the evidence for punctuated sedimentation in the Kalambo basin proposed that intermittent blocking of the spillway gorge, at undated intervals in the Pleistocene, provided the conditions for cyclic aggradation in the basin (Bond 1969: Appendix A; Clark 2001: 3–4). These blockage events were interpreted to have occurred primarily during humid intervals owing to tributary inputs, with breaching of the blockages occurring during more arid periods when tributary inputs decreased. Bond (1969) speculated that aggregate horizons or rubble lines represented land surfaces exposed during dry phases and that the onset of wetter conditions buried these surfaces with sediments liberated from sparsely vegetated slopes, although tectonic activity may also have played a role (*e.g.*, Haldemann 1969). Clark (1969; Plate 6) added a personal observation and photograph noting that following the 1961–62 rainy season sediments slumped into a part of the river channel and altered its course. He asserted that the inclusion of tree trunks in the sediment load could have effectively blocked the spillway gorge in the past, leading to renewed depositional phases.

Detailed surveys during August 2006, however, failed to locate any unequivocal geomorphological or sedimentological evidence for previous substantial or long-lasting blockage events in the vicinity of the spillway gorge. The Kalambo River's flow appears to be competent to transport all the sediment supplied by the small tributaries that join the river as it traverses the basin, including the sediment from the small tributary that joins the river from the south immediately upstream of the entrance to the gorge. On this southern side, around the entrance of the gorge, there are numerous high-elevation rounded to subrounded quartzite boulders with percussion marks consistent with fluvial transport or abrasion, but because these occur at levels many metres above the top of the Site C North deposits, these are most likely palaeoriver deposits preserved from the earlier (but temporally unconstrained) history of gorge cutting, rather than evidence for deposition at higher levels during postulated mid to late Pleistocene blockage events. Along the margins of the gorge itself, we found no evidence of truncated debris flows or substantial rock-falls that would be consistent with former blockage events.

Although we cannot totally discount the role of climatically- and/or tectonically-induced blockage events, we prefer not to make such interpretations at present, especially given the large uncertainties in the age ranges derived from TT-OSL and the absence of reliable dates for Quaternary rifting stages in this region of the East African Rift System (Delvaux *et al.* 2012: 177). Instead, rather than appealing to intermittent blockage of the spillway gorge as a key control on sedimentation in the basin, our interpretations suggest that the fluvial deposits at Site C North can be explained more simply as a result of meander migration and concomitant aggradation, and with a cut-and-fill event in the very late Holocene. The palaeoclimatic significance of this river activity also remains open to debate. When encountering abrupt changes in sedimentation within fluvial sedimentary successions, it is tempting to invoke climate change as the cause, but lateral meander migration is essentially an ongoing autogenic process that can occur largely independently of climate change under conditions of steady discharge and sediment supply. Vertical river activity, however, is a function of changes in the relative balance between discharge and sediment supply, as this influences the river's sediment transport capacity. An imbalance resulting from decreased discharge or increased sediment supply leads to aggradation (the river's transport capacity is insufficient to ensure onward transport of supplied sediment) while an imbalance resulting from increased discharge and/or decreased sediment supply leads to incision (the river's transport capacity exceeds that needed to convey the supplied sediment). Both discharge and sediment supply can be influenced directly and indirectly by climate changes, although the relationship with incision and aggradation is far from straightforward with catchment scale and geomorphic setting being important determinants of how different rivers will respond to changing climatic conditions (*e.g.*, Nanson & Tooth 1999; Tooth in press).

At Site C North, the luminescence ages help to constrain the timing of aggradation and incision, but it remains uncertain whether these phases of activity have been driven by regionally-significant palaeoclimatic changes. This uncertainty partly results from the large analytical uncertainties on the TT-OSL ages, but also from the paucity of chronologically-constrained mid to late Quaternary palaeoclimatic proxy records in this part of central southern Africa. Limited luminescence ages for hillslope and river deposits in central Tanzania (Eriksson *et al.* 2000) and southeast Zambia (Thomas & Thorpe 1995; Thomas 1999; Thomas & Murray 2001; Barham *et al.* 2011) and dated cores from Lake Tanganyika and Lake Malawi (*e.g.*, Scholz *et al.* 2003, 2007; McGlue *et al.* 2008) all indicate repeated phases of landscape stability and instability under changing climatic and vegetation conditions during the mid to late Quaternary. Much more work, however, will be needed to relate findings derived from one short bank section in the centre of the Kalambo basin to broader palaeoclimatic and landscape changes across central southern Africa.

Regional archaeological significance

The archaeological value of the Site C North succession as a whole lies in the fact that the majority of the deposits are stratigraphically and technologically in a coherent order, albeit laterally discontinuous across the site. The lowermost sedimentary package, correlated with the Mkamba Member, contains Mode 2 artefacts in relatively fresh condition and above them early Mode 3 artefacts in more weathered condition. The succeeding two sedimentary packages, corresponding to the Mbwilo Member, contain later Mode 3 horizons. The uppermost sedimentary package, associated with the palaeochannel fill and correlated with the Chiungu Member, hosts mixed archaeological deposits including late Holocene artefacts.

Previous investigators at Kalambo Falls have made similar observations to those presented here about the secondary context of the archaeological record and its discontinuous succession (Sheppard & Kleindienst 1996; Schick 2001). The site's formation history poses limitations on our ability to characterise in detail the process of technological change from the late Acheulean to the early Middle Stone Age. Fluvial winnowing and weathering have affected the completeness of the archaeological record with small artefacts removed. Post-depositional weathering has altered the surface features of artefacts in the upper part of the Mkamba Member and in the Mbwilo Member. Feldspathic quartzite artefacts, in particular, have become friable as a result of the loss of feldspar. Mudstone artefacts typically have a patina and there is some degree of abrasive wear on most artefacts in these upper artefact horizons. As a result, use-wear analyses are limited to low-power microscopy (Taylor 2009). The lag deposits at Site C North do preserve evidence of localities of hominin activity including place of discard. With the exception of the Unit C3 palaeochannel, these are not horizons of artefacts transported long distances by fluvial activity.

There is then the potential for future researchers to examine temporal changes in the choice of raw material and later stages of artefact production, use and discard. This kind of *chaîne opératoire* approach (*e.g.*, Soressi & Geneste 2011) is feasible in a moderated form, but we do not have evidence for the initial stages of raw material reduction. Mudstone and quartzite workshops may exist on the basin margins and remain to be explored and dated (Kleindienst, *pers. comm*.). The existing large collections of flakes and cores from the previous excavations at Kalambo Falls offer a complementary source of technical and quantitative data with which to examine the Mode 2/3 transition (*e.g.*, Tryon & Potts 2011).

What is new in this study is the application of TT-OSL dating to the oldest sedimentary package known at Kalambo Falls. Reliable radiometric ages have been lacking for the Mkamba Member, and by implication for the age of the late Acheulean (Mode 2) and the earliest Middle Stone Age (Mode 3) at Kalambo Falls. In effect, the Mode 2/3 transition has not been dated at this site previously. TT-OSL has been used elsewhere to extend the age range of luminescence dating methods (*e.g.*, Jacobs *et al.* 2011), and at Kalambo Falls it extends the age of the Mkamba Member well into the Middle Pleistocene with a broad age range of ~500–300 ka (Duller *et al.* 2015). At present, it is not possible to refine the age range of this deposit further. The late Mode 2 horizons fall within this time frame, as does a single Mode 3 horizon in Unit C. The broad age range of the Mkamba Member does not give us a clear view of the timing of the technological changes underway, but it does provide the first chronological boundaries on this process in this region.

The technological differences between the various Mode 3 horizons in Site C North reflect a combination of differences in sample size, depositional history and, to some degree, technological change over time. The Unit C, Level 3 aggregate poses a particular methodological and interpretative challenge. This dense concentration of artefacts is too poorly constrained in time by its bracketing ages to contribute to discussions about technological trends, locally or regionally. Based on our interpretation of the formation of this deposit, its contents cannot be assumed to be contemporaneous. Given the likelihood that time-averaging has affected its content, we cannot assign the artefacts to a particular industry or phase. If this horizon is the techno-stratigraphic equivalent of Rubble I elsewhere at Kalambo Falls, then the previous recognition of two phases in the Lupemban Industry should be treated with caution. Clark (2001: 84, 89) distinguished an early from a later phase in Rubble I based on differing degrees of abrasion and on distinctions between the morphology of large tools, in particular core-axes, and an increase in the manufacture of blades and small backed tools in the later phase.

The mechanical and chemical weathering evident in the Level 3 horizon undermines our confidence in the use of surface condition as a marker of relative age. Artefacts attributed to the early Lupemban (Nakisasa Industry), however, were recovered from Ochreous Sands (Mkamba Member) deposits at Site A (in 1959 and 1963) and not described as exhibiting highly varying degrees of surface alteration (Rubble II, Kleindienst 1969; Clark 2001: figs. 4.18, 3.19). The inference is drawn that these horizons are similar in generation and preservation to the horizons found in the Mkamba Member in Site C North. The Unit C, Level 2 material recovered in 2006 might be a comparable early Lupemban horizon, but a much larger artefact sample is needed to support this attribution. The Sangoan Industrial Complex at Kalambo Falls (Chipeta Industry) is also identified from archaeological horizons in the Ochreous Sands of Sites A and B (Mkamba Member), which raises the possibility that Unit C, Level 2 could be attributed to this industry. The Chipeta repertoire includes rare handaxes and cleavers, large scrapers, knives, core-axes, picks, core-scrapers, and core choppers (Clark 1974: table 10; Clark 2001: 235–245). Core-axe and pick morphologies overlap with those of the early Lupemban. Scrapers are common; in the debitage category, prepared and blade cores occur but are rare (Sheppard & Kleindienst 1996: 182–183). Clark (2001: 245–246) observed an emergent trend in the Kalambo Acheulean/Sangoan towards the production of long blade-like and triangular flakes, but any faceting of butts is considered the unintentional by-product of biface thinning or from the knapping of discoidal cores. Gowlett *et al.* (2001) saw a closer technological affinity of the Sangoan to the Acheulean than to the MSA based on continuity in the use of LCTs, the rarity of specialised core forms, and the absence of points.

The small sample of artefacts recovered from Unit C, Level 2 cannot resolve the debate about the affinity of the Sangoan, and arguably the material from this horizon could be placed in either the Sangoan or the early Lupemban based on the absence of LCTs, the presence of a blade core, a prepared core, a prismatic/radial core, and the high frequency of faceted flakes. A much larger artefact sample is needed to assess either attribution. For now, the use of generic Mode labels is preferred for the Site C North material given the limited sample sizes.

Core-axes and picks continued to be made late in the development of the Site C North succession. They occur in Unit C2, Level 2 with an associated OSL age of 43.7 ± 2.0 ka. These heavy-duty tools have not been found in the Late Pleistocene (MIS 5-MIS 2) record at Mumbwa Caves which is the only well-dated succession in the region (Barham 2000). Their presence in Unit C2 may be the result of the fluvial reworking of older sediments or may represent local continuity in technological traditions. If the latter is the case, then the Kalambo Falls Late Pleistocene archaeological succession more closely resembles that of the Congo Basin (Cornelissen 2002) than that of the Zambia plateau.

The age range of the Unit C Mkamba Member has a bearing on another regional issue, the time span of the Lupemban Industry. The collapsed cave system of Twin Rivers, Zambia, provides the only other dated deposits in south-central Africa attributed to the Lupemban (Clark & Brown 2001). A single U-series date of ~265 ka is associated with the earliest part of the cave system and the Lupemban fill (Barham 2000), but the contact between the dated sample and the archaeological deposits has been questioned (Herries 2011; *cf.* Barham 2012). In the Congo Basin the Lupemban appears to be a Late Pleistocene entity younger than 40 ka based on radiocarbon dates (Cornelissen 2002, but see Taylor 2009). If the artefacts in Unit C, Level 2 are Lupemban, then a Middle Pleistocene age for the industry is supported in south-central Africa, which raises a wider issue about the meaning of the Lupemban as an archaeological construct. A much larger artefact sample from Site C North is needed to move this debate forward, along with a re-examination of the early and later Lupemban aggregates from Kalambo Falls.

Looking beyond the immediate region, Kalambo Falls remains one of the few sites in Africa which encompasses the Acheulean to Middle Stone Age transition in a stratified, though discontinuous, succession. In eastern Africa, the Kapthurin Formation in the Baringo basin, Kenya, offers the most complete and well-dated record of a continuum of change from the late Acheulean to the early Middle Stone Age (~549–285 ka). Blade (Mode 4) and prepared core (Mode 3) technologies emerge from a Mode 2 foundation and these technologies co-exist in the behavioural repertoire of their Middle Pleistocene makers (Tryon *et al.* 2006; Johnson & McBrearty 2010). Mode 2 handaxes and cleavers disappear from the Kapthurin record after 285 ka. The Olkesiteti Formation in the Olorgesailie basin, Kenya, promises to provide a comparable record of increasing technological variability, co-existence, and change in the Middle Pleistocene (Brooks *et al.* 2007). Elsewhere in the region there is now well-dated evidence for Mode 3 technology: at Gademotta in the Ethiopian Rift Valley by >279 ka in the form of prepared core technology and the production of hafted tools (Sahle *et al.* 2013). At Mieso, Ethiopia, on the southern margin of the Afar area, there is now well-dated evidence for persistence of Mode 2 handaxes and cleavers until 212 ka (de la Torre *et al.* 2014). In southern Africa, the site of Kathu Pan 1 provides early evidence for the hafting of artefacts, the use of prepared cores (Mode 3), blade making (Mode 4), and the making of small handaxes (Mode 2) — all of which lie in the 500–400 ka time range (Wilkins *et al.* 2012; *cf.* Rots & Plisson 2014).

The co-existence of multiple Modes may be a general feature of the Acheulean to Middle Stone Age transition as new technologies eventually replace older traditions. The longevity of the overlap of old and new technologies can be expected to vary regionally according to demographic, social and ecological conditions that can affect rates of cultural transmission (Barham 2013). In this wider continental perspective Kalambo Falls regains its importance as it bridges the geographical and chronological gap between the archaeological records of eastern and southern Africa. The site offers large existing collections of relevant artefacts from deposits that can now be dated more reliably. We cannot as yet characterise the transition as gradual or abrupt because of the uncertainties on the TT-OSL age ranges, combined with the discontinuous depositional record at Site C North and the size of the early Mode 3 sample. Further refinements in dating methods will be needed to constrain the age of the transition at Kalambo Falls, along with new excavations focussed on key parts of the succession relevant to the transition. In addition, a comprehensive re-analysis of artefacts from the Mkamba and Mbwilo Members would help to clarify the process of technological change that took place between the late Acheulean and early Middle Stone Age. As Sheppard & Kleindienst (1996: 173) conclude, comparisons between industries do not provide explanations for the observed changes but they focus our attention on the differences that need explaining.

Conclusion

This study is an important first step in realising Clark's vision of transforming Kalambo Falls into a site with a well-dated behavioural and palaeoenvironmental record. The application of TT-OSL and OSL dating, in combination with geomorphological, sedimentological, pollen, and mineral magnetic analyses, has helped refine our understanding of the genesis of the Kalambo Formation and its constituent Members as represented at Site C North. The complex processes of deposition and erosion that characterise meandering river systems are used to explain how the archaeological record formed as a largely coherent succession of discontinuous horizons that preserve a record of technological change spanning at least 300 ka. Poor pollen preservation, however, limits our ability to draw any meaningful conclusions about changes in the local habitat over time or to link our results to previous pollen studies at the site (*e.g.*, Taylor *et al.* 2001). Larger areal exposures are needed to develop an adequate pollen sample from this particular part of the site.

Fluvial winnowing and weathering processes have affected the completeness and surface quality of the archaeological evidence, but the lag deposits preserve spatial and technological information in a stratified succession. Kalambo Falls remains the key site in the region to document the shift from Mode 2 to Mode 3 technologies (Barham & Mitchell 2008). It offers large samples of artefacts representing variability in the late Acheulean and early Middle Stone Age (*i.e*., Sangoan and Lupemban horizons). The ability to date these horizons is critical to understanding their relationship to preceding and succeeding technologies in the region. In the case of Site C North, the dating results and sedimentological analyses place the Acheulean to Middle Stone Age transition within a broad time interval of 500–300 ka. The artefact sample excavated in 2006 is small, but suggests that the transition took place in this region of south-central Africa during the Middle Pleistocene. Further research is needed now to clarify the timing and process of technological change at Kalambo Falls.

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