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New Geomorphological and Archaeological Evidence for Drainage Evolution in the Luangwa Valley (Zambia) during the Late Pleistocene

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ABSTRACT

This is the first systematic investigation of two distinctive geomorphological features recorded in the central Luangwa River valley, Zambia. A series of low hills was found to be capped by thin (~1 m) gravel deposits containing stratified Stone Age artefacts. More widespread gravels occur on the margins of the Luangwa River floodplain lacking stratified artefacts. The previously unreported hilltop deposits are interpreted as remnants of a dissected land-surface, and the valley floor gravels as redeposited clasts from c. 20 m of down-cutting. Clast analysis and drainage basin size analysis support a hypothesis of gravel deposition by unconstrained debris flows from the distant Muchinga escarpment, or from an intermediate zone. Excavation of a perched deposit revealed a coarsely stratified Stone Age record indicating periodic emplacement of artefact-bearing gravels over an extended period. Deposition of these perched gravels continued into the Late Pleistocene (~77 ka), based on OSL dating, after which the current dissected landscape formed. We hypothesise further, based on a regional record of landscape instability and core data from Lake Malawi, that fan formation in the valley was linked to periods of extended aridity and reduced vegetation cover followed by episodic erosional events on the return to wetter conditions. We argue that the

subsequent dissection of the land-surface is the end state of a sequence of responses to base-level changes and climate change.

Keywords: fan deposits, landscape dissection, Stone Age archaeology, Late Quaternary, Luangwa Valley, Zambia

1.0 Research questions and research contexts

The Luangwa Valley of eastern Zambia is an extension of the East African Rift System (EARS) (Delvaux et al., 2012), but unlike the better-known rift valleys to the north and east it does not preserve detailed records of Quaternary climate change in datable contexts. As a result, comparatively little research effort has been invested in studying the valley's geomorphology or its archaeological record (Barham et al., 2011). A systematic programme of survey and excavation was undertaken between 2002 and 2008 in the central portion of the valley. Two distinctive geomorphological features were identified, mapped and their lithology examined. The first comprises gravels containing Stone Age artefacts in coarsely stratified deposits that cap a series of low-lying hills northwest of the Luangwa River. The second comprises gravel spreads on the floodplain on both sides of the river characterised by few artefacts and no stratification.

Two questions arise from these observations: 1) what local and regional conditions led to fan formation in the Luangwa Valley; and 2) what processes initiated the erosion of the fan deposits? The regional context of previous research provides the basis for generating two testable hypotheses linked to climate change and neotectonics as both processes have the potential to increase landscape relief relative to the base level, and thus cause down-cutting and the recycling of the perched gravels in the landscape as it adjusts to a lower base level (Harvey, 2005).

1.1. Regional research context

Thomas (1999, 2002, 2004), working near the Luangwa Valley in eastern Zambia identified extensive evidence of Middle and Late Pleistocene landscape instability characterised by slope failure and debris flow sequences. Fans and broad sheets of colluvium spread from the base of hillslopes towards river valleys in the Middle Pleistocene (>200 ka) and at least four times in the Late Pleistocene based on the OSL dating of colluvium at the base of flows (Thomas, 2002). Thomas (2004) interprets the periodic high energy flows as evidence of regional responses to periods of increased aridity during which reduced vegetation cover led to increased slope destabilisation, with debris flows following the onset of wetter conditions that initiated landscape dissection. More detailed hydroclimate data has since emerged for south-eastern Africa with evidence for increased aridity from the Limpopo River catchment during the Middle Pleistocene Transition (1.0-0.6 Ma) in response to high latitude ice-sheet expansion and global cooling of sea surface temperatures (Caley et al., 2018). Core data from Lake Malawi indicate an earlier shift to wetter conditions in the Middle Pleistocene after 800 ka punctuated by 15 episodes of drought followed by return to wetter conditions, with an increase in the frequency of drought after 450 ka (Lyons et al., 2015). These two records indicate a contraction of rainfall to lower latitudes or from the Limpopo to the Lake Malawi catchment (Caley et al., 2018). This evidence for large regional variability in hydroclimate reflects multiple forcing mechanisms governing moisture variability (e.g., eccentricity, precession, changes in ice volumes) (Caley et al., 2018). The Lake Malawi data are particularly relevant here given the lake's proximity to the Luangwa Valley and equivalence of latitude (9-13°S). There is evidence of a drought termination ~75 ka followed by increased precipitation transporting sediments from de-vegetated slopes into the lake (Brown, 2011). Stabilisation of the landscape occurs with the subsequent reforestation of the catchment area (Beuning et al., 2011). Increased precipitation is seen in the Lake Tanganyika record ~78 ka which may correlate with the end of drought in the Lake Malawi record, indicating a broad shift in climate dynamics at this time (Burnett et al., 2011).

1.2 A test hypothesis

We hypothesize a direct impact of these climate-driven arid intervals on vegetation cover and landscape instability in the Luangwa Valley in the Middle and Late Pleistocene. Aperiodic flash flooding created fans as they opened into the valley floor and deposited their sediment load. Archaeological material would be entrained in these flood events forming over time a discontinuous, partially mixed but coherent archaeological succession (Lang and Hönscheidt, 1999). In this model, dissection of the valley fill requires base level lowering during arid phases, possibly enhanced by gradual regional neotectonic uplift (Delvaux et al., 1992), that creates slope instability. A reduction of vegetation during dry phases would magnify the effect of mechanical erosion on the landscape initiated by the return of wet conditions. Active dissection of the fan deposits caused by flash flooding would leave perched gravels and redeposit gravels on the floodplain. Dissection switches off when a wet phase eventually comes to an end and the landscape becomes stabilised by vegetation cover.

Base-level lowering or uplift may not have been sufficient to cause dissection without increased wetness (Frostick and Reid, 1989). Regional uplift post-600 ka (Delvaux et al., 1992) may have affected sediment supply and the gradient of the Luangwa River, but without flash flooding there is no mechanism sufficient to initiate landscape dissection.

The Luangwa River as a tributary of the Zambezi is affected by base-level changes of this larger system. The modern Zambezi formed as the result of the merger of two independent drainage systems at Victoria Falls which increased the sediment discharge of the combined system with its additional tributaries (Thomas and Shaw, 1988). The mechanisms and timing of the merger, however, remain unresolved (e.g., Moore et al., 2012), and data from the Zambezi delta are too poorly constrained chronologically and spatially to provide a reliable record of base-level change over time (Castelino et al., 2017). The regional hydroclimatic data from the Limpopo basin, Lake Malawi and Lake Tanganyika collectively point to base-level lowering as being primarily climate driven with aridity being caused by ice-sheet expansion (Caley et al., 2018). Neotectonic uplift may play a role in the Luangwa Valley but at present it is not possible to distinguish its effects on base-level change from that of climate (e.g., Ritter et al., 1995). The limited chronology from the Luangwa Valley fan deposits (Section 3.5) supports a linkage between aridity then wet phase erosion as sculpting factors of the Late Pleistocene landscape.

1.3 Geological research contexts in the Luangwa Valley

The most prominent geological feature in eastern Zambia is the Luangwa River Valley which extends 700 km across eastern Zambia from its source in the highlands of northern Malawi to its confluence with the Zambezi River (Figure 1). The river meanders over an area of relatively low topographic relief within the confines of an elongated trough of half-grabens that form a southwest – northeast extension of the EARS (Utting, 1976; Sepulchre et al., 2006). Rifting was reactivated in the late Miocene after a long hiatus (Daly and Watts, 2017). The valley is up to 90 km wide, with a floor ranging in elevation from 400 m above mean sea level (a.s.l.) at its lower reaches to 1000 m a.s.l. at its upper reaches (Astle et al., 1969). The valley is bounded by steep escarpments of Archean granites and metamorphic rocks on its western and eastern margins (Dixey, 1937; Utting, 1976; Thieme and Johnson, 1981) (Figure 1). The underlying basin fill lithology is characterized by Karoo Supergroup sediments from the Later Carboniferous to the Early Jurassic (c. 190 Ma) (Drysdall and Weller, 1966; Kemp, 1975; Utting, 1988). A thin mantle of Quaternary surface deposits lies unconformably on the Karoo mudstone and shale deposits and includes Holocene floodplain sediments as well as Pleistocene sands and gravels (Utting, 1988). The Karoo and Quaternary deposits offer siliceous materials that were used by early humans for toolmaking, including silicified wood, quartzite, quartz and a chert-like material (silcrete) (Barham et al., 2011). Stratified Stone Age sites are rare, however, because of site destruction caused by the high rate of channel migration during wet season discharge (Gilvear et al., 2000; Colton, 2009; Bishop et al., 2016).

1.4 Archaeological research context

Before 2002 limited archaeological research had been undertaken in the Luangwa Valley (e.g., MacCrae and Lancaster, 1937; Clark, 1950). Of relevance here are the reports by Dixey (1944) of stone tools of presumed Pleistocene age found overlying extensive gravel deposits that occur up to 60 m above the river channel. Dixey also found Stone Age artefacts on the surfaces of low gravel mounds located beyond the floodplain. Clark (1950) used the differences in the elevations of the gravels and the typology surface artefacts to develop a relative chronology for the valley.

The first systematic geomorphological and archaeological research in the valley took place between 2002 and 2008. The aim of the research was to map the Quaternary landscape of the central portion of the valley and to develop a chronology of human settlement. The study area was located near the town of Mfuwe and encompassed part of the South Luangwa National Park (SNLP) and adjacent game management area (Figure 1). The results included a detailed geomorphological map of the area (Colton, 2009), and the foundations of a Pleistocene framework for the human use of the valley (Barham et al., 2011; Bishop et al., 2016).

The mapping programme recorded the low mounds (<1 m high) of cobbles described by Dixey (1944) beyond the active floodplain and confirmed his observation that they have no internal structure and no consistency in artefact content (Colton, 2009). The first stratified Stone Age succession was excavated along the Manzi River, a tributary of the Luangwa River (Figure 2). Early and Middle Stone Age artefacts occur here in a discontinuous sequence of fluvial and colluvial deposits uncomformably overlying Karoo sediments. The fluvial context of the Early Stone Age (ESA) artefacts was dated by palaeomagnetic correlation to ~1.1 Ma and the Middle Stone Age bearing colluvium (MSA) was dated by isothermal luminescence to 78 ka (Barham et al., 2011). Elsewhere in the central part of the valley, Holocene sites (Later Stone Age, Iron Age) have been excavated in rock shelters and along tributaries of the Luangwa River (Barham and Jarman, 2005; Fletcher, 2010). Large gaps remain in the Stone Age record of the valley, but more broadly the evidence from Zambia points to a transition from the ESA to MSA occurring between 500 ka – 300 ka (Barham et al., 2015), and the MSA ending

~25 ka (Phillipson, 1976). These date ranges provide a framework for the Stone Age used in this study.

2.0 Research Methods

Outlined briefly are the methods used to map and source the gravels within the study area. A single hilltop site was selected for excavation and the methods are described. The artefact analyses are designed to assess the relative age of the deposits and provide evidence of depositional processes. Optically stimulated luminescence (OSL) protocols are presented for sand samples collected from the hilltop excavation.

2.1 Mapping the gravels

The study area (16 km x 14 km) encompasses the Luangwa River, its floodplain and flanking features to the southeast and northwest. The Luangwa River enters from the north and exits to the southwest, cutting a diagonal course at an elevation of 530 m – 520 m a.s.l. (Figure 2). Aerial photographs (1:50,000) were used to initiate the mapping and to direct field analysis of the landform assemblage and sedimentary exposures. These data were recorded by GPS. The deposits were georeferenced onto 1:50,000 Zambian Survey maps in Arc GISTM which was used to store and edit data and create maps. Figure 2 shows the geomorphological features and clast sampling areas recorded in the study area.

Wallace (1907) noted the presence of gravels at the edges of the Luangwa floodplain, and the current survey built on this observation. On the floodplain, few large clasts are visible on its sand and silt surface and our sampling strategy focused on exposures in channel cuts of ephemeral tributary streams. The Nchindeni Hills are the dominant feature on the southeast bank which is drained by six seasonal streams including two named rivers, the Chowo and Kafunta (Figure 2). Gravel capped low hills of Karoo sediments (540 m a.s.l. and higher) occur only on the northwest bank and rise 20 m above the floodplain and valley floor gravels. Chipembele Ridge is a separate feature on the northwest bank; a prominent hill rising 60m above the floodplain (580 m a.s.l.). The ridge is also formed of Karoo sediment and capped by gravel deposits of unknown depth (Figure 2). Behind the ridge the topography drops sharply by 20 m and then rises gradually 140 – 200 m above the floodplain westwards towards the Muchinga Escarpment (Figures 2, 3).

The spatially restricted hilltop deposits contrast with the widespread distribution of unstructured gravels on the margins of the valley floodplain (Colton, 2009). To understand the relationship, if any, between these two geomorphological features their distribution was mapped, and lithology described using coarse clast analysis. Coarse clast (B-axis > 2 cm) analysis enables a rapid assessment of probable sources of pebble to boulder grade material (Howard, 1993; Mather, 2011). The method is particularly useful in logistically challenging areas (e.g., Adhikari and Koshimizu, 2005). Although attempts have been made to quantify errors associated with the datasets created by clast analysis (e.g., Howard, 1993; Wohl et al., 1996), most studies continue to employ qualitative methods (e.g., Steel et al., 1977; Heward, 1978; Adhikari and Koshimizu, 2005; Went, 2005).

The localities for clast counts were selected to give a broad coverage of the survey area given the limitations of the network of unsurfaced roads and availability of sections. Sections were described in terms of sedimentary structures after Miall (1977). At each locality 100 clasts greater than 2 cm were selected and their lithology recorded. Where time and safety permitted, angularity and clast size (A, B and C axis measurements) were recorded in the field. Twenty-three localities were sampled with the lithology recorded for 2300 clasts, B-axis for 1400 of the clasts, and angularity for 1600 of the clasts (SM Tables 1-3a). Twelve localities were recorded on the northwest bank and fourteen on the southeast bank (Figure 2) and the results are outlined in section 3.1.

1.2 Archaeological methods

On the northwest bank of the Luangwa River, four concordant hills (NW-SE) were surveyed with the hilltops rising 20 m above (540 m a.s.l.) the Luangwa floodplain (Figure 2). Each hilltop had microlithic quartz artefacts (Later Stone Age, LSA) on the surface and larger artefacts (quartzite, silcrete) on adjacent slopes. The least vegetated hill-top platform was chosen for excavation and labelled SL8 (South Luangwa 8) and referred to as Locality 28 in the geomorphological survey.

The hilltop and slopes were sampled in three separate excavation blocks: Block 1 (B1, 2x7m), Block 2 (B2, 2x3m) and Block 3 (B3, $2m^2$) (Figure 4a). Each block was excavated into the clay surface of the weathered Karoo mudstone. Artefacts are found in the upper 5-7cm of the clay, but no deeper. B1 and B2 sampled the steep slope on the southwest side of the ridge and B1 was subdivided into Areas 1-3 (Figure 4b). The deepest deposits were sampled in B1, Area 1 on the edge of the hilltop platform, and in B3 located in the centre of the platform (Figure 4b).

Excavation took place in natural levels identified by changes in artefact content, sediment colour, texture or composition and followed the slope of deposits. Arbitrary excavation levels (5-10 cm) were used within thick natural levels where no changes were evident in sediment or content. All deposits were sieved (2 mm mesh); no bone or charcoal was found. The B3 section (Figure 5) was sampled for OSL dating with dosimetry measured in situ.

The SL8 material was analysed using the techno-typological approach described in Barham (2000: appendix 1) and which has been applied to other Stone Age sites in Zambia (Barham et al., 2011, 2015). Emphasis is placed on the analysis of the attributes of flakes and cores as these are the most common artefacts in the regional Stone Age (Tryon and Potts, 2011). Supporting evidence of Stone Age affinity is drawn from the types of retouched tools, trends in raw material selection and relative stratigraphic position. The resulting evidence of patterns of tool reduction is linked to culture-stratigraphic labels of Early, Middle and Later Stone Age (Barham and Mitchell, 2008). The Age attributions provide a coarse relative chronology.

The extent of surface abrasion was recorded on artefacts to assess the formation of the gravels in terms of movement, mixing or compaction (Shea, 1999). Qualitative criteria were applied based on

Clark (1974, p.103) with five categories based on a gradation of edge abrasion from fresh to heavily worn. If an artefact exhibited more than one category of abrasion the highest level was recorded. Refitting flakes to cores was also attempted as an indicator of taphonomic disturbance, with only one refit found (basal clay B1, Area 3). The quantity and size distribution of small flaking debris (<20mm) was recorded as evidence of artefact manufacture where abundant (Andrefsky, 2005) or evidence of sorting by depositional processes where rare or absent (Sheppard and Kleindienst, 1996). The results are analysed in Section 3.3.

1.3 Dating method

Three sediment samples were collected from the upper part of the B3 section for optically stimulated luminescence (OSL) dating. Quartz grains 90 to 250 μm in diameter were separated for luminescence analysis, and dose rates calculated in the field (gamma spectrometry) and in the laboratory based upon thick source alpha counting and beta counting (Table 1a). Small aliquot measurements including a preheat plateau test were undertaken to assess the luminescence behaviour of the quartz, but the focus here is on the single grain measurements for the three samples. Measurements followed the procedures described in Duller et al. (2015) and the results are discussed in Section 3.5.

3.0 Results and interpretation

The results of the mapping and clast analyses are discussed including the lithology of the SL8 sediments. The archaeological succession is outlined in terms of a relative chronology and the emplacement of deposits is interpreted based on artefact content and abrasion data. The dating results are summarised and interpreted using a maximum age model (Duller et al., 2015). The clast data are used to assess potential sources for the hilltop gravels and depositional processes able to generate a long but discontinuous archaeological record.

3.1 Clast analysis

The clast count results at each of the 23 sampling locations are summarised in Figure 6. The perched gravels on the northwest bank were examined in sections exposed at SL8 and Locality 12, a quarry, and as surface collection made on adjacent hilltops (Localities 22, 23). At SL8 the sediments are poorly sorted with little internal structure or stratification, although there are localised loose imbrications (Figures 5, 7). The matrix comprises fine to coarse sand, with little silt and usually no clay component. The clasts are 94% quartzite, 5% other metamorphics and 1% sandstone. Chert (silcrete), quartz and silicified wood occur locally within a 3 km radius but are rare components of the gravels (Colton, 2009). The clasts are sub-angular (39%) to sub-rounded (32%), with a small angular component (9%), and the remainder rounded (18%) or well rounded (2%) (Stow, 2005). A similar sedimentary matrix and lithology was recorded at Locality 12.

At Locality 32 on the northwest bank and below the perched gravels a thin scatter of quartzite gravel was found on well-lithified Karoo mudstone and interpreted as outwash erosion from the hilltops as there are no other gravel sources nearby.

On the southeast side of the Luangwa River the geography is dominated by the Nchindeni Hills which occupy a large portion of the survey area. Localities 34 and 35 were at altitudes of 640 m and 570 m a.s.l. respectively and sample the thin hill slope regolith. No artefacts were found and were rare at these altitudes generally (Colton 2009). Most sampling areas were stream exposures that gave access to sections and stream beds of debris flows at the foot of the hills (Localities 8.1, 8.2, 11, 19, 33, 9.1, and 9.2). Localities 17 and 18 were bedload samples from small ephemeral streams on the easternmost edge of the Nchindeni Hills in the study area. Also notable are Localities 16 and 31 which sampled gravels from an area of deep sandy sediments that support mature woodland (*Colophospermum mopane*). Artefacts were noted at, or in the vicinity of counts 16 and 31. Excavation at a spring site near Locality 16, to be reportedly separately, produced stratified evidence of Iron Age and Later Stone Age occupation in 3 m of sands and silts overlying gravels. These finegrained deposits are unlike the perched gravels at SL8 and their proximity to the Luangwa River and shared elevation with the floodplain suggests a different depositional history.

A lithological comparison of gravels either side of the Luangwa River reveals differences in composition (SM Table 1). Gravels from the northwest side are characterised by a predominance of quartzite clasts and are broadly similar in composition to the key hill-top section at SL8. The exceptions are deposits in proximity to the uplifted Archaean block of Chichele Hill (Localities 14 and 24, Figures 2, 3), where the clasts are exclusively granitic and metamorphic. By contrast the lithologies to the southeast bank of the Luangwa adjacent to the Nchindeni Hills are more varied. Quartzite still comprises the majority component (63% - 85%) with the remainder a mix of metamorphics, granites, quartz, and chert (silcrete). At higher elevations (Localities 34, 35) there are no traces of the quartzite, and here, clasts occur as part of the thin regolith covering the hills. Quartzite is also absent from the stream bed and channel wall at Localities 8.1 and 8.2 where metamorphic and granite clasts predominate. Their lithology is similar to that of the adjacent Nchindeni Hills indicating a local origin.

The bedloads of the larger seasonal rivers that flow from deep within the Nchindeni (Chowo, Kafunta) resemble the lithology of the hills in the high proportions of metamorphic or granitic clasts though they do contain quartzite. The quartzite from the Kafunta, however, differs in structure from the Chowo quartzite and is unlike that found northwest of the river, as there is a lineation in the crystal fabric that causes the rock to weather and erode in tabular rather than rounded clasts. [A single Acheulean handaxe (Early Stone Age) made on tabular quartzite was found in the Kafunta stream bed.] The Chowo quartzite is more similar in structure to that found to the northwest as is the quartzite from Localities 11, 16, and 31. These localities are within the Luangwa floodplain and the material sampled does not derive from perched deposits as at SL8, but from more discrete scatters on the floodplain sands and silts (16 and 31), or channel wall lag deposits (Locality 11). They are interpreted as recent lag deposits of the Luangwa River cut and fill activity.

The angularity data (SM Table 2) show a difference between the hilltop gravels on the northwest bank which have higher proportions of rounded clasts than gravels on the southeast bank on or near the Nchindeni Hills which tend to be more angular indicating they have not been transported far. The difference in angularity is interpreted as an indication of distance transported rather than differences in hardness of the primarily metamorphic and granitic materials.

3.2 Clast data interpretation

There are clear differences in geomorphological contexts and lithologies of the gravels either side of the river. There are no perched gravels to the southeast, and the perched and valley gravels on the northwest bank differ lithologically in their higher percentages of quartzite. The floodplain gravels on southeast bank are probably lag deposits of previous channel offcuts and represent recent re-deposition of clasts local to the Nchindeni Hills.

The clast size results do not indicate significant differences (paired t-tests) across the survey area (SM Table 3b[B]). These data cannot be used to indicate fining out in any direction from a particular source. To the northwest of the Luangwa, however, towards the Muchinga Escarpment clast size is statistically larger than elsewhere (SM Table 3b[A] suggesting that the Muchinga may be the ultimate source of material, assuming larger clasts have been deposited nearer to a potential source and lighter material was transported further. The angularity data are inconclusive; the larger proportion of rounded clasts indicates that they have been transported further, but potentially from either the centre of the valley or the Nchindeni Hills.

There are no modern equivalents of the SL8 hill-top deposits forming today, and this observation applies to the gravels across the study area (e.g., Localities 22, 23 and 32) — they are a relict feature. The modern drainage system is dominated by the sand bed fluvial system of the Luangwa River and its tributaries which are developed on both sides of the Luangwa floodplain, but predominantly on the western side rising from the Muchinga Escarpment. The Holocene and modern fluvial system does not appear to be carrying significant coarse clast assemblages, beyond the limited lag deposits in the floodplain streams. There are, however, geomorphic processes producing lag deposits of gravels as seen in the vicinity of Localities 26 and 27 (Figure 2) where localised seasonal flooding is removing a large proportion of fine material from the Holocene sedimentary sequence that overlies unconformably the Karoo, leaving a collapsed sequence of only the coarser Holocene material. In this environment the mixing of sediments results in late Holocene Iron Age pottery being found underneath Early Stone Age artefacts (Colton, 2009). Such stratigraphic displacement is not present in the SL8 Stone Age sequence making this an unlikely formation process among the exposures studied.

Sedimentary structures are extremely rare in the gravels generally, with only partial imbrication in places and little by the way of bedding or internal structure. The fabric of the material displays characteristics associated with tractional flow events, as well as more debris rich hyper-concentrated type flows. Only a few loose imbrications were observed (Figure 6) and we would expect more clast imbrication to be preserved in a fluvially dominated environment (see Prothero and Schwab, 1996; Knighton, 1998) as is the case at the Manzi River section (Barham et al., 2011). As an alternative formation process, we consider the Muchinga Escarpment as a potential source of material distributed by alluvial fans. This hypothesis is developed further in Section 4.1.

3.3 Archaeological results

The artefact analyses focus on the hilltop deposits in B3 and in B1, Area 1, as they offer the greatest potential for detecting chronological patterning and for inferring formation processes. B1, Areas 2-3 are not discussed except in relation to specific artefacts that contribute to building a relative chronology for the site. The results are presented by flake and core attributes including, whole flake size (length), extent of abrasion and raw materials used, distinctive core types and retouched tool type frequencies (after Barham, 2000).

3.3.1 B3 Results

Eleven levels were identified from surface to base with Level 9 being a small feature within Level 8 and Level 11 excavated into the top of the basal clay (Figure 7). For this study, the Level 9 material is integrated into Level 8 and the revised Level 9 is a combination of Levels 10 and 11 (7 cm of deposit). The Level 1 artefacts were missing in 2008 when the analyses were undertaken, but the context sheet records "a dense concentration of small quartz debitage with bladelet cores, retouched tools (segments, scrapers), some fire-cracked rock and pigment…. A drop in artefact content 5 cm below the surface led to a level change". A total of 685 artefacts were recovered from B3 excluding Level 1. Of these, 206 artefacts were small flakes and chunks (<20 mm), 67 angular chunks (>21 mm), 200 broken flakes (>21 mm), 119 whole flakes, 80 cores, 8 retouched pieces and 5 utilised pieces. The numbers of flakes, cores and retouched tools are too small to make meaningful statistical comparisons between levels. Qualitative differences are noted when useful for comparisons.

The distribution of flake types by level shows a prevalence of quadrilateral and irregular forms throughout the sequence. These flake forms are not time or technology sensitive, however, from Level 4 and below there are increased frequencies of convergent and pentagonal flake morphologies, and these are indicative of a centripetal flaking strategy (Barham et al., 2011) (Figure 8h, i) (Barham, 2000). Centripetal flaking occurs in the LSA but is a more consistent feature of MSA and ESA flaking strategies. A split spheroid in Level 8 (Figure 8l), perhaps used as a hammerstone, also points to either an MSA or ESA attribution as these objects are not part of the LSA technological repertoire.

The sample of cores shows some qualitative trends that reflect differing techniques of core production indicative of broader technological patterns. Bipolar cores are found only in Level 2 and this technique of working small quartz cobbles is a feature of the local LSA (Fletcher, 2010). Centripetal flaking (radial and disc cores) as well as the peripheral flaking of split cobbles occurs from Level 3 to Level 9. The centripetal strategy is a feature of the MSA and later ESA regionally (Barham et al., 2015). There are no prepared cores. Split and flaked cobbles ('choppers') occur in Levels 7 – 9 (e.g., Figure 8j).

Among the retouched tools a quartz segment (Figure 8a) and 'chert' (silcrete) borer from Level 2 are distinctive LSA tools found widely across Zambia (Miller, 1971; Phillipson, 1976), including the Luangwa Valley (Fletcher, 2010). A broken pick was found in Level 9 and this heavy-duty tool occurs in the ESA and early MSA (Clark, 1974; Barham et al., 2015). The single scraper in Level 7 is not diagnostic of a particular technological tradition, but awls ('becs') like those from this level feature in the regional MSA (Barham, 2000).

The majority of small flakes and chunks occur in Level 2 (n=122, 59.2%) decreasing in Level 3 (n=47, 22.8%) and Level 4 (n=26, 12.6%) and then below 1.5% (n= ≤ 3) in Levels 5-9. A boxplot of flake length (Figure 9a) shows the median to lie between 30-40 mm in Levels 2-5 and to be in the 40-50mm range in Level 6-9. The size of the largest non-outliers also increases in the lower levels as does the size and number of outliers above 80 mm. The higher frequencies of larger flakes in the lower levels correspond with an increase in quartzite as a raw material and decline in the use of quartz which is most common in Levels 2-3 among the knapping debris. Chert (silcrete) occurs infrequently with no patterning through the deposit and silicified wood is rare.

A cross-tabulation of abrasion categories on whole flakes by raw material shows Levels 2 and 3 as having the highest frequencies of the least damaged artefacts (SM Table 4). Moderate and worn to very worn degrees of abrasion, however, occur in all levels excepting Level 3. This consistency of the abrasion mix points to a similar depositional process throughout the sequence except near the surface.

3.3.2 B1 (Area 1) results

Seven excavation levels were identified from top to bottom with Level 7 being the basal clay (Figure 10). A total of 533 artefacts was recovered: 100 small flakes and chunks (<20 mm), 44 chunks (>21 mm), 146 broken flakes (>21 mm), 126 whole flakes, 103 cores, 6 utilised and 8 retouched pieces. As in B3, the upper two levels contain the bulk of the small flaking debris <20 mm and most of this is quartz in Level 1 (n= 57; 93%). Below the surface (Level 1), artefact frequencies are low excepting Levels 4 and 6 which provide the most useful chronological markers.

Non-diagnostic quadrilateral and irregular flake forms are the most common throughout the sequence as in B3. Pentagonal flakes as indicators of centripetal flaking occur in each level and are most numerous in Level 4. This level also contains a single convergent flake with a multi-facetted butt potentially indicative of MSA prepared core technology (Clark, 1974). A boxplot of flake length by level shows an increase in median and range from Level 2 and below (Figure 12). As in B3 there is consistency in abrasion distribution on whole flakes throughout the deposit with all levels showing a range from sharp to very worn, with the least abraded pieces in the upper deposit (Levels 1, 2) (SM Table 5).

Among cores, the most distinctive indicator of flaking methods is the presence of radial (quartzite and conglomerate) and prepared cores (silcrete, milky quartz in Levels 4-6 (SM Table 6). The size and raw material (quartzite) are indicative of MSA techniques of core reduction in contrast with the small quartz cores in Level 1 (Figure 8b) which are typical of LSA strategies.

Of the eight the retouched tools (Figure 11), three are useful culture-stratigraphic markers. A quartz segment in Level 1 (Figure 8a) is distinctive of the LSA and the two picks in Level 5 are suggestive of the ESA based on research elsewhere in Zambia (Clark, 2001). Downslope in B1, Area 3, a weathered core-axe (Figure 8d) was found on the surface and this tool form associated with the late ESA and early MSA (Barham et al., 2015). The basal clay of B1, Area 2, preserved an unabraded core and refitting flake of silicified wood (Figure 8f) that were found together suggesting that this lowest deposit is the least disturbed.

3.4. Interpretation of the archaeological data

SL8 preserves a discontinuous but coherent archaeological succession. The hill-top surface and upper 10-15 cm contain artefacts which in size, raw material, and form are consistent with the regional LSA (Phillipson, 1976; Musonda, 1984; Fletcher, 2010). The abundance of flaking debris indicates tool-making on the surface of the hill, and this relatively fresh material contrasts with the more abraded artefacts below. Beneath the LSA are found sporadic artefacts of MSA affinity (e.g., prepared cores) with some large flakes and cores in the basal deposits which may represent ESA reduction strategies. The identification of an Early Stone Age component is tentative given the absence of diagnostic large cutting tools (cleavers, handaxes). A similar problem of attribution was faced at Localities 21 and 30 where previous excavations identified the ESA by the presence of large flakes (>10cm) and the age of the deposit (1.1 Ma) (Barham et al., 2011). As a generalisation, large bifaces (handaxes, cleavers) are rare in this central area of the Luangwa Valley, but the core-axe from B1, Area 3, and the picks from B1, Area 1, Area 3 and B3 (e.g., Figure 8c) are the clearest indicators of an early human presence in this deposit.

The co-occurrence of artefacts with contrasting degrees of abrasion through the deposits reflects processes that delivered clasts with differing states of surface preservation, excepting the comparatively fresh surface LSA material. A coarsely resolved archaeological succession also indicates a process that was repeated at intervals by intermittent episodes of entrainment in flowing sediments (Malinsky-Buller et al., 2011). The LSA record post-dates this process and subsequent bioturbation has mixed some of the LSA with more abraded MSA material.

3.5 OSL dating results and interpretation

Three sediment samples were collected from the upper part of the B3 section for OSL dating (Figure 7) and the results and analytical data are summarised in Figure 13a.

Sample 1 (SL8-1) was collected from a depth of 5 cm below the surface associated with the LSA occupation of the hilltop (Level 1). Samples 2 and 3 (SL8-2, SL8-3) were collected from a depth of 23 cm (Level 3) and 43 cm (Level 5) respectively and are associated with MSA artefacts. No samples were collected from the lower levels. The near surface sample (SL8-1, Figure 13b) is relatively well bleached and gives an apparent age (using the minimum age model) of 210±10 years. This could date deposition of the sediment at the site, but it could also reflect the rate at which modern surface processes are moving sand sized material in the profile and bringing it to the surface. The two deeper samples have very widely scattered data sets (Figure 13c, d), though the equivalent dose values for SL8-3 are higher than those for SL8-2, implying that it is older, as would be expected given their stratigraphy.

SL8-1 has been very effectively reset, indicating either that the sediment has been deposited very recently (within the last 200 years), or that modern processes (including bioturbation) are moving the 90-250 µm diameter grains through the sediment sequence, giving them the opportunity to be bleached at the surface. The age of the surface sample could be recording the most recent use of the site by LSA hunter-gatherers, but we interpret the young age of these surface sediments as the product of reworking by bioturbation, and possibly the incorporation of recent aeolian sands.

The scatter in SL8-2 may be indicating deposition by either fluvial or colluvial processes which can produce incomplete bleaching. This degree of incomplete bleaching, however, is very large (Figure 13c) and the age calculated using the minimum age model (Table 1b) would imply that deposition occurred very recently (2.88 ka). Alternatively, this deposit may be much older, and the scatter is the result of post-depositional movement of sediments in the profile by bioturbation. If the scatter results primarily from bioturbation bringing younger grains from the surface, then the population of grains that most closely records the original deposition of the sediment would be the oldest grains. The maximum age model was applied to this data set to statistically isolate this oldest population of grains (cf. Olley et al., 2006) and gave an age of 77.0±7.9 ka. The youngest grains give ages that are in stratigraphic order, and these may be indicating the rate at which sand sized grains are migrating up and down this profile from processes including bioturbation (cf. Heimsath et al., 2002). The very small number of saturated grains in this sample (Table 1b) suggests that the maximum age calculated is credible (77.0 ± 7.9 ka) but we remain cautious about this interpretation in the absence of other samples from this depth to test for stratigraphic consistency.

There is indirect support for the reliability of the maximum age of SL8-2 from the nearby Manzi River section where MSA artefacts in colluvium are found near the top of the section and dated to 78.1 ± 5.0 ka using isothermal luminescence (Barham et al., 2011). The similarity in dates between the two sites may be coincidental or indicate a period of active deposition locally. Resolution of this issue will require further sampling and dating at SL8.

The single-grain De distribution in the lowest sample, SL8-3, is also very scattered with a considerable proportion of the grains in saturation (>30%, Table 1b). Mixing among very old samples may account for the broad range of the scatter including the saturated component, but if this is the case then we would expect to see more saturated grains in SL8-2. Bioturbation alone is also unlikely to account for this complex pattern. We suggest that the maximum age model De value could well be a significant underestimate, and that this sample is beyond the OSL dating range. Other dating methods, such as thermally transferred – OSL (TT-OSL) (Duller et al., 2015) or ESR single grain dating (Tsukamoto et al., 2015) will need to be considered if we are to develop a chronology for these lower deposits.

The dating results support the archaeological evidence for deposition of the upper ~45 cm in the Late Pleistocene, with possibly earlier deposits which are beyond the age range of OSL dating. The recent age of the surface sands is attributed to bioturbation and possibly aeolian activity.

4.0 Hypothesis testing

4.1 Fan deposits in the Luangwa Valley

Our hypothesis that climate change and possibly neotectonic activity altered drainage patterns in the central Luangwa Valley derives primarily from the research of Thomas (1999) near Chipata 80 km to the southeast of the Luangwa Valley (Figure 1). He identified alluvial fan deposits (sands and gravel) overlain by landslide and debris flows comprising local weathered basement rocks (granulites, schist, quartzite). This evidence of high energy events occurs on all hills of similar geology in a study area of 10 km^2 indicating events on a regional scale (Thomas, 2004, p. 120). More than 200 landslips have been reported from the granitic Nyika Plateau in northern Malawi, the area of the headwaters of the Luangwa River (Shroder, 1976).

In the Chipata area, OSL dating of colluvial sediments indicates active deposition in the Middle Pleistocene (>180 ka), and at intervals in the Late Pleistocene (65 ± 5.0 ka; 56 ± 6.0 ka; 22.8 ± 1.5 ka) and in the early Holocene (9.1 ± 0.6 ka) (Thomas, 2002). Increased aridity destabilised slopes in the region by reducing vegetation cover, and slope failure led to the formation of piedmont slopes of colluvium and alluvium accumulated during short, intense periods of landscape change following the onset of wetter conditions (Thomas and Murray, 2001; Thomas, 2004).

In the Luangwa Valley study area, debris flow deposits consisting of granite and metamorphic fragments were mapped at the base of the Nchindeni Hills (Localities 8.1, 8.2). On the northwest bank of the river, the hill-top gravels with their discontinuous archaeological succession are interpreted as evidence of periodic fan deposits derived from the Muchinga Escarpment or an intermediate source. The escarpment dominates the topography of the valley when viewed from the valley floor and is incised with deep river channels (Figure 2). Two of the largest rivers are the Mupamadzi and Kapamba that drain into the Luangwa (Figure 1). Under more arid conditions these river channels would be much less defined and conducive to the development of alluvial fans (Harvey, 1997). Alluvial fans comprise a suite of diagnostic depositional features and sequences, some of which might be expected in the Luangwa Valley including gravels, cross-bedded sandstones, debris flow, fluid flow, and hyperconcentrated flow deposits, as well as channel cut and fill structures (Wells and Harvey, 1987; Blair, 1999; Mahapatra and Dana, 2009; Pendea et al., 2009).

The gravels on both banks of the river with their poorly sorted clasts in a matrix of coarse-to-fine sands, some silt, but little clay resemble hyperconcentrated deposits (Smith, 1986; Wells and Harvey, 1987; Harvey, 1997; Mather and Hartley, 2005; Meetei et al., 2007). Such deposits typically contain gravels and cobbles deposited during unusually large flood events in environments where there is a large amount of available sediment (Smith, 1986; Batalla et al., 1999; Meetei et al., 2007).

Hyperconcentrated deposits are documented in alluvial fan systems (Batalla et al., 1999; Mather and Hartley, 2005; Lafortune et al., 2006; Meetei et al., 2007; Pope and Wilkinson, 2005). As noted above, typically a suite of deposits would be used to identify the depositional environment as an alluvial fan, although not all features would necessarily be present in any one fan as the architecture and range of deposits would vary dependant on past and present environmental and geomorphological factors (see Wells and Harvey, 1987; Blair, 1999; Mahapatra and Dana, 2009; Pendea et al., 2009; Aharipour et al., 2010).

In the case of the Luangwa gravels, there are no other associated fan deposits, and they are perhaps best described as a relict palaeodrainage system that has created a pediment surface, now eroded, and perched 20 m above the modern floodplain. In this scenario where the confined streams from the valley sides open to unconfined flows on the valley floor, material has been deposited during high energy runoff events. If other typical alluvial fan sequences did exist then they have either not yet been discovered or been removed; such differential erosion has been documented in other semi-arid environments (e.g., Maizels, 1990).

The data presented here can provide more insight into the origin of the deposits but must be understood in relation to potential sediment sources and Pleistocene environments (see 5.1). Two separate sources are suggested for the gravel deposits on either side of the Luangwa River. The variable lithologies seen in the localities on and close to the Nchindeni Hills indicate a localised source for the gravels on the southeastern side of the Luangwa River. The gravels on the northwest bank with the exceptions of those sampled near Chichele Hill, are uniformly quartzite, suggesting a different source than the Nchindeni Hills. The clast size analysis suggests a direction of transport from the centre of the valley towards the Luangwa, as the clasts are demonstrably larger behind Chipembele Ridge which would indicate a source from the Muchinga Escarpment 44 km distant.

Given the distance involved, a spatial analysis was undertaken to estimate drainage basin size and likely fan sizes of the local rivers based on the correlation between alluvial fan area and drainage basin size (Guzzetti et al., 1997; Leeder, 1999). Other variables can affect the correlation such as basin slope, sediment yield (Oguchi and Ohmori, 1994), length of the mainstream, and drainage density (Church and Mark, 1980; Prabhakaran and Jawahar Raj 2018), but in this study it is only feasible to estimate the current drainage basin size of tributaries. We used tables from Guzzetti et al. (1997) and Leeder (1999) (Table 2), and on the northwest and southeast sides of the Luangwa gravels cover approximately 22 km^2 and 14.4 km^2 respectively. The fan area required to include all the gravels was calculated assuming deposits would have covered the modern floodplain of the Luangwa. On this basis, the gravels covered 100 km^2, which is the upper range of fan areas that could be produced by the Chowo River. The Chowo, however, is located on the southeastern bank and is unlikely to have been the primary source for the material on the northwest bank given the differences in lithologies between the two areas.

Despite the distance of the Muchinga Escarpment from the survey area, it is not unknown for a fan to extend this far. The Kosi megafan in India has an area of 16,000 km^2 and a length of 150 km while the Gandak fan has an area of 32,000 km^2. Notably these fans have very large catchments, 50,000 km^2 in the case of the Kosi megafan (Gupta, 1997), and both formed in the Himalayas where the basin slope is far greater than any of the rivers in Zambia. The two largest drainage systems near the survey area that drain the Muchinga Escarpment are the Kapamba and the Mupamadzi (Figure 1), and neither would have produced fans that could have spanned the distance to the deposits (Table 2) as the fans would need to be a minimum 1400 km^2 and 4000 km^2 respectively. The Kapamba system, however, may have created a fan large enough to contribute material to within 8 km of

Chipembele Ridge, which could encompass two of the higher elevation clast localities (26, 27). This would explain the high sand content seen behind the ridge where cobbles would only be transported in the event of larger flood events.

Further observations on the valley floor indicate that the gravels on the northwest bank may have been deposited by hyperconcentrated flows originating in the centre of the valley within the range of fans originating from the escarpment. In this scenario, the cobbles in the sand and silt layers behind Chipembele Ridge are reworked in the valley and the coarser material is deposited on the proximal area of the proposed alluvial fans on the northwest bank encompassing site SL8, while the sand and silt are transported to the distal part of the fan in the area now occupied by the Luangwa floodplain. This model of an interim source of fan material is supported by the lithological and clast size data, but it was not possible in the current study to ascertain if clasts nearer the base of the Muchinga Escarpment are the same lithology. Observations made along a track leading to the escarpment (Localities 26, 27) revealed that the deep sands and silts with cobble layers behind Chipembele Ridge are being eroded over large areas. The channels removing this material are confined and would have high flow rates in the wet season, and currently drain into tributaries that meet the Manzi River before reaching the Luangwa. If these tributaries in the past had acted as feeds for alluvial fans, with only occasional flash floods, rather than seasonal streams and rivers, the channels on meeting the Luangwa floodplain might have then deposited material in an alluvial fan environment. A key issue is that the high elevation sands behind Chipembele Ridge which would need to have been the source for the alluvial deposits dated at 77 ka and perhaps considerably earlier for the development of the archaeological sequence to include an Early Stone Age component. Considering the apparent fast rate of erosion in the area today it is probable that the material would have been exhausted some time ago.

4.2 Neotectonics, base level, and climate change

Whether the Muchinga or the Chimpembele area was the source, there would have been periods of abandonment and reactivation linked to cyclical changes in rainfall and susceptibility of the land surface to erosion due to vegetation change. A process of intermittent emplacement and erosion of artefact-bearing gravels would account for the large gaps in the chronology of the upper portion of the SL8 sequence (Lang and Hönscheidt, 1999). The undated lower deposits hint at a much older process of periodic deposition perhaps extending into the Middle Pleistocene. The remaining issue to be addressed is what caused the cessation of fan deposition and dissection of the landscape after 77 ka. Neotectonics, climate change, and base-level change are all potential contributing factors (McCarthy et al., 1993; Harvey, 2005; Harvey et al., 2005).

4.2.1 Neotectonics and drainage evolution

There is little evidence of recent tectonic activity in the Luangwa graben (Fosters and Jackson, 1998), however, research in the adjacent triple junction regions of the EARS (SW Tanzania, N Malawi) indicates that there has been regional doming centred on the Rungwe-Ngozi volcanoes in the Pleistocene (Delvaux, 2001). Middle Pleistocene volcanism in the Rungwe Volcanic Zone (SW Tanzania) has been dated to post-600 ka (Delvaux et al., 1992) and linked to stresses on the local NE-SW compression zone (Fontijn et al., 2010). Uplift in this region could have had an impact on the evolution of the Luangwa Valley landscape through changes in sediment supply and gradient (Keller and Pinter, 2002) but it is not possible at present to test this hypothesis without further fieldwork and the dating of the gravels.

Even if gradual uplift is accompanied by an arid period, the land would be elevated without any substantial geomorphic or sedimentary response. In this scenario, as the landscape becomes progressively elevated above its base level it loses its protective vegetation cover. The land will be subsequently dissected to its new base level with the onset of a wetter climate as runoff erodes the denuded surfaces.

The planform of the drainage of the key rivers in the area provides some possible evidence of a substantial change in topography linked to tectonic movement. The Mupamadzi River flows northward after reaching the Luangwa Valley floor from the escarpment, the opposite direction to the Luangwa River before turning east, and then southeast to meet the Luangwa River. The Kapamba River on meeting the valley floor connects to the Luangwa River more directly (Figure 1), the small tributaries of the Kapamba River on the valley are a minimum of 300 m distant from the Mupamadzi River's tributaries, suggesting that as the drainage system develops this part of the Mupamadzi system may eventually be captured by the Kapamba. For this study, these divergent drainage systems may be linked to tectonic movements that led to the dissection and isolation of the pediment gravels, but this remains a speculative hypothesis until reliable chronological controls are available for these deposits.

4.3 Climate change and drainage development

As no depositional mechanism is producing alluvial fans in the valley today, it is assumed that they were the result of a transition from cooler and more arid conditions (Partridge et al., 1997; Gingele et al., 1998; Schefuß et al., 2003), though with considerable regional heterogeneity in wet/dry responses after 70ka (Thomas and Burrough, 2012; Singarayer and Burrough, 2015; Burrough et al., 2019). The Luangwa Valley lacks the morphological features that trap deep sequences of sediment that can be used to construct chronostratigraphic environmental models (Barham et al., 2011), and at present it is only feasible to produce simple models of the distribution of vegetation during dry and wet phases to assist in understanding past erosional and depositional conditions. Overall, rainfall is the critical factor affecting vegetation and thus erodibility of the land surface in differing climatic regimes across central Africa (deMenocal, 1995; Dupont et al., 2000; Schefuß et al., 2003; Hopley et al., 2007)

Today, the Luangwa Valley is hotter and drier than the surrounding plateau of the same latitude (Archer, 1971). The low rainfall in combination with nutrient rich soils supports a variety of vegetation types dominated by woodland consisting primarily of a single species *Colophospernum mopane* (Mäckel, 1971; Astle, 1995), accounting for 55% of the valley floor vegetation (Astle, 1995). The high central plateau of Zambia by comparison has higher rainfall, but leached and nutrient poor soils, supporting comparatively low biodiversity and low herbivore biomass (East, 1984; Barham 2000). Under the current climatic regime, the Luangwa River remains watered all year round, fed by its headwaters in the Nyika plateau (Malawi) and by a few perennial rivers draining the Muchinga escarpment. The latter are fed by small, waterlogged basins (*dambos*) on top of the escarpment. By the end of the dry season the main channel of the Luangwa is greatly diminished and most tributaries in the valley are dry. Presuming the modern climatic regime can be used to model climate during cooler and drier phases, there would be a considerable reduction in the amount of rainfall in the valley. Mopane woodlands are currently found in more arid conditions bordering the Kalahari (Thomas and Shaw, 2002) and would presumably have survived a certain amount of rainfall reduction in the Luangwa Valley, but in general all vegetation types and the animals they support would have become concentrated nearer the Luangwa and any flowing tributaries (Colton, 2009).

During the driest parts of a glacial or stadial, the landscape would have become denuded of vegetation rendering underlying sediments unprotected and unconsolidated, and thus vulnerable to erosion during flash flood events. Thomas and Thorp (1995) and Thomas (1999) documented evidence of a series of large-scale landslides that occurred 80 km to the south of the Luangwa Valley on the steep slopes of quartzite hills with deeply weathered metamorphics near Chipata. One slope failure occurred >180 ka as dated by OSL on intercalated alluvial deposits and may be indicative of a major transformative event in the landscape in the latter part of the Middle Pleistocene (Thomas and Murray, 2001). Coarse fan deposits and sheets of colluvium occur in the same area, and OSL dating provides evidence of periodic pulses of high energy sedimentation between 90 ka and 9 ka (Thomas, 2002). These same slopes and surfaces are stable today and little affected by recent deforestation (Thomas, 2004). The pulses of colluviation may be linked to regional climate events associated with the last glacial cycle, in particular the extended periods of drought recorded in the

Lake Malawi pollen record from 90-75 ka (Beuning et al., 2011). The colluviation process may reflect more subtle geomorphic responses to base-level lowering affecting the steep slopes around Chipata. The fan deposits and dissected gravels dated to 65 ± 5.0 ka and 56 ± 6.0 correlate more closely with the erosional phases recorded in the Lake Malawi record which mark the return of wet conditions and rapid runoff on de-vegetated surfaces 72 ka and 62 ka (Brown, 2011).

Similar episodes of climate-linked instability are presumed to have occurred in the Luangwa Valley given its proximity to Chipata thus providing the conditions for alluvial fan deposition. With the onset of interglacial or interstadial conditions the denuded landscape, with unconsolidated sediments, would have provided a large sediment supply for hyperconcentrated flows, landslides, debris flows, and other semi-arid geomorphic processes. Thomas (2004, p. 113) comments that in the Luangwa Valley there is evidence of past “torrential conditions leading to boulder-sized fan deposits along hillfronts bordering the floodplain” and massive calcretes formed on the floodplain which together reflect large swings in climate during the Quaternary.

If the OSL date of 77± 7.9 ka from SL8 Block 3 is reliable then it accords with the date of 78±5.0 ka deposition of sediments containing MSA artefacts at the nearby Manzi River section (Barham et al., 2011). Increasingly arid conditions late in MIS 5a may have denuded slopes of their vegetation creating unstable surfaces that would be prone to rapid erosion following the return of rainfall. The limited chronology from the Luangwa Valley gravels accords closely with the regional lake core data and falls within the error margin for the Chipata fan deposit (65 ± 5.0 ka). The Lake Malawi core provides regional evidence of near semi-desert conditions with limited vegetation cover until the termination of drought ~75-72 ka followed by enhanced precipitation and increased physical erosion transporting sediments into the lake (Brown, 2011). Reforestation of the catchment area stabilised the landscape (Beuning et al., 2011). Increased precipitation is seen in the Lake Tanganyika record ~78 ka which may correlate with the end of drought in the Lake Malawi record (Burnett et al., 2011).

4.4 Base-level change and landscape dissection

In the context of the limited data from the Luangwa Valley, it is difficult to distinguish between the impact of neotectonics and climate change on base-level change. As above, we have no direct evidence of uplift in this valley linked to the timescale of the SL8 hilltop deposits. The limited chronology for SL8 and the Manzi River section provides the best link available to regional hydroclimate processes and to global falls in sea level which will lower the base level for the Zambezi River and its tributary the Luangwa River. In this model, the dry phase landscape cannot respond to the base-level fall because of the reduced rainfall and runoff. The landscape response is in suspended animation until the climate becomes wetter, and its unprotected surface is dissected to the lowered base level. There is a lag in the rebound to the new base level because the response time of the global ice-sea system is slower than the regional climate (Compton, 2011). A brief interval exists when wetter conditions return as the perched gravels are dissected, and the sediment is trans-located into the valleys and valley floors by the increased rainfall-runoff. This process then switches off when sea-level rise causes a rise in the river base level, halting the downward adjustment of the river tributaries.

We interpret the perched SL8 deposits as the product of multiple cycles of climate change that switched from drought to wetter conditions. The accumulation of overlaid coarse fan sediments containing Early to Middle Stone Age artefacts indicates more than one period of post-drought high energy deposition. The dissection of the SL8 gravels and their translocation only appears to have happened once which implies that the cycles of climate change were not usually sufficient to cause dissection of the perched gravels. The Late Pleistocene 'megadrought' recorded in the Lake Malawi core and the subsequent return of wetter conditions would have been able to take advantage of severely de-vegetated hillslopes highly susceptible to dissection.

To test this hypothesis of a single, extensive phase of dissection will require the development of a well-constrained chronology of the redeposited gravels on the floodplain margins. The existing geomorphological and grain size data are insufficient to disentangle multiple episodes of deposition from a single rapid event which could produce a complex or overlaid series of fans (e.g., Stanistreet and McCarty, 1993).

5.0 Conclusion

The mapping of landforms in the central Luangwa Valley identified widespread deposits of gravels on both sides of the Luangwa River. The gravels occur as low-lying spreads bordering the floodplain, as reported by earlier researchers. New in this study is the discovery of poorly sorted gravels perched on hill tops 20 m above the current floodplain with Stone Age artefacts stratified in discontinuous but coherent archaeological succession. The excavation of hill-top site SL8 revealed a 1 m-deep profile with concentrations of Later Stone Age artefacts in the upper 15 cm, and diffuse scatters of more abraded Middle Stone Age (MSA) and probable Early Stone Age artefacts in the basal clays. OSL dating was problematical with signal saturation affecting the lowermost sample (43 cm below surface) and bioturbation the uppermost sample (5 cm below surface). The middle sample has a maximum age of 77 ka (23 cm below surface) associated with MSA artefacts. The lower two-thirds of the deposit remain undated and other dating methods, such as electron spin resonance, are needed to develop a full chronology.

The emplacement of artefacts during the Late Pleistocene, and possibly earlier, requires a persistent even if intermittent process. Abrasion on the MSA artefacts ranges from fresh to worn with this highly variable spectrum found through the deposits indicating repeated entrainment of clasts in flow events. The relatively unabraded LSA material post-dates the main flow events, and possibly post-dates the dissection of the hilltop deposits.

A clast analysis was undertaken to identify potential sources of high energy that could transport a coarse load and at a level now 20 m above the river. Twenty-three localities were sampled in the survey area and the lithologies recorded and clast size measured. The results are interpreted as providing evidence that the gravels were deposited by hyper-concentrated flows originating on the western bank of the Luangwa. The fans are not currently active and have been extensively eroded, a process that continues every rainy season. The source for the gravel material is likely to have been a deposit derived ultimately from the Muchinga Escarpment to the west and redeposited across the former landscape.

Regarding the underlying and causal factors controlling the dissection and redistribution of these gravels, the influences of climate change and neotectonics (perhaps in combination) have been explored with reference to landscape evolution during the Late Pleistocene for the Zambezi and Limpopo River systems as well as the Lake Tanganyika catchment. Despite limited chronological data, we propose the following sequence of events as accounting for landscape evolution on the Luangwa region during the Late Pleistocene:

1. Base-level fall due to climate-induced sea-level fall and/or underlying neotectonic uplift;
2. River systems adjust to lower base level during a cold, dry climate phase (MIS 6; 5a), creating a new drainage network adjusted to lower base level;
3. Reduced vegetation cover under this cold, dry climate (woodland gives way to grassland) leaves the landscape susceptible to erosion but reduced rainfall limits response to local colluviation;
4. Increased wetness regionally during the period ~78-72 ka (c. MIS 5a), in combination with a readily erodible land surface due to reduced vegetation cover, results in widespread dissection of perched gravels;
5. High runoff events at the transition from dry to wet conditions translocate perched gravels into alluvial fans at the widening of confined valleys in the valley floor.

Further research is needed to develop our model of late Quaternary landscape evolution in the central Luangwa Valley, particularly with respect to additional chronological data with which to better tie our proposed model to climate change and underlying neotectonics as expressed in the region. We also need to establish the extent of the hill-top gravels, especially towards the proposed source area of the Muchinga escarpment. A programme of systematic survey, excavation and dating will bring into focus these unusual and potentially important geomorphological phenomena in a little studied region of south-central Africa.

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FIGURE CAPTIONS

Figure 1

Location of the main survey area within the South Luangwa National Park (SLNP) Zambia, outlining the major rivers (grey lines), primary areas of uplifted Archean basement rocks (dark grey shading), and some localities mentioned in text. The two points labelled ‘A’ denote the approximate end points of the cross-section sketch of the valley (figure 3). L26 and L27 are the positions of two localities sampled outside of the survey area along the Kasweta Road (black line in main map). Detailed geography and geomorphology within the survey area is mapped in figure 2.

Figure 2

The 14km by 16km survey area outlined in Figure 1. Geomorphological terrains mapped from aerial photography and fieldwork. The localities sampled are labelled Ln, and the major rivers and geographic features are labelled.

Figure 3

A simplified (not to scale) cross-section of the key geological features of the valley between A and A in Figure 1 (not to scale). The end points are labelled in Figure 1, and here they are the Muchinga Escarpment (A, far left) and the Nchindeni Hills (A, far right). Key locations (Ln) as discussed in the text are included.

Figure 4a

A contour map of hilltop site SL8 (Locality 28) showing the location of the excavation Blocks 1, 2 and 3 in relation to the topography of the hilltop and eroded slopes.

Figure 4b

Excavation Blocks 1, 2 and 3 with subdivisions (Areas) shown in Block 1 and Block 2. Block 1, Area 1 samples the break in slope at the edge of the hilltop platform. Block 2 samples the hill slope and Block 3 samples the central platform. Block 3 and Block 1, Area 1 provide the deepest deposits.

Figure 5

Photograph of Block 3 excavation showing the gravel content in a sand matrix with a darker (organic) upper horizon (0-15 cm from surface). The stadia rod sits on the gravels overlying the basal clay.

Figure 6

Pie charts illustrating clast count results at each sampling location; the geomorphological deposits are those in Figure 2. See text for description and interpretation.

Figure 7

Section drawing of Block 3 deposits along to two faces of the 1m square (A-B, C-A) showing excavation levels 1-9, the basal clay, and the location of OSL dating samples (x). The cobble deposits are distinguished from the gravels by clast size, with the cobbles concentrated in the lower half of the deposit.

Figure 8

SL8 artefact illustrations; see text for interpretation of archaeological attribution (Later, Middle and Earlier Stone Age). A), quartz segment (B1, Area 1, Level 1 – length 23mm, not to scale); B), quartz core (B1, Area 1, Level 1, length 18 mm); C), quartzite pick (B1, A3, Level 1); D), quartzite (weathered) core-axe (B1, surface); E), quartzite core (B1, Area 1, Level 4); F) Fossilized wood core and refitting flake (B1, Area 2, Level 3 – basal clay); G), quartzite core (B1, Area 2, Level 3 – basal clay); H), quartzite flake (B1, Area 3, Level 1); J), quartzite core – multiple platforms (B3, Level 8); I), chert flake – pentagonal (B1, Area 3, Level 1); K), quartzite core (B3, Level 8); L), split spheroid, quartzite (B3, Level 8).

Figure 9a: B3 whole flake length (mm) boxplot showing median and size range by level. Figure 9b: A comparison of abrasion category frequencies by level in B3.

Figure 10

Section drawing of Block 1 Area 1 deposits showing excavation levels 1-7 down to the basal clay along the exposure at the edge of the hilltop platform (A-B) and downslope (A-C). The depth of deposits with artefacts attributed to the Later, Middle and possibly Early Stone Age is shown for section line A-B. Cobbles are more frequent in the lower half of the deposit as is the case in Block 3. The archaeological associations and depth are similar to those described in Block 3.

Figure 11

SL8 retouched tool bar chart by Block and Area. Tool frequencies are low, but some are indicative of particular periods (as discussed in the text) and contribute to the collective evidence of an archaeological succession at SL8.

Figure 12

Block 1, Area 1 boxplot of whole flake length showing median and range by level.

Figure 13 A-D.

OSL analytical results for the quartz sand samples from Block 3: (A) Typical dose response curve for a single grain of quartz. The example shown is from 86/SL8-2 and has a De of 9.6±0.6 Gy. The inset shows the OSL decay curve for the natural signal. Radial plots showing the distribution of De values for (B) 86/SL8-1, (C) 86/SL8-2 and (D) 86/SL8-3. The light grey bar in the lower part of figures (B-D) show the value calculated using the minimum age model while the dark grey bar shows the maximum age model.

TABLE CAPTIONS

Table 1.

(a) Dosimetry information for the three OSL samples. The dose rate given in the final column is calculated as the sum of the beta dose rate derived from the beta counting, the gamma dose rate based upon the concentration of K, U and Th and the conversion factors of Adamiec and Aitken (1998), and a cosmic dose rate calculated from the current burial depth (Prescott and Hutton, 1994). The beta and gamma dose rates have been corrected for grain size (90-250 µm) and water content.
(b) The number of individual quartz grains whose luminescence signal was measured, the number

which were saturated, and the number of grains that yielded equivalent dose values that could be used in the age models. Results from both the minimum age and maximum age model are presented. The ages in bold are thought to be the most likely. See text for discussion.

Table 2.

Drainage basin areas of larger rivers and streams in or near the research area, and the likely range of fan sizes that may be produced (after Guzzetti et al. 1997:132, and Leeder 1999:332). The drainage basin areas have either been directly determined from the 1:50,000 scale Zambian Survey maps, or are an estimation based on the available maps. NB these are revised estimates from Colton (2009 p 63), based on maps not previously available.

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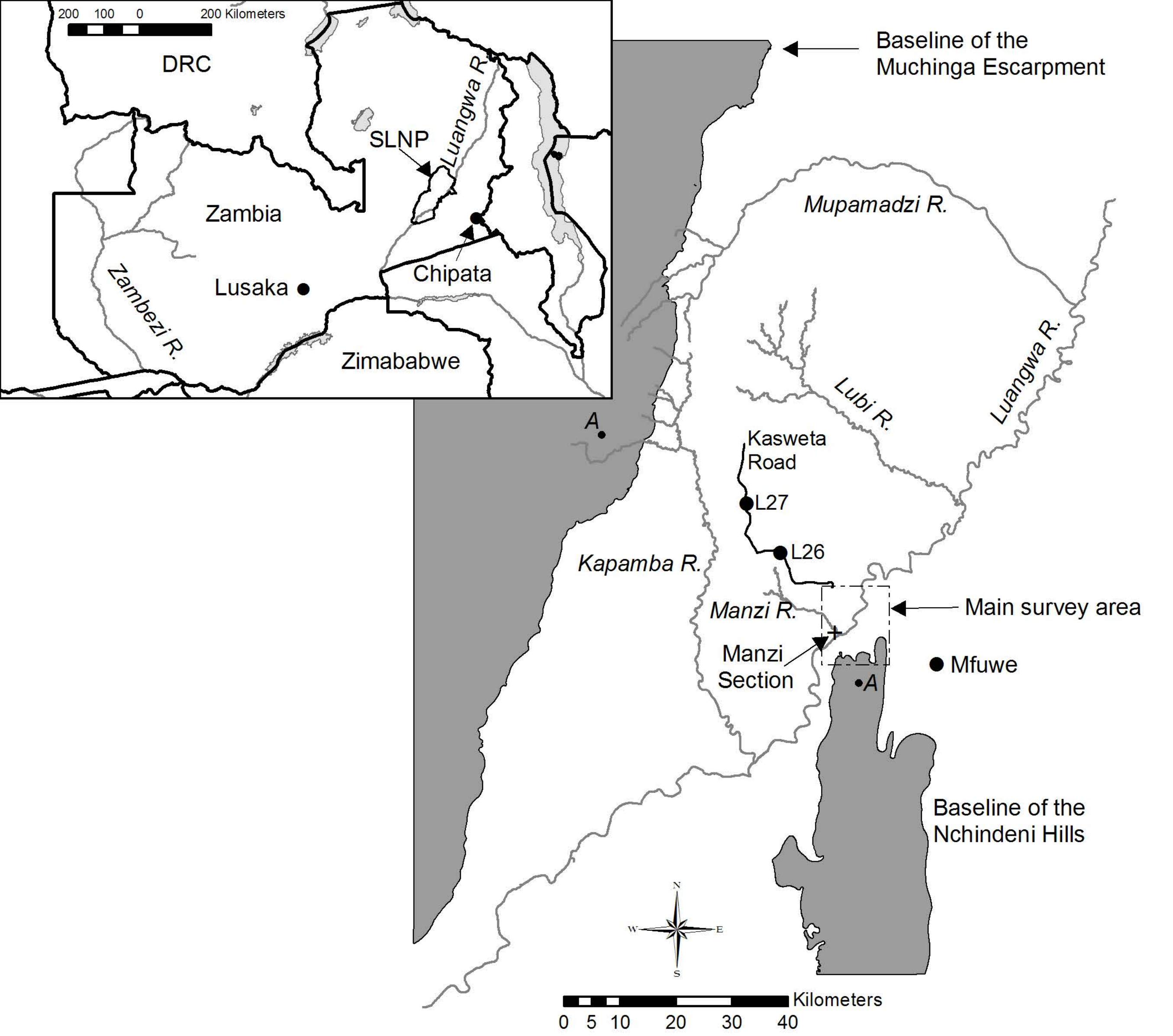
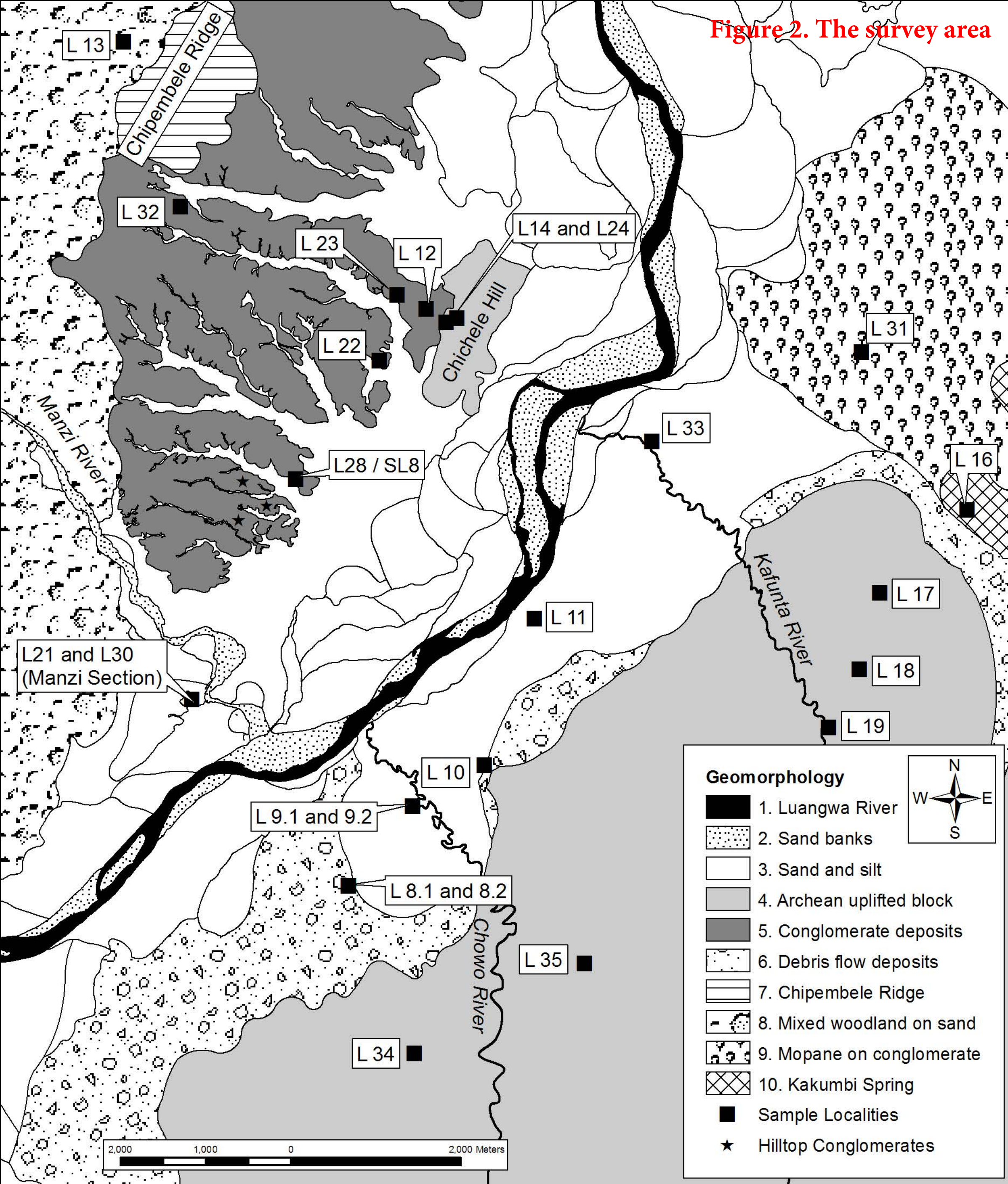


Figure 1. Location map of survey area

Figure 2. The survey area



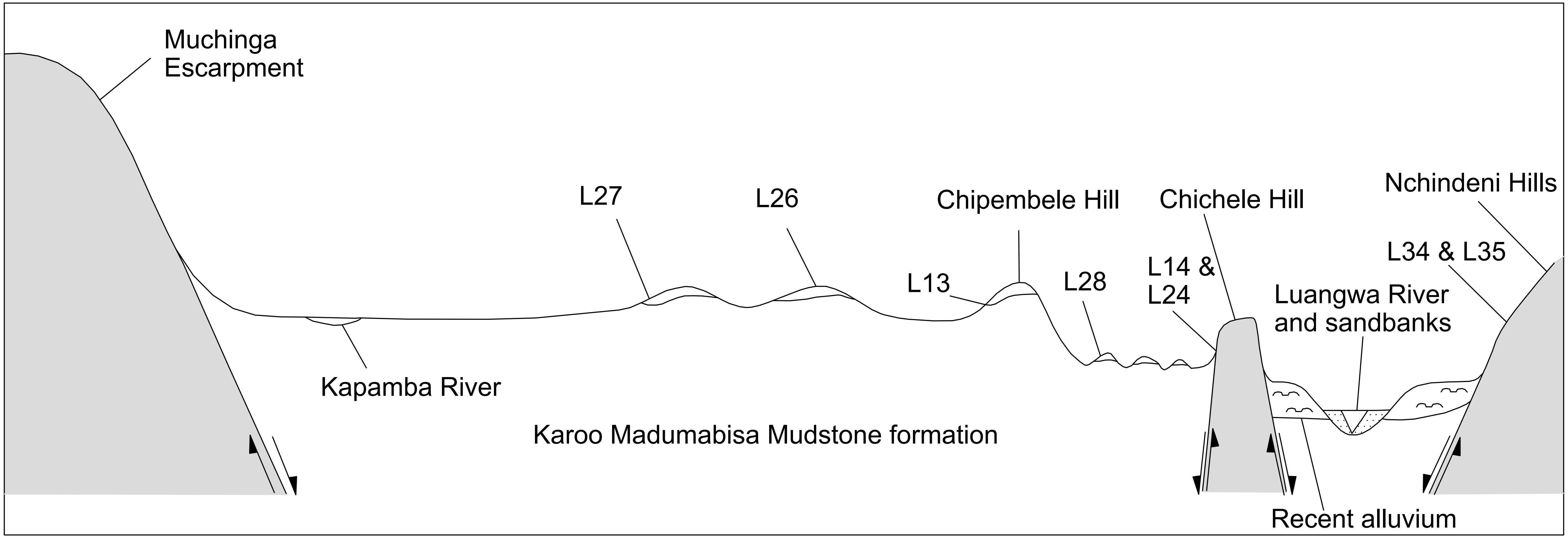
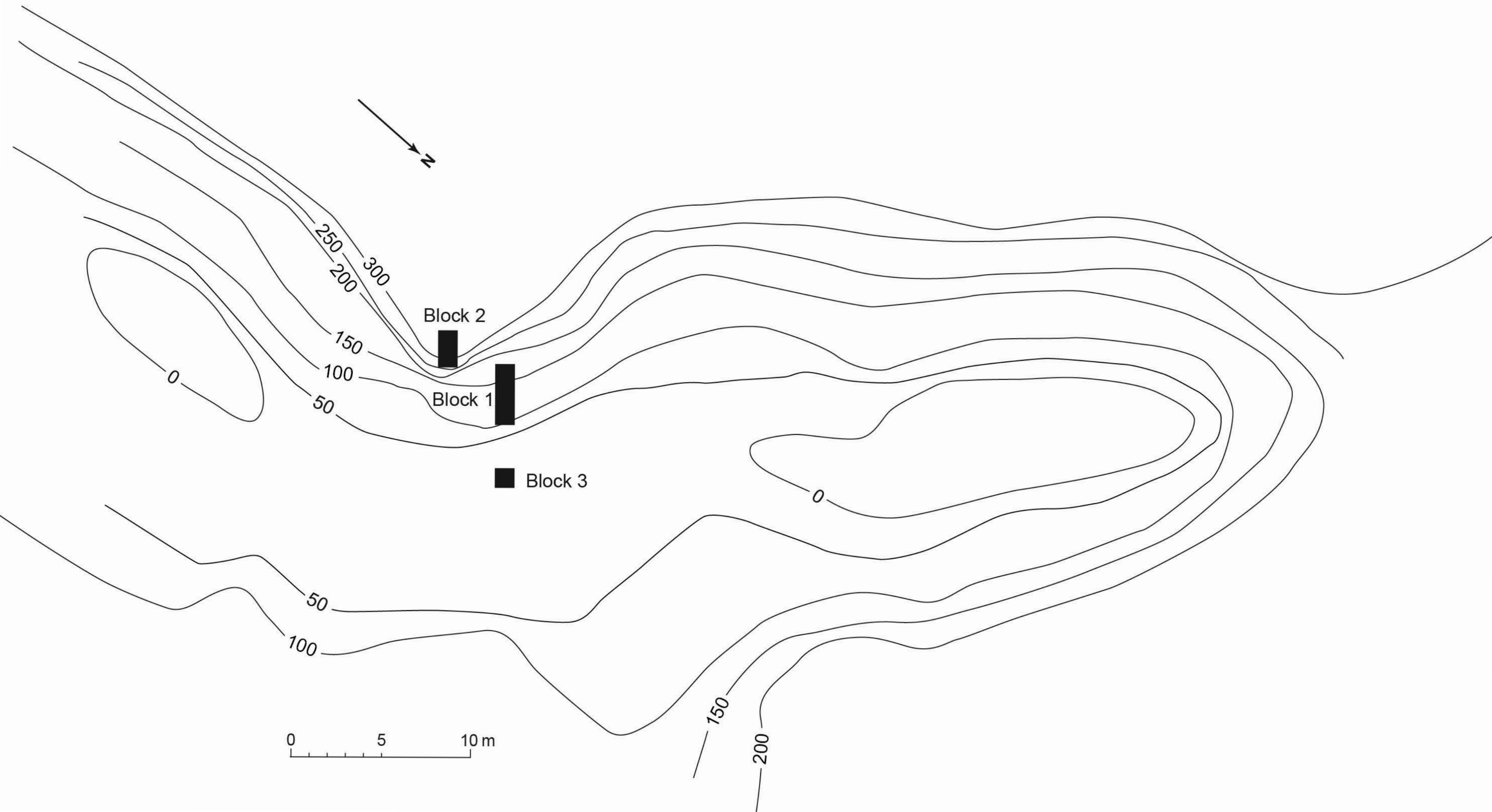


Figure 3. Valley cross-section

SL8

Figure 4a. SL8 contour with Blocks



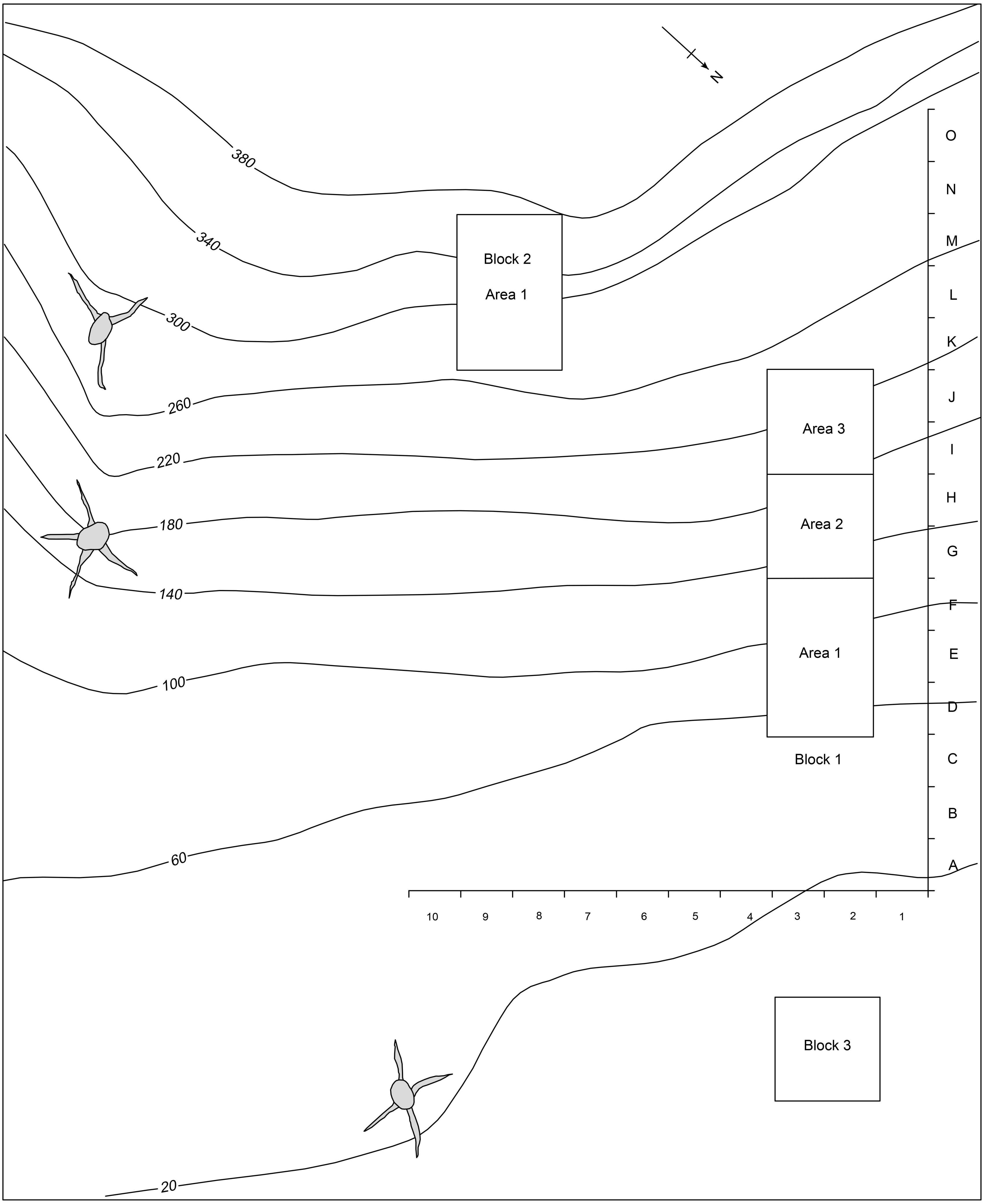


Figure 4b. Excavations trenches B1, B2, B3 revised

Figure 5. Excavation at SL8, Block 3

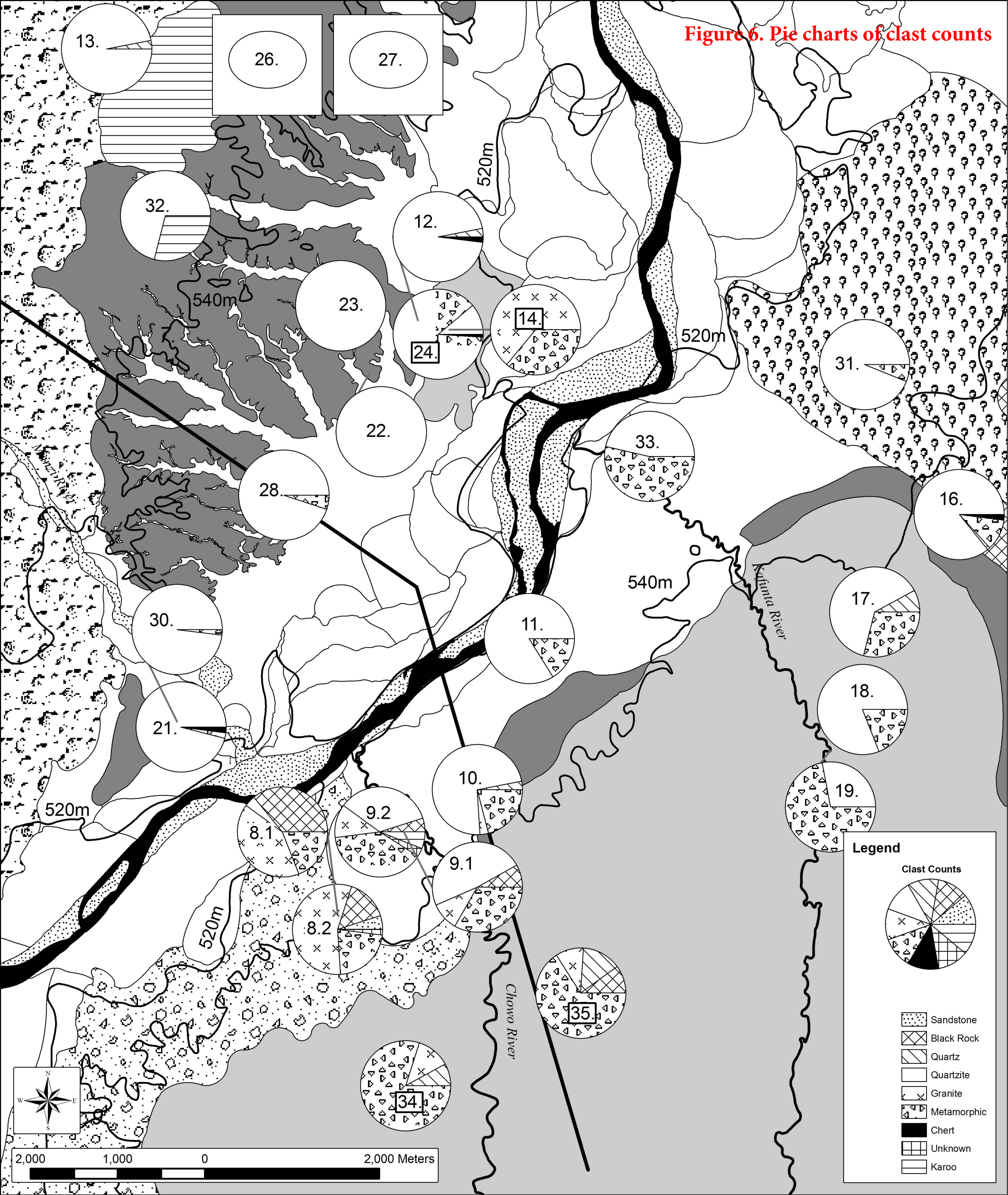
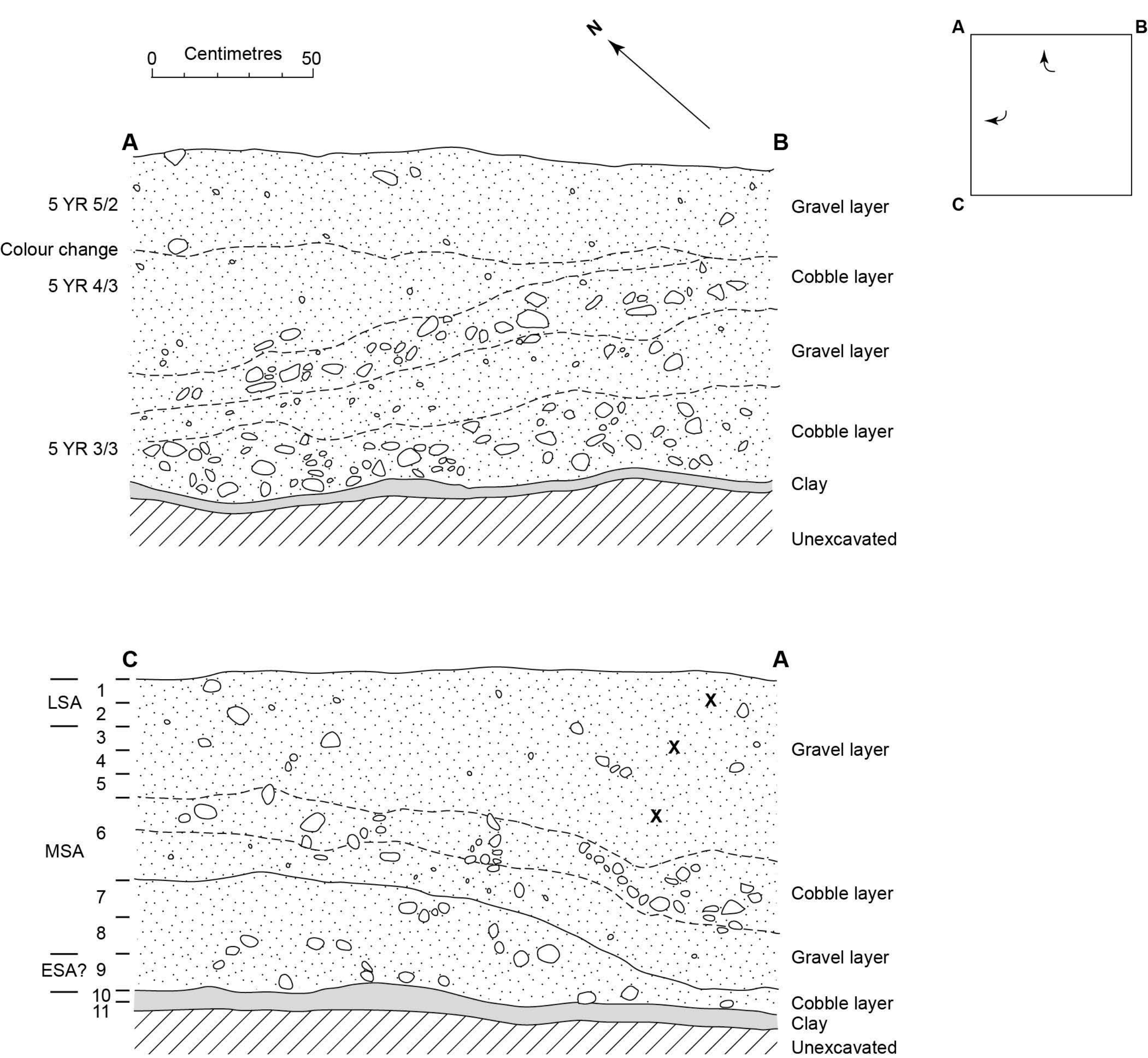


Figure 6. Pie charts of clast counts
13.
26.
27.
32.
12.
520m
540m
23.
24.
14.
520m
31.
22.
33.
28.
16.
Mwanzi River
540m
Kafunta River
17.
30.
11.
18.
21.
10.
19.
520m
8.1
9.2
9.1
8.2
520m
35.
Chowo River
34.
Legend
Clast Counts
Sandstone
Black Rock
Quartz
Quartzite
Granite
Metamorphic
Chert
Unknown
Karoo
N
S
W
E
2,000
1,000
0
2,000 Meters

SL8 Block 3 Main section

Figure 7. SL8 Block 3 Main section



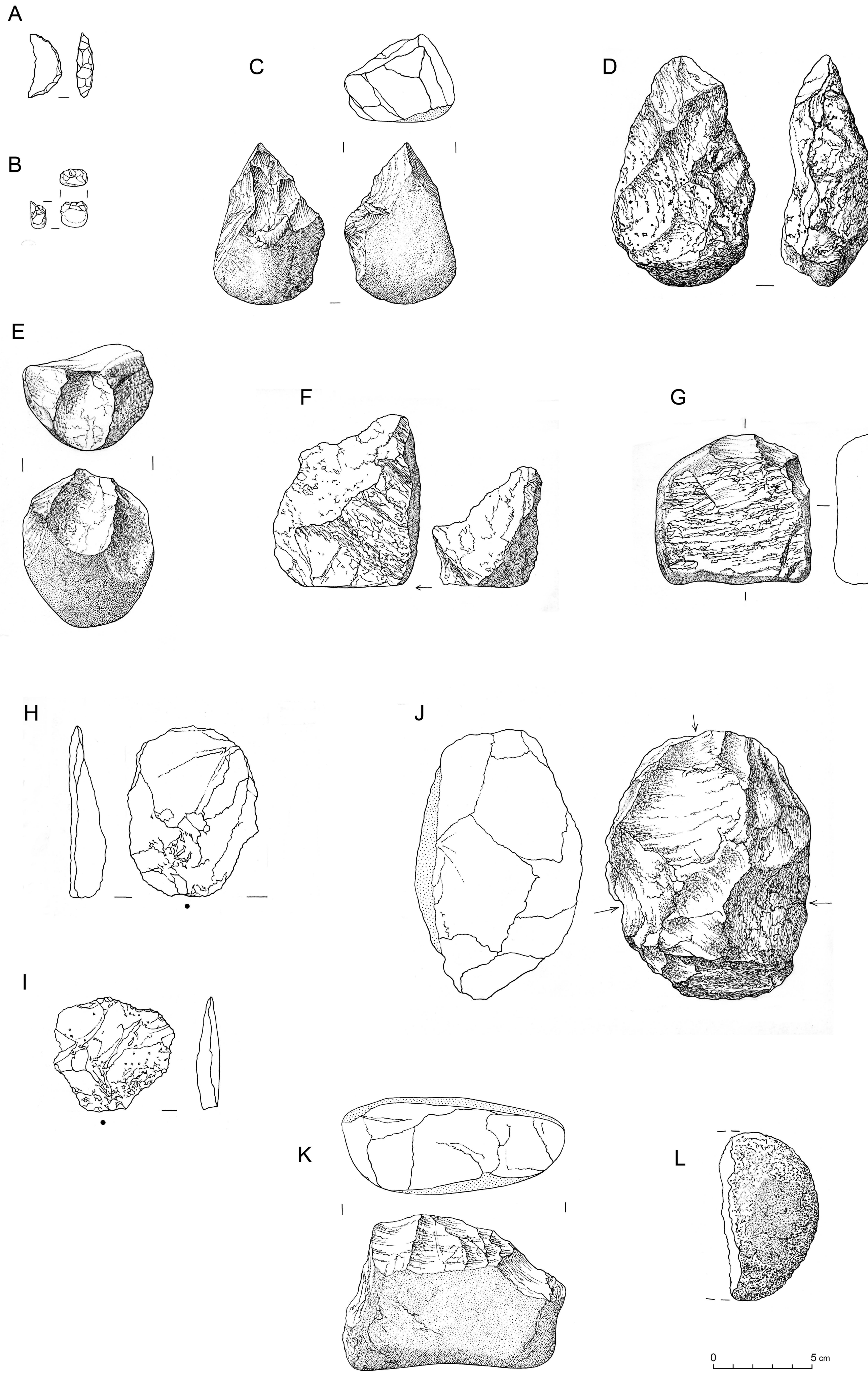


Figure 8. SL8 artefact illustrations

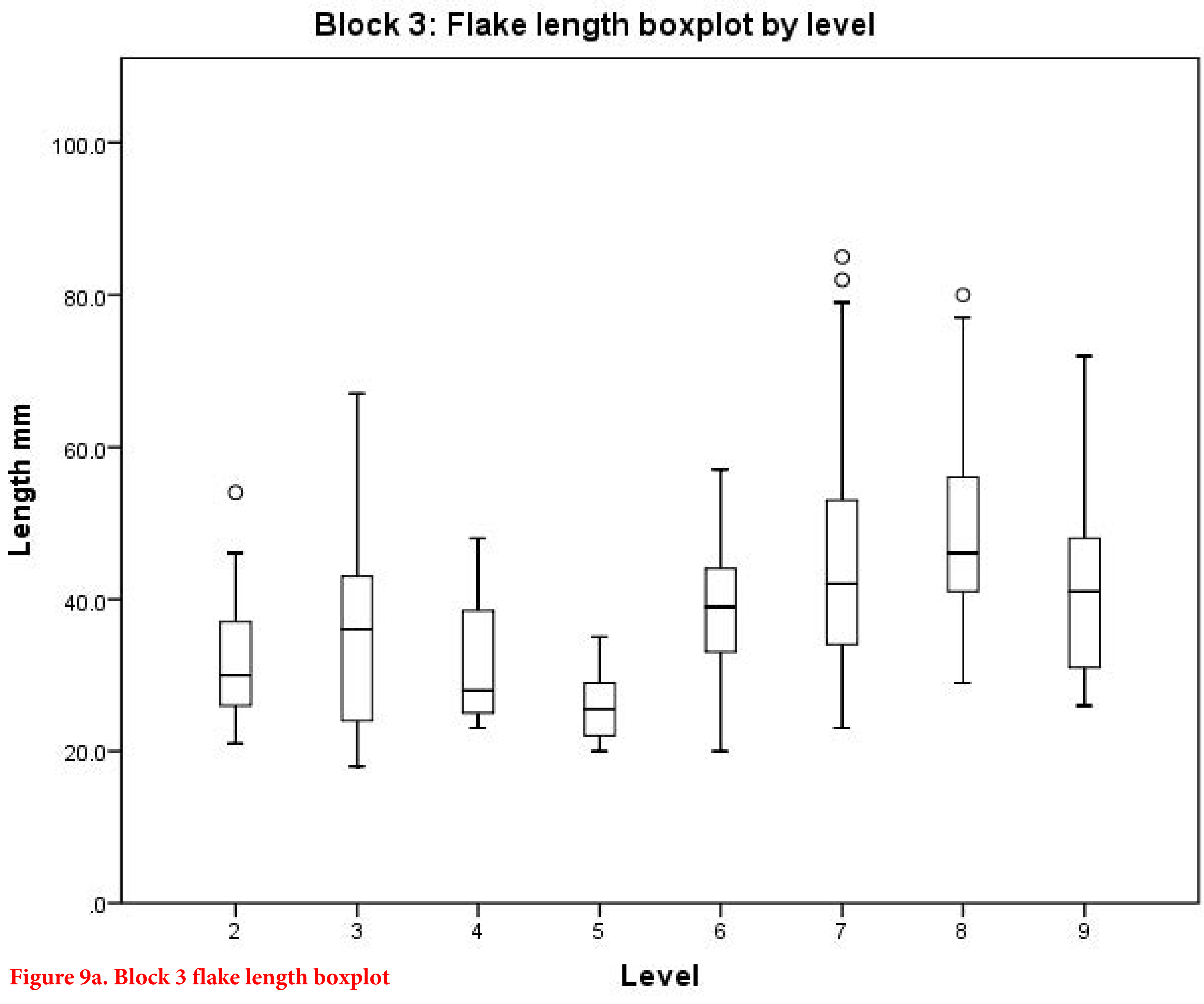


Figure 9a. Block 3 flake length boxplot

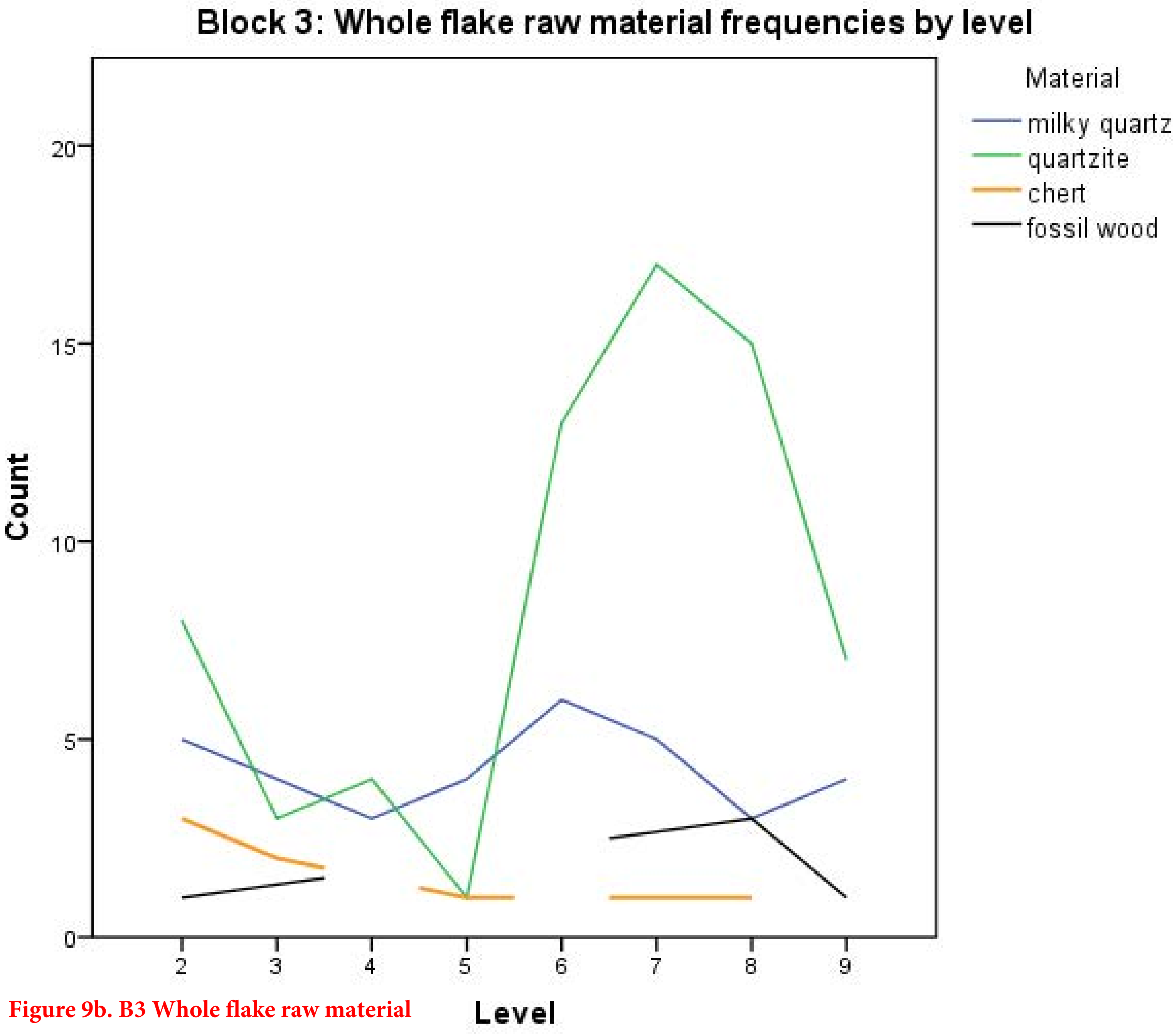


Figure 9b. B3 Whole flake raw material

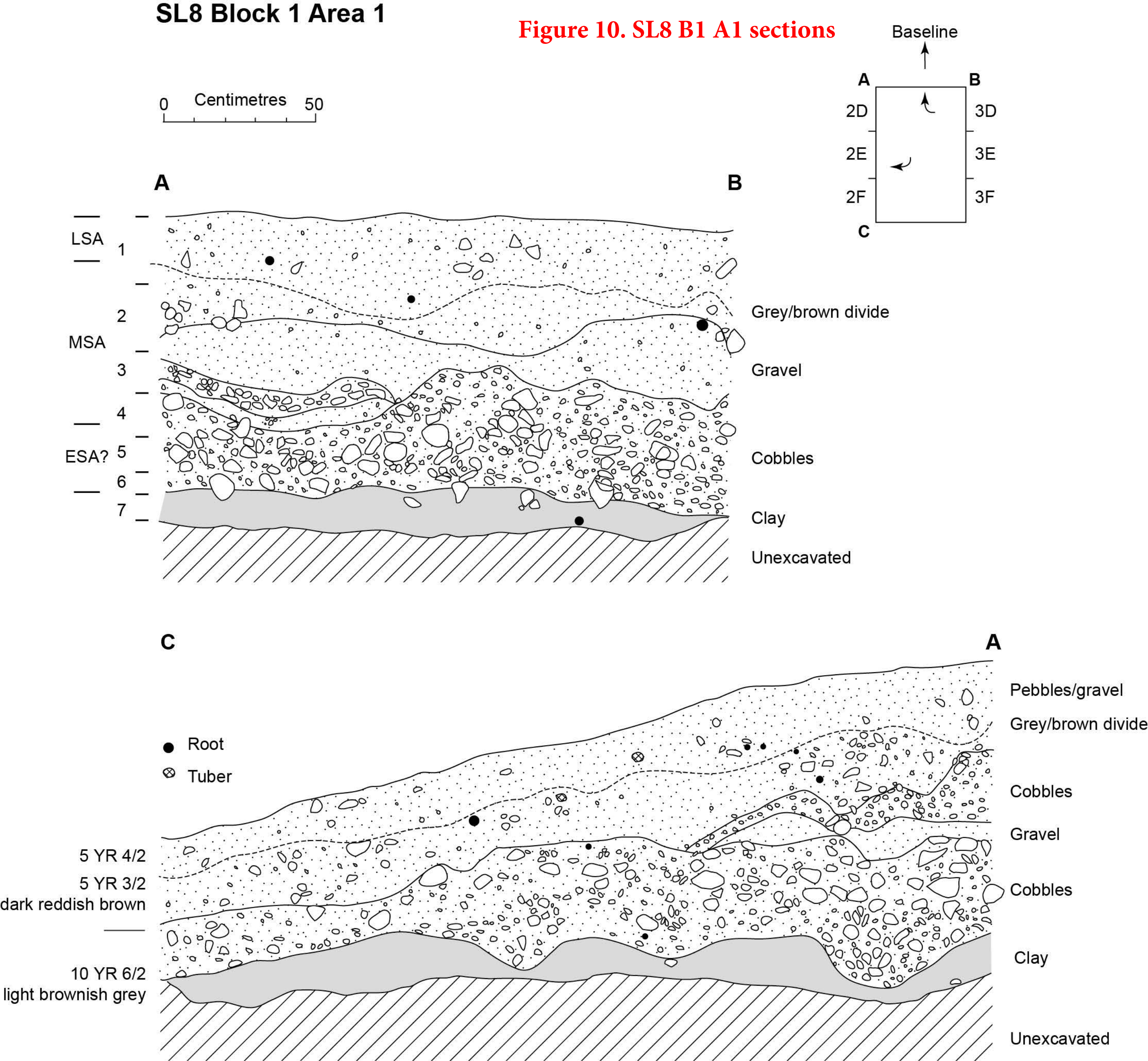
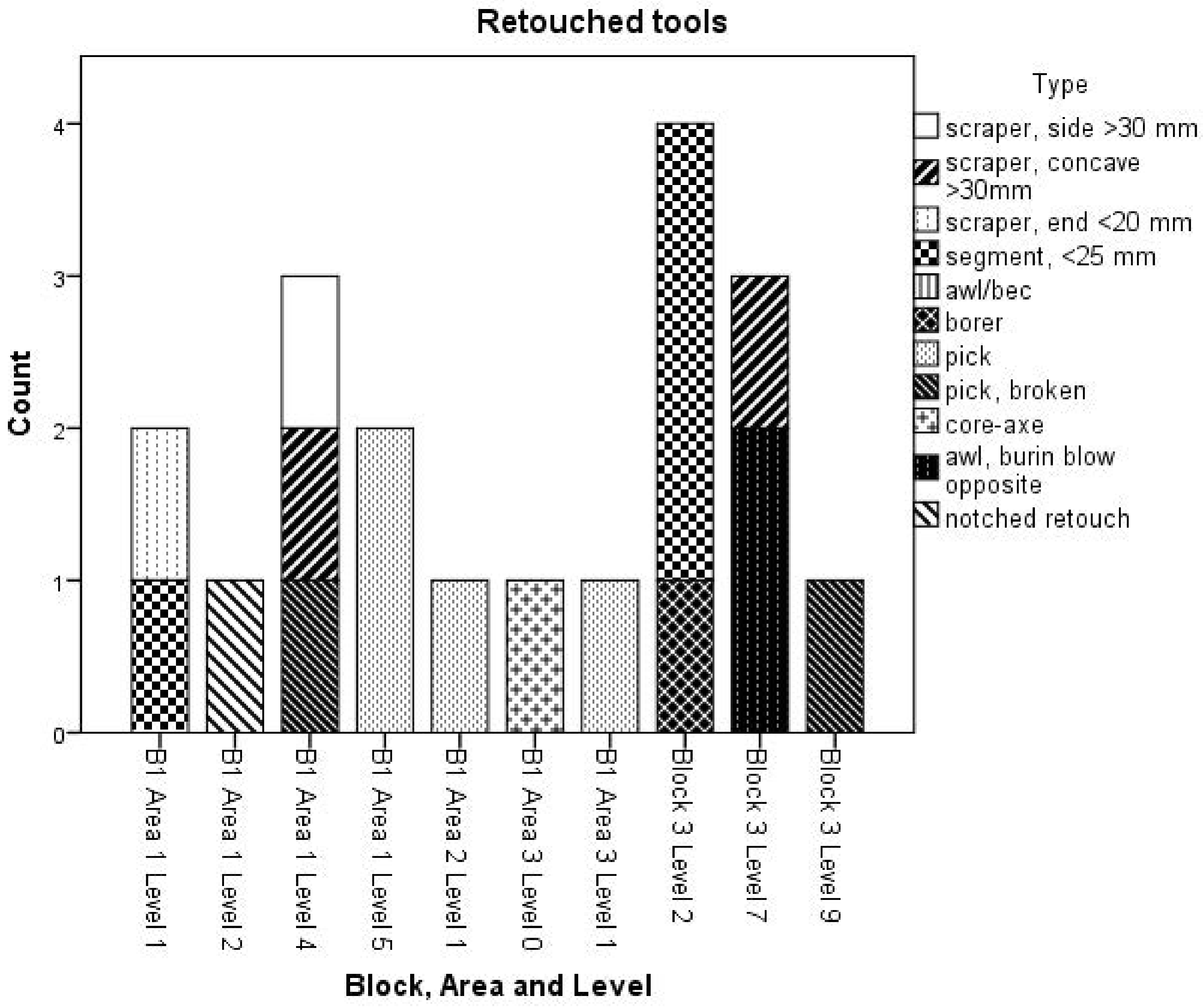


Figure 10. SL8 B1 A1 sections

Figure 11. Retouched tools bar chart



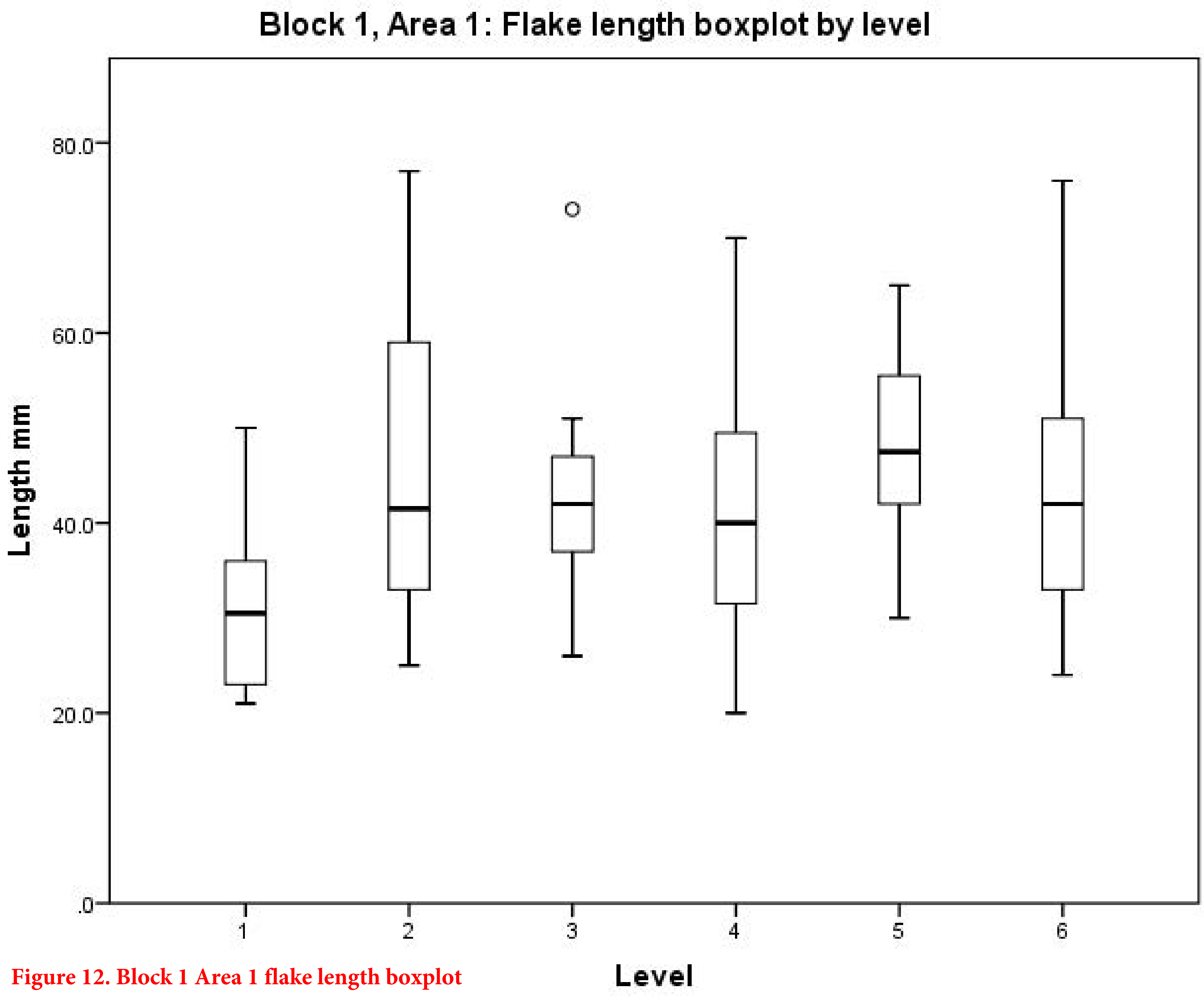


Figure 12. Block 1 Area 1 flake length boxplot

Figure 13a. OSL signal intensity and dose response curve

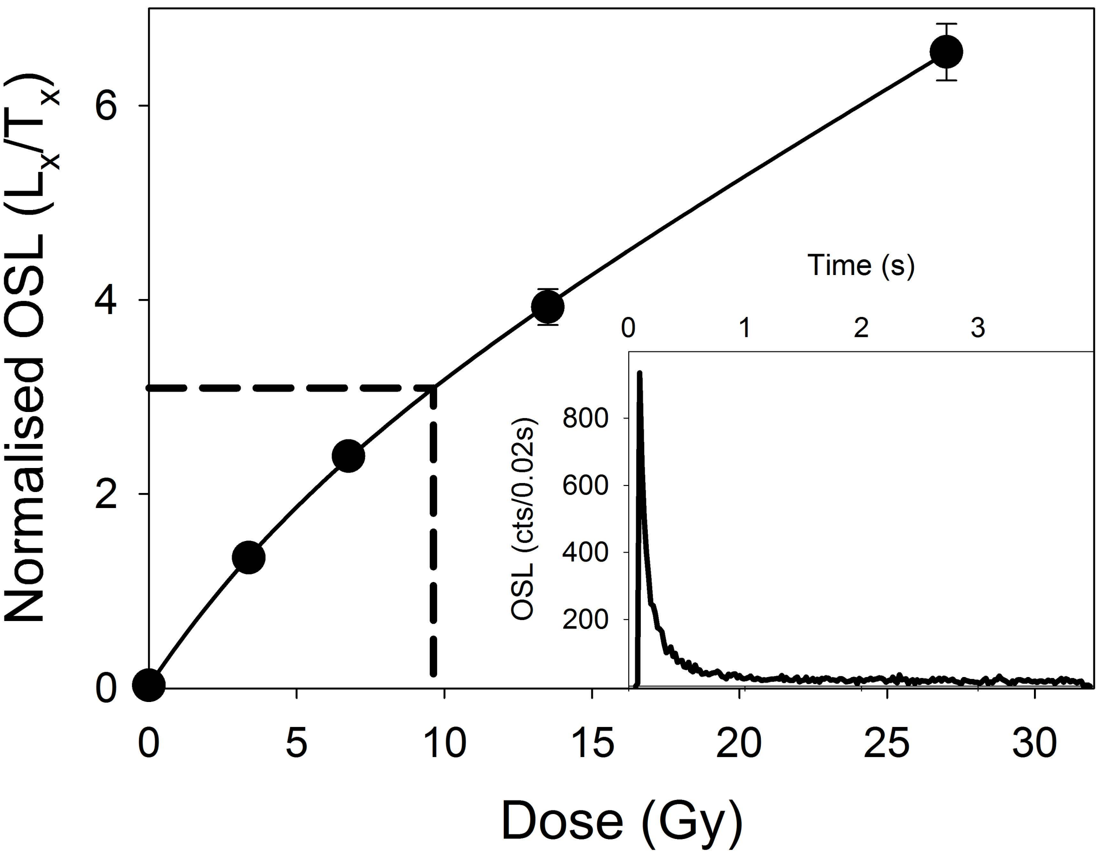


Figure 13b. Dose distribution SL8-1(2)

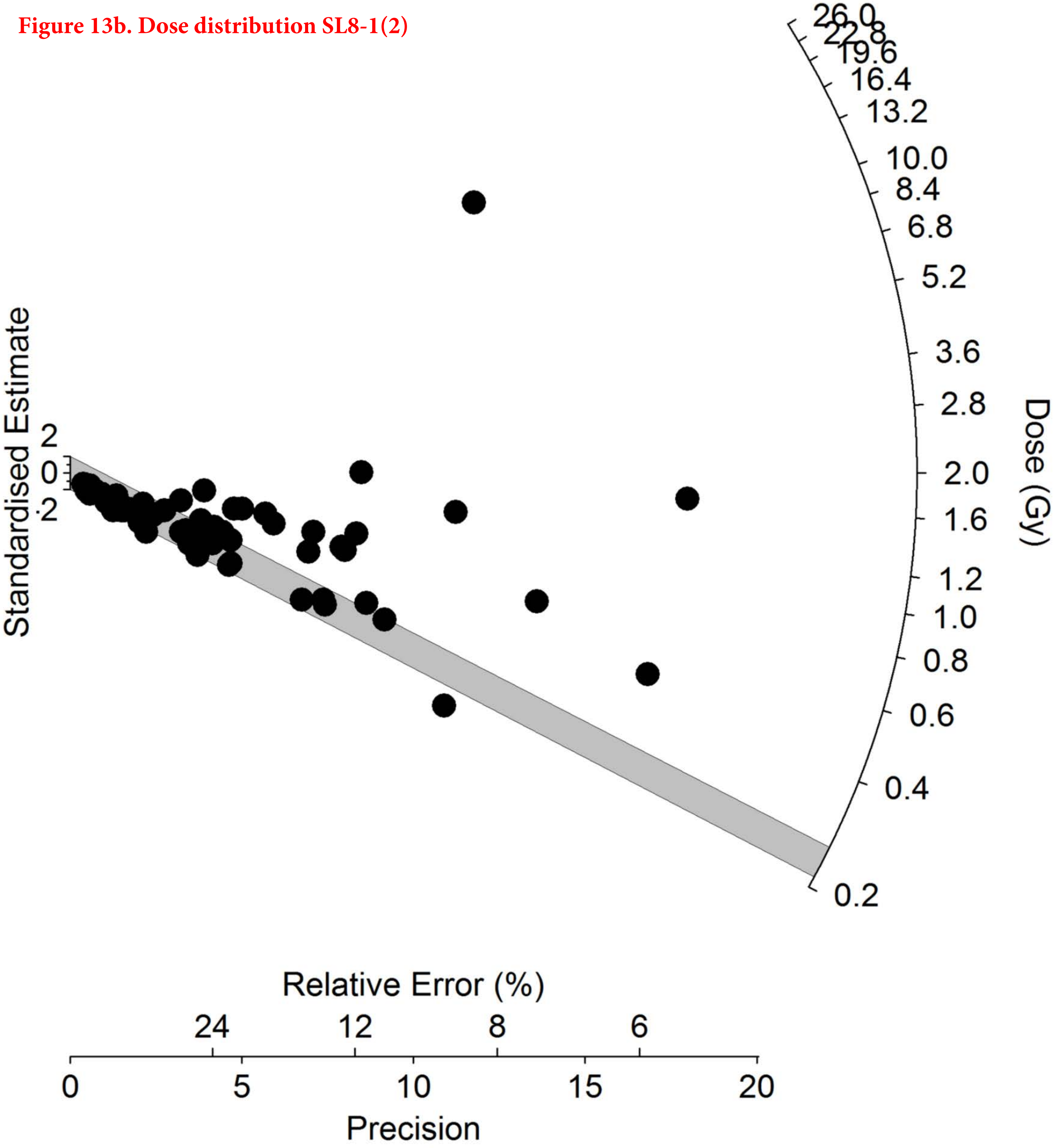


Figure 13c. Dose distribution SL8-2

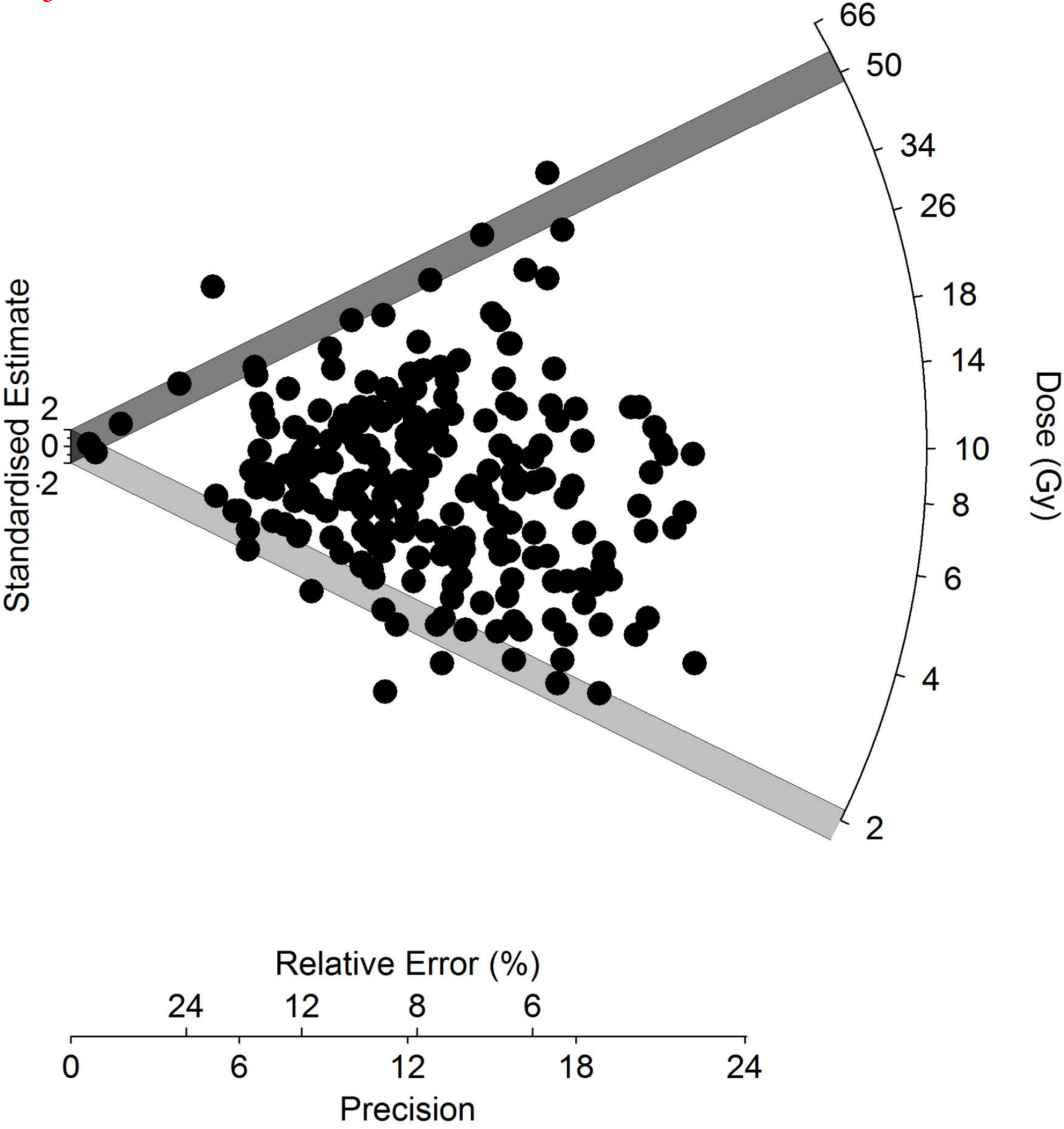
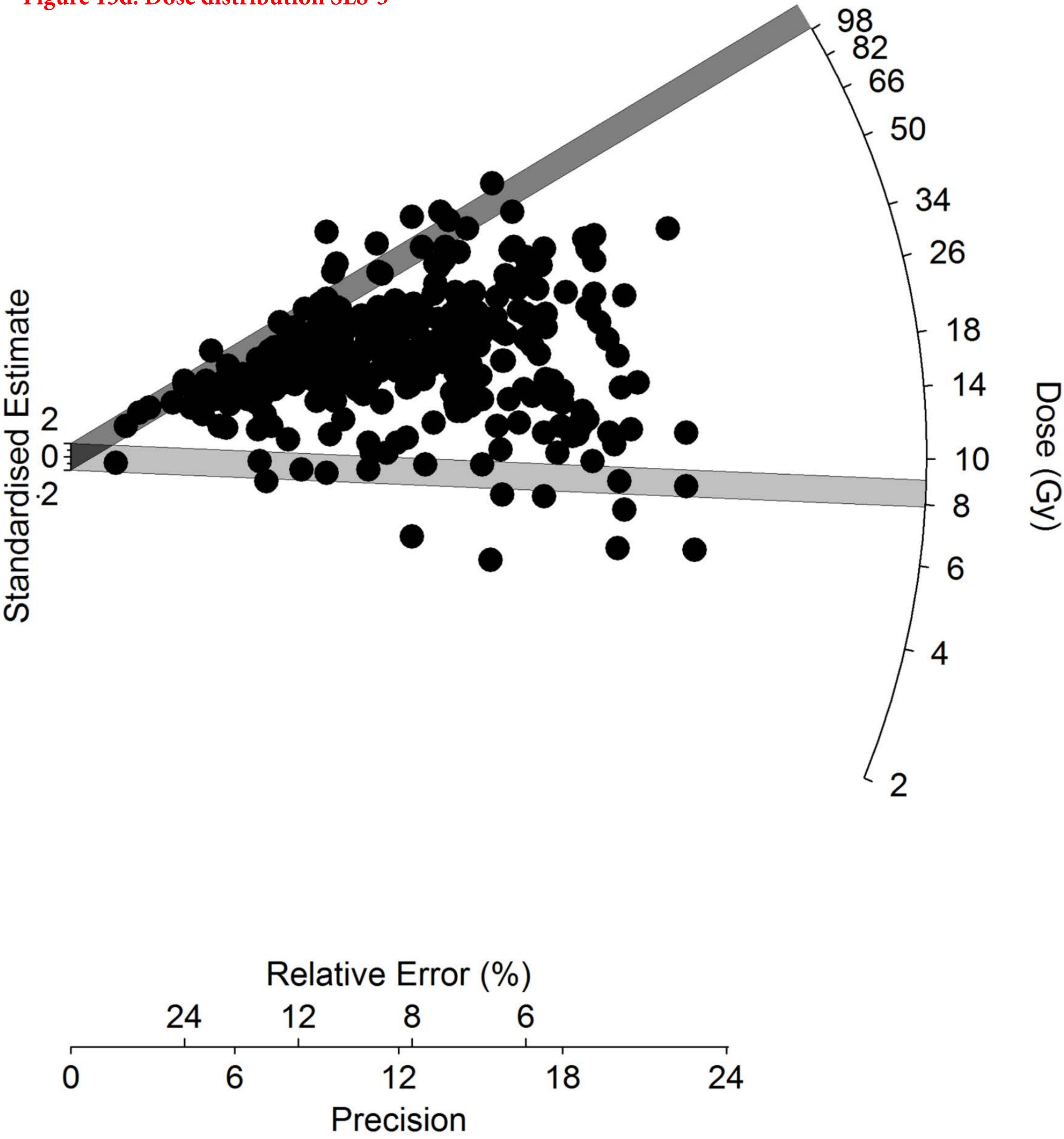


Figure 13d. Dose distribution SL8-3



(a)

Sample (Aber86/)	Depth (cm)	Water content (%)	Alpha count rate (cts/ks/cm^2)	Beta Dose (Gy/ka)	Calculated concentrations K (%)	U (ppm)	Th (ppm)	Total Dose (Gy/ka)
SL8-1	5	5±2	0.379±0.001	0.49±0.02	0.17±0.05	1.27±0.22	6.46±0.72	1.16 ± 0.05
SL8-2	23	10±5	0.141±0.003	0.30±0.01	0.21±0.02	0.50±0.08	2.33±0.26	0.67 ± 0.03
SL8-3	43	10±5	0.163±0.003	0.43±0.01	0.36±0.03	0.45±0.10	3.13±0.33	0.81 ± 0.03

(b)

Sample (Aber86/)	Number of grains: Measured	Saturated	Accepted	Min. Age model D_e (Gy)	Age (ka)	Max. Age model D_e (Gy)	Age (ka)
SL8-1	600	3	240	0.24 ± 0.01	**0.21 ± 0.01**	-	-
SL8-2	500	11	220	1.94 ± 0.01	2.88 ± 0.11	51.9 ± 4.9	**77.0 ± 7.9**
SL8-3	600	149	334	8.42 ± 0.43	10.4 ± 0.7	108 ± 5.0	133 ± 8.2

Table 1: (a) Dosimetry information for the three OSL samples. The dose rate given in the final column is calculated as the sum of the beta dose rate derived from the beta counting, the gamma dose rate based upon the concentration of K, U and Th and the conversion factors of Adamiec and Aitken (1998), and a cosmic dose rate calculated from the current burial depth (Prescott and Hutton 1994). The beta and gamma dose rates have been corrected for grain size (90-250 µm) and water content. (b) The number of individual quartz grains whose luminescence signal was measured, the number which were saturated, and the number of grains that yielded equivalent dose values that could be used in the age models. Results from both the minimum age and maximum age model are presented. The ages in bold are thought to be the most likely. See text for discussion.

Rivers and Streams included in analysis.	**Drainage basin area of streams, before they reach the valley floor.**	**Probable range of fan size.**
All streams leaving the Nchindeni Hills.	62 km^2	2 – 200km^2
Chowo River from Nchindeni Hills	31km^2	0.9 – 100km^2
Kafunta River from Nchindeni Hills	24km^2	0.7 – 80km^2
Mupamadzi River from the Escarpment.	1,500km^2 (conservative estimate based on available maps).	102 – 500km^2
Kapamba River from the Escarpment.	900km^2 (conservative estimate based on available maps).	80 – 300km^2

Table 2. Drainage basin areas of larger rivers and streams in or near the research area, and the likely range of fan sizes that may be produced (after Guzzetti *et al.* 1997:132, and Leeder 1999:332). The drainage basin areas have either been directly determined from the 1:50,000 scale Zambian Survey maps, or are an estimation based on the available maps. NB these are revised estimates from Colton (2009:63), based on maps not previously available.