Geological Society of Zimbabwe Annual Summer Symposium, Victoria Falls, 28-30 November 2013

Field Excursion Guidebook

The Geology of the Victoria Falls Area

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ZIMBABWE GEOLOGICAL SOCIETY SUMMER SYMPOSIUM, 2013.

FIELD GUIDE TO THE GEOLOGY OF THE VICTORIA FALLS AREA

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1. INTRODUCTION

Our understanding of the geology of Victoria Falls and surroundings is underpinned by the meticulous studies and exceptional field observational skills of a remarkable group of geologists. Initial geological field investigations were carried out by AJC Molyneux and GW Lamplugh in the early 1900's. HB Maufe (in 1938) made exceptionally detailed descriptions and prescient interpretations of the Kalahari beds exposed in railway cuttings just south of Victoria Falls Station. Seventy-five years later, these are arguably still the best available records of these enigmatic sediments. In 1950 the archaeologist J Desmond Clark and geologist (Sir) Frank Dixey produced a remarkable monograph on the lithic artefacts associated with the gravels and alluvial sediments fringing the Zambezi channel. These pioneering studies, and the observations of Alex du Toit, John Wellington and Geoff Bond form the basis for our understanding of the evolution of the Victoria Falls and lower gorges.

2. GEOLOGY OF THE VICTORIA FALLS AREA

Table 1 provides a summary of the broad outline of the geology of the Victoria Falls area. A schematic geological section illustrating the relationship between the main geological units is provided in Fig. 1.

2.1 Batoka Basalt

The oldest geological formation in the Victoria Falls area is the Karoo-age (~180 Ma) Batoka basalt. The basalt is well exposed in the gorges below Victoria Falls, where it forms a series of steep near-vertical bare cliffs with, poorly developed vertical columnar jointing, separated by well vegetated breaks in slope (Fig. 2). The former reflect individual massive lava flows of a fine-grained dark bluish basalt, with occasional steamholes and amygdales coated by green celadonite. The breaks in slope reflect a purplish-red, often highly amygdaloidal basalt, which marks the brecciated upper and lower contacts between the individual lava flows. This amygdaloidal unit is typically an aquifer, and less resistant to weathering. This accounts for the break in slope in the succession, and also the attendant vegetation.

Table 1. Summary geology of the Victoria Falls area. Associated lithic artefacts given in brackets. (From Dixey, 1950)

10. Aeolian sand and alluvium (LSA)

9. Redistributed Kalahari Sand (KS II) (Tshangulan – late MSA)

8. Younger Gravels I (Lupemban – MSA)
7. Kalahari Sand I (KS-I) (Lupemban – MSA)

6. Ferricrete 1

-- Erosion

Sangoan (early MSA) entombed in ferricrete on Old Gravels

5. Old Gravels II (OG-II) (Mid- to Late ESA and Sangoan - Early MSA).

4. Old Gravels I (OG-I) (Rolled Oldowan – earliest ESA and Acheulian – late ESA)

--Erosion and silicification

3. Pipe Sandstone

--Erosion and silicification

2. Silicified Limestone or chalcedony

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Marked Unconformity

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1. Karoo Basalt (~180 Ma)

4-10 = Victoria Falls Formation (VFF)

LSA = Late Stone Age (</= ~20 - 30 ka

MSA = Middle Stone Age. (Max Age >/= 500 ka)

ESA = Early Stone Age.

ESA Mode 2 (Acheulian) (~ 1Ma - 500 ka)

ESA Mode 1 (Oldowan) (Earliest Age possibly ~ up to 2.5 Ma)

2.2 Basal Kalahari formation

Basal Kalahari units, which broadly correlate with the Botletle Beds described by Passarge (1904) in the Boteti River in northern Botswana, are exposed in two railway cuttings south of Victoria Falls station. The sequence exposed in the southernmost cutting is summarized in Table 2.

Table 2. Kalahari Section in Rail Cutting south of Victoria Falls Station. (From Maufe, 1938).

Lithology	**Thickness** (feet)
Red Kalahari Sand	Up to 15 feet
Carstone Nodule Bed	4 inches – 2 feet
Red pebbly sand	3 inches – 6 feet
Pipe Sandstone	Up to 3.5 feet
Silicified Limestone or Chalcedony	1-3 feet
Decomposed grey Karoo basalt	up to 5 feet exposed

The Chalcedony Bed or Lithified Limestone is a greyish to yellowish-brown, frequently mottled to translucent flint-like rock. On the basis of thin section studies, it is interpreted to have originally been a slightly gritty limestone, which has been silicified as a result of replacement of most of the original carbonate by silica. This thin unit has a wide distribution, occurring up to 300km to the east-southeast in the Bubi district, and north into Zambia. It also correlates with basal Kalahari units originally described by Passarge (1904) in the Boteti River in north-central Botswana. Fossil gastropods and two species of the freshwater plant *Chara* have been recovered from lithologies closely resembling the Chalcedony bed to the south of Victoria Falls. On the basis of the original lithology and associated fossils, this unit was interpreted by Maufe (1938) to indicate a fluvio-lacustrine or marshland environment.

The Pipe Sandstone is a coarse-grained white to pale pink poorly cemented (silicified) rock, consisting of large (0.75 – 1.5 mm) quartz grains set in a matrix of smaller (0.125 – 0.5mm) quartz grains. It should be noted that in Botswana (Type Area of this unit), the Pipe Sandstone may be highly lithified (Fig. 3a & b). In the Victoria Falls Section, there are also scattered sub-angular pebbles of white and coloured quartz as well as chalcedony, the latter very similar in appearance to the underlying unit. The presence of these chalcedony clasts points to deposition of the Pipe Sandstone after silicification of the underlying Chalcedony, implying that the two units are separated by an erosional hiatus. Small grains of magnetite, not seen in the underlying Chalcedony, are relatively common in the Pipe Sandstone. Dixey reports the presence of the fresh water plant fossil *Chara*, gastropods (*Limnea sp*. and *Planorbis sp.* and freshwater crustaceans of the sub-class Ostracods (*Cypris sp.*) from the Pipe Sandstone. Illustrations of modern analogues of some of these fossils are provided in Fig A1 of the Appendix.

A characteristic feature of the Pipe Sandstone is the presence of numerous hollow tubes, approximately 10mm in diameter, which traverse the rock. These often become horizontal downwards to join with other pipes. In Botswana the pipes in this unit display a variety of orientations (Fig. 3a & b). The origin of these tubular pipes is not well understood. In his original description, Maufe suggested that they are relics of reeds and sedges which grew along vleis or watercourses. Similar features in the basal Kalahari in Botswana have been interpreted to represent the trace fossil *Thalassinoides*, which has been inferred to be related to burrowing by Decapoda crustaceans (prawns and shrimps) Fig. A1.5. However, this trace fossil seems to often occur as positive features in contrast to the hollow tubes that characterize the Pipe Sandstone. Dr. Margaret McFarlane of Maun Botswana (pers com) finds evidence from electron microscope studies that the Pipe Sandstone tubes are secondary, resulting from chemical solution facilitated by microbial activity. It should perhaps be noted that these differing interpretations are not necessarily mutually exclusive. On the basis of the fresh water fossil assemblage and the tubular structures, Maufe (1938) inferred a fluvial-lacustrine origin for the Pipe Sandstone unit.

The Pipe Sandstone passes upward into a red pebbly sand, which is overlain by the Carstone Rubble. The latter is largely comprised of nodular lumps of a ferruginous, well-cemented sandstone (termed carstone in Britain). There are also minor chalcedony fragments, similar in appearance the basal Chalcedony unit. Some of these chalcedony clasts appear to have curved fractures, suggesting that they might be lithic artefacts, but no unequivocal worked nodules were seen. The Carstone Rubble was tentatively interpreted to represent an erosional event that followed silicification of the Pipe Sandstone.

The Railway Cutting section is capped by a bright red Kalahari uniform sand, lacking sedimentary structures. The absence of sedimentary structures is a common feature of much of the Kalahari sand in Botswana, and probably reflects destruction of the original bedding by extensive bioturbation. This may, in turn, be linked to the Neogene radiation of the C4 (Savanna) grasses, which was accompanied by a major radiation of termite species.

2.3 Zambezi river gravels of the Victoria Falls formation (VFF)

River gravels containing lithic artefacts occur on a series of terraces above the Zambezi River, with the highest gravels containing the oldest artefacts. Fig. 1 provides a schematic representation of these different gravel units, while the associated lithic artefacts are documented in Table 1.

3. EVOLUTION OF VICTORIA FALLS AND LOWER GORGES

The Victoria Falls, with a length of 1700m and maximum vertical drop of ~108m, form the world's largest sheet of falling water when the Zambezi is in full flood. Their breathtaking beauty moved David Livingstone to write that "scenes so lovely must have been gazed upon by angels in their flight", and earned their designation as a UNESCO world heritage site.

The Falls demarcates a sharp break in the gradient and character of the Zambezi. Above the Falls, the river flows in a broad channel with a low gradient . Below the falls, the river has incised a deep, much higher gradient (Fig. 4) channel which initially follows a zig-zag course for approximately 10km, before turning sharply eastward just below the confluence with the Songwe River (Fig. 5a). This roughly eastward course is maintained for nearly 90 km before the river widens into the Gwembe Basin, which is the site of Lake Kariba. The deeply incised gorges below the falls are collectively known as the Batoka Gorge, although some reserve the term for the ~90km west-east gorge below the Songwe confluence.

The Batoka Gorge system is the result of headward erosion following the capture of the Upper Zambezi by the mid-Zambezi. Victoria Falls is the nick point marking the present focus of headward erosion. The series of WNW-ESE and NE-SW oriented channels immediately below the falls follow major lines of structural weakness, with the 2nd and 5th gorges being controlled by faults, with downthrow to the north in the case of the Second Gorge and to the south (~45-50m) in the case of the Fifth Gorge. The northern lips of these gorges mark the positions of former lines of the Falls (heavy dashed lines in Fig. 5a). The dotted line in Fig. 5a marks the original banks of the Zambezi prior to incision of the gorges. Lithic artefacts in the gravels associated with the Zambezi have been used to estimate headward erosion rates of the section of the gorge 20km below Victoria Falls within the range of ~42-80 mm/year.

These estimates would imply headward erosion of the total length of the Batoka Gorge over a period of ~1.4 – 2.54 Ma. However, this must be regarded as a very rough estimate, as there has been a progressive decrease in the volume of water (and presumably of erosion) as a result of the stepwise severance of the links between the Upper Zambezi and the former Chambeshi and Kafue headwaters. Flow rates and hence erosion would also be expected to have been significantly influenced by climatic changes associated with the alternating climatic cycles associated with the Plio-Pleistocene glaciations (causing aridity in Africa) and intervening warmer and wetter episodes.

At present, most water flow over the Falls is focussed at the low point of the Devil's Cataract (or Western Cataract), which is well illustrated in an exceptionally accurate painting of this section of the Falls by Baines in 1862 (151 years ago) (Fig. 6). This suggests northward erosion is taking place at this point. Nevertheless, at high flood, considerable flow occurs via a narrow cleft in Cataract Island, which is depicted on the extreme right of the painting by Baines. This cleft seems to be the expression of a NE-SW fracture line which can be identified from satellite imagery (Fig. 5b), and is marked Y-Y in Fig. 5a. It is thus possible that selective erosion along this line of weakness during periods of high flood will eventually lead to a new line of the Falls developing along this NE fracture.

It should be noted that the calculated rates of erosion appear to be inconsistent with the evidence provided by the very accurate painting of the Devil's Cataract by Baines in 1862. Instead of the 6-12m of erosion predicted by the calculated erosion rates, this accurate painting depicts the Devil's Cataract very much as it appears today. This may reflect higher resistance to erosion along north-south lines than along the well-defined NE-SW and WNW-ESE lines of structural weakness.

Some 30 km downstream of the confluence of the Songwe with the Zambezi, the Batoka Gorge narrows, and there is a drop of 6-7m at the Chimamba Rapids (Fig7). (In the local Leya language, these rapids are known by the onomatopoeic name Chomoomba, after the Ground Hormbill, *Bucorvus leadbeateri*). It is here that during peak floods, when

"*one stands on the brink of the lower cataract, and sees the whole volume of the great Zambezi converging into a single pass only 50 to 60 feet in width, shuddering, and then plunding for 20 feet in a massive curve that seems in the impact visibly to tear the grim basaltic rocks asunder, one learns better than from the feathery spray-fans of the Victoria Falls what force there is in the river, and one wonders no longer at the profundity of the gorge*" (Lamplugh, 1907:151).

The Chimamba Rapids mark a dramatic change in the geomorphic character of the Batoka Gorge, which widens downstream with decreasing gradient. It has long been recognized that break in geomorphic character marks a break in erosional regime, and possibly also a break in the erosion of the gorge. This may, in turn, be linked to severance of the original headwaters of the Zambezi (the Chambeshi and Kafue), with the resultant decreasing flow volume being associated with lower rates of erosion. However, because of the inaccessibility of the lower reaches of the Batoka Gorge, much work still remains to be done to refine our understanding of the geomorphic evolution of this dramatic landform.

The symposium coincides with low water flow of the Zambezi, when the Chimamba will not match Lumblugh's dramatic description. And there may simply not be time to get there. We will make a decision in this regard once we have visited Victoria falls and the main outcrops in the vicinity.

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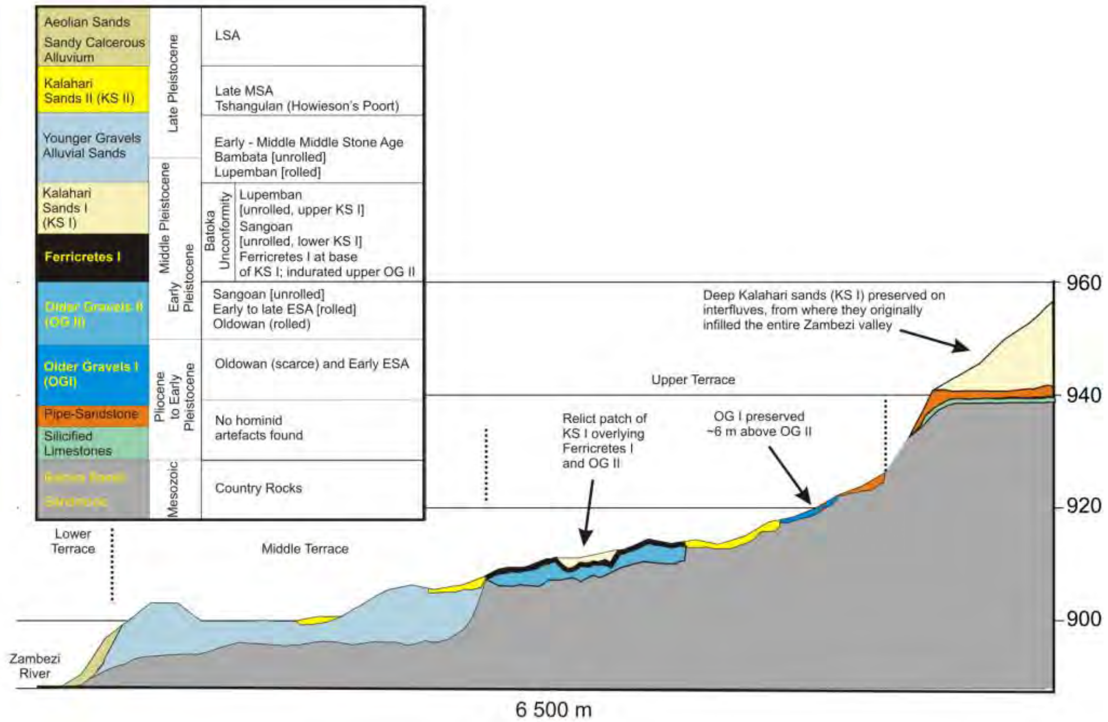

Fig. 1. Schematic representation of the main geological units associated with the Zambezi River in the Victoria Falls region. (Modified from Wellington (1955) by Moore and Cotterill (2010))

Fig. 2 Karoo basalt exposed in the walls of the 2nd and 3rd gorges below Victoria Falls. Steep cliffs represent individual lava flows, comprised of a dark bluish fine-grained basalt. The vegetated breaks in slope reflect an amygdaloidal basalt, which represents the brecciated upper/lower contacts between the individual flows.

Fig. 3a Pipe Sandstone near Mmashoro, central Botswana.

Fig. 3b Detail of pipe sandstone at Mmashoro.

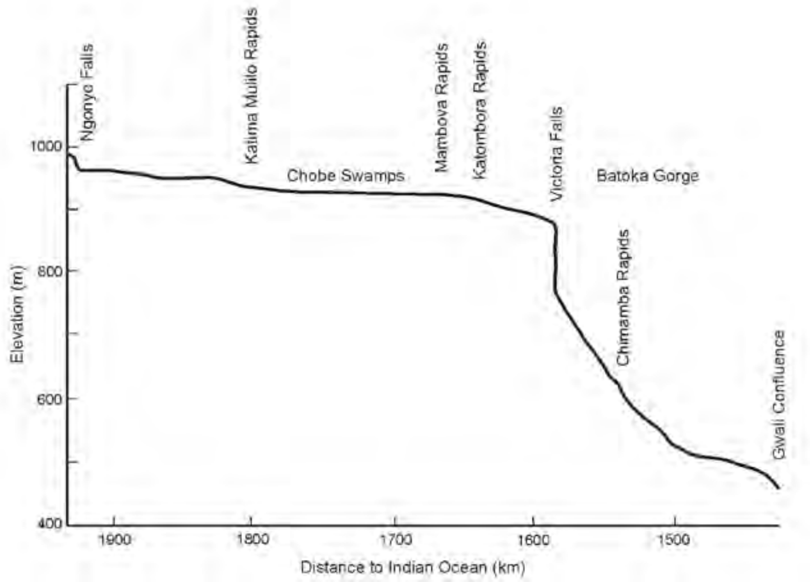

Fig. 4. Profile of the Zambezi above and below Victoria Falls (From Nugent, 1990)

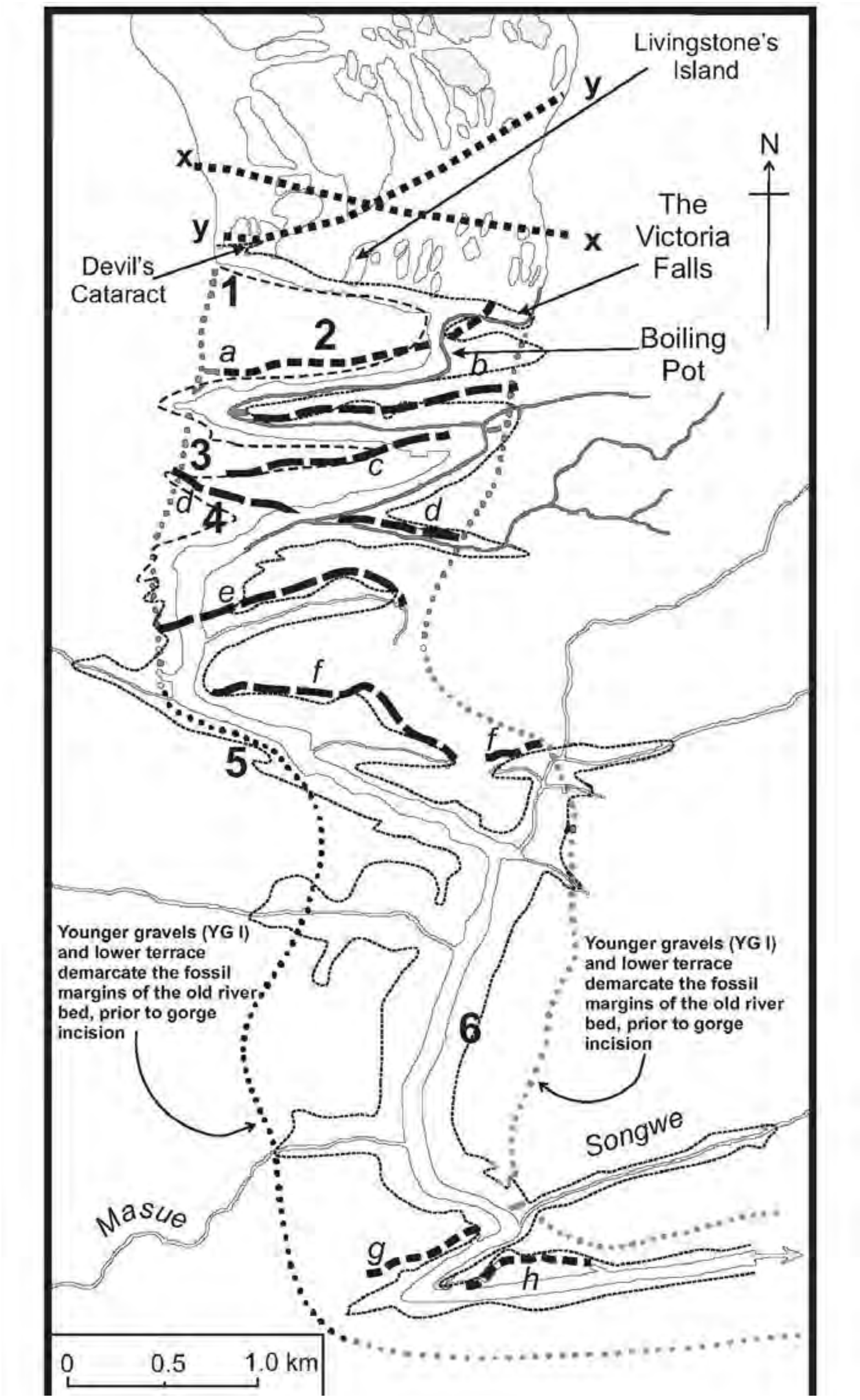

Fig. 5a Victoria Falls and lower Gorges (numbered). Heavy long-dashed lines mark inferred former positions of the Falls. Dotted line denotes the original margin of the Zambezi River bed prior to incision of the Batoka Gorge. Short-dashed lines X-X and Y-Y denote prominent lines of weakness which can be identified from aerial photographs. The line Y-Y appears to control a prominent cleft in Cataract Island, which is the focus of high flow during peak flood periods. (Modified from Wellington (1955) by Moore and Cotterill (2010))

Fig. 5b. Google image of Victoria Falls and upper Zambezi at low flow, illustrating the strong fracture pattern in the Batoka Basalts.

Fig. 6 Painting of the Devil's Cataract or Western Cataract by Thomas Baines in 1862. The cleft in Cataract Island on the extreme right of the painting carries a high volume of water during floods, when erosion and back-cutting would be expected to be highest. This cleft marks the intersection with the Falls of a major NE-SW structural line which can be identified on aerial photographs (shown in Fig. 5). It may ultimately develop into the next line of Falls.

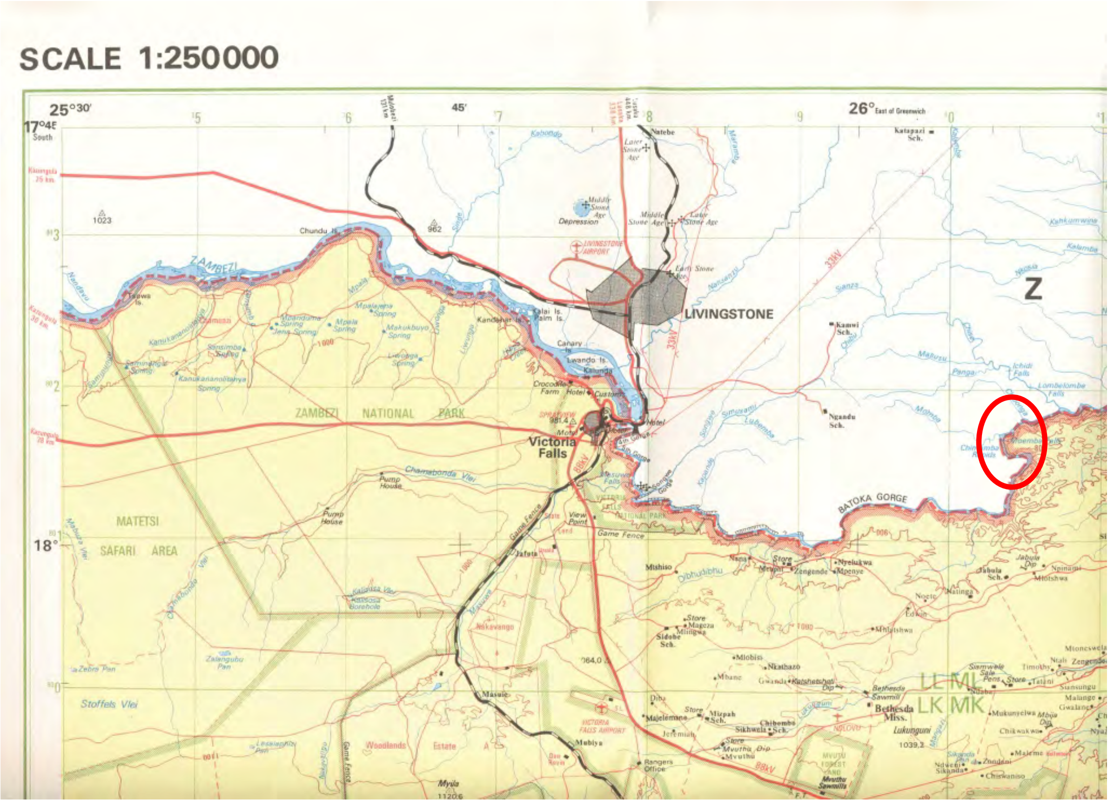

Fig. 7 Location of Chimamba Rapids within the Batoka Gorge (extreme right of this image of the 1:250 000 map covering Victoria Falls and Hwange

APPENDIX

Fossils associated with the basal Kalahari Pipe Sandstone and Chalcedony Beds

and

examples of Stone Age lithic artefacts found in the vicinity of Victoria Falls

Fig. A1.1 Extant *Chara sp*. (muskgrass) growing in Lake Constance, Switzerland

Fig. A1.2 Extant example of the freshwater Ostracod *Cypris sp.*

Fig A1.3 Extant *Planorbis sp*. This is a freshwater gastropod mollusc belonging to the family Planorbidae, and commonly known as the Ram's horn snail.

Fig. A1.4 Modern *Lymnae Sp.*, a freshwater gastropod commonly referred to as The Great Pond Snail

Fig. A1.5 Thalassinoides trace fossils

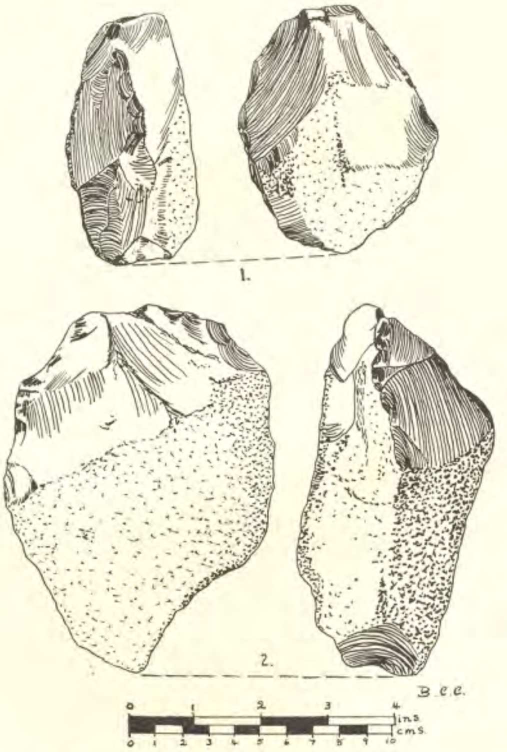

Plate I. PRE-CHELLES-ACHEUL CULTURE

1. Heavily abraded and glazed tool of developed Oldowan form from Older Gravels I. Site Z.Y.40. Zambezi Valley. Material — chalcedony.
2. Heavily abraded and glazed Oldowan-type tool from Older Gravels I. Site Z.Y.40. Zambezi Valley. Material — chalcedony.

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Fig. A2.1 Early Stone Age Mode 1 (Oldowan)

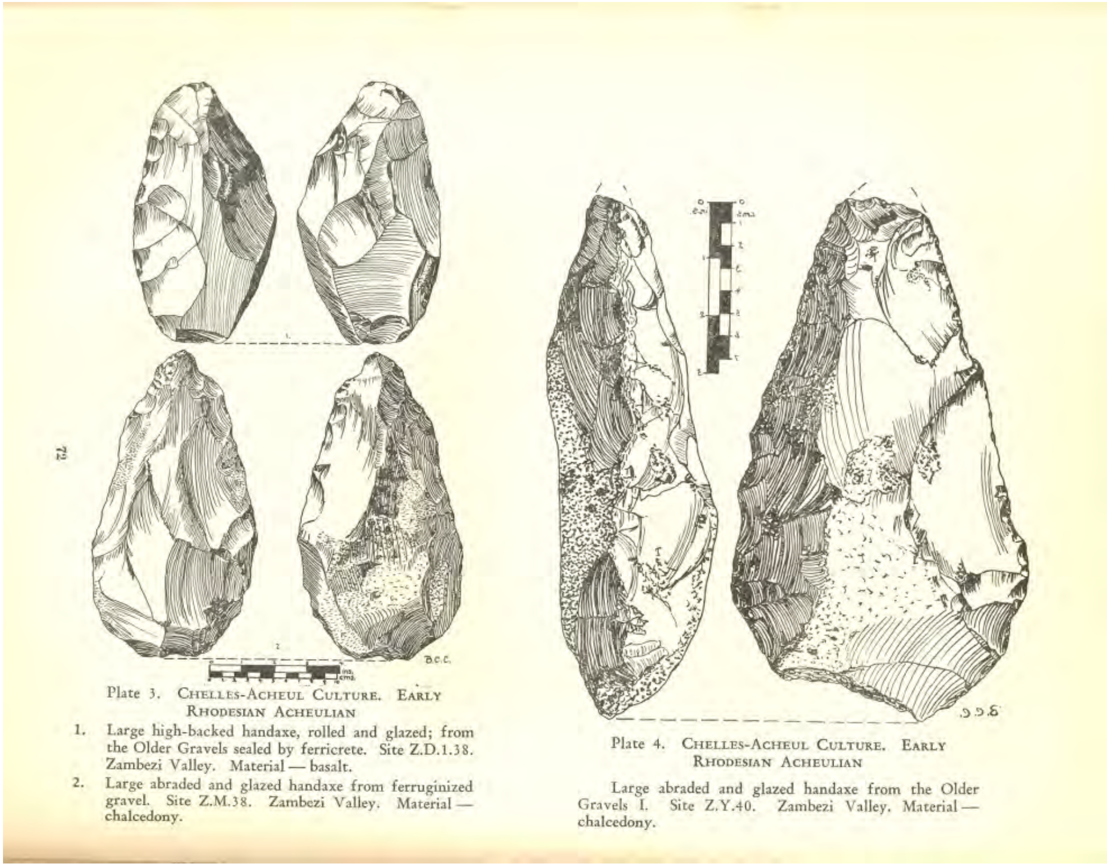

Fig. A2.2 Early Stone Age Mode 2 (Acheulian)

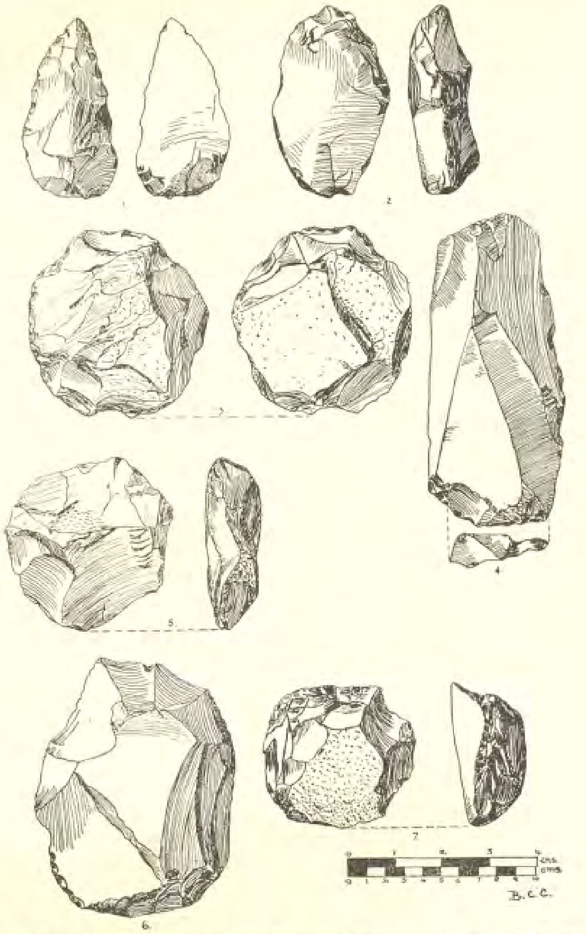

Plate 10. RHODESIAN SANGOAN CULTURE. LUANGWA VARIANT

1. Unifaced point, unrolled. Material — quartzite. From Chikunku, Isoka District, Luangwa Valley.
2. Small handaxe, rolled. Material — quartzite. From Lundu area, Luangwa Valley.
3. Prepared disc-core, unrolled. Material — quartzite. From Chikunku, Isoka District, Luangwa Valley.
4. Large flake-blade with crudely faceted striking platform, unrolled. Material — quartzite. From Mpangala, Luangwa Valley.
5. Prepared disc-core, struck, unrolled and with ferricrete concretions. Material — quartzite. From Mpangala, Luangwa Valley.
6. End-scraper on large prepared flake, the butt and platform have been trimmed away to form the scraping edge, unrolled. Material — quartzite. From Kavengulo River, Luangwa Valley.
7. Discoidal core scraper, unrolled. Material — quartzite. From Chikunku, Isoka District, Luangwa Valley.

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Fig. A2.3 Early Middle Stone Age (Sangoan)

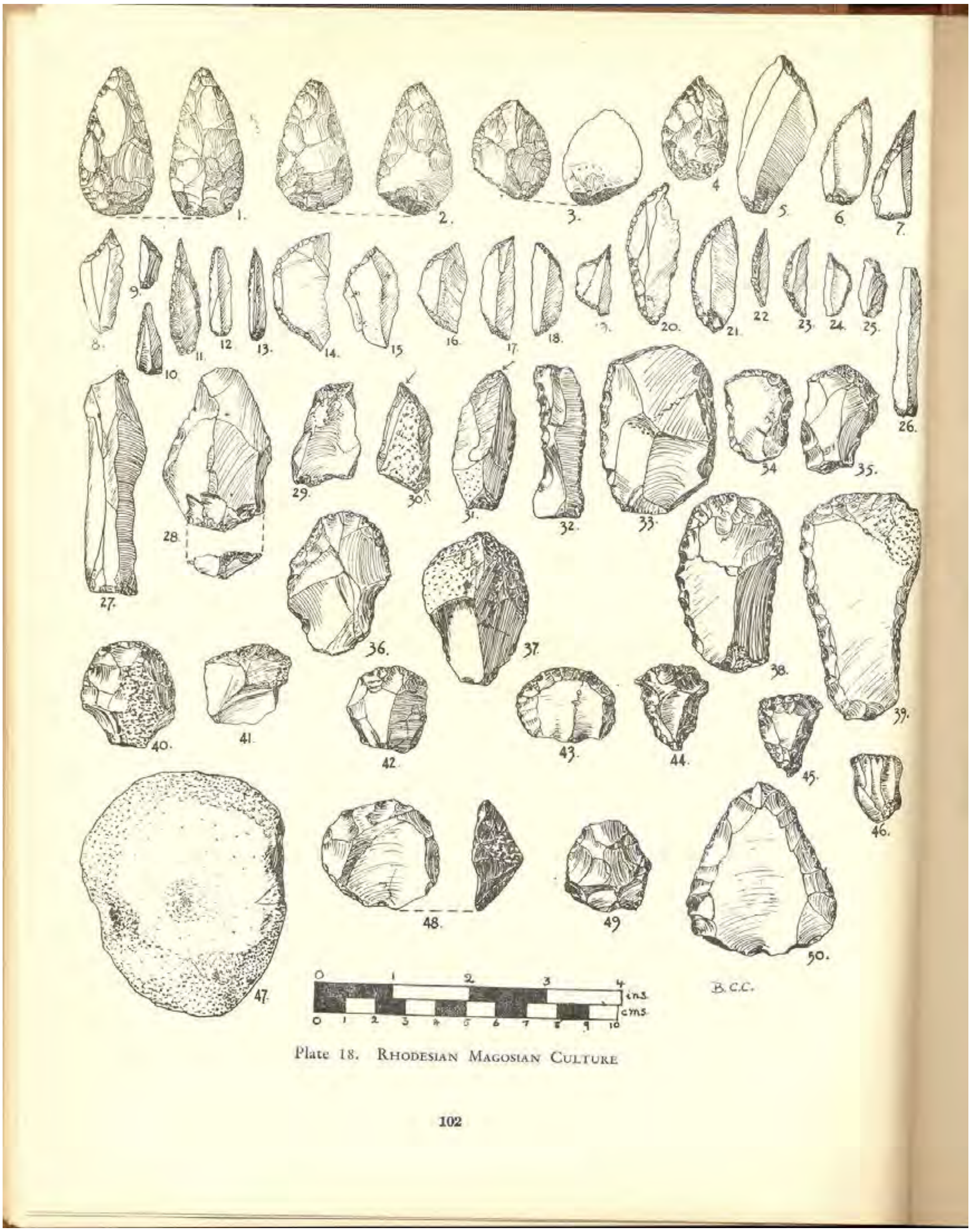

Fig. A2.4 Late Middle Stone Age (Mangosian)

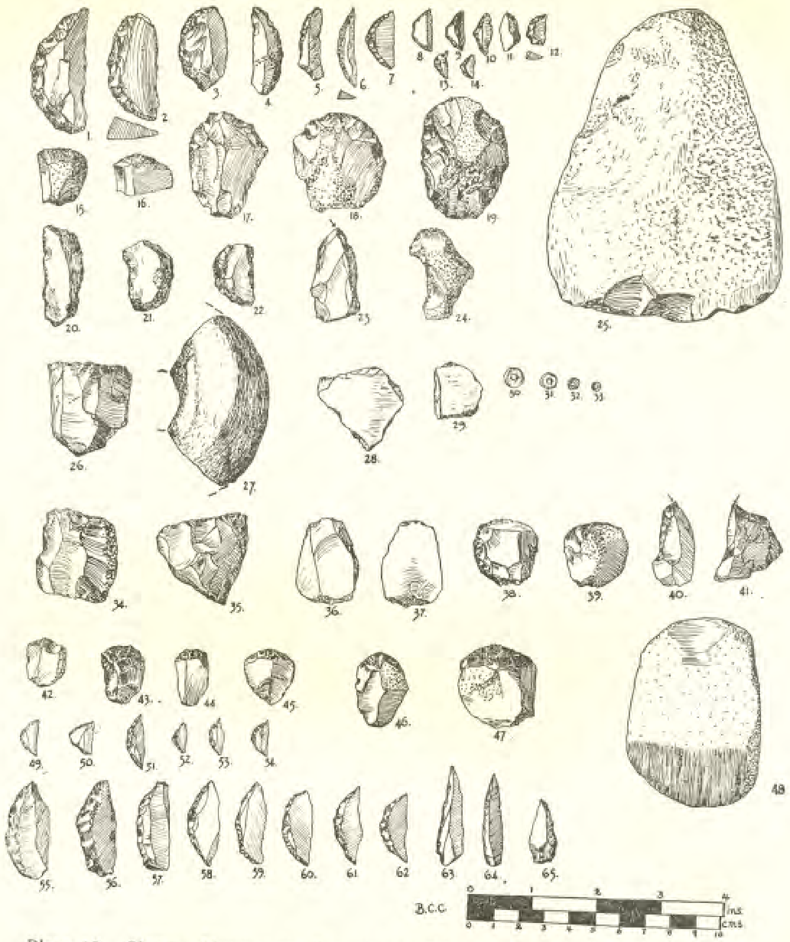

Plate 19. UPPER NORTHERN RHODESIAN WILTON CULTURE Nos. 1 — 33.

1.-3. Large backed blades. Nos. 1 and 2 with Kasouga retouch. Nos. 1 and 3 from Site Z.S.39. No. 2 from Site M.J.2.39. Zambezi Valley.
4.-14. Microlithic backed blades and crescents. No. 4 from site Z.J.2.39, and the remainder from Z.S.39. Zambezi Valley.
15.-16. Thumb-nail scrapers. No. 15 from site Z.D.38. No. 16 from site Z.S.39.
17.-18. Short end-scrapers. No. 17 from site Z.D.38. No. 18 from site Z.U.39.
19. Round scraper or trimming stone from site Z.S.39.
20.-22. Crude backed blades with Kasouga retouch. Site Z.J.2.39.
23. *Bec-de-flute* burin. Site Z.J.2.39.
24. Strangulated scraper from ¼ mile upriver from site Z.G.39.

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Fig. A2.5 Late Stone Age (Wilton)