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Discussion

The Zambezi River: tectonism, climatic change and drainage evolution — is there really evidence for a catastrophic flood? A discussion

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Introduction

The recent paper by Nugent (1990) concerning the evolution of the Zambezi River provides an interesting review of some of the available literature on the post-Gondwanaland evolution of part of southern Africa and an assessment of some new evidence which may shed new light on the development of the present course of the Zambezi. Nugent's presentation raises a number of important issues that are worthy of comment and which we wish to address: first the general evidence for a major change of course of the Zambezi; second, the evidence presented for the relationship between a proto-Upper Zambezi link with Lake Palaeo-Makgadikgadi in the Middle Kalahari, and finally the timing when the link was achieved.

The development of the present course of the Zambezi

Nugent (1990) argues that there are two prevalent theories for the Zambezi having a long profile consisting of two distinct concave-up sections: (1) the up-stream progression of a knick-point in relation to the operation of cycles of erosion and (2) the linking of two earlier rivers — the proto-Upper Zambezi and proto-Middle Zambezi — by drainage capture. The latter is not such a recent theory as suggested by the citations used by Nugent. Over sixty years ago, Du Toit (1927, 1933) proposed that the upper and middle sections of the Zambezi had been joined geologically recently, since when a number of authors have contributed to the growing evidence in favour of this hypothesis (including Wellington, 1955; Bond, 1963; Dixey, 1950 and Lister, 1979).

In a recent paper (Thomas and Shaw, 1988), we evaluated the evidence of these authors for the drainage capture theory of Zambezi evolution. This evidence is largely based on theory, and an understanding of the structural evolution of southern Africa since the division of Gondwanaland (e.g. De Swardt and Bennet, 1974). Additionally, we introduced further geomorphological evidence from northwestern Zimbabwe and adjacent Botswana for the upper Zambezi having once flowed into the Middle Kalahari and possibly south to the Limpopo or Orange Rivers. Perhaps the most compelling evidence for such a scenario though is zoological, based on significant distinctions in the fish faunas of the Upper and Middle Zambezi and similarities in the Upper Zambezi and Limpopo populations (e.g. Jackson, 1961; Balon, 1971, 1974). Nugent (1990) mentions none of this information, but also ignores one of the most obvious characteristics of the present Zambezi course for drainage capture, namely the significant change in direction that its course takes from south-southeasterly to easterly in the flat terrain at the eastern end of Namibia's Caprivi Strip.

This change of direction occurs some 100 km or so west of the meeting point, at Victoria Falls, of the two concave-up sections of the Zambezi

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described by Nugent. Overall, the characteristic of the long profile and the place where the change in profile occurs are not good evidence for or against drainage capture. The structural evolution of southern Africa since the late Jurassic (De Swardt and Bennet, 1974) and the structural activity and uplift of the Chicoa and Gwembe sections of the Middle Zambezi have contributed to the incision of this section of the river and are widely invoked as providing the energy for backcutting and downward incision of the Middle Zambezi. This is regardless of whether or not drainage capture took place in the Zambezi system: the two theories, therefore, need not be seen as competing ones. This incision has to date reached Victoria Falls which, regardless of any of the other issues in Nugget's paper, is effectively a nickpoint.

The greater energy of the Middle compared to Upper Zambezi which Nugent notes in his paper has been used in many of the previous investigations, including Thomas and Shaw (1988), to explain why capture took place. An interesting and neglected point of such explanations, including ours, is why therefore, does the proposed zone of capture (where channel direction changes) lie west of the point where the major change in long profile occurs. It is this point, rather than the general principle of capture, that Nugent (1990) may shed light on.

Relationship between Lake Palaeo-Makgadikgadi and the Zambezi

The means of drainage capture invoked by Nugent is a catastrophic flood event caused by breaching of Palaeo-Lake Makgadikgadi and "lasting in the order of several weeks" (p. 64). This breach is inferred to have taken place at the Katombora Gap, where the Zambezi passes through a gap in a basalt ridge. It is certainly plausable that the eastern extent of Palaeo-Lake Makgadikgadi was at this ridge as it embraces the appropriate altitudinal range (940-945 m âsl), but unfortunately there is a notable lack of geomorphological evidence to confirm this (Shaw, 1988). This is in contrast to the 936 m Lake Thamalakane stage, where water of the Zambezi appears to have been ponded back at Mambova, another basalt bar some 17 km west of Katombora at the Chobe-Zambezi confluence. Geomorphological evidence at this location, and along the Chobe Escarpment to the west where it has been radiometrically dated, provides clear evidence for this stage occurring in the period 17,000–12,000 yr B.P. (Shaw and Thomas, 1988).

It is unclear whether Nugent assumes that at Katombora the basalt ridge itself was breached in a flood or whether this fate fell upon a beach ridge feature comparable say, to the ridges around the Makgadikgadi basin proper (e.g. Cooke, 1980). There is also another role, alluded to by Nugent (p. 66), that the Katombora Ridge may have played in the evolution of Palaeo-Lake Makgadikgadi at the 945 m level, analogous to the one played by the ridge at Mambova for the 936 m lake and for which modern evidence exists. The gaps through which the Zambezi and Chobe pass at this location are not seen as having developed with a catastrophic breaching of the 936 m lake. Instead this constriction in the valley is seen as acting as a barrier to enhanced Zambezi flow, ponding water back and leading to its diversion to the lake system (Shaw and Thomas, 1988). This actually happens today when the Zambezi is in high flood, albeit on a seasonal basis, but it is not an unreasonable mechanism to provide a way in which enhanced Zambezi flow, under increased catchment precipitation, could have been fed to lakes in the Middle Kalahari. Following earlier work, Nugent notes this possibility as a means of switching Zambezi water to and away from the lake system, and it is not implausible given that the ponding capabilities of the various basalt bars may well have been enhanced by the subtle tectonic movements that affect this zone. Equally significant is that this is probably one reason why the Middle Zambezi has little in the way of terrace development in response to Late Pleistocene and Holocene climatic changes "unlike other African rivers" (p. 63), because ponding back of waters from the upper catchment would effectively buffer lower reaches of the river from their effects.

Going beyond this role for the Katombora Ridge and the ponding relationship between Lake Palaeo-Makgadikgadi and the present course of the Zambezi, as Nugent does, points to there being good evidence to do so. There is really only one piece of information in this category in Nugent (1990), namely the "Stoney Ridge" in the Middle Zambezi valley near Mana. We are unable to comment on the interpretation of the general origin of this feature as a flood deposit, having not observed it, but we are able to make some remarks about the completely tenuous link that Nugent makes between this feature and the supposed breach at Katombora, some 600 km upstream. It appears (p. 63) that Stoney Ridge is about 50 m above present river height, which is not considerable given that Pleistocene downcutting achieved in this area has been immense (Dixey, 1945) due to downwarping along the Gwembe Trough. Nugent argues however, that agates contained in the Stoney Ridge deposits were derived from two likely sources, one being "the basalt plateau upstream of the proto-Victoria Falls" (p. 63). This is no evidence for a catastrophic breach at Katombora, nor indeed, for the Stoney Ridge sediments having been derived from that section of the Upper Zambezi. Indeed, Nugent himself gives us an alternative source, at the Batoka Gorge (below Victoria Falls), to which we can add the Gwaai River, which cuts into the same basalt source for the agate, and local basalt outcrops in the Zambezi Escarpment near Matusadona (190 km west of Stoney Ridge) and a further outcrop just 40 km upstream of the ridge, both within the Zambezi valley. All these potential sources are within the Middle Zambezi catchment, and suggest that the lithological evidence which is used to support the theory is unreliable. Overall, while Nugent's catastrophic idea is interesting and does provide a possible mechanism for the capture of the Upper Zambezi, there is no information provided in the paper which actually supports it.

Dating

Nugent also attempts to provide a chronology for the establishment of the present Zambezi course. Previous work has only attempted to do so in the broadest terms (e.g. Dixey, 1950, Bond, 1975, Lister, 1979) placing this event before the late Pleistocene and after the late Tertiary. Using artefactual evidence from the surface of alluviual terraces in the Zambezi valley, and making an extremely tenuous correlation for some of the artefacts with *one* dated tool of the same culture from a cave on the South African coast, the catastrophic flood event is attributed to about 125,000 yr B.P. We need not comment further on the severe limitations in the way in which this actual date was derived, and the problems of attaching dates to southern African archaeological cultures, but the fact that the artefacts are surficial finds, and thus only minimum dates in the loosest possible sense, makes their use in delimiting a narrow time band for one flood event very doubtful.

Overall, there are some interesting ideas introduced in Nugent's paper but the evidence used to support the catastrophic flood theory does not stand up to scrutiny. While we recognise that there is a role for speculation when investigating such complex and seemingly unresolvable issues as the development of the present course of the Zambezi, this does not justify some of the points made in support of the idea by Nugent. We welcome further recognition for the idea of links having existed between the Kalahari palaeolakes and the Zambezi, but more concrete evidence is necessary before the nature of such a link, especially one involving a catastrophic ending, can be expressed with the degree of certitude that Nugent proposes.

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The Zambezi River: tectonism, climatic change and drainage evolution — reply to discussion

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Introduction

I am grateful to Thomas and Shaw for their comments on my paper, which raise some interesting points. It is evident that some of my conclusions require explanation and amplification, so I shall try to answer Thomas and Shaw's queries in the order in which they were raised. Although I wrote this paper almost three years ago and have since developed those aspects of river capture related to catchment denudation, I have continued to find the geology and geomorphology of the Middle Zambezi to be consistent with the mechanism and chronology of capture suggested in this (1990) paper.

The development of the present course of the Zambezi

As noted by Thomas and Shaw, I have not reviewed much of the previous work supporting the theory that the Zambezi developed as two separate rivers. That task was ably completed by Cooke (1976, 1980) and more recently (though not available to me at the time of writing), by Thomas and Shaw (1988). I feel that capture of the Middle Zambezi's upper catchment is now sufficiently well demonstrated to focus on questions of how, why and when the event occurred.

I presented the twin concave-upwards profile of the Zambezi as a major geomorphic anomaly requiring explanation. I then identified the process of pediplanation (with or without river capture) and river capture (with or without pediplanation) as two alternative explanations. I emphasised that these need not be seen as competing, noting that if the Southern African landscape developed through successive episodes of pediplanation "river capture by headwards erosion should then be seen as the inevitable consequence of knickpoint retreat" (p. 61).

Compelling as the fish evidence may appear, it is not unequivocal and Balon (1974) considered that the Victoria Falls may not be as effective a barrier as previously supposed. Citing the appearance of Upper Zambezi fishes in Lake Kariba after impoundment, he suggested that "saturated niches and differences in habitats and not the physical barrier of the Victoria Falls may have been the effective barrier against intermingling of species" (pp. 496–497). If Balon is correct, the fish evidence can be of little or no value in elucidating the regional geomorphic history.

I agree with Thomas and Shaw (p. 176) that "the characteristic of the long profile and the place where the change in profile occurs are not good evidence for or against drainage capture". This evidence may, however (as Thomas and Shaw imply) explain one particular mechanism of capture more easily than others. Since the knickpoint at Victoria Falls lies downstream of the proposed zone of capture, its retrogression could not have initiated the capture process. Joining of the Middle and Upper Zambezi may have been effected by headwards retreat of an earlier knickpoint (for which we have no direct evidence) or alternatively, by overtopping of palaeo-Lake Makgadikgadi. In the latter case, the knickpoint would have been initiated downstream of the zone of capture. Capture by overtopping provides a simpler, and for me a more compelling explanation of this aspect of the regional geomorphology than capture by headwards erosion.

The idea of river capture by overtopping was not originally mine. Bond (1975) suggested that Upper Zambezi and Mashi (Chobe) discharge could have collected over the Makgadikgadi and "the ponded waters of the Upper Zambezi–Mashi system could have escaped eastwards along this gentle depression. The water would have run along the axis of the depression until it spilled over the 250 metre drop of the left flank of the old Middle Zambezi headwaters" (Bond, 1975, p. 24). Assessing the evidence in Botswana for palaeo-Lake Makgadikgadi, Cooke (1980, p. 96) noted that "if this lake did in fact reach the 945 m level as seems likely on the evidence, it would have overflowed northwards, initiating a link between the Upper and Middle Zambezi across the Victoria Falls escarpment".

Relationship between palaeo-Lake Makgadikgadi and the Zambezi

Thomas and Shaw (p. 176) consider that although Katombora is a plausible site for the margin of a palaeo-Lake Makgadikgadi, "there is a notable lack of geomorphological evidence to confirm this". Citing evidence from Shaw and Thomas (1988) of a 936 m lake ponded behind the basalt bar at Mambova, they appear to consider this to be a more plausible lake margin than Katombora, 26 km downstream. While accepting their conclusions regarding the Late Pleistocene and Holocene chronology of palaeo-Lake Caprivi, I doubt whether Mambova ever formed the margin of a 945 m lake and believe that there is evidence for former lacustrine conditions between there and Katombora.

Shaw and Thomas (1988) described various beach features on the southern margin of the Chobe Swamps which they associated with a 936 m lake, controlled by basalt at its outflow at the Mambova Fault. Had this feature once controlled a 945 m lake, then it must subsequently have been lowered (tectonically perhaps) by some 9 m. Yet Shaw and Thomas found evidence of tectonic stability between shorelines. They considered the 936 m Lake Caprivi to have been coeval with a lake over the Okavango (Lake Thamalakane), where Shaw (1985) described remnants of higher shorelines, between 940 m and 945 m. The features described by Shaw and Thomas (1988) at Mambova do not appear to me to be consistent with a 945 m lake margin.

Along much of the North bank between Mambova and Katombora Clark (1950, p. 42) described 12–15 m of freshwater limestone formed *in situ*. Not having visited these exposures, I have not been able to interpret the lithology but consider that it constitutes at least *prima facie* evidence for former lacustrine conditions. The fact that the limestone is not identified downstream of Katombora suggests that these low hills may have formed the lake margin.

Clark (1950, p. 40) noted that "deep deposits of fine grained sediments are present between Katombora and Kazungula, and again above the Mambova Rapids". Such sediments are also consistent with former lacustrine conditions and are probably related to the distribution of modern swamps, which bound much of the Zambezi's channel above Katombora but not below. In summary, I consider that the topographic, geological and geomorphological evidence currently available to me suggests Katombora, rather than Mambova as the former margin of the 945 m lake.

I had not intended to imply that the ridge of hills at Katombora follows an active fault or that outflow from the 945 m lake was in any way tectonically controlled. Although such a relationship evidently exists at Mambova and the Savuti offtake of the Chobe River, I have found no evidence for this structural setting at Katombora. I invoked the tectonic switching of drainage (pp. 65 and 66) to explain the evident development of lakes after the (Last Interglacial) joining of the Upper and Middle Zambezi.

I am puzzled as to why Thomas and Shaw should expect switching of drainage to suppress terrace development downstream. I infer from the alluvial record that the Middle Zambezi aggraded by about 50 m then degraded to bedrock. This grade change is readily explained as the consequence of a large increase in streamflow accompanied by a very small increase in sediment discharge, following capture of the Zambezi's upper catchment. Such changes would be expected, in terms of Lane's (1955) grade relations, to have swung the river towards a degradational regime. It seems to me that subsequent diversion of the Upper Zambezi into the Kalahari would have actually promoted terrace development along the Middle Zambezi, by temporarily re-establishing an aggradational regime.

The link between river capture at Katombora and the Stoney Ridge deposit at Mana that Thomas and Shaw find "completely tenuous" actually embraces more than the rather qualitative conclusions on provenance that I draw from the enclosed agates. I will return to this point, but first wish to explain the topographic and stratigraphic relations.

Notwithstanding Dixey's (1950, p. 11) suggestion of "immense" Pleistocene downcutting within the Middle Zambezi basins, Bond and Clark (1954) described older alluvial desposts in the Gwembe (Lake Kariba) Trough to 55 m above the river and fringing a younger alluvial floodplain. I have found a similar relationship downstream of Kariba, where the top of the alluvial sequence lies some 50 m above river level at Mana and is capped in places by the Stoney Ridge. Stratigraphically, the Stoney Ridge deposit overlies the older alluvial sequence but pre-dates downcutting to modern river level. If this grade change resulted from capture of the Zambezi's upper catchment, then the Stoney Ridge desposit should be seen as chronostratigraphically coincident with river capture.

The increase in the abundance of agates at the time Stoney Ridge was deposited strongly suggests a change in provenance and it is true, as Thomas and Shaw point out, that the Batoka Plateau is not the only possible source. Other river captures have also increased the catchment area underlain by Karoo basalt, most notably capture of the Gwayi River. Karoo basalt is exposed beneath some 7% of the Gwayi catchment, all of it on the gently sloping, mature landscape of the highveld plateau. The basalt itself is not deeply eroded and it is hard to envisage how cobble-sized agates could have been stripped from this source and carried to Stoney Ridge.

In contrast, the Batoka Gorge and tributary gorges are incised by up to 300 m into some 500 km^2 of Karoo basalt forming the Batoka Plateau and sediment production from that area has clearly been considerable. I envisage that the large number of agates in the Stoney Ridge deposit were mainly derived from rapid stripping of the weathered mantle along the new channel downstream of Katombora, during the Stoney Ridge flood. The other basalt outcrops mentioned by Thomas and Shaw are small and have not been associated with drainage capture. I do not believe that any other river capture could have produced both enough water to effect channel degradation *and* a large increase in the supply of agates.

Dating

Lying beyond the limit of radiocarbon techniques, river capture had to be dated in terms of some other yardstick. Fortunately the detailed work of J. D. Clark (1950) and more significantly

Bond and Clark (1954) and Bond (1956) established relationships between the Zambezi's terraces and the Stone Age cultural succession. The evolutionary segment of interest extends from the *Sangoan* (a cultural expression considered to have been intermediate between Early and Middle Stone Age forms) into the first MSA assemblages, which Clark called "Rhodesian Proto-Stillbay".

Clark (1982) considered that the most reliably dated site covering this part of the Stone Age is within a marine cave at Klasies River Mouth (KRM), on the Eastern Cape coast. The KRM site has yielded a single, rolled tool of *Sangoan* affinity, overlain by a sequence of unrolled artifacts spanning the early MSA (Singer and Wymer, 1982). Oxygen isotope measurements on more than 200 mollusc shells (food refuse) from within the cave stratigraphy (Shackleton, 1982) established that the sequence extends from the last interglacial, when high sea level probably rolled the single *Sangoan* tool. The first MSA cultures (MSA I, Singer and Wymer, 1982) appeared during the subsequent cooling phase of oxygen isotope stage 5e, placing them immediately after the interglacial's peak. Clark (1982) confirmed that the MSA I culture was equivalent to his Rhodesian Proto-Stillbay, which he also called "Bambata".

The arrangement of Stone Age artifacts on *and within* the river terraces was summarised by Bond and Clark (1954) and Bond (1956), who identified the following sequence:

(1) Gravel terraces lying between 13 m and 55 m above river level (arl) contain rolled ESA tools, with fresh *Sangoan* on surfaces above about 16 m asl.
(2) Alluvium II extending from 30 m asl to below the modern water line. The older unit (alluvium IIa) is calcified and contains fresh Proto-Stillbay artifacts, with rolled *Sangoan* at its base. Alluvium IIb is less calcified, containing fresh Late Stillbay with rolled Proto-Stillbay at its base. Fresh MSA and LSA artifacts occur on the surfaces.
(3) Alluvium III, Alluvium IV and the modern flood plain all lie within 15 m of river level. They contain little or no Stone Age material.

I believe that the succession is consistent with alluviation during a single degradation event, during which:

(1) *Sangoan* industries had developed by the start of degradation and persisted, at least locally, until the Middle Zambezi River had incised to some 16 m above its modern level.
(2) The first MSA culture (Proto-Stillbay or MSA I) developed when the river was still some 30 m above its modern level, evolving into Stillbay during degradation. Unfortunately, neither Bond and Clark (1954) nor Bond (1956) gave detailed height relations for artifacts found within Alluvium II.
(3) Later MSA and LSA cultures lived in favourable sites on all terraces.

On the adequacy of this evidence Bond (1956, p. 71) stated that "assemblages of stone implements are the only "zone fossils" which can be used in correlating Pleistocene successions in this part of Africa". A major stratigraphic consideration, as with any such lineage biozone, is to what extent points of evolutionary change were everywhere contemporaneous. Without being able to answer this (archaeological) question definatively, I would suggest that the migration of Stone Age industries and cultural trends between Klasies River Mouth and the Middle Zambezi Valley was probably rapid, relative to the rate of cultural evolution. Errors resulting from diachronous cultural development at the two sites are probably of the same order as those inherent in other dating techniques.

Conclusions

The comments of Thomas and Shaw do not seem to have refuted my (1990) analysis, nor identified implications from which such a refutation may later be found. They consider that my evidence is not sufficiently "concrete" and "does not stand up to scrutiny". It is my view that they have not fully considered all the available evidence, some of which is reiterated above. In any case, the "degree of certitude" is far too subjective a measure with which to judge scientific theory and may depend, in this case, on whether one views the Zambezi from its plateau or trough tracts.

If my model is scientifically valid, it must contain falsifiable implications which could show it to be untrue (Popper, 1972). If the model is consistent with the available evidence (and Thomas and Shaw have not shown otherwise) other evidence should be sought with which it may not agree. Since I failed to identify any such tests in the original paper, I shall take the opportunity to do so here:

(1) Facies differences should exist between pre-Late Pleistocene deposits either side of the (proposed) watershed at Katombora. Lacustrine sediments should occur upstream of the watershed but not downstream.

(2) The mineralogy and geochemistry of the older and younger alluvial deposits of the Middle Zambezi should reflect the change in provenance precipitated by river capture (i.e. an increase in basaltic minerals and their weathering products and agates).

(3) The Stoney Ridge deposit should contain rolled ESA and *Sangoan* implements, but no MSA or LSA tools (except perhaps unrolled specimens on the surface).

I hope that I may have the opportunity to investigate these questions in the future and would welcome the participation of Thomas and Shaw in any such venture.

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