

Spatial patterns of islands and salt crusts in the Okavango Delta, Botswana

THOMAS GUMBRICHT, & TERENCE MCCARTHY

Department of Geology, Wits University, Wits 2050, South Africa (E-mail: 065mct@cosmos.wits.ac.za)

Abstract

Islands in the Okavango Delta in Northern Botswana have a large influence on water flow, evapotranspiration and salinity balance. In this study island orientation and occurrence of salt crusts on islands was explored in relation to both regional Delta azimuth and local channel meandering. Islands, particularly those of larger size, are oriented along the azimuth of the Delta surface, with a local variation pertaining to the orientation of nearby channels. Islands with salt crusts are more elongated, with a tendency of more salt being deposited in the downstream direction. It is concluded that island formation and growth creates a radial pattern of elongated islands.

Introduction

The Okavango Delta is a large alluvial fan (40 000 km²) situated in a fault-bounded depression in northern Botswana (Fig. 1). The fan receives water and sediment from the highlands of central Angola. Some 9 km³ of water enters the Delta annually, augmented by 6 km³ of rainfall (McCarthy and Ellery, 1998). About 98% of this is lost by evapotranspiration in the semi-arid climate. The Panhandle entry valley and the permanent swamp of the Delta proper are inundated most of the time. The seasonal swamp is annually flooded, and the occasional swamp is more sporadically flooded.

Sedimentation occurs by a combination of clastic and chemical deposition, and we believe that surface features on the fan may provide insight into the mechanisms involved as well as the current distribution of sediment. Sediment thickness is in the region of 300 metres (m). Sediment deposited on the fan has formed a remarkably smooth cone of fairly uniform gradient (1:3500).

The annual inflow of sediments amounts to approximately 570 000 tons per annum (McCarthy and Ellery, 1998). 2/3 consists of dissolved chemical matter and 1/3 is clastic. To the sediment inflow is added another 250 000 tons of aerosols that are annually deposited over the Delta (Garstang et al., 1998).

The clastic sediments form island nuclei by three different processes (McCarthy and Metcalfe, 1990; McCarthy and Ellery, 1998; Gumbrecht et al, 2002): deposition on channel beds ("inverted channel islands"), deposition on point bars ("point bar islands"), and as randomly elevated points colonised by termites ("anthill islands"). Once an island nucleus has thus formed, it grows by chemical precipitation, a process driven by the high evapotranspiration by trees on island fringes. The chemical precipitation of salts from ground water ultimately leads to the formation of salt crusts, or "trona" on the islands. Presence of trona is an indication of island growth. The actual growth, however, is hypothesised to occur bound to the vegetated fringes of the islands. The position of the trona rather indicates the ground flow direction, with the trona forming in downstream areas.

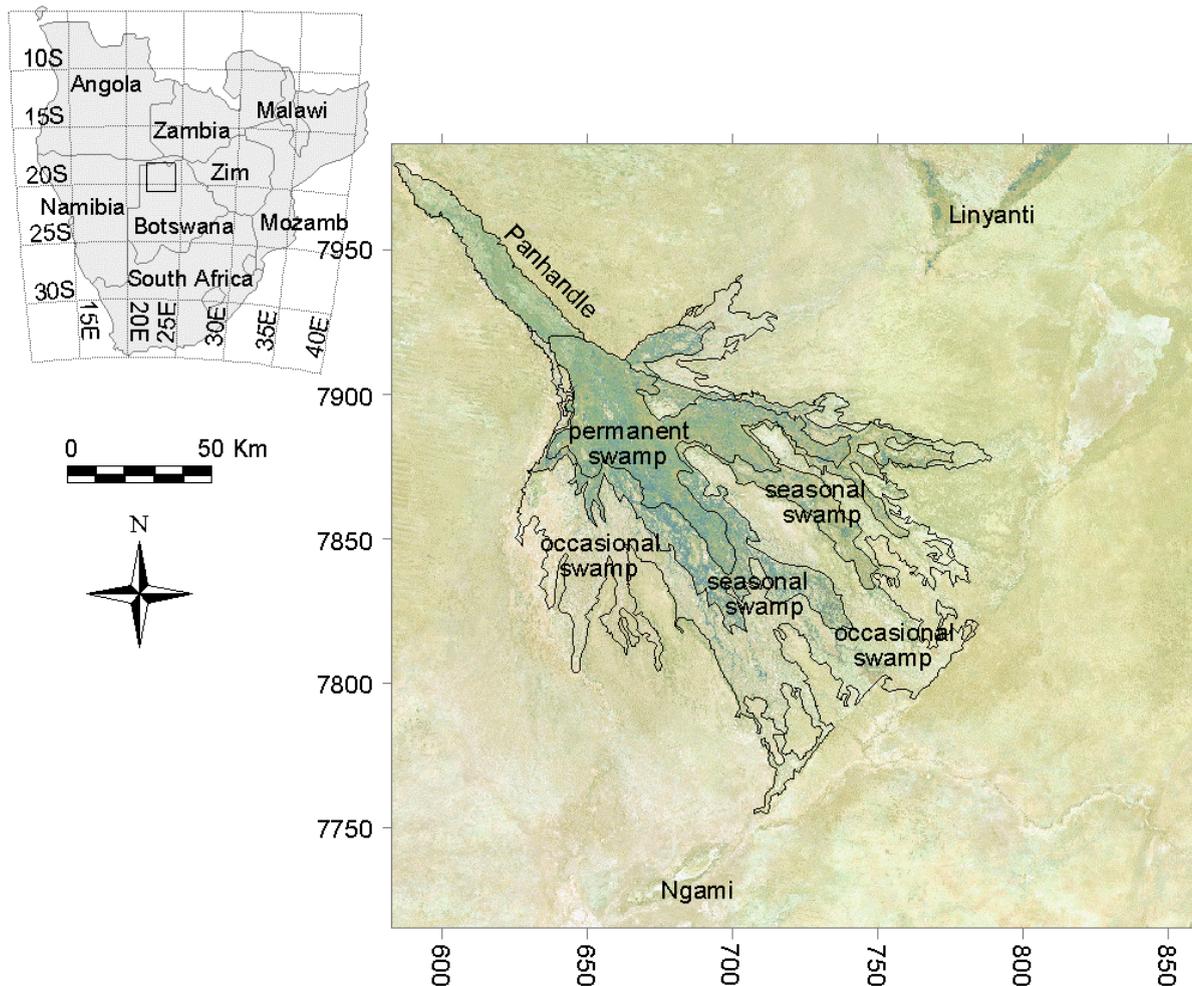


Fig. 1 The Okavango Delta, Botswana, superimposed on a composition of Landsat TM scenes. The large map is projected to S. UTM 34, Cape Datum, False Easting 500 000, False Northing 10 000 00, map distance units in kilometres.

Islands with salt crusts can broadly be divided into two classes – those with salt crusts in the centre and those with salt crusts on the fringes. The former type is thought to result from growth of islands initiated as anthills, with growth in most directions. The trees on the fringes rooted in the fresh water direct groundwater flow towards the centre of the island. As the islands grow larger the interior will become progressively saline. Salt crusts on island fringes indicate that the island rim is saline. This type of island is hence hypothesised to be more common in close proximity to the channels – where water flow is more unidirectional.

From a sedimentological and hydrological viewpoint the orientation of islands, and the distribution of chemical precipitation on islands is important. Anisotropic orientation of islands would mean that water flow is directed. Distribution of chemical precipitates on islands indicates general water flow direction and island growth patterns. Hence the distribution of salts could give insights into the processes of island growth, form and orientation, as well as contribute towards understanding the overall sediment balance of the delta. The whereabouts of the 350 000 tons of chemically dissolved salts entering the Delta annually is also not fully understood.

In this study we explore the orientation of islands in the Okavango Delta, both regionally in relation to the azimuth of the Delta, and to the local scale of channel meanders. We use the salt crusts on islands as proxy for the general ground water flow pattern, and explore their occurrence and positions in relation to both regional and local scale orientation of water flow.

Material and methods

A remote sensing derived dataset with all islands of the Okavango Delta (McCarthy and Gumbricht, 2002) was used for identifying island longest axis, and the distribution of salt crusts of every island. The major axis of each island was simply identified as the two points furthest apart along the island boundary (programmed in avenue – the ArcView GIS script language). The occurrence of salt crusts was extracted from a land cover dataset (Gumbricht et al., 2002). The datasets were developed from the same four Landsat TM scenes (McCarthy and Gumbricht, 2002), with an original resolution of 28.5 m. The classification accuracy of the data is approximately 75 %.

Islands smaller than 50x50 m were omitted from all analysis, as were all islands with a roundness larger than 0.9 (defined as the actual island area divided by the hypothetical round island area estimated from the island actual perimeter – see Fig. 2).

Regional island orientation was explored by dividing the Okavango Delta into 8 equal sectors of 15 degrees (see Fig. 3). The Panhandle was analysed as a separate entity. The distribution of island orientation in each sector was explored by plotting the length of the major axis of each island against the azimuth in a rose plot diagram.

The local (meander-related) island orientation was explored by selecting all islands with centres falling within 500 m from the channels. The length of the major axis was compared to the length of the distance between the two end points of the axis to the nearest channel point. I.e. end points at equal distance from the channel indicate an island parallel to the channel; a difference in distance equalling the length of the island major axis indicates an island perpendicular to the channel.

The regional influence on the internal distribution of salt crusts on islands was analysed by a proximity analyses starting from the bifurcation point of Nqoga and Thaoge (see Fig. 3). For each island the average and variance of the distance to salt and non-salt areas was calculated. The number of islands with salt crusts on the proximal and distal ends ($p < 0.05$) was recorded.

The influence of local channel position on salt crust formation was explored by the distribution of the occurrence of salt on island fringes in relation to channels in close proximity (less than 500 m). The distance from the channels to the island fringes was analysed as travelling distance, calculated using the land cover map as a cost surface, with islands as barriers for travelling (Fig. 2). Travel costs were ranked to 1 for water, 2 for permanent swamp, and 3 for flood plains (classes as given in McCarthy and Gumbricht, 2002). The average travel cost to the salt fringe and the non-salt fringe was explored.

The geographical distribution of positions (i.e. central or fringe) of salt crusts on islands was also investigated; the salt crust position vis-à-vis the island-edge was extracted for each island, and explored as a function of island distance from the nearest channel.

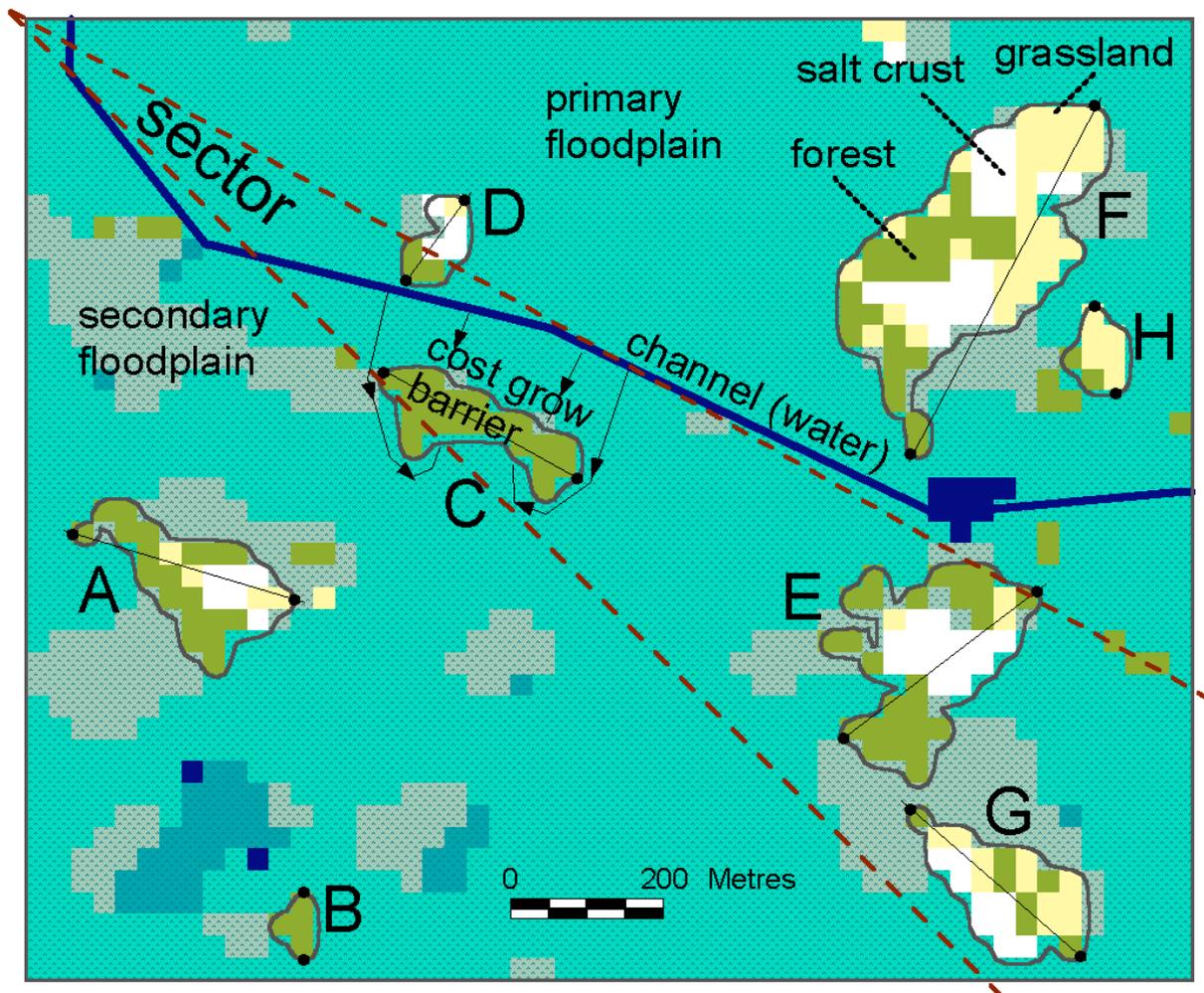


Fig. 2. Illustration of methodological approach (see text). Some of the properties of the 8 islands are given in table 1.

Table 1 Properties of the islands in Fig. 2.

	A	B	C	D	E	F	G	H
Roundness	0.49	0.91	0.51	0.48	0.36	0.47	0.58	0.92
Regional salt position	distal*	na	na	proximal	distal	equal	proximal	na
Channel salt position	front	na	na	back	back	back	back*	na

na not applicable; * significant ($p < 0.05$)

Results

The regional orientation of islands is clearly related to the azimuth over the entire Delta surface (Table 2; Fig. 3). In general the larger the island, the more it is oriented along the azimuth of the Delta. Smaller islands are more randomly oriented. Island elongation in close proximity to channels is related to channel orientation (Fig. 3).

Table 2 Island major axis orientation in the Okavango Delta, Botswana

Sector	No of Islands	Mean Resultant direction	Longest island (km)	Total island length (km)
Panhandle	3089	172 (S)	19	753
75-90	1487	61 (E)	7	377

90-115	1664	87 (E)	13	431
115-130	7223	99 (E)	27	2034
130-145	7049	112 (E)	78	2029
145-160	8720	167 (S)	27	2413
60-175	5367	170 (S)	19	1603
175-180	5304	182 (S)	19	1568
180-195	2817	187 (S)	4	689
Channels	4235	38	27	1231

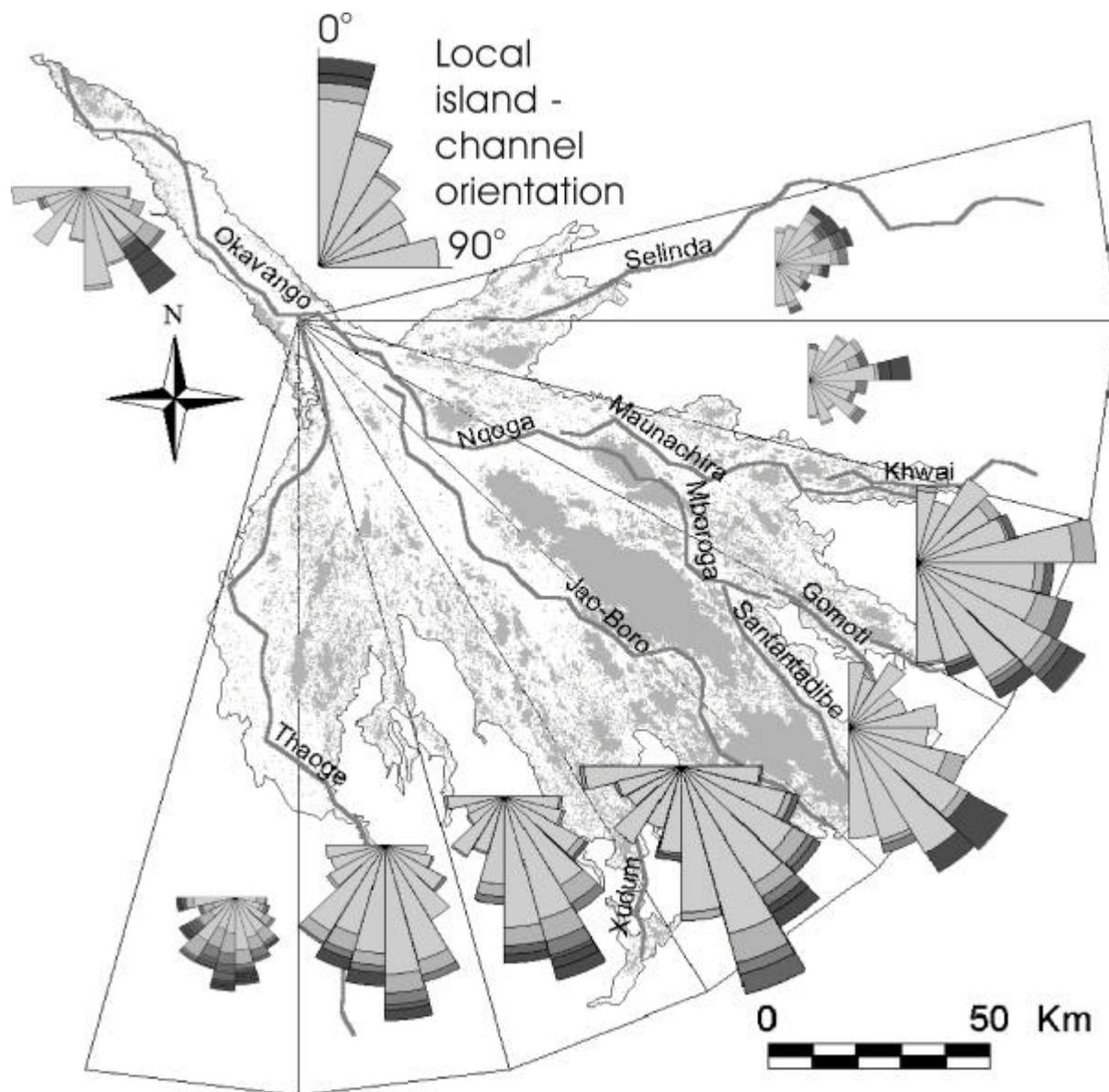


Fig. 3. Island major axis orientation in the Okavango Delta. Rose plot diagram shading is individually metred for each section; darker shades indicate larger island sizes, darkest shade represents the maximum island length of each sector (see table 2).

A majority of islands with salt crusts have the crust oriented to the island distal end (table 3). Of 708 islands with fringe salt crust adjacent to the channels, 42 have the salt crust significantly more on the distal side ($p < 0.05$), compared to 34 having the salt crust on the proximal side (facing the channel). In total 386 (55%) of those islands had salt crusts more oriented to the distal side.

Table 3 Relative positions of salt crusts on islands in the Okavango Delta.

	Permanent		Seasonal		Occasional	
	$p < 0.05$	all	$p < 0.05$	all	$P < 0.05$	All
Salt on proximal end	79	391	219	743	161	1491
Salt on distal end	183	568	479	1065	192	1435

Islands in all of the physiographic regions show a tendency of having those islands with salt crusts on their distal ends ($p < 0.05$), aligned along the general azimuth of the Delta surface (Fig. 4). However, only in the seasonal swamp a substantial portion of all salt islands harbour the salt crust on their distal parts.

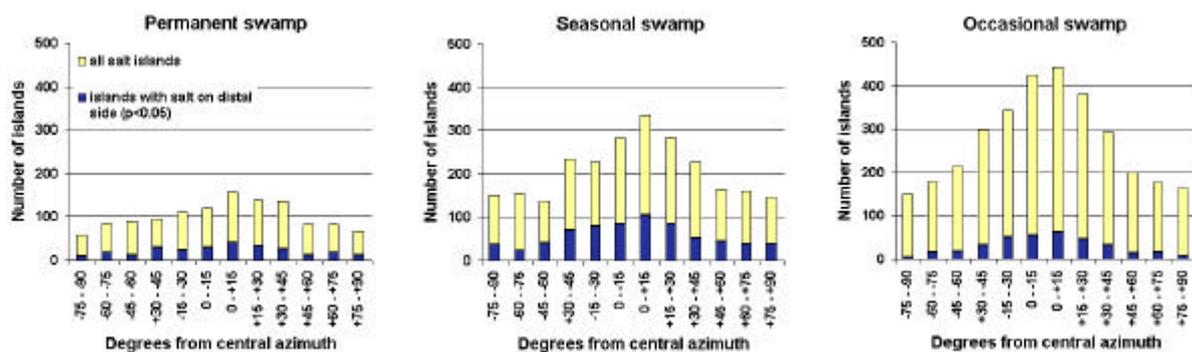


Fig. 4 Relative orientation of islands with salt crusts in the Okavango Delta, Botswana.

There is no relation between the salt crust position vis-à-vis the island-edge as a function of distance from channels.

Errors and uncertainty

The geographical positional error of the datasets is known to be up to 300 m. As they are all created from the same data source, this error does however not influence the result significantly. The stretches of the channels is derived from the same dataset, supplemented with map data were the channels can not be identified in the Landsat TM data. There is hence potentially a larger error in the parts including the channel positions. The largest error stem from misclassifications in the land cover map, leading to erroneous island delineations. The almost random distributions of small islands can potentially be an outcome of this error. Further, the distance from the channels is calculated on a 28.5 m grid, whereas axis length is calculated from vector data – again smaller islands are more prone to errors. The use of surficial salt accumulation (trona) as a proxy for salt accumulation by precipitation also introduces errors. The uncertainty derived from those errors forced us to restrict the study to qualitative results.

Discussion and conclusions

Islands in the Okavango Delta, particularly those of larger size, are oriented along the azimuth of the Delta surface, with a local variation pertaining to the orientation of nearby (< 500 metres) meandering channels. The distribution of salt crusts, indicating secondary island growth, suggests that part of the island orientation is a result of directed growth. The overall flow pattern and local variations due to channel meandering are important influences. More important are the elongated inverted channel islands, which generally trend down the regional slope. These subsequently grow by salt precipitation and eventually lose their channel-like form, but retain their regional orientation. We hence conclude that both island formation and subsequent growth are primarily dependent on the general slope and azimuth of the Delta, forming a radial pattern of elongated islands, and that channel meandering superimposes local scale variations.

Smaller islands have a more random orientation. This, we think is attributed their more recent formation from small anthills (Dangerfield et al., 1998). Islands with salt crusts are more aligned with the azimuth of the Delta and its channels. This leads us to conclude that unidirectional water flow promotes island growth in alignment with the water flow, where calcite and silica are removed in the progressive salinization of the ground water.

The hypothesis that islands with central salt crusts are more common in back swamp areas, and those with salt crusts on fringes more common adjacent to the channels had to be rejected.

The non-random orientation of islands partly control water flow from the apex of the Delta to its distal parts; restricting water flow perpendicular to the major flow directions along the azimuth of the Delta surface.

Acknowledgement

This study was supported by the Swedish International Development Agency. The study was part of SAFARI2000.

References

- Dangerfield J.M., McCarthy T.S. and Ellery W.N. (1998) The mound-building termite *Macrotermes michaelseni* as an ecosystem engineer. *Journal of Tropical Ecology* 14: 507-5
- Garstang, M., W.N. Ellery, T.S. McCarthy, M.C. Scholes, R.J. Scholes, R.J. Swap and P.D. Tyson, 1998. The contribution of aerosol- and water-borne nutrients to the functioning of the Okavango Delta ecosystem, Botswana. *South African Journal of Science*, 94: 223-229.
- Gumbrecht, T., McCarthy, J. and McCarthy, T.S., 2002. Channels wetlands and islands and in the Okavango Delta, Botswana, and their relation to hydrological and sedimentological processes. Submitted to *Earth surface processes and landforms*
- McCarthy, T. S. and Ellery, W. N. (1998) The Okavango Delta. *Trans. Roy. Soc. S. Afr.* 53: 157-182.
- McCarthy, T.S. and Metcalfe, J. (1990) Chemical sedimentation in the semi-arid environment of the Okavango Delta, Botswana. *Chemical geology*, 89: 157-178.
- McCarthy, J. and Gumbrecht, T. Multisource rule-based contextual classification of ecoregions of the Okavango Delta, Botswana. Submitted to *Remote Sensing Reviews*.