

in disparate fields such as climatology, geology and botany as well as major developments in groundwater drilling has far increased our knowledge of the major blank areas on our maps.

With these developments in mind a symposium providing a forum for the discussion of the Kalahari Group was convened in November 1992 under the auspices of the Geological Society of Namibia. These collected abstracts form the bulk of papers presented at the Kalahari Symposium 1992 in Windhoek. This conference was successful in its goals which were to increase general understanding of the Kalahari as well as providing a forum for the many workers in the area to interact. It is hoped that this will not be the last and that continuing research will be presented in the near future.

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November, 1992

OVERALL TECTONICS, MODERN BASIN EVOLUTION AND GROUNDWATER CHEMISTRY OF THE OWAMBO BASIN

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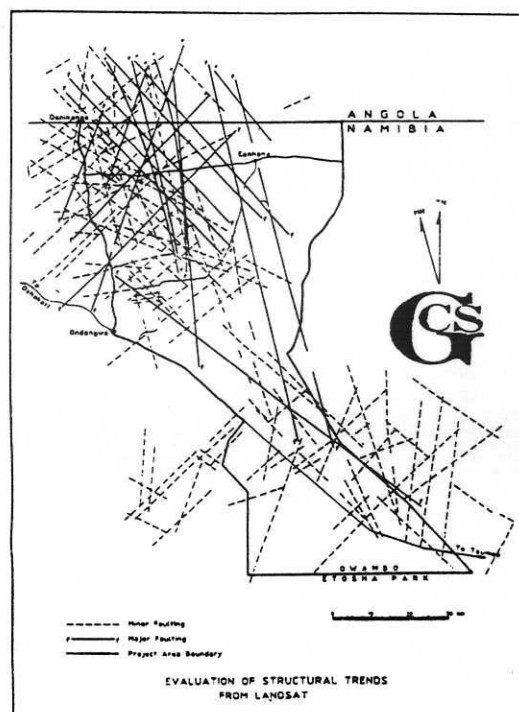
The Tertiary-Quaternary Kalahari Group is found throughout much of southern Africa. This paper deals with the Owambo Basin which lies in north-west Namibia and extends across into southern Angola. The basin attains maximum thickness of about 500 metres in central Owambo, thinning to the north west and south, and extending into other Kalahari basins east and north.

Evidence from aerial photography, field work and satellite imagery suggests that the basin has been erosional and not depositional in its recent past. This is evidenced by extensive faulting throughout the basin and the development of an almost universal rock platform underneath a very thin veneer of modern sediments. The age of the faulting is uncertain but it probably dates from at least the Cretaceous through to the very recent. Some of the larger faults are almost certainly due to basement reactivation.

Faulting is caused by extensive uplift in the west of the basin along the craton margin. The extent of uplift cannot be determined but basal Kalahari Group sediments are found at 1300 metres elevation in the west compared with an average elevation of about 1100 metres for upper Kalahari sediments in the main part of the basin. This suggests that uplift in the west was at least 400 metres at the modern basin's margin and probably much more. The basin originally extended much further west and has been removed by erosion. Uplift was almost certainly episodic.

It would appear that uplift has occurred across much (if not all) of the central and western Owambo Basin (it is recognised to have taken place at least as far east as Eenhana and Okankolo). This is evidenced by the presence of brittle rock fracture (faulting), hard/semi-consolidated rocks at shallow depth throughout this part of the basin and clear evidence of tectonic movement (particularly folding) in several exposures.

Prior to the most recent phases of uplift, the Owambo Basin probably drained to the sea via a drainage to the south of the basin. This is evidenced by all the palaeo-drainages which flow south and west. These drainages include the Cuvelai, Oshigambo, Nipele and Omuramba Owambo Rivers. In addition there are several drainages present under the modern dune fields that originally flowed from the Angolan highlands through into the Etosha Basin.



That uplift was episodic can be demonstrated by the presence of a clear regional step in basin elevation. This step is of the order of only a few metres but is clearly reflected on the satellite photography and by the vegetation. To the west of this step are the grasslands and palm belts while to the east are the forest areas. It is believed that this step represented a major pulse.

The palaeo drainage across the Etosha pan floor (which drained from east to west) is possibly the remnant of this drainage system. The size of the Hoanib River and the fact that it still has the lowest potential outlet level on the south-west basin margin makes it a very likely contender. Drainage would have been via the Beestevlakte (a very broad sand-filled valley) and the Khovarib Schlucht (a large 30 kilometre-long series of gorges). There is no clear evidence that the Cunene River played any role in draining the Etosha Basin at this stage.

Continued uplift possibly combined with a period of lower drainage volumes closed this outlet to the sea generating a saline body of water at least 45 metres deep. This would give the lake a surface area greater than 82 000 square kilometres or larger than Lake Victoria. If the lake was currently full it would be the second biggest inland body of water in the world after the Caspian Sea. Evaporation progressively salinised the waterbody and all of the sediments underlying it.

Uplift in the west, as well as closing the south-western outlet rejuvenated all westward flowing drainages, including the lower reaches of the proto-Cunene, and decreased the gradient of westward flowing rivers (causing them to become largely dormant). As the Cunene drainage assumed its modern form, so it removed by river capture many of the headwaters of the Etosha Lake system. This had the double effect of substantially reducing the water flow into the system and almost certainly allowed water from Lake Etosha to escape to the sea via the 1 100 metre outlet of the Mui River. This outlet is still preserved in the Etaka and Mui Rivers which are one and the same (the Mui drains north, the Etaka drains south). This caused a geologically recent stabilisation of the system at the 1 100 metre level, generating the 1 100 metre shorelines seen at the eastern side of the Andoni Flats and in the west at Okondeka. As the water dissolved salts and flushed them towards the base of the Etosha Pan, so salinities are found to increase in the groundwaters towards the pan centre.

Three hydrogeologically different aquifers were identified within the project area of central Owambo:

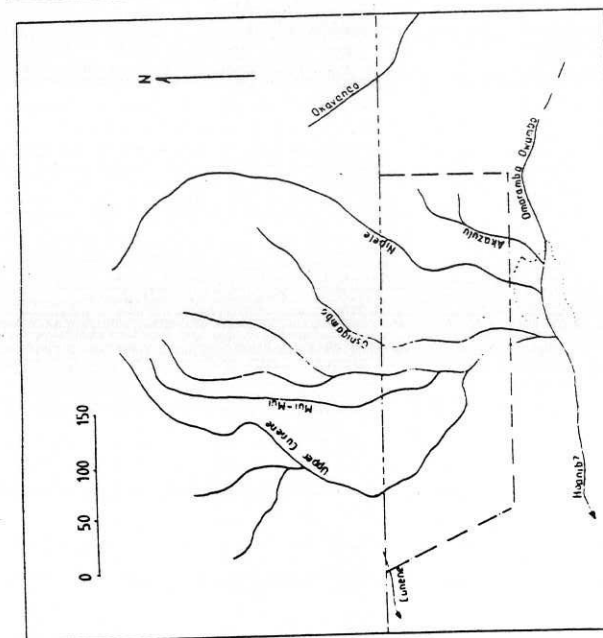
1. The Discontinuous Perched Aquifer. This aquifer was encountered in the northern part of the project area and is very shallow (1-10 metres). It is essentially rainwater accumulating at the base of porous units (e.g., modern sand dunes) on contact with the underlying harder rock units. Water quality is very good but the water volumes present and yields are very small. These are locally tapped by "Omufima" - cone-shaped holes dug in the sand, typically with a brush fence around them. These systems cannot be developed as reliable rural water sources.

2. The Middle Shallow Aquifer. This aquifer varies from about 1 metre deep in the south of the area (adjacent to the Etosha Pan) to as deep as about 40 metres in the north. It can be considered as part of the underlying deep aquifers but is excluded on account of its very variable water quality. Essentially it is a saline aquifer (salinity is probably due to dissolution of soluble evaporites inherent in the system and connate saline water) that has numerous freshwater lenses floating on the upper surface. These freshwater lenses are created by irregular recharge points (faults, animal holes, etc.). This aquifer is therefore extremely variable in nature.

3. The Deep Aquifer. This aquifer lies from about 50 metres downwards and is a continuum with the Middle Shallow Aquifer. Field evidence shows that below about the 1 130m topographic contour (maximum lake stillstand) this aquifer is always saline and salination extends several hundred metres through the sediment pile. Above this contour, water quality progressively improves until above about the 1 140m topographic contour, this aquifer is of a good quality.

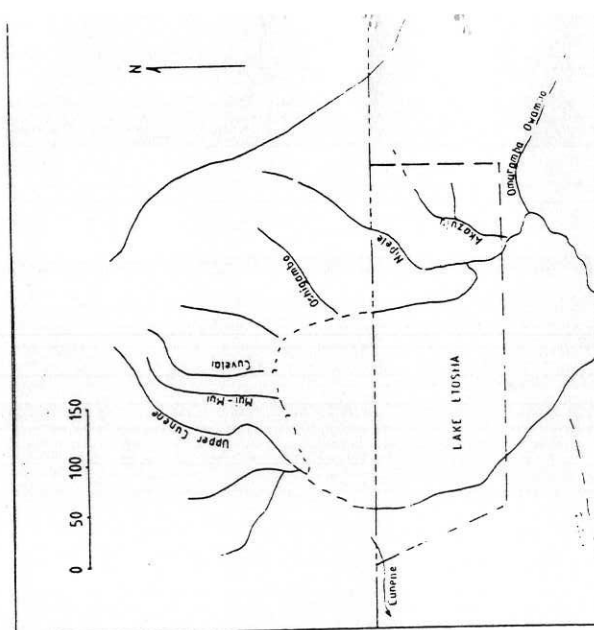
All three aquifers have a very distinct hydrochemistry but dissolution of evaporitic salts within the system is universal to all three. All three water types have high Na^+ , HCO_3^- , Cl^- and SO_4^{2-} , which are typical of basins that have undergone high evaporitic conditions. To prove the point, sediment samples were collected and dissolved over 10 days. Analyses of the water samples showed that Na^+ was combining in a 1:1 ratio with SO_4^{2-} , Cl^- and HCO_3^- . This demonstrated that the more saline fluids are derived by dissolution of evaporitic salts while the less saline are derived by dissolution and mixing processes. Mixing is of essentially

PRE 7 MILLION YEARS AGO



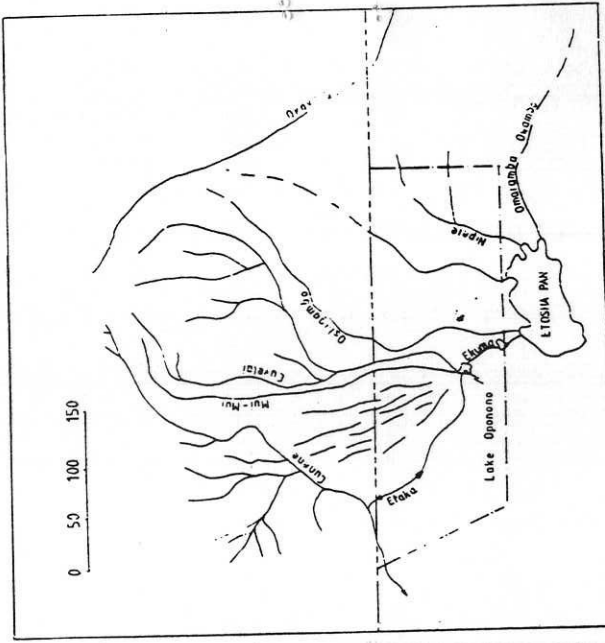
Evidence suggests that the Etosha Basin drained to the sea via the Hoanib River. Both the upper Kunene and Okavango Rivers probably flowed into this major drainage system.

+/- 3 MILLION YEARS AGO



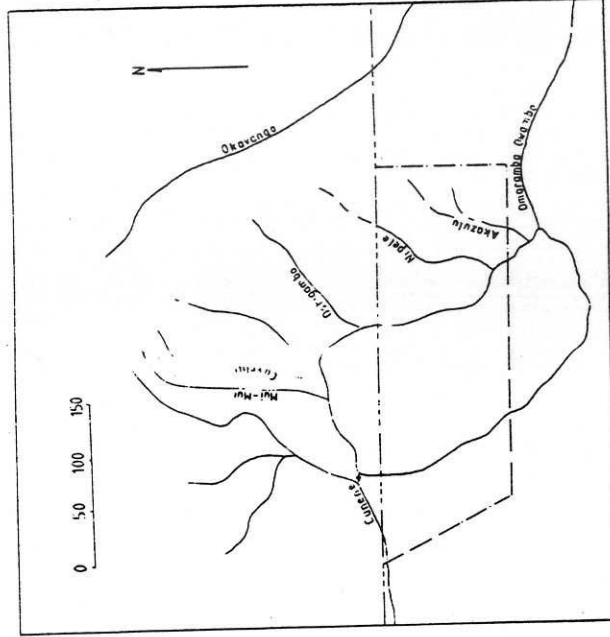
The saline Lake Etosha had a maximum stand equivalent to about the 1130m contour line (depth \pm 50m). The Hoanib River drainage was closed and the Kabango/Okavango headwaters probably drained east. The lake area was an estimated 100 000 km^2 (larger than Lake Victoria).

PRESENT DRAINAGE



The upper portion of the Etaka River flows both north and south. The western oshanas are recent Cunene overflow channels. The Oshana Pan, Akazulu, Nipela and Oshana Rivers are dormant. Current climatic conditions only generate small flows in the Ekuma River.

+/- 35000 YEARS AGO



The Cunene River has captured its modern headwaters. Lake Etosha drains to the sea via the Etaka and Cunene Rivers. This creates the well developed 1100m shoreline (depth of water was $\pm 23m$).

saline fluids and meteoric groundwater. This explains the rapid variation of water quality seen throughout central Owambo.