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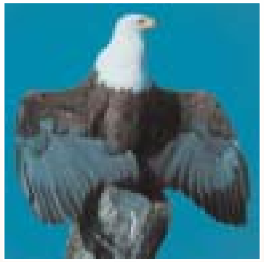
LANDSCAPES

The shape of a river



Near Menongue, the Cuebe River has cut down through layers of Kalahari sand to expose rocks formed between 2,500 and 1,800 million years ago.

A HOST OF FACTORS such as the relief of the land surface, geological structures and rainfall determine the way in which rivers flow. The nature of water flow and shape of continents also means that most rivers around the world carry their water down to the sea. But the Okavango stops in a delta in the middle of a semi-desert, and the delta is over a thousand kilometres from the sea, midway between the east and west coasts of southern Africa. Why should this river be so unusual? The following pages attempt to answer this question by providing a brief overview of the geological history of southern Africa. The story focuses on the three major features that dominate the foundations surrounding and underlying the river basin: the well-watered highland catchment in Angola, the vast expanse of Kalahari sands across which the river flows, and the set of natural walls that confine the Delta. The chapter also looks at the shape and relief of the river, potential mineral resources and the nature of soils in and around the river system.

Geological origins[1]

The origins of the oldest rocks in the Basin are difficult to explain, partly because they were formed so long ago. The shapes of the continents and oceans were then completely different from what they are now, and rocks have been eroded, moved and remoulded in more recent times. However, various volcanic and metamorphic processes between 2,500 and 1,800 million years ago formed all the granite, quartzite and gneiss rocks that make up part of the highland catchment in Angola (Figure 3). That these rocks now stand as a highland is, however, a consequence of more recent events that lifted the edges of the African continent.

The ancient rocks were pushed into their current position by a series of movements of the Earth's plates between 700 and 550 million years ago. The shifts caused several landmasses to move towards each other and join to form what became the continent of Gondwana, and it was Gondwana's land surface that really provided the foundation or basement on which the Okavango river system now lies. This surface consisted of the old rocks formed much earlier but also a complex of so-called Damara Group rocks that were consolidated as the continents collided. These were originally sediments that had been deposited in rift valleys and oceans between the continents. The deposits were then forced upward as the continents pushed up against each other, the forces of compression heating and moulding the deposits into mountains of dolomite, schist and sandstone. Most of the mountains have since eroded away, but remnants remain in eastern Angola and north-western Zambia, as the highlands in central Namibia and belt extending north-eastwards to south of the Delta, and as scattered outcrops in southern Kavango and western Ngamiland. The barrier of rocks over which the Popa Falls cascade is also Damara Group rocks.

The erosion of the Damara mountains continued over the next 350 million years, smoothing and carving Gondwana's landscape and producing new deposits of material eroded off the highlands. Climates fluctuated from dry to wet, or hot to cold. Wind was the main agent of deposition during dry periods, vast seas of sand dunes then being formed. Glaciers scoured the earth's surface during ice ages, and during very wet periods, rivers deposited sediments into massive lakes to form thick layers of mud and other sediments. Plant material in the lakes was later turned to coal, mud became shale while sand dunes were compressed into hard sandstone. Remnants of the sand dunes and lake deposits can now be seen in so-called Karoo rocks formed between 300 and 180 million years ago.

The belt of Karoo-age sandstone on the surface in central Namibia was perhaps formed from dunes deposited in an ancient rift valley. The belt extends as a broad strip below the surface into Ngamiland and underlies much of the Delta (Figure 3). This orientation – from south-west to north-east – is the same as that of many faults in this wider area of central southern Africa. Some of the faults determine the shape of the Delta (see below), and follow a zone of weakness in the crust that may be an extension of the East African rift valley system that runs all the way from the Arabian peninsula south to Malawi, Zambia and Zimbabwe. The valley is now most prominent in East Africa and Malawi, while the arm that extends into Botswana and Namibia has probably never been activated sufficiently for deep valleys to be formed.

Gondwana was a huge expanse of land, but its life came to an end when it started breaking apart about 180 million years ago. The first ruptures caused the parting of what was to become Antarctica and southern Africa. More breaks followed about 132 million years ago when South America began drifting away from Africa, a process that continues today. Terrific volcanic explosions accompanied the breaks, lava forcing its way up through tears in the earth's crust and spewing out over tens of thousands of square kilometres. Relatively few of those volcanic rocks

Kalahari Group
65 million years ago to the present

Karoo Group
300 - 180 million years ago

Damara Group
700 - 550 million years ago

Oldest rocks
2,500 - 1,800 million years ago

Dunes
2 million - 20,000 years ago

International boundary

Figure 3
Geological features formed during four major periods dominate the area in and around the Okavango Basin. For much of its length the river flows across Kalahari sands and other sediments laid down during the past 65 million years. Karoo rocks were mostly deposited between 300 and 180 million years ago, while Damara Group rocks formed when the continent of Gondwana was created between 700 and 550 million years ago. The oldest rocks developed between 2,500 and 1,800 million years ago. The map also shows the distribution of dunes moulded during previous arid periods. The most recent phase that was dry enough for the formation of dunes ended some 20,000 years ago. The orientation of the dunes reflects the direction of winds prevailing during those more arid periods. Consequently, most dunes lie to the west of the major rivers and Delta from where much of the dune sand was scoured by easterly winds.[2]

Popa Falls, where the river cascades down several metres before resuming its normal slow and leisurely flow. The rocks were formed from sediments deposited in rift valleys about 900 million years ago.

remain exposed on the surface in the area underlying the Okavango because most were covered by sediments laid down more recently.

Interestingly, extensions of the belt of faults that run south-west to north-east through Botswana and Namibia can be traced along the same axis into South America. The zone of weakness in the crust thus possibly first appeared in Gondwana when South America and Africa were joined. Around the Okavango Delta, two faults lie along the immediate south-eastern edge of the alluvial fan where they effectively form a wall that stops further spread of the Delta to the south-east (**Figure 4**). The two faults, the Kunyere and Thamalakane faults, rise to the south-east and dip to the north-west. In most places the faults rise no more than five or ten metres on the surface. Another fault, the Gumare, separates the Panhandle from the alluvial fan, but this dips from north-west to south-east. Two other perpendicular faults may have given rise to the relatively high ridges of Kalahari sand on either side of the Panhandle.

In a process and for reasons that are not clear, the margins of southern Africa apparently began to lift up after it and South America shifted apart, although some of the highlands may have risen above the landscape before Gondwana splintered and others may have been pushed up more recently. Whatever the circumstances, this left a rim of highlands surrounding a massive shallow basin in the middle of southern Africa. The rim stretches from central Angola southwards and then all the way round Africa to eastern Africa. A part of the depression is called the Kalahari Basin and it is into this bowl that the Okavango flows (**Figure 5**). The bowl consists of two

The sharp edge at the bottom of the alluvial fan is formed by a rise in elevations along the Kunyere and Thamalakane faults. The fan can thus not grow any further to the south-east, but its sides are not confined and the remnants of much larger regions of flooding are visible as the greyish areas on either side of the present fan.

Legend:
1 – Tsodilo Hills
2 – Panhandle
3 – Gumare fault
4 – Old sand dunes
5 – Areas flooded previously
6 – Lake Ngami
7 – Kunyere fault
8 – Thamalakane fault
9 – Boteti River
10 – Mababe Depression
11 – Kwando River and Linyanti Swamps
12 – Selinda Spillway

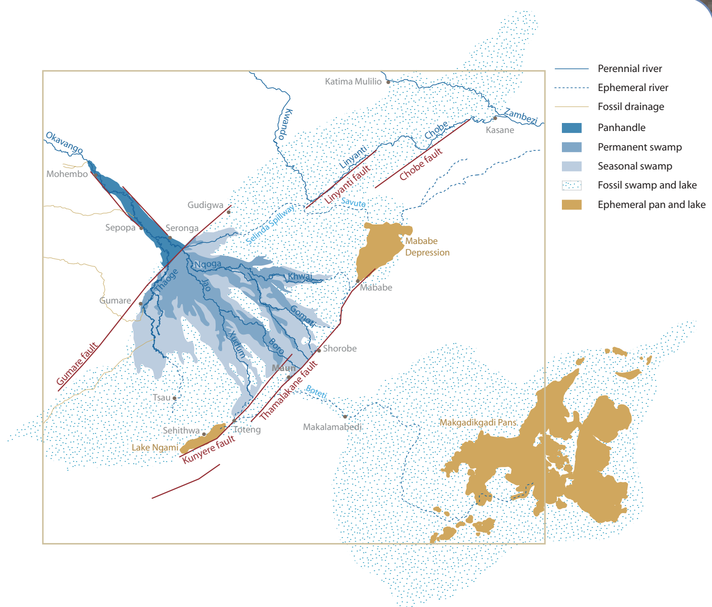


Figure 4
The south-eastern limits of the Delta are confined by the Kunyere and Thamalakane faults. Other faults that run along the same axis and also dip from east to west restrict the Kwando (forcing it to flow north into the Linyanti Swamps) and Chobe rivers. All these faults were formed in a zone of weakness that probably first formed as far back as 250 million years ago. Continuing movements of the faults cause small earthquakes so that frequent shudders and tremors are recorded around the Delta. The biggest recent tremor at Maun measured 6.7 on the Richter scale in 1952. The map also shows the extent of flooding during wetter periods and when the forerunner of the Zambezi used to flow south into Botswana.

sub-Basins: the southern Kalahari centred on Botswana and the Calondo sub-Basin in Angola. The southern sub-Basin may only be about 65 million years old while the Calondo was formed at least 180 million years ago.

The surface of the Kalahari Basin is now remarkably flat, even though it remains a depression with elevations dropping gradually from the margins towards the centre and lowest areas in the Makgadikgadi Pans in Botswana. Its flat surface is a consequence of the Basin being filled by sediments deposited over the past 65 million years. During most of the first 63 million years of its history sediments carried by rivers were laid down in huge lakes and deltas, and it is only during the past two million years that much of the Basin has dried up. Rivers much bigger than the Okavango have flowed into the Basin. For example, there is good evidence that the Zambezi ran here as recently as 50,000 years ago, before being captured by a river that had cut its way back from the east coast.[3] The Zambezi now carries about four times more water than the Okavango, and so imagine how much water it, the Kwando and Okavango together brought into north-eastern Botswana when average rainfalls were perhaps double or more the amounts we receive now. These are the kinds of inflows that created lakes covering about 120,000 square kilometres around the Delta and Makgadikgadi Pans. That would be about ten times bigger than the present Delta (Figure 4).

How old is the river? This is a difficult question because climates have changed so much. A better approach is to ask the age of the river as we know it, and to ask if the river existed in some other form long ago. Starting with the second aspect, rivers must have started to flow into the Kalahari Basin soon after it formed and it seems possible that one of those rivers evolved into the Okavango. Theories have even been developed to suggest that a quite different Okavango cut across the Kalahari to flow all the way into what is now the Orange or the Limpopo River,[4] but more research is needed to establish whether any large river flowed all that way.

Looking at the river as it is now, the tributaries of the Cubango, Cutato, Cuchi and Cutato rivers have a clear trellis pattern because most join the main rivers at right-angles. These angles and the almost perfectly parallel courses of the four rivers suggest that they are very young, perhaps less than several million years old. However, it is also obvious that these and other parts of the river system would have been altered in accordance with changes in climate. During very wet periods much bigger areas were flooded in the Delta and more aggressive flows would have caused rivers to cut new courses. Some of these would have been obliterated during dry cycles when the rivers dried up and much of the area was covered in sand dunes. And then new channels and valleys would have opened up when heavy rains fell in the next wet phase. The Delta is, of course, built of layers of sediment, and its surface now lies between 100 and 270 metres above a basement of rock. How much of the sediment above the bedrock was laid down within the Delta and how much was deposited by wind during drier times or quite different river, lake or delta systems is not known.

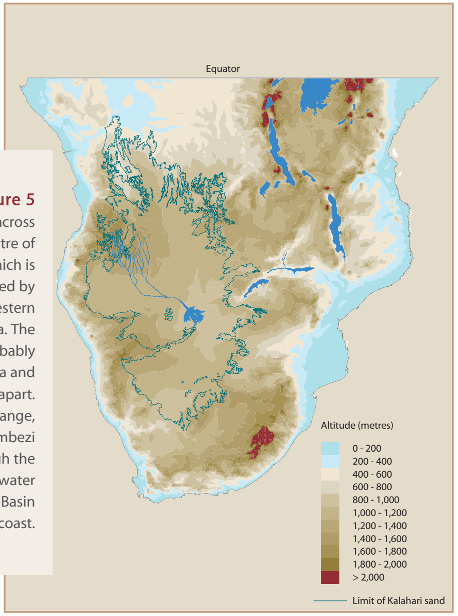
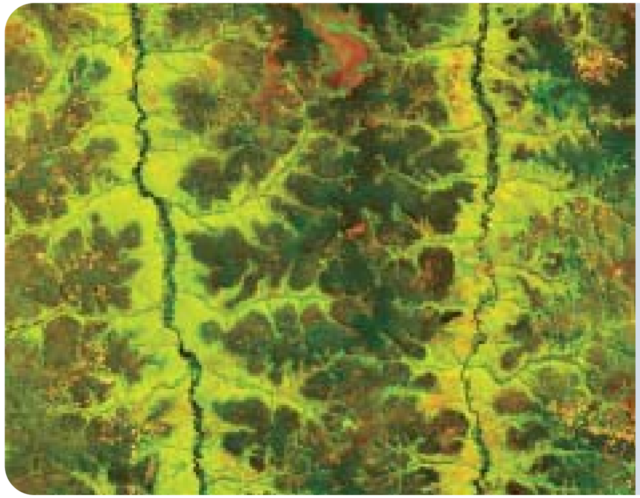


Figure 5
The Okavango flows across and ends in the centre of the Kalahari Basin, which is largely surrounded by highlands in both western and eastern Africa. The highlands were probably formed after Africa and South America split apart. The Kunene, Orange, Limpopo and Zambezi rivers have cut through the escarpments to drain water from the Kalahari Basin to the coast.



Rivers in the north-west of the catchment have developed recently – perhaps during the last few million years – because their trellis-like pattern is characteristic of recently established drainages. The rivers still drain areas of Kalahari sand deposits in some areas while in others the rivers have cut through the sands and now flow off basement rocks of granite, quartzite and gneiss.

Diamonds and other riches

Angola, Namibia and Botswana all earn a high proportion of their income from mineral resources, especially diamonds, gold, coal and oil. However, none of this revenue comes from the Basin because there is not a single mine anywhere near the river system. This is mainly a consequence of the thick mantle of Kalahari deposits. Finding minerals deep beneath the deposits is one major challenge; others are to overcome technical and financial constraints to reach the minerals. However, this has not stopped many people from speculating that riches are to be found, especially diamonds in Angola. With the opening up of southern Angola many prospectors are now scouring the area for new deposits. Speculation is also fuelled by the presence of diamond diggings near Mavinga, 150 kilometres east of Cuito Cuanavale. These diamonds are probably associated with basement rock underlying the Kwando River drainage that is old enough to contain economic kimberlites. By contrast, basement rocks to the west of the Cuito River appear too young to hold much potential for diamondiferous kimberlites.

Further south in Namibia, prospecting is underway in the Kavango part of the Basin, where four kimberlites have been found near Sikeretti and across the border at Nxaunxau in Ngamiland. Some micro-diamonds and minerals associated with diamonds have been found in Kavango, suggesting that economic diamonds might be found. However, more exploration is needed before such a possibility is shown to be valid or not. Other than diamonds, the only other deposits that may be of significance are coal, oil and gas. Deposits of these may be found in Karoo-age rocks, but again they lie deep below the surface and little exploratory work has been done to determine if any useful resources are present.

The relief of the Okavango

The whole river system gradually winds its way across the Kalahari Basin from the highest elevations of between 1,700 and 1,800 metres on the Basin's rim to the bottom of the Delta at 940 metres above sea level (Figure 6). The north-western catchment and highest ground consists of ancient basement rocks covered by patches of Kalahari sand, while the north-eastern reaches of the catchment comprise only Kalahari sand. These two northerly catchment areas lie either side of a giant amphitheatre some 200 kilometres in diameter. This is the most southerly catchment of the Cuanza River, which flows north and then west to its estuary on the Atlantic coast 60 kilometres south of Luanda. The Cuanza flows much more rapidly than any of the Okavango rivers because it drops so much (about 1,500 metres) over a relatively short distance. It is thus a more 'aggressive' river, cutting back and eroding away the ground in its catchment. The walls of the amphitheatre drop rather steeply by about 200 metres into the Cuanza catchment, unlike the much more gentle slopes around the headwaters of Okavango rivers to the south of the watershed.

Okavango River

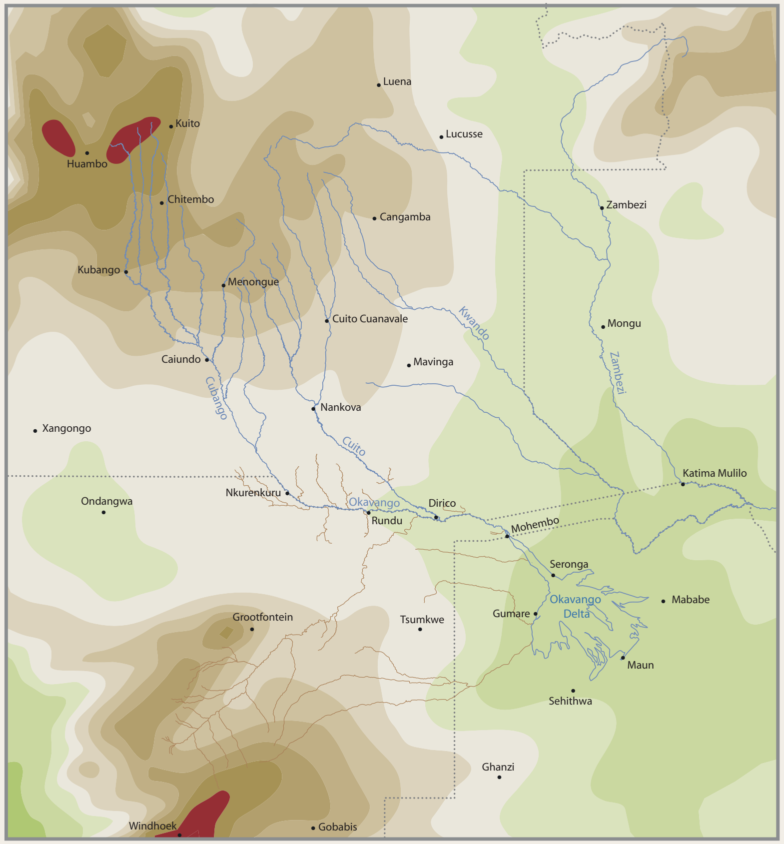


Figure 6

The Okavango starts its flow southwards from about 1,700 metres above sea level (asl) and ends at about 940 metres asl, at the base of the Kunyere and Thamalakane faults on the south-eastern edge of the Delta. The Cuito headwaters lie at just over 1,500 metres asl, about half a kilometre higher than its confluence with the Okavango at just over 1,000 metres asl.

A typical landscape of gentle rolling hills separated by broad shallow valleys in the Angolan highlands in the north-western catchment. The area is high only in relation to the much lower southern parts of the river Basin. The main valley in the centre is that of the Cutato River, while the tributary in the foreground is characteristic of the hundreds of tributaries that give the rivers in this area a trellis-like drainage pattern.

A birds-eye view of the Basin stretching away from the Delta in the foreground to the highest areas in the Angolan catchment. The Omatako flows out of higher ground south-west of Grootfontein. Note the clearly defined amphitheatre shape between the Cubango and Cuito. This depression forms the headwaters of the Cuanza River which flows north and then west to the Atlantic.

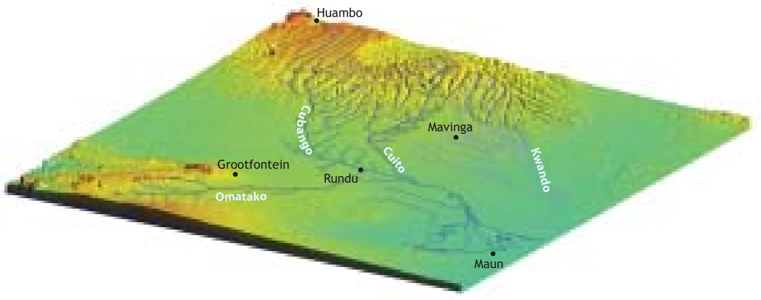


Figure 7
All the Okavango's rivers or tributaries have extremely gentle flows over most of their lengths. The steepest gradients and fastest flows are in the headwaters. The graphs show the altitudes of the Cuito and Cubango/Okavango rivers in relation to the distance from their source.

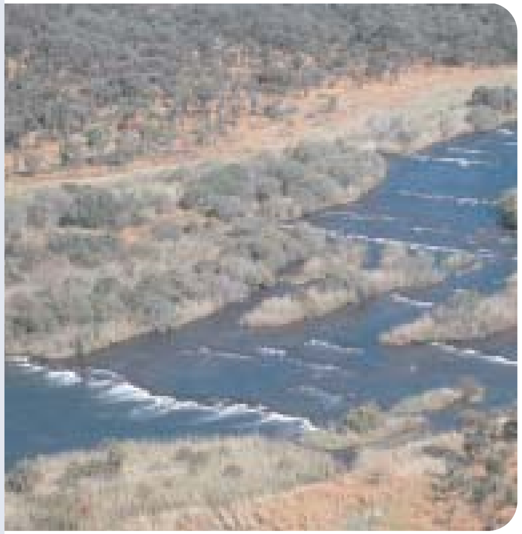
Gradients across the river system are steepest in the north-western catchment and shallowest in the Delta (Figure 7). Rivers in the north-west thus drop by about 300 metres over distances of 300 kilometres. Numerically, this is a gradient of approximately 1:1,000, three to five times steeper than slopes of 1:5,000 in the Panhandle and 1:3,300 in the alluvial fan of the Delta. In fact, elevations drop only 61 metres over 250 kilometres, the distance from the top of the Panhandle to the Thamalakane River at Maun. This gentle slope is one reason why the river's water takes about four months to reach the south-eastern edge of the Delta (see page 85).

The densest network of tributaries is in the north-west where the countryside is hilliest, the bedrock is exposed and the mantle of Kalahari sand is thin. Elsewhere, the landscape of thick sand is much flatter and active drainage lines are spaced far apart. Some tributaries also follow interesting courses. For example those joining the Cubango, Cutato, Cuchi and Cacuchi rivers flow into the rivers at roughly perpendicular angles. The valleys of the Cutato and Cuchi are generally symmetrical so that tributaries from the east and west are similar in length. However, those of the Cubango and Cacuchi are shaped unevenly with the result that western tributaries are considerably longer than the ones from the east. Those patterns of symmetry and asymmetry hold true along the whole lengths of the four river valleys. Many of the tributaries to the Cuanavale run from southeast to northwest along old fossilized interdune valleys, which means that the direction of flow changes abruptly once water reaches the south-flowing main river.

Soils

In one form or another, soils are important to all life in the Okavango Basin. They provide the medium from which plants obtain water and nutrients, and properties of the soils determine what plant species are present and thus the value and diversity of vegetation communities. Properties of soils vary in terms of their depth, structure and chemical composition, and these affect how much water soils retain, the depth to which roots extend, and what nutrients are available. The physical structure of plant communities is also influenced by soils. A plant species may be stunted in one area of shallow or sterile soil but it will grow tall in deep

Rivers in the northwestern catchment cascade over rapids or small waterfalls in many places. The straight lines that break the fall of water along the Cubango are probably layers in a stratified rock formation (left), while the small waterfall on the Cutato (right) was once identified as a potential site for a hydroelectric dam during the 1960s.



soils rich in nutrients elsewhere. All these effects are particularly relevant to crop cultivation, and the generally poor quality of soils in the Basin (see below) has major impacts on the types of crops grown and their yields (see page 141).

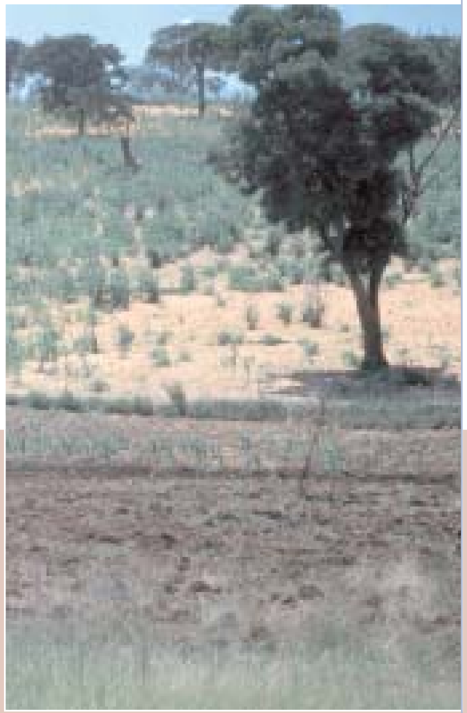
Another significant effect of soils in the Basin is on the quality of water. Compared to most other rivers, the waters of the Okavango contain exceptionally small amounts of mud and dissolved chemicals or minerals (see page 92). The main reason for the clarity and purity is that most water filters out of sandy soils made up largely of quartz grains. These do not easily dissolve or break-up to release soluble chemicals or tiny particles that would otherwise be washed into the river as minerals and mud. The sands also serve to moderate the flow of water since most rainwater sinks into the ground rather than running off the surface and into the tributaries of the major rivers. Flows are thus much more even than those along rivers that drain rocky areas. Within the catchment the effects of sand in providing clean and steady flows are more pronounced in the sandiest areas, especially in the Cuito sub-Basin (see page 83). Flows off basement rocks in the hillier Cubango sub-Basin are more variable and most of the nutrients and sediments that find their way to the Delta probably come from this western area.

The map of soils **(Figure 8)** provides a rough perspective on how soils vary across the Basin. Its roughness is due to the absence of better information for Angola as well as the scale of mapping. Every farmer knows how much soils vary – even within the same field – and it is simply impossible at the kind of scale used here to reflect the patchiness of soils. The map thus attempts to show what types of soil dominate in different areas.

Thick layers of Kalahari sands have been cut away and exposed by this meander on the Cuito River 140 kilometres north of Cuito Cuanavale.

The fine to medium arenosol sands that characterize so much of the Basin are more generally called Kalahari sands. The sands often extend to a depth of at least one metre. Sand grains usually make up more than 70% of the body of the soil and less than 10% consists of clay and silt. There are few nutrients (especially nitrogen, potassium and phosphorous) in the sand and the porous structure means that there is little run-off or water erosion. Water drains through the body of soil rapidly, leaving little moisture at depths to which most plant roots can reach.

The fluvisols shown in **Figure 8** are limited to areas immediately along the major rivers, but fluvisol soils are also found along the many smaller tributaries. Fluvisols were deposited by high water flows on floodplains and are usually characterized elsewhere in the world by a rich organic and nutrient content. However, this is probably only true for fluvisols in the Delta where nutrients have progressively accumulated over long periods. The sediments usually consist of a mix of silt, clay and fine sands.



Darker, more clayey soils characterize lower-lying inter-dune valleys and fossil drainage lines, whereas pale yellow Kalahari sands predominate in higher, surrounding areas.

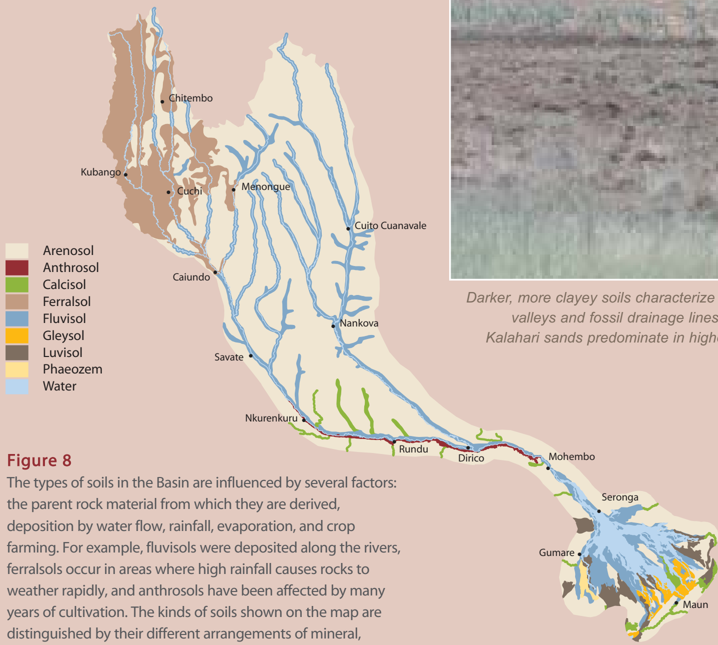


Figure 8

The types of soils in the Basin are influenced by several factors: the parent rock material from which they are derived, deposition by water flow, rainfall, evaporation, and crop farming. For example, fluvisols were deposited along the rivers, ferralsols occur in areas where high rainfall causes rocks to weather rapidly, and anthrosols have been affected by many years of cultivation. The kinds of soils shown on the map are distinguished by their different arrangements of mineral, organic, water and air components within the soil body.[5]

A zone of anthrosols is shown on the southern bank of the river in Kavango. These are soils modified by repeated ploughing and crop production. Smaller areas of anthrosols farmed over long periods in Angola and around the Delta have not been mapped. These soils usually consist of a layer of arenosols overlying deeper deposits of fluvisol sediments, and the layers have since been mixed by ploughing. Anthrosols generally have a low nutrient content. Concerns are often raised about soil erosion as a result of the extensive clearing of land on the southern bank in Kavango. However, this potential problem, and possible increased levels of sediments in the river, requires more investigation.

Calcisols occur along fossil drainage lines in Kavango and adjacent areas in southern Angola. Layers of calcium carbonate salts lying at some depth below the surface characterize these soils, which consist mostly of fine sand and smaller proportions of clay and silt. The calcium carbonate sometimes forms blocks of calcrete. The soils are used for crops because they are potentially quite fertile and retain water to a much greater degree than arenosols.

Ferralsols are widely distributed in the northwestern upper catchment where they have developed as a result of weathering of basement rocks (see Figure 3). The soils are noted for the dominance of kaolinite clays. However, their low nutrient reserves are easily and rapidly exhausted by crop production. Ferralsols are often very deep, permeable and have a stable soil structure, three qualities that make them resistant to water erosion.

Three soils in the Delta directly or indirectly owe their formation to flooding and the presence of decomposed plant material. Phaeozems are found only in the outer reaches of the Delta area where there is infrequent flooding. An accumulation of organic matter on the surface is characteristic of phaeozem soils, which are porous and well-aerated. They are also relatively rich in nutrients and have good agricultural potential. Luvisols are also present around the edges of the Delta, and these are potentially the most fertile soils as a result of deep accumulations of clay and organic material. They, too, are porous and usually retain high levels of moisture. The formation of gleysols is partly due to water logging at shallow depths for some or all of the year. Prolonged water saturation in the presence of organic matter results in the formation of grey, olive or blue-coloured layers beneath the surface.

From this account it should be clear that the greatest area of the Basin consists of soils poorly suited to agriculture, and the only small areas with fertile soils are in the Delta. The concept of soil quality is a relative one, however. For example, people in Kavango often see any soil that contains some moisture and nutrients as being 'a good soil' because so many areas are unsuitable for crops. But Angolan farmers have better soils to choose from and would probably reject what would be the best soils available in Kavango. There are several implications of such generally poor soils. The first is that small-scale farmers will usually not achieve good yields, especially if they do not apply manure, compost or fertilizers. A second consequence is that large-scale, commercial and irrigated crop production will normally require large applications of fertilizers. Thirdly, the application of fertilizers will require careful management to ensure that the correct minerals or nutrients are applied at appropriate times and in adequate amounts. Finally, there is a danger that fertilizers will find their way into the Okavango system, particularly in places where run-off or seepage easily finds its way into nearby rivers.

Kalahari sands are poorly suited to crop production because they hold few nutrients and little water. These constraints can be overcome by adding fertilizers, which are relatively expensive and must be applied carefully, and water, in this case through centre-pivot irrigation at Shadikongoro. Maize, cotton and wheat are the main crops grown here.

Key points

- Tectonic and metamorphic processes between 2,500 and 1,800 million years ago (mya) formed the granite, quartzite and gneiss rocks in the north-west catchment in Angola.
- The foundation on which much of the river system lies was produced between 700 to 550 mya when the continent of Gondwana was formed.
- Gondwana started to break apart 180 mya, while South America and Africa parted ways 132 mya.
- The break-up of Gondwana was followed by the margins of southern Africa being lifted to produce a rim of highlands surrounding a massive shallow basin. Part of this is the Kalahari Basin, which started to fill with sediments 65 mya.
- As recently as 50,000 years ago, much larger flows of water into the Delta and surrounding areas were at times carried by the Okavango, Kwando, the Zambezi and other rivers.
- There are no minerals of economic importance now known in the Basin.
- The Okavango's rivers flow from the highest elevations of between 1,700 and 1,800 metres to the bottom of the Delta at 940 metres above sea level. Gradients generally become gentler along the course of the river.
- The densest network of tributaries is in the north-west where it is hilliest, the bedrock is exposed and the mantle of Kalahari sand is thin. Elsewhere, the landscape of thick sand is flatter and active drainage lines are far apart.
- The predominance of sand in the catchment results in the river water being very clean with low contents of minerals and mud. The sand also gives the river a more even flow than would be the case in a rocky catchment.
- Most soils in the Basin are not good for crop growth as result of low nutrient levels and poor water retention. Only certain areas in the Delta have good quality soils.