REPORT ON A RECONNAISSANCE SOIL SURVEY OF OKAVANGOLAND WITH PARTICULAR REFERENCE TO THE RIPARIAN LAND

UNDERTAKEN FOR THE

SOUTH WEST AFRICA ADMINISTRATION
WATER AFFAIRS BRANCH

FEBRUARY, 1967

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DEPARTMENT OF WATER AFFAIRS

SUMMARY AND RECOMMENDATIONS

1. A reconnaissance soil survey was undertaken of the lower Okavango River in the environs of the Popa Falls followed by a flying reconnaissance survey to cover the remainder of Okavangoland, an area of about 12,900 sq. miles.

2. The soil investigation has determined that the main area of irrigation potential is located on the Okavango River Terrace. The capability assessment for irrigation may be summarised as follows :-

RECOMMENDED	3,400 hectares
MARGINAL	35,000 hectares

3. The Inland Sand Plateau is only suited to a very low intensity of agricultural development and areas of suitable irrigable soils are confined to the Omurambas; their scattered and discontinuous distribution with a low and intermittent availability of suitable soils, and their great distance from water supplies are serious limitations to their effective development. The extension of irrigation onto the Red and Brown Aeolian Sands on the Plateau is subject to experimentation and further detailed

5. The sandy nature and poor moisture properties of the majority of the soils with irrigation potential indicate the general advisability of sprinkler systems of irrigation. Provided reasonable standards of irrigation management are practised, no serious drainage or 'brak' problems are expected to develop.

6. The results of the soil survey are presented on aerial mosaics at 1:75,000 and 1:25,000 scales and on a line map at 250,000 scale (land forms).

7. An economic analysis was undertaken to determine the production potential of the irrigable land on the Okavango River Terrace along its entire length in S.W.A. territory. The study demonstrates that approximately 35,000 hectares could be effectively brought under irrigation. Assuming relatively high levels of crop production and irrigation management, such a scheme could be expected to produce 475,000 tons of primary agricultural produce of which 460,000 tons would be available for export from Okavangoland at a current value of R12,000,000. The main exportable commodities could be cotton, maize, wheat, beans, lucerne and animal products.

8. An assessment has been made of the agricultural resources and land-use potential of Okavangoland as a whole. This should

INTRODUCTION

The investigation comprised a reconnaissance soil survey in the environs of the Popa Falls, located on the lower reaches of the Okavango River, followed by a flying reconnaissance to cover the remainder of Okavangoland. The survey was directed primarily at an assessment of the irrigation potential of the riparian soils situated on the terraces which flank the Okavango River. The soil survey report is supported by an economic assessment of the full irrigation potential of these terrace soils. Included is a general appraisal of settlement and development prospects for the whole area to indicate, inter alia, those areas where the investigation for the provision of permanent water appears to be justified.

The reconnaissance soil survey of the Okavango River Terrace extended some 20 miles downstream - to the Bechuanaland border - and some 50 miles upstream of the Popa Falls, covering an area of 140 sq. miles including both banks of the Okavango River where it passes through the Caprivi strip. Within this area, immediately below the Popa Falls, a detailed soil survey was undertaken of a proposed pilot irrigation scheme, some 500 hectares in area. The adjacent Inland Sand Plateau up to the Bechuanaland Border and extending westwards to the Dossa Pan, an area of about 1,000 sq. miles, was also investigated.

The flying reconnaissance comprised a traverse along the entire length of the Okavango River in S.W.A. plus selected traverses into the interior. Through subsequent photo-interpretation these field observations were interpolated to produce a preliminary map showing physiographic regions defined in terms of the main soil and

In order to present the results of the soil survey in the most efficacious manner, different map forms and scales have been used, namely :-

1)	Detailed survey (500 ha.)	: line map at 1:15,000	
2)	Reconnaissance survey of the lower reach of the Okavango River Terrace	: Mosaics at 1:25,000	
3)	Flying reconnaissance survey (entire riparian land only)	: soil types only	- mosaics at 1:75,000
		capability for irrigation	- line maps at 1:75,000
4)	Flying reconnaissance survey (Okavangoland interior)	: physiographic regions	- line map at 1:250,000

In the capability assessment of the different soils with respect to irrigation potential, we have given three classes: RECOMMENDED, MARGINAL and NOT RECOMMENDED. This assessment assumes at least reasonable standards of irrigation management and crop production. The soils classified as RECOMMENDED are adapted to a wide range of irrigation and cropping practises whereas MARGINAL soils will require special management techniques to attain optimal production; specifically in this instance, the general need for sprinkler systems of irrigation on the sandier soils.

With reservations, we have attempted to demarcate the Red and Brown Aeolian Sands with both a higher clay percentage and geographically more favourably situated in relation to water distribution. Subsequent research and detailed survey may show the feasibility of extending irrigation use on to the more distant and sandier phases. To different-

Geomorphology and Drainage

There are the two main physiographic regions: the Okavango River Terrace and the Inland Sand Plateau.

The Okavango River Terrace comprises a floodplain and an extensively cultivated, even sloping, (2%) high level terrace (20 ft. terrace). In general these river terraces are well developed along the full length of the Okavango, the largest perennial river in S.W.A.

The Inland Sand Plateau is prodominantly a level featureless plain covered with deposits of Recent Aeolian sand. Secondary seif dune formations occur along the margins of the Okavango terrace, the sides of the major tributaries and again in parts of the interior. Here the outstanding feature is the formation of the parallel systems of seif dunes and related omurambas, the current drainage depressions. These formations are clearly expressed in the southern central portion of Okavangoland and to a lesser extent in the eastern part.

The Omuramba Omatake is the largest tributary entering this section of the Okavango River. Small terrace sections are present though, in general, this tributary is incised with steep banks. The other tributaries are also incised and form narrow V shaped valleys. The tributaries have not resulted in any appreciable bevelling or general lowering of the plateau.

Settlement and Land Use

Agricultural production by the indigenous Bantu consists mainly of subsistence level cultivation of millet along the Okavango River Terrace and the valley sides of the major tributaries. This arable production is supported by stock farming of cattle and goats.

Fire control is a pre-requisite for effective pasture and forestry management, and the disciplined fire control measures exercised by the entire population of Ovamboland is of particular interest.

Vegetation

The vegetation can be broadly classified into four main associations :-

1) The Terminalea sericea-Burkia africana Woodland Savanna of the deep aeolian sands.

2) The Acacia giraffae - other species Bush Savanna.

3) The open Grassland of the Omurambas.

4) The Acacia giraffae-Combretum imberbe Tree Savanna of the Okavango River Terrace.

The Terminalia sericea-Burkea africana Woodland Savanna is associated with Guibourtica coleosperma, Baikaea plurijuga and Ricinodendron rautanenii, with a sparse grass cover of dominantly fibrous Aristida spp. On the margins of this vegetation type, within the termitaria zone, Acacia giraffae and Combretum spp. occur. These species are normally indicative of more favourable soil conditions.

The Acacia giraffae Bush Savanna normally occurs on the Brown Aeolian Sands. The bush is of medium density but sufficient to seriously suppress grass growth. Medium sized A. giraffae may occur either as individual trees or in small communities together with Combretum spps.

The Omurambas are essentially open grassland and form a variation to the general Woodland Savanna of the Inland Plateau. The more favourable soils are indicated by scattered well-grown A. giraffae within a dense grass cover characterised by Schmidtia bulbosa. The areas of Grey Sands, usually on to calcrete at shallow depths, carry a tall sour grass cover of mainly Loudetia superba.

nuts has been favourably reported upon as a quick drying oil for use in paint manufacture. Exploitation would require that the Bushman, who now collect the nuts for food, be prevailed upon to collect for sale and to purchase food with the proceeds.

Climate

The climate may be classified as semi-arid and sub-tropical with a mean annual precipitation of from 525 to 575 mm. The period of effective rainfall is very short, from December through to March, when 80% of the average precipitation can be expected. Summers are hot and somewhat dry with temperatures of 34°C and higher in October and November, the hottest months of the year, prior to the onset of the rainy season. The winters are mild, July being the coolest month with a mean daily minimum of 6.2°C. The diurnal range varies between 20°C in mid-winter to about 13°C in mid-summer. The temperature data given in Table I have been recorded at Ondangua and, although outside the survey area, may be considered as being representative of Okavangoland. Other relevant climatic data are given in Table I.

TABLE I : CLIMATIC DATA : S.W.A. WEATHER STATIONS

1200/866	Ondangua	Lat.17°56'S	- Long.15°59'E	Altitude 1095m
1160/814	Andara	Lat.18°04'S	- Long.21°28'E	Altitude 1100m
1206/187	Kuring Kuru	Lat.17°37'S	- Long.18°37'E	Altitude 1110m
1208/475	Runtu	Lat.17°55'S	- Long.19°46'E	Altitude 1311m

AIR TEMPERATURES °C : ONDANGUA

Month	Mean Max.	Daily Min.	Mean Highest Monthly Max.	Max & Min. / 2	Monthly Means No. of Days with temp.below 0°C

TABLE 1 (continued)

RAINFALL NORMALS mm

	Ondangua	Andara	Kuring Kuru
January	110	137	110
February	123	130	115
March	93	94	97
April	36	28	34
May	3	5	4
June	0	0	0
July	0	0	0
August	0	0	0
September	2	1	1
October	13	17	18
November	46	52	57
December	91	108	94
Year	517	572	530
Period in Years	44	30	30

FROST INCIDENCE

	Ondangua	Runtu
Average : First Date	1/7	23/6
Average : Last Date	9/7	6/7
Number of Years of Data	15	12
Number of Years in which frost occurred	7	5

THE SOILS AND THEIR CAPABILITY FOR IRRIGATION

According to their occurrence, land-use (both current and potential), and parent materials, the soils can be conveniently grouped according to five separate geomorphological provinces; these are : (a) the Floodplain and Recent Alluvium, (b) the 20 ft. Terrace, (c) the 60 ft. Terrace and Aeolian Sand Plateau, (d) the Omurambas, and (e) the Pan-veld of the south west. The classification, general characteristics and capability for irrigation development are summarised in Table 2.

THE FLOODPLAIN AND RECENT ALLUVIUM

This area is situated between the river and the 20 ft. Terrace. Its boundaries are demarcated by the distinct topographical changes associated with the geomorphology of fluviatile cycles.

The associated soils are not cultivated by the inhabitants, either because of the inherent low fertility (Type D), a high water table (Type F) or inundation by floodwater.

Type D : Grey Sands (Profile No. 21)

The Grey sands within this geomorphological province are generally limited to the levee and its immediate proximity; they do sometimes extend further from the river - as in the vicinity of Masivi - in which case a water table is present at about 3 ft. These sands are very loose and generally contain less than 4% clay; they support only a sparse grass vegetation. The inhabitants build their kraals on these sands but never cultivate them.

The vast expanse of type D occurs on the Inland Plateau; the Grey sands on the Floodplain are not true examples of the type since

In some places, such as in the wide swamp at the Bechuanaland border, the soil underlying the permanent water falls within the definition of this soil type.

In the mapping unit there normally occurs a complex of soils comprising types F and D. This complexity of pattern is due to the discontinuity of the black sandy loam to silty clay over a deposit of sand. The heavy material varies in depth, often disappearing in places.

The inhabitants do not utilize this soil except as grazing - it supports a grass and reed vegetation.

At Shamvura the F.C.U. Jute scheme was established on this soil. Here the overlying materials were found to be heavier and more impermeable than normal and the underlying (and surrounding) sandy materials to be coarser than normal. A prominent permanent water table is present at 3 ft.

These soils cannot be recommended for irrigation but they could be used for certain specialised crops such as rice or jute. More detailed soil surveys of the complex pattern would be essential to establish final capability. The feasibility of flood control works is unknown at this writing but would appear to be formidable.

THE 20 FT. TERRACE

The boundary between the Floodplain and this physiographic region is quite distinct, though the outer boundary does tend to vagueness in places where it is defined by only a gradual rise in elevation.

relative to total sand content. Local mixing of the terrace material with aeolian sand undoubtedly occurred as manifested by the tendency of the materials to become sandier from the inner to the outer edge.

Type B2 : Red Sands - Riparian phase (Profile 2)

These Red sands occur along the outer edge of the 20 ft. terrace where the parent materials are sandiest; they normally occupy a narrow band of soil in the zone transitional between the riverine plain and the Aeolian Sand Plateau. The slope here averages about 5% - steeper than on the actual terrace itself.

These soils are cultivated by the inhabitants in areas where there is insufficiency of the better class soils.

With a silt and clay content of between 7% and 9%, these sands can be compared with those of the Vaalhartz irrigation scheme, where experience has demonstrated that similar red sands have a high potential under irrigation. This scheme has also shown that conventional flood irrigation is somewhat hazardous due to the rapid internal drainage which leads to the build-up of a water table. In view of the situation of these soils (along the Okavango) on the outer edge of the heavier terrace soils it is our considered opinion that only sprinkler irrigation should be attempted on Type B2. Water holding and cation exchange capacities are somewhat low, and frequent water and fertilizer applications will be necessary. With judicious management, the irrigation development of these soils is a feasible proposition; they remain marginal, however, due to the limitation of internal drainage.

Type E2 : Brown to Yellowish Brown Sands - Riparian phase

These normally occupy a position similar to B2 - the Red sand

Low water holding and cation exchange capacities will necessitate frequent fertilizer and water applications.

Type A1 : Red Loamy Sands of the Terrace - Deep phase
(Profile 101)

The red loamy fine sands normally occur in complex association with Type C1, between B2 and the heavier terrace soils. In the mapping of this soil, two phases have been recognised: the deep phase (A1) and the shallow phase (As), in which the gravel and/or calcrete layer is found at less than 30 inches below surface. The latter is more fully described in a later section. Slope averages about 3%.

The soils included in this unit generally have a gradual increase in silt and clay content from about 7-9% in the surface horizon to about 15% at 36 inches. Occasional soils with a marked increase in clay content to about 20% at depth have been included in this unit. The main diagnostic characteristic distinguishing A1 from A2, which is somewhat similar, is that A1 has less than 15% clay in the upper subsurface horizons while A2 has 15% and more.

These soils are invariably cultivated by the inhabitants. With adequate fertilizer treatment and correct management techniques, the potential of these soils is high. For the same reasons as outlined under Type B2, sprinkler systems are to be preferred on this soil.

Type As ; Red Loamy Sands of the Terrace - Shallow phase
(Profile 27)

More than one soil has been included in this unit for sake of convenience since they are closely related and their potentials are similar. Typically the soils encountered here have a loamy fine sand surface horizon with a sandy clay loam sub-soil overlying a variety of

Type A2 : Red Sandy Loams of the Terrace (Profile 3)

These red sandy loam soils are nowhere very extensive. They normally occur in association with the Grey Brown sandy loams (Type C).

The surface horizon is generally a fine sandy loam with clay increasing with depth to a sandy clay loam within 36 inches. Generally these soils overly terrace gravels and often occur in a complex with the shallow As.

This soil type, which is invariably cultivated by the inhabitants, is a very good irrigable soil; indeed, the best encountered within the survey area. These soils will require fairly heavy fertilization for realisation of their optimum potential. Due to their good physical characteristics their potential is very high.

Type C1 : Grey Brown Sands to Loamy Sands (Profile 17)

These soils are quite extensive on the 20 ft. Terrace, especially west of Shamvura, where they supercede Type C in dominance within this province. They occur either alone on flat terrain or in complex association with A1 in micro-undulating terrain of low relief. They occupy the position either closest to the inner edge of the plain or between the red soils (B2 and B1) and Type Cs. Average slope is 1-2%.

Included in this unit are all grey brown soils with a sandy surface horizon, with a gradual increase in clay content to about 15% at 30 inches, as well as those soils with 10-15% clay throughout the upper 36 inches. Differentiation between type C and these soils is made on the basis of surface texture. Type C has 15% clay or more in the surface horizon normally increasing with depth (though not necessarily) while C1 must have less than 15% in the surface

Type C : Dark Grey Brown Sandy Loams - Deep phase
(Profile 16)

These soils are extensive on the 20 ft. Terrace between Bogani Pont and Shamvura. East of Bogani the terrace has been invaded by sand or is very limited, west of Shamvura Cl dominates the landscape. Type C invariably occurs along the inner edge of the terrace - closest to the river. It is normally associated with Cs especially at the inner margin where the terrace material has been removed to some extent, exposing the basement limestone in places. It may occasionally be found in association with Type A2.

Included in this unit are all brown to dark grey brown soils with 15-35% clay in which the surface horizon has about 15% or more clay and in which the depth to underlying limestone is 36 inches or more. The soil generally is dark grey brown with a sandy loam (15-20%) clay) surface horizon with a gradual increase in clay content with depth to about 20%. Lime in the form of powdery accumulations overlying nodules and limestone occur at about 60 inches. Although the associated termite mounds are saline the soil itself is not; it is neutral becoming slightly alkaline in the lower horizons.

About all of Type C encountered is at present under cultivation. This soil has no apparent limitations to irrigation and has a high potential. Inherent fertility is expected to be fairly high - higher than the red soils, although physical characteristics are not as favourable as Type A2. The proximity of Type C to the river simplifies drainage control provided the higher lying land is not over-irrigated. Either sprinkler or flood irrigation can be practised.

When levelling the land of termite mounds, due cognizance must be taken of their high sodium content; indiscriminate spreading have been cultivated.

The shallow effective rooting depth and slight impedance of the calcrete to water penetration are limitations to irrigation use; Sprinkler irrigation systems would be preferred should the soil be extensively irrigated.

The Vungu Vungu irrigation scheme is located partly on this soil, and by using short beds, flood irrigation has proved successful without the apparent build-up of a water table. Here the problem with flood irrigation appears to be rather that of excessive drainage than of water table. The area is adjacent to the river and sub-surface drainage is not impeded.

Type A : Red Sandy Clay Loams to Clays

Only one significant area of this soil was encountered; at Mamano near Andara, occupying a flat slightly depressed site. This was a red sandy clay soil, strongly saline, moderately alkaline and moderately to slowly permeable.

The few areas which were mapped as Type A had more than 35% clay in the lower horizons (below 15 inches) and more than 20% clay in the surface horizon.

These soils are cultivated by the inhabitants although at Mamano it would not appear to be a favoured soil since cultivation is only patchy.

Before Type A could be extensively irrigated it would have to be drained and leached of excess salts. The slow permeability would present some difficulties as would the high sodium content;

alkaline and slowly permeable; other more saline forms are likely, but were not encountered.

Generally, the solonetzic soil - the type of the minor drainage lines - is not cultivated and cannot be recommended for irrigation due to both the salinity hazard and the impeded sub-surface drainage.

The black clay, sensu stricto, although poorly drained and slowly permeable, could be used with specialised management techniques.

THE 60 FT. TERRACE AND AEOLIAN SAND PLATEAU

The riverine margin of this province is generally marked by a distinct rise in elevation, forming a minor scarp, as at Runtu for instance. It is presumed that the high level terrace everywhere underlies the aeolian sand, though only rarely at the edges, as at TP. No. 18, was the terrace material actually encountered under the sand mantle. It is postulated that the sandy loam material at depth in Type A1 as well as the heavier material in the Omurambas may be related to this terrace deposit - a postulation borne out by the uniformity in texture of the deeper materials in Type G and by the occurrence of outcrops of the basement limestone in the Omurambas.

The soils of this province are sandy, but for a few low lying areas; the generalised catena being Type B1 on higher lying steeper sloping sites, E on middle medium sloping sites, D on flat sites and G in slightly depressed sites (excluding the Omurambas).

It is seldom that any of these soils are cultivated by the members, e.g. Profile 18, have a very low clay content (approx. 3%).

Soils with such low clay percentages cannot normally be recommended for irrigation even though the sand content is largely of the fine sand fraction. The reasons for this lie in their excessively rapid permeability, inherent low water holding capacity and low cation exchange capacity. Sprinkler irrigation is essential, frequent water and fertilizer applications are necessary; moreover, in areas with such a high evapo-transpiration rate only crops with extensive root systems can obtain sufficient water to supply their needs from a soil of great depth but low available moisture capacity.

The Red Sand as a type, incorporating the Riparian phase (B2) and the Plateau phase (B1), is a marginal soil due to its low clay content and poor moisture retention properties. The crop potential of these sands under irrigation is directly related to the percentage clay; the productivity, mutatis mutandis, decreasing proportionately with decreasing colloid content, till a point is reached where production is uneconomic and the sand then cannot be recommended for irrigation development. The precise point of change-over or economic break-even is not accurately known and can only be determined by experimentation and field testing in the local environment, both natural and sociological.

By both laboratory and field test, we have attempted to differentiate between the very low and, say, moderate percentage clay classes because of the obvious land use significance. We feel we have been partially successful though only detailed soil survey can solve this problem with any degree of certainty. There is an apparent indication - though not proven to our complete satisfaction - that in the upper 36 inches the Riparian phase has 7-9% silt plus clay and the Plateau phase has about 4-5% silt plus clay. The Riparian phase is

Type El : Brown to Yellowish Brown Sands - Plateau phase (Profile No. 219)

These Brown Sands generally occupy slightly flatter or lower lying positions than Bl. Average slope is about 2-3%.

Mapped as Type El are all sands which are brown to strong brown or yellow brown in colour. Generally, the surface is a dark brown with chroma's gradually increasing with depth to above 4 (10YR 5/6 5/8 yellowish brown or 7.5YR 5/6 5/8 strong brown). The clay content is low, apparently in the order of 3% in the top 36 inches. Brown sands with higher clay appeared to be limited and ubiquitous.

As with Type Bl these soils are provisionally not recommended.

Type D : Grey Sands (Auger boring No. 44)

These grey loose sands occupy a flat more or less featureless plain , typically with an average slope of 0-1%. They average less than 1-2% clay in the top 36 inches.

At no time were these soils found to be cultivated nor could they be recommended for irrigation use; they have lower water holding and cation exchange capacities than either El or Bl the Brown and Red sands.

Type G : Solonetz soils (Profile No. 10)

These solonetzic sandy soils occupy flat somewhat depressed areas with little or no slope.

Typically, a grey loose sand abruptly overlies an olive grey sandy loam at about 48 inches. This sandy loam is extremely hard when finer in texture than the surrounding soils and in some places they have quite a high potential. Similar soils are also found on the riverine terrace; indeed, the sequence of soils is almost identical, at least in those Omurambas which were investigated. For instance, starting at the river in Omuramba Mahango, Type F is found in the lower part, whereafter C and Cs may be encountered with rare patches of A1. Further up the Omuramba C1 and A2 are found. This analogous soil sequence does tend to substantiate the existence of the terrace materials and limestone basement below the Aeolian Plain.

By comparison with the Terrace, the pattern of distribution is complex on a micro-scale due to the narrow cross-section of the Omurambas. Detailed soil survey would be required to establish the distribution of the soils, and thereby, the overall potential of Omurambas. The irrigation potential of individual soils are similar to that of their counterparts occurring on the Terrace.

Field reconnaissance suggested that the suitable soils are scattered and discontinuous; the general irrigation potential of Omurambas thus being of not much significance. Engineering problems of water supply may be formidable, except in isolated cases, such as the very long Omurambas where further detailed study may be justified.

THE PAN-VELD OF THE SOUTH WEST

This area is quite flat, marked by numbers of blow holes and pans now serving as waterholes for the game. There appears to be a marked change in particle size distribution which suggests that these sands represent the residue after deflation and local resorting by wind.

Type K : Reddish Brown Pan-veld Sands (Auger boring No. 49)

SSIFICATION AND GENERAL CHARACTERISTICS OF THE SOILS OF OKAVANGOLAND

GENERAL CHARACTERISTICS	SUITABILITY FOR IRRIGATION DEVELOPMENT
Heavy red soils overlying lime. Very minor occurrence Moderately permeable. Slightly to moderately saline.	MARGINAL Salinity hazard.
Red loamy sands with 10-15% silt plus clay in the surface horizons. Rapidly permeable and moderate water holding capacity. Non-saline. Limited extent only.	RECOMMENDED Highly recommended under sprinkler irrigation.
Gravels and/or limestone occur at less than 30 inches below surface. Mapped in complexes only.	MARGINAL Limitation of shallow soil. Recommended under sprinkler irrigation only.
Red sandy loams with 15-20% clay in the surface horizons; at depth the clay sometimes increases to 20-35%. Excellent irrigation soils. Rapidly permeable. Limited extent only.	RECOMMENDED Highly recommended under sprinkler irrigation.
Red aeolian sands - 5YR and redder throughout. Slightly loose and less than 10% silt plus clay in the upper 36 inches. Very rapidly to excessively permeable. Low water holding capacity.	Phases detailed below.
Red sands with less than 7% silt plus clay in the upper 36 inches, commonly 4%. Occurs extensively on the Inland Sand Plateau.	NOT RECOMMENDED for time being. Low water holding capacity, low colloid content and excessive internal drainage are limiting. Development potential pending research and detailed study.

GENERAL CHARACTERISTICS	SUITABILITY FOR IRRIGATION DEVELOPMENT
Red sands commonly with 7-10% silt plus clay in the upper 36 inches. These sands have been separated from B1 due to physiographic position, topography and slightly higher clay content.	MARGINAL Limiting factors as above (B1). Can be used under sprinkler irrigation only. (c.f. Vaalhartz Scheme).
Brown to dark grey brown sandy loams with no clay increase or with a gradual clay increase with depth. May have 15-35% clay. Overlies lime in nodular or massive (calcrete) forms at depth. Rapidly permeable; good water holding properties. Non-saline.	RECOMMENDED Sprinkler irrigation systems preferred.
Less than 30 inches soil depth to calcrete on rock.	MARGINAL Shallow soil depth. Recommended under sprinkler irrigation only.
Grey brown sands to loamy sands with a gradual to clear increase in clay content to 10-15% clay at 36 inches. Included in this unit are those soils with less than 15% clay in the upper horizons increasing with depth to 20%. Overlies lime at depth. Rapidly permeable and low to moderate water holding capacity.	MARGINAL Soil moisture properties are not optimal. Recommended under sprinkler irrigation only.
Less than 30 inches soil depth to calcrete on rock.	NOT RECOMMENDED. Variable and shallow soil depth.

GENERAL CHARACTERISTICS	SUITABILITY FOR IRRIGATION DEVELOPMENT
Loose grey to grey brown sands with less than 7% silt plus clay within the upper 36 inches, commonly less than 4% clay. Excessively permeable; and very low water holding capacity. Occurs very extensively on the Inland Sand Plateau. Also included in this mapping unit are those loose grey sands of the river levees and Floodplain.	NOT RECOMMENDED Very unfavourable soil moisture properties and low inherent fertility are limitations.
Brown sands which become yellowish brown with depth. Slightly loose and less than 10% clay. Very rapid to excessive permeability. Low water holding capacity.	Phases detailed below.
Brown to yellowish brown sands with less than 7% silt plus clay (commonly <4%). Extensively developed on the Inland Sand Plateau.	NOT RECOMMENDED for the time being. Low water holding, low colloid content as well as excessive drainage are limiting.
Brown to yellowish brown sands with 7-9% silt plus clay in the upper 36 inches. These sands have been separated from E1 due to physiographic position, topography and slightly higher clay content.	MARGINAL Recommended under sprinkler irrigation only. Low water holding capacity and somewhat excessive internal drainage are limiting.
Black sandy loam to sandy clay loam (commonly 6-12 in. thick) abruptly overlying bleached coarse sands at between 6" and 36". Rapidly permeable but poor internal drainage; seasonally flooded. Due to a high silt content the upper material may be very slowly permeable at some sites.	MARGINAL Limitation of shallow rooting depth, seasonal water table and flooding. (See FP).

GENERAL CHARACTERISTICS	SUITABILITY FOR IRRIGATION DEVELOPMENT
Grey loose sands abruptly overlying a grey brown loamy fine sand to fine sandy loam at about 36 inches. This heavier material becomes extremely hard when dry. Saline/sodic in the heavier material. Drainage impeded at about 36 inches.	NOT RECOMMENDED Under irrigation the build-up of illuvial clay at the abrupt textural change will lead to the formation of a dense impermeable clay pan.
Black clay soils overlying lime. Of very minor occurrence. Slowly permeable. Very firm consistence. Poor surface drainage.	MARGINAL Drainage hazard.
Brown to red brown aeolian sands with significantly higher coarse sand fractions. Less than 7% clay, commonly about 4%. Excessively permeable. Very low water holding capacity.	NOT RECOMMENDED Soil moisture properties are limiting.

PHYSIOGRAPHIC REGIONS AND ASSOCIATED SOILS AND VEGETATION

In this chapter a brief outline of the classification and the general characteristics of the various physiographic regions and their components will be given; the relevant cartographic data are presented on a map at a scale of 1:250,000.

There are two major physiographic regions, the Okavango River Terrace and the Inland Sand Plateau.

THE OKAVANGO RIVER TERRACE

The limits of the Terrace and the extent of the land classified as RECOMMENDED and MARGINAL for irrigation are shown on the 1:250,000 map. The favourable geographical location of the Terrace in relation to the Okavango - a permanent source of water for domestic, stock and irrigation use - and the occurrence of favourable soils and terrain constitute an environment of outstanding potential for intensive agricultural development based on irrigation. Provided reasonable standards of irrigation management are maintained, no problem of drainage or salinisation are likely to develop.

THE INLAND SAND PLATEAU

There is evidence to suggest that the Plateau is a river terrace, with a calcrete base, over which aeolian sands have been deposited. Seif dune formations are a striking feature of an otherwise monotonous sand plain; and of particular interest, is the system of parallel dunes and Omurambas. Variations in the depth and uniformity

SUMMARY AND RECOMMENDATIONS

A reconnaissance soil survey was undertaken of the lower Okavango River in the environs of the Popa Falls followed by a flying reconnaissance survey to cover the remainder of Okavangoland, an area of about 12,900 sq. miles.

The soil investigation has determined that the main area of irrigation potential is located on the Okavango River Terrace. The capability assessment for irrigation may be summarised as follows :-

RECOMMENDED	3,400 hectares
MARGINAL	35,000 hectares

The Inland Sand Plateau is only suited to a very low intensity of agricultural development and areas of suitable irrigable soils are confined to the Omurambas; their scattered and discontinuous distribution with a low and intermittent availability of suitable soils, and their great distance from water supplies are serious limitations to their effective developmen The extension of irrigation onto the Red and Brown Aeolian Sa on the Plateau is subject to experimentation and further detai

Seif Dune Formations

The seif dune formations have been differentiated on the form and degree of development of the dunes. Four types were recognised :

Map Unit 31 : This unit consists of uneven dunes developed along the margin of the Okavango Terrace and the sides of the major tributaries. Omurambas are absent. Observations indicate the accumulation of deep sand deposits. Within this mapping unit - shown by the map symbol Bl-El - areas of more level, even sloping Red and Brown Sands occur. Selected areas would be capable of exploitation through traditional agricultural methods and it may be possible through research to extend irrigation onto portions of these soils. For the balance of Map Unit 31, the only utilization could be low quality grazing for stock.

The remaining three types consist of variations of the Parallel Systems of Seif Dunes and Omurambas:

Map Unit 32 : System faintly discernible
Map Unit 33 : System clearly discernible
Map Unit 34 : Prominent dunes

Map Unit 32 : Here the parallel system of seif dunes and Omurambas is just discernible. The Omurambas are few and normally poorly developed. The area consists predominantly of Grey Sands supporting Woodland Savanna suited only to extensive grazing.

Map Unit 33 : The system is clearly discernible but the dunes are normally small and discontinuous. The soils of the dune areas are Grey Sands with small sections of Brown

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Map Unit 33 : The system is clearly discernible but the dunes are normally small and discontinuous. The soils of the dune areas are Grey Sands with small sections of and is recognised both by the soils and the very open low Burkea africana - Terminalia sericea tree communities. Here the grass cover is very sparse, mainly Loudetia superba and fibrous Aristida spp. In this mapping unit the Omurambas are well developed with a significant proportion of favourable soils except in the southern section, where, although the Omurambas are wide there appears to be a secondary infilling of loose sand supporting short Terminalia - Bauhinia scrub which lowers the agricultural potential. The more favourable soils of the Omurambas would support dryland arable production and the balance of the Omurambas together with the Red and Brown sands of the dunes could provide medium quality grazing. The best prospects for settlement, based on dryland arable production supplemented by livestock production, would be found within this unit.

Flat Featureless Plains

Map Unit 41 : This unit comprises large, incipient, poorly defined Omurambas within the extensive featureless Grey Sand areas. The drainage pattern is very diffuse. The Omurambas consist mainly of Grey Sands with areas of skeletal soils onto calcrete carrying a very sparse grass cover. Large termitaria mounds are prominent. Areas of more favourable soils are extremely limited and will support only localised settlement. The unit as a whole could be utilized only for very extensive livestock production.

Map Unit 42 : This is the most extensive soil and vegetation type encountered. It consists of uniform featureless Grey Sands with no Omurambas. The variations are the very occasional small depressions and isolated low mounds of Red and Brown

Map Unit 44 : A faint hummocky relief is apparent. The soils are Brown Sands with Grey Sands occupying the depressed areas. Within this mapping unit isolated rises carrying well grown stands of Acacia giraffae and Combretum spps. occur. Omurambas are absent and no defined drainage pattern is evident. Certain of the isolated rises carrying well grown A. giraffae could provide sites for dryland arable production, but in general, and similar to the previous mapping units, the possibilities of permanent arable production are extremely limited. The only land use potential is very extensive livestock production.

Map Unit 45 : This unit consists of a very flat plain supporting Bush Savanna and wide poorly defined Omurambas with numerous large deep waterholes. Extensive areas of Red and Brown Sands are encountered within the general Grey Sand areas. The soils vary slightly from the previous units in that the coarse sand fraction is higher. The deep waterholes and higher coarse sand fraction indicate the action of recent deflation and resorting by wind. The areas of Red and Brown Sands support Acacia - other species bush and scrub whilst the Grey Sands carry Terminalia-Burkea bush. Extensive areas of Grey Sands occur in the Omurambas with minor areas of more favourable soils. These latter areas would permit dryland arable production which might be extended onto portions of the Red Sands. Veld management would provide particular problems in the control of scrub communities which have seriously suppressed the grass cover. In these communities, browse provides a valuable source of fodder, but any further increase in the density of bush will seriously reduce the carrying capacity.

of the Omurambas are outlined by a sloping section of hummocky Brown Sands with termitaria mounds and well grown A. giraffae and Combretum spps. The centres are wide and level except for the waterholes which provide secondary relief. The more favourable soils, mainly Grey Brown Sands to Loamy Sands (type C), are indicated by scattered well grown A. giraffae and a dense grass cover characterised by Schmidtia bulbosa, often with vigorous A. giraffae scrub regeneration. Associated with these better soils are the Grey Sands, normally onto calcrete at shallow depths, carrying a tall mixed sour grass cover, mainly Loudetia superba and fibrous Aristida spp. The waterholes consist of Black Clays with calcrete often outcropping along the margins.

Poorly Developed Omurambas

These Omurambas do not show the pronounced form or step down from the sides into the centre of the depression as do the previous ones. They are generally wide and very flat with little variation in height from the surrounding Grey Sand areas. The soils are predominantly Grey Sands with a sour grass cover. Included within this category are those Omurambas found in the Southern portion of the prominent dune formations, Map Unit 34, containing extensive deposits of loose Red and Brown Sands.

Poorly Defined Omurambas

These consist predominantly of Grey Sands with areas of skeletal soils onto calcrete. The regular parallel pattern of the previous Omurambas is not evident; these consist of very wide, very diffuse depressed drainage areas.

Raised Omurambas

ECONOMIC ASSESSMENT OF THE IRRIGATION POTENTIAL OF THE OKAVANGO RIVER TERRACE

A rainfall which is both erratic and low in average, and soils of inherently low fertility are the main limiting factors to increased agricultural production. The climatic records show that the area is virtually frost free and irrigation can extend the growing season throughout the year. The most important practices required are : a degree of mechanisation to allow adequate and timely land preparation, optimum use of fertilizers, effective weed and insect control and efficient water use. This economic analysis assumes that high standards of irrigation farming will be practised.

A wide range of crops are suited to the environment; for instance, the perennial crops: lucerne, citrus, tropical and sub-tropical fruits; the summer annuals: maize, cotton, groundnuts, sorghum, millets; the winter annuals : wheat and beans, in addition to plantation fibre crops, sugar cane, tobacco and vegetables.

For comparative purposes an annual summer cropping programme of cotton and maize, followed by beans and wheat, combined with an equal area of lucerne have been selected as parameters in this study. It would be possible with careful planning to double-crop annually. Under the prevailing climatic conditions lucerne could be expected to persist for at least four years before a serious decline in vigour and yield can be expected due to weed encroachment. This programme would meet rotational needs and furthermore, these crops present no serious difficulties either in their cultivation or in their bulk handling and marketing.

Vegetables, citrus and sub-tropical fruits can be expected

Comparison of the profitability of various crops

Production -

Crop	Yield/Hectare (less retentions)	Unit Sale Price R	Total Production R	Road Transport R	Sale Value f.o.r. R
Cotton	5000 lbs	0.065	325	12	313
Maize	50 bags	3.50	175	25	150
Wheat	30 bags	5.75	172	15	157
Beans	20 bags	10.00	200	10	190
Lucerne	20 tons	19.00	380	100	280

Note : a) Road transport based on rates Tsumeb-Ondangua 497 cents/ton.

b) Retentions, maize 6 bags per hectare; beans 1 bag per hectare.

Direct Costs per Hectare

	Cotton R	Maize R	Wheat R	Beans R	Lucerne R
Labour (assume family labour)	Nil	Nil	Nil	Nil	Nil
Fertilizer plus transport	39	39	39	25	25
Seed	3	6	5	17	5
Insecticides plus application	30	1	1	1	7
Contract ploughing/transport to market depots	22	26	22	20	20
Bags/twine	4	15	9	6	4
Threshing/baling	-	5	3	2	20
Incidentals	5	1	1	1	9
TOTAL	103	93	80	72	90
Sale Value	313	150	157	190	280
Gross Margin	210	57	77	118	190

Crop	Hectares	Gross Margin R
Cotton	0.75	168
Maize	0.75	42
Wheat	0.75	57
Beans	0.75	88
Lucerne	1.50	285
		640

The gross margin of R640 per three hectare holding is the difference between sales and direct costs of production. From this figure must be met all the extra charges inherent in the operation of a scheme, namely :-

(a) General management and supervision;
(b) The annual operating costs of supplying water;
(c) The annual charges on the capital costs of works required for the distribution of water and the preparation of lands for effective irrigation, and finally
(d) The returns to the individual co-operators.

For this latter figure to exceed the existing casual labour rates, the individual would expect a minimum return of R160 or 25% of the Gross Margin as determined above. This would leave a balance of R480 to meet the other charges, equivalent to R160 reduced to a per hectare basis.

In respect of labour an average family unit is capable of supplying approximately 50 labour man-days per month. The peak labour demands can be expected to fall during the summer harvesting

The labour requirements for lucerne would be low as the harvesting of the crop is normally mechanised. Approximately 150 labour man-days would be available to meet the 143 man-day requirements as determined above. Labour demands and output are subject to wide variations but it can be assumed that a 3 hectare holding as visualised would be within the capabilities of an average family. It is estimated that each family unit would retain for personal use, 10 bags of maize and 2 bags of beans.

The total extent of soils suitable for irrigation is approximately 40,000 hectares. With the provision for access, canals and irregular shaped blocks a maximum of approximately 35,000 hectares could be developed. This gives a total of 35,000 x 160 = R5,600,000 to meet the other charges over and above the return to the individual co-operator, for which provision has already been made. To accommodate adverse seasonal effects, changing tenants, etc. it would be advisable to reduce this figure by, say, 20% to give a total of R4,480,000.

If this sum is allocated pro rata then approximately R1,500,000 each would be available for general management and supervision, the annual operating costs of supplying water, and finally, the annual charges on capital works.

In respect of management and supervision, a permanent organisation should be set up for the overall direction and running of the scheme, outside of the extension assistance that might be provided by interested Government Departments. Such an organisation should assume responsibility for the care and use of the capital works, the distribution of power and water, the setting up and supervision of irrigation schedules, the use of spray and mechanical equipment, the

the majority of the soils. The annual irrigation requirements, considering rainfall, drying off periods, are estimated as follows :

Lucerne	60 inches
Winter crops	20 inches
Summer crops (supplementary)	20 inches

This gives an average of 50 inches per hectare. With an allowance of R43 per hectare - the total of R1,500,000 divided by 35,000 hectares - the expenditure which can be allocated to the operating costs of water supply would be R0.80 per hectare/ins. of water or R1.00 per 70,000 gallons.

The capital investment which such a scheme could theoretically support, calculated on an annual charge of 10%, is about R15,000,000; which is more or less in the same order of magnitude as the calculated value of exportable annual output of R12,000,000.

The above figures should be measured against the total costs of the civil engineering aspects of the scheme; they also indicate the upper limit of the financial contribution which irrigation might make and can also estalbish the basis for cost benefit studies.

The quality of the land will effect yields and profitability, and with comparable standards of management, higher yields can be expected from the heavier textured more favourable soils which have been classified as Recommended. Similarly, through improvement in skills, irrigation and crop management, appreciably higher yields could be obtained with the same scale of inputs; profitability would thus

MAP SYMBOL : D GREY SANDS TEST PIT No. 21

Site: On river levee; 75 yards from Okavango River.

Parent Material: Alluvium/aeolian sand on Tertiary limestone.

Sample No.	Horizon	Depth (in.)	Description
F174	A1	0-14	(10YR 3/2) very dark greyish brown; fine sand; apedal; soft consistence; very rapid permeability; gradual transition.
F175	AC	14-34	(10YR 4/2) dark greyish brown; fine sand; apedal; soft to loose consistence; very rapid permeability; gradual transition.
F176	C1	34-64	(10YR 5/3) brown; fine sand; apedal; loose consistence; very rapid permeability; abrupt transition.
F177	C2ca	64-70	(10YR 7/3) very pale brown; loamy fine sand; apedal; slightly hard consistence; very rapid permeability; rare soft $CaCO_3$ accumulations.

ANALYTICAL DATA

Sample No.	F174	F175	F176	F177
Depth in.	0-14	14-34	34-64	64-70
Horizon	A1	AC	C1	C2ca
Particle size distribution (%)				
c. sand	3.1	4.0	3.1	3.7
m. sand	27.4	31.4	21.8	23.8
f. sand	63.8	59.6	69.8	60.4
silt	2.8	1.5	2.2	2.5
clay	2.4	2.5	3.3	9.6
pH.H_2O	7.4	7.7	7.7	8.0
Ohms R 60°F	2000	2200	2250	2700

MAP SYMBOL : F	BLACK SANDY LOAMS OF OMURAMBAS AND FLOODPLAIN	AUGER SITE No. 30

Site: On bank of Okavango River at F.C.U Jute scheme.

Parent Material: Alluvium.

Sample No.	Horizon	Depth (in.)	Description
T179	A1	0-6	(10YR 2/1) black; silty clay; apedal; hard consistence; few worm casts; slow permeability; gradual transition.
	AC	6-12	(10YR 2/1) black; clay; apedal; hard consistence; slow permeability; gradual transition.
T180	C1g	12-24	(10YR 3/1) very dark grey; clay; weak coarse blocky structure; firm consistence; weak slickensides; slow permeability; gradual transition.
	C2g	24-30	(N4/0) dark grey; clay; apedal; plastic consistency; abundant distinct fine (5YR 4/6) yellowish red mottles; very slow permeability; abrupt transition.
	W.T.(C3)	30+	Sand and free water.

ANALYTICAL DATA

Sample No.	T179	T180
Depth in.	0-12	12-24
Horizon	A1	C1g
Particle size distribution (%)		
c. sand	0.1	2.3
m. sand	2.5	1.5
f. sand	14.0	8.7
silt	28.9	17.0
clay	[illegible]	[illegible]

MAP SYMBOL : B2 RED SANDS TEST PIT No. 2

Site: On 60 ft. terrace; 1-2% slope.

Parent Material: Aeolian sand on terrace material.

Sample No.	Horizon	Depth (in.)	Description
F91	A1	0-11	(5YR 3/4) dark reddish brown; sand; apedal; soft consistence; very rapid permeability; rare distinct brown inclusions; gradual transition.
F92	B21	11-30	(5YR 5/6) yellowish red; sand; apedal; soft consistence; very rapid permeability; rare distinct brown inclusions; gradual transition.
F94	B22	30-48	(2.5YR 5/6) red to (5YR 5/6) yellowish red; sand; apedal; soft consistence; rapid permeability; rare distinct brown inclusions; rare sub-angular fine quartz gravel; gradual transition.
F95	B23 + C	48-72	(5YR 5/6) yellowish red; sand; apedal; friable consistence; rare distinct brown inclusions; rare sub-angular fine quartz gravel. Included in this horizon is a lens, of small sub-angular quartz stones and laterite fragments, in which stratification is evident. This lens dips from 56 inches to 72 inches.

ANALYTICAL DATA

Sample No.	F91	F92	F94	F95
Depth in.	0-11	11-30	30-48	48-72
Horizon	A1	B21	B22	B23/C
Particle size distribution (%)				
c. sand	6.1	5.4	7.3	7.1

MAP SYMBOL : A1 RED LOAMY SANDS OF THE TERRACE - DEEP PHASE TEST PIT No. 101

Site : On 20 ft. terrace; old land.

Parent Material: Aeolian sand on terrace material.

Sample No.	Horizon	Depth (in.)	Description
T22	A1	0-12	(5YR 4/6) yellowish red; sand; apedal; soft consistence; frequent fine grit; rapid permeability; gradual transition.
T23	B21	12-32	(5YR 4/8) yellowish red; loamy sand; apedal; soft consistence; frequent yellow inclusions; frequent fine grit; rapid permeability; gradual transition.
T24	B22	32-44	(5YR 4.5/8) yellowish red; loamy sand; apedal; soft consistence; frequent fine grit; few small sub-angular stones; rapid permeability; abrupt wavy transition.
	C	44-60+	Slightly loose mass of rounded and sub-angular stones and Fe/Mn concretions in a yellowish red sandy loam matrix.

ANALYTICAL DATA

Sample No.	T22	T23	T24
Depth in.	0-12	12-32	32-44
Horizon	A1	B21	B22
Particle size distribution (%)			
c. sand	10.5	13.0	11.7
m. sand	37.0	39.1	37.3
f. sand	44.1	33.9	36.6
silt	2.6	2.9	2.9
clay	6.5	11.0	11.9

MAP SYMBOL : As — RED LOAMY SANDS OF THE TERRACE - SHALLOW PHASE — TEST PIT No. 27

Site: On 15 ft. terrace; 100 yards from river; 1% slope.

Parent Material: Terrace material.

Sample No.	Horizon	Depth (in.)	Description
F13	Ap	0-6	(5YR 3/2) dark reddish brown; fine sandy loam; apedal; hard consistence; rapid permeability; clear transition.
F14	B2	6-18	(5YR 3/3) dark reddish brown; fine sandy loam; weak blocky structure; hard consistence; moderate permeability; abrupt transition.
	C	18+	Semi-continuous $CaCO_3$ in a dark reddish brown sandy clay loam matrix.

ANALYTICAL DATA

Sample No.	F13	F14
Depth in.	0-6	6-18
Horizon	Ap	B2
Particle size distribution (%)		
c. sand	3.3	5.0
m. sand	24.9	27.5
f. sand	54.2	46.2
silt	6.8	6.1
clay	11.9	15.8
texture	SaLM	SaLM
Net extractable cations (me/100 gm.)		
Na	0.10	0.05
K	0.10	0.10
Ca	4.90	
Mg	6.80	
S. value	11.90	

MAP SYMBOL : A2 RED SANDY LOAMS OF THE TERRACE TEST PIT No. 3

Site: On 20 ft. terrace; 2% slope.

Parent Material: Aeolian sand on terrace material.

Sample No.	Horizon	Depth (in.)	Description
F87	A1	0-14	(7.5YR 4/4) brown to dark brown; loamy fine sand; apedal; slightly hard; rapid permeability; gradual transition.
F88	B21	14-27	(5YR 4/8) yellowish red; sandy loam; apedal; firm consistence; rare faint brown inclusions; rapid permeability; rare termite channels; gradual transition.
F89	B22	27-49	(5YR 4/6) yellowish red; fine sandy loam to sandy clay loam, apedal; friable consistence; frequent distinct brown inclusions - old termite channels; rapid permeability; gradual transition.
F90	B23	49-63	(5YR 4/6) yellowish red; sandy loam; apedal; friable consistence; rapid permeability; abrupt wavy transition.
	C	63-83	Slightly loose mass of laterite fragments and small sub-angular quartz stones, with thin $CaCO_3$ encrustations, in a yellowish brown sandy loam matrix.

ANALYTICAL DATA

Sample No.	F87	F88	F89	F90
Depth in.	0-14	14-27	27-49	49-63
Horizon	A1	B21	B22	B23

Particle size distribution (%)

MAP SYMBOL : C1 GREY BROWN SANDS TO LOAMY SANDS TEST PIT No. 17

Site: On 15 ft. terrace; 3% slope.

Parent Material: Old alluvium on basement Tertiary limestone.

Sample No.	Horizon	Depth (in.)	Description
F147	Ap	0-8	(10YR 3/1.5) very dark greyish brown; loamy fine sand; apedal; soft consistence; very rapid permeability; gradual transition.
F148	B21	8-20	(10YR 4/1.5) dark greyish brown; loamy fine sand; apedal; soft consistence; very rapid permeability; gradual transition.
F149	B22	20-31	(10YR 4/2) dark greyish brown; loamy fine sand; apedal; soft consistence; rare fine soft $CaCO_3$ accumulations; rapid permeability; gradual transition.
F150	B3	31-40	(10YR 4/2) dark greyish brown; fine sandy loam; apedal; soft to slightly hard consistence; rare small $CaCO_3$ concretions; rapid permeability; clear transition.
	Cca	40-52+	(10YR 5/3) brown; gravelly fine sandy loam; apedal; soft consistence; abundant $CaCO_3$ concretions forming in the lower part, a semi-continuous vesicular limepan.

ANALYTICAL DATA

Sample No.	F147	F148	F149	F150
Depth in.	0-8	8-20	20-31	31-60
Horizon	Ap	B21	B22	B3

Particle size distribution (%)

MAP SYMBOL : C — DARK GREY BROWN SANDY LOAMS - DEEP PHASE — TEST PIT No. 16

Site: On 15 ft. terrace; 4% slope; numerous large anthills.

Parent Material: Old alluvium on basement Tertiary limestone.

Sample No.	Horizon	Depth (in.)	Description
F143	A1	0-8	(10YR 3/2) very dark grey brown; fine sandy loam; apedal to weak very coarse blocky structure; hard consistence; rapid permeability; gradual transition.
F143	B21	8-16	(10YR 3/2) very dark grey brown; fine sandy loam; apedal to weak blocky structure; slightly hard consistence; rare soft white $CaCO_3$ accumulations; rapid to moderate permeability; gradual transition.
F144	B22ca	16-38	(10YR 3/2) very dark grey brown; sandy clay loam; apedal to weak blocky structure; soft to slightly hard consistence; frequent fine $CaCO_3$ concretions and fine mycelia; moderate permeability; gradual transition.
F145	B3ca	38-54	(10YR 4/3) dark grey brown; sandy clay loam; apedal to weak blocky structure; hard consistence; rare $CaCO_3$ concretions; frequent mycelia; moderate permeability; gradual transition.
F146	C	54-78	(10YR 6/3) pale brown; gravelly sandy clay loam; apedal; soft to slightly hard consistence; abundant small $CaCO_3$ concretions; moderate to rapid permeability.

ANALYTICAL DATA

MAP SYMBOL : Cs   DARK GREY BROWN SANDY LOAMS - SHALLOW PHASE   TEST PIT No. 23

Site: Dissected 15 ft. terrace; lowerslope; 4% slope.

Parent Material: Old alluvium overlying basement Tertiary limestone.

Sample No.	Horizon	Depth (in.)	Description
F182	Ap	0-8	(10YR 3/2) very dark greyish brown; fine sandy loam; apedal to weak blocky structure; slightly hard consistence; rapid permeability; gradual transition.
F183	B21	8-24	(10YR 3/2) very dark greyish brown; sandy clay loam; weak fine blocky structure; slightly hard consistence; rare fine mycelia; rapid to moderate permeability; gradual transition.
F184	B22ca	24-36	(10YR 4/2) dark greyish brown; sandy clay loam; weak fine blocky; slightly hard consistence; frequent soft and hard $CaCO_3$ nodules; rapid to moderate permeability; gradual to clear transition.
	Cca	36+	Semi-continuous $CaCO_3$ nodules in a grey brown sandy clay loam matrix.

ANALYTICAL DATA

Sample No.	F182	F183	F184
Depth in.	0-8	8-24	24-36
Horizon	Ap	B21	B22ca
Particle size distribution (%)			
c. sand	2.0	1.9	1.9
m. sand	13.1	11.4	9.2
f. sand	60.7	57.3	53.8
silt	7.3	9.3	10.8
clay	17.0	20.9	25.5

MAP SYMBOL : H — BLACK CLAYS — AUGER SITE No. 12

Site: Slightly depressed area on 20 ft. terrace in S.W.A. - B.P. border trace.

Parent Material: Alluvium.

Sample No.	Horizon	Depth (in.)	Description
F162	A1	0-6	(10YR 4/1) dark grey; sandy clay loam; weak coarse blocky structure; hard consistence; weak self-mulching properties; abundant surface cracks; weak crusting; slow permeability; gradual transition.
F163	C1	6-12	(10YR 4/1) dark grey; clay; weak coarse blocky structure; extremely hard consistence; rare fine $CaCO_3$ concretions; slow permeability.
F164	C2	12-24	(10YR 4/1) dark grey; sandy clay loam; moderate coarse blocky structure; very firm consistence; weak slickensides; frequent fine $CaCO_3$ concretions; slow permeability.

ANALYTICAL DATA

Sample No.	F162	F164
Depth in.	0-6	12-24
Horizon	A1	C2
Particle size distribution (%)		
c. sand	3.4	5.6
m. sand	26.8	26.4
f. sand	26.8	26.2
silt	12.5	8.2
clay	31.8	34.6
Net extractable cations (me/100 gm.)		

MAP SYMBOL : H — FINE TEXTURED SOILS OF MINOR DRAINAGE LINES — TEST PIT No. 28

Site: Dissected 15 ft. terrace; in drainage line; 1% slope.

Parent Material: Alluvium.

Sample No.	Horizon	Depth (in.)	Description
F15	A1	0-8	(10YR 3/1) very dark grey; loam with stratified lenses of brown fine sand and an overburden of pale brown sand; apedal; slightly hard consistence; moderate permeability; abrupt transition.
F16	A1b	8-20	(10YR 2/1) black; loam; weak coarse blocky structure; slightly firm to firm consistence; slow permeability; gradual transition.
F17	C1	20-30	(10YR 3/1) very dark grey; sandy clay loam; weak to moderate coarse blocky structure; slightly firm consistence; rare weakly formed slickensides; slow permeability; gradual transition.
F18	C2	30-40	(10YR 3/1) very dark grey; sandy clay loam; weak coarse blocky structure; firm consistence; rare soft $CaCO_3$ accumulations; slow permeability.

ANALYTICAL DATA

Sample No.	F15	F16	F17	F18
Depth in.	0-8	8-20	20-30	30-40
Horizon	A1	A1b	C1	C2

MAP SYMBOL : B1 RED SANDS - PLATEAU PHASE TEST PIT No. 18

Site: On 60 ft. terrace covered by seif dune; 3% slope.

Parent Material: Aeolian sand.

Sample No.	Horizon	Depth (in.)	Description
F153	A11	0-12	(5YR 4/3) reddish brown; sand; apedal; soft consistence; very rapid permeability; gradual transition.
F154	A12	12-30	(5YR 4/4) reddish brown; sand; apedal; soft consistence; very rapid permeability; gradual transition.
F155	B21	30-78	(5YR 5/8) yellowish red; loamy sand; apedal; soft consistence; very rapid permeability; clear transition.
	C	78+	Laterite boulders, terrace gravels and artifacts in a yellowish red loamy fine sand matrix.

ANALYTICAL DATA

Sample No.	F153	F154	F155
Depth in.	0-12	12-30	30-78
Horizon	A11	A12	B2
Particle size distribution (%)			
c. sand	2.0	2.1	1.6
m. sand	45.7	43.2	39.7
f. sand	48.1	51.7	53.3
silt	1.0	1.7	1.7
clay	2.7	3.0	3.1

MAP SYMBOL : E1 BROWN TO YELLOWISH BROWN SANDS - PLATEAU PHASE TEST PIT No. 219

Site: Flat aeolian plain.

Parent Material: Aeolian sand.

Sample No.	Horizon	Depth (in.)	Description
T110	A1	0-12	(10YR 5/2) grey brown; sand; apedal; loose consistence; very rapid permeability; gradual transition.
T111	B21	12-30	(10YR 6/4) light yellowish brown; sand; apedal; loose consistence; very rapid permeability; gradual transition.
T112	B22	30-60	(10YR 7/6) yellow; sand; apedal; loose consistence; very rapid permeability.

ANALYTICAL DATA

Sample No.	T110	T111	T112
Depth in.	0-12	12-30	30-60
Horizon	A1	B21	B22
Particle size distribution (%)			
c. sand	2.3	2.3	2.1
m. sand	54.6	50.9	46.1
f. sand	40.6	44.6	48.9
silt	1.2	0.9	0.3
clay	2.1	1.8	2.3
Net extractable cations (me/100 gm.)			
Na	0.10	0.10	0.10
K	0.05	0.00	0.00
Ca	0.75	0.35	0.35
Mg	0.00	1.15	0.05
S. value	0.90	0.60	0.50
T. value/C.E.C.	0.65	0.40	0.50

MAP SYMBOL : D   GREY AEOLIAN SANDS   AUGER BORING No. 44

Site: On flat featureless plain; 16 miles south of Gaudam.

Parent Material: Aeolian sand.

Sample No.	Horizon	Depth (in.)	Description
T154	A1	0-10	(10YR 4/1) dark grey; sand; apedal; loose consistence; very rapid permeability; gradual transition.
T163	C	10-48	(10YR 5/2) greyish brown; sand; apedal; loose consistence; very rapid permeability.

ANALYTICAL DATA

Sample No.	T154	T163
Depth in.	0-10	10-48
Horizon	A1	C
Particle size distribution (%)		
c. sand	2.7	3.7
m. sand	51.0	42.5
f. sand	43.0	52.1
silt	1.7	1.4
clay	2.2	0.5