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SOILS OF THE CENTRAL ORANGE RIVER BASIN

by

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Submitted in fulfilment of the requirements for the degree of
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ABSTRACT

The work reported in this thesis is based on a reconnaissance soil survey of the Central Orange River Basin with the object to identify and select soils suitable for irrigation under the Orange River Development Project. The demarcated area constitutes 3,1 million hectares and is situated between latitudes $28^{\circ} 45'$ and $30^{\circ} 45'$ and longitudes $22^{\circ} 37'$ and $25^{\circ} 15'$ in the South Western Orange Free State and Northern Cape Province. This is an arid to semi-arid region according to climatic classification.

During the soil survey particular attention was paid to those factors of the environment which have a bearing on soils found in this area, and especially on their morphology, genesis and distribution. The environment, apart from the soils, is dominated by the general aridity, low relief with isolated hilly features and Karroo System rocks. Soils identified fall in two general classes, viz. clayey soils of colluvial, alluvial and sedentary origin and sandy soils of aeolian origin. The former are mostly of a saline nature and have poor physical properties with respect to irrigability. The sandy soils contain little or no soluble salts, are well drained and well suited towards irrigation.

Identification and mapping of the soils were carried out in accordance with a current classification system of the Soil and Irrigation Research Institute. Seventeen soil series of six soil forms and various land classes and complexes were identified and mapped. A soil map on a scale of approximately 1:320 000 accompanies this thesis.

Soil samples of representative profiles were collected and analysed in order to further characterize soils. Chemical analyses substantiated field observations that the clayey soils were, in most cases, highly saline and the sandy soils non-saline. Clayey soils were furthermore alkaline in reaction, and rich in exchangeable cations, notably Ca^{++} , Mg^{++} and Na^{+} . High CEC values indicated a dominance of 2:1 clay minerals,

whereas X-ray diffractograms gave evidence of mixed layering of these minerals.

The aeolian sands generally had lower pH values, low clay contents and hence low CEC and exchangeable cations. Clay mineral suites appeared to be of a similar nature to those of the clayey soils.

The prominence of large aeolian deposits in the landscape and their importance towards irrigation prompted an investigation on the origin of the aeolian sandy parent materials. Morphological and mineralogical studies proved that two types of aeolian sandy deposits, distinctly different in origin, occur. It is postulated that the yellowish sands were blown from the Orange River bed in situations favourable for westerly winds. The red sands are of Vaal River origin and were blown from the river bed towards the east and south-east by westerly to north-westerly winds.

CHAPTER 1

INTRODUCTION

1.1 HISTORICAL

In his Report of The Proposed Orange River Development Project the Secretary of Water Affairs (Jordaan, 1962-63) states: "A certain Captain R. J. Jordan (sic), a Netherlands officer who was in command of the garrison in Cape Town, arrived at the Orange in its middle reaches in the year 1777 and gave the river its name in honour of the Prince of Orange. Thereafter a hundred years passed before the first mention is made of investigational work directed to the development of the water resources of the river.

"It is recorded that in 1872 the survey began of a portion of the present Boegoeberg Government Water Scheme, but intensive survey was only put in hand in 1919. The construction of the scheme began only in 1929.

"Two major proposals were also investigated in some detail, namely the Confluence - Prieska and the Van der Kloof - Brak River Project. These received attention in 1910 and were more thoroughly surveyed after 1919, but were in course of time put aside in favour of a more profitable major scheme on the Vaal River, on which attention was concentrated in the thirties."

Mention was made of further survey work on the Orange River undertaken during 1944 to 1953. Investigations were again continued in 1959 after a temporary interruption and were concentrated on collecting data for a plan to develop the Orange River comprehensively and to its maximum potential.

"While the field work was proceeding, studies continued of the technical feasibility, efficiency and advantages of various proposals and combinations of proposals for the development of the Orange River. These studies have led to the formulation of the development plan as set out in this White Paper" (Jordaan, (1962-63).

The long-term plan, as set out in this report, includes the building of storage and regulating dams with pumping and canal systems. This comprehensive

project is aimed at the supply of water for (a) irrigation (b) urban and industrial purposes (c) various local authorities and (d) hydro-electric power development. Agriculture at present consumes by far the largest percentage of available water supplies in South Africa. Municipal authorities and industry are demanding more and more water for their respective needs. All these consumers of water are expected to tax the water resources of the country to its utmost in another three or four decades. It is therefore necessary that all consumers should use their share of the supplies in the most efficient manner, that water be conserved and that untapped sources be developed. It is likewise necessary to conserve the soil and vegetative resources of catchment areas.

In the catchment area of the Orange River most of the land is only suitable for utilization as natural pasture. Parts with a lower rainfall have a very low grazing potential. Dryland cropping is only possible in the upper catchment area where rainfall exceeds 500 mm per annum. In the central and lower catchment areas, limited irrigation is practised by individual farmers, except for large scale government irrigation schemes immediately along the Orange River. Water supplies for these schemes were dependent upon uncontrolled flow of the Orange. This resulted in times of water deficiency and in floods, both causing damage to crops. The Orange River Development Project announced in 1962 could therefore provide for a constant supply for existing irrigation schemes, and in addition, a considerable area of new irrigation development. "There is at least 360,000 morgen of irrigable soil available, which can be considered for irrigation by the waters of the Orange River at the ultimate stage when these water resources are fully developed. Of this area 247,000 morgen of existing and potential development lies inside and 113,000 morgen of existing and potential development outside, the watershed of the Orange River" (Jordaan, 1962-63). Water for approximately 100 000 ha will be diverted from the Orange River through a tunnel to the Fish and Sundays Rivers. The majority of the water in the storage dams will, however, be required for existing irrigation schemes and soil for future development in the Orange River valley.

With the announcement of the Orange River Development Project very little information was available on the soils of the Central Orange River Basin covering an area of approximately 3,3 million hectares. Existing irrigation schemes along the Orange and Ongers Rivers comprised approximately 22 000 ha. Another 167 000 ha were surveyed in detail for irrigation, viz. Prieska - Confluence Scheme (Meyer, 1931), Riet River Irrigation Project (Louw & Rosenstrauch, 1935) and Vanderkloof Irrigation Project (Bruwer, Hensley & Louw, 1961). An area of approximately 3,1 million hectares had never been surveyed pedologically before. The Department of Water Affairs requested the Soil and Irrigation Research Institute to undertake a soil survey in this area with the object of finding soils suitable for irrigation development.

Superficial investigations by engineers of the Department of Water Affairs proved that insufficient potentially irrigable soils were located in this area under direct gravitational control of canals (Jordaan, 1962-63). The proposed survey area therefore included areas of an elevation higher than gravitational reach.

1.2 LOCATION OF AREA AND PURPOSE OF SOIL SURVEY

The location of the demarcated area is situated in the South Western Orange Free State and Northern Cape Province, on both sides of the Orange River (vide Figures 1.1 and 1.2). It lies roughly within a quadrangle described by Kimberley (north), Koffiefontein (east), Britstown (south) and Prieska (west).

Because of the size of the area and the limited time available, it was decided to make the soil survey on a reconnaissance scale. This would allow the identification of major soil series, the classification of the soils with respect to irrigability and demarcation of soil areas for further intensive investigation.

During the course of the survey interesting phenomena of certain soils were observed. This led to an attempt to clarify the origin of certain presumed

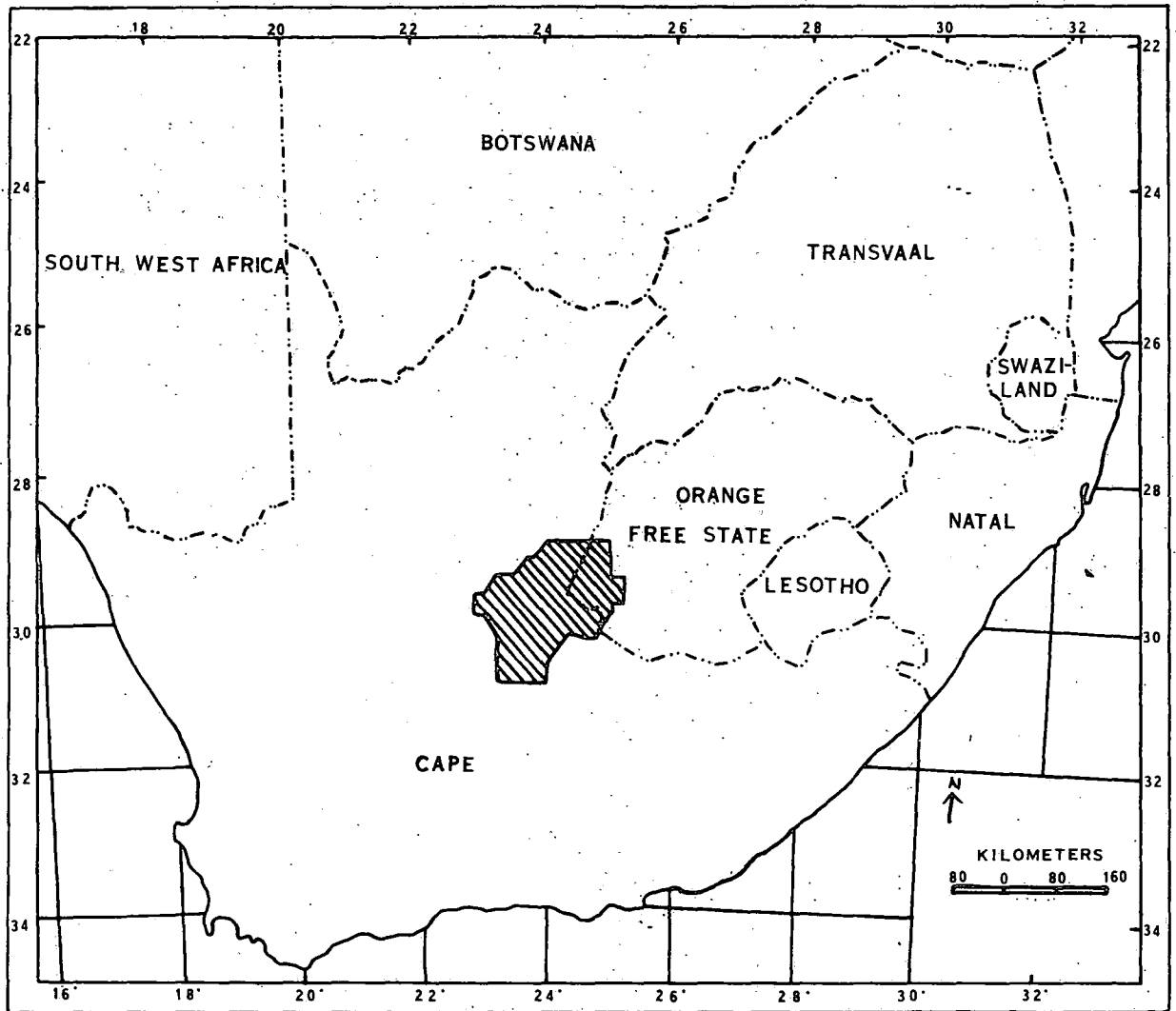


FIGURE 1.1 LOCALITY MAP

aeolian deposits, using morphological and geomorphological evidence.

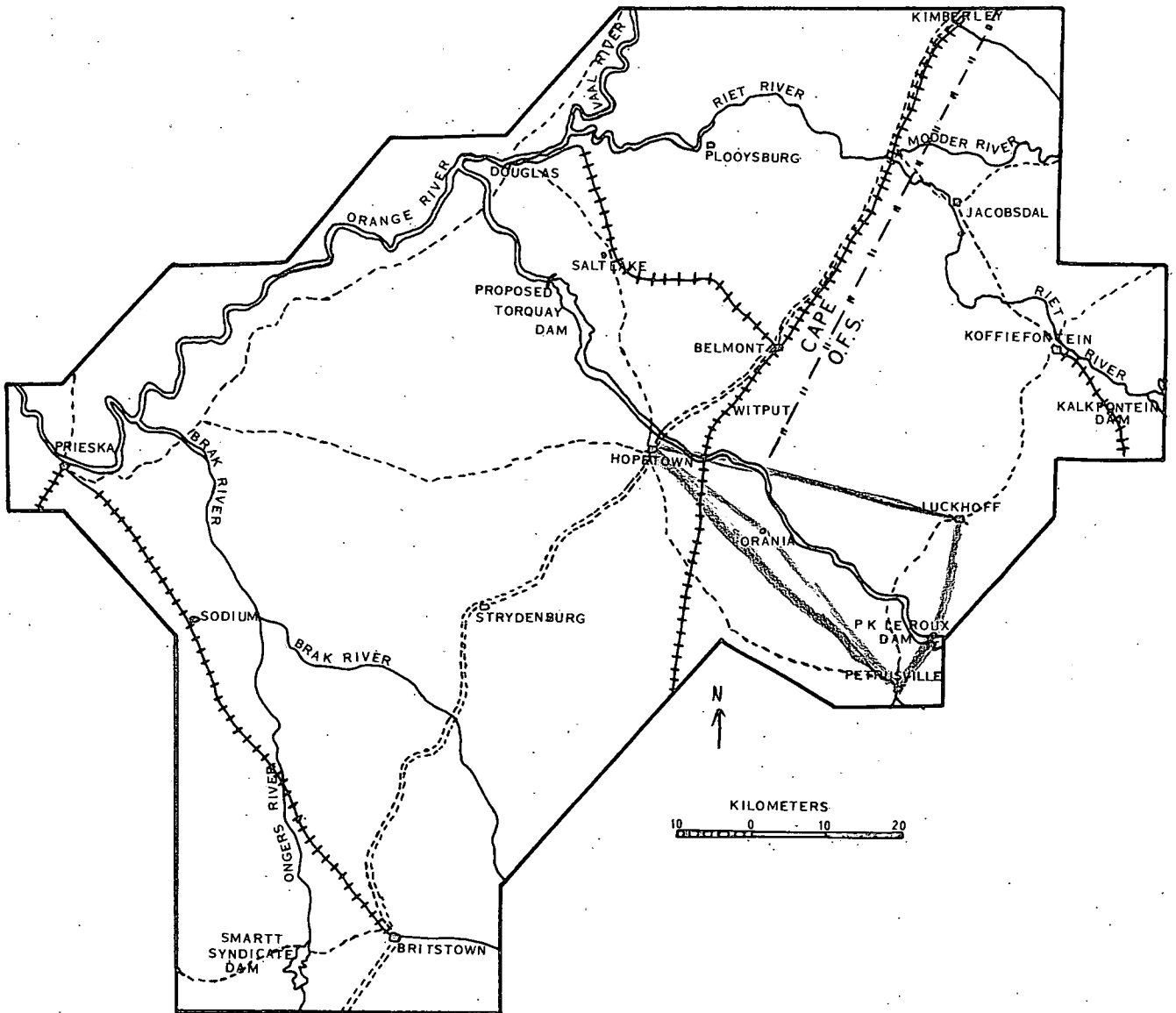


FIGURE 1.2 - MAP OF THE SURVEY AREA

CHAPTER 2

THE ENVIRONMENT

In order to assess the potentialities of a region, whether for extensive agricultural purposes, intensive development such as irrigation farming or any other development projects, it is necessary to evaluate the individual components of the natural environment. These major components are climate, vegetation, geology, physiographic features and soils. Interaction of these factors produces an environment of a specific nature.

The area under discussion falls within the Karroo, has a typically arid to semi-arid climate, a karroid type of vegetation, a generally low relief, predominantly shallow and saline soils on sedimentary rocks with areas of aeolian deposits. Such an environment is not conducive to intensive agricultural or other development. Lack of water is the major limiting factor. The only way open for man to bring about a favourable change in such an environment is to introduce large quantities of water to that area from elsewhere.

In this chapter attention will be focused upon the environmental factors climate, vegetation, geology and physiography, with a view to a subsequent discussion of the soils.

2.1 CLIMATE

Climate determines the distribution of both soil types and vegetation over the face of the earth. Likewise, climate determines the movement and settlement of man in certain areas. Despite the measure of control man has over some of the forces of nature, he is still fundamentally influenced by his climatic environment.

In this section the major climatic components will be discussed. The objectives are mainly directed towards climate as a factor of soil formation and its effect on vegetation and physiography, which are also soil-forming factors. Soil genesis is discussed in Chapter 4.

Climatic data were obtained from reports of the South African Weather Bureau (1954, 1960 and 1965) which were compiled from records of several meteorological stations in the area.

TABLE 2.1 - Average monthly (mm) and percentage seasonal distribution of rainfall for seven stations

Station	Koffiefontein	Luckhoff	Jacobsdal	Hope-town	Douglas	Brits-town	Prieska
Altitude (m)	1216	1280	1143	1098	1030	1122	933
Latitude	29° 24'	29° 45'	29° 08'	29° 37'	29° 03'	30° 35'	29° 40'
Longitude	25° 00'	24° 47'	24° 46'	24° 05'	23° 46'	23° 31'	22° 45'
No. of years	55	44	66	81	70	58	75
January	48	48	56	41	46	26	31
February	60	63	55	46	60	42	39
March	76	73	69	62	69	57	49
April	39	36	39	32	29	36	29
May	19	23	19	20	17	15	14
June	7	6	7	7	4	8	5
July	8	7	6	6	4	6	5
August	11	11	9	8	7	6	4
September	15	15	12	12	10	12	6
October	30	24	28	19	19	15	12
November	42	38	39	31	27	21	17
December	42	40	44	30	34	20	20
Year	396	384	384	313	326	265	232
Percentage distribution during:							
December-February	38	39	40	37	43	33	39
March-May	34	34	33	36	35	41	40
June-August	7	6	6	7	5	8	6
September-November	22	20	21	20	17	18	15
October-March	75	74	76	73	78	68	73
April-September	25	26	24	27	22	32	27

Average annual rainfall of the 7 stations = 327 mm

2.1.1 Precipitation

Rainfall records for seven stations, regarded as representative of the area are given in Table 2.1. It is evident that the area has a distinctly low rainfall, with a general average of 327 mm per annum. This figure is lower than the average for South Africa, which is also low at 471 mm per annum. The average for the world is 1 000 mm per annum.

The seasonal nature of the rainfall is pronounced. Approximately 75% of the annual precipitation falls from October to March, mainly in the form of heavy showers and thunderstorms. It reaches a maximum in February and March and a minimum in the winter months. A further notable feature brought out by the rainfall data is that the rainfall decreases in a south-westerly direction. Scrutiny of yearly rainfall records reveals that the total annual rainfall varies considerably. It is extremely irregular and unreliable. Periodic droughts are therefore a general phenomenon over the entire area.

Another factor of importance is the incidence of hail which often accompanies thunderstorms in the early summer. Although these hailstorms are sometimes very severe, causing much damage, they usually cover relatively small areas.

Snowfalls occur but rarely in the eastern and southern parts and are practically unknown in the area towards Prieska.

The precipitation is of rather limited use to plants. This is due not only to the high evapotranspiration rate under the prevailing high summer temperatures, but also to the fact that much of the summer rain falls in occasional heavy showers of short duration. Unfavourable soil conditions aggravate the latter factor because some soils have a rather dense surface layer which impedes rapid infiltration of rain water. Consequently there are heavy losses due to run-off, and surface ponding on the clayey plains leads to excessive evaporation during the hot, dry windy conditions which usually follow the summer rainstorms. All these combined factors reduce the efficiency of precipitation as a leaching agent.

2.1.2 Temperature and humidity

Air temperatures are subject to large diurnal and seasonal variations according to the temperature data for four stations summarised in Table 2.2.

TABLE 2.2 - Average temperature data ($^{\circ}\text{C}$) for four stations

Data for:		Britstown	Hopetown	Kimberley*	Kalkfontein-Dam
	January	24,4	25,6	25,1	25,2
	February	23,8	24,7	23,8	23,9
	March	21,2	22,5	21,8	21,9
	April	17,4	17,7	18,2	17,8
	May	13,2	13,3	14,3	13,6
Daily max. + daily min. <hr/> 2	June	9,2	10,3	11,1	10,1
	July	8,6	8,9	10,7	9,7
	August	10,9	12,3	13,5	12,7
	September	13,7	15,4	16,7	16,3
	October	18,3	19,2	20,6	20,1
	November	20,8	21,8	22,0	21,8
	December	23,6	24,7	24,3	24,7
	Year	17,1	18,0	18,5	18,1
Daily maximum	January	33,3	32,9	32,5	32,4
	July	16,3	17,2	18,5	16,9
Daily minimum	January	15,4	18,3	17,7	18,0
	July	0,8	0,6	2,9	2,5
Highest monthly	January	37,9	38,7	37,5	37,6
	July	22,7	24,6	23,9	22,8
Lowest monthly	January	8,8	11,2	11,9	13,2
	July	-3,6	-5,8	-3,3	-2,9

* De Beers

These data give a reasonable picture of temperature conditions in the area. The highest average temperatures are experienced from December to February, January is the hottest month with an average daily maximum of approximately 33°C . May to September is the coldest period, with July the coldest month.

Average daily maximum and minimum temperatures for July are approximately 17°C and $1,5^{\circ}\text{C}$, respectively. These considerable fluctuations in temperatures, both on a diurnal and seasonal basis, are characteristic of a continental climate. Extreme temperatures of more than 40°C maximum and less than -6°C have been recorded. This is brought out by the average hottest and coldest temperatures for many years at the various stations. Absolute highest and lowest values known are $43,9^{\circ}\text{C}$ and $-8,3^{\circ}\text{C}$.

As a result of frequent calms during winter nights, cold air collects in low topographic positions. Even lower temperatures are experienced on account of the resulting inversions in low-lying areas.

Frost is common during the winter months. The period of maximum incidence of frost is from May to September. Frost data are presented in Table 2.3. Average duration of frost varies from 55 days to 102 days per annum at the various stations.

TABLE 2.3 - Average duration of frost period

Station	First date	Last date	Duration (days)	Earliest	Latest
Hopetown	24/5	3/9	102	26/4	1/10
Kalkfontein Dam	4/6	14/8	111	1/5	17/9
Kimberley*	8/6	2/8	55	2/5	8/9
Prieska	27/5	28/8	93	2/5	8/10

* De Beers

Frosts may be much more common and severe in low-lying areas where frost damage is more likely than on higher ground. Late spring and early autumn frosts affect vegetation growing in bottomlands and small depressions.

The average annual relative humidity at 0800 hours is approximately 60%, and at 1400 hours approximately 30% (vide Table 2.4). The high relative humidity from March to July with the highest value recorded in June is caused by a drop in temperature during the period coinciding with the last summer

rains. From September to December the relative humidity is low with its minimum in September and is due to the large increase in temperature during spring before the onset of summer rains in October and November.

TABLE 2.4 - Average relative humidity (%) for the year and each month at 0800 and 1400 hours

	Time	Year	J	F	M	A	M	J	J	A	S	O	N	D
Fauresmith*	0800	63	57	64	71	72	75	76	73	62	51	52	55	53
	1400	32	28	32	37	36	36	36	32	31	27	27	30	27
Kimberley**	0800	59	55	62	69	69	70	71	66	55	48	48	48	50
	1400	29	28	32	37	35	34	33	30	26	23	24	25	26
Prieska	0800	59	52	55	60	66	71	74	72	60	53	49	48	46
	1400	27	23	24	27	34	31	32	31	29	23	23	25	26

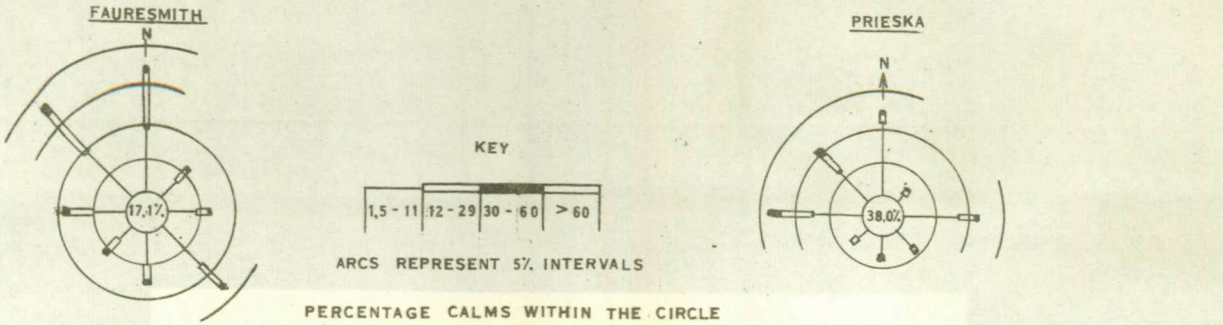
* Fauresmith is near the north-eastern boundary of the survey area

** Weather Office

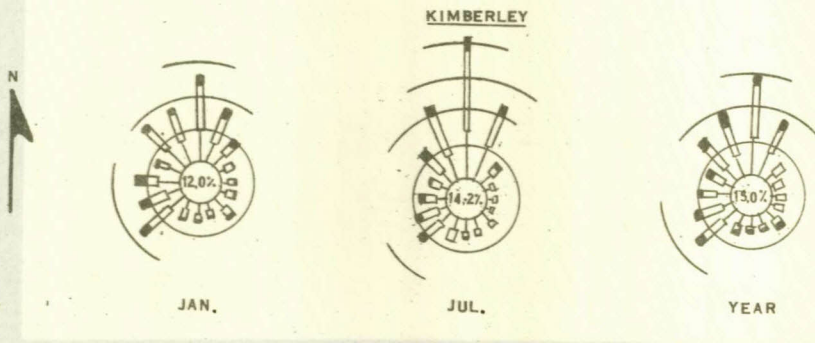
2.1.3 Winds

In this region wind is a major climatic component by virtue of its influence on the evaporating power of the air. Evapotranspiration is therefore accelerated by windy conditions prevailing in the period August to December. Winds play an additional role in the dispersal of seeds ripening during autumn and winter. It probable also played a major role in the distribution of the sandy parent materials of some soils (vide Chapter 5).

In common with the climatic conditions of the greater inland plateau, strong and prevailing winds in the sector north to west during August to December are a marked phenomenon. In Figure 2.1 the wind roses of surface winds at three stations are given. At Kimberley in the northern part of the area the dominant wind direction is from the north but the strongest winds are north-westerly. North-westerly winds are the strongest winds at Fauresmith in the east. Further to the south-western sector of the area (Prieska), the strongest and most prevailing winds are predominantly westerly. It is also evident that the percentage calms increases to the south-west.



(a)



KEY

PERCENTAGE OF CALMS WITHIN THE CIRCLE

5-13	14-24	25-40	41-60	> 60
------	-------	-------	-------	------

km/h ARCS REPRESENT 9% INTERVALS

(b)

FIGURE 2.1- (a) WIND ROSES FOR THE YEAR BASED ON VISUAL OBSERVATIONS AT 0830 AND 1500 HOURS FOR FAURESMTIH AND PRIESKA

(b) WIND ROSES FOR JANUARY, JULY AND THE YEAR (FOR DAY AND NIGHT TOGETHER) FOR KIMBERLEY (WEATHER OFFICE)



PLATE 1 - Barchan dunes to the east of the
Orange- Vaal River confluence.
Ghaap Plateau in background.

The given wind roses do not perhaps illustrate conditions as experienced during the windiest months of September to November. During these months strong northerly to north-westerly winds are most common with accompanying dust storms. Wind speeds usually reach their maximum during afternoons. At this time of the year the veld is generally in a poor condition after winter droughts and accompanying overgrazing. The result is that the sandy soils are most subjected to ravages of wind erosion. During these months, often before the beginning of summer rains, winds are hot and desiccating, aggravating the droughty conditions of the veld.

The strength and constancy of the northerly to westerly winds are evidenced by the formation of longitudinal dunes parallel to the direction of the wind. These seif dunes are similar to dune systems in the Kalahari. At the confluence of the Orange and Vaal Rivers, large areas are covered by thick deposits of sand blown from the Orange River bed. This is further evidence of the strength of the winds over long periods. Some of these deposits are evidently quite old compared with presently blown sand. On a windy day it may be observed that sand is at present still being blown from the river bed and deposited on the river banks. An extensive barchan dune system occurs immediately to the east of the Orange-Vaal confluence (vide Plate 1).

Apart from these prevailing winds, strong gusts frequently accompany thunderstorms. In 1959 a storm of hurricane force caused extensive damage at Prieska. During winter, dry south-westerly winds bring bitterly cold weather for short periods, usually lasting from one to three days. Generally autumn is the calmest season of the year.

2.1.4 Evapotranspiration

From the foregoing it is clear that this area is subjected to a harsh climate. Low rainfall, low relative humidity, dry winds and extremely high summer temperatures are inducive of high rates of evapotranspiration. Evaporation from class A pans, as an indication of potential evapotranspiration rates, is given in Table 2.5 for three stations. It is abundantly evident that potential evapotranspiration exceeds precipitation by a factor of more than five. Taking

also into consideration the high rates of run-off from sparsely covered veld, the extreme water deficit of the soils is very marked. This was also experienced during field surveying, the soils being desiccated almost entirely. Only deep sandy soils were moist for any appreciable time after rains. Clayey soils even in low-lying situations were thoroughly desiccated.

TABLE 2.5 - Evaporation data for three stations

Station	Evaporation* (mm/annum)
Kalkfontein Dam	2 130
Kimberley**	2 200
Prieska	2 500

* Data are based on measurements from a class A evaporation pan

** Weather Office

Climatologists classify the climate of this area as arid to semi-arid continental, being defined as an area with annual moisture deficits between potential evapotranspiration and precipitation of, respectively, from 1 500 to 1 000 mm and from 1 000 to 500 mm (Thornthwaite, 1948). In more general terms, these areas are described as those receiving less than 500 mm of precipitation annually. Arid soils of such climatic regions have been defined as those which will not support crop plants without irrigation (Kellogg, 1953). The data presented as well as personal observation and experience of the author confirm that the Central Orange River Basin is arid to semi-arid with arid region soils. The general and specific effects of the climate and its components on soil genesis will be discussed in Chapter 4.

2.2 VEGETATION

The vegetation of the area consists of a large variety of plant types, viz. grasses, shrubs and trees making it difficult to give a brief description.

According to Acocks (1953) there is no doubt that the greater part of the area once consisted of grassveld which has been degraded to Karroo veld. Although areas of sweet grassveld (Themeda-Cymbopogon Grassveld) exist in the



PLATE 2 - Acacia giraffae on deep Hutton soils.
Undergrowth of perennial grasses.

northern and north-eastern parts, it is nowhere widespread or continuous. Regression of the veld may be attributed primarily to overgrazing and mismanagement. It is clear that the veld composition is not only dependent upon the total amount of rain, but also to a considerable extent on the distribution thereof. As already stated (vide Section 2. 1. 1) the greater portion of the annual rain falls in the late summer and is thus of limited value for most plant species. Consequently undesirable plants of poor grazing value become dominant on overgrazed areas. This veld degeneration encourages sheet and gully erosion and in this manner the carrying capacity of the veld is further reduced. On sandy soils denudation is accompanied by wind erosion, causing damage to the remaining vegetation.

In general the plant cover varies from a very sparse, desert-like shrub vegetation to dense thornveld, both interspersed with various grass species. Soil and drainage conditions, rather than rainfall, appear to control the distribution of various plant communities. Of the edaphic factors, fertility status of the soils may influence plant distribution, but physical characteristics of the soils and their effect on the availability of soil moisture are probably of more importance.

2. 2. 1 Ecological significance of the soils

Soil, climate and topography may be regarded as the most significant plant ecological factors. Although much research has been done on the influence of the latter two factors, South African plant ecological literature reveals a dearth of quantified plant habitat data, especially with regards to the soil factor. Observational data in this regard have been reported by Mostert (1957) on soil pH, Van der Schÿff (1957) on soil texture and Roberts (1963) on soil pH, texture, colour and aspect.

Recently, Müller (1970) made an intensive soil and plant survey of the Orange Free State Botanical Garden at Bloemfontein. He found a significant correlation between soil type and vegetation. In defining soil type in this survey he made use of the proposed South African national soil classification system. By using this classification system, Müller (1970) made the first attempt to correlate all soil properties, used to define soil series, with vegetation.

The importance of basic plant habitat data, as manifested by soil types, has recently also come to light in the planning of the Upper Orange River Catchment Area. It was generally accepted that the erosion problem, with which is associated the silting up of the major dams in the Orange River, is caused by overgrazing of the vegetation and mismanagement of soil resources. However, it became clear that a soil map was needed for fully defining the plant habitat of that area. This may serve as a basis for planning purposes with soil-water-plant conservation as the main objective.

The soil survey of the Central Orange River Catchment Basin was intended primarily to indicate soil areas suitable for irrigation development. Although no intentional ecological studies were made, field observations clearly showed significant relationships between soil landscapes and associated vegetation. During the soil survey careful note was taken of plant species growing in particular areas. By this means it was possible to gain much pertinent information on the occurrence and distribution of plant species. Certain soil types (soil forms and/or soil series) are always associated with particular plant communities. Similarly, some individual species are very selective in their soil environment, but others exhibit considerable tolerance. In view of a generally consistent soil-plant relation observed in this area, it may be reasoned that the soil factor should be taken into consideration in defining and mapping of veld types in future. This may provide a more useful basis for detailed veld type demarcation than that of Acocks (1953). The vegetation of this area has been treated on a very broad basis by Acocks in his discussion of the veld types of South Africa.

In order to discuss the relation between soil types and vegetation, it is necessary to mention soil forms and land classes by name. Descriptions and discussions on the relevant soil forms and land classes are, however, given in Chapter 3.

Field observations in this area suggest that the strongest relation between soil and vegetation is found on the red sandy soils of the Hutton form. These soils are deficient in certain plant nutrients, have a neutral to slightly alkaline reaction and have a considerable water storage capacity when deep. It is very obvious that the Acacia giraffae (kameeldoring) - A. haematoxylon (vaalkameel)



PLATE 3 - Typical barchan dune formation on shallow Hutton soils. Othonna pallens in foreground.

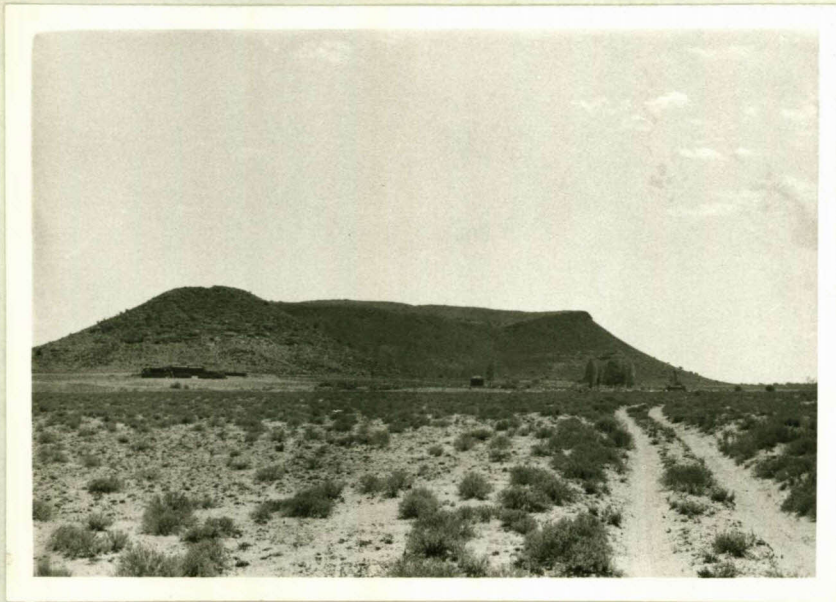
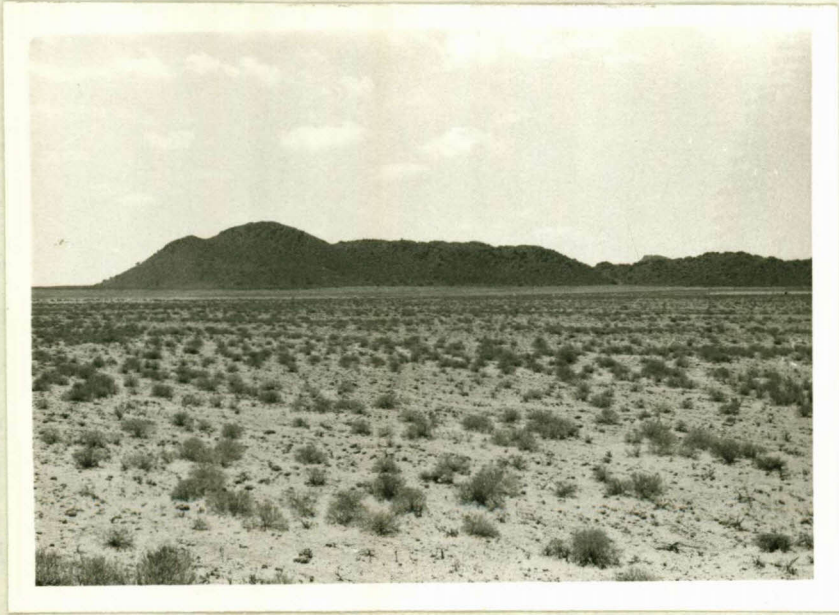


PLATE 4 - Typical vegetation on overgrazed
Clovelly soils. Short-grazed Stipagrostis
grass spp. with Arthosolen polycephalus
shrubs.

thornveld communities serve as distinctive indicators of deep Hutton soils and they are confined to soils generally deeper than 1 m (vide Plate 2). Dense communities of A. mellifera subsp. detinens (swarthaak) - A. tortilis (withaak) thornveld are also confined to deep Hutton soils, usually on northern to north-western slopes, but always at an elevation somewhat higher than the former thornveld community. Boscia albitrunca (witgat) are usually associated with both communities.

Acocks (1953) described these communities as "Kalahari Thornveld" and did not distinguish between them. The undergrowth consists chiefly of perennial grasses of which the most important are Stipagrostis spp. (boesmangras), Eragrostis lehmanniana (knietjiesgras), Panicum spp. (blousaadgras) and Themeda triandra (rooigras). Other grasses include coarse types such as Schmidtia spp. (sandkweek) mainly in dune areas, Heteropogon contortus (asse-gaaigras) and some of the coarser species of Eragrostis.

A shrub savannah community is closely associated with shallow Hutton soils. Dominant shrubs of this community are Rhigozum trichotomum (driedoring), Erioccephalus spp. (kapokbos), Tarchonanthus spp. (vaalbos) and some other minor species. Rhigozum trichotomum is very common on most shallow Hutton soils and to a lesser extent also on deep soils of this form. Being a pioneer plant it flourishes on overgrazed sandy areas and may grow so dense that large patches become impenetrable to both man and beast.

Except for dense growths of R. trichotomum, the shrub savannah vegetation is relatively sparse and becomes more so under heavy browsing pressure. In such overgrazed areas dune formations are sometimes in evidence on these shallow sandy soils (vide Plate 3). Under these conditions perennial pioneer bushes, e.g. Chrysocoma tenuifolia (bitterbos), Othonna pallens (springbokbos), Arthrosolen polycephalus (januariebos) and pioneer grasses such as Aristida spp. (steekgras) intrude. Under the prevailing farming practice it is difficult to conceive to what extent present vegetative cover of the Hutton soils, both shallow and deep, is a consequence of overgrazing. There is no doubt, however, that the vegetation on these soils, is very susceptible to overgrazing.

In view of their sandy nature Hutton soils absorb practically all rain water that falls, but have relatively low waterholding capacities. The shallow soils are therefore of a more droughty nature irrespective of geographical situation with regard to rainfall. On the other hand, the deep soils have a large reservoir for water storage. Therefore they are able to support deep rooting trees, e.g. Acacia giraffae. Under favourable rainfall conditions undergrowth grasses in these tree communities may flourish temporarily, making use of available moisture and mineralized nitrogen from the legumes (Acacia spp.). The low phosphate status of these soils (Van der Merwe, 1954 and Botha, 1971) had great economic implications with regard to cattle production in the previous century and the first decades of the 20th century. Cattle suffered heavily from bovine paratuberculosis, a contagious disease contracted from eating bones as a result of phosphate hunger. Sir Arnold Theiler solved this mystery disease by feeding the cattle phosphate licks. It remains a mystery, however, how these large Acacia giraffae trees are able to absorb sufficient phosphate from these extremely P deficient soils.

In contrast to the Hutton soils which support mainly tree and shrub vegetation with grass as an undergrowth, the Clovelly soils have an entirely treeless grass vegetation. Being also of a sandy nature these soils differ from the Hutton soils in that they are calcareous. Grass species are mainly Stipagrostis ciliata (langbeenboesmangras), S. obtusa (kortbeenboesmangras) and S. uniplumus (blinkaargras). Most effective sand-binders occurring on dunes of the Clovelly soils are Eragrostis pallens (duingras), Stipagrostis amabilis (duinriet or steekriet) and Schmidtia spp. On overgrazed areas Aristida spp. and Arthrosoelen polycephalus are most conspicuous (vide Plate 4).

Soils of the Shortlands, Willemsdal and Katspruit forms, varying in degree of calcareousness and salinity, support a typical karroid type of vegetation which apparently has a wide tolerance of soil conditions. Bare patches are often encountered on these fine-textured soils, especially on the Willemsdal form (vide Plate 5). They are of a somewhat higher elevation than the general plains on which they occur. Only Atriplex bushes are occasionally able to take root on them. Water appears to run off this slightly higher ground before it can penetrate to any depth into these soils with poor physical properties. It appears

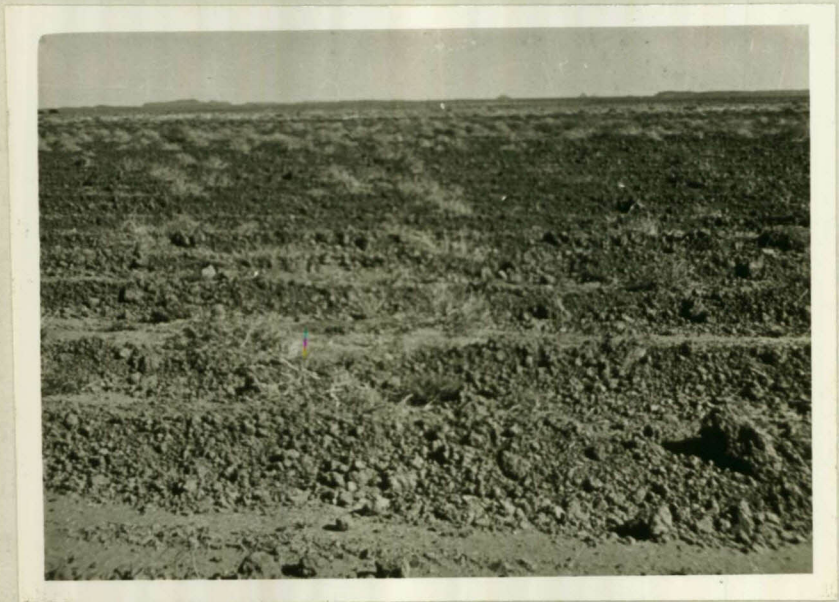


PLATE 5 - Reclamation of bare patches
on Willemsdal soils.

further that any decrease in plant density, and hence decrease in water penetration, enhances the development of bare patches.

The vegetation of these three soil forms is generally similar, except for Atriplex spp. which occur chiefly on more saline soils of the Willemsdal and Katspruit forms. Various Pentzia spp. (karoobossies), Lycium spp. (kriedoring), Phaeoptilum spinosum (brostdoring), Salsola spp. (ganna) and other bushes are supported by these soils. Grass species most commonly encountered are Eragrostis spp.; Aristida spp. and Enneapogon brachystachyus (haasgras or agtdaegras). Old man salt-bush (Atriplex nummularia) often grows in isolated patches on the more saline soils near pans.

Most of the pan floors are completely devoid of any vegetation, perennial plants growing only along the outer edges. In the lowest parts of the floors soluble salts accumulate to such an extent that no plants can exist there. Where plants can exist, the vegetation is similar to that of the Willemsdal and Katspruit soils, but sparser.

On the eastern periphery, the lee side of the pans, lunettes often occur. The soils of these lunettes are sandy and calcareous and usually support Stipagrostis spp., Schmidtia spp. and Aristida spp.

On all the shallow soils less than 0,45 m in depth, including those of the Mispah form and other shallow phases, and on stony land, the vegetation varies from grass-shrub to mixed karroo. This type of vegetation probably corresponds to the "Orange River Broken Veld" and "Arid Karroo" veld types of Acocks (1953). The most common shrubs and bushes are various species of Pentzia, including P. virgata (skaapbossie), P. incana (goeie karoo) and P. globosa (bitterkaroo), Europs spp. (harpuisbos), Chrysocoma tenuifolia, Nestlera conferta (perdekaroo), Lycium spp. and Tarchonanthus spp. Many grass species, e. g. Aristida spp. on overgrazed areas, Stipagrostis and Eragrostis spp. are found on these shallow soils and in good seasons flourish to such an extent that they conceal the bushes. Enneapogon brachystachyus is a rapid growing grass, emerging quickly after even light showers, but disappearing equally rapidly. The only tree that appears to be able to exist on these soils is Boscia albitrunca.

In the rocky hills, koppies and ridges Acacia mellifera subsp. detinens, A. tortilis, Rhus spp. (karee), Boscia albitrunca, Olea africana (olienhout) and Grewia flawa (rosyntjebos) are the most common trees and shrubs. The above bush and grass species are also found here.

It is surprising that succulents are scarce in the arid areas. Many of the succulents are, however, palatable and stock grazing may be partly blamed for their scarcity. A few Aloe species were encountered, mostly in the Asbestos Mountains and koppies in the vicinity of the Smartt Syndicate Dam.

Very little soil covers the dolomite formation of the Ghaap Plateau which falls within the survey area. The most conspicuous plants on these shallow calcareous soils are the Tarchonanthus spp. and Olea africana. Other shrubs are Rhus ciliata (suurkaree), R. pyroides (taaibos) and Grewia cana (rosyntjebos) and also some karroo bushes. Grasses are quite common on the plateau, e.g. Cymbopogon spp. (terpentyngras), Heteropogon contortus and Stipagrostis spp. Poisonous plants such as Geigeria passenoides (vermeerbos) often cause stock losses. On the lower pediment slopes various Acacia species, noticeably A. mellifera subsp. detinens and A. tortilis proliferate.

Along the river banks and minor watercourses, A. karroo (soetdoring) other Acacia species, Lebeckia spp. (bloubos), Salix capensis (wilger), Zizyphus spp. (blinkblaar-wag-'n-bietjie) and Rhus spp. are abundant.

The alluvial flats along the rivers carry a vegetation consisting mainly of mixed karroo bushes, shrubs and various sweet grasses similar to those on the Willemsdal and Katspruit soils. In areas where the floodplains of the Brak (Beervlei) and Ongers Rivers are irrigated by seasonal flooding from weirs, the vegetation is very dense and of high grazing value.

It is clear from this account that there are marked relationships between vegetation and the soils of the area. From a detailed examination of the plant communities in any one area, it is possible to deduce a considerable amount of information on the soils occurring in that area. Conversely, knowledge of the soils in such an area may provide considerable information on the vegetation to be expected.

Vegetation as a soil-forming factor will be discussed in Chapter 4.

2.3 GEOLOGY

2.3.1 Regional geology

A variety of rocks of different age occur in the area, but no detailed geological maps are available. The distribution of geological formations, (vide Figure 2.2) is based on the geological map of the Republic of South Africa of 1955. In certain parts the geology is fairly complicated and a discussion of these features in general requires a simplification. Table 2.6 shows the formations in chronological sequence.

TABLE 2.6 - Stratigraphical column

Tertiary to Recent		Soil, calcrete, gravel and unconsolidated surface deposits
Kimberlite		
Karoo dolerite		
Karoo System	{ Beaufort Series	Mudstone, siltstone, sandstone
	{ Ecca Series	Shale
	{ Dwyka Series	Tillite and shale
Transvaal System	{ Pretoria Series	Banded ironstone, andesite, shale, conglomerate and quartzite
	{ Dolomite Series	Dolomite, limestone, chert, shale
	{ Black Reef Series	Quartzite, shale, conglomerate, tuff, lava
Ventersdorp System		Andesitic lava, quartzite, tuff, arkose
Dominion Reef		Andesitic lava
Basement Complex		Granite, gneiss and metasediments

The Karroo System, which straddles the Palaeozoic and Mesozoic eras, and consisting of the Dwyka, Ecca and Beaufort Series, covers approximately 75% of the area. Tillites and shales of the Dwyka Series occupy large areas in the western and north-western sectors. The tillites vary from a typical ground moraine to a fluvio-glacial drift deposited during a Late Carboniferous period of glaciation (Du Toit, 1966). They consist of a very fine-grained argillaceous

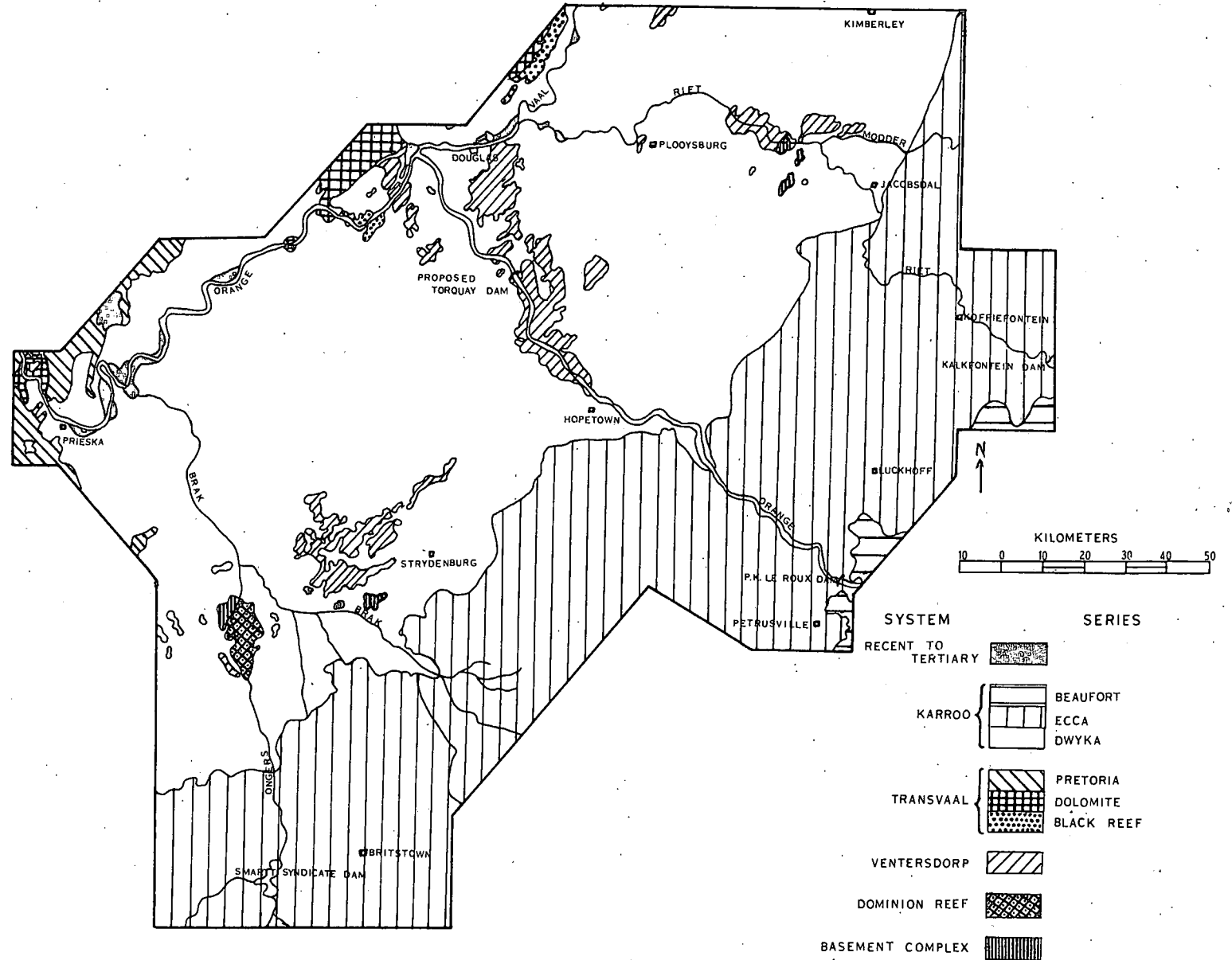


FIGURE 2.2 - GEOLOGICAL MAP OF THE AREA (COMPILED FROM THE GEOLOGY MAP OF SOUTH AFRICA, 1955)

groundmass containing sand, pebbles and boulders up to 1 m in diameter. These inclusions are derived from all the pre-Karoo formations, and include a variety of rocks such as granite, gneiss, conglomerate, quartzite, dolomite and jasper, derived from the Basement Complex, and the Ventersdorp and Transvaal Systems. The inclusions are often faceted and striated.

The pre-Karoo floor, on which the tillite rests, and over which the ice sheets had moved, is exposed at several places, mainly in the river beds of the Orange, Vaal and Riet Rivers. This floor is scraped and planed in places, e. g. Vilets Kuil (Hopetown) in the Orange River, Douglas in the Vaal River and Driekop (Plooyburg) in the Riet River. Roches moutonnees are also visible. The palaeo-direction, as deduced from striation and roches moutonnees indicates movement of glaciers and ice sheets from north to south (Du Toit, 1966).

Approximately 40% of the area is occupied by rocks of the Ecca Series (Permian). This series covers the eastern and southern sectors. The Ecca sediments consist mainly of dark coloured grey to green shales, sandstones being absent.

A small area in the eastern part is occupied by rocks of the Beaufort Series (Late Permian to mid-Triassic). These sediments are grey, blue, green, red and purple mudstones and siltstones, with interbeds of blue to yellow, fine- to medium-grained felspathic sandstone.

Numerous sills and dykes of Karroo dolerite presently form conspicuous landforms. These dolerite outcrops are confined to the area covered by Karroo sediments. Sills are more common than dykes and the metamorphic effects on the Karroo sediments are well displayed where shales and mudstones are commonly altered to lydianite. This indurated rock was widely used for the manufacture of artifacts and scattered over all the area by Stone Age Man.

Of the Proterozoic Systems, viz. the Ventersdorp, Transvaal and Dominion Reef Systems, the first occupies the largest area. Rocks of this System outcrop as inliers in the Dwyka Series. They consist of green andesitic lava which is either amygdaloidal or massive and diabasic. Minor quartzite, tuff and arkose outcrops are sometimes associated with the lava. Amygdales in the lava are mainly agate and chalcedony.



PLATE 6 - Calcrete.

The Pretoria Series is exposed in the vicinity of Prieska and consists of banded ironstones forming the Asbestos Mountain Range. These ironstones are extensively folded and tilted.

The Dolomite Series occur in the north-western parts of the area and forms the Ghaap Plateau. A typical karst topography, with local elephant skin-type weathering (lapies) is very common; hence the local name of "olifantsklip" for this rock. On the plateau and on the edge of the escarpment limestone there may be extensive development of travertine carapaces and aprons, the carbonates of which are derived from the Precambrian dolomites.

A few minor outcrops of the Black Reef Series and of the Dominion Reef System are also present in the area. The former occur in very small areas in the vicinity of Douglas. The Soetlief Formation (Dominion Reef System) forms a few small outcrops, e. g. near Modder River Station. It is an acidic lava with subordinate sediments.

A few outcrops of Basement rocks, mainly granite and gneiss, are found near Sodium.

Limestones in South Africa have a wide distribution (Wybergh, 1920) and are more or less confined to areas with an annual rainfall of less than 630 mm. In the Central Orange River Catchment Area limestone is a striking feature of the geology. Considerable areas are underlain by the Karroo sediments and dolerite. Particularly on flattish ground, limestone is present in this area either as nodules and powdery lime in some soils or as extensive sheets on top of dolerite and other geological strata. The sheet limestone varies in thickness from a few centimeters to several meters. In the vicinity of rivers and minor watercourses, remnants of limestone sheets form striking and well-defined plateaux of varying size from very small to some hundreds of hectares. These remnant lime plateaux were probably formed by erosional and pedimentation processes.

Sheet limestone deposits, variously known as surface limestone, lime pan, calcrete, caliche and kankar, vary in colour from white to yellowish white to greyish. The uppermost layer (vide Plate 6), whether exposed or covered by a sandy layer, is usually very hard and impervious. This layer is sometimes fissured breaking into blocks and known by geologists as boulder lime-

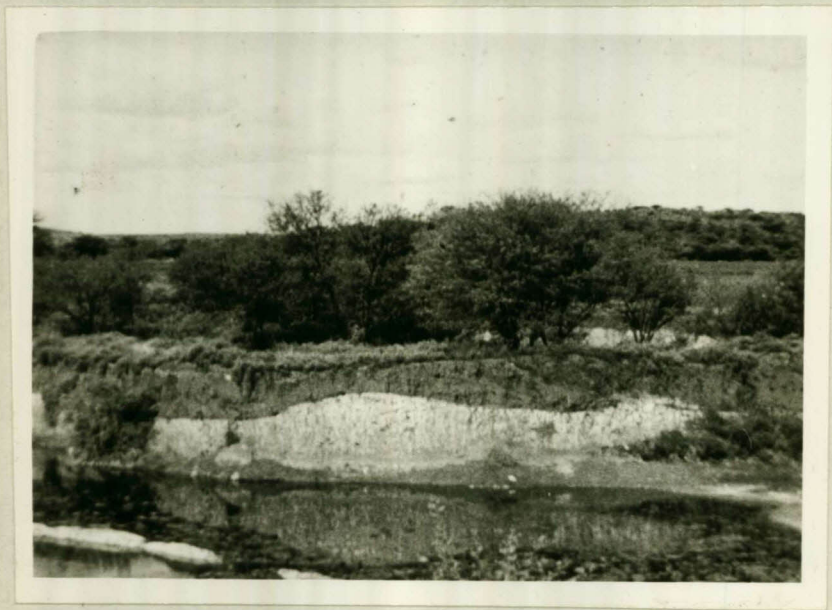


PLATE 7 - Wavy limestone buried under a Hutton soil mantle.

stone. Certain plants are able to send their roots through these fissures, e. g. *Tarhonanthus* spp., probably to tap a deeper lying water-table (Van der Merwe, 1962). The thickness of the boulder limestone varies from a few centimeters to approximately 60 cm.

Underlying the boulder limestone is a softer porous limestone consisting of a matrix of powder lime with hard and soft lime nodules. This calcareous layer can reach a thickness of probably 10 m or more, gradually passing into the underlying disintegrated rock (Van der Merwe, 1962). The limestone deposits invariably contain impurities, e. g. quartz sand, clay minerals, sesquioxides, etc. Sometimes stones of considerable size are encrusted in the lime deposits.

Generally the boulder limestone has a surface layer of some millimeter thickness. It is extremely hard compared with the interior boulder lime and according to Du Toit (1966) this crust may be silicified. Van der Merwe (1962) also thought it to be composed of calcium silicate. On analysis, however, he found that its chemical composition was almost identical to that of the interior of the boulders. He was further of the opinion that this surface crust had been formed by precipitation from calcium bicarbonate solution upon evaporation. A chemical analysis of crust and interior of a limestone boulder is given in Table 2.7.

TABLE 2.7 - Chemical analysis (%) of crust and interior of limestone boulder (Van der Merwe, 1962)

	SiO ₂	Fe ₂ O ₃	Al ₂ O ₃	CaO	MgO
Crust	6,60	0,40	2,08	47,04	Trace
Interior	6,80	0,70	2,10	47,04	Trace

The limestone is often buried under a soil mantle (mainly superficial sand deposits) of varying thickness and forms a continuous, wavy substratum (vide Plate 7). Calcareous deposits in depressions, which are intermittently submerged, are composed of granular material and soft powdery lime. Such deposits are quite pervious to water.

The origin of these limestones is of special interest. According to Van der Merwe (1962) they were formed differently from the calcium carbonate horizons generally found in soils of semi-arid regions. In the latter case calcium carbonate is leached from the surface and deposited in the B horizon. In the area under discussion, soil materials associated with the boulder lime deposits are invariably of a siliceous nature, extremely poor in weatherable minerals and can therefore not contribute to the formation of underlying lime deposits. The parent materials of fine-textured soils, on the other hand, contain calcium-bearing minerals, which upon weathering, contribute to calcium carbonate soil horizons.

Wybergh (1920) concluded that the limestones in this area derived largely from lime-bearing igneous rocks, viz. dolerite. Other calcium-bearing rocks are dolomite, Ventersdorp lava and Karroo sediments. Rogers, Wagner and Du Toit according to Van der Merwe (1962) postulated that limestone horizons formed by evaporation of water, charged with dissolved calcium carbonate, rising to the surface by capillary action. This limestone layer is deposited in the superficial sand layer from below.

On the banks of the Orange, Vaal and Riet Rivers geological formations are overlain by terraces of river gravels. These gravels are often cemented by "lime intergrowth from below", producing calcareous conglomerates (Van der Merwe, 1962). Calcareous conglomerates of this nature were encountered during the survey at various localities along the above-mentioned rivers, e. g. at Brakfontein, Kalkkrans, Higgs Hope, Koedoesberg etc. In these conglomerates, solution pipes are a common phenomenon. The surface lime crusts in these hollows are extremely hard, similar to the crusts of boulder limestone.

An important deposit, from a pedological viewpoint, is a Tertiary to Recent sand mantle of varying thickness, covering large areas of limestone and other geological strata. In view of its pedological significance a full and detailed discussion on these superficial aeolian materials is presented in Chapter 5.

2.3.2 Economic geology

Although this dissertation is directed towards pedological objectives, with the pedological significance of the geological formations of prime concern, a short note on the economic geology is nevertheless of interest. Large-scale mining operations are restricted to diamond and asbestos mining. Except for a profitable salt recovery industry, the greater part of the area has few exploitable mineral deposits.

Diamonds are mined at Kimberley and Koffiefontein, where rich diamond-bearing kimberlite pipes and fissures are exploited. Diamondiferous gravels were once extensively mined in the world-famous diggings along the Orange, Vaal and Riet Rivers. The only interesting feature of these gravels at present is the occurrence, in them, of large numbers of stone-age implements.

Some of the numerous pans are true salt pans and salt works are found on them e.g. Salt Lake, Wanda, Sodium, etc. These salt pans produce high-quality domestic industrial and agricultural salt. They are restricted to the Ecca and Dwyka formations.

Most of the other mineral deposits are confined to the south-western fringe of the area, especially in the Asbestos Mountain Range. Asbestos and tiger's eye of jewellery quality are mined in this area. Despite the widespread occurrence of limestone, none is exploited for industrial or agricultural purposes. Limestone and dolerite are however used for building purposes and as road metal.

2.4 PHYSIOGRAPHIC FEATURES

2.4.1 Surface drainage

The area is drained by the Orange and Vaal Rivers and several of their major tributaries, e.g. the Brak and Ongers Rivers, and the Riet and Modder Rivers respectively. On examining the topography of the area a striking feature of the drainage pattern is that the general direction of the drainage is in a north-westerly direction (vide Figure 1.2). Only the Vaal River flows from north east to south west. The Orange at its confluence with the Vaal sharply alters its

course to coincide with the course of the Vaal. In this south-westerly tract between Douglas and Prieska the Brak, after its confluence with the Ongers, flows into the Orange.

The sharp deflection of the Orange at Douglas is attributed to the Ghaap Plateau and the Asbestos Mountains which form a natural barrier to its flow in a north-westerly direction. Only at Prieska the river could cut its way through the hard banded ironstones of the Asbestos Mountains.

The rivers, with their relatively low gradients, are incised mainly into the soft Beaufort, Ecca and Dwyka sediments of the Karroo System, forming broad valleys and alluvial floodplains. The Karroo sediments are extensively intersected by hard dolerite dykes and sills. Ventersdorp lava outcrops and ironstones of the Asbestos Mountains are other hard rocks which, on account of their resistance to erosion, form comparatively deep and narrow gorges where cut by the rivers. Such deep and narrow valleys flanked by hard rocks in general provide the best dam sites.

The Kalkfontein Dam in the Riet River, the Smart Syndicate Dam on the Ongers, and numerous existing weirs are built in such situations, viz. in river constrictions formed either by dolerite dykes or lava outcrops. The proposed Torquay and P. K. le Roux Dam sites are of a similar nature, the former on lava and the latter on dolerite. The depth of the Orange River below the land surface in places is one of the topographic features of the area. This characteristic is most marked in sections where it flows through predominantly mountainous and hilly country, e. g. between Hopetown and Torquay and in the section from the Vaal confluence to beyond Prieska.

In addition to these principal rivers there are minor watercourses, some of which drain into natural basins or pans. This, together with the generally low relief and low rainfall, is responsible for the low drainage density of the area.

In order to provide a general background for the influence of the whole drainage pattern on the transport and distribution of erosion products of the upper reaches of these rivers, it is necessary to examine their drainage patterns in the upper catchment areas.

Compared with the large rivers of Central and North Africa, the Orange is rather small. It has the distinction, however, that it is the only river to rise on one edge of the African Plateau and to flow to the opposite edge where it enters the Atlantic Ocean at Alexander Bay. Its source is the Drakensberg Range at an altitude in the region of 3 330 m. With its tributaries, the Orange drains the plateau west of the watershed. It flows for the first part of its course through hard basaltic rock which is the only bedrock of the Maluti Mountains. Then at a lower level it cuts through the more easily-eroded sandstones of the Stormberg Series and thereafter successively through shales, mudstones and sandstones of the Beaufort, Ecca and Dwyka Series of the Karroo System. Abundant dolerite intrusions are encountered along its course.

About 85 km below Aliwal North the Orange receives its largest headwater affluent, the Caledon River, which drains the Cave Sandstone country in Western Lesotho and the Eastern Orange Free State. A second major tributary is the Kraai River which rises in the highlands of North-Eastern Cape near Barkly-East and joins the Orange near Aliwal North. They are perennial streams (Wellington, 1955) and contribute largely to the winter flow of the Orange from melting snows on the mountains of Lesotho and the North-Eastern Cape. During summer these tributaries have erratic flows and deliver large quantities of suspended material, derived from eroded soils and rocks of their catchment areas, to the Orange.

Duration of flow and amount of discharge are determined by the intensity and duration of storms in the catchment area. The softer formations, combined with the sparse vegetal cover, consisting mainly of grassveld, changing gradually to karroid vegetation, are responsible for the relatively high sediment load of the floodwaters. Sampling over long periods proved that the average sediment load of the Orange River amounts to 0,8% (mass/volume) (Jordaan, 1962-63).

It may be assumed that the sediment load of the river water during floods immediately after prolonged droughts will reach higher proportions. The method of sampling during floods is also questioned because it is a fact that the coarse sediment and gravel are dragged along in the centre and bottom of the current where flow velocity and turbulence are at their maximum. Further, as a result of a deterioration of veld conditions on farms in the catchment area, the severity

of erosion has increased over the past number of years. It is generally accepted by pasture scientists that the vegetative cover in these areas has deteriorated at an increased rate with accompanying increase in run-off and erosion. In contrast to the Upper Orange and its headwater tributaries, the Vaal, Riet, Modder, Brak and Ongers Rivers and all other small tributaries are non-perennial. They lack the sustained flow of the Upper Orange and those tributaries from Lesotho, Eastern Free State and North-East Free State and North-Eastern Cape.

At Mazelsfontein, some 16 km downstream from the village of Douglas, the Orange receives its largest tributary, the Vaal, which has actually a larger headwater system than the Upper Orange itself. The Vaal River rises in the Eastern Transvaal, and together with its tributary streams, drains the major portion of the Transvaal Highveld, the South and South-Eastern Transvaal and the Orange Free State. It meanders "in its sandchoked valley through various geological formations of the Interior Plateau" (Wellington, 1955).

Before its confluence with the Orange, the Vaal receives the water of the Riet River, which with its almost equally large tributary, the Modder, forms the largest single tributary of the Lower Vaal. The Hartz River which also flows into the Vaal near Delpoortshoop is important for the discussion of soil parent materials. Its catchment is in a region west of the Vaal in an area of extensive superficial sands. Other tributaries are of lesser importance with respect to parent materials of the soils later discussed.

With regard to sediment load it is significant that the Vaal River has a lower gradient than the Orange. This is illustrated by an average gradient of 0,48 m per km for the whole length of the Vaal compared with 0,65 m per km for the section of the Orange between Aliwal North and their confluence at Douglas (Wellington, 1955). It is evident therefore that the Vaal with its lower gradient has a lower potential sediment carrying capacity per volume than the Orange. This fact may throw some light on the origin of parent materials of certain soils investigated.

2.4.2 Landforms and pedimentation

The area surveyed forms part of the Interior Plateau of South Africa with an elevation ranging from 900 m to 1600 m above sea-level. The landscape is a result of a long and continuing period of denudation and dissection (King, 1963) under arid and semi-arid conditions giving rise to a generally subdued pediplain. The topography varies from nearly level to rolling and even mountainous. Numerous depressions or pans are generally associated with areas of level topography.

An examination of the generalized morphology shows that the area reveals seven major physiographic units. These units were identified as a basis for the discussion of the soils. They are:

- 1 Mountains and hills
- 2 Undulating plains with minor knolls and ridges
- 3 Sand plains
- 4 River floodplains
- 5 Clay plains
- 6 Calcareous plateaux
- 7 Pans.

Figure 2.3 is a schematic cross-section illustrating physiographic units and associated soil types.

2.4.2.1 Mountains and hills

This physiographic unit is composed mainly of the hard rocks previously mentioned. The only mountain range, in the accepted sense of the term, is the Asbestos Mountain Range extending from Griekwastad to beyond Prieska in a north-south direction. This range forms a prominent rocky boundary to the south-eastern sector of the survey area. The ironstones weather to steep slopes and deep valleys with practically no soil formation. The little soil that forms is shallow and rocky.

Apart from this mountain range, striking hills are formed by dolerite outcrops. These are usually detached steep-sloped hills of considerable dimensions, but dolerite dykes may often form a collection of hillocks and ridges. Dolerite sills tend to occur as residuals carrying sedimentary rocks or as thick sills



PLATE 8 - Dolerite mesa standing out above sediment plain.

KEY TO ASSOCIATIONS AND OTHER UNITS

L	LITHOSOLS
BO	BRAK - ONGERS ALLUVIUM
R	ROCK
LO	LUCKHOFF-OMDRAAI SOIL ASSOCIATIONS
FK	FERRY - KINROSS ASSOCIATION
AO	ORANGE - VAAL ALLUVIUM
BT	BLESKOP TORQUAY ASSOCIATION
MZ	MANGANO - ZWARTFONTEIN ASSOCIATION

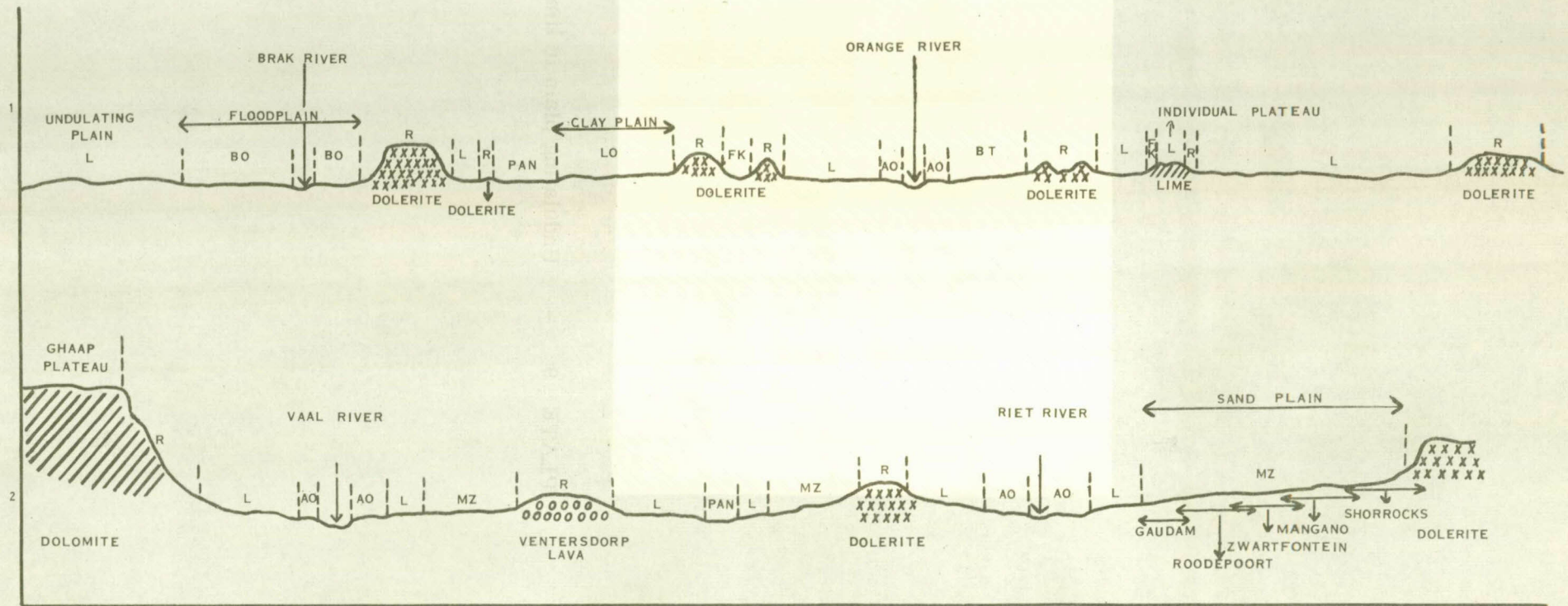


FIGURE 2.3 - SCHEMATIC CROSS-SECTION FROM (1) NORTH TO SOUTH AND (2) FROM WEST TO EAST THROUGH THE AREA SHOWING LANDSCAPE POSITIONS OF SOIL ASSOCIATIONS AND OTHER MAPPING UNITS



PLATE 9 - Undulating plain in limestone area.

standing out above the sediment plains (vide Plate 8). Typical mesas, buttes and cuestas are of widespread occurrence. The highest hills of dolerite origin are encountered in the areas around Luckhoff, Petrusville, Potfontein, Koedoesberg and Leeuberg. Ventersdorp lava outcrops are a common feature of the area south of Kimberley towards Prieska. Nowhere does the Ventersdorp lava form prominent hills except where deeply incised by the Orange River. Elsewhere this rock, together with small outcrops of pre-Karoo granite, forms smooth-sided dome-shaped hills that frequently permit a glimpse of the surface at the time of the pre-Permocarboniferous glaciation. Recent erosion has probably effected very little change on such glacier eroded floor whenever exposed.

2.4.2.2 Undulating plains with minor knolls and ridges

This type of landform usually occurs adjacent to and sloping away from the mountains and hills. The slopes are low and in many places can be seen to grade imperceptibly into the sand- and clay plains. Erosion and pedimentation have caused a lowering of the general relief with the result that resistant rocks are exposed forming minor knolls and ridges.

Considerable areas of this landform are composed of hard, surface limestone deposits (vide Plate 9). In various places the limestone deposits are overlain by aeolian materials to form sand plains, described in Section 2.4.2.3. Other rock outcrops on these surfaces include shales, dolerite and lava. In areas of Dwyka tillite and near the Asbestos Mountains and dolerite hills, loose stones and gravels of varying size occur in abundance on the surface of level and sloping areas. These stones often form a continuous pavement typical of desert areas.

The principal soil on this type of landform is shallow sandy materials. The topography is gently rolling and sometimes fairly dissected near the major streams. Run-off occurs as sheet flow, but its rate is much lower than that off the rocky mountains and hills, and heavier rainfall is necessary to initiate flow.

2.4.2.3 Sand plains

The sand plains as stated earlier are associated with the undulating plains. The sandy material of these plains has a general west-east drift and is undoubtedly of aeolian origin. In some areas these sand plains are a very conspicuous feature, forming continuous sheets of thousands of hectares in area (vide Plate 2). Smaller isolated sheets occur on gentle slopes against the western aspect of natural impediments such as dolerite hills and ridges. The depth of the sand mantle varies from a few centimeters to scores of meters. A striking characteristic of the sand plains is the reddish colour of the sandy deposits. The sand plains are generally well stabilized by vegetation, but they are susceptible to wind erosion when denuded either by ploughing or overgrazing. Where wind erosion is severe, e. g. on the farm Tipperary (Koffiefontein), barchan dunes are formed.

In all, some 441 000 ha of the area are occupied by sand plains of which more than 75% is situated to the north of the Orange River. The largest continuous area occurs in the vicinity of the Vaal-Riet confluence, extending from the Vaal towards the east along both sides of the Riet River. Apart from a few comparatively large continuous sheets in the Luckhoff-Koffiefontein area and those near Hope-town, all the other occurrences are relatively isolated, ranging in size to some hundreds of hectares. Significant deposits of aeolian sand are found in the valleys of the Asbestos Mountains in the form of bahadas.

Distinctly separate occurrences of this landform are deposits of yellowish sand along the north to north-eastern banks of the Orange River. These sand deposits are somewhat different from the reddish sands both in situation and topography. Near the river distinct dune-like features are characteristic, e. g. at the Orange-Vaal confluence where typical merging barchan dunes are much in evidence. Further away from the river this aeolian sand is fairly well stabilized by grass vegetation, but still provides an undulating topography.

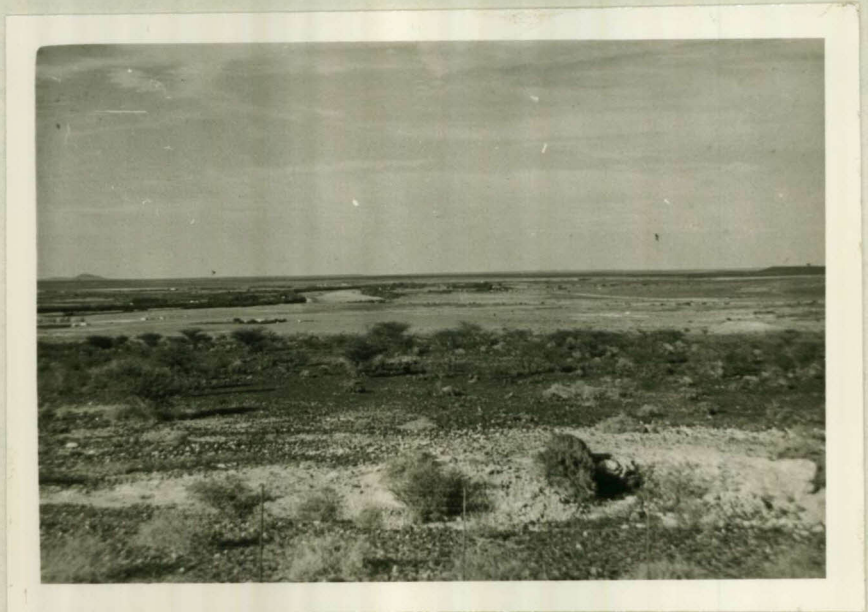


PLATE 10 - Orange River floodplain with
desert pavement in foreground.

2.4.2.4 River floodplains

Wherever river valleys are situated in an area of flat topography extensive floodplains occur (vide Plate 10). Alluviation on the broad valley floors build large floodplains, especially along the Brak, Ongers and Riet Rivers. Floodplains along the Orange are somewhat isolated, but may nevertheless occupy areas of up to 2 000 ha. The alluvium forming these floodplains is of variable textural and mineralogical composition, ranging from sand immediately along the river banks to clay further away. Along the section of the Vaal River between Schmidtsdrif and Douglas, there are a few relatively isolated floodplains, also of variable texture.

The Brak and Ongers floodplains are extremely level and extend up to 3 km from the river bed, where they merge gradually with the adjacent clay plains. These floodplains give the impression of large vleis and hence the name Beervlei (Brak River). During floods large tracts of this vlei are submerged. These floodplains occupy 41 000 ha.

The drainage pattern has been changed to some extent by relatively recent streambed erosion in places, e. g. along the Riet, Brak and Ongers Rivers. On the banks of these rivers rill erosion assumes menacing proportions. The flood caused by the Smartt Syndicate Dam disaster in 1960 extensively eroded parts of the floodplains of the Ongers and lower Brak Rivers.

On the very flat floodplains of the Beervlei an interesting method of irrigation had been practised, viz. the "sowing dam" system. Irrigation beds were surrounded by earth walls into which periodic floodwaters from weirs in the river bed were conveyed. These sowing dams were allowed to fill progressively as far as the available water allowed. By this means a single irrigation of approximately 500 to 600 mm sufficed for a wheat crop. On account of progressive salinization this method of cropping was abandoned some years ago. Today the weirs and channels are still used but for irrigation of brack-resistant natural vegetation.

Of much interest in the valleys of the Vaal, Orange and Riet Rivers, is the occurrence of river terraces. They consist of river gravels deposited in step-like succession from the oldest and highest down to the youngest, nearest to the present river beds. A considerable amount of attention was given to these terraces along



PLATE 11 - Clay plain. Willemsdal and Katspruit soils.

the Vaal River banks by Söhngé & Visser, 1937; Van Riet Lowe, 1937 and Cooke, 1946. These authors interpreted the succession of terraces as indications of pluvial and interpluvial periods. This interpretation did not receive universal acceptance. The author is of the opinion that the terraces along the Vaal River within the survey area are merely remnants of a succession of landsurfaces left behind during the river's incision into the bedrock.

Between Hopetown and the Orange-Vaal confluence Du Toit (1966) found a series of terraces along the Orange River valley where it cut through the Ventersdorp lava. These terraces are from 50 to 120 m above the stream level and contain pebbles of amygdaloidal basalt from Lesotho. The author also examined these terraces and found similar terraces upstream from Hopetown. The Orange River valley in this sector is not as narrow as in the Ventersdorp lava below Hopetown. The terraces here are also not as high as those in the latter case, but they consist of stratified clay, sand and gravelly materials. The gravels contain pebbles of basalt. Many of these terraces are buried under younger deposits of aeolian materials. On the banks of the Riet River similar terrace gravels are found.

2.4.2.5 Clay plains

As already mentioned, pediplanation is a dominant factor in the landscape evolution of this region. The clay plains and other plains were formed by the combined processes of pediplanation, pedimentation and weathering of the readily weatherable Karroo shales, mudstones and tillites. The result is the formation of complex pediment surfaces running parallel to the main channels, with secondary pediments cut by lateral planation along secondary streams traversing the major pediments.

The mature stage of pediplanation, as defined by King (1963), can be observed in the greater part of those areas where clay plains predominate. Remnants of an older surface, in the form of resistant dolerite hills and ridges, are widespread on these plains. These hills are conspicuous, rising from the surrounding plains and often producing typical mesas and buttes.

In areas of very low relief, the surface of the clay plains is almost level (vide Plate 11). Apart from the major streams very few drainage channels dissect the flat surface and much of the surface drainage is effected by sheet flow, little of

which drains away to adjacent landform units. Because these flats gradually merge with either slightly lower lying floodplains or pans, such areas collect most of their run-off. In view of the clayey nature of the soils of these plains and their low infiltration rate, rain water often collects in broad but very shallow depressions. The clay plains also collect much run-off from higher lying ground and together with the pans serve as natural evaporation basins. In view of the low rainfall and low infiltration rate of the clayey soils, one would expect that very little water should be able to percolate through the soil. However, because of the almost level topography, and the consequent accumulation of water in such low-lying areas, considerable penetration of water does take place. The result is that soluble salts accumulate in the profile of these soils. Salt crusts form commonly upon evaporation and drying out of the profile.

Under these conditions it is not surprising that the micro-relief phenomenon known as gilgai may develop. This is a result of extremes in moisture content of soils that contain swelling clays. Associated with this phenomenon is the appearance of dehydration crack networks on the surface during dry periods. This property further aggravates the water deficit in the soils by providing a further means of desiccating the subsoil. On the other hand these crack systems also provide a means of conveying water into the subsoil, aiding in the weathering cycle.

In the south-western part of the survey area, where the Dwyka tillites predominate, many resistant stones lie on the surface. The soil underneath also contains stones, but it appears that their concentration on the surface is somewhat higher than that in the soil. It may be reasoned that a certain amount of upward movement carried some of these stones to the surface by processes of swelling and shrinking (Buol, 1965).

2.4.2.6 Calcareous plateaux

In correspondence with the general aridity of the region, calcareous deposits are a common feature. In places, extensive sheets of lime occur, either as surface deposits or overlain by soil or aeolian sand (vide Section 2.3). Lime-bearing rocks are of widespread occurrence. At this stage it is premature to

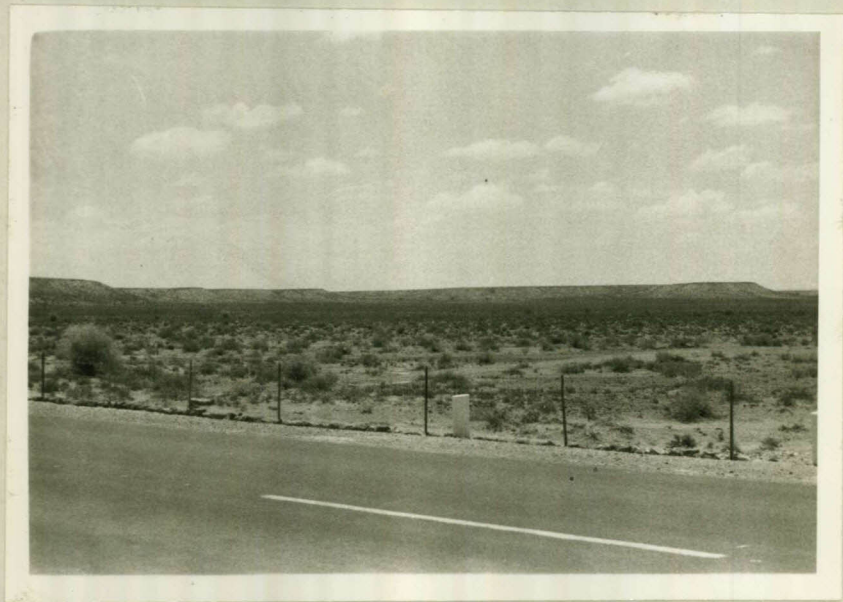


PLATE 12 - Lime plateau forming terrace
above clay plain.

speculate as to the age of the surface limestones. From topographical evidence it may, however, be deduced that extensive lime deposits formed part of an older landscape and have, in part, been subjected to denudation. At present, remnants of earlier large sheets of lime are sometimes found as minor and sometimes isolated plateaux, especially in the area of riverine erosion (vide Plate 12).

Although these calcareous plateaux may be found practically along the whole stretch of the Orange River from the vicinity of Petrusville to Prieska, they are particularly abundant in the area around Orania, north and south of the river. A most striking example is one such plateau on the right bank of the Orange River opposite Orania (vide Plate 13). This plateau extends for approximately 16 km in an east-westerly direction parallel to the river. When viewed from a point to the east, this plateau appears to have a horizontal flat top with steep whitish scarps, both east and south. The southern scarp parallel to the river is quite irregular as a result of the undercutting of lateral streams into the face of the slope. The formation of this and other plateau slopes may be regarded as typical of the hillslope cycle and pedimentation processes as recognized by King (1963) and Ruhe (1960). The elements of these plateaux are illustrated in Figure 2.4a. The oldest surface probably co-incides with the general surface of the undulating plains (vide Section 2.4.2.2 and Figure 2.4b).

Although geologically unrelated to the afore-mentioned secondary lime plateaux, the Ghaap Plateau, a pre-Karoo formation of dolomite, is in appearance quite similar. Only the southern most part of the Ghaap Plateau falls in the survey area. This part, however, is representative of the large area constituted by the Ghaap Plateau, which is also flat-topped. It is terminated abruptly by an escarpment on the eastern and southern edges. The flat summit rises in this area to a maximum of approximately 250 m above the surrounding plain. The eastern and southern scarps are the result of lateral pedimentation by minor tributaries.

2.4.2.7 Pans

The last landform unit recognized in this area is the pans that are of widespread distribution. Pans are usually associated with level topography such as represented by the clay plains. Most of the pans are found on the boundary of the clay plains as natural depressions, some seemingly without any obstructing barriers.

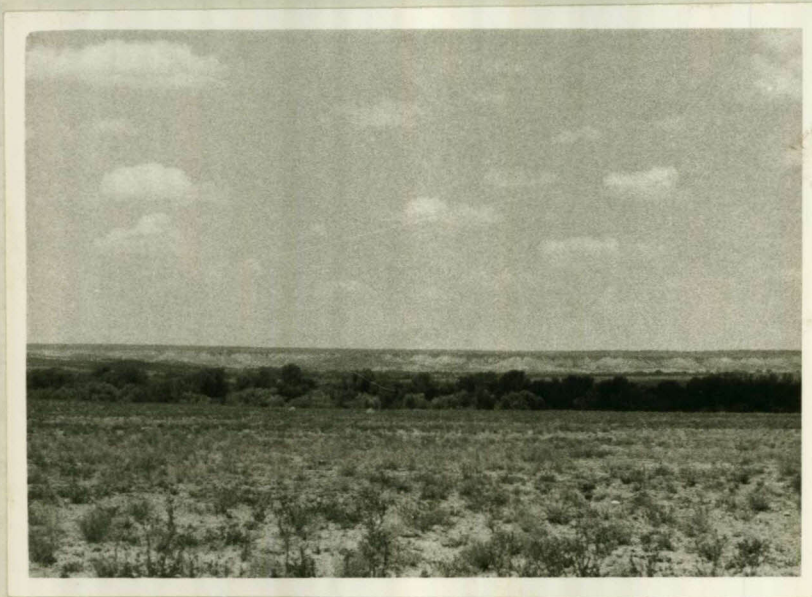


PLATE 13 - Lime plateau with Orange River in foreground.

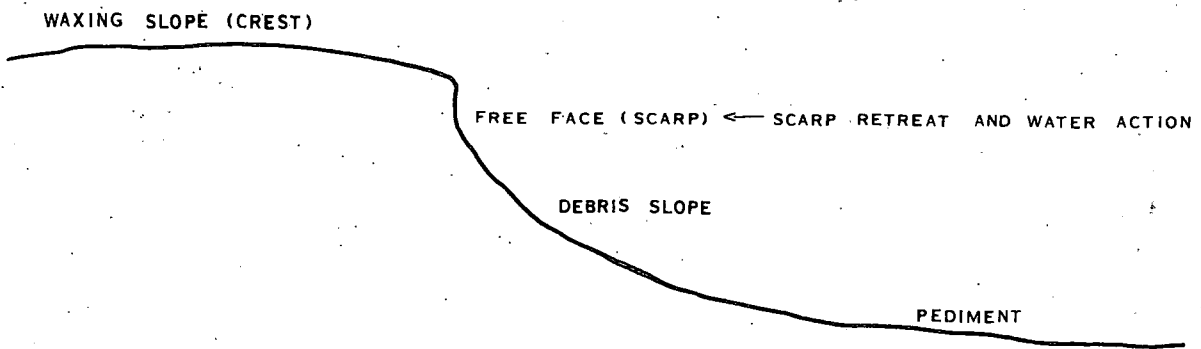
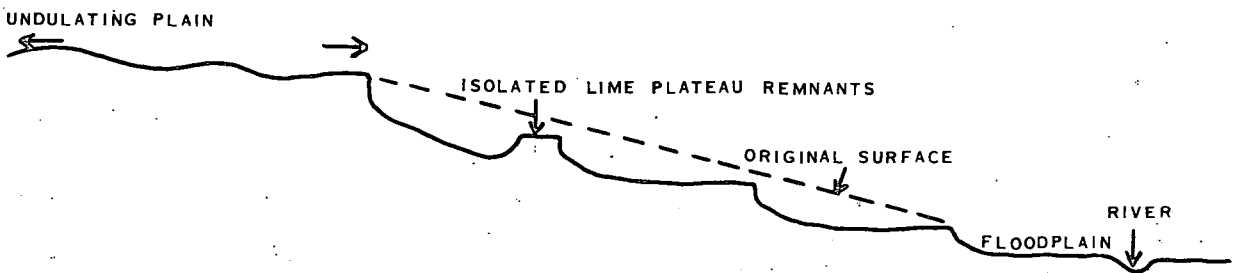


FIGURE 2.4(a) HILLSLOPE PROFILE OF LIME PLATEAU SHOWING THE WELL-DEFINED FOUR SLOPE ELEMENTS BY SCARP RETREAT AND WATER ACTION



(b) SERIES OF LIME PLATEAUX COINCIDING WITH THE UNDULATING PLAINS AND FLOODPLAINS



PLATE 14 - Salt Lake.

Others, however, are clearly formed in drainageways obstructed by dolerite dykes. They vary in size from a few square meters to more than 1 000 ha.

The floors of some pans may be 5 to 10 m below the surrounding land-surface; others are merely slight depressions. Very often the perimeter of a pan is built up of sand banks, which may cover either dolerite or limestone obstructions. In other cases only the eastern leeward side may show smallish lunettes of windblown sand. This sand, was probably blown out of the pans during dry periods and varies in colour from reddish yellow (7.5YR 7/6) to very pale brown (10YR 7/4). The sands contain calcium carbonate and some grains are covered with thin lime films.

The floors of the pans are usually very level but larger pans may have slight depressions. Soil material of the floors has a fine texture and contains swelling clay minerals. Underlying this very impermeable clay floor are easily-weathered argillaceous Karroo sediments. Because of the impermeable nature of the floor materials, water collecting in these pans evaporates almost entirely, with little contribution to the ground water.

Pans may be divided into salt pans and fresh water pans. The source of the salts (largely sodium chloride) is undoubtedly the underlying and surrounding shale bedrock; surface run-off from surrounding saline soils draining into these pans also contributes to the salt content. Fresh water pans cannot be distinguished from salt pans by the geological formations on which they occur.

It was noted that the average size of pans on the Dwyka Series is considerably less than that of pans on the Ecca Series (vide Figure 2.2 and Appendix 2). Salt Lake between Douglas and Hopetown is the largest pan on the Dwyka (vide Plate 14). Kaalpan, Brinkspan and Bloubospan on Ecca Series are all larger than Salt Lake.

Many theories on the evolution of pans have been advanced and this topic is widely discussed in literature. King (1963) stated that the drainage of the area is dominated by the Orange River and opined that the Orange changed its course over the aeons of time, with pans having their origin in the old stream beds. Geyser (1950) came to the same conclusion and postulated that the Orange once followed a course from Hopetown through Strydenburg, Beervlei, Keikamspoor, Olifantsvlei and further along the present course of the Hartbees River. He

further reasoned that the Vaal at that time followed a course from Riverton through Kimberley to join the Orange at Hopetown. He coupled the formation of pan systems to the alteration of the Orange and Vaal River courses.

Piaget (1963) gave an extensive review of the theories relating to pan formation. His own observations were confined to the south-western Orange Free State. Harmse (1963) made a survey and study of pans in the North-Western Orange Free State. He related the size of pans to age, viz. large pans are older than smaller pans.

In view of the extensive literature and various theories on pan formation, it serves no purpose to discuss this phenomenon at length. Regarding the postulation that the Orange River changed course, however, the author can find no support for such a theory. From the generally low relief of the said area and the present relatively deep channel of the Orange, one would expect evidence of riverine deposits and channel remains somewhere on this postulated course. During the soil survey, this area was thoroughly investigated and hundreds of profile pits and augering observations proved the complete absence of riverine deposits. No topographical, sedimentological or any other evidence could be related to a previous watercourse of the magnitude of the Orange and Vaal River.

An explanation for the formation of pans in this area is afforded by examining numerous small and large pans. Pans are generally associated with dolerite outcrops or rarely with Ventersdorp lava. These hard rocks form barriers across waterways and under these low rainfall conditions, stream erosion is unable to cut channels through. Over a long time of intermittent flooding and drying out, loose material is transported out of initial small hollows in the softer shale and mudstone. The initial formation cannot be ascertained, but animals probably played an important role in the initiation of such hollows: animals drinking at such water holes probably carried out small quantities of mud on their hooves etc. Upon drying of these hollows, wind removed loosened material and in this manner pan development proceeded bit by bit over long periods.

CHAPTER 3

THE SOILS

Soils, their origin, classification and distribution with the view to irrigation development, form the motivation and basis for this survey. In the preceding chapter, attention was focussed upon the physical environment, excluding the soils. Discussion, in this chapter, is confined to the soils, with special reference to their properties, classification and distribution. Mapping units for the different soil types are also described. The genesis of the fine-textured soils and alluvia is discussed in Chapter 4 and that of the sandy soils in Chapter 5.

At the commencement of this survey, a national soil classification system for South Africa had not been accepted. The only comparable soil survey was still in progress in the Tugela Basin, of which methods and principles, were to some extent applied to form a basis for the Central Orange River Basin survey.

3.1 MAPPING TECHNIQUE AND SOIL SURVEY PROCEDURE

In the study of the soils of a large area, it is necessary to commence with a study of the available information about the soil-forming factors. The necessity of such a study is to decide whether there is need to carry out detailed soil surveys of small but representative so-called key areas to identify the main soil types. A study of the environmental factors of the Central Orange River Basin, combined with a broad reconnaissance trip through the whole area, revealed that it was not necessary to use key areas as a prerequisite to the systematic reconnaissance soil survey. Soil types and their distribution in the landscape were relatively easy to recognize in the field. The differences between soil types were very marked and it was reasoned that with a minimum of pits dug for survey purposes, an adequately accurate reconnaissance survey could commence immediately.

As an initial step in the study of the soils of the area, 200 pits were dug in representative soils to identify and define the soil types. The methods used to describe

profiles were standard methods of the Soil and Irrigation Research Institute, Department of Agricultural Technical Services (1964, personal communication), which are based on those described in the Soil Survey Manual (1961). Soil colours were determined by using the Munsell Soil Color Charts (1954). pH and electrical resistance values of all samples from soil pits were determined in a field laboratory. Samples of representative profiles of each soil type were taken for further laboratory investigation.

After identification of the soils at the series level, mapping units were established to allow mapping to proceed as quickly as possible. Soil associations were chosen as mapping units. The mapping procedure consisted briefly of the following: cross-country traverses were made and soil areas were firstly recognized by means of geomorphological and air-photo interpretation. Soil boundaries were established by inspection of auger holes along these traverses. A Thompson auger which allowed augering to a depth of 1,2 m was used. Where necessary additional soils pits, approximately 500 in all, were dug to verify auger observations. Other inspection sites, e. g. dongas, road cuttings and post holes were also examined. Spacing of auger holes was determined by soil type. Experience gained during the survey indicated that the fine-textured soils were more uniform with regard to depth than the coarse-textured soils. The latter soils therefore required a closer spacing for the establishment of soil boundaries between depth phases.

Mapping was done directly, either on air-photos (1:36 000), where available, or on the 1:50 000 topo-cadastral sheets. The soil boundaries on air-photos were transferred visually and free-hand on to 1:50 000 uncontrolled mosaics. These were further used to reproduce an air-photo map of 1:100 000. This covered the Koffiefontein-Luckhoff area. For the remainder of the area air-photos were not available and only 1:50 000 topo-cadastral sheets were used for field mapping. It should be pointed out that, for a large area between Douglas and Kimberley, the only maps available were compiled during the first World War (1914-1918). Inaccuracies on these maps had to be corrected during the survey. Soil boundaries on both the 1:50 000 field sheets and 1:100 000 air-photo map were transferred by means of a pantograph on to a 1:250 000 topo-cadastral map. This map was photographically reduced to 1:320 000 and is the final soil map for which a legend, denoting soil mapping units, was constructed (vide Appendix 2).

3.2 CLASSIFICATION AND NOMENCLATURE

Until recently, there was no classification system available for systematic soil surveys in South Africa, and the only soil surveys carried out had been for irrigation schemes. All systematic soil surveys prior to the Tugela Basin survey (Van der Eyk, Macvicar & De Villiers, 1969), was made by one-man teams, e. g. Van der Merwe (1962) and Beater (1957, 1959, 1962). A review of the development of soil survey work in South Africa is contained in a report by Macvicar, Loxton & Van der Eyk (1965).

Recently, systematic soil surveys in South Africa made progress in more than one respect. The most notable achievement was the recent publication of the report on the soils of the Tugela Basin (Van der Eyk, et al 1969) in which a new approach to soil classification in South Africa was proposed. This systematic classification of a large number of soils provided the basis for a national soil classification system. With the contribution and co-operation of pedologists throughout the country, South African soil scientists have at their disposal a classification system that can be improved upon in time and which might be of great value to South African agriculture and other users of soil.

During the survey of the Central Orange River Basin, the soils were tentatively identified and classified at the series level. Local names were given to the soil series identified. At this stage there still was a lack of finality with regard to soil classification. Immediately upon the publication of the Soils of the Tugela Basin (Van der Eyk, et al 1969) and the proposal of the national soil classification system, it was deemed necessary to adapt the results of this survey to that system. The criteria of this two-category system for classification of soil forms, based on diagnostic horizons, and of series (Soil and Irrigation Research Institute, June 1970 - personal communication) were used. In view of the procedures followed and the fact that the soils were defined on a series basis, adaptation was easily achieved. The soil series of this survey could be identified with soil series defined and described elsewhere in South Africa. Besides the fact that most of these soil series fitted conveniently into the respective categories of this system, five new series were identified. Furthermore, a redefinition of one soil form was necessitated by in-



PLATE 15 - HUTTON form-Shorrocks series.

formation gathered in this area. This survey was therefore instrumental in further developing a national soil classification system. It also proved that soil surveys for irrigation purposes could be carried out on a series basis, providing much information on which high intensity irrigation surveys can be based.

3.3 DESCRIPTION OF THE SOILS

Seventeen soil series of six soil forms, and various land classes and -complexes were identified. For mapping purposes certain soil series were grouped together in soil associations and others were sub-divided into depth phases. Because this survey was intended primarily for irrigation purposes, particular attention was given to soils regarded as suitable for irrigation development. For this reason, phase differentiation was only applied to certain soil series. These will be elucidated further under the discussion of the particular soils.

Discussions on the environmental and morphological characteristics of individual soil series and associations follow the sequence of the map legend. Full profile descriptions and analytical data are presented in Appendix 1. These are discussed for each soil under its heading.

3.3.1 Soils of the HUTTON FORM

Although less significant in areal distribution than some other soils and land classes, the soils of this form assume significance when considered with a view to irrigation. This soil form therefore takes primality over the other soils in these discussions.

Hutton soils are characterized by prominent red colours and weak horizon differentiation. Profiles consist of a reddish orthic A horizon of varying thickness, overlying a red B horizon, which is either apedal or has weakly developed blocky structure (vide Plate 15).

Differentiation into series is based upon clay content (0-6%, 6-15% and 15-35%), sand grade and exchangeable base status of the clay fraction. Series identified during the survey are summarized in Table 3.1.

Table 3.1 - Criteria for series differentiation of the Hutton form and relevant profile numbers

Series	Percentage clay in upper B horizon	Sand grade in upper B horizon	Profile Nos.
Roodepoort	0 - 6	fine	25, 34
Gaudam	0 - 6	medium	10, 46, 67
Mangano	6 - 15	fine	44, 47, 18, 29
Zwartfontein	6 - 15	medium	30, 135, 148, 157
Shorrocks	15 - 35	any sand	11, 14, 19

It is noteworthy that Hutton soils occurring in the survey area all fall in the classes with clay content of between 0 and 35%, clay %/S-value of less than 7 and sand grade fine or medium. Most soils have clay contents between 4% and 12%. Only small areas are composed of Shorrocks series and their clay content rarely exceeds 25%. The overall impression these soils present is their predominantly fine sandy nature and reddish colour.

In view of their similarity with regard to distribution, profile properties etc. the soils of the Hutton form are grouped together to facilitate discussion. Although the Shorrocks series differs to a certain extent from the other four soil series with regard to genesis and agricultural practice, it was deemed advantageous to discuss this series together with the other series of this form. Morphologically the B horizon of Shorrocks soils has a higher clay content and the colour is mostly redder than those of the Roodepoort, Gaudam, Mangano and Zwartfontein series. Soils of the Shorrocks series very often occupy minor areas of the landscape adjacent to the others. They are usually found in the vicinity of dolerite which causes the intense red colours by way of weathering of iron-bearing minerals.

As stated earlier, these soil series differ only in respect of clay content and sand grade. Profiles of all the different series are very similar in morphology, parent material, chemical and physical properties. Vertically the texture of the profile is very homogeneous and may continue so for great depths in certain areas.

In fact the depth of the profiles varies from a few centimeters to scores of meters as indicated by boreholes. Quite large expanses of uniformly textured soils, i. e. of a particular series or of an association of two closely related series, were mapped.

3.3.1.1 Site

The Hutton soils generally occupy positions in the sand plains (vide Figure 2.3). Their occurrence is characteristic in that the Roodepoort and Gaudam series are confined to the lower positions or slight slopes and the Mangano and Zwartfontein to the middle to upper slopes. Where the sand plains terminate against the western slopes of dolerite ridges and hills, the uppermost belt of Hutton soils is occupied by Shorrocks. Sometimes Shorrocks occupies slight prominences on dolerite, usually being shallow.

Hutton soils occupy some 441 000 ha, individual occurrences varying from small patches and belts of only a few hectares to the extensive sand plains south-west of Kimberley. The largest continuous area near Plooyburg is approximately 74 000 ha in size.

3.3.1.2 Parent material

The country rocks are quite unrelated to the parent material of these soils, except for the Shorrocks which is of mixed origin. Iron oxide coated quartz grains form the major constituent (up to 96%) of the soils, the clay content varying between 4% and 23%. Minor quantities of heavy minerals (approximately 1,3%) consist largely of opaque minerals. Aeolian transportation is undoubtedly responsible for the distribution of their sandy parent materials over large areas and, in some cases, long distances. Sand grains are well rounded and sorted. Admixture of these materials with locally derived minerals from Ventersdorp lava, dolerite and Karroo sediments has taken place during distribution.

The parent materials of the Shorrocks soils are also largely aeolian sand enriched with the weathered products of dolerite. Their higher clay content and more intense red colour, compared with the other Hutton soils, are attributed to weatherable minerals supplied by the dolerite and in very rare instances by lava.

In Chapter 5 an extensive discussion on the origin and distribution of these parent materials will be given.

3.3.1.3 Morphology

As stated earlier the morphology of these soils is dominated by striking reddish colours, weak horizon differentiation and virtual absence of structure. The orthic A horizon of the Roodepoort, Gaudam, Mangano and Zwartfontein soil series has colours varying from reddish to yellowish red, texture from sandy to loamy sand, sand grades from fine to medium and soft consistence, and is structureless usually single grained. The transition from A to B horizon is very diffuse, the B being essentially similar to the A horizon. With depth very slight changes in colour, texture and consistence are observable. Colour tends to become redder, varying from red to yellowish red and clay content increases slightly down the profile. The texture of the B horizon varies from a sand to a sandy loam with a soft to friable consistence. From a depth of approximately 2 m the colour of the deeper layers becomes yellowish red (5YR 5/6 to 5/8 and 4/6 to 4/8).

Morphologically Shorrocks soils differ somewhat from those previously described. The A horizon of the Shorrocks series is a dark red, structureless, soft to friable, loamy fine sand to fine sandy loam. The B horizon has uniform red colours, slightly hard consistence, is either apedal (structureless) or has weakly developed blocky structure, and fine sandy loam to fine sandy clay loam texture. Although the upper limit of clay content of the upper B horizon for this series is 35%, Shorrocks soils in the survey area seldom contain more than 25% clay.

In light of the sandy nature of both topsoil and subsoil, the Hutton soils are freely permeable to water. Concretions of lime and sesquioxide, stones and mottling are absent. In the Shorrocks series angular to rounded, fine doleritic gravel is sometimes scattered throughout the profile. Sesquioxides and calcium carbonate rarely form cemented layers or duripans of limited extent along drainage-ways of the sand plains.

The solum of Hutton soils is underlain, at various depths and with a clear to abrupt transition, by either calcrete or country rock (lava, dolerite or Karroo sediments). The most common substratum is calcrete, which may be regarded as a geological formation and not as a soil horizon.

3.3.1.4 Chemical properties

Roodepoort, Gaudam, Mangano and Zwartfontein soils are very homogeneous with respect to chemical properties. pH and electrical resistance values vary little, both vertically and laterally over large areas. Reaction of the topsoil is neutral (pH 6,5-7,0) tending to increase slightly with depth, whereas Shorrocks is neutral to moderately alkaline (pH 6,8-8,0). High electrical resistance values of all the Hutton soils indicate that they are relatively free from soluble salts, but are nevertheless base saturated. The total exchangeable cation contents of these soils vary according to their clay contents, CEC of the clay being approximately 1me/g. In all the soils Ca^{++} and Mg^{++} are the dominant exchangeable cations. Organic carbon content of the topsoils is less than 0,3% and decreases rapidly with depth. The general fertility status of Hutton soils is discussed in Chapter 6.

3.3.1.5 Mineralogical properties

The sand fraction consists almost exclusively of quartz grains coated with films of reddish iron oxide, the quartz content being approximately 96%. Less than 4% consists of heavy minerals, of which approximately half are iron-bearing. Weatherable minerals are practically non-existent, except the Shorrocks in which some are responsible for the higher percentage clay.

The silt fraction of the soils, often used for mineralogical characterization, is less than 2%. CEC values of up to 1me/1g clay indicate a preponderance of 2:1 clay minerals. X-ray diffraction analysis proved inconclusive as a means to identify specific clay minerals. Weak diffraction peaks point to weakly crystallized mixed layer 2:1 clay minerals and probably illite. The only well-defined peaks represent small quantities of quartz and traces of 1:1 minerals.

3.3.1.6 Drainage

Because of the sandy nature and relatively level situation of the Hutton soils, practically all rain water is absorbed. Infiltration and internal drainage are very rapid or rapid. In keeping with their coarse texture, these soils have low moisture retaining capacities, especially Roodepoort and Gaudam which have less than 6% clay and even less silt. Soils of these two series are somewhat droughty when of shallow depth. Soils deeper than 3 m have, however, considerable moisture storage capacities for deep-rooted plants, e.g. Acacia spp. Field observations showed that moisture is retained for a considerable time after penetrating rains, especially under a good grass cover. Only the topsoil dries out relatively quickly. After good late summer rains the deeper soils stay moist for several months during the following winter, when vegetative activity is at its minimum.

Under the prevailing climatic conditions it is most probable that rain water rarely if ever penetrates to soil layers or geological substrata in excess of 3 m, except in natural drainageways which receive water from higherlying rocky ground. An example of such a drainageway is found on the farm Valsfontein in the district of Douglas. Run-off water from the higher dolerite ridge collects in this slot and runs for some distance into the sand plain where it gradually disappears and probably penetrates to deeper layers.

3.3.1.7 Mapping

All the identified soils of the Hutton form were mapped as a soil association with Mangano and Zwartfontein as dominant series. Therefore it is designated on the map as Mangano-Zwartfontein soil association (map symbol MZ). Although Roodepoort and Gaudam also occur in association with the other two series, their areal extent is usually rather limited.

For the purposes of this survey, i. e. irrigation development, the Hutton soil were regarded as the most important. Considerable areas of shallow Hutton soils, unsuitable or less suitable for irrigation, occur in association with



PLATE 16 - CLOVELLY form-Torquay series.

deep phase soils. It was therefore considered necessary to distinguish between deep and shallow phases. This decision was made from a practical consideration and it proved possible to map depth phases on this reconnaissance scale. Arbitrary depth limits of 0,45 m and 1,2 m were established. Very shallow soils with a depth of less than 0,45 m were grouped with very shallow phases of other soil forms and stony land and designated as lithosols (map symbol L).

Soils with a depth between 0,45 m and 1,20 m were mapped as the shallow phase (map symbol MZs) and those deeper than 1,20 m, as the deep phase (map symbol MZd). Because of topographical unevenness of the surface and the wavy nature of the calcrete substratum, shallow phase soils as mapped are not always necessarily within strict depth limits. Over a short distance they may vary in depth from less than 0,45 m to over 1,20 m. Care was taken, however, to ensure that areas mapped as the deep phase exceeded a depth of 1,20 m. Experience gained during mapping proved that detailed mapping at the series level should be achieved without difficulty.

3.3.2 Soils of the CLOVELLY FORM

The soils of this form are similar to the soils of the Hutton form with respect to aeolian origin and texture. They are, however, markedly different in colour, genesis and chemical and mineralogical properties. They are also of a characteristic geographical and positional occurrence.

The profiles has a yellowish to yellowish red orthic A horizon overlying a yellow structureless B horizon (vide Plate 16). Horizon differentiation is very weak and the clay/S-value is less than 7. Soil series differentiation is based upon clay percentage and sand grade of the upper B horizon. In Table 3.2 the identified soil series in this form are tabulated.

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TABLE 3.2 - Criteria for series differentiation of the Clovelly form and relevant profile numbers

Series	Percentage clay in upper B horizon	Sand grade in upper B horizon	Profile Nos.
Bleskop	0 - 6	fine	41; 119
Oranje	0 - 6	medium	7
Vaalbank	6 - 15	fine	115
Torquay	6 - 15	medium	8

These four soil series are closely related with regard to origin of their parent material, morphology, and chemical and mineralogical properties. The Bleskop, Oranje and Torquay series were first identified and described during this survey. Because these soils are closely related and because they occur geographically associated with each other, they are discussed as a group.

3.3.2.1 Site

The soils occupy a characteristic position in the immediate vicinity of the Orange River. Their occurrence is limited to the banks of the Orange and especially where the direction of the river course permits westerly to north-westerly winds to blow sandy material out of the river bed. Their geomorphological situation is thus confined to areas between the river and nearby dolerite and lava ridges and koppies. The latter serve as natural obstacles for the deposition of aeolian material.

The landsurface on which these soils occur has a somewhat undulating appearance. These undulations are probably the result of dune-like formations of aeolian origin. On sites close to the river, e. g. at the Orange-Vaal confluence, present aeolian activity is much in evidence. On an extensive area of shifting sand typical barchan and seif dunes occur. There is no vegetation on these dunes to stabilize the loose sand (vide Plate 1).

3.3.2.2 Parent material

Windblown materials of riverine origin (Orange River) form the main source of parent material. These materials have been and still are blown out of the river bed by the prevailing westerly to north-westerly winds during winter months when the water level of the Orange is at its lowest. The aeolian material has never been transported over long distances as evidenced by its confinement to the river valley. In light of their distribution pattern and weak horizon differentiation it is concluded that these soils are comparatively young. At least part of the parent material is of very recent age material still being blown out of the river bed under favourable conditions.

Although quartz is dominant, these soils contain a considerable proportion of weatherable minerals, most of which are derived from the basic rocks of the Upper Catchment Area of the Orange. Some admixture with doleritic weathering products has also taken place where these soils occur adjacent to dolerite outcrops. The latter is indicated by somewhat redder tints due to iron oxide weathering products of dolerite. The origin and mode of distribution of these parent materials are discussed in detail in Chapter 5.

3.3.2.3 Morphology

Horizon development is generally very weak. The A horizon is a structureless, loose sand overlying a yellow structureless B horizon. The latter consists of a soft or friable sand, loamy sand or sandy loam. The sand grade varies between fine and medium for the respective series. Profiles are freely permeable down to the substratum. Small soft and hard lime fragments are frequent in the sand fraction and distributed throughout the profile. The solum is free from mottling and varies in depth between 0,45 m and 6 m. Substrata may be calcrete, dolerite, lava or terrace gravels.

3.3.2.4 Chemical properties

Soil reaction is moderately to strongly alkaline (pH 7,8-8,7) due to the preponderance of calcareous components. Electrical resistance is high. The S-value of the yellow B horizon is between 1 and 10 me/100g. Divalent cations are dominant and soils are 100% base saturated. Organic carbon content of the A horizon is very low, about 0,2%.

3.3.2.5 Mineralogical properties

The sand fraction comprises mainly quartz and a relatively high percentage of heavy minerals. Heavy mineral residues show appreciable weatherable mineral reserves, mainly pyroxene and amphibole. Large numbers of lime fragments are contained in the coarse sand fraction.

The principal minerals in the clay fraction are illite and mixed layer minerals with lesser amounts of quartz and feldspar. Iron oxide content is less than 1%.

3.3.2.6 Drainage

The internal drainage down the profile is excessively rapid (more so than in the case of the red soils) and waterholding capacity and run-off are low. The overall moisture regime of deep soils is somewhat droughty compared to that of the Hutton soils. That of the shallow phase soils is distinctly droughty.

3.3.2.7 Mapping

For purposes of mapping, soil series of the Clovelly form were grouped as an association, with the Bleskop and Torquay series dominating (map symbol BT). The four series are closely associated in the landscape and due to complex variations in the soil pattern, it will be difficult to map these soils separately even in a detailed survey. For irrigation purposes the soils were subdivided into depth phases similar to those of the Hutton form, viz:

- (i) shallow phase - depth varying between 0,45 m and 1,2 m (map symbol BTs) and
- (ii) deeper than 1,2 m (map symbol BTd).

The same remarks concerning mapping of the Hutton soils apply to the Clovelly soils.

3.3.3 Soils of the SHORTLANDS FORM

The orthic A horizon of these soils is commonly a thin reddish brown fine sandy loam to fine sandy clay loam with weakly to moderately developed blocky structure. The B horizon is a reddish clay loam to clay with strongly developed blocky structure. Three soil series of this form were identified, differentiating criteria being the clay content of the upper B horizon and calcareousness. Another criterion for series differentiation is the clay/S-value which is less than 7 for all identified series (Table 3.3).

TABLE 3.3 - Criteria for series differentiation of the Shortlands form and relevant profile numbers

Percentage clay in upper B horizon	Calcareous in red structured B horizon	Non-calcareous in red structured B horizon	Profile Nos.
15 - 35	Ferry series		27
15 - 35		Kinross series	5
35 - 55	Sunvalley series		130

These soils occur patchily and not very extensively in the area and are usually restricted to the close proximity of dolerite. The solum is generally shallow with a moderate permeability. The moisture regime varies from wet during the rainy season, to dry during winter.

3.3.3.1 Site

They occur on upper to middle erosion slopes of short and gentle pediments of dolerite koppies and ridges (vide Figure 2.3) and sometimes along watercourses. Their habitat is therefore confined to somewhat rocky areas.

3.3.3.2 Parent material

The soils, like those of the Shorrocks series, developed from mixed parent materials. Whereas the latter are derived largely from aeolian sand, the Ferry, Kinross and Sunvalley soils developed mainly from doleritic colluvium. This is evidenced by the higher percentage of clay, presence of doleritic gravel in the entire profile and a reddish brown colour. Aeolian sand and colluvium from sedimentary rocks have had a secondary influence on the genesis of the soils.

3.3.3.3 Morphology

The profile has a thin dark reddish brown orthic A horizon, consisting of a friable to slightly hard fine sandy loam to fine sandy clay loam with a weakly to moderately developed blocky structure. It is followed, with a diffuse to clear transition, by a reddish brown to red fine sandy clay loam to clay loam structured B horizon. The structure is usually moderately blocky with a hard, but sometimes very hard consistence. Weak vertic properties are not uncommon in the B horizon. A few profiles have rare faint yellow and reddish mottles in the lower B horizon with rare sesquioxide concretions. Small hard and soft calcium carbonate concretions are present in the B horizons of the Ferry and Sunvalley series. Gypsum crystals are sometimes present in subsoils. The substratum is mostly calcrete and occasionally dolerite or Karroo sediments.

3.3.3.4 Chemical properties

Reaction of the surface soil is mildly alkaline and moderately alkaline in the subsoil. Electrical resistance is mostly relatively high, e. g. profile 130, but some members occurring in low-lying areas, may be saline ($R < 200$ ohms) to severly saline ($R < 50$ ohms), e. g. profile 27.

3.3.3.5 Mineralogical properties

The sand fraction contains a high percentage of iron oxide-coated quartz grains, which are undoubtedly of windblown origin. Depending upon the degree of weathering, variable quantities of doleritic minerals make up part of the sand fraction. Ilmenite and magnetite are particularly prominent in the heavy mineral fraction. In the field black streaks of these minerals are often observed on the soil surface where run-off collects.

X-ray diffractograms confirm that the clay fraction contains predominantly 2:1 clay minerals, 1,4 nm peaks being most prominent. Because with the accepted identification procedures specific clay minerals, could not be identified, mixed layer minerals are probably the major components. Quartz of clay size dimensions is an accessory mineral. X-ray diffractograms show weak 0,74 nm peaks which may represent traces of kaolinitic minerals. The dominance of 2:1 clay minerals is further confirmed by vertic properties often exhibited by subsoils.

3.3.3.6 Drainage

Infiltration rate and hydraulic conductivity of Kinross and Ferry soils are rapid to moderate, decreasing somewhat in the more clayey B horizon. Where these soils occur on level surfaces, evidence of temporary wetness is manifested by diffuse mottling and occurrence of ferriferous concretions in the lower part of the solum.

In general, however, these soils occupy short, moderate pediment slopes from which run-off is somewhat excessive. This is further enhanced by the reception of run-off from higher lying rocky ground during heavy showers. Therefore these soils are subjected to high rates of run-off which often result in sheet and rill erosion. The Sunvalley, occupying very small areas and containing a higher percentage of clay, is accordingly more subject to run-off than the Ferry and Kinross soils.

3.3.3.7 Mapping

The Ferry, Kinross and Sunvalley soils were mapped as a soil association. A map symbol FK to denote this association, was introduced in view of the dominance of the first two series. Sunvalley, the more clayey member, seldom covers a mappable (1:50 000) area and was therefore mapped with the others. Soils of the Ferry and Kinross series, distinguished by presence or absence of lime in the B horizon, may be mapped separately on an intensive survey basis. In areas where these series adjoin soils of the Willemsdal form, difficulties in establishing boundaries were experienced because of a very diffuse lateral transition.

3.3.4 Soils of the WILLEMSDAL FORM

The Willemsdal soils have a thin orthic A horizon underlain by a yellow-brown structured B horizon. In this form two soil series, the Omdraai and Luckhoff, were defined for the first time. The criterion for differentiation between these two soils is clay content of the B horizon. Both series have a clay/S-value of less than 7 and are calcareous.

In Table 3.4 a list of Omdraai and Luckhoff profiles is given. The column denoting phase needs some explanation. In view of the abundance of these soils in the arid and semi-arid regions of South Africa and also their possible irrigation development, a consideration of salinity hazards is appropriate. A tentative suggestion is therefore made to distinguish salinity phases within these series. Although not thus mapped during the survey, the given profiles in Table 3.4 and Appendix 1 are designated accordingly. Also for reasons of possible irrigation development, depth phases were assigned to individual profiles (also not mapped). Depth limits for phases were defined under the Hutton form (vide Section 3.3.1.7). With regard to salinity phases, an arbitrary limit of 200 ohms resistance of saturated paste was assigned.

TABLE 3.4 - Series of the Willemsdal form with relevant phase differentiation and profile numbers

Percentage clay in upper B horizon	Series	Phases	Profile Nos.
15-35	Omdraai	deep saline	16
	Omdraai	shallow saline	92
	Omdraai	shallow non-saline	94
	Omdraai	shallow non-saline	136
	Omdraai	deep saline	141
35-55	Luckhoff	deep saline	49
	Luckhoff	deep saline	56
	Luckhoff	shallow non-saline	57
	Luckhoff	deep saline	83
	Luckhoff	deep non-saline	113
	Luckhoff	shallow saline	216

A marked feature of the occurrence of these soils is their situation to the south of the Orange River on the clay plains (vide Appendix 2). The fine texture together with relatively high silt contents give rise to generally poor physical conditions in the profile, especially in the B horizon. With regard to irrigability these poor physical conditions are often aggravated by high alkalinity and salinity.

3.3.4.1 Site

Their site is confined to the clay plains which are somewhat convex in cross-section (vide Figure 2.3). Generally the Luckhoff soils occupy the lower parts of the clay plains often associated with Killarney series of the Katspruit form. The latter is periodically subjected to waterlogged conditions in the lowermost parts of the plains. Omdraai soils occupy slightly higher ground and their formation is probably more influenced by colluviation than that of the Luckhoff series.

3.3.4.2 Parent material

Parent materials are derived from Karroo rocks but the soils occur only on either Ecca or Dwyka shales or mudstones. The lower part of the solum most often developed from sedentary weathering products of the underlying shales and mudstones. Colluviation of erosion debris from surrounding rocks during pediplanation mostly accounts for the upper part of the profile. Admixture with foreign matter such as aeolian deposits may have taken place in certain areas. Shales of the Karroo System are responsible for high percentages of silt and saline-alkaline conditions. In areas where colluviation has taken place from Dwyka tillite, rounded stones of tillite origin are found in the solum or upon the surface.

3.3.4.3 Morphology

Profiles are generally well developed. The sequence of horizons is: A thin yellowish-brown to brown fine sandy clay loam to silty clay orthic A horizon, structureless to moderate blocky structure and firm to slightly hard consistence; with gradual to clear transition, a yellow-brown blocky structured B horizon. This yellow-brown colour is predominantly of a Munsell notation 7.5YR 4/4 (dry). The blocky structure is moderately to strongly developed and the consistence is hard to extremely hard.

Texture of the B horizon is the differentiating criterion between series; Omdraai has a silty clay loam and Luckhoff a clay texture. The solum invariably has calcareous accumulation in the form of hard lime concretions, powder lime pockets and infiltrations along cracks, with a maximum in the B horizon. Crystals of either sodium salts or gypsum are often encountered in the lower parts of profiles. Sometimes sodium salt crusts are found on the surface. Prominent slickensides and cracks in the B horizon are an indication of vertic properties, which are also manifested in micro-relief features.

Depth of the solum varies between 0,45 m and 3 m. Partly weathered shales and mudstones invariably form the substratum of the Willemsdal soils. These sediments are very impermeable to water and contain soluble salts.

3.3.4.4 Chemical properties

A marked feature of these soils is their alkaline nature. All soils tested had pH values over 7. Subsoils are generally moderately to strongly alkaline with extreme values of up to pH 10,2 (profile 49). High concentrations of soluble salts are often recorded, electrical resistance ranging to extreme values of 20 ohms. Not all soils are extremely saline, probably because of varying contents of soluble salts in the parent rocks and to varying degrees of weathering and lateral drainage. In some instances electrical resistance values of up to 1 000 ohms were measured in the B horizon. Soils with high salt contents have extremely high exchangeable sodium contents (profile 49 and 83). The relative increase of Na^+ with depth as reflected by the exchangeable sodium percentage (ESP) is an indication of real and potential salinity hazards which may develop upon irrigation.

Exchangeable potassium contents are relatively high in surface soils and generally decrease somewhat with depth. Ca^{++} and Mg^{++} are the principal exchangeable cations in the soils not affected by high salinity. It is noteworthy that Mg^{++} often exceeds Ca^{++} . Topsoils generally have less than 0,5% organic carbon. Low C:N ratios are encountered throughout the entire profile.

3.3.4.5 Mineralogical properties

The clay and silt fractions are the dominant mineralogical components of these soils. Having been developed mainly from Karroo sediments, e. g. shales, mudstones and tillite, it may be deduced that the clay minerals are to some extent of lithological origin. The shales and mudstones largely consist of 2:1 clay minerals (vide Section 4.2.4). X-ray diffratograms indicate that well crystallized vermiculite is a principal clay mineral. Diffuse peaks show that a major portion of the clay minerals are of mixed layer types, e. g. illite-montmorillonite and vermiculite-montmorillonite. The presence of vermiculite and montmorillonite was confirmed by quantitative chemical analysis of a sample of Luckhoff series.* The method of Alexiades & Jackson (1966) with slight modification (J. M. de Villiers, 1969 -

* Analysed by J. G. K. Coetzee.

personal communication) was employed, yielding 39,2% vermiculite and 13% montmorillonite. The remainder of the clay fraction defied identification and probably consisted of illitic and mixed layer minerals.

Soils of the Omdraai and Luckhoff series invariably exhibit vertic properties which are also indicative of montmorillonite. Large and deep cracks, micro-relief features and slickensides are most common in these soils.

A marked feature of the Willemsdal soils is their high silt content. The silt size minerals were not microscopically investigated. They are probably quartz and feldspathic minerals inherited from the sediments. X-ray diffractograms of the clay fraction show clear peaks for quartz and feldspar, indicating well crystallized primary minerals.

3.3.4.6 Drainage

The flat topography of the clay plains results in poor surface drainage conditions. Ponding over large low-lying areas of the plains is a common feature during the rainy season. Although high salinity is widespread in these soils, large areas are low in soluble salts but are affected by high Na^+ saturation. Such soils are easily dispersed upon wetting with pure water becoming impermeable. During the field work, it was noticed in several instances that standing water did not penetrate deeper than 5 cm or 6 cm after several days.

High clay and silt contents of the B horizons, presence of swelling clays and high degrees of Na^+ saturation combine to affect permeability of the profile most adversely.

3.3.4.7 Mapping

In view of their situation and general correspondence, soils of the Omdraai and Luckhoff series together with the Killarney series (vide Section 3.3.5) were mapped as an association. A map symbol LO was assigned to this association. Boundaries between the Luckhoff-Omdraai association and other soils are generally well defined. Only the transition to the alluvial soils of the floodplains necessitated careful observation and identification.

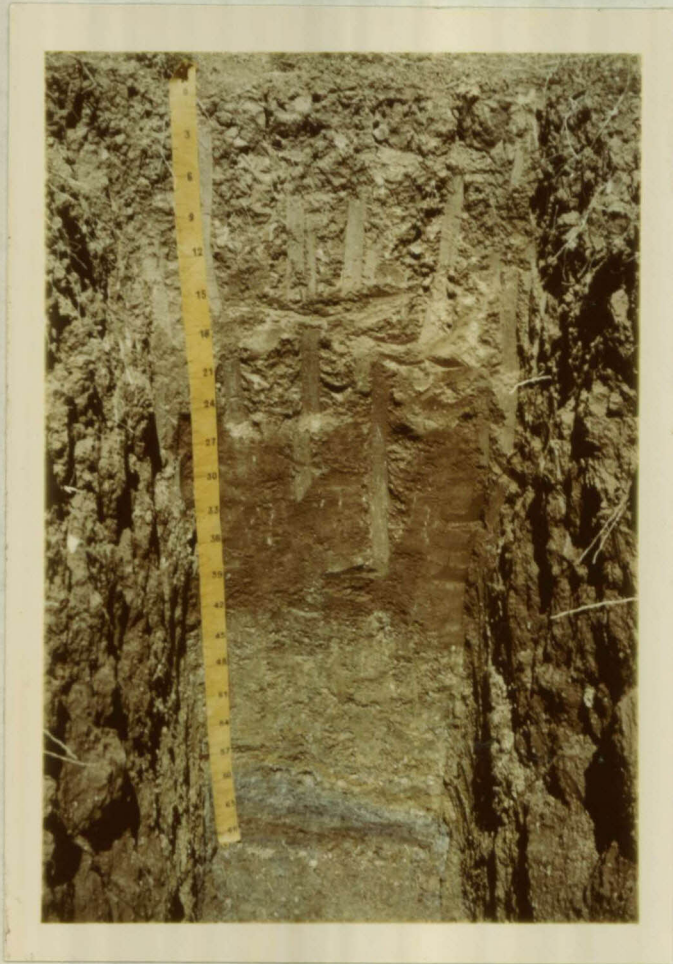


PLATE 17 - KATSPRUIT form-Killarney series.

Soils of the Killarney series (Katspruit form) were identified during the survey but in view of their limited areal distribution and their close association with the former two series, these relatively small areas were also mapped with the former. Since Killarney series belongs to a separate soil form, this soil type is described in some detail in the following section.

3.3.5 Soils of the KATSPRUIT FORM

Only one series, viz. the Killarney was identified. The Katspruit soil form is distinguished from the Willemsdal form by a B horizon which is affected by hydromorphism and is designated as a firm gley (G).

Profiles 62 and 101 are examples of Killarney soils. From the profile description (vide Appendix 1) it is evident that these soils are characterized by gleying of the B horizon (vide Plate 17). This is due to their situation in low-lying areas of a generally flat topography. Run-off water accumulates here causing intermittent or permanent waterlogged conditions. The firm gley B horizon has a moderate to strong blocky structure and firm consistence. Upon wetting, soil of this horizon becomes sticky and impermeable. The colour is yellow brown to brownish grey, mottled red and grey. Exposed B horizons in soil pits show upon drying out higher colour values than in the wet condition. Salt crystals also appear on dried out surfaces. Crystallization of soluble salts on the surface is a common feature. In this dry climate, desiccation of the salt encrusted surface soil leads to the formation of a fluffy surface layer. This type of salt crust is characteristic of areas where low air humidity prevails with consequent desiccation and pulverization of the salt crust upon and in the uppermost soil layer. Thus a porous fluffy salty surface layer is formed.

The position of the Killarney soils in the clay plains where run-off and possibly seepage water of the adjoining higher lying soils - Omdraai and Luckhoff series - is the cause of the soluble salt accumulation in this low-lying ground. Of these soils, viz. Omdraai, Luckhoff and Killarney series, the last generally has the finest texture, clay contents in some instances exceeding 60%, but developed

from similar parent materials. These high clay contents may be attributed to more intense weathering of the silt-sized primary minerals from the sedimentary parent rocks under the hydromorphic influence. It may therefore be reasoned that Killarney series is merely a hydromorphic relative of Omdraai and Luckhoff series. A further development of this reasoning may lead one to predict that Killarney series may ultimately develop from Omdraai and Luckhoff upon long-term irrigation.

3.3.6 Soils of the MISPAH FORM

A characteristic feature of the soils of the Mispah form is their relatively shallow depth. These soils have a thin (usually less than 0,45 m) A horizon, very low in organic matter, overlying calcrete and various other rock types. The two series distinguished, viz. the Mispah series (non-calcareous) and the Mudén series (calcareous) are described briefly in the following paragraphs.

In the survey area the A horizon of Mispah series soils has a sand, loamy sand or sandy loam texture, the parent materials being partly of aeolian origin (profile 144).

Muden series has formed from colluvial materials admixed with aeolian sand usually overlying Karroo sediments and various other rocks. The texture of the A horizon varies from a sandy clay loam to a silty clay (profile 65). Mudén occupies the lower slopes of pediments of the undulating plains and Mispah occurs on the undulating plains in association with calcrete and various other surface rocks. Soils of these two series and shallow phases of all other soils previously discussed ($< 0,45$ m), lithosols and very stony land were mapped as a complex using the mapping symbol L.

3.3.7 ALLUVIAL SOILS

Alluvial soils are confined to areas immediately adjacent to the principal rivers, viz. Orange, Vaal, Ongers and Brak. They occur either as narrow continuous strips on river terraces or on relatively broad floodplains

comprising areas of up to a few thousand hectares each. Along minor water-courses insignificant areas of alluvial soils were neglected as unmappable on a reconnaissance scale. These alluvial soils, as elsewhere occur on a very level topography.

Because alluvial soils usually have such variable texture, both vertically and laterally, no attempt was made during the survey to classify and map textural types. A broad distinction was made between alluvial soils of the Orange, Vaal and Riet Rivers (map symbol AO) and those of the Ongers and Brak Rivers (map symbol BO). This was partly for the reason that they form more or less separate physiographic entities and that the latter group of soils, is of a finer texture and are more saline and alkaline.

3.3.7.1 Orange, Vaal and Riet River Alluvium

Morphologically the topsoil varies from sandy loam or a sandy clay loam to a clay loam with a structureless to moderate blocky structure. The subsoil is sometimes a firm, dark coloured sandy clay or clay with a strong blocky structure. Lime concretions and infiltrations are commonly present in the subsoil with occasional gypsum crystals. Soluble salt contents vary considerably and soil reaction is generally alkaline, more so, the finer the texture. This type of morphology is characteristic of most alluvium.

In some places stratification appears and these soils probably belong to the Dundee form of the proposed national classification system. The alluvia along the Orange and Vaal Rivers are chiefly of this nature, with alternating sandy and silty layers of variable thickness. The colour ranges from grey brown to light grey. Large areas of the Orange, Vaal, Riet and Ongers River alluvia are at present under irrigation and are well-known for their high fertility, although not free from widespread waterlogging and salinity problems. Profiles 36, 40 and 145 are representative of irrigated alluvia, all containing undesirably high concentrations of saline salts. Profile 152 represents virgin alluvial soil.

3.3.7.2 Brak and Ongers River Alluvium

Along the Ongers and Brak Rivers, extensive areas of alluvia occurs. The floodplains are very broad in certain areas, e. g. Beervlei. The soils on these floodplains are mainly of a fine texture and micro-relief features are characteristic of this fine-textured alluvial soils. A coarser textured type, somewhat stratified occur on the immediate levees of the rivers, but they are narrow strips and of limited occurrence.

The soils are otherwise similar to the Willemsdal soils as far as chemical and mineralogical properties, and internal drainage are concerned. Profiles 90, 117 and 127 represent Brak and Ongers River alluvium.

3.3.8 MISCELLANEOUS LAND TYPES

3.3.8.1 Stony land and land with very shallow soils

This land comprises:

- (i) rock outcrops such as surface calcrete, dolerite, lava, shale and granite, as well as gravels and desert pavements. The rocky outcrops are usually of a very low relief. Scattered occurrences of Vaal, Riet and Orange River gravels were rent by diamond diggers, such as the well-known Brakfontein diggings on the Orange River;
- (ii) various undifferentiated lithosols which occur in complex association with rock outcrops. Very shallow soils which are often very stony occur on gentle to steep concave slopes of hills and ridges;
- (iii) shallow phases (<0,45 m) of all the soil series previously discussed.

All the above-mentioned land types, including the shallow soils of the Mispah form, were included in one mapping unit with the map symbol L.

3.3.8.2 Rock

Rocky areas with relatively high relief and of mappable surface exposure were included in one unit (R). This unit includes mountains, hills, mesas and buttes of dolerite, lava, banded ironstone, etc.

3.4 THE SOIL MAP AND LEGEND

The soil survey of the area was, of necessity, on a reconnaissance scale. For the reconnaissance soil map it was necessary to employ broad and convenient mapping units. The soil association was selected and is a most useful unit for this type of survey. All the soils were mapped on the basis of soil associations, because of their intimate pattern of occurrence. To be of any practical value, a mapping unit such as the soil association, should be capable, of reasonably precise definition with respect to individual soil series, within it, and their boundaries within the area. Therefore the soil associations defined, consist of two dominant soil series and associated minor soil series. The soil associations were given the names of the dominant series.

The occurrence of the soils is remarkably well correlated with readily recognisable landscape features. The age of these land surfaces is an important factor in determining the characteristics of the soils. The soil map is therefore more or less equivalent to a geomorphological map, and the soils were most conveniently described according to the surfaces on which they occur. During mapping of the soils, it was possible to deduce, with a fair degree of accuracy the occurrence and distribution of soils and phases on certain geomorphological surfaces during parallel traverses. Differentiation of depth phases was considered justified only for the sandy soils because of their irrigation potential. The clayey soils were regarded as unsuitable for irrigation and depth phase differentiation seemed unjustified.

In some cases plant species - distribution was used to indicate depth phases. For example Acacia giraffae only grows on the deep red sandy soils of the Hutton form. Within the area of any one land surface the soils vary according to parent material and drainage status. Soil series and depth phases are listed in the legend of the soil map. (vide Appendix 2).

It must be appreciated that the units on a reconnaissance soil map cannot display all the soils in the areas delineated. For instance, an area shown as consisting of the Mangano-Zwartfontein soil association of the shallow phase (MZs) may well include minor areas of soil belonging to the deep phase (MZd) etc.

The soil map indicates the distribution of the various soil associations and other mapping units which were defined. The interpretation of the map for general purposes is not difficult, but for specific purposes some care must be exercised, because the greater the degree of generalization and inclusiveness of mapping units, the more difficult it is to locate given soil areas in the field. This applies more to some associations and land classes than to others and, particularly to those associations for which depth phases were mapped.

It is intended that this reconnaissance soil map should form the basis for further detailed surveys and studies of individual soil series and their depth phases falling under the sandy soils. Such a study is necessary for utilizing these soils under irrigation.

CHAPTER 4

GENESIS OF THE SOILS

4.1 INTRODUCTION

Soil is the product of the forces of weathering and soil development acting upon the parent material deposited or accumulated by geological agencies. The characteristics of the soil at any given place depend upon: (i) the physical and mineralogical composition of the parent material; (ii) the climate under which the parent material has accumulated and has existed since accumulation; (iii) the plant and animal life in and on the soil; (iv) the topography and (v) the length of time the forces of soil development have acted on the soil material.

Climate and vegetation are the active forces in soil genesis. They act upon the parent material accumulated through the weathering of rocks and slowly change it into a natural body having genetically related horizons. The effects of climate and vegetation are modified by relief, nature of the parent material and age. Interaction of these soil-forming factors determines the nature of the soil profile.

Horizon differentiation is ascribed to soil-forming processes, viz. additions, removals, transfers and transformations within the soil system. These processes are governed by the soil-forming factors. It is postulated that all these processes and hence a wide range of changes proceed simultaneously in any given soil. Soil development under differing environmental conditions produces as its ultimate product a soil that reflects a balance between these changes, which differ only in degree and intensity. Some changes oppose soil horizonation and others enhance it (Jenny, 1941 and Simonson, 1959).

It is logical therefore that soil development in the Central Orange River Basin has proceeded in accordance with the soil-forming factors of the area and hence also according to the processes of horizonation. The aridity of the climate is perhaps the most influential factor which limits chemical weathering and leaching, but causes erosion and hence retardation of soil development. In arid to semi-arid regions, alluvial soils often command most attention from soil scientists (Kovda, 1964 and Buol, 1965).

This stems perhaps from either their abundance or their economic value for irrigation in such areas. In this connection Buol (1965) stated: "Since alluvial soils lend themselves most readily to irrigation and other agricultural practices necessary for crop production, this emphasis is understandable. Various intrazonal soils, such as the solonchak and solonetz soils, have also received attention because of their unique accumulation of various salts and the associated problems the salts present to agriculture".

Under the prevailing low average annual rainfall, general sparse vegetation cover, and relatively gentle slopes, the soils of the Central Orange River Basin strongly reflect the influence of parent material and time. Where stratified soils of alluvial origin occur, the time factor is negligible. Some such soils are little more than unmodified parent material, often consisting largely of lithogenic silt, clay and shale fragments. Soils of the sandy deposits are also little more than aeolian parent material with poor horizon development. Their properties are essentially hereditary, and many profiles exhibit a minimum of soil development and horizon differentiation. Where the parent material has been in place for a longer period of time, the influence of other soil-forming factors is more apparent.

The following discussion will focus on the influence of soil-forming factors and processes responsible for development of the various soils of the Central Orange River Basin.

4.2 THE SOILS

4.2.1 Clovelly and Hutton soils

Soils of both these forms have developed from aeolian deposits as parent materials. The marked differences between these two soil forms are primarily due to differences in parent material composition and probably age. Although both types of aeolian deposits are dominated by their high percentage of quartz, Clovelly soils contain appreciable fractions of primary and secondary weatherable minerals, e. g. pyroxenes and calcium carbonate. Under climatic conditions favouring high rates of soil formation, this parent material could be expected to

produce soils with a fair degree of horizonation. Under the prevailing climate and because of the apparent young age of this aeolian material, however, little or no soil formation could be detected. In areas where Clovelly soils carry a fair vegetative cover, they have reached a stable state where soil formation can proceed, given favourable climatic conditions. In other areas aeolian action is still in progress and soil material is continually deposited or removed. Under these unstable conditions soil formation is out of the question.

Red aeolian deposits giving rise to Hutton soils are probably much older in actual age than the Clovelly parent material. They are, however, extremely deficient in weatherable minerals and contain no free lime. Deep profiles are very uniform in texture and practically no clay migration from the surface, to form distinct B horizons, could be detected in Roodepoort, Gaudam, Mangano and Zwartfontein soils which all contain low percentages of clay. The origin of the clay in these series is unknown. The clay could have been co-deposited during the deposition of the sand, being derived from surrounding sediments.

The only Hutton soil showing any appreciable degree of horizon development is the finer textured Shorrocks series. Soils of this series have increasing clay contents with depth; B horizons show some degree of structure development. Shorrocks soils most often occur in close proximity to dolerite outcrops and their genesis is undoubtedly strongly influenced by doleritic colluvium. Weathering products of dolerite contribute, through admixture with the aeolian deposits, to the higher clay content of these soils.

Because of their unique occurrence and origin in this area, the parent materials of these soils, i. e. the Clovelly and Hutton soils, will be further discussed in detail in Chapter 5.

4.2.2 Alluvial soils

In general soils of the river floodplains consist of alluvium of varying textural composition, differences being largely dependent upon the nature of parent material and mode of deposition. As stated earlier the stratified alluvial soils are often little more than unmodified parent material. The parent

materials of alluvial soils are of mixed origin, derived from sediments and igneous rocks in the catchment areas. Field observations during the survey showed that Orange and Vaal River alluvia generally have a coarser texture than the alluvia of the Ongers, Brak and Riet Rivers. Alluvial materials of the former rivers, originate from and are transported over the whole range of Karroo rocks, e.g. basalt, dolerite, sandstones of the Stormberg Series, Beaufort, Eccca and Dwyka sandstones, shales and mudstones, Ventersdorp lava, superficial deposits and various other geological formations. Alluvia of the Brak and Ongers Rivers are practically entirely derived from shales and mudstones of Eccca and Dwyka sediments.

In most of the finer textured and older alluvia, a certain degree of horizon differentiation has taken place. This is evident from a relatively high calcium carbonate accumulation in the subsoil, forming a distinct layer. The lime probably originated largely from weathering products of igneous parent materials, e.g. dolerite, basalt and Ventersdorp lava. Calcium carbonate appears infrequently in the Vaal River alluvia because there are few basic rock outcrops in its catchment area, compared to those of the other catchments.

Under the arid climate of the area, associated with the type of parent materials, i. e. inherently saline Karroo sediments, it is not surprising that extensive areas of saline and alkaline soils occur. Brack soils are found particularly in the southern part of the area. Most severely saline are soils of the Willemsdal and Katspruit forms and those of the pans.

Many of the clayey alluvia also contain large quantities of soluble salts, mainly sodium chloride, for example large portions along the Brak, Ongers and Riet Rivers. These accumulations are largely derived from salts transported in solution by run-off water from higher lying ground, especially from the adjoining clay plains. Where large areas of alluvia soils are irrigated, severe water-logging and brack problems are often experienced. Through uncontrolled water application, water-tables develop, with a consequent concentration of salts. Salts rise through capillary action to the surface, resulting in crop failures.

4.2.3 Shortlands soils

Under arid to semi-arid climate dolerite generally weathers rather slowly, especially where exposed. Where dolerite is covered by aeolian sand, weathering proceeds at a greater rate, producing deep partly weathered material. Weathering products from this source, when admixed with Karroo sediments and aeolian sand, produce soils of the Shortlands form. These soils are characterized by a reddish B horizon with moderate to strong structure development and much material of clearly doleritic origin. Partly weathered rock fragments in the form of fine gravel occur frequently. The reddish colours originate undoubtedly from the iron-rich minerals of dolerite. Lime deposits and calcareous horizons are often associated with these soils, the lime being liberated from calcium feldspar and augite of the dolerite.

The amount of admixture with either aeolian sand or Karroo sediments determines the texture of the resultant soil. The role of the climate in this particular type of soil formation is associated with moisture conditions for chemical weathering and colluviation, wind for aeolian admixture and temperature for physical disintegration of the hard rock. As stated earlier, an aeolian sand cover accelerates the weathering of dolerite. This is most probably the result of more favourable moisture conditions, rain water being absorbed completely through the porous sand and protected against evaporation. There is much evidence that a fair amount of lateral movement of soluble weathering products takes place downslope through the porous sand cover. This is especially true for the removal of lime from weathering dolerite ridges and deposition in the lower lying Shortlands soils. Colluviation may occur as a result of the high rate of water absorbance through the porous sand cover and saturation of the underlying weathered material during occasional high rainfall periods. Downslope viscous flow of such saturated material under a thin sand cover may then produce lateral distribution and admixture of parent materials mentioned above. Apart from colluviation, weathered material is transported downslope through the process of soil erosion during heavy downpours.

These soils are therefore generally situated in a belt on the lower slight slopes of dolerite ridges and koppies and along watercourses which drain these dolerite areas. They always occur in positions where the direct influence of doleritic parent material is present.

With regard to chemical weathering products of doleritic origin, it is noteworthy that lateral distribution of lime and iron oxides sometimes produce duripans in soils associated with dolerite. These duripans are formed through cementation of soil layers by the deposition of lime and/or iron oxide liberated from dolerite. They were found not only in Shortlands soils but also in adjacent lower lying Hutton soils. Individual occurrences of duripans are small in area and from an agricultural viewpoint of little significance.

Notwithstanding a fair degree of horizon development, the Shortlands soils bear evidence of arid region soils. Lime accumulation and the occurrence of easily weatherable minerals of doleritic origin were mentioned. In positions favourable for salt accumulation under low rainfall conditions, these soils are often afflicted with salinity.

B horizons usually have a finer texture than A horizons. This, together with moderately to strongly developed structure of the B horizons, would therefore lead one to expect that clay migration from A to B horizons took place. On the other hand, aeolian sandy materials in close proximity to these soils, might have provided sufficient sand to the surface layers to have caused textural differences between A and B horizons.

The clay fraction predominantly consists of 2:1 mixed layer clay minerals (vide Sections 3.3.3.5 and 4.4). These are of mixed origin, part being lithogenic from Karroo sediments and part neogenetic from doleritic minerals. Dolerite, under this type of climate favours formation of 2:1 clay minerals (Jackson & Sherman, 1953 and Van der Merwe & Heystek, 1955). Primary minerals of dolerite which may be expected to yield clay minerals are plagioclase, augite and olivine. All these minerals are rich in either Ca and/or Mg. Illite formation may therefore be expected to be minimal. From X-ray

diffractograms of clay separates, no clear cut identification of specific clay minerals was possible as in the case of Willemsdal and Katspruit soils (vide Section 4.2.4). There is evidence of extensive mixed-layering in these clay mineral suites. Layer components are probably largely vermiculite-montmorillonoid. Illite, although not definitely identified, may be of lithogenic origin from the sediments (Van der Merwe & Heystek, 1955). Similarly, weak evidence of kaolinite may be attributed to a lithogenic source.

The formation of Shortlands soils may be regarded as dominated by the parent materials. This is in keeping with general soil-forming conditions in the area.

4.2.4 Willemsdal and Katspruit soils

These soils were partly formed in situ, by decomposition of Karroo sediments and partly from transported materials. The latter materials were transported from their original positions and deposited on lower slopes, in depressions and along drainageways. Soils of the pan floors were formed in a similar way. These soils of the clay plains are probably the oldest of the area as indicated by their degree of horizon development. Their situation on the clay plains, which are regarded as very old physiographic features, confirms their relative age. Most profiles show an increase in clay content with depth. Another feature of these soils is a high silt content of approximately 20% throughout the entire solum. The A horizon is usually shallow. Scarcity of evidence of an eluvial horizon and persistence of the dry state of surface layers of many soils of arid and semi-arid regions, have led to the conclusion that clay in the B horizon is formed in situ and is not illuvial (Buol, 1965). The hypothesis, that conditions are more favourable for clay formation in the B horizon than in the A horizon, is based on the assumption that the B horizon is wet for a longer period of the year (Buol, 1965). This hypothesis can be supported by evidence of soil development on the clay plains. Willemsdal soils are usually shallower than Katspruit soils and contain less clay in the B horizon. Compared with Willemsdal, Katspruit soils occupy the lower parts of the clay plains. Run-off water accumulates on these lower

parts, and is of great importance with regard to soil formation. The wetter conditions are responsible for a higher rate of chemical weathering of primary minerals in the substratum, producing a deeper solum with more clay and soluble salts than the Willemsdal soils. In fact Katspruit soils with a permanent water-table were encountered.

Soluble salts in Katspruit and Willemsdal soils are derived from salt-rich Karroo sediments and accumulate in the solum because of limited leaching. Katspruit soils, situated in bottomland positions, undoubtedly receive salts from external origin through lateral seepage and run-off. Gypsum is found in appreciable quantities in the lower horizons of most of these soils. Gypsum crystals increase in size with depth, quite large crystals being found in the substrata. It is noteworthy that shale samples of Ecca series contain up to 22% $\text{SO}_4^{=}$ (vide Table 4.1).

The increase in crystal size of gypsum with depth may be attributed to the fact that gypsum is derived through solubilization from the underlying sediments. The largest crystals would then be expected nearest to the source and smaller crystals, formed through capillary rise, nearer to the surface.

Table 4.1 - Chemical composition of shale samples in %

Lab. No.	Ecca shales			Dwyka shales		
	B9678	B9697	B9711	B9693	B9718	B9771
SiO ₂	33,74	49,96	36,92	47,63	51,82	52,77
Al ₂ O ₃	11,62	15,57	12,01	15,57	16,36	16,27
Fe ₂ O ₃	4,47	4,91	4,80	4,39	6,71	4,40
FeO	0,00	1,22	0,57	1,80	0,11	0,93
MnO	0,02	0,10	0,05	0,11	0,10	0,05
MgO	1,48	1,87	2,26	3,66	2,49	3,46
CaO	13,61	8,16	12,66	7,62	5,98	5,08
Na ₂ O	0,81	0,70	0,96	2,70	1,48	0,81
K ₂ O	1,49	2,09	2,89	3,37	2,41	2,27
H ₂ O ⁺	5,06	6,16	4,60	5,43	5,38	6,88
H ₂ O ⁻	8,76	2,98	6,52	1,73	2,42	2,68
TiO ₂	0,67	0,74	0,63	0,61	0,89	0,81
P ₂ O ₅	0,12	0,19	0,12	0,19	0,18	0,11
CO ₂	0,40	4,84	1,80	4,71	2,95	2,64
SO ₃	17,40	0,22	13,20	0,20	0,32	0,35
	99,65	99,71	99,99	99,61	99,60	99,51

Saline crusts on the surface of some low-lying soils develop as a result of high rates of evaporation. In most soils the soluble salts are distributed throughout the whole solum, increasing in concentration with depth. Seasonal variations in moisture conditions of the solum have an influence on the vertical distribution of soluble salts.

Without exception the Willemsdal and Katspruit soils contain free lime in their subsurface horizons and often also in the A horizons. The origin of the Ca^{++} is the lime rich Ecca and Dwyka sediments. It is evident (vide Table 4.1) that calcium compounds other than gypsum are present in these shales. These compounds may form the source of lime deposits in the solum. Where dolerite, lava or dolomite occur adjacent or near to the clay plains, weathering products of these rocks may also contribute to lime accumulation.

Further consideration of the genesis of these soils with regard to the clay fraction, may be compared with studies of Buol & Yesilsoy (1964) on arid Arizona soils. Examining B horizon samples they found no clay skin formation. Ordinarily this is proof of the absence of illuviation in soil formation. Buol & Yesilsoy (1964), however, stated that the orientation of clay in clay skins could have been disrupted by excessive desiccation under such arid conditions. Soils on the arid to semi-arid clay plains in the survey area, although also subjected to seasonal desiccation, do however, show varying degrees of clay skin formation, slickensides, cracking and gilgai formation. Extensive and careful determination of relative clay contents in the A and B horizons is necessary to prove conclusively that clay migration has taken place. Slickensides may easily be mistaken for clay skins. Furthermore, cracks are pathways for the migration of fine material downwards from the surface.

In view of the foregoing, some consideration may be given to the origin of silicate clay minerals in these soils. It is an accepted fact that arid region soils are largely influenced by the nature of the parent materials, with regard to physical, chemical and mineralogical properties. Arid region soils are popularly believed to contain a predominance of expanding lattice clay minerals, but Buol (1965) stated that this is not necessarily so. Koalinite, illite and mixed layer

clay minerals have often been reported to occur in such soils (Buol, 1965). Van der Merwe and Heystek (1955) examined the clay fractions of various soils on Karroo sediments of arid regions in South Africa. They found clay mineral suites to consist almost entirely of illite, montmorillonite and mixed layer clay minerals. In rare profiles, e. g. Carnarvon and Kenhardt, soil kaolin was identified but the authors stated that soil kaolin appeared to diminish towards the surface. This was taken as an indication that the parent sediments initially contained kaolinitic material.

In addition to the above-mentioned clay minerals, vermiculite contributes significantly to the clay mineral suites in at least certain profiles. Van der Merwe & Heystek (1955) identified mica-vermiculite mixed layer minerals in some soils, e. g. Loeriesfontein, Beaufort West and Carnarvon. Chemical analysis of a Luckhoff soil (vide Section 3. 3. 4. 4) revealed a vermiculite content of 39%. It is not known whether vermiculite found in soil samples was initially present in the sediments or formed during soil formation. It is also not clear whether the mica-vermiculite mixed layer minerals found by Van der Merwe & Heystek (1955) were lithological or of a neogenetic nature.

The presence of primary minerals such as fine quartz and feldspars in the clay fraction (vide Section 3. 3. 4. 4) raises the possibility of a significant formation of neogenetic clay minerals. These soils contain appreciable quantities of silt which may be regarded to consisting largely of primary minerals. A further significant fact is that Katspruit soils contain more clay and less silt than Willemsdal soils, although both originated from similar parent materials. It may therefore be regarded that the former, a soil of more advanced developmental stage has yielded a considerable proportion of its initial silt content to the formation of clay minerals.

A complete comparative investigation of weathering sequences of primary and secondary minerals in these two soil forms should form an interesting field of study in soil formation from sediments under arid conditions.

4.3 GENERAL DISCUSSION

From the foregoing it is clear that the soils, with regard to physical and chemical properties and to genesis, are representative of arid zone soils. Differences among the soils are largely produced by differences in parent materials. Climatic differences are, on the whole, relatively small, the only notable feature being a gradual decrease in rainfall towards the southwest.

Although some evidence was presented to show that certain plant communities are associated with specific soils (vide Section 2. 2. 1), vegetation in the broad sense of soil formation has a subordinate influence. Its major role may be regarded as a protection against wind and water erosion. The contribution of organic matter to the soil is minimal. Furthermore, organic matter is oxidized very quickly.

The influence of topography on soil formation is, to a large extent, associated with the occurrence and distribution of primary and secondary parent materials. The generally low relief of the area results in poor surface drainage conditions. Where hills and ridges, mostly of dolerite steep slopes cause rapid run-off, some soil erosion takes place. On the clay plains sheet erosion of insignificant proportions produces some amount of redistribution of soil materials.

Moisture, as the major component of the climatic soil-forming factor, is almost universally deficient. Low total rainfall and high rates of evaporation are the cause of droughty conditions. It must be kept in mind, however, that occasional very heavy downpours, up to 150 mm, are experienced in places, causing floods on the river floodplains and clay plains. Water may thus accumulate in bottomlands and remain standing for several days. In spite of poor permeability these clayey soils in low-lying areas can, under such prolonged flooding, absorb considerable quantities of water. Such moist conditions favour the formation of the Katspruit soils, which may be regarded as hydromorphic relatives of the adjacent Willemsdal soils.

The Hutton and Clovelly soils bear no relation to the fine-textured soils of the area. They are, however, merely a product of their aeolian parent deposits.

No means of absolute age determination for soils in this area could be established. There exists no direct relation between soils and known geologic events such as glacials and inter-glacials. The only possibility which affords absolute dating may lie in the calcium carbonate deposits, through radio carbon dating.

CHAPTER 5

ORIGIN OF THE SANDY PARENT MATERIALS

5.1 INTRODUCTION

Soils of the Hutton and Clovelly forms constitute a conspicuous group of soils within the survey area. They are not only regarded as soils with a high potential for agricultural development, especially in respect of irrigation, but they present much pedogenetic and geologic interest. From cursory field observations and from published reports on these soils and/or parent materials, it is logical to conclude that they are, without question of aeolian origin. The question arises, however, where the source of such vast quantities of sand should lie.

Söhnge & Visser (1937), Van der Merwe (1962), Thompson (1965), Du Toit (1966), inter alia stated that the red sandy soils of the western parts of Rhodesia, Transvaal, Orange Free State and parts of the Northern Cape Province are aeolian deposits of so-called Kalahari origin. The sands of the Kalahari basin are the most recent member of the Kalahari System and they are derived from rocks within the Kalahari basin itself (King, 1963). King further stated that the Kalahari sand was formed and probably originally distributed during the Tertiary, then later redistributed during the Pleistocene by both water and wind.

Piaget (1963) questioned the Kalahari (proper) provenance of the eastern "outliers of Kalahari sand". He postulated that the sandy soil parent materials of the South-Western Orange Free State and the eastern part of the Northern Cape Province, probably originated from an easterly source, i. e. from sandstones of the Karroo sediments. According to Piaget (1963) the main transporting agents are the rivers flowing in a westerly direction and subsequent redistribution from the river beds.

The sands in the North-Western Orange Free State were shown by Harmse (1963) to be of aeolian origin. He correlated them with Kalahari sands by means of mineralogical methods and recognises three types of sand, viz.

- (i) older red sand partly consolidated and accumulated as river-border dunes during Early Middle Pleistocene;
- (ii) aeolian-flat sand which originated in the Kalahari and was blown in, to form seif dunes with a south-easterly trend during Late Middle to Early Upper Pleistocene; and
- (iii) garnet-bearing sand which accumulated as river-border dunes during Late Upper Pleistocene.

Recently in a soil survey of the Makwassie area in the Western Transvaal, Verster (1969) found mineralogical support for the findings of Harmse (1963).

In a study to elucidate the origin of soil parent materials, it is important to consider the geological history and its role, together with the climatic factor, in soil formation. In order to investigate the above role, it is illuminating to consider the views expressed by Van der Merwe (1954): "Reviewing the literature on soils of various regions one often finds the opinion expressed that the soils of a certain region are identical with or related to soils occurring elsewhere, thousands of miles away. A good instance of this state of affairs is found in the literature dealing with the soils derived from the sands of the Kalahari and Sahara Deserts.

"The general concensus of opinion is that the soil material is of windblown origin laid down during an arid period. The material is of granitic, quartzose and sandstone origin. The thickness of these superficial sand deposits varies from 40 to 300 feet. This uniform parent material is now exposed to a variety of climates".

It is most significant to note the statement made by Van der Merwe (1954) in the discussion of the soil-forming factors of the sandy soils of different climatic regions that: "Certain aspects which are based on the different characteristics produced by the higher precipitation, have to receive special consideration. The notable differences are colour, soil reaction, and probable removal of colloids from the profiles. Are they of such importance to justify classifying soils developed under high and low precipitation in different classes? No doubt they are. The number of

types would, however, be extremely limited. The authors of publications, dealing with these sandy soils, have therefore, not erred to any extent, when they have concluded that their soils are similar or related to those of another region already known.

"In any case these sandy soils which have a pedogenetic equilibrium with the material from the Desert Sands under the influence of the respective climatic conditions of the various regions, seem to form a class by themselves. They cut right across the various climatic zones where any other material, but this sand, would have produced a variety of soil groups. The explanation is to be found in the fact that the passive soil-forming factor, the sand, is not conducive to the accumulation of material, sesquioxide or clay, in the soil section and that the high temperatures and moisture promote the destruction or mineralization of the organic matter" (Van der Merwe, 1954).

He further gave a vivid description of the various types of "Kalahari" sandy soils. Apart from the many things these types have in common, they differ in a few important aspects. "Under arid conditions the soils are coloured brick-red. As the rainfall increases the colour changes to reddish and goldenbrown to light yellow to grey and ultimately to white. Associated with this change in colour from red to white the soil reaction changes from slightly alkaline to acid. Clay and silt content appear to decrease with increased rainfall".

Most attention has thus far been paid to the red sandy soils (Hutton). A far more insignificant soil group, regarding areal distribution is the yellowish sandy soils (Clovelly). They are not insignificant, however, with regard to origin and potential agricultural development. The origin of the yellowish aeolian sands along the Orange River has not been investigated previously in any pedological sense. An attempt will therefore be made to clarify their origin in relation to that of the red sands.

In view of the foregoing, these sandy parent materials were thoroughly investigated both in the field and in the laboratory. Laboratory investigations included colour, granulometry and heavy mineral studies. Field studies were so directed to include a wider distribution than those confined to the survey area.

5.2 GEOGRAPHICAL DISTRIBUTION OF THE SANDY DEPOSITS

In light of the general acceptance of the aeolian nature of the sandy materials, an investigation on their origin was based on this presumption. Although various soil series were recognized, field evidence showed a common aeolian origin of their parent materials. Their geographical distribution, situation in the landscape and the orientation of individual occurrences with regard to wind direction (vide Appendix 2, Figure 2.3 and Section 2.1.3) all contribute to the proof of their aeolian origin.

Individual deposits cover areas of 1 or 2 ha to two very large areas, comprising approximately 170 000 ha in extent. From a geomorphological view it is significant that the largest uninterrupted areas of sandy deposits are found immediately to the east of the Vaal-Riet confluence. These two areas are separated by the Riet River and two comparatively narrow strips of alluvial and shallow soils. They are further likewise separated from the Vaal River. Natural vegetation which may be quite dense, has a stabilizing effect on these sand deposits. Slight undulations can be distinguished and these may be taken as evidence of ancient dune systems. In some isolated areas where the soil has been denuded, present activity takes place.

To the south-east of the above-mentioned deposits, much sand occurs over a wide area, but more discontinuous. Individual deposits range in area from small patches to some 20 000 ha. This area of discontinuous deposits lies roughly in a triangle between Luckhoff, Heuningneskloof and Koffiefontein within the survey area. Deposits of sand extend, however, eastward towards Petrusburg and Bloemfontein. It must be emphasised that a mere inspection of the soil map does not give a clear indication of the real extent of the sand. For soil survey purposes sandy deposits shallower than 0,45 m were mapped as shallow soils. If these shallow deposits were mapped as Hutton and Clovelly soils, many isolated areas on the soil map would be continuous.

A third area, completely disconnected with the above, occurs to the south of the Orange River. These deposits occur in a narrowish discontinuous belt with a west-east orientation extending from some kilometers above the Brak-Orange confluence to Orania. It is significant that this belt of sand occurs east of the Orange River in the section where it flows in a south-westerly direction towards Prieska.

In these three areas red sandy deposits of varying texture, five soil series developed, the only distinguishing criterion being the texture (vide Section 3.3.1). Another type of sandy deposit, which is distinctly different from the above, occurs in the immediate vicinity of the Orange River, the largest being near the Orange-Vaal confluence. These yellowish sands differ from the red sands in both colour and mineralogy (vide Section 3.3.2). The high content of weatherable minerals and calcareous components indicates part derivation from igneous rocks in the upper catchment area of the Orange. It is most probable that these sands were blown out of the Orange River bed during low water periods. Aeolian activity presently takes place as is evident on windy days during late winter. Nearest to the Orange-Vaal confluence an area of approximately 100 ha is covered with active barchan dunes.

South-east of Douglas an area of red sand lies adjacent to the yellowish sands with a very clear boundary. This points to a difference in origin between these sands.

Discussion

The distribution and situation of the above-mentioned deposits together with similar deposits outside the survey area, may lead to some speculation on their origin and mode of transport. In this respect the red sands of the Vaalhartz Irrigation Scheme may also be considered. This large deposit is also situated on the eastern side of a river, viz. the Hartz River. Towards the west, virtually no sandy deposits are encountered for a distance of 150 km. This also applies to those within the survey area towards the south.

Du Toit (1910), in his survey of the Vaalhartz region, arrived at the conclusion that these red sands were not derived from local rocks only, but that the sand was probably brought down from the Transvaal by the Hartz River. It is noteworthy that the Vaalhartz sandy deposits occur immediately above the confluence of the Vaal and Hartz Rivers. The striking similarity in occurrence of all these sandy deposits, viz. their relation to river confluences and their west-east distribution

and orientation from rivers flowing in a southerly direction, leads to the following conclusion: water is the major transporting agent for erosional debris in the catchment areas of the rivers. During its transport down river, a certain degree of sorting takes place. In areas where the flow of the river slackens, e. g. at its confluence with another, or in flat topographical situations, deposition of the coarse material is enhanced. These rivers, being perennial in flow, allow therefore for the sand to be blown from the river-bed deposits. A study of the prevailing wind direction (vide Section 2.1.3) reveals that north-westerly to westerly winds are dominant during dry periods.

It is generally accepted that climatic changes took place during Tertiary and Pleistocene times (Söhnge & Visser, 1937; Van Zinderen Bakker, 1957; King, 1963, inter alia). Authors on the so-called Kalahari sands agree that major shifting of sand by wind took place during interpluvial periods (Van Garderen & Rosentrauch, 1936; Cooke, 1946; Van der Merwe, 1954 and Du Toit, 1966) and that stabilization of aeolian sand by vegetation occurred during pluvial periods. Examination of the red sandy deposits indicates that they are at present relatively stable. It is not known when the last major shifting of sand occurred, but from morphological and topographical evidence, it may be deduced that the red sands are relatively old deposits. It is quite probably that their areal extent was reduced considerably by water erosion since deposition.

The yellowish sands of Orange River origin are probably much younger than the red sands and are probably still being actively deposited, although not as extensively as may be expected during interpluvial periods.

5.3 COLOUR OF THE SANDY DEPOSITS

Most conspicuous of the properties of the so-called Kalahari sands is their red colour (Du Toit, 1966). This red colour has led to an arbitrary labelling of all and every red sand deposit as Kalahari sand. Through scientific measuring of colour by means of the Munsell Color Chart (1954), notable colour differences have been recorded for these sands.

Axiomatically iron oxide coatings on the sand grains are responsible for the reddish colour. Open to speculation is the source of the iron oxide and the initial colour of the sand during deposition. A further speculative point is the change in colour of soils derived from the sandy deposits. Harmse (1963) stated that the colour of aeolian sands in the North-Western Orange Free State ranges from reddish to greyish. Evidence supplied by him excludes any possibility that these colour differences are related to different aged parent sands. Furthermore, according to Harmse, it should be remembered that these aeolian soils are lithomorphic members in the landscape. He emphasised that colour modifications are due to differences in physico-chemical and hydromorphic conditions in the deposit and not to sedimentological differences. Verster (1969), in a soil survey of the Makwassie area, concluded likewise. The grey Waaisand and yellow Bleeksand soil series, owe their colour to some degree of hydromorphism. "It is, however, considered likely that the initial colour was reddish and that discolouration took place subsequent to deposition. Otherwise it will be difficult to explain the relatively high iron content of the Mangano Series in view of the extreme paucity of weatherable iron-bearing minerals (Verster, 1969).

Apart from the iron oxide coatings on the sand grains, iron oxide is also present in the clay fraction, probably also as coatings and/or discrete colloidal particles. This is clearly illustrated during granulometric fractionation, the clay being intensely red in colour. This is particularly notable in the Shorrocks series. The latter soil originates partly from weathered dolerite which is rich in iron-bearing minerals. A characteristic of Shorrocks soils is the abundance of ilmenite and magnetite in the sand fraction. The majority of red iron oxide in the soil is probably, however, derived from augite in the dolerite. In a survey of the soils of Bloemfontein, Dohse (1971) also reported the obvious influence of dolerite on cover sands.

The yellowish sands associated with the Orange River have colours distinctly paler than those of the red sands, ranging from 10YR 3/4 to 7.5YR 6/6 (vide Appendix 1). Apart from their different situation, these yellowish sands are, in common with the reddish sands, also well-drained without any traces of hydromorphism. The latter condition could therefore not be the cause of any bleaching.

Where these sands occur adjacent to dolerite, somewhat redder tints are discernable and may be attributed to the weathering of iron-bearing minerals of doleritic origin.

A comparison between intensity of redness and ferric oxide content may provide a guide to origin and age of the respective sands. Ten B horizon samples of various soil series were analysed for free Fe_2O_3 content (Coffin, 1961), and their Munsell colour notations were determined (Table 5.1).

Table 5.1 - Relationship between colour of the aeolian sands and total Fe_2O_3 content in mass per cent

Sample No.	Series	% Fe_2O_3	Colour (dry)
72	Shorrocks	1,74	10 R 4/3
175	Shorrocks	1,69	2.5 YR 4/6
117	Shorrocks	1,62	2.5 YR 4/6
124	Zwartfontein	1,33	2.5 YR 4/6
138	Mangano	1,17	2.5 YR 4/8
30	Roodepoort	0,89	2.5 YR 4/8
151	Mangano	0,86	5 YR 4/6
84	Gaudam	0,79	5 YR 4/6
583	Torquay	0,79	7.5 YR 5/4
10	Torquay	0,74	7.5 YR 5/6

A clear relationship between intensity of redness and Fe_2O_3 content was recorded for Hutton form soils. Harmse (1963) found a similar relationship for aeolian sands of the North-Western Orange Free State. He recorded considerably higher Fe_2O_3 contents for sands with colour notations similar to those listed in Table 5.1. The method of extraction employed is, however, not mentioned. The Clovelly sands have only slightly lower Fe_2O_3 contents than the Mangano, Gaudam and Roodepoort soils, but their colours are distinctly yellower.

5.4 GRANULOMETRIC ANALYSIS OF THE SANDY DEPOSITS

The purpose of a granulometric analysis and calculation of various parameters from the grain-size distribution is, firstly, to classify sediments. The classification is based upon mean grain-size and sorting. Secondly, qualitative stratigraphical and sedimentological conclusions may be drawn from a study of the physical properties of sediments. Thirdly, recognition of depositional environments may be attempted by comparing the parameters with one another (Rogers, 1965).

Selected samples of the red and yellowish sandy deposits were analysed granulometrically in order to investigate the pedological meaning of certain granulometric parameters and the behaviour of size fractions during transport of the depositional material. An attempt is also made to deduce the provenance of the different sands. Numerous measures are described in the literature to characterise grain-size distribution of sediments. Textural parameters, viz. mean grain size, graphic standard deviation (sorting), skewness and kurtosis were calculated in this investigation.

5.4.1 Sampling and preparation of samples

Samples of representative soil profiles of the red and yellowish soils were taken. The localities where these samples were collected are shown on the soil map (vide Appendix 2). A factor considered in taking samples for this study, is the recent redistribution in the surface layers of some soils, which might have a definite influence on the particle-size distribution (Chepil, 1957). Samples of surface layers were therefore ignored and samples of sub-surface layers were analysed.

All samples were air-dried and passed through a 2 mm sieve. The < 2 mm material was brought into suspension, using Calgon as dispersing agent. Silt and clay were decanted repeatedly after the appropriate sedimentation period for the fine sand fraction. Total sand between $20\mu\text{m}$ and $2000\mu\text{m}$ was collected and oven-dried. Twelve samples were used to determine the effect of deferration on sieve-size distribution. No significant effect was recorded. All samples were deferrated by the method of Aquilera & Jackson (1953) in order to allow both granulometric and microscopic analysis on a single prepared sample.

In order to find the most suitable combination of quantity and shaking time, a further test was carried out, using a standard set of Endecott test sieves and on a mechanical sieve-shaker. A satisfactory separation was achieved on a 100 g sand sample with shaking for 30 minutes. The sieve openings of consecutive sieves differed by $\frac{1}{2}$ phi units. After screening the grains sticking in the openings of a sieve were carefully removed and dislodged grains were returned to the fraction on that sieve. Size fractions were weighed accurately to 0,01 g and expressed as a percentage of total sand.

5.4.2 Measures and calculation of data

A geometrical scale produces more symmetrical size-frequency curves than the phi-scale. For this reason all calculations were based on phi-units, phi-millimeter conversions being carried out by means of tables computed by Page (1955).

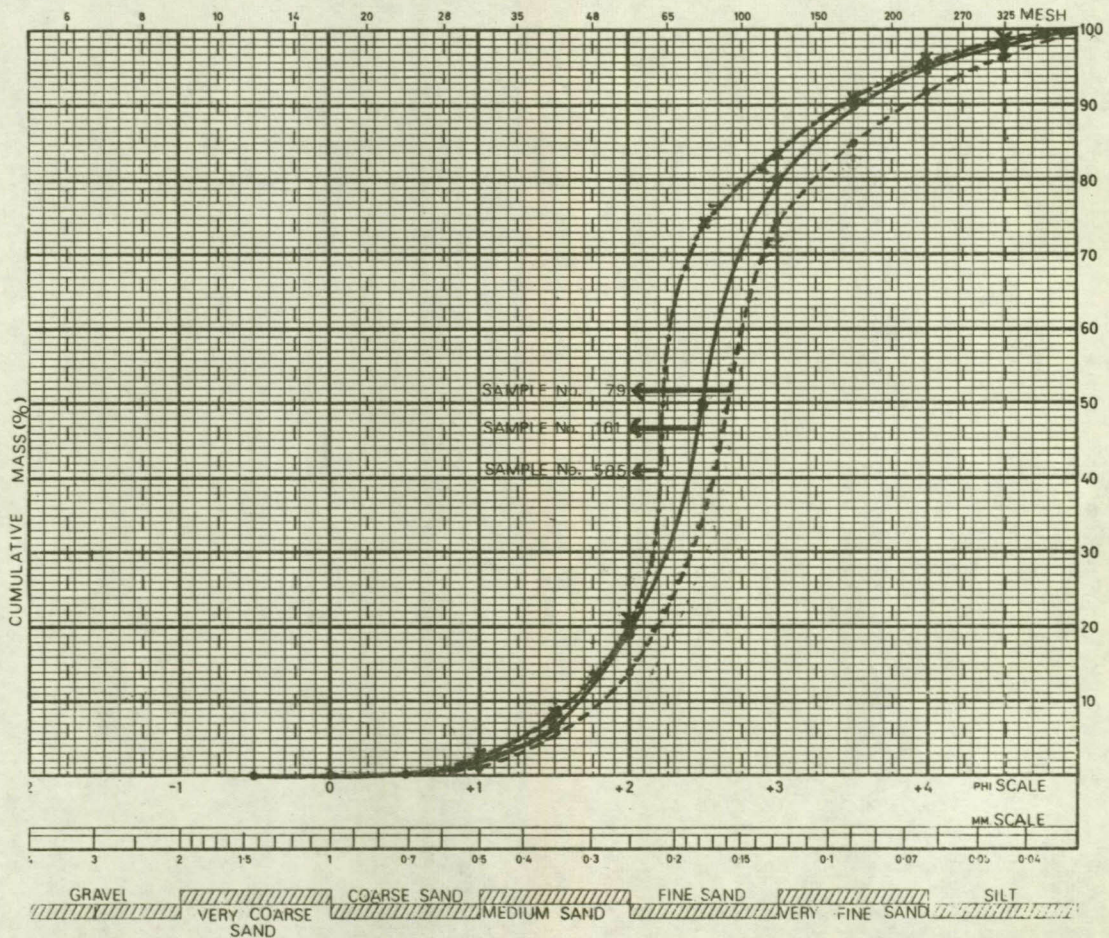


FIGURE 5.1 CUMULATIVE CURVES OF AEOLIAN SANDS

The cumulative mass percentages were plotted against grain-size on linear graph paper. As an example, the typical size distributions of three samples are illustrated in Figure 5.1. The median grain size (50 percentile), the two quartiles (25 and 75 percentiles) and the 5, 16, 84 and 95 percentiles were obtained from cumulative curves for each sample. For purposes of this study, the following parameters (Folk & Ward, 1957) were computed for these percentiles:

$$\text{Median Diameter (Md)} = \phi 50$$

$$\text{Mean Diameter (Mz)} = \frac{1}{3} (\phi 16 + \phi 50 + \phi 84)$$

$$\text{Sorting or Inclusive graphic standard deviation (So}_2) = \frac{1}{4} (\phi 84 - \phi 16 + \frac{1}{6.6} (\phi 95 - \phi 5))$$

$$\text{Skewness (Sk}_1) = \frac{\phi 16 + \phi 84 - 2\phi 50}{2(\phi 84 - \phi 16)} + \frac{\phi 5 + \phi 95 - 2\phi 50}{2(\phi 95 - \phi 5)}$$

$$\text{Graphic Kurtosis (Kg)} = \frac{\phi 95 - \phi 5}{2.44 (\phi 75 - \phi 25)}$$

5.4.3 Results and discussion

In order to decide whether valid pedological deductions could be made from the size distribution, it was important to have some insight into the meaning of these parameters. Calculations of the measures in phi (ϕ) notations are given in Table 5.2 and a summary of values for these parameters in Table 5.3.

5.4.3.1 Mean grain size

Average grain size of the sand in a sediment is given by the median and the mean parameters. These parameters for a given sediment are influenced by source of supply, environment of deposition, etc. (Folk, 1966). According to Bagnold (1941) sand in saltation separates out in a diminishing wind into a series of accretion deposits, each having a smaller and smaller peak diameter as wind slackens. Grains coarser than $+1\phi$ will soon lag behind, whereas material finer than $+4\phi$ will be carried away in suspension. A systematic decrease in mean grain size in a certain direction will therefore indicate the direction of transport.

Table 5.2 - Grain-size parameters of the aeolian deposits

1. Red sands

Profile No.	Lab. No.	Md	Mz	So ₂	Sk ₁	Kg
7	17	2,25	2,32	0,70	+0,17	1,10
10	25	2,25	2,29	0,97	+0,13	1,03
11	30	2,25	2,29	0,78	+0,10	1,11
12	36	2,07	2,15	1,10	+0,16	0,97
	39	1,95	2,04	1,10	+0,26	1,03
13	43	2,25	2,18	0,99	-0,01	1,07
	46	2,23	2,20	1,03	+0,04	1,06
14	51	2,75	2,80	1,02	+0,05	1,35
	52	2,75	2,78	1,02	-0,01	1,43
	53	2,63	2,63	1,03	-0,05	1,39
18	64	2,64	2,71	0,79	+0,15	1,52
	67	2,63	2,70	0,75	+0,16	1,64
	69	2,57	2,65	0,77	+0,18	1,70
19	73	2,63	2,61	0,68	+0,25	1,28
	74	2,70	2,81	0,65	+0,19	1,45
	75	2,65	2,78	0,65	+0,39	1,65
64	78	2,60	2,65	0,76	+0,11	1,56
	79	2,60	2,71	0,77	+0,20	1,46
	80	2,63	2,65	0,79	+0,17	1,49
67	84	2,37	2,42	0,79	+0,17	1,05
	86	2,26	2,30	0,83	+0,18	1,14
70	89	2,26	2,32	0,84	+0,16	1,31
	91	2,31	2,36	0,81	+0,19	1,26
107	103	2,38	2,41	0,81	+0,15	1,16
	106	2,38	2,42	0,77	+0,13	1,25
	109	2,35	2,34	1,20	+0,01	0,96
114	112	2,43	2,41	1,24	+0,03	0,62
135	115	2,45	2,39	1,01	-0,05	1,11
	118	2,18	2,19	0,94	+0,08	0,94
137	121	2,27	2,23	0,95	+0,04	0,91
148	127	2,57	2,65	0,75	+0,19	1,39
	128	2,47	2,47	0,73	+0,07	1,43
	129	2,52	2,59	0,74	+0,15	1,41
149	133	2,43	2,44	0,77	+0,09	1,25
	136	2,41	2,41	0,77	+0,08	1,22
150	138	2,37	2,35	0,92	-0,07	1,11
	142	2,37	2,33	0,95	-0,02	1,23
153	145	2,56	2,62	0,72	+0,19	1,66
	148	2,57	2,59	0,72	+0,10	1,58
155	151	2,60	2,59	0,77	+0,01	1,60
	154	2,60	2,64	0,80	+0,07	1,66
157	161	2,55	2,53	0,74	+0,01	1,73
	162	2,53	2,48	0,86	+0,01	1,55
159	175	2,59	2,67	0,72	+0,22	1,67
163	191	2,65	2,72	0,69	+0,21	1,60
166	209	2,71	2,73	0,82	+0,05	1,55
168	217	2,63	2,80	0,80	+0,21	1,83

2. Yellowish sands

4	573	2,78	2,76	0,86	-0,01	1,02
5	577	2,48	2,54	0,97	+0,12	1,17
6	581	2,58	2,67	0,72	+0,22	1,38
8	9	2,26	2,33	0,73	+0,31	2,94
	11	2,28	2,29	0,64	+0,18	2,14
	13	2,27	2,35	0,66	+0,27	2,20
9	585	2,50	2,60	0,93	+0,17	1,08

Table 5.3 - Values of the parameters of the aeolian deposits

Parameter	Lower limit		Upper limit		Average	
	Red	Yellow	Red	Yellow	Red	Yellow
Median Diameter (Md)	1,95	2,26	2,75	2,78	2,46	2,45
Mean Diameter (Mz)	2,04	2,29	2,80	2,76	2,50	2,51
Sorting (So ₂)	0,65	0,64	1,24	0,97	0,84	0,79
Skewness (Sk ₁)	-0,01	-0,01	+0,39	+0,31	+0,11	+0,18
Kurtosis (Kg)	0,62	1,02	2,41	2,94	1,35	1,70

Grain size analysis of the samples shows that values for the median and the mean diameter are very similar for each sample (vide Table 5.2). The close similarity indicates that grain size distribution for most of the samples is very slightly asymmetrical. Mean grain size (Mz) of 47 selected samples of red sands examined, ranges from 2,04 ϕ (0,24 mm) to 2,80 ϕ (0,14 mm), with an average of 2,50 ϕ (0,18 mm). These values correspond well with those obtained by Harmse (1963) for sands in the North-Western Orange Free State. Values of this order are diagnostic of aeolian sand, which is in equilibrium with the limited capacity of wind (Doeglas, 1946 and Bagnold, 1941).

Mean grain size diminished from the Vaal River in a southerly to south-easterly direction (vide Figure 5.2). This decrease was measured over a distance of approximately 150 km and follows the spread of the red sandy deposits almost to their extreme easterly extent at Koffiefontein. The inference from such a diminishing mean grain size is that the sands were wind borne and that the Vaal River was the immediate source of the sandy material. Over the first 40 to 50 km mean grain size decreased fairly rapidly and thereafter tends to remain more or less constant. The initial rapid decrease is caused by selective lagging behind of coarser grains owing to difference in fall velocity between coarse and fine grains (Bagnold, 1941). Harmse (1963) also found a decrease in mean grain size down wind from the source of some sands in the North-Western Orange Free State. From a distance of some 50 km, mean grain size remains relatively constant towards the east. Minor variations between 2,56 ϕ and 2,80 ϕ may be attributed to admixture of local geological materials, e.g. Ventersdorp lava outcrops.

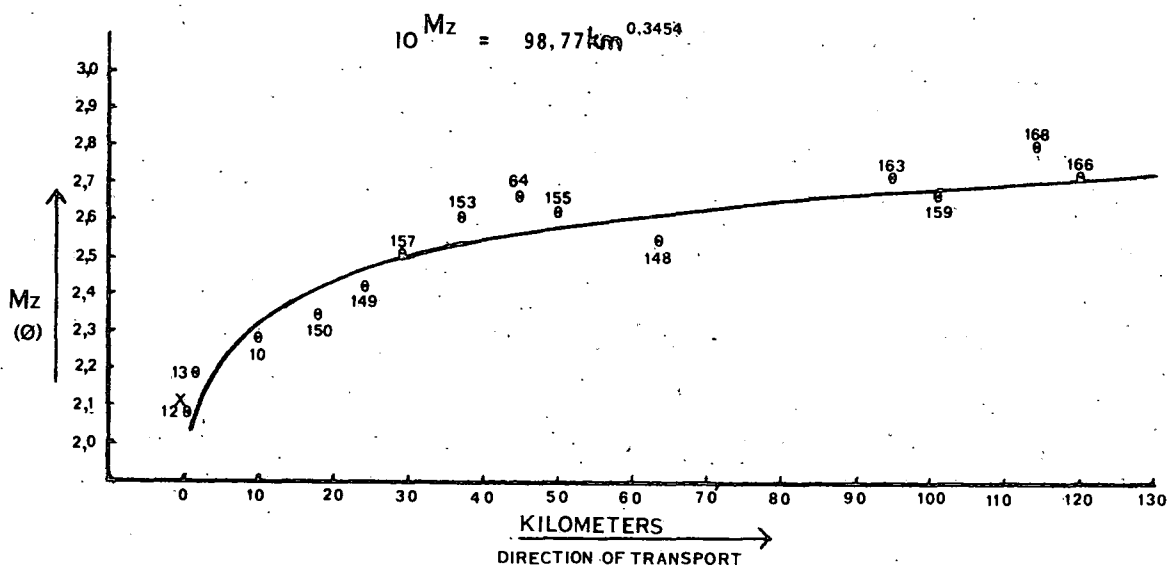


FIGURE 5.2 - DECREASE IN MEAN GRAIN-SIZE, WITH DISTANCE FROM VAAL RIVER, FOR THE RED SANDS. MZ VALUES REPRESENT AVERAGE OF ALL SUBSURFACE SAMPLES OF EACH PROFILE

X PROFILE NO.

In view of the limited occurrences of the yellowish Orange River aeolian sands, traverse sampling for the above purpose was not sensible. It is notable, however, that the average value for mean grain size of all red sandy samples (47 samples) is almost identical to the average value for the yellowish sands (7 samples) (vide Table 5.3).

5.4.3.2 Sorting

Degree of sorting of a sediment is determined by the standard deviation from its mean grain-size and is therefore a statistical measure of the dimensional spread. Sorting depends upon the competence of the transporting agent, distance of transportation and availability of material (Krumbein & Sloss, 1963). Wind has a limited carrying capacity and this capacity is subject to continual velocity fluctuations (Bagnold, 1941). The fine sand fraction is best sorted by wind, but the degree

of sorting is worse for both coarser and finer sediments (Folk, 1966). This results in limited grain-size ranges, provided negligible admixture from local sources took place.

Wind-blown sediments show improved sorting with distance from the source, in the direction of transport (Doeglas, 1946; Harmse, 1963 and Pienaar, 1969). Since mean grain-size decreases in the same direction, a relationship between mean-grain-size and degree of sorting for a particular deposit may be expected. Where a large deposit of aeolian sand occurs, a sequence of samples taken from the presumed source, in the direction of the presumed transport, should therefore yield a negative correlation between mean-grain-size and degree of sorting.

Sorting (S_{02}) of the red sands ranges from 0,65 ϕ to 1,24 ϕ with an average of 0,84 ϕ . That of the yellowish sands ranges between 0,64 ϕ and 0,97 ϕ , with an average of 0,79 ϕ . According to the classification of Folk & Ward (1957), the sands are moderately to poorly sorted, the majority, however, being moderately sorted. Comparing the sorting values for the red and yellowish sand respectively, differences between average values are relatively small, the yellowish sands being slightly better sorted.

Most significant of the sorting values of the red sands is that, in the immediate vicinity of the Vaal River, these sands are poorly sorted, but sorting improves with distance from the river (vide Figure 5.3). This may be attributed to improvement of sorting in the direction of transport by selective lagging behind of coarser grains (Doeglas, 1946). A south-easterly to easterly direction of transportation by wind is thus indicated.

5.4.3.3 Skewness

Skewness is a measure of symmetry of grain-size distribution curves (Folk & Ward, 1957). If the distribution is skewed, mean diameter departs from the median, and the extent of this departure may be used as a measure of skewness. Skewness measures have a zero value for a symmetrical size distribution. If the distribution is skewed towards smaller ϕ units, the ϕ mean is negative. Conversely

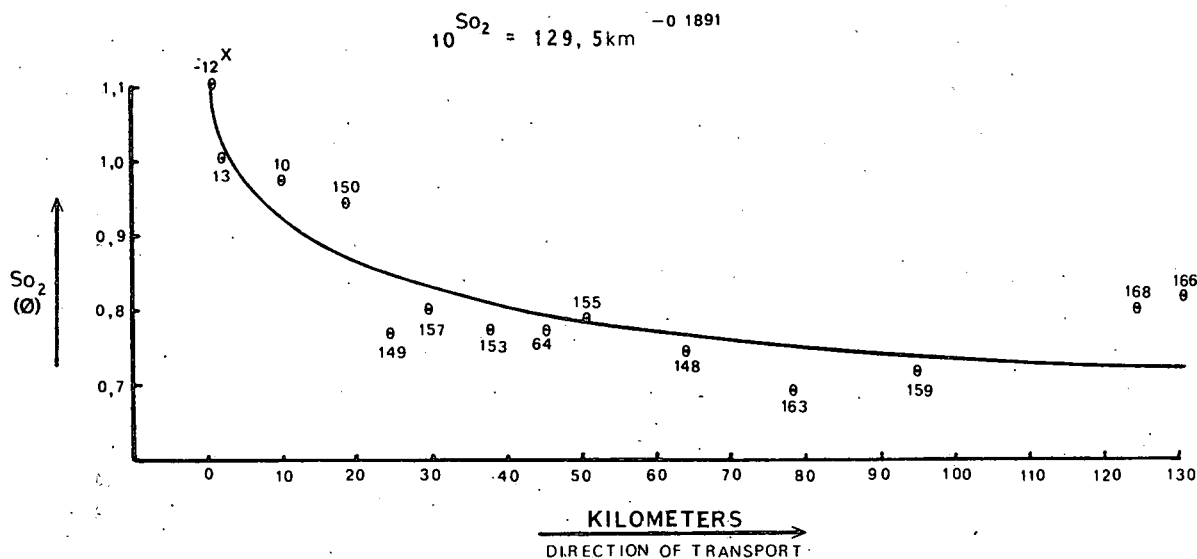


FIGURE 5.3 — INCREASE IN SORTING WITH DISTANCE FROM VAAL RIVER, FOR THE RED SANDS. So_2 VALUES REPRESENT AVERAGE OF ALL SUB-SURFACE SAMPLES OF EACH PROFILE.

X PROFILE NO.

the measure of skewness is positive for distributions skewed towards higher ϕ values.

Friedman (1961) showed that the majority of dune and river sands are positively skewed, whereas most beach sands are negatively skewed. The explanation for this observation is that wind and water transportation results from unidirectional flow and the lack of coarse material is due to the limited competency of the transporting agent. Negative skewness is due to opposite and unequal forces. To distinguish between dune and river sand, Friedman also stated that dune sands are better sorted than river sands. It would appear that skewness is the best interpretive measure to express influence of environment.

Skewness is positive for most samples, suggesting an environment of unidirectional flow by water and/or wind. Values (Sk_1) for the red sands range from $-0,01 \phi$

to +0,39 ϕ , with an average of +0,11 ϕ and for the yellowish sands from -0,01 ϕ to +0,31 ϕ , with an average of +0,18 ϕ . These values confirm that these sands have a near symmetrical size distribution (vide Section 5.4.3.1).

5.4.3.4 Kurtosis

Most measures of kurtosis reflect the ratio between spread in the central part of the distribution and spread in the tails (Folk, 1966). Kurtosis may be used as a test of normality of a distribution. As a measure to characterise sediments, the significance of kurtosis has not been clarified. Krumbein & Pettijohn (1938) remarked that little is known about the significance of kurtosis in sediments, but that it appears to be related to selective action of certain geological factors.

Most of the samples in this investigation have a kurtosis value $> 1,0 \phi$ (1,0 = mesokurtic). The sands are therefore leptokurtic which means that the central part of the curves is better sorted than the tails.

5.5 HEAVY MINERAL ANALYSIS OF THE SANDY DEPOSITS

The study of the mineralogical composition of superficial deposits, e.g. loess, desert sand, etc. has gained wide application by mineralogists. Many such deposits are, however, regarded by soil scientists as soil. The agricultural utilization of aeolian deposits necessitates a wider study of their morphological characteristics, mineralogical composition and origin. It is therefore logical that pedologists interest themselves in a sphere of study usually claimed by mineralogists and sedimentologists.

The sandy deposits in the survey area offer a good opportunity to bring together a study aimed at agricultural utilization and a basic study of aeolian sedimentology. Petrographical methods devised by sedimentary petrologists for the recognition of geological differences of sediments (Krumbein & Pettijohn, 1957 and Milner, 1962) are applicable to the study of soil horizons. These methods are employed to characterise sediments granulometrically (vide Section 5.4) and mineralogically. Traditionally the heavy mineral fraction (relative density $> 2,85$), although consti-

tuting a minor percentage of the total sand, receives most attention. The reason is the usefulness of this fraction for characterization of the deposit. Some of the heavy minerals, e.g. zircon, tourmaline, rutile, garnet, etc. are highly resistant to weathering and may survive more than one weathering cycle. Some are also known to be associated with specific primary rocks and may be used to trace the origin of sediments. Epidote, for example, is a major constituent of Ventersdorp lava but it is not highly resistant to weathering. Likewise, augite from dolerite weathers easily and is rare in old deposits. These two minerals are, however, abundant in sediments adjacent to Ventersdorp lava and dolerite respectively. The highly resistant minerals may persist through several weathering cycles and are usually widely distributed among sedimentary rocks. Certain sediments, however, can often be identified by their content of one or more resistant heavy minerals. Sediments of the Beaufort Series have characteristically relatively high garnet counts (Le Roux, 1969 and Theron, 1965 & 1970).

Heavy mineral studies conducted on the red and yellowish sandy deposits of the survey area were intended to throw light on their probable provenance. Information on the content of minerals which are likely to furnish plant nutrients could also be obtained. For this investigation fractionated fine sand samples obtained during the granulometric analysis of the listed profiles (vide Table 5.2) were used.

5.5.1 Procedure for heavy mineral separation

Deferrated samples of the 3,75 ϕ to 3,0 ϕ and 3,0 ϕ to 2,0 ϕ fractions respectively were used for heavy mineral separations. These fractions are of approximately the same dimensions as those used by Harmse (1963) and Piaget (1963) on sands of similar nature. The size of these fractions was also large enough to yield adequate quantities of heavy minerals for microscopic study.

In order to choose the more suitable separation method, a pilot study employing the gravity settling (funnel) method and the centrifuge method was conducted. The latter is described by Theron (1970). No significant differences in yield of heavy minerals, as a percentage of total sand, could be detected between the two methods (vide Table 5.4).

Table 5.4 - Comparison of funnel and centrifuge method on yield of heavy minerals in the 3,75 ϕ to 3,0 ϕ fraction

Sampe No.	Funnel method		Centrifuge method	
	Mass of sample (g)	Percentage	Mass of sample (g)	Percentage
86	0,0513	0,51	0,0525	0,53
89	0,3892	0,89	0,3937	3,94
93	0,4590	4,59	0,4592	4,59
109	0,2838	2,84	0,2642	2,64
Average	0,2958	2,96	0,2974	2,97

The funnel method was therefore chosen because of its simplicity and because more samples could be separated simultaneously. The method is briefly as follows: the total size fraction was reduced in size by means of a split-sampler to obtain a 10 g subsample. This 10 g sample was divided into two equal parts, 5 g being the optimum quantity for efficient separation in a funnel. In every case one 5 g subsample was first treated to judge visually the yield of heavy minerals. If an insufficient yield was obtained, the other 5 g was also treated or otherwise returned to the sample bottle.

Separation was effected by settling of the heavy minerals from 70 ml of bromoform (relative density 2,85 - 2,90) in specially constructed steep-sided separation funnels (40^o angle). Ten funnels could be handled conveniently. Intermittent stirring for six hours effected separation of a sufficient order of accuracy. The heavy mineral fraction was drained off into a small beaker, washed with alcohol and finally with di-ethyl ether. The residues of two subsamples, where applicable, were combined and weighed. The total heavy mineral fraction was calculated as a percentage of the total sand.

For microscopical identification and counting, portions of the 3,0 ϕ to 2,0 ϕ fraction were mounted on glass slides using Polyolith 710 A resin with 1% hardener. Heavy minerals were identified and counted under a petrographical microscope by

means of parallel line traverses. All grains touching the intersection of the cross hairs were recorded. Counting continued until 100 grains of non-opaque minerals were recorded. Grains of opaque minerals were simultaneously counted and finally expressed as a percentage of the heavy mineral fraction. Non-opaque grains with a turbid appearance were identified as alterites (Van Andel, 1958), consisting of aggregates and partly or completely altered non-opaque minerals.

5.5.2 Results and discussion

The most striking feature of the total heavy mineral contents of the yellowish and red sands, is the exceptionally high percentage in the former sands (vide Table 5.5). The yellowish sands are further exceptionally poor in opaque minerals and rich in pyroxenes. The red sands on the other hand contain rarely more than 5% total heavy minerals in the finer fraction (3,75 ϕ to 3,0 ϕ), the coarser fraction containing much less, average approximately 1,3%. Opaque minerals in these sands are much more in evidence, average approximately 50%. It is also noteworthy that the differences in total heavy mineral contents between the coarse and fine fractions of the red sands are much greater than those for the yellowish sands.

The fact that the yellowish sands contain such high percentages of heavy minerals and that these minerals consist predominantly of pyroxenes, is an indication of their mineralogical origin. The Upper Orange River catchment area consists entirely of Karroo sediments and basic rocks, viz. basalt and dolerite. Pyroxenes in the yellowish sands are therefore undoubtedly a product of basalt-dolerite weathering. Because these minerals are relatively easily weatherable, their presence in such large quantities confirms that the yellowish sands are younger than the red sands. Their confinement to a relatively narrow strip near the Orange River, prohibits traverse sampling over long distances and studies on selective deposition of heavy minerals. The paucity of other heavy minerals relative to pyroxenes further prohibits any conclusions from their distribution.

TABLE 5.5 - Heavy mineral analysis of the aeolian deposits

1. Red sands

Profile No.	Lab. No.	Heavy fraction ¹⁾ %	Opagues ²⁾ %	Non-opagues ²⁾ %	Alterites ²⁾ %	Zircon ²⁾ %	Tourmaline ²⁾ %	Rutile ²⁾ %	Garnet ²⁾ %	Epidote ²⁾ %	Pyroxene ²⁾ %
7	17	0,71 ³⁾ 3,95 ⁴⁾	61	39	21	13	8	5	15	15	23
10	25	0,31 1,83	54	46	23	20	10	11	11	17	7
11	30	0,61 2,04	40	60	30	10	7	3	12	12	26
12	39	0,29 1,58	40	60	24	12	10	8	18	23	5
13	46	0,52 2,71	35	65	15	8	6	8	15	9	39
14	51	2,19 3,07	38	62	17	2	0	2	0	3	76
	52	2,73 3,71	36	64	40	5	2	0	3	5	45
	53	3,23 4,55	27	73	14	0	0	0	1	1	84
18	67	0,51 2,35	57	43	23	9	5	2	5	54	2
19	73	1,77 4,25	44	56	22	4	2	0	2	4	66
	74	2,03 4,33	46	54	9	11	4	0	2	11	63
	75	2,20 4,35	37	63	13	3	3	2	3	5	71
64	78	1,18 2,81	34	66	11	3	3	3	1	79	0
	79	1,09 2,59	42	58	18	3	3	2	2	69	3
	80	1,23 3,36	40	60	12	5	2	2	2	71	6
67	84	0,53 2,85	63	37	14	11	11	11	24	8	21
	86	0,51 3,04	61	39	18	12	5	8	18	21	18
70	89	3,94 7,57	25	75	14	3	1	0	4	1	77
107	103	1,79 5,97	71	29	18	10	3	3	21	10	35
114	112	2,84 3,33	64	36	22	6	8	0	11	36	17
135	115	3,15 6,25	55	45	23	9	4	0	27	4	33
137	121	3,76 6,95	58	42	26	7	3	2	24	2	36
148	129	0,49 3,18	62	38	16	13	15	5	4	44	3
149	133	0,33 2,22	53	47	30	11	17	11	6	21	4
150	142	0,37 2,56	60	40	30	15	23	5	3	12	12
153	148	0,68 3,00	46	54	7	4	9	4	2	68	6
155	154	0,47 2,36	67	33	12	12	12	6	6	46	6
157	162	0,48 2,91	67	33	6	12	12	9	3	52	6
159	175	0,63 3,06	71	29	20	14	14	7	10	10	25
163	191	0,70 3,00	80	20	15	25	10	5	10	10	25
166	209	0,48 4,49	69	31	25	19	10	10	10	3	23
168	217	0,99 3,61	78	22	18	22	5	5	14	4	32
Average		1,33 3,24	53	47	19	10	7	4	9	23	28
2. Yellowish sands											
4	573	15,82 18,52	13	87	15	1	0	0	0	0	84
5	577	17,01 15,15	15	85	14	0	0	0	0	0	86
6	581	8,40 11,69	16	84	18	2	0	0	0	1	79
8	13	14,91 9,13	15	85	11	1	0	0	0	0	88
9	585	22,58 16,36	7	93	18	4	0	0	1	2	75
Average		15,74 14,17	13	87	15	2	0	0	0	1	82

1) Mass % of total sand

2) Count % of total heavy fraction

3) 3,0 φ - 2,0 φ fraction

4) 3,75 φ - 3,0 φ fraction.

The red sands are so markedly different in heavy mineral content and composition from the yellowish sands that their provenance must lie elsewhere. From granulometric and other evidence it was deduced that these sands were initially transported down the Vaal River and subsequently blown from the river bed towards the south-east. Since the catchment area of the Vaal River is geologically different from that of the Orange River, e. g. occurrence of rocks of the Transvaal and Ventersdorp Systems, it is to be expected that the red sands should yield different heavy mineral suites. Basic rocks in this catchment area are less plentiful than in the Orange River catchment. These sands have, as expected, low percentages of total heavy minerals. This is in accordance with findings of Harmse (1963), Piaget (1963) and Verster (1969) on red sands in areas towards the north of the survey area. Opaque minerals probably mostly magnetite and ilmenite abound in the heavy mineral fraction. In some profiles both total heavy mineral fraction and either epidote or pyroxene contents are relatively much higher than in others. Since many profiles distributed throughout the area contain few epidotes or pyroxenes, it can only be concluded that these minerals were not initially present in the sand before aeolian distribution. They must have been derived from local rocks and, through admixture, become part of the heavy mineral suites. From an examination of the physiography, it is evident that profiles with high epidote counts were invariably in close proximity to Ventersdorp lava, either adjacent to or overlying this rock or Dwyka tillite containing Ventersdorp lava debris. Epidote is a major constituent of Ventersdorp lava, but according to Harmse (1963) it is completely absent in Ecca and Beaufort sediments and occurs very rarely in "Kalahari" sands. Profiles with high pyroxene counts were similarly in the vicinity of dolerite. It must be pointed out, however, that "high" contents of pyroxene in the red sands are still very much lower in total mass than those of the yellowish sands.

According to the laws of sedimentation, small grains with high relative density, settle together with larger grains of low relative density (Van Andel, 1950). During aeolian distribution of sandy material it may be expected that heavy minerals of a certain size fraction would show a certain measure of sorting relative to quartz grains in the direction of transportation over long distances. Traverse sampling

failed, however, to show any trend in this kind of sorting (vide Table 5.6). Neither the coarse fraction, nor the fine fraction of the heavy minerals show any consistent decrease with presumed direction of transport as indicated by mean grain size decrease. The reason for this failure, is the amount of admixture with locally derived heavy minerals. From the data for resistant heavy minerals the zircon, tourmaline, rutile and garnet, very little information is gained. Zircon grains are relatively the most abundant of these four minerals. Their geographical distribution is consistent with the occurrence of geological strata, being most abundant in Beaufort sediments. From profile 163 to profile 166 (vide Table 5.6) occur nearest to Beaufort sediments. The other three minerals appear to be slightly affected by admixture, but no definite trends can be detected.

Table 5.6 - Heavy mineral data for profiles along a traverse

Profile No.	Heavy fraction		Zircon	Tourmaline	Rutile	Garnet	Epidote
	3,00-2,00 %	3,750-3,00 %					
12	0,29	1,58	12	10	8	18	23
13	0,52	2,71	8	6	8	15	9
10	0,61	2,04	15	13	11	11	17
150	0,37	2,56	15	23	5	3	12
149	0,33	2,22	11	17	11	6	21
157	0,48	2,91	12	12	9	3	52
153	0,51	2,35	9	5	2	5	54
64*	1,17	2,92	4	3	2	2	73
155	0,47	2,36	12	12	6	6	46
148	0,49	3,18	13	15	5	3	44
163	0,70	3,00	25	10	5	10	10
159	0,63	3,06	14	14	7	10	10
168	0,99	3,61	22	5	5	14	4
166	0,48	4,49	19	10	10	10	7

* Average of 3 horizons (vide Table 5.5).

From the foregoing it may be concluded that the red and yellowish sands are of different origin. The yellowish sands, although mineralogically strongly affected by basic rocks, may be regarded as younger aeolian material than the red sands.

5.6 GENERAL DISCUSSION

In this chapter several properties, and other features of the red and yellowish sandy deposits were discussed in order to find an explanation for their origin. From the colour and heavy mineral composition very little can be deduced as to provenance and properties of the initial material. It has been demonstrated that local rocks had a definite influence on the mineralogical composition and hence also on the colour, particularly in the case of the red sands. Ventersdorp lava and dolerite in the area exerted their influence upon these sands through weathering of their iron-bearing minerals providing iron oxides for the red colouration.

Without systematic sampling and analysis of sandy materials in the direction of any presumed or possible sources, no definite conclusion can be arrived at. Sands of a similar nature in the North-Western Orange Free State, presumably also transported by the Vaal River and subsequently by wind (Loxton, 1962 and Harmse, 1963) present an interesting comparison. Under the higher rainfall (Kroonstad, 600 mm/annum) these soils may assume paler colours from yellowish to brownish, than the red aeolian sands of the survey area (327 mm/annum). Outcrops of Ventersdorp lava and dolerite in the North-Western Orange Free State do, however, produce quite intense red colours in sandy deposits of this area. Generally the sands near the Vaal River in this area are rather paler in colour.

Sandy deposits in the vicinity of the Vaal-Riet confluence as well as those of Vaalhartz Irrigation Scheme are distinctly reddish in colour - more so than those of the North-Western Orange Free State. Traverse sampling proved that the intensity of the red colour generally increased towards the east, i. e. with distance from the Vaal River (vide Table 5.7). The frequency of occurrence of lava and dolerite outcrops in this area is, however, greater than that of the North-Western Orange Free State.

It is therefore not possible to come to any definite conclusion as to initial colour, influence on colour by transporting agent and colouration subsequent to deposition. It seems probable that sands transported by the Vaal River and further distributed by aeolian action must have had at least an initial iron oxide coating, hence the universal reddishness of all associated deposits in the survey area, whether in direct contact with dolerite and lava or not.

Table 5.7 - Colour of travers samples of Hutton soils in south-easterly direction from Vaal River

Profile No.	Munsell notation		Distance km
	Dry	Moist	
12	5YR 4/8	5YR 4/8	0,5
13	5YR 4/6	5YR 4/8	1,5
10	5YR 4/8	5YR 4/8	10,0
150	2.5YR 5/8	2.5YR 4/8	18,0
149	5YR 5/8	2.5YR 4/6	24,0
157	5YR 4/6	5YR 4/6	29,0
153	5YR 4/6	2.5YR 4/6	37,0
64	2.5YR 3/6	2.5YR 3/6	45,0
155	2.5YR 4/6	2.5YR 4/6	50,0
148	2.5YR 4/6	2.5YR 4/6	63,0
163	2.5YR 4/8	2.5YR 3/6	95,0
159	2.5YR 4/6	2.5YR 3/6	101,0
168	10R 3/6	10R 3/6	114,0
166	10R 4/6	10R 4/6	120,0

A possible source for the red sands of Vaalhartz and those of the survey area lies in the catchment area of the Hartz River. This does not exclude sorted sands from any other source in the catchment area of the Vaal River.

At present there is little evidence of an appreciable transport of sandy materials by the Vaal River and its tributaries. The Hartz River rarely comes down in flood to transport sand. It is postulated, however, that during former pluvial periods a major transport of sand by river action took place (Söhnge & Visser, 1937; Brain, 1957; Clark, 1959; Boocock & Van Straten, 1962; *inter alia*). On the other hand, it is generally accepted that large scale aeolian shifting of sand takes place during interpluvials. These two conditions appear to oppose each other as an explanation for the distribution of the red sandy materials. In view of the observed present day distribution of Orange River borne sand at the Orange-Vaal confluence, it is possible that rivers with perennial flow can transport large quantities of sand during floods. This sand can be deposited as river-bed sand banks at situations favourable for deposition (*vide* Section 5.2). Such a situation is provided by the Vaal-Riet confluence, and the

Vaal-Hartz confluence. During dry seasons north-westerly winds can blow the sand from these river-bed deposits. An explanation for the absence of any noticeable present-day sand transportation and distribution via the Vaal River is lacking. Climatic conditions are apparently favourable as proved by the deposition and distribution of Orange River borne sand. It may be possible that present rainfall in the Hartz River catchment area is not sufficient for large scale erosion and transport of sandy material.

Accepting that the red sands were distributed and deposited during Tertiary and Pleistocene times (Söhnge & Visser, 1937; Brain, 1957; Clark, 1959; Boocock & Van Straaten, 1962; Harmse, 1963; Du Toit, 1966. *inter alia*), these deposits should exhibit features consistent with their age and long-term influence of their environment. Where left under a natural vegetation, these deposits are largely stabilized. Definite dune-like features are absent and water erosional influence is more pronounced than aeolian influence. Mineralogically they are influenced by local base rocks. This is also demonstrated by more intense red colours where weathering of rocks rich in iron-bearing minerals occur in their vicinity. From all these it may be concluded that these red sands were deposited a long time ago and that after deposition and stabilization water erosion was more pronounced than aeolian redistribution.

Geographical situation and granulometric data, both indicate that the red sands were finally distributed through aeolian action from the Vaal River in a south-easterly direction. Diminishing grain size and improved sorting from the immediate vicinity of the Vaal River towards the south-east is taken as proof of direction of transport (*vide* Figures 5.2 and 5.3). It is noteworthy that mean grain size and degree of sorting are significantly correlated for these sands along direction of transport ($r = -0,85$), i. e. as grain size decreases with distance, degree of sorting improves (*vide* Figure 5.4).

At this stage it is necessary to consider the other extensive deposit of red sands in the survey area south of the Orange River (*vide* Section 5.2). In the foregoing paragraphs it was stressed that the origin of the red sands may be traced at least to Vaal River transportation. The last mentioned deposit appears to be disconnected

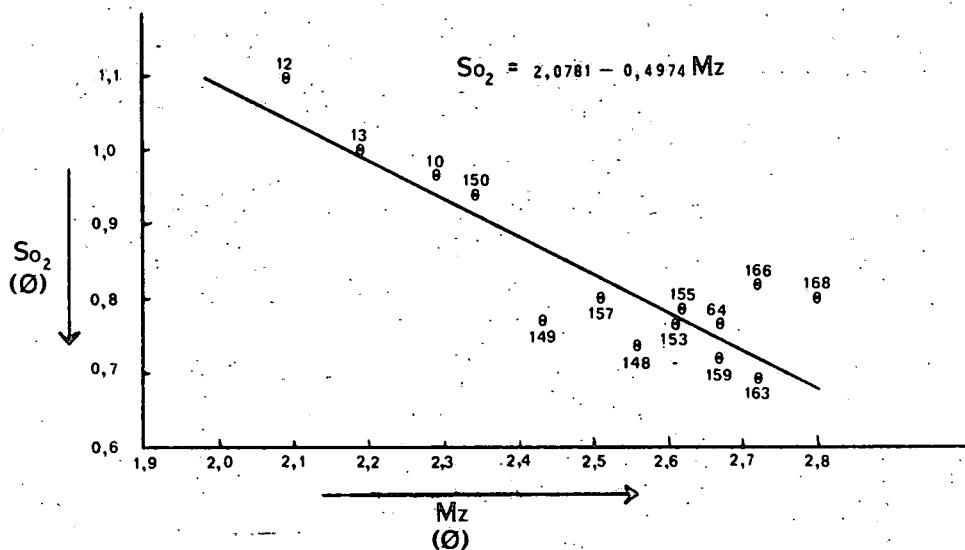


FIGURE 5.4 - MEAN GRAIN SIZE VERSUS SORTING FOR THE RED SANDS

from Vaal River influence. It is significant, however, that this deposit extends eastward from the Orange River where its course follows a south-westerly direction and allows westerly winds to cross its course. Furthermore, this deposit extends eastward from another significant confluence, i. e. the Orange-Brak confluence. It may thus be reasoned that during the time when the other sands were deposited, some sand could have been transported further along the Vaal and Orange Rivers, deposited here, subsequently blown out by westerly winds (vide Section 2.1.3) and distributed eastwards.

Although no definite conclusion, as to the primary origin of the red sands, could be reached, it may be stated with confidence that these sands were largely influenced by mode of transport and geological formations on the course of transport. Some occurrences of sand were even affected by local rocks after deposition. Despite this evidence of admixture, the red sands are extremely poor in weatherable minerals. They are also generally deficient in both major and minor plant nutrient elements.

In contrast with these, the yellowish sands of Orange River origin are exceptionally rich in weatherable minerals, notably augite and related pyroxenes. These mineral grains are in all stages of weathering and, given long enough time, should ultimately weather out completely with formation of clay, iron oxides etc. On the other hand, these sands are at present still added to by new aeolian deposition.

CHAPTER 6

THE SOILS IN RELATION TO IRRIGABILITY

6.1 INTRODUCTION

Soil and water management have long been recognised as perhaps the most important factors affecting yield and quality of arable crops. The importance of these two factors is well illustrated when the complex interrelationships, which exist within the dynamic system soil-water-plant is considered, and how a variation in one factor can change the overall equilibrium of the system.

In irrigation practice water is most often brought from a high rainfall region and large storage dams to soils in semi-arid to arid regions. Provided large areas of soils of good irrigable quality are available, an agreeable combination of water-soil-climate-plant is often found. The climate of semi-arid to arid regions is suited to many crops traditionally cultivated under irrigation, e. g. groundnuts, lucerne, cotton and many vegetable, horticultural and grain crops. Solar energy radiation is unrestricted and damage by untimely rain, especially during harvesting, is limited, but hail damage may be a hazard. Windblown sand in such regions may also damage crops.

A major deciding factor in the selection of areas for irrigation is conveyance of irrigation water. To convey water under gravity in canals means that the irrigation areas must lie down-stream from the storage. In planning the Orange River Development Project it was obvious that irrigable soils were to be sought towards the West of the Hendrik Verwoerd and P. K. le Roux Dams. The reconnaissance survey on which this study is based, was therefore, conducted in this area. Soils suitable for irrigation could be identified and earmarked for further intensive surveying and characterisation for irrigation development.

There are no ideal soils for irrigation. Any given soil has one or more properties which may, at some stage, prove disadvantageous to irrigation. Soil properties may be adversely affected during longterm irrigation; to list but a

few: alkalinity, salinity, waterlogging, excessive drainage, poor drainage, low waterholding capacity, shallowness, impermeable layers, stratification, stoniness, excessive slope, calcareousness, acidity, toxic substances, infertility etc. Some of these maladies may be ameliorated either by drastic treatment or by judicious management; others are incurable by general economic standards. There are, however, many soil types in a region such as the surveyed one. Some of these soils are incurably unsuitable for irrigation, others have less or no incurable adverse properties. Chemical infertility, for instance, is the least objectionable property. It can be easily cured by chemical fertilizers.

In the selection of soils for an irrigation scheme in a given region, it is most unlikely that any sufficient acreage with no shortcomings will be found. Through surveying and identifying all the soils in that region a balance sheet of properties will show those soils which may be safely developed and those likely to fail under irrigation practice.

Considering the choice of soils for irrigation development, Huffman (1953) stated: "The land is of equal importance with water in the development of irrigation projects. Many irrigation projects have failed or faced serious problems because the land was not studied sufficiently before it was determined that a project should be constructed. The type of soil, its susceptibility to irrigation, and the availability of drainage, as well as the topography are more important in the ultimate success of irrigation projects than are considerations of engineering feasibility McMartin describes a Department of Agriculture soils survey of the Belle Fourche Area of South Dakota published in 1908 as having been too little and too late It was too late because the project was under construction two years before the soils survey was made and water was available eight months before the results of the soil survey were published. It was too little because the author did not positively state that the clay soils were not irrigable, though it was evident from reading between the lines of the report that he had grave misgivings about their suitability".

Scrutiny of the literature reveals that many, if not all, irrigation projects in arid and semi-arid climatic regions of the world are afflicted by poor

soil conditions (Huffman, 1953; Thorne & Peterson, 1954 and Kovda, 1964). These soil conditions are closely associated with soil-forming processes under such climates, viz. inadequate leaching of dissolved weathering products and the formation of 2:1 expanding lattice type clay minerals. Excessive salinity and/or poor internal drainage of such soils are usually the cause of failure under irrigation and are further aggravated by irrigation. Thorne & Peterson (1954) listed problems encountered by irrigation technologists the world over. The most common were waterlogging and salinity in all arid and semi-arid regions.

Discussing the threat of poor drainage, waterlogging and salinity to irrigation projects, Olivier (1962) gave the following example: "A comprehensive survey of the Indus Plain made seven years ago showed that 11.3 million acres were waterlogged or poorly drained, and another 4.8 million acres were severely saline and 11.2 million acres had saline patches. It is now estimated that approximately 100,000 acres a year are lost through the spread of waterlogging and salinity, which accounts for the 1,000 million dollar reclamation programme just announced. Such problems are generally most serious in the flat plains of the lower reaches of the river..."

It is thus clear that past and present irrigation practices in many parts of the world, and especially those situated in arid and semi-arid regions, have taught man to consider all factors which may affect the ultimate success or failure of such projects. Apart from economical, sociological and husbandry factors, the most fundamental factor is probably the soil to be irrigated.

6.2 FACTORS INVOLVED IN IRRIGABILITY OF THE SOILS

From the preceding and from experience gained during the survey of certain irrigated soils within and adjacent to the survey area, it is deemed necessary to consider some basic requirements in the evaluation and selection of soils suitable for irrigation. These requirements may be grouped under physical conditions and chemical properties. Not all the aspects are of immediate or potential danger rating for all soils identified. Some aspects are, however, of immediate concern should, these soils be brought under ir-

rigation. Others are likely to acquire danger proportions during the course of time under irrigation.

6.2.1 Soil physical conditions

The intrinsic properties of undeveloped or virgin soils are a good starting point for the evaluation of such. They also afford a means to predict the behaviour of a given soil when such a drastic change in milieu as irrigation is brought about. In this instance it is the physical conditions which are a deciding factor. Movement and retention of water and air in the soil mass affect plant growth not only directly, but also through their effect on native and applied nutrients. Accumulation or leaching of undesirable soluble salts are also affected by the physical conditions.

6.2.1.1 Soil texture

The balance between movement and retention of water and air is dependent upon the balance between micro and macro pores. Although structure affects the soil pores, it is a property easily changed under cultivation - mostly adversely. Texture, however, is a stable property and is by and large the determining factor in pore space division.

Considering the soils of the Central Orange River Basin in light of water movement and retention there is an overwhelming preponderance of the two extremes, viz. sandy soils and clayey soils. The former are well drained and well aerated, but have a low waterholding capacity; the latter are poorly drained and aerated, but have a high waterholding capacity. Medium-textured soils are scarce and mostly confined to small areas of river valley alluvia.

A choice between the sandy soils and clayey soils of the area, based merely upon texture and not upon other considerations, is by no means obvious. An indication towards which soil the choice should be made, is afforded by a clayey Ongers River alluvium on the Smartt Syndicate Irrigation Scheme. Infiltration into this soil is so slow that water was still standing on a field three days after a heavy application of water. Depth of penetration was only 5 cm to 6 cm.

Field capacity at root depth was seldom if ever reached and most of the irrigation water was lost through direct evaporation. Run-off losses during rains are excessively high on unlevelled soils.

On the other hand sandy soils in this region absorb practically all water falling upon them even in heavy showers. Field capacity is reached within hours after rain showers. Despite their low waterholding capacity the sandy soils remained moist for considerable periods after the summer rains. During the survey profile pits revealed moist soil down to 2 m depth, even after prolonged rainless periods. Generally sandy soils dried out quickly to approximately 10 cm to 15 cm. At depths below 15 cm the soil only loses moisture through transpiring plants.

With a view to cultivation sandy textured soils are also preferable to the clayey soils. The latter all contain expanding lattice 2:1 clay minerals, which are known to possess properties hampering cultivation and seed bed preparation. Sticky point, plasticity, clod formation are all associated with clay content and the worst physical conditions are related to expanding lattice clays.

Poor root development of crop plants was encountered on both clayey and sandy soils. In the former this malady could be ascribed to poor aeration and perhaps high soil strength, both associated with poor structure. The sandy soils on the other hand are quite well supplied with air, even at or above field capacity. High soil strength values, above which normal root growth is stopped, have for the past few years caused much concern on irrigated sandy soils. These high values are probably the result of a combination of factors, e. g. homogeneous grain size (50% or more in one phi unit size), virtual absence of structure formation, cultivation with disc implements and compaction by heavy implements. Cotton, wheat, groundnuts and maize are known to suffer heavily from poor root development on the sandy soils of the Vaalhartz and Riet River Irrigation Schemes.

6.2.1.2 Soil depth

For optimum crop growth a reasonable depth of the solum is required and this depth must be occupied by soil material of a reasonably homogeneous texture. Depending upon the type of crop, it is generally taken that a solum

depth of at least 1,5 m should be maintained. Any impermeable layer, e. g. dense clay, calcrete and solid rock within that depth is a disqualification. Not only is root growth hampered, but free water movement is restricted and waterlogging is inevitable.

Unless over-irrigation is limited to the absolute minimum or artificial drainage is installed, a soil depth of 1,5 m is inadequate. Sandy soils underlain by impervious calcrete at depths exceeding 3 m have already been waterlogged to within the root zone at Vaalhartz and Riet River. Uncontrolled flood irrigation without artificial drainage is the cause.

Deep boreholes at several localities in the red sandy soils prove that these soils may reach depths of up to 30 m. Such depths are naturally more than even the most deep rooted plant can utilize. It may, however, serve as a drainage reservoir and could reduce capital outlay on drainage systems. Sandy soils of less than 1,5 m should, however, be treated with the utmost care. If utilized, management must be of a very high order of efficiency.

6.2.1.3 Soil moisture

A further consideration of the moisture characteristics of these soils in relation to their irrigability, is focused upon their waterholding capacity, field capacity, wilting coefficient, drainage properties, etc. For irrigation a soil needs to absorb applied water at a rate of at least 7 mm per hour. It needs to retain a reasonable quantity of available water to provide for crop consumption. This quantity of water is dependent upon field capacity and wilting coefficient, i. e. quantity of available water, crop grown, development stage of crop, root depth and meteorological conditions, i. e. rate of evapotranspiration. Frequency of water application, from a practical viewpoint, should not be less than 10 days.

The clayey soils, e. g. Brak and Ongers River alluvium Willemsdal and Katspruit soils, possess waterholding capacities of a high order. Field capacity values range from 15% to 24% (Van der Merwe, 1971 - personal communication). Evaluation based merely upon field capacity is, however, misleading.

These clayey soils are liable to either slow water penetration (vide Section 6. 2. 1. 1) or waterlogging. They are further subject to cracking, which leads to quick drying out of the subsoil. With their high wilting coefficient (8% to 12%) (Van der Merwe, 1971 - personal communication) and consequent poorish available moisture capacity, these soils have by no means an ideal soil moisture regime.

On the other hand the sandy soils, viz. Clovelly and Hutton soils, have field capacities ranging from 5% to 12% (Bennie, 1971 - personal communication). They do not suffer from slow penetration and excessive drying due to cracking. Unless impermeable calcrete occurs at shallow depths, waterlogging is not a hazard. Wilting coefficients range from 1,5% to 4,5% (Bennie, 1971 - personal communication). It is therefore clear that the sandy soils with their considerable depths of storage, have none too poor a moisture regime. In the field this fact was observed time and time again, namely that deep sandy soils were generally moist, compared with the clayey soils which were generally droughty.

Presently irrigated Hutton soils on Vaalhartz and Riet River Irrigation Schemes nevertheless prove to be inadequate in so far as waterholding capacity is concerned. Combined with the afore-mentioned soil compaction and consequent shallow rootedness of crop plants, this disadvantage of the sandy soils must not be overlooked. Since texture and waterholding capacity of a soil cannot be altered in practice, these sandy soils need amelioration with regard to soil strength and root penetration. Work under progress in the Department of Soil Science, University of the Orange Free State, strengthens confidence that this problem may be overcome by management practices.

The method of water application also needs consideration. In view of the excessive infiltration and drainage properties, these sandy soils must under no circumstances be flood irrigated. This method of irrigation leads to uncontrolled over-irrigation, wastage of water, waterlogging and wastage of plant nutrients. Control of quantity of water applied and rate and uniformity of application must be made possible by the method of irrigation, i. e. either sprinkler or drip irrigation.

6.2.1.4 Topography, waterlogging and salinity

"Flat land may look deceptively easy to the uninitiated, but it may be the hardest and most expensive to develop" (Zimmerman, 1966). In irrigation practice, topography of the area under development determines the feasibility of large scale irrigation. Excessively flat topography often is the cause of poor drainage conditions and waterlogging. Too steep slopes on the other hand are not suited to irrigation practice unless terracing is possible. Moderate slopes are necessary for external drainage of floodwaters and disposal of seepage through artificial drains.

An example of drainage, waterlogging and salinity problems on excessively flat land is provided by the Indus Plain Irrigation Project (vide Section 6.1). Conditions approaching those on the Indus Plain are found here on the clay plains and on the floodplains of the Brak and Ongers Rivers and also to some extent along the Orange, Vaal and Riet Rivers. In addition to the topographical hazard, the soils on these plains are afflicted with poor textural and high salinity hazards. Irrigation of these flat, clayey, saline soils will inevitably result in conditions similar to those described by Olivier (1962) for the Indus flats. Artificial drainage is virtually impossible and without sufficient drainage amelioration of saline conditions is also impossible.

It is paradoxical that in the dry region of the Central Orange River Basin on the clayey soils with restricted internal drainage, waterlogging conditions could be found. During the survey Katspruit soils with permanent water-tables under natural veld conditions were encountered. Such a water-table presumably develops on an impermeable subsoil, Karroo shales and mudstones. Since these Katspruit soils occur in the bottommost situations in the landscape (apart from the pans), they collect most of the rain water. Although infiltration is slow, they can apparently accumulate sufficient soil water to over-saturate the deeper substrata immediately above the impermeable shales and mudstones. The most disturbing aspect of these permanent water-tables is that the water and subsoil are extremely saline. From an ameliorative viewpoint these soils may be regarded as "impossible" soils.

Willemsdal soils and clayey alluvia situated on very level flats may equally be regarded as "difficult" soils with regard to irrigation. Soluble salts are abundant in both soil and underlying sediments (vide Sections 3.3.4 and 4.2.4). Again, poor drainage, waterlogging and salinity go hand in hand where such soils are brought under irrigation.

Waterlogging and saline conditions have already developed on soils of this type in three major localities in this region. Some clayey alluvial soils of the Smartt Syndicate, Riet River and Bucklands (Douglas) Irrigation Schemes are fast coming to a state of permanent ruin and abandonment. It may be stated with confidence that many soils of the Smartt Syndicate are presently still in production only because the supply of water from the storage dam has never been adequate. At Malabar, Blakelow and Atherton farms (Douglas) where supply of water is more than adequate, waterlogging and salinity have taken on a very serious threat over a considerable area. Waterlogging under these conditions is of a periodic nature where the water-table rises to within 0,60 m of the soil surface. This rise depends upon application of irrigation water and rainfall. A survey showed that during dry periods the water-tables retreated to deeper levels and soluble salts increased in the upper layers due to capillary rise and drying out. In some areas salt crusts formed on the surface during such dry periods. Figure 6.1 shows schematically a probable situation should soils of the clay plains be irrigated.

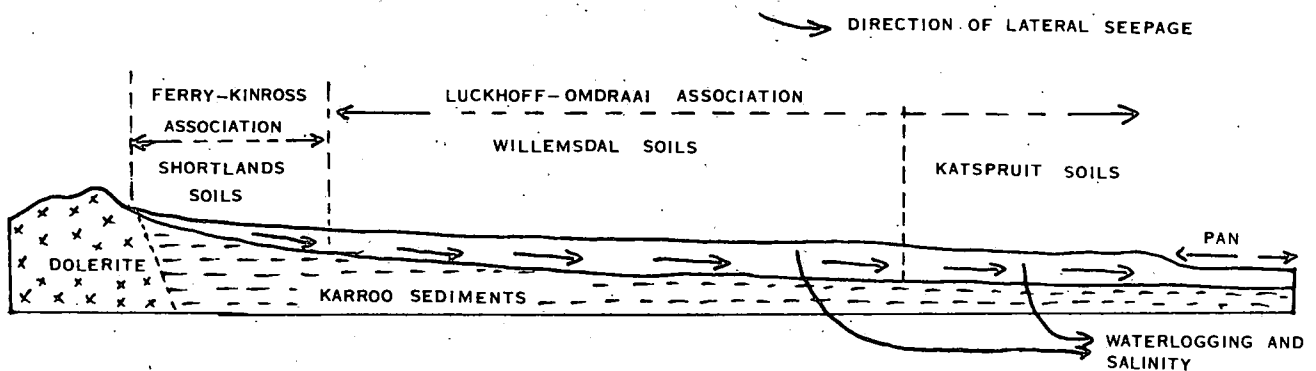


FIGURE 6.1- SCHEMATIC CROSS-SECTION OF CLAYEY SOILS ON KARROO SEDIMENTS

The preponderance of saline crusts and salinity conditions in soils of especially the area around Prieska, Britstown, Strydenburg and Hopetown is expressed in local place names, e. g. Brak River, Sodium, Salt Lake. etc.

In contrast to the level clayey soils, sandy soils of the Hutton and Clovelly forms are inherently non-saline and generally occur in well drained situations. They lend themselves to an easily executed artificial drainage system. Slopes are moderate which preclude large scale levelling and terracing especially with a view to sprinkler irrigation. Sandy soils of less than 2 m depth on impermeable calcrete are subject to waterlogging should uncontrolled flood irrigation be practised. In Figure 6.2 a schematic illustration of the occurrence of a sandy deposit of Hutton soils on calcrete is given. It is obvious that over-irrigation may easily lead to lateral seepage and accumulation of water in lower lying soils and will give rise to water-table development. It is known that calcrete occurs as a continuous wavy substratum under sandy deposits (vide Plate 7). At Vaalhartz Irrigation Scheme accumulation of water in the troughs of this wavy calcrete layer is the most serious cause of waterlogging. Installation of a proper drainage system should, however, overcome this problem.

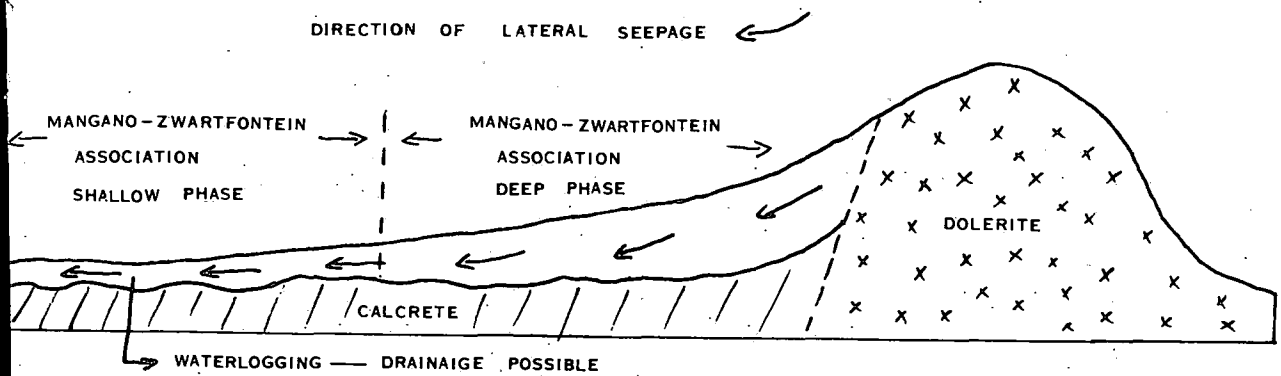


FIGURE 6.2— SCHEMATIC CROSS SECTION OF HUTTON SOILS ON CALCRETE

6.2.2 Plant nutrient status of the soils

The plant nutrient status of any soil, whether cultivated or utilized in its natural state as pasture, needs consideration. Not only the size of yield produced, but also the quality is of importance. In irrigation farming plant nutrient status is of much greater significance, since the physical environment for the plant is made as near to optimal as possible. A deficiency in one or more plant nutrients or a state of unbalance among nutrients have a much greater and more immediate influence on plant growth.

By means of modern techniques, e. g. soil analysis, pot experiments, field trials and tissue analysis, any real or potential deficiencies in nutrient status may be identified in time. Many such deficiencies may easily be rectified even before the first crop is planted on newly developed irrigation soils. Fertilizers are inexpensive compared with capital expenditure invested in development of an irrigation scheme. Moreover, fertilizer costs are a trifle against large scale reclamation of physically unfavourable soils, e. g. saline-alkaline clay soils.

The soils of arid and semi-arid regions are as a rule, well supplied with most of the essential plant nutrients. Such soils suffer little loss of solubilized nutrient compounds through leaching. Weathering products tend to accumulate in the solum. Depending upon the mineralogical composition of the rocks, the resultant soils differ little in chemical composition from their parent materials. It is, however, unfortunate that undesirable soluble salts, especially those of sodium and magnesium, also accumulate in the solum. Calcium carbonate is also often present in concentrations which are unfavourable for most crop plants. Therefore, although most arid and semi-arid region soils are rich in plant nutrients, conditions in them may cause the non-availability of one or more nutrients, notably zinc, copper, manganese and iron. Boron toxicity is not unknown in the Orange River Basin.

Soils in this region derived from local Karroo System rocks may all be classed as highly fertile. Fertilizers are, as a rule, not used by farmers on local irrigation projects. Soils of Shortlands, Willemsdal and Katspruit forms

and the alluvial soils are rich in exchangeable cations (vide Appendix 1). Available phosphate content of virgin members of these soils range from 0 to 5 ppm (Van der Merwe, 1971 - personal communication).

Total nitrogen which is mainly contained in the organic matter fraction is generally low (vide Appendix 1), but due to the high mineralisation rate of organic matter, soils upon cultivation yield ample nitrogen to crops grown. The most serious shortcomings of these particular soils are associated with their calcareous nature, salinity and high pH, which cause minor-element disorders.

In contrast to the soils derived from Karroo System rocks, the sandy soils of Hutton and Clovelly forms are inherently infertile. Hutton soils are extremely deficient in available phosphate and virgin soils often contain less than 1 ppm NaHCO_3 , soluble P (Olsen's method) (Du Plessis & Burger, 1965 and Botha, 1971). Exchangeable cation contents are in keeping with the clay contents, viz. Shorrocks series soils have C E C values of up to 11,5 me/100g and are often fully saturated with cations. Gaudam and Roodepoort series soils have clay contents of less than 6% and are correspondingly poor in exchangeable cations. A notable feature of these soils is that they often contain more exchangeable Mg^{++} than Ca^{++} . Availability of K^+ may under these circumstances be inadequate to certain crops. Cotton plants suffering from red leaf disease on Mangano soils at Vaalhartz Irrigation Scheme generally contain K at a deficiency level and correspondingly higher Mg levels (Laker, 1971 - personal communication).

Botha (1971) made a survey of the plant nutrient status of a number of Hutton and Clovelly soils. He concluded that these soils are adequately supplied with most of the major and minor plant nutrients, with the exception of P, N and Zn. These deficiencies are easily rectified by normal fertilizing practices.

The major qualification of these soils, from an irrigability viewpoint, is their freedom from soluble salts and especially exchangeable Na^+ and sodium salts. With the exception of one horizon sample, exchangeable plus soluble Na^+ , in soils analysed, never exceeded 0,8% of the total cations (vide Appendix 1).

6.3 CONCLUSION

In the introduction to this chapter it was stated that there are no ideal soils for irrigation. Comparing the different soils identified in the survey area, it may be stated with more confidence that in this area no ideal irrigation soils were found. Discussions on soil properties dealt with the pros and cons of each soil type with regard to irrigability. It is evident that the soil types which lend themselves best to management are to be selected for irrigation development.

The sandy soils are therefore unequivocally recommended. Alluvial soils along the Orange and Vaal Rivers which have a relatively sandy texture, are also regarded as suitable for irrigation. Their recommendation depends, however, upon topographical site, drainage potential etc. Heavy clay alluvial soils, and especially those along the Brak and Ongers Rivers cannot be recommended for irrigation for the same reasons as for the Shortlands, Willemsdal and Katspruit soils.

In the legend to the soil map soil associations and appropriate depth phases, as well as land classes, are summarized with regard to map symbol, short description of soil types, irrigation value (Louw, 1955) and total area of each mapped (ha).

SUMMARY

A reconnaissance soil survey of the Central Orange River Basin was carried out at the request of the Department of Water Affairs. The objective was to identify and select soils suitable for irrigation under the Orange River Development Project. An area of 3,1 million hectares was demarcated in the South Western Orange Free State and Northern Cape Province.

The first step was to identify soil series. Since no classification system was in current use with the commencement of the survey in 1964, soils were preliminarily identified and given series names. With the introduction of the proposed soil classification system of the Soil and Irrigation Research Institute, the identified series were easily accommodated in this system.

Field work consisted of an initial reconnaissance of the whole area and identification of soil types by examining a large number of profiles. Identification of soil types was at the series level and mapping at the soil association level. Field mapping was done on air-photos (1:36 000) and on 1:50 000 topo-cadastral maps. A final soil map with scale of approximately 1:320 000 was drawn up. Seventeen soil series of six soil forms were identified and mapped as associations, with depth phases of two forms, viz. Hutton and Clovelly. Soils shallower than 0,45 m were classed as shallow soils and mapped together with stony soils.

During the soil survey a study was made of the environment: climatic, vegetational, geological and physiographical data were collected. The salient features of these data are:

- (i) Climate - The area has an arid to semi-arid climate, with an episodic summer rainfall. Temperature fluctuations between both night and day and winter and summer are large. Annual rainfall varies between

250 mm in the south-west and 400 mm in the north-east. Relative humidity is low and prevailing winds are north-westerly to westerly.

- (ii) Vegetation - Vegetation is generally sparse ranging from karroo shrub veld to acacia grass savannah. Vegetation has little influence on soil formation and is itself largely influenced by soil type. Acacia giraffae for instance is closely associated with deep Hutton soils, Rhigozum trichotomum with shallow Hutton soils and Atriplex species with clayey saline soils.
- (iii) Geology - The geological formations of the area consist mainly of Karroo System sediments with numerous dolerite sills and dykes. Ventersdorp lava, granite, banded ironstones and dolomite are of minor areal distribution. Large tracts of aeolian deposits are widely distributed. Surface deposits of limestone are widespread and originated from basic igneous rocks.
- (iv) Physiography - The area has a generally low relief with many isolated hilly features. No large mountains occur anywhere, except for the Asbestos Mountain Range near Prieska. Several landscape forms were identified, viz. mountains and hills, undulating plains with minor knolls and ridges, sand plains, river floodplains, clay plains, calcareous plateaux and pans. Surface drainage has a low density and the area is drained by the Orange and Vaal Rivers and their tributaries.
- (v) Soils - The soils identified during the survey are tabulated below:

Soil forms	Soil series	Prominent characteristics and origin
HUTTON	Mangano	Red, apedal, sandy soils, non-calcareous, non-saline. Aeolian sands.
	Zwartfontein	
	Roodepoort	
	Gaudam	
	Shorrocks	
CLOVELLY	Bleskop	Yellowish, apedal, sandy soils, calcareous, non-saline. Aeolian sands.
	Torquay	
	Oranje	
	Vaalbank	
SHORTLANDS	Ferry	Reddish brown, structured, clay loam. Ferry and Kinross are calcareous. Sunvalley non-calcareous. Mixed drift of mainly doleritic material.
	Kinross	
	Sunvalley	
WILLEMSDAL	Luckhoff	Yellowish brown, structured, clay loam to clay, calcareous, generally saline. Colluvial and sedentary on Karroo sediments.
	Omdraai	
KATSPRUIT	Killarney	Greyish, structured, gleyed, clay, calcareous, saline. Colluvial and sedentary on Karroo sediments.

Soil forms	Soil series	Prominent characteristics and origin
MISPAH	Mispah Muden	Shallow soils, weakly developed. Mixed drift.
ALLUVIUM (Dundee)	Orange, Vaal, Riet, Brak and Ongers River alluvium	Stratified alluvium, including fine, medium and coarse textured alluvial soils.

The prominence of large aeolian deposits in the landscape and the importance of these sandy soils towards irrigation, led to a study on the origin of the aeolian parent materials. Morphological and mineralogical analyses were carried out on selected profile samples. Traverse samples of the red sands showed a decrease in mean grain size and improved sorting from the Vaal River towards the east and south-east. This is an indication that aeolian transportation of the red sands, with the Vaal River as source, took place in that direction. It is therefore postulated that the red sands were initially transported by the Vaal River to areas topographically favourable for temporary deposition in the river bed, from where westerly and north-westerly winds could blow the sand during dry periods. The provenance of the majority of these sands probably lies in the catchment area of the Hartz River. It is noteworthy that large aeolian deposits extend from the banks of the Vaal River at or immediately above its confluence with the Hartz, Riet and Orange Rivers. These situations are invariably favourable for sand deposition.

The heavy mineral composition of the red sands gave no evidence either of

their origin or direction of transport. Admixture with minerals of local rocks undoubtedly took place.

The yellowish sands occur only on the north bank of the Orange River, at or near north-turning bends where westerly winds are able to blow the sand out of the river bed. These sands differ markedly from the red sands in colour and heavy mineral content. The heavy minerals, up to 22%, are mainly of doleritic and basaltic origin and consist largely of pyroxenes and opaque minerals. Basaltic and doleritic influence is further shown by free lime fragments.

The soils of the survey area were judged with a view to irrigation development. Both the sandy and clayey soil groups have properties not ideal for irrigation. Poor permeability and the saline nature of the Willemsdal, Katspruit, Shortlands and most alluvial soils were regarded as more hazardous towards irrigation than excessive permeability and infertility of the Hutton and Clovelly soils. Because sufficiently large areas of Hutton soils are available for large scale irrigation development, these soils are recommended for irrigation under the Orange River Development Project.

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