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Soil Mapping and Advisory Services

Botswana

SOILS AND LAND SUITABILITY FOR ARABLE FARMING OF SOUTH-EAST CENTRAL DISTRICT

FOOD & AGRICULTURE ORGANIZATION OF THE UNITED NATIONS

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SOILS AND LAND SUITABILITY FOR ARABLE FARMING OF SOUTHEAST CENTRAL DISTRICT

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Gaborone, 1989

The conclusions given in this report are those considered appropriate at the time of its preparation.
They may be modified in the light of further knowledge gained at subsequent stages of this project.

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Abstract

This report presents the results from soil surveys carried out in Southeast Central District, it covers the soil maps of Serowe, Palapye, Mahalapye and Lephepe at a scale 1:250 000, and includes generalized information of more detailed surveys.

Chapter 1 describes the natural environment of the study area. In Chapter 2 the soil units occurring in Southeast Central District are discussed. Chapter 3 gives the physiographic units and the interelationships between landscape, soils and vegetation, whilst in Chapter 4 the potential of the land for arable farming is discussed.

The Annex that accompanies this report describes the methods used in the investigation, and provides detailed descriptions and characterizations of thirty seven soil profiles. Land suitability ratings for a number of typical soil units occurring in the different climatic zones of the area are also given. In a separate volume the soil maps and the land suitability maps for rainfed sorghum are presented.

CONTENTS

INTRODUCTION

This report is basically a revised edition of the previously issued report "Soils of Central District, Botswana" (Remmelzwaal, 1984). The reasons for updating are the following:

1. A standard format for soils reports of the 1:250 000 reconnaissance soil map series of Botswana has been introduced.

2. Parts of the old report were transferred to general volumes and to other regional standard reconnaissance volumes.

3. Methods of land evaluation have changed and Land Suitability maps are now available with the report.

4. Soil analytical data with the old report were incomplete and unreliable and have since then been improved.

5. The general Soil Legend and Soil Classification have been revised and completed and now include correlation with Soil Taxonomy and the revised FAO Legend.

6. Soil data storage has been standardized with the Botswana Soil Database which includes an upgrading of all existing analyzed soil profiles.

The soil surveys for the four presented sheets were carried out from 1980 to 1983. The sheets were printed during 1984/85. The revision did not include any new surveys, but some new data were incorporated.

Summary of Conclusions and Recommendations

1. The results of the Soil Survey and Land Evaluation show that only limited areas of SE Central District have marginal suitability for dryland farming, these are found in the Serowe, Shoshong and Mahalapye areas.

2. The larger part of the surveyed area is unsuitable for dryland farming. The more arid areas towards the Northeast and also in the South have predominantly shallow and/or sandy soils. Only the river valleys which are partly water receiving have potential for dryland farming.

3. It is strongly recommended to evaluate land with respect to its suitability for water harvesting. In particular very gently sloping pediments, alluvial terraces and flats as well as upland depressions should be investigated into more detail, and pilot areas should be selected.

4. The results of the reconnaissance mapping should be consulted when making a first selection of areas for irrigated agriculture. The ongoing semi-detailed surveys should be continued along the Limpopo river and its tributaries.

5. The update of soil and evaluation data for the Botswana Soil Database should be continued and extended to other areas in order to facilitate countrywide comparison and evaluation of soil data. This is especially important as climatic conditions are marginal, and minor differences in soil properties may strongly influence suitability.

6. Soil chemical and physical data are essential for soil characterization and evaluation. It is therefore recommended to make every effort to ensure proper functioning of the Laboratory, and to make preparations for integration with the new Agricultural Research Laboratory, which is planned.

7. It is recommended to develop a more quantified land evaluation system for application at scales of 1:50 000 (semi-detailed) and larger, especially for irrigated agriculture.

Acknowledgments

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Important contributions have also been made by Mr R. Breitbart (Soil Analysis), Mr G. M. Segonetso (field assistance), Ms J. Maembolwa (soil database, Mr P. de Wit (land evaluation), and Ms K. Verbeek (proof reading).

1. GENERAL DESCRIPTION OF THE AREA

1.1 LOCATION

1.1.1 Location

The investigated area is situated in Central-Eastern Botswana (see Figure 1.1). It comprises the southern part of Central District, and the northern parts of Kweneng and Kgatleng Districts. The only natural boundary is the river Limpopo, forming the eastern limit. The other boundaries are artificial, the western one running through the Kalahari.

The area is confined by the following coordinates:

$22^{o}00'$ - $24^{o}00'$ South
$25^{o}30'$ - $28^{o}30'$ East

The total area mapped is approximately 54 000 km^2 (5 400 000 ha) which is about 10% of the total area of Botswana, a country the size of France. The Hardveld comprised by the study area is roughly 50% of the total eastern Hardveld.

1.1.2 Population

The latest census carried out at the end of 1981 has recorded the total population of Botswana as 941.000 (Ministry of Finance and Development Planning, 1982). At present the population is estimated at 1.2 million. The population of Central District, largely covered by the survey, was counted at 324.000 which is 34% of the total population. A minor part, however, is living north of the mapped area, whereas in the south a small part of the population of Kweneng and Kgatleng Districts should be added.

The main tribes living in the surveyed area are the Bamangwato (by far the majority, they occupy the area between Serowe - Mahalapye - Palapye), the Batswapong (the area east of Mahalapye-Palapye) and the Babirwa (in the north-eastern part, around Bobonong). In the southern part the Bakwena and the Bakgatla are the major tribes. The administrative center of the district is Serowe (24 000), whereas Mahalapye (20 000) and Palapye (10 000) are other major regional centers. There are many other villages, most of which have a population of 500-2 000.

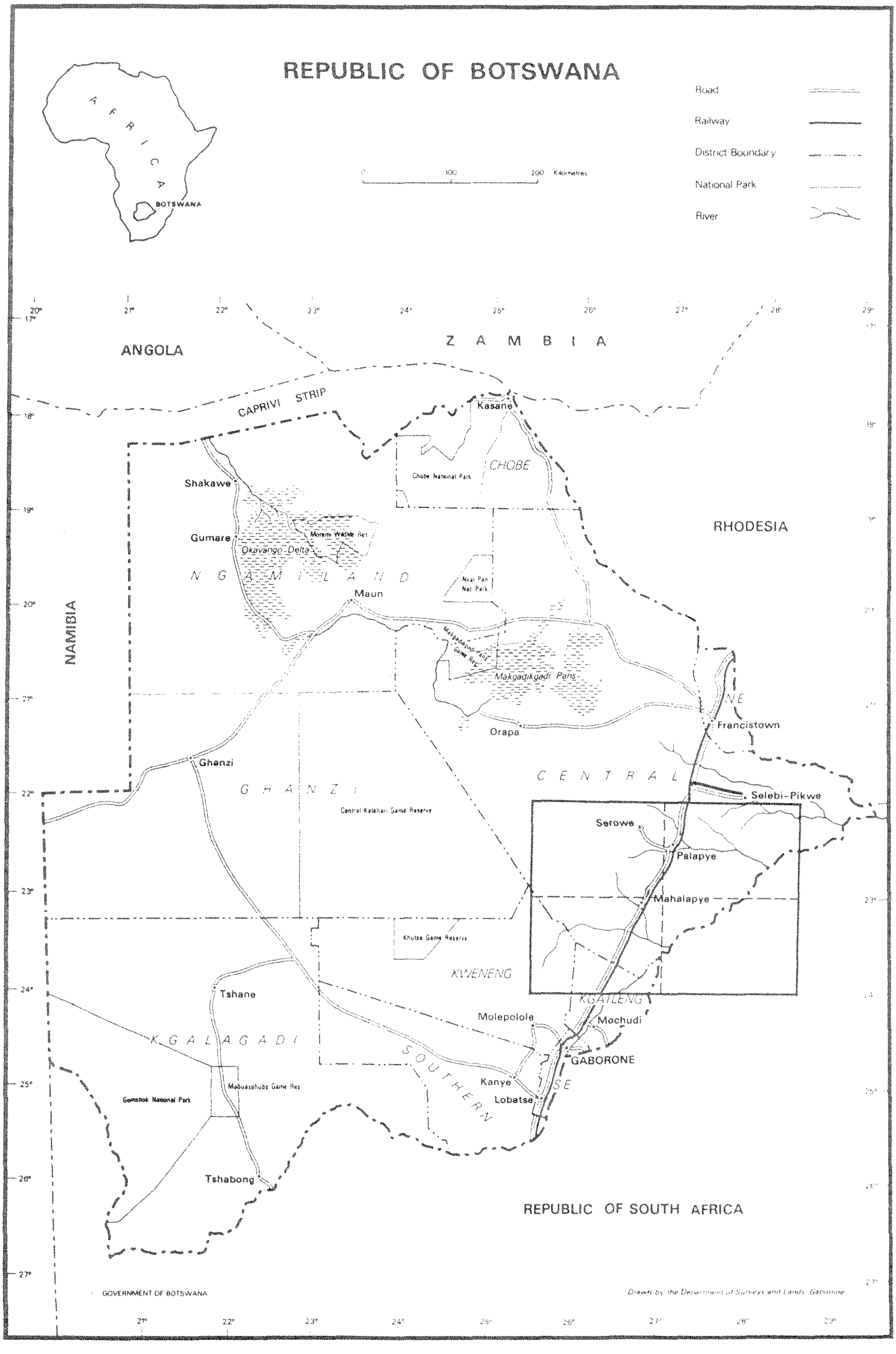

Fig. 1.1 LOCATION MAP

1.1.3 Communications

Air transport
All major villages, including some of the smaller ones, have air strips which are suitable for small aircraft. There are, however, no regular services with Gaborone or Francistown, this is only possible from Selebi-Phikwe, just north of the mapped area.

Railway
A major railway runs north-south, through Mahalapye and Palapye, connecting with Francistown and Zimbabwe in the north and with Gaborone and South Africa in the south. Branches from Serule to Selebi-Phikwe and Palapye to Morupule connect the southeast mining centers with the main line.

Roads

(a) Main tarmac roads
The principal national highway runs south-north, from Gaborone to Francistown, parallel to the railway. A major tarred road connects Serowe with Palapye and an extension to Orapa (via Paje, Mmashoro and Letlhakane) is presently under construction. Another tarmac road connects Selebi-Phikwe, Sephope and Bobonong with Serule along the main highway.

(b) Secondary roads
Most of the larger villages are connected with the principal highway via upgraded secondary gravel roads. The main ones are:

- Dikabeya (north of Palapye) - Sefophe - Bobonong
- Palapye (10 km S) - Martins Drift (border post)
- Mahalapye - Makwate - Parrs Halt (border post), and a junction connecting with Machaneng and Tuli Block
- Mahalapye - Kalamare
- Mahalapye - Shoshong
- Serurume river (just south of) - Tuli Block (Buffels Drift)
- Dibete - Mookane - Maphashalala, and connecting with Buffels Drift.

Other secondary roads are:

- Tuli Block Black Line, running parallel to the Limpopo river, connecting Maphashalala, Makwate, Machaneng, Sherwood, Zanzibar (border post), Baines drift (border post) and Ponts Drift (border post).
- Sefophe - Tsetsejwe - Zanzibar
- Kgagodi - Maunatlala - Lerala, connecting with Martins Drift.

(c) Other roads
There are numerous other roads and tracks, of which many trafficable. Some of the major ones to the west follow cordon fences: Dibete - Lephephe, Makoro - Makoba (via Thabala) and Serule - Tlalamabele. Many of the important rural roads inter connecting villages are improved under labour intensive road projects, as e.g. the road from Serowe to Mogorosi, Thabala and Moijabana, connecting with Shoshong and Kalamare.

1.2 CLIMATE

1.2.1 Atmospheric Climate

Introduction

The climate of eastern Botswana is semi-arid with hot and relatively moist summers and dry and cool winters. A general summary of the climate of Botswana is presented by Bhalotra (1987) from which most of the following data are derived. For additional information reference is also made to Pike (1971) and Sims (1981).

The climatic conditions in Botswana are mainly controlled by the presence of a subtropical high pressure belt (anticyclone) situated east of Botswana. This belt induces a general downward movement of air masses resulting in stable atmospheric conditions with generally low, erratic rainfall.

In summer, the Intertropical Convergence Zone (I.T.C.Z.) moves south over Zambia, influencing the climate in the northern part of the country, where the highest mean annual rainfall is recorded.

In the southern half of Botswana the summer climate is influenced by antcyclone systems, which are positioned over the Atlantic and Indian Oceans.

The relatively high rainfall in the eastern part is caused by the more frequent occurrence of unstable conditions, when the anticyclone moves further east over the Indian Ocean. The anticyclone over the Atlantic coast causes subsidence of dry air over the south western part of the country, resulting in low rainfall.

Except for the extreme north, where the I.T.C.Z. has its influence, most rainfall is received from local convection showers, which are highly variable both in time and space.

A summary of the climatic data of the synoptic station Mahalapye, is given in Table 1.1. Rainfall data of other selected stations are given in Table 1.2.

Precipitation

The rainfall is between 300 and 500mm in the surveyed area and decreases to both the west (Kalahari) and the east (Limpopo). There is a large variation in annual totals and seasonal distribution. The rainfall may also differ considerably over short distances, which is due to the fact that most rain falls in short and heavy showers. Apart from the highly erratic character of the precipitation, effective rainfall for crops is also reduced by run off, the occurrence of early and late rains, and the high potential evapotranspiration.

Table 1.1 : Summary of climatic data for Mahalapye

		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
P mean	(mm)	89	81	67	25	10	3	2	3	8	30	68	79	465
Variability P	(%)	75	87	81	–	–	–	–	–	–	–	65	73	35
T mean	(°C)	250	25.1	22.6	19.9	16.3	13.5	13.1	16.1	20.9	22.7	24.2	24.8	20.3
T mean max	(°C)	30.9	30.9	28.6	26.5	24.4	22.1	22.3	25.1	29.2	29.8	30.4	30.6	27.5
T mean min	(°C)	19.1	19.2	16.6	13.2	8.1	4.9	3.9	7.1	12.6	15.6	18.0	19.0	13.1
Rel Humidity														
mean	(%)	52.5	59.0	61.0	54.0	48.5	53.0	43.5	43.0	40.0	45.0	535	52.0	50.5
Windspeed	(m/s)	1.5	1.3	1.2	1.1	0.9	1.1	1.0	1.3	1.6	1.9	1.6	1.6	1.3
PET 1/	(mm)	142	120	112	83	61	44	48	76	113	137	138	153	1227
PET 2/	(mm)	173	147	138	109	88	69	78	104	137	161	163	183	1550

1/ Pike, 1971
2/ SMEC, 1987

Table 1.2 : Mean monthly and annual rainfall data for selected climatic stations in Southeast Central district.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
Kalamare	86	76	61	28	8	2	1	2	8	30	63	71	436
Phala Road	76	71	52	38	7	2	1	2	3	32	63	64	411
Mahalapye	89	81	67	25	10	3	2	3	8	30	68	79	465
Serowe	90	87	67	25	8	2	1	1	6	30	59	84	460
Machaneng	83	77	54	31	8	1	1	1	5	30	62	67	420
Palapye	84	70	60	25	7	2	1	2	7	26	54	69	407
Martin's Drift	101	48	43	30	5	1	1	1	8	32	67	55	392
Bobonong	68	80	33	30	4	3	0	0	4	24	47	61	354

Temperature

The mean monthly maximum temperature in Central District ranges from about 22^{o}C in winter to 34^{o}C in summer, the mean monthly minimum from about 4^{o}C to 20^{o}C. Temperature changes occur rapidly and frequently during all seasons resulting in considerable deviations from the mean temperature. Absolute maximum recorded at Mahalapye is 41^{o}C and minimum - 6^{o}C.

The average number of days of air frost recorded at Mahalapye (1976-85) is 4 but of ground frost 26. Occurrence of frost is strongly related to the position in the landscape. Frost occurs more frequently in depressions.

Relative humidity of the air

The mean monthly values of relative humidity are at a maximum during the period January - March and at a minimum in the months of August and September. Considerable variations can be observed between day and night. Whereas humidity is generally at its maximum in the early morning, (59% in August and 73% in March - Mahalapye) it rapidly decreases with increasing temperatures and reaches its minimum in the late afternoon. (3% in August and 44% in March - Mahalapye)

Evapotranspiration

The values of the potential evapotranspiration have been obtained from the Penman formula as suggested by SMEC (1987). The calculated mean annual value for Mahalapye is 1,550 mm. The mean monthly values are lowest in June (2.3mm per day); the highest monthly values occur in December (5,4 mm per day). The annual variability compared to rainfall is relatively very small.

1.2.2 Soil Climate

Soil Temperature

Available data for Gaborone, comparable to conditions in Central District , show that soil temperatures, both under bare soils and under short grass cover, are higher than air temperatures throughout the year (Bhalotra 1987). Average differences at 2cm depth are 5^{o}C, and at 60cm 3^{o}C. These differences vary over the year, being largest in summer.

The difference between maximum air and soil temperatures are largest at 2cm depth, from 15^{o}C in winter to 27^{o}C in summer, in extreme cases the temperature of the 2cm surface soil layer may be over 60^{o}C.

Soil temperature regime

In Central District, the mean annual soil temperature at 60cm depth, which is representative for the upper meter of the soil, is 23°C or more and the difference between mean summer and winter temperatures is about 11°C. The classification of the soil temperature regime as defined by Soil Taxonomy (Soil Survey Staff, 1975), is therefore **hyperthermic**.

Soil moisture regime

The soil moisture regime is diagnostic for soil classification in both the Soil Taxonomy and FAO systems, and as a concept important in land suitability classification.

Soil moisture regimes as ustic, aridic and aquic moisture regimes are defined in Soil Taxonomy (Soil Survey Staff, 1975). Classifications for Botswana were given by Van Wambeke (1982) and S.S.M.S. (1987).

If the mean annual soil temperature is 22°C or higher, the definition of an **ustic** moisture regime reads as follows: "the soil moisture control section in the ustic regime is dry in some or all parts for 90 or more cumulative days in most years. But the moisture control section is moist in some part for more than 180 cumulative days, or it is continuously moist in some parts for at least 90 consecutive days.". Soil Taxonomy gives approximate limits for the moisture control section : between 10 and 30 cm if the particle-size class is fine-loamy to clayey, extending to 20 and 60cm depth if coarse loamy and to 30 and 90cm depth if sandy. The boundaries of the control section are the depths to which a dry (tension> 15 bars, but not air dry) soil is moistened by 25 respectively. 75mm of water within 24 hours (exclusive of cracks).

The boundary between the **ustic** and **aridic** moisture regimes is defined at the point where the soil moisture control section is moist in some part for more than 180 cumulative or at least 90 consecutive days (annual soil temperature being 22°C or higher). If less, an aridic moisture regime is applicable.

At the end of the dry period the soils in Central District having normal drainage conditions are completely dry. Average rains in September and October will only moisten the part above the control section. In the average year part of the control section will be moistened in November and will remain moist for about four months or slightly longer.

Following Soil Taxonomy's "crude calculation" (p.54), a soil at field capacity with 200mm storage will be dry in all parts of the control section after 175mm of evapotranspiration. In east Botswana this would take 4-6 weeks in the period November to February (Table 1.1). However, in view of the high potential evapotranspiration in relation to the precipitation, a more likely figure for storage will be in the order of 100mm.
After a dry spell of about 3 weeks during the rainy season, the soil moisture control section may be completely dry. It should be noted that soil moisture conditions must be considered under the normal native, vegetation, whether grass or crops. As indicated by the precipitation records, this will occur in the southern, western and central parts of the investigated area, but most probably not in more than four years out of ten. In this major part of the mapped area an **ustic** moisture regime is applicable.

In areas where the mean annual precipitation is decreasing below 400mm as in the Bobonong area, dry periods within the rainy season occur more frequently and have a longer duration. Especially where soils are shallow and/or massive (with relatively high run-off), the soil moisture control section is neither moist for 180 days cumulatively, nor for 90 days consecutively, for six or more years out of ten. Thus an **aridic** soil moisture regime is applicable in the north eastern area.

1.2.3. Agro-Climatic Zones

Agro-Climatic Zones Of Botswana

In order to assess climate for arable farming, the concept of the growing periods is applied. The analysis was carried out by the Department of Meteorological Services in close cooperation with the Soil Mapping Project. (Dambe 1987).

The calculation of the growing period is based on a water balance model, which compares precipitation with the potential evapotranspiration (FAO 1978). The growing period is defined as the period in days during a year (hydrological year) when precipitation exceeds half the potential evapotranspiration, plus a period required to evapotranspire an assumed 100mm of water from excess precipitation, or less, if not available, stored in the soil profile. The period when precipitation exceeds full potential evapotranspiration is defined as the humid period. The growing season is equal to the length of the growing period if one growing period occurs or equals the total length of the growing periods, when two or more growing periods occur plus the number of dry days.

For the analysis of the growing periods, data were used of all synoptic stations (9) and about 50 rainfall stations with long term records. The rainfall of each 10 - day period was determined by calculating the running average over three 10-day periods, thus reducing the influence of extreme and isolated rainfall events. The potential evapotranspiration has been calculated applying the Penman formula adopted to Botswana conditions by SMEC (1987), see Table 1.1.

As the rainfall in Botswana is very erratic and highly variable from year to year, the use of mean figures is generally not appropriate as probabilities of actual occurrence can be low. Therefore a frequency analysis of growing season lengths was done. The results form the basis of the climatic zones differentiation, combined with the number of dry days (50% frequency) and the length of the humid period.

Figure 1.2 depicts the agro-climatic zones of Botswana.
Agro-climatic zones 2(c-d)3 and 3(b-c)3 can be considered as transitional areas between the northern belt influenced by the I.T.C.Z. and the (south) eastern belt, which is outside this influence.

REPUBLIC OF BOTSWANA

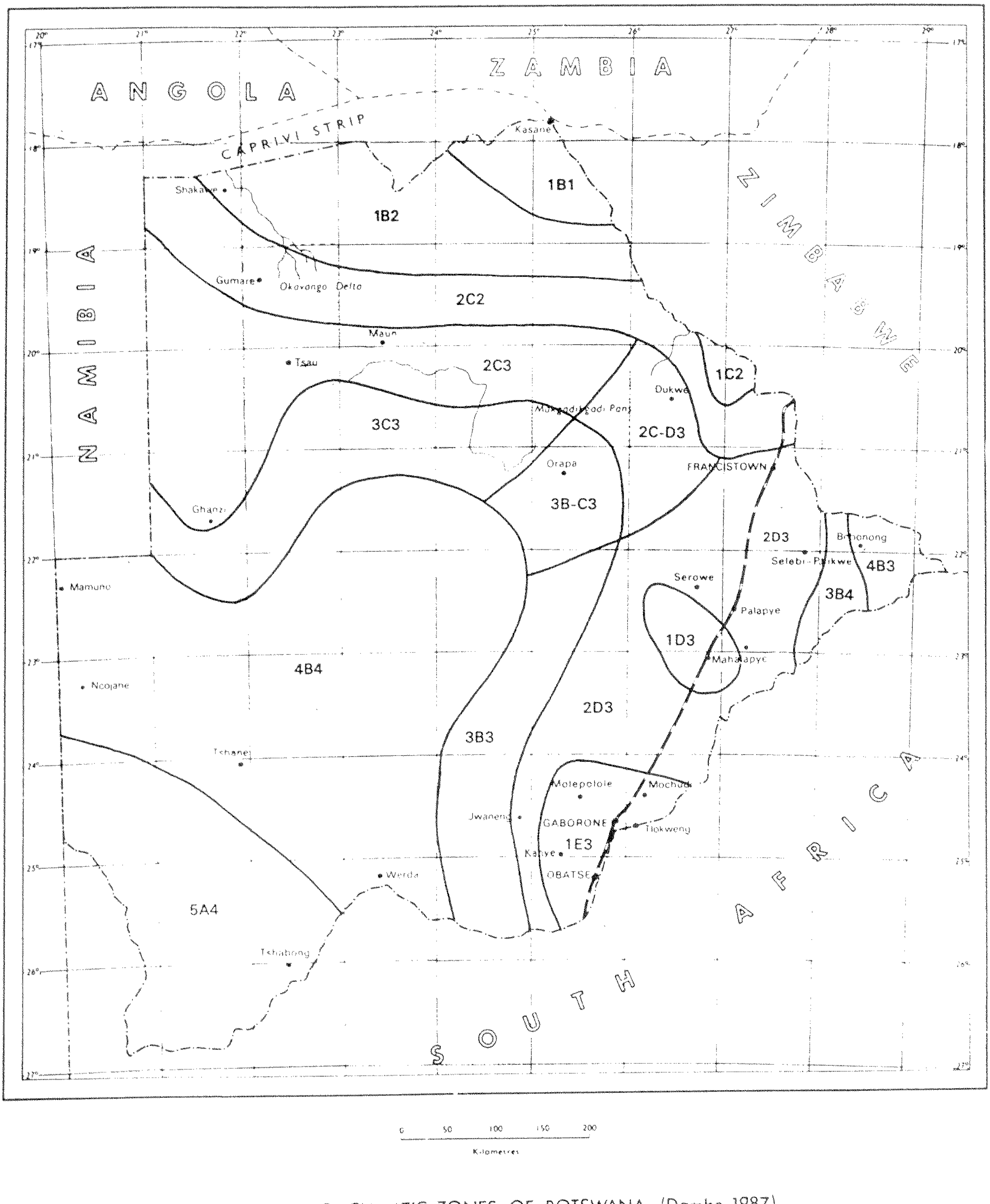

Fig. 1.2 AGRO-CLIMATIC ZONES OF BOTSWANA (Dambe, 1987)

Correlation agro-climatic zones with soil moisture regimes

As outlined in section 1.2.2 the major soil moisture regimes in Botswana are **ustic** and **aridic.** The third applicable one is **aquic**, which is related rather to position in the landscape than to climate. In the routine soil description (Remmelzwaal and Van Waveren, 1988) transitional moisture regimes are also distinguished, (ustic/aridic and aridic/ustic).

Most of the agro-climatic zones as represented in Figure 1.2 can easily be correlated with soil moisture regimes.The duration of the moist period of zone 1 indicates an ustic regime. Zones 3, 4 and 5 have a short moist period corresponding with an aquic moisture regime.

Agro-climatic zone 2 is clearly the transitional zone, assuming soils with average depth, texture and water holding capacity (100mm). The rainfall pattern indicates that the criterion of a partly moist moisture section for more than 180 cumulative days in order to qualify for ustic will not be met. Thus, the criterion of 90 consecutive days is the crucial one. Although definitions of agro-climatic zones and soil moisture regimes differ, it is assumed that both the beginning and the length of the moist period can be correlated. The amount of 7.5cm rain monthly is comparable to 25mm per decade, and this is about half the PET of 50mm per decade, indicating the beginning of the growing period. The average duration of the agro-climatic zone 2 is 90 days and the frequency is 75% or more, which is within the requirement of 6 years out of 10 for ustic.

The correlation between agro-climatic zone 2 and ustic moisture regime does not corroborate the findings of Van Wambeke (1982) and should at the present moment be considered as crude and provisional, and needs to be validated by actual soil moisture monitoring. For shallow and/or sandy soils in zone 3 correlation with aridic soil moisture is considered more appropriate.

The general correlation presently used is as follows:
agro-climatic zones 1 - ustic
agro-climatic zones 2 - ustic to aridic
agro-climatic zones 3 - aridic to ustic
agro-climatic zones 4 - aridic
agro-climatic zones 5 - aridic

1.3 GEOLOGY

1.3.1 Stratigraphy and Lithology

The solid geology is relatively well exposed in the eastern hardveld part of Botswana, but is largely covered by superficial deposits in the western sandveld part.

A stratigraphic summary of the geology in the investigated area is given in Table 1.3, compiled from various geological maps issued by the Geological Survey of Botswana, such as the Photo-geological map of Botswana based on Landsat interpretation (Mallick et al) and the geological map of the Republic of Botswana (Geological Survey Department, 1984).

Systematic geological survey in eastern Botswana has resulted in a series of maps at a scale of 1:125.000. Recent quarter degree sheets published by the Geological Survey Department are:

2227 B Selebi, 2228 B + 2229 A Bains Drift
2226 C Moijabana, 2226 D Mokgware Hills, 2227 C Palapye 2227 D Moeng, 2228 C Zanzibar
2326 A Kodibeleng, 2326 B Mahalapye, 2327 A Machaneng, 2327 B Chadibe

Rocks of the Basement complex are predominant, with sedimentary rocks of the Palapye and Karoo systems subordinate. Faults with most frequent NW-SW strike control the distributions of the Palapye Group Sediments, and to a lesser degree also the Karoo Supergroup.

In Table 1.3 a generalized compilation of the stratigraphy and lithology of the pre-Tertiary Sedimentary rocks is given. For rocks which occur near the surface, a correlation is given with the main soil units. Lithology (parent material) is used as a major differential criterion in the soil legend (see Chapter 2).

The Basement Complex of metamorphic and granitoid rocks are the oldest rocks, of Archean and Early Proterozoic age (Early and Middle Precambrian). Several tectonic events, mainly characterized by folding, igneous events and phases of metamorphism during the Archean and Early Proterozoic have been recognized. Subsequent tectonism is mainly restricted to faulting and extends to the post-Karoo period.

The Sedimentary rocks of the Waterberg Supergroup, which include lava and tuff stages, are relatively weakly affected by metamorphism. There is uncertainty about the correlation with the systems recognized in South Africa. Part of the Palapye group (the Shoshong formation) used to be correlated with the Transvaal System, (older than Waterberg), but it now forms the youngest foundation of the Palapye group. (see Table 1.3). Most of the groups of hills in the hardveld consist of rocks of the Palapye group. Some of the formations outcrop only in places and other are found partly covered with superficial deposits. A summary of the lithology is given in Table 1.4.

Dolerite Sheets have intruded the older formations and have caused widespread metamorphism. There are two major types of dolerite:
(1) Shoshong dolerite, the more basic type characterized by 'knots' of mafic minerals, and (2) the 'hybrid' dolerite. The Shoshong dolerite forms the hills around Shoshong, and its weathering product is more clayey than that of other dolerites. There are also numerous dykes of dolerite or related rock, which quite vary in age.
The formations of the Karoo Supergroup used to be correlated with the series recognized in South Africa (Stormberg, Ecca, Dwyka) but strict correlation is no longer shown on the recent geological maps. Names and definitions of sub-divisions are not always indicated in a consistent way on the geolocial maps. A compilation of the new Karoo stratigraphy is given in table 1.3. Most of the older formations are poorly exposed and are often found covered with recent superficial deposits. The formation of the lower Karroo form a succession of sandstone, grits, siltstones, shales, mudstones, etc, including coal bearing strata.

Kalahari beds are consolidated and unconsolidated sediments of Tertiary and Quaternary age which consists of mainly calcretes, silcretes, aeolian sands and alluvial deposits. Their thickness is over 200m in the Central Kalahari but strata are thinner towards the East. Aeolian Kalahari sands are normally found at the surface.

Coal is exploited at the Morupule Collier (west of Palapye). Detailed explorations in other areas may result in the opening of more mines.

The upper Karoo is characterized by two well exposed formations. The Ntane formation is the youngest sedimentary Karoo formation (equal to the Cave Sandstone). It is a very well sorted aeolian fine sandstone, very distinct and recognizable. The grain-size distribution is markedly similar to the sands of the eastern and northern parts of the Kalahari.

The only younger rocks of the Karoo are the **Stormberg Basalt** outflows(correlated with Drakensberg Lava stage), which dominate the physiography near Serowe, Mmashoro and Bobonong. They underlie the greater part of the Kalahari sands between Lephepe, Serowe and Makgadikgadi Pans.

Other Quaternary Sediments consist of a variety of alluvial and aeolian deposits. The nature of the alluvium is usually related to the sources of the material, but this may also depend on the topography. Heavy clays are found near basalts and dolerites (Serowe, Shoshong), but most alluvium contains a quite strong sandy component. The occurrence of calcrete is related to the occurrence of rock types which are relatively high in calcium (basalt) but also to a favorable topography, where there is the possibility of regular supply of water and evaporation (pans, lower valley slopes, depressions in general).

Aeolian deposits within the hardveld area are usually Kalahari sands, or related wind-blown sands with an admixture of weathering material from the local rocks. In many places there are indications that the local superficial material has been reworked by wind.

1.3.2 Hydrology

Drainage of the hardveld

The general drainage system of the hardveld region is consequent towards the Limpopo river, which drains to the Indian Ocean. The main tributaries of the Limpopo are the Notwane, Bonwapitse-Serurume, Mahalapye-Taupye, Lotsane, Motloutse-Thune and Shashe, usually forming a dendritic drainage pattern. All rivers are ephemeral, except perhaps for the Limpopo, which may be considered transitional to perennial. In most dry years there are still large pools of water, especially downstream. However after a succession of dry years the upstream part is completely dry and only some pools are left in the downstream part.

Drainage of the sandveld

The drainage system of the major part of the sandveld is internal, draining to the Makgadikgadi Pans. The eastern part of the Kalahari does not have a well developed drainage pattern. There are only a few dry river beds towards the hardveld or the Makgadikgadi pans, of which the Letlhakane dry river is the largest.

Water Resources

Sources of water are divided into surface and underground water sources. **surface water** is found in rivers, reservoirs (dams), springs and pans. **Groundwater or underground water** is made available through wells and boreholes. An inventory of water points was made by the Water Point Survey (Ministry of Agriculture of Botswana 1981).

The following categories of water sources in the investigated area exist:

- **Natural springs.** Springs which yield water throughout most years are found in the Tswapong hills at Moeng College, Lecheng, Moremi, Malaka, in the Tshweneng hills at Malete, Chadibe, Sefhare, Seleka 2 and in the Bobirwa area at Famo, a farm about 5 km S. of Bobonong, and 8 km N. of Motongolong Lands.
- **Water from rivers in flow.** This is a most unreliable source of water and available from mainly the Limpopo and to some extent its tributaries.
- **Water from sand bodies of main rivers.** The sand rivers are valuable in many areas as perennial water reservoirs. The potential yield may be high in some rivers such as the Limpopo, Motloutse, Thune and Shashe (Mitchell, 1976).
- **Water from shallow wells.**In some areas favourable conditions exist for shallow aquifers related to water supply, slope, stratification and permeability of strata or soil layers. Such conditions occur between Tswapong and Tshweneng hills, where extensive alluvial deposits are found with ironstone (laterite) layers at 1-2mm depth. Water is often found below this layer, as is indicated by the numerous wells dug in that area
- **Water from boreholes.** In both hardveld and sandveld boreholes are the most common and most reliable source of water.

Table 1.3 Generalized geological stratigraphy of eastern Botswana

Age (my)	Era	Period	Lithology, igneous event	
0-2	Cainozoic	Quaternary	Recent alluvial and aeolian deposits	
	Tertiary	Kalahari Beds		
(90-160)	Upper Mesozoic	(Cretaceous) intrusions	Dolerite and Kimberlite	
135-290	Mesozoic/Late Paleozoic	Jurassic-Late Carboniferous	Karoo sedimentary rocks and basalts	
600-1250	Upper/Middle Proterozoic	Upper/middle Precambrian	Dolerite instrusions	
1400-1900	Middle Proterozoic	Late Middle Precambrian	Waterberg sedimentary rock	
2000	Early Proterozoic	Middle Precambrian	Mahalapye migmatite	Basement Complex
2600	Early Proterozoic	Middle Precambrian	Gaborone granite	
pre 2700	Archean	Early Precambrian	Ellington gneiss	

Table 1.4 Stratigraphy and lithology of Pre-Tertiary sedimentary rocks in Central District (between 22and 24°S) (compiled from data from Geological Survey of Botswana).

Supergroup	Group	Formation	Symbol	Lithology	Soil Unit
	Stormberg		Kb	basalt	B
	Lava	Ntane	Ks	fine-grained sand (Cave ss)	S (S5)
	Lebung	Mosolotsane	Kst	siltstone,mudstone	-
KAROO		Tlhabala	Km	mudstone, shale, siltstone	- -
		Morupule	Kg,Kc	sandstone, grit, shale, coal seams	S
	Ecca	Kamotaka	Kc"	coarse sandstone, arkosik grit	S4(D,S)
		Makoro pp	K'	fine sandstone	S
	Dwyka		Kds	sandstone, shale conglomerate,	-
			Pgl	limestone	-
			Pgq	upper quartzite and shale	S (D)
		Shoshong	Pgs	lower quartzite and shale	D(D5,S)
			Pgg	greywacke,shale, quartzite	D
	Palapye				
WATERBERG		Lotsane	Pl	flagstone, siltstone sandy shale	
		Tswapong	Pt*	quartzite, quartz-pebble conglomerate	- (S)
		Moeng	Pm	shale, siltstone	(D)
		Selika	Ps*	quartzite quartz - pebble conglomerate	-
	Waterberg undifferentiated		W	sandstone,shale, siltstone, grit	S4(S)

* more than one lithological series distinguished

1.4 GEOMORPHOLOGY

1.4.1 Erosion Surfaces

The main distinction in the landscape is between the **Sandveld** in the West and the **Hardveld** in the east. The boundary is gradual and smooth in the southern part, but marked by an escarpment in the north, Kalahari sands covering the Western plateau. The major part of the hardveld country is a flat to gentle undulating peneplain with several groups of steep hills (inselbergs). Erosional processes have played a more prominent role than aggradational processes. Four dominant erosion surfaces are recognized (Bawden and Stobbs, 1963, after Jennings):

1 **Pre-African Surface.**
This highest surface is only represented by summit levels over 1350m above sea level in the SE part of Botswana (outside the mapped area). This surface is thought to be pre-Tertiary.

African Surface of Early Tertiary age
The most extensive area is the plateau covered with Kalahari sands west of the escarpment forming the boundary between sandveld and hardveld. The highest altitude of 1250m above sea level is found near Serowe. Outliers near Serowe are slightly lower: Swaneng Hill (1240m), Leruti hill (1230m). Groups of hills with partially flat tops ascribed to the same level are: Tswapong hills (top 1355m,) Shoshong hills (top 1325), Mokgware hills (top 1295m), Morale hills (top 1270m), Tshweneng-Sefhare (Borotsi) group of hills (top 1295m, but usually 1200-1100m), and various other smaller and more eroded hills with lower top levels.

3 **Late Tertiary Surface**
This surface covers most of the hardveld excluding the area affected by more recent erosion of the Limpopo river system. The altitude ranges from about 1300 to 900m.

4 **Quaternary Surface**
This surface comprises the eastern hardveld area affected by recent polycyclic erosion of Limpopo river and tributaries, of which Shashe, Motloutse, Thune, Lotsane, Mhalatswe and Bonwapitse are the major ones. There is no clear boundary with the Late Tertiary surface. In fact, the transition is usually gradual, and a large part of what is shown by Bawden and Stobbs (1963) as Late Tertiary Surface has been seriously affected by Quaternary erosion, such as the upper Mahalapye catchment north east of Kalamare.The Quarternary surface is widest in the north (Bobonong area). The altitude ranges from about 900 to 537m, the latter being the lowest point of the Limpopo at the confluence with the Shashe river. The altitude of the highest point of the Limpopo is 857m at the confluence of Marico and Crocodile rivers at Oliphants Drift.

1.4.2 Geomorphological Features

The following geomorphological features are distinguished:

1 **Steep hills, ridges and escarpments**

Escarpments. Primarily the scarp between the Late Tertiary hardveld surface and the Kalahari plateau (Early Tertiary African Surface). Most pronounced developments are found S. of Mmashoro, NE and SW of Serowe, W of Moijabana, NW of Kalamare and Mosolotshane and SE of Lephepe. Scarps within the eroded hardveld occur N. of Thune river.
Large hills and ridges. These are the major groups of inselbergs such as Shoshong, Tswapong. Mokgware and Tshweneng/Borotsi hills, with steep sides and flat tops, about 200m above the surrounding country.
Isolated small hills. There are numerous small hills, or kopjes rising above the plains. They vary in size and geology, but occur mostly on the granite-gneiss Basement complex.

2. **Incised valleys**

Valleys are those of the Limpopo river and tributaries, which have incised mainly in the rocks of the basement complex. The valley bottoms include minor terraces and floodplains , which are often sandy. Only the Limpopo has in places a somewhat wider strip of recent alluvium, including back-swamp areas. Where possible, differentiation is made between floodplains natural levees, backswamps and terraces.

3. **Uplands of the Basement complex**

The granite/gneiss uplands form the most extensive unit within the central hardveld plains. According to slope and erosion this peneplain is divided into:

Slightly undulating plain with occasional kopjes. This comprises a Large area from Mahalapye to Machaneng, but also N. and E. of Palapye, where it becomes moderately dissected.
Undulating plains with frequent kopjes. This more variable landscape is found in the central part of the Palapye sheet. Small pediments are associated with the rock outcrops.
Dissected plain. Occurs south of Mokgware hills, extending to Kalamare and Mahalapye. This is the upper catchment area of the Mhalatswe river and the strongly incised valleys form a complex pattern with the remnants of the upland peneplain.
Pediment slopes. Smooth pediment slopes have developed on granite and gneiss at the foot of larger outcrops, with a very distinct break in the slope between rock and pediment. Main occurrence is near Shoshong (associated with Shoshong dolerite hills) and Mahalapye (Morale granite hills) and on the northern part of Palapye sheet, associated with kopjes.

4. Uplands of sedimentary rock

These comprise a variety of intermediate levels on the late Tertiary Surface, between Kalahari plateau and the eroded surface of Quarternary age. The superficial deposits are usually sandy, and often aeolian reworked.

5. Eroded Uplands of basaltic rock

There are two main occurrences. The first is the higher area at Serowe and in the zone associated with the sandveld escarpment, extending irregularly to the north. The second is the Lower Bobonong area, affected by Quarternary erosion in the extreme NE.

6. Alluvial flats

Textures vary from sand to heavy clay, and are often related to a nearby source of material. The major occurrences of alluvial flats is confined to the upper catchment areas on the high parts of the hardveld, (Late Tertiary Surface). The textures of the deposits vary from sand to clay, which relate to the sources of the material. Most alluvium is found in association with other sediments and rocks. The major alluvial flats are:

Serurume catchment This is basically a complex fossil valley system where extensive calcretisation has taken place, in association with aeolian deposition.
Bonwapitse valley. The alluvial flats have their widest development near Shoshong, where the influx of weathering material from the dolerite hills has resulted in clayey deposits. Downstream from the valley is confined to a narrow channel running through sandy areas.
Lotsane system. The main branches of the Lotsane are separated by rises and low hills of mainly sedimentary rock. Three major areas can be distinguished: (1) the colluvio-alluvial slopes, north of the Mokgware hills, with loamy to clayey deposits derived from sandy, shaly and granitic rocks, (2) the valley system south and north of Serowe with alternating sandy and clayey deposits, from sandstones and basalts respectively, and (3) the flats and valleys north and north west of Palapaye where the major sources are the shales of the Matepitepi hills and the basement complex in the north
Upper Motloutse system at Mmashoro The clayey alluvial flats derived from basalt form the southern upper catchment area of the Moutloutse river. Only a minor part occurs on the Serowe sheet, most is found on the Letlhakane sheet.

7. The Kalahari sandveld plateau

Although there is large variation of aeolian features elsewhere in the Kalahari, the sandveld part on the Serowe and Lephepe sheets is flat, uniform and featureless.

1.5 NATURAL VEGETATION

1.5.1 General Vegetation Structures

The vegetation structure with tree and shrub species of the soil unit were systematically described during this survey. The following vegetation structures were recognized (Remmelzwaal and Van Waveren, 1988):

Grassland - Grasses, subordinate forbs, no woody species
Forbland - Herbaceous plants predominant
Forest - Climax vegetation with a large number of tree and shrub species, the structure is characterized by distinct tree and shrub layers, the crowns are overlapping (only in northern Botswana)
Woodland - Continuous tree layer, crowns usually not touching. Understorey may be present.
Shrubland - A continuous layer of shrub, crown are touching
Savanna - Discontinuous layer of trees and/or shrubs:

The savanna type is subdivided as follows:

Savanna - Scattered trees and shrubs, moderately dense.
Dense savanna - Species approximately a few crown diameters apart.
Open savanna - Few isolated trees and shrubs.
Tree savanna - Predominantly trees, scattered moderately dense.
Dense tree savanna- Trees approximately a few crown diameters apart.
Open tree savanna - Few isolated trees.
Shrub savanna - Predominantly shrubs, scattered moderately dense.
Dense shrub savanna- Shrubs approximately a few crown diameters apart
Open shrub savanna- Few isolated shrubs
Low shrub savanna - Predominantly low shrubs, scattered moderately dense
Dense low shrub savanna- Low shrub approximately a few crown diameters apart
Open low shrub savanna - Few isolated low shrubs

Trees are defined as: mostly single stemmed species with a height of more than 3m
Shrubs are defined as:Mostly multi stemmed species with a height of between 1-3m and
Low shrubs as: Shrubs lower that 1m

The most typical and predominant vegetation structure in eastern Botswana is the arid savanna type. Timberlake (1980) has described and mapped the vegetation of southeastern Botswana. He also gives a comprehensive review of previous plant studies and vegetation mapping in Botswana. Five main categories of vegetation types are distinguished by Timberlake:

1. **sandveld tree and shrub savanna**
2. **hardveld woodland and tree savanna**
3. **woodland on hills**
4. **shrub savanna on clay and calcrete**
5. **riverine woodland**

These main types are subdivided into twenty-one vegetation types.

In overgrazed areas or other places where the natural vegetation has been disturbed, such as abandoned land areas, secondary regenerating vegetation types are found,usually dominated by encroaching species as Acacia tortilis, A. erubescens, Dichrostachys cinerea, and Colophospermum mopane.The occurrence of frequent veld fires may result in impoverished shrub savanna or even grassland.

An important vegetation boundary is the occurrence of Colophospermum mopane, which starts just north of Radisele, extending westward to the north side of the Mokgware hills. Mopane does not occur in the sand and basalt area of Serowe, but is found again just north of Paje, on both basalt and alluvium. From Radisele to the east, it extends north of the Borotsi hills, reaching the Limpopo river at Martins Drift. The mopane boundary may be related to the occurrence of frost. Mopane seems to grow on a large variety of soils, from sandy to very clayey, shallow to very deep and covering a wide pH range. On heavy soils with imperfect or poor drainage the species tends to grow as a low shrub, but on well drained soils as large trees. The most southern occurrence of mopane is associated with fine textured poorly and imperfectly drained soils. More to the north it is also found on pure sands, e.g. as dense mopane shrub or as woodland on the beach ridges south of the Makgadikgadi salt pans. Where mopane occurs on sand the pH is usually high to very high.

1.5.2 Vegetation types related to main mapping units

Timberlake's classification forms a good basis for the description of the vegetation of Eastern Botswana in relation to the soil pattern. A modified arrangement of vegetation types is used, combining several and adding some new ones, mainly from the northern area not surveyed by Timberlake. Only a limited number of tree species is listed, with additions characteristic for specific environments. As compared to Timberlake's classification, vegetation types are arranged related to the main soil units (see Chapter 3). However, not all main soil units relate to markedly different vegetation type.

R. Hills and scarps with very shallow soils

Woodland characterized by Terminalia prunoides, Combretum apiculatum, Croton gratissimus and Acacia nigrescens.

C. Calcrete and other highly calcareous rocks

Shrub savanna (mainly open) with Acacia mellifera, Rhigozum brevispinosum, Combretum hereroense, Combretum imberbe, Boscia albitrunca, Acacia nebrownii, Catophractes alexandrii. The latter two only start to occur in the NW part of the survey area.

A. Alluvial deposits

There is quite a variety of vegetation on alluvium, reflecting the range of soils and drainage conditions. The vegetation is often similar or comparable to the vegetation type of the rock from which the alluvium was derived. In the northern areas mopane shrubland or woodland is common on alluvium. When soils are strongly calcareous, a vegetation type similar to main unit C may be found.

Two typical subdivisions are:

(a) Grassland and open shrub savanna on heavy clay soils
Grassland and open savanna with thickets and shrubs characterized by Acacia tenuispina, A. grandicornuta, A. mellifera, A. tortilis and Colophospermum mopane in the north. Vertisols often have a grass vegetation only. Where there is a gilgai pattern, shrubs grow on the mounds.

(b) Riverine woodland
The woodland of the riverine fringes shows quite a variation of species, the most frequently occurring being Acacia karroo, A. galpinii, A. tortilis, A. albida, Combretum imberbe, Ziziphus mucronata.

S. Sandy sedimentary rocks (Sandveld)

The major part of this unit is formed by the Kalahari, but also in the eastern part of the mapped area large sandy areas occur, mainly on sandstones. The sandveld savanna is in places characterized by broad-leaved species, but in most areas it is found mixed broad-leaved - microphyllous. In general the broad-leaved savanna has a denser vegetation, especially where Colophespermum mopane occurs, and the microphyllous savanna is usually more open.

(a) Broad-Leaved savanna
Although not really occurring in well defined zones, general vegetation sub types can be distinguished, characterized by one or two species, with others occurring subordinately. (Lonchocarpus nelsii, Ochna pulchra, Terminalia sericea, Burkea africana).

Lonchocarpus nelsii. Predominantly in the southern and central Kalahari. Mostly occurring as shrub, especially in the northern part of Central Kalahari Game Reserve, where it becomes subordinate, but in the southern part also as trees (south west of Lephepe).

Burkea africana. Occurring as predominant species in parts of the eastern central Kalahari, e.g. in the sandveld west and south of Lephepe, east of Dibete.

Terminalia sericea. Occurring very frequently as the predominant species in sandy areas, especially on acid to neutral soils in the eastern S units on sandstones or mixed Kalahari sands.

Colophospermum mopane. Mainly as shrubland on non-acid soils, and only in the northern part of the country. Mopane shrub and woodland (small trees only) is the typical to exclusive vegetation of the beach-dune ridges of various levels of the Makgadikgadi lacustrine system.

Croton gratissimus. Most typical in places where there is a relatively shallow sandcover overlying bedrock, such as in the escarpment zone (e.g. just west of Serowe).

(b) Microphyllous savanna
This open tree savanna type is found in various parts of the surveyed sandveld area, as in the south east and far west. The most characteristic species are Acacia erioloba and A.luederitzii. Other common species are Peltophorum africanum, Grewia flava and A. fleckii. Microphyllous savanna types also occur in association with broad-leaved types.

G Granite and gneiss (acid rocks)

A division can be made according to the textural class of the soil.

(a) Woodland and savanna on medium to fine textured soils
Predominant species are Acacia nigrescens, Combretum apiculatum, A. erubescens, Colophospermum mopane, Sclerocarya caffra. Mopane occurs only in the northern part, above the line as indicated in section 1.5.1. There are often distinct vegetation zones with a predominance of one or two species, following terrain and soil patterns. On the well drained ridges large tree savanna is found, A. nigrescens, with also C. apiculatum and tall mopane. C. apiculatum shrub predominates on the more acid and shallow soils. Low mopane shrub characterizes the imperfectly drained lower slopes.

(b) Savanna on coarse sandy acid soils
The dominant species are Terminalia sericea and Peltophorum africanum, with A. fleckii and A. erubescens occurring subordinately.

B. Basic rocks (mainly basalt and dolerite)

In the southern dolerite areas of Shoshong, Ziziphus mucronata, Combertum imberbe as well as Acacia species such as A. tortilis, A. grandicornuta and A. karoo predominate. This applies also to the Serowe basalt area, but here the natural vegetation has been largely disturbed.

In the northern basalt area of Bobonong, the major vegetation type is Colophospermum mopane woodland on the better drained soils and shrubland on the poorer drained soils.

D. Fine-textured sedimentary rocks

This main unit has the least distinct vegetation types. There are many changes and gradual transitions to other units, especially sandy ones. Most D areas occur as small and scattered units. and parts have a sand cover of variable thickness. Common species are Dichrostachys cinerea, Acacia tortilis and Colophospermum mopane (in the north). On acid and more sandy soils Terminalia sericea predominates. Main species on shallow D units soils are Terminalia prunoides, Combretum apiculatum and Colophospermum mopane (in the north).

1.6 LAND USE

1.6.1 Land tenure systems

The following land tenure systems occur in Botswana:

1. **Statelands,** such as Forest Reserves, Game Reserves, National Parks.
2. **Tribal land,** subdivided into Communal, Commercial and Wildlife management areas.
3. **Freehold Farms**

Large Statelands do not occur in the survey area, only relatively small areas were reserved by Government as e.g. Livestock quarantine camps, Artificial Insemination, camps and Animal Production Research farms.
Most of the tribal land in this eastern part of Central District is communal land, used as rangeland and arable land. Traditionally the Batswana have three types of settlements: villages, cattleposts and dwellings on arable land.

Most of the communal leasehold farms are found in the Kalahari e.g. between Serowe and Makoba. These farms have been allocated under TGLP (Tribal Grazing Land Policy) scheme as leasehold to individual.

Part of the tribal land has been declared Wildlife management area. These areas are found more towards the north, often adjacent to Statelands.

Freehold Farms occur in a strip along the Limpopo river. These farms are called the Tuli Block, and commercial cattle grazing is the main land use type. Some farms have also areas reserved for game farming and safari activities. Only a minor part of the land is under irrigation.

1.6.2 Major land use types

Traditional dryland farming is the common type of arable agriculture, where the produce from the field is for subsistence (main product sorghum, but also maize, watermelon, beans, cowpeas, pumpkin etc). Under the encouraging schemes of the Government (such as ALDEP - Arable Land Development Programme, and ARAP - Accelerated Rainfall Arable Programme), there is presently a shift towards improved types of traditional farming, including partly mechanized farming. In good years, yields may be more than sufficient for subsistence, and a surplus can be sold. As the presence of cattle in farming land areas creates problems, farmers, individuals or syndicates, were forced to fence the fields. The Botswana Government is subsidizing these activities.

Irrigated farming is practiced at medium to large scale along the Limpopo and Motloutse rivers. However, the total area covered is very small, and only few farmers irrigate their fields in addition to their main activity of livestock grazing. Talana farm, at the confluence of Motloutse and Limpopo rivers is the only large scale irrigation farm. Main crops are cotton, wheat, citrus, maize, tobacco and vegetables such as potatoes, cabbage and onion.Small scale irrigated horticulture is found in a few scattered plots only, using water from boreholes.

Livestock grazing. Cattle grazing is the predominant agricultural activity, but also smallstock grazing, mainly by goats is very common, especially around villages. The most intensive grazing is in the hardveld, especially around waterpoints (pans, well, boreholes). Stocking rates beyond the carrying capacity have led to overgrazing of areas. The results of overgrazing are shown by the destruction of the natural vegetation and subsequent bush encroachment and acceleration of wind and water erosion.

2 SOILS

2.1 INTRODUCTION

2.1.1 Previous Investigations

Prior to 1978 there has not been a systematic approach in soil survey in Botswana. Results of earlier investigations are fragmentary and soil maps were almost completely lacking. The first soil map of Botswana, at that time the Bechuanaland Protectorate, was prepared by van Straten and de Beer (1959), using an early version of the Inter-African Pedological Service classification. The map is provisional and very simple, at a scale of 1:6 000 000. Seven main groups were distinguished, with a subdivision based on geology and some soil characteristics: Lithosols, Desert Soils, Sub-Desert Soils, Young Soils on fairly recent material, Calcimorphic non-illuvial Soils, Ferruginous Tropical Soils and Halomorphic Soils. Bawden and Stobbs (1963) did a land resources survey of Eastern Bechuanaland but presented only some general information on soils, without description or maps. They adopted the concept of van Straten and de Beer.

A detailed soil classification system was developed during the survey of Mitchell (1964-7) in eastern Botswana, where it was applied to selected areas along the main rivers (Mitchell, 1976). The basic principles of the system were adopted from the classification of the soils of Rhodesia (Zimbabwe) (Thompson, 1965; see also the later edition by Thompson and Purves, 1978). This system has a pedogenetic concept similar to that of Inter-African Pedological Service, which served as a basis for the 1:5 000 000 soil map of Africa (d'Hoore, 1964). Mitchell distinguished three soil orders, subdivided into five soil groups:

Weakly developed soils	1.	Regosols
	2.	Lithosols
Calcimorphic soils	3.	Vertisols
	4.	Siallitic soils
Kaolinitic soils	5.	Fersiallitic soils

The distinction between the calcimorphic and kaolinitic soils is based on leaching, the kaolinitic soils being leached and the calcimorphic soils being enriched in lime . The groups are further subdivided into families and series. From the descriptions it can be read that the siallitic soils occur on alluvia and colluvial mainly, and a few on basic rock, and the fersiallitic soils on hard rock only. The system has not been applied by others and can be considered as over-systematic and less practical.

Siderius (1970) introduced a soil identification system for Botswana identical to the system at that time developed in South Africa. This system, the Binominal System for South Africa, was finally published in 1977 (MacVicar et al.). It is a relatively simple but comprehensive system, which recognizes two levels of classification, soil forms and soil series.

The system shows similarities to the USDA Soil Taxonomy (Soil Survey Staff, 1975) as it also uses diagnostic horizons and properties. In Botswana it has been applied apparently to some extent. In his later work (1972, 1973) Siderius used Soil Taxonomy (at that time the provisional 'Selected Chapters' edition) and he also correlated with the FAO Legend of the Soil Map of the World (also a preliminary edition). Most of Siderius' soil investigations were carried out in Central District in the Mahalapye - Shoshong area. He produced sets of soils data with full profile description and analysis. His data have been updated, reclassified and stored in the Botswana database.

Within the Ministry of Agriculture of Botswana, it was decided in 1978 to use the FAO Legend of the Soil Map of the World (1974) as a general basis for soil classification in Botswana. Reports on soil surveys have since been produced by Staring (1978), Venema (1980) and Breyer (1983,1986). Data produced by Breyer in cooperation with the Soil Survey project have been incorporated in the Botswana database. Reports on soil surveys carried out by the FAO Soil Mapping Project include Venema (1983), Remmelzwaal (1984), Remmelzwaal and Rhebergen (1984), Rhebergen (1985) and Baert (1987).

2.1.2 Soil Forming Factors

Soils in Botswana show a strong textural relationship with the underlying rock. This is the reason that the soil forming factor **parent material** is used at the first level of classification. Most soils retain a strong relationship with the rock they are derived from, such as sand/sandstone, granite, basalts. The influence of other soil forming factors is more variable.

The soil forming factor **climate** had a clear impact on soil formation but the effects are not always strongly differentiating, Under a semi-arid climate processes of weathering and leaching are slow, as they are confined to the moist summer only. Most soils are dry for the larger part of the year, and during the period of drying up, an upward movement of water containing soluble components may take place. The most common phenomenon in the more arid areas is the accumulation of lime in the upper part of the soil. Other materials that are found enriched are salts, gypsum and silica.

Usually the combination of the soil forming factors climate and **topography** control the leaching processes. On the higher and steeper slopes soils have lost more fine materials than soils on the lower slopes. Leaching takes place through surface processes or via vertical or lateral subsurface translocation. The result is coarser-textured and more acid soils on the higher well drained parts, and finer-textured and more alkaline soils on the imperfectly drained lower parts (see section 3.2 for examples of catenary relationships). However , it should be noted that over large parts of Botswana the differences in relief are slight, restricting the influence of the topography on soil development.

The soil forming factor **vegetation** in itself does not have a strong influence on soil formation in Botswana. The production of organic matter may be relatively high, but little is added to the soil, due to the high oxidation under the present climatic conditions. Only under wet conditions levels of organic matter may be substantially higher. On highly calcareous materials usually higher organic matter contents are found.

The soil forming factor **time** generally has a strong influence on the development of the soil profile. Soils in Botswana show a distinct horizon development, which indicates a certain minimum age. The development is less in eroded, recent alluvial and sandy aeolian sands. The soils of the older surfaces do not show a strong differentiation due to time, when comparing similar soils in landscapes of different age.

2.2 SOIL CLASSIFICATION

2.2.1 General

The Legend of the Soil Map of the World (FAO-UNESCO, 1974) was selected as the general soil classification system in Botswana. Although not strictly a taxonomic classification system, it is based on measurable criteria and proved very useful as a soil classification system. Considerations for the selections were:

1. The system is relatively simple, and yet comprehensive.
2 It provides a suitable framework for the distinction of soil units at lower levels.
3. The system has been internationally accepted and is widely used. It forms a good basis for correlation with other countries, especially in Africa.
4. It is closely linked with USDA Soil Taxonomy, by having largely similar diagnostic horizons and other criteria.

Soil Taxonomy (Soil Survey Staff, 1975, 1987) is used as a second classification system. It is not used for general mapping purposes, but FAO soil units are correlated with Soil Taxonomy and analyzed soil profiles are also classified according to Soil Taxonomy.

Soils are also correlated with the Revised Legend of the Soil map of the World (FAO/Unesco/ISRIC 1988).

A full description of the soils of Botswana and correlation between the FAO and Soil Taxonomy classification systems is given in the General Soil Legend of Botswana (Remmelzwaal, 1988). In this Legend also new soil units and modifications of the FAO system are introduced. Some of the relevant changes or interpretations are mentioned in the following sections.

2.2.2 Legend of the Soil Map of the World (1974)

Soil phases

Of several phases a shallow variety, occurring within 50cm of the surface, is introduced (petric, petrocalcic, petroferric).

Diagnostic horizons

Mollic horizon
The part of the definition "Soil structure is strong enough that the major part of the horizon is not both massive and hard, or very hard when dry" is interpreted as such that epipedons having a very hard consistency and coarse blocky structure are excluded from mollic horizons, considering the general concept as given in Soil Taxonomy (Soil Survey Staff, 1975).

Ochric Horizon
The concept of 'weak ochric horizon' was not considered useful.

Cambic Horizon
The complete Soil Taxonomy definition is used.

Calcic and Petrocalcic Horizons
Petrocalcic horizons are considered diagnostic horizons with the same taxonomic value as calcic horizons. Both horizons were given diagnostic value to enter Arenosols and Cambisols.

Albic Horizons
The complete Soil Taxonomy definition is used.

Diagnostic properties

Albic material
The diagnostic property albic material was replaced by albic horizon

Ferralic and Ferric Properties
For the calculation of the CEC clay values a correction is applied for organic carbon, 400me9 per 100g carbon. In sandy soils the calculated CEC clay is a rather meaningless figure, as the CEC is relatively strongly influenced by the components sand and silt. Therefore an additional criterion for the definition of ferralic properties is introduced, namely the CEC of the total fine earth fraction, which should be lower that 4me9/100g to qualify for ferralic properties.

Hydromorphic properties
The corresponding full Soil Taxonomy definitions are used, as there appeared to be some errors in the FAO definition.

Vertic properties
The definition was replaced by the Soil Taxonomy definition as used for subgroups: ' having cracks at some period in most years that are 1cm or more wide at a depth of 50cm, that are at least 30cm long in some part and that extend upwards to the surface of the Ap (A) horizon, if not irrigated'.

Soil Units
The soil units are subdivided at second level and some at third level. The soil units at third level have the additional characteristics of another soil unit at second level. The only exception is the third level addition **Arenic**, defined as having a texture of loamy fine sand or coarser in the upper 50 cm from the surface.

The soil units have their upper boundary at the surface or at less than 30 - 50 cm below the surface. When covered with a thicker layer of new material, the diagnostic horizons have no longer diagnostic value for classification. The variable thickness of 30 - 50 cm is following the concept of buried soils in Soil Taxonomy (Soil Survey Staff, 1987). In practice this means that clay covers on sandy soils may not be thicker than 30 cm, as the sand normally does not have diagnostic subsurface horizons. Sand covers on loam or clay may be up to 50 cm thick if the diagnostic horizons in the buried soil are 1 m or more in thickness.

Gleysols
Calcaric Gleysols were renamed Calcic Gleysols, as in Botswana these soils always have a calcic horizon or soft powdery lime.

Arenosols
The definition of Arenosols was not considered useful in the mapping of Botswana soils and was changed for the following reasons:
1. All deep sandy soils should be grouped together.
2. The present boundary of coarse texture allows soils with a high clay percentage of up to 18 percent and in addition silt. The boundary used in Soil Taxonomy, basically between loamy and sandy loam is considered more appropriate.
3. Gravely soils should be excluded.
4. Redistribution or enrichment of carbonates, even in the form of a calcic or petrocalcic horizon, should be permitted.
5. For reasons of correlation with Soil Taxonomy and other practical reasons as to include soils on non-gravelly sandstone, lithic and petroferric contacts (phases) should be permitted.
6. There should be no restriction as to the soil moisture regime.

The revised key reads as follows:

Other soils which are coarser than sandy loam and having less than 35 percent of rock fragments or other coarse fragments in all sub-horizons to a depth of at least 100 cm from the surface or to a lithic or petroferric contact, having no diagnostic horizons other than an ochric A horizon, an albic E horizon, a calcic or petrocalcic horizon.

Arenosols having an albic E horizon to a depth of at least 50 cm below the surface.

Albic Arenosols

Other Arenosols having a petrocalcic horizon within 125 cm of the surface.
Petrocalcic Arenosol

Other Arenosols having a calcic horizon or soft powdery lime within 125 cm of the surface.

Calcic Arenosols

Other Arenosols which are calcareous at least between 20 and 50 cm below the surface.

Calcaric Arenosols

Other Arenosols showing a clay increase of 3% or more or lamellae of clay accumulation within 125 cm of the surface.

Luvic Arenosols

Other Arenosols showing colouring and ferralic properties within 125 cm of the surface.

Ferralic Arenosols

Other Arenosols showing colouring.

Cambic Arenosols

Other Arenosols having a base saturation (by NH4OAc) of less than 50 percent, at least in some part of the soil between 20 and 50 cm below the surface.

Dystric Arenosols

Other Arenosols.

Eutric Arenosols

Notes

- Ferralic should include colouring in order to distinguish from recent sands (beach, dune) which may have ferralic properties.
- Cambic should exclude other alteration than colouring. This could only be structure (or decalcification), which often is a questionable property.
- Some very weak structure alone should not lead to classification as Cambic Arenosol or Ferralic Arenosol.

Planosols

The abrupt textural change is recognized as a unique property of Planosols, and is an essential diagnostic criterion. The word 'abruptly' was added to the text of definition and key between "E horizon" and "overlying". The requirements of hydromorphic properties in at least part of the E horizons is interpreted with some liberty, as mottling or other evidence does hardly or not appear in deferrated material (see also FAO, 1988).

Nitosols

The same colour requirement as for Paleustalfs is applied to Nitosols, which means that if the colour is not redder than 10YR, the soil is classified as an Orthic Luvisols.

Cambisols

Calcic and petrocalcic horizons are considered key horizons to enter Cambisols. Otherwise soils having a calcic or petrocalcic horizon and not a cambic and which do not qualify for any other soil unit, do not key out at all. Calcaric Cambisols were split up into calcic (having a calcic or petrocalcic horizon or soft powdery lime within 125cm of the surface) and Calcaric Cambisols (others).

2.2.3 The Revised Legend of the Soil Map of the World (1988)

The Revised Legend of the Soil Map of the World (FAO/Unesco/ISRIC, August 1988) is applied in all standard routine soil descriptions. A general correlation with the 1974 Legend for Botswana soils is given in Remmelzwaal (1988). The following interpretations or modifications are made:

Mollic horizon
See remark section 2.2.2

Cambic horizon
The definition is different from the definition in Soil Taxonomy, which may lead to confusion. In soils with gleyic or stagnic properties the "gray color requirement" may be the difference in recognizing a cambic horizon or not. See also under Cambisols.

Salic properties
Depth within 100 cm of the surface.

Soft powdery lime
Significant is quantified as follows: at least few (5-15%) by volume, or covering at least 50% of the ped surfaces.

Vertic properties
Definition used see Section 2.2.2

Prevalence of diagnostic B horizons
General rule of upper B horizon is not observed in the case of cambic horizon overlying argic horizon (within 125 cm of the surface).

Leptosols
Other diagnostic horizons permitted: calcic and petrocalcic horizons, as these are difficult to distinguish from highly calcareous material. New soil unit introduced: **Calcaric Leptosols** (following Umbric Leptosols in key) which are calcareous at least from 20 to 50 cm below the surface, in order to separate Leptosols on soft calcareous materials.

Vertisols
Pellic and Chromic Vertisols are kept at second level, as defined in 1974 edition. Calci- is used at third level. The key is as follows:
Gypsic Vertisols
Dystric Vertisols
Pellic Vertisols
Chromic Vertisols.

Arenosols
The key as given in Section 3.2.4 is changed as follows:
Gleyic Arenosols are added, Petrocalcic Arenosols are deleted (petri- distinguished at third level), Dystric Arenosols are deleted and Eutric changed in Haplic. It should be noted that the requirement of less than 8% clay is not observed.

Calcisols
The following definition for the key applies:
"Other soils having a calcic or a petrocalcic horizon, or a concentration of soft powdery lime within 125 cm of the surface; having no other diagnostic horizon than an ochric horizon, a cambic B horizon, or an argic B horizon underlying a calcic horizon, or overlying a calcic or petrocalcic horizon which occurs within 50 cm of the surface". New soil unit introduced: **Stagnic Calcisols** (following Luvic Calcisols in the key) which has stagnic properties within 100 cm of the surface.

Ferric properties
As with Alisols, Acrisols, Luvisols, Lixisols, occurrence within 125 cm of the surface.

Alisols
The defined cation exchange capacity occurs throughout the B horizon to a depth of 125 cm.

Acrisols
The defined cation exchange capacity occurs in at least some part of the B horizon within a depth of 125 cm.

Luvisols
The defined cation exchange capacity occurs throughout the B horizon to a depth of 125 cm.

Lixisols
The defined cation exchange capacity occurs in at least some part of the B horizon within a depth of 125 cm.

Cambisols
New soil unit introduced: **Stagnic Cambisols** (following Gleyic Cambisols in the key) showing stagnic properties within 50cm of the surface. Soils which have stagnic properties but not a cambic horizon do not key out.

Letter suffices
The modified arrangement (based on Soil Taxonomy) as defined in Botswana Soil Database (Remmelzwaal and Waveren, 1988) applies.

Soil Subunits (third level and lower level codes)
The third level was introduced to indicate intergrades between major soil groupings at the first or second level, or to further characterize or specify the second level soil groupings. Definitions of soil subunit connotatives as used in Botswana are given in Remmelzwaal (1988) with rules for priority.

The rule normally followed is that definitions at the third level correspond with second level definitions, and do not represent weaker expressions of the relevant phenomenon. A stronger or weaker development can be indicated by prefixes such as hyper-, hypo-, epi-, whereas orthi- can be used to indicate the typical or general occurrence, e.g. orthi-calcic when having a calcic horizon and not only soft powdery lime.

2.2.4 Soil Taxonomy

Soil Taxonomy (Soil Survey Staff, 1975, 1987) is used as the second classification system and applied to all standard routine soil descriptions. Soil Taxonomy definitions are normally followed when FAO uses identical diagnostic criteria, but defined in abbreviated form. For remarks on interpretation of diagnostic horizons and criteria see Section 3.1.

The subdivision of certain great groups appears to be insufficient. Therefore a number of subgroups has been introduced, defined as identical subgroups already identified with comparable other great groups (e.g. petrocalcic, petroferric, ustalfic, calciorthidic, arenic). Also some new compound subgroups were added, e.g. Arenic Kandic Rhodic, Arenic Petrocalcic. Completely new soil units were not defined. New subgroups are listed in Annex 2, Soil Unit Correlation FAO-Soil Taxonomy, of the General Legend of Soils of Botswana (Remmelzwaal, 1988).

2.3 SOIL LEGEND

2.3.1 Legend Construction

The legend consists of two components, Main Units and Soil Units.

Main Units
The first or Main Unit distinction is based on parent material and rock. The key to the main units reads as follows:

R - VERY SHALLOW SOILS ON STEEP HILLS, RIDGES AND ESCARPMENTS

C - SOILS ON HIGHLY CALCAREOUS ROCKS AND MATERIALS

L - SOILS ON LACUSTRINE DEPOSITS

A - SOILS ON ALLUVIAL DEPOSITS

S - SOILS ON COARSE-GRAINED SEDIMENTARY ROCKS

D - SOILS ON FINE-GRAINED SEDIMENTARY ROCKS

G - SOILS ON ACID IGNEOUS AND METAMORPHIC ROCKS

B - SOILS ON BASIC IGNEOUS AND METAMORPHIC ROCKS

The above classification is according to the nature of the superficial deposits. Diagnostic criteria are defined as follows:

Main Unit R contains at least 30 percent Lithosols and is not further subdivided. Remaining soils include Regosols, Cambisols and locally Luvisols and Arenosols. This unit is unsuitable for arable farming.

Main Unit C contains all highly calcareous materials, such as calcrete and nodular calcareous materials, as well as minor limestone and dolomites, which have a calcium carbonate content of 40 percent or more equivalent, occurring within a depth of 50 cm of the surface. The unit is indicated as LC when occurring in lacustrine deposits.

Main Unit L comprises all lake and pan deposits, such as in the (sub) recent depositional environments of Makgadikgadi, as well as on older plains such as Pandamatenga.

Main Unit A is exclusive of lacustrine sediments but includes alluvial reworked lacustrine, indicated as LA; as well as deltaic deposits. The unit includes colluvium of mixed origin, but not partly colluviated and unmixed material, which are hardly or not distinguishable from in situ weathered material.

Main Unit S occurs on coarse-grained sedimentary rocks, whether consolidated or unconsolidated. When the sediment consists of unmixed Kalahari sand the unit is indicated as KS. The general criterion is that the texture is loamy fine sand or coarser to a depth of 50 cm from the surface and not finer than fine sandy loam at a depth of 100 cm. However, occasional exceptions are made for aeolian features such as dunes which are allowed to have slightly finer textures.

Main Unit D has a texture of sandy loam or finer within a depth of 50 cm of the surface. The unit occurs on a variety of rocks such as shales, siltstones, grits, conglomerates, feldspatic sandstones etc.

Main Unit G is mainly found on the acid and intermediate granite and gneiss rocks of the Basement Complex as well as on metamorphic rocks such as quartzites.

Main Unit B is related to the Karroo basalts, various dolerite/diabase intrusions and ultrabasic rocks.

Soil Units

The soil units are defined according to a standard format which contains the following elements:

- **Soil unit number.**

- **Soil depth.** The range is indicated using soil depth classes:
  0 - 25 cm very shallow
  25 - 50 cm shallow
  50 - 100 cm moderately deep
  100 - 150 cm deep
  > 150 cm very deep.

The lower limit indicated is the depth to which roots of grasses and annual crops can penetrate. The depth is normally limited by the occurrence of slightly weathered or unweathered hard rock or cemented layers.

- **Drainage.** The classes follow the standard FAO/SSM classification. Normally the range is one or two classes, occasionally three.

- **Colour.** The colours are described according to the Munsell Soil Color Charts (Munsell, 1975). The range is indicated from one value/chroma to limit diagonally over one or more hues to the other value/chroma limit. The colours refer to the colours of the B horizon (or C horizon if there is no B horizon) in the moist state.

- **Texture**. Textural classes are described following the revised subdivision by Remmelzwaal and Waveren (1988). The texture generally refers to the texture at a depth of 100 cm (or immediately above a lithic or paralithic contact or cemented horizon) and occasionally to a depth of 125-150 cm if this influences the soil classification, as for some sandy soils. Normally the textural range is restricted to two or three classes.
- **Classification**. The soil classification system is the Legend of the Soil Map of the World (FAO/Unesco, 1974), with modifications (see section 2.2.2) Correlation is made with the Revised Legend of the Soil Map of the World (FAO, UNESCO, ISRIC, 1988) and with the Soil Taxonomy (1987). Normally only the main correlation is indicated.

- **Phases**. Phases used are derived from the Legend of the Soil Map of the World (FAO/Unesco,1974), with amendments (see section 2.2.2). The full phase occurs in 70 percent or more of the soil unit, 'partly' in about 30-70 percent of the soil unit. Lesser occurrence of phases is normally not indicated.

- **Topography**. A general indication of the topography of the unit is given with sometimes a description of the physiography added.

- **Site characteristics**. A characterization of the site in general hydrological terms is given, as this is essential for land evaluation. One defined soil unit is normally not both water receiving and shedding. The following classes are distinguished:

  - receiving
  - slightly receiving
  - normal to (slightly) receiving
  - normal
  - normal to (slightly) shedding
  - slightly shedding
  - shedding.

2.3.2 Soil Units

Soil units recognized in the survey area and represented on the maps are listed below. For a full list of soils in Botswana reference is made to Remmelzwaal (1988).

Details are given on occurrence, soil characteristics and vegetation. When no details are given with a soil unit, reference is usually made to the unit above. The soil units occur on the map either as single mapping or together with other soil units as complex mapping units. Some of the units appear on the map as incorrectly classified. This is due to changes in the approach of soil moisture regimes.

Selected profiles are given in Annex 2, with analytical results. Other profiles are available from the Botswana Soil Database.

The proper Soil Unit in the Legend is found by (1) determining the Main Unit (A, B, C etc.) and (2) classifying the soils according to the FAO system. If there is more than one Soil Unit with the same classification within the Main Unit, the one with the applicable description is selected.

The appropriate Soil Unit can also be selected with the aid of the Key to the General Soil Legend of Botswana (see Remmelzwaal 1988), which gives an abbreviated system of description.

A SOILS ON ALLUVIAL DEPOSITS

A1 **FAO:** Pellic Vertisols (1974)
Pellic Vertisols (1988)
ST : Typic Pellusterts
Description: Deep to very deep poorly to imperfectly drained very dark gray to dark grayish brown clay
Topography: Flat to almost flat
Site: Normal to receiving
Representative Profile: SH901
Occurrence: In flood plains and alluvial flats derived from basic rocks as basalt (Serowe) and dolerite (Shoshong). Locally also in backswamps along the Limpopo river.
Characteristics: Self mulching heavy clay soil with wide cracks in the dry season. Top layer of 2-5cm has fine granular structure. Structure is moderate to strong prismatic falling apart in angular blocky, often wedge shaped. Has low to medium gilgai.
Vegetation: Savanna to open savanna with predominantly shrubs. Typical species: Acacia grandicornuta and A. tenuispina.
Other species: Acacia mellifera, A.tortilis, A. nilotica

A3 **FAO:** Vertic Cambisols (1974)
Vertic Cambisols (1988)
ST : Vertic Ustochrepts
Description: Deep to very deep imperfectly drained dark grayish brown sandy clayloam to clay
Topography: Flat to gently undulating
Site: Normal to receiving
Occurrence: In floodplains and alluvial flats mainly derived from basic rocks. Occurs as transitional soil between Vertisols and other Cambisols
Characteristics: Strong cracking in top soil or upper B horizon occurs in dry season. Structure is moderate subangular to angular blocking (not: wedge shaped).Slickensides may occur, but are not intersecting.
Vegetation: Savanna to open savanna with Acacia karroo, A. tortilis, A. nilotica, A. mellifera etc.

A4 **FAO:** Calcaric Cambisols (1974)
Calcaric Cambisols (1988)
ST : Typic Ustochrepts
Description: Moderately deep to very deep imperfectly to moderately well drained dark grayish brown to brown sandy loams to sandy clay
Topography: Flat to gently undulating
Site: Normal to receiving
Occurrence: A4 and A4b are frequently occurring in valleys in all areas in association with Calcic Luvisols (A9) and Orthic Luvisols (A14,15) and also Vertisols. The other units are minor, mainly in Serowe area.

Characteristics: There is a very large variety of textures and appearance of lime (nodules, soft powdery, petrocalcic or in the matrix).
Vegetation: The vegetation type ranges from riverine woodland to savanna and open shrub savanna. Most occurring species are Acacia spp. such as A. tortilis, A. karroo, A. galpinii, A. mellifera, A. albida.

A4a **FAO:** Calcic Cambisols (1974)
Haplic Calcisols (1988)
ST : Typic Ustochrepts
Description: Deep to very deep imperfectly drained massive gray to grayish brown sandy clayloam to clay, strongly calcareous within 50cm
Topography: Flat to almost flat
Site: Normal to receiving

A4b **FAO:** Calcic Cambisols
Haplic Calcisols (1988)
ST : Typic Ustochrepts
Description: Moderately deep to very deep imperfectly to moderately well drained dark grayish brown to brown clayloam to clay
Topography: Flat to gently undulating
Site: Normal to receiving

A4c **FAO:** Calcic Cambisols(1974)
Haplic Calcisols(1988)
ST : Typic Ustochrepts
Description: Moderately deep to very deep moderately well drained grayish brown to brown sandy loams to sandy clayloam.
Topography: Flat to gently undulating
Site: Normal to receiving

A4d **FAO:** Calcic Cambisols, petrocalcic (1974)
Petric Calcisols (1988)
ST : Petrocalcic Ustochrepts
Description: As A4a/A4b/A4c, but with petrocalcic horizon
Topography: Flat to gently undulating
Site: Normal to receiving

A5b **FAO:** Orthic Solonetz (1974)
Haplic Solonetz (1988)
ST : Typic/Mollic Natrustalfs
Description: Deep to very deep imperfectly to moderately well drained dark grayish brown to strong brown sandy clayloam to clay
Topography: Flat to gently undulating
Site: (Slightly) receiving
Representative Profile: SH 14
Occurrence: Minor occurrence in alluvial depressions in plains mostly associated with granite/gneiss of the basement complex.
Characteristics: Ochric and/or albic horizon overlying prismatic or columnar natric B horizon with continuous grayish clay cutans.
Vegetation: Savanna with mainly Acacia spp such as A. karroo, A. nilotica, A. mellifera, A nigrescens, A. erubescens.

A6 **FAO:** Solodic Planasols(1974)
Albic-Abrupti-Stagnic Solonetz (1988)
ST : Typic Natrustalfs
Representative Profile: M330
Description: Deep to very deep poorly to imperfectly drained dark grayish brown to dark yellowish brown sandy clay to clay.
Topography: Flat to almost flat
Site: (Slightly) receiving
Representative Profile: M330
Occurrence: Minor on gentle alluvial slopes of hills and escarpments on granite. Transitional to Planosols on granite (G15). In association with Calcic Luvisols.
Characteristics: Sandy albic horizon abruptly overlying clayey natric or argillic, often having interfingering of albic material into B horizon.
Vegetation: Savanna with Acacia spp (A. nigrescens, a.o) and Combretum apiculatum.

A7 **FAO:** Gleyic Luvisols, partly sodic (1974)
Stagnic Luvisols (1988)
ST : Typic/Aeric/Mollic Ochraqualfs
Description: Deep to very deep poorly to imperfectly drained dark gray to grayish brown sandy clayloam to clay
Topography: Flat
Site: (Slightly) receiving
Occurrence Minor unit in lower parts of alluvial flats, e.g. south of Serowe, in association with Orthic Luvisols (A14).
Characteristics: Moderately structured with mostly weakly developed argillic horizon.
Vegetation: Dense Colophospermum mopane shrub savanna.

A8 **FAO:** Vertic Luvisols (1974)
Vertic Luvisols (1988)
ST : Vertic Haplustalfs
Description: Deep to very deep imperfectly to moderately well drained dark grayish brown to reddish brown sandy clayloam to clay
Topography: Flat to gently undulating
Site: Normal to receiving
Occurrence: Very minor as transitional soil between Vertisols and Chromic or Calcic Luvisols. e.g. in Shoshong area.

A9 **FAO:** Calcic Luvisols (1974)
Calcic Luvisols (1988)
ST : Typic Haplustalfs

Description: Deep to very deep imperfectly to moderately well drained dark grayish brown to yellowish brown sandy clayloam to clay
Topography: Flat to gently undulating
Site: Normal to slightly receiving
Representative Profile: MC 65
Occurrence: Very common soils occurring in depressional areas and on the lower valley slopes or lower terraces as along the Limpopo. In association with a variety of other alluvial soils: Calcic Cambisols (A4b/d), Chromic and Orthic Luvisols (A13,14) and C5 with shallow calcrete.
Characteristics: Varies in texure (A9a sandy top), sodicity (A9c), colour (A10) and depth of calcic or petrocalcic horizon (A9b). Soil structure also varies from moderately prismatic to almost massive.
Vegetation: Shrub savanna or savanna with a strong shrub component Predominant species Acacia mellifera, with A. tortilis, A. nilotica, Combretum imberbe, Grewia flava. In the north also Colophospermum mopane, and riverine woodland with A. albida along the Limpopo.

A9a **FAO:** Arenic Calcic Luvisols (1974)
Arenic-Calcic Luvisols (1988)
ST : Arenic Haplustalfs
Description: Moderately deep to very deep imperfectly to moderately well drained dark grayish brown to strong brown sandy loams to sandy clayloam
Topography: Flat to gently undulating
Site: Normal to slightly receiving

A9b **FAO:** Calcic Luvisols,petrocalcic(1974)
Petri-Calcic Luvisols (1988)
ST : Petrocalcic Paleustalf
Description: As A9, but with petrocalcic horizon
Topography: Flat to gently undulating
Site: Normal to slightly receiving

A9c **FAO:** Calcic Luvisols, sodic, saline (1974)
Calcic Luvisols, Sodi-Calcic Luvisols (1988)
ST : Typic Haplustalfs
Description: Deep to very deep imperfectly drained dark grayish brown sandy clay loam to clay.
Topography: Flat
Site: Normal to slightly receiving

A10 **FAO:** Chromic Calcic Luvisols, partly petrocalcic (1974)
Chromic-Calcic Luvisols (1989)
ST : Typic Haplustalfs
Description: Deep to very deep moderately well drained strong brown to yellowish red sandy loams to sandy clayloam
Topography: Flat to gently undulating
Site: Normal to slightly receiving

A11 **FAO:** Ferric Luvisols (1974)
Haplic/Ferric Lixisols (1988)
ST : Kanhaplic Haplustalfs, Kandic Paleustalfs, Kandic Rhodustalfs
Description: Moderately deep to very deep moderately well to well drained red to strong brown sandy loams to sandy clay
Topography: Flat to gently undulating
Site: Normal to slightly receiving
Representative Profile: PS10, MC59,
Occurrence: Most common soil on alluvium, especially on the older alluvial flats and terraces associated with groups of hills of sedimentary rock such as Tswapong, Mokware, Botepitepi, Borotsi. Found in association with Chromic, Orthic and Calcic Luvisols. (A13,14 10). Arenic Ferric Luvisols occur in the more sandy areas, as in the valleys of the sandveld transition.
Characterisitcs: Weakly developed structure and often hard con sistence. On basis of CEC clay values very gradual transitions to Chromic Luvisols. Commonly occurring with petric phase on ironstone (A11a) or with sandy top (A12).
Vegetation: Due to cultivation natural vegetation often is disturbed. Colophospermum mopane savanna in the northern (Palapye and Serowe) areas, savanna with predominatly A. tortilis and Boscia albitrunca in the southern areas.

A11a **FAO:** Ferric Luvisols (1974)
Ferric/Haplic Lixisols (1988)
ST : Kanhaplic/Petroferric Haplustalfs
Description: Moderately deep to deep moderately well drained red to brown sandy loams to sandy clayloam
Topography: Flat to gently undulating
Site: Normal
Representative Profile: MC58

A12 **FAO:** Arenic Ferric Luvisols (1974)
Areni-Haplic/Ferric Luvisols (1988)
ST : Arenic Kanhaplic Haplustalfs
Description: Moderately deep to deep moderately well drained brown to yellowish red sandy loams
Topography: Almost flat to gently undulating
Site: Normal to slightly receiving

A13 **FAO:** Chromic Luvisols (1974)
Chromic Luvisols (1988)
ST : Typic/Ultic Haplustalfs, Typic Rhodustalfs

Description: Moderately deep to deep moderately well to well drained strong brown to dark red sandy loams to sandy clayloam
Topography: Almost flat to gently undulating
Site: normal to slightly receiving
Occurrence: Very common in al alluvial flats and valleys with moderate drainage. Also Limpopo terraces. In association with Ferric Luvisols (A11), Eutric Nitosols (A16, 16a) and Chromic Calcic Luvisols (A10)
Characteristics: Moderate to good soil structure for A13 if not transitional to Ferric Luvisols with relatively low CEC clay. Massive ructure for A13a with minor occurrence. Locally with petric phase (A13b)
Vegetation: Mostly cultivated but has Colophospermum mopane savanna in the northern parts and Acacia savanna in the southern parts (A.tortilis, A. karroo, A. nilotica, A. galpinii a.o). Along Limpopo riverine woodland with Acacia albida and A. karroo.

A13a **FAO:** Chromic Luvisols (1974)
Chromic Luvisols (1988)
ST : Typic/Ultic Haplustalfs, Typic Rhodustalfs
Description: Moderately deep to deep moderately well drained strong brown to dark red massive sandy clayloam to sandy clay
Topography: Flat to gently undulating
Site: Normal to slightly receiving

A13b **FAO:** Chromic Luvisols (1974)
Chromic Luvisols (1988)
ST : Typic/Ultic Haplustalfs, Typic Rhodustalfs
Description: Moderately deep to deep well drained strong brown to red sandy loam to sandy clayloam
Topography: Flat to gently undulating
Site: Normal

A14 **FAO:** Orthic Luvisols (1974)
Haplic Luvisols (1988)
ST : Typic/Ultic Haplustalfs

Description: Moderately deep to very deep moderately well to well drained dark brown to yellowish brown sandy loams to sandy clay
Topography: Flat to gently undulating
Site: Normal to slightly receiving
Occurrence: Common in all areas, mainly in valleys or the somewhat less well drained alluvial flats or terraces, with Ferric and Chromic Luvisols on the somewhat higher parts. Arenic Orthic Luvisols (A15) are typical for the valleys in the sandveld area.
Characteristics: Mostly weak structure and hard consistence with often poorly developed argillic horizon (transitional to cambic)
Vegetation: Variable vegetation with Colophospermum mopane predominant in the north and Acacia spp in the south.

A14a **FAO:** Orthic Luvisols (1974)
Haplic Luvisols (1988)
ST : Aquic Haplustalfs
Description: As A14, but imperfectly to moderately well drained very dark gray to grayish brown
Topography: Flat to gently undulating
Site: normal to slightly receiving

A15 **FAO:** Arenic Orthic Luvisols (1974)
Areni-Haplic Luvisols (1988)
ST : Arenic Haplustalfs
Description: Moderately deep to very deep well drained pale brown to yellowish brown sandy loams to sandy clayloam
Topography: Flat to gently undulating
Site: Normal to slightly receiving

A15a **FAO:** Arenic Orthic Luvisols (1974)
Areni-Haplic Luvisols (1988)
ST : Aquic Arenic Haplustalfs
Description: as A15, but imperfectly to moderately well drained very dark gray to grayish brown
Topography: Flat

A16 **FAO:** Eutric Nitosols (1974)
Pale-Chromic Luvisols (1988)
ST : Typic/Rhodic Paleustalfs
Description: Very deep moderately well to well drained strong brown to dark red sandy loams to sandy clayloam
Topography: Almost flat to gently undulating
Site: Normal to slightly receiving
Representative Profile: S0001
Occurrence: Common in all areas, occurrence similar to Chromic Luvisols (A13)

Characteristics: As A13 but soil with well developed argillic horizon deeper than 150 cm. A16a has a calcic horizon, is mostly also strongly calcareous in the top and has often a dark gray sedimentary toplayer. A16a has a sandy top.
Vegetation: As A13

A16a **FAO:** Calcic Eutric Nitosols (1974)
Chromi-Calcic Luvisols (1988)
ST : Typic/Calciorthidic Paleustalfs
Description: Very deep imperfectly to moderately well drained dark brown to dark red sandy clayloam to sandy clay
Topography: Flat to almost flat
Site: Normal to slightly receiving

A16b **FAO:** Arenic Eutric Nitosols (1974)
Pale-Areni-Chromic Luvisols (1988)
ST : Arenic (Rhodic) Paleustalfs
Description: Very deep well drained reddish yellow to red sandy loams to siltloam
Topography: Gently undulating (terraces),
Site: Normal

A17 **FAO:** Arenic Dystric Nitosols (1974)
Areni-Halpic Alisols (1988)
ST : Arenic Paleustults

Description: Very deep well drained reddish yellow to red sandy loams
Topography: Almost flat to gently undulating
Site: Normal
Occurrence: Very minor

A18 **FAO:** Ferric Acrisols (1974)
Haplic/Ferric Acrisols (1988)
ST : Kanhaplic Haplustults

Description: Moderately deep to deep moderately well to well drained strong brown to red sandy loams to sandy clayloam
Topography: Gently undulating
Site: Normal
Occurrence: Very minor

A19 **FAO:** Ferralic Arenosols(1974)
Ferralic/Luvic Arenosols (1988)
ST : Typic Ustipsamments
Description: Deep to very deep well to somewhat excessively drained yellowish brown to dark red sands to loamy sands
Topography: Flat to gently undulating
Site: Normal
Occurrence: Very minor

A22a **FAO:** Cambic Arenosols (1974)
Cambic/Luvic Arenosols (1988)
ST : Ustic Torripsamments
Description: Deep to very deep well to somewhat excessively drained dark brown to yellowish red sands to loamy sands
Topography: Flat to gently undulating (levees)
Site: Normal
Representative Profiles: BS100
Occurrence: On sandy natural levees of Limpopo tributaries, mainly the Thune river (mapped as A22)
Characteristics: Sands to loamy sands with very gradual clay increase. Have relatively high CEC and organic carbon levels. Difference between A22 and 22a is colour only. Transitional to Haplic Xerosols, A39, and Chromic and Eutric Cambisols (ustic) A33
Vegetation: Savanna with Combretum imberbe and Acacia tortilis.

A24a **FAO:** Arenic Eutric Fluvisols (1974)
Gleyic Arenosols (1988)
ST : Typic/Mollic Psammaquents
Description: Very deep poorly drained white to dark grayish brown sands to loamy sands
Topography: Flat (Channels)
Site: Receiving
Occurrence: Minor unit mostly in northern channels and sandy riverbeds, liable to annual flooding.
Characteristics: Recent channel deposits without any soil formation
Vegetation: None

A30 **FAO:** Calcic Gleysols (1974)
Stagnic Calcisols (1988)
ST : Mollic/Aeric Haplaquepts

Description: Deep to very deep poorly to imperfectly drained very dark gray sandy clay to clay
Topography: Flat
Site: (Slightly) receiving
Occurrence: Very minor

A33 **FAO:** Eutric Cambisols (1974)
Eutric Cambisols (1988)
ST : Typic Ustochrepts
Description: Very deep well drained dark brown to brown sandy loam
Topography: Gently undulating (natural levees)
Site: Normal
Occurrence: On natural levees of Limpopo and tributaries, mainly Thune river. In the aridic zone, A33 should have been mapped and classified as Haplic Xerosols, A39.
Characteristics: Includes transition to Chromic Cambisols with more reddish colour.

A36 **FAO:** Luvic Xerosols (1974)
Chromic/Orthic Luvisols(1988)
ST : Ustalfic Haplargids
Description: Deep to very deep moderately well to well drained dark yellowish brown to dark reddish brown sandy loams to sandy clayloam
Topography: Flat to gently undulating
Site: Normal
Occurrence: On natural levees and terraces of the Limpopo. In association with Haplic Xerosols, A39 (Eutric Cambisols A33) and sandier A22a Cambic Arenosols on the levees and Calcic and Luvic Xerosols in backswamps.
Characteristics: Very deep mostly reddish fine to medium sandy loams with relatively high CEC.
Vegetation: Riverine woodland or savanna, mostly disturbed or under cultivation.

A39 **FAO:** Haplic Xerosols (1974)
Chromic/Eutric Cambisols (1988)
ST : Ustochreptic Camborthids
Description: Deep moderately well to well drained brown to reddish yellow sandy loams to sandy clay
Topography: Flat to gently undulating
Site: Normal
Occurrence: On levees and terraces of the Limpopo system. On the map represented by, A33 Eutric Cambisols, which are mostly within the aridic zone.
Characteristics: The levee soils are sandy and very deep, the terrace soils mostly more clayey and less deep.
Vegetation: Savanna or open savanna with variable species as Colophospermum mopane, Boscia albitrunca, Acacia tortilis, Ziziphus mucronata.

B SOILS ON BASIC IGNEOUS AND METAMORPHIC ROCKS

B1 **FAO:** Eutric Regosols, lithic (1974)
Eutric Leptosols, Eutric Regosols, (1988)
ST : Lithic Ustorthents
Description: Very shallow to shallow well to somewhat excessively drained reddish brown to dark brown sandy loams to clayloam
Topography: Undulating to hilly
Site: Shedding
Occurrence: In the Serowe/Mmashoro and Bobonong eroded basalt areas and Shoshong dolerite hills. Calcaric Regosols B1b hardly occur in the Serowe area, but are very common in the Bobonong area.
Characteristics: Shallow to very shallow soils, very often with a lithic phase or otherwise gravel within 50cm, but mostly within 25cm. The lime often occurs as soft coatings on the weathered basalt.
Vegetation: In the Serowe area disturbed Acacia type savanna, in Bobonong Colophospermum mopane shrub savanna, and on the Shoshong dolerite hills open tree savanna with Commiphora africana, Kirkea acuminata and Sclerocarya caffra. The latter species also occur on the basalt near Mmashoro.

B1b **FAO:** Calcaric Regosols, lithic, shallow petric (1974)
Calcaric Regosols, Calcaric Leptosols (1988)
ST : Lithic/Typic Ustorthents
Description: As B1, but calcareous

B2 **FAO:** Chromic Luvisols, petric, partly lithic (1974)
Chromic Luvisols, Rhodi-Chromic Luvisols (1988)
ST : Typic/Ultic/Lithic Haplustalfs, Typic/Lithic Rhodustalfs
Description: Shallow to moderately deep well drained red to strong brown sandy loams to clayloam (dolerite/diabase mainly)
Topography: Almost flat to rolling
Site: (Slightly) shedding
Occurrence: Fairly minor and scattered occurrence on mainly diabase and dolerite intrusives, e.g. at the Mokwane hills, N and S of Shoshong hills and in the southern Limpopo valley. In places in complex with shallow Eutric Regosols. (B1).
Characteristics: Similar soils apart from soil depth and occurrence of mostly weak calcic horizon. The topsoil has often an admixture of aeolian sand. As compared to soils on basalt the soil structure is weakly developed, textures are more sandy, and CEC values lower.
Vegetation: Savanna or open savanna with a variety of species

B3 **FAO:** Chromic Luvisols (1974)
Chromic Luvisols, Rhodi-Chromic Luvisols (1988)
ST : Typic/Ultic Haplustalfs, Typic Rhodustalfs
Description: Deep moderately well to well drained red to strong brown sandy loams to clayloam (dolerite/diabase mainly)
Topography: Almost flat to undulating
Site: Normal to slightly shedding

B4 **FAO:** Chromic Calcic Luvisols, partly petric (1974)
Chromi-Calcic Luvisols, Rhodi-Calcic Luvisols (1988)
ST : Typic Haplustalfs, Typic/Calciorthidic Rhodustalfs
Description: Moderately deep to deep moderately well to well drained reddish brown to red sandy clayloam (dolerite/diabase mainly)
Topography: Almost flat to undulating,
Site: normal to slightly shedding

B5 **FAO:** Chromic Luvisols (1974)
Chromic Luvisols (1988)
ST : Typic Haplustalfs
Description: Deep moderately well to well drained reddish brown to strong brown sandy clayloam to clay (basalt)
Topography: Undulating rolling
Site: (Slightly) shedding
Occurrence: Serowe and Mmashoro basalt areas, in complex with Calcic Luvisols B6/6a and Eutric Regosols B1
Characteristics: Especially in unit B5a argillic horizons, weakly developed above rock or weathered rock that occurs within 75cm. B5 mostly has weathered rock at about 1m depth.
Vegetation: Savanna with Acacia tortilis, A.nigrescens. Often disturbed.

B5a **FAO:** Chromic Luvisols, petric, partly lithic (1974)
Chromic Luvisols (1988)
ST : Typic/Lithic Haplustalfs
Description: Shallow to moderately deep well drained reddish brown to strong brown sandy clayloam to sandy clay (basalt)
Topography: Undulating to rolling,
Site: (Slightly) shedding

B6 **FAO:** Calcic Luvisols (1974)
Calcic Luvisols (1988)
ST : Typic Haplustalfs
Description: Deep moderately well to well drained dark brown to reddish brown sandy clayloam to clay (basalt)
Topography: Undulating to rolling
Site: (Slightly) shedding
Representative Profile: S 0005
Occurrence: Serowe and Mmashoro basalt areas, in complex with Chromic Luvisols B5/5a and Eutric Regosols B1. Also quite extensive in Lephepe area in association with shallow soils on calcrete (C unit).
Characteristics: Unit B6 mostly has weathered rock or gravel at about 1m from the surface, B6a normally within 75cm or has even rock within 50 cm. Calcic horizons have formed in the C horizon and are mostly weakly developed in the Serowe area but strongly in the Lephepe area.
Vegetation: Savanna with <u>Acacia tortilis</u>, <u>A. nigrescens</u>, <u>Ziziphus mucronata</u>. Often disturbed.

B6a **FAO:** Calcic Luvisols, petric partly lithic (1974)
Calcic Luvisols, Luvic Calcisols (1988)
ST : Typic/Lithic Haplustalfs.
Description: Shallow to moderately deep well drained dark brown to reddish brown clayloam to clay (basalt)
Topography: Undulating to rolling
Site: (Slightly) shedding

B6c **FAO:** Calcic Luvic Xerosols, petric partly lithic (1974)
Calcic Luvisols, Luvic Calcisols (1988)
ST : Typic/Lithic Haplargids
Description: as B6a, but with aridic moisture regime
Occurrence: On basalt in Bobonong area, in complex with B1/1a, Eutric and Calcaric Regosols and C1a Rendzinas.
Characteristics: Mostly quite shallow soils with weakly developed argillic horizon. Often strong concentrations of soft powdery lime in the upper zone of the weathered basalt.
Vegetation: Savanna with <u>Colophospermum mopane</u>.

B7 **FAO:** Eutric Nitosols (1974)
(Rhodi-)Pale-Chromic Luvisols (1988)
ST : Rhodic/Typic Paleustalfs

Description: Very deep moderately well to well drained red to yellowish red sandy clayloam
Topography: Almost flat to undulating
Site: Normal to slightly shedding
Representative Profile: SH 0016
Occurrence: Very minor occurrence at colluviated transitions of dolerite rock outcrops and alluvium. In association with B2-4.
Characteristics: Very deep moderately well structured red soils, often having a calcic horizon at depth.
Vegetation: Savanna with various species as on unit B1, also including Acacia spp.

C (OR LC) SOILS ON HIGHLY CALCAREOUS MATERIALS

C1 **FAO:** Lithosols (1974)
Calci-Lithic Leptosols (1988)
ST : Lithic Ustorthents
Description: Very shallow (less than 10cm) moderately well to well drained dark grayish brown to brown loamy sands to clayloam.
Topography: Flat to gently undulating
Site: Normal to shedding
Occurrence: Frequently occurring in low position associated with basalt in the more arid areas, around Lephepe and south of Bobonong (C1a Rendzinas). In very complex pattern with other C units (C3-4-5). Elsewhere minor.
Characteristics: Lithosols on massive calcrete (C1) or shallow soils with a mollic (C1a) or ochric (C1b) directly on a petrocalcic horizon.
Vegetation: Open savanna or shrub savanna with Combretum imberbe, Acacia mellifera, A. tortilis, Grewia flava and in the northern areas also Colophospermum mopane (Bobonong) and north west also Acacia nebrownii and Catophractes alexandrii.

C1a **FAO:** Rendzinas, shallow petrocalcic (1974)
Epi-Petri-Rendzic Leptosols (1988)
ST : Petrocalcic Calciustolls
Description: Very shallow imperfectly to well drained very dark gray to dark brown loamy sands to clayloam.
Topography: Flat to gently undulating
Site: Normal to shedding
Representative Profile: D 0041

C2 **FAO:** Calcaric Regosols, shallow petrocalcic (1974)
Petri-Calcaric Leptosols, Epi-Petrocalcic Calcisols (1988)
ST : Lithic Ustorthents, Petrocalcic Ustochrepts, Ustochreptic/ Typic Paleorthids
Description: Very shallow to shallow imperfectly to well drained very dark gray to brown sandy loams to clayloam
Topography: Flat to gently undulating
Site: Normal to shedding

C3 **FAO:** Petrocalcic Arenosols, shallow petrocalcic (1974)
Areni-Petri-Calcaric Leptosols, Epi-Petri-Calcic Arenosols(1988)
ST : Petrocalcic Ustochrepts, Ustochreptic/Typic Paleorthids
Description: Very shallow to shallow imperfectly to moderately well drained dark grayish brown to reddish brown sands to loamy sands
Topography: Flat to gently undulating
Site: Normal to slightly receiving
Occurrence: In the transitional zone to the Kalahari, elsewhere minor on sandstones, e.g. south of Bobonong. Also as overshifted sands on calcrete. Associated with S12, 13 and A10.
Characteristics: Abruptly overlying shallow petrocalcic horizon (C3), or having more gradual increase in carbonates (nodular calcic horizon) and with depth developing into petrocalcic horizon.
Vegetation: Variable savanna vegetation with Acacia mellifera, A.luederitzii, A. tortilis a.o.

C3b **FAO:** Calcic Arenosols, partly petrocalcic (1974)
Areni-Calcaric Leptosols, Epi-Hyper-Calcic Arenosols
Petri-Calcic Arenosols (1988)
ST : Typic/Arenic Ustochrepts, Ustochreptic/Typic Calciorthids, Arenic Petrocalcic Ustochrepts
Description: Moderately deep moderately well to well drained light grayish brown to dark yellowish brown sands to loamy sands
Topography: Flat to gently undulating,
Site: Normal

C4 **FAO:** Calcic Cambisols, partly petrocalcic (1974)
Hyper-Calcaric Leptosols, Epi-Hypercalci-Haplic Calcisols(1988)
ST : Typic/ Petrocalcic Ustochrepts
Description: Shallow to moderately deep imperfectly to well drained very dark gray to reddish brown sandy loams to clayloam
Topography: Flat to gently undulating
Site: Normal to slightly receiving
Occurrence: Frequently only in Lephepe area, elsewhere minor. Occurs on basalt in association with other C units and B6, minor on other rocks on lower valley slopes, as associated with G13 Calcic Luvisols, or in complex with Calcic Luvisols A9-10
Characteristics: Ochric over shallow cambic or argillic which are often difficult to distinguish and gradual transgrade
Vegetation: Savanna with Combretum imberbe, Acacia mellifera, A.tortilis, A. karroo.

C5 **FAO:** Calcic Luvisols, partly petrocalcic (1974)
Hypercalci-Luvi-Petri Calcisols, Hypercalci-Luvic Calcisols(1988)
ST : Petrocalcic Paleustalfs, Typic Haplustalfs
Description: Shallow to moderately deep moderately well to well drained dark yellowish brown to yellowish red sandy loams to clayloam
Topography: Flat to gently undulating
Site: Normal to slightly receiving

D SOILS ON FINE GRAINED SEDIMENTARY ROCKS

D1 **FAO:** Dystric Regosols, shallow petric, partly lithic (1974)
Dystric Regosols, Dystric Leptosols (1988)
ST : Typic/Lithic Ustorthents
Description: Very shallow to moderately deep well drained yellowish brown to reddish brown sandy loams to clayloam
Topography: Undulating to hilly
Site: Shedding
Occurrence: Undulating to hilly areas of shale, siltstone, conglomerate on all sheets. Eutric Regosols, D1a and D1c most commonly occurring, as in Palapye area. Dystric Regosols, D1, are mainly found in the southern areas.
Characteristics: Very weakly developed shallow and gravelly. A-C profiles
Vegetation: Shrub and low tree savanna, often dense, with predominant Combretum apiculatum.

D1a **FAO:** Eutric Regosols, shallow petric, partly lithic (1974)
Eutric Regosols, Eutric Leptosols (1988)
ST : Typic/Lithic Ustorthents
Description: As D1

D1b **FAO:** Calcaric Regosols, shallow petric, partly lithic (1974)
Calcaric Leptosols, Calcaric Regosols (1988)
ST : Typic/Lithic Ustorthents
Description: As D1

D1c **FAO:** Eutric Regosols, petric, partly lithic (1974)
Eutric Regosols, Eutric Leptosols (1988)
ST : Typic/Lithic Ustorthents
Description: Very shallow to moderately deep well to moderately well drained yellowish brown to reddish brown sandy clay to clay
Topography: Almost flat to undulating
Site: Normal to shedding

D2 **FAO:** Ferric Luvisols, petric, petroferric (1974)
Haplic Lixisols (1988)
ST : Kanhaplic/Petroferric Haplustults
Description: Moderately deep well drained yellowish red to brown sandy loams
Topography: Flat to undulating
Site: Normal to slightly receiving
Occurrence: On the Serowe and Lephepe sheets near the sandveld on quartzite, feldspatic grit and siltstone, also in the southern part of the Tuli Block on Karroo sediments.
Characteristics: Very weak to massive structure and weakly developed argillic horizons with gradual changes in base saturation. Mostly having ironstone within 150cm.
Vegetation: Shrub savanna with Terminalia sericea and Combretum apiculatum predominant.

D3 **FAO:** Ferric Acrisols (1974)
Haplic Acrisols (1988)
ST : Kanhaplic Haplustults
Description: Deep to very deep well drained yellowish red sandy loams
Topography: Flat to undulating
Site: Normal to slightly receiving
Representative Profile: SH005

D5 **FAO:** Ferric Luvisols, partly petric(1974)
Haplic /Ferric Lixisols (1988)
ST : Kanhaplic Paleustalfs
Description: Moderately deep to deep moderately well to well drained reddish brown to strong brown sandy loams to sandy clayloam
Topography: Flat to gently undulating
Site: Normal to slightly shedding
Occurrence: Most common soils of the D main unit, found on a variety of Palapye and and karroo sedimentary rock. Most frequently on the Mahalapye sheet as D5 and D5a, often in complex with D7 and sandy soils S10,11. D5b is a later defined unit representing the deeper Ferric soils of D5/5a.
Characteristics: Difficult to distinguish into Ferric and Chromic Luvisols as all have weak structure and CEC clay values in a close range of 20-30 me/100gr)
Vegetation: Open savanna to open shrub savanna with Acacia erioloba A. erubescens, A. nigrescens, Boscia albitrunca, Combretum apiculatum, Grewia flava.

D5a **FAO:** Chromic Luvisols (1974)
Chromic Luvisols (1988)
ST : Typic/Ultic Haplustalfs
Description: Deep to very deep moderately well to well drained reddish yellow to yellowish red sandy loams to sandy clayloam
Topography: Flat to gently undulating
Site: Normal to slightly shedding

D5b **FAO:** Ferric Luvisols (1974)
Haplic/Ferric Lixisols, Pale-Haplic/Ferric Lixisols (1988)
ST : Kanhaplic Paleustalfs, Haplic Paleustalfs
Description: As D5a
Representative Profile: PS 0901

D6 **FAO:** Ferric Luvisols, petric(1974)
Haplic/Ferric Lixisols (1988)
ST : Kanhaplic Haplustalfs
Description: Moderately deep moderately well to well drained reddish brown to yellowish red sandy loams to sandy clayloam
Topography: Undulating to hilly
Site: Shedding
Occurrence: Very minor in association with D1 units.

D7 **FAO:** Ferric Luvisols, partly petric, petroferric (1974)
Ferric/Haplic Lixisols (1988)
ST : Kanhaplic/Petroferric Haplustalfs
Description: Massive moderately deep to very deep moderately well drained dark brown to yellowish red sandy clay loam to sandy clay
Topography: Flat to gently undulating
Site: Normal
Occurrence: In a quite scattered pattern on feldspatic grits and sandstones, conglomerates and shales e.g. near Moijabana (D7), near the Segakwane river (D7a), north of Mokware hills of south of Mhalatswe river near Tuli Block (D7c). In association with mainly D5 and S units.
Characteristics: D7 units have generally a massive (or very weak) structure with a hard consistence. Gradual transitions exist in base saturation, CEC clay and colour between the four soil units of D7.
Vegetation: Savanna or shrub savanna with Combretum apiculatum, Acacia nigrescens, A. erubescens.

D7a **FAO:** Orthic Luvisols, partly petric(1974)
Haplic Luvisols (1988)
ST : Typic/Ultic Haplustalfs
Descritpion: Massive deep imperfectly to moderately well drained dark brown to yellowish brown clayloam to sandy clay
Topography: Flat to almost flat
Site: Normal

D7b **FAO:** Chromic Luvisols (1974)
Rhodi-Chromic Luvisols (1988)
ST : Typic Rhodustalfs
Description: Massive deep moderately well drained yellowish red to red clayloam to sandy clay
Topography: Flat to gently undulating
Site: Normal

D7c **FAO:** Ferric Acrisols, partly petroferric (1974)
Haplic Acrisols (1988)
ST : Kanhaplic/Petroferric Haplustalfs, Kandic/Petroferric Rhodustults
Kandic/Petroferric Paleustults
Description: Massive moderately deep to very deep moderately well drained brown to red sandy clayloam to sandy clay
Topography: Flat to gently undulating
Site: Normal
Representative Profile: MC 37

D8 **FAO:** Chromic Luvisols (1974)
(Rhodi-)Chromic Luvisols (1988)
ST : Typic Rhodustalfs/Haplustalfs
Description: Deep moderately well drained yellowish red to red sandy clayloam to sandy clay
Topography: Flat to gently undulating
Site: Normal to slightly shedding

Occurrence: Minor occurrence in association with other D units, e.g. near Bobothokhama (D8) and north and north east of Mokware hills (D9, 9a), north east of Serowe.
Characteristics: This group has generally better structure than other D units, also a higher base status and higher CEC clay. In places calcic or petrocalcic horizons occur.
Vegetation: Savanna with Acacia nigrescens, A. tortilis, Combretum imberbe, north of Serowe shrub savanna with Colophospermum mopane.

D9 **FAO:** Calcic Luvisols (1974)
Calcic Luvisols (1988)
ST : Typic Haplustalfs
Description: Deep moderately well drained reddish brown to dark yellowish brown sandy clayloam to sandy clay
Topography: Flat to gently undulating
Site: Normal to slightly shedding

D9a **FAO:** Calcic Luvisols,petrocalcic (1974)
Petric-Calcic Luvisols (1988)
ST : Petrocalcic Paleustalfs
Description: As D9, but with petrocalcic horizon

D10 **FAO:** Eutric Nitosols (1974)
Rhodi-Chromic Luvisols (1988)
ST : Rhodic Paleustalfs
Description: Very deep moderately well to well drained red sandy loams to sandy clayloam
Topography: Flat to gently undulating
Site: normal to slightly shedding

G SOILS ON ACID IGNEOUS AND METAMORPHIC ROCKS

G1 **FAO:** Dystric Regosols, lithic (1974)
Dystric Leptosols, Dystric Regosols (1988)
ST : Lithic Ustorthents
Description: Very shallow to shallow moderately well to somewhat excessively drained grayish brown to yellowish red coarse sands to coarse sandy loams
Topography: Undulating to hilly
Site: Shedding
Occurrence: Extensive on the most eroded parts of the plains, often in complex with rock outcrops and hills of main unit R.
Characteristics: Very shallow to shallow gravelly soils with a lithic contact within 50 cm. Transitional to the somewhat deeper Regosols G1b/c/d and G2/2a
Vegetation: Savanna or shrub savanna with predominantly Combretum apiculatum, Croton gratissimus, Sclerocarya caffra, Acacia nigrescens, A. erubescens. In the north Colophospermum mopane often dominant on the less acid soils.

G1a **FAO:** Eutric Regosols,lithic (1974)
Eutric Leptosols , Eutric Regosols (1988)
ST : Lithic Ustorthents
Description: As G1

G1e **FAO:** Lithosols (1974)
Lithic Leptosols (1988)
ST : Lithic Ustorthents
Description: Very shallow well to somewhat excessively drained grayish brown to brown coarse sands to loamy coarse sands
Topography: Undulating
Site: Shedding

G1b **FAO:** Dystric Regosols, shallow petric (1974)
Dystric Regosols (1988)
ST : Typic Ustorthents
Description: Moderately deep moderately well to well drained dark grayish brown to reddish brown coarse sands to coarse loamy sands.
Topography: Almost flat to rolling
Site: (Slightly) shedding
Occurrence: Extensive on the more eroded and steeper parts of the interfluves, but also on relative flat parts of plains, as west of Mahalapye. In complex with shallower Regosols G1,1a and moderately deep Regosols and Luvisols of the G2 and G6 units.
Characteristics: Shallow petric or petroferric phase within 50 cm from the surface. Very poor soil horizon development.
Vegetation: As G1

G1c **FAO:** Eutric Regosols, shallow petric (1974)
Eutric Regosols (1988)
ST : Typic Ustorthents
Description: As G1b

G1d **FAO:** Calcaric Regosols, shallow petric (1974)
Calcaric Regosols (1988)
ST : Typic Ustorthents
Description: As G1b

G2 **FAO:** Dystric Regosols, petric, partly petroferric (1974)
Dystric Regosols (1988)
ST : Typic Ustorthents
Description: Moderately deep to deep moderately well to well drained dark grayish brown to reddish brown coarse loamy sands. Petric or petroferric within 75cm
Topography: Almost flat to undulating
Site: Shedding to normal.
Representative Profiles: M201

Occurrence: Very extensively occurring with ustic or ustic to aridic moisture regime, on moderately to strongly eroded interfluves. Dystric and Eutric Regosols and Ferric and Chromic Luvisols occur in close complex, also with deeper Luvisols and Acrisols (G5,6,6a,8).
Characteristics: Moderately deep soils with petric or petroferric phase occurring between 40 and 75cm below the surface. Transitions between Regosols, Cambisols (minor) and Luvisols are very gradual. Argillic horizons are often weakly developed with marginal clay increase and poor structure.
Vegetation: Savanna to low tree and shrub savanna with Combretum apiculatum (on the poorer and more acid soils) and Acacia nigrescens (on the somewhat better soils) as predominant species. On the more alkaline soils in the north Colosphospermum mopane replaces Combretum.

G2a **FAO:** Eutric Regosols, petric (1974)
Eutric Regosols (1988)
ST : Typic Ustorthents
Description: As G2. Petric within 75 cm.

G2b **FAO:** Ferralic Cambisols, petric (1974)
Ferralic Cambisols (1988)
ST : Typic Ustochrepts
Description: Moderately deep to deep moderately well to well drained brown to yellowish red coarse sandy loams. Petric within 75cm
Topography: Almost flat to undulating.
Site: Shedding to normal

G2c **FAO:** Chromic Luvisols, shallow petric, petric (1974)
Chromic Luvisols, Rhodi-Chromic Luvisols (1988)
ST : Typic/Ultic Haplustalfs, Typic Rhodustalfs
Description: Moderately deep moderately well to well drained strong brown to red coarse sandy loams to sandy clayloam. Petric within 75cm.
Topography: Almost flat to undualting
Site: Shedding to normal

G2d **FAO:** Ferric Luvisols, shallow petric, petric, petroferric (1974)
Ferric/Haplic Lixisols , Rhodi-Ferric Lixisols(1988)
ST : Kanhaplic/Petroferric Haplustalfs, Haplic/Petroferric Rhodustalfs
Description: As G2c, but grayish brown to red. Petric or petroferric within 75cm
Representative Profile: M901

G2e **FAO:** Luvic Xerosols, shallow petric, petric, petroferric (1974)
Chromic/Haplic/Ferric Luvisols (1988)
ST : Ustalfic Haplargids
Description: As G2c/G2d, but with aridic moisture regime. Petric or petroferric within 75 cm.
Occurrence: Very extensively on the gneiss uplands in the north eastern part of the Palapye Sheet, where the soil moisture regime is aridic-ustic to aridic. Occurs in complex with Eutric Regosols (G1e) and deeper Luvic Xerosols (G6b).

Characteristics: Very frequent to dominant gravel occurs between 40 and 75cm below the surface. The gravel is mainly quartz but iron-manganese concretions occur. Weathered rock normally occurs within 1m. The soil structure is weak to massive but the CEC clay is relatively high. Texture of the B horizon is mostly coarse sandy loam.
Vegetation: Savanna with tree species Combretum apiculatum, dominant, Acacia nigrescens, Sclerocarya caffra, Kirkia acuminata. Also Colophospermum mopane savanna or shrub savanna.

G3 **FAO:** Albic Arenosols, partly petroferric(1974)
Albic Arenosols (1988)
ST : Typic Ustipamments
Description: Moderately deep to deep moderately well drained, brown to light gray massive coarse sands to loamy coarse sands
Topography: Flat to gently undulating
Site: Normal to shedding
Occurrence: Irregular occurrence on higher and medium parts of gently undulating plains. Mostly having petroferric phase. In association with sandy Ferric Luvisols G6 and Orthic Luvisols G7 and 7a.
Characteristics: Unit G3 has moderately deep albic horizons often with red mottling, overlying petroferric material with various degrees of cementation. With loamy texture or on gravel classified as Regosols (G3a)
Vegetation: Shrub savanna, or open savanna with low trees. Common species are Combretum apiculatum, Terminalia sericea, Acacia erubescens.

G3a **FAO:** Eutric Regosols, partly petric, petroferric (1974)
Eutric Regosols (1988)
ST : Typic Ustorthents
Description: As G3, but coarse sandy loams or gravelly

G4 **FAO:** Ferralic Arenosols, partly petroferric (1974)
Ferralic Arenosols (1988)
ST : Typic Ustipsamments
Description: Moderately deep to very deep well to somewhat excessively drained strong brown to yellowish red coarse sands to loamy coarse sands
Topography: Almost flat to gently undulating
Site: Normal to shedding
Representative Profiles: SH6
Occurrence: General occurrence on the higher slopes or crests of interfluves where soils have been strongly leached (lateral eluviation of clay), but mostly in complex with shallow Regosols (G2/2a) and sandy Ferric Luvisols (G2d, G6).
Characteristics: Deep to very deep soils with very poor structure, often petroferric in deeper subsoil.
Vegetation: Shrub savanna with a variety of species such as Acacia fleckii, A. erubescens, Terminalia sericea, Pelthophorum africanum, Combretum apiculatum.

G5 **FAO:** Ferric Acrisols, partly petric, petroferric (1974)
Ferric/Haplic Acrisols, Ferric Alisols (1988)
ST : Kanhaplic/Petroferric Haplustults, Kandic/Petroferric Rhodustults
Description: Moderately deep to deep moderately well to well drained yellowish red to dark yellowish brown coarse sandy loams to sandy clay
Topography: Almost flat to undulating
Site: Normal to shedding
Representative Profile: TS5
Occurrence: Common in the ustic areas as near Mahalapye and Tuli block, even in the transitional zone to aridic. In close association with Ferric Luvisols (G6, G2d) and Dystric Regosols (G2).
Characteristics: Structure is very weak to massive and CEC clay values are low. Acid soils with very frequently subsoil horizons rich in sesquinoxide nodules or cemented (petroferric). Very gradual transitions to Ferric Luvisols (G6.6a)
Vegetation: Most typically dense low tree or shrub savanna, with Combretum apiculatum strongly dominant. Relatively few other species occur, as Acacia nigrescens, A. erubescens and A. tortilis.

G6 **FAO:** Arenic Ferric Luvisols, partly petric, petroferric (1974)
Areni-Ferric/Haplic Lixisols, Rhodi-Areni-Ferric/Haplic Lixisols (1988)
ST : Arenic Kanhaplic/Petroferric Haplustalfs,
Arenic Kandic/Petroferric Rhodustalfs
Description: Moderately deep to deep moderately well to well drained reddish yellow to red loamy coarse sands to coarse sandy loams. Petric/petroferric not within 75cm
Topography: Almost flat to undulating
Site: Normal to shedding
Representative Profiles: TS3
Occurrence: Very extensive in all areas. Major moderately deep soil type on the less eroded plains. More typical on gneiss than on granite. Occur in association with shallower Ferric Luvisols (G2d/f) Chromic Luvisols (G8), Ferric Acrisols (G5) and Regosols.
Characteristics: Very weak to massive structure and relatively low CEC clay values. Weathered rock gravel or petroferric horizon mostly occurs around 1m depth, sometimes deeper. Gradual transitions to Chromic Luvisols G8 and G9 and Luvic Xerosols G6b and G8a in the arid areas to the northeast.
Vegetation: Savanna to open savanna, with a predominance of low trees, Combretum apiculatum and Acacia nigrescens. Other species include Acacia erubescens, Sclerocarya caffra, Albizia harveyii.

G6a **FAO:** Ferric Luvisols, partly petric, petroferric (1974)
Ferric/Haplic Lixisols, Rhodi-Ferric/Haplic Lixisols, (Rhodi-) Ferric Luvisols (1988)
ST : Kanhaplic/Petroferric Haplustalfs, Kandic/Petroferric Rhodustalfs
Ultic Haplustalfs/Typic Rhodustalfs
Description: Moderately deep to deep moderately well drained yellowish red to red sandy clayloam to clay. Petric/petroferric not within 75cm

Topography: Almost flat to undulating
Site: Normal to slightly shedding
Representative Profile: M224

G6b **FAO:** Luvic Xerosols, partly petric, petroferric (1974)
(Areni-)Ferric/Haplic Lixisols, Ferric Luvisols
ST : (Arenic) Ustalfic/Typic Haplargids
Description: As G6/6a, but with aridic moisture regime.
Occurrence: Extensive in the northern part of the Basement complex at the transition ustic-aridic. In complex with Luvic Xerosols (G2e).The major part mapped as G6b is actually G8a.
Characteristics: Gravel occurs mostly between 75 and 125cm. Soil structure is weak to very weak but the CEC clay is relatively low in the argillic B horizon. Has gradual transitions to unit G8a
Vegetation: As G8a

G7 **FAO:** Orthic Luvisols, petric (1974)
Haplic Luvisols (1988)
ST : Typic/Ultic Haplustalfs
Description: Moderately deep to deep imperfectly to moderately well drained brown to dark grayish brown massive coarse sandy loams to sandy clayloam.
Topography: Flat to gently undulating.
Site: Normal to slightly receiving
Occurrence: On middle valley slopes in the more eroded plains mainly between Mahalapye, Kalamare and Mosoletshane, in association with Ferralic and Albic Arenosols (upper slopes) and Solodic and Eutric Planosols (lower slopes). Elsewhere minor in valleys (west of Palapye) and associated with Ferric and Orthic Luvisols.
Characteristics: Massive hard gray soils with mostly marginal argillic horizons, partly with albic horizon or petroferric (G7a). Gradual transistions to Albic Arenosols (G3) and Orthic Luvisols (G10a).
Vegetation: Mostly low open savanna or shrub savanna with species such as Acacia erubescens, A. robusta, Terminalia sericea, Euclea undulata.

G7a **FAO:** Ferric Luvisols, petroferric (1974)
Ferric Lixisols, Ferric Luvisols (1988
ST : Petroferric Haplustalfs
Description: As G7, but with petroferric

G8 **FAO:** Chromic Luvisols, petric (1974)
Chromic Luvisols, Rhodi-Chromic Luvisols (1988)
ST : Typic/Ultic Haplustalfs, Typic Rhodustalfs
Description: Moderately deep to deep moderately well to well drained yellowish red to red coarse sany loams to sandy clayloam. Petric not within 75cm.
Topography: Almost flat to undulating

Site: Normal to slightly shedding
Occurrence: Common soil unit on the weakly eroded plains. Occurs in association with other Chromic Luvisols (G2d, G9), Ferric Luvisols (G6, 6a), and also Ferric Acrisols (G5)
Characteristics: Moderately deep soils with weak structures and gravel or weathered rock occurring between 75 and 100 cm. Has relatively low CEC clay values with gradual transitions to Ferric Luvisols.
Vegetation: Savanna with Acacia nigrescens and Combretum apiculatum and other Acacia species as A. gerardii and A. nilotica.

G8a **FAO:** Luvic Xerosols, partly petric (1974)
Chromic Luvisols, Rhodi-Chromic Luvisols (1988)
ST : Ustalfic/Typic Haplargids
Description: Moderately deep to very deep moderately well to well drained yellowish red to red coarse sandy loams to sandy clay
Topography: Almost flat to undulating
Site: normal to slightly shedding
Occurrence: Extensive on the gneiss uplands in the northeastern part of the Palapye sheet where the soil moisture regime is aridic-ustic and aridic. Occurs mostly in complex with shallower Luvic Xerosols G2e on the lower slopes. For the major part mapped as G6b on the Palapye sheet.
Characteristics: Gravel mostly occurs between 75 and 125cm below the surface. The soil structure is weak to very weak subangular blocky but the CEC clay is relatively high in the argillic B, which has mostly sandy clayloam to sandy clay texture. Gradual transitions to similar G6b.
Vegetation: Shrub or low tree savanna with Combretum apiculatum dominant on the higher slopes and Colophospermum mopane on the more clayey lower slopes.

G9 **FAO:** Chromic Luvisols (1974)
Chromic Luvisols, Rhodi-Chromic Luvisols (1988)
ST : Typic/Ultic Haplustalfs, Typic Rhodustalfs

Description: Deep to very deep modertely well to well drained yellowish red to dark red sandy clayloam to sandy clay
Topography: Almost flat to undulating
Site: Normal to slightly shedding
Representative Profile: M0083
Occurrence: Common soil unit on the non or weakly eroded gently undulating plains and pediments, especially around Mahalapye on granite. Occurs with other Chromic Luvisols (G8,G2d) and Ferric Luvisols (G6a).
Characteristics: Deep reddish soils on weathered rock between 100 and 150cm. Structure is weak to moderate. CEC clay ranges from about 40 to 24, thus forming gradual transitions with Ferric Luvisols G6a. Also gradual transitions with deeper Eutric Nitosols (G14) and shallower G8.
Vegetation: Savanna to woodland with predominant Acacia nigrescens and subordinate or codominant Combretum apiculatum. Other species include Acacia tortilis, A. nilotica, A. gerradii, Sclerocarya caffra.

G10 **FAO:** Chromic Luvisols (1974)
Chromic Luvisols, Rhodi-Chromic Luvisols (1988)
ST : Typic Halpustalfs
Description: Deep to very deep moderately well drained yellowish red to strong brown sandy clayloam to clay.
Topography: Almost flat
Site: Normal to slightly receiving
Occurrence: Common in Mahalapye area especially but also elsewhere in relatively low or depressional parts of gently undulating plains, mostly water receiving and never shedding. G10, 10a, 10b occur in close association with each other and occur also with a variety of other soils such as Gleyic and Calcic Luvisols.
Characteristcs: Structure is weak to massive and the clay content is relatively high compared to other G unit soils. Minor differences in CEC clay and colour determine classification as Chromic, Ferric and Orthic Luvisols.
Vegetation: Savanna to woodland with predominant Acacia nigrescens and other common species Sclerocarya caffra, Combretum imberbe, A nilotica, A. gerradii as often occurring. Colophospermum mopane dominant in the north.

G10a **FAO:** Orthic Luvisols (1974)
Haplic Luvisols (1988)
ST : Typic Haplustalfs
Description: As G10, but dark brown and imperfectly drained
Topography: Almost flat
Site: Normal to receiving

G10b **FAO:** Ferric Luvisols (1974)
Ferric Lixisols, Ferric Luvisols (1988)
ST : Kanhaplic Haplustalfs, Typic Haplustalfs
Description: As G10/10a

G11 **FAO:** Plinthic Luvisols (1974)
Albic Plinthosols (1988)
ST : Plinthustalfs
Description: Deep imperfectly to moderately well drained gray and red to yellowish red mottled coarse sandy loams to sandy clayloam
Topography: Flat to gently undulating
Site: (Slightly) receiving
Representative Profile: M361
Occurrence: Minor occurrence in places with water throughflow at shallow to moderted shallow depth. In relatively low positions of gently undulating plains in association with Ferric Luvisols (G10b, G7a) and Gleyic Luvisols (G12).
Characteristics: Plinthite characterised by strong prominent gray and red mottling, the red mottles/nodules being weakly cemented. Weak developments transitional to ferric properties with many prominent reddish mottles or sesquioxide nodules.
Vegetation: Savanna with Acacia spp. and Combretum apiculatum.

G12 **FAO:** Gleyic Luvisols (1974)
Stagnic Luvisols (1988)
ST : Aeric Ochraqualfs
Description: Moderately deep to deep poorly to imperfectly drained dark grayish brown to dark gray coarse sandy loams to clay
Topography: Flat
Site: (Slightly) receiving
Representative Profiles: M362
Occurrence: Minor occurrence mainly west of Mahalapye in depressions and lower parts of gently undulating plains. In association with occassional Plinthic Luvisols (G11) and Orthic and Calcic Luvisols (G10a, 13a).
Characteristics: Marginal hydromorphic properties. (chromas of 2 with brownish mottling). Subsoil mostly calcareous (calcic horizon) and/ or having strongly gravelly layers.
Vegetation: Savanna with predominantly Acacia ssp, such as A.tortilis, A. nigrescens, A. robusta, A. erubescens.

G13 **FAO:** Calcic Luvisols (1974)
Calcic Luvisols (1988)
ST : Typic Haplustalfs
Description: Moderately deep to deep imperfectly to well drained dark grayish brown to dark reddish brown coarse sandy loams to sandy clay.
Topography: Flat to undulating
Site: Normal to slightly receiving
Occurrence: On lower slope positions of valleys and depressions. Common soils, increasingly so towards more arid areas. Occurs in complex or association with Chromic and Ferric Luvisols (Luvic Xerosols) also Orthic and Gleyic Luvisols.
Characteristics: Having a calcic horizon within 125cm, sometimes only few soft powdery lime. In subsoil mostly very frequent nodules which may transgrade into petrocalcic horizon. Petrocalcic horizon also found with abrupt boundary.
Vegetation: Savanna or woodland with predominatly Acacia nigrescens, also A. mellifera, A. tortilis, A.gerradii, Combretum imberbe, and Colophospermum mopane.

G13a **FAO:** Calcic Luvisols, petrocalcic (1974)
Petri-Calcic Luvisols (1988)
ST : Petrocalcic Paleustalfs
Description: As G13, but with petrocalcic horizon
Topography: Flat to undulating
Site: Normal to (slightly) receiving
Representative Profile: MC 901

G14 **FAO:** Eutric Nitosols (1974)
Pale-Chromic Luvisols (1988)
ST : Rhodic/Typic Paleustalfs
Description: Very deep moderately well to well drained yellowish red to dark red sandy clayloam to sandy clay
Topography: Almost flat to gently undulating (pediments mainly).
Site: Normal
Representative Profile SH902
Occurrence: Typical on the granite pediments in the Shoshong valley and minor elsewhere as at Morale (Mahalapye). In association with the slightly shallower Chromic Luvisols, G9.
Characteristics: Very deep (1.5-2.5m) mostly red or yellowish red soils with weak to moderate structure. Soil material mostly to some extent alluvial reworked or colluviated but unmixed. Relatively good structure and high CEC may be due to enrichment by drainage water derived from dolerite rock.
Vegetation: Savanna to woodland with dominant Acacia nigrescens and subordinate Combretum apiculatum and other Acacia species (as G9)

G15 **FAO:** Solodic Planosols (1974)
Albi-Abrupti-Stagnic Solonetz, Eutric Planosols(1988)
ST : Albic Natraqualfs, Aeric/Arenic Albaqualfs
Description: Deep to very deep imperfectly drained yellowish brown to strong brown sandy clay to clay
Topography: Flat to gently undulating
Site: Slightly receiving
Representative Profiles: M 295
Occurrence: On the lower slopes in the dissected granite/gneiss areas, predominantly in the Kalamare area.
Characteristics: Coarse sandy albic horizon abruptly overlying clayey natric or argillic horizon. Exchangeable sodium percentage variable and mostly not very high. Transitional to Eutric Planosols and Orthic Luvisols.
Vegetation: Open savanna with Acacia karroo mostly dominant, with Combretum imberbe, C. hereroense, A. tortilis.

G16 **FAO:** Gleyic Solonetz 1974)
Stagnic Solonetz (1988)
ST : Typic Natraqualfs
Description: Deep to very deep poorly to imperfectly drained dark gray to grayish brown sandy clayloam to sandy clay
Topography: Flat to almost flat
Site: (Slightly) receiving
Occurrence: Minor units in valleys and depressions mainly in the Mahalpye - Kalamare area, in association with G15 Solodic Planosols.
Characteristics: Ochric and/or albic horizons overlying prismatic or columnar natric B horizon with continuous gray clay cutans.
Vegetation: Savanna with mainly Acacia spp (A. karroo, A. nilotica)

L (AND AL) SOILS ON LACUTRINE DEPOSITS

L6 **FAO:** Calcic Gleysols, partly sodic (1974)
Calcic Gleysols, Stagnic Calcisols (1988)
ST : Mollic Haplaquepts, Typic Halaquepts, Typic Tropaquepts
Decription: Very deep poorly to imperfectly drained very dark gray to gray sandy clay to clay
Topography: Flat
Site: Receiving
Occurrence: Minor in pans and depressions in the sandveld, in association with Eutric Arenosols S17 and Petrocalcic Arenosols C3.
Characteristics: Gradual transitions between units depending on drainage, texture and depth of calcareous horizons.
Vegetation: Savanna or shrub savanna with species as Acacia mellifera, A.tortilis, Combretum imberbe. Towards north east also A.nebrownii and Catophractes alexandrii.

L10 **FAO:** Calcaric Arenosols(1974)
Calcaric Arenosols(1988)
ST : Ustic Quartzipsmments, Ustic Torripsamments
Description: Deep to very deep moderately well to well drained dark gray to pale brown fine sands to loamy fine sands
Topography: Almost flat to gently undulating
Site: Normal

L11 **FAO:** Calcic Arenosols, partly sodic (1974)
Calcic Arenosols (1988)
ST : Grossarenic (Ustollic)Calciorthids, Grossarenic (Aridic) Ustochrepts
Description: Deep to very deep moderately well to well drained dark gray to pale brown fine sands to loamy fine sands. Having a calcic horizon, calcareous between 0-50cm
Topography: Almost flat to gently undulating
Site: Normal

L19 **FAO:** Calcaric Cambisols (1974)
Calcaric Cambisols (1988)
ST : Typic Ustorthents, Ustollic /Typic Camborthids
Description: Deep to very deep imperfectly to moderately well drained very dark grayish brown to brown sandy clayloam to clay.
Topography: Flat
Site: Normal

S (OR KS, LS) SOILS ON COARSE GRAINED SEDIMENTARY ROCKS

S1 **FAO:** Ferralic Arenosols, lithic (1974)
Ferralic Arenosols (1988)
ST : Lithic Ustipsamments, Lithic Quartzipsamments
Description: Very shallow to shallow excessively drained yellowish brown to yellowish red sands and loamy sands.
Topography: Undulating to hilly
Site: Shedding
Occurrence: On eroded sandstone hills and the Kalahari Scarp in the Serowe area, also south of Bobonong along the Thune river and minor elsewhere. In complex with deeper sandy soils.
Characteristics: There is mostly a gradual transition from the sand to the weathered rock which disintegrates into loose sand, as on the Ntane (Cave) Sandstone. Some other sandstones weather to gravel, hence a petric phase and classification as Regosol (S1b).
Vegetation: Savanna or woodland with Croton gratissimus as most typical species also Ochna pulchra and Pelthophorum africanum.

S1a **FAO:** Ferralic Arenosols (1974)
Ferralic Arenosols (1988)
ST : Typic Ustipsamments, Ustic Quartzipsamments
Description: Moderately deep somewhat excessively drained yellowish to yellowish red or dark reddish brown sands and loamy sands (lithic between 50-100cm)
Topography: Undulating to hilly
Site: Shedding

S1b **FAO:** Arenic Eutric Regosols, petric (1974)
Areni-Eutric Regosols (1988)
ST : Typic Ustorthents
Description: Shallow to moderately deep somewhat excessively drained brownish yellow to yellowish red sands and loamy sands
Topography: Undulating to hilly
Site: Shedding

S3 **FAO:** Ferralic Arenosols (1974)
Ferralic Arenosols (1988)
ST : Ustic Quartzipsamments, Typic Ustipsamments

Description: Deep to very deep well to somewhat excessively drained yellowish brown (with chroma of 5 or more) to yellowish red fine and fine-medium sands
Topography: Flat to undulating
Site: Normal
Representative Profiles: DI901
Occurrence: Most common soil unit in Botswana. KS3 is the predominant soil of the Kalahari sandveld in Serowe-Lephepe area in association with KS16 Dystric Arenosols. On sandstone and reworked within hard-veld area in complex with S5 and S7, Arenic Ferric Luvisols.

Characteristics: Very weak or single grain loose soil structure. Colours range from red (S3a) to yellowish brown, the boundary colour where the soil transgrades to Dystric or Eutric Arenosols. CEC and clay percentages are very low (3-5%), and there is no increase of the clay content with depth.
Vegetation: Savanna to open shrub savanna with a variety of predominant species such as Terminalia sericea, Lonchocarpus nelsii, Burkea africana with Ochna pulchra, Acacia fleckii, Bauhinia petersiana, Peltophorum africanum as typical species.

S4 **FAO:** Ferralic Arenosols (1974)
Ferralic Arenosols (1988)
ST : Typic Ustipsamments, Ustic Quartzipsamments

Description: Deep to very deep somewhat excessively drained brownish yellow to reddish brown medium to coarse sands and loamy sands.
Occurrence: On medium to coarse sandstones of the Waterberg and Karroo Supergroups. Most frequently occurring in south east Central District and Kweneng on Waterberg sandstone. Minor in other areas such as south of Shoshong hills.
Characteristics: Yellowish and brownish sands, mostly structureless, with low CEC and low clay contents (loamy sands only in places)
Vegetation: Open savanna and shrub savanna with Terminalia sericea, Combretum apiculatum, Peltophorum africanum.

S5 **FAO:** Ferralic Arenosols (1974)
Luvic Arenosols (1988)
ST : Ustic Quartzipsamments, Typic Ustipsamments
Description: Deep to very deep well to somewhat excessively drained yellowish brown to red fine and fine-medium sands to loamy fine sand.
Topography: Flat to undulating
Site: Normal
Represenative Profile: S10 (KS5), S2 (S5)
Occurrence: Common in transitional Kalahari sand areas and typical on fine sandstones as Ntane or Cave Sandstone. In association with S3, S7 and S10. Most frequent in the Serowe and Lephepe - Dinokwe areas, also south of Bobonong.
Characteristics: A gradual clay increase with depth to 6-10% at 125cm depth (S5) or have clay lamellae within 125 cm (S5a). Structure is very weak and CEC normally less than 4me9/100g.
Vegetation: As S3 but with a more variable vegetation including Sclerocarya caffra, Kirkea acuminata, Acacia spp.

S5a **FAO:** Luvic Arenosols (1974)
Lamelli-Luvic Arenosols (1988)
ST : Alfic Quartzipsamments, Alfic Ustipsamments
Description: as S5, but showing lamellae of clay accumulation.

S6 **FAO:** Ferralic Arenosols (1974)
Ferralic/Luvic Arenosols (1988)
ST : Ustic Quartzipsamments, Typic Ustipsamments

Description: Deep to very deep somewhat excessively to excessively drained yellowish brown to red fine and fine-medium sands to loamy fine sands
Topography: Undulating to rolling (dunes, hills)
Site: Shedding to normal
Representative Profiles: S13
Occurrence: On the steeper (undulating to rolling) watershedding hills in mainly the Serowe area, and minor at Dinokwe.
Characteristics: Similar to either S3/3a or S5/5a
Vegetation: As S3 - S5

S6a **FAO:** Luvic Arenosols (1974)
Lamelli-Luvic Arenosols (1988)
ST : Alfic Quartzipsamments
Alfic Ustipsamments
Description: As S6, but showing lamellae of clay accumulation

S7 **FAO:** Arenic Ferric Luvisols(1974)
Argi-Luvic Arenosols (1988)
ST : Psammentic Kandic (Rhodic) Paleustalfs
Description: Deep to very deep well to somewhat excessively drained strong brown to red loamy fine and fine-medium sands.
Topography: Flat to undulating
Site : Normal to shedding
Representative Profile: S507
Occurrence: Common as S5, but more on the lower slopes of sand units. In association with S5 and S10 mainly. S8 occurs only in places on the Lephepe sheet.
Characteristics: Very weak argillic horizon with loamy sand texture. Very weak to weak coarse structure with clay cutans on pedfaces and/or having clay lamellae. The clay content often still increases below 125cm from the surface.
Vegetation: As S5 but including less specific sandveld species such as Acacia tortilis, A gerrardii.

S8 **FAO:** Arenic Ferric Luvisols (1974)
Argi-Luvic Arenosols (1988)
ST : Psammentic Kandic (Rhodic) Paleustalfs
Description: Deep to very deep somewhat excessively to excessively drained yellowish red to red loamy fine and fine-medium sands
Topography: Undulating to rolling (dunes, hills)
Site: Shedding to normal.

S9 **FAO:** Arenic Ferric Acrisols (1974)
Dystric-Argi-Luvic Arenosols (1988)
ST : Psammentic Kandic (Rhodic) Paleustults
Description: Deep to very deep somewhat excessively drained strong brown to red loamy sands.
Topography: Flat to undulating
Site: Normal
Representative Profile: S11
Occurrence: Fairly minor occurrence on the middle slopes of low hills on Karroo sandstones (Serowe area), the lower pediment slopes on quartzites (south of Morale hills and south east of Dibete). In association with Luvic Arenosols (S5a, 6a), Arenic Ferric Luvisls (S7,10) and Ferric Acrisols D3.
Characteristics: Weakly developed argillic horizon with deep and very gradual clay increase. S9a has slightly more clay, sandy loam at 125cm (argic horizon). Clay illuviation lamellae commonly occur.
Vegetation: Low tree or shrub savanna with Terminalia sericea or combrtum apiculutam. Subordinate Acacia erioloba, A. fleckii, Dichrostachys cinerea and Pelthophorum africanum.

S9a **FAO:** Arenic Ferric Acrisols (1974)
Pale-Areni-Haplic Acrisols (1988)
ST: Grossarenic Kandic (Rhodic) Paleustults
Description: As S9, but sandy loams

S10 **FAO:** Arenic Ferric Luvisols (1974)
Pale-Areni-Haplic Lixisols (1988)
ST : Grossarenic Kandic (Rhodic) Paleustalfs
Description: Deep to very deep well to somewhat excessively drained yellowish red to red fine and fine-medium sandy loams
Topography: Flat to undulating
Site: Normal to slightly receiving
Occurrence: Common, but mainly around Palapaye, east of Dinokwe and around Dibete. Mostly in lower slope position (partly water receiving) of transitional Kalahari sand units or on coarse sedimentary rock. In association with a variety of other S units. (S5,7,9,11) and also D units (D5,7c)
Characteristics: Having an argillic horizon (better developed than S7) with find sandy loam texture in the subhorizon at 125cm depth, which also qualifies for argic horizon. Often the clay content still increases below 150cm. Clay lamellae may occur. CEC values are 4me9 or less in at least the upper part of the argillic horizon.
Vegetation: As S5 and S7 but more often a microphyllous savanna type with a variable composition including Acacia tortilis, A. erioloba, A. erubescens, A. gerrardii, A. luederitzii and Combretum apiculatum.

S11 **FAO:** Arenic Eutric Nitosols (1974)
Pale-Areni-Chromic Luvisols (1988)
ST : Grossarenic (Rhodic) Paleustalfs
Description: Very deep well to somewhat excessively drained red to brown fine and fine-medium sandy loams
Topography: Flat to undulating
Site: Normal to slightly receiving
Resspresentative Profiles: S512
Occurrence: As S10
Characteristics: Similar to S10 and very difficult to separate from S10. CEC values are higher than 4 in the argillic/argic horizon
Vegetation: As S10

S12 **FAO:** Arenic Calcic Luvisols (1974)
Arenic Calcic Luvisols (1988)
ST : (Gross)arenic Paleustalfs/Haplustalfs
Description: Deep to very deep well to somewhat excessively drained dark grayish brown to yellowish red sandy loams
Topography: Flat to undulating
Site: Normal
Occurrence: S12 is found mostly in the Serurume valley and adjacent areas, in complex with C and other S units. S12a (mapped as S12) occurs north of the Thune river in complex with mainly calcareous and shallow sandy soils.
Characteristics: The argillic horizon is marginal with a very gradual clay increase. In lower positions colours are grayish but on slopes reddish. The calcic horizon occurs irregularly.
Vegetation: Variable savanna vegetation with commonly Acacia mellifera and Combretum imberbe. In northern areas Catophractes alexandrii and Acacia nebrownii.

S12a **FAO:** Arenic Luvic Xerosols(1974)
Areni-Calci Luvisols(1988)
ST : (Gross)arenic (Ustollic) Haplargids
Description: As S12, but aridic moisture regime

S13 **FAO:** Calcic Arenosols (1974)
Calcic Arenosols (1988)
ST : Grossarenic (Ustollic) Calciorthids, Grossarenic (Aridic) Ustochrepts, Grossarenic Ustropepts
Description: Moderately deep to very deep well to somewhat excessively drained grayish brown to yellowish red sands and loamy sands
Topography: Flat to undulating
Site: Normal to slightly shedding
Occurrence: Arenosols with a calcic or petrocalcic horizon occur more frequently in the areas with a more aridic moisture regime, as in the Thune area or towards the Sandveld but (petro)calcic horizons occur also irregularly as relict features. In complex with various S and C units.

Characteristics: The calcic or petrocalcic occurs at any depth between 50 and 125cm below the surface. Colours vary strongly from brownish to reddish depending on position. There is mostly a gradual clay increase with depth.
Vegetation: Varies strongly from tree to shrub savanna with diverse species as Terminalia sericea, Acacia mellifera and Combretum imberbe.

S13a **FAO:** Petrocalcic Arenosols (1974)
Petri-Calcic Arenosols (1988)
ST : (Gross)arenic (Ustollic) Paleorthids
(Gross)arenic Petrocalcic Ustochrepts
Description: As S13, but having a petrocalcic horizon

KS16 **FAO:** Dystric Arenosols (1974)
Dystric-Haplic Arenosols (1988)
ST : Ustic Quartzipsamment
Description: Deep to very deep somewhat excessively drained dark grayish brown to light yellowish brown fine and fine-medium sands to loamy fine sands
Topography: Flat to undulating
Site: Normal
Occurrence: Major unit of the flat eastern Kalahari sandveld in association with Ferralic Arenosols KS3.
Characteristics: Pale yellowish single grained loose fine sands with very low CEC, clay content, and base saturation.
Vegetation: As KS3 Kalahari part but more often an open shrub savanna.

S17 **FAO:** Dystric Arenosols (1974)
Eutri-Haplic Arenosols
ST: Ustic Quartzipsamments, Typic Ustipsamments
Description: Deep to very deep well to somewhat excessively drained dark grayish brown to light yellowish brown fine and fine-medium sands to loamy find sands, non calcareous between 50 and 100 cm
Topography: Flat to undulating
Site: Normal
Representative Profile: S6
Occurrence: Relatively minor occurrence in lower positions in association with mainly S3, S5, S7. S17c minor on low ridges.
Characteristics: Grayish to pale yellow fine sands, simple grained or with very weak structure, low CEC and low clay content.
Vegetation: As S3, but has more often inclusions or patches of microphyllous savanna with e.g. Acacia erioloba, A. erubescens, A. luederitzii.

S17c **FAO:** Dystric Arenosols (1974)
Eutri-Haplic Arenosols(1988)
ST: Ustic Quartzipsamments, Typic Ustipsamments

Description: as S17/17a, but medium to coarse sand to loamy sands
Topography: Flat to undulating (dunes, beachridges)
Site: Shedding to normal

3 PHYSIOGRAPHIC RELATIONSHIPS

3.1 PHYSIOGRAPHIC UNITS

The physiographic units or landscapes as shown on the 1:1 million map (figure 3.1) represent areas which have defined sets of related or associated geomorphological and pedological characteristics. The units form a base for the mapping of soil associations at exploratory (1:1 000 000) scale. Combined with the agro-climatic zonation (see section 1.2) these units can basically be considered as broadly defined **agro-ecological units.** The more precise suitability assessment as per soil mapping unit is given in Chapter 4.

Most of the physiographic units have characteristic assocations of vegetation types and species, but the vegetation is not further described in this section as the general relationship with the major soil groupings is already discussed in section 1.5, and further details are given with the soil unit description in section 2.3.2.

The physiographic units are defined and briefly described as follows:

1. Flat featureless Kalahari sandveld plateau

Agro-climatic zone 3d4 with ustic to aridic soil moisture regime. See cross section no 1 (Figure 3.2).

Soils are very deep acid sands with very low inherent fertility and very low water holding capacity.

2. Flat to gently undulating transition Kalahari sandveld to hardveld

2A. Kalahari aeolian sands with subordinate sandy alluvial valleys and sedimentary rock

Agro-climatic zone 2d3 and minor 1d3 with ustic to aridic soil moisture regime.

Predominant flat Kalahari sands as unit 1

Minor alluvial valleys have soils which are sandy to loamy, partly calcareous, and low in inherent fertility

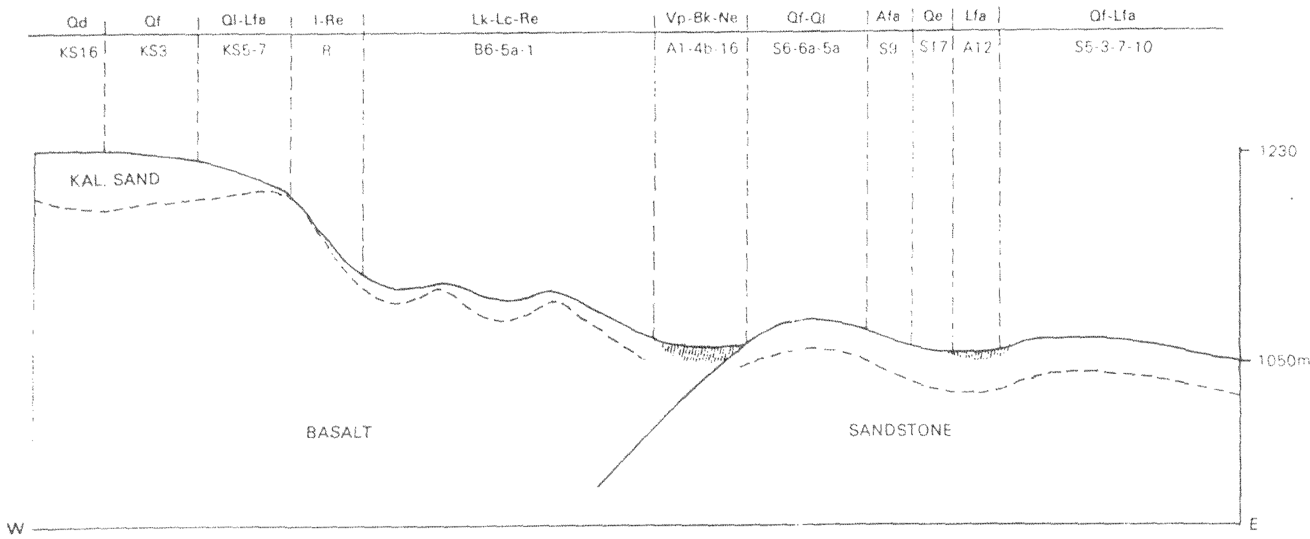

FIG. 3.2 SCHEMATIC CROSS SECTION NO 1 (SEROWE)

LEGEND

Qf - Ferralic Arenosols
Ql - Luvic Arenosols
Qd - Dystric Arenosols
Qa - Albic Arenosols
Lfa - Arenic Ferric Luvisols
Lc - Chromic Luvisols
Lk - Calcic Luvisols
Lv - Vertic Luvisols
Lf - Ferric Luvisols
Lo - Orthic Luvisols
I - Lithosols
Ws - Solodic Planosols

Re - Eutric Regosols
Rc - Calcaric Regosols
Rd - Dystric Regosols
Vp - Pellic Vertisols
Vc - Chromic Vertisols
Afa - Arenic Ferric Acrisols
Af - Ferric Acrisols
Bk - Calcic Cambisols
Bv - Vertic Cambisols
Ne - Eutric Nitosols
Xl - Luvic Xerosols
Xh - Haplic Xerosols

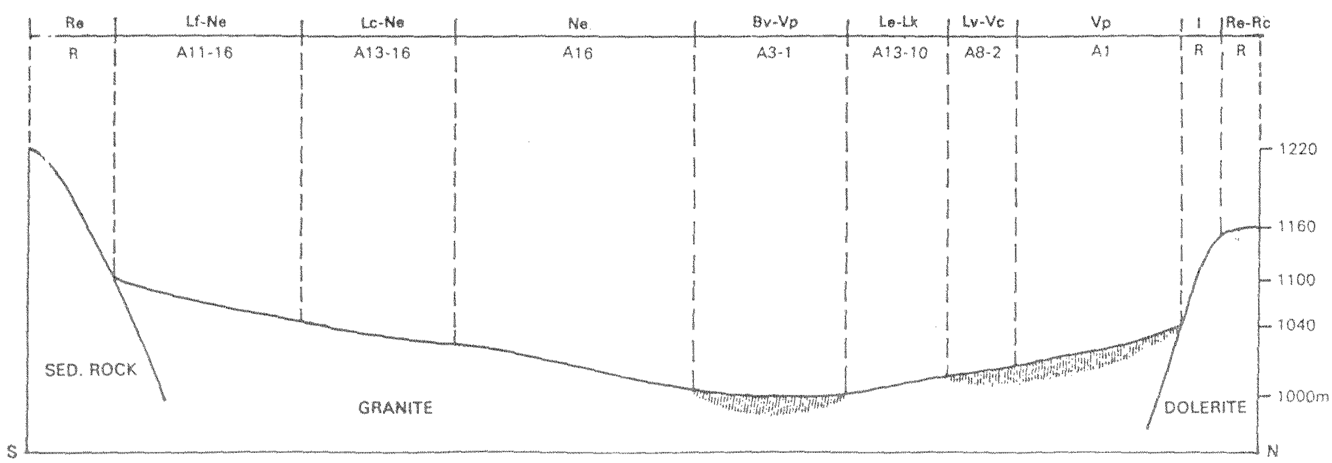

FIG. 3.3 SCHEMATIC CROSS SECTION NO. 2 (SHOSHONG)

2B. Serurume upper catchment, flat to gently undulating calcretised alluvial valleys in association with aeolian sands and subordinate basalts and sandstones

Agro-climatic zones 2d3 with ustic to aridic soil moisture regime

(1) Western part with predominant calcrete, alluvium and basalt, and subordinate aeolian sands.

(2) Middle part with predominant aeolian sands and alluvium, and minor calcrete.

(3) Eastern part with predominant aeolian sand and minor alluvium, calcrete and diabase.

Major aeolian sand plains have very deep neutral to acid sands and loamy sands with low inherent fertility and low water holding capacity.

Major calcretes, associated with alluvium in broad valleys, have soils which are shallow to moderately deep, strongly alkaline sandy loams to sandy clays, with low fertility, low water holding capacity and toxicity in the subsoil.

Subordinate basalt, partly calcretised has soils which are shallow to moderately deep alkaline sandy clayloam to sandy clays, with moderate fertility and moderate water holding capacity.

2C. Lotsane upper catchment, flat to gently undulating aeolian reworked sandstone plains with subordinate mixed alluvium and minor basalt and other rocks.

Agro-climatic zones 2d3 and 1d3 with ustic and ustic to aridic soil moisture regime.
See cross section no 1 (Figure 3.2)

Major aeolian sand plains have very deep, neutral to acid sands and loamy sands with low inherent fertility and low water holding capacity, but lower valley slopes are partly water receiving.
Subordinate alluvial valleys have soils which are deep neutral to alkaline, partly calcareous, mixed sandy and clayey, with moderate to high fertility and medium to high water holding capacity, and are partly water receiving and in places flooded.

2D. Motloutse upper catchment.

Agro climatic zone 2d3 with ustic to aridic soil moisture regime.
As unit 2C.

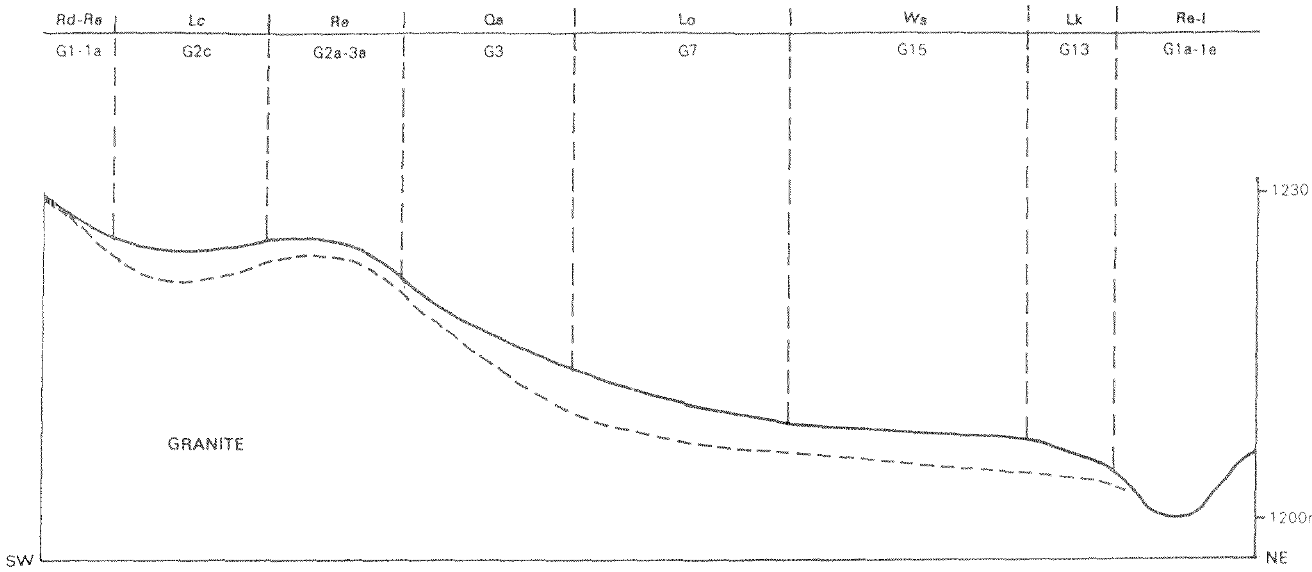

FIG. 3.4 SCHEMATIC CROSS SECTION NO. 3 (KALAMARE)

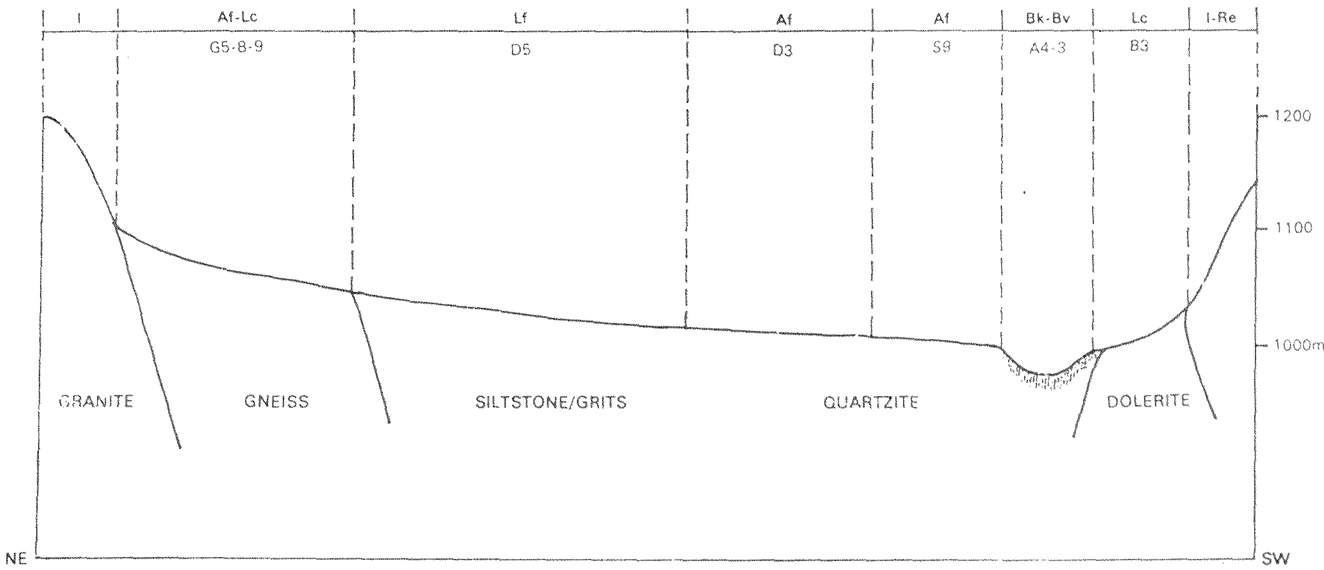

FIG. 3.5 SCHEMATIC CROSS SECTION NO. 4 (MORALE HILLS)

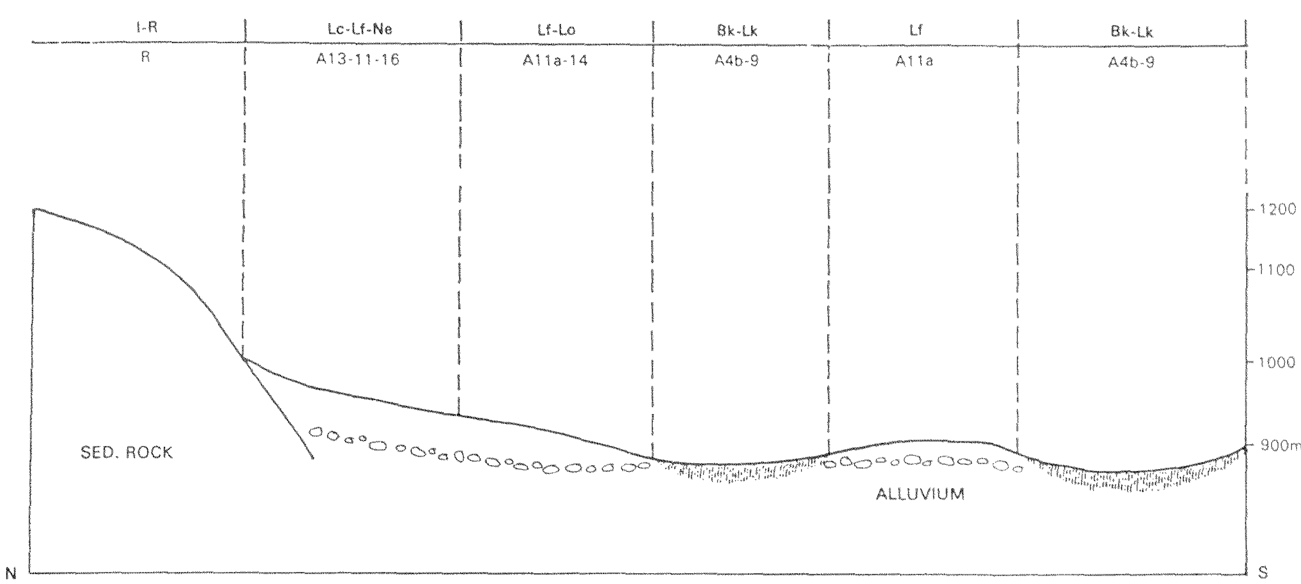

FIG. 3.6 SCHEMATIC CROSS SECTION NO. 5 (SOUTH OF TSWAPONG HILLS)

Note : For explanation of abbreviations see fig. 3.2
For definition of soil units see section 2.3

3 Rolling to undulating basalt uplands with associated alluvium and minor sandstone hills

3A. Serowe and Mmashoro basalt hills and scarps with associated alluvial flats

Agro-climatic zones 1d3 (Serowe) and 2d3 (Mmashoro) with ustic and ustic to aridic soil moisture regime.
See cross section No 1 (Figure 3.2).
Major basalt hills have soils which are shallow to moderately deep, alkaline sandy clayloam to sandy clays, partly calcareous with high inherent fertility and low to moderate waterholding capacity.
Major alluvial flats have, depending on sand influx, soils which are very deep, neutral to alkaline, loamy to clayey with moderate to high fertility and high water holding capacity, in part water receiving, and in part having poor physical properties.

3B. Bobonong undulating eroded basalt plain with minor sandstones

Agro-climatic zone 4b3 with aridic soil moisture regime.

Predominant basalt plain has soils which are shallow strongly calcareous sandy clayloam with high fertility and low waterholding capacity.

4. Shoshong dolerite hills with associated alluvium and pediments on granite, minor other rocks

Agro-climatic zone 1d3 with ustic soil moisture regime.
See cross section No 2 (Figure 3.3).

Major steep and flat topped dolerite hills have soils which are very shallow with high inherent fertility and low water holding capacity.
Major very gently sloping pediments on granite have soils which are deep to very deep, neutral to slightly acid, sandy clayloam, with moderate fertility and moderate to high water holding capacity, in part on other rock acid and sandy.
Subordinate alluvial flats and valleys have very deep slightly alkaline to alkaline sandy clayloam to clays, with high fertility and moderate to high water holding capacity, in part with poor physical properties, and in part water receiving and also flooded.

5. Uplands of the gneiss-granite Basement Complex

5A. Strongly dissected upper Mhalatswe catchment

Agro-climatic zone 1d3 with ustic soil moisture regime.
See cross section No 3 (Figure 3.4).

Soils are shallow to moderately deep, neutral to acid, sandy to loamy on the eroded crests and upper slopes, and moderately deep to deep, alkaline, partly calcareous, sandy clayloam on the lower slopes with poor physical properties.

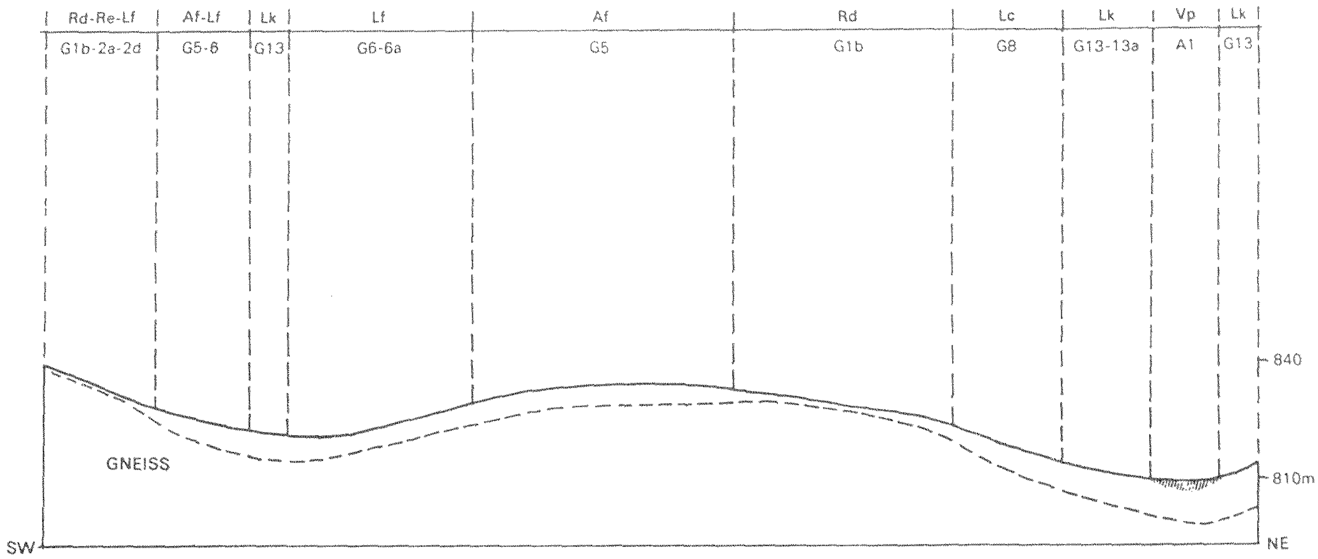

FIG. 3.7 SCHEMATIC CROSS SECTION NO. 6 (TULI BLOCK)

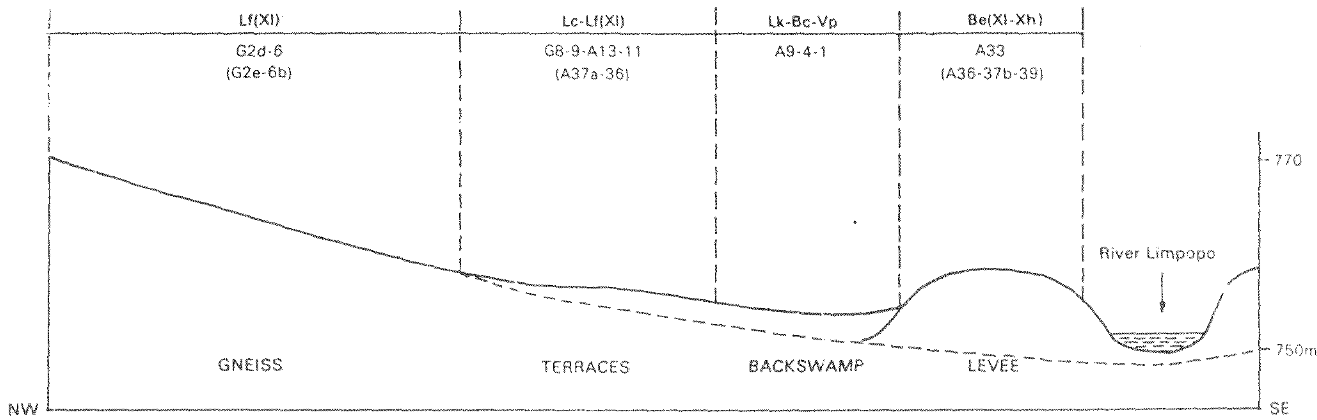

FIG. 3.8 SCHEMATIC CROSS SECTION NO. 7 (LIMPOPO)

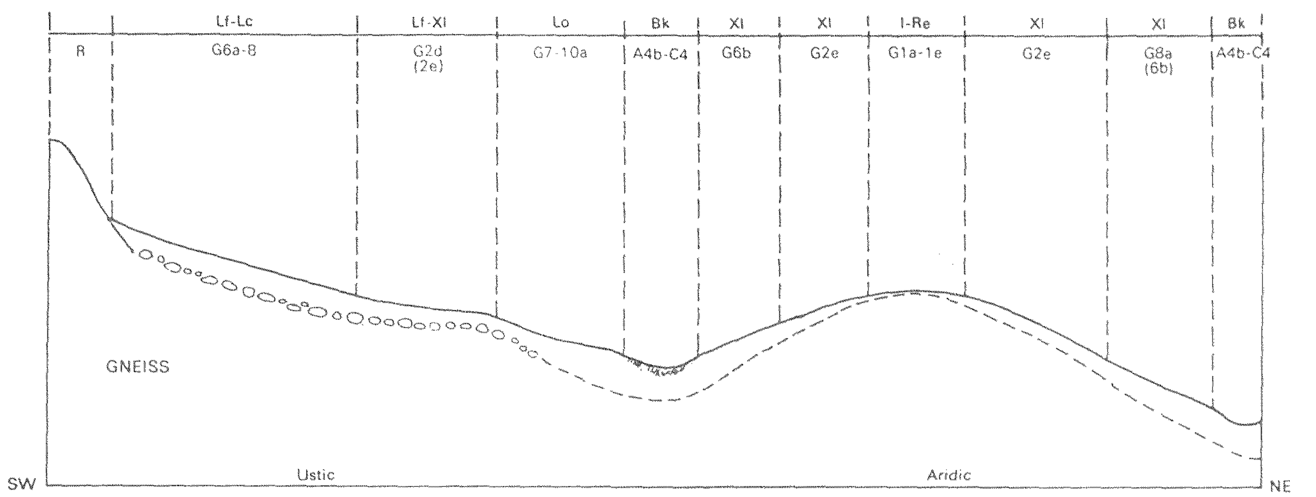

FIG. 3.9 SCHEMATIC CROSS SECTION NO. 8 (MOGAPI)

Note : For explanation of abbreviations see fig. 3.2
For definition of soil units see section 2.3

5B. Flat to gently undulating Mahalapye pediments and associated upland depressions
Agro-climatic zone 1d3 with ustic soil moisture regime.
See cross section No 4 (Figure 3.5)

Major pediments (minor on other rock) have soils which are deep to very deep slightly acid to acid, coarse sandy loams to sandy clayloam, with low to moderate fertility and moderate water holding capacity.
Subordinate depressions have soils which are moderately deep to deep neutral to alkaline sandy clayloam to sandy clays, in part water receiving.

5C. Gently undulating to almost flat upland plains with subordinate eroded valleys
Agro-climatic zones 2d3 with ustic to aridic soil moisture regime.
See cross section No 6 (Figure 3.7).

Soils are shallow to deep neutral to acid coarse sandy loam to clayloam with moderate to low fertility and moderate to low water holding capacity.

5D. Undulating moderately dissected gneiss upland plains with eroded valley sides and minor valley bottoms
(1) Western part, agro-climatic zone 2d3 with ustic to aridic soil moisture regime.
(2) Central part, agro-climatic zone 3b4 with aridic to ustic soil moisture regime.
(3) Eastern part, agro-climatic zone 4b3 with aridic soil moisture regime

See cross section No 8 (Figure 3.9)

Predominant plain with valley sides have soils which are shallow to moderately deep, slightly acid to slightly alkaline, coarse sandy loams to sandy clayloam with low to moderate fertility and low to moderate water holding capacity.
Valley bottoms have soils which are moderately deep to deep neutral to alkaline, partly calcareous sandy clayloam with moderate to high fertility and moderate waterholding capacity, water receiving and in part flooded.

5E. Undulating to rolling moderately dissected gneiss upland plain with frequent kopjes and associated pediments
Agro-climatic zone 2d3 with ustic to aridic soil moisture regime.
See cross section 8 (Figure 3.9)

Predominant Plain As unit 5D
Subordinate pediments As unit 5B
Minor valley bottoms As unit 5D

6. Hills of sedimentary rock with associated alluvial systems

6A. Mokware hills with associated alluvial plain including sedimentary and igneous rock.
Agro-climatic zone 1d3 with ustic soil moisture regime.

Major hills have soils which are very shallow to moderately deep neutral to acid sandy loams with low fertility and low water holding capacity.
Major alluvial flats and valleys have soils which are deep to very deep, neutral to slightly acid, sandy clayloam with moderate fertility and moderate to high water holding capacity, in part water receiving.

6B. Tswapong hills with associated terraces and alluvial valleys
Agro-climatic zone 2d3 with ustic to aridic soil moisture regime.
See cross section No 5 (Figure 3.6)

Major hills As unit 6A
Major alluvial terraces and valleys as unit 6A but valley soils are slightly alkaline, part calcareous and terrace soils are slightly acid.

6C. Borotsi hill complex with associated terraces and alluvial valleys
Agro-climatic zone 2d3 with ustic to aridic soil moisture.

Major hills as unit 6B
Major alluvial terraces and valleys as unit 6B

6D Botepipi hill complex with associated alluvial slopes and flats
Agro-climatic zone 2d3 with ustic to aridic soil moisture regime

Major hills as unit 6A
Major alluvium as unit 6A

7 Flat to undulating upland plains on predominant sandstones and subordinate other sedimentary rock.

7A. Undulating plains with isolated hills and minor other lithology (dolerite, diabase), and subordinate alluvium
Agro-climatic zone 2d3 and part 1d3 with ustic to aridic and ustic soil moisture regime.

Predominant undulating plains have soils which are moderately to very deep, neutral to slightly acid, sands to sandy loams, with minor sandy clayloam, with low to moderate fertility and low to moderate water holding capacity.

Minor alluvium has soils which are deep to very deep, neutral to slightly acid sandy loams to sandy clayloam, with moderate fertility and moderate water holding capacity, in part water receiving.

7B Gently undulating to undulating sandstone plain with subordinate alluvium and minor basalt
Agro-climatic zone 2d3 with ustic to aridic soil moisture regime.
Predominantly gently undulating plain has soils which are deep to very deep slightly acid sands to loamy sands, with low fertility and low to moderate water holding capacity.
Minor alluvial depressions and valleys have soils which are deep to very deep, neutral to alkaline, partly calcareous, sandy loams to sandy clayloam, with moderate fertility and moderate water holding capacity, partly water receiving.

7C Flat to gently undulating sandstone plain with minor depressions and minor rock outcrops
Agro-climatic zone 2d3 with ustic to aridic soil moisture regime.
As unit 7B.

8 Alluvial valleys and flats

8A Limpopo terraces and floodplains
Agro-climatic zones 2d3 and 3b4 with ustic and ustic to aridic soil moisture regime.
See cross section No. 7 (Figure 3.8).

Soils vary strongly from eroded moderately deep to deep neutral sandy clayloam terraces, deep and very deep slightly alkaline clays in backswamps (water receiving and liable to flooding) to very deep neutral loamy sands to sandy loams on natural levees, all having moderate to high fertility and moderate to high water holding capacity.

8B Alluvial flats
Agro-climatic zone 2d3 with ustic to aridic soil moisture regime.

Soils are deep to very deep neutral to slightly acid sandy loams to sandy clayloam with moderate fertility and moderate to high water holding capacity, partly water receiving.

Schematic Cross Section No 1 (Serowe)

Cross section No. 1 is very schematic across the landscapes 1, 3A and 2C north of Serowe, running West to East over a distance of about 15km. The following physiographic elements are distinguished:

1. Kalahari sandveld plateau. In the west the plateau is very flat and featureless and soils are light yellowish in colour, have a low pH and a very low clay content (Dystric Arenosols). Towards the scarp the soils have more chroma (KS3 - Ferralic Arenosols) and become reddish with some increase in clay as cutans on ped faces (KS5-7, Ferralic Arenosols (and Arenic Ferric Luvisols). See profile S10, Annex 2.

2. Escarpment. Slopes vary from 5% to over 20% and soils on basalt are shallow and rocky (Lithosols, Eutric Regosols. lithic phase).

3. Undulating to rolling basalt upland. The terrain is quite irregular with shallow Eutric Regosols occurring in complex with deeper Chromic and Calcic Luvisols. See profile S5, Annex 2.

4. Alluvial Valleys and flats. Basalt derived alluvium is very clayey, with Pellic Vertisols (A1), also Chromic Vertisols (A2) and a range of vertic and Calcic Cambisols (A3, A4b). Mixed alluvia are characterized by Eutric Nitosols (A16) and the more sandy alluvial deposits have Arenic Ferric Luvisols (A12). See profile S1, Annex 2.

5. Hills. Hills on sandstone, with an admixture of Kalahari sand have dominantly Ferralic and Luvic Arenosols (S6, 6a, 5a) but also Arenic Ferric Arenosols are formed on the middle and lower slopes. As a result of lateral translocation of clay weak argillic horizons with clay bands have formed. Flat bottoms have leached sands with little colour (Eutric Arenosols, S17)

6. Sandplains. Towards the east gently undulating plains occur with a complex pattern of Ferralic Arenosols (S3,5) on the somewhat higher parts, and Arenic Ferric Luvisols(S7,10) or Arenic Eutric Nitosols (S11) on the lower parts. The topsoils have a clean aeolian component but subsoils at greater depth (1.5 - 2m) are often more clayey, overlying sedimentary rock. See profiles S2, S507, S512.
The vegetation on the Kalahari plateau is a low tree shrub savanna with Burkea africana, Terminalia sericea, Croton gratissimus and Acacia fleckii as characteristic species. Similar vegetation is also found on the lower sand areas, but here the vegetation is more mixed with other species. The vegetation on the basalt and alluvium around Serowe is disturbed but Acacia spp. as A. tortilis, A. karroo and A. mellifera are common.
The sandy and shallow soils are used for extensive grazing and arable farming is practiced on the alluvial soils, except for the Vertisols.

Schematic Cross Section No 2 (Shoshong)

Cross section no 2 of about 10km is across the Shoshong valley, approximately 5 km east of Shoshong village. Part of the soils data used is from Siderius (1973).

The valley extends in a east-west direction, structurally controlled by dolerite sills in the north and hills of sedimentary rock (quartzites, siltstones of the Palapye group) in the south. The valley itself consists of granites (Mahalapye Migmatites) of the Basement Complex, partly overlain by Quaternary alluvium.

The northern part of the valley is characterized by alluvial flats with clay derived from the dolerite hills, on which Pellic Vertisols have formed. When granite is near the surface the soil pattern is complex with Chromic Vertisols and Vertic Luvisols at the transition from the Pellic Vertisol flats to the Calci and Chromic Luvisols on the granite.

The central floodplain of the Bonwapitse river consists of a complex of Vertic Cambisols and Pellic Vertisols and has a sharp boundary with the adjacent pediment. See profile SH 901, Annex 2.

The southern slope is a pediment formed on a granite with generally very deep soils, Eutric Nitosols, having a weak to moderate structure. In places the surface material shows a more alluvial character, and Chromic Luvisols are found associated. The upper pediment soils seem more strongly leached and have less soil structure (weak to massive) and transgrade to Ferric Luvisols. See profile SH 903, Annex 2

The soils on the hills consist of a complex of Eutric and Calcaric Regosols with Lithosols.

The vegetation type on the granite pediment is savanna with Acacia nigrecens and Combretum apiculatum predominant. The alluvial areas have a more open tree to shrub savanna with a variety of Acacia spp (A.karroo, A. tortilis, A. mellifera, A. grandicornuta, A. tenuispina).A. galpinii is very characteristic along the Bonwapitse channel.

The pediment soils are widely used for arable farming, and these soils belong to the best soils found in the area, although the topsoil may be eroded. The alluvial areas are used for grazing.

Schematic Cross Section No 3 (Kalamare)

Cross section No 3 is found in the dissected gneiss/granite area between Kalamare and Mokware (Landscape 5A) as it runs over slopes of about 2km. The soil catenas in the area vary in composition, depending on steepness and irregularities of the slope, texture and rate of erosion.

At the top of the interfluves a variety of soils is found, from Lithosols and shallow Regosols to somewhat deeper soils which have an argillic horizon developed (units G2C and G8). Upper slopes are often leached and sandy (Albic Arenosols and Regosols G3 and G3a).

The middle slopes have massive gray soils with week argillic horizon (Orthic Luvisols G7) which gradually transgrade to Solodic Planosols (G15) with a well developed albic horizon and a natric or argillic horizon. See profile M295, Annex 2.
In the subsoil normally nodular calcic horizons occur, which also can be found at the transition to the gully if not eroded. The gully itself is often strongly eroded and shows rock outcrops (Lithosols) and coarse sandy material in the gully bed.

The vegetation type varies from moderately dense savanna with Combretum opiculatum and Acacia nigrescens on the higher parts, to open shrub savanna with Terminalia sericea, Acacia erubescense and A. fleckii on the sandy parts and A. tortilis, A. mellifera and A. nilotica on the lower slopes.

The area is poorly accessible and is used for extensive grazing.

Schematic Cross Section No 4 (Morale Hills)

Cross section No 4 in landscape 5B runs from the Morale Hills (west of Mahalapye) south west for about 12km. The section is across a very regularly developed pediment with upper slopes of 1 - 2% and lower slopes of about 0.5%.

The geological formations from north to south are respectively granite (Mahalapye Migmatite) and gneiss of the Basement Complex, siltstone/grits and quartzites of the Shoshong Formation of the Palapye Group (Precambrium), a dolerite intrusion and again Shoshong Formation.

The upper pediment slope is on gneiss and soils are predominantly deep to very deep Ferric Acrisols and Chromic Luvisols, also with intermediate Ferric Luvisols, having coarse sandy loam to sandy clayloam textures. The boundaries with the rocks of the Shoshong Formation is irregular and difficult to define at the surface on the basis of soil characteristics. The vegetation structure is savanna with Acacia nigrescens and Combretum apiculatum as dominant species. See profile M83, Annex 2.

The middle pediment slope has predominantly deep Ferric Luvisols (to Acrisols), mostly sandy loams with less coarse sand than the soils on gneiss. The savanna type is more open with smaller trees and Combretum apiculatum dominant.

The lower pediment slope has deep Ferric Acrisols which become downslope more sandy (unit S9) and transgrade to Arenosols. Here a shrub savanna occurs, with Acacia erubescense and Terminalia sericea.

The alluvial deposits of the Bonwapitse valley has Calcic and Vertic Cambisols, and Chromic Luvisols have formed on the dolerite on the south bank.

The area is used for extensive grazing but the upper pediment slope would have some suitability for arable farming.

Schematic Cross Section No 5 (south of Tswapong hills)

Cross section no 5 over approximately 10km in landscape 6B shows the old alluvial terraces which occur associated with the Tswapong Hills.

The hills have shallow soil (Lithosols and Regosols) on the sandstones, quartzites and conglomerates of the Palapye group (Waterberg formation, Precambrium).

The upper terrace has deep to very deep red Chromic and Ferric Luvisols as well as Eutric Nitosols but the lower terraces have gravel at shallow to moderate depth, with mostly a petroferric horizon at 1-1,5m depth. Most soils are reddish Ferric luvisols transgrading to brownish Orthic Luvisols in the lower positions.

The lower alluvial valleys are old drainage ways from the Tswapong hills and have Calcic Cambisols (A46) and Calcic Luvisols (A9), the latter in the slightly higher positions. The valleys and lower terraces form a repetitive pattern.

The terraces are widely used for arable farming as the soils are deep and sites may receive additional run-off water from the hills. Frequently wells are made through the ironstone into aquifers in the subsoil.

Schematic Cross Section No 6 (Tuli Block)

Cross section no 6 runs over above 4 km in landscape 5C southwest - northeast towards a small tributary at the Limpopo river, south of Selika hill. The location is in the northeastern corner of the Mahalapye sheet, at the transition from ustic to aridic soil moisture regime.

The plain is almost flat to gently undulating with gradual soil transitions. The higher and steeper parts have sandy shallow and rocky soils (Eutric and Dystric Regosols), and Ferric Luvisols and Acrisols are found on the flatter parts. In an irregular pattern minor Calcic Luvisols occur in low to intermediate positions, partly with a petrocalcic horizon. See profile TS3, Annex 2.

On flat interfluves as in the middle part of the section, moderately deep Ferric Acrisols (G5) are the characteristic soils often with a petroferric horizon, gradually transgrading to gravelly Dystric and Eutric Regosols. See profile TS5, Annex 2.

Only locally on the lower slopes Chromic Luvisols occur, whereas Calcic Luvisols on calcrete are found on the lowest valley slope. The valley bottom has a 200m wide strip of Pellic Vertisols (A1). See profile TS7, Annex 2.

The vegetation on the Regosols and Acrisols is a dense low tree or shrub savanna with a strong dominance of Combretum apiculatum. On the Luvisols the savanna or woodland has a co-dominance of Acacia nigrescens.

The area is used for grazing mainly, but some commercial dryland farming is practiced on the lower parts with deeper soils. Minor parts of the land are used for irrigation farming (mainly citrus).

Schematic Cross Section No 7 (Limpopo)

Cross section no 7 shows a lower Limpopo valley slope catena. Natural levees with Eutric Cambisols, but also Haplic/Calcic/Luvic Xerosols in the zone with an aridic moisture regime, occur more frequently downstream (Palapaye Sheet) than upstream. The levees are normally only a few hundred meters wide and about 5m higher than the adjacent backswamp. The backswamps are very irregular in occurrence with a variety of soils such as Calcic Luvisols (A9), Calcaric Cambisols (A4) and Pellic Vertisols (A1).

Terraces may be present on the lower slopes but are often eroded and may occur G8-9, in complex with gneiss (Chromic Luvisols,G8-9). The terrace soils, Chromic and Ferric luvisols (A13-11), or (Calcic) Luvic Xerosols (A37a,36) with an aridic moisture regime, have a high potential as arable land under irrigation but are limited in occurrence.

Also the levee soils, if not too sandy, are suitable for irrigation farming. The soils of the backswamp areas have less potential, due to poor drainage and flooding hazard. See profile TC4, annex 2.

On the middle slope various shallow to moderately deep Luvisols or Xerosols are found . This area is mostly used for grazing.

Schematic Cross Section No 8 (Mogapi)

The schematized cross section no 8 (approximately 15 km), as occurring north of Mogapi, shows the transition from landscape 5E to 5D, which roughly coincides with the transition from soils with an ustic to aridic moisture regime.

The pediments associated with the kopjes (rock outcrops) have moderately deep to deep Ferric and Chromic Luvisols. Classification in fact depends only on CEC clay values which are around the boundary value of 24 me9/100g. Quartz gravel, and in places petroferric horizons, occur at a depth of about 1m.

On the flat parts of the plain soils are relatively shallow, having a petric phase (quartz gravel or weathered rock) at about 50cm depth. Shallow argillic horizons have developed (Ferric Luvisols or Luvic Xerosols G2d/2e)

In the upper catchment of side valleys or depressional drainage ways, grayish massive soils with sandy clayloam to clay texture are found, in places with mottling indicating water stagnation.

In the valleys the dominant soils are Calcic Cambisols, partly with shallow calcrete (petrocalcic horizon), especially at the riverbanks (units A4b and C4).

In the zone with aridic soil moisture regime, kopjes are less frequent. Sandy shallow Regosols and Lithosols occur on the interfluve crests and weakly structured to massive shallow to moderately deep Luvic Xerosols, with more clayey texture, are found on the middle and lower slopes. The gravel in the subsoil is mostly quartz, but also iron/manganese concretions and ironstone occur. CEC clay values increase in the aridic zone.

The vegetation type is mostly low tree to shrub savanna with Combretum apiculatum, Acacia nigrescens and Kirkia acuminata characteristic for the upper slopes and Colophosperum mopane dominant on the lower slopes.

The pediments are widely used for arable farming because of the greater soil depth and better structure than the other soils. Also in places there may be some lateral subsurface water supply. In the aridic zone, soils are rather unsuitable for dryland farming. The valleys are partly water receiving but have the risk of flooding.

4 LAND EVALUATION

4.1 OBJECTIVES AND ASSUMPTIONS

The principal objectives of the land evaluation at reconnaissance level in Botswana are to:

- locate the potential arable lands and determine their surfaces
- reflect the relative importance of the output to expect, as compared to the optimum.
- indicate the importance and kind of undesirable environmental hazards.

The proposed system is based on the FAO publication: " A Framework for land evaluation" (1976). The framework gives the principles and concepts on which land suitability evaluation is based, and indicates overall strategies for their application.

The Botswana system evaluates different land units for relevant existing, arable farming land use types, as defined by agronomists. Emphasis has been put on sorghum growing under different management levels. Sorghum represents more that 50% of the planted area, and is traditionally the first nutritional source in rural areas. Several alternative crops, which are actually cultivated at a smaller scale than sorghum, have been proposed and can be evaluated: maize, millet, dolichos, cowpeas and sunflower. In the light of further rural development, other crops under different management levels have to be identified and potential new uses have to be described.

For the location of arable land, a qualitative land evaluation system has been recommended. The suitability is expressed in qualitative terms only, based on physical elements, without specific estimates of outputs (crop yields), inputs, costs and returns.
The system is worked out according to the limitations approach. The limiting effect of each land quality is evaluated using an ordinal scale.
The system refers to current suitability. Minor land requirements which use common practice for the defined land uses are included.

4.2 OUTLINE OF PROCEDURES

Following steps are to be considered for the evaluation:

(a) delimitation of relevant zones
(b) definition of land utilization types
(c) identification of land use requirements
(d) description of land units
(e) matching the land units with the land use requirements

(a) The delimitation of the relevant zones is based on actual land use studies. National parks and game reserves are to be excluded for the evaluation. Emphasis is put on presently cultivated land and the surrounding extensive grazing lands. The hardveld area with Northwest, Central, Southern and Kweneng districts, representing 75% of the total cultivated area in Botswana,(DHV 1980) are the target areas.

(b) The choice of relevant land utilization types for arable farming in Botswana is mainly determined by existing farming systems. Three major land use types are retained; dryland farming, irrigated farming and Molapo farming. By far, dryland farming is the most practiced (815,000 for 4,800 ha/annum Molapo farming and some 2000 ha irrigation) (DHV 1980). The developed system is thus focused on dryland farming. On a basis of different management systems, dryland farming is divided into 4 management types:

- traditional
- partly mechanized traditional
- improved traditional
- mechanized commercial

The different crops, cultivated under a specific management type, define the land use types, which are to be evaluated (e.g. improved traditional sorghum)

(c) After the definition of the land use type (LUT), the land use requirements for that specific LUT are to be stated. Land use requirements, i.e. the conditions of land necessary or desirable for the successful and sustained practice of a given LUT (FAO 1983), can be expressed by land qualities or land characteristics.

As land characteristics have to be considered in terms of limited interpretations because of their specific interaction, land qualities have been retained. Land qualities have to be determined and evaluated in accordance to their affecting land characteristics (SYS 1985).

The identification of land use requirements is done by establishing factor ratings for each relevant land quality.

Diagnostic factors are selected to be used for the assessment of the quality. Simultaneously, the critical values of the diagnostic factors are proposed for the different suitability classes. The land requirements already indicate the information needed for the evaluation and consequently direct the survey activities. The information requirements for the evaluation are focused on production in the first place, and on management and conservation in the second place.

(d) Description of land units. The soil maps, derived from the systematic Botswana Soil survey at scale 1:250 000 produced by BOT/80/003 and BOT/85/011, combined with recent climatological studies (Dambe 1987), constitute the basic information for the evaluation exercise.

The soil data have proven to be very reliable. Although some land qualities, such as temperature regime, absence of damaging floods, absence of pests and diseases, adequacy of topography are less developed, homogeneous mapping units can be considered for dryland farming evaluation.

(e) Matching land units with land use requirements. The principal stage in the evaluation procedure is the matching of the land use requirements with the land quality of the considered land units, according to a limitations approach. Each individual land quality is rated on a scale from 1 to 6 for the corresponding requirements.
Using a well defined set of rules, reflecting the importance of the different land qualities for the specific land utilization type, these limitations are transferred into another ordinal scale from S1 (very suitable) to N2 (unsuitable). The overall suitability is determined by the lowest suitability class(es) of the land qualities. This method implicates that land with one or several limitations of the same level is classified in the the same suitability class, which can be unrealistic. An advantage is that the interactions between the land qualities are not important using this method.

4.3 LAND SUITABILITY CLASSIFICATION AND MAPPING

The outcome of the matching procedure of land use requirements with land qualities is an overall land suitability, i.e. the fitness of a given land for a specified LUT.

Six land suitability classes can be distinguished; these are defined as follows:

S1 highly suitable: Land which is expected to be highly productive for the defined use. High return amply justify required inputs. No significant limitations.

S2 moderately suitable: Land which is expected to be moderately productive for the defined use. Moderate returns justify required inputs. Limitations reduce crop yield 20-40% and/or increase recurrent costs for production and conservation.

S3 marginally suitable: Land which is expected to have a low productivity for the defined use. Yield benefits are just high enough to justify required inputs. Limitations reduce crop yield 40-60% and/or considerably increase costs for production and conservation.

S4 very marginally suitable: Land which is expected to have a very low productivity for the defined use. It is doubtful whether yield benefits alone justify required inputs. Severe limitations reduce crop yields with 60-80% and/or considerable increase costs for production and conservation.

N1 currently unsuitable land: Land with very severe limitations, which at present cannot be corrected economically.

N2 permanently unsuitable land

Subdivision of the classes is as follows:

Subclasses: Land suitability subclasses reflect kinds of limitations. They are indicated by lower-case letters, symbolizing the kind of limitation (e.g. subclass S2e: limitations caused by erosion.

The classes S1 and N2 have no subclasses.
Seasonal cultivation of land classed as S4 will not be profitable over a long period in terms of money. However, part of this land is used and will be used in the future, either permanently or periodically, for the following reasons:

a. In traditional dryland farming economic considerations do not play a role, or only a minor one. In this concept very low yields can be accepted,

b. In countries which have a highly erratic rainfall such as Botswana, some years have sufficient rainfall to produce an acceptable yield.

c. Considerations other than economic, such as employment and self - sufficiency, justify strongly reduced crop yields

The soil mapping units as shown on the soil maps, often consist of 2 or more soil units (either as an association or as a complex). It appears impractical for cartographic reasons to evaluate all soil units and to map an association of land suitability (sub) classes. The number of characteristics would be too big (e.g. S3mn-S3m-S2mnot).

In Botswana conditions for dryland farming are generally poor, mainly due to the marginal climatic conditions. Often only the best part of a soil mapping unit offers some potential for dryland farming. For this reason only the soil unit with the highest suitability class will be mapped. In order to give and indication of the area covered by the mapped suitability class the letter S will be printed in three lettertypes:

bold capital **S** : area coverage per mapping unit 60-80%
capital S : area coverage per mapping unit 40-60%
lower case s : area coverage per mapping unit 20-40%

It should be noted that generally 30% or less of the area of the soil mapping unit is covered by minor soil units, which are not mentioned in the soil association or complex.

4.4 AGRO-CLIMATIC ZONES AND LAND SUITABILITY

In order to assess the climatic suitability for arable farming, the concept of the growing periods is applied. The calculation of the growing period is based on a water balance model, which compares precipitation with the potential evapotranspiration. (FAO, 1978). The growing period is defined as the period in days during a year when precipitation exceeds half the potential evapotranspiration, plus a period required to evapotranspire and assumed 100mm of water from excess precipitation (or less if not available) stored in the soil profile. The period when precipitation exceeds full potential evapotranspiration is defined as the humid period. The growing season is equal to the length of the growing period if one growing period occurs, or equals the total length of the growing periods, when two or more growing periods occur plus the number of dry days.

For the analysis of the growing periods data of 9 synoptic stations and about 50 rainfall stations with long term records were used.

The rainfall of each 10-day period was determined by calculating the running average over three 10-day periods, thus reducing the influence of extreme and isolated rainfall events.

The potential evapotranspiration has been calculated applying the Penman formula adapted to Botswana conditions by SMEC (1987).

As the rainfall in Botswana is very erratic and highly variable in time, the use of mean figures is generally not appropriate. Therefore a frequency analyses of growing seasons lengths was done. The results form the basis of the climatic zones differentiation, combined with the number of dry days (50% frequency) and the length of the humid period.
Figure 1.2 depicts the agro-climatic zones of Botswana.

The Land quality "moisture availability" is mainly determined by the climate, and by the agro-climatic zones. To define the factor rating for moisture suitability , the following steps have to be considered:

- determine the available water holding capacity (AWHC) of the soil in function of texture, effective depth and subsoil stoniness.

- correct AWHC for infiltration rate

- determine moisture availability rating in function of the agro-climatic zone and the site

- correct the rating for texture and establish the final rating

Examples of land suitability for typical soils are given in the following sections. Selected Land Quality rating are given in annex 3.

Land Suitability for representative alluvial soils (main unit : A)

Chromic Luvisol A13 is an example of the best alluvial soils that occur in Botswana, having hardly any limitations for dryland farming, apart from the moisture availability. Its common texture is sandy clayloam, usually with a more sandy topsoil (sandy loam). Soils with similar characteristics occur in a.o. Soil Units A16 (Eutric Nitosol), A10 (Chromic Calcic Luvisol), A14 (Orthic Luvisol), A16a (Calcic Eutric Nitosol) and A44 and A4d (Calcaric respectively. Calcic Cambisols). The corresponding soils in the zone with an aridic soil moisture regime are the Luvic, Calcic and Haplic Xerosols (Bobonong area). However, these also may include soils having ferric properties, which is usually related to some other less favourable characteristics.

Examples of similar soils but having a more sandy texture, usually sandy loam, are A16b (Arenic Eutric Nitosol) and A33 (Eutric Cambisols), occurring on natural levees. As an example of a sandy soil, A12 (Arenic Ferric Luvisol) is given, usually having a deep loamy sand topsoil, which may become sandy loam in the subsoil. Several other sandy alluvial soils have quite similar characteristics, such as A15 (Arenic Orthic Luvisol), A17 (Arenic Dystric Nitosol), A19 (Ferallic Arenosol). In Table 4.1 the land suitability classification is given for the tracts of land where these soils dominate the soil pattern, in average environmental conditions. It is clear that for this group of well drained and deep soils, the overall suitability class is governed by the moisture availability (for dryland farming). For a large number of other alluvial soils a similar outcome can be found. There are, of course, other groups of alluvial soils, where different land qualities, such as oxygen availability, resistance to erosion or workability play an important role.

Table 4.1 Land suitability classification for rainfed sorghum and maize some representative alluvial soils in the Mahalapye, Francistown and Bobonong climatic zones.

Soil unit	**A13**				**A37**	
agro-climatological zone	**1d3**		**2d3**		**3b4**	
crop	**sorghum**	**maize**	**sorghum**	**maize**	**sorghum**	**maize**
land quality						
accessibility	S1	S1	S1	S1	S1	S1
temperature regime	S1	S1	S1	S1	S1	S1
soil erosion	S2	S2	S2	S2	S2	S2
floods	S1	S1	S1	S1	S1	S1
germination	S1	S1	S1	S1	S1	S1
moisture availability	S3	S4	S4	N2	S4	N2
nutrient availability	S1	S2	S1	S2	S1	S2
oxygen availability	S1	S1	S1	S1	S1	S1
pest and disease	S1	S1	S1	S1	S1	S1
foothold for roots	S1	S1	S1	S1	S1	S1
absence of toxic substance	S1	S1	S1	S1	S1	S1
workability	S1	S1	S1	S1	S1	S1
overall suitability	S3m	S4m	S4m	N2	S4m	N2

Table 4.1 Land suitability classification for rainfed sorghum and maize som representative alluvial soils in the Mahalapye, Francistown and Bobonong climati zones.

Soil unit		A16b				A12
agro-climatological zone 1d3	1d3			2	d	
crop	**sorghum**	**maize**	**sorghum**	**maize**	**sorghum**	**maize**
land quality						
accessibility	S1	S1	S1	S1	S1	S1
temperature regime	S1	S1	S1	S1	S1	S1
soil erosion	S2	S2	S2	S2	S2	S2
floods	S1	S1	S1	S1	S1	S1
germination	S1	S1	S1	S1	S1	S1
moisture availability	S3	S4	S4	N2	S4	N2
nutrient availability	S1	S2	S1	S2	S1	S2
oxygen availability	S1	S1	S1	S1	S1	S1
pest and disease	S1	S1	S1	S1	S1	S1
foothold for roots	S1	S1	S1	S1	S1	S1
absence of toxic substance	S1	S1	S1	S1	S1	S1
workability	S1	S1	S1	S1	S1	S1
overall suitability	S3m	S4m	S4m	N2	S4m	N2

Soil unit	**A12**	
Agro-climatological zone	**2d3**	
crop	**sorghum**	**maize**
accessibility	S1	S1
temperature regime	S1	S1
soil erosion	S2	S2
floods	S1	S1
germination	S1	S1
moisture availability	S4	N2
nutrient availability	S1	S2
oxygen availability	S1	S1
pest and disease	S1	S1
foothold for roots	S1	S1
absence of toxic substance	S1	S1
workability	S1	S1
overall suitability	S3m	S4m

Land suitability for representative soils on acid rocks (main unit: G)

The soil units G9, G8, (Chromic Luvisols), G6 (Ferric Luvisols) and G2e (Luvic Xerosols) are representative for the soil associations that occur over large land areas in the region where the geology is dominated by acid igneous and metamorphic rocks (mainly granite and gneiss). Chromic Luvisol G9 is a deep soil with a high water holding capacity whereas Chromic Luvisol G8 is petric at moderate depth and one class lower in AWHC rating. AWHC is again reduced in Ferric Luvisol G6 (coarser texture) and in Luvic Xerosol G2e (shallower soil, petric horizon usually at about 50-60 cm depth). Other differences are in e - resistance to erosion, n - nutrient availability and r - adequacy of foothold for roots (with some minor differences in w - workability).

Table 4.2 Land Suitability for rainfed sorghum in the Mahalapye, Bobonong and Francistown climatic zones on acid rock soils.

Soil unit	G2e	G6		G8		G9	
agro-climatic zone	**3b4**	**1d3**	**2d3**	**1d3**	**2d3**	**1d3**	**2d3**
land quality							
accessibility	S1	S1	S1	S1	S1	S1	S1
temperature regime	S1	S1	S1	S1	S1	S1	S1
soil erosion	S2-3	S2	S2	S1	S1	S1	S1
floods	S1	S1	S1	S1	S1	S1	S1
germination	S1	S1	S1	S1	S1	S1	S1
moisture availability	N2	S4	S4	S4	S4	S3	S4
nutrient availability	S2	S2	S2	S1	S1	S1	S1
oxygen availability	S1	S1	S1	S1	S1	S1	S1
pest and disease	S1	S1	S1	S1	S1	S1	S1
foothold for roots	S2	S1	S1	S1	S1	S1	S1
absence of toxic substance	S2	S1	S1	S1	S1	S1	S1
workability	S2	S1	S1	S1	S1	S1	S1
overall suitability	N2	S4m	N2	S4m	S4m	S3m	Sm4

In Table 4.2 the suitability classes for sorghum are given for the Mahalapye and Bobonong climatic zones, and also the overall subclass for Francistown. The suitability for maize is N2 for all soils in all zones, except for G9 in the Mahalapye zone, where the suitability is very marginal S4m. Some other soils quite similar to G8-9 are found in soil units G14 (Eutric Nitosol), G6a (Ferric Luvisol) and G13 (Calcic Luvisol). Soil on sites which may receive water occur in soil units G10 (Chromic Luvisol), G10a (Orthic Luvisol), G7 (Orthic/Ferric Luvisol), G12 (Gleyic Luvisol), G15 (Solodic Planosol), G16 (Gleyic Solonetz). The availability of water (m) may be upgraded, but other land qualities of areas dominated by several of these soils are less favourable compared to the well drained soil, especially oxygen availability. However, some of better soils of main unit G can be identified in these units (notably G10-10a).

The soils in units G1 and G2 are in general not suitable for dryland farming (sorghum), as well as the soils with an aridic soil moisture regime (Xerosols). Only the better part of soil units G2c and G2d (Chromic and Ferric Luvisols), which are transitional to G8 and G6/6a may be considered as very marginally suitable, S4m, for sorghum, but only in climatic zone IV Mahalapye (and III Gaborone).

Some other soils have a very low nutrient availability (G3-4-5, Albic and Ferralic Arenosols, Ferric Acrisols) or may have too high levels of toxic substances (G15-16, Solodic Planosol, Gleyic Solonetz).

Land Suitability of soils on coarse-grained sedimentary rock (main unit S).

The major limitation of the sandy soils for dryland farming is the moisture availability. The majority of the S soil units has no other limitations apart from nutrient availability, which is usually low, and resistance to erosions (by wind mainly), which is usually rated as low to moderate (in disturbed or other specific places).

The Nutrient availability rating of most of the soil, where the pH in relation to the crop (sorghum, maize) is correct, is 3 (low), giving suitability class S2 for sorghum, and S3 for maize.

The Moisture availability of practically none of the soils need to be corrected for the infiltration rate. There is also hardly any correction for rooting depth and stoniness (soil unit S1 and S13 only). Available water holding capacity (AWHC) is directly related to texture. It should be noted that textures as they are given in the soil legend represent the texture of the B horizon, which is in most cases finer textured than the topsoil.
Most of the S soils are rated 4 for coarse sand textures and 3 for loamy fine and texture. Some of the S soil units with a fine sandy loam or even sandy clay loam texture in the subsoil may have an AWHC rated 2, but this is not separately evaluated, as this varies within the soil units and local situations may be more important, as e.g. water shedding positions of unit S14.

In Table 4.3 the suitability classes for sorghum and maize (improved traditional dryland farming) for some of the most frequently occurring sandy soils units are given, without site corrections.

Table 4.3 Land suitability subclasses for some sandy soils, for sorghum and maize (improved traditional dryland farming), in the various agro-climatic zones.

Soil unit	**S3 Ferralic Arenosol**					
agro-climatic zone	**1d3**		**2d3**		**4b3**	
crop	**sorghum**	**maize**	**sorghum**	**maize**	**sorghum**	**maize**
land quality						
accessibility	S1	S1	S1	S1	S1	S1
temperature regime	S1	S1	S1	S1	S1	S1
soil erosion	S3	S3	S3	S3	S3	S3
floods	S1	S1	S1	S1	S1	S1
germination	S1	S1	S1	S1	S1	S1
moisture availability	S4	N2	N2	N2	N2	N2
nutrient availability	S2	S3	S2	S3	S1	S3
oxygen availability	S1	S1	S1	S1	S1	S1
pests and diseases	S1	S1	S1	S1	S1	S1
foothold for roots	S1	S1	S1	S1	S1	S1
absence of toxic substances	S1	S1	S1	S1	S1	S1
workability	S1	S1	S1	S1	S1	S1
overall suitability	S4m	N2	N2	N2	N2	N2

Table 4.3 Land suitability subclasses for some sandy soils, for sorghum and maize (improved traditional dryland farming), in the various agro-climatic zones.

Soil unit	S3 Ferralic Arenosol					
agro-climatic zone	1d3		2d3		4b3	
crop	sorghum	maize	sorghum	maize	sorghum	maize
land quality						
accessibility	S1	S1	S1	S1	S1	S1
temperature regime	S1	S1	S1	S1	S1	S1
soil erosion	S3	S3	S3	S3	S3	S3
floods	S1	S1	S1	S1	S1	S1
germination	S1	S1	S1	S1	S1	S1
moisture availability	S4	N2	S4	N2	N2	N2
nutrient availability	S2	S3	S2	S3	S2	S3
oxygen availability	S1	S1	S1	S1	S1	S1
est and disease	S1	S1	S1	S1	S1	S1
foothold for roots	S1	S1	S1	S1	S1	S1
absence of toxic substance	S1	S1	S1	S1	S1	S1
workability	S1	S1	S1	S1	S1	S1
overall suitability	S4m	N2	S4m	N2	N2	N2

Gains and losses of moisture due to site characteristics are important in areas dominated by sandy soils. It is difficult to estimate, and impractical to characterize a unit in general, as the local conditions differ from site to site. Most of the sandy soils (unit S) are in a relatively high positions, and it is though that in most cases there will be a loss rather than a gain, also taking into account the possibility of water that has gone deep in the subsoil and is lost for the plant (a break in the capillary rise).

The suitability classification as given in Table 4.3 should therefore be considered with greatest care. The local circumstances play a very important role, and it may be well possible that considerable corrections should be applied. Some large areas are likely to be downgraded (when hilly or rolling), but other areas, e.g. lower valley sides, will be upgraded. Most of the areas receiving extra water have soils with slightly higher clay content compared to the related soils on top of the watershed, which is most probably due to lateral transport of clay. Typical soils in these positions are S5a and especially S7 and S10 (Luvic Arenosols and Arenic Ferric Luvisols); very often they can be upgraded, as e.g. in valleys south of Serowe and areas near Bobonong with S10 soils, normally rated as non suitable, but in these positions better classified as S4m.

Some of the soil units have been introduced especially to indicate the water shedding character of the land areas they characterize. They are:
- unit S1-a-b, shallow to moderately deep soils in undulating to hilly areas. AWHC rates 5-6 plus additional downgrading for site gives overall N2 rating (for sorghum).
- unit S6, undulating to rolling, including dunes. AWHC rates 3, but suitability class one down, resulting in N2.
- unit S17c, undulating (with the exclusion of minor flat parts), mainly coarse sands, AWHC rating 5, downgraded to practically everywhere N2 (sorghum)

Land Suitability of the Pellic Vertisol

There is some variation in the land qualities, depending on the local conditions. In table no the suitability is given for the common range; extremes are not considered.

Table 4.4 Land suitability for rainfed sorghum and maize on Pellic Vertisols in the Mahalapye, Francistown and Central Tuli Block climatic zone.

Soil unit	**A1 - Pellic Vertisols**					
agro-climatological zone	**1d3**		**2d3**		**3b4**	
crop	**sorghum**	**maize**	**sorghum**	**maize**	**sorghum**	**maize**
land quality						
accessibility	S2	S2	S2	S2	S2	S2
temperature regime	S1	S1	S1	S1	S1	S1
soil erosion	S1	S1	S1	S1	S1	S1
floods	S2	S2	S2	S2	S2	S2
germination	S1	S1	S1	S1	S1	S1
moisture availability	S3	S4	S4	N2	S4	N2
nutrient availability	S1	S1	S1	S1	S1	S1
oxygen availability	S3	S4	S3	S4	S3	S4
pest and disease	S1	S1	S1	S1	S1	S1
foothold for roots	S1	S1	S1	S1	S1	S1
absence of toxic substance	S2	S2	S2	S2	S2	S2
workability	S3	S3	S3	S3	S3	S3
overall suitability	S3mow	S4m	S4m	N2	S4m	N2

Table 4.4 gives suitability for improved traditional dryland farming with sorghum and maize of the Pellic Vertisol.

The cultivation of sorghum under a 1d3 climate is marginally suitable. Limiting factors are moisture availability, oxygen availability and workability. Under the drier climates (2d3 and 3b4) sorghum becomes very marginally suitable.

Maize is only very marginally suitable in the Mahalapye climate, and unsuitable in the other areas. The major constraint is water availability.

4.5 Conclusions

Land qualities

The land quality that has the greatest influence on the land suitability rating for dryland farming is:

m - moisture availability

The rating of (m) is to a great deal governed by the climatic zone, for which a new system is presented. Next important are the following land qualities:
n - nutrient availability
r - adequacy of foothold for roots

Local importance in specific environments have:

e - resistance to erosion
g - adequacy of conditions for germination
o - oxygen availability in the root zone
t - absence of toxic substances
w - workability

The other land qualities only incidentally play a role in dryland farming.

General suitability for improved traditional dryland farming

The climatic zones occurring in the mapped area are:

1d3 Mahalapye - Serowe
2d3 Francistown - Palapye
3b4 Central Tuli Block
4b3 Bobonong

Some conclusions can be given as for the suitability for sorghum and maize in these climatic zones, differentiated into Sandveld and Hardveld.

Sandveld

Land characterized by KS and S soil units occurs in all three climatic zones, the major part having a texture of fine sand to loamy fine sand. In the Mahalapye - Serowe (1d3) this land can be considered as very marginally suitable S4 (subclass S4m) for sorghum, provided these areas have a gain rather than a loss of water, which is, however, very often not the case. In Francistown (2d3) and Bobonong zone (3b4) , this land is unsuitable N2. The sands with a higher clay content (loamy fine sand to fine sandy loam), are very marginally suitable, S4m, in Mahalapye and Francistown zones, and unsuitable N2 in Bobonong zone.
Some land in favourable, water receiving position, may be upgraded to marginally suitable S3 (subclass S3mn0, occurring mainly in Mahalapye - Serowe zone, and to very marginally suitable, S4m, in Bobonong zone. For maize all land with predominantly soils of S unit is unsuitable N2

Hardveld

The best land, mainly found in areas where soils on alluvium or granite/gneiss predominate (for details see section 5.4), is rated as marginally suitable S3 (mainly subclass S3m) in the Mahalapye/Serowe zone, and as very marginally suitable S4 (predominantly S4m) in Francistown zone, both for sorghum. In the Bobonong area very little land rates S4 is found. Some upgrading is applicable to land occupying favourable sites. In the Mahalapye-Serowe zone, only some land with the best soils and in the best position can be considered as being very marginally suitable, S4, (mainly S4m) for maize. Land in the other three zones is almost exclusively unsuitable N2 for maize. These general indications of the suitability of the whole area do not exclude that where minor land areas exist (in all climatic zones) having optimally favourable conditions, suitability for sorghum may be better than marginal.

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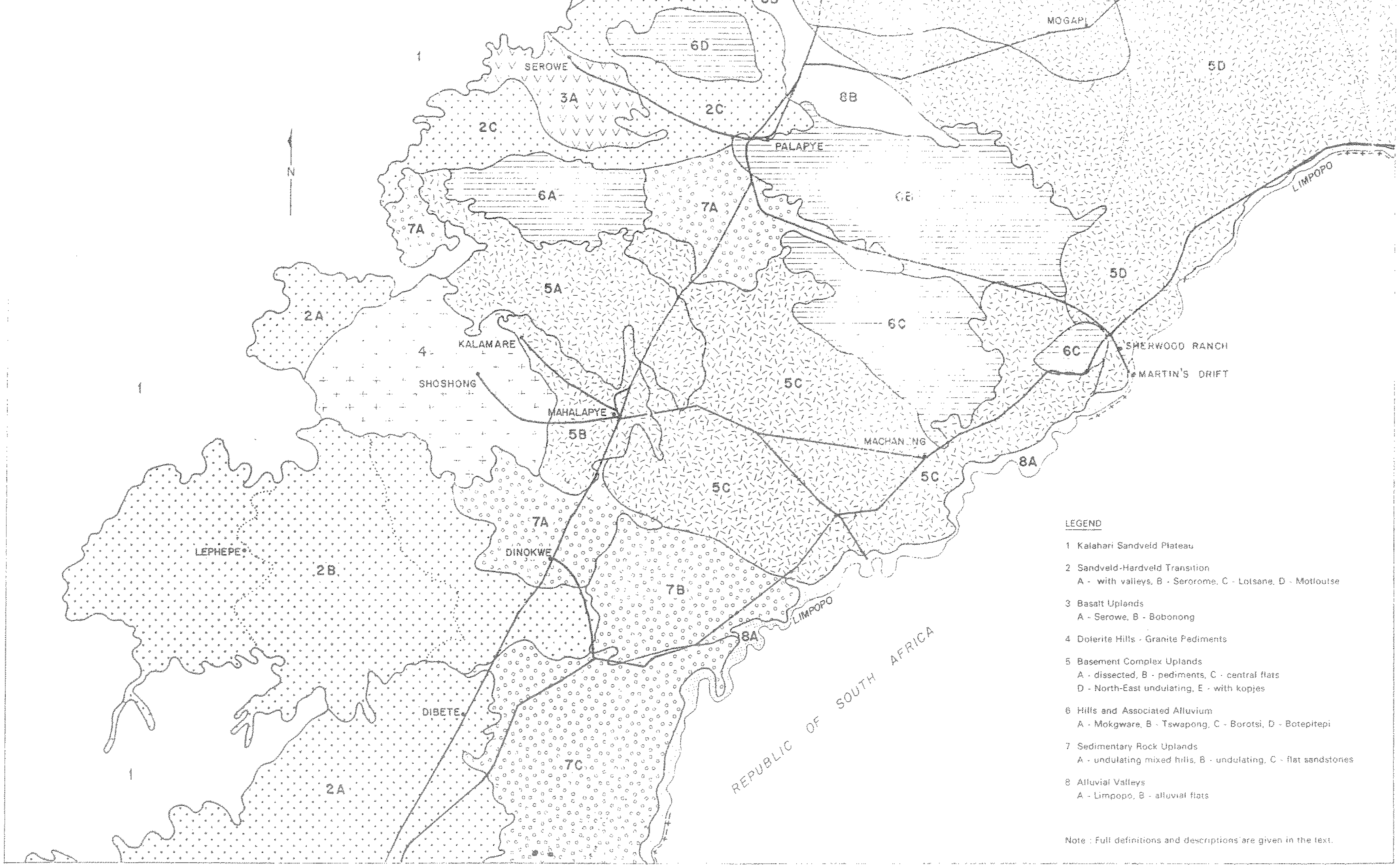
FIG. 3.1

PHYSIOGRAPHIC MAP OF SE CENTRAL DISTRICT

SCALE 1:1,000,000



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