Methods and Procedures for Prospecting for Road Construction Materials

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ROADS DEPARTMENT

Under the policy direction of the Ministry of Works, Transport & Communications, Roads Department is responsible for providing an adequate, safe, cost-effective and efficient road infrastructure within the borders of Botswana as well as for facilitating cross-border road communications with neighbouring countries. Implied in these far-ranging responsibilities is the obligation to:

1. ensure that existing roads are adequately maintained in order to provide appropriate level of service for road users;

2. improve existing roads to required standards to enable them to carry prevailing levels of traffic with the required degree of safety;

3. provide new roads to the required geometric, pavement design and safety standards.

The Department has been vested with the strategic responsibility for overall management of the Public Highway Network (PHN) of some 18, 300 km of roads. This confers authority for setting of national specifications and standards and sheared responsibility with the District Councils and Department of Wildlife and National Parks for the co-ordinated planning of the PHN.

Roads Department is also responsible for administering the relevant sections of the Public Roads Act, assisting local road authorities on technical matters and providing assistance in the national effort to promote citizen contractors in the road construction industry by giving technical advice wherever possible. This task is facilitated by the publication of a series of Technical Guidelines dealing with standards, general procedures and best practice on a variety of aspects of the planning, design, construction and maintenance of roads in Botswana that take full account of local conditions.

Guideline No. 1 The Design, Construction and Maintenance of Otta Seals (1999)

Workshop Proceedings, September 2000, Addendum with reference to
Guideline No. 1 The Design, Construction and Maintenance of Otta Seals (1999)

Guideline No. 2 Pavement Testing, Analysis and Interpretation of Test Data (2000)

Guideline No. 3 Methods and Procedures for Prospecting for Road Construction Materials (2000)

Guideline No. 4 Axle Load Surveys (2000)

FOREWORD

Construction materials and related issues typically account for over 75% of road construction cost. The general scarcity of conventional road building materials in Botswana has led to substantial research, over the past 25 years, by Roads Department to identify, test and develop specifications for the use of the available local materials. This research work has been carried out in-house and in collaboration with the following organizations:

Transport Research Laboratory (TRL) funded by DFID,
Norwegian Public Roads Administration (NPRA), funded by NORAD,
Center for Scientific and Industrial Research (CSIR) funded by the Government of Botswana,
Dr. Frank Netterberg, funded by the Government of Botswana.

The materials prospecting techniques that are embodied in this guideline are the results of decades of work and should provide an invaluable document for both engineers and technicians and trainers working in the road construction industry in the country. Ultimately, it is myfervent hope that the Guideline will assist in insuring that the best appropriate materials are identified for each road project at economical haul distances. Thereby, minimizing the construction costs and reducing materials related claims.

The Guideline is another in a series of documents intended to insure that significant technological developments within the Roads Department over a number of decades are put on sound sustainable footing for future efficient development and maintenance of our road network.

Gaborone
December 2000

Andrew Nkaro
Director of Roads

Roads Department
Ministry of Works, Transport and Communications

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The production of the Guideline has been a joint effort between the Roads Department, the NPRA, the Transport Research Laboratory, TRL (UK), the CSIR (South Africa) and Civil and Planning Partnership, CPP (Botswana) who was the consultant for the Working Group. The staff members involved were:

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Mr. L. Von Straaten, ACE, commented the first draft Guideline and his contribution is highly appreciated.

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1 INTRODUCTION

1.1 Background

In order to maintain, construct, rehabilitate or upgrade any road network, large quantities of gravel are required. This Guideline gives advice on the methods and procedures that are appropriate in Botswana for the location and proving of material sources for road construction. The Guideline presents the knowledge of experienced, practising prospectors in the country so that everyone can be aware of the best practice available. It has been compiled by combining the technological approach of scientists with the hard won experience of long-time prospectors.

There is no materials map, similar to a geological map, covering Botswana. Gravels occur as relatively small localised deposits, scattered around the landscape and usually buried. The art of prospecting involves looking for clues to the occurrence of useful materials and then digging to see what may be there. Learning to identify features that indicate the presence of gravel from the interpretation of maps and other information is a central activity in prospecting. However, the most important parts are the desk study followed by the field survey and pit evaluation, the latter being a mechanical process that depends on the prospector's experience and the quality and thoroughness of preparatory work.

Information about gravels in the landscape comes from three main sources. This is analysed all together to assess the likelihood that gravel may occur at a particular place:

- Geological information, coming from geological maps and reports.
- Soils information, coming from agricultural soils maps and reports.
- Landscape information, coming from topographic maps, aerial photo graphs and satellite images.

The techniques given in the Guideline may be thought of as a 'tool kit', each being available independently for a range of purposes. They are presented within a framework of the procedure for materials studies, so that the prospector can know when and how to use them. But it remains for the prospector to decide which techniques are appropriate at any stage or in any particular location.

Construction materials are a non-renewable resource and in view of the increasing importance attached to protecting the natural environment, it is important to make the best use of a source, once found. This implies mapping it and describing it accurately so that it can be correctly classified and therefore correctly applied to a specification. Ideally, a record of extraction should also be kept so that reserves can be utilised economically. These comments are especially true of the Kalahari and Okavango regions, where materials occur only in small amounts, are widely scattered and can be difficult to find.

The Guideline covers natural gravels that occur in the country and deals with weathered, transported and pedogenic materials. Hard rocks are excluded because the methods of finding and extracting these sources are in many respects different from those appropriate for weathered, transported and pedogenic materials.

View from a light aircraft. Ancient water channels and the pans coneasity be seen.

The calcrete probe has been a very useful tool for materials prospecting in the Kalahari region.

Natural gravels are defined in this Guideline as rock products that have been partially broken down chemically and physically by weathering. Some of these products may have undergone transport and re-deposition, or reworking of their constituents by water movement and chemical processes within the soil profile.

Calcrete borrow pit. Tsabong area.

Dumped base course material. Molepoloe-Lephepe road.

The end product, a new road Molepolole-Thamaga road.

1.2 Purpose and scope

The Guideline is intended primarily for technicians responsible for carrying out surveys to identify new sources of material. It contains information on how to plan, organise and carry out surveys. It also summarises the types of gravel that occur in various parts of the country and describes the gravel indicators to look for during prospecting.

The Guideline is also intended for highway engineers and project managers who make design decisions based upon survey results. The Guideline contains information on the interpretation of maps and the application of remote sensing survey methods, not normally used locally because of the need for specialised knowledge. There will be occasions when consultancy services should be used in order to optimise these techniques. The advantages of these methods and how to obtain appropriate assistance are explained.

Textbooks and other standard documents that relate to the Guideline are listed in the References. These works are all available as sources of reference. Their most important procedural points are summarised in the Guideline. Organisations that are able to offer other assistance, such as sources of mapping and consultancy services, are listed in Appendix 1.

1.3 Structure of the guideline

The Guideline is arranged into three sections covering the background, theory and the procedure by which this knowledge is put into practice, as follows:

1 Introduction

2 Environmental Regions of Botswana

3 Gravels in Botswana

4 Gravel Indicators

5 Interpretation of Maps and Photographs

6 Survey Methodology

7 Evaluation of Gravel source

8 Reporting

9 References

10 Abbreviations

11 Appencices

- Appendix 1 - Other relevant Organisations
- Appendix 2 - Weathering and weathered materials
- Appendix 3 - Botanical indicator Species
- Appendix 4 - Various logging forms

- The first part covers the geographical setting, the types of gravels that are found in different parts of the country, and the important landforms and other indicators that are a key to locating gravel deposits. Chapter 2 provides background information on the principal environmental co trols that have led to the development of gravels. This is followed by a description of the main types of gravel that occur, and includes a generalised map of prospecting regions, reflecting a combination of materials type, geographical factors and prospecting methodology. Chapter 4 describes the types of landforms that are usually associated with gravels.
- The second part (Chapter 5) introduces the interpretation of maps, aerial photographs and satellite images. The chapter describes the principal types of maps used in the detection of gravel sources, and how to interpret them.
- The third part covers the methods and procedures to be followed in order to produce a successful survey. This includes summaries of the desk study and field survey procedures in the form of checklists of the activities described. The procedure for evaluating a gravel source is also outlined. Chapter 8 summarises the information that should be included in a report on the materials survey.

1.4 Summary of procedure

The overall procedure is reviewed here in order to show how information about the route corridor is built up in a logical way. Refer to the flow diagram in Figure 1.1.

The foundation of all prospecting work is the desk study. During this stage the main decisions are made concerning the types of materials that occur, where they are most likely to be found and the manner in which the field survey is to be conducted.

The phases of the desk study are:

- Identify the project requirement including road location and length; specifications for materials in the formation and pavement layers; volumes of material required. This information is not within the scope of the Guideline.
- Produce a provisional materials map.
- Plan the field survey, e.g. route, sites to be visited and equipment and resources required.

The extent of the desk study should be linked to the size of the field survey in order to balance the efforts of each exercise.

Data should be recorded in a computerised materials database in order to facilitate easy access to information and help to plan future prospecting activities.

Indicators of the occurrence of gravel in the project area may come from many sources including reports, maps, aerial photographs, and past experience. The principal outcome of the desk study is a 'provisional materials map' showing existing and possible sources of material within the exploration corridor. This information is used as the basis for planning all following work. Planning of the field survey forms the final stage of the desk study and assists the prospector with assembling adequate resources for the field survey and carrying it out efficiently.

The field survey consists of two phases:

- Locating potential sources of material
- Evaluation of each source.

The field survey, which includes a reconnaissance traverse follows the desk study. Having obtained an overview of materials within the route corridor, the most favourable sites are investigated fully with trial pitting and sampling.

At present, reporting the results of materials surveys is limited to the production of a printed report.

PROJECT PREPARATION

DESK STUDY
- Specification and quantity of materials required
- Interpretation of background information

↓

Provisional materials map

↓

PLAN SURVEY
- Decide survey methodology and procedure
- Carry out in-house or use consultant
- Environmental considerations

↓

FIND & MAP SOURCES
- Reconnaissance field survey
- Detailed field survey

↓

SOURCE EVALUATION (FIELD)
- Areal extent
- Profile description
- Visual classification
- Sample

→ **SOURCE EVALUATION (LABORATORY)**
- Laboratory testing

↓

DATA CAPTURE & FEEDBACK
- Reporting
- Materials inventory (database)

Figure 1.1 Flow diagram stages, for material prospecting.

2 ENVIRONMENTAL REGIONS OF BOTSWANA

2.1 Introduction

Botswana can be divided into natural regions based primarily on the geology and climate. Different landscapes and geomorphological processes have characteristic soil and weathering profiles and these can be used for material location purposes.

Botswana's landscapes are the result of continental uplifts, changes of climate, sea level and cycles of erosion and deposition occurring over geological time. These geomorphological processes have had a profound influence on the weathering of the rocks and the development of surface and pedocrete deposits

2.2 Climate

Climate affects rock weathering and hence the formation of natural gravels. Hot, wet conditions cause the rapid chemical breakdown of rocks. In dry conditions, chemical reactions are restricted even though temperatures may be high. Large daily temperature fluctuations contribute to rapid physical disintegration

The climate over most of the country is semi-arid, with a narrow band along the southwestern border with South Africa classified as desert. Thus, chemical weathering for the most part is slow. The Weinert N-value ranges between 2 at Kazungula to more than 30 in the extreme southwestern areas. Typically, where N < 5 chemical decomposition of rock material prevails, while physical disintegration of the rock predominates where N > 5. This means that chemical decomposition is restricted to the area north of about 20°S latitude under present-day climatic conditions.

For additional information, refer to Weinert's book: "The natural road construction materials of southern Africa".

The annual rainfall follows the same trend as the Weinert N-values with about 650 mm of rain falling at Kazungula and less than 175 mm falling in the extreme south-west areas.

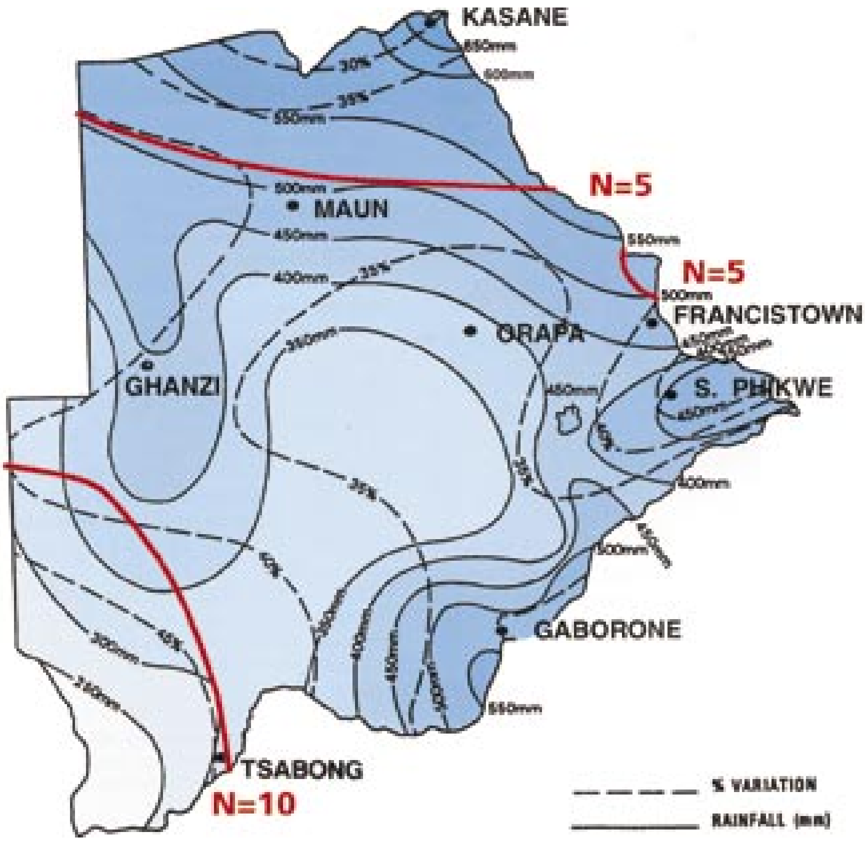


Figure 2.1 Annual mean rainfall in the country and N-values.

The standard deviation of the annual rainfall is very high and extreme wet and dry periods are not uncommon.

The minimum rainfall exceeds the 100 mm threshold value for dune activity and thus active sand movement is restricted to dune crests in localised areas.

Sand dunes can be seen in the extream south-western part of the country (Bokspits).

The climate has varied significantly in recent geological time. Evidence suggests that chemical weathering associated with alternating wet and dry cycles during the last two million years affected the weathering of rock outcrops and formation of pedocretes. The presence of ferricrete, for example, in eastern Botswana is evidence of tropical conditions in the past.

2.3 Geomorphology

Geomorphology concerns the interaction of rocks (parent materials) with the processes of weathering, erosion and deposition, over geological time. Water is the primary agent of erosion, but wind and gravity also play a considerable part

Geomorphology is an important factor in determining the characteristics and engineering properties of a weathered material.

Three aspects of geomorphology are of concern to the prospector:

- Weathering, past and present (see Appendix 2).
- Landscape formation - erosion and deposition.
- Pedocrete formation (combination of the above two).

Botswana can be divided into three principal geomorphological regions:

i) **Eastern region**
Rock landscapes, comprising hills and valleys and containing mostly residual and transported gravels.

ii) Central region
Mixed landscapes, intermediate between Regions 1 and 3.

iii) Western region
An ancient basin now filled with deep sand (Kalahari). Subdued landforms with pans, ancient dune fields with inter-dune hollows and old river valleys, now dry (e.g. Okwa River, Mmone River, Naledi Valley). Pedocretes (calcrete and silcrete) are the principal construction materials.

The Kalahari also contains ancient drainage lines, which are now dry. These ancient drainage systems are now the site of pedogenic calcretes and silcretes within the Kalahari sand regions.

There is evidence that a large river system once ran south through Botswana into the Orange River. Similarly, the Makgadikgadi Pan area was apparently once fed from the Okavango River as well as other smaller rivers to the east.

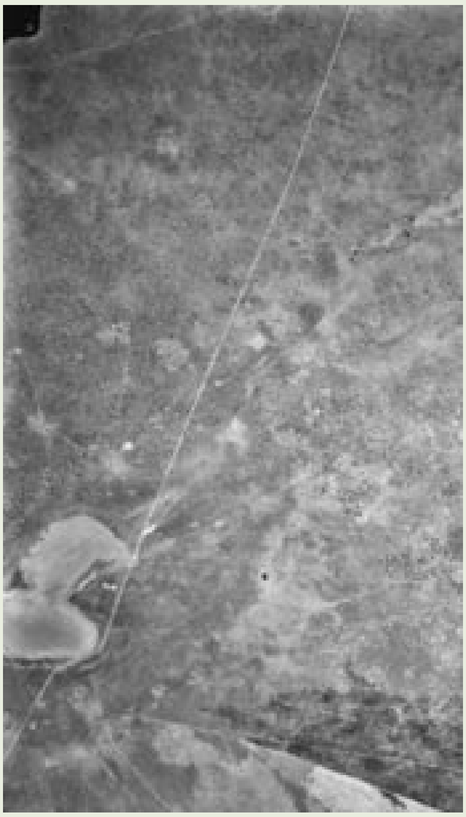
2.4 Geology

Where gravel is derived from weathered rock, the parent material is the most important factor governing the properties of the gravels. The bulk of the exposed hard-rock geology occurs in the eastern third of the country, the remainder being covered with young sands. In these areas, therefore, prospecting for road gravels should take the local geology into consideration.

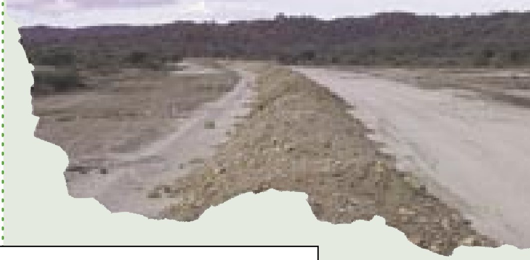
Botswana consists of five geological regions: four ‘solid rock’ regions and one sand region. In each of the rock regions there is a mixture of rocks but one or two predominate. The regions are:

- Karoo sediments and lavas.
- Mixed igneous, sedimentary and metamorphic rocks.
- Non-metamorphic rocks.
- Basement rocks, into which various igneous rocks (mostly granites) have been intruded.
- Geologically recent sands (Kalahari).

A simplified map of the geology is included as Figure 2.2.



Aerial photograph, showing Sekoma Pan.



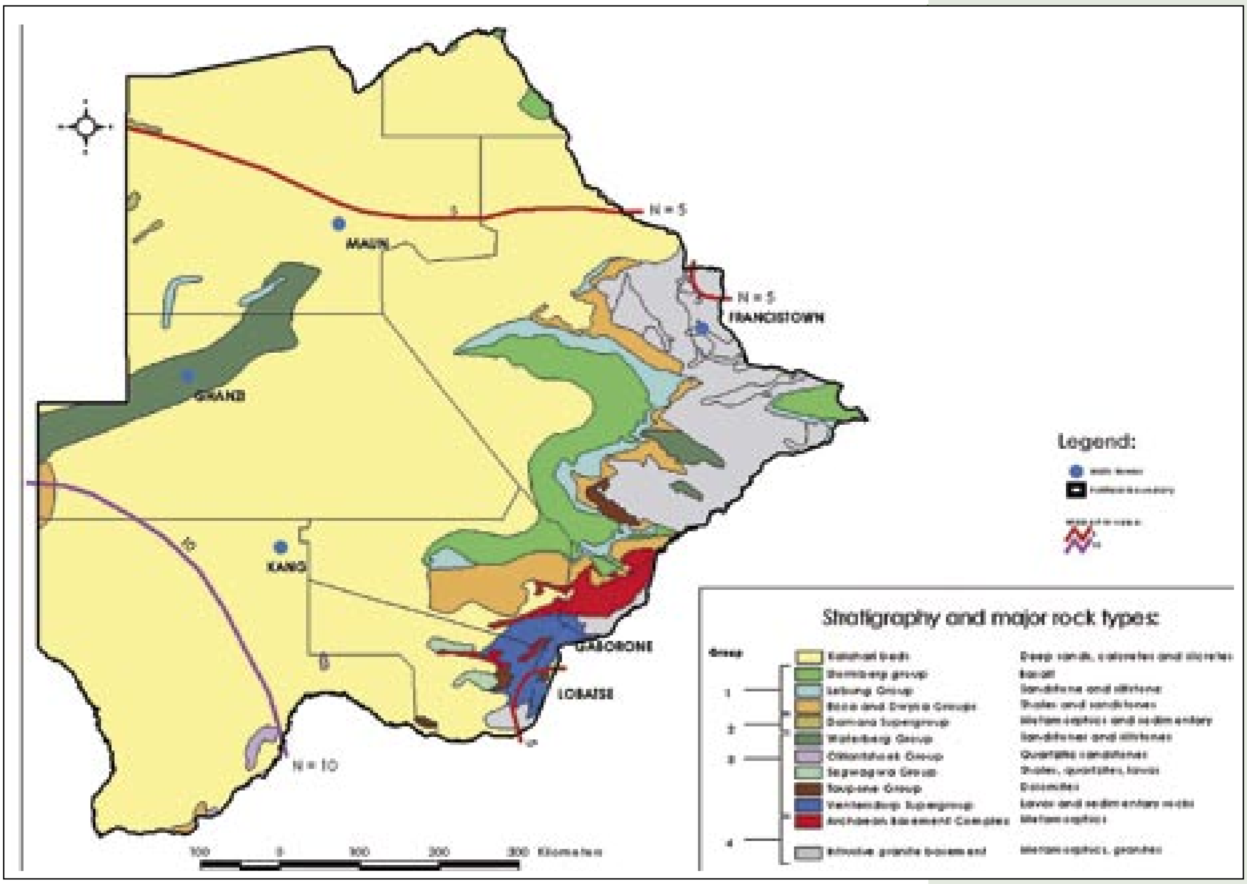


Figure 2.2 Simplified Geology MAP - Stratigraphy and major rock types.

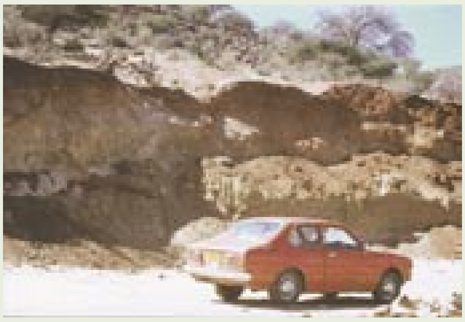
2.4.1 Engineering classification of rock types

The actual rocks making up the four solid rock geological regions have been grouped by Weinert (1980) into 10 classes for road building purposes, of which seven are relevant in this Guideline. The residual component of the first five comprise natural gravels for use in roads.

- Basic crystalline
- Acid crystalline
- High silica
- Arenaceous
- Argillaceous
- Pedocretes
- Transported soils

The **basic crystalline group** comprises those rocks with plagioclase feldspar and mafic minerals (pyroxene, amphibole, olivine) as their main constituents and only small quantities (if any) of quartz present. Typical rocks in this group are gabbro, basalt, diabase, basic and ultrabasic metamorphics and metavolcanics. When the Weinert N-value is < 5, these materials weather to montmorillonitic clays and thus have high plasticities and clay contents. Where N > 5, the rocks disintegrate, any clays that do form are hydromicas, and their properties are less problematic in road construction. The basalts north of Nata (N < 5) are renowned for their high smectite contents and poor performance in roads.

Basalt outcrop in a road cutting, Kasane - Ngoma road.



Thick seam of decomposed granite gravel at a foothill in Shoshong Village.

Arkose gravel burried in a fossil river valley near Tsabong.

Prehistoric wetter conditions produced the formation of ferricretes on rocks in eastern areas of the country.

A calcrete borrow pit along Molepolole-Lephepe road.

Acid crystalline materials consist primarily of granites, gneisses and felsites with a significant quartz component. The quartz is stable and the feldspar components generally weather to low activity clays (illite and kaolinite). Although N > 5 in the area south of Nata, certain materials show evidence of chemical decomposition indicating that the local N-value has probably been less than 5 in the recent past. Some of these materials (e.g. felsites around Mochudi) have marginal plasticity index values (PI about 10) in terms of base course specifications.

The **high silica materials** consist mostly of quartzites and quartz porphyries. These materials only disintegrate leaving a quartz-rich sandy to fine gravel material. Where present in sufficient quantities these gravels make good base and subbase materials.

Arenaceous rocks comprise mostly sandstones and arkoses and are a potentially important construction material. The aggregate strengths are generally related to the cementing material and those that are cemented by silica are usually more durable and stronger than those cemented by calcite or clay.

The argillaceous rock group is represented mostly by mudstones and shales. These materials, by definition, contain clay minerals and are seldom suitable as construction materials for roads. Weathering of the materials is generally in the form of disintegration resulting in clayey gravels to clays. At best, argillaceous rocks can be used as subbase although when slightly metamorphosed they can be used as a base material in light pavement structures. Argillaceous rocks tend to be moisture sensitive and strength testing of soaked materials is essential.

Pedocretes are probably the most useful natural gravel materials for road construction in the country, particularly in areas covered by Kalahari sand. They include primarily calcrete and silcrete with lesser volumes of ferricrete.

Pedocretes are variable in their composition and thickness, varying from isolated pockets of gravels (nodules or glaebules) to thick deposits of hardpan that can be ripped or crushed. Their formation is related mostly to drainage structures, with the best materials being associated with fossil pans and stream courses.

Transported soils cover a large proportion of the country and have been used in road construction. They include unconsolidated material such as alluvial gravels and sands (deposited by rivers), wind-blown sands, and material accumulated by gravity on the lower parts of slopes (called colluvium or talus).

2.5 Agricultural soils

Agricultural soils are of concern to the engineer because some soil groups have distinctive characteristics of drainage, texture or structure that affect aspects of engineering design, for example, subgrade bearing capacity or depth to solid bedrock. From the prospector's point of view, some groups develop nodular horizons that can be used as gravel for road construction. The 1:1 000 000 soils map of Botswana (and the 1:250 000 series of the eastern half) can provide useful information on the types of soils occurring in certain areas. Indications of ferricrete and calcrete are particularly relevant in this regard.

Botswana contains six main groups of agricultural soils. They are described below:

- **Arenosols.** Sandy soils occupying the whole western two thirds of the country (the Kalahari). A large area around Metsematlulu (north west of Molepolole) is mapped as possessing 'duripan' in the soil profile, a hard (though not neceessarily thick) horizon cemented by silica.

- **Fluvisols.** Soils developed on recent alluvium, wet but open-textured. They are not of interest to prospectors.

- **Solonchaks.** Structureless, open-textured soils of high salinity, often containing calcic or gypsic horizons. These are found in the Makgadik-gadi Pans.

- **Luvisols.** Non-expansive clayey soils. The luvisol region occupies the rock landscapes east of the Kalahari sand region. Those luvisols devel oped on Basement Complex rocks are mapped as stony, which suggests an increased frequency of gravel occurrence, probably quartzose. Some of the luvisols will contain ferricrete.

- **Vertisols.** Expansive clay soils. These occur in pockets, especially on basalts. Not of interest to the prospector.

- **Lithosols.** and regosols. Soils less than 0.5 m thick over bedrock. They can constitute good engineering gravel.

2.6 Vegetation

The vegetation consists primarily of savanna (tree, shrub, and grass) with aquatic grassland surrounding the large pans and swamps and limited forest in the north. Vegetation can indicate the occurrence of gravel beneath the soil. The type and health of vegetation is partly a function of the properties of the soil. Certain plants have adapted to specific soil conditions and can be used as indicators of the presence of particular materials. Of particular importance are the calcium tolerant species that indicate calcrete, discussed in Chapter 4.

Calcrete vegetation indicator - P. Lcubnitziae.

2.7 Prospecting regions

Taking consideration of the environmental factors discussed previously, Botswana can be divided into three regions based primarily on geomor-phology. These are subsequently sub-divided into specific prospecting regions based on geology and climate. These are shown in Figure 2.3 and Table 2.1.

- The main types of material that occur within region.

- By implication, the techniques that are appropriate for prospecting in each region.

- The regions where prospecting may be particularly difficult (e.g. the Okavango Delta). The map and Table indicate to the prospector:

The Okavango Delta has proved to be particulary difficult to locate road construction materials.

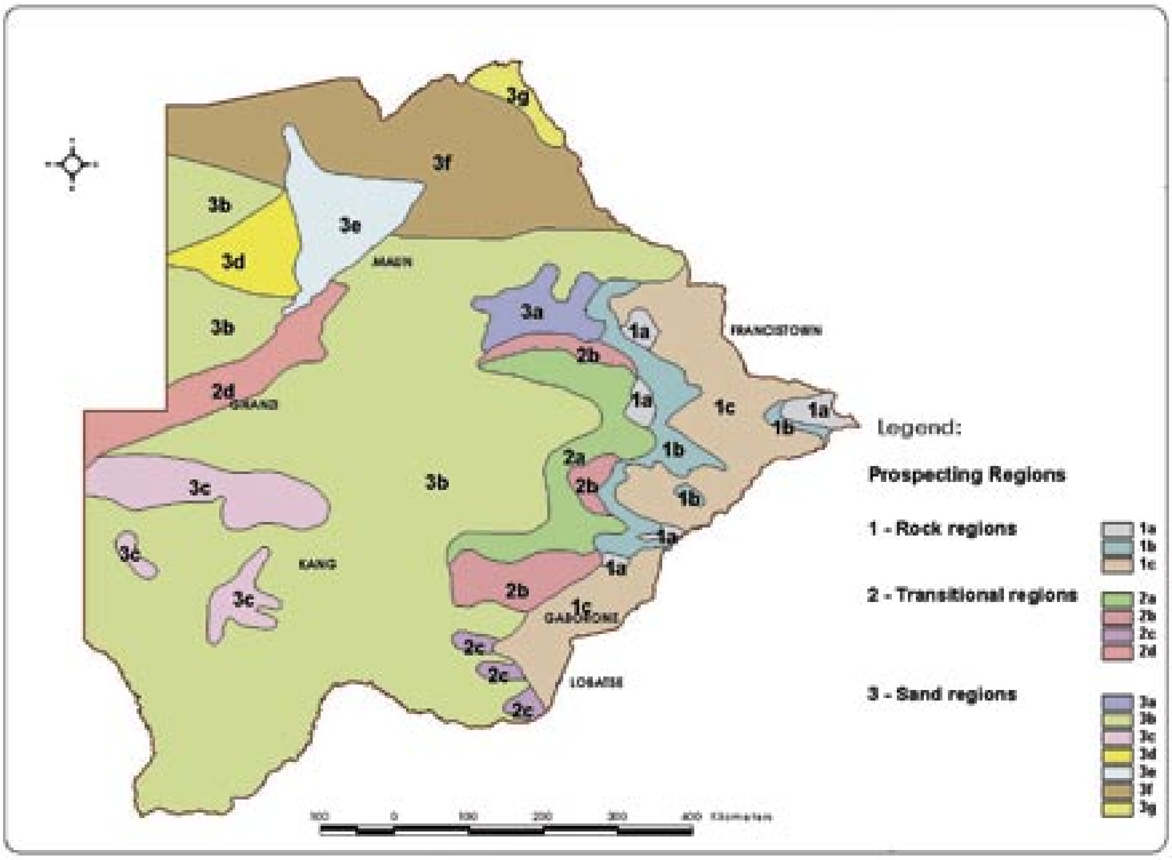
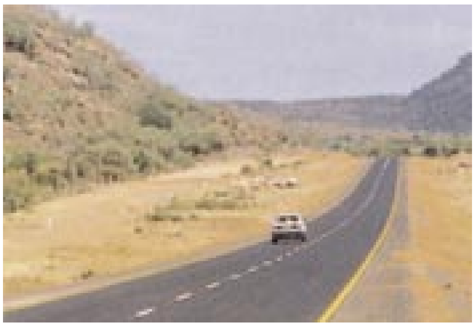


Figure 2.3 Prospecting regions of Botswana.

Sand region.



Rock region.

Transitional region.

Prospect-ing region	Stratigraphic groups, in order of predominance	Parent material	Engineering materials (Weinert groups in italics)	Other characteristics of the region
1. ROCK REGIONS Materials derived from rock. Gravel landforms of rock regions.				
1a	Stormberg Series Basement Complex basic intrusives Ventersdorp System	Basalt lavas Metavolcanics & metasediments Volcanics	*Basic crystalline* Potentially poor materials. Residual gravels have high PI, but are good if associ-ated with calcrete.	Residual and transported gravels that can be re-worked into calcareous or ferruginous gravels. Felsites associated with sandy slopes of hills
1b	Lebung Ecca & Dwyka Waterberg Taupone Archaean Basement Complex.	Sandstones & siltstones Shales & sandstones Some basic intrusions Metamorphic rocks	*Arenaceous & argillaceous* Mixed materials, mostly of moderate to poor quality. Some residual gravels; pedocretes (calcretes with associated materials)	Prominent residual basalt gravels in Serowe area. Thick sand overburden. Black cotton soil in places, overlain by transported granitic soils
1c	Precambrian Intrusive granitic basement Archaean Basement Complex	Gneisses, granites Granitic rocks	*Acid crystalline* Good quality sandy gravels of low PI. Residual felsites form good construction materials	
2. TRANSITIONAL REGIONS - THIN KALAHARI SAND OVER ROCK. Materials derived from rock, plus pedocretes developed within sand. Gravel landforms derived from both rock and sand regions.				
2a	Kalahari beds over Karroo	Sand with calcrete & silcrete Basalt lavas	*Pedocretes* *Basic*	Transitional equivalent of Region 1a
2b	Kalahari beds over Lebung Ecca & Dwyka	Sand with calcrete & silcrete Sandstones & siltstones Shales & sandstones	*Pedocretes* *Arenaceous & argillaceous*	Transitional equivalent of Region 1b
2c	Kalahari beds over Precambrian granitic basement, Segwagwa, Taupone, Archaean Basement Complex	Sand with calcrete & silcrete Shales, quartzites, lavas, dolomites, metamorphics, granitic rocks	*Pedocretes Arenaceous, high silica, carbonaceous, acid; basic*	Transitional equivalent of Region 1c
2d Ghanzi Ridge	Waterberg (Ghanzi) Ecca & Dwyka	Sandstones, siltstones & arkose Shales & sandstones	*Arenaceous; arenaceous & argillaceous, associated with pedocrete*	Rock outcrops with sand. Arkose forms good quality construction material
3. SAND REGIONS Mainly pedocretes developed within sand. Some regions are mostly sand with rock outcrops. Gravel landforms derived from sand regions.				
3a Makgadikga di Pans	Kalahari beds	Calcrete & silcrete	*Pedocrete*	Very saline soils
3b Southern and central Kalahari	Kalahari beds Outcrops of Oliphantshoek, Ecca & Dwyka, Lebung and Damara in S around Tshabong and Bogogobo	Deep sand with calcretes & silcretes. Mixed sediments	*Soils & pedocretes* *Arenaceous; argillaceous; high silica; carbonaceous*	N boundary is climatic 'N' value = 5 Mostly sand, with rock outcrops
3c	Kalahari beds (Botletle Beds)	Deep sand with calcretes & silcretes	*Soils & pedocretes*	Botletle erosion surface; few pans
3d	Kalahari beds	Deep sand with calcretes & silcretes	*Soils & pedocretes*	Seasonal/periodic swamp
3e Okavango Delta	Kalahari beds	Deep sand with calcretes & silcretes	*Soils & pedocretes*	Permanent swamp Few materials sources
3f Northern Kalahari	Kalahari beds	Deep sand, calcretes & silcretes	*Soils & pedocretes*	Similar to 3b, but climatic 'N' value < 5
3g	Kalahari beds Stormberg Series	Deep sand with calcretes & silcretes Basalt lavas	*Soils & pedocretes; basic*	Sand with rock outcrops. Climatic 'N' value = 2. Poor quality gravels

Table 2.1. Prospecting regions of Botswana.

3 GRAVELS IN BOTSWANA

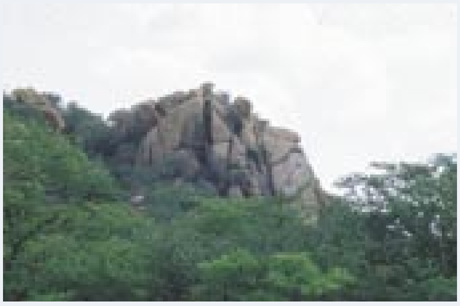
3.1 Introduction

The gravel prospecting regions have been defined in the previous chapter. Typical gravels likely to be encountered in these regions are discussed in this chapter.

3.2 Residual gravels

Information about the origin of residual gravels comes mainly from geological maps and reports.

Residual materials are the in situ, weathered remains of any parent rock. Residual materials are arguably the least variable of potential construction materials and where readily available would often be the first choice construction material. The chemical and physical nature of the material is primarily a function of the parent material (composition and structure) but is also strongly affected by the mode of weathering. The quality of residual soils in terms of road building generally improves with depth. Characteristics such as the plasticity decreases, the grading improves and the strength of both the bulk material and its aggregate component increases. At some point, however, the material strength reaches a value that ripping becomes impracticable and blasting is necessary.



A granite outcrop in the Thamaga area.

3.2.1 Acid crystalline rock gravels

The most common and most used residual gravels are derived from the weathering of acid crystalline rocks, particularly granitic rocks, gneisses and felsites.

Granite gravels (and soils) are typically found in the southeastern parts of the country where the Gaborone granite complex outcrops extensively, and in parts of the central region where the Mahalapye Granite outcrops (Region 1c).

Borrowpit in the Shoshong area.

These residual granite gravels are typified by the medium to coarse sub-rounded quartz grains and large, pale white, sub-rounded feldspar grains of the Gaborone granite. Granitic gravels usually exhibit very good compaction characteristics, low to moderate PI (0 to 10) and moderate to high GM (1.5 - 2), all of which improve with depth.

Gneiss gravels (soils) are fairly widespread, being derived from metamorphic rocks. They are abundant north of the residual granites (Region 1c) around Francistown. The gneiss gravels are similar in character to the residual granite gravels. Their engineering properties depend on the extent of the weathering and the depth of the weathering zone, both of which are con-trolled by climatic N-value and geomorphology.

Decomposed felsite, also showing unweathered core stones. Area near Sikwane.

Felsite gravels are found in the southern parts of the country, north of Gaborone (Region 1c around Mochudi). Felsite residual soils tend to have a higher clay content and therefore if completely decomposed may not be suitable for most pavement layers. Where disintegration was the primary mode of weathering, the gravel exhibits good engineering properties.

3.2.2 Basic crystalline rock gravels

Basic crystalline residual gravels are not very common. Where they occur, they seldom have good engineering properties. This is a result of basic crystalline rocks weathering rapidly to active clay minerals where the climatic N-value is less than 5.

Basalt gravels occur as isolated pockets spread throughout the country but the most prominent locations are within the Stormberg basalt lavas. They are found mostly in Regions 1a, 2a and 3g.

The basalt residual gravels are typically associated with black cotton clay, which are derived from the decomposition of mafic minerals. The gravel may have high plasticity, especially where the rock is completely decomposed. Where the rock is disintegrated the gravels tend to have angular rock fragments, which improves the engineering properties of the material. When impregnated with calcareous material the residual basalt gravel usually exhibits good engineering characteristics if the PI is low.

Dolerite gravels are not very common as they tend to be in the form of linear or localised intrusions. They typically form kopjies or dykes in Region 1b.

The residual dolerite gravels are similar to the basalt gravels. The dolerite however tends to weather into sub-rounded core stones through the “onion skin” peeling mechanism. This results in an abundance of oversized core stones, which are usually difficult to break during construction

Unweathered dolerite core stones can be useful for stone pitching and gabion basket filling. Mahalapye - Shoshong road, Bonwapitse river crossing.

3.2.3 Arenaceous rock gravels

Arenaceous residual gravels are widespread as the Transvaal, Waterberg and Karoo Supergroups, and the Ghanzi Group occupy a substantial outcrop area (Regions 1b, 2b, 2d and 3b).

Most of the sandstones do not weather into good quality gravels unless impregnated with pedogenic materials. However, those cemented with silica tend to be more durable.

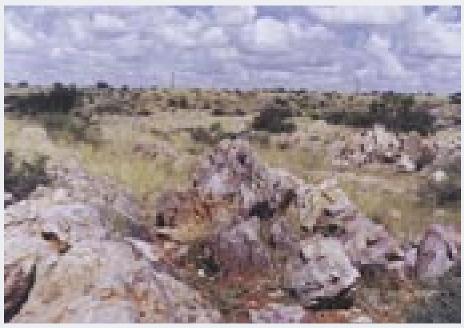
The arkose of the Ghanzi group (Region 2d) weathers into good quality residual gravels. The residual arkose gravel is often cemented by calcrete, silcrete or ferricrete material to form pedogenic gravel.

3.2.4 High silica gravels

High silica gravels consist primarily of quartzite and quartz porphyries.

Quartzites are associated with areanceous rocks of the Waterberg and Transvaal Supergroups (Region 1c). They are usually good construction materials as they are composed almost entirely of quartz. Their characteristic hardness can result in difficulty during processing to an acceptable grading.

A pebble marker is a stone or gravel layer between residual weathered rock and overlying transported soil, consisting of quartzitic pebbles in a soil matrix. Pebble markers are not very common and are usually too thin and too localised to be considered as sources of road building material on their own.



An outcrop of quartzite on a ridge near Middelpits.

3.3 Pedogenic gravels

Pedogenic gravels or pedocretes are formed when rock or soil particles become impregnated with, or cemented or replaced by, an additional component. The most common impregnating components are calcium carbonate, to form calcrete, iron hydroxide to form ferricrete and amorphous silica to form silcrete.

Pedogenic gravels are identified mainly by interpretation of landscape features (geomorphology), supplemented by information from soil maps and occasionally geological maps. (Except in the case of the Kalahari region, which is shown on the national geological map).(Exept in the case of the Kalahari region, which is shown on the national geological map).

For details on the formation and development of calcrete refer to Netterberg (1969). For the location, selection and use of calcrete in Botswana, see TRRL Report No. 1122 (1984).

Silcretes are increasingly being quarried for crusher run base course and chippings for surfacing in areas lacking conventional sources of aggregate, particularly in the Kgalagadi and Ngamiland districts.

Pedogenic gravels are probably the most useful, and often the only suitable construction materials in the sandy areas of Botswana. Their unique mode of formation also makes them the most variable materials and the most difficult to locate, particularly as they tend to occur in relatively small and localised occurrences.

Calcrete is the most common pedogenic gravel in Botswana. It is found almost everywhere associated with both residual and transported materials. Where calcrete is associated with residual gravel it is usually nodular in nature, whereby the nodules are derived from parent rock fragments (Regions 1, 2 and 3g predominantly). Such calcretes are common in the eastern corridor, where borrow pits are often overlain by clayey soils, especially where the parent rock is a basic crystalline rock. Calcretes formed by the cementation of fine-grained soils are the most common and important construction material in Regions 2 and 3. These calcretes occur typically in pans of various sizes in inter-dunal depressions and in areas of grey sands.

Four types of Calcrete:

Upper right - Nodular
Upper left - Hard plan
Bottom right - Calsified sand
Bottom left - Powder

Powder calcrete, Sekoma area.

Calcified sand, Tsau area.

Nodular calcrete, Tsabong area.

Ferricrete borrow pit along the Mahalapye - Machaneng road.

Hardpan calcrete, Sekoma area.

Silcrete is the second most widespread pedogenic material. Silcretes are often found in association with nodular or hard-pan calcrete. Most of the large calcrete pans have silcrete in the outer margin of the pan (Region 3). These are usually difficult to break with a pickaxe and may require drilling to explore and blasting to exploit.

Ferricrete is found along the eastern corridor and is probably associated with historically wet conditions, as it is un-likely that they would form under the prevailing climatic conditions (Region 1).

3.4 Transported materials

Transported materials are widespread and varied. The type and quality of the material is highly dependent on the geology of the source, the type and extent of weathering, the mode and energy of transportation, the age of the transported sediments and whether any pedogenic modification has occurred

Information on transported soils comes from interpretation of features in the landscape, plus analysis of soil maps. Sometimes geological maps also give clues.

Transported materials can be classified as:

- Colluvial - associated with hill slopes.
- Alluvial - associated with river courses.
- Aeolian - windblown sands.

Colluvial gravels are typically coarse grained i.e. gravel, cobble and boulders and therefore tend to have a high proportion of oversize material.

Alluvial gravel can be found along both active and ancient river courses. In active channels, gravel is usually found on the inner side of river meanders and on terraces. Rivers produce large quantities of coarse and fine sand that can be used for concrete and for sand seals on surfaced roads.

Buried alluvial gravels associated with ancient basins and braided rivers are potentially useful sources of materials in the Kgalagadi Region. These gravels are particularly useful in the Molopo River, Lake Ngami and Gweta areas. Alluvial gravel can be impregnated with calcrete, silcrete or ferricrete especially where it is deposited within a drainage basin such as a pan. Alluvial soils range from clay, sands and gravel to boulders.

Typical quartz pebbly gravel found in burried braided river channels near Middlepits.

Aeolian soils are fine grained. The most abundant aeolian soils are the single sized sands of the Kalahari beds. These sands are found everywhere in the region west of 26°E latitude (Region 3). The sands:

- Form dune features, which are easily distinguishable on aerial photographs and satellite imagery.
- Have varying colour and characteristics reflecting variation in engineering characteristics. Colour varies from pure white (common in pockets under grey sand) to greyish, and from light brown to dark brown and reddish.
- Have characteristics that change with depth. They are normally non-plastic on the 0.425mm sieve, but may exhibit plasticity (PI > 10) on the minus 0.075mm sieve.

Burried alluvial gravel west of Gweta.

It is important that the material prospector also takes note or even samples sources of Kalahari sand, as they could be used for road construction. Kalahari sand blended with calcrete has been successfully used in pavements both as selected subgrade and subbase. Laboratory testing should be carried out to determine the optimum mix proportions

Kalahari sand has been successfully used as fill, selected subgrade and subbase on low volume roads. The grey sands, which often have good compaction characteristics, occur as overburden to calcrete gravels and on inter-dune depressions.

The sketch map showing available road construction materials in the country.

The two predominant types of materials in the country. Kalahari sand and calcrete cover about 80% of the country`s area.

Kalahari sands varies in thickness from a few metres to approximately 300 metres.

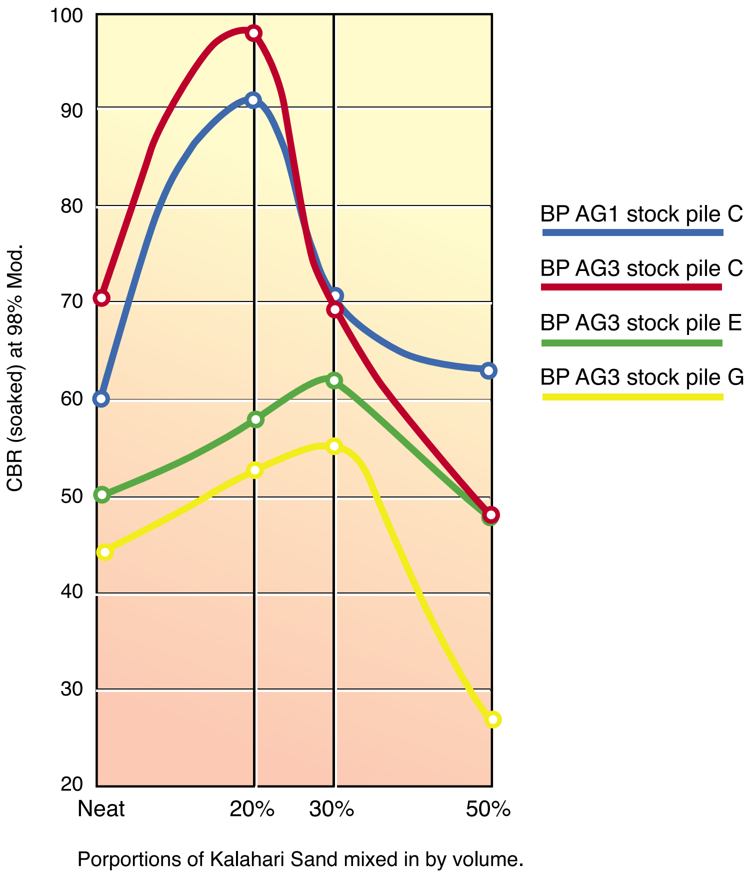


Figure 3.1. *Relationship between soaked CBR and proportion of Kalahari sand mixed in with calcrete.*

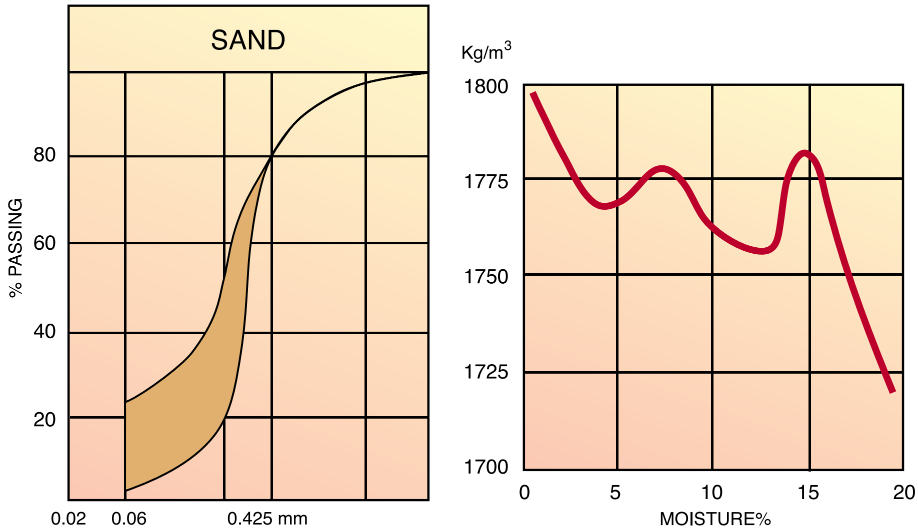


Figure 3.2. *Typical grading envelope of Kalahari sand.*

Figure 3.3. *Typical density curve of Kalahari sand.*

4 GRAVEL INDICATORS

4.1 Introduction

Three types of gravel indicator are recognised in Botswana:

- Landform.
- Botanical indicators (specialised plants).
- Animal indicators (traces left by animal activity).

4.2 Landform

Landform refers to the configuration of the ground surface in a distinctive shape. Landform is important in gravel location, as different types of gravel are associated with particular landforms. This association is due to:

- The presence of material near the surface giving rise directly to a particular type of landform. (e.g. a band of harder rock gives rise to a bump on a slope or a flat hill top, depending upon the rock's position and orientation).
- The development of a particular type of gravel in relation to a geomorphological feature (e.g. a river terrace typically is made up of alluvial gravel).

A number of small and larger pans occur in the Kgalagadi region.These often contain good quality calcrete. This pan is the Sekoma Pan.

Identification of landforms should be done during the desk study using aerial photographs and maps.

4.2.1 Landforms of rock regions

Rock regions have the typical range of gravel landforms illustrated in Table 4.1. This table is the key to the landform names given in Table 4.2. Table 4.2 takes the main parent materials described in Chapters 2 and 3 and indicates the landforms that are commonly associated with each.

Not all occurrences of 'gravel landforms' are necessarily associated with gravel suitable for road construction, nor do all occurrences of gravel necessarily give rise to an identifiable landform.

4.2.2 Landforms of sand regions

The landforms in the sand regions of the country are given in Table 4.3, and the gravels associated with them are given in Table 4.4.

If gravel particles are present in the soil, the processes of weathering and erosion will tend to bring some of these to the surface. The accumulation of a layer of stones and gravel on the surface can give the false impression that the soil is composed of gravel, or that a gravel layer lies at depth. Before marking the area as a potential source of gravel it is important to check that a gravel layer is actually present, by finding an exposed profile. A good indication as to whether there is a possibility of finding good gravel is to look around the base of trees to see if growth has brought pebbles to the surface. Check by digging a profile near the tree or by use of the calcrete probe

4.3 Botanical Indicators

The presence of certain plant species and sometimes the nature of their growth can depend upon the mineralogical and physical properties of the soil in which they are growing. Botanical indicators can thus be a useful

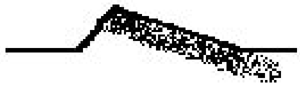
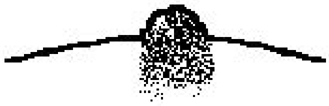
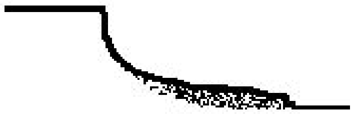
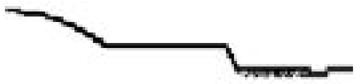
Landform	Diagram (cross-section)
Flat hill top Flat, level hill top (plateau) with sharp edges at margins	
Sloping hill top Inclined, flat hill top with sharp edge between (steep) scarp slope and (more gentle) dip slope	
Conical hill Hill with pointed top, more or less circular in plan. Sides may be irregular or smooth	
Mound Rounded hill top with convex slopes, or convex 'bump' on a plateau or hill top	
Ridge Long, straight, narrow ridge running across country. Usually formed by an igneous intrusion (dyke or sill) or a quartz vein	
Trench Long, straight, narrow depression running across country. Like the Ridge landform (above), usually formed by an igneous intrusion. However, in this case the surrounding rocks are more resistant than the intrusion. Sometimes the trench is formed by a pair of closely-spaced parallel ridges, formed by he surrounding rock being 'baked' hard by the heat of the intrusion	
Footslope Gentle slope at the foot of a steeper slope, formed (in this case) by the accumulation of pedogenic gravel (usually ferricrete) in the soil profile	
Terrace Raised platform situated at the edge of a valley, deposited by a river	
Floodplain Broad, flat valley floor with winding river. Sand and gravel accumulate on the inside of river bends	

Table 4.1 Landforms of rock regions,associated with gravel deposits.

Common land form in the eastern part of the country. Ridge alonge the Dikabeya - Kgagodi - Jct. Sefhophe - Martins Drift.

Large borrowpit on the Lephphe-Shoshong road. Base quality material (granite, quartz-rich gravel).

Dumped gravel base course, Lephephe-Shoshong road.

Various publications have excellent leaf keys, photographs, distribution maps and descriptions that are suitable for the identification of the botanical indicator species. Assistance can also be obtained from the Botany Department at the University of Botswana.

If local inhabitants are questioned or involved in the study, knowing the local names of plants is often useful. Note, however, that identification of plants using local names can be misleading due to the wide variety of names used for the same plant.

aid to materials location. However, plants are adaptable and the absence of an indicator species does not necessarily mean that the material is absent, whilst the presence of the indicator species does not always signify that the underlying material is suitable for engineering purposes.

A list of species used for the location of pedogenic materials is provided in Table 4.5. A guide to the identification of the listed species, together with illustrations, is provided in Appendix 3. Plants are usually used to help identify pedogenic materials in sand regions. In some instances, an abundance of certain species indicates the absence of road construction materials near the surface. In rock regions landform features are usually a more direct indicator.

A distinct change in the species type, a dense thicket of a particular species or a change in the form of the plants may be sufficient to identify a potential source. The ability to identify the exact species is not always necessary in these instances.

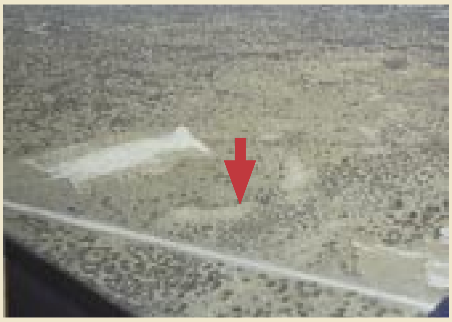
Gravel type	Parent material	Landform	Possible engineering problems
RESIDUAL GRAVELS			
Weathered rock	Lava	Flat hill top, sloping hill top	Lava of basic composition may contain weatherable minerals
	Igneous dyke	Ridge or trench	Lavas of basic composition may contain weatherable minerals
	Igneous sill	Ridge on side of hill	Lavas of basic composition may contain weatherable minerals. Sill may be difficult to exploit, owing to position on side of hill (- overburden)
	Granite, quartz-rich gneiss	Mound None	Gneisses may contain weatherable minerals
	Sandstone	Mound, flat hill top None	Particles may be rather soft
	Conglomerate, breccia	Flat hill top, sloping hill top Mound None	Conglomerate particles are rounded. Properties of the coarse particles may be different from those of the matrix
	Limestone, marble, dolomite	Flat hill top, sloping hill top Mound None	
Vein quartz	Granite, gneisses of all types	Ridge	Poor mechanical interlock of particles
TRANSPORTED GRAVELS			
Quartz stone line		Footslope None Footslope	Poor mechanical interlock of particles. May tend to contain too many fines.
Colluvium		Footslope	May contain too many fines
Alluvium		Terrace Floodplain	Rounded particles, often sandy and lacking in fines

Table 4.2 Types of gravel associated with rock regions.

Granite, quartz-rich gneiss. Mmadinare area.

Landform	Diagram (cross-section)
Pan with 'platform' Flat-floored pan with no or minimal vegetation. 'Platform' is a low bench situated on the edge of the pan but usually not extending all the way round. May be more than 500m across, or less	 *Note: Platform is not usually as distinctive or obvious as shown here*
Pan without 'platform' Flat-floored pan with no development of a low bench around the edge. May be more than 500m across, or less. May be without vegetation, or contain grasses	
Depression Concave hollow in the sand surface, containing grasses. The grass communities are often arranged in concentric zones around the depression	
Inter-dune hollow Very long, straight concave channel in sand surface. One of many forming parallel linear rises with hollows between. Typified in the area south of Takatswaane. Calcretes are developed at intervals along the line of the hollow.	
Valley (old river channel) A dry river valley, filled in with sand. Takes the form of a broad, gentle elongated depression that extends for many kilometres, as seen between Khakea and Werda. In places, easily visible on the ground but in others, so wide and shallow as to be hardly detectable	
Grey sand No topographic relief, only grey sand contrasting with surrounding reddish or brown sands	

Table 4.3 Landforms of sand regions,associated with gravel deposits.



Old river channel. (At left a borrow pit area). Sehitwa - Tsau road.

Landform	Material	Characteristics and comments
Pan with platform around rim	Calcrete, possibly hardpan or nodular Silcrete	The best quality calcrete is found in the pan platform
Pan without platform	Calcrete Silcrete	Good calcrete may occur but is not usual. Quality is not predictable. Large pans may contain hard or boulder calcrete Silcrete forms in the large pans of the Kgalakgadi
Depression	Calcrete can be nodular. Often no occurrence, or calcareous sand	Usually poor quality calcrete. May occur on the side slopes
Inter-dune hollow	Calcrete and silcrete hardpan or honeycomb or nodular	Locally, good quality materials but generally none over most of the hollow's length
Valley (old river channel)	Calcrete, possibly hardpan or nodular	Locally, good quality materials but generally none over most of the valley's length. Some valleys contain extensive calcified sands
No landform - grey sand only, contrasting with surrounding red sand	Calcareous sand. Possibly some calcrete	Usually poor quality calcrete but may be better if sand is non-plastic. Blackish sands usually yields better quality material

Table 4.4 Gravel types accociated with sand regions.

Material type	Botanical name	Common name	Local name
Calcrete	*Acacia fleckii* *Acacia mellifera* *Acacia nebrownii* *Acacia reficiens* *Catophractes alexandri* *Combretum imberbe* *Dichrostachys cinera* *Eriocephalus ericoides* *Grewia bicolour* *Grewia flava* *Grewia flavescens* *Maytenus senegalensis* *Pechuel-loeschea leubnitziae* *Tarchonanthus camphorates* *Terminalia prunoides*	Blade thorn Hook thorn Water acacia False umbrella thorn Trumpet thorn Leadwood Sickle bush Snowbush False brandybush Brandybush Donkeyberry Confetti tree Bitterbush Camphor bush	Mokala/Mohahu Mongana Orupunguya Orupunguya Moselesele Lewisi Mogwana Morêtlwa Mokgamphatha Mothono Motlalemetsi/Mokudi Mohatlha Motsiara
Ferricrete	Andropogon eucomus Combretum apiculatum Stoebe vulgaris	Snowflake grass Red bushwillow Bankrotbush	 Mohudiri
Deep sand (*Indicates absence of gravels)*	Acacia haematoxylon Baphia massaiensis Burkea africana Terminalia sericea	Grey camel thorn Sand camwood Red syringa Silver terminalia	Mokholo Monato Mogonono

Table 4.5 Indicator plants for pedogenic gravels.

Plants may be good indicators for pedogenic gravel. Makopong area.

4.3.1 Factors influencing the use of botanical indicators

Although botanical indicators are a valuable source of information for material location, certain human and natural influences can limit their effectiveness.

Species identification may be difficult for inexperienced persons. Reference to a suitable leaf key and books for identification will be helpful.

Human occupation in rural areas, where shifting cultivation and the regular cutting of trees changes the natural species mix, may suppress the normal spread of indicator plants. Certain species have cultural significance or are used for medicinal purposes. These are left uncut and can become disproportionately frequent.

In areas where **livestock overgrazing** occurs, significant changes in the vegetation become evident and indicator species can be trampled or eaten back to ground level. Selective browsing can give the false impression that the remaining unpalatable species are dominant. In areas where the natural pasture grass is unacceptable for grazing, other more suitable species are often planted, thus giving a false indication of the ecology.

Natural **bush fires** or regular burning of grassland for grazing purposes may eliminate species that could be suitable for indicator purposes.

Riverine vegetation may give false indications of the underlying material, because some of the species may have been transported in from distant localities

The environmental constraints associated with working adjacent to rivers must also be considered before excavating in these areas.

4.4 Animal indicators

The activity of certain animals results in gravel particles, soil or stones being brought to the surface. Examples are termites, porcupines, suricates, ground squirrels (Sekate-Mosima), Ant eater (takadu) and serunya. Examination of the material in termite mounds and anthills, and material excavated from burrows should be carried out for indications of any gravelly material brought to the surface.

Ant-hills may give valuable information for a gravel prospector. Orapa area.

5 INTERPRETATION OF MAPS AND PHOTOGRAPHS

5.1 Introduction

The use of existing maps, aerial photographs and in certain instances, satellite images are essential for a successful field survey. These are best utilised during the desk study when all possible sources of material can be identified.

Topographic and geological maps are most useful for prospectors as they provide information about landform and parent materials. To a lesser extent, agricultural soil maps can also be used.

Aerial photographs and satellite images are supplementary sources of information as they show information additional to that contained in maps. Maps and photographs, interpreted together, form the best combination for identifying possible material sources.

All interpreted features should be marked on a base map to bring all information together and to guide fieldwork.

5.2 Topographic maps

Medium- or large-scale topographic maps can indicate the landforms associated with gravels. They also contain other useful information such as roads, access, land-use, mines and quarries, development and water, which could provide indications of potential sources of material and assistance with appraisal of the area.

Topographic maps, aerial photographs, air photo mosaics and information about other sources of remote sensing aid is available from the Department of Surveying and Mapping, Gaborone.

For additional information on terrain evaluation and the interpretation of geological maps and aerial photographs for materials location, refer to the Terrain Evaluation Manual and Road building materials in Botswana.

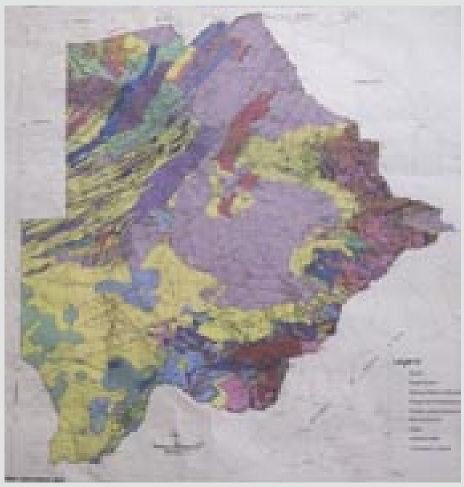
5.3 Geological maps

Geological maps are probably the most important source of preliminary information available to a prospector. They indicate the parent materials in the area and details such as quarries, faults, rock outcrops and igneous intrusions. The types of weathering products can be inferred from this information. All geological maps are accompanied by a narrative memoir. Reference to these is recommended. A generalised geological map is given in Figure 2.1.

The 1:1 000 000 geological map of Botswana is sufficient for an initial estimate of road construction materials for the purposes of prospecting, and more detail can be obtained from larger scale geological maps. Regional geological maps are usually published in conjunction with a report (or 'memoir'), describing the geology of the area in detail. The Geological Survey in Lobatse may be consulted for information on the availability of geological maps.

The features of geological maps that prospectors need to be aware of are:

- The map shows the rocks as they would appear if all the superficial deposits such as soil or unconsolidated materials (e.g. thin windblown sand and alluvium) were removed. However, very thick surface deposits such as the sands of the Kalahari are shown because they are the dominant material for all practical purposes.
- Geological maps rarely indicate the presence of gravel deposits. However, geological memoirs often contain information on the degree of weathering or fracturing of the rocks and therefore indicate the possibility of a suitable gravel source. Memoirs also describe superficial deposits such as pedogenic and coarse alluvial materials.



Geological Map.

- The map legend (the key to the rock types on the map) may identify features that are related to gravel deposits, such as quartz veins, dykes or alluvial materials.

Geological maps are used as follows:

i) Draw the road corridor on the geological map or a copy, in order to determine the approximate chainages at which geological units cross the road alignment. The 1:250 000 geological maps, usually appended to the District Memoirs, are recommended for this exercise.

ii) Read the map legend and the accompanying geological report for any mention of rocks that potentially contain gravel-sized weathering products, such as "gneiss with quartz veins". Note the geological units within which these are found.

iii) Identify these geological units on the map, within the exploration corridor. Pay particular attention to 'oddities' on the map such as minor igneous intrusions and unusually prominent hills (often named). These features often contain gravels when the surrounding country has none.

iv) Identify possible sources of material as detailed in Chapters 3 and 4 and from past experience.

v) Study the identified areas of geological interest in aerial photographs to pinpoint the locations most favourable for field investigation.

5.4 Agricultural soil maps

Agricultural soil maps and reports give indications of the presence of pedogenic gravels if these occur in the area. Agricultural soils maps are not concerned with the deeper parts of the weathering profile or with gravels specifically, and therefore rarely contain information relating to in situ gravels or transported gravels. However, as with a geological map, it is worth reading the soil legend and regional soil report for mention of features such as "stony phase" of a soil.

5.5 Remote sensing techniques

Black and white aerial photographs are the most commonly used remote sensing technique for gravel prospecting in Botswana.

Aerial photographs and satellite images (collectively called remote sensing systems) are valuable sources of information, which can be used for material location. This information is obtained by filtering out aspects of the landscape that are relevant to prospecting and using this to supplement the information taken from maps.

5.5.1 Aerial photographs and interpretation

Transferring information from aerial photographs to maps is most easily done freehand to overcome scale inconsistency. When using aerial photographs for navigation in the field, distances measured from a photograph may only be approximate.

The resolution of aerial photographs is of high quality and every detail of the ground surface down to one or a few metres in size is shown. Features such as minor rock outcrops can be seen clearly. Aerial photographs are not consistent in terms of scale. Change in scale within a photograph does not affect interpretation, but this situation needs to be appreciated whenever measurement or calculation of distance is involved.

Aerial photographs can be viewed in three dimensions, that is, slopes and relief can be seen. The vertical relief in aerial photographs is exaggerated, making slopes appear steeper than they really are. This characteristic is an advantage because it enables very small changes of elevation, that on the ground are barely discernible, to be seen. For example, in aerial photographs one can readily recognise low relief landforms such as the calcrete features in the Kalahari.

Aerial photographs can be laid out and re-photographed as a single sheet, called an air photo mosaic. Air photo mosaics are useful as compilation sheets upon which to record the results of an air photo interpretation or map interpretation exercise, especially in areas such as the Kalahari where relief is very low and landmarks are few.

The air photo interpretation commences during the desk study. Photographs covering the corridor to be investigated should be ordered prior to commencement of the desk study. These should be interpreted in parallel with the study of the maps.

When carrying out an interpretation, begin by making a note of the following general characteristics of the terrain. Afterwards, look in detail for the landforms described in Chapter 4.

i) **Relief and landform.**
Hill areas, rolling or undulating land, terraces, floodplains and low-lying land. Look especially for relief features that are too small to be shown on maps.

ii) **Drainage.**
- Note areas where drainage pattern is consistent, and boundaries where one pattern changes to another. Boundaries between drainage patterns often signify geological boundaries.
- Note particularly areas where drainage is absent (indicating highly permeable soils), or consists of parallel streams or straight stream courses (rock is controlling the stream pattern and is therefore near the surface).

iii) **Vegetation and land use.**
Although it is not possible at normal air photo scales to distinguish individual plant species such as gravel indicator plants, plant communities of a type that may contain indicator plants are often identifiable.

iv) **Human features**
Farm boundaries, mining companies' fences and buildings give indications of the extent of properties and where the owners may be contacted.

Based on all of the information gathered above, as well as that gathered from maps, identify possible prospecting sites.

During the desk study:

i) Identify a spot on the aerial photograph that appears to be most typical of the whole site, or that seems to offer the best prospect of finding material.

ii) Identify routes of access to the prospecting sites if these are not clear from the topographic map.

iii) Mark all interpreted features on the base map or directly onto the photos using a thin wax pencil.

These photographs are then used during the field study to:

- Locate the sites identified during the desk study. These sites should be inspected and a decision made as to whether to investigate further. This decision will be based on the indicators discussed previously.
- Determine the extent of the deposit and to set the position of trial pits within the site. If a decision is made to investigate the site in more detail, trial pits will have to be excavated.
- Plan the site investigation programme based on the information being gathered.

The basic skills of air photo interpretation are not difficult to learn, but require some training when getting started. This is particularly important in a flat and featureless terrain such as the Kalahari. Reference is made to the stereoscopic aerial photographs illustrating landform features in Chapter 4.

Proper care of aerial photographs is important. They are expensive to buy and may be needed for use by others at a later date. Annotate the photographs with a wax pencil ('chinagraph') only. Wax pencil can be easily removed with cotton wool moistened with a little alcohol. Do not use an ordinary pencil or pen - this will make marks on the photograph that cannot be removed.

Aerial photographs are easily scratched and stained by dust and dirt left on the surface. This is especially true of photographs taken into the field. In the field, keep them clean and dry. Have as few as possible in use at any one time and keep those that are in use covered, in a plastic bag for example. Brush off dust gently with a dry cloth. Store the remaining photographs in a closed file away from dust.

Satellite pictures are referred to technically as 'images' rather than 'photographs' because they are collected by electronic sensors, not by a camera. The use of satellite images requires more experience than the use of air photos.

5.5.2 Satellite images and interpretation

Satellite images are similar to aerial photographs in the sense that they, too, are vertical pictures of the earth's surface showing landform, drainage patterns and vegetation cover, but on a much smaller scale.

Satellite images are planimetrically fairly accurate, more so than air photo mosaics. They can be used to make measurements of direction and distance, and can act as a base map when a topographic map is not available.

The use of a satellite image will strengthen a desk study in the following ways:

- The very large area covered shows an 'overview' of the area under study, and may reveal terrain patterns that are not shown in maps or air photos. For example, the 'fossil' drainage patterns in the Kalahari show up much better on satellite images than on any other form of presentation.
- Satellite images show differences in colour of soils, rocks and vegetation communities. It should be noted that these are not true colours because the satellite 'sees' a broader range of colours than does the human eye. However, this does not affect interpretation.
- Specialised digital image processing techniques can be used to bring out information that normally is very hard to see. Such processing is available from the Satellite Applications Centre (SAC) in South Africa or from a consultant.
- The characteristics of optical satellite imagery are in many ways complementary to those of aerial photographs. This is illustrated by a comparison of the satellite images and air photos in the Plates. Ideally, the two types of imagery should be used in conjunction to take advantage of this fact.

Landsat image - fossil drainage channels (blue) also showing Sekoma pan (red).

Landsat - grey sand. Sekoma colour PC image.

The smallest scale of satellite image that should be considered for interpretation is 1:500 000, although 1:250 000 images are preferred. However, sub-scenes can be produced to order, at any specified scale.

As with aerial photographs, interpretation of satellite images is done essentially on the basis of the shape of objects (including their size and context), in colour but without the benefit of a stereoscopic view. The unreal appearance of the false colours is often problematical. However, the most important aspect of colour in satellite images is that areas of colour similarity or colour differences are clearly shown.

Satellite images are most useful for the featureless Kalahari region. The colour information varies according to the ground characteristics and can be used for the following purposes:

- To help in the identification of landforms. Colour in combination with shape is very good for interpretation. Some landforms show up very clearly, such as the ancient beach ridges associated with the Makgadikgadi Pans.
- To distinguish terrain features that have no landform but are a distinctive colour, such as grey sand areas (which contrast with the surrounding red sands).
- To help identify terrain features that are very indistinct and tend to blend in with their surroundings, such as the upper reaches of fossil drainage lines.
- To distinguish terrain features that are obvious but very small, such as minor calcrete pans.

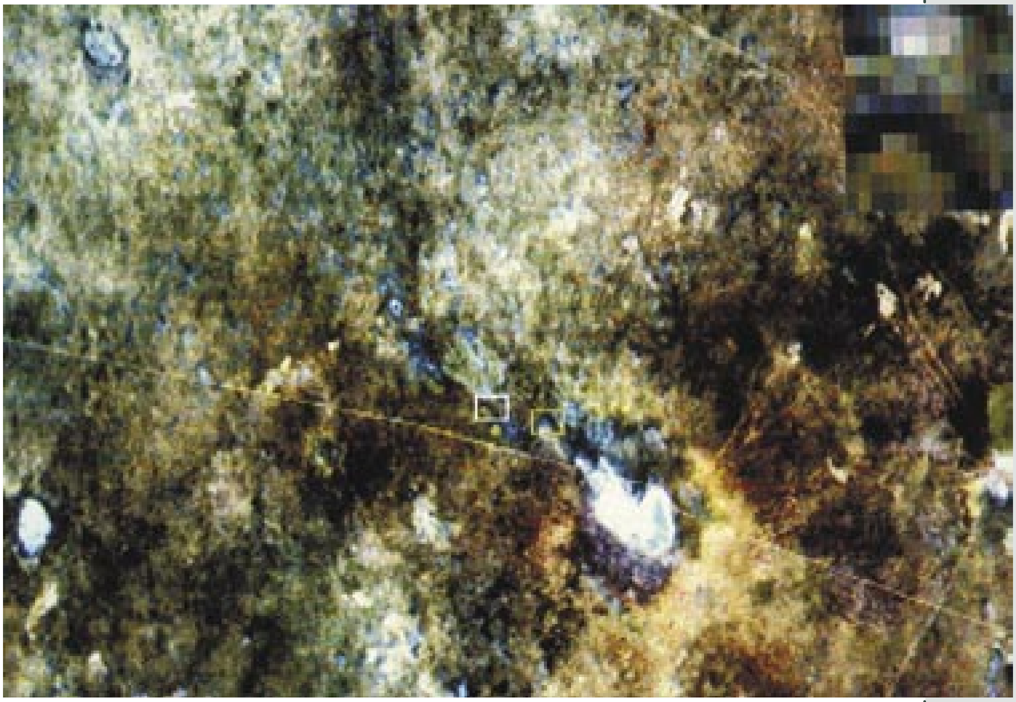


Figure 5.1. Landsat extract. Sekoma Pan plus pixel extract in top right.

Figure 5.2. Aerial photo - Sekoma pan and part of Sekoma - Kang road before it was bituminised.

6 SURVEY METHODOLOGY

6.1 Introduction

The interpretation of background information constitutes the desk study, which is essential to carry out a cost-effective and successful field survey. The results of the desk study are analysed and collated onto a base map, laying the foundation for the field survey. The information is used to plan the field surveys and guide the survey work.

6.2 Desk study

The duration and input of the desk study is related to the complexity and extent of the project.

Proper planning is essential for a successful material prospecting survey.

The desk study is carried out to collate information about the project itself, the site and the materials in the area from published and sometimes unpublished sources, in order to plan the field survey. It forms the first stage of project planning and is undertaken at the office prior to any fieldwork. The issues covered in the desk study are:

- Project briefing.
- Interpretation of background information: maps, aerial photographs, satellite images, reports and prospectors' previous experience.
- Collation of the information onto a base map.
- Planning the field survey including resources and logistics.

6.2.1 Project briefing

This establishes the purpose for which the materials will be used and the quantity required. The prospector, engineer, project manager and other relevant stakeholders meet to discuss the following details regarding the project:

- Location and length.
- The volume and quality (specification) of the materials required.
- The desired spacing of sources.
- The resources and amount of time available for the materials survey to be completed.

This information is provided as part of the normal project briefing. Its importance lies in the fact that the prospector is given a clear indication of the scope of his task.

Environmental factors must be considered. The presence of reserved areas (e.g. game parks) and rehabilitation requirements may place restrictions on the size, spacing or management of borrow pits. Any such restrictions will have to be planned into the extraction programme from the beginning.

6.2.2 Interpretation of background information

Background information on geology, soils, climate, relief etc., comes from maps, remotely sensed images and reports describing the area in which the road is to be built. Thus, information about the project area is assembled and analysed as discussed in the preceding chapters.

Information is often available from projects constructed elsewhere in the region. This typically comprises:

- The types of materials that were found.
- Availability of materials.
- The general engineering characteristics of materials in the region, such as their overall quality, volume per pit and the thickness of the overburden.
- Materials location techniques used and known indicators of material identified.
- Landforms in which the material was located.

6.2.3 Collation of information

During the desk study, the following procedure (in check list form) should be followed for prospecting for any material for any type of road project:

Information coming from past surveys cannot always be related directly to the current survey.

i) Obtain two sets of 1:50 000 topographic maps covering the route corridor. One set of these will be used as base maps for collation of information coming from various sources during the desk study. The other is for general project use and navigation in the field.

ii) Mark out the route corridor on the base maps.

iii) Confirm the material requirements in terms of both quality and quantity for the project.

iv) Establish land use, land ownership and potential environmental constraints within the route corridor.

v) Obtain relevant materials investigation reports for previous projects from the Central Materials Laboratory or any other appropriate source.

vi) Discuss material types and existing and potential sources with district maintenance supervisors and other people with experience of the area. Establish whether there is sufficient gravel at existing and known sources. If not, continue with the study.

vii) Obtain geological maps, agricultural soils maps, aerial photographs and, if necessary, satellite images, as well as any past records for this and other roads in the area.

viii) Determine the coordinates of existing gravel sources and locate these on the base maps, photographs and images. Note the terrain features at these coordinates and then look for other similar features elsewhere along the proposed corridor. Transfer the information to the base map.

ix) Examine the topographic maps, looking for the occurrence of any of the landforms associated with gravel in hard rock regions, and pans in Kalahari regions, as described in Chapter 4. Transfer the information to the base map.

x) If the proposed route is in a hard rock area, examine the geological maps for rock types that are likely to yield suitable gravel, plus other indications interpreted from the map legend and accompanying geological report. Transfer the information to the base map.

xi) Study the aerial photographs (in stereoscopic mode) in conjunction

1:50 000 topographic mapping is the best form of base map to use in Botswana's rock regions, because there are numerous relief and terrain features to relate to. However, in the featureless sand regions, topographic maps tend to contain large blank areas and it is difficult to pinpoint a position without using a nearby road intersection or pan as a guide. In the sand regions air photo mosaics or satellite images may be more useful for field orientation, because they show small and indistinct ground features that can be used for navigation.

If GPS (Global Positioning System) equipment is being used to obtain a fix of ground positions, it is important to carry a base map that contains geographical co-ordinates, so that the GPS waypoints can be accurately transferred to the map. Note that not all air photo mosaics include a co-ordinate grid. The cartographic accuracy is lower than on published maps, so transferred waypoints will only be approximate. When using GPS in conjunction with a topographic map, make sure to set the co-ordinate system in the GPS to be the same as that of the map

with information from the topographic, geological and agricultural soil maps to identify landforms associated with gravel. Make a note of all features, no matter how small, and mark their location and extent on the base map. In Kalahari regions, examine the pans and identify those that contain a calcrete 'platform' around the rim, as well as those that do not. If there are no large pans, or not enough to fill the needs of the project, a more intensive study of gravel-bearing features will be required, to identify smaller ones. The use of satellite imagery may be useful at this stage. This will enable a large area to be evaluated quickly, and to take advantage of colour to distinguish subtle landforms.

xii) Transfer all relevant information to the base map and identify the best potential sites, as well as the best location to begin field work and the route to follow.

xiii) Obtain the necessary permission or authorisation to prospect.

xiv) Contact the landowners to make the necessary arrangements for access to properties during the reconnaissance visit.

xv) Establish the most appropriate method for the field survey. Indications of this by physiographic unit are provided in Table 6.1.

By the end of the desk study, locations of potential sources of material (and their appropriate indicators) should be known and transferred to the base map. As a summary, Figure 6.1 gives an overview of the process guiding the prospector towards the types of material he can expect to find.

Prospecting regions	**Methodology**									
	Desk study				**Field survey**					
	Geological maps	Air photos	Satellite images	Past records	Macro topography	Micro topography	Vegetation	Animal	Soil colour	Direct air observation
1a	1	1	2	1	3	2	3	2	2	1
1b	1	1	2	1	2	1	3	1	1	1
1c	1	1	2	1	2	1	3	2	2	2
2a	2	1	2	1	1	3	3	2	2	3
2b	2	1	2	1	1	2	3	2	3	3
2c	2	1	2	1	2	1	1	1	1	1
2d	1	1	2	1	1	2	3	2	3	3
3a	3	1	2	1	2	1	1	1	1	1
3b	3	1	2	1	2	1	1	1	1	1
3c	2	1	2	1	2	1	1	1	1	1
3d	2	1	2	1	2	1	1	1	1	1
3e	2	2	2	1	3	2	1	2	2	1
3f	1	1	2	1	2	1	2	2	2	2
3g	1	1	3	1	2	1	2	1	1	2
1. Strongly recommended 2. Useful 3. Of marginal benefit										

Table 6.1 Appropriate methods for field survey.

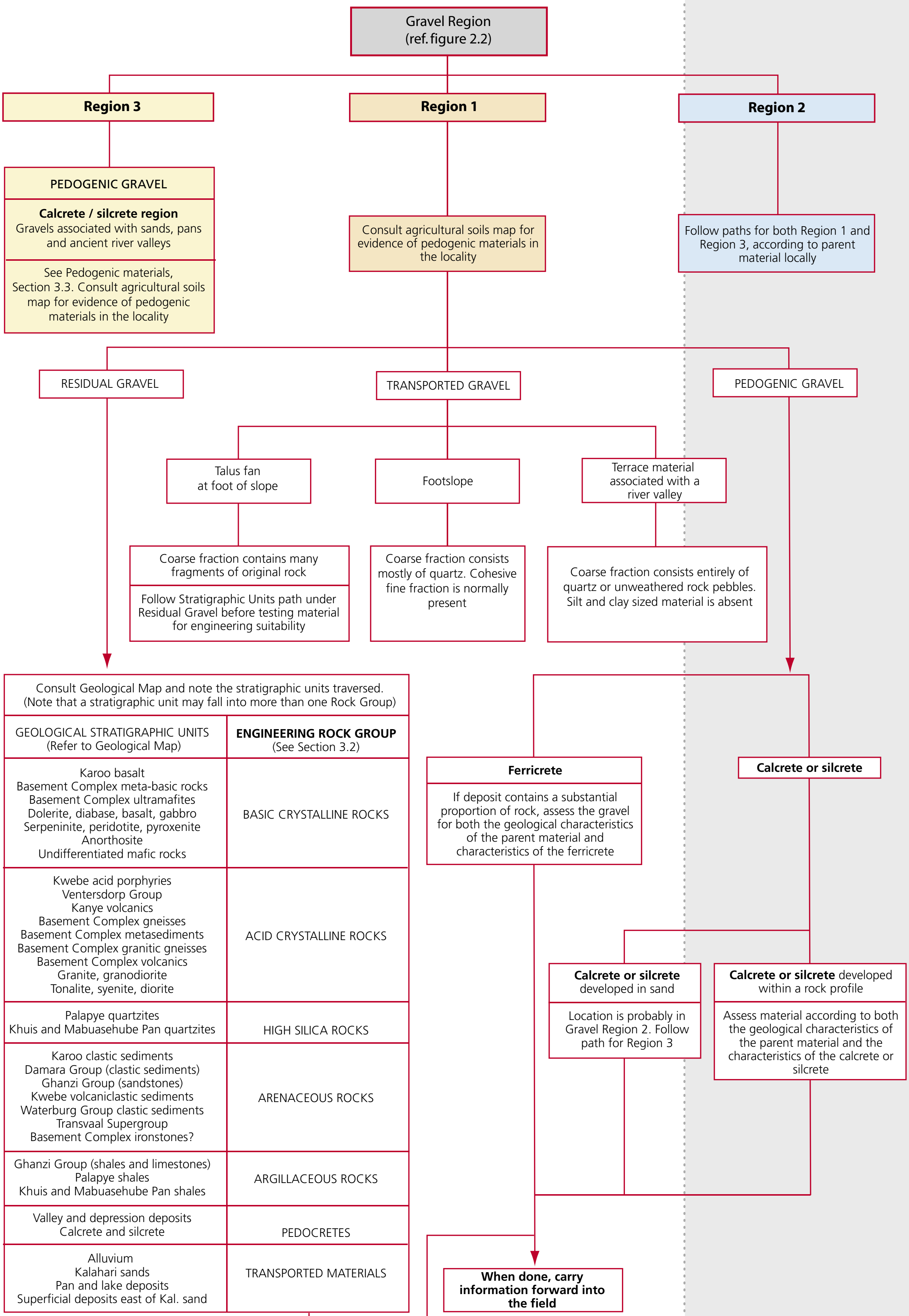


Figure 6.1 Flow chart summary of desk study activities leading to early assessement of gravel types to be found.

Typical equipment for field surveys includes, picks and shovels, geologist hammer, water containers, camping equipment, portable toilets, measuring tapes, compass, GPS, first aid kit, snake bit kit, Munsell colour disk, calcrete probe, step ladder, note books, data sheets and a trunk for the safe keeping of data.

An important aspect of any survey is to become sensitive to the terrain indicators. Landform changes can be very subtle, even in areas of normal relief. It may take several days to acquire this sensitivity, especially in an area like the Kalahari where the landforms are very low and dispersed.

Refer to Netterberg 1996 & 1978b for details on how to use a calcrete probe and hand augers.

6.2.4 Planning the field survey

The following three issues are important when planning the field survey:

i) Plan the logistics of the survey, of which an important aspect is the tools and techniques to be used especially with regard to the use of labour or equipment intensive methods. If labour is used, transport ation, accommodation, food, water and sanitation will also have to be arranged. If work is to be conducted in environmentally sensitive areas the survey plan must take account of restrictions placed on the exploration programme.

ii) Sufficient sample bags, marking pens and labels must be included with the equipment, and arrangements must be made to transport the samples to the laboratory. Sample sizes must be in accordance with the requirements of the Botswana Road Design Manual.

iii) The prospecting team should consist of experienced technicians and assistants to maximise chances of success in finding gravel. The team should have a minimum of the following personnel:

- **Project manager.** The project manager should be a qualified Engineer or Engineering Geologist with a sufficient experience in materials prospecting. The project manager is not expected to stay in the field for the entire investigation but should at least assist in the reconnaissance survey and soil profiling and visit the team as and when the need arises.

- **Team leader.** The team leader should be a qualified Technician with sufficient experience in gravel prospecting, testing and profiling. His role includes the day to day running and management of the field crew.

- **Materials assistants** must be experienced in gravel searches and should know the specific area. They are responsible for the direct supervision of labourers and for managing smaller crews from the team. On large projects, at least two Material Assistants should be included in the team to supervise labour groups.

- **Labourers** should be sourced from the nearest village. The number of labourers required will depend on the size and time constraints of the project.

- **Camp keeper.** The need for a camp keeper should be assessed by the Team Leader depending on the state of security in the area.

- **Field equipment.** The Team Leader should ensure that all resources and equipment needed in the field are provided. The equipment and tools will differ from one project to the other but the following are some of the basic needs that should be budgeted for:

  Vehicles for transporting workers to and from the field every day as well a transporting samples to the camp. Bigger trucks can be sourced when the need arise to transport samples to the laboratory. Some areas such as the Kgalagadi region would require four-wheel drive vehicles.

  Other necessary equipment include, picks and shovels, geologist hammer, sample bags capable of holding 20 kg of soil, water container or water cat, camping equipment, pens, wax pencils, sample labels, measuring tapes (long say at least 50 m and short say 5m long), campus or GPS, firstaid kit including, snake bit kit, portable

toilets where required, Munsell colour disk, calcrete probe where required, step ladder for use on deep pits, note books, a set of data sheets, stationary and a trunk for the safe keeping of data.

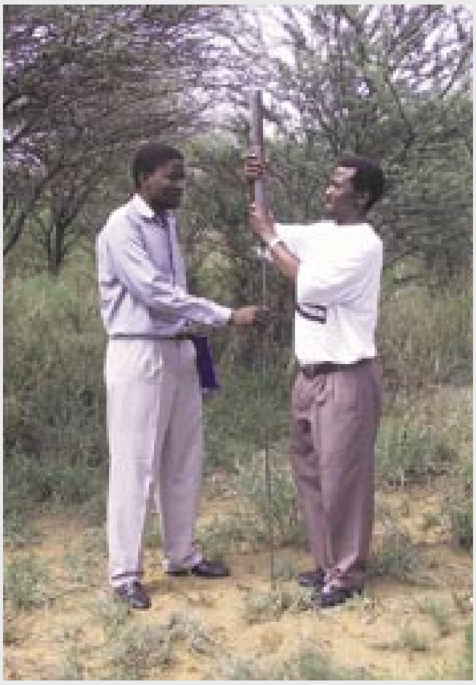
6.3 The field survey

The most successful field survey procedure is to systematically traverse the route relating the information on the map prepared during the desk study to the prospecting corridor.

During a field survey, a calcrete probe, DCP or hand auger are useful for providing a quick indication of success before following up with more time consuming trial pitting. The calcrete probe is the most suitable instrument for locating pedogenic materials beneath a sand cover. After probing, the depth should be recorded and the tip of the probe should be examined to identify the likely calcrete type A summary of the interpretation is provided in Table 6.2.

Penetration resistance	**Calcrete probe tip appearance**	**Likely calcrete type**
Varies form almost none to refusal within a few meters	No deposit if little resistance; white or pale pink colour on refusal; *cannot be rubbed off with fingers*.	Loose sand mixed with boulder calcrete
Refusal	White or pale colour; *cannot be rubbed off with fingers.*	Hardpan or boulder calcrete, probably unpickable
High resistance	White or pale pink colour; *cannot be rubbed off with fingers*.	Loose, hard nodular calcrete, stiff hardpan or calcified sand
Fair to high resistance	Pale mauve; *cannot be rubbed off with fingers.*	Tufaceous hard pan calcrete
Low to Fair resistance	White; *cannot be rubbed off with fingers.*	Powder calcrete
Low resistance	White sandy deposit; *easily rubbed off with fingers*	Calcareous soil.

Table 6.2 Interpretation of calcrete probe result (modified from Netterberg 1996).



The calcrete probe in operation.

The type of calcrete material may be indentified at the tip of the probe.

Dilute hydrochloric acid can be used to indicate carbonate at depth on termite mounds and soil around animal burrows.

6.3.1 Reconnaissance survey

The reconnaissance survey is recommended to familiarise the prospector with the project area. It is usually carried out as part of the detailed investigation, but can be done as a separate trip. Its main purpose is to familiarise the prospector with the corridor, mark the existing pits and potential sites identified during the desk study as well as to note any other potential sites that may have been missed. The detailed study can then be planned in order to optimise resources. The purpose of the reconnaissance survey as opposed to the detailed investigation is clarified in Table 6.3.

In the Okavango delta good materials are scarse and the located borrow pit area may change significally, depending on material quality.

Pans in the Okavango area does not necessarily yeild good gravel.

In a featureless area landforms can be very difficult to identify. Tsabong area.

Light helicopters have been used successfully in material prospecting. Tsau area.

Reconnaissance survey	**Detailed survey**
Purpose is to obtain an overview of the types and distribution of materials within the whole route corridor, and possibly outside, i.e. to identify sites.	Purpose is to make detailed record of the most appropriate sources of material for the project in hand, i.e. to investigate sites identified in reconnaissance survey.
Large distances are covered quickly, to obtain an overview of potential sites. Route is varied as necessary to visit as many sites as possible within the area of search.	The sites are covered methodically, therefore in much more detail. Route is planned to progress from one site to the next.
Usually no samples are taken.	Samples are taken as necessary, appropriate for the specification of the material in the context of the project.

Table 6.3 Differences between reconnaissance surveys and detailed surveys.

The following procedure, in the form of a checklist, is recommended for the reconnaissance survey:

i) Begin the traverse of the road or the proposed alignment approximately 2 km before the actual start (there may be very good material at the beginning of the project). Continually refer to the base map and aerial photographs.

ii) The first traverse should confirm the conclusions drawn during the desk study. Visit existing gravel sources and potential sites identified from geological maps, aerial photographs and satellite imagery. Use GPS to determine their locations. Estimate the areal extent and available quantities without excavation. This can be done with simple techniques such as a calcrete probe or a DCP.

iii) Identify any significant geomorphological, soil or vegetation characteristics at existing borrow pits that can be used to indicate similar sources elsewhere along the route. Identify these characteristics on the maps and aerial photographs and look for similar features else where on the images.

iv) Study the geomorphology and decide which areas are likely to have a high potential for material - e.g. pan rims, scree slopes and drainage channels.

v) Study the vegetation and note any significant changes, such as species groupings or changes in plant characteristics (e.g. shape, height, form).

vi) Note factors pertaining to accessibility of each site.

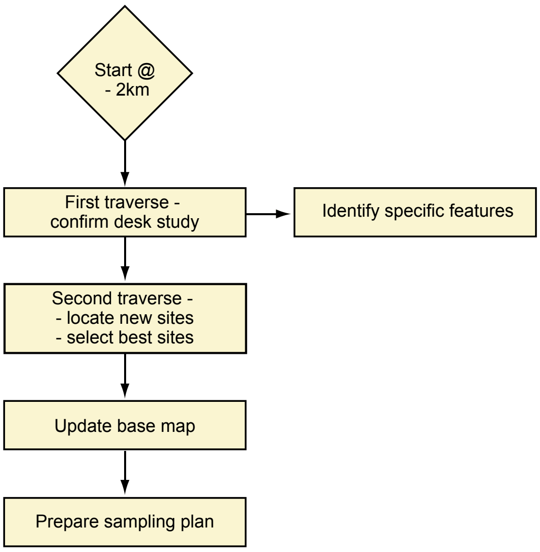
vii) List GPS co-ordinates of potential sites and summarise the observations.

viii) Plot new sites on the sketch map. Review the pattern of pits on the map to see if the pits lie in clusters or straight lines, which would help in showing where to look for additional material.

ix) Record other important information including thickness of overburden, ease of access, distance to nearest source of water, distance to nearest supplies and distance to nearest fuel.

x) Update the base map accordingly.

xi) Draw up a plan for the detailed study, prioritising the most suitable sites according to the required material qualities and quantities. Identify a second set of sites in case the first selection proves to be unsuccessful.



If the area in which the reconnaissance is carried out is flat and featureless, it is possible that the ground reconnaissance survey will be difficult, if not unsuccessful. In such cases, an aerial visual survey should be considered. A helicopter or ultralight aircraft should be used for the survey. Normal fixed-wing light aircraft are not suitable as they are too fast to allow inspection of potential sites. Although expensive, it is very quick and the costs incurred are usually considerably less than lengthy ground surveys that often miss potential gravel sources. The following procedure is recommended:

i) The aircraft should be flown approximately 200m above the ground along the proposed alignment.

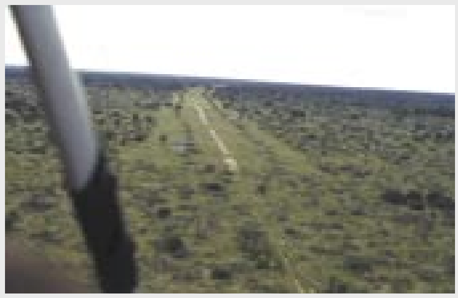
ii) Any abnormalities in micro-topography (e.g. pan rim), vegetation (distinct change of species, dense thicket of one or two species, change in plant morphology (e.g. stunted or multi-stemmed)) or soil colour should be sought to the left or right of the route alignment.

iii) Once observed, the aircraft is flown to these areas and a closer inspection is made from the air while circling the area. If a suitable area is available, the aircraft can be landed and a closer inspection made of the site with a probe. If landing is not possible, GPS co-ordinates should be taken and the site revisited after the aerial survey has been completed.

iv) Once a site has been inspected, the aircraft is flown back to the route alignment and the flight along the route is continued until a new potential site is observed.

v) Since it is difficult to write in a helicopter or ultralight aircraft, a pocket tape recorder should be used for capturing verbal descriptions during the flight and for noting GPS co-ordinates or waypoints. Depending on the stability of the aircraft, photographs can be taken of potential sites and studied in more detail on the ground.

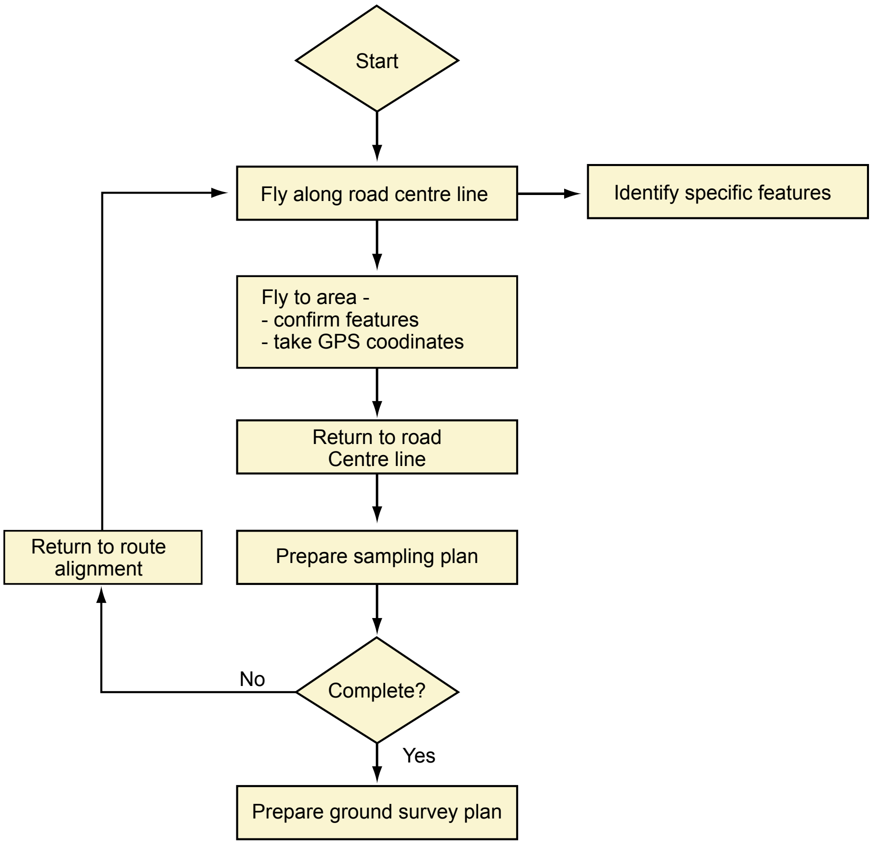
Ultralight aircraft is useful in material prospecting.



View from a ultralight aircraft.

6.3.2 *Detailed survey*

The detailed survey involves the evaluation of the potential gravel sources at the sites judged to be most appropriate for the project. The process to be followed is provided in Chapter 7.



7 EVALUATION OF A GRAVEL SOURCE

7.1 Introduction

The process of searching for suitable gravel sources culminates with the evaluation and proving of the identified potential construction material source. The objective of this part of the investigation is to establish:

- The areal extent of a potential gravel source.
- The thickness and hence quantity of the identified deposit.
- The characteristics of the identified deposit (i.e. in which layer they can be used).
- The type and properties of the overlying material.
- The thickness and hence volume of the overburden.

A flow diagram showing the overall procedure is given in Figure 6.3.

Ground investigation is a potentially hazardous activity and accidents with hand tools, diggers, etc can easily happen. All staff should be aware of the dangers.

7.2 Detailed field study

For each potential source identified, the following procedure should be followed:

- Demarcate the approximate areal extent of the site with stakes. This can be determined with a calcrete probe or DCP. In sandy areas, the calcrete probe should also be used to determine the thickness of the overburden.
- Identify the source with a unique location number, its chainage from the start of the route and the chainage offset from the centreline.
- Lay out a 50 m staggered grid. The grid pattern may be reduced to a 25 m spacing in one or both directions if the material within the potential source changes in a short distance. The grid can be aligned in any direction convenient to cover the shape of the deposit. Setting out of the trial pits should be carefully planned taking the characteristics of the site, such as vegetation and rock exposure, into consideration. Trial pitting should also encompass as much of the potential borrow pit as is necessary to establish the deposit's extent and variability.
- Record the grid pattern with holes running in one direction left to right being labelled A, B, C, D, etc and holes running perpendicular to this (i.e. top to bottom) being numbered 1, 2, 3, 4, etc. Trial pits should be selected statistically (preferably on a stratified systematic herring bone pattern) and would then be numbered A.1, A.2….B.1, B.2……..D.1, D.2 etc. This shown in figure 7.2.

The thickness of overburden is important to identify. Large coste are involud in removing a thick layer of overburden. Tsau area.

Similar for the gravel layer. If not properly indentified the material source may be ruined during stock piling. Tsau area.

The trial pitting and sampling are expected to show the variability and quality of the material. Variability can occur in all planes and will not be the same for each property tested. It is obvious that the more samples taken the better the chance of arriving at a reasonable statistical view of the quality of the material. However, there is practical limit as to how much can be sampled and tested.

There are several sampling patterns:

A) Systematic, (square or rectangular grid);

B) Stratified random;

C) Unaligned stratified systematic, (or herring bone);

D) Random;

E) Judgmental.

The use of a grid system ensures a well co-ordinated study and simplifies the location of each trial pit. The system also facilitates selective stockpiling if different areas of the borrow pit are recommended for different pavement layers.

In the latter method the sampler decides according to his own judgement where to dig the trial pits. The method does not guard against human bias and some good areas of gravel may be overlooked and not sampled. The sampling patterns of the other methods are shown in Figure 7.1

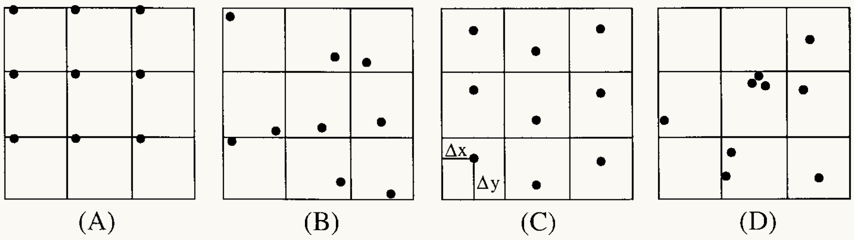


Figure 7.1. Illustration of varieous sampling pattern.

This pattern requires a little more care in setting out, but if the odd number cells are set out at 1 00 metres intervals first, and then the even number cells are set out midway of the odd numbers but displaced the herring bone pattern will be set out very simply.

Of these designs the unaligned stratified systematic, based on a herring bone pattem is the most effective i.e. it is most likely to detect differences in the gravel using the least amount trial pits. The application of the herring bone pattern requires that the site is divided into cells and each alternate cell has a fixed point for a trial pit.

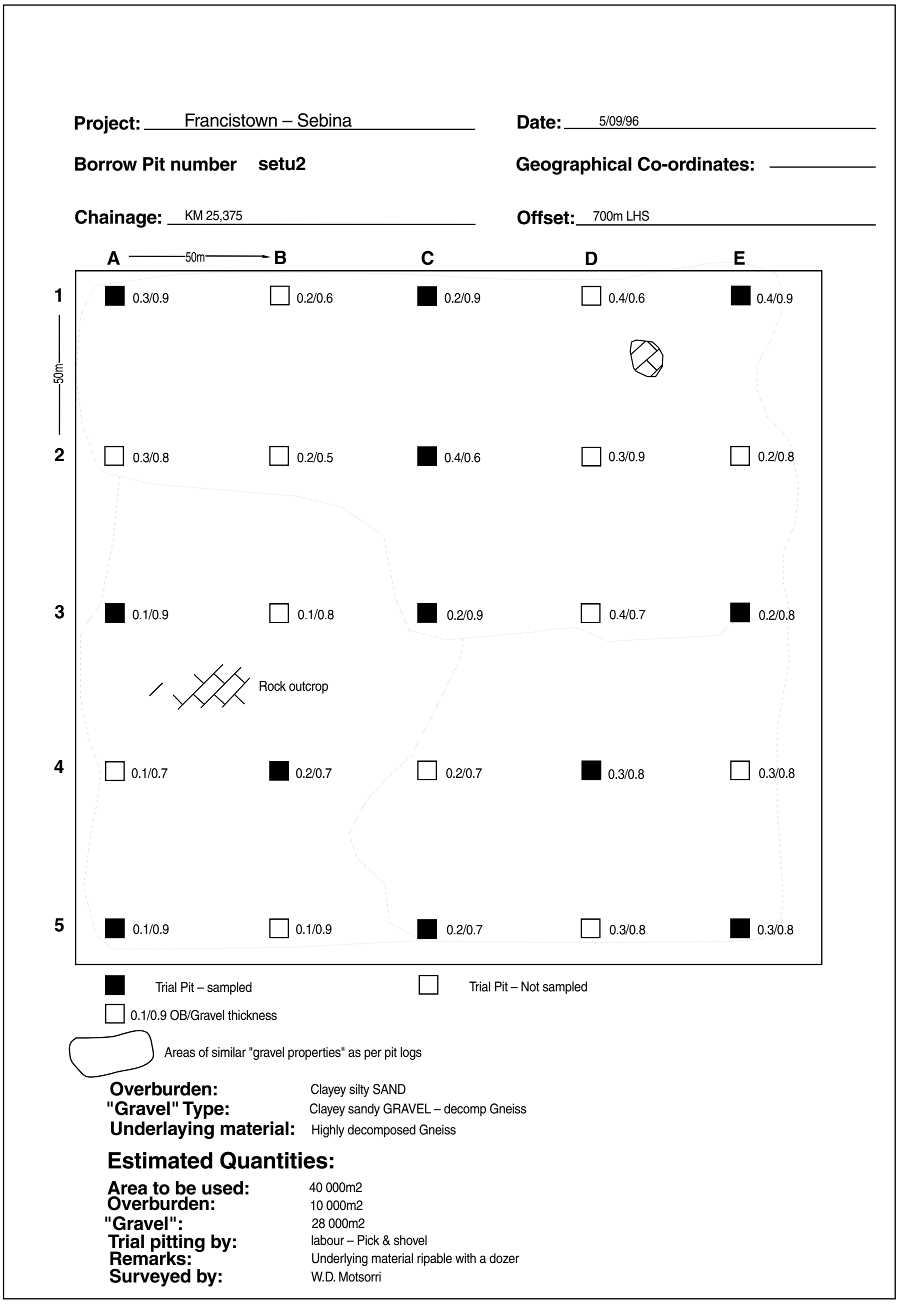
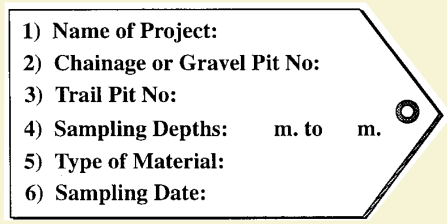


Figure 7.2. *Typical layout of trial pits.*

Digging a trial pit for sampling. It is importent to make the pit large enough for proper sampling and identification.

When a pit is dug to a depth greater than about 2 m, there is a danger of the sides collapsing. The team leader should assess the risk of this happening and take all practical steps to prevent it, such as providing support for the sides. Pits dug below the water table should be avoided, but where unavoidable they must be fully braced.



- Excavate a pit to the bottom of the suitable material. This can be done either manually or by machine depending on the particular circumstance of the project. The width of the pit will vary depending on the excavation method. Ensure that the necessary safety precautions are taken during excavation and examination of the pit.
- Describe the soil profile in detail using the standard Jennings, Brink and Williams (1973) method. Profiling is described in more detail in Section 7.3 below. Profiling must include the overburden and the ratio of overburden thickness to gravel thickness should be recorded. During profiling, identify the horizons that are potentially suitable for meeting the material requirements of the road design.
- Collect sufficiently large samples of material for the intended tests. Sampling is discussed in more detail in Section 7.4 below. Place the sampled material in bags (it is suggested that high quality sewn canvas bags are used for sampling) and carefully label each bag ensuring that the label is permanent. Label tags should be placed in a transparent waterproof plastic bag before being placed inside the sample bag to avoid moisture damage. Information on the label must include the following:
    - Project name
    - Date
    - Source location number (see ii above)
    - Trial pit number (see iv above)
    - Depth
    - Type of material
    - Name of person sampling

The samples should be carefully handled and dispatched to the laboratory as soon as possible.

- Reinstate the pits with similar quality material from within the staked area. Remember that this material may be used in the road and therefore deleterious material from outside the staked area should not be used for backfill. If the pits have to be left open for more than one day, they should be clearly identified with hazard tape or covered with wood to prevent people or animals from falling into them.
- Estimate the volume of gravel in the source. To do this, determine the mean thickness of the gravel and multiply it by the areal extent of the source. Estimation of quantities is discussed in more detail in Section 7.5.
- Draw a detailed sketch map of the area and include the following:
    - Distance from the road or proposed alignment.
    - Potential access routes.
    - GPS co-ordinates if available.
    - Trial pit grid and location of pits that were sampled. Also include any additional information gathered from calcrete probe or DCP penetrations.
    - Pertinent features such as outcrops, anthills, big trees (which may be protected by order), streams, etc.
    - North direction marker.
- List any potential problems that may affect the exploitation of the pit such as boulders, presence of water, etc on the sketch map.
- List any environmental factors of concern in the area.

The survey site should be kept clean and all litter should be collected and returned to the camp for appropriate disposal.

- Where necessary list the names of landowners e.g. if the potential gravel source is in a field or farm or affects other land users.
- Mark the position of each potential borrow area on the 1:50 000 topographic map which serves as the working map.

Repeat this process for each identified potential source. When each source has been evaluated, add the estimated total volume from each source and compare this figure with the project requirements. Remember to make sufficient allowances for compaction or bulking and wastage (e.g. oversize).

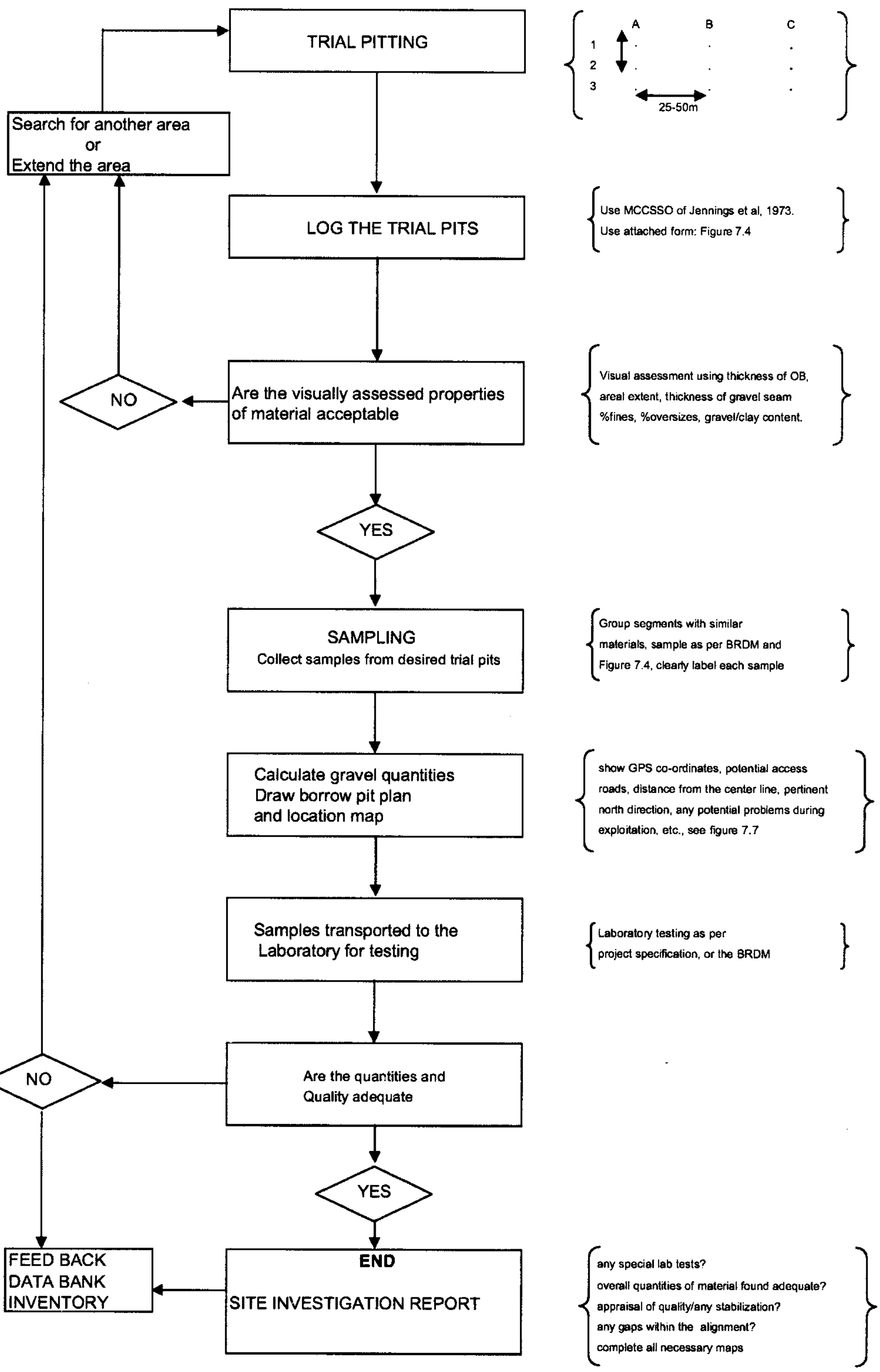


Figure 7.3 Flow diagram: Evaluation of a gravel source.

7.3 Trial pit logging

The first stage of material classification is an accurate description and measurement of material thickness encountered within the trial pit, i.e. logging or profiling. The trial pit log is a record of the vertical succession of the different layers of soil as they occur at any particular location of a potential borrow area. The description should be detailed enough to facilitate the acceptance or rejection of the area for further evaluation, while the measurement of the thickness of each stratum provides for estimation of quantities on the basis of which the area may be rejected or accepted. If done properly therefore, the soil profile provides basic information for the approximate quantitative assessment of properties of the material.

The trial pit logging should as much as possible transparent the situation when the BP has been opened. Molepolole - Lephepe road.

For the safety of digging labourers and the profiler, a code of practice such as South African Institution of Civil Engineers (1980) must be adhered to. Generally, holes dug as per code of practice have a low risk of collapse, es-pecially above the water table. Extra care should, however, be taken when profiling below the water table and in cohesionless sands such as Kgalagadi sands where the trial holes tend to be more than two metres deep. A com-petent and experienced person must be in charge of trial pitting and the entire site investigation in order to ensure the safety of the workers.

The profiling should be done in terms of its Moisture condition, Colour, Consistency, Structure, Soil texture and Origin (MCCSSO) as detailed by Jennings, Brink and Williams (1973). Basic equipment for profiling includes:

- Measuring tape
- Geological pick
- Small bottle of water
- Pocket-knife
- Standardised soil colour chart or colour disk
- Pen and field notebook
- Ladder for descending into deep trial pits.
- Camera

The profiling should be done using the format shown in Figure 7.7. Photographs of typical profiles are sometimes desirable as they can be used to recall specific features at a later time. When all the trial holes have been profiled, their logs should be presented in a format similar to Figure 7.3 using proposed symbols for soil profiles (Jennings et al. 1973). The logs should indicate the method of digging, whether the pit was dug to refusal on the exploitable strata or on underlying material and whether the underlying strata can be dug with a pickaxe. The proposed symbols indicating end-of-hole (EoH) on refusal at the bottom of the trial pit are shown in Figure 7.4.

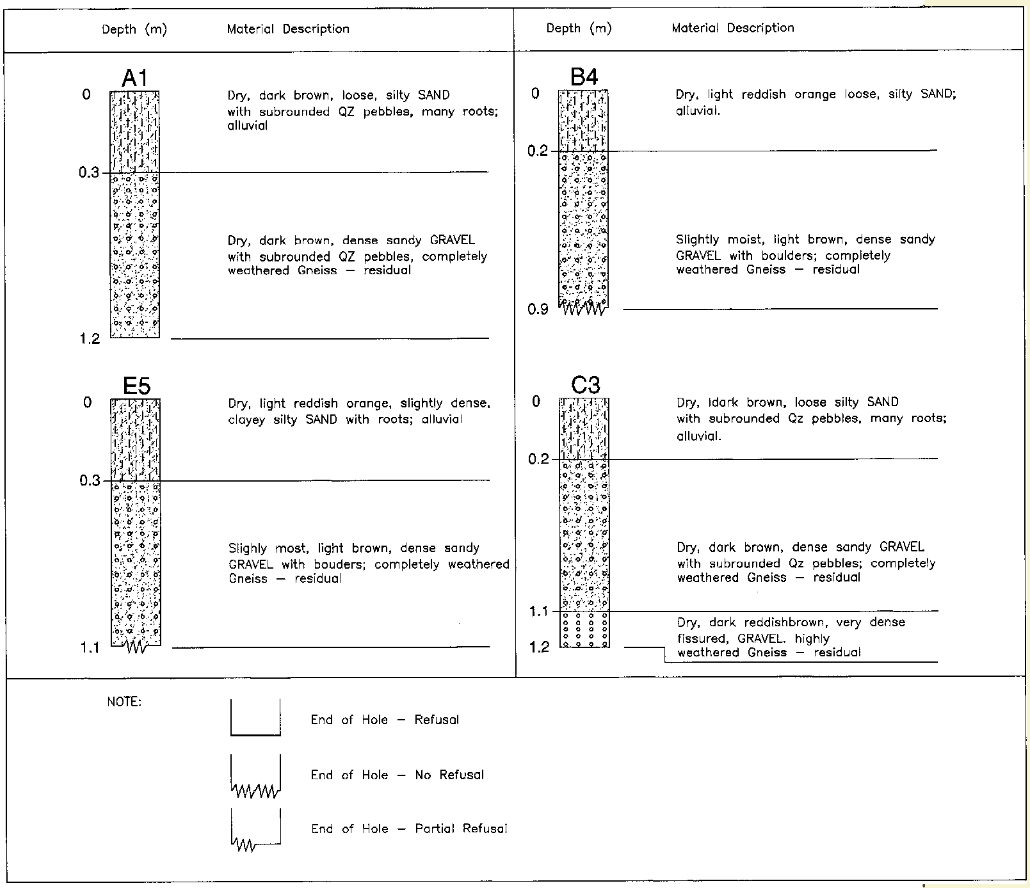


Figure 7.4. *Example of trial pit logs.*

The information obtained during the trial pit profiling should be assessed in terms of:

- The lateral extent and uniformity of various strata and horizons.
- Thickness of layers in relation to required quantities.
- The thickness of overburden in relation to the thickness for the required 'gravel' strata. Ideally, this should be not less than 1:3 and the overburden should preferably be less than 0.5 metres thick. In practice this is not always achievable and the extent to which the ratio can be relaxed depends on the availability of alternative construction materials, allowable haulage distance and whether the overburden has potential to be used in road or detour construction.
- Engineering properties of the overburden and the 'gravel', e.g. proportions of clay, sand, gravel and oversize material. If it is clear that these properties do not meet the project requirements, the source can be rejected without sampling and testing and not considered further at this stage.
- Anticipated practical problems pertaining to exploiting the material from the pit.

If the assessment is positive then the layers should be sampled.

7.4 Sampling

In order to appreciate the importance of taking representative samples a simple calculation will show that if the trial pits are spaced at 50 m intervals and the gravel is 1 m thick a 40kg sample must represent 4,000,000 kg of gravel. I.e. it is the ratio of 1,000,000; and a 4kg sample will represent 1:1,000,000. The size of the sample therefore has an important bearing on representation. Theoretical analyses have shown that a good indication of the correct mass of sample needed for it to be representative can be obtained from the figure below. Certain assumptions have been made arriving at this relationship, but for laboratory analyses, at least, the figure should be applied in practice.

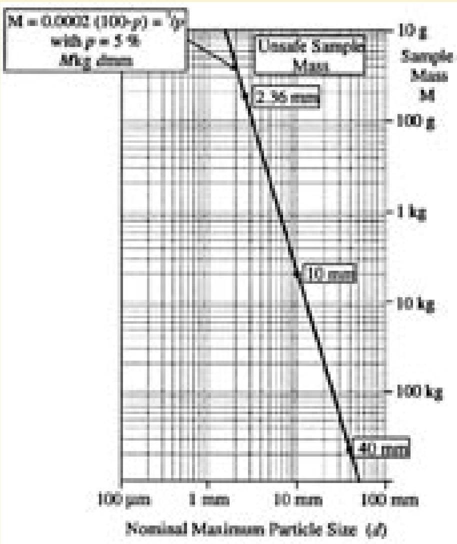


Diagram to estimate correct mass of sample needed.

The data obtained from trial pit logs should be used to subdivide the borrow pit into segments comprising materials of similar characteristics. At least one sample should be taken from each different material unless they are clearly unusable. When profiling the pit, the following factors should be taken into consideration:

Colour

The colour of the material may reflect the gravel type, e.g. calcrete rich gravels tend to be whitish while decomposed felsite in the same area devoid of calcareous cement would be reddish brown. The colours should be based on a standardised colour chart.

Soil type

The grain size proportion of the material determines the engineering properties of the material and its behaviour within the pavement. The material would have been described as boulders, gravel, sand, silt, clay or some combination of these, e.g. clayey gravel with boulders, gravelly sandy clay, etc. In addition, the prospector's knowledge of the local soil types in terms of performance should be used.

Origin

Where the origin of the material can be clearly defined, especially in terms of residual, transported or pedogenic materials, then it should be used to refine the grouping further. This should include the parent material if possible. The degree of induration or development of pedogenic materials should be noted, e.g. calcified sand or nodular calcrete.

The quantity of samples required should be specified by the project engineer depending on the tests required. Where no specific quantities are specified then the guidelines in the BRDM (1986) shall be followed.

The suitability of the overburden for use as road building material shall be assessed. At least four samples for indicator tests and two for CBR tests, depending on uniformity of the overburden, shall be obtained.

While sampling, care shall be taken to avoid contamination of different strata. The following procedure should be followed (see Figure 7.4):

- Choose one section of the trial pit that contains a representative profile of the material.
- Remove the topsoil (usually 0-200 mm thick) in order to create a groove suitable to yield sufficient quantities of gravel.
- Clean the bottom of the trial pit.
- When sampling the overburden, place a sample bag (flat) at the bottom of the pit. Using a shovel or pick, break the material along the groove such that the material falls on top of the sample bag at the bottom of the pit. Put the material into a clean bag and place it outside the trial pit. The exercise should be repeated until sufficient quantity of material has been collected. Make sure that the layer being sampled is not contaminated by material accidentally falling in or scooped up with the sample.
- To prepare the next stratum for sampling, clean the groove to the top of the stratum to be sampled, also clean the bottom of the pit. Break the material along the groove as above until sufficient quantity of the material has been collected.
- Place another sample bag at the bottom of the pit and repeat iv above.

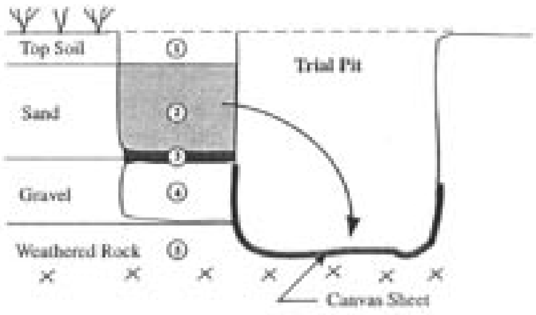


Figure 7.5. *Method of sampling from trial pit.*

The procedure should be repeated until all relevant strata are sampled. When sampling a stratum ensure that the full thickness of the material is collected. If necessary, collect a large sample and quarter it down to the required sample size.

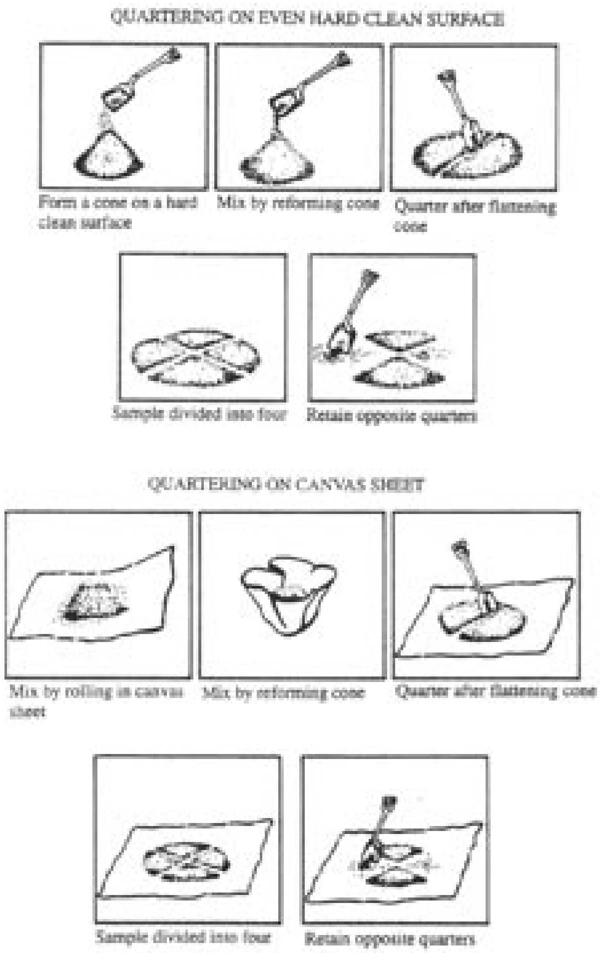


Figure 7.6. *Correct method for reducing the size of a sample.*

After each sample has been collected it must be labelled immediately.

Dense, hard in situ material can be considered to have approximately the same volume after compaction. In contrast, a loose in situ material intended for use in a well-compacted layer such as road base may have a bulking factor as high as 30%. This needs to be taken into account when matching the quantity of material available to the requirement

7.5 Estimating material quantity

The quantity of material available for exploitation of a potential borrow area must be estimated. The estimates are used for materials utilisation planning, haulage cost estimates and overall project planning and construction costing.

Unforeseen difficulties such as deterioration of the quality of material or the presence of water may arise and thus reduce the estimated quantities. It is preferable to underestimate rather than overestimate and, if possible, to select a site containing a greater volume of potential construction materials than required, rather than one which is estimated to meet only the specified requirements.

There are various methods of estimating the volume of material in a potential borrow area. The main objective, however, is to establish the thickness over a portion or the entire borrow area. A simple, yet adequate method is outlined below:

i) Divide the borrow area into segments with simple ‘shapes’ - squares, rectangles and triangles refer to Figure 7.7.

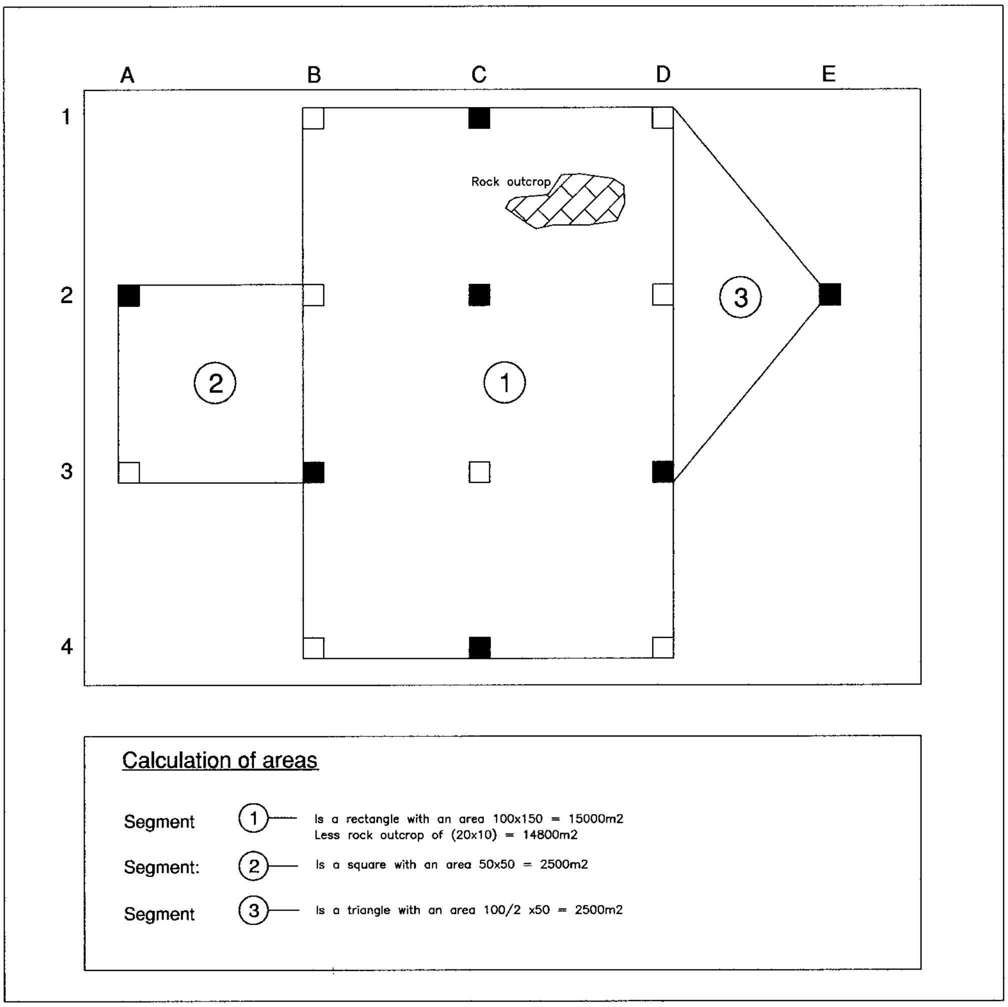


Figure 7.7. Subdividing a borrow area in order to calculate gravel quantities.

ii) Determine the total area of each segment and make adjustments for obstacles such as big trees or vegetation that should be preserved, rock outcrops, areas of unsuitable materials etc., to determine a 'useable' area.

iii) Within each segment, determine the average thickness of the material strata of interest (overburden or gravel) from trial pit profiles or as estimated with DCP, calcrete probe or auger.

iv) Determine the approximate volume of the material that the strata can yield per segment by multiplying the average thickness (c) by the area of each segment.

v) Add the volume of material from all segments.

vi) To account for compaction or bulking factor, waste during stockpiling, transportation and construction, reduce the estimated quantities according to the degree of induration of the in situ gravel in comparison with the expected densities after compaction.

vii) Consider whether all materials from the pit would be used. In particular, note oversize materials that are not likely to break during con struction. However, the total volume of the material from the borrow pit (including oversize) must be reported for transport cost-estimation purposes unless such oversize can be removed at the borrow pit.

viii) Carefully study the trial pit logs and determine whether the thicknesses reported in the logs are based on refusal (i.e. whether the pit was sampled to its full depth) or no refusal and whether the trial pitting was machine or labourer based. For pits not sampled to full depth the volume calculated could be considered to be conservative while pits sampled to refusal could imply that no additional material will be excavated, especially if a machine, such as tractor loading backhoe, was used for trial pitting.

ix) While preparations are being made for digging, make a location plan of the site in relation to roads, access tracks, old borrow pits, major vegetation features, and any other landmarks or surface features that make the site easy to find. (An example is given in Figure 7.8).

Open borrow pit, seen with a "bird eye" along the Trans Kalahari road.

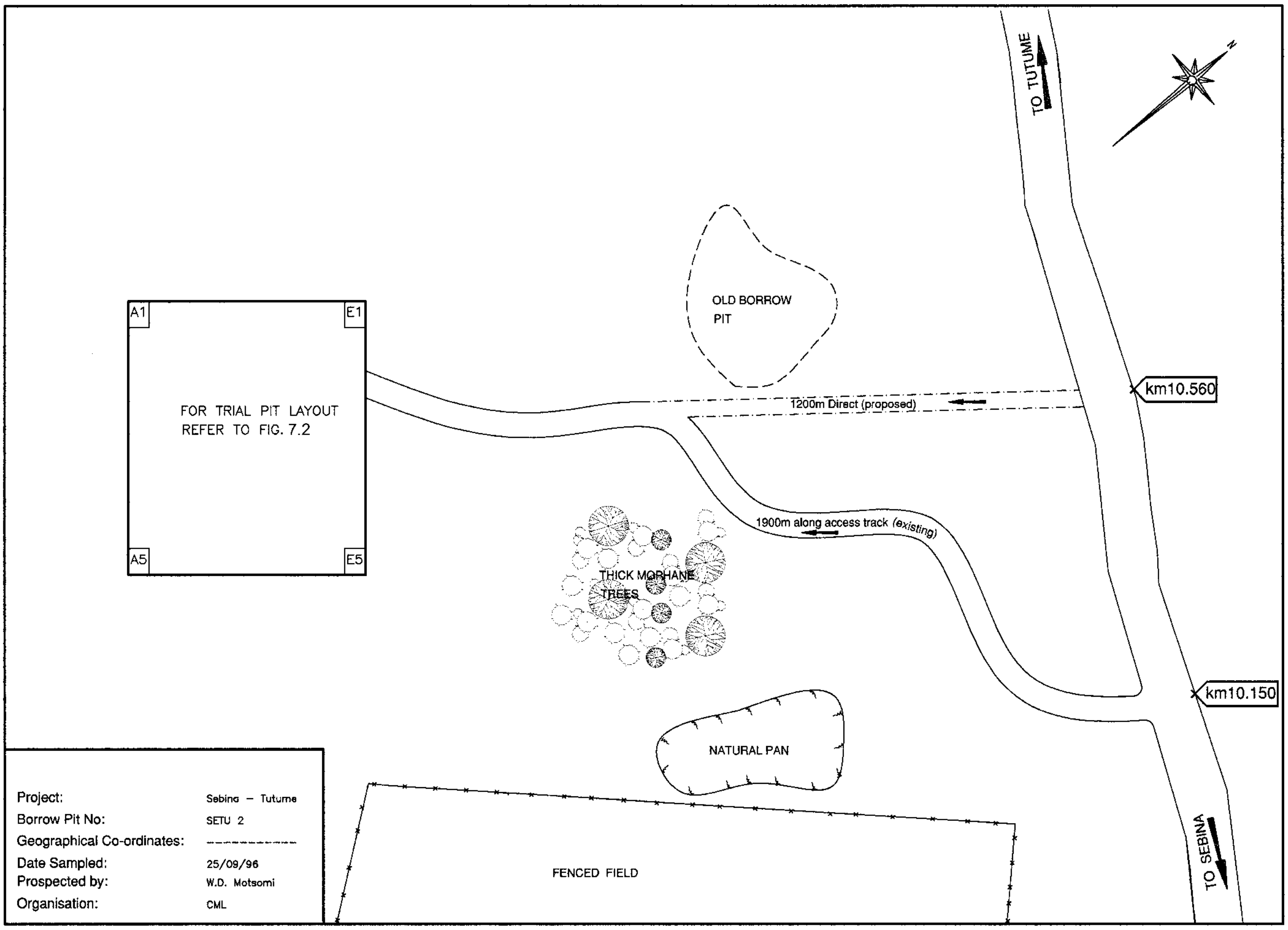


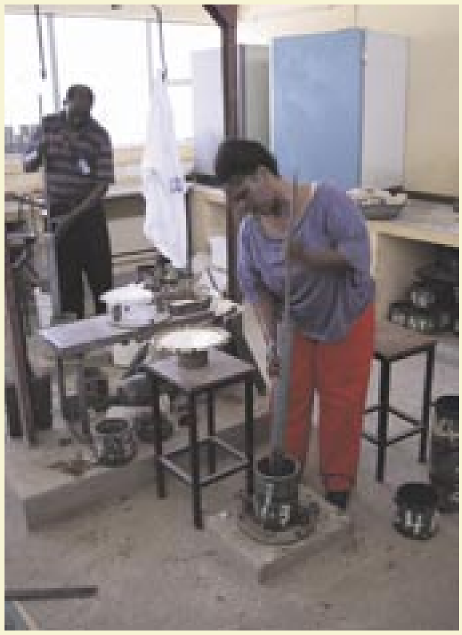
Figure 7.8. Typical borrow pit location plan.

7.5.1 Laboratory testing

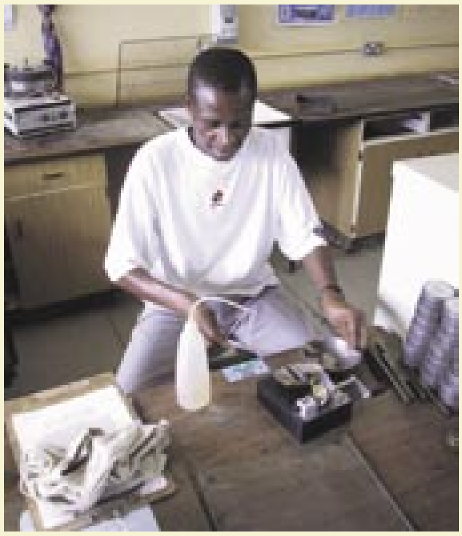
Routine indicator and classification testing must be carried out before submission of the prospecting report.

A wide range of tests have been devised to describe material and assess its potential use in road construction. These tests are primarily to provide information to assist in predicting the "in-service" performance of the material and to compare materials from alternative sources. Not unlikely the need for, and the importance of, taking samples carefully is the need to follow the correct laboratory procedures to obtain results which portray the true characteristics of the material.

Test methods are standardised and the technician will meet these standards in his soil mechanics course. However as an introduction to laboratory testing the technican needs to be made aware of the difficulties and precautions needed for obtaining valid test results.



Determination of MDD/OMC in the main Laboratory(CML).



Laboratory testing, Liquid Limit (LL) apparatus.

8 REPORTING

8.1 Introduction

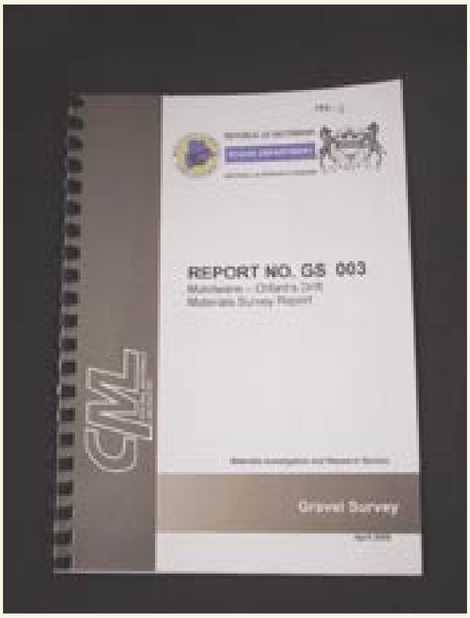
A site investigation report generally comprises two parts, namely:

- The factual or descriptive record part.
- The engineering interpretation and recommendation part.

The factual report should describe concisely and accurately the site, the work carried out and the results obtained. The interpretation results detail the analysis of field and laboratory results together with recommendations for usage.

The report must contain the essential information that the client needs to exploit the gravel from borrow pits or that the contractors needs during tendering. The numbering and layout of the report shall be in accordance with The Materials and Research Division Report System (No. 1C 001).

This chapter is concerned primarily with the internal structure and contents of the report.



8.2 Report structure

The following structure is recommended.

Introduction

- The background should include the name of the project, the client, the prospecting division (company), date started and finished and details regarding the awarding of the project.
- The objectives of the project should be as detailed in the terms of reference or the project brief.
- The scope of works. State what the project entails as given in the terms of reference or the project brief.

Description of site

- Give a description of the site location with respect to districts, major towns or villages and the specific villages being connected by the road. A general site location map is necessary.
- Give a description of the vegetation and terrain occurring along the road corridor. Any apparent correlation between vegetation and terrain with construction materials should be reported.
- Include a summary of local climatic indicators such as annual average rainfall, temperature ranges as provided by Meteorological Department records and the Weinert N-value.
- Describe the main land use patterns in the project area.
- Describe the general geology of the area and the associated weathering products (natural gravels). The approximate boundaries of geological units along the road corridor should be described. It may be desirable to present this in a map.

Investigation methodology

- Describe the desk study, field investigation and the method of site investigation used.

Field investigation results

- As an introduction to the chapter, give a brief outline of how the chapter is arranged and how the borrow pits are numbered. State the total number of borrow pits investigated and state how many are reported upon.
- For each borrow pit, provide information on location, description and quantity and quality of material as follows.
- Show the borrow pit location sketch and describe the area round the borrow pit such as vegetation, watercourses, obstacles, areal extent, etc (Figure 7.6). Describe features that are associated with good or poor quality material within the borrow area and indicate how this compares with the desk study recommendations. Attach the sketch plan made of the trial pit layout (Figure 7.2).
- Summarise the trial pit logs and briefly describe the properties of the materials. Show a detailed borrow pit plan including depths of material horizons in each trial pit.
- State the quantities of overburden and selected materials found in this borrow area. Discuss the implications of having dug the pits to refusal or no refusal on the total quantities expected.
- Give a preliminary appraisal of the quality of construction materials encountered and make recommendations on testing and any precautions that may have to be taken when exploiting the borrow pit.

Conclusions and recommendations

- Summarise the information obtained from the desk study and fieldwork and state whether the objectives of the project as set out in the introduction have been met.
- Make an overall conclusion on quantities, quality and expected difficulties in exploiting the borrow pits. State whether the quantities found are adequate for the project, whether the materials from the various borrow pits are expected to meet the specified properties, whether quality is expected to be marginal, how they could be improved if necessary (e.g. chemical stabilisation and/or mechanical stabilisation).
- Make recommendations on specialised laboratory testing taking into consideration any treatment that could be required such as stabilisation. Make a preliminary borrow pit utilisation plan.

Appendices

Trial pit logs, test results and location and geological maps should be included as appendices.

8.3 Materials inventory

An inventory of materials should be maintained to enable the utilisation of reserves to be monitored and the environment thereby to be protected. The database should include data on source location and field descriptions and should be linked to the laboratory test data.

Materials data being enterred into the materials data inventory bank.

9 REFERENCES

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10 ABBREVIATIONS

BRDM................Botswana Road Design Manual
DCP....................Dynamic Cone Penetrometer
CBR ....California Bearing Ratio
GM ....Grading Modulus
GPS ....Global Positioning System
LL.......................Liquid Limit
MCCSSO ....Moisture, colour, consistency, soil structure, soil texture and origin
N.........................Weinert N-Value
PI ....Plasticity Index
SAC....................Satellite Applications Centre
NORAD ....Norwegian Agency for Devlopment Cooperation
DFID ....Department for International Development
PHN ....Public Highway Network
NPRA.................Norwegian Public Roads Administration
TRL ....Transport Research Laboratory
CSIR...................Counsil for Scientific and Industrial Research
CPP.....................Civil and Planning Partnership
ACE....................Africon Consulting Engineers

11 APPENDICES

APPENDIX 1 - OTHER RELEVANT ORGANISATIONS

APPENDIX 2 - WEATHERING AND WEATHERED MATERIALS

APPENDIX 3 - BOTANICAL INDICATOR SPECIES

APPENDIX 4 - VARIOUS LOGGING FORMS
- Trial pits layout form
- Trial pit logging form

APPENDIX 1 - Other relevant organisations

Addresses of organisations offering advice, services and information:

Organisation	Tel:	Fax:	Address:
Department of Geological Survey, Botswana	330327	332013	Bag 14
	E-mail: Geo @ Global.BW		
Department of Surveying and Mapping	302050	356015	Bag 0037
University of Botswana, Department of Environmental Science - Soils Division - Remote Sensing Division	3552527	585097	
University of Botswana, Depart of Biological Science - Plant Science Botany Division	3552601	585097	
University of Botswana, Department of Geology	3552529	585097	
Botswana College of Agriculture - Plant Science and Botany	3650100	328753	Bag0027
	Web site: www.bca.bw		

APPENDIX 2 - WEATHERING AND WEATHERED MATERIALS

Weathering

Weathering is a general term referring to the breaking down of rocks into smaller particles. The process can involve chemical or physical breakdown, often both. Weathering is a major factor controlling the engineering properties of a rock.

Decomposition is the breakdown of a rock by chemical processes. It acts by the alteration of the minerals making up the rock to new minerals, more stable but weaker.

Decomposition requires moisture for the reactions to take place, and is more active where the climate is warm. Thus, decomposition is most prevalent in the wetter north of the country.

Disintegration is the physical fragmentation of rock into smaller pieces, without significant alteration of the minerals inside.

Disintegration predominates in Botswana in the driest areas, where the daily temperature range is high. Here heating and cooling of the rock surface results in the splitting off of minerals and rock fragments from the rock surface.

Weathering typically results in an accumulation of natural gravel and soil. Natural gravels can usually be ripped or excavated with normal road construction plant, i.e. small to medium bulldozers and excavators, wheel loaders or backhoe loaders

For more information on the effect of rock weathering in potential road construction materials, refer to Weinert (1980).

Weathering, transport, deposition and pedogenic processes give rise to the three main groups of weathered materials - residual, transported and pedogenic.

Residual materials

Residual materials are those formed directly from the breakdown of rocks. The hard particles consist of partially weathered rock fragments and the matrix consists of highly or completely weathered minerals. The factors controlling the characteristics of residual gravels are:

i) Mineral composition of the parent material
Minerals such as plagioclase feldspar and dark minerals are susceptible to weathering. Orthoclase feldspar and dark mica are less so. Quartz and white mica are highly resistant to weathering, and remain intact after all the other minerals have weathered to soil.

ii) Degree of weathering
The rate of weathering of rocks is determined mainly by the annual rainfall and the ambient temperature. In simple terms, the hotter and wetter the climate, the greater is the weathering action upon rock. A moderate amount of weathering reduces small particles to an appropriate proportion of fine material, while leaving larger fragments only slightly weathered and therefore harder.

iii) Degree of fracturing
Fracturing breaks up a rock, allowing weathering to take place along the fracture planes into the body of the rock. The potential for gravel formation depends upon the spacing of the fractures. Unfractured rocks such as sandstones rarely form gravels.

After complete weathering, most rocks are reduced to a fine residue of clays or sandy clays.

Transported gravels

Transported gravels are materials carried by water, wind, ice or gravity and re-deposited. The primary transportation agents in Botswana are wind and water.

The characteristics of transported gravels depend upon many factors, such as the nature of the original material, climate and distance of transportation, which can vary from a few tens of metres to thousands of kilometres. In general, the effects of erosion and redeposition are twofold:

- Unstable minerals weather to stable forms. Transported gravels consist mainly of quartz, mica, silt or clay, in any combination.
- The original constituents become separated into fractions of uniform grain size. An extreme example is the case of desert sands, which tend to be single-sized.

Note that when a rock is partially weathered then rapidly transported and re-deposited, potentially unstable minerals may be preserved. Arkose (sandstone containing feldspars) is one such rock.

The most obvious transported materials are the Kalahari sands, but the most useful transported materials for road construction are the alluvial gravels carried by water and to a lesser extent the colluvial gravels transported by gravity (particularly in the sand-free eastern areas). By the nature of their formation, alluvial gravels are variable, comprising mixtures of the geological materials through which the rivers carrying the gravels have eroded. The particle size gradation within alluvial gravels is mostly a function of the “size” of the river (the faster its velocity, the larger the particles that can be transported) but is also a function of the resistance to abrasion of the material being transported, and the depositional environment.

Pedogenic gravels

Pedogenic gravels or pedocretes are those which have formed by the accumulation in the soil profile of chemical constituents coming in from outside. The chemical environment is such that the deposit becomes less soluble after precipitation and cannot be removed when inundated. It accumulates in the soil as nodules, or vesicular or massive horizons. Compounds of calcium, iron and silica are the chief substances accumulated in this way, giving rise respectively to calcrete (most commonly), ferricrete and silcrete.

The quality of pedogenic gravels as engineering materials is determined by their inherent characteristics, not by current environment or associations. Most have little or no relationship with the rocks upon which they are found, and most formed under a different climate than today. Mapping the distribution of pedogenic gravels is therefore more likely to be successful by the use of terrain classification techniques than by attempting to predict them from current climatic and geological conditions.

The quality of gravel is governed by:

- Hardness of particles, i.e. the hardness of concretionary nodules and of individual lumps after extraction. The shape of these particles can also be important.
- Grading of extracted material.
- Composition and plasticity of the matrix.

Pedocretes dominate in the sandy areas of Botswana. By definition, pedocretes should contain more than 50 per cent of the cementing or replacing material. Where less than 50 per cent of the cementing or replacing material exists, the material will be described as a calcified, silicified or ferruginised soil.

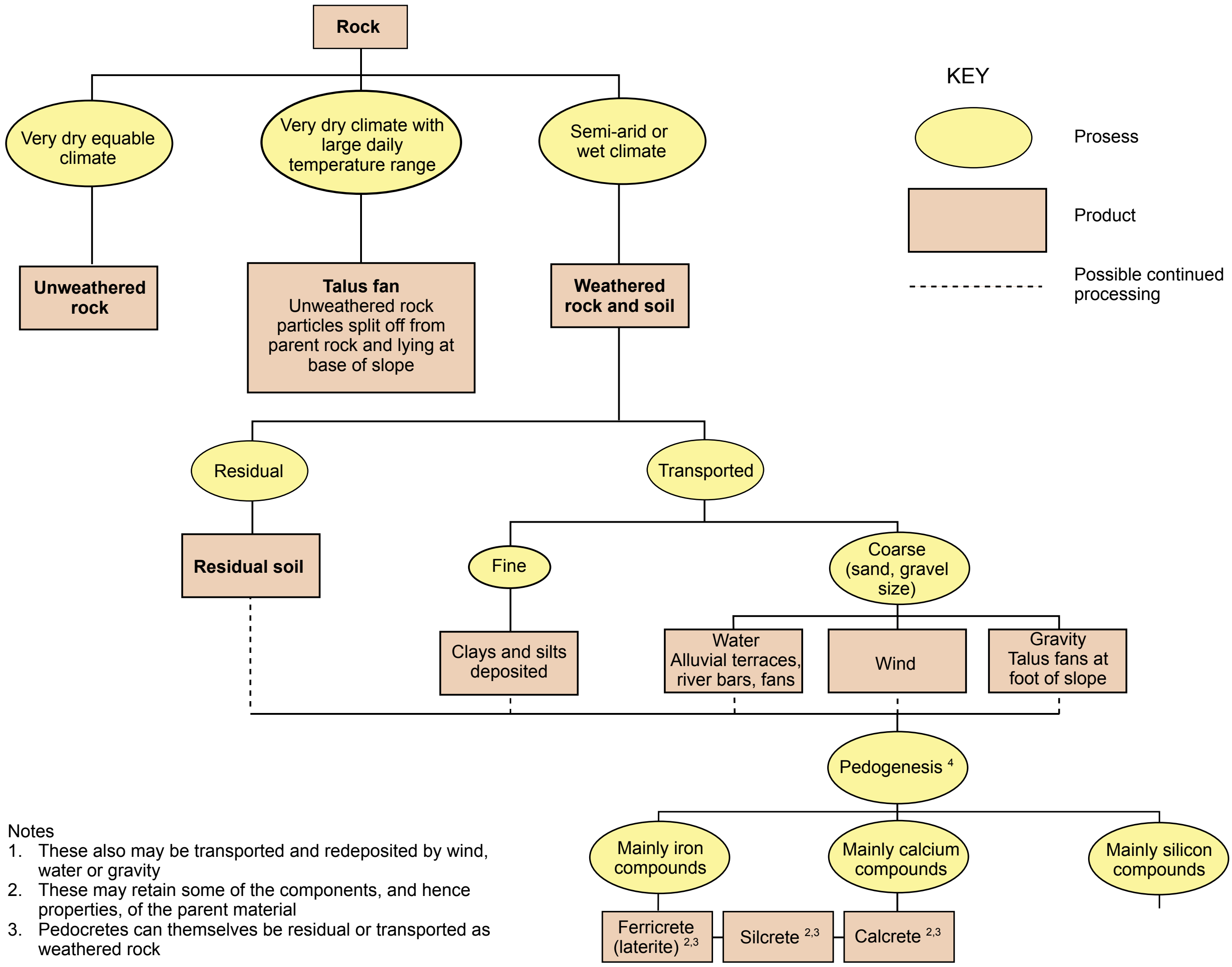
Calcretes form when drainage conditions are favourable - usually associated with ephemeral or seasonal water courses or areas with shallow water tables in arid or semi-arid climates. A necessary characteristic is seasonal fluctuation of precipitation resulting in downward leaching during the wet season and upward capillary suction during the dry season.

The genesis of silcretes is not as simple, with various theories being proposed. The precipitation of dissolved silica from percolating groundwater is generally accepted but the reasons for precipitation differ. Temperature changes and evaporation of ground water near the surface assist with precipitation of shallow silcretes whilst those occurring at greater depths have probably resulted from pH changes in the groundwater.

Ferricretes need at least a subhumid climate where chemical decomposition can release the necessary iron from the parent rock. Ferricretes usually occur at gully-heads, hillslope-pediment junctions and on pan side slopes and are associated with other areas of impeded drainage.

Origin of weathering products

The diagram in Figure A2.1 shows how the geomorphological agents of climate, parent material, transportation and pedogenesis give rise to the main types of natural gravels occurring in Botswana.



Notes
1. These also may be transported and redeposited by wind, water or gravity
2. These may retain some of the components, and hence properties, of the parent material
3. Pedocretes can themselves be residual or transported as weathered rock

Figure A2.1 Geomorphological processes and their products

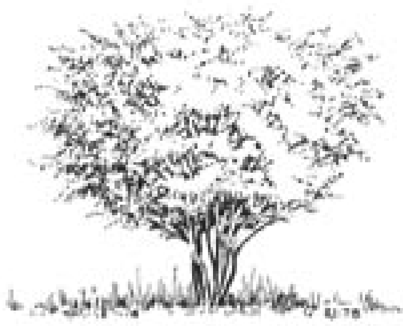
APPENDIX 3 - Guide to the identification of botanical indicators

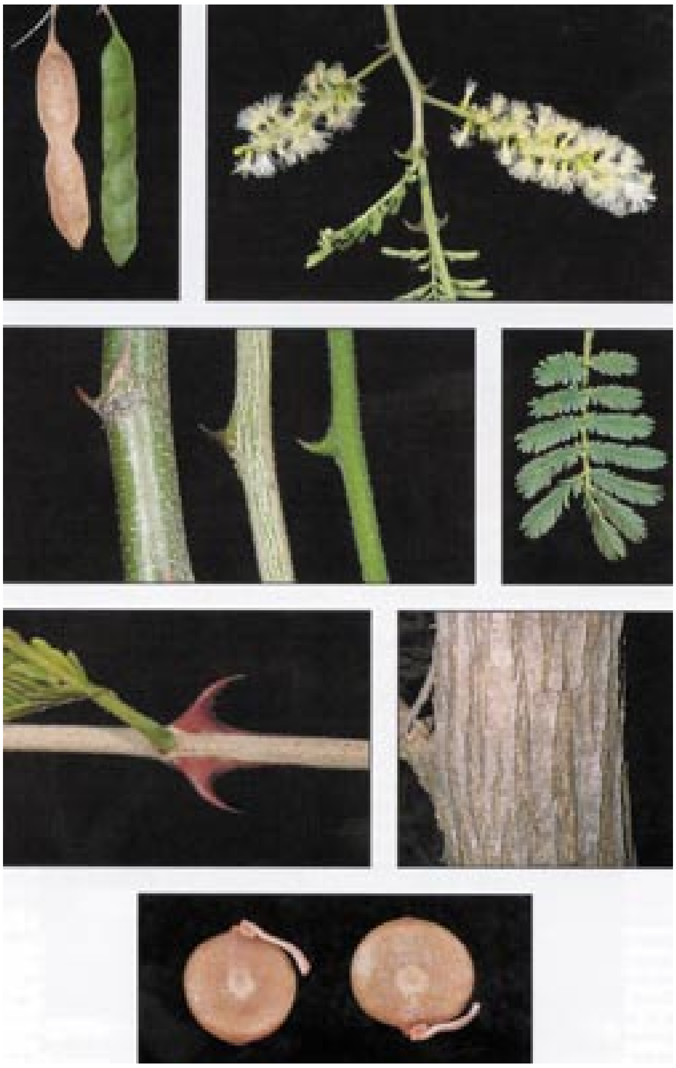
CONTENTS

Acacia fleckii Schinz
Blade thorn, Mokala/Mohahu
SA No 165

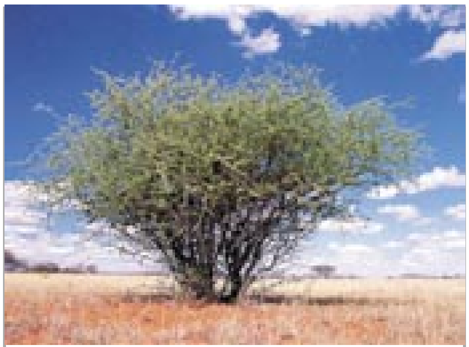
Acacia fleckii Schinz
Blade thorn, Mokala/Mohahu
SA No 165

Indicator of:	Calcrete.
General:	Shrub with many stems or a small tree with a flattened crown.
Habitat:	Dry areas, scrub, Kalahari sands.
Leaves:	8 to 16 pairs of pinnae, 9 to 30 pairs of leaflets per pinna.
Flowers:	Elongate yellow-white; flowering time midsummer.
Bark:	Yellowish to grey, papery and flaking.
Thorns:	In pairs below the nodes, dark coloured, and broad based, strongly recurved.
Fruit:	Light brown, dehiscent.
Reference:	Davidson and Jeppe, 1981; Coates-Palgrave, 1977, Smit, 1999.





Acacia mellifera sub-species detinens (Vahl) Benth
Hook thorn, Mongana
SA No 176



Indicator of: Calcrete.

General: Shrub or small tree up to 6 m high with spreading flat crown, very thorny, forming dense thickets. Young branches are greyish-brown to purplish-black.

Habitat: Dry thornveld, bushveld, Kalahari sands.

Leaves: 3 pairs of pinnae, 1 to 2 pairs of leaflets per pinna, leaflets large, petiolar gland usually present.

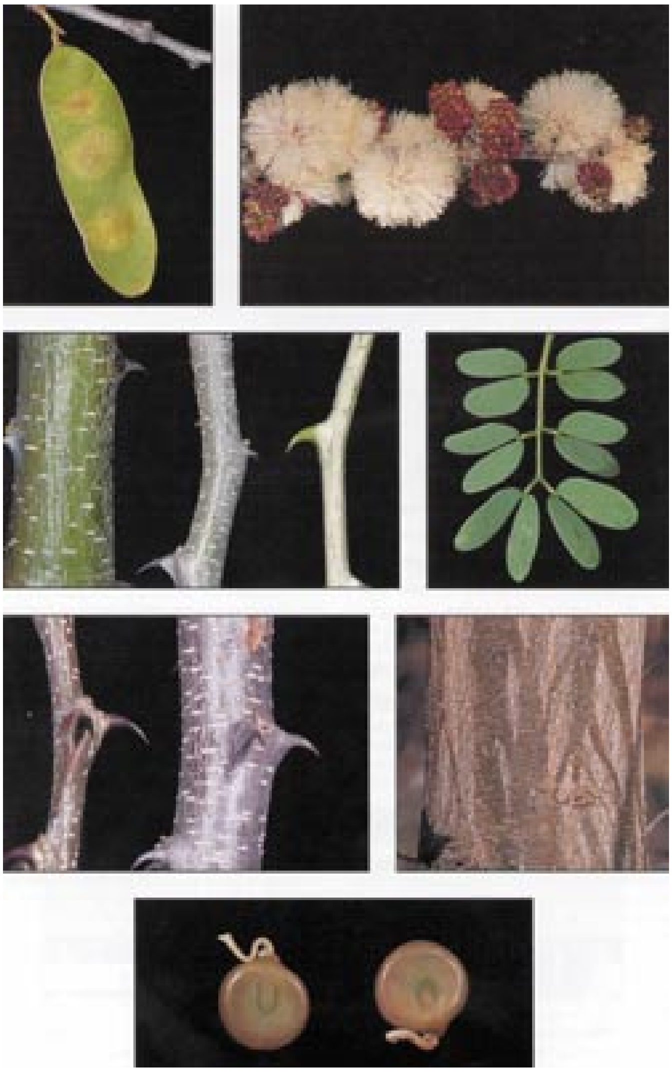
Flowers: Elongate creamy-white sweet scented especially towards evening; flowering time spring.

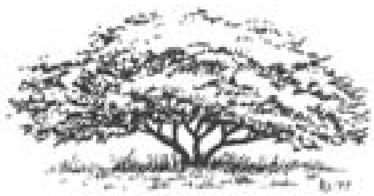
Bark: Red.

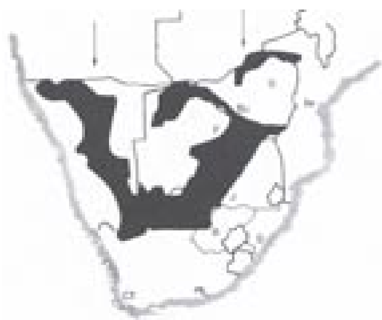
Thorns: In pairs below each node, blackish and, strongly recurved.

Fruit: Flat, papery, straw coloured to brown, dehiscent.

Reference: Davidson and Jeppe, 1981; Coates-Palgrave, 1977, Smit, 1999.





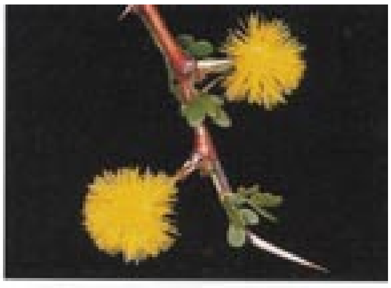


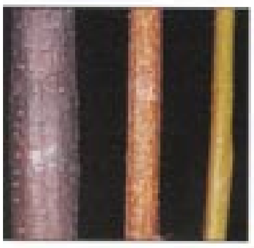
Acacia nebrownii Burtt Davy

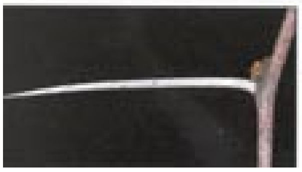
Water acacia, Orupunguya

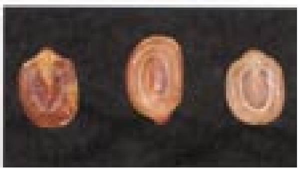
SA No 177.1

Indicator of:	Calcrete.
General:	Usually a shrub with slender stems but may be a small tree.
Habitat:	Low lying areas and along banks of dry watercourses.
Leaves:	Usually a single pinna pair, 3 to 5 pairs of leaflets per pinna. Raised gland present at the base of the pinna pair.
Flowers:	Globose golden-yellow, sweet-scented, solitary or in groups. Flowering time September to October.
Bark:	Reddish. Young branches yellowish with numerous dark glands.
Thorns:	Spinescent in pairs. Slender white, dark at tips.
Fruit:	Light brown, slightly to strongly curved, dehiscent, numer ous dark glands scattered over the surface.
Reference:	Davidson and Jeppe, 1981; Coates-Palgrave, 1977, Smit, 1999.





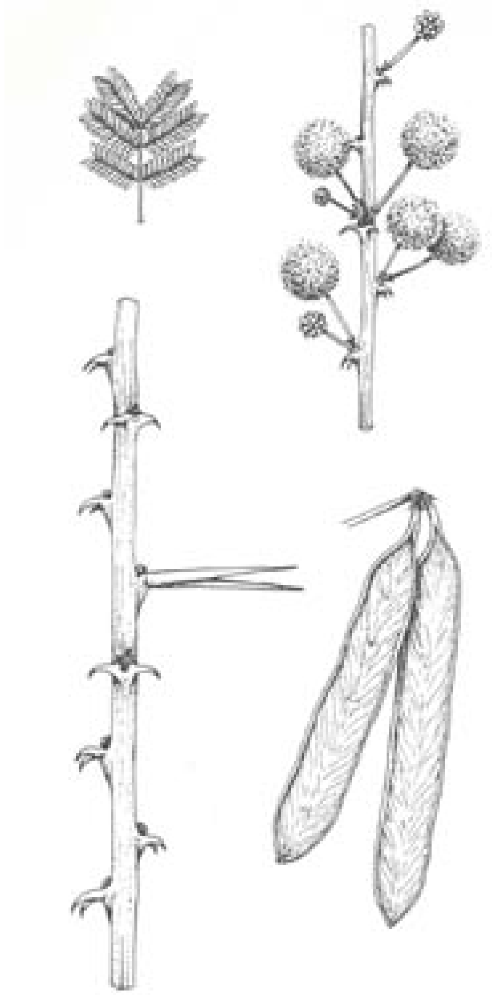


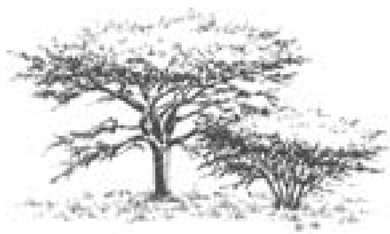


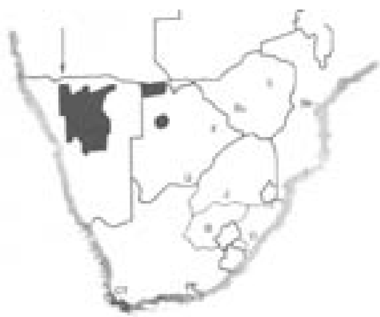
Acacia reficiens Wawra

False umbrella thorn
SA No 181

Indicator of:	Calcrete.
General:	Shrub or tree up to 6 m high with a spreading crown.
Habitat:	Dry watercourses, scrubland and occasionally on brackish soils.
Leaves:	1 to 4 pinnae pairs, 7 to 11 pairs of leaflets per pinna; petiolar gland if present near basal pinnae, small glands at bases of pinnae sometimes present.
Flowers:	Globose yellowish-white, usually grouped together; involucel near base of peduncle. Flowering time late summer.
Bark:	Grey or brown to black, rough and fissured.
Thorns:	Spinescent in pairs, short and recurved and occasionally a few long straight greyish spines.
Fruit:	Brown to reddish-brown, brittle, dehiscent, longitudinally veined.
Reference:	Davidson and Jeppe, 1981; Coates-Palgrave, 1977.





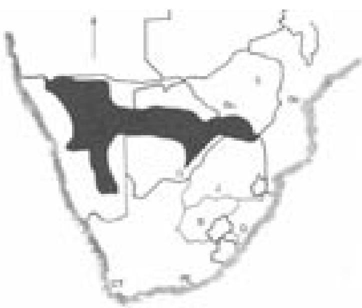


Catophractes alexandri D. Don

Trumpet thorn

SA No 676.1

Indicator of:	Calcrete.
General:	An erect spiny shrub or small tree, 1 to 3 m in height.
Habitat:	Occurs in very arid country, often on limestone (calcrete) ridges and outcrops, sometimes forming pure communities.
Leaves:	Opposite or fascicled along the stem; simple; oblong; 2 to 4 x 1 to 2.5 cm, covered with dense grey wooly hairs, giving the whole plant a pale grey appearance.
Flowers:	Showy, pure white, sometimes tinged with pink, with a yellow throat; about 5 cm in diameter; axillary; solitary; sweet smelling. Flowering time soon after rain, intermittently throughout the year.
Bark:	Shiny brown.
Thorns:	Slender very sharp spines up to 5 cm long arising above the leaves.
Fruit:	Thickly woody elliptic capsule, 5 x 2.5 cm, rather flattened, becoming grey and finally dark brown when mature; warty; finally dehiscing along the flat faces to release many papery winged seeds.
Reference:	Coates-Palgrave, 1977, Van Wyk and Van Wyk, 1977.



Combretum imberbe Wawra

Leadwood, Motswere

SA No 539

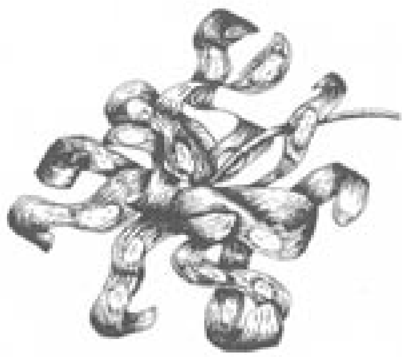
Indicator of:	Calcrete.
General:	Occasionally a shrub, but usually a small to large tree 7 to 15 m in height.
Habitat:	Occurs at medium to low altitudes, in mixed woodland, often along rivers or dry watercourses, particularly on alluvial soils.
Leaves:	Small obovate to oval, 2.5 to 8 x 1 to 3 cm, very character istically grey-green, giving the whole tree a greyish appearance (except when heavy in fruit), often produced on short spinescent lateral shoots, thinly textured to rather leathery, without hairs, but with silvery, microscopic scales densely covering both surfaces; apex broadly tapering; margin entire, often wavy;, petiole 4 to 10 cm long.
Flowers:	Cream to yellow, sweetly scented, in rather slender spikes, 4 to 8 cm long, in the axils of the leaves, or sometimes forming a terminal head. Flowering time November to March.
Bark:	Dark grey to almost black and rough with characteristic deep longitudinal furrows and irregular traverse cracks.
Thorns:	Not present.
Fruit:	4-winged, about 1.5 x 1.5 cm, densely covered with silvery scales, characteristically pale yellowish-green even when mature, giving the tree a distinctive appearance, drying to a light brown; sometime persisting into the next flowering season. Fruiting time February to June or on to December.
Reference:	Coates-Palgrave, 1977.

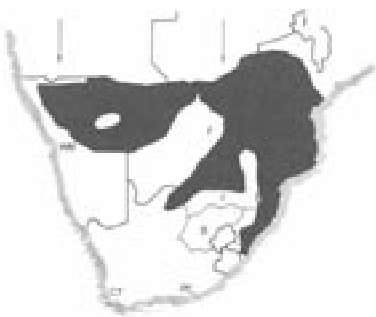
Dichrostachys cinera (L) Wight and Arn

Sickle bush, Moselesele

SA No 190

Indicator of:	Calcrete.
General:	A shrub or small acacia like tree 5 to 6 m in height.
Habitat:	Grows on a variety of soils, more common at low altitudes. It often forms secondary bush on impoverished ground.
Leaves:	Compound paripinnate, with 4 to 13 pairs of pinnae, each carrying up to 27 pairs of leaflets; leaflets narrowly obovate to lanceolate, up to 10 x 3 mm, dark green rather glossy above but dull below; glands are conspicuous on the petiole and on the rachis.
Flowers:	In axillary spikes, all floral parts in fives; stamens in 2 whorls of 5; the spike is clearly two coloured, half the spike being formed by long, slender, pink, sterile staminodes, and the other half formed by the fertile flowers-this section forms a short, very compact yellow catkin; the whole flower spike droops and hangs upside down on the tree, so the pink section is seen above the yellow section. The pink colour varies considerably from almost white to mauve and bright pink, in different areas, between trees in the same area, and even on the same tree. Flowering time October to January.
Bark:	Dark grey-brown, the stems often twisted and seamed and the branches intertwined, giving a thick matted appearance.
Thorns:	Dwarf lateral shoots are modified to form short compact spines.
Fruit:	A cluster of pods each up to 10 x 1 cm, twisted and contorted, indehiscent, falling from the tree and rotting on the ground. Fruiting time May to September.
Reference:	Coates-Palgrave, 1977.

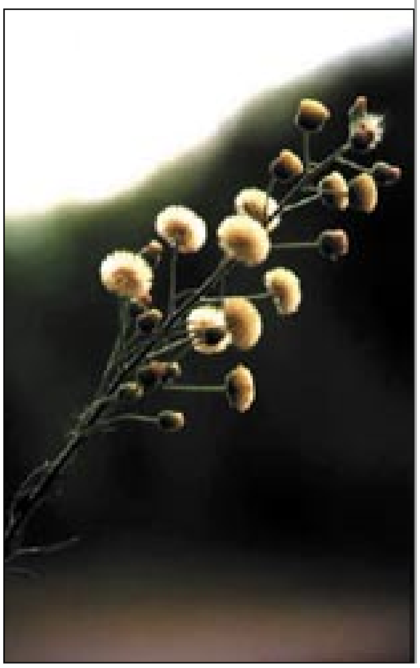




Eriocephalus ericoides Druce
Snowbush, Lewisi
SA No 9320

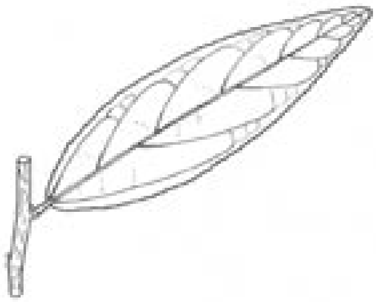
Indicator of:	Calcrete.
General:	Multi-stemmed woody shrub 0.5 to 1 m high.
Leaves:	Dark green, 3 to 5 x 0.3 cm, covered in fine silvery hairs, linear, twisted, apex tapering, base rounded; petiole very short or not present.
Flowers:	Small, red, inconspicuous. Flowering time June to July.
Bark:	
Thorns:	Not present.
Fruit:	Ripe seed covered by soft white fluff.

Reference:



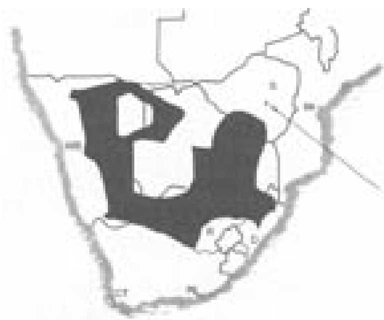
Grewia bicolor Juss
False brandybush, Mogwana
SA No 458

Indicator of:	Calcrete.
General:	Usually a many-stemmed shrub, occasionally a small tree up to 7 m in height.
Habitat:	Occurs most frequently in dry, deciduous woodland at low altitudes, on sandy flats and rocky mountain slopes.
Leaves:	Elliptic to elliptic-oblong or lanceolate, 1.5 to 7 x 1 to 3.5 cm, dark dull green above, almost silvery-white with fine hairs below; the leaves are held horizontally or slightly drooping; apex tapering to rounded; base broadly tapering to rounded, asymmetric, or almost symmetric; margin finely toothed; petiole very short.
Flowers:	Yellow, about 1.5 cm in diameter, axillary, often produced in profusion. Flowering time October to January.
Bark: old	Dark grey, deeply fissured and peeling away in strips in specimens, grey to reddish-grey and smooth when young.
Thorns:	Not present.
Fruit:	Single or 2-lobed, each lobe about 6 mm in diameter, reddish-brown when mature. Fruiting time March to June.
Reference:	Coates-Palgrave, 1977, Van Wyk and Van Wyk, 1977.



Grewia flava DC
Brandybush, Morêtlwa
SA No 459.1

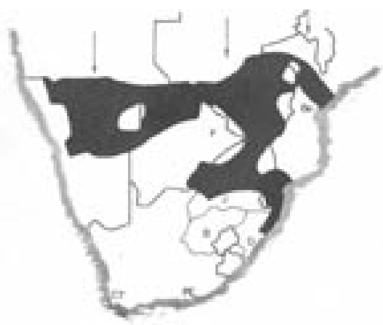
Indicator of:	Calcrete.
Habitat:	Occurs in dry, deciduous woodland and bushveld.
General:	A compact shrub or small tree up to 4 m in height.
Leaves:	Elliptic or oblanceolate, 2 to 7 x 1 to 3 cm, greyish-green and very finely hairy above, more densely hairy and quite markedly paler green below; net veining conspicuous; apex rounded; base tapering; margin toothed; petiole up to 2 mm long.
Flowers:	Yellow, about 1.5 cm in diameter, in short branched axil lary heads; the sepals are yellow and contribute largely towards the colour of the flowers. Flowering time October to March.
Bark:	Dark grey-brown.
Thorns:	Not present.
Fruit:	Almost spherical, usually 2-lobed, about 8 mm in diameter. Red-brown when mature. Fruiting time December to April.
Reference:	Coates-Palgrave, 1977, Van Wyk and Malan, 1988



Grewia flavescens Juss

Donkeyberry, Mokgamphatha
SA No 459.2

Indicator of:	Calcrete.
General:	A shrub with a tendency to scramble, or a small shruby tree up to 5 m in height.
Habitat:	Occurs at medium to low altitudes, in open woodland, frequently on termite mounds, on rocky koppies, in riverine fringes and at the margins of forest patches.
Leaves:	Oblanceolate to obovate, 4 to 12 x 2 to 9 cm; light green; stellate hairs on both surfaces, but especially on the under surface which is markedly rough to the touch; apex tapering; base rounded to lobed, almost symmetric; margin irregularly but markedly toothed; petiole up to 7 mm long, hairy. Stipules up to 10 mm long, oblong, hairy but falling early.
Flowers:	Yellow, about 2 cm in diameter, sometimes fragrant, axillary, usually in threes on short stalks, or peduncles, up to 1.5 cm long. Flowering time December to March.
Bark:	Dark grey-brown with fluted ridges; the trunk and larger branches are square.
Thorns:	Not present.
Fruit:	Shallowly furrowed, 2-lobed, each lobe 8 to 14 mm in diameter. Shiny yellowish-brown when mature, with sparse long, white hairs. Fruiting time July to August.
Reference:	Coates-Palgrave, 1977, Van Gogh and Anderson, 1988.



Maytenus senegalensis (Lam) Exell.
Confetti tree, Mothono
SA No 402

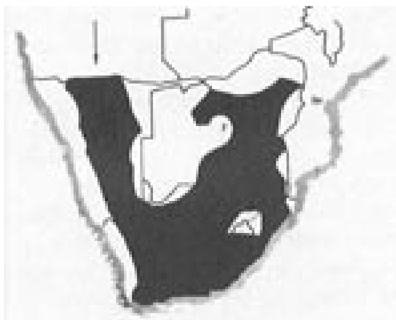
Indicator of:	Calcrete.
General:	A shrub or small tree, usually 3 to 5 m in height, but reaching 9 m on occasions.
Habitat:	Occurs on a wide variety of habitats, particularly common to open woodland, often on termite mounds, but found also in riverine fringe thicket and at the margins of vleis.
Leaves:	Alternate or fascicled, oblong to obovate, 2 to 12 x 4 to 6 cm, pale blue-green with a whitish or grey bloom, the petiole and midrib frequently pink tinged, thick and leathery in texture, veining not conspicuous; apex rounded, often notched; base tapering, margin with shallow, rather rounded teeth, or scalloped; petiole short.
Flowers:	Cream, white or greenish-white, 4 to 6 mm in diameter, in dense axillary clusters about 4 cm in diameter, often sweetly scented, produced in profusion. Flowering time May to June, but may be found from March to December.
Bark:	Light grey, smooth.
Thorns:	Rigid spines up to 4 cm long.
Fruit:	A 2-lobed capsule, 2 to 6 mm in diameter, greenish with a red flush when mature, occasionally becoming reddish-brown; seeds with yellowish or pinkish arils. Fruiting time October, but may occur from July to January.
Reference:	Coates-Palgrave, 1977.

Pechuel-loeschea leubnitziae Kuntze
Bitterbush, Motlalemetsi/Mokudi
SA No

Indicator of:	Calcrete.
General:	Pungently aromatic shrubby perennial up to 1.3 m high.
Leaves:	Sessile or subsessile, up to 4.5 x 0.7 cm, very narrowly elliptic to elliptic or very narrowly obovate-elliptic; apex acute; base cuneate; margin entire; midrib prominent on both sides, appressed grey-pubuscent on both sides.
Flowers:	Capitula 1 to 3 in the axils of the leaves or at the ends of the branchlets, 1 cm wide x 1.3 cm long, funnel shaped to campanulate, sessile or on pubescent peduncles up to 3 mm long.
Bark:	Older branches woody, glabrescent, younger densely glan dular-pubescent, striate.
Thorns:	Not present.
Fruit:	None.

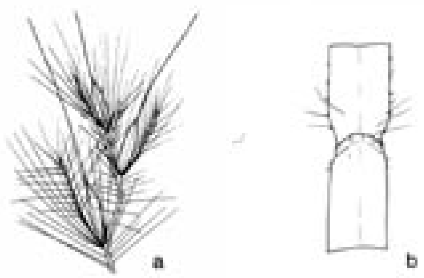
Tarchonanthus camphoratus L
Camphor bush, Mohatlha
SA No 733

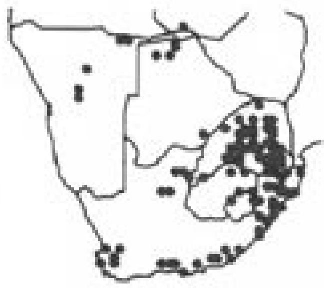
Indicator of:	Calcrete.
General:	A shrub or small tree up to 9 m in height.
Habitat:	Occurs in a wide variety of habitats.
Leaves:	Narrowly oblong to elliptic, 1.3 to 15 x 1 to 4 cm, leathery, green to grey-green above, pale greyish-white and velvety below; fine net veining is visible on both surfaces; glandular; apex tapering to narrowly rounded; base tapering; margin entire to finely toothed; petiole 1 to 7 mm long.
Flowers:	Thistle form, individual flowers creamy-white, grouped into 3 to 5 flowered capitula, about 1 cm long, in terminally leafed branched sprays up to 9 x 5 cm, more or less covered with white woolly hairs. Flowering time April to June but also sporadic throughout the year.
Bark:	Brownish-grey, rough; all parts have a strong smell of camphor.
Thorns:	Not present.
Fruit:	A small nutlet, covered with white woolly hairs, the heads resembling balls of cotton wool, about 12 x 9 cm. Fruiting time June to December, but also sporadic throughout the year.
Reference:	Coates-Palgrave, 1977.



Andropogon eucomus Nees
Snowflake grass
SA No

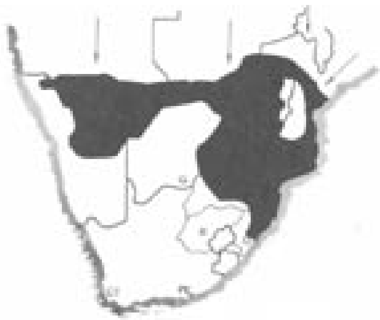
Indicator of:	Ferricrete.
General:	Perennial grass; densely tufted; 200 to 900 mm tall.
Habitat:	Common occurrence in Fynbos, Savanna and Grassland Biomes.
Leaves:	Leaf blades 40 to 200 mm long; to 4 mm wide. Spikelets 2 to 3 mm long (all sessile, accompanied by a hairy empty pedicel.
Flowers:	Inflorescence plumose, of 2 to 6 flowering branches; racemes 2 to 5 per spathe, with white silky hairs twice as long as the spikelets; lower glume of sessile spikelets deeply and narrowly grooved. Flowering time November to May.
Reference:	Gibbs Russell et al, 1990, Van Wyk and Malan, 1988.





Combretum apiculatum Sonder
Red bushwillow, Mohudiri
SA No 532

Indicator of:	Ferricrete.
General:	A small to medium sized tree, 3 to 10 m in height, occasionally bushy and shrub-like.
Habitat:	Occurs at medium to low altitudes in dry open woodland.
Leaves:	Opposite, narrowly to broadly obovate-elliptic, oblong or broadly ovate, 3 to 13 x 1.5 to 8 cm, thinly leathery, young leaves sticky and glutinous with a varnished shine, without hairs or with dense to sparse hairs on both surfaces, some times with rusty microscopic, transparent, thin-walled scales present; apex abruptly attenuate, forming a slender tip, often twisted; base rounded to slightly lobed; margin entire, wavy; petiole up to 10 mm long.
Flowers:	Yellow to creamy-green, heavily scented, in axillary spikes up to 7 x 1.5 cm. Flowering time September to February.
Bark:	Grey to dark grey or brownish-grey, smooth becoming scaly and rough with age.
Thorns:	Not present.
Fruit:	4-winged, 2 to 3 x 1.5 to 2.5 cm, reddish-brown when mature, with a satiny sheen and possibly soft hairs, at least on the body. Fruiting time January to May.
Reference:	Coates-Palgrave, 1977, Van Gogh and Anderson, 1988.



Stoebe vulgaris Levyns
Bankrotbos
SA No

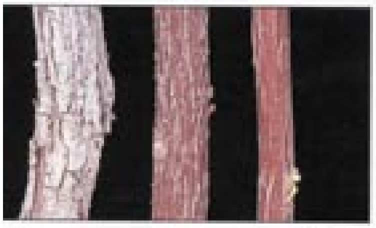
Indicator of:	Ferricrete.
General:	Intricately branched, grayish perennial shrublet approximately 1 m high. Branches slender and wiry with numerous tufts of small, heath-like leaves.
Habitat:	Widespread, occurs in grassland, proliferating in over grazed areas.
Leaves:	Linear, 4 x 0.5 mm. Upper surfaces covered with white wooly hairs. Often pungent.
Flowers:	Flower heads minute, surrounded by brownish-yellow inner involucral bracts; arranged in large panicles. Flowers inconspicuous, purple tipped. Characteristic globose galls covered with white woolly hairs are usually present and frequently mistaken for the flower heads. Flowering time March to May.
Bark:	Stems more or less woolly.
Thorns:	Not present.
Fruit:	None.
Reference:	Van Wyk and Malan, 1988.

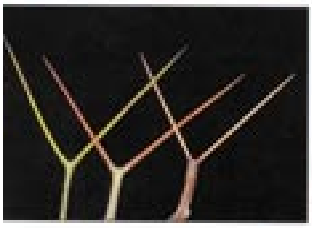
Acacia haematoxylon Willd.

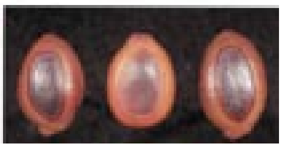
Grey camel thorn, Mokholo
SA No 168.1

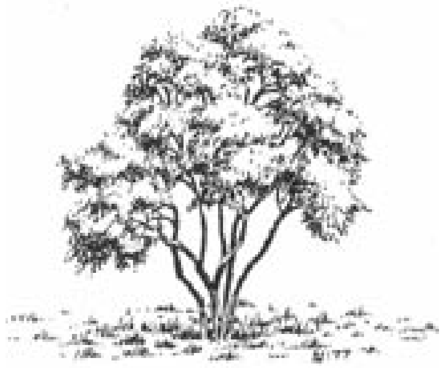
Indicator of:	Deep sand.
General:	A shrub or small tree up to 6 m high.
Habitat:	Characteristic of desert and semi-desert areas, often occurring on deep red sandy soils.
Leaves:	Grey to grey-green, all parts densely covered with fine grey hairs, each pinna superficially resembling a single leaflet as leaflets are extremely small and difficult to distinguish from each other; petiolar gland usually absent, yellow glands present at bases of some lower and upper pinnae pairs.
Flowers:	Globose bright golden-yellow. Flowering time November to February.
Bark:	Grey-brown, branchlets often densely velvety grey.
Thorns:	Spinescent in slender pairs.
Fruit:	Densely velvety, grey with dark glands, curved, may be constricted between the seeds, indehiscent.
Reference:	Davidson and Jeppe, 1981; Coates-Palgrave, 1977, Smit, 1999.





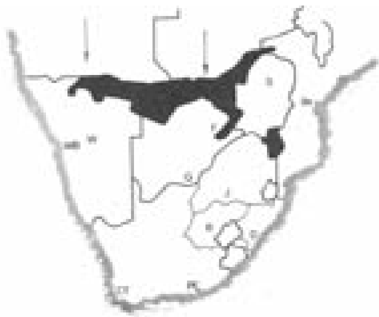




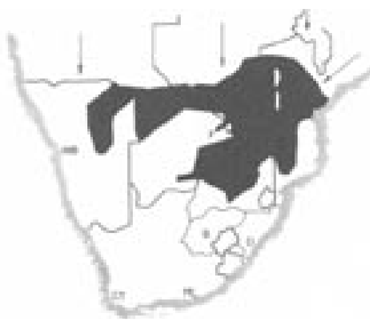
Baphia massaiensis Taub.
Sand camwood,
SA No 223

Indicator of:	Deep sand.
General:	Shrub to small tree, usually 2 to 4 m in height, but reaching 6 m on occasions.
Habitat:	Occurs on deep Kalahari sand.
Leaves:	Simple, obovate, 4 to 9 x 9 to 5.5 cm, dull green above and pale green below, with 6 to 10 conspicuous lateral veins especially on the under surface, the leaf often being folded inwards along the midrib; apex broadly tapering to rounded and notched; base tapering; margin entire; petiole with 2 distinct swellings.
Flowers:	Attractive, white, in short sprays 5 to 8 cm long. Flowering time October to January.
Bark:	Dark brown to reddish-black and smooth; branchlets often velvety.
Thorns:	Not present.
Fruit:	Long (up to 12 cm), narrow pod; hard, rather woody, reddish-brown to dark shiny brown, splitting when mature. Fruiting time April to May.
Reference:	Coates-Palgrave, 1977.



Burkea africana Hook
Red Syringa, Monato
SA No 197

Indicator of:	Deep sand.
General:	A medium sized tree, 8 to 10 m in height.
Habitat:	Occurs in various types of woodland over a wide range of altitudes and habitats, but most characteristic of the hot, low-lying areas.
Leaves:	Crowded at the end of the branchlets; bipinnate with two pairs of pinnae and 5 to 9 alternate leaflets per pinna; leaflets elliptic, 3 to 6 x 1.5 to 3 cm, grey-green to dark green, with silvery apressed hairs when very young, losing these later; apex rounded and notched; base oblique; margin entire.
Flowers:	Creamy-white, about 5 mm in diameter, produced in long graceful, pendulous spikes up to 24 cm long, crowded near the end of the branchlets. Flowering time September to November, often appearing before the leaves, giving the tree a showy, shaggy white appearance.
Bark:	Dark grey, rough and flaking. Young shoots and tips to young branches densely velvety and rusty-red to maroon. This can extend along the leaf petioles.
Thorns:	Not present.
Fruit:	A thin, flat pod, about 8 x 2.5 cm, pale brown, indehiscent, hanging in conspicuous clusters from the ends of the branches. Fruiting time February to July, but remaining on the tree for months, frequently until after the leaves have fallen at the end of the season.
Reference:	Coates-Palgrave, 1977.



Terminalia sericea Burch. Ex DC.

Silver terminalia, Mogonono

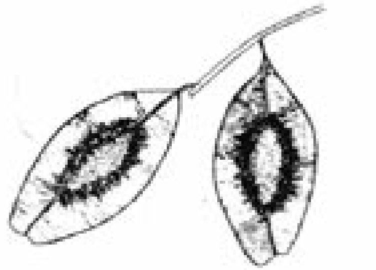
SA No 551

Indicator of: Deep sand.

General: Small to medium sized well-shaped tree, usually 4 to 6 m in height but occasionally reaching 10 m.

Habitat: Occurs in open woodland, frequently on sandy soils and often at vlei margins, locally very common, even dominant or co-dominant.

Leaves: Clustered towards the tips of the slender branchlets; narrowly obovate-elliptic, 5.5 to 12 x 1.5 to 4.5 cm, pale green, covered with silvery silky hairs which give a characteristic sheen, lateral veins obscure; apex broadly tapering to rounded; base narrowly tapering; margin entire; petiole up to 10 mm long.



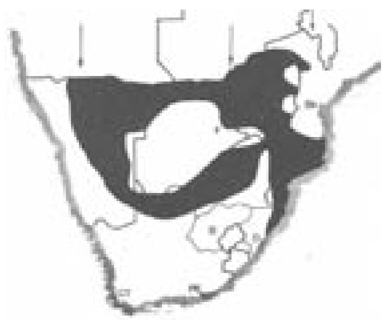
Flowers: Small, cream to pale yellow, heavily and rather unpleasantly scented, in axillary spikes up to 7 cm long. Flowering time September to January.

Bark: Dark grey or brownish and deeply vertically fissured; the slender branchlets dark brown or purplish, peeling and flaking in rings and strips exposing light brown underbark; young stems are often parasitised and, as a result, bear round galls often up to 2 to 3 cm in diameter frequently with leaves growing from them.

Thorns: Not present.

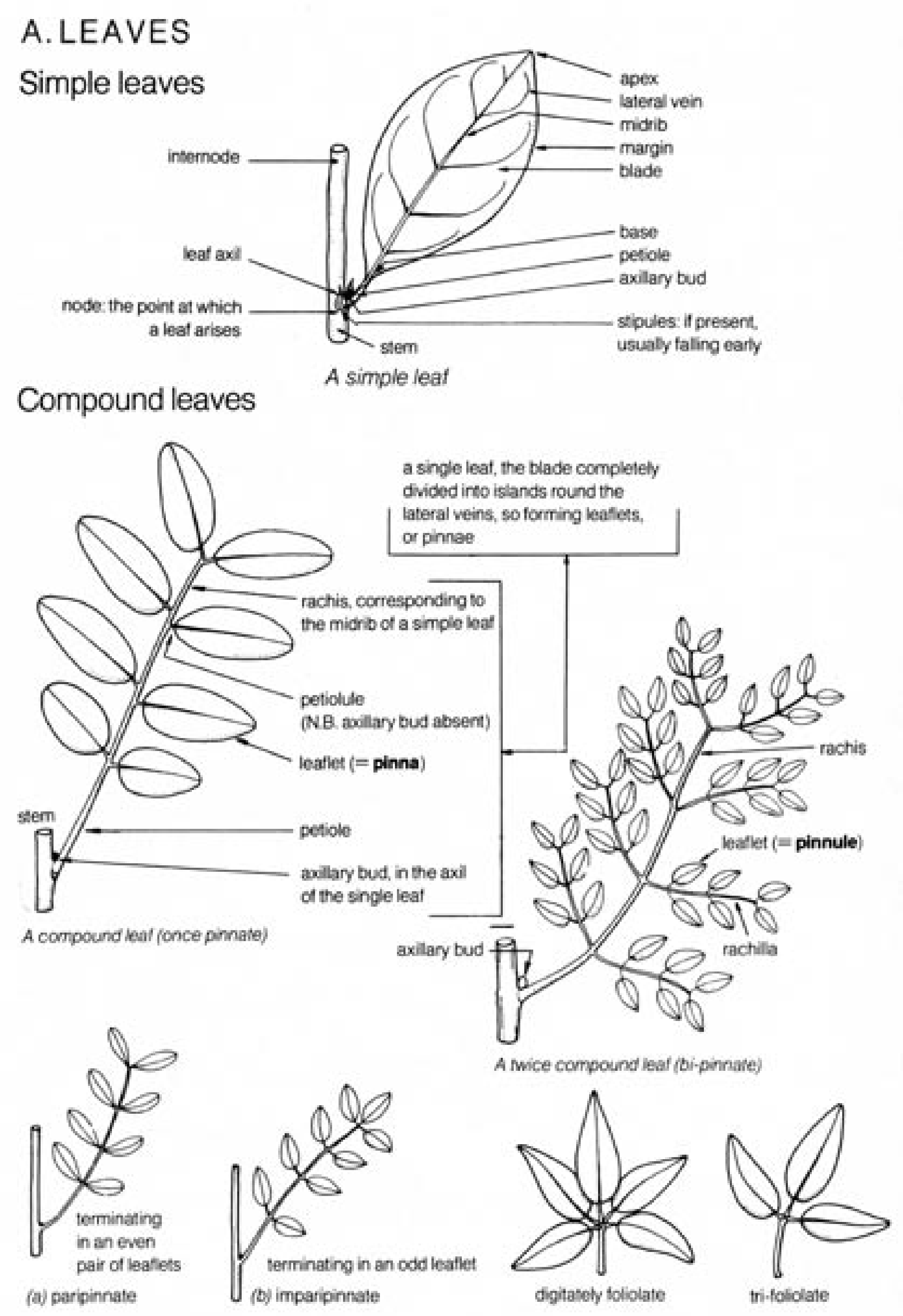
Fruit: 2.5 to 3.5 x 1.5 to 2.5 cm, pink to rose-red when mature, drying to reddish-brown. Fruiting time January to May, but they remain on the tree almost until the next flowering season.

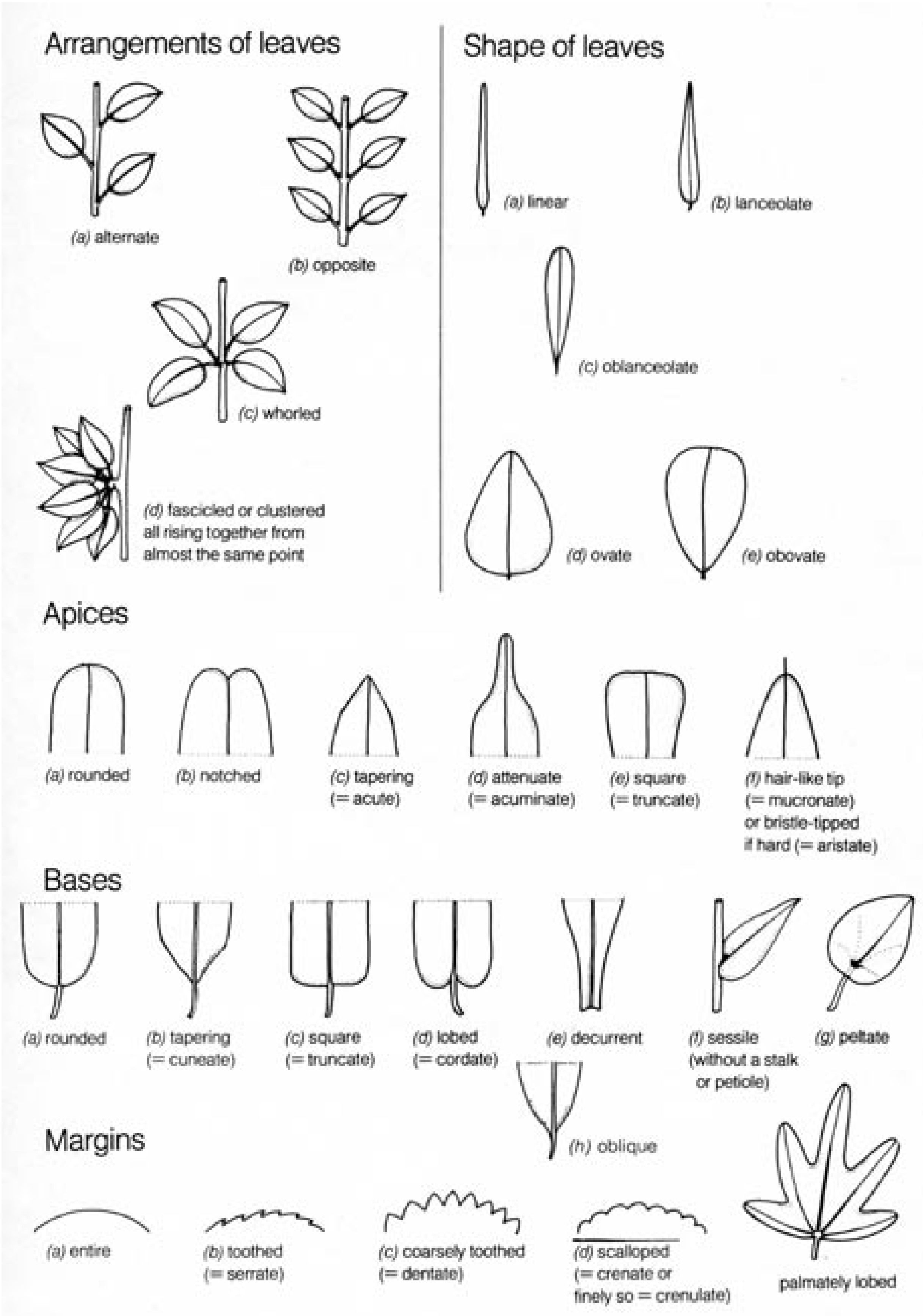
Reference: Coates-Palgrave, 1977.



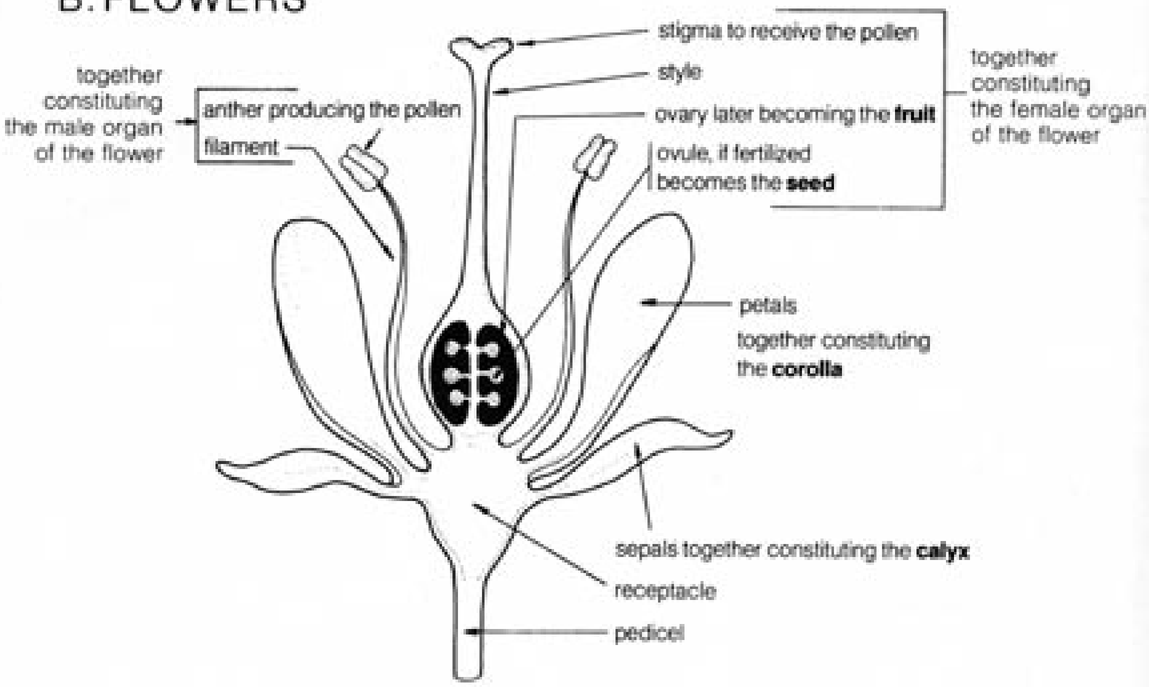
GLOSSARY

(Source: Coates-Palgrave, 1977)




Arrangements of leaves
(a) alternate
(b) opposite
(c) whorled
(d) fascicled or clustered all rising together from almost the same point
Shape of leaves
(a) linear
(b) lanceolate
(c) oblanceolate
(d) ovate
(e) obovate
Apices
(a) rounded
(b) notched
(c) tapering (= acute)
(d) attenuate (= acuminate)
(e) square (= truncate)
(f) hair-like tip (= mucronate) or bristle-tipped if hard (= aristate)
Bases
(a) rounded
(b) tapering (= cuneate)
(c) square (= truncate)
(d) lobed (= cordate)
(e) decurrent
(f) sessile (without a stalk or peticle)
(g) peltate
(h) oblique
Margins
(a) entire
(b) toothed (= serrate)
(c) coarsely toothed (= dentate)
(d) scalloped (= crenate or finely so = crenulate)
palmately lobed

B. FLOWERS

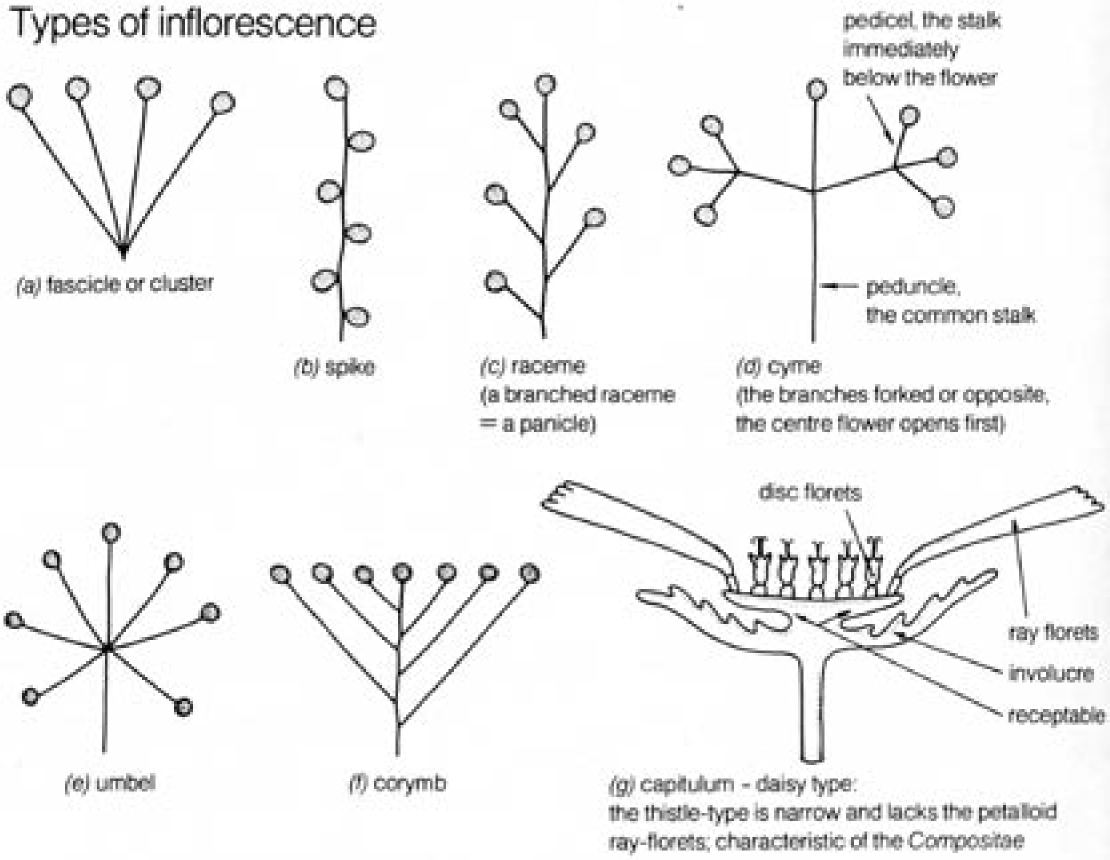


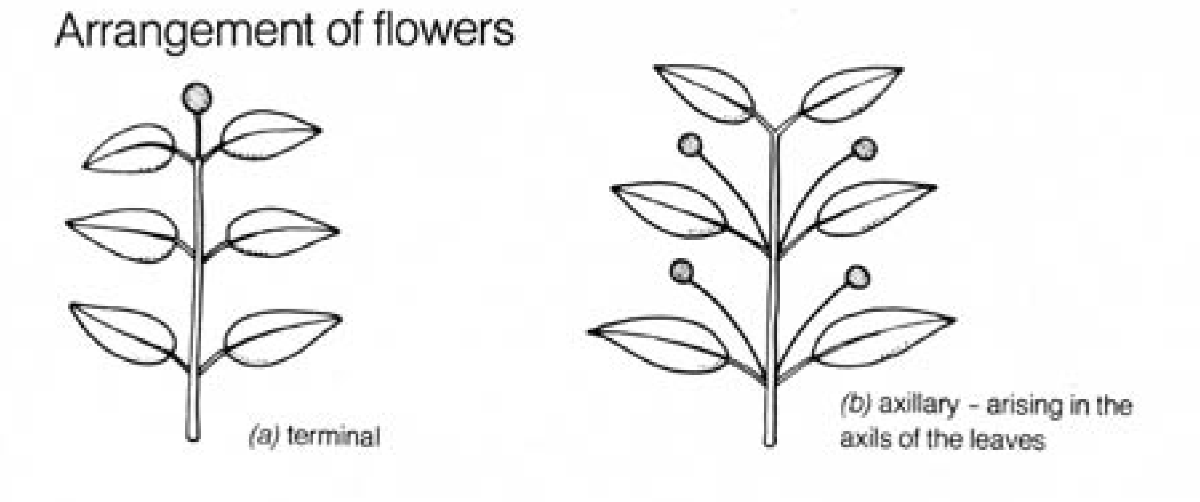
Diagrammatic section through a flower

Inflorescence

A group of flowers together forming a definite structure

Types of inflorescence





Other terms

Dehiscent: splitting to shed seeds.

Glabrous: without hairs.

Globose: spherical, rounded.

Glutinous: sticky.

Indehiscent: not splitting.

Inflorescence: flower cluster.

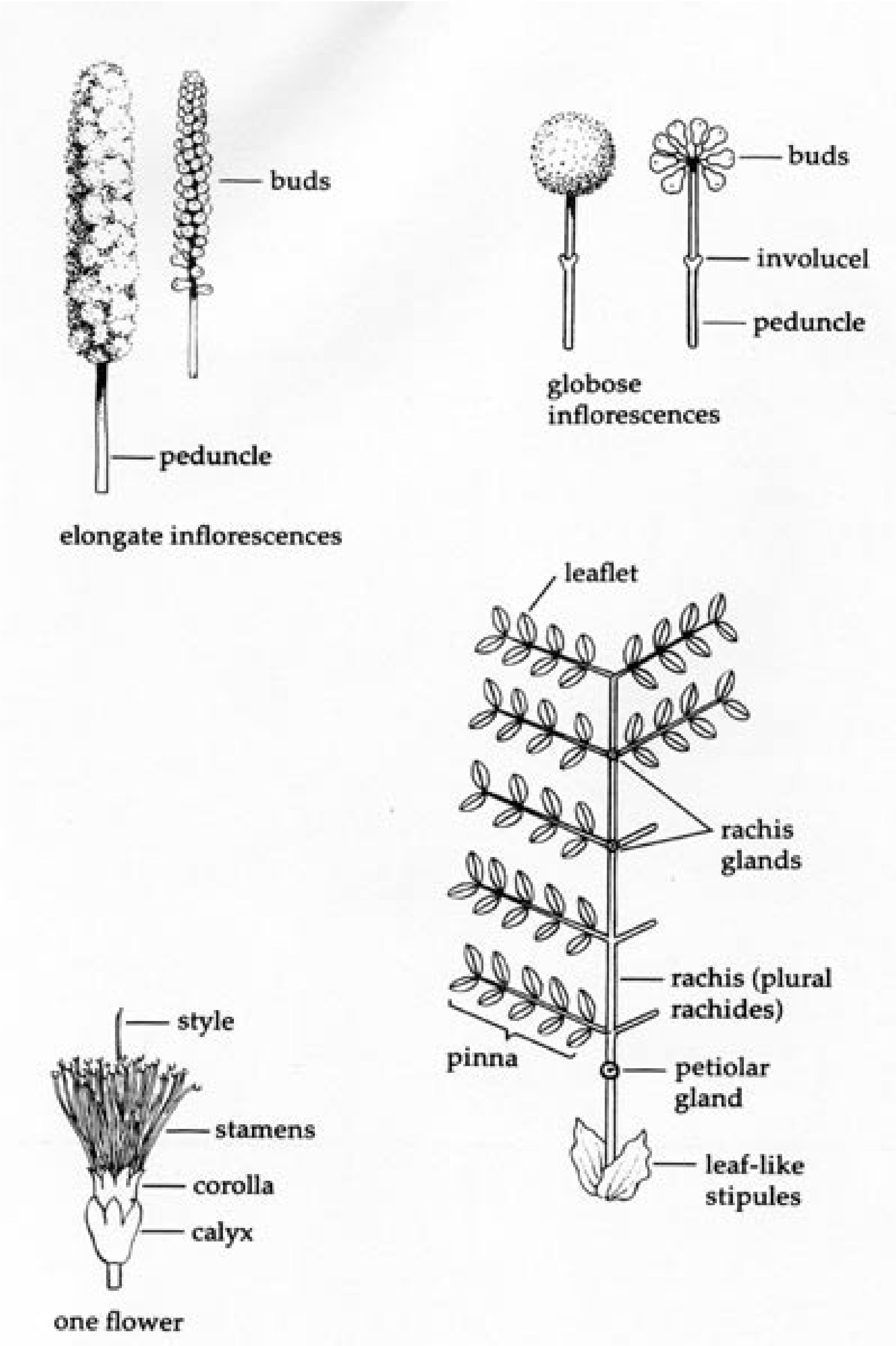
Pubescent: covered with short downy hairs.

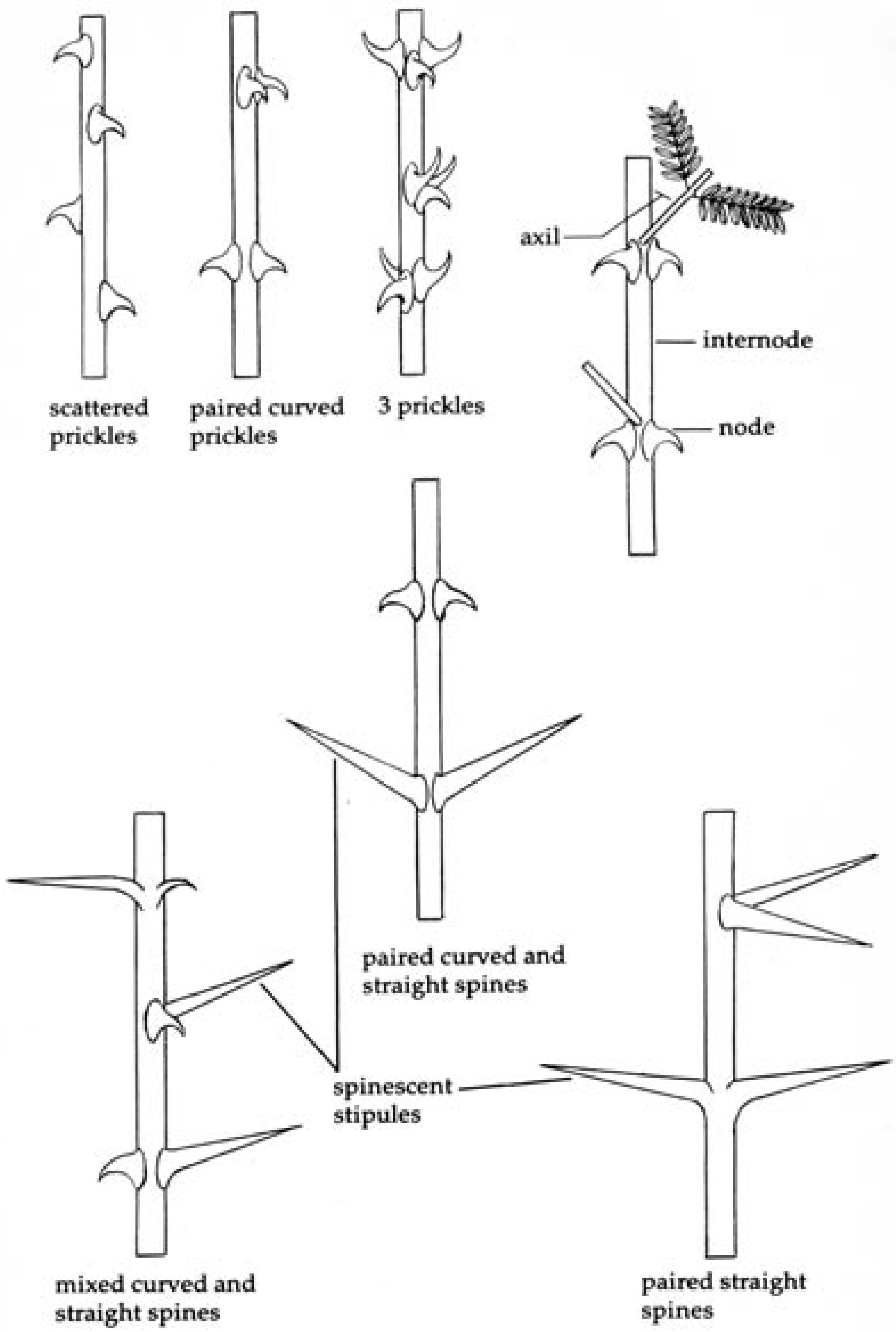
Spikelet: small spike in which the flowers are subtended by and enclosed in bracts; the unit of the grass inflorescence.

Spinescent: ending in a spine or in a very sharp hard point.

GLOSSARY SPECIFIC TO ACACIA SPECIES

(Source: Davidson and Jeppe, 1981)




scattered prickles
paired curved prickles
3 prickles
axil
internode
node
paired curved and straight spines
spinescent stipules
mixed curved and straight spines
paired straight spines

APPENDIX 4 - Various logging forms

TRIAL PITS LAYOUT FORM

Project: ______________________ Date: ______________________

Borrow Pit number: __________ Geographical Co-ordinates: __________

Chainage: ______________________ Offset: ______________________

	A	B	C	D	E
1	☐ --/--	☐ --/--	☐ --/--	☐ --/--	☐ --/--
2	☐ --/--	☐ --/--	☐ --/--	☐ --/--	☐ --/--
3	☐ --/--	☐ --/--	☐ --/--	☐ --/--	☐ --/--
4	☐ --/--	☐ --/--	☐ --/--	☐ --/--	☐ --/--
5	☐ --/--	☐ --/--	☐ --/--	☐ --/--	☐ --/--

■ Trial Pit – sampled ☐ Trial Pit – Not sampled

☐ --/-- OB/Gravel thickness

Areas of similar 'gravel properties' as per pit logs

Overburden: -----------

'Gravel' Type: -----------

Underlaying material: -----------

Estimated Quantities:

Area to be used: ---------

Overburden: -----------

'Gravel': ----------

Remarks: -------------------------

Trial Pitting by: ----------

Surveyed by: -----------

Trial Pit logging form (use a new form for each trial pit)

Project ………………………………… Location (chainage & offset). ………………… Excavated by (hand/machine)…………………………

Borrow Pit number ……………………… GPS co-ordinates …………………………… Excavated on ………../………/……………………

Trial pit No. ……………………………… Water table depth ………………………… Profiled on ……./……./……… By ……………………

Depth (m)	Moisture	Colour	Consistency	Structure	Soil Type	Origin	Remarks
to							
to							
to							
to							
to							