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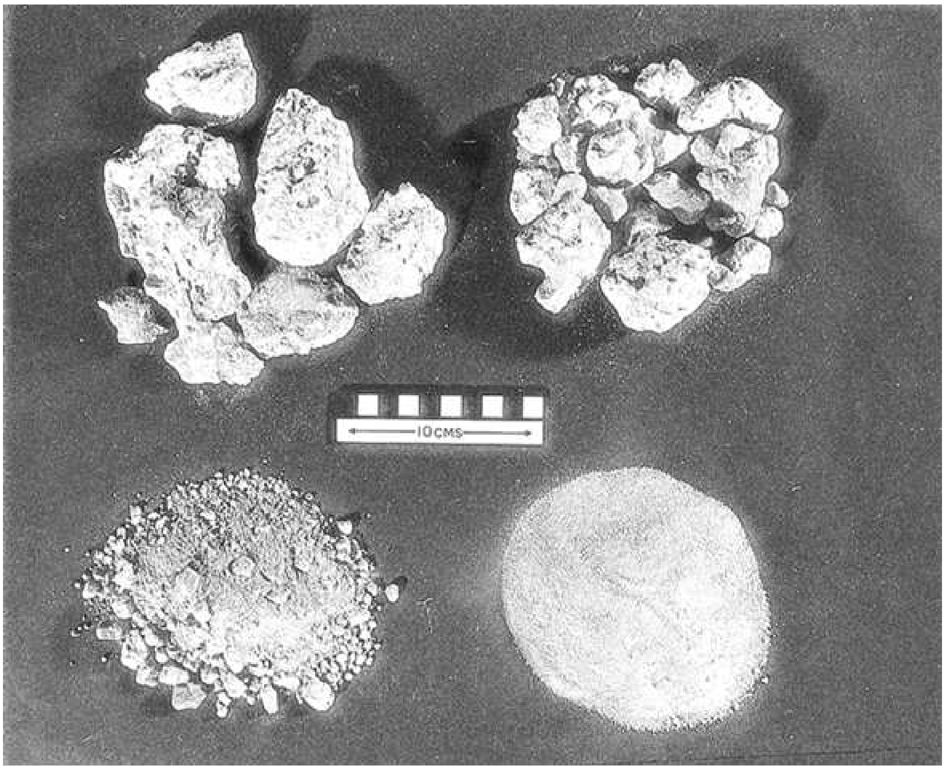

Identification and Mapping of Calcrete Deposits in Inhambane Province and Preparation of a Calcrete Classification System and Specifications for the Use of Calcrete in Road Construction in Mozambique
AFCAP/MOZ/091

TECHNICAL REVIEW
Report No. RPN 2326

TRL Limited, UK, in Association with InfraAfrica (Pty) Ltd, Botswana

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The programme is currently active in Ethiopia, Kenya, Ghana, Malawi, Mozambique, Tanzania, Zambia, South Africa, Democratic Republic of Congo and South Sudan and is developing relationships with a number of other countries and regional organisations across Africa.

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LIST OF ABBREVIATIONS

AADT	Average Annual Daily Traffic
AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transport Officials
ANE	Administração Nacional de Estradas (National Roads Agency)
AFV	Aggregate fingers value
APV	Aggregate pliers value
ASTM	American Society of Testing Materials
BLS	Bar Linear Shrinkage
BS	British Standard
CBR	California Bearing Ratio
CSIR	Council for Scientific and Industrial Research
DCP	Dynamic Cone Penetrometer
ESA	Equivalent Standard Axle
FACT	Fines Aggregate Crushing Test
GM	Grading Modulus
Kg	Kilogram
kN	Kilo-Newton
LL	Liquid Limit
LS	Linear Shrinkage
M	Million
MC	Moisture content
MDD	Maximum Dry Density
N	Weinert's climatic N-value
OMC	Optimum Moisture Content
pH	Percentage hydrogen
PI	Plasticity index
PL	Plastic Limit
PSD	Particle Size Distribution
P425	Percentage material passing the 0.425 mm Sieve
P075	Percentage material passing the 0.425 mm Sieve
SP	Slightly Plastic
TMH	Technical Methods for Highways
TRL	Transport Research Laboratory
UK	United Kingdom

1. INTRODUCTION

1.1 Background

Road-building materials meeting conventional specifications are scarce along much of the coastal and inland areas of Mozambique and, in particular, in Inhambane Province. Road bases for sealed roads have conventionally been constructed by stabilizing local sands with high proportions of cement. Stabilisation of the sand can also be achieved using bitumen. Both of these options are expensive, thereby constraining the expansion of the paved road network. The non-availability of good natural gravels for the construction of wearing courses on unpaved roads has resulted in high maintenance costs for roads in the province, and unreliable access during the rains. Hence, the innovative use of locally available materials, which are considered marginal or rejected by traditional specifications for road construction, needs to be investigated for use in the construction of roads in the province.

Calcrete - a pedogenic material that commonly occurs in arid and semi-arid regions of Southern Africa – is one of the locally available materials found in Inhambane Province. Recent experience on projects implemented by the Mozambique National Road Administration (ANE) in the province has shown that calcrete can be used both as base material when blended with local sand and in graded aggregate seals with a soft bituminous binder. This approach offers considerable cost savings over conventional design approaches for paved roads. Thus, if the suspected abundant calcrete deposits in the province can be relatively easily located, this will lead to more extensive use of this material, either neat or blended with local sands, to provide durable road bases for sealed roads. This will alleviate the perennial problem of maintaining unsealed roads constructed from non-durable local sands or sand-calcrete admixtures which tend to deteriorate fairly rapidly under traffic..

1.2 Purpose and Scope of Project

The main purpose of the project is to provide guidance to ANE and the Inhambane provincial authorities on the location of calcrete deposits as well as on their classification as road building materials and appropriate technical specifications for their use in road construction. To this end, the project comprises the following overall scope of work:

(1) **Technical review** – entailing an extensive review of previous research, experience and studies on the use of calcrete in road construction in the region, along with any existing guidelines, standards and specifications.

(2) **Calcrete classification system** – involving an evaluation of the suitability and, if necessary, the amendment of existing systems to classify the Inhambane calcretes based on a review of existing test data.

(3) **Technical specifications** – covering the use of calcrete in all layers of the road pavement (base, subbase, subgrade, wearing course and bituminous surfacing).

(4) **Identiifcation and mapping of calcrete deposits** – based on a range of exploration techniques and covering the full geographical extent of Inhambane province for subsequent capture in a GIS database.

(5) **Guideline** – comprising a compilation of all information obtained from the main components of the project.

1.3 Background to Technical Review

Although calcretes occur abundantly in the Southern Africa region, prior to 1970 very little was known about their general characteristics and engineering properties for use in road construction. However, between 1964 and 1969, a major research project was undertaken on this ubiquitous material by the then South Africa National Institute for Road Research (NIRR) which was entitled "*A study of a manner of formation and engineering properties of the surface limestones (calcretes) especially in the north, but also elsewhere in South West Africa and in the Republic".* This seminal work was summarized in a very comprehensive report entitled "*Calcrete in road construction*" (Netterberg, 1969, 1971) in which several, very interesting findings of fundamental importance were reported including the composition of calcretes and a new explanation for their mode of formation.

Subsequent to the research work on calcrete undertaken by NIRR in the 1960s, other research and investigations were carried out in the Southern African region, mostly in Botswana (Netterberg and Overby, 1980; Overby, 1983, 1990; Toole, 1986; Greening and Rolt, 1996) and, to a lesser extent, in Zimbabwe (Delph, 1971) and Kenya (Godana et al, 2010). As a result of these initiatives, as well as independently of them, several other papers have appeared in proceedings of conferences and technical journals (for example the collection of papers published in the volume edited by Wright and Tucker (1991), which includes papers on Kalahari calcretes by Watts (1991), Caliche soil profiles in Saldanha Bay, South Africa by Knox (1991) and calcretes in Tanzania by Hay and Wiggins (1991)). It is this collective body of information that provides the major inputs to this Technical Review report. Less attention is paid in the review to similar work carried out outside of the Southern African region, such as in the United States, Brazil and North Africa.

1.4 Structure of Report

This Technical Review report is structured as follows:

Section 1 (this section): provides the background to the project, as well as its purpose and scope, and the underlying basis of the Technical Review.

Section 2: Presents the general characteristics of calcretes including the terminology used to describe them, their definition, composition, classification, origin and distribution.

Section 3: Outlines the various methods used, and stages followed, in prospecting for calcretes from the initial desk study to the final reporting of the results obtained.

Section 4: Summarises the engineering properties of the various types of calcretes used in road construction.

Section 5: Presents the various test methods used for evaluating the suitability of calcretes, and the current specifications that have been developed in the region, for using this material in the various layers of the road pavement.

Section 6: Summarises various issues associated with the use of calcretes in road construction.

Section 7: Summarises the key issues arising from the Technical Review of the use of calcrete in road construction in the region.

2. GENERAL CHARACTERISTICS OF CALCRETES

2.1 Introduction

A common understanding of the term "calcrete" and a knowledge of the general characteristics of this very variable material can provide useful insights as to how best to utilise it in road construction. Such characteristics include the material's formation and composition, distribution, origin, age, classification and engineering properties as discussed below.

2.2 Terminology

There is a general lack of consistency with the terminology used in relation to calcretes. Terms found in the international literature to describe the same material, though with varying definitions, include: "surface limestone" and "calcareous duricrust" (general), "caliche" (USA), "kankar" (East Africa, India, Australia), "kurkar" (Israel), "jiglin" (Nigeria), "tosca" (Argentina and Spain), "encroûtements calcaires" (North Africa – Tunisia, Algeria, Morocco). In this report, the term "calcrete" will be use throughout to refer to the same material that may be referred to otherwise in the literature.

2.3 Definition

According to Netterberg (1969), calcrete can be regarded as "a material formed by the *in situ* cementation and/or replacement of almost any pre-existing soil by calcium carbonate deposited from the soil or ground water". Thus, although calcrete contains a high proportion of calcium carbonate, it is not a sedimentary rock like limestone which also contains a high proportion of calcium carbonate ($CaCO_3$) but which has a quite different origin. Instead, calcrete is a secondary product formed within or on top of an existing soil and is a member of the useful group of road building materials known as pedogenic materials, of which ferricrete (laterite) and silcrete are prominent members.

2.4 Formation and Composition

As may be inferred from the definition of a calcrete, this material is formed in place either by cementation or replacement – sometimes both – of pre-existing soils, usually by calcium carbonate and, to a lesser extent, by magnesium carbonate precipitated from the soil or ground water. This results in the original material being transformed into a new one - calcrete - comprising varying quantities of $CaCO_3$ whose properties vary from an almost pure, very hard, massive limestone, in which there is hardly any trace of the host material, to a very loose material consisting largely of the host material.

The most commonly encountered clay minerals in calcretes are palygorskite, montmorillonite and seopilite. These minerals possess a number of unusual properties, most of which are likely to be beneficial to a road material (Netterberg, 1969). For example, palygorskite clay (and probably sepiolite) possesses a far greater shear strength at the same moisture content than other clays. Calcretes therefore possess a composition which is unusual among road materials. Because of the high carbonate content, the usual clay minerals present (palygorskite and sepiolite) and the presence of compound porous particles and amorphous silica micro-fossil remains, they can be expected to exhibit some unusual properties.

2.5 Classification

A relatively simple morphological classification for calcretes based on standard descriptors, secondary structures and other properties has been developed from research in the Southern African region by Netterberg (1969) and modified by Goudie (1983). In this classification system which is presented in Table 2-1, six types of calcrete are recognised that relate to Southern Africa groupings. Each group not only reflects a significantly different range of engineering properties and physical appearance, but also represents a particular stage in the development of a pedogenic calcrete.

Table 2-1: A morphological classification of calcretes (after Goudie, 1983)

Calcrete type	Characteristics	Occurrence	Excavation
Calcified soil	Very weakly cemented soil representing an early stage in calcrete formation. Retains characteristics of host soil.	Soil horizons	Loose
Powder calcrete	Loose powder consisting predominantly of silt and sand-sized carbonate particles with little or no nodular development.	Pans and playas	Excavated with a pick-axe
Nodular calcrete	Concretions or nodules in a calcareous matrix. Nodules vary in size from silt size to about 60 mm and their shapes vary from spherical to highly irregular. Most useful type of calcrete for road making.	Various	Ripping generally sufficient
Honeycomb calcrete	Honeycomb texture of coalesced nodules representing a stage of development between nodular and hardpan calcrete.	Various	Excavation generally requires mechanical ripper
Hardpan calcrete	Hard layer, often composed of cemented honeycomb or nodular horizons. Includes calcretised gravels. Represents the final stage of calcrete development.	Above or between nodular or powder calcretes. Frequent as a surface horizon.	Blasting, crushing and screening commonly needed.
Boulder calcrete	Discrete to coalesced boulders.	Secondary calcrete formed from other types.	Usually rippable.

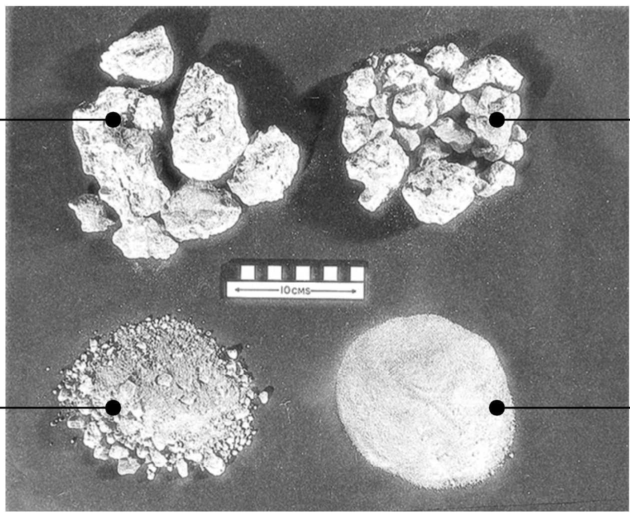


Photo 2-1: Typical types of calcretes

In Mozambique, the various types of calcrete have not yet been mapped and this is a key objective of the project. Nonetheless, from observations in a number of existing borrow pits, it is apparent that various types of calcrete do exist. Photos 2-2 and 2-3 provide an example of a borrow pit at Km 33.2 on the R483 road in Inhambane Province showing calcrete bands up to 0.25m thick, but mostly nodular and local boulder calcrete and calcrete conglomerate.

Photos 2-2 and 2-3: Existing calcrete borrow pit in Inhambane Province

2.6 Origin

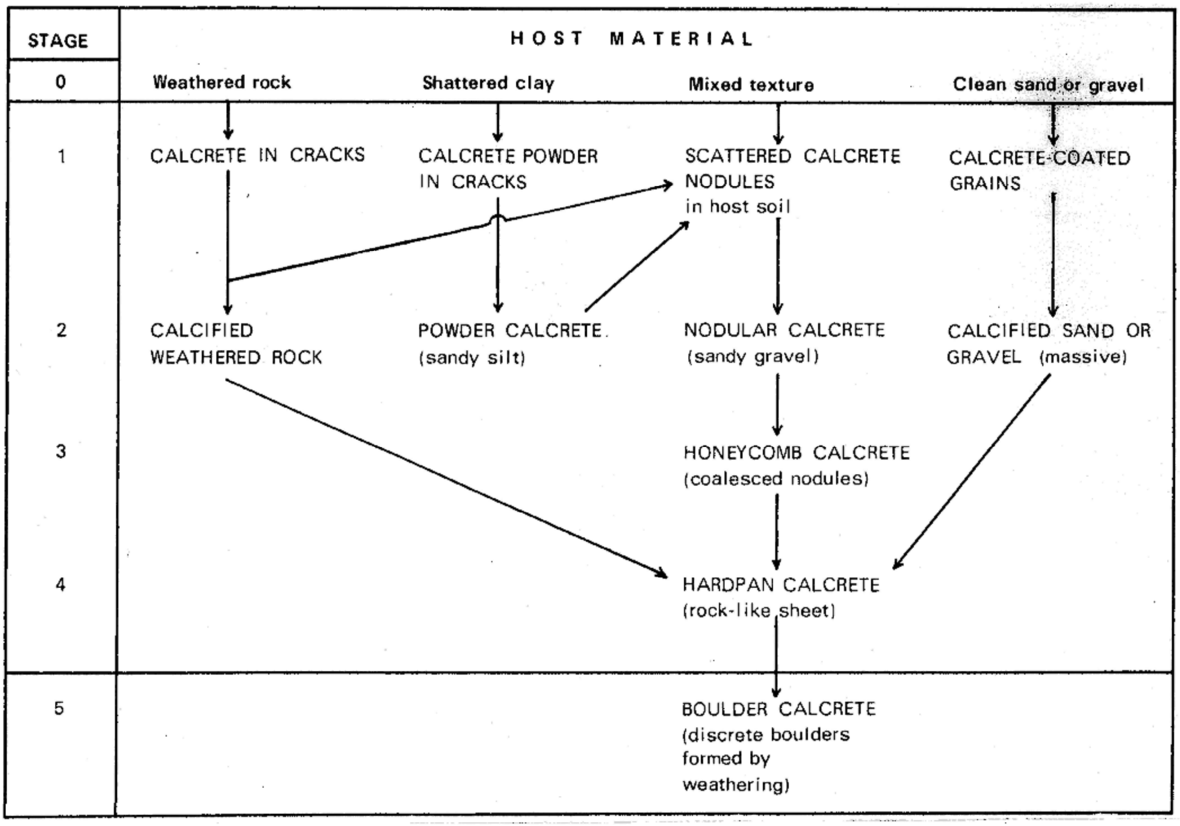
2.6.1 General

Southern African calcrete deposits are thought to be of two basic origins (1) by deposition of carbonate in the host material above a shallow perched or permanent water table (groundwater calcretes), or (2) by downward leaching of carbonate from the upper soil horizons by infiltrating rainwater and its deposition down in the profile (pedogenic calcretes). (Netterberg,1969,1971). Pedogenic calcretes are very common in the Southern African region and can form in any calcareous profile, with the mature profile consisting typically of a harder calcrete crust overlying weaker calcrete of a less mature type (lower stage of development). In contrast, groundwater calcretes are almost invariably capped by a crust of pedogenic hardpan calcrete, and can form in a completely non-calcareous profile.

2.6.2 Stages of development

Calcrete formation is a process of deposition and crystal growth of carbonate in the host soil in which the host particles are pushed apart and the relative carbonate content increases with development. Under ideal conditions this is probably a continuous process in that all gradations between the stages are possible. Table 2-2 shows the stages in the development of a pedogenic calcrete (Neterberg, 1969). Each of the categories represents a particular stage in the growth or weathering of a calcrete horizon and possesses a significantly different range of geotechnical properties (see Section 4).

Table 2-2: Stages in the development of calcrete (Netterberg, 1969)



2.7 Distribution

There are a number of fundamental factors that control the distribution of calcretes in Southern Africa. Of major importance is the fact that calcretes are not sedimentary rocks but soils. Thus, their distribution is not governed solely by geology but, rather, by the availability of carbonate as well as the following soil-forming factors as discussed further below:

- Climate
- Topography and drainage
- Parent material
- Biological factors
- Time

2.7.1 Climate

In southern Africa, calcretes that are sufficiently well developed for use in road construction generally occur in the drier areas, typically where rainfall is less than about 550 mm (Weinert N-value > 5). In sub-humid, warm areas receiving 550–800 mm of rainfall (Weinert N-Value 2-5), any calcretes that have formed would normally be too thin to be economically worked for road material. In wetter areas receiving rainfall in excess of 800 mm (Weinert N-Value <2) calcification, and hence, any type of calcrete, would generally be absent. Based on these climatic indicators, the likely distribution of the different types of calcretes in Southern Africa is shown in Figure 2-1 (Netterberg, 1969).

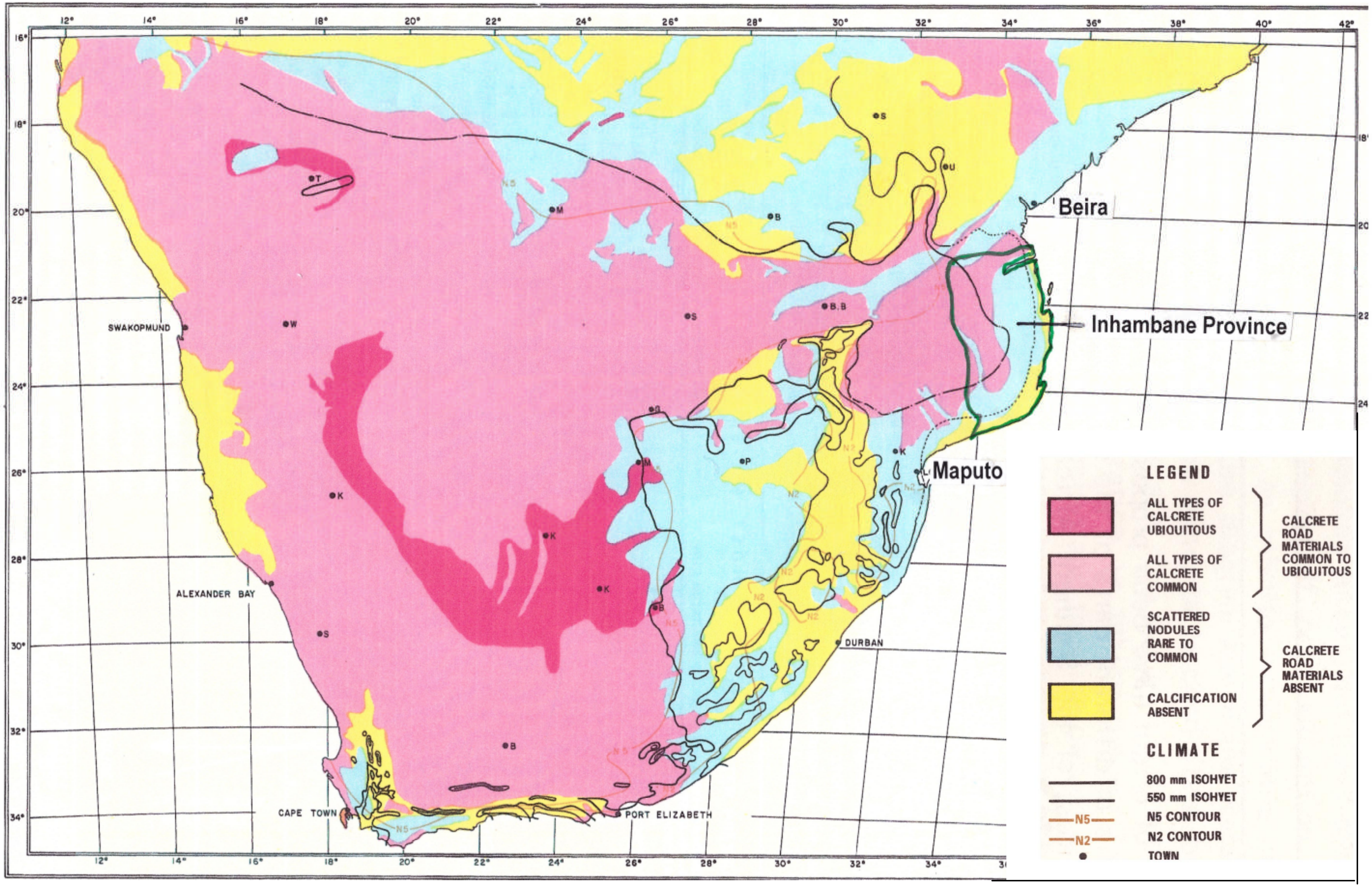


Figure 2-1: Distribution of calcretes in Southern Africa in relation to climate

The distribution of calcretes broadly indicated in Figure 2-1 is based on a 1:5,000,000 rainfall map of the Southern African region and partially calibrated by occurrences of calcrete found on the ground. This map indicates that the western half of Inhambane Province would seem likely to yield all types of calcrete while in the eastern half they are likely to be generally absent.

In order to provide a better indication of the likely distribution of calcrete in Inhambane Province, a detailed N-value contour map has been prepared and is presented in Figure 2-2.

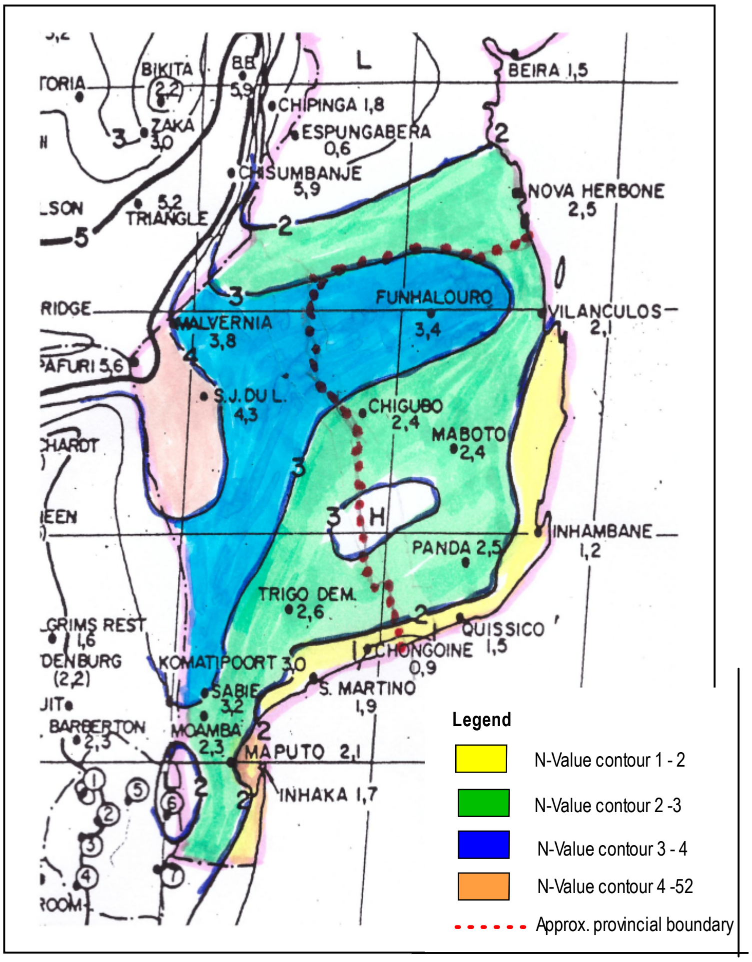


Figure 2-2: N-value contour map for Inhambane Province
(Adapted from Weinert, 1980)

As indicated in Figure 2-2, Inhambane Province falls in a climatic area where the N-values range between 1 and 4, indicating a relatively wet region with rainfall generally in excess of 550 mm. As a result, it seems unlikely that any calcretes located in the province will be well developed and are more likely to be of relatively inferior quality for road building purposes. However, the use of N-value maps is but one source of information that should be complemented by a number of other methods of prospecting for calcrete which are discussed in Section 3.

2.7.2 Topography and drainage

In general, topography plays a large part in calcrete formation and a study of the local topography may often provide clues as to where certain types of calcrete may be found. For example, where hardpan calcrete is prominent, it forms thick layers that do not erode easily and, accordingly, it will form positive topographical surfaces, as opposed to powder calcrete that erodes easily and results mostly in incised surfaces. Calcrete also tends to form on flattish land, topographic depressions, low-lying pans as well as along old river channels and terraces where moisture may already possess carbonate in solution which is able to evaporate and to deposit calcium carbonate which can then cement and/or replace the pre-existing soil in situ. Table 2-3 presents landforms of sand regions associated with calcrete deposits (Botswana Roads Department, 2000).

Table 2-3: Landforms of sand regions associated with gravel deposits

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

A idealised section across a river and pan terrace is shown in Figure 2-3 which postulates the sequence of calcrete development (not always fully represented) from a calcareous soil via a calcified soil, or nodular and honeycomb stage, to a hardpan and finally weathers to a boulder calcrete.

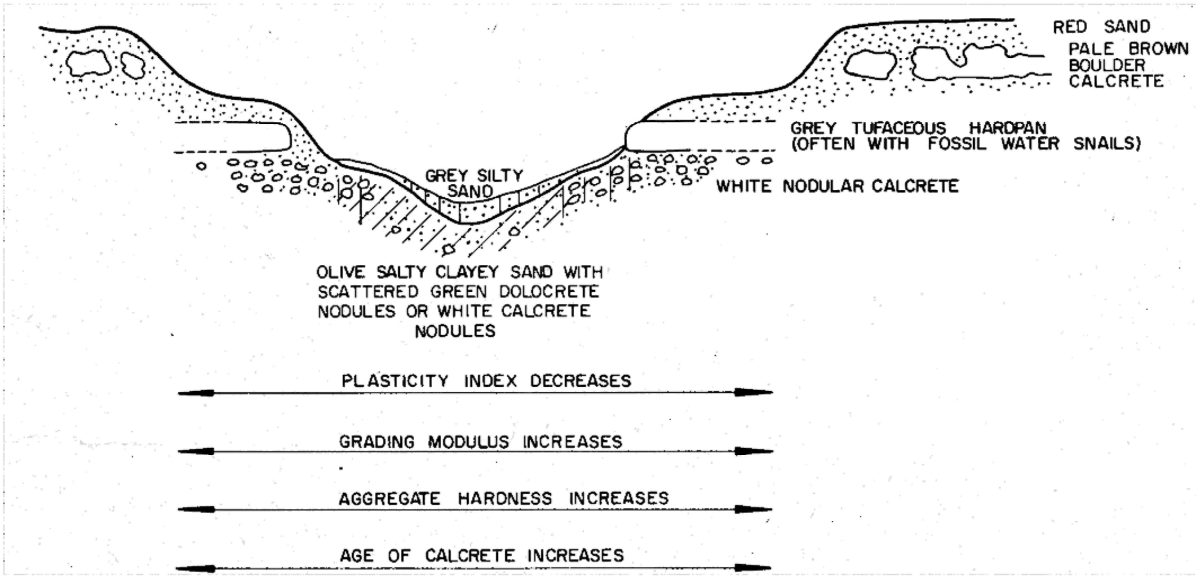


Figure 2-3: Idealised section across calcrete-forming depression
(After Netterberg, 1969)

2.7.3 Parent or host material

While calcretes form by growing in an existing soil, this soil may or may not provide carbonate. It may, in fact, merely act as a host material in which the carbonate is precipitated (Netterberg, 1969). Only when the soil profile is residual or the thickness of the transported cover is reasonably thin does the solid geology determine whether calcrete will form. In such profiles calcrete formation is likely over calcareous rocks such as limestone, dolomite, calcareous shales and mudstones or the more basic rocks like dolerite and basalt which release calcium and magnesium on weathering.

If the above principles are applied to the soil map of Southern Africa, it can be predicted that workable calcrete deposits will be extremely rare in the areas shown under the soil legend as rock and rock debris and rare in all weakly developed soils except those on calcareous crusts (actually hardpan calcrete). Heavy clay soils like Vertisols would be the best types in which to search for calcrete in the sub-humid zone (Weinert N-Value 2-5) although these calcretes are likely to be rather plastic.

2.7.4 Biological factors

The presence of certain plant species and 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 aid to the location of calcretes. However, plants are adaptable and the absence of an indicator species does not necessarily mean the material is absent whilst, conversely, the presence of the indicator species does not always signify that the underlying material contains calcium carbonate and is suitable for road construction purposes.

A list of plant species used for the location of calcretes is provided in Table 2-4. A guide to the identification of the listed species, together with illustrations, may be found in Appendix 3 of the Botswana Roads Department guideline on Methods and Procedures for Prospecting for Road Construction Materials (Botswana Roads Department, 2000).

Table 2-4: Indicator plants for locating calcrete

Material type	Botanical name	Common name	Local name
Calcrete	*Acacia fleckii*	Blade thorn	Mokala/Mohahu
	Acacia mellifera	Hook thorn	Mongana
	Acacia nebrownii	Water acacia	Orupunguya
	Acacia reficiens	False umbrella thorn	
	Catophractes alexandri	Trumpet thorn	Orupunguya
	Combretum imberbe	Leadwood	Moselesele
	Dichrostachys cinera	Sickle bush	Lewisi
	Eriocephalus ericoides	Snowbush	Mogwana
	Grewia bicolour	False brandybush	Morêtlwa
	Grewia flava	Brandybush	Mokgamphatha
	Grewia flavescens	Donkeyberry	Mothono
	Maytenus senegalensis	Confetti tree	Motlalemetsi/Mokudi
	Pechuel-loeschea leubnitziae	Bitterbush	Mohatlha
	Tarchonanthus camphorates	Camphor bush	Motsiara
	Terminalia prunoides		

2.7.5 Time

If all the other pedogenic (soil – forming) factors remain constant, the effect of time is to increase the stage of development of the calcrete. Thus, the oldest calcretes tend to be the hardest, the strongest and possess the best grading and lowest PI (Figure 2-3). The highest river or pan terraces are the oldest and the calcretes on the highest terraces are usually the best developed and thickest although they may not be those most useful in road construction.

If one of the other pedogenic factors (particularly climate and drainage) change with time, a fossil calcrete may result and, indeed, many calcretes in Southern Africa are in fact fossil. Since they are not forming at the present time, fossil calcretes need not occur under the present-day conditions favourable for calcrete formation, and when they do not outcrop they can be extremely difficult to locate. Empirically it is, however, found that even fossil calcretes obey the climatic correlations mentioned above and do not occur over non-calcareous rocks like granite and sandstone unless the drainage was once favourable, i.e. it imported calcium carbonate to the area.

The ages of calcretes in Southern Africa have been grouped into five categories (netterberg, 1969):

- Pre-*Pliocene*
- Upper *Pliocene* (probably 2 – 5 million years old)
- Uppermost *Middle Pleistocene* (perhaps 100,000 years old)
- Uppermost *Upper Pleistocene* (probably 10,000 – 20,000 years old)
- *Recent* (younger than about 1,000 years old)

According to Netterberg (1969), the most widespread calcretes of importance to the road builder probably fall into the Pliocene and Upper Pleistocene categories.

Since they are not forming at the present time, ***fossil calcretes need not occur under the present-day conditions favourable for calcrete formation***, and when they do outcrop can be extremely difficult to locate. Empirically it is, however, found that even fossil calcretes obey the climatic correlations mentioned previously and do not occur over non-calcareous rocks like granite. Fossil drainage features are just as useful sources of calcretes as are present-day drainage features and are often detectable on air photos.

3. METHODS OF PROSPECTING

3.1 Introduction

By virtue of the fact that the distribution of calcretes is not governed solely by geology, but rather by other soil-forming factors, as discussed in Section 2.7, this material can be very difficult to locate in the typically relatively flat, often featureless, arid to semi-arid areas where it is likely to be found. This requires that a well structured prospecting process is followed that progresses from a desk study phase, through to an intermediate field survey stage, culminating in the final stage of proving, sampling and testing of the material from the potential borrow pit.

This main stages typically followed in prospecting for calcretes are summarised below (Netterberg, 1996; Botswana Roads Department, 2000) and discussed in more detail in the proceeding sub-sections.

- Desk study
- Field survey
- Source evaluation (Field)
- Source evaluation (Laboratory)
- Reporting

It must be assumed that sufficiently qualified and experienced personnel are involved in all stages of prospecting, as the success of the road project will hinge critically on the quality and accuracy of the information contained in the final report.

3.2 Desk Study

The desk study forms the first stage of the materials prospecting exercise with the main objective of collating all relevant information pertaining to the area of interest onto a base map from which the field survey can then be planned.

From the research carried out so far in the region, calcrete is associated with a number of distinct landform features as indicated in Table 2-3, i.e. essentially pans, depressions, inter-dune hollows and old river channels. Only in a very cases has calcrete not been found in association with these features (Netterberg, 1978, 1996; Lawrance and Toole, 1984). This important circumstance has enabled remote sensing images to be used effectively in the past for mapping calcretes. However***, it must be stressed that prospecting for calcretes can be a very time consuming process and that the remote sensing images that have been used successfully in the past in certain areas of Southern Africa (primarily South Africa, Namibia and Botswana) may not necessarily also be effective in mapping calcretes in a new area such Inhambane Province in Mozambique where such prospecting has not been carried out before and where the calcrete-bearing landforms may be different.***

The main sources of information at the desk study stage would ideally, but not necessarily, include all of the following:

- Soil engineering, geotechnical, terrain evaluation maps
- Geological maps
- Pedological maps
- Topographic maps
- Contour maps of climatic N-values
- Remote sensing: landsat, thermal infrared imagery, side looking radar
- Aerial photographs: black and white, colour, false colour, infrared, orthophoto maps, airphoto mosaic
- Aerial reconnaissance (exceptional): helicopter, light aircraft
- Local information

By the end of the desk study, a reasonable indication should be had of locations of potential sources of calcrete (and possibly their appropriate indicators) for transfer to a base map for use during the fieldwork.

3.3 Field survey

The field survey is normally undertaken in two stages; (a) a reconnaissance survey, and (b) a detailed survey with different objectives as summarised in Table 3-1.

Table 3-1: Differences between reconnaissance surveys and field survey

Reconnaissance survey	Detailed Survey
Purpose is to obtain an overview of the types and distribution of materials within the whole area of interest, i.e. to identify specific sites.	Purpose is to make a detailed record of the most appropriate sources of material for the project, i.e. to investigate specific sites identified in the reconnaissance survey.
Large distances are covered quickly to obtain an overview of potential sites and to cover as many of them as possible within the area of interest.	The sites are covered methodically, in much more detail. The coverage is planned to progress from one site to the next.
Usually no samples are taken, but a sampling plan is prepared.	Samples are taken as necessary, appropriate for the specification of the material in the context of the project.

3.3.1 Reconnaissance survey

The following are typical activities undertaken during the reconnaissance:

(1) In order to confirm the conclusions drawn during the desk study, visit existing borrow pits identified from the geological maps, aerial photographs and satellite imagery, etc. Use a GPS to record their locations. Estimate the areal extent and available quantities without excavation. This can be done with simple techniques such as a calcrete probe or DCP.

(2) Identify any significant geomorphological, soil or vegetation characteristics at existing borrow pits that can be used to indicate similar sources elsewhere in the area. of interest. Identify these characteristics on the maps and aerial photographs and look for similar features elsewhere on images.

(3) Study the geomorphology and decide which areas are likely to have a high potential for material, e.g. edges of pans and ephemeral water courses, scree slopes and drainage channels.

(4) Study the vegetation and note any significant changes and species groupings such as Water Acacia and Snowbush which are good calcrete indicators (see Photos 3-1).

(5) Note factors pertaining to accessibility of each site.

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

(7) 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.

(8) Record other important information including thicknesses of overburden, ease of access, etc.

(9) Update the base map accordingly.

(10) Draw up a plan for the detailed survey, 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.

Name: Eriocephalus ericoides
Snowbush, lewisi

General: multi-stemmed woody shrub0.5 to 1 m high.

Leaves: Dark green, 3 to 5 x 0.3 cm, covered in fine silvery hairs, twisted, apex tapering, abse rounded; petiole very short or not present.

Flowers: Small, red, inconspicuous. Flowering time June to July.

Fruit: Ripe seed covered by soft white fluff.

Photo 3-1: Typical botanical indicators for calcrete

The ability of remote sensing systems to identify calcrete-bearing landforms does vary and none of the systems alone can be expected to show all the features. By way of example, Table 3-2 summarises the ability of particular types of remote sensing techniques to identify the type of calcrete-bearing landforms that prevail in Botswana (Lawrance and Toole, 1984)

Table 3-2: Ability of remote sensing techniques to identify calcrete-bearing landforms

Remote sensing technique \ Calcrete-bearing landform	Bare pans		Platform	Grassed pans (vegetative zoning)	Valley and inter-dune hollow		Depression (no vegetative zoning)	Grey sand areas
	500 m across or more	Less than 500 m across			Well-defined	Diffuse		
Black and white air photographs (stereo) Scale 1:50 000 and 1:70 000	Very Good	Very Good	Good	Good	Moderate	Poor to not able	Good	Poor to not able
Natural colour air photographs (stereo) Scale 1:15 000 – 1:25 000	Very Good	Very Good	Good to Moderate	Very Good	Poor	Poor to not able	Good	Very Good
Landsat satellite imagery (photographic product) Scale 1:500 000	Very Good	Moderate	Not able	Not able	Good to Moderate	Good	Not able	Moderate
Landsat satellite imagery (digitally processed) Scale 1:50 000 – 1:250 000	Very Good	Good	Not able	Poor	Very Good	Very Good	Not able	Good

In an area where mapping has not been previously carried out to locate calcrete, such as Inhambane province, the process can initially be quite time-consuming until clear calcrete-bearing landforms begin to emerge. Moreover, if the area in which the reconnaissance is carried out is flat and featureless, it is likely that the ground reconnaissance survey will prove to be very difficult. In such cases, an aerial visual survey should be considered, using a helicopter or ultralight aircraft. Normal fixed-wing light aircraft are not suitable as they are too fast to allow inspection of potential sites. Such aerial surveys using botanical and geomorphological indicators have been used successfully in Southern Africa in flat, featureless areas covered with thick layers of sand to locate potentially suitable sources of materials in a matter of hours (Netterberg and Overby, 1986; Jones, 2006).

3.3.2 Detailed survey

The detailed survey is the immediate follow-up to the reconnaissance survey and involves the evaluation of the potential borrow pits at the sites judged to be the most appropriate. This process entails the preparation of a sampling plan and a ground survey plan which are discussed in the next sub-section.

3.4 Evaluation of Gravel Source (Field)

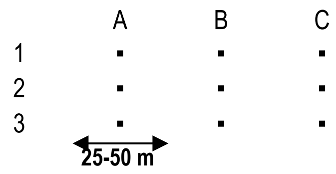
3.4.1 Detailed field study

The objective of this intermediate phase of the investigation is to evaluate and prove the potential sources of construction material identified from the reconnaissance survey in order to establish:

- The areal extent of the potential calcrete source.
- The thickness, quality and characteristics of the identified deposit.
- The type, properties and thickness of the overlying material.

For each potential source identified, the evaluation procedure that is typically followed is illustrated in Figure 3-1.

Notes



Borrow pit layout

Use MCCSSO of Jennings et ak, 1973

Visual assessment using thickness of overburden, areal extent, thickness of gravel seam, 5 fines, % oversize, etc.

Group segments with similar materials

Show GPS co-ordinates, potential access roads,distance from centre line, north direction, any potential problems during exploitation, etc.

Obtain sufficient size of representative sample for laboratory testing as per project specification.

Any special lab tetst?
State overall quantities of material found.
Appraisal of quality/stabilisation required?
Include all necessary maps

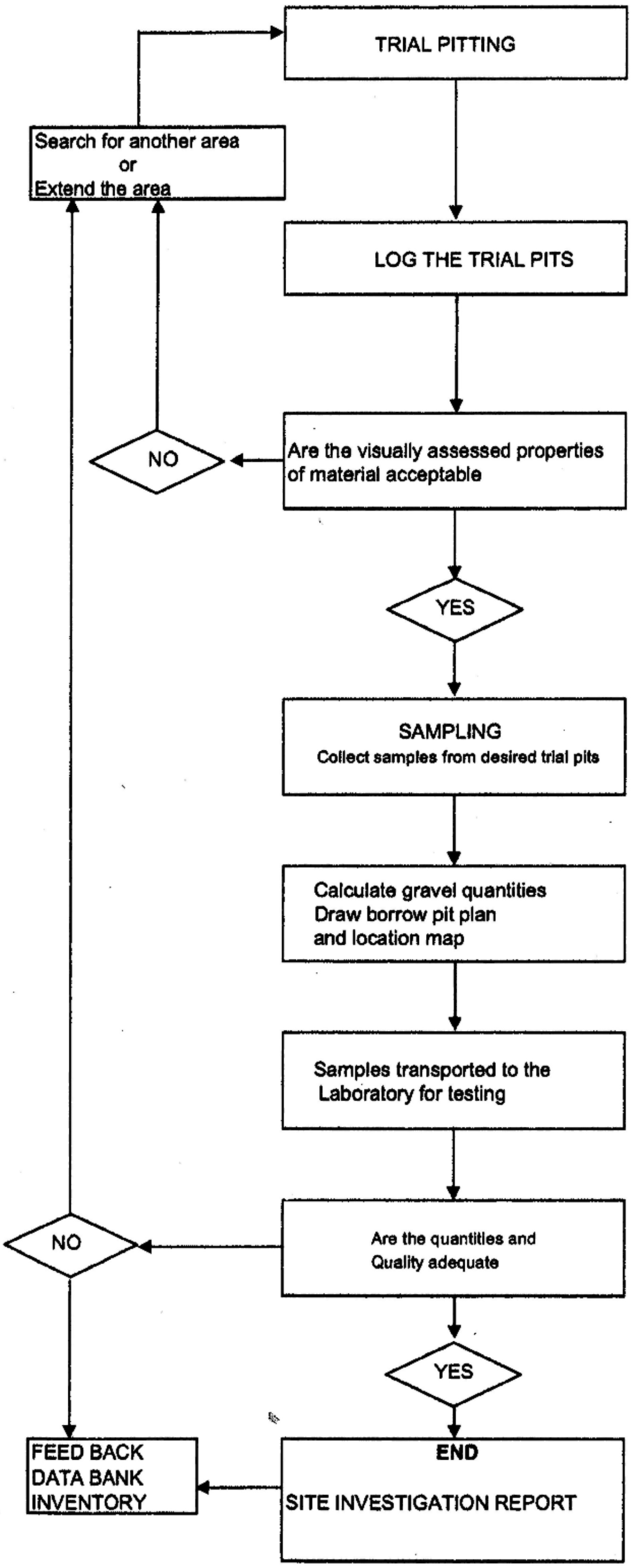


Figure 3-1: Flow chart for evaluation of calcrete source

A calcrete probe, and to a lesser extent, a DCP or hand auger, are very useful for providing a quick indication of success before following up with more time consuming trial pitting. After probing, the depth should be recorded and the tip of the probe should be examined to identify the likely calcrete type. A sketch of a calcrete probe is presented in Figure 3-2 whilst a summary of the interpretation of the probe's resistance to penetration is provided in Table 3-3.

Figure 3-2: Rapid calcrete probing device
(after Netterberg, 1969)

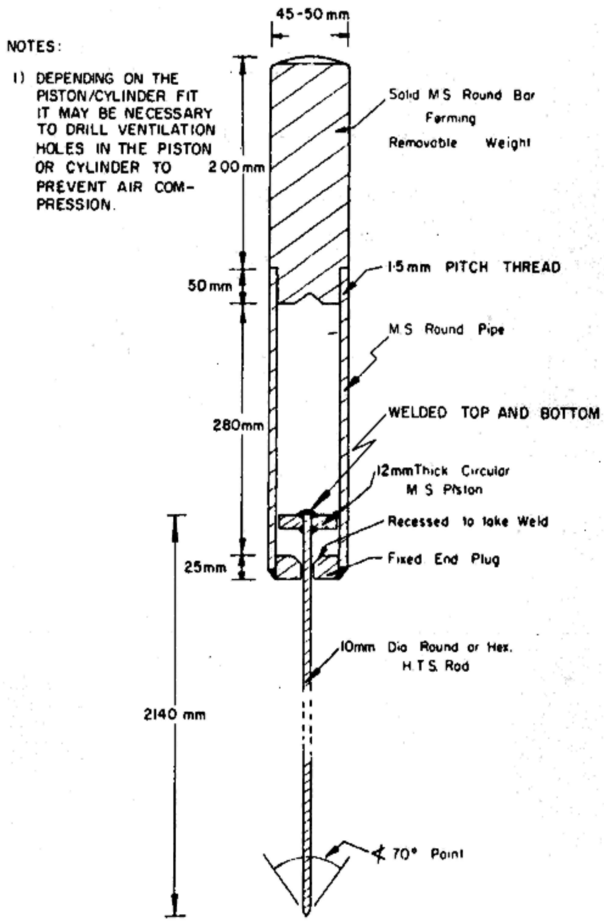


Photo 3-2: The calcrete probe in operation

Table 3-3: Interpretation of calcrete probe result (Netterberg, 1996)

Penetration resistance	Calcrete probe tip appearance	Likely calcrete type
Varies from almost none to refusal within a few metres	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

3.4.2 Trial pit logging

The objective of logging the trial pits is to provide an accurate description of the material thickness encountered within the pit. This log provides a description 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 sufficiently detailed to allow a decision to be made as to whether the material in the area of the pit should be further investigated or not. 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.

The profiling should be done in terms of its Moisture condition, Colour, Consistency, Structure, Soil texture and Origin (MCCSSO), for example using the approach detailed in Jennings, Brink and Williams (1973). A typical trial pit log is shown in Figure 3-3.

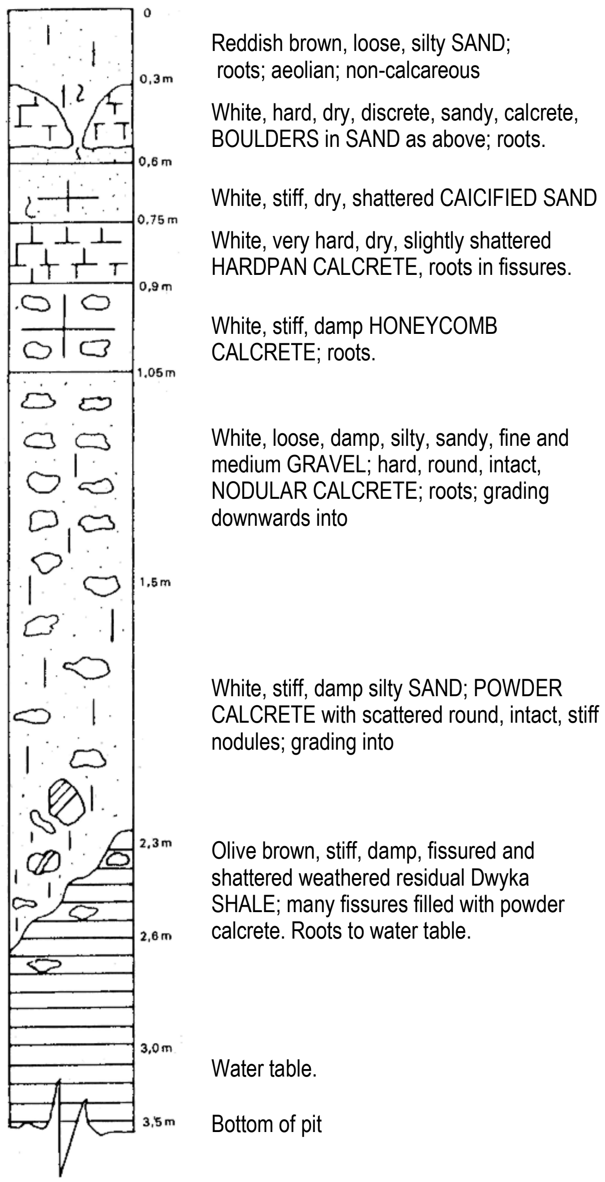


Figure 3-3: Suggested method of describing a hypothetical calcrete profile for engineering purposes (After Netterberg, 1969)

3.4.3 Field sampling and testing

At least one sample representative should be taken from each different material type unless the material is clearly unusable. While sampling, care must be taken to avoid contamination of different strata.

The size of the sample has an important bearing on representation and should be large enough to reasonably representative of the original material and to enable the required laboratory tests to be performed. The larger the grain size the larger the size of the sample required to represent the original material and to compensate for the oversize that will be discarded. Figure 3-4 provides a reliable guide to determining the size of sample needed to be representative of the mass of the original material in relation to its nominal maximum particle size (Botswana Roads Department, 2000).

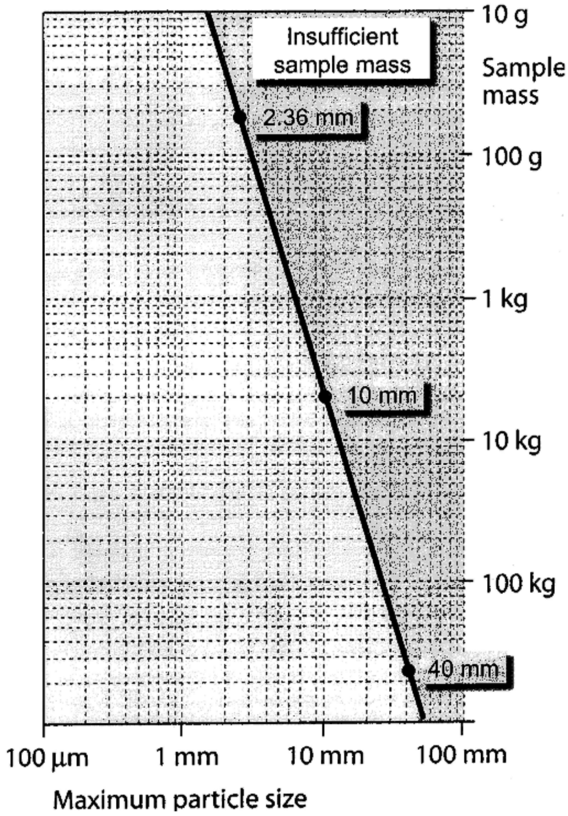


Figure 3-4: Estimation of sample size laboratory testing

A good estimate of the suitability of the material in the borrow pit for road construction can be obtained by making the following simple measurements:

- Grading
- Plasticity
- Hardness (Aggregate Pliers Value)

The above field tests can be carried out at the base camp of a field party and are intended to group materials into suitable, marginal and unsuitable types. Wet sieving may be impractical in the field, so a dry sieve analysis will have to suffice.

These tests provide preliminary engineering test data, rather than waiting until samples have been tested in a laboratory before the silting of borrow pits is finalised. Samples taken to a central laboratory for testing can then be limited to those that are likely to pass the specification, resulting in savings in transport costs, in testing the samples, and in redundant testing of samples that prove to be unsuitable.

3.4.4 Estimating material quantity

An estimate of the quantity of each type of material in a borrow pit is required for overall project planning. Such an estimate can be determined relatively simply by:

(a) dividing the borrow area into segments, with simple shapes;
(b) determining the total area of each segment, making adjustments for rock outcrops, areas of unsuitable materials, etc.
(c) determining the average thickness of material in each segment from the trial pit profiles or as estimated from a calcrete probe;
(d) determining the approximate volume of the material in each segment (area of segment x average thickness of segment)
(e) adding the volume of material from all the segments.

3.5 Evaluation of Gravel Source (laboratory)

3.5.1 Laboratory testing

A wide range of laboratory tests have been devised to assess the various properties of the borrow pit materials for 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 and are discussed in Section 5.

3.6 Reporting

After completion of the materials prospecting exercise, a site investigation report should be produced which would typically comprise two parts, namely:

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

The factual report should describe concisely and accurately the sites investigated, the work carried out and the results obtained. The interpretation part would report on the analysis of the field and laboratory results together with recommendations for usage.

4. ENGINEERING PROPERTIES

4.1 Introduction

The engineering properties of calcretes depend, in a generalised manner, on two main factors:

- The nature of the host or parent material, i.e. whether it was clay or sand, and
- The stage of development of the materials, i.e. the extent to which it has been cemented or replaced or both by carbonate.

In view of the above, the properties of calcareous soils are dominated by those of the host soil whereas, at the other extreme, hardpan calcretes behave like limestone.

4.2 Peculiarities of Calcretes

As discussed in Section 2.4, apart from hardpan calcrete, most other road building calcretes can be regarded as being composed of a large number of small host soil-particles cemented together by the carbonate into larger, somewhat porous particles. These particles or aggregations may or may not break down during laboratory testing and under compaction. Moreover, the mineralogy of the cementing material and of the clay fraction is different to those of normal, temperate zone soils from which most geotechnical experience and many specifications have been derived.

As a result of the differences in mineralogy and clay fraction between calcretes and other more traditional, non-pedogenic road building materials, the former can be expected to exhibit certain differences in behaviour from those of traditional materials as summarised in Table 4-1.

Table 4-1: Differences between conventional and pedogenic materials

Property	Conventional (Crushed Rock Base, River Gravels, Glacial Outwash)	Pedogenic (Laterites, Calcretes, Ferricretes, Silcretes)
Climate	Temperate to cold	Arid, tropical, warm temperate
Composition	Natural or crushed with fines	Varies from rock to clay
Aggregate	Solid, strong rock	Sometimes porous, weakly cemented fines
Fines	Rock particles with or without clay	Cemented, coated and aggregated clay and/or silt particles.
Clay minerals	Mostly illite or smectite	Wide variety, e.g. palygorskite, halloysite
Cement	None (usually)	Iron oxides, aluminium hydroxide, calcium carbonate, etc
Chemical reactivity	Inert	Reactive
Grading	Stable	Sensitivity to drying and working
Solubility	Insoluble	May be soluble
Weathering	Weathering or stable	Forming or weathering

Consistency limits	Stable	Sensitive to drying and mixing
Salinity	Non-saline	May be saline
Self-stabilisation	Non-self stabilising	May be self-stabilising
Stabilisation (cement	Increases strength	Usually increases strength
Stabilisation (lime)	Decreases plasticity	Usually decreases plasticity and/or increases strength
Variability	Homogeneous	Extremely variable

Some of the peculiarities of calcretes manifest themselves in ways which make them exhibit certain differences in behaviour from those of traditional materials. For example:

- In traditional soil mechanics it is usually assumed that all the water is outside the particles, whereas porous calcrete aggregates retain moisture and this affects conventional moisture content and Atterberg limit determinations.

- Palygorskite, which is the dominant clay in many calcretes (Netterberg, 1969, 1971; Watts, 1980), has approximately the same plasticity index as some smectites (present in expansive Vertisols), but has a non-expansive lattice and a hollow needle-like shape, instead of the usual flaky particle shape of most other clays.

- Palygorskite has the lowest shrinkage limit and dry density and the highest optimum moisture content and shear strength of all the clays, while its compressibility coefficients are comparable to those of illite (Hough, 1969).

Some of the engineering properties of calcrete which are noteworthy, particularly with regard to the specification for their use in road construction and their performance in service include (Netterberg, 1969):

(1) Soil constants

(a) Calcretes plot on both sides of the Casagrande A-line chart. They tend to possess higher Liquid Limits and Linear Shrinkages relative to their Plasticity Index than other soils.

(b) The Linear Shrinkage of calcretes is often less than the commonly assumed value of half the Plasticity Index while the Shrinkage Limit is often higher than the Plastic Limit and the swell is relatively low even when the Atterberg Limits are high

(c) The above properties of calcretes tend to cast doubt on the usual interpretation of the Atterberg Limits and/or other test methods employed when applied to this material. .

(2) Particle specific gravity

(a) The solid-particle specific gravity does not differ greatly from other soils. Owing to particle porosity, the bulk-particle specific gravity may, however, be appreciably less than the specific gravity of solids, and as the bulk specific gravity also appears to vary with particle size, the reliability of a number of common tests is reduced.

(b) Calcretes are prone to yield apparently poor gradings by weight, with an excess of fine sand and a deficiency of coarse sand, generally coupled with a high fines content. However, *despite their apparently poor gradings and Atterberg Limits, they often yield good CBRs and low CBR swell.*

(3) Self-cementation

(a) Some calcretes possess the ability to undergo self-hardening and has been reported widely in practice. However, conclusive evidence of this happening under a bituminous surfacing is still lacking although this phenomenon is compatible with the known origin of the material and large increases in CBR have been obtained in the laboratory after a number of wetting and drying cycles.

(4) Chemical stabilisation

(a) Some calcretes contain amorphous silica which reacts rapidly with lime to form cementitious bonds. This has implications in practice in terms of the need to compact lime stabilised materials in a relatively short period of time in order to attain the necessary density before hardening of the admixture begins.

(b) The usual rule that clayey materials stabilise best with lime, and sandy materials best with cement, does not hold for calcretes and each calcrete must be treated on its own merits. Calcretes with high amorphous silica contents yield higher strengths more rapidly when stabilised with lime than with cement.

(5) Soluble salts

(c) Some calcretes may contain highly soluble salts which, in road pavements, tend to migrate to the top of the base, crystallise there, and if present in excess, cause blistering of the surfacing and loss of density and cohesion of the upper base, leading to problems including cracking, scabbing and potholing.

(d) Conductivity and durability testing of proposed base materials should be carried out to detect the presence of salts in the material (and testing surface

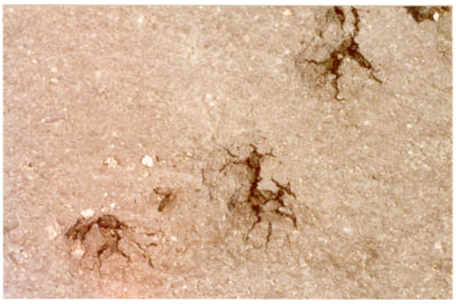


Photo 4-1: Salt damage due to high soluble salt content of the calcrete base.

Photo 4-2: Example of severe distress to a runway surfacing due to salt damage

4.3 Typical Calcrete Properties

Table 4-2 which, although based on data collected at the time of the initial reserach work on calcretes in the late 1960s (Netterberg, 1969) is nonetheless, broadly indicative of the main road-making properties of the basic calcrete types found in the Southern African region.

Table 4-2: Summary of typical calcrete properties

Material type	Total carbonate[1] as $CaCO_3$	Grading Modulus	Classification			Mod. AASHO Soaked CBR %	< 0.425 mm fraction			ACV %	10% FACT kN	Workablity
			AASHTO M145	Group Index	Unified		PI[1,2] %	Bar LS %	Sat. paste Elec. Cond[1,2] S/m @ 25°C			
Calcareous Soil	1-10?[4]	Variable	Variable	Variable	Variable	Variable	Variable	Variable	Variable	Variable	Variable	Variable
Calcified sand	10? --- 50	1.5? --- 1.8?	A-1-b to A-2-7	0-2	GP-GF? To SF-GF?	25? To 60?	NP - 20	1 - 9	0.2 – 0.3	35? --- 55?	18? --- 70?	Doze-rip
Calcified gravel	10? --- 50	1.8?	A-1-a To A-1-b	0-1?	GW To GF?	> 80?	<8?	< 3	< 1?	25? --- 35?	70? --- 135?	Rip?
Powder calcrete	70 --- 99	0.4 --- 1.5	A-2-4 To A-7-5	0-13	ML To GF	25? To 70?	SP – 22	1 – 11	1 – 21	33? --- 55	18 --- 90?	Doze-shovel
Nodular calcrete	50 --- 75	1.5 --- 2.3	A-1-a To A-6	0-3	SF-GF To GP	40 --- > 120	NP – 25	1 – 12	0.2 – 7.4	20 --- 57	9 --- 178	Doze-shovel
Honeycomb calcrete	70 --- 90	---	Rock?	---	Rock?	> 80?[3]	SP – 8?	1 – 3	0.1 – 1?	16 --- 35	80? --- 205	Rip and grid
Hardpan calcrete	50 --- 99	---	Rock?	---	Rock?	10? To > 100[3]	NP – 7	1 – 3	0.1 – 0.6	19 --- 33	27 --- 196	Rip – blast
Calcrete boulders	50 --- 99	---	Boulders	---	Boulders	>100[3]	NP - 3	1 - 2	0.1 – 0.2	20 --- 33	98 --- 205	Rip and crush

Notes: 1 – Without the loose soil in the large voids in honeycomb and boulder calcrete
2 – On the 0.425 mm fines produced after 500 revolutions in the Los Angeles test in the case of honeycomb, hardpan and boulder calcretes
3 – Crusher run
4 – Up to 50% when many nodules present

5. TEST METHODS AND SPECIFICATIONS

5.1 Introduction

In general, calcretes are among those materials which are most sensitive to changes in the test standards employed and results obtained. Materials specifications derived by one test standard (e.g. AASHTO) cannot therefore be assumed to be the same when another test standard (e.g. BS) (Pinard and Netterberg, 2012). In this regard, it is noteworthy that the initial research carried out in Southern Africa in the 1960s (Netterberg, 1969) was based on TMH1 soil test standards which are generally similar to AASHTO whilst those carried out by other researchers (e.g. Toole 1986; Greening and Rolt, 1996) are based on British Standards. Thus, materials specifications developed from these two test standards will not be comparable, particularly due to the sensitivity of calcrete to the test method employed

5.2 Influence of Test Methods on Calcrete Properties

In the case of calcretes, they differ from most roadbuilding materials in that they have an unusual composition and may exhibit unusual properties, including their high specific surface area and the degradation that can occur during handling. These properties need to be carefully considered when carrying out certain tests.

Some of the most significant differences in test methods which yield very different results include (Pinard and Netterberg, 2012):

1. The Liquid Limit (LL) and, hence, Plasticity Index (PI) of soils determined from the BS LL which, all other factors being equal, yields LL and PI results 4 units higher than the ASTM/AASHTO-type LL device.

2. There are significant differences in grading results depending on whether dry or wet sieving procedures are followed. Although both procedures are catered for in the standard test procedures, dry sieving should only be used for materials containing little or no silt or clay. In all other cases, wet sieving should be mandatory.

3. The CBR of soils determined from the BS and AASHTO tests which, due to higher 5.08 mm penetration depth at which the CBR is measured, produces CBRs that are approximately 30% higher than the TMH1 testing standard in which the CBR is measured at a penetration depth of 2.54 mm.

4. Due to the test procedure requirement of not compensating for oversize material in the sample preparation for CBR testing, the BS tests would yield lower CBRs than the TMH1 and AASHTO test which does compensate of oversize in the test sample.

5. When both the penetration depth at which the CBR is measured and the manner of compensating for oversize material are considered, the use of the BS 1377 test will produce in practice, i.e. in the pavement where particle sizes larger than 20 mm are allowed (up to 40% on the 20 mm sieve) far superior quality material to that produced when applying the TMH1 and AASHTO CBR testing standards.

5.3 Selection of Test Methods

5.3.1 Material classification

If the proposed, "relaxed" calcrete specifications given in Tables 5-1 and 5-2 are to be applied, then visual and chemical tests, as described below, are required to determine whether or not the material is a calcrete and, if so, whether these relaxed specifications are appropriate.

A. Necessary tests

1. ***Visual classification*** as apparently a calcrete, and classification as per Section 2.5.

2. ***Carbonate content*** (determined by means of a carbonate or neutralisation-type analysis and <u>not</u> a calcium analysis.

   a. If $CaCO_3$ equivalent of whole grading ≥ 50% then material is a calcrete and not just a calcrete or calcified soil.

   b. If $CaCO_3$ equivalent of < 425 micron fraction prepared for Atterberg limits ≥ 10% then relaxations of LL and PI can be considered, even if only a calcified soil.

B. Desirable tests

1. ***Mineralogy of soil fines***: Preferably XRD analysis of < 425 micron fraction prepared for Atterberg limits: If dominant clay mineral is palygorskite and/or sepiolite and not smectite then added confidence given to any relaxations on LL and PI.

2. ***Shrinkage factors:*** Preferably determine shrinkage factors from the LL on the < 425 micron fraction prepared for Atterberg limits: if SL > PL then added confidence given to any relaxations of LL, PI and LS.

3. ***Potential self-stabilisation:*** Preferably determine the soaked CBR, swell and PI (even just at Mod. AASHTO compaction) after five wetting and drying cycles (Netterberg, 1977): If the soaked CBR increases substantially after cycling and swell and PI decrease, further confidence given to any relaxations, even CBR.

5.3.2 Standard tests

Although it is necessary to employ a wide range of tests to fully assess the quality of a calcrete for road construction, it is possible to reduce tests to a minimum when making a preliminary appraisal of a large number of samples. The "essential" tests to be undertaken initially are those that evaluate those properties of calcrete that influence its behaviour in a road. These properties are:

- Grading modulus
- Percentage passing the 0.425 mm sieve
- Bar linear shrinkage
- Aggregate Pliers value.

From experience of the calcrete types in the Southern African region (Lawrance and Toole, 1984), the product of the linear shrinkage and percentage passing the 0.425 mm sieve gives a reasonable estimate of the CBR of the sample, as shown in Figure 5-1. Once such a correlation is established in any country from the results of previous laboratory tests, then this would eliminate the need to carry out the less convenient CBR test at the borrow pit appraisal stage.

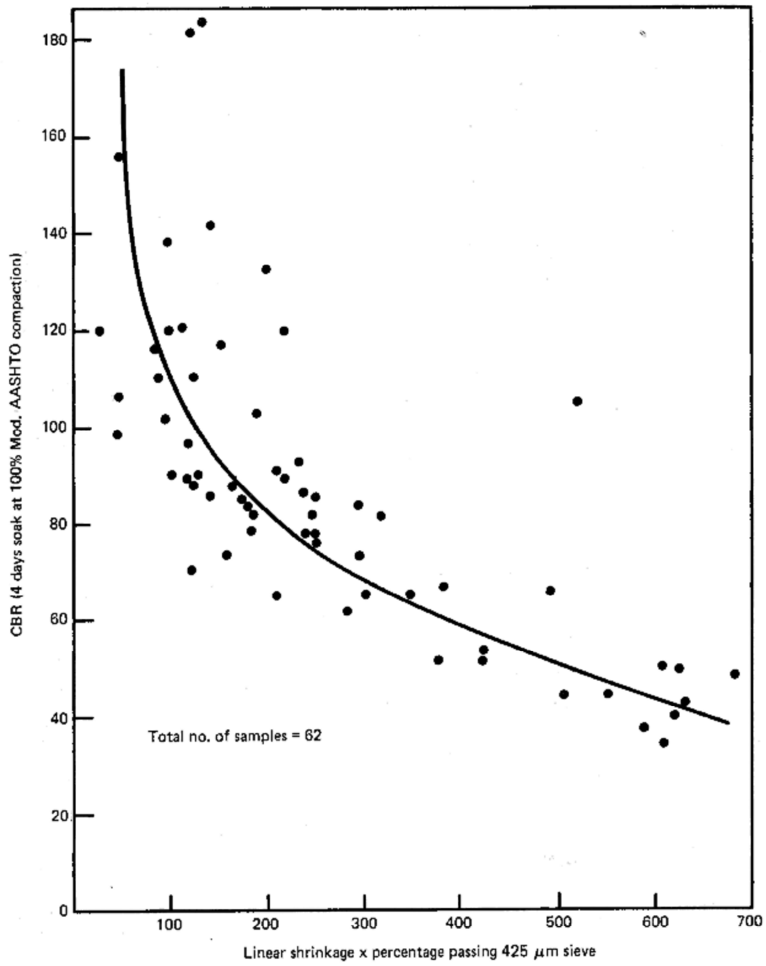


Figure 5-1: Relationship between CBR and product of Linear Shrinkage and percentage passing 0.425 mm sieve.

The full range of laboratory test that would be required to assess the suitability of a calcrete for use in road construction would necessarily be those indicated in the specifications given in Table 5-1, 5-2 and 5-3. These include:

.

1. **Visual description:** including colour of fines and coarse aggregate, and strength of coarse aggregate.

2. **Soil constants:** LL, PI and LS (preparation of soil fines by wet method).

3. **Soluble salts:** Saturated pasts EC and saturated paste pH, with pH done on the same paste after the EC test.

4. **Particle size distribution:** Sieve grading (wet method). Consider also doing by dry method to assess relative breakdown.

5. **Compaction characteristics:** Mod. AASHTO, OMC and MDD

6. **Soaked strength and potential expansion after compaction:** Soaked CBR and swell at three efforts, also reporting soaked moisture content by weighing the moulds or by a separate determination on the whole material removed form the mould.

7. **Unsoaked strength after compaction:** Preferably unsoaked CBR at OMC, preferably at all three efforts, but at least at effort appropriate for proposed use – e.g. Mod. AASHTO for base. (N.B. After compaction the moulds are not soaked, but sealed in plastic bags overnight to dissipate compaction stresses and penetrated without soaking the next day. Report the moisture content at test by weighing the mould.

8. **Coarse and fine aggregate strength and durability and potential to increase in PI after compaction and/or during service.** Durability Mill test with full gradings as well as LL, OI and LS on all treatments.

9. **Strength of coarse aggregate:** Dry and soaked 10% FACTand/or Durability mill test. (N.B: The > 13 mm fraction can be lightly crushed < 13 mm and the 9-13 mm fraction of this added to the 9-13 mm to give a better average aggregate strength. Report what is done.

5.4 Specifications

5.4.1 Bitumen surfaced roads

Despite their non-compliance with traditional specifications, calcretes have been used successfully as gravel wearing courses and in all layers of paved roads in a number of countries in the region. Generally, traditional specifications are of limited applicability and, instead, recourse must be made to the use of performance-related specifications. Fortunately, the research work carried out in the region, notably initially South Africa and Namibia and, latterly, Botswana, Zimbabwe and Kenya has allowed such specifications to be developed. However, as indicated above, these specifications have been developed on the basis of different test standards and, as a result, are not directly comparable. Nonetheless, typical, traffic related specifications developed on the basis of TMHI test standards and BS standards are presented in Tables 5-1 and 5-2 respectively.

The specifications in Table 5-1 have been derived by means of an investigation of six roads in South Africa and Namibia then varying in age from six years to more than 33 years (Netterberg, 1969). The specifications in Table 5-2 are based on a long term study of the behaviour of samples of the four main types of calcrete in the road bases of a full scale experimental trial constructed in Botswana in the mid-1980s and designed to develop methods for their use (Greening and Rolt, 1996).

Table 5-1: Recommended specifications for bitumen-surfaced calcrete bases (Netterberg, 1982)

Property[1]	Expected traffic category, vpd, <20% > 3 tonnes			
	< 500	500 - 1000	1000 - 2000	2000 - 5000
Max. size (mm)	19 – 38	38 – 53	38 – 53	38 – 53
Min. Grading Modulus[2]	1.5	1.5	1.5	1.5
% passing 0.425 mm by mass	15 - 55	15 - 55	15 - 55	15 - 55
Max. Liquid Limit (%)	40	35	30	35
Max. Plasticity Index (%)	15	12	10	8
Max. Bar Linear shrinkage (%)	6.0	4.0	3.0	3.0
Max. Sat. Paste Elec. Cond.[3] (S/m @ 25°C	0.15	0.15	0.15	0.15
Max. Group Index	0.5	0.0	0.0	0.0
Worst ASTM D 3282 class	A-2-6	A-2-4	A-2-4	A-2-4
Max. Bar Lin. Shrinkage x % < 0.425 mm	320	170	170	170
Min. Dry 10% FACT[4] value (kN) or	50?	80?	110?	110?
Max. Dry Aggregate Crushing value (%)	40?	35?	30?	30?
Min. Soaked/Dry 10% FACT value (%)	50?	50?	50?	50?
Max. Water Absorption (%)	-	-	5?	5?
Min. Dry Aggregate Pliers Value (%)	50?	60?	70?	70?
Min. 98% Mod. AASHO 0.1" CBR (%)	60	80	80	80
Min. 98% Mod. AASHO 0.2" CBR (%)	80	80	100	100
Max. Mod. AASHO Swell (%)	0.5	0.5	0.5	0.5
Min. relative Field Comp. % Mod. AASHO	98	98	98	98

Notes: 1 – Test methods must be comparable with those of the South Africa Dept. of Transport
2 – Grading modulus = cumulative % retained on 2.0, 0.425 and 0.075 mm sieves
3 – On dry-screened < 6.7 mm fraction; or on 0.20 dry-screened < 0.425 mm fraction
4 – All coarse aggregate tests carried out on a mixture of 9.5 – 13.2 mm material prepared by screening and that prepared by crushing the 13.2 mm aggregate.

Table 5-2: Recommended specifications for calcrete bases (Greening and Rolt, 1986)

Property	Maximum traffic (ESA x 10^6)				
	0.3	0.5	0.7	1.0	1.5
Maximum particle size (mm)	75	75	75	75	75
Max % passing 0.425mm sieve	80	65	65	45	30
Max % passing 0.063mm sieve	30	30	25	20	15
Maximum liquid limit	60	55	50	40	30
Maximum plasticity index	25	20	15	12	10
Maximum linear shrinkage (%)	12	12	8	6	5
LS x % passing 0.425mm sieve	800	700	550	400	200
LS x % passing 0.063mm sieve	300	300	300	200	100
Minimum soaked CBR(1)	40	50	60	60	80

Notes: 1 – At BS heavy or Mod. AASHO compaction.

5.4.2 Gravel wearing course

Aggregate strength has been to be one of the greatest single factors determining the performance of calcrete roads (Netterberg, 1982). In addition, unsurfaced calcrete roads can tolerate poorer gradings and higher Plasticity Indices than other materials. Based on investigation of over forty variably performing calcrete wearing courses in South Africa and Namibia, a suggested specification has been developed (Netterberg, 1982).

Table 5-3: Recommended specifications for calcrete wearing course

Property[1]	Per cent by weight passing 0.425 mm sieve			
	20 - 40	**41 - 50**	**51 - 60**	**61 - 75**
Maximum size (mm)	53	53	53	38
Liquid Limit (%)	30 – 65	22 – 48	22 – 40	18 – 36
Plasticity Index (%)	9 – 22	7 – 23	5 – 13	8 – 13
Bar Linear Shrinkage (%)	2.0 – 9.5[2]	2.7– 9	2.0 – 5.5[2]	2.0 – 5.0
Lin. Shrinkage x % < 0.425 mm	70 – 340[3]	130 – 395	100 – 320[3]	130 – 330[3]
Min. Aggregate Finger value (%)	65	60	35	40
Min. Aggregate Pliers value (%)	20	20[4]	15	-

Notes: 1 – Test methods to be comparable with South African DOT, 1970
2 - Linear Shrinkages between 2.0 and 2.7 may cause slight looseness and dust.
3 – Values between 70 and 100 may cause slight looseness and dust.
4 – A minimum APV of 14 is permissible if the APV > 75.

As indicated in table 5-3, a wide tolerance in the grading is permitted, but the soil constants allowable depend on the amount passing the 0.425 mm sieve while an aggregate strength is required on the coarser calcretes.

5.4.3 Surfacing aggregate

Performance data from trials in Botswana (Toole, 1984; Woodbridge and Slater, 1995) have enabled a traffic-based specification to be developed for using certain types of the harder calcretes for surfacing aggregate. This specification precludes the use of calcrete-rich aggregate on all but the lowest trafficked roads but permits the use of silcrete-rich aggregate on all roads. This specification is presented in Table 5-4.

Table 5-4: Recommended specification for calcrete surfacing aggregate

Traffic (ADT)	10% FACT (kN dry)	AIV (% Dry)
< 200	150	24
> 200	180	21

To exclude the use of calcrete-rich aggregates susceptible to significant weakening on wetting, it is recommended that the soaked TFV and AIV should be at least 50% of the dry value for the higher traffic category. Also, other test criteria, such as Water Absorption (no more than 2%) and Soundness (no less than 95%) could be used as guides to indicate the durability of the aggregate.

6. USE OF CALCRETES

6.1 Introduction

Following the research and investigations carried out in the Southern African region in the past forty years, new, more appropriate, performance-related specifications have been developed as indicated in Section 5. These specifications permit the use of calcrete in all layers of a road pavement, as fill, as a wearing course and as surfacing aggregate. The degree of cementation is the main factor which determines the suitability of calcrete for specific use in road construction.

6.2 Lessons learned

Experience gained from the design and construction of road trials in the region has enabled the following recommendations to be made:

(a) Natural calcretes

- To use calcretes satisfactorily, great care is needed in quarrying, sampling and testing.
- Due to variability of materials, pre-stockpiling is recommended.
- Due to particle breakdown, the results of laboratory compaction tests should be treated with caution.
- Compaction trials should be carried out to match plant, moisture and material type.

(b) Mechanically stabilised calcrete

- Caution should be exercised if planning to mechanically stabilise calcrete with sand. The amount of sand added to calcrete should not exceed about 30% if instability of the admixture is to be avoided.

(c) Chemically stabilised calcrete

- Caution should be exercised if planning to stabilise calcrete with lime or cement in terms of potential problems with carbonation, especially with fine-grained calcrete and calcified sand, which could lead to premature distress.

(e) Unsealed shoulders

- Calcareous sand is unstable on the shoulders and should be avoided unless sealed.
- Powder calcrete is subject to rapid erosion.

(f) Salt damage

- Highly soluble salts, such as sodium chloride, may be present in some calcretes. salts can migrate to the surface and disrupt the bond berween the prime and bituminous surfacing. Calcretes with soluble salt contents of >0.1% can be problematic.

6.3 Use in Mozambique

Recent experience on projects implemented by ANE in Inhambane has shown that calcrete can be used both as base material when blended with local sand and in graded aggregate seals with a soft bituminous binder. The admixture of sand to calcrete improves the material properties by reducing plasticity and improving stability, thus reducing the damaging effect of soluble salts in the calcrete and improving workability to achieve the required density. Nodular calcrete has also been blended with red sands to provide an effective, armoured wearing course.

It can be expected that there will be more effective and efficient utilisation of calcrete in road construction in Inhambane Province after the various deposits are evaluated and their engineering properties determined. This will be facilitated by the development of GIS database for calcretes which is one of the key outputs of the project.

7. SUMMARY

1. Calcrete deposits occur in many countries in the Southern African region. Their geotechnical properties can vary from a soft weakly cemented sand to a hard rock and these would determine the suitability of a calcrete for use in road construction.

2. Calcretes possess a chemical and mineralogical composition which differs greatly from that most other road materials and can therefore be expected to exhibit some unusual properties.

3. For engineering and most geological purposes the calcretes of Southern Africa can be classified into six basic types, namely: calcified soils, powder calcretes, nodular calcretes, honeycomb calcretes, hardpan calcretes and boulder calcretes. This classification represents particular stages of calcrete development and each stage differes significantly in its engineering properties form each of the other stages.

4. Calcretes of road making quality generally occur in the drier areas of Southern Africa where the annual rainfall is less than about 550 mm or the Weinert N-value is more than 5.

5. Calcretes in Southern Africa can be divided into two basic types: (1) ground water calcretes formed by deposition of carbonate in the host material above a shallow water table, and (2) pedogenic calcretes which are formed by downward leaching of carbonate from the upper soil horizons and its deposition in the lower regions.

6. Methods of prospecting for calcretes include the combined use of various remote sensing techniques including black and white air photos (stereo), natural colour air photographs (stereo), and landsat satellite imagery as well as topographic maps, soils maps and plant indicators aided by the ground use of a calcrete probe.

7. The engineering properties of a calcrete depend on the nature of the host material and the extent to which it has been cemented and replaced by the carbonate. The clay minerals most commonly present are palygorskite and sepiolite which possess a number of unusual engineering properties not shared bt other clays.

8. Calcretes are prone to have higher apparent Liquid limits, Shrinkage Limits and Plasticity Indices than most other materials of the same Linear Shrinkage.

9. Calcretes are prone to yield apparently poor gradings by weight, with an excess of fine sand and a deficiency of coarse sand, generally coupled with a high fines content. Despite their poor gradings and Atterberg Limits, they often yeld good CBRs and low swell.

10. The properties of lime stabilised calcretes are controlled by their amorphous silica content with high amounts yielding higher strengths more rapidly when stabilised with lime than with cement.

11. Some calcretes may contain deleterious amounts of soluble salts which can cause disintegration of the upper base and blistering of a bituminous surfacing. Conductivity and durability testing should therefore be carried out testing as a preventative measure.

12. The combined difficulties in determining the Liquid Limit and Plastic Limits of calcrets and their statistically high Liquid Limits, Shrinkage Limits and Plasticity Indices in comparison with their Linear Shrinkages suggest that the Liquid Limit and Plasticity Index tests on calcretes tend to yield results which are unrealistically high and generally unreliable.

13. Linear Shrinkage is the only soil constant which is considered to be reliable in regard to calcretes and should be regarded as the primary means of control in place of the Liquid Limit and Plasticity Index test.

14. The product of the Linear Shrinkage and percentage passing the 0.425 mm sieve gives a good estimate of the CBR of the sample.

15. Performance related revised specifications derived from research work in the region have been developed for all classes of calcrete road materials for various categories of traffic loading.

16. Depending largely on their stage of development, calcrete can be used in a variety of ways in road construction that range from surfacing chippings, through base and subbase to gravel-road wearing courses and fill.

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