Prospecting for calcrete road materials in South and South West Africa

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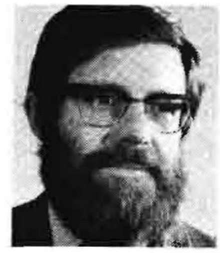

Synopsis

The location of calcrete deposits for use as road construction material is discussed. It is concluded that a knowledge of the fundamental factors controlling the formation and distribution of calcretes, together with the combined use of airphoto interpretation, plant indicators and a certain rapid-probing device should be used, in addition to the more usual techniques of augering and pitting.

Samevatting

Die opsporing van kalkreetafsettings vir gebruik as padboumateriaal word behandel. Die gevolgtrekking is dat kennis van die grondliggende faktore wat die vorming en verspreiding van kalkrete beheer, tesame met die gekombineerde gebruik van lugfoto-interpretasie, kenmerkende plantegroei en 'n sekere snelpeil apparaat gebruik moet word bykomstig tot die meer gewone tegnieke soos awegaarboorwerk en die grawe van toetsputte.

Frank Netterberg, *BSc, PhD, C Eng, MICE, MIHE, MAEG, FGS, was educated chiefly at Selborne College, East London, and graduated BSc in geology at the University of Cape Town in 1960 and BSc Hons in engineering geology at the University of the Witwatersrand in 1963. The latter university granted him a PhD degree in 1970 for his work on the geology and engineering properties of calcretes, carried out while at the National Institute for Road Research on secondment from Kantey and Templar. For this work he also received the Holdredge Award of the Association of Engineering Geologists in 1975. He has published a number of papers, chiefly on pedogenic materials and salt damage to roads, and has worked for mining companies, consulting engineers in Cape town and in London, and has lectured and consulted in engineering geology in Johannesburg. At present he is employed by the National Institute for Transport and Road Research where he is engaged in applied research into the engineering geological problems of roads. He is a past chairman of the South Africa Section of the Association of Engineering Geologists.*

Introduction

Calcretes are common features of the arid and semiarid zone of Southern Africa and at present probably constitute the most widely used class of road material in the subcontinent south of latitude 17°S. Windblown sands apart, calcretes often constitute the sole source of road construction material in the vast area underlain by the Kalahari Beds. In spite of this they can be among the most difficult of materials to locate, often occurring in small deposits overlain by sand. This paper presents the results of an investigation into methods of locating calcretes for road construction in the Republic and South West Africa.

Fundamental factors controlling the distribution of calcretes

The first fundamental fact which the calcrete prospector must realize is that calcretes are not sedimentary rocks but soils. They are in fact members of that most useful group known as *pedogenic materials* and have been formed by the near-surface cementation and replacement of a pre-existing host soil by carbonate precipitated from the soil water or ground water. Their distribution is therefore not governed solely by geology, but by the five soil-forming factors of climate, topography, parent material, biological factors and time, geology being merely a subfactor of parent material[1].

Climate

In Southern Africa sufficiently well-developed calcretes occurring in sufficient quantities to be economically workable for any purpose generally only occur in areas receiving a mean annual rainfall of less than about 550 mm[1,2]. As the carbonate part of calcretes is slightly soluble in water only very weakly developed types are generally able to exist in the wetter areas, while in the rare cases where further development has been possible the quantities formed are usually unworkably small. By increasing the evaporation rate and decreasing the solubility of carbonate, higher temperatures increase the amount of rainfall required to achieve the same degree of leaching. In the hotter areas of Southern Africa economic calcrete deposits can occur under a maximum rainfall of about 625 mm. Exceptions to this rule are very rare.

Disintegration is the dominant form of weathering where Weinert's climatic N-value is greater than five and decomposition the dominant form where N is less than five[3]. Since the plasticity of a calcrete depends to a large extent on the plasticity of the host material, the plasticity index of a calcrete in the residual Stormberg basalt soils of the Springbok Flats (N about three?) will be higher than that of one at the same stage of development in the residual Stormberg basalt soils of the area east of Mariental (N about 30).

Due to the increased depth of leaching there is some tendency for the depth at which calcrete occurs to increase with rainfall[1], yielding some idea of the prospecting depth required under any given rainfall.

Other factors which affect the macro- or micro-climate close to the ground will also affect the distribution of calcrete. One such factor appears to be the hydrogen sulphide gas which is blown inland along the coast of parts of South West Africa and appears to have converted the coastal calcretes to gypsum or gypseous calcretes[4], a most undesirable feature as far as cement or lime stabilization of these materials is concerned.

Topography

Calcretes generally *form* on flattish land or in depressions where moisture, which may already possess carbonate in solution, is able to accumulate, weather the underlying material, release calcium and magnesium and, eventually, be evaporated in-situ. The rate of runoff and mechanical erosion on steep slopes is too rapid for much calcrete to form. Calcretes forming cliffs like the Weissrand near Mariental, or high ground, are invariably fossil and are themselves being eroded. In this connection calcretes should not be confused with cliff limestone *(drupkalk)*.

Calcretes may often be found by a study of their relation to the topography, for example hardpan calcretes often occur on rises or cementing alluvial or pan terraces, and the calcretes with the hardest aggregate, best grading and lowest plasticity index will normally be found on rises or slopes. Only a rather plastic calcareous or calcified soil with scattered nodules will usually be found in pan floors although the intermittent streams known as *omirimbi* in the northern part of South West Africa may possess a better-developed calcrete of the nodular type in their beds.

According to the theory of calcrete development, calcrete grows from a calcareous soil via a calcified soil, or nodular and honeycomb stage, to a hardpan and finally weathers to a boulder calcrete[1,5]. This sequence, not always fully represented, is often found in *omuramba*, river and pan sections, and an idealized section is shown in Fig 1. The decrease of plasticity index away from the centre is probably due to four factors:

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1. Washing of clay out of the banks into the centre.
2. Selective exclusion of fines from the growing carbonate fraction.
3. Weathering of the more active clay minerals to less active types by virtue of their favourable situation in relation to leaching and oxidation.
4. Cementation of clay particles into coarser silt and sand-sized particles.

As one prospects further up the bank of an *omuramba,* river or pan on the first terrace, the overburden thickness over the tufaceous hardpan may increase to a point which is beyond the range of a short hand auger or the rapid calcrete probing device[6], or the calcrete may even peter out altogether. One should not then be lured into thinking that this is the end of the calcrete deposit as the hardest material is yet to come and a hardpan or boulder calcrete of crusher-run quality may occur on the next terrace under a shallow overburden.

Fig 1 also applies in a more general way to the types of calcretes occurring on landsurfaces of increasing age, though these erosion cycles move relatively slowly so that it is possible to have several different types of calcrete on the same landsurface.

Drainage

This subfactor is so important, especially in areas of non-calcareous rocks or parent (host) materials, that it merits a discussion on its own.

In dune areas, for example Okavangoland, the south west Kalahari and parts of southern Owambo, calcretes are found in *streets,* and especially pans, between the dunes. Where the amplitude of the dunes decreases, for example north of the Gaza line in Okavangoland and just north of the Andoni flats in Owambo, the most pronounced depression (or the edges of it) usually contains the best-developed calcrete. This is probably due to two factors, of which the second is probably the most important:

1. Decreased depth to a calcareous source-rock.
2. Increased effective rainfall and inflow which allow deeper penetration and solution of carbonate, which may also contribute carbonate, and which bring in more fines, assisting in the production of a relatively impermeable horizon and a perched water table.

Aerial photographs illustrating these depressions have been presented by Caiger[7].

Calcretes developed or apparently developed over granite were found to be associated with either drainage lines (near Aus, west of Usakos, and north of Beit Bridge), basic intrusions (west of Usakos), limestone outcrops upslope (east of Usakos) or had been mechanically eluviated from an older calcrete plateau still existing in parts of the area (between Lüderitz and Aus).

The drainage factor probably entered into all of these cases to some extent; even the profiles developed over basic intrusions were generally in depressions. The importance of drainage is also clearly apparent by Van der Merwe's work on desert soils[8]. Drainage is not only important in the arid and semiarid zone. In the subhumid zone it is the bottomland soils that are most likely to be calcareous.

In general topography plays a large part in calcrete formation through its assistance in creating shallow perched or permanent water tables. In any area calcrete tends to be associated with water and the banks and terraces of all drainage features are good places to look for it. In some cases calcrete may only occur on one side of the drainage feature. Topography may also influence calcrete formation through its influence on the climate. Calcrete may only be found on the rain-shadowed side of a mountain, for example.

Parent or host material

While calcretes form by growing in an existing soil, this soil may or may not provide the carbonate. It may in fact merely act as a host material in which the carbonate is precipitated.

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. Calcrete is not likely to occur over rocks like sandstone and granite if the drainage is unfavourable, even in a favourable climate. Calcretes also sometimes mark faults and dykes, probably in many cases largely due to shallow water table conditions.

A thickness of soil cover within certain limits appears necessary for significant calcrete formation. If the soil is too thin, little rainwater can be retained and calcrete formation is limited to that in cracks and fissures in the underlying rock. If it is too thick and the water table is deep, the soil will absorb all the water and prevent or retard weathering and dissolution of the underlying rock.

A good example of the influence of non-calcareous soil-cover thickness appears to be the case of the Grootfontein-Tsumkwe road in South West Africa. Very little calcrete occurs between Kanovlei and Tsumkwe on this road but it is abundant around Tsumkwe. Borehole data show that Stormberg basalt comes within 13 m of the surface at Tsumkwe but drops to a depth of 300 m towards Kanovlei.

One effect of the texture of the soil cover or the parent material is through its effect on the leaching rate. The more impermeable

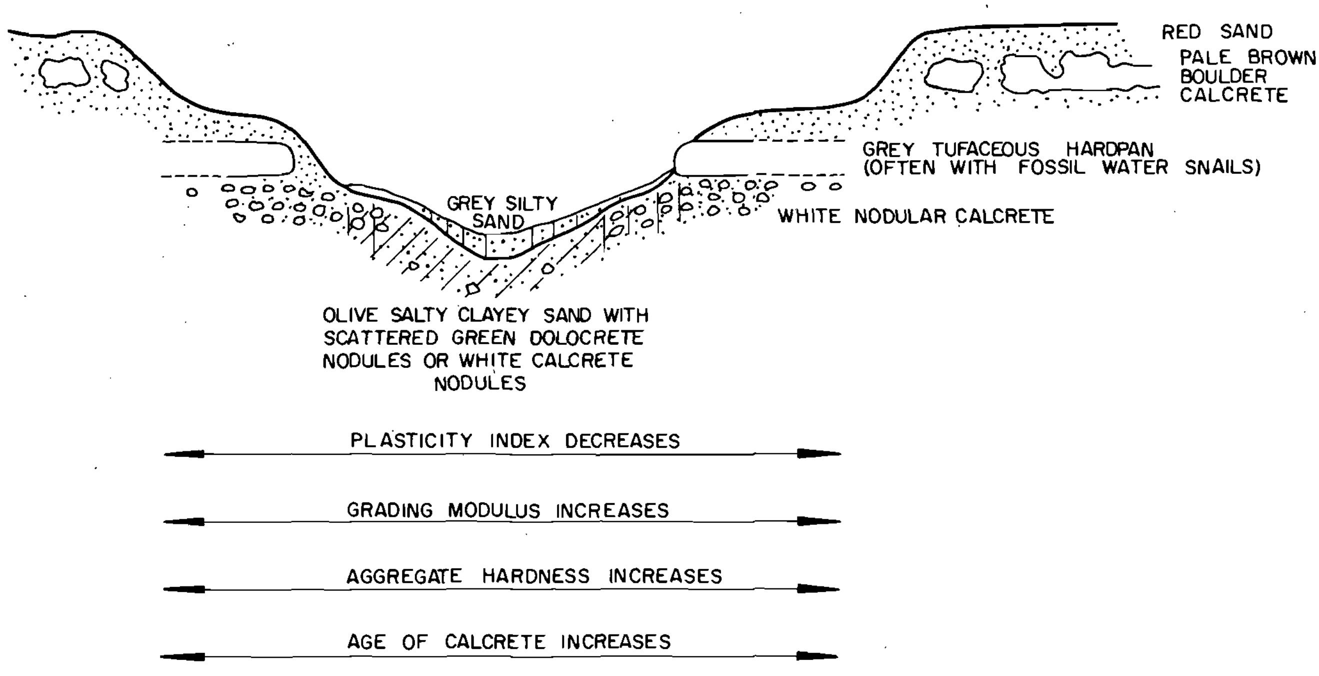

Fig 1: Idealized section across calcrete-containing depression

the soil, the more humid the climate under which the calcrete can form or survive and the shallower the calcrete horizon is likely to be. Under the same climate the rate of calcrete development would be slower in a less permeable soil than in a more permeable one.

A second effect of texture is on the actual type of calcrete formed and its plasticity. Calcretes developed in clays will possess high plasticity while those developed in sands will be non-plastic. In general the plasticity index of a calcrete deposit *increases* with depth.

If these principles are applied to the soil map of Southern Africa[8,9] 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 and subdesert soils except those on calcareous crusts (the calcareous crusts are actually hardpan calcretes). Heavy clay soils like vertisols would be the best types in which to search for calcrete in the subhumid zone. These calcretes are likely to be rather plastic.

Biological factors

Vegetation plays a very important role in calcrete formation through transpiration but the best use of vegetation in calcrete prospecting is through the recognition of calciphilous plants, which will be dealt with in a separate section. The only generalized statement that can be made at this stage is that calcretes which are not obviously fossil tend to be associated with bush and grass rather than trees.

The only other biological factor thought to play a rôle in calcrete formation is termites and, again, the recognition of white termitaries on aerial photographs is the best way of using them.

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. The oldest calcretes are therefore the hardest, the strongest and possess the best grading and lowest plasticity index (Fig 1). 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 or more of the other pedogenic factors (particularly climate and drainage) change with time, a fossil calcrete may result and many calcretes in Southern Africa are in fact fossil. There appear to have been definite periods of calcrete formation during geological history and some idea of the ages of the calcretes in his area in relation to the other strata and the topography can be of considerable value to the prospector.

The ages of calcretes in Southern Africa have been grouped into five categories[10]: pre-Pliocene, upper Pliocene (probably 2 to 5.10^6 years old), uppermost Middle Pleistocene (perhaps 10^5 years old), uppermost Upper Pleistocene (probably 10 to 20.10^3 years old) and Recent (younger than about 10^3 years old). The most widespread calcretes of importance to the roadbuilder 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 not outcrop can be extremely difficult to locate. Empirically it is, however, found that even fossil calcretes obey the climatic correlations mentioned and do not occur over non-calcareous rocks like granite and the Waterberg and Table Mountain sandstones unless the drainage was once favourable. Fossil drainage features are just as useful sources of calcretes as are present-day drainage features and are often detectable on airphotos. They usually yield well-developed calcretes. The fossil drainage-line calcretes at Operet on the new Tsumeb-Ondangua road are among the best-developed calcretes yet found and stood out clearly on airphotos.

The best calcretes in the Ondangua area are associated with the most pronounced drainage lines and seem to represent old *oshana* (vague, intermittent stream) lines. The elements of the airphoto pattern of these two occurrences are given in Table 1 and stereopairs or triplets are available[1]. The Operet fossil drainage-line calcretes represent former courses of the Omuramba Ovambo[11].

Some indication of the nature of the calcretes in a particular area may be obtained from a knowledge of the age of the landsurface on which they rest or form. The Kalahari Limestone (probably Pliocene in age) which forms the African erosion surface is extremely thick and indurated, and along the Weissrand has passed the hardpan stage and is disintegrating. The calcrete on the probably post-African surface east of Aus is much thinner and has only reached the honeycomb stage, but is also disintegrating, and neither of these two calcretes is forming today. Calcretes between Tsumeb and Namutoni are very well developed, while those between Namutoni and Ondangua are generally rather poorly developed.

Examination of a map of cyclic landsurfaces[12] shows that the Tsumeb-Namutoni area represents part of the African landsurface (late Cretaceous at the coast) and the Namutoni-Ondangua area one of the younger post-African Landsurfaces (Oligocene and Miocene at the coast). The reason for the paucity or absence of calcrete development in the weakly developed soils and the windblown sands in South West Africa is thus at least partly attributable to their very young age. Apart from other factors the shifting sands of the Namib, for example, have not yet had time to develop any soil horizons.

Calcrete maps

If materials are a consideration over a long route, before the route is fixed a calcrete map should be consulted. Several maps are available[2,13,14,15,16], the largest being on a scale of $1:5.10^6$ [1,14]. This latter map shows the regional distribution of calcretes of various types within Southern Africa. Its practical interpretation in terms of the availability of calcretes for road construction is as follows:

Group HA (hardpans always present): all types of calcrete construction material, including in some cases chips and concrete aggregate, will be readily available in the area shown as always possessing hardpans. The material will, however, often be difficult to work and natural calcrete gravels (nodular calcretes) will be difficult to find. Honeycomb calcretes may be useful alternatives. Calcretes will be practically the only type of conventional construction materials available.

Group HC (hardpan common): all types of calcrete construction material up to base and concrete aggregate are relatively common in areas shown as those in which hardpans are common. The calcretes are on the whole less indurated and thick than in the HA group, but good nodular calcrete gravels are more common.

Group HR (hardpans rare): the types of calcrete found in this group are similar to those found in the HC group but they are on the whole thinner, less well developed and less common.

Group NA (nodules always present): while scattered nodules are always present in the soil profiles of this group, nodular calcrete gravels will be difficult to find and will normally be of greater value for cement or lime manufacture. Plasticity indices are also usually very high and the material will usually only be suitable if stabilized or for use in unpaved roads. Calcareous and calcified weathered rocks in these areas usually have lower plasticity indices than the non-calcareous weathered rocks.

Group NR (nodules rare): the same remarks as for group NA apply to this group but any form of workable calcrete deposit is likely to be so rare and so valuable that its use as a road material will not normally be considered.

Group Gc (gypseous calcretes): gypseous calcretes and gypsums are relatively common in this group.

Group X (all calcification absent): no form of calcrete suitable for any purpose will normally be encountered in these areas. The strip along the west coast of the Republic and South West Africa is probably an exception and some of it may be incorrectly classified.

Further subdivision of any areas of particular interest may be made by an application of the soil legend on the calcrete map. For example, although the entire southern part of South West Africa is shown as being in the rare hardpan category (HR), the areas marked Ac Bd (rock debris and lithosols) will be poorer still in calcretes than the areas classified as lithosols (Bd Bf). The same would apply in the Cape Province while in the Transvaal nodules are much scarcer in the lithosol and fersiallitic zones (Bd Jd) of the Western Transvaal than they are in the pseudo-podsolic and vertisol soils (Fa Da) of the Orange Free State.

Once the prospector has gained some idea of what to expect he can use any geological, pedological or soil engineering maps of the general area on a larger scale to good account. The subsequent steps should involve airphoto interpretation and field work, discussed in more detail in the following sections.

Airphoto interpretation

Convential panchromatic photography

In recent years this method has proved to be invaluable in materials surveys. While workers may differ in their approach, agreement as to the value of this technique is unanimous. Aerial reconnaissance has also proved useful[17]. The location of calcretes by airphoto interpretation has been shown to work well in the *sandveld* of Okavangoland and the south west Kalahari[7,17,18] and in southern Owambo[11]. In areas outside the Kalahari Beds, however, and occasionally even in this area, airphoto detection and delineation of calcretes is more difficult and less reliable.

For example, it was found possible using airphotos to differentiate between calcretes of greater and lesser plasticity between Okaputa and Otavi[19] and to differentiate between shoulder quality and inferior material near Sukses, but not between Otjiwarongo and Okaputa[7]. The calcretes in the Vryburg area with high plasticity indices were developed over Dwyka shale, while those developed over dolomite possessed consistently lower plasticity indices[20]. Certain calcretes near Mariental could not be detected at all using airphotos[21] and it has been stated that calcretes are among the most difficult materials to locate and delineate by means of airphoto interpretation[7,22,23].

After establishing the airphoto pattern, 80 per cent success has been claimed in predicting the occurrence of further deposits of kankar (calcrete) in the alluvial plains of India[24]. The kankar was found to occur under gentle treeless slopes (grey on airphotos) surrounding similarly treeless depressions (dark). Drainage was poor and the land was either cultivated or covered by grass and used for pasture. This also describes well the setting of most of the younger calcretes within the area of Southern Africa covered by the Kalahari beds. A hard, thick, fossil calcrete, the Kalahari Limestone, frequently crops out around the edges of the Kalahari Beds and is indicated as HA on the calcrete map[1,14].

My experience with airphoto location of calcretes has generally been similar to that of other workers. In one experiment all known borrow pits for the proposed new Tsumeb-Namutoni road were plotted on the airphotos and, by looking for areas with similar airphoto patterns, 44 sites were suggested where further materials of similar quality should be found or where the existing borrow pits should be improved by extension to one side. The consulting engineers eventually dug trial holes at 21 of the sites. Of the 14 sites where calcretes of a certain quality were predicted, four were successful, three were completely unsuccessful, five yielded material somewhat inferior to that predicted and insufficient information had been recorded to classify the remaining three. Of the seven improvements suggested all but one were unsuccessful. The success rate in location of material in this case was therefore nine cases out of eleven (82 per cent), that of predicting the quality only five out of eighteen (28 per cent).

Nearly all the good quality calcretes in the area around Ondangua were found on the insides of *oshana* bends without the aid of airphotos. These features stand out so well on airphotos that a stereoscope is unnecessary to predict where further materials of this quality will be found. At all other sites with dissimilar photo patterns investigated, only very inferior calcretes and calcified or calcareous soils were found. The *oshanas* represent present-day or partly fossilized drainage lines. Ancient fossil drainage lines often show up well on airphotos and are likely to be good sources of hardpan and boulder calcretes.

In order to determine which elements of the airphoto pattern are the most useful for the location of calcretes a list of patterns for some calcrete deposits in various parts of the Republic and South West Africa has been compiled (Table 1).

It was found that, in general, the elements of topography, drainage and tone and texture of surface material are the most useful, generally confirming the statements made by Caiger[7]. It would be misleading, however, to conclude that calcretes usually occur in depressions, possess a colinear drainage pattern and a mottled surface tone (all indicators of poor drainage) as the position of a calcrete deposit in relation to the present-day topography and drainage depends mainly on its stage of development. Thus, while the younger calcretes are in fact associated with poor drainage conditions, the better-developed ones tend to occur under better-drained conditions, and a fossil calcrete deposit could possess virtually any elements of the airphoto pattern. Fossil calcretes frequently crop out on rises or cap small ridges or plateaus, protecting them from erosion.

In general, apart from possible improvements in contrast which could be obtained by experimentation with different film/filter/camera combinations and image-processing techniques, there do not appear to be any improvements to the conventional techniques of airphoto procurement and interpretation which can be suggested to make calcretes more amenable to location by this method.

Interpretation from diapositives

Contact prints possess a resolution of only 13 lines/mm while diapositives possess the same resolution as negatives, namely about 48 lines/mm[25]. Diapositives should therefore allow easier interpretation of some features.

Fourteen glass diapositives on a scale of 1:36 000 and nine plastic diapositives on a scale of 1:72 000 were obtained, covering known areas in the vicinity of the Operet-Ondangua and Grootfontein-Runtu roads in South West Africa. The diapositives were viewed by transmitted light on a light table with an Oude Delft scanning stereoscope and compared with conventional 1:36 000 semi-matt and 1:72 000 glossy contact prints made from the same negatives.

It was found that the diapositives definitely allowed more detail to be seen at the maximum Oude Delft magnification of 4,5. Gabbabos and calcrete outcrops could be more easily detected and delineated on some diapositives, but others seemed to possess no advantage over contact prints. A higher magnification than 4,5 may be required for their best utilization.

Colour photography

Colour airphotos frequently possess definite advantages in soils work but are not invariably more useful than conventional panchromatic photography[26,27]. However, colour infra-red airphotos were found to be superior to panchromatic photography for the location of deeply buried (deeper than 2 m) calcrete deposits on one job in the northern Cape Province[28].

The colour of the overburden is a fairly good guide to the quality of the calcrete, generally both the plasticity index decreasing and the aggregate hardness increasing as the overburden colour changes from grey to red and as the ground rises away from the bed, or edge, of a drainage feature. The good quality calcretes occurring in the fossil *oshana* lines around Ondangua are good examples of this. Camouflage detection film may also be useful since it is often better than panchromatic in tracing mineral deposits through plant patterns[29]

Infra-red photography

Ordinary panchromatic film is sensitive only to visible light, ie that section of the electromagnetic spectrum possessing wavelengths between about 0,3 and 0,7 μm. Infra-red photography merely involves the use of film which is also or mainly sensitive to infra-red light, having wavelengths up to about 1,2 μm. The sensitivity of the emulsion to infra-red radiation means that the tone will depend to some extent on the temperature and emissivity of the object. The former is influenced by near-surface bodies and the body will thus show up as a tonal difference on the infra-red airphoto.

From the information available it would appear that infra-red photography is more sensitive to variations in drainage, moisture conditions and plant species than conventional panchromatic photography. This means that although buried calcrete deposits may result in tonal differences, these other factors may be even more important in the interpretation of infra-red airphotos. Other advantages of infra-red photos are a better haze-penetration and sharper contrast than in panchromatic photography.

Infra-red imagery and other remote sensors

Table 1
Elements of the photographic pattern of some calcrete deposits

Area	Source of elements	Calcrete quality	*Elements of form*			*Elements of tone and texture*				Soil profile
			Topo-graphic	*Drainage*	*Erosional*	*Vegetation*	*Land use*	*Surface material*		
30 km east of Kimberley	[22]	Fill	Gentle slopes	Well integrated, sub-parallel	Sheetwash and flattened V-section. Gulley erosion	Thornbush along gulleys	Partly cultivated	White tone, light grey in poorly drained depressions		Hillwash/ calcrete/ shale
Winter Rush – Koopmansfontein	Author from[22]	Subbase	Flat lowlands	Very poor	Sheetwash	Scattered bush	Grazing	Mottled dark and medium grey		Calcrete/ alluvium/ shale
Kaap Plateau NE of Griquatown	Author from[19]	Unknown	Plains	Swallow holes, colinear	None or sheetwash	Scattered bush	Grazing	Light grey		Calcrete/ dolomite
Operet end of Operet-Andoni, SWA	Author from[11]	Base, subbase	Low ridge	Good, itself probably a fossil drainage line	None or sheetwash	Dense forest	Grazing	Light grey		Calcrete and sand/ calcrete
Glen, near Bloemfontein	Author	Subbase	Plains, very gentle slopes	Poor	Vertical walled shallow gulley	Scattered bush and grass	Grazing	Mottled medium and light grey		Aeolian sand/ calcrete
Operet 312, SWA	Author	Unpaved road	Depres-sions, pans	Poor, colinear	Shallow *oshanas*	Scattered bush, close gabbabos and grass	Game reserve	Mottled light to medium grey and white (anthills and drainage)		Aeolian sand/ calcrete
South edge of Andoni Flats, Etosha Game Reserve, SWA	Author	Unpaved road (good)	Fossil pan terrace	Good	Sheetwash	Scattered gabbabos and grass	Game reserve	Medium grey		Aeolian sand/ calcrete
Andoni-Ondangua, SWA	Author	Unpaved road	Pan	Nil	Sheetwash	Gabbabos, grass, scattered bush	Game reserve	Mottled medium grey and white		Aeolian sand/ calcrete
Andoni Flats, Etosha Game Reserve	Author	Unpaved road (poor)	Fossil pan floor	Nil to poor	Sheetwash	Grass tussocks	Game reserve	Mottled dark and medium grey		Aeolian sand/ calcrete & calcified soil
Ondangua, SWA	Author	Subbase, base	Low rises at pinched out *oshanas* and inside *oshana* bends	*Oshanas* colinear – sub-parallel	*Oshana* shallow, gently sloping sides	Crops or bitterbos and scattered bush	Cultivated or grazing	Light to medium grey, white termitaries		Aeolian sand/ calcrete
Ondangua	Author	Unpaved road (poor)	*Oshana* beds	*Oshanas* colinear – sub-parallel	*Oshana* shallow, gently sloping sides	Grass tussocks	Poor grazing	Medium to dark grey		Alluvial soil/ calcified soil
Grootfontein – Runtu (south of Gaza line), SWA	Author	Unpaved road (good)	Streets between high seif dunes	Nil or colinear	Nil or shallow, gently sloping sides	Grass, scattered bush	Grazing	Light grey		Aeolian sand/ calcrete
Gaza Line (Grootfontein – Runtu)	Author	Unpaved road (poor)	Street between poorly developed seif dunes	Poor	Sheetwash	Grass, scattered bush	Game reserve	Medium grey		Aeolian sand/ calcrete and calcified soil
Gaza Line (Grootfontein – Runtu)	Author	Unpaved road (good)	Pan in street between poorly developed seif dunes	Nil	Sheetwash	Grass, scattered bush	Game reserve	Light grey with medium grey rim		Aeolian sand/ calcrete
Bloemfontein – Soutpan	[23] and author	Sub-grade, possibly subbase	Flat, tabular sand covered area be-between pans	No surface drainage. Rectangular sub-surface drainage	Pans	Grass?	Grazing	Grey mottled lighter grey. White when outcropping		Sand/ calcrete
Vryburg – Terrafirma	[23] and author	Unpaved road (quality not stated)	Caps on ancient land surface. No relief	Converging on pans	Pans	Grass, scattered bush	Grazing, partly cultivated	White when outcropping		Aeolian sand/ calcrete

While all types of photography, imagery and conventional geophysical methods could be classed as remote sensors, only imagery and related methods are discussed in this section.

Brief details of the types of remote sensors available and their applications are available[27,30,31]. Of all the devices mentioned, the infra-red imager, radar imager, infra-red radiometer/spectrometer, microwave imager, microwave radiometer and the ultra-violet imager would appear to have possibilities for materials surveys in general, including the location of buried calcrete deposits. The infra-red imager, radar imager, infra-red radiometer/spectrometer, microwave radiometer, absorption spectrometer, radio-frequency reflections and possibly the microwave imager are also sensitive to variations in soil moisture distribution. Many of these methods are unfortunately both in the developmental stage and more or less 'classified' in the military sense. All are applicable to airborne use.

Of all these devices the most developed and most potentially useful appears to be the infra-red imager. Principles and use of the technique have been described[32,33]. Infra-red imagery involves the use of a scanner sensitive to emitted infra-red radiation with a wavelength of the order of three µm. The image is not photographed directly but, in common with other types of imagery, is projected by means of a cathode-ray tube and then photographed. The technique is far more sensitive to buried objects than infra-red photography and it would appear that it should be easily capable of detecting buried calcrete deposits.

Multispectral sensing covering a large part of the electromagnetic spectrum will possibly become a useful technique of the future.

Apart from other advantages, remote sensing devices do not generally appear to be affected by weather conditions.

Botanical indicators

Of all the methods of calcrete prospecting this is one of the most widely used. Hawke[34] has defined a plant indicator as 'a species whose distribution is affected by the chemical constituents of an ore deposit' – in this case calcrete. A list of 31 calciphilous plants known to be indicators of at least a calcareous subsoil in Southern Africa has been compiled[1]. Of these plants I only have personal experience of the gabbabos *(Catophractes alexandri)*, saliebos or bitterbos *(Pechuel-Loeschea-leubnitziae)* and vaalbos *(Tarchonanthus camphoratus)* and have found them to be very reliable indicators. The *absence* of a plant indicator does not necessarily mean the absence of a calcareous subsoil. The *presence* of one of the above three plants has, however, invariably been found to indicate at least a calcareous subsoil, normally within a depth of about 1,5 m. Generally, the denser the growth of indicator bushes, the more strongly calcified the subsoil.

In addition, *Acacia reficiens* (rooihaak), although not a calciphilous plant, is a water-loving one and the presence of shallow water itself in an arid or semiarid area is a likely indicator of calcrete.

When present in quantity some calciphilous plants give rise to characteristic airphoto patterns. Brink[21] was able to delineate calcrete occurrences in the Vryburg area by this means using the vaalbos while I was able to do likewise in the Stinkwater area of the Etosha Pan, using the gabbabos. The value of the textural pattern due to vegetation was noted by Caiger[7].

Zoological indicators

The spoils from burrowing animals and insects should be examined for traces of calcrete. These indicators can be just as useful and more positive than plant indicators. White termitaries often show up well on airphotos but usually indicate a fairly plastic calcrete and a plasticity index of the topsoil in excess of eight[7].

Overburden and calcrete colour and overburden type

The best graded, hardest and least plastic calcretes are usually found under a reddish sandy overburden on slopes or rises. Furthermore, reddish and brownish calcretes also invariably have lower plasticity indices, are better graded and possess harder aggregate than white, grey, pink or bluish calcretes. Bluish calcretes invariably have a high plasticity index. Greenish ones often have a low plasticity index but are usually saline.

This method of prospecting works well in the *oshana* country around Ondangua for example. In the *oshana* beds, with their grey silty or clayey sand overburden, only olive green calcareous or calcified clayey sands with scattered soft nodules are found. The quality then increases away from the *oshana* to a nodular calcrete and then, when the reddish sand is encountered, a hardpan overlying or adjacent to hard nodular calcrete of low plasticity may be found.

Probing, augering and pitting

A rapid probing device invented by the late Senior Road Inspector at Upington, Mr T. van der Westhuizen, has been found by me to be an excellent quick indicator of the presence of calcrete[1,6]. Depending on the texture of the soil, it was found to require only half to one minute to complete a probe to 2 m which was about ten times as fast as the Edelmann hand-auger, which was in turn faster than the Hardy Pick type. The probing device has been thoroughly tested out by me and I have found it to be unsurpassed as a preliminary indicator of calcrete within a usable depth.

I have found this device to be inexpensive to make, foolproof, almost unbreakable and capable of indicating the location, extent, type and overburden thickness of a calcrete deposit. An area can either be prospected in about one tenth of the time required to prospect the same area by hand-auger or, and possibly more important when hunting for calcretes, prospected about ten times as thoroughly in the same time that it would have taken by hand-auger. With experience, the type of calcrete can also be estimated from the resistance to penetration and the colour and texture of the deposit on the point of the probing device. A rough guide is given in Table 2.

Table 2
Interpretation of probe results

Penetration resistance	*Point appearance*		*Calcrete type*
Varies from almost none to refusal within a few square metres	No deposit if little resistance; white or pale pink colour on refusal	Cannot all be rubbed off with the fingers (applies to all rows down to "Fair to low")	Loose sand interspersed with boulder calcrete
Refusal	White or pale pink colour		Hard hardpan or boulder, probably unpickable
High	White or pale pink colour		Loose, hard nodular calcrete, stiff hardpan or calcified sand
High to fair	Pale mauve		Tufaceous hardpan
Fair to low	White		Powder calcrete
Low	White sandy deposit; can be rubbed off easily with the fingers		Calcareous soil

Geophysical methods

Over the last ten years the resistivity and shallow seismic refraction methods have found increasing application in materials surveying and other road work in the United States and elsewhere. The shallow seismic refraction method has been successfully applied to calcretes in the Republic and South West Africa[1,35] and good results have been obtained with the resistivity method in the Western Transvaal[36]. These methods are best suited to more detailed investigations such as for rippability, consistency and as a supplement to drilling. While calcretes are among the more easily rippable of materials[37], hardpan and boulder calcretes frequently rip into large slabs which may be uneconomic to reduce further and a relatively useless powder calcrete may be found below. A case such as this where a low velocity (softer) layer underlies one of higher velocity (harder) is not detected by the seismic refraction method and is a common feature of calcrete deposits.

The seismic velocities of Southern African calcretes have been found to range from about 400 m/s for a powder calcrete to about 4 500 m/s for a very hard, intact hardpan[1]. A total of 53 seismic traverses were made with a Viatec instrument, some for exploratory purposes but mostly over already or subsequently known profiles. It was found that the different varieties of calcrete could be grouped roughly according to their seismic velocities (Table 3). Figures obtained at the same time for sands of Kalahari type are also shown for comparison. The varieties of calcrete listed have been defined and described in detail elsewhere[1,2].

Table 3
Seismic velocities of calcretes and some other materials

Material type	*Seismic velocity (m/s)*		*Probable common range (m/s)*	*Number of determinations*
	Actual range	*Mean*		
Boulder calcrete	Probably unreliable		Erratic	6
Hardpan calcrete	1170 – 4600	2040	1200 – 4500	11
Honeycomb calcrete	810 – 1550	980	900 – 1200	6
Nodular calcrete	370 – 940	650	600 – 900	21
Powder calcrete	410 – 1310	760	400 – 1000	11
Calcified sand	–	–	450 – 1200	0
Calcareous sand	340 – 400	360	300 – 450	6
Red Kalahari-type sand	260 – 450	340	240 – 450	22

Very erratic time-distance graphs were obtained in the case of boulder calcretes and in most cases a velocity could not be calculated. Possible velocities obtained varied between 1 500 and 3 000 m/s in some cases. Only five out of 21 nodular calcrete determinations fell below 600 m/s and it was possible that these particular profiles had been disturbed during bulldozing operations.

It is considered that nodular calcretes will normally fall within the range 600 to 900 m/s. The relatively high velocities of some powder calcretes emphasize their sometimes stiff in-situ nature. The powder calcrete with an apparent velocity of 1 310 m/s nevertheless broke down into a powder with a grading modulus of 0,6 when excavated with an RB23 excavator. Two further determinations over the same deposit yielded velocities of 840 and 700 m/s which are probably more realistic values. Allowing for experimental errors in Table 3, it is considered that the values shown in column four will in most cases be found to hold and could be used to some extent for prospecting and site investigation purposes.

It would appear that calcretes with seismic velocities of less than about 900 m/s can be bulldozed without ripping, while those with velocities above 2 500 to 3 000 m/s cannot be ripped by any Caterpillar tractor/ripper combination at present in service and have to be blasted[38]. Blasting of calcrete hardpan can be difficult owing to dissipation of the blast by the softer layer below. The technique in this case is not to drill the shot holes completely through the hardpan. Calcretes shatter readily and black powder or a low per cent dynamite was said to give the best results in New Mexico although TNT also yielded excellent results[39]. Limited experimental work suggests that the resistivity technique could be useful in estimating the bearing capacity of calcrete layers[1].

Sampling

Most calcrete deposits are variable, both laterally and vertically (Fig 1), and great care is therefore necessary if the sampling is to be representative. Many borrow pits have also been ruined by careless working and have had to be downgraded after opening up.

Conclusions

1. A clear understanding of the mode of origin and the factors influencing the formation of calcretes can be usefully applied to the problem of the location of economic deposits of these materials. The influence of climate and drainage on calcrete distribution is perhaps the most marked.
2. In the interpretation of airphotos for buried calcrete deposits the elements of topography, drainage and tone and texture of surface material are in general the most useful elements of the airphoto pattern. While the technique of airphoto interpretation is an indispensable tool, its success rate for calcretes may be lower than for other materials.
3. It is concluded that the following sequence of prospecting operations offers the best chances of success at the present time at the minimum cost.:

   Paved roads or major unpaved roads
   a. Stereoscopic airphoto interpretation by an expert interpreter with photos specially taken if not already available.
   b. Checking of likely airphoto patterns with the rapid probing device and use of plant indicators, soil and calcrete colours, drainage and topography.
   c. Delineation of calcrete deposits with the rapid probing device.
   d. Pitting, with some preliminary auger holes as a check on the probe.
   e. Seismic survey for rippability if necessary.
   f. Opening up of deposit.

   Minor unpaved roads
   a. Provision of airphotos, if available, to road superintendents or inspectors (one photo wide coverage only) together with advice on airphoto navigation and non-stereoscopic interpretation.
   b. Rapid probing of areas seen on the airphotos to have an appearance similar to known good deposits.
   c. Use of plant indicators, soil and calcrete colours, drainage and topography.
   d. Pitting and opening up of deposit.

   In both cases further deposits can usually be located with little effort by plotting known deposits on the airphotos and looking for areas possessing similar airphoto patterns.
4. The use of colour and infra-red airphotos, diapositives and infra-red imagery (particularly the latter) hold promise in calcrete prospecting.

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DISCUSSION

Written discussion on the above paper will be accepted until 15 March 1978. This together with the author's reply, will be published in the August 1978 issue of *The Civil Engineer in South Africa,* or later.

Such written discussion, which must be submitted in duplicate, should be in the first person present tense, and should be typed in double spacing. It should be as short as possible and should not normally exceed 600 words in length. It should also conform to the requirements laid down in the 'Notes for the Guidance of Authors and Contributors' as published in the September 1974 issue of *The Civil Engineer in South Africa.*

Overseas contributors

For the convenience of overseas contributors only, the closing date for discussion will be extended to 31 March 1978 upon a receipt of a request together with an assurance that the material will be received by the Institution by the date. No request for any further extension can be considered.

Reference

Whenever reference is made to the above paper this publication should be referred to as *The Civil Engineer in South Africa* and the volume and date given thus: **Civ Engr S Afr, Vol 20, No. 1, 1978.**

Publikasies van belang

The proceedings of the Second International Symposium on Land Subsidence held at California, USA, in December 1976 is now available. The symposium was sponsored by the International Association of Hydrologic Sciences, International Association of Hydrogeologists, International Society for Soil Mechanics and Foundation Engineering, US National Committee for Scientific Hydrology and United Nations Educational, Scientific and Cultural Organization. The 60 technicial papers range from mathematical modelling studies through general descriptions of project progress and subsidence case histories to legal and economic aspects of subsidence. The scope is very broad, covering theory, investigation, measurement, prediction and control of subsidence, including land-surface sinking resulting from withdrawal of water, oil or gas, dewatering of organic deposits, hydrocompaction, extraction of solids by mining and collapse of limestones. Published as IAHS Publication No. 121, price US$30. Available from the Treasurer, International Association of Hydrological Sciences, 1909 K Street, NW., Lower Level, Washington, DC 20006.

Memoires of the International Association for Bridge and Structural Engineering, Vol 36-II, Septmber 1976. 196 pp, 160 photos, figs and tables. Contains 11 articles – seven in English, two in French, two in German. Three articles describe original tests carried out on the model of a pre-stressed concrete nuclear vessel, on light gauge steel folded plate construction, on teflon sliding bearings of a bridge under service. Two articles are concerned with a theory and its application to the analysis of a box girder bridge under dynamic actions of moving loads. The other articles present various analysis and design methods – theoretical or practical – for elements or whole structures: space-curved rod elements, composite columns under concentric loading, steel multistory frame, reinforced concrete beams, shells, folded plates and frames. Available from the Secretariat of IABSE, ETH-Hönggerberg, CH-8093 Zurich, Switzerland.

Health implications of direct and indirect re-use of waste water. Recently published as IRC Technical Paper Series No. 7 is the report of an International Working Meeting of Experts, held in Amsterdam, Netherlands, in January 1975. The report reviews the current knowledge with respect to refractory water contaminants and the possible health effects relating to the direct and indirect re-use of waste water for human consumption. A detailed survey of maximum reported concentrations of organic, inorganic and micro-biological contaminants is included. Also presented is a tentative evaluation of the health implications of the detected chemical compounds. Recommendations are made for specific toxicological and epidemiological studies as well as research on the efficiency of various advanced treatment processes in removing suspect chemical contaminants. Available from WHO International Reference Centre for Community Water Supply, P.O. Box 140, Leidschendam, The Netherlands.

The use of plastics for load bearing and infil panels, edited by L. Hollaway, has 13 chapters based upon papers presented at a symposium on the use of plastics for load bearing and infil panels organized by the Structural Plastics Research Unit, Department of Civil Engineering, University of Surrey. The papers illustrate the increasing use of plastics for prefabrication and industrialized building and it is hoped that their contents will help those who have not had experience with this relatively new constructional material to overcome their initial reluctance to use it, and will convince those who are conversant with plastics that this material has a place in the construction industry. Available from Manning Rapley Publishing Ltd, 42 High St, Croydon, Surrey, CRO 1RB. Price £6.