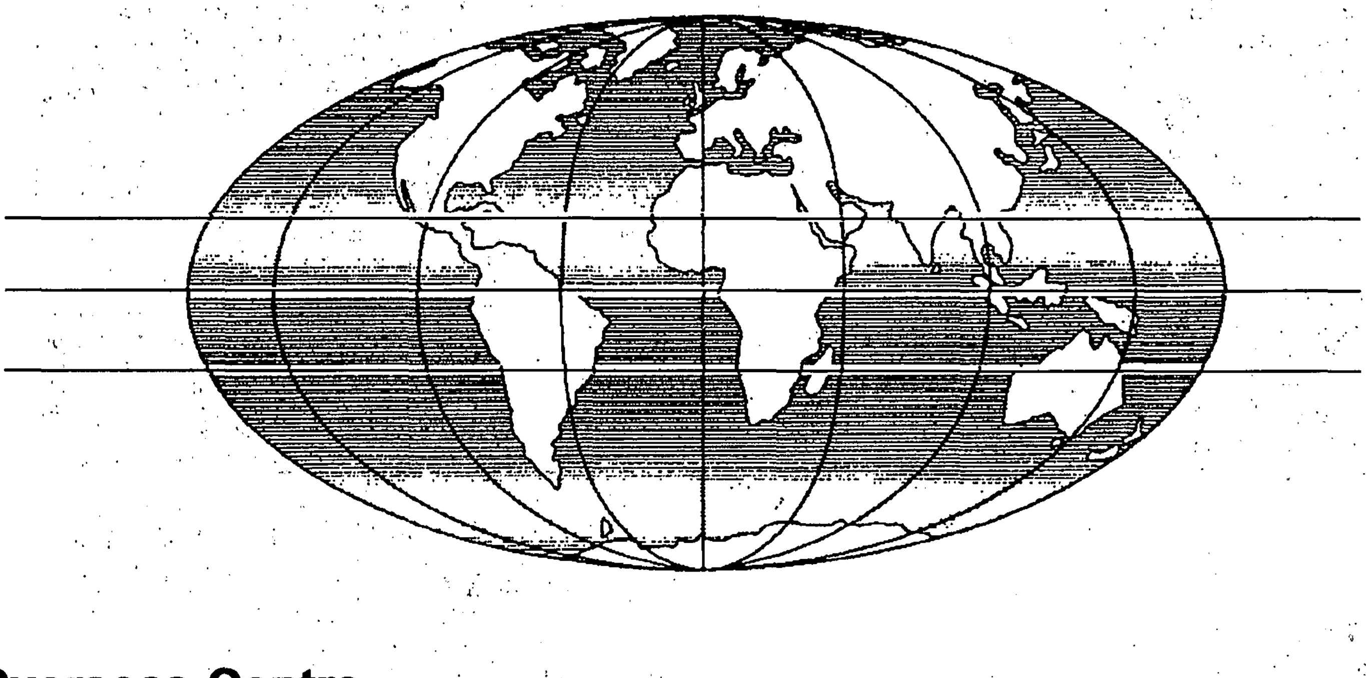
TRANSPORT RESEARCH LABORATORY

ODA

Reprint

TITLE **Evaluation of weak aggregates for surface dressing on low-volume roads**

by M E Woodbridge, P A K Greening and D Newill



Overseas Centre
Transport Research Laboratory
Crowthorne Berkshire United Kingdom

WOODBRIDGE, M E PAK GREENING and D NEWILL, 1991. Evaluation of weak aggregates for surface dressing on low volume roads. In: **Fifth International Conference on Low Volume Roads, Raleigh, North Carolina 19-23 May, 1991. Transportation Research Record 1291, Volume 2.** Washington DC: Transportation Research Board, National Research Council, 263-274.

Evaluation of Weak Aggregates for Surface Dressing on Low-Volume Roads

M. E. WOODBRIDGE, P. A. K. GREENING, AND D. NEWILL

New roads in the Kalahari Desert region of Botswana must make best use of local materials if they are to be built economically. In the absence of rock outcrops, the main sources of roadstone are the variable duricrust deposits, described as calcrete or silcrete, which form in association with landform features such as pans or old river valleys. A study of four duricrusts for use as aggregate for surface dressing in lightly trafficked roads is described. Investigations included the determination of chemical and mineralogical composition, mechanical properties, and an assessment of the duricrusts' performance in full-scale road trials. Although generally described as calcrete or silcrete, the materials commonly contain mixed, disparate calcareous and siliceous fractions. In such cases, tests on representative samples of the whole material do not readily identify the influence of the weaker calcareous fraction on engineering properties. One of the road trials was designed specifically to examine the effect of varied proportions of calcareous and siliceous material on behavior under traffic. The results of the mechanical tests showed that with the exception of the one silcrete sample the materials were not strong enough to meet the strict Botswana specifications for surfacing aggregates. However, from the performance of the road trials and from a number of other countries where specifications are related to different traffic levels, new interim specifications were proposed in agreement with the Botswana Roads Department. On the basis of the recommended lowest traffic category of less than 0.8 million equivalent standard axles and 10 percent fines aggregate crushing test values of 130 and 100 kN for dry and soaked samples, respectively, it was considered that all of the materials investigated would be suitable for use in surface dressings for roads in the Kalahari Desert region.

The Transport and Road Research Laboratory (TRRL), United Kingdom, and the Ministry of Works, Transport and Communications (MOWTC), Botswana, are undertaking a joint research program in Botswana aimed at making best use of locally available materials for road construction. The work began because major new road projects, totaling some 1200 km, were planed to cross large areas of the Kalahari Desert, which covers more than three-quarters of the country (see Figure 1).

In the region, conventional sources of roadbuilding material, such as exposed rock, are scarce. Research, therefore, has concentrated on the main alternative sources—granular or gravelly materials known as calcrete or silcrete. These indurated materials, or duricrusts, are typical of those found in arid climates; by their process of formation within the soil profile, they are subject to considerable physicochemical variability.

Transport and Road Research Laboratory, Old Wokingham Road, Crowthorne, Berkshire RG11 6AU, United Kingdom.

Earlier work in the research program (*1*) concentrated on calcretes and described the relationship among different types of calcretes, their properties, and the landform features where they occur. This work provided a basis for their identification and distribution. In another part of the work (*2*), calcretes of different quality have been and are continuing to be assessed in full-scale road experiments as base materials for lightly-trafficked bituminous-surfaced roads (*2*).

A study of duricrust materials from four different sources for use as surface dressing aggregate is described. Although the materials are referred to as calcretes or silcretes, some were of mixed composition. Because it was not known how this composition would affect the results of conventional aggregate tests or the duricrusts' performance in practice, special attention was placed on the relationship among physical, chemical, and petrographic properties. For one of the materials, additional subsamples were prepared by hand-sorting dominantly calcrete-rich and silcrete-rich fractions for inclusion in the testing program.

In assessing the results of the investigation, a comparison was made between the existing Botswana specifications for the use of surfacing aggregates, which have been adopted from the more demanding specifications of South Africa, and those of other countries that take account of lightly trafficked roads. This comparison, together with an assessment of a series of road trials carried out in Botswana and the United Kingdom using the materials in surfacing dressings, enabled recommendations to be made for the use of the Botswana aggregates.

DEFINITION AND DESCRIPTION OF CALCRETE AND SILCRETE

The calcretes and silcretes of Botswana are part of a wider group of materials described as duricrusts, which by pedogenic processes form as an indurated layer in the soil profile. Calcretes are characterized by the presence of calcium carbonate, although magnesium carbonate may also be present. Silcrete contains an accumulation of silica. Another important member of the group is ferricrete, or laterite, identified by high concentrations of sesquioxides (the oxides of iron and aluminum). The deposition of these materials is controlled by the solubility of the chemicals concerned, the original parent rock from which they were leached, the climatic and topographic environment, and the water table conditions. Calcretes and silcretes are distributed widely throughout the Kalahari and, although ferricretes also occur, these are confined to the eastern fringes closer to rock sources. A fuller definition of duricrusts is given by Goudie (*3*) and of calcretes

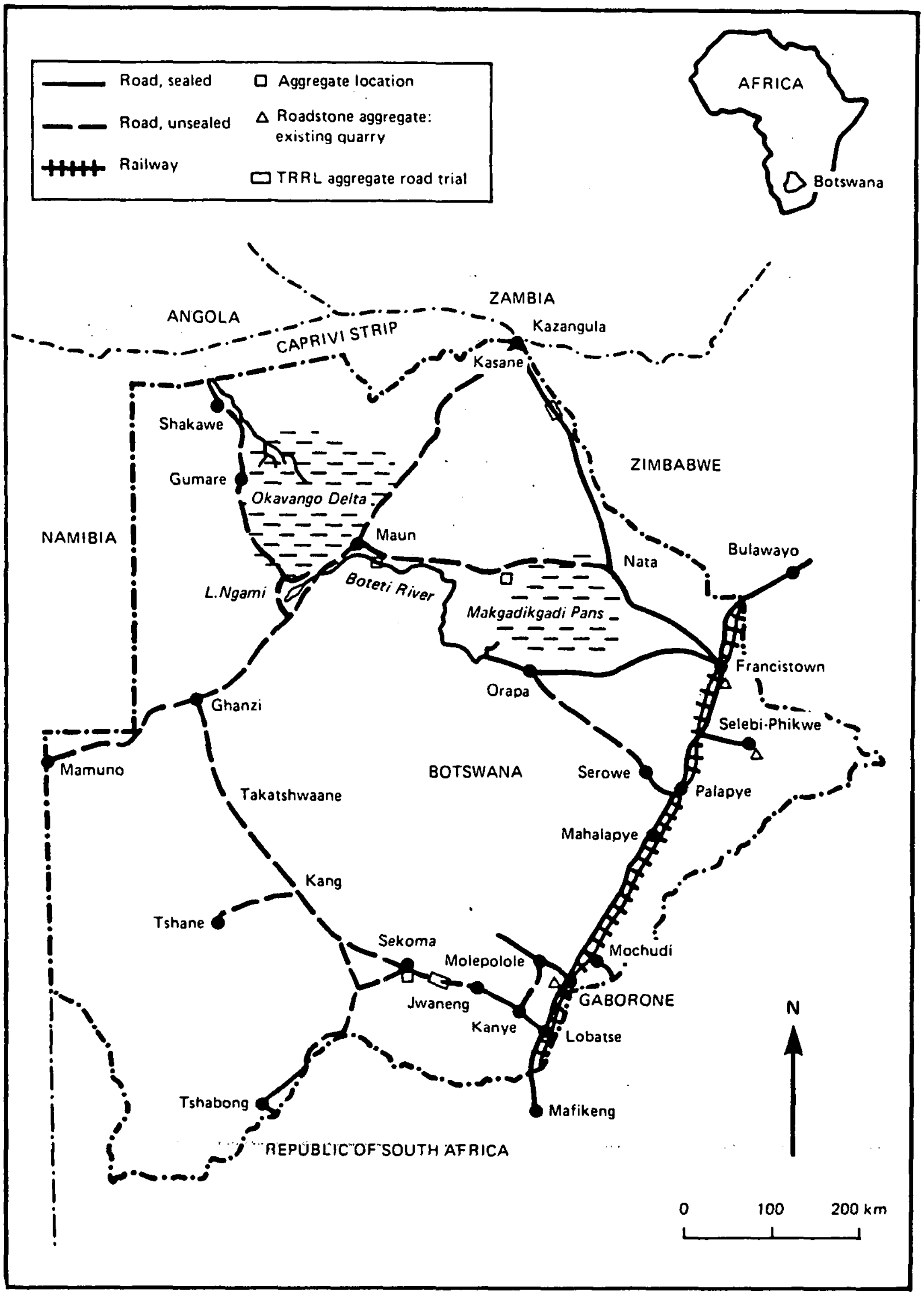


FIGURE 1 Republic of Botswana road network.

by Netterberg (*4*). From his work in southern Africa, Netterberg developed a geotechnical classification of calcrete related to an evolutionary sequence. Each type of calcrete can be recognized in the soil profile and represents a stage in the growth or weathering of a calcrete horizon with a significantly different range of geotechnical properties. The categories, in order of ascending evolutionary sequence, are as follows:

1. Calcified Soil. A soil horizon cemented by calcium carbonate to give a stiff consistency.
2. Powder Calcrete. Typically composed of loose silt or sand-sized carbonate particles, which when cemented together readily break down on working.
3. Nodular, Honeycomb, and Hardpan Calcretes. Mixtures of silt to gravel-sized, carbonate-cemented, host soil particles in a matrix of calcareous soil. The soil matrix is almost absent in the case of honeycomb calcrete and is completely replaced by hard carbonate cement in the case of hardpan calcrete.

Only the calcretes in Category 3 are hard and strong enough to be potentially suitable for surface dressing aggregate. The other categories are too soft or contain too much plastic clay-sized material.

A definition of silcrete provided by Grant and Aitchinson (*5*) states that, "silcrete is a siliceous material formed in a zone of silica accumulation in the earth's crust. The silica accumulation is produced by superficial physico-chemical processes and not by normal sedimentary, metamorphic, volcanic or plutonic processes." The main advantage of silcrete over calcrete is its potential for being harder and more resistant to abrasion. However, silcretes, like calcretes, are variable in quality depending on the degree of silicification and the nature of the material that is being replaced by silica. The silica is frequently chalcedony.

In Botswana, calcrete and silcrete are associated with a number of distinct landform features, such as interdune hollows, old river courses, topographic depressions, and the distinctive pans (enclosed depressions) of roughly circular shape. A loose relationship exists between landform and calcrete type, with the larger pans generally containing the higher quality nodular, hardpan, or honeycomb type of calcrete. Extensive work by TRRL (*1*) has led to a recommendation for the use of remote-sensing techniques, such as aerial photographs and Landsat imagery, to identify the geomorphological and landform features associated with calcretes. These techniques could be used at an early stage of road planning to help with materials surveys.

LOCATION AND DESCRIPTION OF SAMPLES

The two roads to be built to bitumen-surfaced standard associated with this aggregate study are the 300-km road from Maun to Nata in northern Botswana and the 650-km road from Jwaneng to Mamuno in the south. Both routes and the locations of the samples are shown in Figure 1.

For the Maun to Nata route, a reconnaissance survey that included borehole drilling of the best prospects was carried out along the proposed alignment. Those materials selected for the testing program were from km 175 from Maun (identified as the MN2 sample) and from the bed of the Boteti River at Samedupe, 13 km from Maun (identified as the Samedupe sample). The Nata sample came from a roadside quarry 9 km north of Nata. Numerous large pans likely to contain good quality calcrete or silcrete were located during the materials survey carried out between Jwaneng and Takatshwaane, which covers part of the area of the Jwaneng to Mamuno road project. The sample included in this study was from Sekoma pan (identified as the Sekoma sample). More detailed descriptions of the samples and the soil profiles are provided in the following paragraphs.

Maun-Nata (MN2) Sample

Figure 2 shows the location and borehole program undertaken to investigate the pan deposit, with typical borehole profiles. The material comprises thin, interbedded lenses of white calcrete and green/black silcrete in a fine-grained, sometimes soft sandy matrix. The upper 1 to 2 m is dense, whereas the lower layers become increasingly porous. Boreholes were drilled to a depth of 6 m on a 50-m grid and indicated an average thickness of 4-m stone of suitable quality. Potential gross reserves of the silcrete, assuming a density of 2.5 ton/m^3, were 0.2 million tons. The reserve of usable stone, which will depend on the proportion of acceptable quality for the surface dressing aggregate, is estimated to be 65 percent. Additional stone reserves may occur beneath or outside the drilled area. Because this was one of the materials containing a mixture of calcareous and siliceous fractions that could be distinguished by color, the samples for testing were hand-sorted into three parts. One was the run-of-quarry sample (comprising roughly equal proportions of calcrete and silcrete), and the other two were calcrete-enriched and silcrete-enriched fractions.

Samedupe Sample

The Samedupe material consists of abundant hard boulders of homogeneous quartzite occurring in and apparently limited to the bed of the Boteti River. Drilling failed to prove an extension of the quartzite beyond the river bank. The material is periodically extracted by local contractors for use as building stone and aggregate. Larger scale extraction may be inhibited by environmental considerations.

Sekoma Sample

The Sekoma material occurs in substantial quantities in the rim of a large pan. Following an exploratory borehole program, a pit 6 m deep was blasted near surface outcrops of hard calcrete. Disaggregated rubbly calcrete overlaid a hard calcrete breccia, comprising largely angular fragments of dark grey or reddish siliceous material in a light brown calcareous, sandy matrix. The breccia is the potential surfacing aggregate. In the base of the pit, unusable soft, calcareous, sandy material was found. Material from this source was used in a surface dressing trial constructed at Jwaneng in 1984.

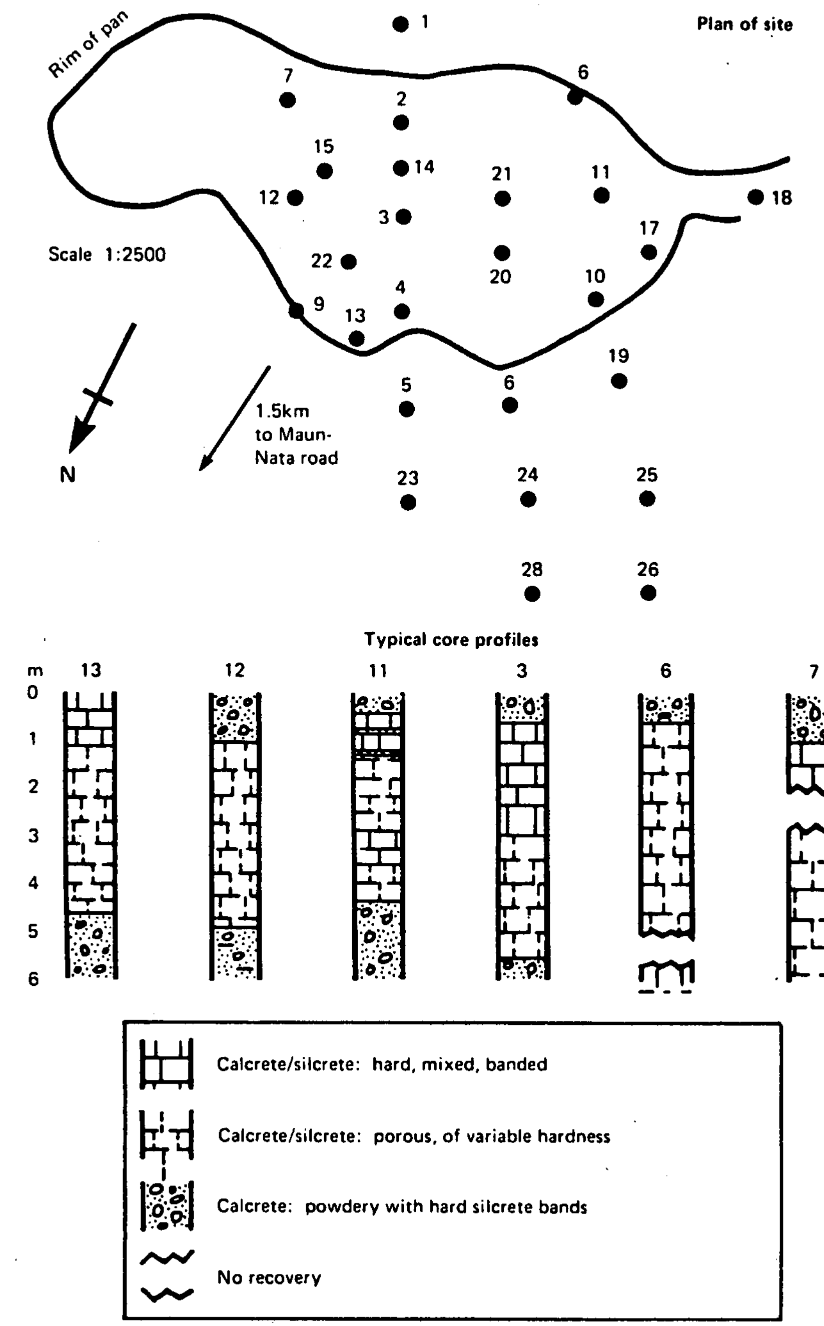


FIGURE 2 Borehole location and typical profiles at MN2 site on Maun-Nata Road.

Nata Sample

The Nata material is a fine-grained, hard, white-to-light-green sandy calcrete. It has already been used as roadbase for construction of the Nata-Kazangula Road, but the harder fraction was selected for a surface dressing trial at km 235 from Nata constructed in 1983. A 3-m face has been developed in the borrow pit, and the material has a rubbly appearance.

PETROLOGIC, CHEMICAL, AND MINERALOGICAL PROPERTIES

Visual examination indicated that, although the Samedupe and Nata materials were homogeneous, the MN2 and Sekoma materials were of varied composition. Therefore, the samples were examined more closely using a number of techniques. Thin sections were prepared and petrologically examined to identify constituent mineralogy and fabric. Also, with the exception of the Nata sample, X-ray diffraction analysis, scanning electron microscopy, and microprobe techniques were used to examine certain zones of the samples and their microtexture before and after the accelerated abrasion and polishing tests. In addition, light emission spectrography and microprobe techniques were used for chemical analysis of these samples.

The results of the work are presented in Tables 1A, 1B, and 1C. The compositional differences among the samples are clearly indicated. The Samedupe sample was made up entirely of quartz grains welded together in a siliceous matrix, the Nata sample comprised quartz grains in a very-fine-grained carbonate matrix, and the MN2 and Sekoma samples included mixed but mainly quartz fragments in an essentially carbonate matrix. In the MN2 sample, individual fragments were strongly

TABLE 1A RESULTS OF PETROLOGIC TESTS—THIN-SECTION ANALYSIS (POINT COUNTING)

	MN2					
Component	Run-of-Quarry Stone (%)	Calcrete-Enriched Stone (%)	Silcrete-Enriched Stone (%)	Samedupe (%)	Sekoma (%)	Nata (%)
Carbonate	[a]	80	25	–	48	53
Quartz	[a]	12	63	99	35	42
Chalcedony	[a]	7	10	–	–	1
Olivine	[a]	–	–	–	10	–
Mica	[a]	–	–	–	5	–
Other	[a]	1	2	1	2	4

[a]Not determined.

TABLE 1B RESULTS OF PETROLOGIC TESTS—CHEMICAL COMPOSITION (EMISSION SPECTROGRAPHY AND MICROPROBE)

	MN2					
Component	Run-of-Quarry Stone (%)	Calcrete-Enriched Stone (%)	Silcrete-Enriched Stone (%)	Samedupe (%)	Sekoma (%)	Nata (%)
SiO_2 (median)	50.9	12.4	66.9	97.0	31.1	[a]
SiO_2 (range)	38–51	4–31	62–94	–	22–77	[a]
Al_2O_3 (median)	1.2	1.2	1.3	1.1	2.0	[a]
Al_2O_3 (range)	0.8–2.4	0–1.4	0.8–5.0	–	3–6	[a]
Fe_2O_3 (median)	0.5	0.5	0.6	0.5	1.3	[a]
Fe_2O_3 (range)	0.5–1.0	0.5–1.7	0.4–8.0	–	1–3	[a]
$CaCO_3$ (median)	39.6	80.1	22.7	0.3	57.6	[a]
$CaCO_3$ (range)	40–87	50–81	1–25	–	5–95	[a]
$MgCO_3$ (median)	10.2	5.6	12.3	0.2	6.0	[a]
$MgCO_3$ (range)	10–50	6–43	3–56	–	1–8	[a]
Na_2O_3 (median)	0.1	0.1	0.6	0.1	0.1	[a]
Na_2O_3 (range)	0–0.1	0.1–0.2	0–1.0	–	–	[a]
K_2O (median)	0.8	0.8	0.6	0.1	0.3	[a]
K_2O (range)	0–0.8	0.2–1.0	0–4.5	–	0.1–0.7	[a]

[a]Not determined.

TABLE 1C RESULTS OF PETROLOGIC TESTS—X-RAY DIFFRACTION AND MICROTEXTURE

Test	MN2	Samedupe	Sekoma	Nata
X-ray diffraction (CuK and radiation on nonoriented samples)	Alpha quartz, calcite, microcline felspar and dolomite	Alpha quartz	Quartz, calcite, felspar	Not determined
Microtexture (scanning electron microscope, after abrasion and polishing tests)	An overall decrease in roughness, with localized areas where the removal of large grains has increased roughness	An overall decrease of roughness caused by in-filling of the original pitted surface	An overall retention of roughness caused by removal of hard quartz grains	Not determined

differentiated into carbonate- or silica-rich constituents. Mineralogical and color differences coincided, the latter being used to sort the MN2 subsamples for the engineering tests, in which clear variations were established. The chemical analyses generally agreed with the composition determined by thin-section analysis.

In the examination of microtexture by the scanning electron microscope after the accelerated abrasion and polishing tests, the MN2 sample showed an overall decrease in roughness except in localized areas where quartz grains were plucked out to expose new surfaces. This plucking action appeared to be more dominant in the Sekoma sample. In the Samedupe aggregate, roughness decreased because of wearing of the original pitted surface.

SPECIFICATIONS FOR SURFACE DRESSING AGGREGATES

Surface dressing treatment is widely used in road maintenance to restore surface texture and resistance to polishing. It is also used to seal cracks in roads that are not structurally damaged. In many countries, double surface dressing treatments are used as the bituminous surface layer for lightly trafficked new roads. Assuming that good construction standards are achieved, surface treatments can be expected to last between 7 and 12 years, depending on the level of traffic and serviceability required.

Specifications for aggregates are based on a range of requirements relating to strength (resistance to crushing under traffic loading), durability (resistance to abrasive wear), resistance to the polishing action of traffic, and good adhesion to bitumen. In the present study, these properties were determined and initially compared to the current Botswana specifications for surface dressing stone (*6*), which are based on those used in South Africa (*7*). However, Botswana does not take into account different traffic levels, whereas a number of other countries do. A comparison was made, therefore, with neighboring countries in Africa and with Australia, the United Kingdom, and the United States, all of which permit a relaxation of specifications for low traffic volumes (see Table 2). Because the lower traffic volumes are more relevant to the design traffic levels for roads in Botswana, there clearly appears to be a need for more appropriate specifications that would allow a wider range of materials to be used. It was partly on this expectation that the present study was carried out.

Table 2 also shows that countries use different tests to specify aggregate requirements. In order to make comparisons among countries' specifications, use has been made of correlations that have been established between tests. For example, work by Shergold (*8*) and Minty et al. (9) showed good correlations between the aggregate crushing values, the 10 percent fines aggregate crushing values (10 percent FACT), and Los Angeles abrasion values, whereas Tubey and Beaven (*10*) and Hawkes and Hosking (*11*) demonstrated the correlation between the 10 percent FACT and the standard and modified aggregate impact values. The numbers in parentheses in Table 2 indicate where correlations have been made. To a certain extent, the degree of correlation is dependent on the rock properties being tested, although factors such as particle size and shape can also influence the results.

TABLE 2 COMPARISON OF SPECIFICATIONS FOR SURFACING AGGREGATES (FOR LIGHTLY TRAFFICKED ROADS)

Test	Botswana[a]	South Africa[b]	Kenya[c]	Zimbabwe[d]	Australia[e]	United States[f]	United Kingdom[g]
Aggregate crushing value (maximum, %)	(21)	21	26	30	(23)	(30)	-
10% fines aggregate crushing value (minimum, kN)							
Dry	210	210	(140)	120	(150)	(120)	-
Wet	160	160	(105)	90	(110)	(90)	-
Aggregate impact value (maximum, %)	(17)	(17)	(22)	(25)	(20)	(25)	-
Los Angeles abrasion value (maximum, %)	(21)	(21)	35	(40)	30–35	40–50	-
Aggregate abrasion value (maximum, %)	-	-	-	-	-	-	14
Polished stone value (minimum)	-	-	-	-	-	-	45
Flakiness index (maximum, %)	30	25–30	25	30	35	-	35
Sodium/magnesium sulphate soundness value (maximum, %, 5 cycles)	-	15	-	20	12	-	12
Adhesion to bitumen	>1[h]	>1[h]	-	-	-	-	<20[i]

[a]*Road Design Manual*, Ministry of Works, Transport and Communication, Botswana, 1982.
[b]*Technical Recommendations for Highways*, TRH 14, 1985.
[c]*Road Design Manual*, Part III, Ministry of Works, Transport and Communication, Botswana, May 1981 (less than 500 vehicles per day).
[d]*Zimbabwe: Part P*, Ministry of Roads and Road Traffic, Zimbabwe, Aug. 1973.
[e]*Principles and Practice of Bituminous Surfacing*, Vol. 1, National Association of Australian Road Authorities, 1984 (less than 300 vehicles per day).
[f]AASHTO 1986, M283-83.
[g]Department of Transport, Memo H176/76.
[h]Riedel and Weber Test (National Institute for Transport and Road Research, South Africa, 1979).
[i]Immersion Tray Test (Transport and Road Research Laboratory, United Kingdom, 1972).

PHYSICAL AND MECHANICAL PROPERTIES—TEST METHODS AND RESULTS

The engineering tests carried out, the methods used, and the results are presented in Table 3. The size of aggregate particles used in the tests was between 10 and 14 mm.

For weaker aggregates, the modified versions of the standard engineering tests are considered to be more appropriate because they accommodate the potential cushioning effect of the comparatively large amount of fine material produced during the tests. These tests, the modified aggregate impact test and the 10 percent FACT, can also be carried out on water-saturated, surface-dried samples to indicate their soundness. Unsoundness in aggregates is generally caused by weathering of primary rock minerals and is thus more applicable to igneous rocks. In sedimentary rocks, however, the presence of microcracks and pores may also be an indication of unsoundness. Thus, soundness tests were used to evaluate the inherent weakness of the material rather than its weathering potential. Normally, a petrologic test indicates soundness, but a chemical test using a saturated solution of sodium or magnesium sulphate is widely employed. This test, however, has poor reproducibility, especially with the sodium sulphate salt, which has several states of crystallization. It is also reported (*12*) that carbonate rocks are susceptible to chemical attack by the salt solution.

TABLE 3 RESULTS OF PHYSICAL AND MECHANICAL TESTS

	Maun-Nata (MN2)											
	Run-of-Quarry Stone		Calcrete-Enriched Stone		Silcrete-Enriched Stone		Samedupe		Sekoma		Nata	
Test and Method	Dry	Soaked	Dry	Soaked	Dry	Soaked	Dry	Soaked	Dry	Soaked	Dry	Soaked
Aggregate crushing value (%) (BS812:1975, Part 3)	23	27	24	31	23	24	19	17	18	22	20	22
10 percent fines aggregate crushing value (kN) (BS812:1975, Part 3)	180	120	160	80	200	170	240	250	220	140	200	170
Aggregate impact value (%) (BS812:1975, Part 3)	25	25	25	29	20	24	20	23	20	22	21	21
Modified aggregate impact value (%) (Hosking and Tubey, 1969)	30	33	33	36	27	24	37	30	-	-	22	24
Aggregate abrasion value (%) (BS812:1975, Part 3)	2.0	-	6.3	-	1.4	-	1.7	-	6.4	-	6.0	-
Polished stone value (BS812:1975, Part 3)	46	-	-	-	-	-	48	-	57	-	Not tested	
$MgSO_4$ soundness test (%) (ASTM C88)	0.2	-	0.8	-	0.4	-	0	-	6.5	-	Not tested	
Water absorption test (%) (BS812:1975, Part 3)	1.1	-	2.3	-	1.0	-	0.6	-	2.4–3.5	-	1.4	-
Flakiness index (%) (BS812:1990, Section 105.1)	27	-	25	-	30	-	50	-	25	-	15	-
Static immersion adhesion test at 40°C using MC30 (*Bituminous Materials in Road Construction*), TRRL, 1972)	No reaction	-	-	-	-	-	5%	-	No reaction	-	Not tested	

In order to assess the adhesion of aggregate to bitumen, the Riedel and Weber test (*13*) was attempted. It was not possible to obtain consistent results even using aggregate known to have good adhesion properties. The immersion tray test (*14*) was therefore used in which a visual assessment was made of stone coated with different binders and immersed in water at 25°C and 40°C for periods from 1 hr to 8 days. The results presented are those with MC 3000, a cutback binder commonly used in Botswana. The samples were immersed for 24 hr at 40°C.

The results of the mechanical tests showed that, if the stricter specifications of the Botswana Road Design Manual are applied (on the basis of the 10 percent FACT test), then only the Samedupe material met the requirement for surface dressing aggregate. The Nata and Sekoma materials were marginal, and MN2 was below the requirement.

The only other country whose specifications for aggregate strength are based on the 10 percent FACT test is Zimbabwe (*15*), which sets minimum values of 120 and 90 kN, respectively, for tests on dry and soaked samples. All of the aggregates satisfied these criteria. It is interesting, however, to consider the MN2 and Sekoma samples, which as mixed aggregates had relatively high proportions of calcrete. The presence of this calcareous fraction resulted in a considerable reduction in strength when the samples were saturated in water, more than the allowable 25 percent difference between samples tested in the dry and soaked condition. The effect of the weaker calcrete fraction was clearly demonstrated in the tests on the separated fractions of MN2 aggregate. A 50 percent loss of strength (from 160 to 80 kN) was obtained for the calcrete-enriched stone compared with 15 percent for the silcrete-enriched stone. The loss of strength on soaking the mixed material was 33 percent (from 180 to 120 kN). These results indicated that, for variable samples, tests on notionally representative samples may not truly reflect performance because of the disparate nature of the constituents. The application of normal specifications for acceptance of the material is also made difficult. It was mainly for this reason that a separate laboratory investigation was undertaken in which a range of engineering tests was carried out on mixtures of rock comprising different proportions of relatively hard and soft U.K. aggregates (flint and limestone). This work is reported elsewhere (*16*) but, in general, it was shown that there was a linear relationship between the aggregate strength and the ratio of hard to soft particles.

Other tests on the MN2 samples, such as aggregate abrasion, magnesium sulphate soundness, and water absorption, also reflected the difference between the calcrete and silcrete fractions, although the abrasion values were well within the U.K. Department of Transport specifications for lightly trafficked roads. The other samples also met this requirement. Further tests on the samples, not including the Nata aggregate, showed that they satisfied the minimum value of 45 in the Department of Transport's specification for polished stone value. They also showed satisfactory adhesion to bitumen. The Samedupe sample, although being a strong and sound material, failed the flakiness specification. It may be possible, however, to modify the crushing technique to increase the proportion of nonflaky stone.

The engineering tests showed that care has to be taken when applying test results of aggregates of mixed composition. To deal with these problems, it was clear that further assessments based on performance in practice were important. Thus, a series of road trials was undertaken as part of the study; two of these were in Botswana and one was in the United Kingdom.

ROAD TRIALS

The first Botswana trial, constructed in June 1983 on the Nata-Kazangula Road, used the Nata material; the second, constructed in June 1984 close to Jwaneng, used the Sekoma material (see Figure 1). The materials were laid in various sections as single and double seals. In the Nata-Kazangula trials, the underlying roadbase material was a basaltic gravel. In the Jwaneng trial, two different roadbase materials were used: one was a plastic calcified sand (Kalahari sand loosely consolidated in a carbonate matrix) and the other was a nodular calcrete gravel. These are materials likely to be used in the Kalahari region. In this trial, graded aggregates as well as single-sized aggregates were used as the surfacing material.

The performance of the surface dressing trials was subjectively assessed and is summarized in Table 4. The Nata material has performed particularly well, especially the double surface dressings, which have not received any maintenance to date. The Jwaneng trial with the Sekoma material has not performed as well; generally, there was an underapplication of a low viscosity binder due to the absorptive calcrete roadbases. The Sekoma aggregate, which had water absorption values between 2.4 and 3.5, also probably absorbed binder. As a result, most of the single seals and the top layer of the double surface dressings were lost in this trial. Inspection of the longer term performance of the aggregate in the double seals indicated that some of the softer calcrete particles were cracked and abraded, although generally the surface dressing matrix remained in place. The performance of the graded seals compared with the single seals plus crusher fines was obscured by the problem with binder application. Since this road trial, however, the Botswana Ministry of Works has been carrying out further work using graded seals. The traffic levels in the Botswana trials, between 100 and 150 vehicles per day, were what might be expected on trans-Kalahari routes.

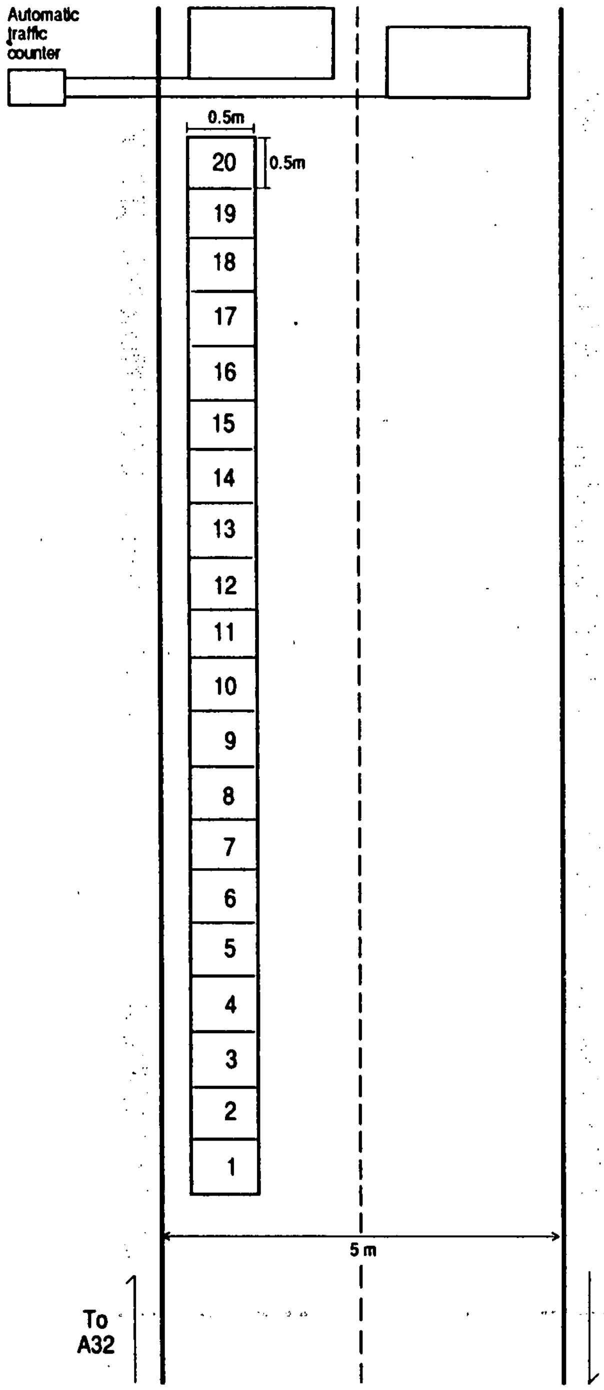
In order to assess the other aggregates included in the study—the MN2 and Samedupe materials—a pilot scale trial was constructed in August 1989 near Winchester in the United Kingdom on a minor road whose premix macadam wearing course was being surface dressed with a single seal. This action was part of a normal periodic maintenance operation. Twenty small sections, each 0.25 m², were laid in the verge side wheeltrack. Sekoma aggregate was included, as well as the Samedupe and MN2 aggregates. For the MN2 materials, some sections comprised different proportions of calcrete- and silcrete-rich material. Several mixtures of the U.K.-derived flint and soft limestone were also included. The layout of the trial sections is shown in Figure 3. A cutback bitumen binder was applied at a rate of 1.1 L/m² for all sections. Although this rate was the design rate for the control stone, which was of 10-mm nominal size, several of the experimental sections were of 14-mm size. Stone application rate was 10 kg/m².

Traffic on the road is 700 vehicles per lane per day, and measurements to date have recorded 170,000 vehicle passes over the sections in an 8-month period. This traffic level is

TABLE 4 SURFACE DRESSING ROAD TRIALS IN BOTSWANA

Section	Road base	Surface Aggregate	Surface Treatment (Single or Double Seal, Stone Size)	Binder Application Rate (L/m²) 1st Seal	Binder Application Rate (L/m²) 2nd Seal	Stone Application Rate (kg/m²) 1st Seal	Stone Application Rate (kg/m²) 2nd Seal	Traffic (1987 veh/day)	Maintenance Treatment	Performance Rating Scale After 5 Years[a]
Nata-Kazangula Road Trials (Constructed June 1983)										
1			13 mm	1.6	–	12	–		Slurry seal (Nov. 1986)	4 to 1
2			13 mm, with fog spray	1.6	–	12	–			3 to 1
3	Basalt gravel	Nata calcrete	13 mm + crusher waste	1.6	1.2	12	12	140 (52% > 5 t.)		2
4			13 mm + 6.7 mm double	1.6	1.1	12	5		No treatment	2
Jwaneng-Sekoma Road Trial (Constructed June 1984)										
1[b]		Dolerite[c]	19 mm + 6.5 mm	1.5	1.5	19	11			3
2			19 mm + 6.5 mm	2.1	1.6	19	11			3
3	Calcified sand		19 mm + fines	2.7	0.9	19	12			3–4
7		Sekoma calcrete	Double graded seal[d]	1.4	1.5	30	24	112 (34% > 5 t.)	Fog spray (July 1985)	3
15			13 mm + fines	1.6	1.2	12	12			3
17	Nodular calcrete		19 mm + 9.5 mm	1.8	1.4	19	11			4
18		Dolerite[c]	19 mm + 9.5 mm	1.6	2.0	19	11			3

[a]Performance rating based on TRH 6, South Africa, 1985, Table V, p. 29. 1 = no discernible loss of stone; 2 = same as 1 with assessed hardening of binder; 3 and 4 – progressive loss of stone from top layer of multiple seals; 5 = loss of stone from all layers of multiple seals. Cutback bitumen binder used in both trials.
[b]Sections 4, 5, 6, 8–14, and 16 of the Jwaneng-Sekoma road trial were all single seals and were lost within 5 years.
[c]The dolerite aggregate used was a control, with 10 percent FACT values of 240 to 270 kN.
[d]Double-graded seal of Section 7 comprised 19- to 3-mm and 14- to 3-mm aggregate.



PLAN OF ROAD

Date of Inception: 9 August 1989
Location: O.S.Ref.632238
Traffic: ca.700vpd per lane

EXPLANATION OF TRIAL SECTIONS

Section no.	Material	Description	Stone size (mm)
20	Control (UK)	Basalt	-10 + 6.7
19	Samedupe (Botswana	Silcrete	-14 +10
18	Sekoma (Botswana)	Calcrete breccia	-14 +10
17 16 15	MN2; Silcrete-calcrete (Botswana)	100% Calcrete; 0% silcrete 50% Calcrete; 50% silcrete 0% Calcrete; 100% silcrete	-14 +10 -14 +10 -14 +10
14 13 12 11 10	UK aggregates	100% Limestone; 0% flint 75% Limestone; 25% flint 50% Limestone; 50% flint 25% Limestone; 75% flint 0% Limestone; 100% flint	-14 +10 -14 +10 -14 +10 -14 +10 -14 +10
9 8	MN2 (Botswana)	100% Calcrete; 0% silcrete 0% Calcrete; 100% silcrete	-10 + 6.7 -10 + 6.7
7 6	Sekoma (Botswana)	Calcrete breccia	-10 + 6.7 -10 + 6.7
5 4 3 2 1	MN2 (Botswana)	100% Calcrete; 0% silcrete 75% Calcrete; 25% silcrete 50% Calcrete; 50% silcrete 25% Calcrete; 75% silcrete 0% Calcrete; 100% silcrete	-10 + 6.7 -10 + 6.7 -10 + 6.7 -10 + 6.7 -10 + 6.7

Notes:
Binder type: 'cutback' bitumen
Quantity: 1.1 litres /m²
Stone application rate: 10kg/m²
Section 20 is the same material as applied to the rest of the road surface on 9 August

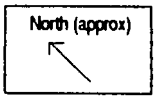


FIGURE 3 Surface dressing trial layout at Ropley, near Winchester, United Kingdom.

about 10 times more than would be expected on trans-Kalahari roads and is therefore approaching the total traffic expected during a 7- to 10-year design life of a surface dressing. So far the sections have performed well with the exception of the two Sekoma sections, where approximately 20 percent of stone has been lost. Even the calcrete-enriched fractions of MN2 laid in Sections 5, 9, and 17, which have lower aggregate strengths than the Sekoma material, have performed better. So has the U.K. soft limestone in Section 14. Satisfactory performance has been obtained from the larger sizes laid in Sections 10 to 19 inclusive (with the exception of the Sekoma stone), even though the bitumen application rate was designed for the 10-mm size.

At this stage, it is probably premature to rate the Sekoma aggregate as unsatisfactory because in practice it would be laid in new construction as a double surface dressing and not as a single seal. Also, in the wintry conditions of the U.K. trials, the wetness and frosts are more severe than would be experienced in Botswana. However, further evidence of the weakness of the Sekoma aggregate was shown by the results of the mechanical tests, in which the water absorption, abrasion loss, and magnesium sulphate soundness values were higher than the other aggregates examined.

CONCLUSIONS AND RECOMMENDATIONS

The wide variation in the types of duricrust occurring in the Kalahari region of Botswana means that careful attention must be paid to methods of identification to recognize deposits likely to be suitable as aggregate for use in road construction. Even among the harder materials, the mode of deposition requires that cores from drilling have to be examined to estimate the quantities or reserves of material available. Four different duricrusts identified as potential surface dressing aggregates for major new road projects were investigated in this study by examining their composition, mechanical and engineering properties, and performance in road trials.

Although the materials were initially classified as calcretes or silcretes, they were more typically of mixed composition. The calcareous and siliceous fractions were variable and could strongly influence properties and behavior. Examination of the separated fractions of one of the aggregates (MN2 sample) showed that the calcareous portion was weaker and susceptible to further softening when saturated with water. The disparate nature of individual fractions makes it more difficult to assess test results of representative samples of the whole material.

In order to determine the mechanical strength of weaker or marginal quality aggregates, it is important to use the now generally recognized modified forms of standard tests such as the 10 percent FACT or modified aggregate impact test. In this study, the 10 percent FACT test was more discriminating, although the apparatus for the aggregate impact test is simpler, cheaper, and portable. Other tests that can be used to differentiate weaker aggregates are the aggregate abrasion test and water absorption.

All of the aggregates included in the study were incorporated into road trials. The Sekoma aggregate performed less well, but there is sufficient evidence to indicate that they would all be satisfactory as surfacing aggregates for lightly trafficked roads. This is especially the case for new roads when double surface treatments are used. The use of graded aggregate seals as opposed to using single-sized chippings and the use of a slurry seal in the second application may also provide better protection of exposed aggregate particles. These construction practices are currently being examined by the Roads Department in Botswana together with a wider range of test methods on other marginal materials.

The results of the study and the comparison made of different specifications used by other countries for surfacing aggregates have shown clearly that the existing Botswana specifications were too stringent for lightly trafficked roads. Following discussions with the Botswana Roads Department on the results of the work and evidence from other work in Botswana, new interim specifications have now been proposed, which are set out below. (Generally, values of tests on soaked samples should be 75 percent of those on dry samples. However, this requirement may be relaxed for roads constructed in the drier regions of the Kalahari provided that the minimum soaked test value is satisfied.

Minimum 10% FACT Values (kN)		*Pavement Design Category [equivalent standard axles (esa)]*
Dry Test	*Soaked Test*	
180	135	>3 million
150	115	0.8–3 million
130	100	<0.8 million

ACKNOWLEDGMENTS

This paper is published with permission of the Director of the Transport and Road Research Laboratory and Her Britannic Majesty's Stationery Office, United Kingdom, and the Roads Department of the Ministry of Works, Transport, and Communications, Botswana. Assistance in materials testing was provided by Queen Mary College, London, and in the U.K. road trial by Hampshire County Council. The work described here is part of the program carried out for the Overseas Development Administration.

REFERENCES

1. C. J. Lawrance and T. Toole. *The Location, Selection and Use of Calcrete for Bituminous Road Construction in Botswana.* TRRL Laboratory Report 1122. Transport and Road Research Laboratory, Crowthorne, England, 1984.
2. T. Toole, D. Newill, and A. V. Lionjanga. The Development of Specifications for the Use of Calcretes in Lightly-Trafficked Roads in Botswana. In *Transportation Research Record 1106, Vol. 1,* TRB, National Research Council, Washington, D.C., 1987.
3. A. Goudie. Duricrusts in Tropical and Subtropical Landscapes. Clarendon Press, Oxford, 1973.
4. F. Netterberg. *Calcrete in Road Construction.* CSIR Research Report RR 286. National Institute for Road Research Bulletin 10, Pretoria, South Africa, 1971.
5. K. Grant and G. D. Aitchinson. The Engineering Significance of Silcretes and Ferricretes in Australia. *Engineering Geology,* Vol. 41, 1970, pp. 93–120.
6. *Road Design Manual.* Roads Department, Ministry of Works, Transport, and Communications, Gaborone, Botswana, 1982.
7. *Guidelines for Road Construction Materials.* Report TRH 14. National Institute for Transport and Road Research, Pretoria, South Africa, 1985.

8. F. A. Shergold. *A Review of Available Information on the Significance of Road Stone Tests*. Road Research Technical Paper 10. Department of Scientific and Industrial Research, Road Research Laboratory, Her Majesty's Stationery Office, London, 1948.
9. E. J. Minty, D. N. Pratt, and A. J. Brett. Aggregate Durability Tests Compared. *Proc., Australian Road Research Board*, Vol. 10, Part 3, 1980.
10. L. W. Tubey and P. J. Beaven. *A Study of Petrology of Some Soft Limestones from Jamaica in Relation to Their Engineering Properties*. RRL Report 21. Road Research Laboratory, Crowthorne, England, 1966.
11. J. R. Hawkes and J. R. Hosking. *British Arenaceous Rocks for Skid-Resistant Road Surfacings*. TRRL Laboratory Report 488. Transport and Road Research Laboratory, Crowthorne, England, 1972.
12. P. M. Gandhi and R. L. Lytton. Evaluation of Aggregates for Acceptance in Asphalt Paving Mixtures. Presented at Annual Meeting of the Association of Asphalt Paving Technicians, Scottsdale, Ariz., 1984.
13. *Standard Methods for Testing Road Construction Materials*. Report TMH 1. National Institute for Transport and Road Research, Pretoria, South Africa, 1979.
14. *Bituminous Materials in Road Construction*. Road Research Laboratory, Her Majesty's Stationery Office, London, 1962.
15. *Zimbabwe: Part P*. Ministry of Roads and Road Traffic, Zimbabwe, Aug. 1973.
16. C. W. M. Slater. *Engineering Test Characteristics of Siliceous/Calcareous Mixtures*. M.Sc. thesis. Queen Mary College, University of London, England, 1989.

Views expressed herein are not necessarily those of the British government.