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PROJECT REPORT 115

DEVELOPMENT OF A REDUCED SPECIFICATION FOR SURFACING AGGREGATE ON LOW TRAFFIC ROADS IN BOTSWANA

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EXECUTIVE SUMMARY

Current specifications for surface dressing aggregate in Botswana are demanding and exclude the use of local materials that could be suitable. Use of these materials, known as duricrusts, on low traffic roads would result in reduced road construction and maintenance costs.

The petrographic characteristics and engineering test values of three typical duricrusts are described. The duricrusts as a whole exhibit a wide spectrum of properties because they are a mixture of calcareous material, or calcrete, and siliceous material, or silcrete. The calcrete is typically much weaker and less durable than the silcrete. The silcrete, although strong and durable, can show other undesirable properties such as flakiness and poor adhesion to bitumen.

The variability of the duricrusts can make it difficult to predict their suitability for surface dressing aggregate from the engineering test results alone. A field trial was therefore constructed in the UK incorporating the duricrusts as surface dressing and comparing their performance to a proprietary UK aggregate. Traffic levels were higher than normal for Botswana roads, thus accelerating wear and tear on the aggregate and producing a result in a shorter time.

The results of the field trial confirm that the calcrete-rich duricrusts are susceptible to breakdown principally caused by traffic whereas the silcretes are far more resistant. The lack of durability of the calcretes, possibly exacerbated by the British climate, was also demonstrated. The breakdown of the calcretes was manifested in aggregate cracking and surfacing loss and by the end of the trial the chippings had abraded and polished. The silcretes, in contrast, showed only minor wear and tear.

The performance data from this trial and other field trials, and from contract experience in Botswana, enables a revised, traffic-based specification to be proposed. It precludes the use of calcrete-rich aggregate on all but the lowest trafficked roads but permits the use of silcrete-rich aggregate on any Botswana roads. The revised specification applies both to new (double) surfacings and to (single) maintenance treatments. The construction of a full scale field trial in Botswana is recommended to confirm the revised specification.

It is also proposed that the Aggregate Impact Test could replace the Ten Percent Fines Aggregate Crushing Test for routine testing of a known source. It requires a smaller sample and less expensive apparatus. However, further laboratory testing to confirm the relationship between the two tests is recommended.

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ABSTRACT

The Paper discusses the results of a surface dressing road trial constructed in the UK to assess the performance of aggregates from Botswana that do not meet the specifications but may be usable. The aggregates are duricrust materials (calcrete and silcrete) which are very variable in quality; the main reason in seeking to utilise them is to reduce the cost of road construction in the remoter regions of Botswana. The results indicate that the aggregates are certainly suitable for use as surface dressing aggregate under low traffic conditions and also under higher traffic conditions depending on their composition. Amendment of the Botswana standards is proposed.

1. INTRODUCTION

A programme of reconstruction is being carried out in Botswana whereby the main routes are being upgraded from gravel roads to bituminous surface dressed roads. Fig 1 shows the principal roads in question, totalling about 3000km, of which about half have already been upgraded.

A surface dressing comprises a thin film of bitumen sprayed onto the road surface into which a layer of stone chippings is rolled. The bitumen acts as a binder for the chippings and also as a waterproofing agent against surface water ingress. The chippings protect the binder from damage and provide a durable and skid-resistant wearing surface; therefore, to be suitable for surface dressing, the aggregate must be of high strength to resist the impact and abrasive effects of traffic, and durable to resist weathering.

In many countries surface dressing is applied directly to the roadbase (the main load-bearing layer of the road structure) to form a wearing surface. In the Kalahari desert, which comprises 80% of the surface area of Botswana, the only locally available roadstones are calcrete, a gravelly calcareous material, and silcrete, a similar siliceous material. Collectively these materials are known as duricrusts as they generally occur close to the surface and are formed by the cementation and/or replacement of pre-existing soil (Netterberg, 1971). Calcrete is characterised by an accumulation of calcium carbonate, and sometimes also magnesium carbonate. Silcrete is characterised by an accumulation of silica. Use of the duricrusts for road construction is potentially economically advantageous due to their widespread occurrence and low cost of extraction but they require careful assessment due to their variability. This variability is related to the mode of formation of the duricrusts; generally the hard silcrete and soft calcrete are combined together and cannot easily be separated by normal quarrying techniques.

The road reconstruction programme referred to above has relied on the extensive use of the duricrusts. TRL, in collaboration with the Botswana Ministry of Works, Transport & Communications, investigated the duricrusts during the 1980's with the objective of proposing appropriate specifications for their use. The work included studies relating to the location of the duricrusts (Lawrance et al, 1984), their use as roadbase (Greening et al, 1994) and as surface dressing aggregate. This report summarises the results of the research into the use of the duricrusts as surface dressing aggregate.

2. ORIGIN OF THE RESEARCH

At an early stage in the site investigations two road trials were constructed to test the suitability of selected duricrust deposits as surface dressing. In one trial a locally occurring hard white calcrete was used (the Pandamatenga trial, site 1 on Fig 1). Its quality was exceptionally good for duricrust and only slightly below the Botswana specifications for surface dressing. It has now been trafficked for 11 years, with only minor aggregate loss and polishing. Current traffic flows are about 170 ADT (average daily traffic), with about 12% commercial vehicles. In the other trial (the Jwaneng 2 trial, site 2 on Fig 1) a much more variable calcrete from Sekoma was used for surface dressing calcrete roadbases. After 5 years traffic, averaging 100 ADT with about 5% commercial vehicles, the calcrete showed considerable cracking, abrasion and loss. The trial has since been reconstructed.

It is clear that the duricrusts are being used as surface dressing aggregate but the conditions for their use have not been formalised. Use of silcrete or silcrete-rich duricrusts as surface dressing aggregate has usually been approved by the Botswana Ministry of Works. Silcrete is generally much stronger and durable than calcrete and in general will satisfy the Botswana specifications if the silcrete proportion is high enough. However, it can exhibit other undesirable characteristics such as flakiness and/or poor adhesion to bitumen. Part of the Serowe to Orapa road was surfaced with a locally occurring silcrete in 1989. Although there was some serious initial cracking of the stone owing to the presence of soft, leached zones, performance has been satisfactory since. Traffic averages 200 ADT. In the early 1990's the whole of the 300 km long Nata to Maun road was surfaced with silcrete obtained from two separate, locally occurring sources. Although the silcrete from both

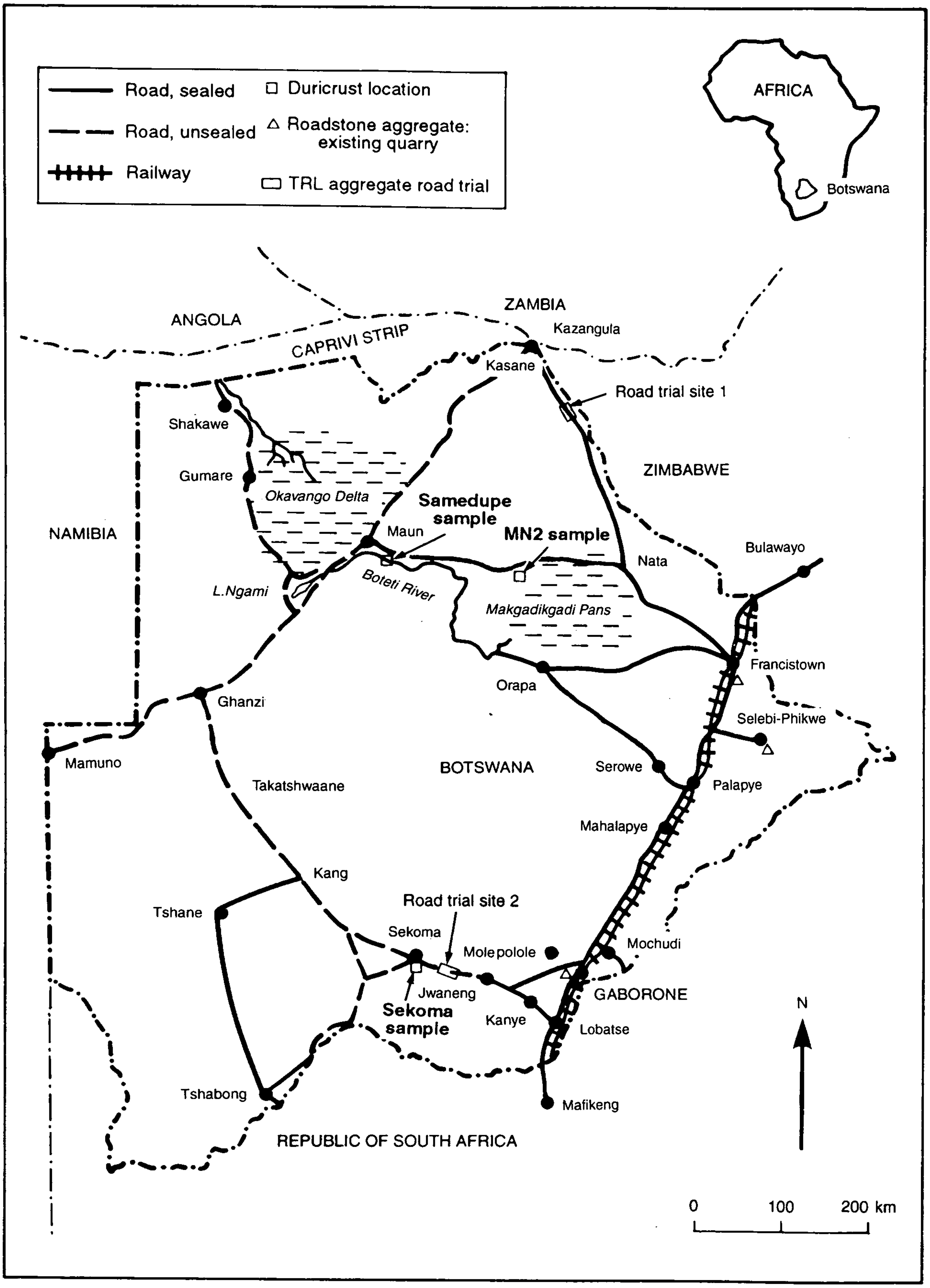


Fig. 1 Botswana: road network

sources was strong it contained thin, minor soft calcrete veins resulting in some initial cracking just after construction. It also showed poor adhesion to bitumen, necessitating special techniques for application. Traffic averages 200 ADT on this road, with 18% commercial vehicles. Currently, a section of the Sekoma to Kang road is being surfaced with a locally occurring silcrete obtained from near Kang, to which reference is made later in the report.

3. OBJECTIVES AND METHODOLOGY

The main objective of the research was therefore to derive a suitable specification. More specifically, the objectives were as follows:

- to find out whether duricrust aggregate is suitable as surface dressing aggregate and, if so, for what level of traffic,
- to assess whether the existing specification is too rigorous and, if so, how it might be revised,
- to evaluate what physical changes take place in aggregate after laying and whether and how this affects performance,
- to determine the effectiveness or otherwise of mixing a harder aggregate (silcrete) with a softer aggregate (calcrete).

The approach adopted was to carry out petrographic and engineering tests on several examples of duricrust and then to construct a surface dressing field trial to compare the performance of the duricrust with aggregate of proven quality. Appropriate specifications in the form of minimum engineering test criteria could then be recommended for the traffic conditions in Botswana.

The field trial was carried out in the UK, at a site selected so that traffic levels were significantly higher than Botswana, thereby accelerating the wear and tear on the aggregate and obtaining results within a shorter period of time.

4. PETROGRAPHY OF AGGREGATES

Petrographic examination of the duricrusts was carried out because it identifies the minerals associated with the engineering test values and explains performance better. The examination carried out for this research included detailed microscopic analysis: normally this would only be necessary for new sources of aggregate.

The three duricrust aggregates were a calcrete from Sekoma pan; a layered calcrete/silcrete referred to as the MN2 deposit; and a silcrete, referred to as the Samedupe deposit. The locations of the three trial aggregates are shown in Fig 1. Photomicrographs of the duricrusts are shown in Plates 1a to 1d.

The Sekoma calcrete occurs in substantial quantities in the rim of a large pan. A quarry face has been developed and stone has been extracted for local construction purposes. The calcrete is quite crumbly in the upper 1 metre of the face but grades down into a massive stone comprising angular fragments of dark grey or reddish siliceous material in a light brown calcareous matrix. Crushed fragments are subangular in shape with a rough surface texture and a dusty surface coating and each fragment is different in the proportion of carbonate matrix to siliceous material. Examination of the carbonate matrix under the petrographic microscope reveals independent quartz grains (< 0.5mm to 2.0mm size) in a fine grained calcite matrix.

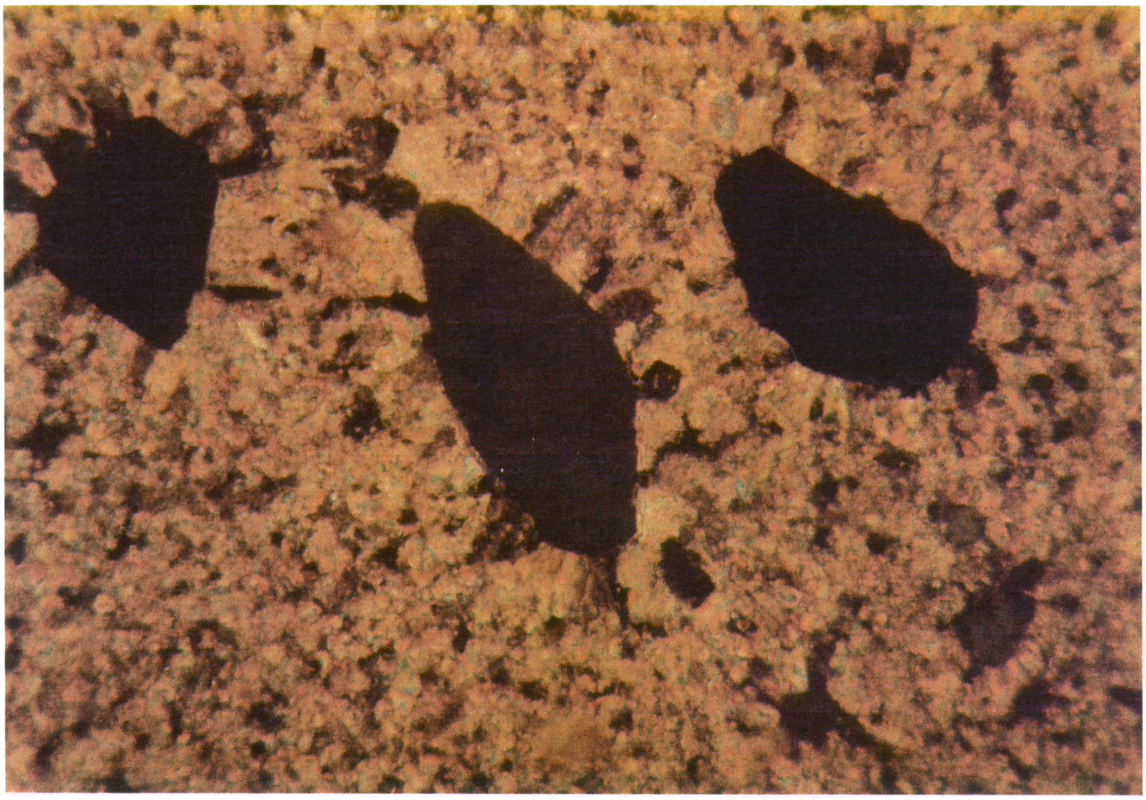
The Samedupe silcrete occurs as boulders in the bed of the Boteti river, a seasonal water course. It is cream-brown to reddish in colour; individual aggregate particles are hard and brittle, are subangular to angular in shape and are flaky. Under microscopic examination the silcrete comprises very small and closely packed quartz grains in a siliceous cement.

The MN2 material occurs in a small pan. It is predominately a silcrete with thin calcrete layers. The deposit averages about 6 metres thickness, comprising about 70% green or black silcrete with thin beds of white calcrete and loose sand. The upper 2 metres of the deposit is dense and compact but the lower layers become increasingly porous and soft. It is possible to separate the calcrete-rich and silcrete-rich fractions so that tests can be determined on each but it would probably not be feasible to quarry the rock in this way. The aggregate particles produced are therefore either silcrete or mixed silcrete and calcrete.

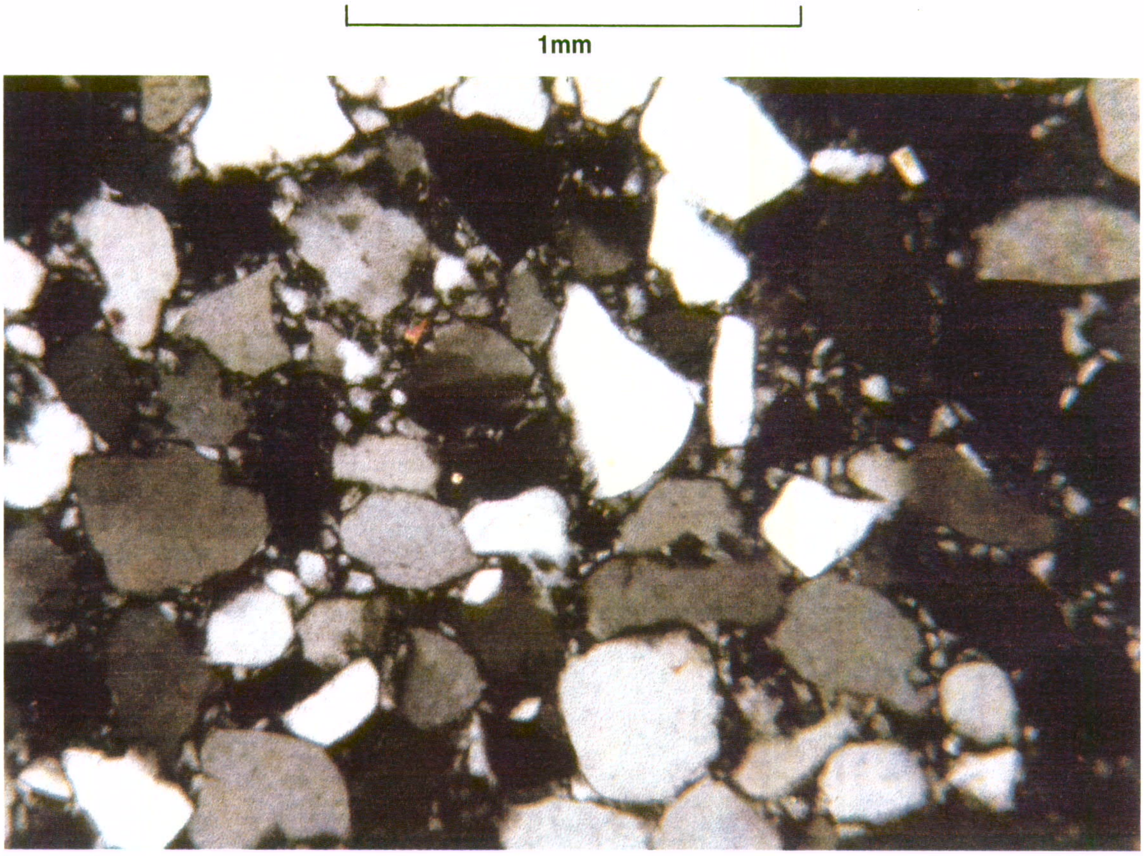
For comparative purposes siliceous and calcareous aggregates of UK origin were used in the field trial. These were flint, obtained from a gravel pit near Reading, and oolitic limestone, obtained from a quarry near Pickering, Yorkshire. The aggregate used as a control in the field trial was a basalt from Somerset.

5. ENGINEERING SPECIFICATIONS

Specifications for surface dressing aggregate are described in terms of a series of engineering test values. The values required by Botswana, its neighbouring countries, Australia and the United Kingdom are shown in Table 1. The specifications vary and it is noteworthy how more demanding the Botswana (and South Africa) specifications are compared to those of the other countries. However, the other countries qualify their specifications according to traffic category and Table 1 gives the specifications for the low traffic categories: those of Botswana and South Africa are not differentiated in this way, probably because of the traditional use of steel-

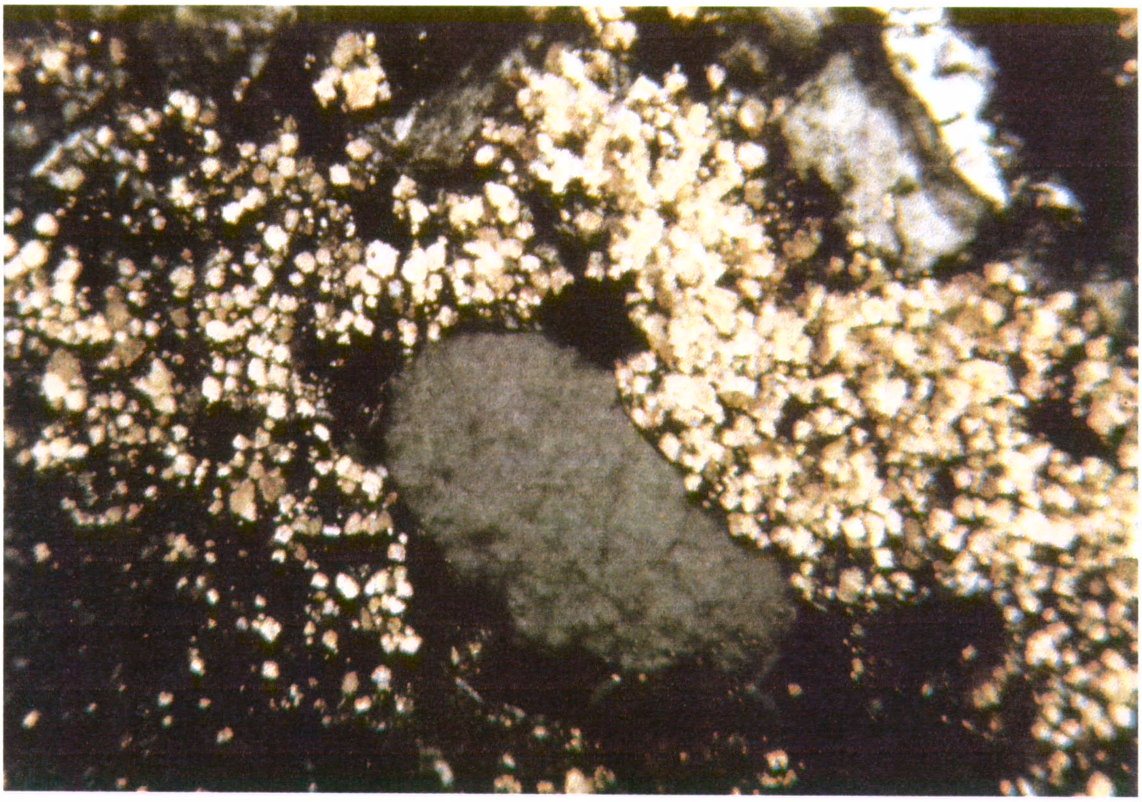


(a) Sekoma Calcrete: brown/yellow fine grained calcite crystals radially developed around black quartz grains.
Photo taken under crossed polarised light.

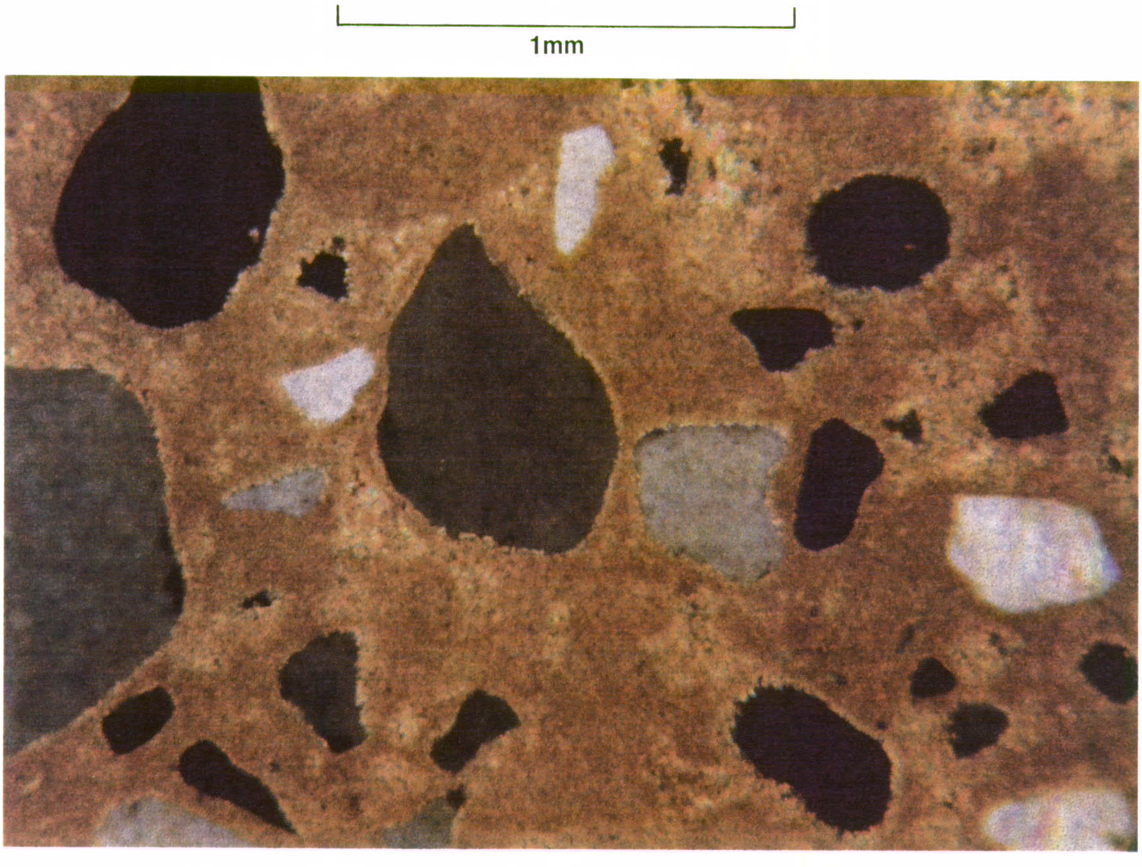


(b) Samedupe Silcrete: all crystals are of quartz, closely packed, amongst siliceous cement.
Photo taken under crossed polarised light.

Plates 1 (a) & (b) Photomicrographs of Duricrusts



(c) MN2 Aggregate: quartz (sand) particles surrounded by very fine grained calcite (light colour) and quartz (dark colour).
Photo taken under crossed polarised light.



(d) MN2 Aggregate: sand particles in very fine grained (brown) calcite matrix.
Photo taken under crossed polarised light.

Plates 1 (c) & (d) Photomicrographs of Duricrusts

TABLE 1

Specifications for Surfacing Aggregates

Engineering Test	United Kingdom	TRL ORN 3	Botswana	South Africa	Zimbabwe	Kenya	Australia
Aggregate Crushing Value, (ACV),max %		35		21	30	26	
Ten Percent Fines Value (TFV), kN, min	160		210 {160}	210 {160}	120 {90}	140 {105}	150 {110}
Los Angeles Abrasion value, max %						35	25 to 45 (Note 2)
Flakiness Index, max %	35	35	30	30	30	25	35
Na/MgSO$_4$ Soundness Value, max % (Note 3)					20	12	12

Notes:

1) For Ten Percent Fines (TFV), values in brackets {} are determined on the aggregate in a saturated but surface-dry state
2) Value recommended depends on stone type
3) Determined after 5 cycles in the test: values quoted are amounts of material lost after test
4) United Kingdom: BS 63: Part 2: 1987
5) TRL ORN 3: A Guide to Surface Dressing in Tropical & Sub-tropical Countries
6) Botswana: Road Design Manual, 1982
7) South Africa: Technical Recommendations for Highways (TRH) 14, 1985
8) Zimbabwe: Min of Roads & Road Traffic, Part P, 1973 (for road design life of < 2 million equivalent standard axles)
9) Kenya: Road Design Manual, Part III (Min of Trans & Comm), 1981 (for traffic of < 500 vehicles per day in both lanes)
10) Australia: NAASRA, Pavement Materials, Part 4-Aggregates, 1982 (for roads carrying < 200 vehicles per lane per day).

wheeled rollers to emplace the chippings. TRL Overseas Road Note 6 defines low traffic as less than 400 ADT, or 200 passes per lane per day.

Various tests are used to describe aggregate strength, defined as resistance to crushing, impact and abrasion. The Aggregate Crushing Value (ACV), derived from the Aggregate Crushing Test (BS 812: Part 110:1990) is quoted in most specifications; the modified version, the Ten Percent Fines Aggregate Crushing Value (TFV) (BS 812: Part 111:1990) is now preferred, especially when the ACV exceeds 30. When the ACV exceeds 30 it implies that the aggregate is weak: in these circumstances the test procedure used to obtain the TFV is more appropriate than that for the ACV. Furthermore, the TFV test incorporates a procedure for testing samples that have been soaked in water for 24 hours beforehand. This procedure often highlights the lack of durability of the weaker aggregates. Other durability tests are the Soundness Test (BS 812: Part 121: 1989) and the Water Absorption Test (BS 812: Part 2:1975).

The Aggregate Impact Test (BS 812: Part 112:1990) is of interest because it requires a small sample and relatively inexpensive equipment. A modified Aggregate Impact Test was developed by Hosking and Tubey (1969), whereby the number of blows was reduced so as to produce between 5 and 20% of fines, i.e. material passing the 2.36mm sieve. The Modified Aggregate Impact Value (MAIV) is equal to the product of the amount of fines produced and the number of blows given, proportioned to 15, the standard number of blows given in the Aggregate Impact Test. Thus, if 5 blows produced 10% of fines, the MAIV is equal to 15/5 x 10 = 30. The Modified Aggregate Impact Test was first introduced in BS 812: Part 112: 1990, for testing aggregates in a soaked (but surface dry) condition.

The Aggregate Abrasion Test (BS 812: Part 113: 1990) is sometimes used to evaluate the degree of wear. Aggregate Abrasion Values not exceeding 14 are required for surface dressing aggregate by the UK Department of Transport. The Los Angeles Abrasion Test is more popular elsewhere and combines elements of abrasion and impact.

Various workers have determined the relationships between the engineering tests. They are discussed in Geological Society Engineering Geology Special Publication Number 9 (Aggregates); Hosking (1993); and Sampson, (1989). The relationship between the ACV and AIV is of interest. Sampson states that the relationship between ACV and AIV, for values of ACV between 10 and 30 is as follows:

$$ACV \sim 1.1(AIV)_{15\ \text{blows}}$$

The relationship apparently varies slightly according to rock type. Hosking (1993) also cites the close numerical agreement between the ACV and AIV.

Weinert (1980) states, and inspection of the data in Minty et al (1980) confirms, that the relationship between the ACV and TFV, for values of ACV between 14 and 30, is approximately:

$$ACV \sim 38 - 0.08(TFV)$$

Thus a relationship can be obtained between TFV and AIV:

$$AIV \sim 38 - 0.08(TFV) / 1.1$$

The last relationship is refered to later. Further work could be done to verify this relationship for the weaker aggregates (ACV > 30) using the modified Aggregate Impact Test. As the Aggregate Impact Test is inexpensive to carry out, more frequent testing of variable materials would be encouraged, which would be desirable for quality control purposes.

6. ENGINEERING TEST RESULTS

The engineering test results for all the aggregates used in the road trial are presented in Table 2. The tests were carried out according to the British Standards on single samples taken as randomly as possible from bulk samples of crushed aggregate. The duricrust aggregates were all of slightly non-standard size for testing by BS procedures, having been crushed according to South African size specifications. The British Standards state that smaller sizes tend to give lower values, indicating a stronger stone.

With the exception of the Samedupe aggregate, the duricrusts failed to meet the Botswana standards for surface dressing aggregate owing to inadequate dry or

TABLE 2

Engineering Test Results of Aggregates

Engineering Test	No of Blows	MN2: whole rock	MN2: calcrete rich	MN2: silcrete rich	Samedupe silcrete	Sekoma calcrete	Control: basalt	UK: flint	UK: limestone
Aggregate Crushing Value, (ACV), %		23 (27)	24 (31)	20 (20)	19 (17)	18 (22)	11		
Ten Percent Fines Aggregate Crushing Value, (TFV), kN		180 (120)	160 (80)	200 (170)	240 (250)	190 (100)	360	210 (230)	140 (110)
Aggregate Impact Value, (AIV),(*) and MAIV, (#), %	#5	25 (30)	24 (30)	21 (24)	30 (25)	22 (27)		18 (18)	25 (28)
	#10	26 (29)	23 (26)	20 (21)	26 (24)	23 (28)		19 (18)	23 (25)
	*15	25 (27)	20 (23)	18 (20)	24 (24)	22 (26)	13	5 (15)	20 (22)
Aggregate Abrasion Value, %		2.0	6.3	1.4	1.7	6.4	2.9		
Flakiness Index, %		26			50	34		20	22
Soundness Value, %		99	99	99	100	93	97		
Water Absorption, %		1.1	2.3	1.0	0.6	2.9	0.7	0.7	3.0
Relative Density (oven-dried), Mg/m^3		2.57	2.49	2.59	2.58	2.48	2.73	2.57	2.50
Static Immersion at 40°C (Adhesion to Bitumen Test)			No reaction	10 % stripped	5 % stripped	No reaction			

Notes:

1) Values given within and without brackets refer to samples tested in a soaked and dry condition respectively.

2) All test procedures are described in BS 812 (1990) except for the Adhesion to Bitumen Test which is described in 'Bituminous Materials in Road Construction', Road Research Laboratory, 1962.

3) Engineering test values for Botswana duricrusts determined by Scott (1988) and others; for control aggregate by Hampshire County Council; for UK flint and limestone by Slater (1989).

soaked strength, or both, expressed as the TFV. However, they all met the less stringent requirements of the other countries listed in Table 1. The calcrete component of the duricrusts was particularly weak in the soaked tests and also showed relatively high values of water absorption. The Sekoma calcrete also gave a poor result in the Soundness test. In the case of the MN2 mixed calcrete/ silcrete duricrust, separate tests were carried out on the whole rock, as excavated in situ, and the (manually separated) calcrete-rich and silcrete-rich components. The results showed that the silcrete fraction was stronger and more durable.

In the case of the Samedupe silcrete the high flakiness index would also have resulted in non-compliance with the Botswana specifications but it may have been possible to reduce this to an acceptable level by using a different crushing technique. Reducing the flakiness may also increase its strength, as determined in the engineering test.

The Adhesion to Bitumen test results indicated a potential problem with the silcrete-rich duricrust.

Three sets of Aggregate Impact Values, i.e. after 5, 10 and 15 blows are shown in Table 2. The AIVs are derived from the results for 15 blows. As the AIVs for the duricrusts were close to or exceeding the 20% fines criterion, modified Aggregate Impact tests were also carried out. Thus, results for 5 and 10 blows are proportioned to 15 blows to give the MAIVs. Although not enough determinations were made to be statistically significant, the results indicate that the MAIVs can be higher than the AIVs for the same sample. This applied especially to the soaked samples.

The equations between ACV, TFV and AIV quoted from other researchers in Section 5 do not relate well to the values actually obtained, as quoted in Table 2. This may reflect the difficulty in obtaining consistent results from variable materials and underlines the need to undertake repeated testing of them.

The control aggregate, a basalt, was of high strength and good durability. The UK flint and limestone aggregates, which were used together in controlled proportions in the road trial, were respectively of high and low strengths. The indications from the soaked TFV and AIV tests were that they showed comparable durability.

7. CONSTRUCTION OF THE FIELD TRIAL

A convenient site near Ropley, 15 km east of Winchester (UK), was selected where a narrow country road connecting the A31 and A32 was given a single surface dressing to restore skidding resistance. The road surface was a hard bitumen macadam. The site was straight with well-channelled traffic.

Nineteen trial panels of single surface dressing, each about 0.5 m^2, see Fig 2, were laid end to end in the vergeside wheelpath of the east-moving traffic lane. A twentieth panel, comprising a basalt used by Hampshire County Council for the resurfacing contract, was used as the control.

The three Botswana duricrusts comprised most of the panels. The MN2 aggregate was segregated into panels containing different proportions of calcrete-rich to silcrete-rich stone, viz, panels 1 to 5, 8 and 9. Two different chip sizes were selected to determine whether this affected performance. For the purposes of comparison, panels containing mixed proportions of the UK flint and oolitic limestone were also laid (nos. 10 to 14), but only at the larger aggregate size.

The Sekoma aggregate was placed in panels at two different chipping sizes (panel nos. 6, 7 and 18) but it was not possible to separate the harder from the softer fraction because, as explained earlier, each chipping often consisted of hard and soft constituents.

Only a large chipping size of the Samedupe silcrete was available (panel 19).

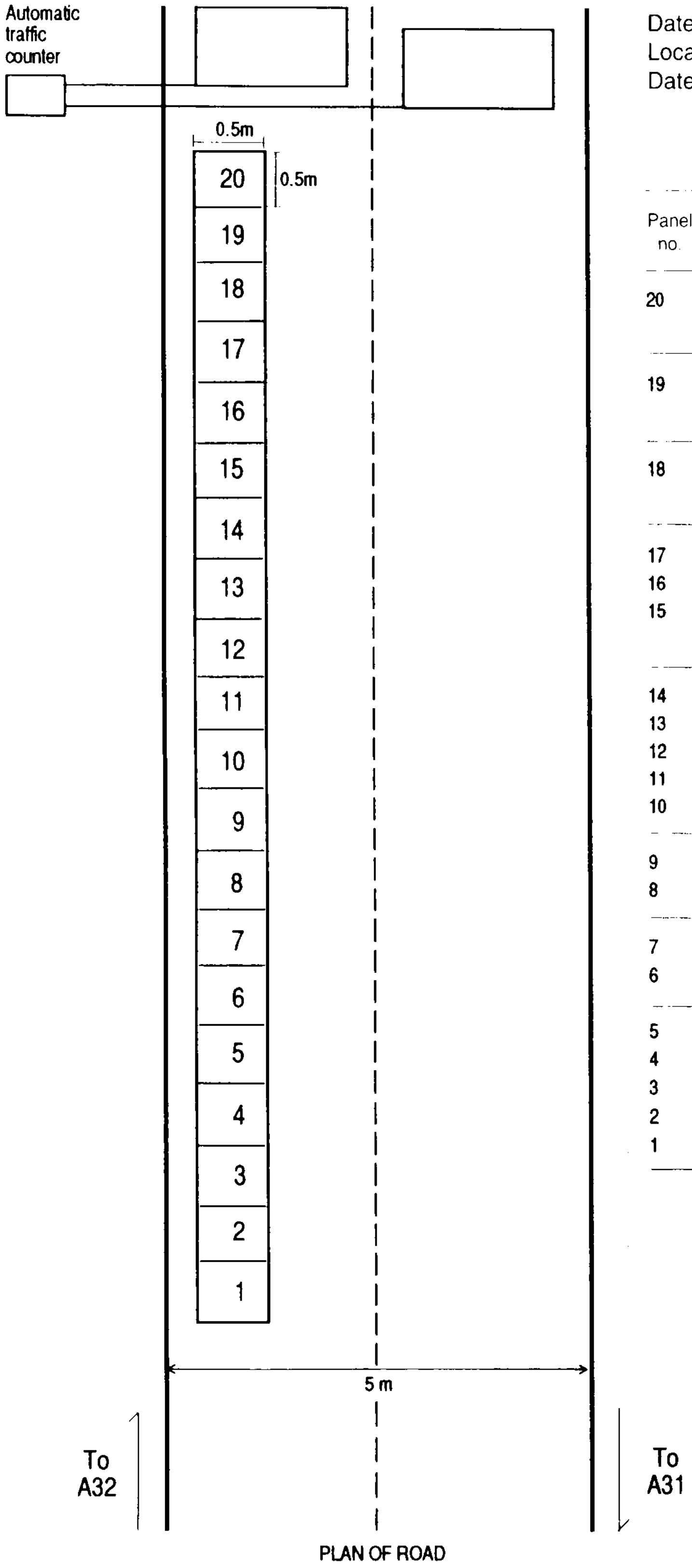
A cutback bitumen binder was sprayed onto the road at a rate of 1.1 l/m^2. Average aggregate application rate was 10 kg/m^2. Wooden trays of the required dimensions were placed over the hot bitumen just before the chippings lorry passed, then removed immediately after the lorry passed to allow the manual application of the trial aggregate. A heavy, rubber-tyred roller was then used to consolidate the aggregate. The trial sections were thus laid flush with the contract aggregate, except that the larger sized stone had a naturally coarser texture than the smaller size stone.

An automatic, wire-loop counter was installed after three months to provide a continuous traffic count. For the first three months a manual count was made sporadically on a daily basis.

8. MONITORING OF THE FIELD TRIAL

The trial sections were monitored regularly for three years until the road was overlaid. During each visit the sections were visually examined to detect the condition of the stone, and a traffic count obtained. Sand patch measurements (BS 598: Part 3:1985) were taken to determine texture depth (see Plate 2).

At approximately six monthly intervals the sections were photographed using the apparatus shown in Plate 3. This enabled a camera to be placed in a fixed position over the panels and photographs taken with a uniform illumination.



Date of Inception: 9 August 1989
Location: O.S.Ref.632238
Date of Overlay: August 1992

EXPLANATION OF TRIAL SECTIONS

Panel no.	Aggregate type	Description	Aggregate size (mm)
20	Control (UK)	Basalt	-10 + 6.3
19	Samedupe (Botswana	Silcrete	-13.2+9.5
18	Sekoma (Botswana)	Calcrete breccia	-13.2+9.5
17	MN2; Silcrete-calcrete (Botswana)	100% Calcrete; 0% silcrete	-13.2+9.5
16		50% Calcrete; 50% silcrete	-13.2+9.5
15		0% Calcrete; 100% silcrete	-13.2+9.5
14	UK aggregates	100% Limestone; 0% flint	-14 +10
13		75% Limestone; 25% flint	-14 +10
12		50% Limestone; 50% flint	-14 +10
11		25% Limestone; 75% flint	-14 +10
10		0% Limestone; 100% flint	-14 +10
9	MN2 (Botswana)	100% Calcrete; 0% silcrete	-9.5+6.7
8		0% Calcrete; 100% silcrete	-9.5+6.7
7	Sekoma (Botswana)	Calcrete breccia	-9.5+6.7
6			-9.5+6.7
5	MN2 (Botswana)	100% Calcrete; 0% silcrete	-9.5+6.7
4		75% Calcrete; 25% silcrete	-9.5+6.7
3		50% Calcrete; 50% silcrete	-9.5+6.7
2		25% Calcrete; 75% silcrete	-9.5+6.7
1		0% Calcrete; 100% silcrete	-9.5+6.7

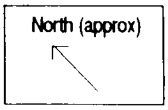


Fig. 2 Surface dressing trial design at Ropley, near Winchester, UK

Neg. no. CR1006/89/3

Plate 2 Measuring texture depth of trial panels by sand patch method

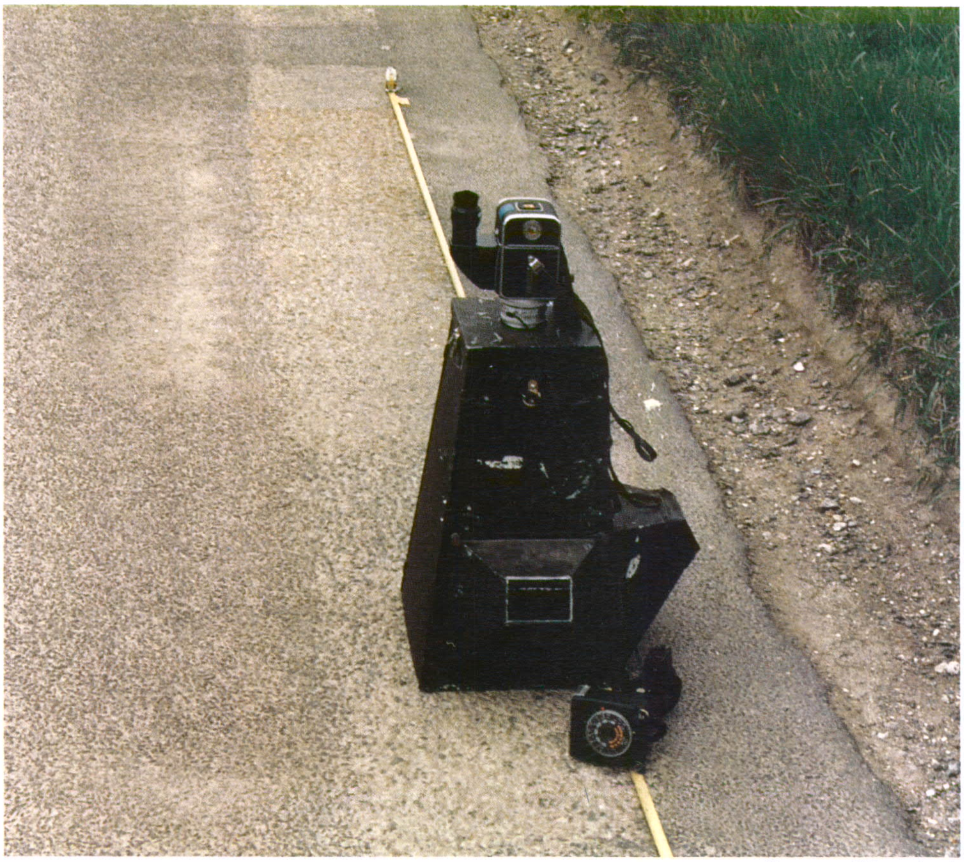


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Plate 3 Box for taking photography of trial panels

9. RESULTS OF THE FIELD TRIAL

9.1 TRAFFIC COUNT

Traffic during the trial averaged 1800 ADT, or approximately 900 per day passing over the panels. A single count of commercial vehicles was carried out by Hampshire County Council and found to be 6%.

In Table 3, current traffic data for the main Botswana roads, as supplied by the Ministry of Works, Transport & Communications, are given. The highest traffic levels occur on the eastern side of the country between Gaborone and Francistown and approach those of the field trial. In the rest of the country there is wide variation but flows of 200 ADT are typical away from the main population centres. Commercial vehicle flows on these roads are, however, at least double those measured on the field trial. This could be important because the higher tyre pressures of commercial vehicles (car tyre pressures are typically 172kPa (1.7bar) whilst those of lorries are three times as much) would increase the stress on the surface dressing aggregate. The effect of different tyres and tyre pressures on the road surface is, however, a complex subject (Tielking & Roberts, 1987). Some specifications for surface dressing (e.g. Zimbabwe) are expressed in terms of equivalent standard axles (esa) whilst others (Kenya and Australia) are expressed in terms of vehicles per day. When traffic is expressed in terms of esa, the only significant contribution arises from the medium and heavy lorries because the esa for cars is so small. Conversely, when traffic is expressed in terms of numbers of vehicles, the contribution from lorries is usually less than passenger cars.

9.2 EMBEDMENT

The texture depth data measured using the sand patch method are presented in Fig 3.

There are two groups of curves; one group for the passing 13.2mm aggregate and the other for the passing 9.5mm aggregate. Texture depth was reduced rapidly at first, then gradually for both groups. By about 250,000 vehicle passes most of the embedment had occurred. The larger stone ultimately retained a texture depth of approximately 1.5mm; the smaller stone was about 0.9mm. It was not possible to measure properly the texture depth of the Sekoma calcrete and calcrete-rich MN2 stone after about 400,000 passes because of the excessive cracking and stone loss.

9.3 AGGREGATE PERFORMANCE

The performance of the aggregates over the three year duration of the trial is summarised by the photographic data presented in Plates 4 to 11 which appear after the references. Each plate represents a key trial panel and shows four images taken after 10 days, 350 days, 800 days and 1000 days. (Soon after 1000 days the trial panels were overlaid).

The calcrete panels performed poorly. This is exemplified by the Sekoma aggregate shown in Plates 4 (larger size aggregate) and Plate 5 (smaller size aggregate). They were subject to initial cracking caused by rolling and also thereafter by traffic, so that by 300,000 vehicle passes, roughly equivalent to 350 days, a substantial amount of cracking and stone loss had occurred. The cracking was much more pronounced for the smaller size aggregate than the larger size. Thereafter the calcretes softened and became susceptible to further deterioration, probably assisted by the wetting and drying cycles and the freezing and thawing of the British winter, so that eventually many of the individual chippings became seriously abraded. The MN2 calcrete-rich aggregate, shown in Plate 6, showed similar early deterioration and eventual disintegration owing to softening.

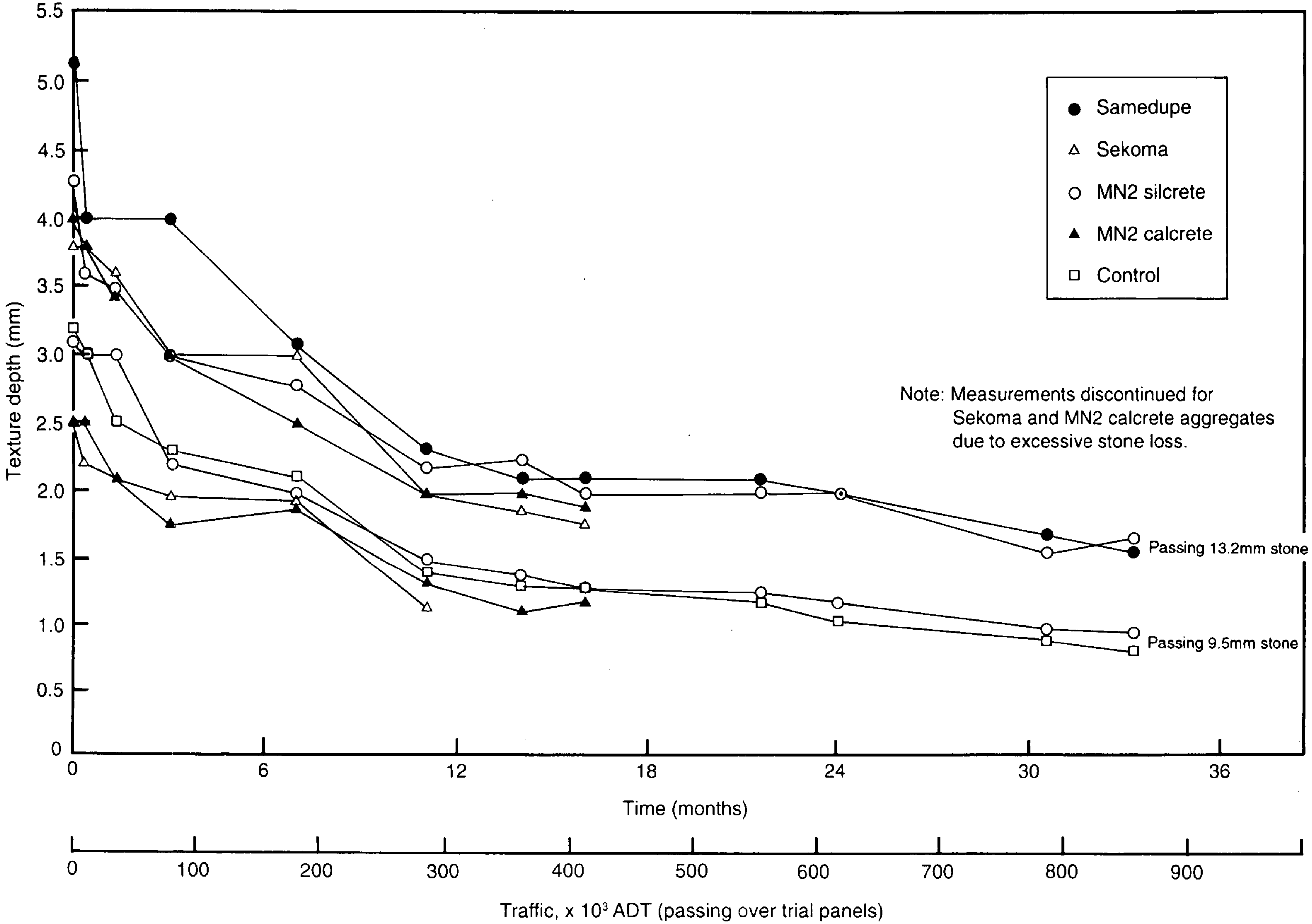
The silcrete aggregate (Plate 7, Samedupe) and silcrete-rich MN2 aggregate (Plate 8) performed well and were

TABLE 3

Traffic Data, Botswana

Direction	ADT,1993	Commercial Vehicles, % 1993	ADT, 1994
Mafikeng to Lobatse	676	5	623
Lobatse to Gaborone	1850	5	2114
Lobatse to Kanye	1351	6	1188
Gaborone to Palapye	1326	11	1325
Palapye to Francistown	1134	10	1078
Francistown to Nata	519	12	548
Nata to Kazangula	134	12	169
Nata to Maun	176	18	194
Maun to Ghanzi	35	17	29
Kanye to Jwaneng	925	11	900
Kang to Ghanzi	100	27	90

Data supplied by Botswana Ministry of Works, Transport & Communications



Note: Measurements discontinued for Sekoma and MN2 calcrete aggregates due to excessive stone loss.

Fig. 3 Progression of texture depth, surface dressing road trial, Ropley (Hants) UK

still in good condition after 1000 days, corresponding to about 1 million vehicle passes. Their performance was as good as the basalt control aggregate (Plate 9), for this level of traffic.

The deterioration of the aggregates in service was estimated quantitatively by means of a simple procedure. Approximately 200 chippings of the fresh aggregate, obtained from the crushed stockpile, and the worn aggregate, removed from the road and separated from the bitumen before the panels were overlaid, were weighed and the masses compared. In the case of the worn aggregate there was some difficulty identifying and separating out the fine material produced from the host aggregate by wear and tear and from other (foreign) material introduced by the passing of traffic, etc. Nevertheless, the results are presented in Table 4. Comparing the results for the Samedupe silcrete and the Sekoma calcrete indicates that the loss in mass of the latter is greater compared to the former, as expected. However, the small difference between the worn MN2 silcrete and calcrete fractions is surprising.

One of the objectives of the field trial was to determine whether the silcrete would protect the calcrete in the panels where the two aggregates were intermixed. It was concluded that the silcrete did not noticeably protect the calcrete. It was also observed that the cracking of the chippings did not necessarily lead to their loss. If cracking occurred at an early stage the chance of aggregate loss was greater than if it occurred later, possibly owing to less embedment having occurred.

The panels containing the combinations of flint and soft oolitic limestone performed well and all were in good condition at the end of the trial (Plates 10 and 11). Although there was initial cracking of the limestone, there was virtually no loss. In this respect, the UK aggregates performed differently (better) than the duricrusts even though their engineering test results are comparable.

By the end of the trial the limestone (and the calcrete) surfaces had become highly polished. This characteristic generally precludes the use of limestone as surfacing aggregate in the UK.

10. DISCUSSION

10.1 COST SAVING

Is there a significant economic advantage to be gained from the use of the duricrust aggregates?

Outcrops of conventional hard rock aggregates are restricted to the eastern side of Botswana beyond the Kalahari sand cover. As Botswana is a large country, significant cost savings would therefore be made in transport costs if duricrust could be used. For example, the Sekoma to Kang section of the new Transkalahari road is being constructed at an average price of £110,000 per km. Dolerite aggregate was initially purchased for surface dressing and hauled an average round-trip distance of 420km at an approximate cost of £0.06 per tonne per km. The cost of haulage was thus £25 per tonne: the supplier's aggregate price was £10 per tonne. Total aggregate cost was thus £35 per tonne. For this road the surface dressing aggregate requirement per km was about 400 tonnes, equivalent to 12% to 13% of the overall contract price. A silcrete aggregate which occurs near Kang is now in use, replacing the dolerite and minimising the haulage cost.

10.2 TEST RESULTS

What are the main conclusions reached in the practical work?

The petrographic examination confirmed the mineralogical differences between the calcrete and silcrete duricrusts. Calcrete was characterised by a preponderance of calcite, usually within the (fine grained) matrix; silcrete was characterised by fine grained quartz sand grains cemented by secondary silica. Both rock types are normally heterogenous and individual chippings consist of both hard (silcrete) and soft (calcrete) fractions.

The engineering tests highlighted the differences in strength between the calcrete and silcrete and the soaked tests indicate the poor durability of the calcrete.

TABLE 4

Mass of 200 aggregate chippings (passing 13.2mm size) before and after road trial.

Aggregate Name	Condition	Average Mass, g	Range of Chipping Mass, g	Standard Deviation
Samedupe silcrete	fresh	1.93	0.33 to 4.53	0.72
" "	worn	1.64	0.20 to 4.14	0.82
Sekoma calcrete	fresh	1.95	0.70 to 4.12	0.67
" "	worn	1.13	0.10 to 3.67	0.66
MN2 silcrete	fresh	1.82	0.30 to 4.13	0.67
" "	worn	0.94	0.15 to 3.82	0.65
MN2 calcrete	fresh	1.85	0.27 to 6.24	0.67
" "	worn	0.84	0.13 to 3.07	0.64

The road trial confirmed the differences in performance between the calcrete-rich and silcrete-rich materials. The silcrete-rich materials performed as well as the control aggregate and were in good condition at the end of the trial. In contrast, the calcrete-rich materials soon became cracked and much aggregate was lost. There were also indications of strong abrasion and polishing. It is possible that the cracking of the softer calcrete chippings was exacerbated on the hard premix macadam substrate. It is also possible that the deterioration of the calcrete was accelerated by the wetness and frost of the British climate. By contrast one of the main problems affecting the durability of surface dressings in Botswana is the hardening of the bitumen caused by high temperature and strong sunlight. For this reason surface dressings in Botswana (and countries with similar climates) are renewed on average every seven years.

Could the calcrete-rich duricrusts be used in low traffic conditions?

The indications from the field trial are that they could be used for surfacings whose design life is no more than 300,000 vehicle passes. In Botswana this would correspond to 200 ADT (100 passes per lane per day) for eight to nine years, or roughly equivalent to the binder life.

Single surface dressings were laid in the field trial, a common maintenance practice. However, in new road construction in Botswana, double surface dressings are normally used. It is therefore possible that the calcretes would be more durable for new or reconstructed roads.

The silcrete-rich aggregates performed as well as the control stone in this trial and there are no problems in using this aggregate on any Botswana roads, as far as strength or durability is concerned.

10.3 SPECIFICATIONS

Can the current specifications be modified as a result of the field trial?

It is clear that the current Botswana specifications are too high. This has been tacitly accepted because silcretes have already been used for surface dressing in new road construction. However, the specifications could not be reduced to the levels used by the other countries shown in Table 1 because of the weakness of the calcrete, perhaps particularly where levels of commercial traffic are high, i.e. > 15%. In very low traffic circumstances and where the use of alternative aggregate would result in a high additional cost, it may be possible to use calcrete duricrusts as long as they satisfy minimum strength criteria. New specifications are proposed below, expressed primarily as minimum TFV values. Tentative AIV values, obtained from the relationship quoted on page 9, are also given. However, there is a difference between the AIV obtained from this relationship and that obtained in this research. This anomaly needs to be clarified.

Traffic, ADT	TFV, kN (dry)	AIV, % (dry)
< 200	150	24
> 200	180	21

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

A high flakiness index, particularly characteristic of the silcrete aggregate, did not adversely affect their performance in this trial. The current Botswana specification for flakiness could possibly be relaxed further but full scale testing is necessary.

11. CONCLUSIONS

1) Duricrust aggregates rich in calcrete should be suitable for surface dressing low volume roads with less than 300,000 vehicles design life. Duricrust aggregates rich in silcrete could be used on any Botswana roads.

2) The Botswana specification for surface dressing aggregate could be lowered but not as far as other countries because of the high percentage of commercial traffic.

3) Duricrust aggregates are very variable but quality control could be maintained less expensively by using the Aggregate Impact Test.

12. RECOMMENDATIONS FOR FURTHER WORK

1) A full scale surface dressing field trial is proposed for Botswana, which would expect to confirm the results of the UK trial and answer any queries raised. It should incorporate the following variables:

- different duricrust aggregates
- double and single surface dressings, and possibly Cape seals
- normal and polymer-modified binders
- a range of traffic types

2) Further laboratory testing is proposed:

- to determine the strength of the relationship between the Ten Percent Fines Aggregate Crushing Value and the Aggregate Impact Value
- to determine the effect of using a different number of blows when obtaining the Aggregate Impact Value

13. ACKNOWLEDGEMENTS

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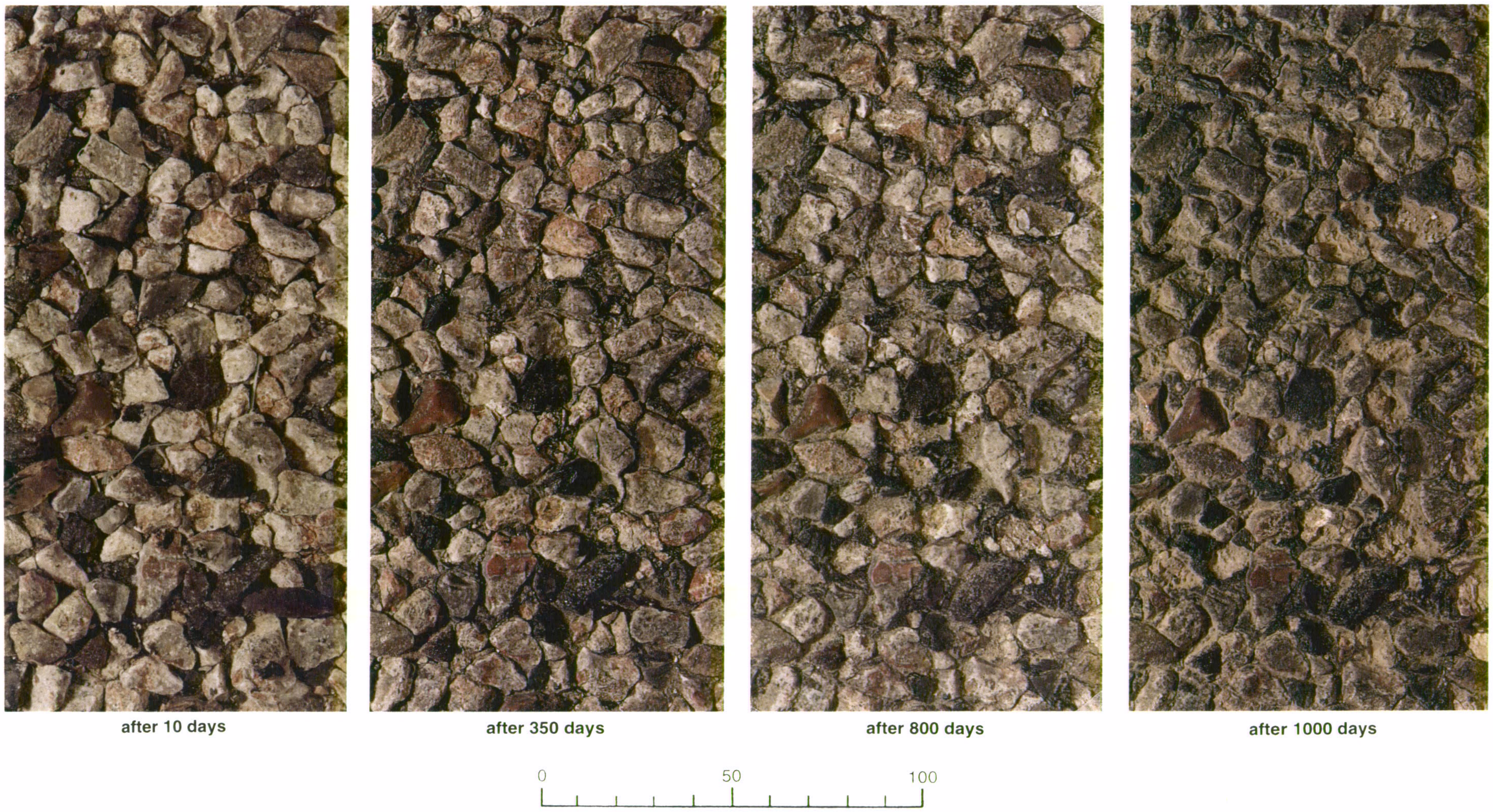

Sekoma calcrete (-13.2+9.5mm)

after 10 days

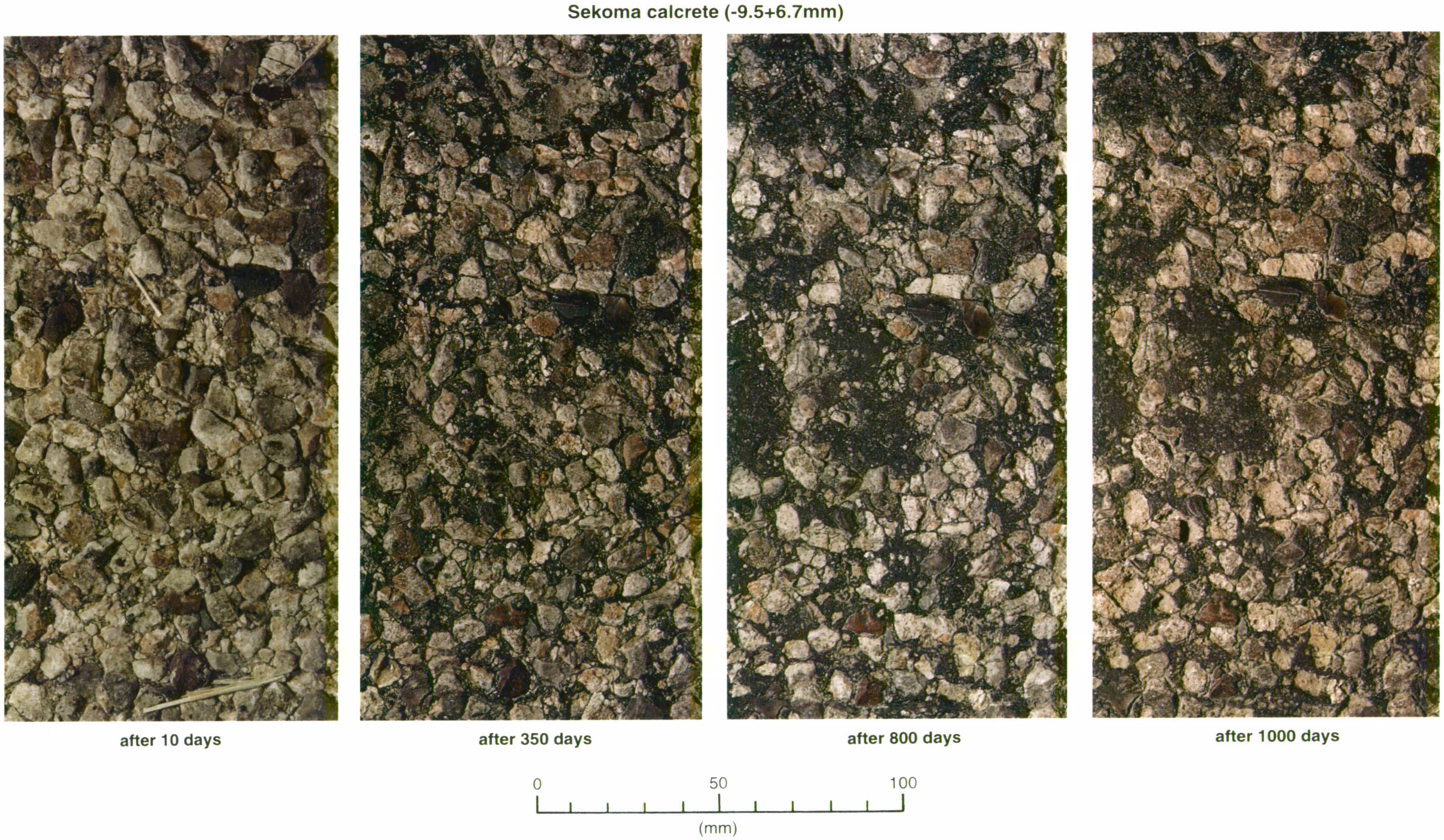
after 350 days

after 800 days

after 1000 days

About 140 chippings in plate. The larger size aggregate has performed better than the smaller size (i.e. passing 9.5mm: Plate 5) but there is nevertheless progressive cracking and whip-off of the light-coloured calcrete after 10 days. Aggregate surfaces also become quite polished. The dark coloured silcrete has performed well although there has been some loss where individual chippings were surrounded by calcrete.

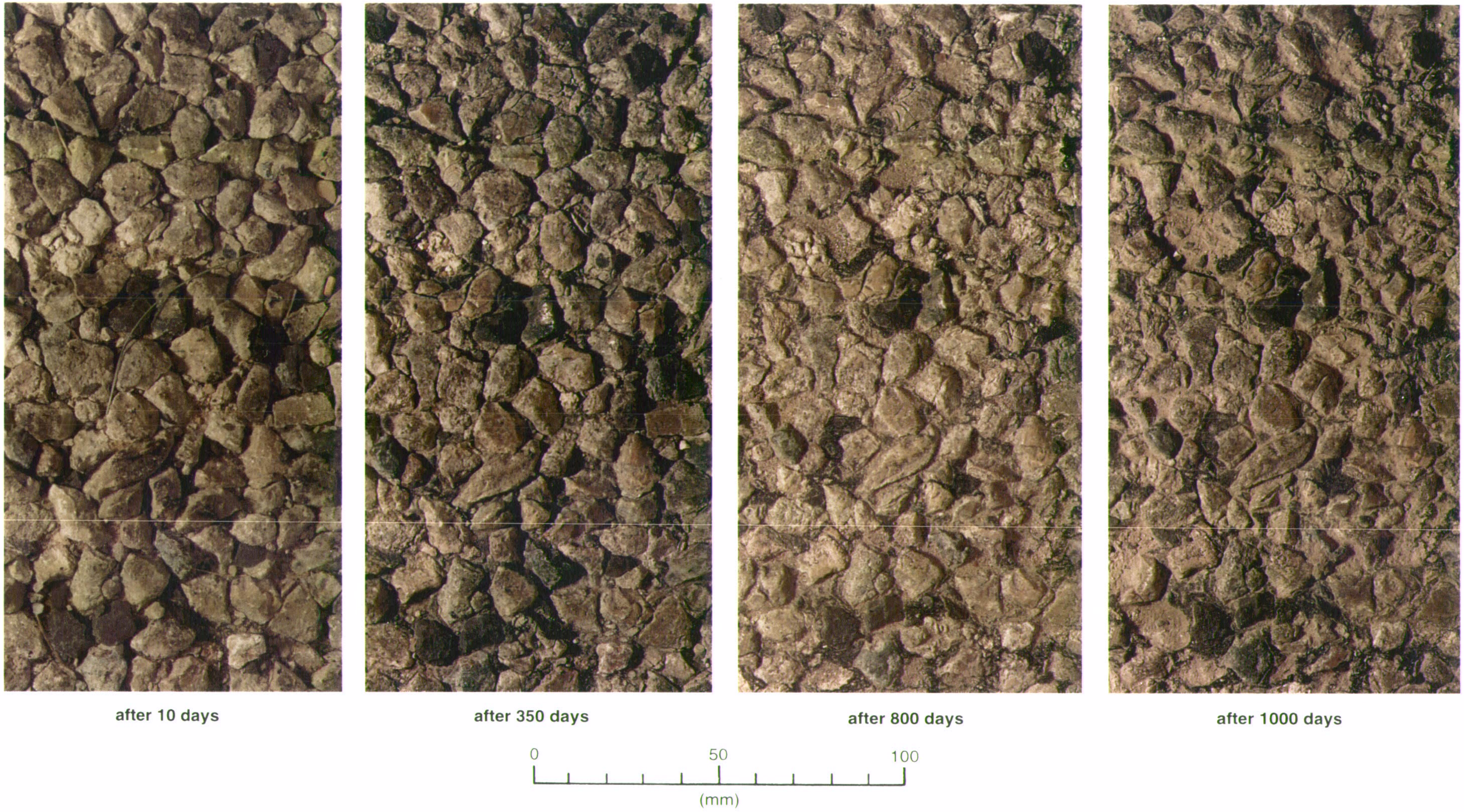
Plate 4 Sekoma calcrete, passing 13.2mm: Panel 18



About 225 chippings in plate. Much early cracking and loss of the light coloured calcrete. Bitumen fills the gaps created by lost chippings. At 800 days nearly 50% of the calcrete lost. Apart from cracking also progressive abrasion of the calcrete caused by softening due to wetting/drying cycles. The dark-coloured silcrete chippings have performed well. This section had failed by 350 days.

Plate 5 Sekoma calcrete, passing 9.5mm: Panel 7

MN2, calcrete-rich (-13.2+9.5mm)



after 10 days

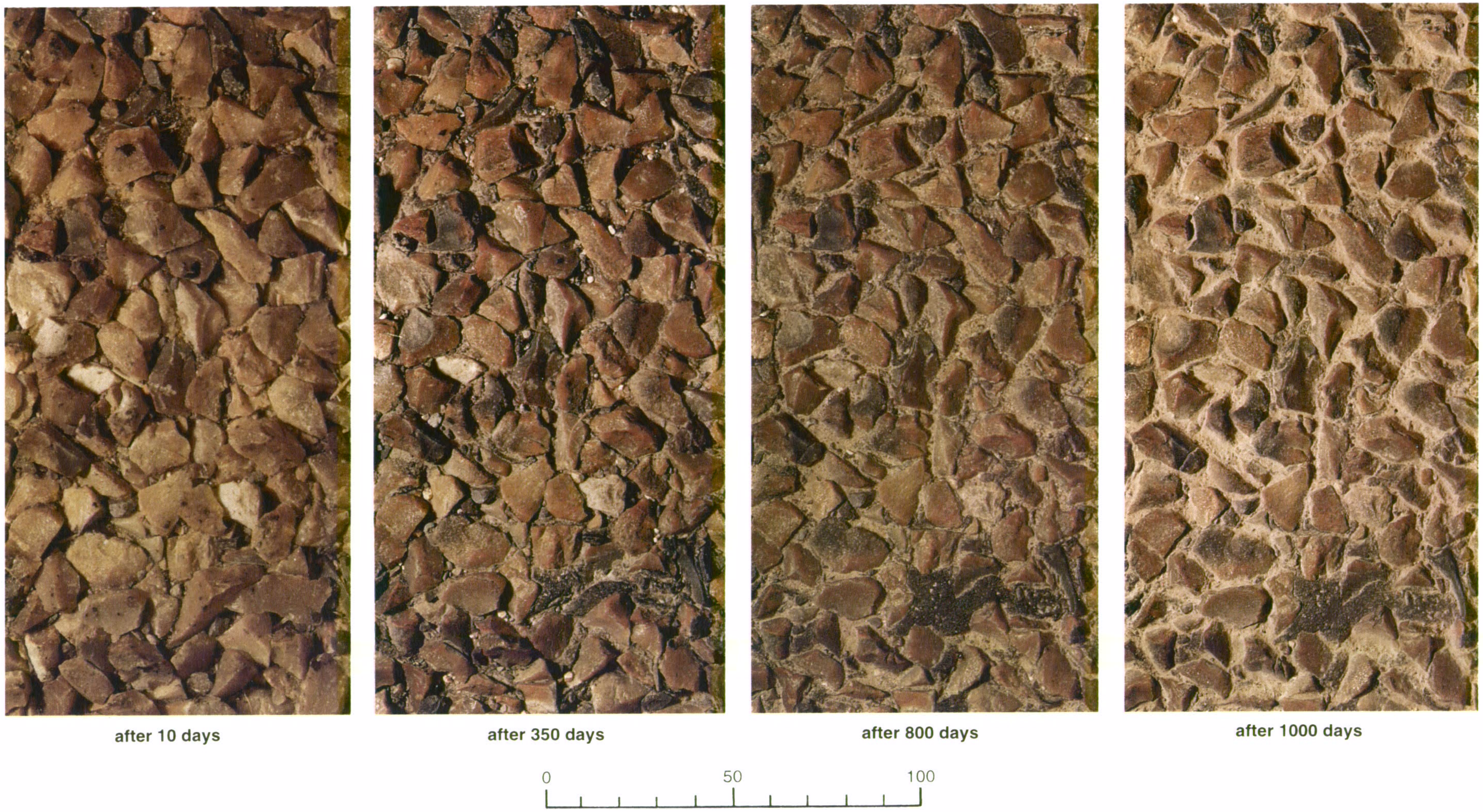
after 350 days

after 800 days

after 1000 days

About 140 chippings in plate. Some cracking and noticeable polishing (and abrasion?) between 10 and 350 days, which is not as marked thereafter. However, by 1000 days there are many gaps in the texture and the stone seems considerably polished.

Plate 6 MN2 aggregate, calcrete-rich, passing 13.2mm: Panel 17



Samedupe silcrete (-13.2+9.5mm)

after 10 days

after 350 days

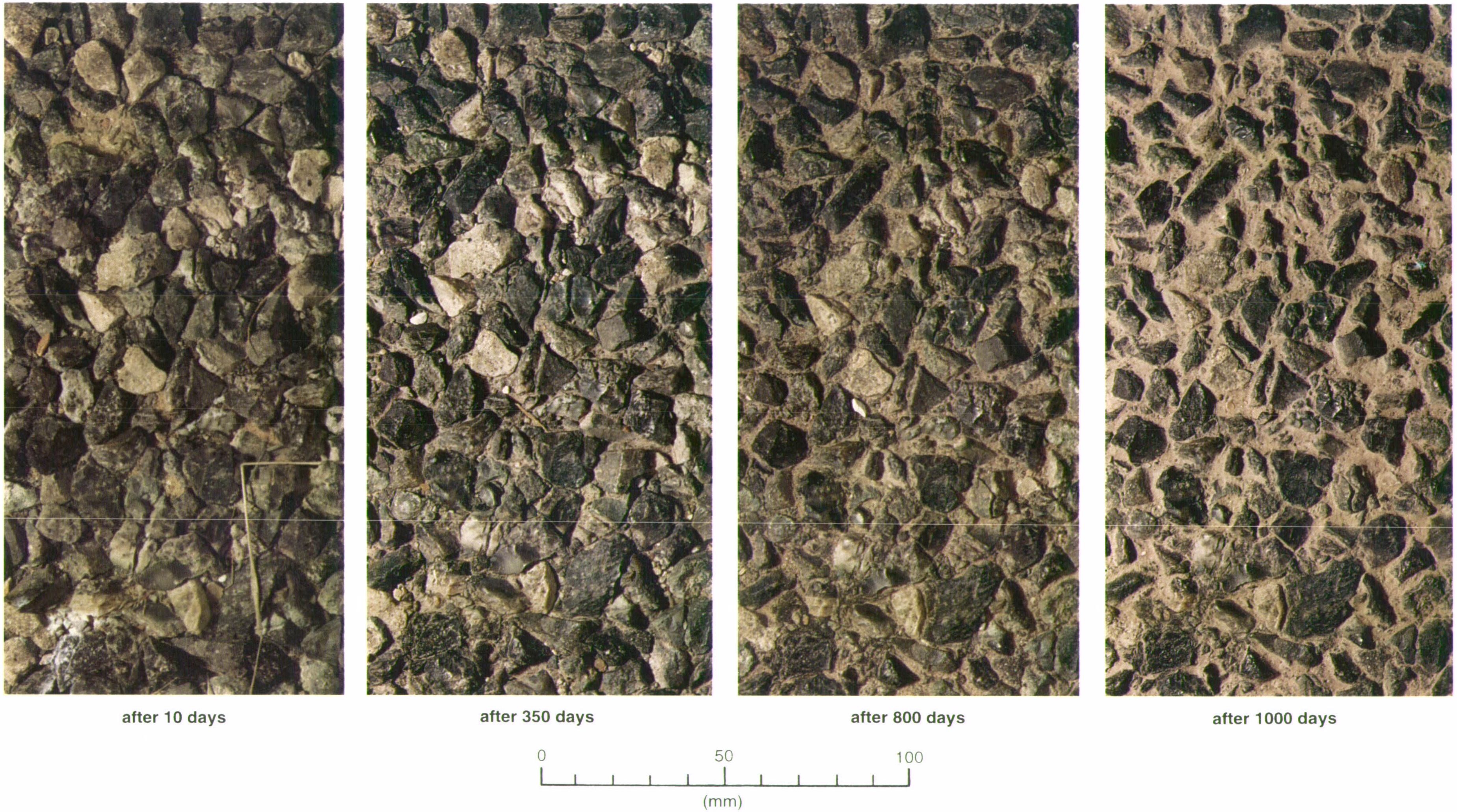
after 800 days

after 1000 days

About 145 chippings in plate. The pronounced flakiness (FI, 50%) of the aggregate is evident from the shape. Some chippings lost early in the trial; their strength (TFV, 240 kN) indicated by little subsequent cracking. Apart from embeddment, there has been little change. The size of the chippings has resulted in good residual texture although their smooth faces are evident.

Plate 7. Samedupe silcrete, passing 13.2mm: Panel 19

MN2, silcrete-rich (-13.2+9.5mm)



after 10 days

after 350 days

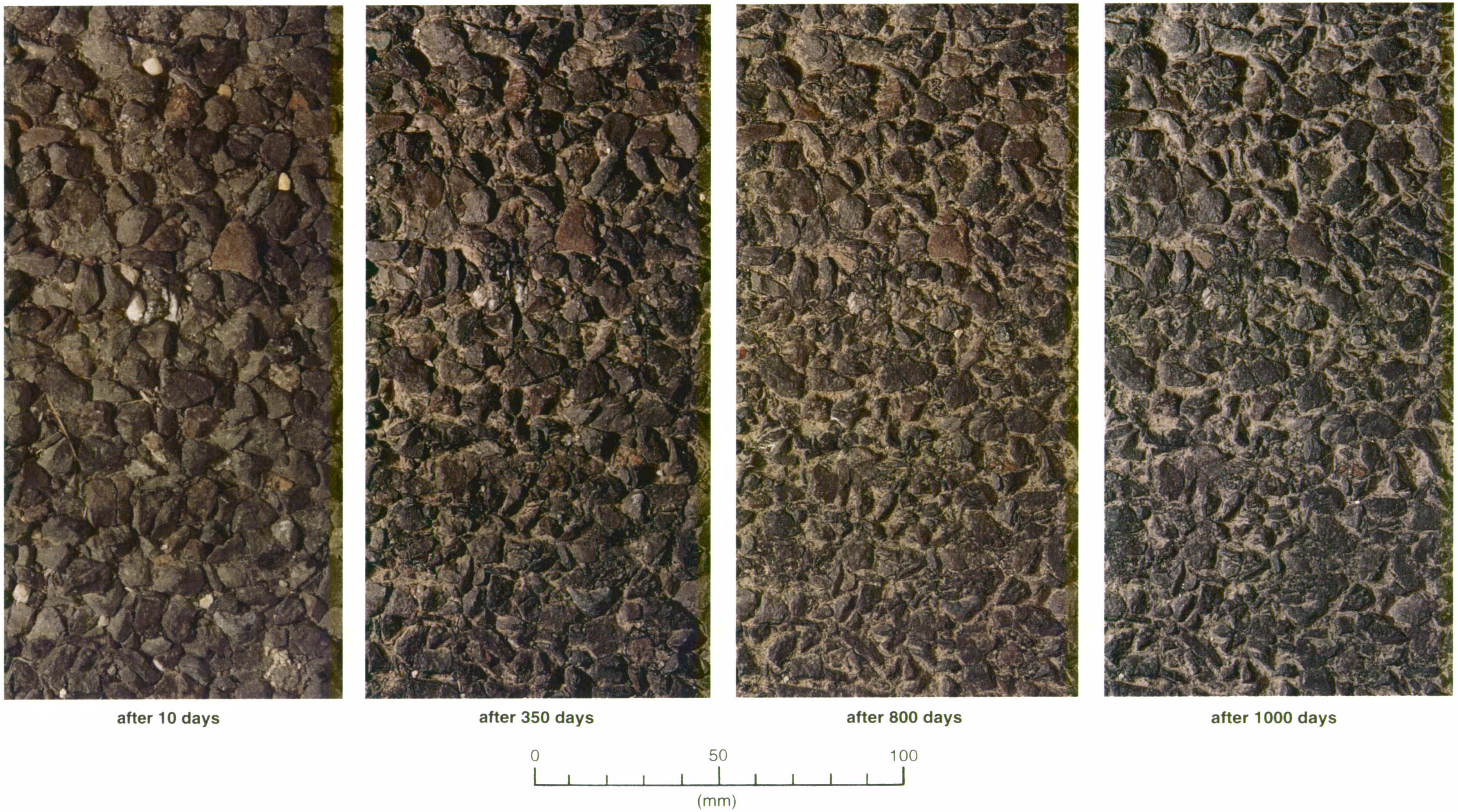
after 800 days

after 1000 days

About 142 chippings in plate. Good performance, little cracking and good retention of texture. Observation at 1000 days difficult due to blanketing of section with chalk dust.

Plate 8 MN2 aggregate, silcrete-rich, passing 13.2mm: Panel 15

UK, Basalt (-10+6.3mm)



after 10 days

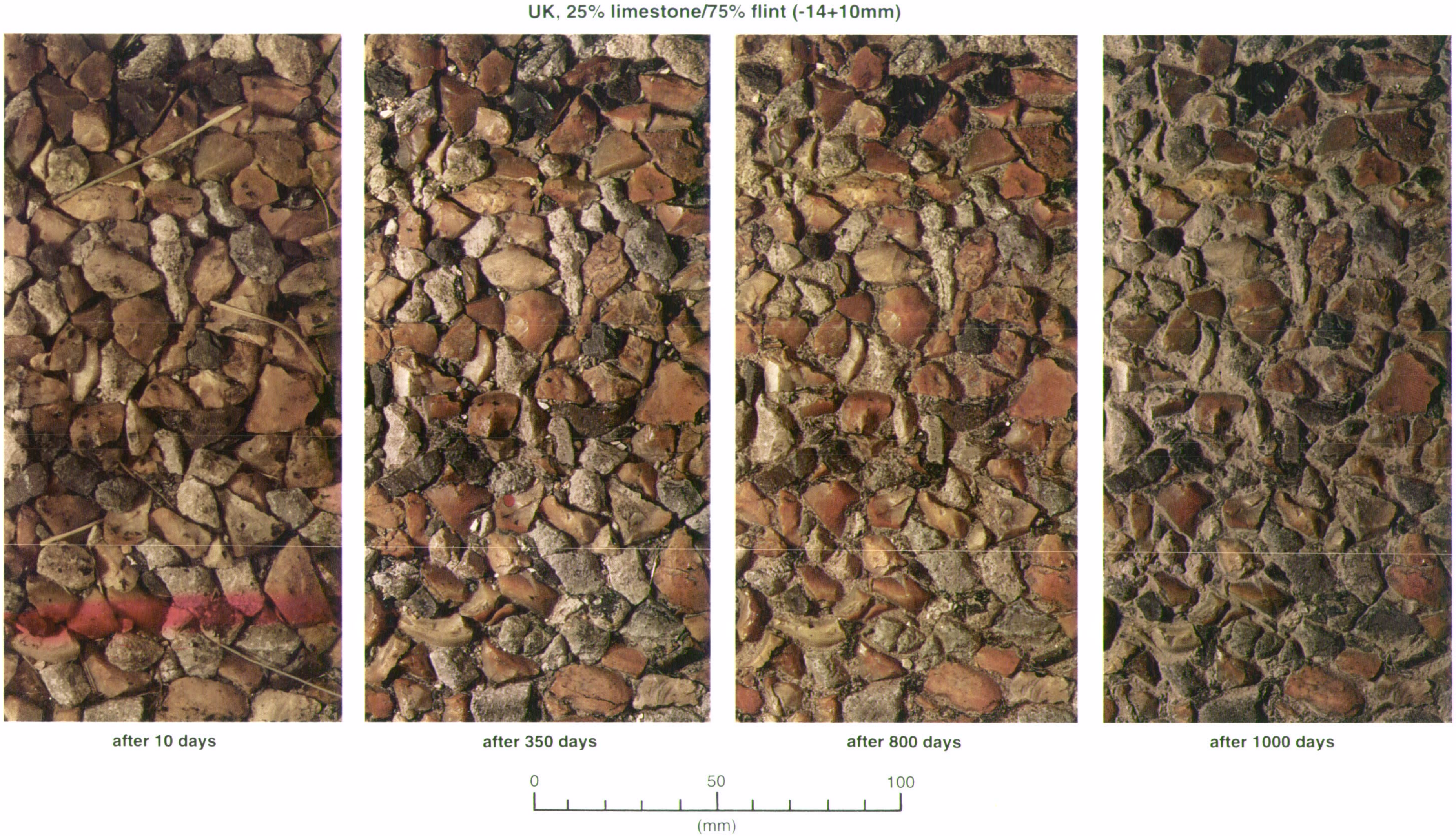
after 350 days

after 800 days

after 1000 days

About 250 chippings in plate. A very strong aggregate (TFV, 360 kN): some chippings cracked during construction but none during the trial. Good interlock developed. Apart from gradual embeddment resulting in loss of texture depth, the aggregate performed well.

Plate 9 UK basalt, passing 10mm: Panel 20



UK, 25% limestone/75% flint (-14+10mm)

after 10 days

after 350 days

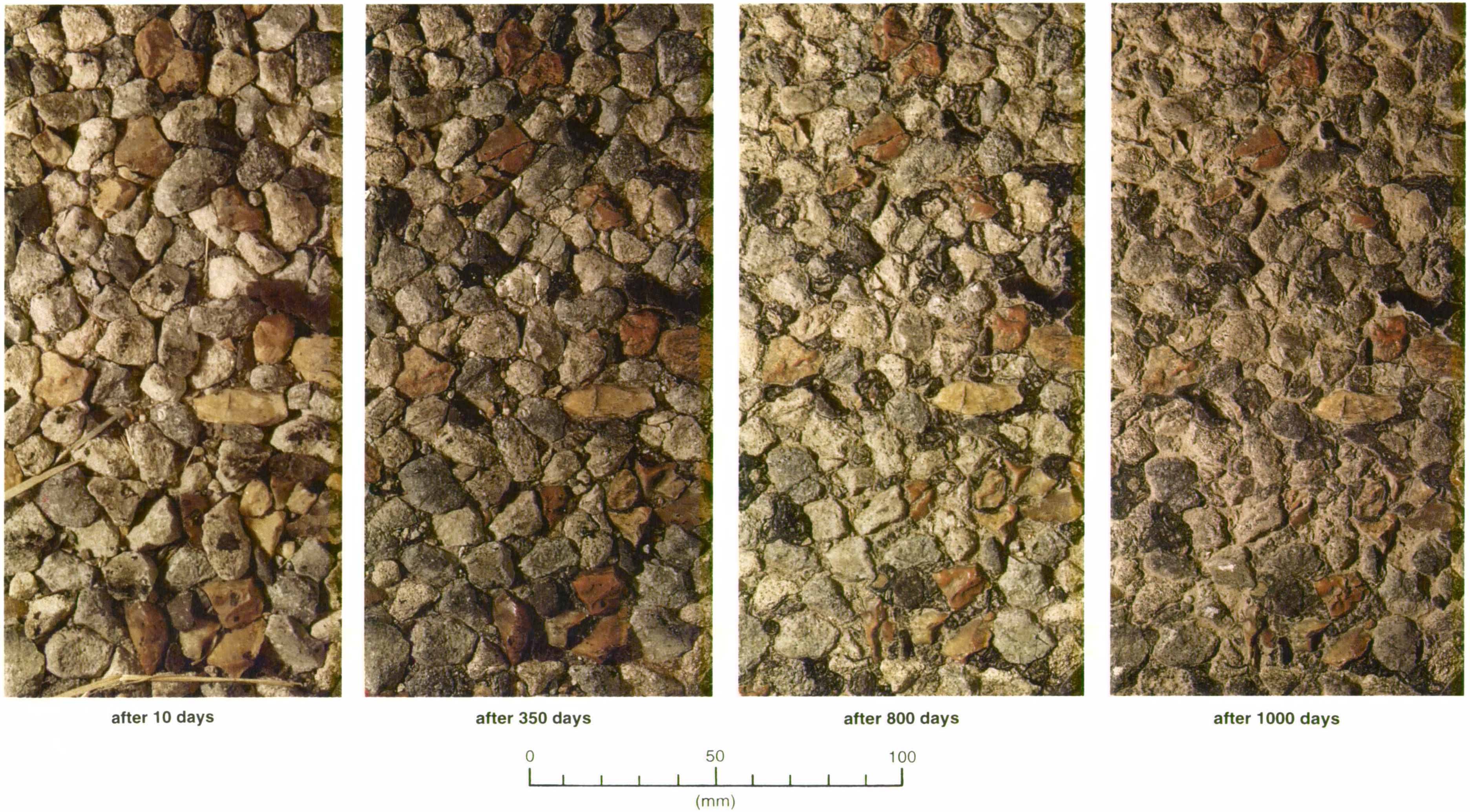
after 800 days

after 1000 days

About 135 chippings in plate. Both aggregates performed well during the trial; the development of smooth polished surfaces is noticeable on the limestone by 800 days but there is negligible cracking. Good residual texture due to large initial aggregate size.

Plate 10 UK aggregate, 25% limestone/75% flint, passing 14mm: Panel 11

UK, 75% limestone/25% flint (-14+10mm)



after 10 days

after 350 days

after 800 days

after 1000 days

About 133 chippings in plate. Cracking of 6 limestones by 350 days but no chipping loss; by 800 days the polishing (and abrasion?) of the limestone is severe. This is also possibly reflected in the degree of embeddment. The flint has performed well.

Plate 11 UK aggregate, 75% limestone/25% flint, passing 14mm: Panel 13