The Geology and Engineering Properties of South African Calcretes

by F. Netterberg

Volume IV

THE GEOLOGY AND ENGINEERING PROPERTIES OF SOUTH AFRICAN CALCRETES

(IN FOUR VOLUMES)

VOLUME IV

APPENDICES AND MAPS

THE GEOLOGY AND ENGINEERING PROPERTIES OF SOUTH AFRICAN CALCRETES

BY

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VOLUME I: SUMMARY, CLASSIFICATION, DISTRIBUTION, COMPOSITION AND ORIGIN

VOLUME II: AGE, PROSPECTING METHODS AND ENGINEERING TEST METHODS

VOLUME III: ENGINEERING PROPERTIES AND SPECIFICATIONS FOR ROADS

VOLUME IV: APPENDICES AND MAPS

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APPENDIX A

PROFILE DESCRIPTIONS

A.1 METHODS

The soil description method of Jennings and Brink (1961), modified as detailed in Section 1.3.2 (the CCCSSOI system) was employed. In retrospect, it would have been of advantage in the origin studies if a pedological system, such as that given by the Soil Survey Staff (1951), had been employed on some profiles in addition to the Jennings and Brink system.

Several methods of obtaining soil profiles were used. These included test pits specially excavated by hand, bulldozer or a special truck-mounted power auger, simple hand augering and probing, and the examination of natural exposures and the faces of existing borrow pits and cuttings. The method used and the purpose for which the profile was examined determined the amount of information recorded. The full CCCSSOI system was not therefore used in every case. The information noted and the abbreviations used in the tables to indicate the profiling method employed is shown in Table A.1

Accurate colour estimation was not considered important, but the condensed Munsell soil colour chart of the Soils Research Institute of the South African Department of Agriculture was followed as a guide and with a few additions the colours in Table A.2 are essentially those found on this chart. All colours, except where otherwise indicated, are at natural moisture content. Natural (field) moisture content was almost invariably dry , or at the most damp .

A.2 NUMBERING SYSTEM

All profiles and samples taken during the course of the work were allocated a number and entered in a master list

showing/ ...

TABLE A.1 INFORMATION NORMALLY NOTED AND LIST OF ABBREVIATIONS INDICATING THE METHOD OF PROFILING EMPLOYED

ABBREVIATION	PROFILING METHOD	INFORMATION NOTED
NP	Natural profile	CCCSSOI
BP	Borrow pit, or, rarely, a road cutting	"
TP	Test pit, hand or machine excavated	"
A	Auger hole, 30" or 24" diameter	"
FA	Flight auger, 6" diameter continuous flight	C-C-SOI
HA	Hand auger, 3" diameter	"
RP	Rapid probe	C---SO-
BH	Water borehole	C---SOI

showing container number, sample number, laboratory sample number, RRO number, profile number, locality, depth, description, remarks and proposed and completed tests. Most of the profiles are included here and the approximate location of all of them is shown on Map 1. The exact location of any profile or sample can be found by referring to the master list kept at the National Institute for Road Research. Where a site was investigated in more detail and samples taken for laboratory investigation, the profile or group of profiles was also allocated an RRO number in the usual fashion of the NIRR.

Soil profile symbols used at the NIRR are shown in Figure A.1

A.3 ABBREVIATIONS

Full CCCSSOI details where applicable are not shown owing to space considerations and the necessary complication of any abbreviation system. Only the following details are therefore shown to a varying degree: colour, structure,

soil/ ...

soil type, origin and inclusions. Profiles were almost invariably either dry or damp and the range of consistency encountered in the various types of calcrete is discussed in Section 1.3.3.

The abbreviations used are shown in Table A.2. Further details concerning the various types of calcretes will be found in Chapter 1.

TABLE A.2 LIST OF ABBREVIATIONS

COLOUR	SOIL TYPE	MINERAL OR ROCK TYPE
Or Orange	Cl Clay, clayey	Q Quartz
Wh White	Si Silt, silty	QE Quartzite
Gr Grey, greyish	Sd Sand, sandy	GRT Granite
Br Brown, brownish	G Gravel, gravelly	DO Dolomite
Rd Red, reddish	Bo Boulders, bouldery	D Dolerite
Y Yellow, yellowish	C Calcrete, undifferentiated	SS Sandstone
Ol Olive	B Boulder calcrete	SH Shale
Bl Black	H Hardpan calcrete, undifferentiated	GS Greenstone
Pi Pink	H_i Hardpan calcrete, intact	MS Mica schist
Pu Purple	H_t Hardpan calcrete, tufaceous	GW Graywacke
Dk Dark	H_{sh} Hardpan calcrete, shattered	VA Ventersdorp andesite
Lt Light	H_{be} Hardpan calcrete, bedded	SB Stormberg basalt
P Pale	H_p Hardpan calcrete, platy	CH Chalcedony
V Very	Ho Honeycomb calcrete	PH Phyllite
Str Strong	N Glaebular calcrete, undifferentiated	CT Chert
	P Powder calcrete	T Tillite
	Cal Calcified	GN Gneiss
		Gyp Gypsum, gypseous

TABLE A.2 (CONTINUED)

SOIL TYPE		GENERAL	
Ca	Calcareous	O	Occasional
F	Ferricrete, undifferentiated	Alt	Alternating
		WT	Water table
H_F	Hardpan ferricrete, undifferentiated	A	Stone artefacts, undifferentiated
Ho_F	Honeycomb ferricrete, undifferentiated		
N_F	Glaebular ferricrete, undifferentiated		
Fe	Ferruginised		
S	Silcrete, undifferentiated		
H_S	Hardpan silcrete, undifferentiated		
Ho_S	Honeycomb silcrete, undifferentiated		
N_S	Glaebular silcrete, undifferentiated		
Sil	Silicified		
MG	Made ground		
PM	Pebble marker		
N_P	Phoscrete nodules		

Notes

(1) Colour of calcrete and silcrete between white (10 YR 8/1), grey (10 YR 6/1) and pale brown (10 YR 6/3) unless otherwise stated.

(2) Colour of ferricrete yellowish red (5 YR 4/6) to dark reddish brown (5 YR 3/3) unless otherwise stated.

(3) Rocks normally weathered unless otherwise stated.

(4)/ ...

(4) Depths shown in feet and inches are normally ± 1". Depths shown only as whole numbers of feet are normally ± 6".

(5) Calcrete types 1-6 are described in Section 1.3.4.

Example

Gr Br Si Sd + 01N/0-1'6/Rd 1H_i/3'0"/Br 1 N→/7'/P Br 1 + P Br Si GRT Sd/9'0/GRT/10'6"+

would mean:

0-1'6" 0 to 1'6" of greyish brown non-calcareous silty sand with occasional type 1 calcrete nodules.

0-3'0" Sometimes outcropping, but usually covered by up to 1'6" of above soil, red type 1 intact hardpan calcrete.

3'0" - 7' Brown type 1 nodular calcrete in a calcareous matrix grading downwards to:

7'-9'0" Pale brown type 1 nodular calcrete in a pale brown non-calcareous silty sand matrix derived from granite. Seven foot contact transitional.

9'0" - 10'6" + Weathered granite. 9'0" contact relatively sharp. No water table encountered.

TABLE A.3 ABBREVIATED PROFILE DESCRIPTIONS

PROFILE No.	METHOD	RRO No.	DESCRIPTION
1	BP	222	H/2'/P/6'+
2	BP	223	Gr Si Sd/2'/H_S/6'
3	BP	224	Gr Si Sd/2'/H/4'/01 Ca Sd Cl/6'+
4	BP	225	Gr Si Sd/2'/P/8'/01 Cl Sd/10'/01 5 H/10'+

TABLE A.3 (CONTINUED)

PROFILE No.	METHOD	RRO No.	DESCRIPTION
5	BP	226	Gr Si Sd/5'/H/6'/Ca Sd + ON/10'+
6	BP	227	Gr Si Sd/1'/Y Ca Cl Sd/8'+
7	BP	228	Gr Si Sd/3'/Y Cal Cl Sd/10'+
8	BP	229	Gr Si Sd/3'/Y Ca Cl Sd + ON/10'+
9	BP	230	Gr Si Sd/3'/Y Ca Cl Sd/10'+
10	BP	232	Gr Cl Sd/3'/Y Cl Sd + ON/10'+
11	BP	233	Gr Si Sd/2'/Y Cal Cl Sd + N/10'+
12	BP	234	Gr Cl Sd/3'/Y Cal Cl Sd/10'+
13	BP	235	Gr Cl Sd/3'/Y Ca Cl Sd/10'+
14	BP	236	Gr Cl Sd/3'/Y Ca Cl Sd/10'+
15	BP	238	Gr Si Sd/6'/Ol Ca Sd + N/12'/Ol Ca Sd + ON/15'+
16	BP	239	Gr Sd/2'/H
17	BP	242	Gr Sd/2'/H/3'+
18	A	506	Lt Br Sd/2'/Or Sd/34'/SS/34'+
19	A	507	Lt Br Sd/2'6"/N/6'/H/12'9"
20	A	508	Or Sd/8'6"/Y Sd + N_F + ON/12'3"/ Cal Sd/14'9"/Y Sd + N_F/15'9"/SS
21	A	509	Lt Rd Sd/9'9"/CaSS/11'+
22	A	-	Br Sd/1'6"/N + Br Sd/3'3"/Pi H/7'6"+
23	A	510	Gr Cl Sd/6"/Pi N/7"/PiH/10'+
24	A	511	Rd Sd/10'/Wh Sd/19'+
25	BH	512A	Rd Sd/40'/Rd SS/80'/Ol CaSS/130'/ Water/Rd SS
26	A	512	Lt Br Sd/5'/N/8'

TABLE A.3 (CONTINUED)

PROFILE No.	METHOD	RRO No.	DESCRIPTION
27	A	513	Lt Br Sd/6'6"/N + Lt Br Sd/7'3"/ Ho/8'9"/N/9'6"/Lt Br Sd
28	A	514	Sd/7'/Wh Sd/9'6"/Wh Sd + O N_S/10' 6"+
29	FA	514	Lt Br Sd/9'/Wh Sd/23'/Ol Ca SS/ 26'+
30	FA	511	Rd Sd/22'/Ol CaSS/24'+
31	A	515	Gr Sd/1'0"/Br Sd/2'9"/Pi H/4'/P/ 4'6"/Pi H/6'0"/ Sd + N/7'/Sd/8'0"/ Pi H/8'9"/Pi N + Ca Sd/9'6"/Pi H/11'6"/Ca Sd/14'0"/Ca Sd + ON/ 18'+
32	A	516	Br Sd/10'0"/P Br Sd + N_F + N/19'+
33	A	517	Dk Br Sd/0'7"/N + Dk Br Sd/1'4"/ Pi H/6'+
34	A	517A	Dk Gr Si Sd → Lt Br Ca Si Sd + ON/6'+
35	FA	-	Br Sd/16'/Gr CaSS/16'+
36	A	518	Rd Br Sd/5'8"/B/7'+
37	A	519	Dk Br Sd/4'/B/4'+
38	A	520	Gr Si Sd/4'9"/Lt Gr Si Sd + ON/ 5'9"/Lt Gr Cal Sd + ON/7'6"/Ho/ 8'3"+
39	A	521	Dk Br Sd/5'/B + Dk Br Sd/5'+
40	A	522	Br Sd/5'6"/H/5'6"+
41	FA	523	Br Sd/18'/C + SS/18'+
43	TP	524	Gr Sd/1'6"/H/3'
46	FA	526	Rd Sd/60'+
47	FA	-	Rd Sd/60'+
48	FA	527	Br Sd/46'+
49	FA	528	Rd Br Sd/46'+

TABLE A.3 (CONTINUED)

PROFILE No.	METHOD	RRO No.	DESCRIPTION
50	FA	529	Br Y Sd/42'+
51	FA	530	Rd Br Sd/59'+
52	FA	531	Y Rd Sd/59'+
53	A	-	Br Sd/4'/C/4'+
54	FA	532	Y Rd Sd/48'+
55	FA	533	Y Rd Sd/47'+
62	BP	257	Rd Br Fe Sd G/1'6"/B/2'6"+
63	BP	-	Br Fe Sd G/3'+
64	BP	258	Gr Br G Si Sd + ON/1'/H/1'+
65	BP	-	Br Si Sd/0'6"/N + Br Si Sd/1'0"/H/1'6"/N/5'+
66	BP	259	Dk Br Si Sd + ON/0'8"/Lt Br Ca Sd G + ON/2'/Ca GS
67	BP	260	Dk Br Si Sd G/Wh Ca GW
68	BP	261	Dk Br Si Sd/0'6"/N + Dk Br Si Sd/2'/Ho/4'+/MC
69	BP	261A	H → Ho → /2'/N/3'+
70	BP	-	Dk Br Si Sd/0'6"/Dk Br Si Sd G/1'6"/Wh Ca GW
71	BP	261A	Dr Br Si Sd + ON/0'7"/3N/3'+
72	BP	261A	Dk Br Sd + ON/1'/H/2'/3N/4'+
73	BP	261A	Br Sd/0'6"/H → 3N/3'6"+
74	BP	261A	Br Sd + ON/0'1"/1H → 3N/4'+
75	BP	261A	Br Sd + ON/0'3"/1H → Ho → 4N/0'9"
76	BP	262	Dk Br Si Sd/0'6"/Ho/3N/3'+
77	BP	263	1H/2'/Cal Sd G/8'+
78	BP	-	Br Sd → N/0'6"/4N/2'6"Wh Ca GW

TABLE A.3 (CONTINUED)

PROFILE No.	METHOD	RRO No.	DESCRIPTION
79	BP	257	Ho_F + Fe Sd G/2'/1B/6'+
81	BP	257	Dk Br G Si Sd/0'4"/F/1'0"/Rd Fe Sd G/1'6"/B/3'3"+
82	BP	264	Br Si Sd/0'6" - 2'9"/Ca G+ Br Si Sd/4'/3Ho/5'/3N/8'/3H/8'+
83	BP	264A	Gr Si Sd/1'4"/3N/1'8"/3,1,4N/2'5"/1N/3'0"/1N/4'0"/Ol GW
84	BP	264A	G Si Sd/1'0"/3,4,1N/1'6"/3,4, Ho/3'0"/3N/5'/GW
85	NP	265	Dk Gr Br Si Sd/0'4"/3,4N/2'0"/Ho/4'3"/3N/8'0"/Br H_S/10'+
86	BP	-	Gr Si Sd/0'6"/4N/2'/P"/H/2'0"+
88	BP	267	V Dk Br Si Sd/0'9"/3N/2'9"/Ol Cal Cl Sd/5'6"/Alt. 4" Ol Cl + W Sd/10'9"
89	BP	268	Dk Gr Si Sd/0'6"/3N + Dk Gr Si Sd/1'0"/3H/3'6"/Br Ca Sd/3'9"/Br Ca Sd G→N→H/5'6"/Br Ca Sd + ON/6'0"/H + Ca Sd + ON/7'+
90	BH	-	Dk Gr Br Sd/6'/P Br Ca Sd + ON/30'/Wh Ca Sd/70'/Alt. C & Sd/100'/Wh Ca Sd/140'/Wh Ca Sd + C/150'/W Ca Sd/170'/W Ca Sd + C/190'+
91	BP	-	Str Br Sd/6'/3N/10'+
92	BP	274A	3Ho-3N/1'/Ca SH/10'+
93	BP	274	4N + Gr Sd/2'/Ca SS/10'+
94	HA	-	Dk Br Sd 1'0"/C/1'+
95	HA	-	Dk Br Sd/2'0"/4N/2'+
96	HA	-	Dk Br Sd/2'6"/C/2'6"+
97	HA	-	Dk Br Sd/4'
98	HA	-	Gr Br Sd/2'0"/Dk Br Sd/6'0"/C/6'0"+

TABLE A.3 (CONTINUED)

PROFILE No.	METHOD	RRO No.	DESCRIPTION
99	HA	-	Str Br Sd/9'6"+
100	HA	-	P Br→Br Y Sd/9'6"+
101	HA	-	P Br→Br Y Sd/9'6"+
102	HA	-	Dk Gr→Dk Br Sd/6'0"/Lt Gr Ca Sd/9'6"+
103	HA	-	Dk Br Sd/0'-2'/C/0'-2'+
104	HA	-	Dk Gr Sd/2'0"/Ca Sd/4'0"+
105	HA	-	Rd Y Sd/5'+
106	HA	-	P Br→Str Br Sd/9'6"+
107	HA	-	Dk Br Sd/2'0"/C/2'0"+
108	HA	-	Dk Gr Br Sd/2'6"/C/2'6"+
109	HA	-	Dk Br Sd/3'0"/C/3'0"+
110	HA	-	Dk Gr Sd/5'0"/Ca Sd/5'0"+
111	HA	-	Str Br Sd/9'6"+
112	HA	-	Br Y Sd/9'6"+
113	HA	-	Br→Str Br Sd/9'6"+
114	HA	-	Dk Gr→Dk Br Wh Sd/9'6"+
115	HA	-	Dk Br Sd/5'0"/C/5'0"+
116	HA	-	Dk Br Sd/1'0"/C/1'0"+
117	HA	-	Dk Br Sd/2'0"/C/2'0"+
119	HA	-	Dk Br Sd/0'4"/C/0'4"+
121	HA	-	MG/1'0"/Str Br Sd/7'0"/→P Br Sd/9'6"+
122	HA	-	Dk Gr Cl Sd/8'0"+
124	TP	-	Br→Str Br Sd/0'-3'/B/0'-3'+
125	NP	371	Bl Cl/1'6"/Green Cl + N/1'6"+

TABLE A.3 (CONTINUED)

PROFILE No.	METHOD	RRO No.	DESCRIPTION
126	BP	371A	1Hi/1'0" - 1'6"/N + P /4'0"/Rd Br Si Sd/6'/H/6'+
127	BP	372	Br Si Sd/1'0"/N/1'3"/N→/4'/Ca Sd + N/12'/D
128	BP	373	Br Si Sd/2'/H/4'3"/P Br Sd/5'11"/N + P Br Si Sd/7'2"/Ca Sd + N/8'2"/ Sd/8'2"+
129	BP	376	P Br Si Sd G/0'3"/Ho→N/2'6"+
130	NP	377	1 H_{sh}/12'/H/14'/2 H/17'/H/20'/Lt Rd - Y Br SS/17'+
131	TP	379	Gr Cl Sd/3'/Ol Cl Sd/20'/Ol Cl Sd + ON/20'6"/Ol Cl Sd/22'+
132	BP	381	Gr Si Sd + ON/2'/N/12'+
133	TP	-	Bl Cl Sd/7'/N/7'+
134	BP	385	Dk Gr Cl Sd/4'10"/Ol Cl Sd + 3N/ 15'/Ol SS/15'+
135	BP	387	Gr Br Si Sd/2'6"/N + Gr Br Si Sd/ 3'4"/H/6'4"+
136	NP	388	H/2'/N/8'+
137	BP	390	Gr Br Si Sd/2'/N + Gr Br Si Sd + H/3'/H/5'+
138	HA	391	N→Ca Sd/6'6"+
139	HA	391	Gr Si Sd/5'0"/Ca Sd/5'7"+
140	TP	391	Gr Si Sd/4'11"/Gr Si Cl Sd/11'5"/ Ca Sd/11'5"+
141	RP	391	Gr Si Sd/5'7"
142	RP	391	Si Sd/5'7"+
143	HA	391	Gr Sd Cl/7'+
144	RP	391	Gr Sd/1'1"/Cl/5'3"/C/5'3"+
145	RP	391	Gr Sd/0'4"/Cl/5'7"+

TABLE A.3 (CONTINUED)

PROFILE No.	METHOD	RRO No.	DESCRIPTION
146	TP	391	Dk Gr Sd Cl/8'/→/13'/P Br Cl Sd + N_F/18' + C at 25', W. T. at 39'
147	RP	391	Rd Si Sd/4'4"/C/4'4"+
148	BP	391	Sd/4'/H/4'+
149	BP	391	H + N/1'+
150	BP	391	G/0'6"/H/0'6"+
151	TP	391	P + ON/2'6"+
152	HA	391	Gr Cl Sd/7'+
153	TP HA	391	Gr Cl Sd/8'6"/Ca Cl Sd/9'6"+
154	HA	391	Gr Si Sd/2'/Br Sd Cl/6'6"
155	HA	391	Gr Si Sd/3'9"/P/4'8"+
156	TP	391	P + ON/5'+
157	TP	391	Gr Si Sd + ON/1'6"/Wh Ca Sd + N/5'5"+
158	HA	379	Lt Y Br Cl Sd + ON/7'+
159	HA	379	Lt Y Br Cl Sd + ON/6'0"/Lt Y Br Ca Cl Sd + ON/7'0"+
160	HA	379	Gr Br Si Sd/3'6"/P + ON/7'0"+
161	TP	379	Gr Br Ca Si Sd ON/0'10"/N - Gr Br Ca Si Sd/2'0"/Ho/3'6"/N/10'0",
162	TP	379	Gr Si Sd/0'9"/N + Gr Si Sd/1'9"/N/4'4"+
163	HA	379	Gr Si Sd/3'/P/7'+
164	HA	379	Gr Si Sd/3'/P/7'+
165	HA	379	Gr Si Sd/3'/Lt Y Br Cl Sd/7'+
166	HA	379	Gr Si Sd/4'/Lt Y Br Cl Sd/7'+
167	BP	229	Gr Si Sd/2'/P Br Ca Sd Cl/11'6"+

TABLE A.3 (CONTINUED)

PROFILE No.	METHOD	RRO No.	DESCRIPTION
168	BP	228	P Br Cl Sd/7'/N + P Br Cl Sd/10'/ P Br Cl Sd/15'+ W.T. at 16'
169	BP	384	Gr Si Sd + ON/2'/Y Ca Cl Sd + N/7'+
170	BP	-	P Br Si Sd/1'4"/Ol Y Ca Cl Sd + ON
171	BP	385	Gr Si Sd/0'8"/N + Gr Si Sd/0'11"/ Gr Si Sd + N/1'6"/Ol Y Ca Cl Sd + ON/15'+
172	BP	390	Rd Br Si Sd/0'6"/l B/2'+
173	BP	391	Gr Si Sd + ON/0'6"/H/2'0"/N/5'1"+
174	BP	393	Gr Si Sd/1'6"/Gr Ca Si Sd + ON
175	BP	393	Gr Si Sd/0'6"/H/1'6"/N/10'+
176	BP	393	H/Ol Ca Sd/10'/Br N/14'+
177	TP	-	N + Gr Si Sd/1'10"/H/3'10"/Ol N/6'+
178	TP	-	Gr Si Sd/0'10"/H/1'8"/Ol N/5'0"+
179	TP	-	Gr Si Sd/2'6"/Ho/3'0"+
180	TP	-	Gr Si Sd/1'3"/H/4'0"+
181	TP	-	H/1'6"/H/3'6"+
182	TP	-	Gr Si Sd/1'2"/Ho/2'2"/N/3'9"+
183	TP	-	Gr Si Sd/3'/Ca Sd/5'+
184	TP	396	Gr Si Sd/0'6"/OL N + Gr Si Sd/ 2'0"/Ol N/3'6"+
185	BH	397	Rd Br Sd/9'/P Br Ca Sd/18'/P Ol P/27'/P Ol Ca Sd/72'+
186	TP	400	Rd Br Si Sd/0'6"/Br N + Rd Br Si Sd/2'6"
187	BP	401	Br N/4'2"/D/4'2"+
188	TP	402	Br N + Br Si Sd/0'6"/H/1'0"/N/3'+

TABLE A.3 (CONTINUED)

PROFILE No.	METHOD	RRO No.	DESCRIPTION
189	TP	-	N/3'9"/B/3'9"+
190	TP	404	R Br Sd/3'9"/3 N + P Br Cl Sd/ 5'5"+
191	NP	406	Ho/N + Gr Si Sd
192	NP	-	Gr B + Br Sd/N
193	TP	-	Gr Si Sd/0'3"/N/3'+
194	TP	407	Rd Si Sd/3 Ho/1'6"+
195	TP	408	Rd Br Si Sd/0'6"/1 B/2'+
196	BP	409	Gr Si Sd + ON/0'4"/N + Gr Si Sd/0'10"/P/15'/GN/15'+
197	TP	412	Rd Sd/1'4"/N_S/2'0"/H_S/2'0"+
198	TP	-	Br Si Sd/0'3"/1 N + Br Si Sd/ 2'0"/Ho/3'2"
199	TP	-	Rd Si G Sd/1'7" - 2'5"/3 N + Rd Si G Sd/4'5"/Ho/4'10"+
200	RP	-	Gr Si Sd/5'7"/Ca S
201	TP	414	P Br Si Sd/3'4"/3 Ho→/5'2"/N + P/5'2"+
202	TP	-	P Br Si Sd/3'4"/W - Gr H - Ho/3' 10"+
203	RP	-	-/5'5"/C/5'7"+
204	RP	-	P Br Si Sd/2'7"/C/2'7"+
205	TP	406	Gr Br Si Sd + ON/Gr Br Ca Si Sd + N/5'0"/N/9'2"+
206	TP	-	P Br Sd/5'7"/N/9'/3 N/9'+
207	RP HA	276	Str Br Sd/6'8"+
208	RP	276	Sd/5'7"+
209	RP HA	276	Str Br Sd/6'8"+

TABLE A.3 (CONTINUED)

PROFILE No.	METHOD	RRO No.	DESCRIPTION
210	HA	276	Str Br Sd/6'8"+
211	RP	276	Sd/3'8"/C/3'8"+
212	RP	276	Sd/3'10"/C/3'10"+
213	RP	276	Sd/2'6"+
214	RP HA	276	Str Br Sd/5'8"/G Sd/6'8"+
215	RP	276	Sd/5'/C/5'+
216	RP	276	Sd/4'1"/C/4'1"+
217	RP	276	Sd/4'8"/C/4'8"+
218	RP	276	Sd/3'10"/C/3'10"+
219	RP	276	Sd/3'8"/C/3'8"+
220	RP	276	Sd/3'8"/C/3'8"+
221	RP	276	Sd/5'4"/C/5'4"+
222	RP HA	276	Str Br Sd Gr Br/5'7"+
223	RP	276	Sd/1'8"/B/1'8"+
224	RP	276	Sd/3'11"/B/3'11"+
225	RP	276	Sd/5'7"+
226	RP	276	Sd/4'2"/C/4'2"+
227	RP HA	276	Str Br Sd/4'6"/1 N/4'6"+
228	RP HA	276	Str Br Sd→R G Sd/6'8"+
229	RP HA	276	Str Br Sd/6'6"+
230	RP	276	Sd/5'6"+
231	RP	276	Sd/5'6"+
232	RP	276	Sd/5'6"+

TABLE A.3 (CONTINUED)

PROFILE No.	METHOD	RRO No.	DESCRIPTION
233	RP HA	276	Str Br Sd/6'6"+
234	RP	276	Sd/5'6"+
235	RP	276	Sd/5'6"+
236	RP	276	Sd/5'6"+
237	RP HA	276	Str Br Sd/7'0"+
238	RP	276	Sd/5'6"+
239	RP	276	Sd/5'6"+
241	RP	276	Sd/5'6"+
242	RP	276	Sd/1'2/C/1'2"+
243	RP	276	Sd/5'6"+
244	RP	276	Sd/3'4"/C/3'4"+
246	TP	276	R Br Si Sd/1'6"/3 N/2'6"/3 Ho/ 2'6"+
248	TP	404	R Br Si Sd/0'6"/1 B/2'+
249	TP	276	Sd/2'/B/2'+
250	TP	404	R Br Sd/0'2"/1, 3 B/1'6"/1, 3 Ho/5'+
251	TP	276	R Br Sd/1'/1, 3 B/1'6P/1, 3 Ho/5'+
252	TP	276	Str Br Sd/4'2"/B/4'2"+
253	TP	276	Str Br Sd/6'/B/6'+
254	TP	404	Str Br Sd/2'0"/B/2'0"/B/2'0"+
255	TP	276	Str Br Sd/6'6"+
256	TP	276	Sd/3'4"/1 B/3'4"+
257	TP	276	Sd/5'+
258	RP	276	Sd/3'1"/B/3'1"+
259	RP	276	Sd/5'6"+

TABLE A.3 (CONTINUED)

PROFILE No.	METHOD	RRO No.	DESCRIPTION
260	RP	276	Sd/5'6"+
261	RP	276	Sd/5'6"+
262	RP	276	Sd/5'6"+
263	RP	276	Sd/5'6"+
264	RP	276	Sd/5'6"+
265	RP	276	Sd/2'11"/C/2'11"+
266	RP	276	Sd/5'6"+
267	RP	276	Sd/3'7"/C/3'7"+
268	RP	276	Sd/5'/C/5'+
269	RP	276	Sd/4'0"/C/4'0"+
270	RP	276	Sd/5'6"+
271	RP	276	Sd/5'5"/C/5'5"+
272	RP	276	Sd/5'6"+
273	RP	276	Sd/4'6"+
274	RP	276	Sd/4'4"/C/4'4"+
275	RP	276	Sd/5'0"/C?/5'0"+
276	RP	276	Sd/5'6"+
277	RP	276	Sd/5'C?/5'+
278	RP	276	Sd/3'2"/C/3'2"+
279	RP	276	Sd/3'4"/C/3'4"+
280	RP	276	Sd/4'5"/C/4'5"+
281	RP	276	Sd/4'1"/C/4'1"+
282	RP	276	Sd/5'1"/C/5'1"+
283	TP	-	Gr Br Si Sd/0'6"/01 N/0'6"+
284	TP	404A	Gr Br Si Sd/1'0"/B/2'/3 H/4'6"+

TABLE A.3 (CONTINUED)

PROFILE No.	METHOD	RRO No.	DESCRIPTION
285	RP	523	Sd/5'6"+
286	RP	523	Sd/5'6"+
287	RP	523	Sd/5'6"+
288	RP	523	Sd/5'6"+
289	RP	523	Sd/5'6"+
290	RP	523	Sd/5'6"+
291	RP	523	Sd/5'6"+
292	RP	523	Sd/5'6"+
293	RP	523	Sd/5'6"+
294	RP	523	Sd/4'9"/C/4'9"+
295	RP	523	Sd/4'8"/C/4'8"+
296	RP	523	Sd/4'2"/C/4'2"+
297	RP	523	Sd/5'2"/C/5'2"+
298	RP	523	Sd/4'4"/C/4'4"+
299	RP	523	Sd/3'4"/C/3'4"+
301	RP	523	Sd/2'10"/C/2'10"+
302	RP	523	Sd/1'1"/C/1'1"+
303	RP	523	Sd/3'10"/C/3'10"+
304	RP	523	Sd/3'7"/C/3'7"+
305	RP	523	Sd/2'3"/C/2'3"+
306	RP	523	Sd/2'5"/C/2'5"+
307	RP	523	Sd/1'2"/C/1'2"+
308	RP	523	Sd/2'1"/C/2'1"+
309	RP	523	Sd/1'10"/C/1'10"+
310	RP	-	Ol Ca Cl Sd + ON_S

TABLE A.3 (CONTINUED)

PROFILE No.	METHOD	RRO No.	DESCRIPTION
311	BP	-	Br Cl Sd/2'6"/Br Cl Sd + 5 Ol N/5'10"+
312	BP	-	Gr Br Si Sd/1'/Ol Ca Cl Sd/2'/5 Ol N + Ol Ca Cl Sd/6'+
313	RP	427	Sd/1'0"/C/1'0"+
314	RP	427	Sd/0'11"/C/0'11"+
317	RP	427	Sd/1'6"/C/1'6"+
318	RP	427	Sd/0'5/S/0'5"+
320	RP	427	Ol Cl Sd/1'3"/S?/1'3"+
321	BP	417	Gr Br Si Sd/2'/N/3'/S/4'6"/Sil Sd 4'6"+
322	RP	-	Sd/5'0"/C/5'0"+
323	RP	-	Sd/5'7"/C/5'7"+
324	RP	-	Sd/4'7"/C/4'7"+
325	RP	-	R Sd/3'11"/C/3'11"+
326	RP	-	Br Sd/3'2"/C/3'2"+
327	RP	-	Sd/3'4"/C/3'4"+
328	RP	-	Sd/1'5"/C/1'5"+
329	RP	-	Dk Br Sd/3'8"/C/3'8"+
330	RP	-	Lt Br Sd/3'10"/C/3'10"+
331	BP	417	Gr Br Si Sd/0'4"/Wh sepiolite/4'0"+
332	TP	420	Gr Br Si Sd/1'2" - 2'0"/1 Br B/2' 0"/1 H/4'0"/N/9'0"+
333	BP	226	Gr Br Si Sd/1'6"/Ho/2'6"/P Br Ca Sd/3'6"/ P Br Ca Sd + ON/3'6"+
334	BP	423	P Ol Cl Sd/6'5"/Ol Cl Sd + 3 ON/ 8'1"/Ol Cl/9'7"/ Rd Cl/11'8"+
335	BP	425	P Br Si Sd/2'/N + P Br Si Sd/6'/ S?/6'+

TABLE A.3 (CONTINUED)

PROFILE No.	METHOD	RRO No.	DESCRIPTION
336	BP	425	P Br Si Sd/1'/N + P Br Si Sd/H_T/ 2'6"+/Ol Ca Cl Sd/S
337	HA	426	Ol Cl Sd/0'3"/Br S/0'9"/Wh Sd/ 4'0"+
338	HA	426	Ol Ca Cl/0'$\frac{1}{4}$"/Ol Ca Cl Sd/0'6"/ Water/P Ol Ca Sd/7'0"+
339	TP	-	Br Si Sd/1'0"/N_S/1'6"/H_S/3'+
340	BP	427	Br Si Sd/0 - 6"/H_t/1'+
341	TP	528	5N/4'+/S
342	BP	428	5 N/5 H
343	BP	429	Br Si Sd/3'/5 N/8'+
344	TP	426A	Br Si Sd/1'0"/1,7 H/1'10"/Ho/ 2'8"/P/4'7"+
345	TP	427A	Dk Gr Si Sd + N/0'10"/1 N/2'6"/1 H/4'2"+
346	TP	428A	Dk Gr Si Sd/0'8"/1 N + Dk Gr Si Sd/1'8"/ Br 1 H/2'8"/Br 1 H/4'4"+
347	TP	-	Gr Br Si Sd/0'9"/1 B/4'2"+
348	TP	-	Gr Br Si Sd/0'9"/1 B/2'0"/1 H/4'5"+
349	TP	-	Br Si Sd/0'9"/1 B/2'0"/1 H/3'0"/1 N + Br Si Sd/4'9"+
350	TP	407	R Br Si Sd/0'6"/1 B/2'0"/1 Ho→3 Ho/4'5"
351	RP	-	Sd/5'6"+
352	RP	-	Sd/2'8"/C/2'8"+
353	BP	-	Gr Sd/2'/R Sd/10'/Ca Sd + N/10'+
354	BP	431	Br Sd/8'6"/N/9'10"/Br Wh Ca Sd/16'+
355	BP	432	Gr Br Sd/1'/H/1'+
356	BP	433	Gr Br Si Sd/3'0"/H/4'6"/P/5'6"/ H/7'0"/I Br Cl Sd/7'0"+

TABLE A.3 (CONTINUED)

PROFILE No.	METHOD	RRO No.	DESCRIPTION
357	BP	-	Gr Br Sd/2'/Rd Sd/1'/Br Ca Sd/12'+
358	TP	434	Rd Sd/0'6"/A + Rd Sd/0'8"/RD Fe G/1'1"/N_S/1'2"/H_S/2'8"/N_S/3'0"/1 H/3'3"/N/3'6"+
359	TP	434	Rd Sd/1'8"/A + Rd Sd/1'10"/Rd Fe G/2'6"/N_S/4'/H_S/5'+
360	TP	434	H/N_S/1 H/H_S
361	TP	434	Rd Sd/Rd G + A/N/N/N/B/H
362	TP	434	Wh 1 H/Wh Br H_S
363	TP	434	N/1 H/H_S/1 H
364	TP	434	Rd Sd/A + Rd Sd/G/N_S/C/H_S
365	NP	434	N/1H/H_S
366	NP	434	N/H_S/1 H/H_S
367	NP	434	N/H_S
368	NP	434	N/H_S/S,N/1 H
369	HA	242	Rd Sd/6'11"+
370	HA	242	Rd Sd/6'11"+
371	HA	242	Br Si Sd/3'0"/Gr P/5'0"/Wh Ca Sd/7'0"+
372	HA	242	Gr Sd/0'½"/Br→P Br Sd/7'0"+
373	HA	242	Rd Br→Str Br Sd/7'0"+
374	HA	242	P Br Sd/0'⅛"/Br Sd/0'6"/Str Br Sd/7'0"+
375	TP	242	Gr Ca Cl/1'7"/P/2'0"/Gr Ca Cl Sd/ 2'3"/N_F/ 2'4"/Gr Ca Cl Sd/2'9"/W Sd/5'6"+
376	NP	242	Gr Br Sd/Gr Br/Ho
377	TP	242	Gr Ca Si Sd/1'/P Gr Sd/6'6"/1 N/7'+

TABLE A.3 (CONTINUED)

PROFILE No.	METHOD	RRO No.	DESCRIPTION
378	HA	242	Gr Ca Si Sd/0'6"/Gr Ca Si Sd + ON/ 1'0"/Br Sd/4'0"/Ca Cl Sd/5'0"/Y Cl Sd/7'+
379	HA	242	Ca Si Sd/0'6"/P Br Sd/2'6"/N/2'6"+
380	HA	242	P Br Sd/1'/Rd Sd/7'0"+
381	HA	242	P Br Sd/1'/Rd Sd/7'0"+
382	HA	242	Wh Sd/0'1"/Ol Y Cl Sd/7'0"+
383	HA	242	Gr Br Sd/0'6"/Ol Y Sd/5'0"/Wh Sd/6'0"/Ol Y Sd/7'0"+
384	HA	242	P Br Sd/1'/Rd Sd/7'0"+
385	TP	242	Gr V W Si Sd/1'10"/1 Ho/2'10"/ N/3'6"/ P Br Ca Sd/4'0"+
387	TP	242	Gr Si Sd/2'6"/H + N/2'6"+
388	HA	242	Bl Sd Cl/4'6"/Br Cl Sd
389	TP	242	Gr Br Si/0'11"/Br Si Sd/1'10"/Gr Cl/3'4"/ Wh Sd/5'10"/N_S + Wh Sd/7½"/Ho_S/9'2"
390	TP	242	Dk Gr Br Si Sd/4'/Y Br N/4'+
391	TP	242	Gr Br Si Sd/0'6"/Str Br Sd/3'0"+
392	BP	242	Br Si Sd/1'3"/P Br Si Sd/2'2"/P Br Ca Sd + ON/3'6"/N + P Br Ca Sd/5'6"/Lt Ol Br - P Br H - N/ 8'6"+
393	BP	242	Gr Ca Sd/0'3"/Br Ca Si Sd/1'0"/Br Ca Si Sd + ON_F/2'4"/P Br H - N/3' 4"+
394	TP	242	Br Si Sd/3'4"/Ca Sd + N/5'4"/1 N/10'0"+
395	TP	242	Gr Br Si Sd/0'8"/P Br Sd/3'2"/Wh Sd/3'6"/Ca Sd + N/4'10"/P Br N - H/7'0"+
396	TP	242	Gr Si/2'6"/Wh + Rd Sd/5'3"/Br N_S/6'3"+

TABLE A.3 (CONTINUED)

PROFILE No.	METHOD	RRO No.	DESCRIPTION
397	TP	242	Gr Si/2'6"/Wh + Rd Sd/5'3"/Br N/6'+
398	BP	242	Gr Ca Si Sd/0'10"/H_S/2'0"+
399	BP	242	Br Si Sd/1'8"/Gr H_{o-t} - H_t/2'8"/ N_S + N + Ca Si Sd/3'6"/N/4'6"/Sd 4H - Ho/10'0"+
400	BP	242	Gr Br Si Sd/0'4"/B/0'4" - 0'8"/ N_S/1'6"/Sd 4 H/2'2"/Sd 4 N/3'6"+
401	TP	242	Gr W Ca Si Sd/1'0"/H_t/CalA Cal Si Sd/3'6"/ Ca N_S+ Ca Ho_S/4'2"/N_S + P Br Ca Si Sd/5'10"+
402	TP	242	Gr Br Si Sd/2'/N/3'+
403	HA	242	Gr Si Sd/2'6"/Wh Sd/3'0"/P Br Cl Sd/7'0"+
404	HA	242	Wh Sd/0'1"/Br Sd/1'0"/Lt Rd Sd/ 5'6"/Wh Sd/6'0"/Ol Y Cl Sd/7'0"+
405	HA	242	Gr Br Si Sd + ON/2'0"/Ol Y W Cl Sd/7'0"+
406	TP	242	Alt Ol Cl Sd + Wh Sd/7'0"/P Br Sd 4 N/7'0"+
407	TP	242	Gr Br Si Sd/3'0"/Gr Ca Si Sd/7'0"+
408	TP	242	Gr Br Si Sd/2'0" - 3'0"/Ol Y W Cl Sd/10'0"/Sd 4 C + N_S/10'0"+
409	BP	242	Rd Br Sd/1'0"/N_S - H_S/4'0"+
410	BP	242	Br Si Sd + ON_S/2'0"/Sd 4 N + N_S + Ca Sd/2'6"/N_S + Ca Sd/4'0"+
411	TP	242	Wh - P Br Sd/0'3"/Ol Y V W Cl Sd/2'0"+
412	TP	242	Gr Br Si Sd/3'/Gr Si Sd/5'/Gr Si Sd + ON/7'/Ol Y W Cl Sd/8'+

TABLE A.3 (CONTINUED)

PROFILE No.	METHOD	RRO No.	DESCRIPTION
413	BP	242	Gr Br Si Sd + ON/2'6"/H_t + Sd/Ho/ 5'0"+
414	HA	242	Wh Sd/0'3"/P Ol Cl Sd/5'6"/Rd Cl Sd/5'6"+
415	HA	242	Br Ca Cl Sd/7'0"+
416	TP	242	Wh P Br Sd/0'1"/P Br→Wh Sd/4'0"+
417	HA	242	Rd Br Sd/5'6"/P Br Ca Sd + ON/ 6'6"+
418	TP	242	Gr Br Cl Sd/3'+
419	BP	438	Gr Br Sd/2'/N/4'/5 N/6'+
420	BP	440	Br Si Sd/1'/4 H/2'0"/Gr Br Sd + ON/2'3"/4 H/3'0"/Wh 2 Ca Cl/5'0"+
421	BP	445	Dk Gr Si Sd/2'/Wh 2 Ca Cl + ON/5'+
422	BP	-	Br Si Sd/2'0"/Wh N + Cl Sd/8'0"+
423	BP	446	Gr Br Si Sd/0'6"/Gr Br Si Sd + OlN/1'0"/H/1'6"/H_t/5'0"+
424	BP	447	Wh H_t + O/N/2'6"/P Br N + P/7'6"+
425	TP	448	Dk Br Sd Si Cl/1'0"/Rd 1 N/3'+
426	BP	448	Br Si Sd + ON/1'0"/Rd G/N + Br Si Sd/1'8"/Rd G/N→/2'2"/Rd 1 Ho/ 3'2"/Rd 1 N + Str Br Si/9'2"/ Sesfontein PH/9'2"+
427	NP	449	GH/D
428	TP	456	Dk Br Si Sd/0'6"/H/1'0"/P + ON/7'0"+
429	NP	455	Wh 4 H + Br G Sd 4 H/0'6"/Khomas (?) Marble/0'6"+
430	TP	455	Br Si Sd/1' - 3'/Khomas(?) Marble
431	TP	-	H + N + B/2'/P + Si Sd + OlN/7'+
432	BP	-	Rd Br Si Sd/5'/1 N + Rd Br Si Sd/ 6'/1 Ho/6'+

TABLE A.3 (CONTINUED)

PROFILE No.	METHOD	RRO No.	DESCRIPTION
433	BP	-	Rd Br Si Sd/2'1"/1 Ho - 1 N/6' + Q + GRT
434	BP	-	Rd Br Si G Sd/6'/Sd 1 H/6'2"/M S/ 6'2"+
435	BP	-	Rd Br Si Sd/4'/3 Ho/4'+
436	BP	-	P Br 4 N + P Br Si Sd/0'9"/H/1'8"/ P + O 4 N/5'0"+
437	BP	-	1, 3, 4 N + P Br Si Sd/1'0"/G 1H →/1'3"/ 1 N + P Br Si Sd/6'0"+
438	BP	-	Gr Si Sd/1'/4 H/2'6"/P/6'+
439	BP	465	1 B + G/2'/N/6'+
440	BP	466	1 B/1 N + P Br Si Sd/GRT
441	BP	468	1 B + 1 Ho/1 N
442	TP	470	P Br Si Sd G/0'3"/G Ho - N/5'+
443	BP	471	P Br G Si Sd + ON/0'6"/G 4 H/0'10" /P Br Ca G Si Sd/2'0"+
444	BP	472	P Br Gyp Si Sd G/3'+
445	BP	473	G/0'1"/Br Si Sd G/0'3"/Br 3 N + Br Si Sd/2'6" + /MS
446	NP	-	Br Si Sd G/0'2"/Br Gyp H/1'2"/ Br Gyp Sd G/4'6"+
447	NP	475	Br G Si Sd/N/GRT
448	TP	476	Br G Si Sd/0'10"/1 N + Br G Si Sd/ 1'10"/1 N + Br GRT G Si Sd/3'0"/ GRT/3'0"+
449	BP	-	N + Grt G/0'2"/1 Ho - 1 N/1'2"/ Br Ca GRT G Sd + ON/2'4"/Grt/2'4"+
450	BP	480	Br Sd 4 H/1'8"/Br Ca Si Sd G/2'10"/ Br P/6'6"/ Br Ca Si Sd G/8'6"/ Br P/8'6"+
451	BP	-	B + H/Br 1 B + 1 Ho + 1 H + 1 N + Br GRT Si Sd + P/GRT?

TABLE A.3 (CONTINUED)

PROFILE No.	METHOD	RRO No.	DESCRIPTION
452	BP	-	1 N + Br Si Sd/GRT
453	BP	-	Br G Si Sd/0'6"/Ca GRT G + 1 N + Br Si Sd/2'0"/GRT/2'0"+
454	BP	-	Br G Si Sd/1'0"/Ca GRT G + 01N + Br Si Sd/4'0"/GRT/4'0"+
454A	BP	-	P Br 1 N + P Br GRT Si Sd/GRT + D + MS
455	BP	-	Br Si Sd + 1 N/1'6"/1 H/1'6"+
456	BP	-	Br Si Sd Do G/0'4"/P Br 4 1N + P Br Si Sd/3'6"+
457	BP	-	Br Si Sd G/0'6"/Sd Gl H/2'10"+
458	BP	-	Br Si Sd/1'6"/Sd H→Sd N/3'6"/ GRT/3'6"+
459	BP	-	Br Si Sd + 4 N/0'6"/4 H/1'0"/P + MS/4'+
460	NP	-	Rd Si Sd/2'/1 B + Ho/2'+
461	BP	-	P Br Sd H/2'0"/Rd Br 1 N/6'0"+/ Stormberg Basalt
462	NP	-	Pu Sd SB G/0'3"/Ca SB/0'3¼"/B/0' 3¼"+
463	BP	-	Sd H/1'/Ca SB/6'+
464	NP	-	G/0'1"/Br Sd G 1 H/6'/Wh - Pi C/ 9'/Cal G/9'+
465	NP	-	G 1 H + Rd Si Sd
466	TP	-	Lt Rd Pu Sd Cl/1'6"/4 N/1'6"+
467	TP	-	Rd Sd G/0 - 3'0"/1 G B/3'0"+
468	TP	487	Br Si Sd/1'1"/3 N + Sd 4 N/3'0"/ P 01 Ca Dwyka Boulder Shale/3'0"+
469	TP	487	Br N/1'3"/Alt P 01 Dwyka Boulder Shale + Wh 1 C/2'8"+
470	TP	487	Br 1 N/1'6"/P 01 Dwyka Boulder Shale/1'6"+

TABLE A.3 (CONTINUED)

PROFILE No.	METHOD	RRO No.	DESCRIPTION
471	TP	487	Br Si Sd G/0'8"/Br N/1'3"/P Ol Ca Dwyka Boulder Shale/2'6"+
472	BP	488	P Br Sd/2'/Rd Gyp 1 N + GRT Sd/4'/ GRT/4'+
473	BP	-	Rd Br G Sd/0'6"/Gyp 1 N + Rd Br G Sd
474	BP	-	P Br GS/0'3"/1 Ho/1'3"/N/3'6"/ Rd Gyp Sd/3'6"+
475	NP	-	R Br Sd/Ho/1'/Gyp GRT
476	BP	-	Br G Sd/1'/Wh H→/2'/P Ol GRT G Sd Cl/5'+
477	BP	-	Br Sd/1 N + Sd/Grt
478	TP	-	Br Sd/2'+
479	TP	-	Br Gr Sd/0'3"/Wh 4 H + N + Si Sd/ 2'+
480	NP	-	Sd G N - H/GRT
481	BP	-	G + C/0'4"/4 H_{be}/1'10"/P + O SH G/4'10"+
482	BP	-	Q 6 + C 6/0'6"/4 H/1'6"/P/2'/ Ca Shale/2'+
483	NP	491	Dk Br 1 Ho/1'4" - 1'11"/Br Ca Q G/D
483A	BP	491	Br Sd/Ho/4'8"/Br Ca Q G/5'2"+/D
484	NP	-	Br Sd G/H/3'/C/20'Nama SH/40'+
485	BP	-	Sd 4 H_{sh}/4'0"/N Rd Br Sd/6'+
486	BP	494	Br Si Sd + N/1'/P + Cl Sd/7'/Ol Cl Sd/9'+
487	BP	495	Wh 1 H/1'/4 N - H/2'+
488	BP	496	Br Si Sd/2'6"/H_T/3'6"/P - Ca Sd + O/N/6'+
489	HA	-	Br Si Sd/2'0"/N + Br Si Sd/2'7"/H/ 2'7"+

TABLE A.3 (CONTINUED)

PROFILE No.	METHOD	RRO No.	DESCRIPTION
490	RP	-	Br Sd/5'1"/H/5'1"+
491	RP	-	Br Sd/5'2"/H/5'2"+
492	RP	-	Br Sd/5'3"+
493	NP	-	Rd Sd/3 C/1 C/H_t
494	TP	497	Rd Br Si Sd/1'/1 H/1'6"/Cal Sd/ 10' Cal Sd VA, S, CH G + Bo/26'+ WT at 26'
495	TP	497	Rd Br Si Sd/2'/Rd Br Cal Sd/7'/Sd VA, S, + CH Bo + G + ON/24'+
496	TP	497	Br + Gr Sd Cl + ON/12'/Cl VA, S + CH Bo + G/12'+
497	TP	497	Rd Br Si Sd/0'6"/H/1'0"/Cal Sd/ 8'/H/8'6"/Cal Sd VA, S + CH G/12' 6"/W Cal Sd VA, S + CH G/15'6"/Lt Rd Sd + ON/17'/Wh G Sd/20'/GH/20' 6"/Ca Sd VA, S + CH Bo + G/25'/Lt Rd Sd + ON/29'/G/29'+
498	TP	497	Rd Br Cl Sd/2'/Gr + Br Ca Cl Sd→ Gr + Br Cl Sd/25'/Alt Gr + Br Cl Sd? + G/45'/G/47'+ Water at 47'
499	TP	497	G + Rd Sd/VL
500	RP	497	Rd Sd/3'/Cal VL
501	TP	497	Rd Sd QE, Q + CH G/1'0"/G 1 H/2' 0"/Rd Sd/2'2"/ 4 N + 1 N/7'6"/Ca Sd VA, CH, QE, SH, Q + CT G/7'6"+/ VA
502	TP	497	Rd Br Sd QE, Q + CH G/2'6" - 10'/ Cal QE, Q + CH G/2'6" - 10'3"/Cal Sd VA, CH, QE, SH + QG + O Bo/ 17'/P Br Cal Sd + O VA, CH, QE, SH + Q G/18'6"/Cal Sd VA, CH, QE, SH + Q G + Bo/27'/Fresh VA/27'+
503	TP	497	Rd Sd/1'/C/25'/G/26'/Dwyka SH/26'+
504	TP	498	Gr - P Br 1 N + A/1'6"/Wh P + O 4 N/6'+

TABLE A.3 (CONTINUED)

PROFILE No.	METHOD	RRO No.	DESCRIPTION
505	TP	498	N + Br Sd/1'0"/P Br 3 B/1'9"/4 N/5'6"/P Ol Cal Sd/6'0"/Wh P + A/7'+
506	TP	497	Rd Br Si Sd + QE, Q + CH G/2'/G Sd H/G Sd H/5'6"/ In parts Lt Rd Br Cal Sd G + O Bo/14'9"/In parts Wh - Lt Rd Br Cal Sd/14'9"/H/15' 6"/Cal Bo Sd G/21'/Br Dwyka T/VA
507	TP	497	Rd Si Sd/0'6" - 2'/Lt Rd Br Sd N - Be/8'6"/H/9'3"/Cal Sd VA, CH, QE, SH + Q G + Bo/16'3"+
508	TP	497	G Be - N/5'3"/H/6'6"/Cal Sd VA, CH, QE, SH + Q G + OH/15'/Cal Sd/ 17'3"/GH/18'6"/Cal VA, CH, QE, SH + Q G + Bo/23'6"+
509	TP	497	Rd Br Sd G→/5'/Lt Rd Br Sd VA, CH, QE, SH + Q B G/2'5"+. Water at 25'
510	TP	497	Rd Br Si Sd VA, CH, QE, SH + Q G/2'/Cal Sd VA, CH, QE, SH + Q G/ 6'/G/6'+
511	TP	497	Rd Br Si Sd G/4'/Ca G/10'+
512	TP	502	Gr Br Si Sd/0'6"/N/1'4"/G Be/3'3"/ Ca Sd G PM/Rd - Gr Ca Si Sd G/7'/ Alt Q, MS + GN/13'+
513	TP	502	Gr Br Si Sd + ON/0'6"/H/1'9"/Bl Ca Cl Sd/1'10"/P Ol Ca Sd Cl + ON_S/1'11"/H/3'2"/Gr + Wh Ca Sd Cl_S + ON_S/4'9"/P Ol W Sd Cl + V ON_S/9'+ /GRT
514	TP	502	Gr Br Si Sd/1'0"/H/1'9"/Gr Br Si Sd/1'9¼"/H/2'9"/H P Ol Ca Sd Cl/2'10"/H/4'3"/Gr + Wh Ca Sd Cl/4'3"+
515	TP	502	Gr Br Si Sd/1'9"/H/4'0"/Ol Sd Cl/7'+
516	TP	502	Gr Br Si Sd/1'0"/H/3'0"/H/3'6"/ H/4'0"/Dk Gr Ca Si Sd/4'6" Ol Sd Cl/7'/GRT/9'+

TABLE A.3 (CONTINUED)

PROFILE No.	METHOD	RRO No.	DESCRIPTION
517	TP	503	Br Si Sd/1'0"/Wh - P Br N/6'6"/ H/20'+ Water at 20'
518	TP	502	Bl Si Sd/3'0" - 4'6"/H/4'6"/Bl Ca Si Sd/6'6"/ P Ol Sd Cl/13'0"/P Ol GRT + Q G Sd Cl. PM/13'3"/ NS/14'6"+
519	BP	534	Dk Br Si Sd + V ON/0'3"/Ho→/0'6"/ N + P Br Si Sd/2'6"/H/7'/Wh + Str Br Cal Cl/13'+
520	BP	534	Dk Br Si Sd + V ON/0'2"/N/4'/Cal CT, DO + SH G + B/15'+
521	BP	504	Dk Rd Br Si Sd/3'/Wh + Str Br 6H 15'+
522	BP	504	Dk Br Si Sd/1'/Ol + Br Cal Dwyka SH/18'+
523	NP	536	C/6'/Ca Sd/30'+
524	NP	537	H/H/Ca Sd
525	NP	538	Wh Sd/H/Ca Sd
526	TP	535	Sd l H/0'3"/Cal Sd/2'3"/Sd l B + Cal Sd/6'/Rd + Wh Sd/10"+
527	TP	535	P Br Sd + ON_F/2'/Wh Sd N_P + P Br Sd/4'+
528	TP	535	N_P + Br Sd/0'3"/Br Sd/0'3"+
529	BP	539	Br Si Sd/1'/H_{be}/6'/Beaufort SH/ 6'+
530	TP	505	Br Si Sd/0'6"/N + 0 H + 0 B/1'0"/ P + VON/10 - 16'/ Ol Br Cal Dwyka SH + P + VON/20'+ Water at 20'
531	A	540	Bl Cl + VON/1'10"/Dk Rd Br Cl Si + ON/3'6"/Str Br Sd Cl + N/8'9"/ Br Sd DG/10'8"/Str Br Cl Sd + VON/15'3"/Dk Gr fresh Beaufort SH/15'3"+
532	A	541	Bl Cl + ON/2'6"/Str Br + Bl Sd Cl + ON/3'6"/Str Br Cl Sd + ON/4'9"/ Str Br Sd Cl + ON/10'6"/Str Br Cl Sd/13'0"+

TABLE A.3 (CONTINUED)

PROFILE No.	METHOD	RRO No.	DESCRIPTION
533	A	542	Bl Cl MG/1'3"/Bl Cl + ON/3'0"/Y Br Cl + ON/9'6"/Ol Beaufort SH/9'10"+
534	A	543	Br Cl Sd/1'3"/Gr Br Cl/1'9"/Ol + Y Cl + N_F/ 3'6"/Gr Br Beaufort SH/4'3"+
535	A	-	Br Cl Sd/0'3"/Bl Cl/0'9"/Gr Br Cl + N/1'7"/Ol Ca Beaufort SH/ 2'6"+
536	A	544	Ol Sd Cl + ON/2'6"/Br Cl SH G + N/4'0"/Ol Beaufort SH/5'9"+
537	A	545	Bl Cl + ON/3'6"/Br Beaufort SH/5'6"+
538	NP	546	Bl Sd Cl/3'6"/Ol Br Cl + N/5'0"/ Ol Br Cl/7'+
539	A	547	Rd G Sd MG/0'3"/Ol Sd DG. MG/1'0"/ Bl Cl + ON/2'6"/Gr Br Cl/5'0"/Gr Br Cl + N/6'0"/Gr Br Cl/6'6"/Br Cl D G/7'3"/Ol Beaufort SH/7'6"+
540	A	547	Bl Cl + ON/3'0"/Gr Br Cl + ON/ 6'6"+
541	A	548	Bl Cl/3'0"/Gr Sd Cl + ON/6'0"/Gr Cl/8'6"/Ol Y Sd Cl + ON_F/13'3" Gr Cl/14'0"+
542	A	-	Dk Rd Si Cl/3'6"/Dk Rd + Y Si Cl + ON_F/7'0"/Y + Rd Sd Si/10'+/D
543	BP	499	Wh 4 H_{be}/3'/Wh Sd 4 C/7'+
544	BP	-	Br Si Sd/1'0"/H_{be}/1'6"/Cal G/6'+
545	BP	-	Cal D/6'+
546	BP	-	Str Br Si Sd/3'6"/SS/
547	BP	-	Dk Rd Br Si Sd Cl/0'6"/Gr Br
548	BP	-	Br Si Sd/0'4"/Str Br + Bl H_F/3'9"/ Rd Br + Y Br SS/Wh Ecca SS
549	BP	-	Dk Gr Si Sd/1'6"/GRT Sd G PM/2'0"/ Y Rd→Rd, Wh Sd Si/6'0"/GRT/6'0"+

TABLE A.3 (CONTINUED)

PROFILE No.	METHOD	RRO No.	DESCRIPTION
550	BP	-	Dk Gr→Dk Y Br Si Sd/4'/Rd GRT Si Sd/20'+/GRT
551	BP	-	Dk Gr Si Sd/0'9"/Rd GRT Si Sd/ 15'+/GRT
552	NP	-	Br Si Sd/4'/Y Rd H_F/GRT
553	RP	-	Bl Sd Cl/8'/GRT
554	HP	549	Gr Br Si Sd/0'9"/Br Cl Sd/3'/Br Cl Sd + ON/5'/Br Cl Sd + N/10' + WT at 10"/GRT
555	NP	-	Gr Br Si Sd/1'/Ol Br VW Ca Sd Cl/4'+
556	NP	550	Dk Rd Br Si Sd Cl/2'/Gr H/4'+
557	BP	-	Bl Sd Cl/0'6"/Ol Ca D Sd Si ON/8' D
558	NP	-	Gr Br Si Sd/Ecca SH + N
559	NP	551	Dk Gr Cal Sd Cl/6'/Br Cal Sd Cl + Sd 4 N/12'+/GRT
560	BP	-	Dk Rd Br Cl Sd/1'0"/Dk Rd Br W Ca Cl Sd/1'6"/Br Cal G Cl Sd/3'/ Rd Br Cal Cl Sd
561	TP	-	Ol Br W Ca Sd Cl/1'/Ol Br Ca Sd Cl + N/ '+/SB
562	NP	-	Gr Br Si Sd/3'/SS
563	BP	552	Str Br Si Sd/2'6"/Str Br Si Sd + N_F/4'0"/Dk Rd Br + Br Y/N_F →/6'6"/ Dk Rd Br + Br Y Ho_F - H_F/7'0"/ Dk Rd Br + Br Y/Ho_F/12'+/SS
564	NP	-	Gr Br→Y Br Si Sd + N_F + OG/8'+
565	BP	-	Br Si Sd/0'6"/P Br Cal Sd/6'+
566	BP	-	P Br N/5'/Cal arkose + GW/15'+
567	BP	-	Lt Br N + H + Ho/5'/Dk Gr D
568	TP	-	Gr Br Si Sd/0'6"/H + N→/6'/Cal SB

TABLE A.3 (CONTINUED)

PROFILE No.	METHOD	RRO No.	DESCRIPTION
569	BP	-	Rd Br Sd/H_F/H_F/N_F/SB?
570	BP	-	H_F/N_F
571	TP	-	Gr Cl Sd/0'6"/N→Cal SB
572	BP	-	R Sd/0 - 2'/Y Br S
573	BP	-	Dk Gr Sd Cl/6'/N/12'+
574	NP	-	H/2'/N /10'/Cal SH/10'+
575	NP	-	P Br Sd/4'/Ca Sd/6'+
576	BP	-	P Br Cl Sd/10'/3 N/15'+
577	BP	-	Dk Gr Br Si Sd/4'6"/3 N/10'+
578	BP	-	Dk Gr Br Si Sd/3 N/Wh Cal Sd
579	BP	-	Dk Gr Br Si Sd/3 N/1 - 3B/H
580	BP	-	P Br Sd/SS
581	TP	-	R Si Sd/3 N
582	BP	580	Dk Gr Br Ca Cl Sd/3'/P Br - Y Br 3 N/10'+
583	BP	-	Dk Gr Sd→P Ol Ca Sd→P Ol N
584	BP	581	Lt Gr Si Sd→P Ol Cl Sd→/2'/P Ol 5N/8'+/SH
585	BP	227	Gr Si Sd/1'/P Ol Ca Cl Sd/8'+
586	BP	585	Dk Gr Si Sd→P Ol Cal Sd/12'/P Br Cal Sd + N/12'6"/H/13'/Lt Gr 4 H/P Ol Gal Sd + 5 N→/20'/5 N/ 26'/Ol Cal Sd/28'+
587	BP	582	Dk Gr Cl Sd/1'/1 H + 1 B/7'/ Limestone/25'+
588	BP	582	1 H/1'3"/Dk Gr Si Sd/1'6"/1 H/2' 3"/1 H/4'4"+
589	BP	583	1 - 3 Ho/1 - 3N
590	BP	583	1 H/1 Ho

TABLE A.3 (CONTINUED)

PROFILE No.	METHOD	RRO No.	DESCRIPTION
591	BP	-	Gr H_t/1'/N + N_S + Ca Sd/2'/Wh Ca Sd + ON/4'/Wh N_S + O Ho_S/4'3"/ 4 N/5'+
592	BP	584	Bl Cl/1' /1H/2'+
593	BP	-	Dk Rd Br Si Sd/1'6"/Gr S B/3'0"/ Gr Ca SB + N/8'+
594	BP	-	Dk Rd Br Ca Cl Sd/1'6"/Rd Br N/ 6'0"/Dk Rd Br mottled with Lt Gr Cl Si Sd SB G + N + O Gyp/10'+
595	BP	586	Dk Rd Br Si Sd/0'6"/Rd Br 1 H/ 2'0"/Lt Rd mottled with Wh P/4'+
596	BP	-	B + Dk Gr Br Si Sd/1'0'/N→/3'/Br mottled with Wh Cal Cl Sd + O Bo + OG/9'/Gr Ca S B + Wh P + ON/15'+
597	BP	-	Dk Br Si Sd/1'/N/10'+
598	BP	-	Dk Br Si Sd/1'6"/Pi 3 N/6'+
599	BP	587	Dk Br Si Sd/1'10"/1 B/2'4"/Lt Gr - P Br Ca Si Sd/2'6"/3 H/3'6"/ Lt Gr - P Br Ca Si Sd/3'8"/Lt Gr 1 H/4'8"/Lt Gr - P Br Ca Si Sd + 3 N/4'10"/3 H/5'5"/Lt Gr - P Br Ca Si Sd + 3 N/5'7"/1 Hb - H/6' 1"/Lt Gr - P Br Ca Si Sd/6'3"/ Wh 1 H/8'3"/Wh Sd 3 N/8'6"+
600	BP	-	Dk Br Si Sd/1'6"/Br 3 N/10'+

APPENDIX B

SAMPLE LOCATIONS AND DESCRIPTIONS

B.1 INTRODUCTION

Sample numbers shown are the sample numbers of the geological section of the Soil Mechanics Division of the National Institute for Road Research. Any further information required can thus be tracked down at the NIRR. Especially heterogeneous or interesting samples were also divided into further components labelled A, B, C, etc. for more detailed study.

Localities are mostly stated as so many miles along the road from town X to town Y as measured by a vehicle odometer from the town limits. Large distances are therefore subject to a certain amount of error, but have been corrected where possible. The term 'Gaza-Grootfontein' refers to the new Runtu-Grootfontein road from the point of its intersection with the Gaza line (the southern boundary of the Okavango territory). The term 'Runtu-Karakuwisa' refers to the old Runtu-Grootfontein road via Karakuwisa, Kanovlei and Maroelaboom. Oshivello is the name of the new police station on the farm Operet 312 where the new Tsumeb-Ondangua road crosses the Operet/Etosha Game Reserve boundary.

The term 'gravel' as used in Table B.1 only is used in its colloquial roadmaking sense to refer to a material consisting of discrete particles grading downwards in size from some two or three inches to two microns and less. This usage is adopted here to avoid long and awkward circumlocutions such as 'clayey, silty, sandy gravel', etc. in the tables. Full mechanical analyses of the samples are given in Appendix H.

Where/ ...

Where the depth of sampling is shown in feet and inches, an accuracy of ± 1 inch is implied, where only feet are shown, an accuracy of ± 6 inches is implied. These figures relating to accuracy are also intended as the range of sampling depth when only a single figure is given as the sampling depth.

All colours of calcretes and silcretes in Table B.1 are (dry) between white (10 YR 8/1), grey (10 YR 6/1) and pale brown (10 YR 6/3) unless otherwise stated. White, creamy white and pale brown are most common. The grey colour of weathered calcretes is largely due to a thin covering of lichen. All calcretes possess a dull lustre, brittle tenacity, no cleavage and are opaque to the naked eye except the sugar-grained Type 6 which possesses a resinous lustre and can be seen to be macro or microcrystalline and transparent or translucent with the naked eye. Most show an amorphous form to the naked eye, but are cryptocrystalline under the microscope. Very few are macro or microcrystalline. No calcite crystals larger than about 1 mm have so far been observed in calcretes. Colour, fracture and hardness of some typical calcrete types are treated further in Table B.2.

TABLE B.1 SAMPLE LOCATIONS AND DESCRIPTIONS

SAMPLE No.	PRO-FILE No.	DEPTH	LOCATION	DESCRIPTION	REMARKS
890	2	-	Stinkwater 12 NNW of Namutoni	Fresh, white, very hard silcrete. Mixture of 3 types, A & C predominating.	Used as concrete agg. No troubles reported.
890A	2	-	As above	White vitreous type	Part of 890
890B	2	-	As above	Green vitreous type	Part of 890

TABLE B.1 (CONTINUED)

SAMPLE No.	PRO-FILE No.	DEPTH	LOCATION	DESCRIPTION	REMARKS
890C	2	-	As above	Light grey, dolomitic silcrete/ sandstone	Part of 890
891	10	5'	31.6 Ondangua-Ruacana	Yellow, slightly clayey sand with occasional calcrete nodules and salt	
892	-	0	Okatana	Black, sandy clay	Canal bed
893	9	6'	21.8 Ondangua-Ruacana	White, slightly clayey, calcareous sand	
894	8	6'	19.8 Ondangua-Ruacana	White, calcareous, clayey sand with occasional nodules	
895	7	6'	14.9 Ondangua-Ruacana	Yellow, slightly clayey, calcareous sand	
896	5	5'-6'	34.2 Ondangua-Tsumeb	Light olive green, weakly calcified sand with some friable, very sandy, Type 4 nodules	"Hardpan"
897	4	4'	59.1 Ondangua-Tsumeb	White, firm in situ powder calcrete	
898	4	10'	59.1 Ondangua-Tsumeb	Fresh, green, hard dolocrete	
900	3	3'	81.8 Ondangua-Tsumeb	Hardpan calcrete	
901	1	1'	136.6 Ondangua-Tsumeb	Hardpan calcrete	

TABLE B.1 (CONTINUED)

SAMPLE No.	PRO-FILE No.	DEPTH	LOCATION	DESCRIPTION	REMARKS
902	1	3'	136.6 Ondangua-Tsumeb	White, firm in situ pow-der calcrete with some non-sandy, firm, Type 4 nodules	
903	17	2'-3'	5.0 Runtu-Karakuwisa	Grey, tufaceous hardpan with snail shells	
904	-	-	5.0 Runtu-Karakuwisa	Grey, very hard silcrete	Apparent-ly sili-cified calcrete
908	-	0'6"-1'0"	35.9 Runtu-Grootfontein	Pale brown sand of Kalahari type	
909	-	1'	36.4 Runtu-Grootfontein	Reddish brown sand of Kalahari type	
910	16	6'	75.2 Runtu-Grootfontein, 4W	Mixture of hardpan and friable cal-crete	Used for gravel road
911	-	0	3 Grootfontein-Harmonie	Yellowish cal-crete from gravel road	Said to be good?
912	-	0	3 Grootfontein-Harmonie	White calcrete from gravel road	Said to be poor?
913	11	6'	4.2 Ondangua-Otjikango	Yellow, slight-ly clayey cal-cified sand with many nodules	
914	12	7'-9'	7 Ondangua-Otjikango	Yellowish stiff - very stiff clayey calcified sand	Used as wearing course

TABLE B.1 (CONTINUED)

SAMPLE No.	PRO-FILE No.	DEPTH	LOCATION	DESCRIPTION	REMARKS
916	-	-	31.6 Ondangua-Ruacana	Bulk sample similar to 891	
917	12	3'-10'	7 Odangua-Otjikango	Yellowish stiff - very stiff clayey calcified sand	Used as wearing course
918	-	-	81.8 Ondangua-Tsumeb	Mixture of material from Profile 3	As used on gravel road
991	56	0	24.5 Runtu-Andara	Brown hard silcrete?	Outcrop in river
1000	68-75	-	6.9 Andara-Bagani	Pale brown hard Type 1 calcrete nodules (A & B)	A banded B unbanded
1007	76	-	9.0 Andara-Bagani	White, speckled with black, Type 3 nodule	
1015	88	7'	93.3 Andara-Runtu	Calcified sand	
1017	-	-	Gaza-Grootfontein	Loose powder calcrete from road powder hole	Probably degraded by traffic
1019	-	0-4"	1.1 Gaza Grootfontein	Mixed calcrete gravel from gravel road wearing course	Good
1020	-	0-4"	" "	Powder calcrete from gravel road wearing course	Formed powder hole
1021	-	0-4"	17.8 Gaza-Grootfontein	Nodular calcrete gravel from gravel road wearing course	Good

TABLE B.1 (CONTINUED)

SAMPLE No.	PRO-FILE No.	DEPTH	LOCATION	DESCRIPTION	REMARKS
1022	93	-	4.5 Tsumeb-Grootfontein	Mainly calcified weathered felspathic sandstone gravel used for gravel road wearing course	Said to be best calcrete on this road
1024	-	-	2.5 Tsumeb-Namutoni	Reddish nodular calcrete gravel mixed with some black clay used for gravel road wearing course	Said to be best calcrete on this road
1026	-	-	" "	Reddish nodular calcrete gravel used for gravel road wearing course	Said to be very good
1028	124	0-3'	5.6 Oshivello-Tsumeb	Brown and white, hard, Type 1 boulder calcrete	
1028A	124	0-3'	" "	Banded lighter and darker brown crust	Part of 1028
1028B	124	0-3'	" "	Pale brown, cream, hard interior	Part of 1028
1028C	124	0-3'	" "	White interior, softer than B	Part of 1028
1028D	124	0-3'	" "	Greyish brown - reddish brown sandy veins	Part of 1028
1028X	-	-	Omuramba Ovambo on Tsumeb-Oshivello road	Hard Type 1 boulder and hardpan calcrete used for concrete aggregate for bridge	Bridge satisfactory to date

TABLE B.1 (CONTINUED)

SAMPLE No.	PROFILE No.	DEPTH	LOCATION	DESCRIPTION	REMARKS
1028XA	-	-	Omuramba Ovambo on Tsumeb-Oshivello road	Outer, hard, brown coating	Part of 1028X
1028XB	-	-	As above	Interior, softer, white material	Part of 1028X
1028XC	-	-	" "	Outer, harder, black layer	"
1028XD	-	-	" "	Brownish interior	"
1512	-	-	1.5 Lichtenburg-Deelpan	Nodular powder calcrete gravel used for gravel road wearing course	Good
1513	-	-	11.1 Lichtenburg-Deelpan	Mixed nodular and hardpan calcrete gravel used for gravel road wearing course	Good, but a little coarse
1514	-	-	15.5 "	Greyish, pale blue nodular calcrete, used for gravel road wearing course	Very good
1515	-	-	10.6 Lichtenburg-Lushof	White powder calcrete no longer used for gravel road wearing course	Very poor
1516	-	-	6.9 "	Mostly nodular calcrete gravel used for gravel road wearing course	Fairly good
1530	-	-	61.7 Sishen-Upington	Pale grey, firm-stiff, hardpan calcrete	Ripped by Allis Chalmers H.D. 16

TABLE 3.1 (CONTINUED)

SAMPLE No.	PRO-FILE No.	DEPTH	LOCATION	DESCRIPTION	REMARKS
1533	129	-	7.5 Karasburg-Grunau	Brown, hard, nodular calcrete gravel with little calcareous fines used for gravel road wearing course	Said to be good gravel road material
1557	-	-	Ondangua airfield BP 1	Nodular powder calcrete gravel used for lime stabilized base/subbase?	
1561	-	-	Ondangua airfield BP 3	Soft nodular and powder calcrete gravel used for lime stabilized base/subbase	
1562	-	-	" "	White, speckled with black, hard and very stiff Type 3 hardpan calcrete	
1562A	-	-	" "	Darker, harder relict nodules	Part of 1562
1562B	-	-	" "	Lighter coloured, softer matrix	Part of 1562
1565	134	4'10" -15'	10.8 Ondangua-Otjikango	Hard Type 3 nodular calcrete gravel in green clayey sand	
1567	-	-	Ondangua airfield BP 6	Mainly very stiff, light olive green, calcified sand used for Ondangua airfield	Said to yield very high lime stabilized CBR
1569	-	-	Ondangua airfield BP 7	White nodular calcrete used for subbase	Said to yield very high lime stabilized CBR

TABLE B.1 (CONTINUED)

SAMPLE No.	PROFILE No.	DEPTH	LOCATION	DESCRIPTION	REMARKS
1573	-	2'-3'	Ondangua airfield BP 4	Hard Type 3 honeycomb calcrete	
1575	146	~28'	Oshana next to Ondangua airfield BP 9	Hard calcrete nodule or boulder from well	
1598	161	3'6"-4'0"	Ondangua airfield BP 1W	White, hard, hardpan calcrete, faintly very thinly bedded	
1598A	"	"	" "	Relict nodules	Part of 1598
1601	-	-	" 2	Nodular calcrete gravel used for airfield	
1602	-	-	Ondangua airfield BP 3	Nodular calcrete gravel used for Ondangua airfield	Said not to yield very high lime stabilized CBR
1603	161	7'6"-8'0"	Ondangua airfield BP 1W	Cream, friable, nodular and powder calcrete	
1603A	161	"	" "	Nodules (+2 mm) from 1603	
1603B	161	"	" "	Fines (-2 mm) from 1603	
1605	-	-	4.5 Okatana-Ondangua	White salt apparently leached from calcareous sandy clay	Same site as Profile 8
1608	-	-	9.4 Okatana-Ondangua	White salt apparently from nodular calcrete	Same site as Profile 7

TABLE B.1 (CONTINUED)

SAMPLE No.	PRO-FILE No.	DEPTH	LOCATION	DESCRIPTION	REMARKS
1618	-	-	4 BP Grootfontein-Tsumeb	Nodular calcrete gravel used for gravel road wearing course	Said to be fairly good
1620	-	-	0.8 BP Grootfontein-Tsumeb	Yellowish nodular calcrete used for gravel road wearing course	Said to be best calcrete on this road
1621	-	-	Grootfontein airfield	Type 1 calcrete boulders said to be unbreakable by 14½ ton 2 x 3' grid roller	
1622	-		" "	Calcrete boulders said to be breakable by above grid roller	
1623	-	-	" "	Hard calcrete hardpan	
1624	-	-	Grootfontein airfield BP	Yellowish nodular calcrete used for lime stabilized sub-base	Said to yield very high lime stabilized CBR
1625	-	~10'	" "	Mainly white calcified sand underlying 1624	Said to yield poor lime stabilized CBR
1627	172	-	4.6 Grootfontein-Harmonie	Pale brown, hard Type 1 boulder calcrete (A, B & C)	

TABLE B.1 (CONTINUED)

SAMPLE No.	PRO-FILE No.	DEPTH	LOCATION	DESCRIPTION	REMARKS
1627X	-	-	4.6 Grootfontein Harmonie	Further sample from same source and generally similar to 1627	
1638	176	-	Omuramba Ovambo B.P at Operet bridge	Olive brown, hard, dolocrete nodule	Type 5
1639	176	8'	" "	Olive green, hard, dolocrete nodule	Type 5
1642	-	0	Bank of Omuramba Ovambo 1.9 east of Operet bridge	Outcropping, grey, friable, tufaceous hardpan calcrete with snail shells	
1658	195	0-1'	Tsumeb-Namutoni BP B10	Pale brown and light olive green, hard boulder and hardpan calcrete	Required blasting
1658A	"	"	" "	Slightly darker green relict nodules	Type 5
1658B	"	"	" "	Slightly lighter green matrix	Type 1
1658C	"	"	" "	White friable portion	Type 4
1658X	-	-	Tsumeb-Namutoni BP B10	Slightly inferior material similar to and said to be from same source as 1658	
1693	331	~4'	Tsumkwe airfield BP	Olive green, hard calcrete nodule	Type 5

TABLE B.1 (CONTINUED)

SAMPLE No.	PROFILE No.	DEPTH	LOCATION	DESCRIPTION	REMARKS
1694	331	~ 4'	Tsumkwe airfield BP	White meerschaum (sepiolite)	Similar to Type 2 nodules
1696	-	0	" "	Calcrete powdered by traffic	Powder calcrete
1715	-	5"	Floor of Etosha Pan near Namutoni	Green clay	
1724	340	0-1'	Etosha Pan terrace near Stinkwater, Namutoni area	Greyish brown, stiff, brecciated boulder-hardpan calcrete showing upper solutional features and lower depositional banding	Somewhat indurated tufaceous hardpan type
1724A	340	-	As above	Banded, harder, outer layer	Part of 1724
1724B	340	-	" "	Grey, softer interior	" "
1725	-	0	Edge of Etosha Pan near Stinkwater	Sandy calcrete, harder than normal for sand content	
1726	-	0	" "	White, honeycomb silcrete	
1727	-	0	" "	Olive green, hard, sandy, Type 5 calcrete nodules	
1728	-	-	" "	Olive brown, hard, sandy, Type 5 dolocrete nodules	

TABLE B.1 (CONTINUED)

SAMPLE No.	PRO-FILE No.	DEPTH	LOCATION	DESCRIPTION	REMARKS
1737	344	2'10" -4'2"	3.5 Tsumeb-Operet	Powder calcrete underlying hard, intact hardpan calcrete	
1746	250	5'	5.6 Oshivello-Tsumeb	Type 1-3 honeycomb calcrete	
1808	389	7'2"-9'2"	Runtu area	Pale brown, stiff, sandy honeycomb silcrete(?)	
1810	394	5'10"	Runtu area	White speckled with black, hard Type 3 calcrete	
1825	399	9'	Runtu area	White, very stiff, sandy honeycomb - hardpan calcrete	
1828	401	1'0"-1'10"	5.0 Runtu-Karakuwisa	Grey, friable, tufaceous hardpan calcrete	Termites living inside
1828A	401	1'1"-1'2"	5.0 "	Grey part only	Part of 1828
1828C	401	1'8"-1'9"	" "	" " "	"
1830	-	-	Runtu area	Pale brown, friable honeycomb silcrete (?)	
1833	-	-	" "	Reddish brown, crushed silcrete (?) from stockpile	Used as concrete agg.
1833X	-	-	" "	Further sample from same source and similar to 1833	Probably Nosib quartzite

TABLE B.1 (CONTINUED)

SAMPLE No.	PROFILE No.	DEPTH	LOCATION	DESCRIPTION	REMARKS
1838	-	~1'	56.9 Runtu-Grootfontein	Pale brown, sandy Type 1 nodule	
1841	420	3'-5'	5.8 Gaza-Grootfontein	White, shattered, calcified clay	Essentially Type 2 calcrete
1842	420	2'9"-3'0"	" "	Nodules similar to 1841	
1847	421	2'-5'	40.7 Grootfontein-Runtu	White, very stiff, shattered calcified clay	Essentially Type 2 calcrete
1847A	"	"	" "	Harder portion	
1847B	"	"	" "	Softer portion	
1859	425	~5'	Culvert cutting at Otavi	Red, hard honeycomb and nodular calcrete	Type 1
1865	-	-	Otavi-Okaputa BP S.23	Pale brown, very stiff calcrete concretion	
1876	428	1'-7'	Okaputa area	Powder calcrete with a few 1/8" friable nodules	
1877	-	-	1.3 BP Otjiwarongo-Okaputa	Friable nodules screened from nodular calcrete and used for stabilized base	
1881	-	-	Near Outjo on Okaukejo road	Powder calcrete from surface of gravel road	Formed powder hole
1907	-	0	Neuhof-Kowas 233	Calcrete hardpan containing later MSA artefacts	Stream terrace

TABLE B.1 (CONTINUED)

SAMPLE No.	PRO-FILE No.	DEPTH	LOCATION	DESCRIPTION	REMARKS
1926	-	0	22.5 Luderitz-Keetmanshoop	Reddish brown, very sandy calcrete nodules	No selenite seen
1927	479	3"-5"	Aus	Pale brown to light grey, hard, slightly sandy Type 1 calcrete boulder	No selenite visible
1931	483	0	46 Seeheim - Karasburg	Brown, hard honeycomb calcrete	See Plate 1.10
1932	-	-	Near Luderitz	Light red, gypsum-cemented sand	Non-calcareous
1940	494	~4'	'Younger Gravels II', Riverview Estates, Windsorton	White, friable, bedded and thinly bedded calcified alluvial sand	Type 4
1945	497	-	100 ft Gravels, Proksch Koppie, Windsorton	Calcrete boulder from dump	
1949	502	~3'	200 ft Gravels, Ions' Claim, Windsorton	Calcrete boulder	
1950	502	22'	200 ft Gravels, Ion's Claim, Windsorton	Calcified gravel	
1961	513-514	1'0"-1'9"	Kalkbank excavation on De Loskop 127	Grey, very stiff when dry, stiff when damp, intact, non-porous (tufaceous) type hardpan with 1/8" snail shells and opaline silica	A tufaceous type cemented beyond the tufaceous stage. Upper hardpan

TABLE B.1 (CONTINUED)

SAMPLE No.	PRO-FILE No.	DEPTH	LOCATION	DESCRIPTION	REMARKS
				nodules (A & B) and upper surface coated with opaline silica	
1962	514	2'9"-4'3"	Kalkbank excavation on De Loskop 127	Similar to 1961, but usually of stiffer consistency	Lower hardpan
1962A	"	2'10" - 2'11"	As above	Part of 1962	General sample
1962B	"	4'1"-4'2"	"	" "	"
1962C	"	3'11" -4'0"	"	" "	"
1962D	"	3'9"-3'11"	"	" "	"
1979	-	-	Keetmanshoop area	Light reddish nodular calcrete	Ex SWA Roads
1980	-	-	"	Mixed nodular and hardpan calcrete gravel	" "
1981	-	-	"	Mainly nodular calcrete gravel	" "
2114	-	-	BP 15.4 Lichtenburg Deelpan. Same borrow pit as 1514	Light grey nodular calcrete gravel used for PBFC stabilized base	Said to be worst used for stabilized base on this road
2116	517	1'0"-6'6"	Anglo Alpha BP, Dudfield, near Lichtenburg	Pale brown, hard nodular calcrete gravel	Said to be one of the best

TABLE B.1 (CONTINUED)

SAMPLE NUMBER	PRO-FILE No.	DEPTH	LOCATION	DESCRIPTION	REMARKS
				used for PBFC stabilized base	used for stabil-ized base on this road
2123	-	-	Lovedale quarry, Lichtenburg	Pale brown to light grey, very stiff, Type 6 sugary calcrete hard-pan	
2125	-	-	Lichtenburg area	Calcrete boul-der unbreakable by grid roller	Ex Mr. Buckle
2200	521	3'-15'	Lovedale quarry, Lichtenburg	White to light grey, mottled yellowish brown, very stiff, Type 6, sugary calcrete hard-pan	
2204	-	-	Townlands quar-ry, Lichtenburg	Mottled light brown, light red and white, hard hardpan calcrete. Main-ly Type 1	Probably transi-tional between Types 1 and 6
2223	530	1'-10'	Lovedale, Lich-tenburg area	Typical powder calcrete, stiff in situ, but crumbling on excavation	
2224	-	-	Unknown	Calcareous tufa with reed casts	Ex Dr. K.A. Clauss
2225	-	-	Anglo Alpha BP, Dudfield, near Lichtenburg	Mixture of light grey, hard, Type 3 and pale brown to white, very stiff, crys-talline, Type 6 hardpan cal-crete	

TABLE B.1 (CONTINUED)

SAMPLE No.	PRO-FILE No.	DEPTH	LOCATION	DESCRIPTION	REMARKS
2252	527	2'-4'	Depression next to east side of calcrete ridge, Elandsfontein	Grey, friable, calcareous phoscrete nodules	
2258	528	0-3"	Depression ("bay") 300 yds E of N end of calcrete ridge, Elandsfontein	Brown (weathers white), friable phoscrete nodules	A outcropping B from 3"
2259	-	-	Port Alfred area	Calcified root-like objects	Ex Mr. A.B.A. Brink see plate 1.9
2265	559	6'-12'	Zikani soil series profile on Tambuti, near Sipofaneni, Swaziland	Brown, firm, damp, calcareous sandy clay with sandy, Type 4 calcrete nodules	
2302	-	-	Vryburg-Pudimoe	Hard calcrete boulder	Ex Mr. A.A.B. Williams
2318	-	-	Elandsfontein, near Hopefield	Calcrete root-like object	Ex Mr. J. Wymer See Plate 1.9
2319	-	-	Elandsfontein near Hopefield	Calcrete pipe-like object	Ex Mr. J. Wymer See Plate 1.9
2325	-	1'-2'	Elandsfontein fossil site	Calcrete containing snail shells	Ex Mr. J. Wymer
2341	-	-	Makarikari, Botswana	Green, calcareous sandstone containing fossil mammal bone	Ex Prof. G. Bond, Type 5-like
2360	-	-	South West Africa	Nodular powder calcrete gravel	Ex Mr. P. Fossberg

TABLE B.1 (CONTINUED)

SAMPLE No.	PRO-FILE No.	DEPTH	LOCATION	DESCRIPTION	REMARKS
2363	-	-	Ch.1240, near Ruacana airfield on Ondangua-Ruacana falls road	Nodular ferricrete from winrow. Used for base. Similar to that used on Airfield (unstabilized) which uielded extremely high CBRs (~200) and stabilization-type cracking	Probably self-stabilizing
2366	-	-	Ondangua-Andoni BP 38B	Yellow, Type 3 nodular calcrete gravel to be used for lime stabilized base/subbase	Said to yield very high lime stabilized CBR
2367	584	-	Ondangua-Andoni, BP 20A	Olive brown, Type 5 nodular calcrete	
2368	-	-	Ondangua-Oshikati, BP 34B	Good nodular calcrete gravel	Said to yield very high lime stabilized CBR
2377	-	0	Ch.2010, Andoni-Ondangua	White salt crust next to road	
2381	-	0-1' 0"	Ch.181.4 Andoni-Ondangua	Undisturbed sample of lime stabilized nodular calcrete base	
2381A	-	1"-1½"	Ch.181.4 Andoni-Ondangua	White, fur-like crystal growth after standing 2381 in the laboratory	
2493	-	-	Andoni-Ondangua, BP 10	Mostly nodular calcrete gravel used for lime stabilized base	

TABLE B.1 (CONTINUED)

SAMPLE No.	PRO-FILE No.	DEPTH	LOCATION	DESCRIPTION	REMARKS
2494	589, 590	-	Geluk-Namutoni BP 29B	Hard honeycomb calcrete	Proposed for sub-base
2505	-	-	Dump near Profile 502, Windsorton	Very stiff-hard hardpan	
2507	-	-	As above	Very stiff gravelly hardpan	
2513	494	4'-7'	'Younger Gravels II', Riverview Estates, Windsorton	Same as 1940. Possibly better described as dolocrete	
2514	494	1'-1'6"	As above	Hard boulder calcrete	
2516		-	6.9 Andara-Bagani	Type 3 calcrete nodules (A & B)	
2517	-	-	" "	Type 4 calcrete nodules (A, B & C)	
2519	-	-	Umgababa, Natal	Type 4 calcrete nodules	Ex Mr. A.B.A. Brink
2520	-	-	Ovamboland test section borrow pit?	Pale brown nodular? calcrete	Ex Mr. E. David
2521	595	-	16 Potgietersrust Zebediela	Reddish brown, hard calcrete hardpan	
2522	"	3'	As above	Mottled white and red powder calcrete	
2532	-	-	Langebaanweg airfield	Top 1½" of lime-slagment stabilized nodular calcrete base	Ex Mr. Du Plessis
2533	-	-	" "	Top of above base with adhering prime	"
2534	-	-	" "	Surfacing with strongly adhering calcrete	"

TABLE B.1 (CONTINUED)

SAMPLE No.	PRO-FILE No.	DEPTH	LOCATION	DESCRIPTION	REMARKS
2534A	-	-	Langebaanweg airfield	Primed calcrete from one side	Part of 2534
2534B	-	-	" "	Primed calcrete from other side	"
2534C	-	-	" "	White, clay-like material	"
2541	-	0	Edge of Etosha Pan near Stinkwater	Peculiar hard brown mudball-like object about 3" in diameter with facetted weathered surface	Lying on surface of Pan
2549	-	-	Andoni-Ondangua, BP 10	Bright green, hard, Type 5 calcrete nodule	
2555	-	-	Karasburg-Upington, BP 34.7 stockpile	Reddish nodular calcrete. CBR increased from 83 to 149 on curing for 7 days	Ex Mr. J. Caiger
2559	-	-	Heuningvlei, Gordonia	Green glauconite from pan	Ex Mr. E. Schmidt
2561			Wool ridge, 11 N of Matubatuba	Sand said to yield high lime stabilized strength	Ex Dr. K.A. Clauss
2566	-	0-30"	Karasburg-Upington, BP 4.4. Holes 8 and 13 mixed by mistake at NIRR	Reddish nodular calcrete. CBR of Hole 8 material increased from 78 to 98 on curing for 7 days. CBR of Hole 13 material decreased from 159 to 124 on 7 days curing	Ex Mr. J. Caiger
2588	-	-	Bubye river calcrete deposit near Profile 568	Mainly friable to hard nodular calcrete with some broken	Ex Rhodesian Central Roads Lab. PI re-

TABLE B.1 (CONTINUED)

SAMPLE No.	PRO-FILE No.	DEPTH	LOCATION	DESCRIPTION	REMARKS
				hardpan and occasional decomposed basalt fragments	duced from about 30 to NP with 2% lime.
2689	600	1'6"-4'6"	Pretoria Portland Cement Pienaarsrivier quarry B, block 1	Hard Type 2 nodular calcrete with brown fines	

TABLE B.2 SOME DIAGNOSTIC PROPERTIES OF SOME TYPICAL EXAMPLES OF THE SIX CALCRETE TYPES

CALCRETE TYPE	SAMPLE No.	COLOUR (DRY)	STREAK (DRY)	COLOUR (WET)	FRACTURE	MOHS HARDNESS	% SAND GRAINS 1)
Type 1	1000A	Banded Bl 5 YR 2/1 and Dk Gr Br 10 YR 4/2	P Br 10 YR 6/3	Bl 5 YR 2/1 and Dk Br 10 YR 3/3	Conchoidal	4.0	0
	1000B	Br 10 YR 5/3	Lt Gr 10 YR 7/1	Br 10 YR 5/2	Conchoidal	4.3	0
	1627	P Br 10 YR 6/3	Wh 10 YR 8/1	P Br 10 YR 6/3	Conchoidal	4.5	10
	1658B	P Br 10 YR 6/3	Wh 10 YR 8/1	P Br 10 YR 6/3	Subconchoidal	4.5	5
	1859	R Br 2.5 YR4/4	Lt Br 7.5 YR6/4	YR 5 YR 4/6	Subconchoidal	4.7	10
	2521	R Br 2.5 YR4/4	Lt Br 7.5 YR6/4	R 10 R 4/6	Uneven	3.5	0
Type 2	1841	Lt Gr 10 YR7/1	Wh 10 YR 8/1	P Br 10 YR 6/3	Subconchoidal	2.5	0
	1847B	Wh 10 YR 8/1	Wh 10 YR 8/1	Wh 10 YR 8/1	Earthy	2.5	0
Type 3	1007	Lt 01 Gr 5 YR 6/2 speckled with V dk Gr 5 YR 3/1	Lt Gr 10 YR 7/1	P 01 5 YR 6/3	Subconchoidal	3.2 - 4.2	10
	1562A	P Br 10 YR 6/3 speckled with V dk Gr 5 YR 3/1	Lt Gr 10 YR	P 01 5 YR 6/3 speckled with Bl 5 YR 2/1	Subconchoidal	5.0	10
	1562B	Lt Gr 10 YR7/1	Wh 10 YR 8/1	P Br 10 YR 6/3	Uneven	4	60

(1) Estimated by volume in hand specimen

TABLE B.2 (CONTINUED)

CALCRETE TYPE	SAMPLE No.	COLOUR (DRY)	STREAK (DRY)	COLOUR (WET)	FRACTURE	MOHS HARDNESS	% SAND GRAINS 1)
Type 3 (continued)	1810	P Br 10 YR 6/3 ringed and speckled with Bl 5 YR 2/1	P Br 10 YR 6/3	P Ol 5 YR 6/3 ringed and speckled with Bl 5 YR 2/1	Subconchoidal to conchoidal	4	20
	2516A	Br 10 YR 5/3 speckled with V dk Gr Br 10 YR 3/2	Lt Gr 10 YR 7/1	Br 10 YR 5/3 speckled with Bl 5 YR 2/1	Subconchoidal to uneven	3 - 4.5	2
Type 4	1746	Lt Gr 10 YR7/1	Wh 10 YR 8/1	P Br 10 YR6/3	Uneven	4	2
	2223	Wh 10 YR 8/1	Wh 10 YR 8/1	Wh 10 YR 8/1	Earthy to uneven	2.5	0
	2517A	P Br 10 YR 6/3	Lt Gr 10 YR 7/1	Br 10 YR 5/3	Uneven	2.7	20
	2517B	Mottled Lt Gr 10 YR 7/1 & Dk Br 10 YR 4/3 with banded Type 1 Br 10 YR 5/3 outer	Wh 10 YR 5/1	As dry	Uneven to earthy	2.7 - 4	
	2518	Lt Gr 10 YR7/1	Lt Gr 10 YR7/1	P Br 10 YR6/3	Earthy	1.5	5

(1) Estimated by volume in hand specimen

TABLE B.2 (CONTINUED)

CALCRETE TYPE	SAMPLE No.	COLOUR (DRY)	STREAK (DRY)	COLOUR (WET)	FRACTURE	MOHS HARDNESS	% SAND GRAINS 1)
Type 5	898	P Ol 5 YR 6/3	Wh 10 YR 5/1	Ol 5 YR 5/3	Conchoidal	7	60
	1638	Lt Ol Br 2.5 YR 5/4	Lt Gr 10 YR 7/1	Ol 5 YR 5/3	Conchoidal	6	60
	1639	Lt Ol Gr 5 YR 6/2	Lt Gr 10 YR 7/1	Ol 5 YR 5/3	Conchoidal	5.5	20
	1658A	Ol 5 YR 5/3	Wh 10 YR 8/1	Ol 5 YR 5/3	Conchoidal	6.0	5
	1693	Lt Ol Gr 5 YR 6/2		Ol 5 YR 5/3	Conchoidal	5	5
	1725	Lt Ol Gr 5 YR 6/2	Wh 10 YR 5/1	P Ol 5 YR 6/2	Conchoidal	5	30
	1728	Lt Ol Gr 5 YR 6/2	Lt Gr 10 YR 7/1	P Ol 5 YR 6/3	Subconchoidal	6	50
Type 6	2200	Br Y 10 YR 6/6 to P Br 10 YR 6/3 and Lt Gr 10 YR 7/1	P Br 10 YR 6/3	Y Br 10 YR 5/6 to P Br 10 YR 6/3	Subconchoidal to uneven	3.0 - 3.5	0
	2123	P Br 10 YR6/3 to Lt Gr 5 Y 7/1	Wh 10 YR 8/1	P Br 10 YR 6/3 to Lt G 5 YR 7/1	Uneven	3.0	0

(1) Estimated by volume in hand specimen

APPENDIX C

CHEMICAL ANALYSES

C.1 INTRODUCTION

Practically all published chemical analyses of calcretes from Southern Africa are included in the following tables as well as those carried out for the author in the course of this project. The only analyses from the literature not included are those which were not clearly described as calcrete, surface limestone, etc. Classification as powder calcrete, nodular calcrete, calcrete nodule, tufaceous hardpan or hardpan was made according to the authors' descriptions. The authors' descriptions were not always fully adequate and it is possible that a few were wrongly classified. Where any serious doubt occurred, however, the analysis was rejected.

Included under some analyses (particularly those in the earlier literature) in the SiO_2 column are small amounts of "insoluble residue". The average SiO_2 content is thus probably slightly high. Many analyses only showed for example $Al_2O_3 + Fe_2O_3$, $H_2O \pm$, Fe_2O_3 (total Fe) and not the individual oxides. For completeness, in cases where these components were distinguished, they are also shown added together. Many authors did not give totals with their analyses and no attempt has been made to calculate these where not given. Where a result was given as "trace", this was not counted for purposes of calculating the mean and standard deviation, but was counted as an analysis for the purpose of indicating the number of analyses and the range of results. Results given as "present" and "much" were ignored for both purposes. Tables C.1 - C.5 show a statistical treatment of virtually all available results, including those appearing in other tables. Table C.6

shows/ ...

TABLE C.1 CHEMICAL ANALYSES OF POWDER CALCRETES

SiO_2	Al_2O_3	TOTAL Fe AS Fe_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	H_2O+	H_2O-	CO_2	TiO_2	P_2O_5	MnO	BaO	LOSS ON IGN.	Al_2O_3 + Fe_2O_3	$CaCO_3$	SO_3	ORGANIC MATTER	TOTAL	SOURCE
1.3	-	-	-	-	0.6	52.0	-	-	-	-	-	-	-	-	-	45.7	0.3	-	-	-	-	Wybergh (1918)
3.6	0.4	0.4	-	-	0.60	51.7	-	-	-	-	-	-	-	-	-	43.3	0.8	-	-	-	-	" "
3.1	0.4	0.4	-	-	0.90	52.8	-	-	-	-	-	-	-	-	-	42.5	0.7	-	-	-	-	" "
11.1	-	-	-	-	1.7	45.4	-	-	-	-	-	-	-	-	-	41.0	0.8	-	-	-	-	" "
7.5	-	-	-	-	1.9	46.2	-	-	-	-	-	-	-	-	-	42.2	1.3	-	-	-	-	" "
8.8	-	-	-	-	0.9	47.9	-	-	-	-	-	-	-	-	-	38.6	3.8	-	-	-	-	" "
13.8	-	-	-	-	0.8	45.6	-	-	-	-	-	-	-	-	-	38.2	1.6	-	-	-	-	" "
19.85	-	-	-	-	9.6	30.9	-	-	-	-	-	-	-	-	-	36.95	2.5	-	-	-	-	" "
16.6	-	-	-	-	1.4	44.0	-	-	-	-	-	-	-	-	-	36.5	1.4	-	-	-	-	" "
31.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5.5	59.0	-	-	-	Wybergh (1920)
24.0	-	-	-	-	8.5	27.5	-	-	-	-	-	-	-	-	-	32.0	7.0	-	-	-	-	" "
7.95	-	-	-	-	3.0	41.3	-	-	-	-	-	-	-	-	-	41.7	3.9	-	-	-	-	" " (Plus 1% NaCL, KCl & LiCl)
6.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3.0	88.8	-	-	-	Wybergh (1920)
7.1	0.54	0.36	0.36	Nil	0.74	51.0	0.30	0.14	1.6	0.21	37.8	0.09	0.02	0.01	Nil	40.0	0.9	-	Nil	0.55	100.51	Sample 1515
11.55	0.45	0.37	0.36	Nil	2.55	44.69	0.30	0.14	1.6	0.21	37.8	0.09	0.02	0.01	Nil	39.89	2.39	-	Nil	0.55	-	MEAN
8.28	0.07	0.02	-	-	2.99	7.74	-	-	-	-	-	-	-	-	-	3.52	1.94	-	-	-	-	STANDARD DEVIATION
71.7	14.9	5.1	-	-	117	17.3	-	-	-	-	-	-	-	-	-	8.8	81.2	-	-	-	-	PERCENT STANDARD DEVIATION
1.3-24.0	0.4-0.54	0.36-0.4	-	-	0.6-9.6	27.5 52.8	-	-	-	-	-	-	-	-	-	32.0-45.7	0.3-7.0	-	-	-	-	RANGE
14	3	3	1	1	12	12	1	1	1	1	1	1	1	1	1	12	14	-	1	1	14	NUMBER OF ANALYSES

TABLE C.2 CHEMICAL ANALYSES OF NODULAR CALCRETES

SiO_2	Al_2O_3	TOTAL Fe AS Fe_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	H_2O+	H_2O-	CO_2	TiO_2	P_2O_5	SO_3	MnO	BaO	ORGANIC MATTER	LOSS ON IGN.	R_2O_3 $Fe^+_2O_3$	$H_2O\pm$	$MgCO_3$	$CaCO_3$	TOTAL	SOURCE
31.10	2.32	1.18	-	-	0.36	-	-	-	-	-	-	-	-	-	-	-	-	-	3.50	-	3.02	61.50	99.48	Visser (1964)
2.98	0.35	0.54	-	-	nil	-	-	-	-	-	-	-	-	-	-	-	-	-	0.89	-	0.70	94.69	99.26	" "
23.32	1.65	4.12	-	-	19.58	19.68	0.13	0.13	-	-	28.1	trace	0.02	-	0.04	-	-	31.46	5.77	-	-	-	100.13	Van der Merwe (1962)
35.62	7.98	2.89	-	-	2.10	25.38	0.23	0.39	-	-	15.2	0.58	0.06	-	0.04	-	-	23.52	10.87	-	-	-	98.86	" " " "
26.59	6.36	4.16	-	-	2.16	31.92	0.20	0.33	-	-	22.4	0.54	0.06	-	0.03	-	-	27.97	10.52	-	-	-	100.32	" " " "
36.86	7.04	2.02	-	-	3.43	24.85	1.22	1.05	-	-	19.61	0.51	0.08	-	0.01	-	-	23.25	9.42	-	-	-	100.32	" " " "
28.92	5.64	1.51	-	-	4.19	28.96	1.15	0.83	-	-	23.71	0.35	0.06	-	0.01	-	-	27.92	7.15	-	-	-	99.54	" " " "
25.66	5.10	1.82	-	-	3.29	32.58	0.81	0.74	-	-	25.65	0.31	0.07	-	0.02	-	-	28.82	6.92	-	-	-	99.22	" " " "
14.35	-	-	-	-	0.75	45.6	-	-	-	-	-	-	-	-	-	-	-	-	1.95	-	-	-	-	Wybergh (1918)
16.0	-	-	-	-	2.7	42.2	-	-	-	-	-	-	-	-	-	-	-	-	2.8	-	-	-	-	" "
18.1	-	-	-	-	1.5	43.2	-	-	-	-	-	-	-	-	-	-	-	-	1.7	-	-	-	-	" "
33.0	-	-	-	-	2.8	30.2	-	-	-	-	-	-	-	-	1.0	-	-	-	7.2	-	-	-	-	" "
16.8	-	-	-	-	8.8	32.9	-	-	-	-	-	-	-	-	-	-	-	-	4.2	-	-	-	-	" "
1.2	-	-	-	-	1.95	52.0	-	-	-	-	-	-	-	-	-	-	-	44.6	0.4	-	-	-	-	" "
1.2	-	-	-	-	0.3	53.55	-	-	-	-	-	-	-	-	-	-	-	44.8	0.4	-	-	-	-	" "
12.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4.5	-	2.5	78.5	-	Wybergh (1920)
31.0	-	-	-	-	-	-	-	-	-	1.0	-	-	-	-	-	-	-	-	7.0	-	2.0	58.0	-	" "
5.0	-	-	-	-	1.65	50.75	-	-	-	-	-	-	-	-	-	-	-	41.8	0.7	-	-	-	-	" "
27.6	6.1	6.6	1.4	4.5	3.5	30.0	0.85	0.60	3.4	0.78	20.2	0.96	0.09	0.07	0.04	0.03	nil	23.6	12.7	4.18	-	-	100.12	Sample 1533
24.2	1.9	1.5	1.3	0.18	0.88	38.5	0.14	0.37	2.4	0.77	29.5	0.23	0.01	0.02	0.05	0.02	0.04	31.8	3.4	3.17	-	-	100.37	" 1624
24.7	2.1	1.5	1.2	0.21	1.4	37.7	0.02	0.24	2.8	0.86	28.4	0.28	0.01	0.03	0.02	0.02	0.08	31.3	3.6	3.66	-	-	100.09	" 2114
27.5	2.5	1.3	0.98	0.31	1.2	35.8	0.09	0.28	3.3	0.80	27.2	0.25	0.04	0.02	0.05	0.02	0.07	30.4	3.8	4.1	-	-	100.24	" 2116
21.08	4.09	2.43	1.22	1.30	3.13	36.43	0.48	0.50	2.98	0.84	24.00	0.40	0.05	0.04	0.12	0.02	0.05	31.63	4.97	3.78	-	-	-	MEAN
10.84	2.43	1.66	0.16	1.84	4.22	9.52	0.45	0.28	0.40	0.08	4.40	0.25	0.03	0.02	0.28	0.004	0.03	7.24	3.52	0.40	-	-	-	STANDARD DEVIATION
51.4	59.4	68.31	12.8	142	135	26.1	92.1	56.7	13.5	10.1	18.3	61.8	58.6	57.1	234	19.9	66.5	22.9	70.9	10.7	-	-	-	PERCENT STANDARD DEVIATION
1.2- 38.86	0.35- 7.98	0.54- 4.16	0.98- 1.4	0.18- 4.5	nil 19.58	19.68- 53.55	0.02- 1.22	0.13- 1.05	2.4- 3.4	0.77- 1.0	15.2- 29.5	Trace- 0.96	0.01- 0.08	0.02- 0.07	0.01- 1.0	0.02- 0.03	Nil 0.08	23.25- 44.8	0.4- 12.7	3.17- 4.18	-	-	-	RANGE
22	12	12	4	4	20	18	10	10	4	5	10	10	9	4	11	4	4	13	21	4	4	4	22	NUMBER OF ANALYSES

TABLE C.3 CHEMICAL ANALYSES OF CALCRETE NODULES

SiO_2	Al_2O_3	TOTAL Fe AS Fe_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	H_2O+	H_2O-	CO_2	TiO_2	P_2O_5	MnO	BaO	LOSS ON IGN.	Al_2O_3 Fe_2O_3	$MgCO_3$	$CaCO_3$	SO_3	H_2O+	ORGANIC MATTER	TOTAL	SOURCE
26.11	-	-	-	-	1.07	27.39	-	-	-	-	22.67	-	-	-	-	26.11	0.52	-	-	-	-	-	99.69	Hermann (1910)
12.08	-	-	-	-	-	-	-	-	-	0.85	-	-	-	-	-	-	6.02	4.29	76.54	-	-	-	-	Wybergh (1920)
63.00	-	-	-	-	6.90	11.76	-	-	-	-	-	-	-	-	-	15.47	1.95	-	-	-	-	-	-	Gevers (1930)
5.10	0.10	1.27	0.50	0.70	20.25	27.60	-	-	1.35	1.00	42.70	-	nil	-	-	-	2.16	-	-	-	2.35	-	99.30	Hall (1937)
-	-	-	-	-	0.7	45.2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Van der Merwe (1962)
-	-	-	-	-	4.3	47.3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	" " " "
1.34	0.63	1.28	0.40	0.80	1.40	52.79	0.60	0.12	1.20	0.46	39.27	0.13	nil	0.03	1.23	-	2.81	-	-	-	1.66	-	99.94	Sample 1000
2.65	0.85	1.42	0.90	0.47	1.33	51.04	0.62	0.22	1.96	0.23	38.82	0.15	0.007	0.005	1.37	-	2.79	-	-	-	2.19	-	100.39	" 2516
6.82	1.05	1.50	0.98	0.47	1.17	48.83	0.64	0.22	1.00	0.52	37.23	0.17	0.01	0.023	1.43	-	3.07	-	-	-	1.52	-	100.04	" 2517
20.24	5.19	5.16	0.41	4.99	3.15	35.37	0.73	0.40	3.03	0.52	24.81	0.75	0.09	0.04	0.03	27.82	10.35	-	-	0.06	3.55	nil	99.79	" 1533 + 40 mesh
19.89	1.82	1.59	1.59	nil	1.03	41.43	0.14	0.40	1.98	0.26	31.56	0.22	nil	0.07	0.02	33.59	3.41	-	-	0.02	2.24	0.05	100.48	" 1624 + 40 mesh
11.66	0.92	0.80	0.80	nil	0.62	47.93	0.04	0.12	2.23	0.21	34.98	0.28	nil	0.02	0.04	37.34	1.72	-	-	0.03	2.44	0.13	99.91	" 2114 + 40 mesh
21.07	1.48	1.39	1.39	nil	1.44	39.92	0.14	0.22	2.81	0.69	30.51	0.24	0.02	0.08	0.03	33.43	2.87	-	-	0.03	3.50	0.11	100.18	" 2116 + 40 mesh
4.33	0.40	0.50	0.50	nil	0.83	52.40	0.02	0.22	1.61	0.19	39.48	0.10	nil	0.02	0.01	41.12	0.90	-	-	nil	1.80	0.03	100.14	" 1515 + 40 mesh
-	-	-	-	-	0.40	39.49	-	-	-	-	29.34	-	-	-	-	-	-	-	-	-	-	-	-	" 2689 + 40 mesh
-	-	-	-	-	0.79	50.27	-	-	-	-	37.92	-	-	-	-	-	-	-	-	-	-	-	-	" 2223 + 40 mesh
-	-	-	-	-	0.59	33.42	-	-	-	-	23.28	-	-	-	-	-	-	-	-	-	-	-	-	" 2555 + 40 mesh
-	-	-	-	-	0.40	29.83	-	-	-	-	21.60	-	-	-	-	-	-	-	-	-	-	-	-	" 2566 + 40 mesh
-	-	-	-	-	0.40	39.49	-	-	-	-	29.34	-	-	-	-	-	-	-	-	-	-	-	-	" 2689 + 40 mesh
16.19	1.38	1.66	0.83	0.82	2.60	40.08	0.37	0.24	1.91	0.49	32.23	0.26	0.014	0.04	0.52	30.70	3.21	-	-	0.03	2.36	0.06	-	MEAN
16.16	1.43	1.28	0.41	1.50	4.58	10.66	0.29	0.10	0.66	0.27	6.73	0.20	0.028	0.024	0.64	7.84	2.53	-	-	0.02	0.69	0.05	-	STANDARD DEVIATION
99.9	104	77.4	49.2	182	176	26.6	78.1	42.1	34.55	54.5	20.9	76.6	197	68.0	123	25.5	78.7	-	-	69.6	29.19	76.41	-	PERCENT STANDARD DEVIATION
1.34-63.00	0.10-5.19	0.50-5.16	0.40-1.59	Nil-4.99	0.40-20.25	11.76-52.79	0.02-0.73	0.12-0.40	1.00-3.03	0.19-1.00	21.60-42.70	0.10-0.75	Nil-0.09	0.005-0.08	0.01-1.43	15.47-41.12	0.52-10.35	-	-	Nil-0.06	1.52-3.55	Nil-0.13	-	RANGE
12	9	9	9	9	18	18	8	8	9	10	15	8	9	8	8	7	12	1	1	5	9	5	14	NUMBER OF ANALYSES

TABLE C.2 CHEMICAL ANALYSES OF NODULAR CALCRETES

SiO_2	Al_2O_3	TOTAL Fe AS Fe_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	H_2O+	H_2O-	CO_2	TiO_2	P_2O_5	SO_3	MnO	BaO	ORGANIC MATTER	LOSS ON IGN.	Al_2O_3 Fe_2O_3	$H_2O\pm$	$MgCO_3$	$CaCO_3$	TOTAL	SOURCE
31.10	2.32	1.18	-	-	0.36	-	-	-	-	-	-	-	-	-	-	-	-	-	3.50	-	3.02	61.50	99.48	Visser (1964)
2.98	0.35	0.54	-	-	nil	-	-	-	-	-	-	-	-	-	-	-	-	-	0.89	-	0.70	94.69	99.26	" "
23.32	1.65	4.12	-	-	19.58	19.68	0.13	0.13	-	-	28.1	trace	0.02	-	0.04	-	-	31.46	5.77	-	-	-	100.13	Van der Merwe (1962)
35.62	7.98	2.89	-	-	2.10	25.38	0.23	0.39	-	-	15.2	0.58	0.06	-	0.04	-	-	23.52	10.87	-	-	-	98.86	" " " "
26.59	6.36	4.16	-	-	2.16	31.92	0.20	0.33	-	-	22.4	0.54	0.06	-	0.03	-	-	27.97	10.52	-	-	-	100.32	" " " "
36.86	7.04	2.02	-	-	3.43	24.85	1.22	1.05	-	-	19.61	0.51	0.08	-	0.01	-	-	23.25	9.42	-	-	-	100.32	" " " "
28.92	5.64	1.51	-	-	4.19	28.96	1.15	0.83	-	-	23.71	0.35	0.06	-	0.01	-	-	27.92	7.15	-	-	-	99.54	" " " "
25.66	5.10	1.82	-	-	3.29	32.58	0.81	0.74	-	-	25.65	0.31	0.07	-	0.02	-	-	28.82	6.92	-	-	-	99.22	" " " "
14.35	-	-	-	-	0.75	45.6	-	-	-	-	-	-	-	-	-	-	-	-	1.95	-	-	-	-	Wybergh (1918)
16.0	-	-	-	-	2.7	42.2	-	-	-	-	-	-	-	-	-	-	-	-	2.8	-	-	-	-	" "
18.1	-	-	-	-	1.5	43.2	-	-	-	-	-	-	-	-	-	-	-	-	1.7	-	-	-	-	" "
33.0	-	-	-	-	2.8	30.2	-	-	-	-	-	-	-	-	1.0	-	-	-	7.2	-	-	-	-	" "
16.8	-	-	-	-	8.8	32.9	-	-	-	-	-	-	-	-	-	-	-	-	4.2	-	-	-	-	" "
1.2	-	-	-	-	1.95	52.0	-	-	-	-	-	-	-	-	-	-	-	44.6	0.4	-	-	-	-	" "
1.2	-	-	-	-	0.3	53.55	-	-	-	-	-	-	-	-	-	-	-	44.8	0.4	-	-	-	-	" "
12.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4.5	-	2.5	78.5	-	Wybergh (1920)
31.0	-	-	-	-	-	-	-	-	-	1.0	-	-	-	-	-	-	-	-	7.0	-	2.0	58.0	-	" "
5.0	-	-	-	-	1.65	50.75	-	-	-	-	-	-	-	-	-	-	-	41.8	0.7	-	-	-	-	" "
27.6	6.1	6.6	1.4	4.5	3.5	30.0	0.85	0.60	3.4	0.78	20.2	0.96	0.09	0.07	0.04	0.03	nil	23.6	12.7	4.18	-	-	100.12	Sample 1533
24.2	1.9	1.5	1.3	0.18	0.88	38.5	0.14	0.37	2.4	0.77	29.5	0.23	0.01	0.02	0.05	0.02	0.04	31.8	3.4	3.17	-	-	100.37	" 1624
24.7	2.1	1.5	1.2	0.21	1.4	37.7	0.02	0.24	2.8	0.86	28.4	0.28	0.01	0.03	0.02	0.02	0.08	31.3	3.6	3.66	-	-	100.09	" 2114
27.5	2.5	1.3	0.98	0.31	1.2	35.8	0.09	0.28	3.3	0.80	27.2	0.25	0.04	0.02	0.05	0.02	0.07	30.4	3.8	4.1	-	-	100.24	" 2116
21.08	4.09	2.43	1.22	1.30	3.13	36.43	0.48	0.50	2.98	0.84	24.00	0.40	0.05	0.04	0.12	0.02	0.05	31.63	4.97	3.78	-	-	-	MEAN
10.84	2.43	1.66	0.16	1.84	4.22	9.52	0.45	0.28	0.40	0.08	4.40	0.25	0.03	0.02	0.28	0.004	0.03	7.24	3.52	0.40	-	-	-	STANDARD DEVIATION
51.4	59.4	68.31	12.8	142	135	26.1	92.1	56.7	13.5	10.1	18.3	61.8	58.6	57.1	234	19.9	66.5	22.9	70.9	10.7	-	-	-	PERCENT STANDARD DEVIATION
1.2-38.86	0.35-7.98	0.54-4.16	0.98-1.4	0.18-4.5	nil-19.58	19.68-53.55	0.02-1.22	0.13-1.05	2.4-3.4	0.77-1.0	15.2-29.5	Trace-0.96	0.01-0.08	0.02-0.07	0.01-1.0	0.02-0.03	Nil 0.08	23.25-44.8	0.4-12.7	3.17-4.18	-	-	-	RANGE
22	12	12	4	4	20	18	10	10	4	5	10	10	9	4	11	4	4	13	21	4	4	4	22	NUMBER OF ANALYSES

TABLE C.3 CHEMICAL ANALYSES OF CALCRETE NODULES

SiO_2	Al_2O_3	TOTAL Fe AS Fe_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	H_2O+	H_2O-	CO_2	TiO_2	P_2O_5	MnO	BaO	LOSS ON IGN.	Al_2O_3 Fe_2O_3	$MgCO_3$	$CaCO_3$	SO_3	H_2O+	ORGANIC MATTER	TOTAL	SOURCE
26.11	-	-	-	-	1.07	27.39	-	-	-	-	22.67	-	-	-	-	26.11	0.52	-	-	-	-	-	99.69	Hermann (1910)
12.08	-	-	-	-	-	-	-	-	-	0.85	-	-	-	-	-	-	6.02	4.29	76.54	-	-	-	-	Wybergh (1920)
63.00	-	-	-	-	6.90	11.76	-	-	-	-	-	-	-	-	-	15.47	1.95	-	-	-	-	-	-	Gevers (1930)
5.10	0.10	1.27	0.50	0.70	20.25	27.60	-	-	1.35	1.00	42.70	-	nil	-	-	-	2.16	-	-	-	2.35	-	99.30	Hall (1937)
-	-	-	-	-	0.7	45.2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Van der Merwe (1962)
-	-	-	-	-	4.3	47.3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	" " " "
1.34	0.63	1.28	0.40	0.80	1.40	52.79	0.60	0.12	1.20	0.46	39.27	0.13	nil	0.03	1.23	-	2.81	-	-	-	1.66	-	99.94	Sample 1000
2.65	0.85	1.42	0.90	0.47	1.33	51.04	0.62	0.22	1.96	0.23	38.82	0.15	0.007	0.005	1.37	-	2.79	-	-	-	2.19	-	100.39	" 2516
6.82	1.05	1.50	0.98	0.47	1.17	48.83	0.64	0.22	1.00	0.52	37.23	0.17	0.01	0.023	1.43	-	3.07	-	-	-	1.52	-	100.04	" 2517
20.24	5.19	5.16	0.41	4.99	3.15	35.37	0.73	0.40	3.03	0.52	24.81	0.75	0.09	0.04	0.03	27.82	10.35	-	-	0.06	3.55	nil	99.79	" 1533 + 40 mesh
19.89	1.82	1.59	1.59	nil	1.03	41.43	0.14	0.40	1.98	0.26	31.56	0.22	nil	0.07	0.02	33.59	3.41	-	-	0.02	2.24	0.05	100.48	" 1624 + 40 mesh
11.66	0.92	0.80	0.80	nil	0.62	47.93	0.04	0.12	2.23	0.21	34.98	0.28	nil	0.02	0.04	37.34	1.72	-	-	0.03	2.44	0.13	99.91	" 2114 + 40 mesh
21.07	1.48	1.39	1.39	nil	1.44	39.92	0.14	0.22	2.81	0.69	30.51	0.24	0.02	0.08	0.03	33.43	2.87	-	-	0.03	3.50	0.11	100.18	" 2116 + 40 mesh
4.33	0.40	0.50	0.50	nil	0.83	52.40	0.02	0.22	1.61	0.19	39.48	0.10	nil	0.02	0.01	41.12	0.90	-	-	nil	1.80	0.03	100.14	" 1515 + 40 mesh
-	-	-	-	-	0.40	39.49	-	-	-	-	29.34	-	-	-	-	-	-	-	-	-	-	-	-	" 2689 + 40 mesh
-	-	-	-	-	0.79	50.27	-	-	-	-	37.92	-	-	-	-	-	-	-	-	-	-	-	-	" 2223 + 40 mesh
-	-	-	-	-	0.59	33.42	-	-	-	-	23.28	-	-	-	-	-	-	-	-	-	-	-	-	" 2555 + 40 mesh
-	-	-	-	-	0.40	29.83	-	-	-	-	21.60	-	-	-	-	-	-	-	-	-	-	-	-	" 2566 + 40 mesh
-	-	-	-	-	0.40	39.49	-	-	-	-	29.34	-	-	-	-	-	-	-	-	-	-	-	-	" 2689 + 40 mesh
16.19	1.38	1.66	0.83	0.82	2.60	40.08	0.37	0.24	1.91	0.49	32.23	0.26	0.014	0.04	0.52	30.70	3.21	-	-	0.03	2.36	0.06	-	MEAN
16.16	1.43	1.28	0.41	1.50	4.58	10.66	0.29	0.10	0.66	0.27	6.73	0.20	0.028	0.024	0.64	7.84	2.53	-	-	0.02	0.69	0.05	-	STANDARD DEVIATION
99.9	104	77.4	49.2	182	176	26.6	78.1	42.1	34.55	54.5	20.9	76.6	197	68.0	123	25.5	78.7	-	-	69.6	29.19	76.41	-	PERCENT STANDARD DEVIATION
1.34-63.00	0.10-5.19	0.50-5.16	0.40-1.59	Nil-4.99	0.40-20.25	11.76-52.79	0.02-0.73	0.12-0.40	1.00-3.03	0.19-1.00	21.60-42.70	0.10-0.75	Nil-0.09	0.005-0.08	0.01-1.43	15.47-41.12	0.52-10.35	-	-	Nil-0.06	1.52-3.55	Nil-0.13	-	RANGE
12	9	9	9	9	18	18	8	8	9	10	15	8	9	8	8	7	12	1	1	5	9	5	14	NUMBER OF ANALYSES

ATOMACEOUS PAN LIMESTONE, SCHNECKENKALK)

H_2O+	H_2O SOLUBLES	LOSS ON IGN.	Al_2O_3 + Fe_2O_3	$MgCO_3$	$CaCO_3$	OPALINE SiO_2	AMORPHOUS Al_2O_3	TOTAL	SOURCE
-	-	47.76	0.94	-	-	-	-	-	Von Backström et al (1953)
-	-	40.38	1.85	-	-	-	-	-	" " " " "
-	-	43.02	1.24	-	-	-	-	-	" " " " "
-	-	45.00	0.60	-	-	-	-	-	" " " " "
-	-	44.12	0.36	-	-	-	-	-	" " " " "
-	-	43.06	0.68	-	-	-	-	-	" " " " "
-	-	44.50	0.36	-	-	-	-	-	" " " " "
-	-	42.70	1.12	-	-	-	-	-	" " " " "
-	-	42.66	1.08	-	-	-	-	-	" " " " "
-	-	42.96	0.10	-	-	-	-	-	" " " " "
-	-	47.08	0.42	-	-	-	-	-	" " " " "
-	-	-	-	1.8	72.6	-	-	-	" " " " "
-	-	-	-	2.2	66.0	-	-	-	" " " " "
3.60	-	-	-	-	-	-	-	100.32	" " " " "
3.82	-	-	-	-	-	-	-	99.83	Kent & Rogers (1947)
-	0.7	23.8	3.5	-	-	14.8	-	100.55	" " "
-	0.3	31.0	1.0	-	-	10.2	-	100.25	" " "
-	0.2	32.3	1.8	-	-	6.2	-	100.7	" " "
-	1.7	26.3	1.6	-	-	14.7	-	99.9	" " "
-	-	46.68	-	-	-	-	-	-	Gevers (1930)
-	-	-	1.45	-	-	-	-	-	Wybergh (1918)
-	-	43.3	0.8	-	-	-	-	-	" "
-	-	-	0.65	4.15	93.75	-	-	-	" "
-	-	-	trace	3.30	96.70	-	-	-	" "
-	-	-	0.8	-	-	-	-	-	" "
-	-	40.5	1.2	-	-	-	-	-	" "
-	-	41.5	1.5	-	-	-	-	-	" "
-	-	41.8	-	-	-	-	-	-	" "
-	-	36.15	0.8	-	-	-	-	-	" "
-	-	-	2.92	-	-	-	-	-	" "
-	-	-	4.49	-	-	-	-	101.38	Passarge (1904)
-	-	44.04	0.80	-	-	-	-	100.47	" "
-	-	40.59	1.65	-	-	-	-	100.39	Hermann (1910)
-	-	38.82	3.05	-	77.3	-	-	99.34	" "
-	-	36.35	1.83	-	-	-	-	100.45	" "
-	-	35.61	2.06	-	-	-	-	100.01	" "
-	-	38.02	5.10	-	-	-	-	100.58	" "
-	-	-	-	-	-	8.6	0.009	-	Sample 1642
-	-	-	-	-	-	7.9	<0.005	-	" 1724
-	-	-	-	-	-	14.7	<0.005	-	" 1828
3.71	0.73	40.00	1.53	-	-	11.01	-	-	MEAN
-	0.59	5.89	1.18	-	-	3.40	-	-	STANDARD DEVIATION
-	81.8	14.7	77.5	-	-	30.9	-	-	PERCENT STANDARD DEVIATION
3.60-	0.2-	23.8-	Trace-	-	-	6.2-	0.005-	-	RANGE
3.82-	1.7	47.76	4.49			14.8	0.009		
2	4	27	31	4	5	7	3	37	NUMBER OF ANALYSES

OTAL	SOURCE
0.48	Visser (1964)
9.73	" "
0.30	" "
9.53	" "
0.37	" "
9.81	Von Bäckstrom et al (1953)
8.53	" " " " "
9.67	" " " " "
9.95	" " " " "
9.45	" " " " "
9.94	" " " " "
9.99	" " " " "
9.69	" " " " "
9.55	" " " " "
9.43	" " " " "
9.74	" " " " "
9.37	" " " " "
9.94	" " " " "
9.19	" " " " "
-	" " " " "
-	" " " " "
0.00	" " " " "
1.30	" " " " "
7.70	" " " " "
9.70	" " " " "
9.93	" " " " "
1.80	" " " " "
9.80	" " " " "
9.85	" " " " "
9.50	" " " " "
0.34	Hermann (1910)
0.34	" "
9.49	" "
9.83	" "
0.16	" "
9.59	Von Bäckstrom et al (1953)
0.28	" " " " "
0.50	" " " " "
-	" " " " "
0.32	Coetzee (1960)
9.56	" "
9.82	" "
8.66	Kent & Rogers (1947)
9.59	" " "
-	Young (in Hall 1938)

TABLE C.4 CHEMICAL ANNALYSES OF TUFACEOUS HARDPANS (VLEI LIMESTONE, PFANNENKALKTUFF, DIATOMACEOUS PAN LIMESTONE, SCHNECKENKALK)

SiO_2	Al_2O_3	TOTAL Fe AS Fe_2O_3	MgO	CaO	Na_2O	H_2O+	H_2O-	CO_2	TiO_2	P_2O_5	MnO	$H_2O\pm$	H_2O SOLUBLES	LOSS ON IGN.	Al_2O_3 + Fe_2O_3	$MgCO_3$	$CaCO_3$	OPALINE SiO_2	AMORPHOUS Al_2O_3	TOTAL	SOURCE
3.14	-	-	1.40	50.45	-	-	-	-	-	-	-	-	-	47.76	0.94	-	-	-	-	-	Von Backström et al (1953)
9.81	-	-	1.24	46.47	-	-	-	-	-	-	-	-	-	40.38	1.85	-	-	-	-	-	" " " " "
4.88	-	-	2.27	48.12	-	-	-	-	-	-	-	-	-	43.02	1.24	-	-	-	-	-	" " " " "
2.32	-	-	1.25	50.40	-	-	-	-	-	-	-	-	-	45.00	0.60	-	-	-	-	-	" " " " "
2.68	-	-	1.17	51.23	-	-	-	-	-	-	-	-	-	44.12	0.36	-	-	-	-	-	" " " " "
4.36	-	-	1.31	50.52	-	-	-	-	-	-	-	-	-	43.06	0.68	-	-	-	-	-	" " " " "
2.56	-	-	1.21	50.88	-	-	-	-	-	-	-	-	-	44.50	0.36	-	-	-	-	-	" " " " "
4.48	-	-	1.39	50.20	-	-	-	-	-	-	-	-	-	42.70	1.12	-	-	-	-	-	" " " " "
5.78	-	-	0.29	49.88	-	-	-	-	-	-	-	-	-	42.66	1.08	-	-	-	-	-	" " " " "
1.42	-	-	0.32	54.26	-	-	-	-	-	-	-	-	-	42.96	0.10	-	-	-	-	-	" " " " "
3.34	-	-	1.89	46.78	-	-	-	-	-	-	-	-	-	47.08	0.42	-	-	-	-	-	" " " " "
16.19	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.8	72.6	-	-	-	" " " " "
29.60	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2.2	66.0	-	-	-	" " " " "
22.20	2.33	-	2.87	37.74	-	2.40	1.20	31.52	-	0.04	0.02	3.60	-	-	-	-	-	-	-	100.32	Kent & Rogers (1947)
21.18	2.01	-	2.61	38.64	-	2.60	1.22	31.52	-	0.03	0.02	3.82	-	-	-	-	-	-	-	99.83	" " "
39.2	2.2	1.3	2.9	26.0	1.6	-	2.7	-	0.15	-	-	-	0.7	23.8	3.5	-	-	14.8	-	100.55	" " "
29.2	0.5	0.5	2.3	34.3	0.9	-	1.2	-	0.05	-	-	-	0.3	31.0	1.0	-	-	10.2	-	100.25	" " "
24.5	1.2	0.6	1.1	38.4	1.3	-	1.0	-	0.10	-	-	-	0.2	32.3	1.8	-	-	6.2	-	100.7	" " "
36.6	1.2	0.6	1.9	28.3	1.0	-	2.2	-	0.10	-	-	-	1.7	26.3	1.6	-	-	14.7	-	99.9	" " "
1.20	-	-	18.26	33.19	-	-	-	-	-	-	-	-	-	46.68	-	-	-	-	-	-	Gevers (1930)
12.5	-	-	1.2	46.6	-	-	-	-	-	-	-	-	-	-	1.45	-	-	-	-	-	Wybergh (1918)
3.6	0.4	0.4	0.60	51.7	-	-	-	-	-	-	-	-	-	43.3	0.8	-	-	-	-	-	" "
1.00	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.65	4.15	93.75	-	-	-	" "
0.25	-	-	-	-	-	-	-	-	-	-	-	-	-	-	trace	3.30	96.70	-	-	-	" "
1.3	0.45	0.35	0.75	54.0	-	-	-	43.1	-	-	-	-	-	-	0.8	-	-	-	-	-	" "
9.1	-	-	1.45	46.9	-	-	-	-	-	-	-	-	-	40.5	1.2	-	-	-	-	-	" "
7.4	-	-	3.8	45.1	-	-	-	-	-	-	-	-	-	41.5	1.5	-	-	-	-	-	" "
8.5	1.5	-	3.7	44.5	-	-	-	-	-	-	-	-	-	41.8	-	-	-	-	-	-	" "
20.9	-	-	1.5	40.65	-	-	-	-	-	-	-	-	-	36.15	0.8	-	-	-	-	-	" "
27.99	-	-	-	34.08	-	-	-	29.24	-	-	-	-	-	-	2.92	-	-	-	-	-	Passarge (1904)
19.56	-	trace	-	48.81	-	-	-	30.52	-	-	-	-	-	-	4.49	-	-	-	-	101.38	" "
0.87	-	-	0.92	53.84	-	-	-	43.25	-	-	-	-	-	44.04	0.80	-	-	-	-	100.47	Hermann (1910)
9.18	-	-	3.02	45.95	-	-	-	39.35	-	-	-	-	-	40.59	1.65	-	-	-	-	100.39	" "
13.36	-	-	0.82	43.29	-	-	-	34.86	-	-	-	-	-	38.82	3.05	-	77.3	-	-	99.34	" "
20.13	-	-	0.80	41.43	-	-	-	34.38	-	-	-	-	-	36.35	1.83	-	-	-	-	100.45	" "
20.73	-	-	0.30	41.31	-	-	-	32.75	-	-	-	-	-	35.61	2.06	-	-	-	-	100.01	" "
17.74	-	-	0.48	39.24	-	-	-	31.33	-	-	-	-	-	38.02	5.10	-	-	-	-	100.58	" "
-	-	-	-	-	-	-	-	32.1	-	-	-	-	-	-	-	-	-	8.6	0.009	-	Sample 1642
-	-	-	-	-	-	-	-	21.8	-	-	-	-	-	-	-	-	-	7.9	<0.005	-	" 1724
-	-	-	-	-	-	-	-	31.2	-	-	-	-	-	-	-	-	-	14.7	<0.005	-	" 1828
12.40	1.31	0.63	2.10	44.25	1.20	2.50	1.59	33.35	0.10	0.035	0.02	3.71	0.73	40.00	1.53	-	-	11.01	-	-	MEAN
10.85	0.72	0.32	3.10	7.25	0.27	-	0.63	5.40	0.04	-	-	-	0.59	5.89	1.18	-	-	3.40	-	-	STANDARD DEVIATION
87.5	54.6	50.5	148	16.4	22.8	4.00	39.8	16.2	34.6	-	-	-	81.8	14.7	77.5	-	-	30.9	-	-	PERCENT STANDARD DEVIATION
0.25-	0.4-	Trace-	0.29-	26.0-	0.9-	2.40-	1.0-	21.8-	0.05-	0.03-	-	3.60-	0.2-	23.8-	Trace-	-	-	6.2-	0.005-	-	RANGE
39.20	2.33	1.3	18.26	54.0	1.6	2.60	2.7	43.25	0.15	0.04	-	3.82-	1.7	47.76	4.49	-	-	14.8	0.009	-	
37	9	7	31	33	4	2	6	14	4	2	2	2	4	27	31	4	5	7	3	37	NUMBER OF ANALYSES

TABLE C.5 CHEMICAL ANALYSES OF HARDPAN CALCRETES (EXCLUDING TUFACEOUS TYPES)

SiO_2	Al_2O_3	TOTAL Fe AS Fe_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	H_2O+	H_2O-	CO_2	TiO_2	P_2O_5	SO_3	Cl	MnO	BaO	SrO	INSOL.	LOSS ON IGN	Al_2O_3 + Fe_2O_3	$H_2O\pm$	$MgCO_3$	$CaCO_3$	OPALINE SiO_2	AMORPHOUS Al_2O_3	TOTAL	SOURCE
38.48	2.17	1.67	-	-	-	-	-	-	-	1.08	-	-	-	1.02	0.39	-	-	-	-	-	3.84	-	9.72	45.25	-	-	100.48	Visser (1964)
13.74	2.98	2.40	-	-	4.69	39.40	-	-	-	-	-	-	-	-	-	-	-	-	-	36.52	5.38	-	-	70.4	-	-	99.73	" "
32.60	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.84	0.72	2.74	62.4	-	-	100.30	" "
25.06	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2.96	0.92	3.11	67.48	-	-	99.53	" "
22.86	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2.72	0.96	4.14	69.69	-	-	100.37	" "
11.28	-	-	-	-	1.51	46.68	-	-	-	-	-	-	-	-	-	-	-	-	-	39.06	1.28	-	-	-	-	-	99.81	Von Bäckstrom et al (1953)
6.40	-	-	-	-	3.29	47.28	-	-	-	-	-	-	-	-	-	-	-	-	-	40.40	1.16	-	-	-	-	-	98.53	" " " " "
5.86	-	-	-	-	0.83	51.02	-	-	-	-	-	-	-	-	-	-	-	-	-	41.42	0.54	-	-	-	-	-	99.67	" " " " "
4.74	-	-	-	-	0.33	52.34	-	-	-	-	-	-	-	-	-	-	-	-	-	41.88	0.66	-	-	-	-	-	99.95	" " " " "
5.86	-	-	-	-	0.61	51.18	-	-	-	-	-	-	-	-	-	-	-	-	-	41.00	0.80	-	-	-	-	-	99.45	" " " " "
8.08	-	-	-	-	0.38	49.86	-	-	-	-	-	-	-	-	-	-	-	-	-	40.20	1.42	-	-	-	-	-	99.94	" " " " "
7.80	-	-	-	-	0.67	50.50	-	-	-	-	-	-	-	-	-	-	-	-	-	40.08	0.94	-	-	-	-	-	99.99	" " " " "
12.18	-	-	-	-	1.46	43.32	-	-	-	-	-	-	-	-	-	-	-	-	-	41.60	1.13	-	-	-	-	-	99.69	" " " " "
5.92	-	-	-	-	2.89	48.05	-	-	-	-	-	-	-	-	-	-	-	-	-	41.43	1.26	-	-	-	-	-	99.55	" " " " "
4.59	-	-	-	-	0.94	51.69	-	-	-	-	-	-	-	-	-	-	-	-	-	41.87	0.34	-	-	-	-	-	99.43	" " " " "
4.62	-	-	-	-	0.42	52.30	-	-	-	-	-	-	-	-	-	-	-	-	-	41.59	0.81	-	-	-	-	-	99.74	" " " " "
5.23	-	-	-	-	0.52	51.75	-	-	-	-	-	-	-	-	-	-	-	-	-	41.26	0.61	-	-	-	-	-	999.37	" " " " "
6.83	-	-	-	-	0.44	50.66	-	-	-	-	-	-	-	-	-	-	-	-	-	40.30	1.71	-	-	-	-	-	99.94	" " " " "
8.13	-	-	-	-	0.75	49.40	-	-	-	-	-	-	-	-	-	-	-	-	-	39.84	1.07	-	-	-	-	-	99.19	" " " " "
6.10	-	-	-	-	2.15	49.10	-	-	-	-	-	-	-	-	-	-	-	-	-	41.80	0.80	-	-	-	-	-	-	" " " " "
37.00	-	-	-	-	0.80	32.90	-	-	-	-	-	-	-	-	-	-	-	-	-	27.00	2.20	-	-	-	-	-	-	" " " " "
12.10	-	-	-	-	0.53	46.80	-	-	2.00	-	-	-	-	-	-	-	-	-	-	37.40	1.17	-	-	-	-	-	100.00	" " " " "
4.60	-	-	-	-	1.28	52.19	-	-	-	-	-	-	-	-	-	-	-	-	-	42.03	1.20	-	-	-	-	-	101.30	" " " " "
12.70	-	-	-	-	2.40	44.30	-	-	-	-	-	-	-	-	-	-	-	-	-	36.80	1.50	-	-	-	-	-	97.70	" " " " "
9.70	-	-	-	-	1.00	49.20	-	-	-	-	-	-	-	-	-	-	-	-	-	39.50	0.30	-	-	-	-	-	99.70	" " " " "
6.90	-	-	-	-	2.80	48.80	-	-	-	-	-	-	-	-	-	-	-	-	-	40.53	0.90	-	-	-	-	-	99.93	" " " " "
12.10	-	-	-	-	17.50	30.80	-	-	-	-	-	-	-	-	-	-	-	-	-	30.80	0.60	-	-	-	-	-	91.80	" " " " "
6.90	-	-	-	-	1.50	48.80	-	-	-	-	-	-	-	-	-	-	-	-	-	41.50	1.10	-	-	-	-	-	99.80	" " " " "
2.56	-	-	-	-	1.62	52.30	-	-	1.15	0.18	-	-	-	-	-	-	-	-	-	40.97	1.07	-	-	-	-	-	99.85	" " " " "
14.40	-	-	-	-	1.74	45.02	-	-	1.18	0.28	-	-	-	-	-	1.12	-	-	-	34.78	0.98	-	-	-	-	-	99.50	" " " " "
11.26	-	-	-	-	5.14	42.98	-	-	-	-	39.33	-	-	-	-	-	-	-	-	39.65	1.31	-	-	-	-	-	100.34	Hermann (1910)
10.12	-	-	-	-	0.70	48.05	-	-	-	-	38.47	-	-	-	-	-	-	-	-	39.84	1.63	-	-	-	-	-	100.34	" "
11.81	-	-	-	-	0.69	47.49	-	-	-	-	38.02	-	-	-	-	-	-	-	-	38.42	0.98	-	-	-	-	-	99.49	" "
12.20	-	-	-	-	1.85	45.58	-	-	-	-	37.79	-	-	-	-	-	-	-	-	38.24	1.96	-	-	-	-	-	99.83	" "
21.45	-	-	-	-	2.52	39.92	-	-	-	-	34.08	-	-	-	-	-	-	-	-	34.63	1.64	-	-	-	-	-	100.16	" "
14.20	-	-	-	-	4.03	42.00	-	-	1.41	0.24	-	-	-	-	-	-	-	-	-	35.87	1.84	1.65	-	-	-	-	99.59	Von Bäckstrom et al (1953)
3.36	-	-	-	-	1.22	50.96	-	-	0.01	1.80	-	-	-	-	-	-	-	-	-	41.54	1.39	1.81	-	-	-	-	100.28	" " " " "
5.80	-	-	-	-	0.70	52.75	-	-	-	-	-	-	-	-	-	-	-	-	-	40.50	0.30	-	-	-	-	-	100.50	" " " " "
9.10	-	-	-	-	1.45	46.90	-	-	-	-	-	-	-	-	-	-	-	-	-	40.50	1.20	-	-	-	-	-	-	" " " " "
23.30	1.31	1.44	-	-	-	-	-	-	-	-	-	-	-	-	-	trace	-	-	-	-	2.75	2.90	4.82	66.55	-	-	100.32	Coetzee (1960)
7.27	0.91	0.64	-	-	-	-	-	-	-	-	-	-	-	-	-	0.03	-	-	-	-	1.55	1.60	3.93	85.17	-	-	99.56	" "
7.03	0.55	0.60	-	-	-	-	-	-	-	-	-	-	-	-	-	trace	-	-	-	-	1.15	1.85	3.09	86.70	-	-	99.82	" "
23.38	-	1.04	-	-	16.89	18.85	-	-	-	-	-	-	-	-	-	-	-	-	1.96	36.54	-	-	-	-	-	-	98.66	Kent & Rogers (1947)
17.82	-	0.96	-	-	15.78	24.90	-	-	-	-	-	-	-	-	-	-	-	-	1.24	38.89	-	-	-	-	-	-	99.59	" " "
12.04	-	-	-	-	8.33	38.10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.88	-	-	-	-	-	-	Young (in Hall 1938)

BLE C.5 (CONTINUED)

	CaO	Na_2O	K_2O	H_2O+	H_2O-	CO_2	TiO_2	P_2O_5	SO_3	Cl	MnO	BaO	SrO	INSOL.	LOSS ON IGN.	Al_2O_3 + Fe_2O_3	$H_2O\pm$	$MgCO_3$	$CaCO_3$	OPALINE SiO_2	AMORPHOUS Al_2O_3	TOTAL	SOURCE
0	37.64	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3.46	-	-	-	-	-	-	Young (in Hall (1938)
7	27.10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2.20	-	-	-	-	-	-	" " " "
7	51.88	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.94	-	-	-	-	-	-	" " " "
5	49.21	-	-	-	-	-	-	-	-	-	-	-	-	-	40.12	-	-	-	-	-	-	-	Gevers (1930)
0	41.12	-	-	-	-	-	-	-	-	-	-	-	-	-	41.60	-	-	-	-	-	-	-	" "
4	42.70	-	-	-	-	-	-	-	-	-	-	-	-	-	44.80	-	-	-	-	-	-	-	" "
1	15.93	-	-	-	-	-	-	-	-	-	-	-	-	-	22.60	-	-	-	-	-	-	-	" "
	24.4	-	-	-	1.5	35.0	-	-	0.12	nil	-	-	-	-	-	8.3	-	-	-	-	-	99.4	Bond (1945)
8	53.0	-	-	-	0.2	39.66	-	-	0.05	nil	-	-	-	-	-	0.6	-	-	-	-	-	100.05	" "
3	44.5	-	-	-	0.8	33.87	-	-	0.07	nil	-	-	-	-	-	1.1	-	-	-	-	-	100.05	" "
5	49.5	-	-	-	0.7	37.37	-	-	0.14	trace	-	-	-	-	-	0.9	-	-	-	-	-	100.44	" "
5	37.30	-	-	-	-	35.3	-	-	nil	nil	-	-	-	-	-	9.10	-	-	-	-	-	99.75	" "
	28.0	-	-	-	-	-	-	-	nil	nil	-	-	-	-	-	2.0	-	-	-	-	-	-	" "
	45.1	-	-	-	-	-	-	-	nil	nil	-	-	-	-	-	1.2	-	-	-	-	-	-	" "
e	47.04	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2.48	-	-	-	-	-	-	Van der Merwe (1962)
e	47.04	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2.80	-	-	-	-	-	-	" " " "
	49.7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.1	-	-	-	-	-	-	Wybergh (1918)
	45.75	-	0.15	-	-	-	-	-	-	-	-	-	-	-	39.75	2.3	-	-	-	-	-	-	" "
	26.85	-	0.2	-	-	-	-	-	-	-	-	-	-	-	34.9	3.3	-	-	-	-	-	-	" "
	36.2	-	-	-	-	-	-	-	-	-	-	-	-	-	36.0	1.9	-	-	-	-	-	-	" "
5	45.15	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.3	-	-	-	-	-	-	" "
	42.0	-	-	-	-	-	-	-	-	-	-	-	-	-	37.0	3.2	-	-	-	-	-	-	" "
8	34.16	-	-	-	-	31.27	-	-	-	-	-	-	-	-	33.10	4.37	-	-	-	-	-	98.15	Hermann (1914)
5	33.18	-	-	-	-	26.67	-	-	-	-	-	-	-	-	27.10	3.38	-	-	-	-	-	100.50	" "
	41.41	trace	-	-	1.04	35.68	-	-	-	trace	-	-	-	-	-	6.04	-	-	-	-	-	98.69	" "
0	37.09	-	-	-	2.31	36.47	-	-	-	trace	-	-	-	-	-	0.39	-	-	-	-	-	99.41	Passarge (1904)
5	54.21	-	-	-	-	33.85	-	-	-	-	-	-	-	-	-	1.37	-	-	-	-	-	99.88	" "
0	27.87	-	-	-	2.76	21.95	-	-	-	trace	-	-	-	-	-	1.18	-	-	-	-	-	100.76	" "
	40.5	-	-	-	-	-	-	-	-	-	-	-	-	-	37.5	2.95	-	-	-	-	-	-	Wybergh (1918)
5	40.0	-	-	-	-	-	-	-	-	-	-	-	-	-	36.0	1.4	-	-	-	-	-	-	" "
	44.8	-	-	-	-	-	-	-	-	-	-	-	-	-	39.2	1.2	-	-	-	-	-	-	" "
	45.6	-	-	-	-	-	-	-	-	-	-	-	-	-	37.5	1.6	-	-	-	-	-	-	" "
	39.5	-	-	-	-	-	-	-	-	-	-	-	-	-	40.7	-	-	-	-	-	-	-	" "
	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2.0	-	-	-	-	-	-	Wybergh (1920)
	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4.0	-	3.0	71.0	-	-	-	" "
	-	-	-	-	2.0	-	-	-	-	-	-	-	-	-	-	5.0	-	2.6	72.0	-	-	-	" "
	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3.5	-	-	67.0	-	-	-	" "
	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4.0	-	trace	82.0	-	-	-	" "
	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3.0	-	1.5	80.0	-	-	-	" "
	37.3	-	-	-	-	-	-	-	-	-	-	-	-	-	35.3	9.1	-	-	-	-	-	-	" "
	-	-	-	-	2.0	-	-	-	-	-	-	-	-	-	-	1.8	-	3.0	75.0	-	-	-	" "
	-	-	-	-	2.0	-	-	-	-	-	-	-	-	-	-	4.0	-	2.0	84.5	-	-	-	" "
	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4.5	-	-	65.5	-	-	-	" "
	36.5	-	-	-	-	-	-	-	-	-	-	-	-	-	40.0	1.5	-	-	-	-	-	-	" "
	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.0	-	4.0	79.0	-	-	-	" "

Part # 20568540 503
Call 1.800.448.6160 to Reorder

TABLE C.5 (CONTINUED)

SiO_2	Al_2O_3	TOTAL Fe AS Fe_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	H_2O+	H_2O-	CO_2	TiO_2	P_2O_5	SO_3	Cl	MnO	BaO	SrO	INSOL.	LOSS ON IGN.	Al_2O_3 + Fe_2O_3	$H_2O\pm$	$MgCO_3$	$CaCO_3$	OPALINE SiO_2	AMORPHOUS Al_2O_3	TOTAL	SOURCE
23.04	-	-	-	-	2.80	37.64	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3.46	-	-	-	-	-	-	Young (in Hall (1938)
10.40	-	-	-	-	18.57	27.10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2.20	-	-	-	-	-	-	" " " "
1.98	-	-	-	-	1.57	51.88	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.94	-	-	-	-	-	-	" " " "
8.12	present	-	-	-	0.05	49.21	-	-	-	-	-	-	-	-	-	-	-	-	-	40.12	-	-	-	-	-	-	-	Gevers (1930)
7.60	present	-	-	-	8.40	41.12	-	-	-	-	-	-	-	-	-	-	-	-	-	41.60	-	-	-	-	-	-	-	" "
1.80	present	-	-	-	6.14	42.70	-	-	-	-	-	-	-	-	-	-	-	-	-	44.80	-	-	-	-	-	-	-	" "
45.30	much	-	-	-	10.71	15.93	-	-	-	-	-	-	-	-	-	-	-	-	-	22.60	-	-	-	-	-	-	-	" "
24.3	-	-	-	-	5.7	24.4	-	-	-	1.5	35.0	-	-	0.12	nil	-	-	-	-	-	8.3	-	-	-	-	-	99.4	Bond (1945)
6.5	-	-	-	-	0.98	53.0	-	-	-	0.2	39.66	-	-	0.05	nil	-	-	-	-	-	0.6	-	-	-	-	-	100.05	" "
19.08	-	-	-	-	0.63	44.5	-	-	-	0.8	33.87	-	-	0.07	nil	-	-	-	-	-	1.1	-	-	-	-	-	100.05	" "
10.18	-	-	-	-	1.05	49.5	-	-	-	0.7	37.37	-	-	0.14	trace	-	-	-	-	-	0.9	-	-	-	-	-	100.44	" "
16.0	-	-	-	-	2.05	37.30	-	-	-	-	35.3	-	-	nil	nil	-	-	-	-	-	9.10	-	-	-	-	-	99.75	" "
28.0	-	-	-	-	8.0	28.0	-	-	-	-	-	-	-	nil	nil	-	-	-	-	-	2.0	-	-	-	-	-	-	" "
15.37	-	-	-	-	1.3	45.1	-	-	-	-	-	-	-	nil	nil	-	-	-	-	-	1.2	-	-	-	-	-	-	" "
6.60	2.08	0.40	-	-	trace	47.04	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2.48	-	-	-	-	-	-	Van der Merwe (1962)
6.80	2.10	0.70	-	-	trace	47.04	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2.80	-	-	-	-	-	-	" " " "
8.1	-	-	-	-	0.6	49.7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.1	-	-	-	-	-	-	Wybergh (1918)
9.15	2.1	0.2	-	-	2.9	45.75	-	0.15	-	-	-	-	-	-	-	-	-	-	-	39.75	2.3	-	-	-	-	-	-	" "
22.55	1.9	1.4	-	-	12.2	26.85	-	0.2	-	-	-	-	-	-	-	-	-	-	-	34.9	3.3	-	-	-	-	-	-	" "
19.5	1.5	0.4	-	-	6.4	36.2	-	-	-	-	-	-	-	-	-	-	-	-	-	36.0	1.9	-	-	-	-	-	-	" "
14.0	-	-	-	-	1.35	45.15	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.3	-	-	-	-	-	-	" "
14.3	-	-	-	-	3.4	42.0	-	-	-	-	-	-	-	-	-	-	-	-	-	37.0	3.2	-	-	-	-	-	-	" "
22.44	-	-	-	-	4.08	34.16	-	-	-	-	31.27	-	-	-	-	-	-	-	-	33.10	4.37	-	-	-	-	-	98.15	Hermann (1914)
36.19	-	-	-	-	0.65	33.18	-	-	-	-	26.67	-	-	-	trace	-	-	-	-	27.10	3.38	-	-	-	-	-	100.50	" "
13.90	-	trace	-	-	-	41.41	trace	-	-	1.04	35.68	-	-	-	trace	-	-	-	-	-	6.04	-	-	-	-	-	98.69	" "
13.15	-	-	-	-	10.00	37.09	-	-	-	2.31	36.47	-	-	-	-	-	-	-	-	-	0.39	-	-	-	-	-	99.41	Passarge (1904)
9.60	-	-	-	-	0.85	54.21	-	-	-	-	33.85	-	-	-	-	-	-	-	-	-	1.37	-	-	-	-	-	99.88	" "
44.40	-	-	-	-	2.60	27.87	-	-	-	2.76	21.95	-	-	-	trace	-	-	-	-	-	1.18	-	-	-	-	-	100.76	" "
13.7	-	-	-	-	4.9	40.5	-	-	-	-	-	-	-	-	-	-	-	-	-	37.5	2.95	-	-	-	-	-	-	Wybergh (1918)
18.5	-	-	-	-	3.75	40.0	-	-	-	-	-	-	-	-	-	-	-	-	-	36.0	1.4	-	-	-	-	-	-	" "
13.2	-	-	-	-	2.0	44.8	-	-	-	-	-	-	-	-	-	-	-	-	-	39.2	1.2	-	-	-	-	-	-	" "
13.6	-	-	-	-	1.9	45.6	-	-	-	-	-	-	-	-	-	-	-	-	-	37.5	1.6	-	-	-	-	-	-	" "
12.0	-	-	-	-	7.3	39.5	-	-	-	-	-	-	-	-	-	-	-	-	-	40.7	-	-	-	-	-	-	-	" "
25.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2.0	-	-	-	-	-	-	Wybergh (1920)
18.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4.0	-	3.0	71.0	-	-	-	" "
17.5	-	-	-	-	-	-	-	-	-	2.0	-	-	-	-	-	-	-	-	-	-	5.0	-	2.6	72.0	-	-	-	" "
28.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3.5	-	-	67.0	-	-	-	" "
12.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4.0	-	trace	82.0	-	-	-	" "
14.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3.0	-	1.5	80.0	-	-	-	" "
16.0	-	-	-	-	2.1	37.3	-	-	-	-	-	-	-	-	-	-	-	-	-	35.3	9.1	-	-	-	-	-	-	" "
18.0	-	-	-	-	-	-	-	-	-	2.0	-	-	-	-	-	-	-	-	-	-	1.8	-	3.0	75.0	-	-	-	" "
7.0	-	-	-	-	-	-	-	-	-	2.0	-	-	-	-	-	-	-	-	-	-	4.0	-	2.0	84.5	-	-	-	" "
26.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4.5	-	-	65.5	-	-	-	" "
14.6	-	-	-	-	6.3	36.5	-	-	-	-	-	-	-	-	-	-	-	-	-	40.0	1.5	-	-	-	-	-	-	" "
14.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.0	-	4.0	79.0	-	-	-	" "

TABLE C.5 (CONTINUED)

SiO_2	Al_2O_3	TOTAL Fe AS Fe_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	H_2O+	H_2O-	CO_2	TiO_2	P_2O_5	SO_3	Cl	MnO	BaO	SrO	INSOL.	LOSS ON IGN.	Al_2O_3 & Fe_2O_3	H_2O+	$MgCO_3$	$CaCO_3$	OPALINE SiO_2	AMORPHOUS Al_2O_3	TOTAL	SOURCE
16.0	-	-	-	-	2.2	42.0	-	-	-	-	-	-	-	-	-	-	-	-	-	38.4	1.3	-	-	-	-	-	-	Wybergh (1920)
44.21	2.44	0.54	0.13	0.37	3.97	24.01	0.36	0.35	0.28	0.26	24.07	0.05	0.01	-	-	0.05	0.16	0.46	-	-	3.39	0.54	-	-	-	-	99.92	Sample 898
5.88	1.13	1.77	0.91	0.77	1.18	49.80	0.40	0.11	1.72	1.11	38.05	0.09	0.019	-	-	0.023	0.69	-	-	-	3.75	2.83	-	-	-	-	100.77	" 1028A
7.15	nil	0.42	0.16	0.23	11.86	37.76	0.73	0.06	3.62	0.87	38.04	0.03	0.018	-	-	0.024	0.70	-	-	-	0167	3.49	-	-	-	-	100.38	" 1028B
1.43	nil	0.08	0.08	nil	15.10	35.89	1.72	0.02	2.42	0.11	43.84	nil	0.013	-	-	nil	0.20	-	-	-	0.08	2.53	-	-	-	-	100.72	" 1028C
14.08	nil	0.54	0.17	0.33	0.58	46.62	0.47	0.17	1.99	0.77	34.49	nil	0.007	-	-	0.020	0.86	-	-	-	0.90	2.76	-	-	-	-	99.79	" 1028D
7.05	1.41	2.54	1.11	1.29	0.80	47.64	1.22	0.20	2.34	1.05	36.70	0.09	nil	-	-	0.032	0.17	-	-	-	5.38	3.39	-	-	-	-	100.05	" 2581
5.82	1.64	1.79	0.57	1.10	0.40	47.88	2.03	0.34	2.97	0.79	36.71	0.09	nil	-	-	0.030	0.14	-	-	-	4.65	3.76	-	-	-	-	99.72	" 2582
6.48	2.70	1.80	1.10	0.63	0.76	47.97	0.61	0.25	1.53	0.52	36.98	0.10	0.006	-	-	0.030	0.48	-	-	-	5.20	2.05	-	-	-	-	99.63	" 2583
7.72	2.76	1.74	1.30	0.40	1.35	46.35	0.90	0.28	2.94	0.54	34.87	0.10	0.01	-	-	0.027	1.20	-	-	-	4.95	3.48	-	-	-	-	100.20	" 2584
6.46	2.20	1.85	1.25	0.54	1.29	47.53	1.91	0.27	2.61	0.58	36.19	0.10	0.007	-	-	0.029	0.32	-	-	-	4.65	3.19	-	-	-	-	100.71	" 2585
7.25	2.36	1.73	1.33	0.36	1.18	46.32	0.83	0.26	3.40	0.60	34.94	0.09	0.006	-	-	0.03	1.72	-	-	-	4.49	4.00	-	-	-	-	100.08	" 2586
22.88	2.07	0.72	0.56	0.14	6.21	32.48	0.22	0.20	4.62	0.80	29.33	0.03	nil	-	-	0.05	0.85	0.12	-	-	2.94	5.42	-	-	-	-	99.76	" 1028
18.09	1.94	0.50	0.34	0.14	1.15	42.21	0.21	0.22	2.84	0.51	31.30	0.03	nil	-	-	0.03	0.63	0.11	-	-	2.59	3.35	-	-	-	-	99.24	" 1028
-	-	-	-	-	-	-	-	-	-	-	33.8	-	-	-	-	-	-	-	-	-	-	-	-	-	2.52	0.076	-	" 1562
-	-	-	-	-	-	-	-	-	-	-	39.8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	" 1623
-	-	-	-	-	-	-	-	-	-	-	40.5	-	-	-	-	-	-	-	-	-	-	-	-	-	0.57	0.018	-	" 1658
-	-	-	-	-	-	-	-	-	-	-	41.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	" 1658
-	-	-	-	-	-	-	-	-	-	-	20.9	-	-	-	-	-	-	-	-	-	-	-	-	-	0.61	0.132	-	" 2200
-	-	-	-	-	-	-	-	-	-	-	43.0	-	-	-	-	-	-	-	-	-	-	-	-	-	0.69	0.085	-	" 2204
-	-	-	-	-	-	-	-	-	-	-	37.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	" 2225
-	-	-	-	-	-	-	-	-	-	-	33.6	-	-	-	-	-	-	-	-	-	-	-	-	-	0.69	0.151	-	" 2227
-	-	-	-	-	-	-	-	-	-	-	24.9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	" 2505
13.96	1.66	1.11	0.69	0.49	3.59	42.85	0.89	0.21	2.17	0.98	34.89	0.06	0.007	0.18	0.06	0.10	0.62	0.23	1.60	38.33	2.29	2.53	-	-	1.01	0.092	-	MEAN
9.31	0.86	0.70	0.47	0.37	4.31	8.42	0.61	0.09	1.13	0.70	5.33	0.04	0.006	0.32	0.13	0.27	0.45	0.16	-	4.05	1.82	1.22	-	-	0.75	0.046	-	STANDARD DEVIATION
66.7	51.9	62.7	67.9	75.3	120	19.7	68.4	44.1	52.2	71.7	15.3	61.1	85.7	185	245	266	71.5	70.7	-	10.6	79.6	48.1	-	-	74.2	49.6	-	PERCENT STANDARD DEVIATION
1.43-45.30	Nil-2.98	Trace-3.97	0.08-1.33	Nil-1.29	Trace-18.57	15.93-54.21	Trace-2.03	0.06-0.35	0.01-4.62	0.11-2.76	21.95-43.84	Nil-0.10	Nil-0.019	Nil-1.02	Nil-0.39	Nil-1.12	0.16-1.72	0.11-0.46	1.24-1.96	22.60-44.80	0.30-9.10	0.54-5.42	-	-	0.57-2.52	0.018-0.151	-	RANGE
104	23	26	13	13	86	87	14	15	18	28	38	13	13	8	10	17	13	3	2	55	97	21	14	17	5	5	105	NUMBER OF ANALYSES

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shows some analyses for minor elements. Table C.7 shows the total carbonate content of the minus 40 mesh fraction of most of the calcretes appearing in Tables H.1, H.2 and H.4, together with a few MgO and CaO results. Table C.8 shows the total carbonate content of most of the calcretes appearing in Table H.3, i.e. honeycomb, hardpan and boulder calcretes. Two or three samples in these tables have not been subjected to further testing or described elsewhere in this study and have been included merely for completeness. Table C.9 shows some ferrous iron and organic matter contents of the minus 40 mesh fraction of some calcified sands, powder and nodular calcretes. Ferrous iron was determined in the usual way after drying at 105°C, which probably means that some of it was oxidised and therefore underestimated. Check tests by Mclachlan and Lazar Ltd. on Samples 2363 and 2555 after drying by washing with acetone, removing most of the acetone by suction in a gooch crucible and then drying for 2 hours over silica gel in a desiccator yielded results of 0.02 and 0.45% FeO respectively, compared with 0.02 and 0.43% FeO respectively determined after dying at 105°C. While this difference is not serious, all samples had been in dry storage for months or years before analysis and it appears that the ferrous iron available for self-stabilization would have to be determined without drying the material (or perhaps by use of the acetone technique) and as soon as possible after the sample is taken. Organic matter was determined according to the dichromate oxidation method using silver sulphate as protection against chlorides as described by the Road Research Laboratory (1952).
Table C.10 shows some amorphous silica contents of the minus 10 mesh fraction, as determined by the Mellor and Thompson (1938) method. This involves digesting about 2 grams of the sample (in this case minus 10 mesh fractions ground - 40 mesh) with 100 ml of a 5% solution of sodium

carbonate/ ...

carbonate in a platinum dish on a boiling water bath for one hour. The clear liquid is then decanted off through a fine filter paper and the digestion repeated. The residue is then filtered off and washed with hot 5% sodium carbonate. Silica is then determined on the total filtrate. Table C.8 also shows the amorphous silica and amorphous alumina contents of some honeycomb, hardpan and boulder calcretes. Silica was determined by the method just described and amorphous alumina by determining the aluminium in the same filtrate. These samples were crushed and ground minus 300 mesh before digesting.

References will be found at the end of Chapter 3.

TABLE C.6 SEMI-QUANTITATIVE SPECTROCHEMICAL ANALYSES OF SOME CALCRETES AND OTHER MATERIALS

SAMPLE NO.	890	895	898	903	955	991	1028	1028
AMOUNTS (%)	ELEMENTS DETECTED							
>30	Si	Nil	Si	Si	Nil	Si	Nil	Nil
3-30	Nil	Si Ca	Mg Ca	Nil	Si Mg Ca	Fe	Si Mg Ca	Si Ca
1-10	Nil	Al Mg Ba	Al	Mg	Al	Al Mg	Al	Al Mg
0.3-3	Al Mg Fe Ca	Na	Fe	Al Fe Ca	Sr	Ca	Nil	Nil
0.1-1	Nil	Fe Sr	Ba Na Sr	Nil	Fe Na	Ba	Fe Na Sr	Fe

TABLE C.6 (CONTINUED)

SAMPLE NO.	890	895	898	903	955	991	1028	1028
AMOUNTS(%)	ELEMENTS DETECTED							
0.03-0.3	Ba Cr Ti	Mn Ti	V Ti	Ba Cr Ti	Ti	Cr V Ti	Ba Mn Ti	Na Ti
0.01-0.1	B Mn Sn V	B Cr V	B Mn Cr Sn	B Mn Sn V	B Mn V	B Mn Sr	B Cr V	B Mn Cr V Sr
0.003-0.03	Cu	Sn Cu	Cu	Cu	Ba Cu	Cu	Cu	Ba Cu
0.001-0.01	Zr	Nil	Nil	Nil	Sn	Zr	Sn	Nil
0.0003-0.003	Ag	Ag	Ag	Ag Zr	Ag	Ag	Ag	Ag

Analyst: Spectroservices of S.A. Ltd.

TABLE C.7 TOTAL CARBONATE CONTENTS OF THE MINUS 40 MESH (0.42 mm) FRACTION

MATERIAL TYPE	SAMPLE NUMBER	TOTAL CARBONATE (%)		CaO %	MgO %
		AS CO_2	AS $CaCO_3$		
Calcareous soil	893	0.5	1.2	-	-
" "	894	3.2	7.3	-	-
" "	1548	0.7	1.5	-	-
Calcified sand	895	15.9	36.2	-	-
" "	1530	8.9	24.5	-	-
" "	1567	9.3	21.2	-	-
" "	1581	9.1	20.7	-	-
" "	1625	18.8	-	24.6	2.44
" "	2513	24.7	56.1	-	-

TABLE C.7 (CONTINUED)

MATERIAL TYPE	SAMPLE NUMBER	TOTAL CARBONATE (%)		CaO %	MgO %
		AS CO_2	AS $CaCO_3$		
Powder calcrete	902	37.3	84.7	-	-
" "	1515	37.5	85.4	50.7	0.73
" "	1557	4.4	10.1	-	-
" "	1696	24.4	55.5	-	-
" "	1573	34.1	77.4	-	-
" "	1881	30.0	68.1	-	-
" "	2223	37.9	86.3	52.8	0.59
" "	2360	23.4	53.3	-	-
Nodular calcrete	1021M	8.4	19.2	-	-
" "	1024M	16.2	36.9	-	-
" "	1513	26.9	61.2	-	-
" "	1514	20.2	46.0	-	-
" "	1516	35.0	79.7	-	-
" "	1533	5.5	12.5	13.1	4.28
" "	1561	8.0	18.1	-	-
" "	1565	17.5	39.8	-	-
" "	1569	10.5	23.9	-	-
" "	1601	7.6	17.4	-	-
" "	1602	18.9	42.9	-	-
" "	1620	33.6	76.4	-	-
" "	1876	25.6	58.3	-	-
" "	1979	4.1	9.2	-	-
" "	1980	32.5	74.0	-	-
" "	1981	14.5	33.0	-	-
" "	2114	19.9	45.3	24.4	2.45
" "	2116	20.6	46.9	28.0	0.82
" "	2367	39.0	88.8	49.2	0.47
" "	2368	8.9	20.2	-	-
" "	2493	5.3	12.1	6.4	1.89
" "	2555	15.2	34.6	20.2	0.79
" "	2566	6.1	13.9	8.3	1.79
" "	2588	22.3	50.7	-	-
" "	2689	9.5	21.6	13.7	0.40
CALCIFIED SANDS, POWDER & NODULAR CALCRETES	MEAN	19.17	-	-	-
	STD. DEVIATION	10.84	-	-	-
	% STD. DEV.	56.6	-	-	-

TABLE C.7 (CONTINUED)

MATERIAL TYPE	SAMPLE NUMBER	TOTAL CARBONATE (%)		CaO %	MgO %
		AS CO_2	AS $CaCO_3$		
	RANGE	4.1-39.0	-	-	-
	NO. OF ANAL-YSES	39	-	-	-
Calcrete mixture	896	10.1	23.0	-	-
Ferricrete	2363	1.1	2.6	-	-

Analysts: Mclachlan & Lazar (Pty.) Ltd. and F. Netterberg

TABLE C.8 TOTAL CARBONATE, AMORPHOUS SILICA AND AMORPHOUS ALUMINA CONTENTS

MATERIAL TYPE	SAMPLE NUMBER	TOTAL CARBONATE (%)		AMOR-PHOUS SILICA %	AMOR-PHOUS ALUMINA %
		AS CO_2	AS $CaCO_3$		
Honeycomb calcrete*	1931	32.5	74.0	-	-
" " *	1573	34.0	77.4	1.49	0.0845
" " *	1848	35.7	81.2	-	-
" " *	2494	39.3	89.4	0.500	0.081
Hardpan calcrete	1562	33.8	76.9	2.52	0.076
" "	1623	39.8	90.5	-	-
" "	1642	32.1	73.0	8.57	0.009
" "	1658	40.5	92.0	0.57	0.018
" "	1658X	41.5	94.3	-	-
" "	1724	21.8	49.5	7.85	< 0.005
" "	1828	31.2	71.0	14.7	< 0.005
" "	2200	20.9?	47.4?	0.61	0.132

* Excluding soil in pockets

TABLE C.8 (CONTINUED)

MATERIAL TYPE	SAMPLE NUMBER	TOTAL CARBONATE (%)		AMORPHOUS SILICA %	AMORPHOUS ALUMINA %
		AS CO_2	AS $CaCO_3$		
Hardpan calcrete	2204	43.0	97.8	0.69	0.085
" "	2225	37.5	85.3	-	-
" "	2227	33.6	76.3	0.69	0.151
" "	2505	24.9	56.7	-	-
Boulder calcrete	1028	38.8	88.3	-	-
" "	1028X	30.9	70.2	0.43	0.047
" "	1621	37.3	84.8	-	-
" "	1622	37.8	85.9	-	-
" "	1627	37.5	85.3	0.90	0.217
" "	1627X	40.4	91.9	-	-
" "	1945	21.7	49.3	-	-
" "	1949	28.7	65.3	-	-
" "	2125	43.9	99.7	-	-
" "	2228	27.6	62.8	-	-
" "	2302	23.4	53.2	0.69	0.217
Silcrete & dol. sandstone	890	1.2	2.7	-	-

Analysts: Mclachlan & Lazar (Pty.) Ltd. and F. Netterberg

TABLE/ ...

TABLE C.9 SOME FERROUS IRON AND ORGANIC MATTER CONTENTS OF THE MINUS 40 MESH (0.42 mm) FRACTION

MATERIAL TYPE	SAMPLE NUMBER	FeO %	ORGANIC MATTER %
Nodular calcrete	913	0.03	-
Powder calcrete	1515	Nil	0.64†
Nodular calcrete	1533	3.11	0.45, †0.02†
" "	1569	0.06	-
" "	1601	0.09	-
" "	1602	0.07	-
" "	1624	0.03, 0.77	nil†
Calcified sand	1625	0.06, nil	0.24†
Powder calcrete	1881	0.04	-
Nodular calcrete	2114	0.08	0.73, *0.03†
" "	2116	0.13	0.67, * nil†
Powder calcrete	2223	0.02	0.65*
Nodular ferricrete	2363	0.02	-
Nodular calcrete	2367	-	0.23*
" "	2493	-	0.80*
" "	2555	0.43	-
" "	2566	0.32	0.54*
" "	2580	0.05	-
" "	2689	-	1.71*

* By dichromate oxidation.

† By difference: = loss on ignition - (CO_2 plus H_2O+).

Analysts: Mclachlan and Lazar (Pty.) Ltd.

TABLE C.10 SOME AMORPHOUS SILICA CONTENTS OF THE MINUS 10 MESH (2 mm) FRACTION

MATERIAL TYPE	SAMPLE NUMBER	AMORPHOUS SILICA %
Calcified sand	895	2.10
Nodular calcrete	1561	3.13
Calcified sand	1567	1.93
Nodular calcrete	1569	2.65
" "	1601	2.27
" "	1602	2.27
" "	1624	0.17
" "	1980	0.36
" "	2114	0.14
" "	2116	0.09
Powder calcrete	2223	0.45
" "	2360	0.34

Analysts: Mclachlan and Lazar (Pty.) Ltd.

APPENDIX D

OCCURRENCE AND TESTING FOR DELETERIOUS SALTS IN ROAD CONSTRUCTION MATERIALS, WITH PARTICULAR REFERENCE TO CALCRETES

D.1 INTRODUCTION

D.2 TYPES OF SOLUBLE SALTS

- D.2.1 Waters
- D.2.2 Rocks
- D.2.3 Soils

D.3 DELETERIOUS SALTS

D.4 TESTING FOR SOLUBLE SALTS

- D.4.1 Direct methods
- D.4.2 Durability testing of compacted specimens

D.5 SOIL PASTE CONDUCTIVITY AND pH METHOD

- D.5.1 Description
- D.5.2 Conductivity limits for base course
- D.5.3 Procedure for testing waters
- D.5.4 Variables affecting soil paste conductivity results
- D.5.5 Variables affecting soil paste pH results

D.6 CONDUCTIVITY AND PH OF CALCRETES

D.7 ENGINEERING USES OF CONDUCTIVITY AND PH

- D.7.1 Conductivity
- D.7.2 pH

D.8 CONCLUSIONS

D.1/ ...

D.1 INTRODUCTION

As recent papers (Cole and Lewis, 1960; Smith, 1962; and Weinert and Clauss, 1967) testify, the importance of soluble salts is becoming increasingly recognised as a cause of certain types of road failure in the arid and semiarid zones.

The earliest symptoms of impending failure generally seem to occur during or soon after construction, and take the form of a slight powdering of the surface of newly constructed base before and/or after priming and/or white salt deposits in cracks in the surfacing and along the edges of the surfacing. Failure itself takes the form of blistering and cracking of thin surfacings, the lifting of localised patches of thicker surfacings with cracking of the uplifted patches, loss of density of the upper part of all bases, and powdering and loss of cohesion of the upper part of cement stabilized bases and some lime stabilized calcrete bases. In its mildest form the net result is a weakening of the upper base, but in more severe cases a complete loss of bond between the base and the cracked surfacing results, with consequent "scabbing" of the surfacing and potholing. Published descriptions of failures due to soluble salts as well as those observed by the author have in every case exhibited marked similarities.

The problem is characteristic of dry areas simply because the rainfall is insufficient to leach out the secondary minerals released by weathering rocks. Even very soluble minerals ("soluble salts") thus tend to accumulate in the soils and waters of such areas, especially in cases of interior drainage. In more humid areas the more soluble minerals are leached out and carried off to the sea, and under really high rainfall conditions the soil becomes leached of even such relatively insoluble minerals as quartz.

This/ ...

This appendix discusses the types of salts present in construction materials and methods for their detection. The way they find their way into the base, their movement in the road structure, the actual mechanisms of attack on various types of base, and possible preventive and remedial measures will be the subject of a later paper (Netterberg, 1969b).

The references referred to in this appendix will be found at the end of Chapters 3 or 7.

D.2 TYPES OF SOLUBLE SALTS

Relatively little information is available on the amounts and types of salts actually found in construction materials, but a good first approximation may be made by consulting appropriate basic literature.

D.2.1 Waters

Apart from unusual cases like the Red Sea and the Persian Gulf, where inflow and rainfall are low and evaporation high, the composition of sea water does not vary greatly. Even when the salinity does vary, the relative composition remains essentially constant. The content of total dissolved solids (T.D.S.) is about 3.5%, being made up chiefly of Cl^- (1.89%), Na^+ (1.06%), SO_4^{--} (0.26%), Mg^{++} (0.13%), Ca^{++} (0.04%), K^+ (0.04%) and HCO_3^- (0.01%) - Mason (1958).

As any solution is concentrated by evaporation, salts tend to crystallize out in order of solubility, the least soluble first and the most soluble last. In the case of sea water the first salts to crystallize would be very small amounts of Fe_2O_3 and $CaCO_3$, followed by a little $CaSO_4$, and then a large amount of NaCl, followed in turn by $MgSO_4$, $MgCl_2$ and other salts. If evaporation was complete, most of the salt deposit would be made up of NaCl and $MgCl_2$.

The/ ...

The waters of saline lakes can be divided into five basic types: salt, alkali, bitter, nitrate and borate (Bateman, 1950). The dominant salts present are NaCl, Na_2CO_3, Na_2SO_4, $NaNO_3$ and $Na_2B_4O_7$ respectively (existing of course as ions). The waters of salt lakes approximate in relative composition to that of sea water, though the salinity may be higher. Potash lakes are a type of alkali lake in which potassium is dominant over sodium. Borate lakes are uncommon.

The composition of river water in its upper reaches depends largely on the geology and climate, but in their lower reaches most river waters approach a common composition (Livingstone, 1963) and salinity is not normally a problem (the total dissolved solids content of world mean river water is only 120 parts per million). The dominant ions present are HCO_3^-, Ca^{++}, SO_4^{--}, Cl^-, Na^+, Si^{++++}, Mg^{++} and K^+. It is important to realise that the salinity of rivers and streams increases with decreasing flow, so that it is likely to be highest in the dry season.

The types of salts present in groundwaters also depend largely on climate and geology. In general it can be said that highly mineralised chloride-sulphate waters and to a lesser extent alkaline sodium carbonate waters tend to be characteristic of the semiarid and arid zones and this has been well shown for South Africa by Bond (1945). In South Africa, chlorides are the dominant component of chloride-sulphate waters, Cl^- generally making up a quarter to a half of the total dissolved solids. Other important components are sulphates (though SO_4^{--} is usually less than 10% of the T.D.S.) and in some areas groundwater may approximate to the composition of ocean water. Some groundwaters are in fact connate sea water (sea water trapped in sedimentary rock as it was deposited). Some extremely saline borehole waters exceeding the salinity of sea water are encountered in Ovamboland in South West Africa and in parts of Australia.

According/ ...

According to Bond, $NaHCO_3$, Na_2CO_3 and SiO_2 are the most important constituents of the soda carbonate waters in South Africa and chlorides and sulphates are low.

While the foregoing discussion should suffice to yield a good idea of what salts to expect in any particular case, it must however, be emphasised that the composition and total salinity of borehole and inland surface waters is nevertheless likely to be variable, not only from place to place, but also with time, and each case should be treated on its own merits. It would be safe to say that whenever the proposed construction water is too saline for consumption by newcomers to an area it should be analysed and its effects on the particular construction envisaged assessed with respect to the limits of various salts dealt with later in this appendix. Sea water for example contains more SO_4^{--} than the 0.02% SO_3 (0.024% SO_4^{--}) regarded as the maximum advisable for groundwater in content with lean (1:7 or leaner) cast in situ concrete using ordinary portland cement (Fulton, 1964), while 15% sea water used for compacting and curing a cement stabilized base would add 0.04% SO_4^{--}, close to the limit of 0.05% for base suggested by Weinert and Clauss (1967). Animals can tolerate water of greater salinity than humans, but individual species vary in their tolerance (sheep being the most tolerant - Bond, 1945) and the local human inhabitants sometimes drink surprisingly saline water.

On the whole, the deleterious salts present in construction waters are likely to be NaCl, Na_2SO_4 and $MgSO_4$, less often $NaHCO_3$ and Na_2CO_3 and rarely $CaCl_2$, $MgCl_2$ and nitrates.

D.2.2 Rocks

Fresh igneous and metamorphic rocks will generally be free of excessive quantities of soluble salts, but almost any weathered rock in a relatively dry climate (less than

about/ ...

about 800 mm of rainfall per annum in South Africa) could contain salts released by chemical weathering, in particular sulphates formed by the oxidation of sulphides. For this reason the desirable limit of sulphides in Witwatersrand quartzite coarse concrete aggregate is 2% S (Fulton, 1964). Sedimentary rocks are more likely to contain free salts than igneous or metamorphic rocks and Clarke's "average shale" for example contains 0.64% SO_3 (Mason, 1958), though once again some of the sulphur will be in the form of sulphides. The "average sandstone" and the "average limestone" contain 0.07 and 0.05% SO_3 respectively.

The presence of $MgSO_4$, $Fe(SO_4)_3$, $MgSO_4.H_2O$, $CaSO_4.2H_2O$, $CaSO_4.\frac{1}{2}H_2O$, $FeSO_4.H_2O$ and $CaSO_4$ has been recorded from water extracts of bases of oxidised gold mine wastes (mainly Witwatersrand quartzite) in the Johannesburg area (subhumid) of South Africa by Weinert and Clauss (1967), though not all in the same sample. The same authors gave several analyses on water extracts of oxidised copper mine waste (mostly quartzite and granite with a few pieces of copper ore) from the O'Okiep-Steinkopf road in Namaqualand (arid) in South Africa. The main components were Fe, Ca^{++} and SO_4^{--}, with lesser Na^+, Cl^-, Mg^{++} and K^+ in most samples.

D.2.3 Soils

The only salt identified by Cole and Lewis (1960) (bitumen catchments in West Australia) and Smith (1962) (cement stabilized loams and clays in South Australia) was NaCl, but it is apparent from their analyses that other salts were also present. Smith also gave seven analyses of saturation extracts, which showed the presence of Na^+, Ca^{++}, Mg^{++}, Cl^-, HCO_3^- and SO_4^{--}, and unusually large amounts of exchangeable sodium. It can be seen from the analyses that the dominant salts after complete evaporation would be NaCl and $CaCO_3$, the latter being harmless.

Solonetzes/ ...

Solonetzes and solonchaks are probably the most commonly encountered saline soils in the arid and semiarid zone and the only really saline calcretes encountered by the author were in solonetzes in Ovamboland. Table D.1 provides a good idea of what salts can be expected in such soils. It was compiled from 48 analyses of water extracts of solonetzes and solonchaks given by Joffe (1949) after Hilgard and while it probably does not provide a statistically valid survey of these soils, it should at least provide a good indication of the salts most likely to be encountered in soils used for road construction in arid and semiarid areas.

TABLE D.1 THE ABUNDANCE OF SOLUBLE SALTS IN SOLONETZES AND SOLONCHAKS

SALT	FREQUENCY OF OCCURRENCE %	RANGE OF PROPORTION OF TOTAL SALT CONTENT %
NaCl	100	0.2 - 90
Na_2SO_4	83	0 - 93
Na_2CO_3	73	0 - 99
K_2SO_4	38	0 - 21
$MgSO_4$	33	0 - 44
KCl	13	0 - 13
Na_2HPO_4	10	0 - 8
$MgCl_2$	6	0 - 6
$CaCl_2$	4	0 - 58
Na_3PO_4	2	0 - 2
K_2CO_3	2	0 - 7
$NaNO_3$	2	0 - 87
$(NH_4)_2CO_3$	2	0 - 2
$Mg(PO_4)_2$	2	0 - 2

It/ ...

It can be seen for example that NaCl was found to be invariably present, but that it could make up anything from 0.2 to 90% of the total soluble salt content of any one soil sample. Which salts are found in practice depends on the composition of the original solution from which the salts crystallized and the degree to which it was concentrated by evaporation. The very soluble salts are thus relatively rare, and most commercial salt deposits throughout the world consist largely of calcium sulphate and common salt (NaCl). Complex salts are also found in saline soils and salt deposits.

According to Jackson (1958), water soluble salts occurring in total amounts of over 0.1 per cent usually consist principally of the four cations Na^{+}, K^{+}, Ca^{++} and Mg^{++} linked mainly to Cl^{-} and SO_4^{--}, sometimes to NO_3^{-} and CO_3^{--} and to a limited extent to HCO_3^{-}. Usually 98% of the soluble salts of saline soils consist of these ions and soil salinity problems frequently arise from Na^{+}, Cl^{-} and SO_4^{--}, but seldom from Ca^{++}, Mg^{++} or CO_3^{--} Study of other standard pedological works suggests that variable amounts of Ca^{++}, organic matter, SO_4^{--}, NO_3^{-}, HCO_3^{-}, CO_3^{--}, Si^{++++}, Cl^{-}, Na^{+}, Mg^{++}, Fe^{++} and K^{+} are likely to be important constituents of the soil solution in most soils. Gypsum ($CaSO_4 . 2H_2O$) and to a lesser extent anhydrite ($CaSO_4$) are common but relatively insoluble salts that also seem to be deleterious in some cases.

It can thus be confidently predicted that NaCl, Na_2SO_4, $CaSO_4$, Na_2CO_3 and to a lesser extent K_2SO_4 and $MgSO_4$ and/or the hydrates of all these except NaCl will be the salts most commonly encountered in construction soils in the arid and semiarid zones. Anhydrous Na_2CO_3 and $MgSO_4$ are not known as natural minerals. Gypsum ($CaSO_4 . 2H_2O$) is the salt most likely to survive the leaching of wetter areas.

The/ ...

The only analyses of water extracts of calcrete bases known to the author are three incomplete analyses of the upper inch of a lime stabilized nodular calcrete base on the Operet-Ondangua road in Ovamboland, South West Africa, which were kindly made available by Mr. L.F. de Wet. They showed NaCl to be the dominant component (about 60% of the total salts), with the sulphates of Ca, Na and Mg making up about 10%, $CaCl_2$ (in one case only) about 3% and $CaCO_3$ (in all cases) about 1%. The author has identified halite (NaCl) by X-ray diffraction as the salt responsible for the salt encrustations and powdering of the base on this road (Samples 2377, 2381, 2381A and 2381B). Thenardite (Na_2SO_4) was also identified from some calcrete gravel road materials in the Ondangua area (Samples 1605 and 1608). The pH of calcretes is sometimes found to be above 8.6, indicating that Na_2CO_3 or $NaHCO_3$ is also sometimes present.

As both calcretes and soluble salts are products of the arid and semiarid environment, it can be expected that calcretes at an early stage of development (calcified soils, powder calcretes and nodular calcretes) may be saline, and Table 3.22 shows this to be true. Hardpan calcretes and especially boulder calcretes are usually found at well-drained pites, so that any salts which they may have contained will have tended to become leached out.

D.3 DELETERIOUS SALTS

The only salts known to the author which have actually given trouble have been NaCl in rainwater catchments surfaced with a thin bitumen layer in Western Australia (Cole and Lewis, 1960) and on the Operet-Ondangua road in South West Africa; probably Na_2SO_4 in the vicinity of chainage 67,000 on the Lincoln Highway near Whyalla in South Australia (Smith, 1962) and on the O'Okiep-Steinkopf road

in/ ...

in South Africa (Weinert and Clauss, 1967) and probably $MgSO_4$ on roads in the Johannesburg area of South Africa (Weinert and Clauss, 1967), and gypsum. Smith implied that gypsum may have been the cause of the expansion and cracking of compressive test speciments of cement stabilized sandy loam (1.1% SO_3) derived from granite in the vicinity of chainage 95,000 on the Lincoln Highway and the Roads Branch of the South West Africa Administration is reported to have had trouble with gypsum in the Walvis Bay area of that country. The minor blistering and cracking experienced at an airfield near Walvis Bay has also been ascribed to the gypsum deliberately added to the crusher run base, and also possibly to the subbase (compacted gypsum), though other salts such as NaCl in the gypsum are more likely to have been the cause. The deleterious effect of sulphate groundwaters and all types of included sulphates (including gypsum) in concrete work (Fulton, 1964) (including concrete roads - Lossing, 1966), is well known, and Sherwood (1957, 1962) has found gypsum as well as other sulphates to be deleterious in cement and lime stabilized clays. On the other hand, Baudet et al (1959) have reported that bases containing 30-95% of finely divided gypsum (30-60% minus 0.08 mm) in the northeastern Sahara (50-150 mm of rainfall per annum) had given good service for the five years that they had been in service. Materials containing gypsum as coarse crystals were rejected. No reason was given for this. It is interesting to note that priming with a fluid cutback sometimes made the gypsum powdery "by eliminating its cohesion" so that this was abandoned in favour of a lightly sanded, viscous (150/200) cutback tack coat. These bases were apparently all unstabilized.

Mehra et al (1955), Chadda and Raj (1955) and Uppal and Kapur (1957) in a related series of papers plainly implied that Na_2SO_4, Na_2CO_3 and $MgSO_4$ are deleterious in roads. While not documented by case histories, these three salts were found to be deleterious in laboratory experiments

with unstabilized soil blocks and soil blocks stabilized with cement. It would appear that the effect of Na_2SO_4 is the most severe, followed by Na_2CO_3, and that $MgSO_4$ is the least deleterious of the three.

D.4 TESTING FOR SOLUBLE SALTS

D.4.1 Direct methods

A number of methods of determining soluble salt contents are in use and it is important to realise that they are likely to yield somewhat different results (Jackson, 1958). Classical methods all involve leaching the material with water, either crushed and ground or as it is to be used, and performing conventional chemical determinations upon the extract so obtained. The amount of water employed varies from a large excess to that required to just saturate the material, the latter being most commonly employed in pedological work. The former obviously extracts the most salts, particularly when crushed and ground material is employed. The temperatures employed also vary. As such common substances as calcium carbonate and gypsum are slightly soluble, it is obvious that materials containing such substances (such as calcretes) would yield results which are particularly dependant on the soil/water ratio and temperature employed. These classical methods are the most accurate, but are relatively lengthy. A rapid method found suitable on certain oxidised mine wastes was a simple pH determination (Weinert and Clauss, 1967). This method worked simply because the salts were associated with free acid. It is obviously unsuitable as a general method since it is merely a measure of the hydrogen ion concentration.

Ordinary chemical "silicate" analyses are unsuitable methods for the determination of soluble salts since they do not indicate whether the elements analysed for are in a readily soluble form.

The/ ...

The author suggests that two methods are necessary to cover the requirements of road construction: an accurate classical or instrumental (possibly such as the nephelometric method of the South West African Roads Department) method suitable for central laboratory use involving leaching with an excess of water so that when necessary, gypsum can be determined, and a rapid indicator test suitable for routine work in both central and field laboratories. The latter test should be capable of indicating whether the material is suitable for use in road construction, whether it should be rejected, or whether a more accurate determination or durability testing is required. Such a test is indeed available and has been used in agricultural soil surveying for many years. It simply involves the measurement of the conductivity of a standard volume and shape of saturated soil paste, and excluding soil preparation time, takes about one minute. In view of the convenience of conductivity and pH measurements as indicators of the amounts and types of soluble salts in calcretes and other materials, these tests and the variables influencing their results are dealt with in more detail in the following sections.

D.4.2 Durability testing of compacted specimens

The mere limitation of salt content to the limits suggested in the literature should not be completely relied upon, even when the salts present are properly determined by chemical analysis. The limits of 0.5% NaCl and 0.05% SO_4^{--} when occurring as Na_2SO_4 or $MgSO_4$ were determined by analysing the top inch or so of the base after upward migration and concentration of salts must have taken place. Limits determined in this way should therefore not really be applied to material before placing unless some safety factor is applied to allow for the migration of much of the salt into the upper portion of the base. In the absence of information as to the

extent/ ...

extent to which concentration can take place, such a safety factor must perforce be an arbitrary one. In preferring a limit of 0.2%, the West Australian Public Works Department (Cole and Lewis, 1960) were applying a safety factor of 2.5, which seems reasonable enough. Perhaps the 0.05% SO_4^{--} limit should also be reduced by the same factor to 0.02%. Weinert en Clauss (1967) have, however, not completely demonstrated that 0.05% is the best limit and the work of other authors such as Mehra and Uppal (1964) suggests that more sulphate is tolerable. It is not therefore considered necessary to reduce the 0.05% sulphate limit to 0.02% at this stage. The amount of migration which can take place is probably so variable, among other factors depending on the daily suction and temperature cycles in the base and the permeability of the surfacing, that no figure of universal application can be arrived at which would not in many cases be too stringent. It is estimated from a few conductivity measurements that the total salt content of the disintegrated upper inch of base under some uplifted and cracked patches of surfacing around chainage 191 on the Operet-Ondangua road has increased from a probable initial value of about 0.5% to 2% or more. In this case both the calcrete base and the compaction plus curing water were saline, each having contributed about half the salts.

In view of these uncertainties it is suggested that laboratory durability testing should be carried out on all samples which possess salt contents anywhere near the salt limits suggested. In the case of unstabilized soils with some clay content, merely subjecting compacted specimens to humidity and temperature changes as was done by Mehra and co-workers may be sufficient. In the case of soils which set up well with cement or lime the wetting/drying/brushing test (ASTM D559 or AASHO T135) has been found useful by Smith (1962). Unless the test methods are capable

of/ ...

of measuring gypsum (which the saturated paste conductivity method is not) this procedure should in any event be followed when cement or lime stabilization is to be employed. More than about 1.0% $CaSO_4$ calculated as SO_3 is probably deleterious in all cement or lime stabilized bases and more than 0.25% SO_3 when more than about 15% clay is present. The U.S. Bureau of Reclamation limits the gypsum in coarse concrete aggregate to 0.25% (Fulton, 1964). The effect of gypsum in bases will, however, be discussed in a later paper (Netterberg, 1969b).

What is perhaps really needed is a test which simulates the upward migration, crystallization, and hydration and dehydration sufficiently accurately to enable the salt limit to be decided on a more rational basis, each case being treated on its own merits.

D.5 SOIL PASTE CONDUCTIVITY AND PH METHOD

In pedological work this method is usually applied to the material simply screened minus $\frac{1}{4}$ inch or minus 2 mm (10 U.S. mesh), but it is suggested that in road construction the minus 0.420 mm (40 U.S. mesh) fraction be tested since this is already available for Atterberg limits and has been through a standard procedure. The soil fines preparation method must of course be one which cannot leach the material.

D.5.1 Description

The standard pedological soil paste method has been described by Jackson (1958), Davis and Bryan (1910), the Soil Survey Staff (1951), and Richards (1947). The method used in the author's laboratory on calcretes is described below and differs only from the pedological procedure in that minus 0.420 mm material is normally employed (or the minus 0.420 mm fines produced for example in the Los Angeles machine if a material is to be used as a crushed

base/ ...

base), the result is reported in absolute conductivity units instead of simply as the resistance or conductance of the filled soil cup, and the pH is measured directly after the conductivity reading by inserting a glass pH electrode into the soil paste still in the cup. Most of the conductivity measurements referred to in this work were carried out using a mains-powered, non-temperature-compensated Radiometer CDM 2d conductivity meter. A few were made using a portable, temperature-compensated Thornley & Yntema resistivity bridge. Thornley & Yntema manufactured soil cup cells were used in both cases. The cup holders supplied were found to yield an unreliable contact and holes were drilled in the sides of the chromium plated brass electrodes and banana plugs used instead. A mains-powered, temperature-compensated Metrohm E196 pH meter with a Metrohm EA120 UX glass electrode was used for pH measurements. The standard pH temperature is 25°C.

The method is as follows: about 100 grams of material is mixed with distilled water to the saturation moisture content so that while the soil past glistens on the surface no water collects in the hollows (requires 2-3 minutes). Alternatively, soil fines roughly at the liquid limit may be used if available. The paste is then allowed to stand for about 20 minutes after which its temperature is measured. The United States Bureau of Soils standard soil cup (cell constant 0.25) is then filled with paste and the conductance in micromhos or millimhos or the resistance in ohms measured by means of a suitable alternating current conductivity meter or resistivity bridge (1 minute). When required, the pH is then measured by inserting a glass electrode into the soil paste, agitating gently for one minute and noting the highest reading (1 minute). The measured conductance is then converted to absolute conductivity units (millimhos or micromhos per centimetre are convenient) by multiplying by the cell constant of 0.25 and then to the standard temperature of 60°F (15.8°C) by multiplying by a factor

derived/ ...

derived from Figure D.1 (or tables, or a formula - see Jackson, 1958). A similar procedure applies if a resistivity bridge is used except that the resistance is divided by the cell constant to convert to absolute units (ohm-centimetres). Resistance and resistivity are simply the reciprocals of conductance and conducitivity, the latter term in each case being employed where absolute units are used. A semiquantitative estimate of the total soluble salt content can then be made by means of Figure D.2, or Jackson's Table 10-1. It should be noted that Jackson's Tables 10-1 and 10-2 show resistance values, i.e. uncorrected for cell constant. Merely reporting the result in ohms or mhos only saves the small step of converting to absolute units, but the former seems to be common practice in pedological work on soil pastes. The total time required to carry out one conductivity and pH measurement and to estimate the percentage salt present is thus about 25 minutes, of which 20 minutes is equilibration time. When many samples are to be tested the equilibration time is of course not idle time and in practice five or more samples can be tested per hour, including time spent on cleaning the soil cups and pH electrode between samples.

The pH reading is not essential and could be dispensed with entirely if the information is not required. As an electric pH meter is relatively expensive and only the central laboratory would normally possess one, an alternative and very inexpensive procedure would be the use of pH indicator papers. These permit the pH to be assessed to within $\pm$ 0.2 units, which is quite good enough for most purposes and, in fact, this figure cannot be bettered on calcretes by using a pH meter.

An important point that should be realised in connection with conductivity measurements is that the method can only measure total salts and is furthermore unsuitable in the form outlined as a measure of slightly soluble salts such

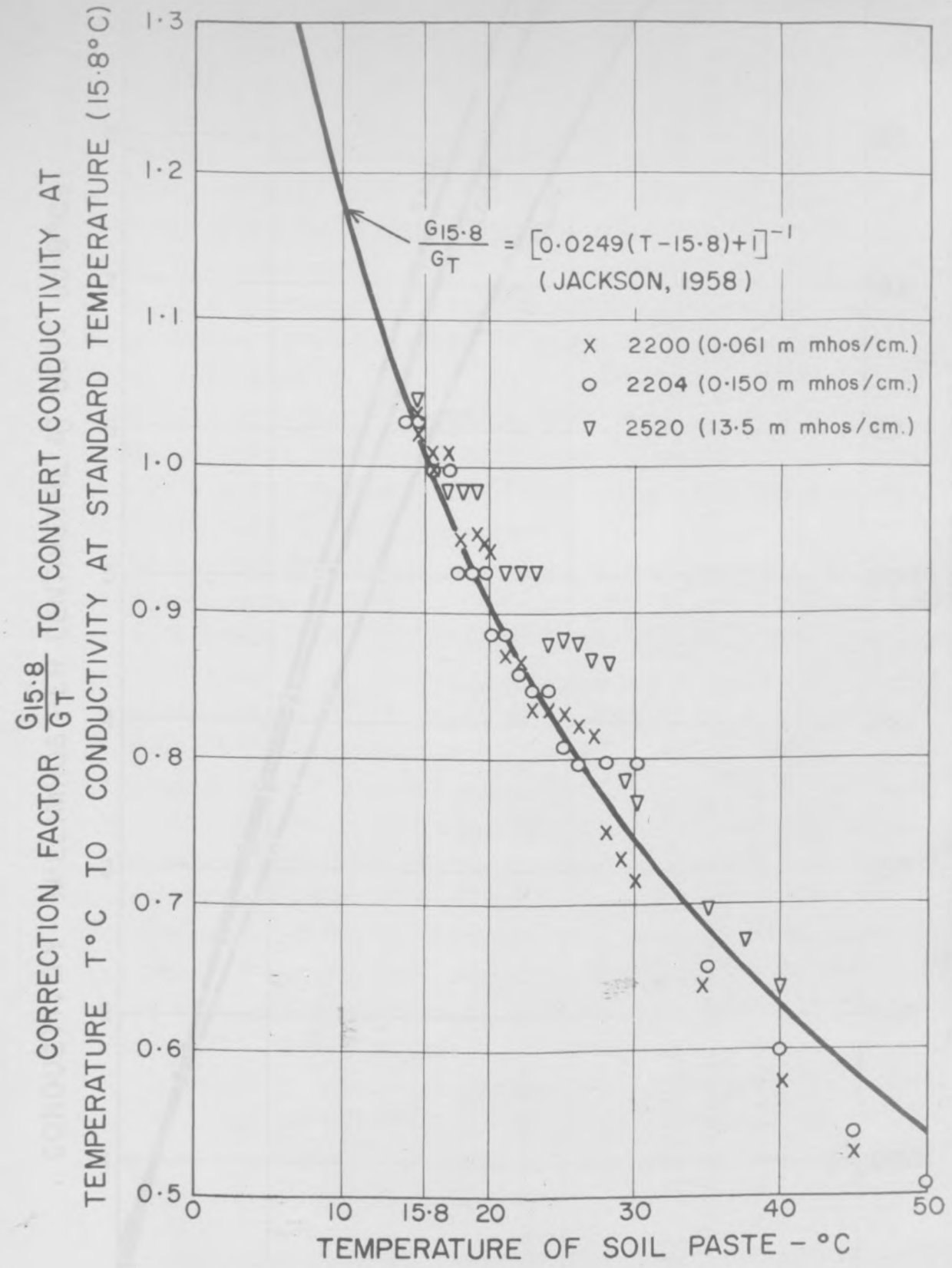


FIGURE D.1

Conversion of soil paste conductivity measurements on calcretes and other materials to the standard temperature of 60°F (15·8°C)

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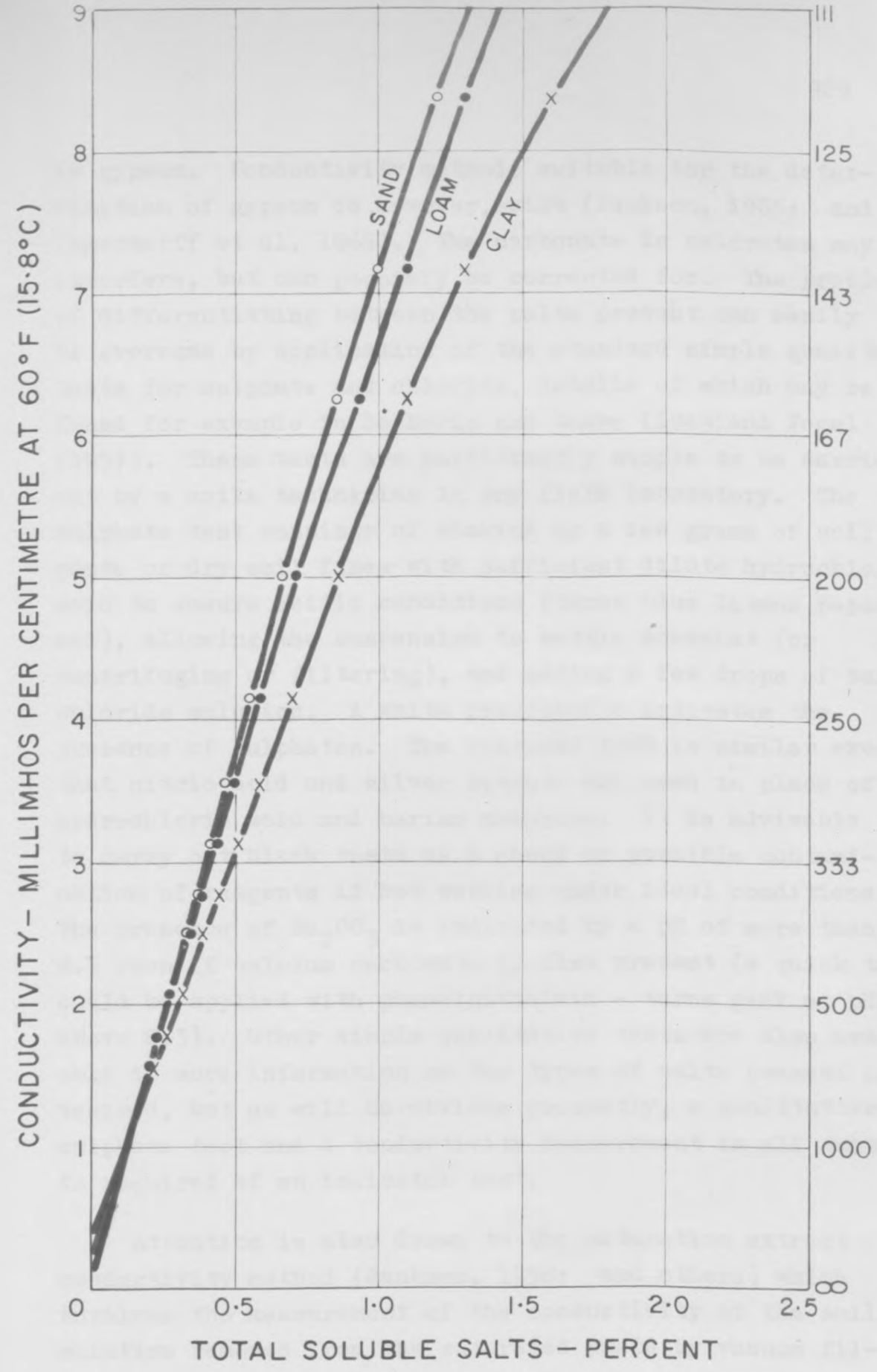


FIGURE D.2

Relation between soil paste conductivity and approximate soluble salt content.

(Calculated and plotted from data in Jackson, 1958)

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as gypsum. Conductivity methods suitable for the determination of gypsum do,however,exist (Jackson, 1965; and Lagerwerff et al, 1965). The carbonate in calcretes may interfere, but can possibly be corrected for. The problem of differentiating between the salts present can easily be overcome by application of the standard simple qualitative tests for sulphate and chloride, details of which may be found for example in De Mello and Lambe (1949)and Vogel (1957). These tests are sufficiently simple to be carried out by a soils technician in any field laboratory. The sulphate test consists of shaking up a few grams of soil paste or dry soil fines with sufficient dilute hydrochloric acid to ensure acidic conditions (turns blue litmus paper red), allowing the suspension to settle somewhat (or centrifuging or filtering), and adding a few drops of barium chloride solution. A white precipitate indicates the presence of sulphates. The chloride test is similar except that nitric acid and silver nitrate are used in place of hydrochloric acid and barium chloride. It is advisable to carry out blank tests as a check on possible contamination of reagents if not working under ideal conditions. The presence of Na_2CO_3 is indicated by a pH of more than 8.6 even if calcium carbonate is also present (a quick test could be applied with phenolphthalein - turns pink at pHs above 8.3). Other simple qualitative tests are also available if more information on the types of salts present is desired, but as will be obvious presently, a qualitative sulphate test and a conductivity measurement is all that is required of an indicator test.

Attention is also drawn to the saturation extract conductivity method (Jackson, 1958; and others) which involves the measurement of the conductivity of the soil solution removed from the saturated paste by vacuum filtration. This is more accurate than the paste method and in pedological work is used either in place of the latter or

as a supplement to it when more accurate results are required. It is a little more trouble to carry out, but a portable vacuum filter and conductivity bridge have been described (Richards, 1955a, 1955b). McCoy (1958) has also proposed a conductivity method for use on road materials which is designed for use on minus 2 mm material with a soil: water ratio of 1:5 and a simple brass electrode. While his method would be better when gypsum is present, the saturated paste method is, however, probably at least as reliable, has been an established method for seventy years or more, and has the advantages that it can be applied to the soil fines left over from a liquid limit determination without any further preparation and that apparatus is already available commercially.

D.5.2 Conductivity limits for base course

An interpretation of soil paste conductivity results on minus 0.420 mm (minus 40 U.S. mesh) calcrete fines and minus $\frac{1}{4}$ inch material of any soil is given in Table D.2. The minus $\frac{1}{4}$ inch material should be measured at the saturation moisture content, but any moisture content between about saturation (1-2 blows in the liquid limit device) and that corresponding to the consistency at which up to 30 blows in the liquid limit device is required to close the groove seems satisfactory for calcrete minus 0.420 mm fines. The effect of moisture content on the conductivity of other materials has not been determined.

The figures given in Table D.2 correspond roughly with the 0.2% NaCl and 0.05% SO_4^{--} as Na_2SO_4 (0.074%) or $MgSO_4$ (0.063%) suggested by Cole and Lewis (1960) and Weinert and Clauss (1957) respectively, and assume that no salts are added in the compaction or curing water. Mehra and Uppal (1964) specified 0.15% SO_4^{--} for bases and subbases stabilized by Mehra's method (a mechanical method), including that added by the construction water. No limit is available

for/ ...

TABLE D.2 SUGGESTED INTERPRETATION OF SOIL PASTE CONDUCTIVITY READINGS ON BASE AND SUBBASE MATERIALS

CONDUCTIVITY (mmhos/cm)		EQUIVALENT TOTAL SALT CONTENT (%)	INTERPRETATION
ANY -¼" FRACTION	CALCRETE* -0.420 mm FRACTION		
> 1.5	> 1.8	0.2	Reject the material
0.6-1.5	0.7-1.8	0.06-0.2	Test for SO_4^{--} with $BaCl_2$. Accept if absent. If present determine SO_4^{--}.** Accept if < 0.05%
< 0.6	< 0.7	0.06	Accept the material

* Ideally only nodular calcretes, but probably not critical.

** By analysis of the saturation extract, in order to minimise the effect of gypsum.

for Na_2CO_3, but Table D.2 effectively specifies a maximum of 0.2% Na_2CO_3. This may possibly be too high. A maximum of 0.5% NaCl for a sandy clay soil, equivalent to a minus ¼ inch conductivity of 3.5 and a calcrete minus 0.420 mm conductivity of 4.3 mmhos/cm. is permissible in the top one to two inches of base itself (Cole and Lewis, 1960). The water extraction method employed by Weinert and Clauss involved an excess of water, so that some of their results will have been influenced by the solution of gypsum. The calcrete minus 0.420 mm figures were derived simply by multiplying the minus ¼ inch fraction figures by the average ratio of the minus 0.420 mm conductivity to the minus ¼

inch/ ...

inch conductivity (1.22) of the nodular calcretes in Table D.8. It is not possible at present to give minus 0.420 mm limits for materials in general since the author is unaware whether the factor 1.22 is a universal factor applying to all soils. If it is not the universal factor it is not likely to differ greatly from it. Information may be available on the influence of the size fraction for some soils in the early literature on the method, for references to which see Jackson (1958) and Davis and Bryan, 1910). It is suggested, however, that roads authorities should carry out a few simple experiments on the effect of moisture content and size fraction on the conductivities of saline soils in their areas with a view to establishing conductivity testing of soil fines paste surplus from the liquid limit determination as a routine test. The presence of possibly deleterious quantities of all the very soluble salts like NaCl, Na_2SO_4, Na_2CO_3 and $MgSO_4$ can then be detected in a routine manner which only adds about one minute to the liquid limit test.

D.5.3 Procedure for testing waters

The procedure for estimating the total dissolved salt content of water is little different from that of the procedure on a soil paste. The only differences are that the soil cup or some other conductivity cell is filled with water instead of soil paste, no equilibration time is necessary, and a different curve (Figure D.3) used to estimate the salt content from the conductivity. In most work, conductivity of waters is reported at 20 or 25°C, but it is convenient to use the same temperature curve (Figure D.1) as for soils and to report it at 60°F (15.8°C). Figure D.3 or a factor derived from it (0.09 at 60°F) is more convenient than the Table 10-2 given by Jackson. Slightly greater accuracy may be attained by using a 2% degree C temperature correction (Jackson, 1958) rather than the 2.49% used to construct Figure D.1. It should, however, be noted that the total dissolved solids in waters

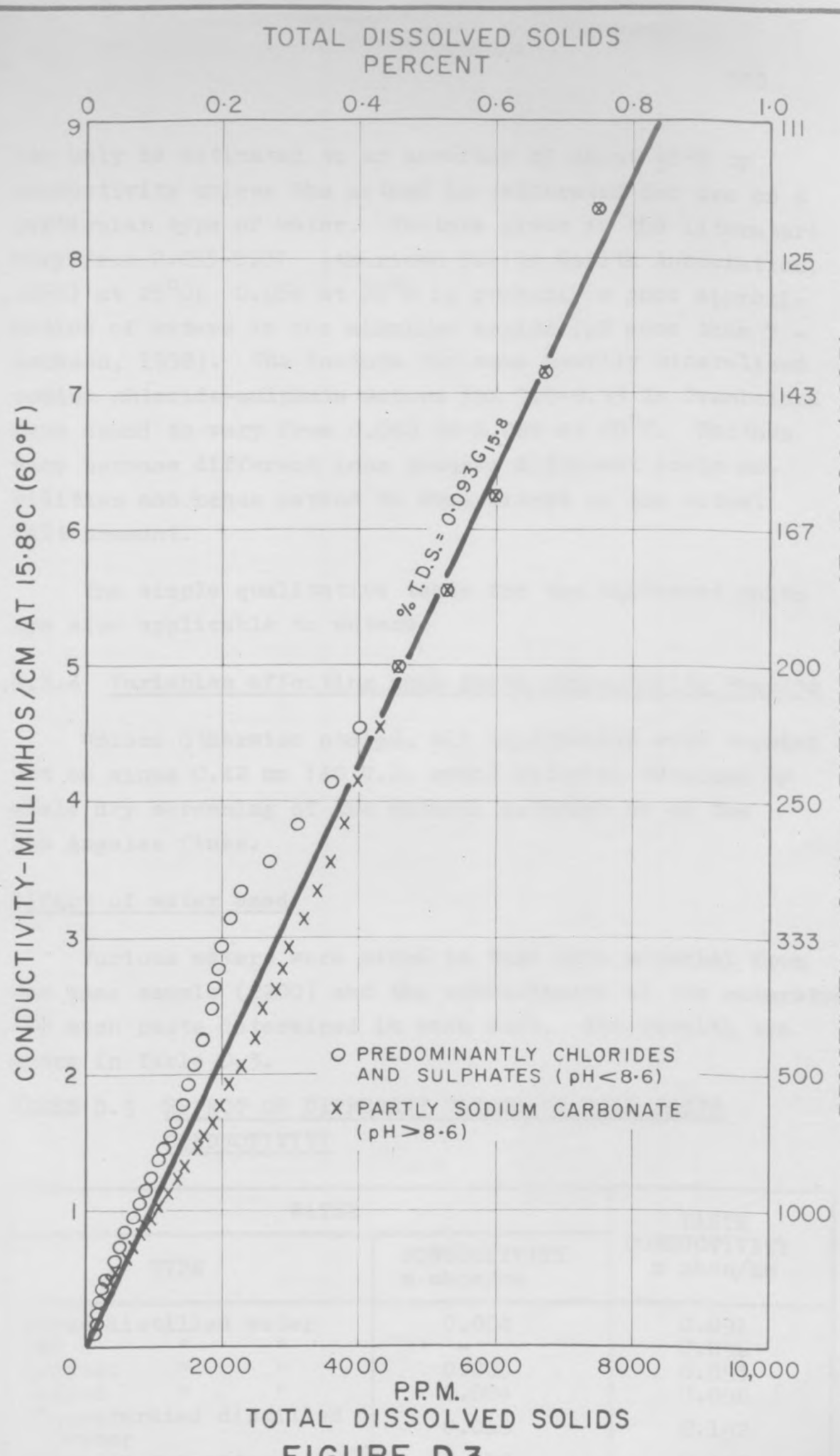


FIGURE D.3

Relation between conductivity of water and total dissolved salts. (Calculated and plotted from data in Jackson, 1958)

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can only be estimated to an accuracy of about ±15% by conductivity unless the method is calibrated for use on a particular type of water. Factors given in the literature vary from 0.055-0.07 (American Public Health Association, 1965) at 25°C; 0.064 at 25°C is probably a good approximation of waters in the alkaline region (pH more than 7 - Jackson, 1958). The factors for some heavily mineralised sodium chloride-sulphate waters (pH 7.5-8.9) in Ovamboland were found to vary from 0.060 to 0.084 at 20°C. Factors vary because different ions possess different ionic mobilities and hence depend to some extent on the actual salt present.

The simple qualitative tests for the different salts are also applicable to waters.

D.5.4 Variables affecting soil paste conductivity results

Unless otherwise stated, all experiments were carried out on minus 0.42 mm (40 U.S. mesh) material obtained by simle dry screening of the natural material or of the Los Angeles fines.

Effect of water used

Various waters were mixed in turn with material from the same sample (2200) and the conductivity of the saturated -40 mesh paste determined in each case. The results are shown in Table D.3.

TABLE D.3 EFFECT OF DIFFERENT WATERS ON SOIL PASTE CONDUCTIVITY

WATER		PASTE CONDUCTIVITY m mhos/cm
TYPE	CONDUCTIVITY m mhos/cm	
Fresh distilled water	0.004	0.091
Old " "	-	0.096
Aerated " "	0.003	0.093
Boiled " "	0.004	0.096
CO_2-saturated distilled water	0.018	0.192
Pretoria tap water	0.312	0.147

It can be seen that for all practical purposes the use of any ordinary distilled water has little effect. The maximum effect of using different distilled water is seen to be only 0.005 mmhos/cm. This figure applies to all strongly calcareous calcrete fines at the same moisture content and temperature and will not be affected by the other variables. CO_2- saturated distilled water and tap water were also tried for interest. Jackson (1958) specified that boiled-out distilled water should be used, but this seems unnecessary for routine work.

Effect of moisture content

While the method specifies that the soil should be at approximately the saturation moisture content and there is no great difficulty in achieving this, it was thought desirable to estimate the effect of extremes of moisture content. The results are shown in Table D.4.

TABLE D.4 EFFECT OF MOISTURE CONTENT ON SOIL PASTE CONDUCTIVITY

SAMPLE NUMBER	CONSISTENCY	CONDUCTIVITY m mhos/cm	DIFFERENCE %
1625	Thick paste	0.263	+5.2
	Approx. liquid limit	0.250	0.0
	Thin paste	0.238	-4.8
2200	Thick paste	0.088	-6.4
	Approx. liquid limit	0.094	0.0
	Thin paste	0.081	-13.8

Sample 1625 suggests that the maximum probable error likely to occur is $\pm$ 5%. Sample 2200 gave rather strange results which cannot be explained. As it would be most convenient if the conductivity could be determined directly

on/ ...

on paste left over from a routine liquid limit test, the effect of moisture content was then evaluated further, using a liquid limit device. The results are shown in Table D.5.

TABLE D.5 EFFECT OF CONSISTENCY ON SOIL PASTE CONDUCTIVITY

SAMPLE NUMBER	NO. OF BLOWS REQD. TO CLOSE GROOVE	CONDUCTIVITY mmhos/cm
2114	2 (saturated)	0.35
	10	0.36
	20	0.36
	23	0.37
	50	0.38
2116	2 (saturated)	0.27
	25	0.29
	35	0.29
2223	1 (saturated)	0.13
	21	0.14
	30	0.14
2367	1 (saturated)	3.1
	27	3.1
	50	3.3
2493	1 (saturated)	0.34
	28	0.33
2555	1 (saturated)	0.47
	20	0.46
	50	0.47

TABLE/ ...

TABLE D.6 MOISTURE CONTENTS AT SATURATION AND AT THE LIQUID LIMIT

SAMPLE NUMBER	MOISTURE CONTENT (%)		$\frac{w_{SAT}}{w_L}$
	SATURATION	LIQUID LIMIT	
1602	39	32	1.22
2114	44*	40	1.10*
2116	32	26	1.23
2223	35*	24	1.46*
2360	63	48	1.31
2367	45	31	1.45
2368	30	NP	-
2493	41	33	1.24
2555	46*	21	2.19*
2566	26	NP	-

* These figures may be slightly high, owing to the oven having overheated.

It can be seen that, as might be expected, the effect of decreasing the moisture content is generally to increase the conductivity. Within the range saturation to about 30 blows the variation is, however, small, the maximum being 8% (Sample 2223), and it would seem that it would make little difference in practice whether the conductivity is measured on a saturated paste or near the liquid limit. It should, however, be stated which is used, in order that decisions whether to accept or reject borderline samples can be facilitated. The effect of moisture content is smaller than might be expected, probably because the conductivity of a soil paste is not only dependent on the salt concentration in the soil solution (which would increase on drying if not already saturated with salt), but also on the amount of solution present. The two effects act of course in opposite directions, tending to minimise the

effect/ ...

effect of moisture content on conductivity.

The saturation moisture content of the soil paste seems to be about 1.1 to 1.4 times the liquid limit. The saturation moisture content determined as outlined is probably fairly closely equivalent to the field moisture equivalent (ASTM D426). If there is any difference, it should tend to be slightly higher than the field moisture equivalent.

Effect of equilibration period

The effect of equilibration period was investigated by taking readings at various intervals without removing the material from the soil cup. The results are shown in Table D.7.

TABLE D.7 EFFECT OF EQUILIBRATION TIME ON SOIL PASTE CONDUCTIVITY

SAMPLE NUMBER	TIME MINUTES	CONDUCTIVITY m mhos/cm
2200	0	0.066
	1	0.066
	5	0.065
	10	0.065
	15	0.065
	30	0.065
2204	0	0.157
	2	0.157
	6	0.157
	15	0.155
	45	0.156
	90	0.156
2520	0	13.9
	1	13.9
	5	13.9
	30	13.7
	60	13.7

TABLE D.7 (CONTINUED)

SAMPLE NUMBER	TIME minutes	CONDUCTIVITY m mhos/cm
1565	0	0.595
	1	0.595
	2	0.595
	5	0.595
	10	0.588
1569	0	0.294
	1	0.294
	45	0.403
1624	0	0.294
	2	0.400
1601	0	0.981
	1	1.02
	3	1.02
1533	0	2.00
	1	2.03
	2	2.34

It can be seen that the results are somewhat erratic and that in some cases the results did change with time. No further work was carried out on this aspect and the minimum equilibration time of 20 minutes advised by Jackson (1958) was adopted.

It was found that it made no difference whether the sample was equilibrated in the mixing dish or in the soil cup (Samples 2360, 2367 and 2368). As soil cups are rather expensive, the former procedure is the only practical one when a large number of samples are to be tested.

Effect/ ...

Effect of temperature

As all soil paste conductivity readings are reported at the standard temperature of 60°F (15.8°C) and, as it was known that the temperature coefficient depends on the ions in solution, it was considered advisable to check the published relation of

$$\frac{G_{15.8}}{G_T} = \{0.0249\ (T-15.8) + 1\}^{-1}$$

given by Jackson (1958).

The conductivity of three -40 mesh calcrete pastes was accordingly measured at various temperatures. The temperature was adjusted by either immersing the soil in initially hot water and allowing it to cool, or by immersing it in initially iced water and allowing it to warm up. The temperature was measured by a permanently inserted thermometer. The experimental setup, though crude, was considered adequate for a rough check on the formula. The results are shown in Figure D.1. It can be seen that while a certain amount of scatter is evident, and that at higher temperatures the correction factor is somewhat dependent on the conductivity of the sample in question, the three calcretes obeyed the published relation adequately well over the temperature range likely to be encountered during conductivity measurements in Southern Africa. The published relation read off from Figure D.1 was therefore used on all samples. The drift, or rather the apparent lag in the results as the specimens were cooled down is presumably due to the fact that, as the thermometer bulb was in the middle of the specimen, it was always warmer than most of the specimen at any given moment. The fit would undoubtedly be improved by cooling very slowly. The use of Figure D.1 was found to be more convenient than applying the formula given by Jackson (1958).

Effect/ ...

Effect of size fraction tested

Table D.8 shows the effect of the size fraction tested on the conductivity of six nodular and one powder (Sample 2360) calcrete. The minus $\frac{1}{4}$ inch (6.35 mm) and minus 10 U.S. mesh (2 mm, 0.0787 inch) fractions are the sizes normally employed in pedological work, while it is suggested that measurements on the minus 40 U.S. mesh (0.420 mm, 0.0164 inch) fraction are the most convenient in roads work. In order to be able to relate a conductivity measurement on a particular size fraction to the published salt limits determined on water extracts of crushed and ground material, the whole calcrete sample was also crushed and ground minus 40 mesh. The solubilities of all the deleterious salts except $CaSO_4$ salts are so great that it is thought that this comparison is valid. As the factors influencing soil paste conductivity are believed to be soil texture, type of clay mineral and type of salt, the samples were chosen to represent base course to fill gradings and soil constants, all the known calcrete clay mineral combinations, and a range of conductivity and pH. The types of salts present were not identified, but are considered to be mostly NaCl with some Na_2SO_4, together with Na_2CO_3 in the case of those samples which yielded a pH greater than 8.6.

TABLE D.8 EFFECT OF THE SIZE FRACTION TESTED ON THE CONDUCTIVITY OF NODULAR CALCRETES

SAMPLE NUMBER	-40 MESH CONDUCTIVITY mmhos/cm	$\frac{G_{40}}{G_{10}}$	$\frac{G_{40}}{G_{\frac{1}{4}}}$	$\frac{G_{40}}{G_{\#}}$
1602	2.25	1.09	1.25	1.18
2116	0.28	0.99	1.18	1.14
2360	1.88	1.07	1.12	1.20
2367	3.21	1.05	1.32	1.32
2368	0.92	1.18	1.26	1.02
2493	0.36	1.03	1.13	1.05
2566	0.27	0.98	1.26	1.29
Mean	-	1.06	1.22	1.17

Analist: Mr. J. Klinck

$G_{\neq}$ = Conductivity of whole sample crushed and ground minus 40 mesh

G_{40} = Conductivity of minus 40 U.S. mesh fraction

G_{10} = Conductivity of minus 10 U.S. mesh fraction

$G_{\frac{1}{4}}$ = Conductivity of minus $\frac{1}{4}$ inch fraction.

It can be seen that the relations between the conductivities of the various size fractions are sufficiently constant to enable interconversion with reasonable accuracy. It is also interesting to note that in most cases the conductivity of the minus $\frac{1}{4}$ inch fraction approximates closely to the conductivity of the whole sample crushed and ground to minus 40 mesh. It seems therefore that it is quite unnecessary to go to the length of crushing and grinding a sample for this type of work. It is also apparent that the salts are mostly concentrated in a free form in the fines rather than as a coating around or bound up inside the nodules.

Reproducibility and variability

The reproducibility and operator variability of soil paste conductivity measurements on calcretes have not been experimentally assessed, but inspection suggests that the combined effect of both will seldom exceed $\pm$10%.

Relation between conductivity and percentage soluble salts

After converting the conductance or resistance at the temperature of measurement to the standard temperature, a semiquantitative estimate of the percentage salts soluble at the moisture content of the saturated paste can be made by means of the table given by Jackson (1958) - see Figure D.2. The relation depends on the actual salts present, the texture of the soil and the types of clay minerals present. Calcretes probably contain mostly NaCl, with lesser Na_2SO_4 and, in some cases, Na_2CO_3, for which Figure D.2 is said

to/ ...

to be valid. Base and subbase materials should fall between the sand and loam curves. The clay minerals present in the samples used to construct Figure D.2 were probably similar to those found in most calcretes. While the indications are therefore that Figure D.2 should be valid for calcretes except at very low conductivities (due to the background conductivity of about 0.07 mmhos/cm of the carbonate), a few checks made by adding known quantities of NaCl and Na_2SO_4 to calcretes of very low conductivity suggested that the use of Figure D.2 might result in an overestimation (by up to 50%) of the salt content of some calcretes. It is therefore desirable that a check calibration curve for calcretes should be established, preferably by vacuum filtration of the saturated paste, evaporating down and drying at 105°C. X-ray diffraction and/or quantitative chemical analyses should be made on the residue in order to determine the salts present.

D.5.5 Variables affecting soil paste pH results

The errors involved in pH determinations on soils have been discussed by a number of authors (see for example Whitney and Gardner 1943; Raupach, 1954; Yaalon, 1957; Turner, 1958; Jackson, 1958; and Ponnamperuma et al, 1966). The pH of a calcareous soil can be expected to increase with dilution and decreasing P_{CO_2}*. Pure $CaCO_3$ when dissolved in CO_2-free water yields a pH of 9.95 at 25°C. In equilibrium with atmospheric air (P_{CO_2} = 0.0003 or 0.03% CO_2 by volume) a pH of only 8.31 is reached, while in equilibrium with soil air (P_{CO_2} = 0.001-0.01) the pH will lie between 7.8 and 7.3 (Yaalon, 1957). Yaalon concluded that "in calcareous soils differences in the range of pH 7.0-8.5 are meaningless unless the measurements are made under standard conditions with respect to CO_2 and Ca ion concentration". Raupach (1954) concluded that "pH measurements can be considered to no greater accuracy than ± 0.1

unit/ ...

* See Figure 4.5

unit ..." and the American Public Health Association (1965) found that the standard deviation on a water sample having a pH of 7.3 sent to 30 laboratories was 0.13 pH units.

It would generally appear that it is desirable to use a method which uses 0.01M $CaCl_2$, 0.015M $CaSO_4$, or aerated distilled water (aerated with outside air, not laboratory air), either a 1:5 soil: water ratio or a saturated paste, and that an equilibration time of up to one hour might be necessary. Furthermore, agitation of the suspension or electrode also appears necessary. While the pH of calcretes is probably not a particularly important property, a few simple experiments were nevertheless carried out in order to assess the probable error involved. The general method adopted was outlined in Section D.5.1 and the results are presented below.

Effect of water type

In order to determine the effect of water type on the pH obtained, the pH of a 50:50 AR $CaCO_3$ (calcite): quartz sand mixture, one calcrete and one weathered dolerite was determined using ordinary distilled water, aerated distilled water, boiled distilled water, 0.01M $CaCl_2$ and 0.015M $CaSO_4$. The results are shown in Table D.9.

TABLE D.9 EFFECT OF LIQUID TYPE ON pH

LIQUID TYPE	LIQUID pH	CALCITE/QTZ. MIXTURE	CAL-CRETE	WEATHERED DOLERITE
Distilled water	5.9	8.6	8.5	7.8
Aerated distilled water	6.8	8.6	8.4	8.0
Boiled distilled water	6.4	8.6	8.5	7.9
0.01M $CaCl_2$	6.2	7.4	7.9	7.6
0.015 M $CaSO_4$	6.0	7.5	8.0	7.5

Analyst: Mr. D. Margetson

It/ ...

It can be seen that the water type had little effect on the calcite/quartz mixture and the calcrete tested and only made a difference of 0.2 units on the weathered dolerite As might be expected, the distilled water containing the least CO_2 (as shown by its relatively high pH) yielded the highest sample pH. The $CaCl_2$ and $CaSO_4$ solutions gave results in close agreement with each other. Yaalon (1957) found calcareous soils ranging in pH from 7.2 to 7.8 with 0.01M $CaCl_2$. Results with 0.015M $CaSO_4$ were up to 0.2 units lower. Most calcareous soils tested had a pH close to 7.5, while those containing Na_2CO_3 had a pH of 8.0 or more (all with $CaCl_2$ or $CaSO_4$). Addition of NaCl had little effect on the pH.

It was eventually decided to use ordinary distilled water for all pH and conductivity determinations.

Effect of equilibration time

It was noticed that the pH reading often varied slightly with time. A few experiments were therefore carried out to determine the effect of this parameter (Table D.10).

It can be seen that the pH reading does vary by up to 0.2 units with time. Whether it decreases or increases probably depends on the extent to which the distilled water used is in CO_2 equilibrium with the laboratory air. It was eventually decided to carry out the pH determinations directly after the conductivity measurements and to allow a one minute equilibration time with the electrode being gently agitated in the soil paste during this time, the highest reading being the one taken. In practice it is found that the readings nearly always increase during the first minute and Table D.10 may represent exceptional conditions. When pH measurements were made without prior conductivity measurements (such as those in Table D.10) an equilibration time of one minute was allowed. According to

Jackson (1958), for most purposes the pH reading can be taken without any equilibration time.

TABLE D.10 EFFECT OF EQUILIBRATION TIME ON pH READINGS

SAMPLE NUMBER	TIME minutes	pH
2204	0	8.40
	0.5	8.50
	1	8.54
	2	8.55
2200	0	8.65
	0.5	8.65
	5	8.59
	10	8.60
2520	0	8.16
	1	8.17
1624 -10#	0	8.47
	1	8.42
	5	8.34
1569 -10#	0	8.14
	1	8.07
	5	8.00
	12 hours	7.75
1567 -10#	0	8.20
	1	8.15
	5	8.05
1625 -10#	0	8.67
	1	8.61
	5	8.54
1602 -10#	0	8.70
	1	8.69
	5	8.67
	12 hours	8.54
1601 -10#	0	8.54
	1	8.52
	5	8.41
2520	0	8.0
	1	8.04
	5	8.12

In another experiment carried out for the author by Mr. D. Margetson the pH of the three samples in Table D.9 was measured at daily intervals for two weeks using various liquids. The calcite/quartz mixture and the calcrete were found to vary in pH by up to 0.5 units during this time, although this was exceptional and for most of the time the pH remained within 0.2 units of its initial value. When these results were plotted (not shown) a sympathetic variation was observed. The specimens in which $CaCl_2$ and $CaSO_4$ were used showed the least variation. No definite trend in the pH was observed during this time, in contrast to the weathered dolerite, the pH of which had risen by about 0.6 units after 5 days. The specimen in which $CaCl_2$ was used rose the least (0.3 units).

In another experiment on the liquids alone, their pHs were measured at hourly intervals for five hours. The pH of the distilled water, $CaCl_2$ and $CaSO_4$ solutions was found to vary by up to 0.3 units during this time while the pH of the aerated and boiled distilled waters dropped erratically by about 1 unit - presumably due to CO_2 takeup from the laboratory air. In another experiment to test the effect of temperature over the range 24-27°C, the boiled and aerated waters dropped in pH by about 1 unit as the temperature was increased, while the other liquids tended to vary erratically with a slight upward trend by about $\pm$0.2 units.

It can be concluded from the work described so far that Yaalon's (1957) conclusion seems unduly pessimistic, and, while results do vary with CO_2 content, reasonable results are nevertheless obtained in practice. For all practical purposes, the system can probably be considered to be in equilibrium with the atmosphere thus fixing P_{CO_2} and, in the case of calcretes, also the Ca ion content.

Effect/ ...

Effect of moisture content

It was noticed that the pH tended to increase with dilution of the soil paste with water and Table D.11 represents an attempt to assess the effect of this. All readings were taken after a one minute equilibration time.

TABLE D.11 EFFECT OF MOISTURE CONTENT ON SOIL PAST pH

SAMPLE NUMBER	pH AT VARIOUS CONSISTENCIES			
	THICK PASTE	APPROX. LL	THIN PASTE	THIN CREAM
2204	8.4	8.3	8.5	8.5
2520	7.92	8.17	8.17	8.17
2200	-	8.65	8.60	-

It can be seen that while readings do alter with dilution, the effect is not particularly serious. Table D.12 shows the results of an experiment using the liquid limit device to control consistincy.

TABLE D.12 EFFECT OF CONSISTENCY ON SOIL PASTE pH

SAMPLE NUMBER	NO. OF BLOWS REQD. TO CLOSE GROOVE	pH
2114	2 (saturated) 23	7.82 7.83
2116	2 (saturated) 35	8.00 7.94
2223	1 (saturated) 21	8.30 8.35
2367	1 (saturated) 27	9.13 9.05

TABLE D.12 (CONTINUED)

SAMPLE NUMBER	NO. OF BLOWS REQD. TO CLOSE GROOVE	pH
2493	1 (saturated) 28	8.06 8.07
2555	1 (saturated) 20	7.78 7.78

It can be seen that the effect of moisture content over the range from saturation to that requiring about 30 blows to close the groove is generally negligible, though it may be up to 0.08 units, also negligible for most purposes.

Effect of temperature

The effect of temperature on the pH of calcretes was not experimentally assessed as the pH meter used possessed a built-in temperature compensator which merely had to be set to the test temperature. Apart from the usual factors affecting pH, the pH of a calcrete can be expected to increase with temperature to a maximum of about 10 as the CO_2 is driven off.

Effect of size fraction tested

Table D.13 shows the effect of the size fraction tested on the pH.

It can be seen that the pH of the different size fractions tested remains constant within the limits of experimental error. The pH of the whole sample ground -40 mesh is, however, in every case significantly higher, by up to nearly one unit. The reason for this is obscure. It may possibly be due to release of an alkali carbonate from the nodules or due to the grinding (it is known that an

abrasion/ ...

abrasion pH differs from a paste pH).

TABLE D.13 EFFECT OF THE SIZE FRACTION TESTED ON THE pH

SAMPLE NUMBER	pH			
	-1/4"	-10 mesh	-40 mesh	GROUND -40 mesh
1602	8.30	8.35	8.40	8.80
2116	7.95	8.00	7.95	8.05
2360	8.70	8.84	8.84	9.05
2367	9.00	9.05	9.05	9.25
2368	7.74	7.82	7.84	7.96
2493	8.05	8.10	8.05	8.25
2566	7.90	7.85	8.00	8.75

Effect of cleaning procedure

It was found that fairly careful cleaning of the glass pH electrode was necessary between samples if residual carry over to the next sample was to be entirely eliminated. Washing five times with distilled water followed by one wipe with a clean tissue was found adequate to cause the electrode to yield the same reading on a distilled water specimen that it had prior to insertion into the calcrete paste for pastes up to a pH of 9. For pastes with a pH above 9, one wash in water, followed by one wash with a very weak acid (one drop of dilute HCl in 10-20 ml of water) followed by three water washes and a wipe was found adequate.

While the above procedure will eliminate all carry over, it is only really necessary when dealing with samples with a pH above 9 or when a very weakly buffered system is to be measured. For routine work on calcretes, merely washing down the electrode in a stream of distilled water from a wash bottle until the pH reading approached that of the

water/ ...

water was found to be rapid and effective. In all cases the wipe may be dispensed with provided the washing is adequate.

Reproducibility and variability

The reproducibility and operator variability of soil paste pH measurements on calcretes have not been experimentally assessed, but inspection suggests that the combined effect of both will seldom exceed ±0.2 units, which is quite adequate for most purposes.

D.6 CONDUCTIVITY AND pH OF CALCRETES

The results of soil paste conductivity and pH measurements on some calcretes and a few other materials are shown in Tables D.14-D.21. All determinations were carried out on the saturated paste of the minus 40 mesh (0.42 mm) fraction dry screened from the natural calcrete or the Los Angeles fines unless otherwise stated. Values for the whole sample ground minus 40 mesh can be obtained for some samples from Tables D.8 and D.13.

It will be observed that in some cases two determinations were carried out on the same sample. The second value does not represent an attempt to assess reproducibility or operator variability, but is merely another result available from some other experiment ostensibly on the same sample. In practice, the sample actually used could, however, have come from another bag, a slightly different part of the same stockpile in a borrow pit and have been determined by a different operator. The results may therefore reflect sample variability as well as reproducibility and operator variability. Most of the conductivity and pH work was carried out by the author, with a little by Mr. J. Klinck, Mr. K. Meadows and Mr. T.E. O'Connor.

For comparison, the conductivity and pH of AR grade $CaCO_3$ were found to be 0.07 mmhos/cm and 8.6 respectively.

TABLE D.14 CONDUCTIVITY AND pH RESULTS - CALCIFIED SANDS

SAMPLE NUMBER	CONDUCTIVITY mmhos/cm	ph	REMARKS
895	2.3	9.2	
1625	0.25	8.6	
2531	1.10	7.7	
2531	0.90	7.7	$-\frac{1}{4}$"
RANGE (-40 mesh)	0.25-2.3	7.7 - 9.2	3 samples

TABLE D.15 CONDUCTIVITY AND pH RESULTS-POWDER CALCRETES

SAMPLE NUMBER	CONDUCTIVITY mmhos/cm	pH	REMARKS
902	21.3	8.5	
1020	0.19	8.1	
1557	0.56	8.2	
1696	0.48	8.2	
2223	0.14	8.2	
2360	1.6,1.9	8.7,8.7	
RANGE (-40 mesh)	0.14-21.3	8.1 - 8.7	6 samples

TABLE D.16 CONDUCTIVITY AND pH RESULTS - NODULAR CALCRETES

SAMPLE NUMBER	CONDUCTIVITY mmhos/cm	pH	REMARKS
978	1.71	8.1	
1016	0.17	8.1	
1024	0.53	8.0	
1513	0.33	8.0	
1514	0.36	7.9	
1516	0.25	8.0	
1533	2.0	-	
1561	2.4	8.2	

TABLE D.16 (CONTINUED)

SAMPLE NUMBER	CONDUCTIVITY mmhos/cm		REMARKS
1565	0.55,0.60	7.8	
1569	0.29	8.1	
1601	1.0	8.5	
1602	1.9, 2.3	8.7,8.7	
1624	0.29	8.5	
1980	0.42	8.3	
1981	2.5	8.8	
2114	0.34	7.9	
2116	0.28,0.31	8.4,8.0	
2367	2.4, 3.2	9.0,9.0	
2368	1,3, 0.92	8.0,8.0	
2478≠	1.8, 2.1	8.6,8.5	
2479≠	0.35,0.25	8.1,8.1	
2480≠	0.40	7.9	
2482≠	0.35	7.9	
2483≠	0.45	8.0	
2484≠	0.4	7.8	
2486≠	7.4	9.6	
2493	0.33.0.36	8.0,8.0	
2555	0.46	8.0	
2566	0.27,0.22	8.0,7.9	
2588	0.35	7.8	
2689	0.64	7.7	
1569	0.25	7.6	-¼"
2532	1.10	8.2	-¼"
RANGE (-40 mesh)	0.17-7.4	7.7-9.6	31 samples

≠ These samples have not been entered in Appendix B as no other work has been carried out on them. They are, in order, from borrow pits number 3,7, 7, 1, 10, 9, and 6 on the Operet-Andoni section of the Tsumeb-Ondangua road (Trunk Route 1/10) in South West Africa.

TABLE D.17 CONDUCTIVITY AND pH - TUFACEOUS HARDPAN CALCRETES

SAMPLE NUMBER	CONDUCTIVITY mmhos/cm	pH	REMARKS
1530	0.19	8.4	LAA fines
1642	0.18	10.0	" "
1724	0.61	9.1	" "
1828	0.18	-	" "
2224	0.36	-	" "
RANGE (-40 mesh)	0.18-0.61	8.4-10.0	5 samples

TABLE D.18 CONDUCTIVITY AND pH RESULTS - OTHER HARDPAN CALCRETES

SAMPLE NUMBER	CONDUCTIVITY mmhos/cm	pH	REMARKS
1562	0.09	9.5	LAA fines
1658	0.10	9.4	" "
2200	0.10	8.7	" "
2204	0.15	8.8	" "
2225	0.13	8.9	" "
2226	0.08	8.6	" "
2227	0.15	8.1	" "
RANGE (-40 mesh)	0.08-0.15	8.1-9.5	7 samples

TABLE D.19 CONDUCTIVITY AND pH RESULTS - BOULDER CALCRETES

SAMPLE NUMBER	CONDUCTIVITY mmhos/cm	pH	REMARKS
1028X	0.16	9.9	LAA fines
1627	0.06	9.2	" "
2228	0.14	8.2	" "
RANGE (-40 mesh)	0.06-0.16	8.2-9.9	3 samples

TABLE D.20 CONDUCTIVITY AND pH RESULTS - CALCRETE MIXTURES

SAMPLE NUMBER	CONDUCTIVITY mmhos/cm	pH	REMARKS
977	0.50	8.1	
1019	0.24	8.2	
1022	0.55	8.0	
RANGE (-40 mesh)	0.24-0.55	8.0-8.2	3 samples

TABLE/ ...

TABLE D.21 CONDUCTIVITY AND pH RESULTS - SPECIAL SAMPLES

SAMPLE NUMBER	DESCRIPTION	CONDUCTIVITY mmhos/cm	pH	REMARKS
890	Mixture of silcrete and sandstone	0.41	9.2	LAA fines
890C	Dolomitic sandstone	0.33	9.3	" "
1833X	Nosib quartzite?	0.05	7.9	" "
2533	Top of primed lime stabilized calcrete base	0.29	8.2	-1/4"
2381A	Material disintegrated by crystal growth from 2381	13.2	7.7	-1/4"

D.7 ENGINEERING USES OF CONDUCTIVITY AND pH

Conductivity is basically a measure of the total concentration of dissolved ions present in a soil of water, while pH is basically a measure of the hydrogen versus hydroxyl ion concentration, or acidity and alkalinity. The conductivity is essentially proportional to the percentage soluble salts present. pH is the reciprocal of the common logarithm of the hydrogen ion concentration The pH scale goes from 0 to 14, 7 being the neutral point at which the concentration of hydrogen and hydroxyl ions are both equal to 10^{-7} gram ions per litre. A pH of less than 7 indicates acidic conditions, while more than 7 indicates alkaline conditions.

D.7.1 Conductivity

The uses of conductivity measurements can be summarised as follows:

1) Conductivity provides an extremely rapid semi-quantitative indication of the total dissolved salt content of a soil or water.

2)/ ...

2) Together with pH it has been used in predicting the life of metal culverts (Benton and Stratfull, 1962).

3) It forms the basis of a rapid method for estimating the lime or cement content of stabilized soils and concrete (Le Clerc and Sandall, 1960).

4) A few experiments by the author (Section 8.14.5) suggest that conductivity can be used as a rapid test for lime-reactive calcretes. Lime-calcrete mixtures which react rapidly with lime to yield very high early strengths fall much more rapidly in conductivity than do slow-reacting lime-calcrete mixtures. This work unfortunately remains incomplete, and precise instructions for the test cannot yet be given.

D.7.2 pH

The uses of pH measurements can be summarised as follows:

1) A low pH indicates an acid reaction, indicating the probability of corrosion of steel and attack on concrete and lime and cement stabilized soils.

2) A high pH generally means less steel corrosion and of course no acid attack on concrete or stabilized basis is possible. An alkaline water may, however, deposit $CaCO_3$ scale in pipes.

3) A pH between about 7.5 and 8.6 indicates the probable presence of calcium carbonate. A pH above 8.6 indicates the presence of sodium carbonate in a natural soil and lime (or cement) in a stabilized soil.

4) The pH forms the basis of the rapid method of Eades and Grim (1966) for determining the lime requirements of a soil.

5) Together with conductivity the pH has been used for estimating the life of metal calverts (Benton and Stratfull, 1962).

6)/ ...

6) The pH gives an indication of the type of clay minerals present and the type of weathering which the soil is undergoing (see Wooltorton, 1954).

7) The pH of fresh and weathered dolorite may be used as an indicator of decomposition and stabilization requirements (Clauss, 1967).

8) When soluble salts are associated with free acid (as in oxidised mine wastes), the pH may be used as an indicator of the presence of excess soluble sulphates (Weinert and Clauss, 1967).

9) Requirements for water purification.

10) As an indicator of the degree of base saturation, the pH affords an indication of the amount of certain stabilizers required (Wooltorton, 1954).

11) Under certain circumstances the pH is indicative of probably bacterial action in cement, resinous, and bituminous soil mixtures (Wooltorton, 1954).

12) In detergent-moisture stabilization work, the pH can be used as an indication as to whether an anionic or cationic additive should be used (Wooltorton, 1954).

13) In natural soils, a high pH usually indicates that little organic matter is present, but that soluble salts may be present; while a soil with a low pH (less than 5.3 - Robbins and Mueller, 1960) is more likely to possess organic matter deleterious in cement and lime stabilization work, but will usually be free of soluble salts. See however also (8) above. pH forms the basis of the BS 812:1967 method of detecting deleterious organic matter in fine aggregate for concrete.

D.8 CONCLUSIONS

1. NaCl, Na_2SO_4 and to a lesser extent Na_2CO_3 and $MgSO_4$ are likely to be the predominant soluble salts found in natural road construction materials. In addition,

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the relatively insoluble salt $CaSO_4$ is common in some soils and oxidised mine waste rocks and $MgSO_4$ and iron sulphates have also been recorded from oxidised mine waste rock. All of these salts and their hydrates, as well as others, are deleterious if present in sufficient quantities in the road structure. NaCl, Na_2SO_4, Na_2CO_3 and $CaSO_4 . 2H_2O$ have been identified from calcretes

2. Calcretes should always be tested for soluble salts before use as base course, binder, subbase, premix filler or surfacing chips.

3. A procedure combining a simple conductivity measurement and a simple qualitative test for sulphate is probably adequate for the routine field and central laboratory checking of soils, waters and crushed rocks for road construction. The procedure given requires no more than about five minutes when applied to water or to soil paste during a routine liquid limit determination and is probably suitable for all the deleterious salts except gypsum and anhydrite.

4. Limits on the salt content of a completed base must allow for the upward migration and concentration of salts below the surfacing. The degree of concentration is, however, probably variable and, in addition, salts can migrate upwards from the subgrade into a non-saline base. The first case calls for the limitation of salt content to be supplemented by some form of durability testing if the limits are not to be unduly conservative in many cases. The second case calls for a road design which prevents the upward migration of salt from the subgrade.

5. Much remains to be learned concerning the behaviour of soluble salts in roads.

6./ ...

6. Using the procedure given, the reproducibility and operator variability of saturated soil paste conductivity and pH measurements on calcretes are probably normally less than ±10% and about ±0.2 units respectively.

7. Important variables affecting conductivity results were found to be the size fraction tested, minimum equilibration period and the moisture content at testing, all of difficulties which are overcome by employing a standard procedure. The pH was affected far less by the above variables than the conductivity. It may possibly, however, be increased by grinding.

8. The salts in calcretes tend to be concentrated in a free form in the fines and the coarser fractions and the aggregate itself are relatively much less saline.

9. Calcretes at early stages of development like calcified soils, powder and nodular calcretes, are much more likely to be saline than well developed calcretes like hardpans and boulders. Little information is available on the types of salts in calcretes.

10. The curve relating soil paste conductivity to soluble salt content has not been adequately checked in the case of calcretes. In all probability, however, the soluble salt content of any material can be estimated to within about ±20% by this method, which should be adequate as an indicator test.

11. Tentative maximum minus 40 mesh conductivity limits for calcrete base course materials of 1.8 and 0.7 mmhos/cm are suggested for NaCl and SO_4^{--} (when present as Na_2SO_4 or $MgSO_4$) respectively, assuming the compaction and curing water to be non-saline.

12. Conductivity and salt limits for compaction, curing and concrete waters should be assessed for each particular case, taking note of the salinity of the base material as well as the amount and types of salts likely to be added by the water.

APPENDIX E

X-RAY DIFFRACTION ANALYSES

E.1 METHOD

All X-ray diffraction analyses were carried out by means of a Philips recording diffractometer using copper Kα radiation and a nickel filter at a scanning speed of half a degree θ per minute. In most cases the standard flat sample holders supplied with the instrument were used and the powdered specimen (ground -270 U.S. mesh) compacted and smoothed with a glass microscope slide. This procedure probably resulted in a fair degree of preferred orientation being achieved when flaky minerals were present. Good diffraction patterns were also obtained using ordinary petrographic thin sections, even after staining with acidic Alizarin Red S. A specially made sample holder only 0.25 mm (0.01 inches) deep instead of the usual 1.5 mm was also found useful when only small quantities of material were available. The holder was made simply by milling a slot of standard size (except for the difference in depth) into a piece of $1\frac{1}{2}$ mm sheet aluminium of the same size as the standard flat powder holder. Use of this shallower sample holder did not give rise to any aluminium peaks, reduction in peak intensities or increase in background.

Preparation of minus two micron (0.002 mm) fractions

Minus two micron (0.00008 inch) fractions of unconsolidated calcretes were prepared during mechanical analysis by withdrawing some of the suspension with a dropper or pipette after the 2 micron reading and allowing it to dry at room temperature on a glass slide. These oriented specimens were first X-rayed untreated and then used for the glycollation procedure (24 hours in vacuo at room temperature in a desiccator with the desiccant replaced by ethylene glycol) and for heating to 550-600^{o}C for one

hour/ ...

hour. This was standard procedure unless otherwise noted. The remaining minus 2 micron material was then collected by siphoning off the remaining suspension until most was withdrawn or until the hydrometer reading altered by up to 20% of its 2 micron reading. The suspension was then evaporated down at 50°C and passed though a 270 U.S. mesh sieve. The oriented specimen was used for identification purposes and the powder mainly for estimating the quantities present. As calcretes tend to flocculate during mechanical analysis, the usual NIRR dispersant of tetrasodium pyrophosphate (NIRR, 1966) was used. The results do not seem to have been affected by the dispersant, which did not even show up in the diffraction analyses. Some ion exchange may perhaps have taken place, but as the clay minerals in calcareous soils are almost fully calcium saturated (Robinson, 1949), they will probably be little affected by a cation of lower value such as the sodium of the dispersant. Some phosphate fixation might have taken place, however. Brown (1961) stated that phosphate dispersants can be used in separations for clay determinations and did not mention any disadvantages in their use. He went on to state that separations without the use of a dispersant can be made by prior washing out of all soluble salts by centrifugation. A better method of removing the water from the siphoned-off suspension would perhaps have been by vacuum distillation at relatively low temperatures or by centrifugation. The former is very slow at room temperature.

Small quantities of montmorillonite may be overlooked if only the 2 micron and not the 0.08 micron fraction is examined (Jackson, 1956), but for the purposes of this project the former procedure is considered adequate.

Preparation of specimens of the coarser calcrete particles for clay mineral analysis

Clay minerals present in the coarser calcrete particles like nodules, hardpans, etc., were normally identified using only the partly oriented powder specimens. In the

case/ ...

case of particularly interesting samples (such as those which appeared to contain glauconite) oriented specimens were also prepared simply by shaking up the -270 mesh powder in water, applying it to a glass microscope slide with an eyedropper and allowing it to sediment and dry at room temperature. This procedure resulted in satisfactory results being obtained in most cases, but sometimes yielded no better results than the standard powder method. When very small quantities of clay are present, prior removal of the carbonate by means of Amberlite IRC-50 ion exchange resin (or less desirably IRC-120), in preference to dilute acids (Lloyd, 1954; Satyabrata et al, 1957) is possibly the best procedure. Use of ion exchange resin apparently increases the clay yield and minimises acid alteration. Such a technique might also be applicable to the concentration of acid-susceptible reaction products such as tobermorite in stabilized calcretes. An alternative procedure for clay mineral analysis of calcretes and limestones which is simpler and it is claimed results in the detection of down to 0.1% clay, involves a sedimentation separation of the powdered sample somewhat similar to that already described for unconsolidated material (Bisque and Lemish, 1958; Gipson, 1966). A modified version of this procedure on a smaller scale using 100 ml cylinders, air dispersion, 5 gms of -270 mesh powder and 2 ml of the pyrophosphate dispersant was used on Samples 8900, 1639, 1693, 1725, 1727, 1728 and 2549 and was found to have little advantage over the simpler orientation procedure already described. It is apparent that for best results the carbonate must be removed prior to sedimentation.

Identification of clay minerals

The diffraction criteria used in the identification of carbonates, quartz, etc., are too well known to need enumerating here. The criteria applied to the clay minerals, however, are not so well known and in fact the author failed to find any succint account of them in the literature.

The/ ...

The following criteria were compiled after a study of Grim (1953), Johns and Grim (1954), Jackson (1956), Brown (1961) and Mackenzie and Mitchell (1966). The effect of heat treatment at 600°C on the hormites does not seem to have been previously recorded in the literature and stems from experience gained during this project. Glycollation as already described and heat treatment to 550-600°C for 1 hour was adopted as standard treatment. The oriented slides were usually used for both glycollation and heat treatment. It seemed to make little difference with the samples tested whether the glycollated slide was heated or whether a separate slide was used. The latter procedure is probably the safest in the absence of definite information on the effect of glycollation on subsequent heat treatment of clays in general and was used on most samples. It is apparently essential when swelling chlorites are dealt with. 2:1 layer lattice minerals can be divided into dioctahedral and trioctahedral types on the basis of the exact spacing of their (060) peaks (Jackson, 1956), but this was not done in this study.

Mr. J.J. de Wet kindly supplied much useful advice on investigational methods, interpretation of results and on clay mineralogy in general.

Kaolinite: 7.2Å peak which remained unchanged on glycollation but disappeard on heating to 550-600°C. The 7.2Å peak is not affected by heat up to 450-500°C (450° according to Jackson, 1956) for 30-45 minutes. Halloysite is apparently the only kaolinite mineral which might survive heating to 600°C.

Chlorite: 14Å peak which remained unchanged on glycollation or heating to 550-600°C. Swelling chlorites might swell by 0.6-2.7Å on glycollation, but always collapse to 14Å on heating. A 7Å peak stable to 500°C indicates either chlorite or antigorite (Jackson, 1956).

Degraded/ ...

Degraded chlorite can apparently be distinguished from bentonite montmorillonite by the fact that, after magnesium saturation with $MgCl_2$ and drying at 110°C, the degraded chlorite peak collapses and does not expand on glycollation like montmorillonite.

Montmorillonite group (Smectites, Montmorillonoids, Montmorillonite-Saponite group): Peak at >14.7Å air dry or 17Å peak after glycollation which was replaced by a 10Å peak on heating to 550-600°C.

Illite (hydromica): 10Å peak unchanged on glycollation or heating to 550-600°C. The presence of the iron-rich variety glauconite was confirmed by an illite diffraction pattern, a reaction for ferrous iron when the cold dilute HCl extract of freshly ground material was tested with potassium ferricyanide, a green colour in the hand specimen or powder which changed to brown on heating to 550-600°C and the absence of any other green mineral confirmed by X-ray diffraction. It was found essential to use freshly ground material for the ferrous ion test. Material which was several weeks old invariably gave no reaction, even if still bright green. Some work on a standard qualitative procedure for differentiating glauconite from illite would be justified. The method used above for ferrous iron would for example also have liberated ferrous iron from ferroan dolomite.

Extremely sharp and narrow 10Å peaks were taken as being micas and not illites.

Degraded illite can apparently be distinguished from bentonitic montmorillonite by the fact that, after potassium saturation with KCl and drying at 110°C, the degraded illite peak collapses and does not expand on glycollation like montmorillonite.

Hormites/ ...

Hormites: Sepiolite was distinguished by a 12.2Å peak which remained unchanged on glycollation, but which either disappeared or became seriously subdued on heating to 550-600°C, together with the appearance of a second peak at 9.8Å. Several peaks (7.5, 6.7, 5.0) were also characteristic of sepiolite.

Palygorskite (attapulgite)* was distinguished by a 10.5Å peak which was unchanged by glycollation and which disappeared or became seriously subdued on heating to 550-600°C. Several other peaks (6.44, 5.42) were also characteristic of palygorskite.

Neither of the hormites are apparently affected by heat up to 300°C.

Mixed layers: No great difficulty was encountered in identifying the different clay minerals when more than one was present. With the exception of one or two doubtful case, no peaks were encountered which could not be attributed to ordinary mechanical mixtures, as shown by the lack of assymmetric peaks and peaks exactly half way between other identifiable peaks. The identification of interstratified clays is, however, a tricky task and it is possible that a few of the clays identified as mixtures may in fact have been randomly stratified mixed layered minerals. The identification of interstratified clays has been discussed by Jackson (1956) and Brown (1961).

Amorphous minerals: The presence of a high background together with reduced peak intensity or the presence of vague "humps" was taken to be indicative of the presence of amorphous material. Jackson (1956) appears to also require a high specific surface and to consider only the intensity of the 4.45Å peak. Allophane is probably neither an important nor an aburdant component of calcretes, but small quantities of amorphous silica greatly influence their engineering properties. Methods for the detection and

* The original term 'palygorskite' is adopted here as it is still uncertain whether there is any difference between the two. Attapulgite may merely be short fibre palygorskite.

characterisation of amorphous minerals have been given by Jackson (1956), and scope exists for their application to calcretes.

Estimation of quantities present

The minerals identified were divided into major, minor and trace components with the limits between these arbitrarily set at about 20% and 5%. Thus for a mineral to classify as a major component for example, it alone must make up at least 20% by weight of the sample. The minerals also appear in each group in order of abundance as determined by peak heights compared with standards made up of calcite, dolomite, quartz, felspar and well-crystalline montmorillonite. It can be assumed that the quantities of non-clay minerals were roughly correctly estimated by this procedure, but it will have resulted in the underestimation of any poorly crystalline minerals present. Since so little information was available on even the qualitative mineralogy of calcretes, it was considered preferable to carry out a relatively large number of roughly semi-quantitative X-ray analyses rather than relatively few fully quantitative analyses. Quantitative X-ray diffraction procedures for dolomite-calcite mixtures have been given by Tennant and Berger (1957), for calcite, dolomite, quartz and clay mixtures by Diebold et al (1963), for calcite, dolomite and apatite mixtures by Bromberger and Hayes (1966) and for clay minerals by Johns et al (1954). A useful short discussion has also been given by Jackson (1956).

The petrographic descriptions in Appendix F should also be consulted where the fullest information on the mineralogy of a particular sample is desired. The mineral lists given there and their estimated quantities are to be preferred to Table E.1 since they are based on the results of all the methods used and not only on the diffractograms. Not all samples were examined petrographically however.

The/ ...

The detection limits of the X-ray diffraction apparatus used were not systematically determined, but appeared to be of the order of 1-2% for calcite, quartz, dolomite, felspar and well crystalline montmorillonite.

TABLE E.1 X-RAY DIFFRACTION ANALYSES

SAMPLE NUMBER	REMARKS	CRYSTALLINE COMPONENTS		
		MAJOR	MINOR	TRACE
890		Quartz	Nil	Felspar, dolomite?
890A		Quartz	Nil	Calcite
890B		Quartz	Nil	Felspar, glauconite, calcite
890C		Quartz	Dolomite, felspar	Nil
894	-40 mesh	Quartz	Calcite, montmorillonite	Nil
896	+40 mesh	Quartz, calcite	Nil	Montmorillonite, illite
896	-40 mesh	Quartz, calcite	Nil	Montmorillonite, illite?
898		Dolomite (probably ferroan), quartz	Nil	Calcite, felspar, glauconite
902	+40 mesh	Dolomite	Quartz	Palygorskite, felspar?
902	-40 mesh	Dolomite	Quartz, palygorskite	Felspar, illite?, montmorillonite?
904	See 1811	-	-	-
955		Dolomite (probably ferroan), quartz	Nil	Felspar, glauconite
991	See 1013	-	-	-
1000A		Calcite	Nil	Nil

TABLE E.1 (CONTINUED)

SAMPLE NUMBER	REMARKS	CRYSTALLINE COMPONENTS		
		MAJOR	MINOR	TRACE
1000B		Calcite	Nil	Quartz, felspar
1007		Calcite, quartz	Nil	Felspar
1013		Quartz	Felspar	Illite?
1019	-2 micron	Sepiolite, calcite	Dolomite, quartz?, palygorskite, amorphous silica	Nil
1022	-2 micron	Muscovite, calcite, sepiolite	Amorphous silica	Quartz?
1028A		Calcite	Dolomite, quartz	Nil
1028B		Dolomite	Calcite	Felspar, quartz
1028C		Dolomite	Calcite	Quartz?
1028D		Calcite, quartz	Dolomite	Nil
1028XA		Calcite, quartz	Nil	Nil
1028XB		Calcite	Quartz	Nil
1028XC		Calcite, quartz	Nil	Nil
1028XD		Calcite	Quartz	Nil
1515	+40 mesh	Calcite	Quartz	Nil
1515	-40 mesh	Calcite	Quartz	Nil
1533	-40 mesh	Quartz, felspar	Nil	Calcite?, dolomite?
1533	-2 micron	Palygorskite	Quartz, Calcite, kaolinite, chlorite	Phlogopite?
1562A		Calcite, quartz	Nil	Nil
1562B		Quartz, calcite	Nil	Nil
1567	+10 mesh	Calcite, quartz	Nil	Nil
1567	-10 mesh	Quartz	Calcite	Montmorillonite
1567	-40 mesh	Quartz	Calcite	Montmorillonite
1567	-2 micron	Poorly crystalline montmorillonite	Calcite	Quartz?, illite
1569	+10 mesh	Calcite, quartz	Nil	Clay

TABLE E.1 (CONTINUED)

SAMPLE NUMBER	REMARKS	CRYSTALLINE COMPONENTS		
		MAJOR	MINOR	TRACE
1569	-10 mesh	Calcite	Quartz	Illite?, montmorillonite?, felspar
1569	-2 micron	Calcite	Quartz, montmorillonite	Nil
1598		Calcite, quartz	Nil	Nil
1598A		Calcite, quartz	Nil	Nil
1601	+10 mesh	Calcite, quartz	Felspar	Montmorillonite, illite
1601	-10 mesh	Calcite, quartz	Felspar	Montmorillonite, illite
1601	-2 micron	Calcite, quartz, montmorillonite	Nil	Illite?
1602	+10 mesh	Calcite, quartz	Nil	Dolomite, felspar?, clay
1602	-10 mesh	Quartz	Dolomite, calcite	Clay
1602	-40 mesh	Dolomite, quartz, calcite	Nil	Clay
1602	-2 micron	Quartz, montmorillonite, calcite, dolomite	Nil	Nil
1603A		Calcite, quartz	Nil	Nil
1603B		Quartz, calcite	Nil	Nil
1605		Quartz, thenardite	Nil	Calcite, dolomite
1608		Quartz	Thenardite	Calcite, dolomite, hydrous mica?
1624	+10 mesh	Quartz, calcite, dolomite	Nil	Sepiolite?, clay

TABLE E.1 (CONTINUED)

SAMPLE NUMBER	REMARKS	CRYSTALLINE COMPONENTS		
		MAJOR	MINOR	TRACE
1624	-10 mesh	Quartz, calcite, felspar	Nil	Montmorillonite, palygorskite?
1624	-40 mesh	Quartz, calcite	Felspar	Montmorillonite, palygorskite
1624	-2 micron	Calcite, quartz	Montmorillonite, palygorskite	Nil
1625	-40 mesh	Quartz, calcite	Felspar, dolomite, montmorillonite	Nil
1625	-2 micron	Calcite, quartz	Felspar, dolomite, palygorskite, montmorillonite	Nil
1627A		Calcite, quartz	Palygorskite	Nil
1627B		Calcite, quartz	Nil	Felspar?
1627C		Calcite	Quartz	Clay
1638		Dolomite, quartz	Nil	Felspar, calcite
1639		Dolomite (probably ferroan), quartz	Nil	Felspar, clino-optilolite?, illite, calcite
1658		Dolomite, calcite	Felspar	Palygorskite?
1658A		Dolomite, quartz	Nil	Calcite, felspar
1658B		Calcite, quartz, dolomite	Nil	Felspar?, palygorskite
1658C		Dolomite, calcite, quartz	Nil	Clay
1693		Calcite	Quartz	Sepiolite, palygorskite
1694		Sepiolite	Nil	Quartz?, calcite?

TABLE E.1 (CONTINUED)

SAMPLE NUMBER	REMARKS	CRYSTALLINE COMPONENTS		
		MAJOR	MINOR	TRACE
1696		Dolomite, sepiolite	Calcite	Palygorskite
1715		Analcime	Glauconite, felspar?, quartz?	Halite?
1724A		Calcite, quartz	Nil	Nil
1724B		Calcite, quartz	Nil	Sepiolite?
1725		Calcite, quartz, dolomite	Nil	Felspar, illite?
1726	Hardest (inside) portion	Quartz	Nil	Calcite
1727		Quartz, calcite, dolomite	Nil	Nil
1728		Quartz, dolomite	Nil	Calcite, felspar
1746		Calcite, dolomite	Quartz, sepiolite?	Nil
1808		Quartz	Felspar, palygorskite	Dolomite?, calcite?
1810		Calcite, quartz	Felspar	Palygorskite?
1811		Quartz	Nil	Calcite
1825		Quartz, calcite	Felspar	Palygorskite
1828	Grey part only from A & C	Quartz	Calcite, amorphous silica?	Nil
1828	Cream sandy channel filling from A & C	Quartz	Calcite	Nil
1830		Quartz	Felspar	Palygorskite?
1833		Quartz	Nil	Felspar, amorphous hydrated iron oxide?

TABLE E.1 (CONTINUED)

SAMPLE NUMBER	REMARKS	CRYSTALLINE COMPONENTS		
		MAJOR	MINOR	TRACE
1833X		Quartz	Nil	Felspar, amorphous hydrated iron oxide?
1838		Quartz, calcite	Nil	Felspar, sepiolite?
1841		Sepiolite, calcite	Nil	Nil
1842		Sepiolite	Nil	Quartz, calcite?
1847A		Dolomite	Nil	Quartz
1847B		Dolomite	Sepiolite	Quartz
1859		Calcite	Quartz	Nil
1865		Dolomite	Quartz	Nil
1876	-40 mesh	Quartz, calcite	Nil	Felspar, montmorillonite?, palygorskite?
1881		Dolomite	Quartz, palygorskite	Calcite
1907		Calcite, quartz	Felspar	Nil
1926		Calcite, quartz	Felspar	Nil
1927		Calcite	Felspar, quartz	Sepiolite? kaolinite
1931		Calcite, quartz	Nil	Felspar?
1932		Gypsum, quartz, felspar	Calcite	Hydrous mica?
1940		Dolomite, quartz	Palygorskite	Nil
1945		Calcite, quartz	Nil	Felspar
1949		Quartz, calcite	Felspar	Kaolinite?
1950A	Matrix	Calcite	Quartz	Felspar
1950B	Matrix	Calcite	Quartz	Nil
1950C	Matrix	Calcite, quartz	Nil	Felspar
1961A		Amorphous matter?	Calcite	Nil

TABLE E.1 (CONTINUED)

SAMPLE NUMBER	REMARKS	CRYSTALLINE COMPONENTS		
		MAJOR	MINOR	TRACE
1961B		Amorphous silica?	Nil	Calcite
1962B - D	Hard dark inclusions	Calcite	Quartz, amorphous silica?	Nil
1962B - D	White soft matrix	Calcite	Quartz, felspar	Nil
2114	+40 mesh	Calcite	Nil	Quartz, illite?
2114	-40 mesh	Quartz, calcite	Palygorskite, montmorillonite?	Nil
2114	-2 micron	Calcite, montmorillonite, palygorskite	Quartz	Nil
2114L	-270 mesh foam	Calcite, quartz	Nil	Dolomite?
2114L	+270 mesh foam	Quartz	Calcite	Dolomite?
2116	+40 mesh	Calcite	Quartz	Clay
2116	-40 mesh	Quartz, calcite	Nil	Palygorskite?
2116	-2 micron	Calcite, palygorskite	Nil	Quartz
2123		Calcite	Nil	Quartz, montmorillonite, illite? kaolinite?
2200		Calcite	Quartz	Illite?, montmorillonite
2204		Calcite	Dolomite, (probably ferroan)	Quartz, montmorillonite, illite?, kaolinite?
2223	-	Calcite	Nil	Muscovite?, quartz
2223	Nodules	Calcite	Nil	Quartz

TABLE E.1 (CONTINUED)

SAMPLE NUMBER	REMARKS	CRYSTALLINE COMPONENTS		
		MAJOR	MINOR	TRACE
2223	+40 mesh	Calcite	Quartz	Clay
2223	-40 mesh	Calcite	Quartz	Montmorillonite, felspar
2223	-2 micron	Calcite, montmorillonite, vermiculite (mixed layer?), quartz	Mica, palygorskite	Nil
2224		Calcite	Nil	Quartz
2241A		Quartz	Nil	Apatite
2241B		Quartz	Nil	Apatite
2241C		Quartz	Nil	Apatite
2242		Quartz	Nil	Apatite, felspar
2244		Calcite	Quartz	Nil
2252		Quartz	Nil	Apatite, felspar?
2258A	Inside of outcropping nodule	Quartz	Nil	Apatite hydrous mica
2258B		Quartz	Nil	Felspar?
2259		Quartz, calcite	Nil	Felspar
2265		Quartz	Felspar, calcite	Nil
2318		Calcite, quartz	Nil	Nil
2325	Insoluble residue	Quartz	Nil	Felspar, clay
2341		Quartz	Calcite	Felspar, glauconite
2360	-40 mesh	Sepiolite, calcite, dolomite	Quartz, palygorskite	Felspar?
2360	-2 micron	Sepiolite	Dolomite, calcite, palygorskite	Quartz
2367	+40 mesh	Calcite, quartz	Dolomite (probably ferroan)	Illite?, montmorillonite
2367	-40 mesh	Quartz	Calcite	Illite?, ferroan dolomite?

TABLE E.1 (CONTINUED)

SAMPLE NUMBER	REMARKS	CRYSTALLINE COMPONENTS		
		MAJOR	MINOR	TRACE
2367	-2 micron	Calcite, illite, montmorillonite	Amorphous silica	Quartz?
2368	+40 mesh	Calcite, quartz	Nil	Illite?
2368	-40 mesh	Quartz	Calcite	Montmoril-lonite
2368	-2 micron	Calcite	Montmorillonite, quartz	Illite
2377		Halite, quartz	Nil	Calcite, dolomite?
2381A	Crys-tals	Quartz, halite	Calcite	Nil
2381B	Remain-der	Quartz	Calcite, halite	Nil
2381AB	General	Quartz, calcite	Halite	Sepiolite?, illite?
2493	+40 mesh	Quartz, calcite	Dolomite	Felspar, clay
2493	-40 mesh	Calcite, quartz, dolomite	Sepiolite	Palygor-skite?, illite
2493	-2 micron	Sepiolite, cal-cite	Dolomite, paly-gorskite?, amorphous sili-ca?	Quartz?
2513		Quartz, dolomite	Nil	Felspar?
2514		Dolomite	Quartz, calcite	Nil
2516A		Calcite	Nil	Quartz
2516B		Calcite	Nil	Quartz
2517A		Calcite	Quartz	Felspar
2517B		Calcite	Nil	Quartz
2517C		Calcite	Nil	Felspar?, sepiolite?, quartz?
2519		Calcite, quartz	Felspar	Nil
2520		Quartz, gypsum	Felspar?, halite, calcite?	Anhydrite?
2521		Calcite	Quartz	Hydrous mica?

TABLE E.1 (CONTINUED)

SAMPLE NUMBER	REMARKS	CRYSTALLINE COMPONENTS		
		MAJOR	MINOR	TRACE
2522		Calcite	Quartz	Hydrous mica?
2532		Quartz, calcite	Felspar	Nil
2533		Quartz, calcite	Nil	Nil
2534A		Quartz, calcite	Nil	Felspar, dolomite?
2534B		Quartz, calcite	Nil	Felspar?
2534C		Calcite, quartz	Nil	Nil
2541		Calcite	Nil	Quartz
2549		Quartz, Calcite	Sepiolite	Glauconite
2555	+40 mesh	Calcite, quartz	Nil	Felspar, palygorskite?
2555	-40 mesh	Calcite, quartz felspar	Palygorskite	Nil
2555	-2 micron	Hydrobiotite?, calcite	Quartz, palygorskite, illite	Kaolinite
2559		Glauconite, quartz	Nil	Halite?, dolomite?
2561	-2 micron	Quartz, amorphous silica?	Nil	Kaolinite
2566	+40 mesh	Quartz, calcite	Nil	Mica, felspar, kaolinite
2566	-40 mesh	Quartz	Calcite	Felspar, palygorskite, illite?, kaolinite
2566	-2 micron	Hydrobiotite?	Calcite, quartz?, palygorskite?	Kaolinite
2588	+40 mesh	Calcite, dolomite	Quartz, clay (mainly montmorillonite)	Felspar
2588	-40 mesh	Calcite, quartz	Total clay	Montmorillonite, dolomite, felspar, other clay minerals

TABLE E.1 (CONTINUED)

SAMPLE NUMBER	REMARKS	CRYSTALLINE COMPONENTS		
		MAJOR	MINOR	TRACE
2588	-2 microns	Calcite, poorly crystalline montmorillonite	Nil, or the poorly crystalline montmorillonite	Quartz, palygorskite?, illite?, dolomite?, felspar?
2588	-40 mesh LAA fines from $\frac{1}{2}$" -$\frac{3}{8}$" aggregate	Calcite, dolomite	Montmorillonite	Quartz
2689	+40 mesh	Calcite, quartz	Nil	Nil
2689	-40 mesh	Quartz	Calcite, Montmorillonite-illite mixed layer?	Felspar?
2689	-2 microns	Montmorillonite-illite mixed layer?, quartz	Kaolinite, calcite	Nil

APPENDIX F

PETROGRAPHIC DESCRIPTIONS

F.1 METHOD

Thin sections of the harder calcretes were made by means of conventional techniques. Friable calcretes were first impregnated with Lakeside 70C resin according to the method described by Van der Merwe in Weinert (1964). This usually resulted in satisfactory thin sections.

Owing to the difficulty of distinguishing between the carbonates in thin sections and the almost opaque nature of many, X-ray diffraction and Warne's (1962) and Dickson's (1965) staining schemes were employed to investigate the carbonate mineralogy and fabric. Dickson's scheme was used for thin sections and Warne's scheme for chips and blocks. Warne's times were found to be much too long for use on calcrete thin sections, but the scheme itself would presumably be suitable once adequately short times are found. It was found that assessment of colours in the dry state was advisable (a point on which no statement was made by either author and that even dolomite often stained a pale pink or mauve in the times given. The diffraction patterns of some of the dolomites indicated probable substitution,however, probably by Fe^{++}. Staining was not found to be entirely satisfactory in all cases, and the thin sections themselves were also often X-rayed for confirmatory evidence. A useful list of all published carbonate staining methods has been given by Wolf et al (1967b) and it is possible that other schemes may be entirely satisfactory. Glauconite was another mineral which did not occur in a manner amenable to petrographic determination. This mineral was confirmed by the olive green colour of the hand specimen, an illite diffraction pattern, a strong reaction for ferrous iron with potassium ferricyanide and the absence of any other possibly green mineral

detectable/

detectable by X-ray diffraction. Infrared absorbtion is also desirable, but was not used.

General scheme used

The following scheme was adopted for the thin section examination of calcretes:

Minerals: (authigenic, allogenic, chief, accessory).

Grain texture (size): (diameter of equant grains, 2 dimensions of elongated grains).

Cement texture (size): (macrocrystalline >0.2 mm, microcrystalline 0.2-0.01 mm, cryptocrystalline <0.01 mm).

Sphericity (shape): (equant, elongated).

Roundness: (angular, subangular, subrounded or rounded).

Crystallinity: (euhedral, subhedral, anhedral)

Orientation.

Packing: (grain/cement ratio, G/C)

Fabric (mainly spatial arrangement).

Recrystallization.

Replacement.

Alteration.

The cementing matrix texture scheme is that of Williams et al (1958).

In reading the descriptions it can be assumed unless otherwise stated that (allogenic) grain shapes vary between equant and elongated, (authigenic) carbonate crystal shapes are all anhedral (or too small to be discernible), grain roundness varies between subrounded and subangular (with the larger grains in a section tending to be subrounded and the smaller ones subangular), orientation of any sort, whether of the grains or in the cementing matrix, is completely lacking, that evidence of alteration and replacement is also lacking and that grains are randomly distributed

in the carbonate matrix. It can also be assumed unless otherwise stated that the coarser (usually five micron) calcite so often mentioned is interpreted as a recrystallization phenomenon. Recrystallization of finer calcite to coarser calcite is thus almost ubiquitous. Dolomite is incongruent in solution, so that it is quite feasible for some of it to be dissolved, the $CaCO_3$ reprecipitated and the more soluble $MgCo_3$ leached out. This is technically replacement, is less common and is mentioned as such. The grain/cement ratio (G/C) should not be confused with the grain-micrite ratio (G.M.R.) of Bissel and Chilingar (1967) intended for use on limestones. The grain-micrite ratio of a limestone is related to wave or current action while the grain/cement ratio of a calcrete is related to its stage of development, decreasing as development progresses. The terms 'cement' and 'matrix' as used here are synonymous, though it may perhaps be better to restrict cement to cases of high grain/cement ratio and 'matrix' to cases of low grain/cement ratio.

The grain/cement or grain/matrix ratio should also not be confused with the grading modulus (GM) of calcified soils, powder calcretes and nodular calcretes, which increases with development. (The grading modulus is the cumulative percentage retained on the U.S. No. 10, 40 and 200 mesh sieves divided by 100).

The fabrics of calcretes vary from truly clastic to truly non-clastic. Calcretes at an early stage of development like weakly calcified sands have essentially clastic textures. As development progresses, the content of cementing matrix increases (grain/cement ratio decreases) and in old hardpan and boulder calcretes (and even some nodules) the allogenic grains may have been virtually completely eliminated by mechanical and chemical replacement. Such non-clastic fabrics are normally cryptocrystalline granular.

Colours are strictly those observed under the Leitz Ortholux binocular petrographic microscope used and were

assessed/

assessed with the aid of the abbreviated Munsell soil colour chart of the Soils Research Institute. No filter was employed in the optical train.

Note

It should be noted that the minerals and their relative proportions listed under each petrographic description are not only those identified by petrographic means, but are all minerals identified with the aid of all the techniques employed (i.e. X-ray diffraction, staining, thin section examination and occasional other tests). Whether a mineral was actually observed in thin section will be mentioned in the description. Quantities were estimated from the semi-quantitative X-ray diffraction analyses in Table E.1 and from thin sections. Comparison with what chemical analyses are available (e.g. Table 3.19) shows that perhaps 5% of components (represented mainly by Al_2O_3, Fe_2O_3 and BaO) were being missed by this procedure.

At least two thin sections of each sample were normally examined.

F.2 PETROGRAPHIC DESCRIPTIONS

890A: Silcrete

Chief minerals: Chalcedony 80-90%
Quartz 5%
Calcite 5-10%

Accessories: Plagioclase

G/C: 1/9

Description: Chiefly made up of a pale olive - olive brown, cryptocrystalline, spherulitic cement of authigenic chalcedony. Scattered, subrounded, 0.5 mm, equant grains of allogenic quartz and plagioclase float in the matrix (cement) which also encloses irregular 0.01-0.02 mm.

patches/

patches of calcite in places. Many of the quartz grains show darker haloes, apparently indicating replacement of quartz by chalcedony. Many ghost structures very similar to the haloes also occur, as well as others of a very slightly oriented breccia-like nature suggesting some flow while in a gel state. Overgrowths of quartz also occur on a few of the quartz grains. Many black spots of unknown composition about 0.03 mm across are present. They do not appear to be ore minerals and may perhaps be carbonized organic matter.

Replacement: Calcite by chalcedony?
Quartz by chalcedony?

890B: Silcrete

G/C: 0

Description: Essentially similar to A except darker (light olive brown) in colour and without quartz and felspar grains. Many ghost structures and patches of dolomite. The glauconite presumably occurs only as a pigment.

890C: Dolomitic quartzite-sandstone

Chief minerals: Quartz 60%
Dolomite 30%
Felspar (microcline and plagioclase) 10%

Accessories: Occasional olive brown, rounded, spherical or banana shaped (1.0 mm x 0.15 mm) pellets of glauconite?

G/C: 7/3

Description: Equant to elongated, subangular to subrounded allogenic 0.3-0.5 mm quartz and felspar grains set in a light olive grey cryptocrystalline cementing

matrix/

matrix of dolomite. Occasional pellets of glauconite?

898: Dolocrete

Chief minerals: Dolomite 50%
Quartz 49%
Felspar 1%

Accessories: Calcite

G/C: 1/1

Description: Equant to elongated, subangular to rounded (mostly subrounded) 0.05-0.5 mm (mostly 0.1-0.2 mm) allogenic quartz and very rare felspar grains floating in an olive cryptocrystalline dolomite cement with a crystal size of about 0.003 mm. The specimen is on the whole very uniform in packing and colour. Rare veins of darker olive dolomite containing fewer sand grains do occur,however, as well as small patches of slightly coarser (0.01 mm) dolomite. Plate F.1.

Staining with acidic alizarin in the cold showed the calcite to be present as rare specks 0.01 mm or smaller in size. Etching alone failed to reveal its presence. A chip specimen stained very pale mauve in acidic alizarin and purple in strongly alkaline alizarin, indicating only the presence of dolomite (possibly slightly ferroan).

1000A: Banded Type 1 nodule

Chief minerals: Calcite 98%
Quartz 2%

Accessories: Biotite

G/C: 2/49

Description: Scattered subangular 0.02-0.03 mm. grains of allogenic quartz floating in a vaguely banded (lighter

and/

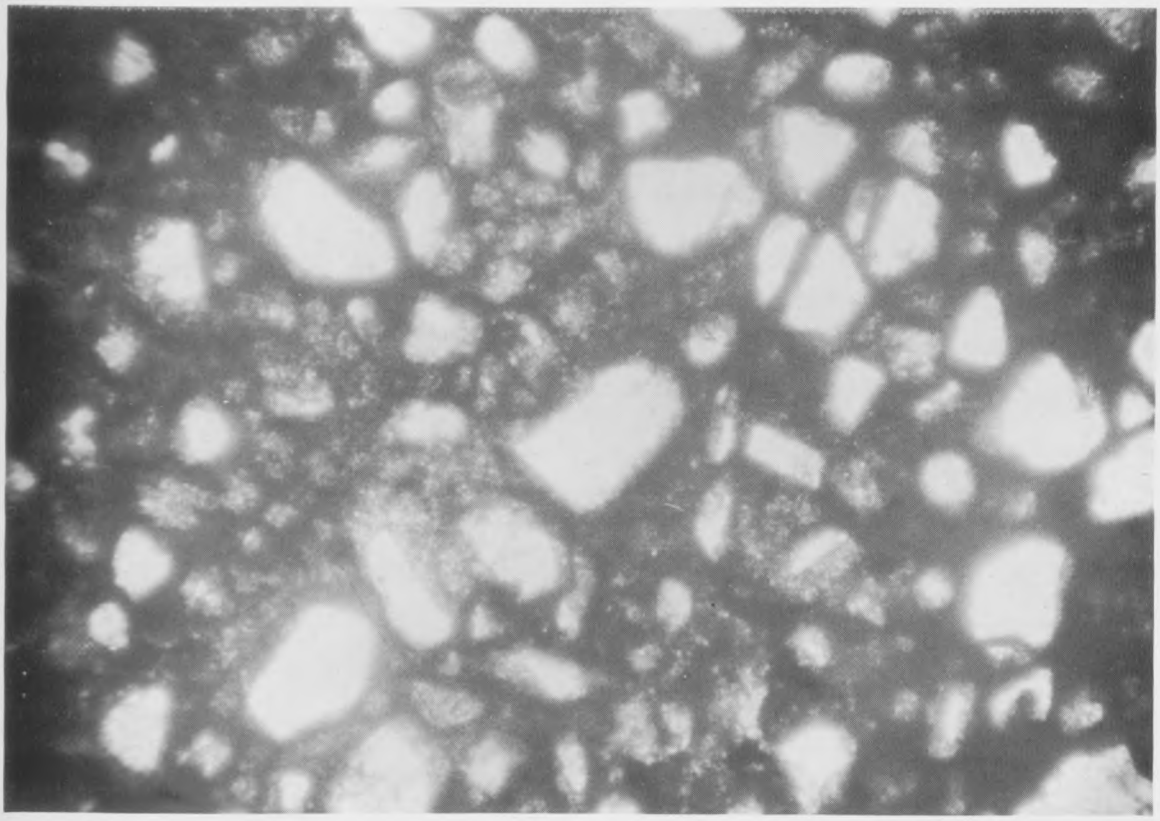


PLATE F.1

Thin section of a dolocrete nodule (Sample 898) at a fairly early stage of development. The quartz sand grains (light) are approximately at the stage where they are becoming pushed apart by the dolomite cement (dark). Ordinary light, X70.

and darker olive brown) cryptocrystalline (~1 μ) calcite cement.

1000B: Type 1 nodule

Chief minerals: Calcite 95%
Quartz 5%

G/C: 1/19

Accessories: Felspar?

Description: Chiefly made up of an olive brown cryptocrystalline (2 μ) cement with small irregular veins and patches of coarser (~5 μ) and lighter coloured calcite. The latter also occurs lining cavities and surrounding and probably replacing the few floating subangular 0.1 mm quartz grains.

Etching and staining using Dickson's method showed dolomite to be absent, in agreement with the X-ray diffraction results. Examination of the etched surface in reflected light also revealed the presence of a few allogenic coloured minerals which could not be distinguished from quartz in transmitted light. Even etching (which resulted in a considerable reduction in thickness of the calcite) failed to achieve any significant lightening of the masking effect of the olive brown colour. A few oolite-like structures and a few grains of ore (grey, metallic lustre) were also noted. No felspar was seen in the thin section examined.

Replacement: Quartz by calcite?

1028A: Laminated outer crust

Chief minerals: Calcite 90%
Quartz 10%

G/C: 1/19

Description: Vaguely banded, dark yellowish brown calcite (~1 μ) with scattered subangular 0.1-0.05 mm allogenic quartz grains. Etching showed the quartz grains to be present as lines, presumably contributing to the banded effect. Staining showed dolomite to be absent. That found in the diffraction analysis was probably incompletely separated 1028B. The quartz grains must be masked to some extent by the matrix since X-ray diffraction indicated that rather more than 5% quartz was present. Etching of a polished block of 1028 also brought out rather more than 5% quartz.

1028B: Hard boulder calcrete

Chief minerals: Dolomite 95%
Calcite 5%

Accessories: Quartz
Felspar

G/C: 1/19

Description: Almost entirely cryptocrystalline (~1 μ) olive brown dolomite with rare patches and veins of coarser (5 μ) calcite and extremely rare subangular 0.1-0.5 mm quartz grains. Occasional breccia-like ghost structures, the lighter coloured lines or veins which stained bright red with alizarin, showing them to be calcite. The patches and veins of coarser material also either stained bright red or showed scattered 5 μ red spots. The dolomite stained a duller red after 8 minutes. Plate F.2.

The coarser calcite is plainly a later phenomenon, related if not equal to 1028D.

No felspar was noted in the thin sections examined.

1028C: Softer boulder calcrete

Description: Identical to 1028B except for a somewhat more porous nature as shown by more voids now filled with

the/

the hardening medium. Calcitic veins are also perhaps more common.

1028D: Sandy vein

Chief minerals: Calcite 70%
Quartz 20%
Dolomite 0-10%

Accessories: Felspar

G/C: 3/7

Description: 6 mm wide vein in 1028B. Mottled olive brown finer (~1-2 μ) dolomite and olive to pale olive coarser (5 - 10 μ) calcite cement containing scattered subangular 0.1-0.2 mm (plus a few larger, subrounded) quartz and occasional felspar grains. The olive brown finer grained matrix is very similar to 1028B, and often forms haloes around the quartz grains. Some rounded to irregular patches of B-like material are also present. Etching showed the coarse material to be calcite and the finer to be dolomite. Alizarin stained the dolomite pale pink after five minutes and the calcite deep red in a shorter time. Plate F.2.

1028XA: Laminated outer coating

Description: Exactly similar to 1028A.

1028XB: Boulder calcrete

Description: Exactly similar to 1028B.

1028C-D: Boulder calcrete

Description: Essentially similar to 1028B

1562A: Type 3 hardpan calcrete

Chief minerals: Calcite 80%
Quartz 20%

Accessories/

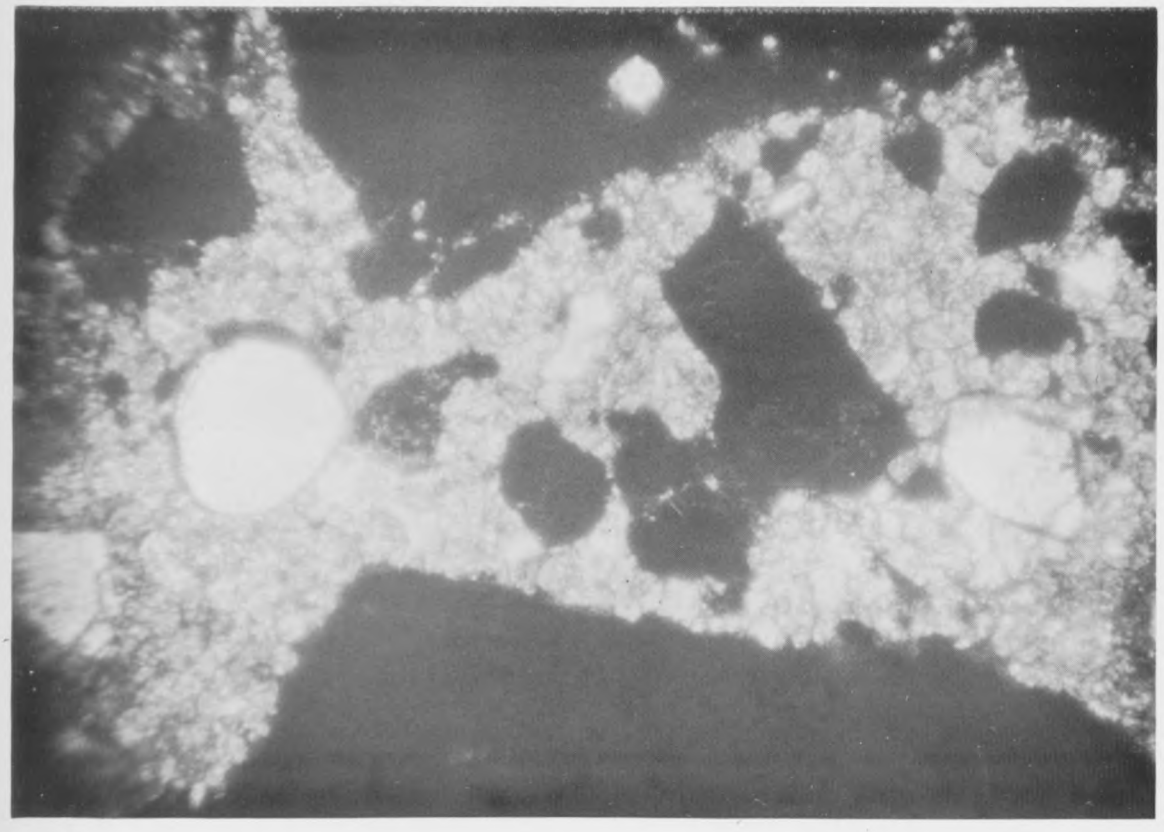


PLATE F.2

Thin section of Sample 1028 showing vein (medium) of coarser calcite (D) in cryptocrystalline dolocrete (B, dark) containing scattered quartz grains (light) and inclusions of dolocrete (dark). Crossed nicols, X70.

Accessories: Manganese oxide

G/C: 1/4

Description: Grey, speckled with black, cryptocrystalline (~5 μ) calcite matrix containing 0.05 mm subangular to 0.3 mm subrounded allogenic quartz grains. Also many rounded to irregular patches of dark grey, opaque, non-pleochroic material which seems to be finer grained (1 μ) calcite.

1562B: Type 3 hardpan calcrete

Similar to A, but somewhat more voids and a higher grain/matrix ratio (i.e. more quartz).

1598A: Relict nodule in hardpan

Chief minerals: Calcite 80%
Quartz 20%

Accessories: Felspar (orthoclase)
Limonite

G/C: 1/4

Description: Olive brown to light olive brown cryptocrystalline (1 - 2 μ) calcite matrix in which float 0.3-0.03 mm quartz grains, some very irregular in shape. Occasional veins and void linings of coarser (5 μ) calcite and strong brown iron staining in patches in the coarser calcite.

1598B: Matrix of hardpan

Description: Identical to A except for somewhat more voids and coarser calcite, and a higher grain/matrix ratio (3/7).

1627A: Boulder calcrete

Chief minerals:	Calcite (probably ferroan)	75%
	Quartz	15%
	Palygorskite	10%
Accessories:	Felspar	
G/C:	1/5	

Description: Olive brown, almost opaque, cryptocrystalline matrix (2μ) in which float scattered subangular quartz and occasional felspar grains averaging about 0.1 mm in size. Many somewhat vaguely defined seams of coarser (5μ) and lighter coloured calcite. Some of these veins are subparallel, most are branched (dendritic) and similar material often surrounds irregularly shaped quartz grains, possibly replacing it. Replacement is not marked, however. Several quartzite fragments are present, as well as a few rounded pieces, apparently of an older calcrete.

Etching with HCl resulted in preferential solution of the coarser veins and pitting of the matrix. Acidic alizarin stained the veins deep red and the matrix mauve after 3 minutes, indicating the veins to be calcite and the matrix to be possibly ferroan dolomite. X-ray diffraction analysis of the thin section itself revealed, however, that only calcite, quartz and palygorskite were present. Palygorskite was not seen in thin section . The darker stained colour of the veins is probably due to the c axis of the calcite vein material being more nearly parallel to the thin section than the c axis of the matrix.

Replacement: Quartz by calcite?

1627B: Boulder calcrete

Description: Exactly similar to 1627A.

1638: Dolocrete nodule

Chief minerals: Dolomite 60%
Quartz 40%

Accessories: Felspar
Calcite?

G/C: 2/3

Description: Subrounded 0.3 mm to subangular 0.1 mm quartz and occasional felspar grains in a cryptocrystalline 1-5μ dolomite matrix. The matrix is made up of two types, the finer grained (1μ), darker olive material grading into the coarser (5μ), lighter coloured, light olive grey material. Some of the quartz grains seem to be in the process of being replaced by the coarser dolomite.

Staining failed to reveal the presence of any calcite.

Replacement: Quartz by dolomite?

1639: Dolocrete nodule

Similar to 1638 except that nearly all matrix is of the fine grained dark olive type, with very little of the coarser material, and the grain/matrix ratio at 3/7 is a little lower.

1658A: Relict nodule in hardpan

Chief minerals: Dolomite 85%
Quartz 10%
Calcite 5%

Accessories: Felspar
Aragonite? (see 1658B)

G/C: 1/9

Description/

Description: Chiefly made up of an olive brown 2μ matrix containing scattered 0.5 - 1 mm quartz and occasional felspar grains, some of which are probably being replaced by coarser (~5μ) calcite. Very little of this coarser calcite present. Staining showed it to occur only as patches surrounding some grains and as occasional veins.

Replacement: Quartz by calcite?

1658B: Matrix of hardpan

Chief minerals: Calcite 60%
Quartz 20%
Dolomite 15%
Palygorskite 5%

Accessories: Aragonite?
Felspar

G/C: 1/4

Description: Somewhat similar to 1658A, but lighter coloured, more coarser calcite and more quartz grains. Also many oolite-like objects about 0.1 mm across. These typically have an irregularly shaped quartz grain as centre (probably being replaced) surrounded by darker, fine grained material similar to 1658A, followed by one or more concentric rings of alternating lighter (and coarser) and darker (and finer) material. The lighter coloured material occasionally has a very faintly radially fibrous structure, possibly indicating an original aragonitic origin.

Many subrounded to rounded fragments of 1658A are also present, often edged by one or more bands similar to those surrounding the colites. The fragments vary in size from 0.05 mm upwards.

Etching/

Etching and staining a thin section containing both A and B using Dickson's method brought out their relationship very clearly. A (dolomitic) is clearly older than B (calcitic) and is enclosed by it. The bands surrounding patches of B and the oolites are alternating calcite and dolomite layers. Different colour intensities also show that the layers often possess different orientation. Slight (very pale pink) staining of material resistant to etching bordering patches of B presumably indicates slight replacement of Mg in the dolomite by Ca. The acid resistant layers furthest into B tend to show the darkest staining, presumably confirming this hypothesis.

Application of Feigl's solution to an etched thin section (10 seconds in 1.5% HCl) showed tiny, scattered dark brown to black irregular to elongated patches of presumably aragonite after 14 minutes. They occurred chiefly in veins of B, but occasionally also in A, and as very thin rims around quartz grains in B.

Palygorskite was not observed in thin section.

Replacement: Quartz by calcite
Dolomite by calcite
Aragonite by calcite?

1724A: Laminated outer crust

Chief minerals: Calcite 80%
Quartz 20%

G/C: 1/99

Description: Light olive brown cryptocrystalline (~1μ) calcite with many small irregular voids and rare 0.1 mm subrounded quartz grains. The latter appear to be in the process of being replaced by calcite. Voids are lined as usual with slightly coarser (~3μ) calcite.

In/

In thin section only about 1% quartz appears to be present. The X-ray diffraction analysis indicated that about 20% was present. Unless contamination was present in the latter, the quartz must be finely disseminated and/or masked by the colour of the carbonate (cf. 1028A and 1724B).

Replacement: Quartz by calcite?

1724B: Boulder-hardpan calcrete

Chief minerals: Calcite 75%?
Quartz 20%?
Sepiolite 5%?

G/C: 1/49

Description: Very dark grey, almost opaque, cryptocrystalline calcite containing rare irregularly shaped 0.1 mm quartz grains. More grains and many more irregular voids present than in 1724A.

Sepiolite was not observed in thin section.

1726: Honeycomb silcrete

Chief minerals: Quartz 70%
Chalcedony 30%

Accessories: Calcite

G/C: 7/3

Description: Densely packed subangular to subrounded 0.1-0.5 mm quartz grains in a chalcedony matrix. Calcite was not observed in thin section.

1727: Type 5 calcrete nodule

Chief minerals: Quartz 40%

Calcite/

Calcite 40%
Dolomite 18%
Felspar 2%

G/C: 2/3

Description: In thin section appears as the usual quartz and subordinate felspar grains in a cryptocrystalline (~2μ) mottled olive brown/lighter olive brown, almost opaque matrix. Small amount of lighter calcite fringing and probably replacing quartz grains. Etching and staining showed the calcite to occur as vaguely defined veins and rims around the quartz grains with the dolomite tending to occur as patches in the calcite. This is an over-simplification, however, the dolomite and calcite are quite intimately related and sharp boundaries between the two are exceptional.

Replacement: Dolomite by calcite?
Quartz by calcite?

1728: Dolocrete nodule

Description: Exactly similar to 1727 except that more replacement of quartz by calcite seems to be taking place and the matrix is dolomite, instead of calcite.

1746: Honeycomb calcrete

Chief minerals: Calcite 35%
Dolomite 35%
Quartz 20%
Sepiolite 10%

Accessories: Felspar

G/C: 1/19 (darker, fine grained dolomite)
1/15 (lighter, coarser calcite).

Description/

Description: Light olive brown, irregular to rounded patches of cryptocrystalline (~2μ) dolomite with few quartz grains enclosed and vaguely veined by a coarser (~5μ) and lighter coloured matrix of calcite. Many of the quartz grains are rimmed by first the lighter (and coarser) calcite and then the darker (and finer) dolomite, giving them an oolitic appearance. The contact between the veins of calcite and the host finer material is gradational rather than sharp.

Etching and staining by Dickson's method showed up the relation between the two main components clearly. Sepiolite was not observed in thin section.

Replacement: Quartz by calcite?
Dolomite by calcite?

1808: Honeycomb silcrete(?)

Chief minerals: Quartz 85%
Felspar 10%
Palygorskite 5%

Accessories: Dolomite?
Calcite?

G/C: 9/1

Description: Densely packed, 0.1-0.2 mm, mainly subangular quartz and occasional possible felspar fragments. The hardening resin has filled the voids and masked any former matrix though this was not a good thin section. No carbonate could be seen and the hand specimen did not react or disintegrate in dilute (1.2N) HCl or stain with alizarin. Soaking for 24 hours in 1.2N NaOH also had no effect, but the material weakened slightly in comparison with a control specimen placed in water after an additional 24 hours in 30% NaOH.

1810/

1810: Type 3 calcrete

Chief minerals: Calcite 70%
Quartz 20%
Felspar 7%
Palygorskite 3%

G/C: 1/4

Description: Greyish brown, cryptocrystalline (~ 2μ), calcite matrix enclosing subangular, subrounded and irregular 0.1-0.5 mm quartz grains. The irregular grains appear to be undergoing replacement by calcite. No felspar or palygorskite seen in thin section. Plate F.3.

Replacement: Quartz by calcite?

1828A: Tufaceous hardpan calcrete

Chief minerals: Calcite 70%
Quartz 20%
Opaline silica 10%?

G/C: 1/4

Description: Opaque cryptocrystalline matrix containing the usual floating subrounded-subangular 0.5-0.1 mm quartz grains. Only quartz and some carbonate can be recognised in thin sections. In one thin section what appeared to be a small nodule was noted. This is about 3 mm in diameter and has a grain/matrix ratio of 2/3, but is otherwise indistinguishable from the rest of the section.

Examination of the residue insoluble in dilute HCl revealed the presence of many diatom shells.

Calcite content estimated by calcimeter determination.

1828C/

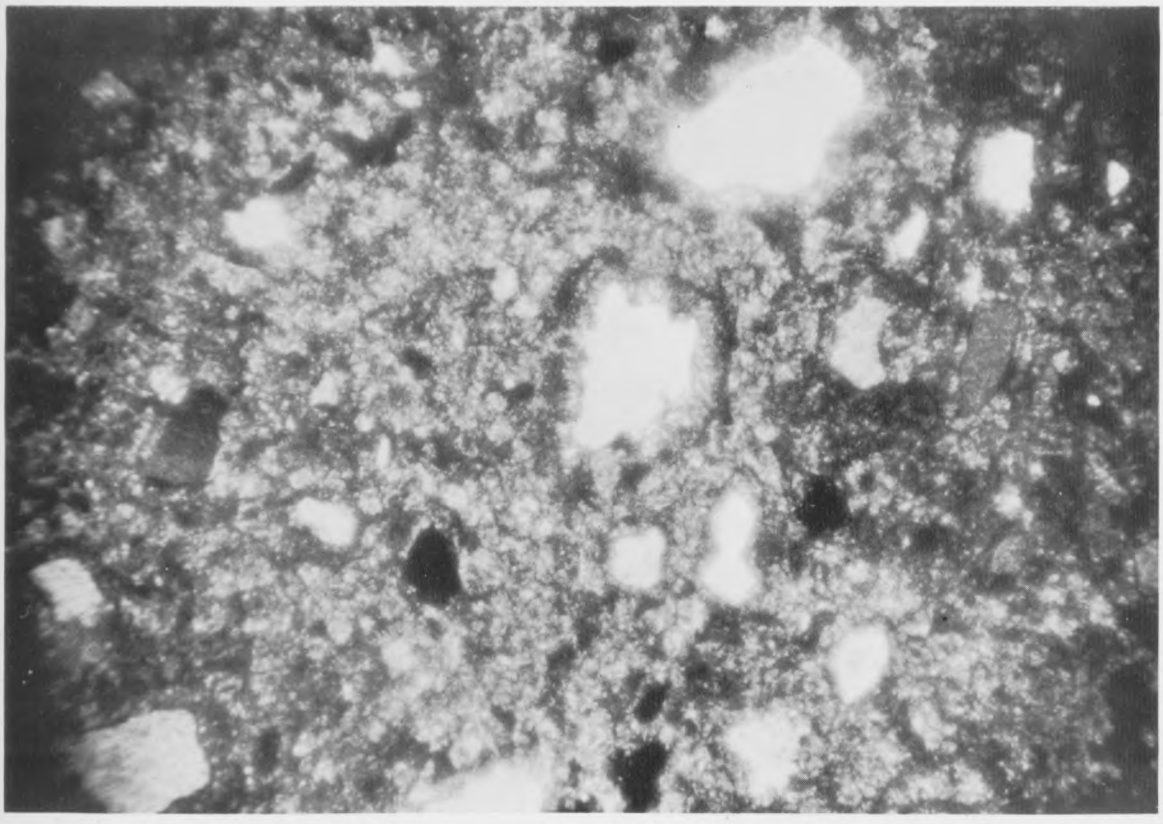


PLATE F.3

Thin section of Sample 1810 showing irregular quartz grains (light) probably undergoing replacement by coarse cryptocrystalline calcite (medium). The dark spots are voids filled with the isotropic resin hardening medium. Crossed nicols, X70.

1828C: Tufaceous hardpan calcrete

Identical to A except that it has more quartz-rich patches with grain/matrix ratios of about 2/3.

1830: Honeycomb silcrete (?)

Chief minerals: Quartz 85%
Palygorskite 5%?
Chalcedony 5%?
Felspar 5%?

G/C: 4/1

Description: Fairly densely packed subangular-subrounded 0.1-0.3 mm quartz grains in a matrix composed chiefly of the resin used for hardening and mounting. Any opaline silica cement would go undetected under these circumstances. If it is present, however, it can only be of very minor importance. Several of the quartz grains possess overgrowths, apparently of quartz or possibly chalcedony which may have been the original cementing medium before impregnation with resin. Black isotropic patches of variable size and shape probably represent the palygorskite identified by X-ray diffraction. Only one grain could be positively identified as felspar by its Carlsbad twinning. Cleavage was absent in all other grains. One or two rounded grains of an olive green pleochroic mineral with masked birefrigence, no cleavage and no adequate interference figure were also noted.

Samples 1808 and 1830 did not disintegrate in water, dilute (1.2N) HCl or NaOH or 30% NaOH, unlike macroscopically identical materials from the Elandsfontein fossil site (2241, 2242, 2252 and 2258), which disintegrated slightly in water and completely or considerably in HCl and NaOH.

1833: Nosib quartzite?

Chief minerals: Quartz 90%
Iron oxide 5%
Felspar 5%

G/C: 19/1

Description: Very densely packed, 0.2 mm, subangular, equant quartz grains in a quartz matrix cement. The matrix is stained strong brown, presumably by iron oxide. A few patches of opaque black and reddish brown material also occur. The rock seems excessively densely packed for a silcrete and is more likely to be a quartzite. The outcrop was unfortunately not seen by the author, but was said to be "surface quartzite". The rock is rather similar to a specimen of Nosib quartzite from the Ruacana Falls area (Sample 2550) and the two are hardly distinguishable in the hand specimen. Nosib quartzite is not known in the Runtu area, but the area has not been surveyed geologically, and it is structurally quite possible.

1841: Type 2 sepiolitic calcrete

Chief minerals: Sepiolite
Calcite

Accessories: Quartz

G/C: 1/99

Description: In thin section appears to be composed entirely of the usual 2 micron calcite in which float rare 0.05 mm subangular to rounded quartz grains. No sepiolite observed in thin section. Etching should bring out the relation between the calcite and sepiolite.

1907: Hardpan calcrete

Chief minerals: Calcite 70%

Quartz/

Quartz 20%
Orthoclase 10%

G/C: 3/7

Description: Opaque to light olive brown cryptocrystalline (~2μ) calcite enclosing mostly subangular 0.2-0.5 mm quartz and felspar grains. Includes also a 3 mm nodule or boulder fragment having a slightly lighter matrix and a few rounded dark inclusions rather similar to those in Samples 1658B and 890A. These ghost structures probably indicate the sites of replaced quartz grains. The nodule or calcrete boulder fragment is edged in part by strong brown cryptocrystalline calcite(?) suggesting that it was a Type 1 boulder fragment rather than a nodule. If inclusions of older calcrete like this specimen were also present in the portion of 1907 radiocarbon dated it may well account for the unexpectedly slightly high age yielded by this sample.

Replacement: Quartz by calcite?

1931: Honeycomb calcrete

Chief minerals: Calcite 70%
Quartz 28%
Felspar 2%

Accessories: Aragonite?
Limonite?

G/C: 3/7

Description: This section clearly shows the original nodules edged with strong brown banding enclosed in a lighter matrix.

By transmitted light the nodules have a highly oolitic appearance. Quartz grains rimmed by relatively coarser and lighter calcite with a radially fibrous structure are

common/

common. Each fibrous rim is then typically itself rimmed by darker material similar to the 2 μ olive brown material so common in calcretes. The oolites are then set in a slightly lighter and coarser matrix much mottled and vaguely veined by the darker, finer material. The darker material gives the impression of merely being iron stains rather than veins. Plate F.4.

The matrix is essentially similar to the nodules, but lacks the spheroidal shape of the latter and the fibrous rims are not quite so well developed.

X-ray diffraction analysis of the thin section itself showed only calcite, quartz and a trace of probable felspar to be present. Aragonite was definitely absent in detectable quantities. Application of Feigl's solution for 10 minutes also showed that the fibrous material around the grains was not aragonite. A very small area right on the edge of the thin section which seemed to be a geode lining turned black, however, indicating that it was probably argonite. It had not shown a markedly fibrous structure.

Etching and staining with alizarin according to Dickson's method showed all the carbonate to be calcite (in agreement with the diffraction results) but the fine darker material was markedly more resistant to etching than the fibrous and coarser (and also lighter coloured) material.

Replacement: Quartz by calcite
Felspar by calcite
Aragonite by calcite?

1940: 'Calcified' sand

Chief minerals: Dolomite 55%
Quartz 35%
Palygorskite 10%

Accessories/

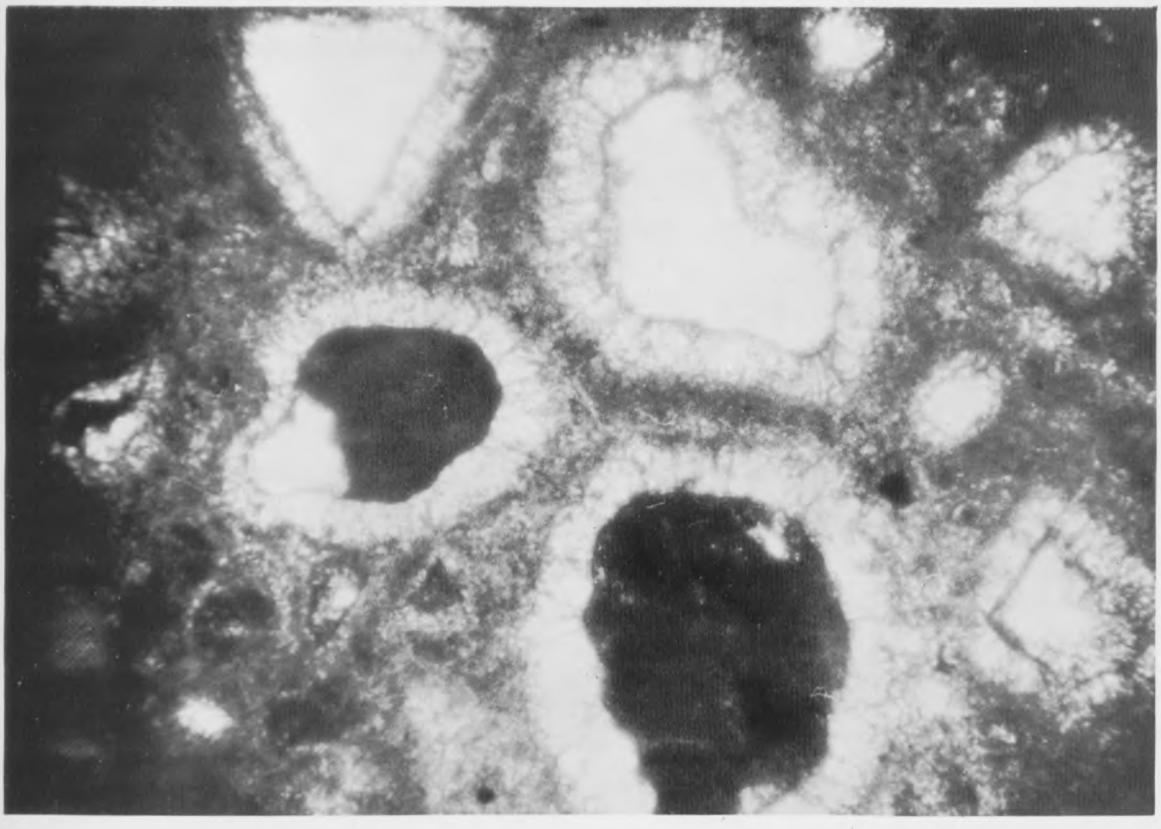


PLATE F.4

Thin section of Sample 1931 showing quartz grains (light to dark) rimmed by radially fibrous calcite (light) set in a cryptocrystalline calcite matrix (medium). Crossed nicols, X70. While coarser calcite rims around quartz grains are common in calcretes, the fibrous structure is rare.

Accessories: Orthoclase
Limonite?

G/C: 2/3

Description: Subangular 0.2-0.4 mm allogenic quartz and felspar grains set in an almost opaque to opaque cryptocrystalline dolomite matrix. Occasional iron oxide staining, particularly along cracks.

Etching and staining according to Dickson's method resulted in the opaque and almost opaque matrix staining pink, apparently indicating calcite. X-ray diffraction analysis of the thin section itself revealed however that crystalline calcite was absent. The pink-stained material immersed in water between crossed nicols showed birefrigence, thus presumably ruling out the possibility of large amounts of amorphous $CaCO_3$ being present, though it should be noted that Odum (1951) has found amorphous birefrigent calcite of organic origin.

It would appear then, that in spite of both Dickson's and Warne's statements that dolomite does not stain with alizarin, the method must be used with caution on dolocretes.

Palygorskite was not identified in thin section.

1950A: Calcified gravel matrix

Chief minerals: Calcite 70%
Quartz 20%
Felspar 5%

Accessories: Pyrop
Iron oxide

G/C: 3/7

Description: 0.03-0.2 mm subangular - subrounded quartz and occasional felspar grains set in an almost opaque crypto-

crystalline/

crystalline matrix which is much randomly veined by slightly coarser (~5μ) and lighter coloured calcite. Opaque rounded and irregular fragments of the darker material also occur in the lighter and the latter predominates in some thin sections.

1961A, B: Opaline silica nodules in tufaceous hardpan calcrete

Chief minerals: Amorphous matter (silica?) 96%
Calcite 5%
Quartz 1%

G/C: 1/99

Description: Mostly made up of a mottled olive yellow/ yellowish brown/ dark brown (10 YR 3/3) amorphous matrix. The dark brown matter does not show birefrigence, but is too soft to be amorphous silica. Many irregular voids, usually occuring in irregularly elongated patches of the yellowish brown material. Occasional subangular 0.1-0.3 mm quartz grains float in the matrix. Two oolite-like structures and two elongated structures possibly of organic origin were noted. Etching and staining by Dickson's method resulted in no colour change at all, although gas was evolved during the process. Examination of the etched section in reflected light showed that only small patches of calcite had been present.

1961B is similar to A, but showed in places a parallel alignment of voids. The calcite tended to occur as a lining to most voids. B also appeared to have a higher calcite content, though the X-ray diffraction pattern indicated the reverse.

Replacement: Calcite by amorphous silica?
Quartz by calcite?

1962, A, B, C, D: Tufaceous hardpan calcrete

Chief minerals: Calcite (probably ferroan) 70%
Opaline silica 25%
Quartz 1-10%
Felspar < 5%?

G/C: 1/99

Description: Dark yellowish brown to opaque black cryptocrystalline matrix partly of calcite in which float very rare, somewhat elongated, subangular to subrounded 0.1 mm quartz grains. Many irregular to wormlike and watermark-like lighter calcite patches in the matrix and similarly shaped voids, varying in size from 0.1 mm to about 0.1 x 1.0 mm or even larger. A few vague shapes in the matrix may be the remains of gasteropod shells. The darker material remains dark between crossed nicols. Etching and staining of 1962A by Dickson's method showed the presence of amorphous silica patches (probably actually nodules in a (probably ferroan) calcite matrix. Much veining by probably amorphous silica was also present. In ordinary thin section the darker calcite could not always be distinguished from the amorphous silica. The silica, however was unscratchable with a needle. On immersion its refractive index was found to be 1.50.

These thin sections are typical of tufaceous hardpans.

2123: Type 6 hardpan calcrete

Chief minerals: Calcite ~95%
Quartz < 3%
Clay minerals < 5%

G/C: 1/200

Description: Similar to 2200 but more finely crystalline (0.01-0.02 mm) and even fewer (subrounded) quartz grains.

In/

In both samples of Type 6 calcrete (2200 and 2123) the coarser calcite tends to occur in patches and vague veins. In one thin section (2123), quite a large amount of the usual 2 micron calcite was seen, which graded into the coarser material. Voids are invariably lined with the coarser calcite.

2200: Type 6 hardpan calcrete

Chief minerals: Calcite 80-99%
Quartz 1-10%
Clay minerals <5%

G/C: 1/99

Description: Quite unlike any other calcrete. Composed almost entirely of an extremely densely packed light olive anhedral calcite matrix (0.05-0.2 mm) in which float rare subangular 0.15 mm quartz grains. A few calcite crystals show a fibrous structure, presumably due to initial crystallisation as aragonite.

Replacement: Aragonite by calcite?

2223: Nodule from powder calcrete

Chief minerals: Calcite 97%
Clay 1%
Quartz 0-2%

G/C: 1/99

Description: Almost entirely made up of a very dense matrix of pale olive, anhedral, equant to elongated 0.05-0.1 mm calcite crystals. Much coarser than the average calcrete. Occasional 0.1-0.2 mm grains of an opaque brown, non pleochroic mineral, probably clay. No quartz grains seen in thin section.

This/

This is a typical example of the nodules (non-sandy Type 4) found in powder calcretes. It is of interest to note that the only other calcretes examined which are not almost entirely cryptocrystalline also came from the Lovedale area of Lichtenburg (2200 and 2123). The latter two are hardpans.

It is actually a moot point as to whether this specimen should be classified as a non-sandy Type 4 or a Type 6 nodule. Hand specimen examination alone would result in the former, while petrographic examination alone would probably classify it as a Type 6 calcrete. Hand lens examination is sufficient to indicate that it is not cryptocrystalline, but probably microcrystalline.

2241A: Weathered phoscrete

Chief minerals: Quartz 70%
Collophane 30%

Accessories: Dahllite?
Felspar, probably orthoclase

G/C: 1/1 - 7/3?

Description: 0.3-0.6 mm rounded or subrounded and 0.1-0.2 mm mainly subangular quartz grains set in a strong brown to black, non-pleochroic, cryptocrystalline matrix probably of collophane. The matrix is normally dark between crossed nicols, but shows very faint first order colours at the edges of the section. Grain/matrix ratio variable and matrix appears to be absent in some cases and the voids have been filled by the hardening resin. Some quartz grains show faint overgrowths which may be dahllite. No apatite could be identified and the apatite indicated by the X-ray diffraction analysis must be collophane and/or dahllite. A few quartz-like grains showing cleavage, but no twinning were presumed to be felspar, probably orthoclase.

Replacement/

Replacement: Collophane by dahllite?

2241B: Weathered phoscrete

Description: Identical to A, but more densely packed (G/M about 4/1) and well cemented by a strong brown matrix.

Samples 2241, 2242, 2252 and 2258 were found to disintegrate only slightly after 10 minutes soaking in water, but disintegraded considerably after 10 minutes in dilute (1:9) HCl (about 1.2N), colouring the HCl a brownish yellow. All four samples treated with dilute HNO_3 yielded a yellow precipitate with ammonium molybdate, thus confirming the presence of a phosphate, while the HCl extract yielded a white precipitate with concentrated H_2SO_4, thus indicating the probable presence of calcium. Samples 2241A, 2252 and 2258 were also soaked in dilute (1.2N) NaOH. This had little or no effect at first, but after half an hour all solutions were coloured brownish yellow and slight disintegration was evident. After 24 hours all pieces had considerably or completely disintegrated.

2241C: Weathered phoscrete

Description: Identical in all respects to 2241A.

2244: Possible algal calcrete(?)

Chief minerals: Calcite 90%
Quartz 10%

Accessories: Collophane?

G/C: 1/99

Description: Mainly made up of light olive brown to reddish brown cryptocrystalline calcite (about 2μ) in which float rare 0.1-0.2 mm subangular to subrounded quartz grains. The matrix may perhaps be stained by collophane (not detected

by/

by the X-ray diffraction analysis). A small amount of preferred orientation is evinced by some of the voids, both in sections cut parallel and transverse to the macroscopic saucerlike structures. No evidence of organic origin.

The X-ray diffraction analysis indicates that more quartz is present than the amount suggested by thin section examination.

2258A: Weathered phoscrete

Description: Essentially similar to 2241A, but also includes subrounded 0.1 mm and larger irregular strong brown, reddish brown and opaque black patches of collophane(?). Most of the matrix can be seen to be merely the impregnating resin stained brownish yellow by the collophane. Finely dispersed collophane probably originally acted as the cement. No felspar noted.

2258B: Weathered phoscrete

Description: Similar to 2241A.

2259A: Calcified root-like object

Chief minerals: Calcite 90%
Quartz 10%

Accessories: Felspar

G/C: 1/9

Description: Thin cross section of a calcified root-like object. While the overall object was 5 cms in diameter, it had the appearance of a cluster of smaller roots rather than one large one. Bits of organic matter were still present.

In thin section a whole host of poorly concentric, light olive brown structures 0.5-2 mm across, very much like the central portion of 2318 and 2319, can be observed. Each possess a central hole just like 2318 and 2319. These structures are set in a darker olive brown to reddish brown 2 micron calcite matrix enclosing scattered 0.05-0.1 mm subangular to irregular quartz and rare felspar grains. As usual, all voids are lined with lighter coloured, apparently coarser (about 5 micron) calcite. A number of black spots, mostly a remarkably uniform 0.02 mm round shape, occur scattered through the specimen. Viewed by reflected light the spots can be seen to be made up of black grains about 0.002 mm in diameter and to have a submetallic lustre. They may be carbonised organic matter representing old roots. Each spot is surrounded by a ring of coarser calcite.

Replacement: Quartz by calcite.

2259B: Calcified root like object

Chief minerals: Calcite 75%
Quartz 25%

Accessories: Felspar

G/C: Central portion 1/4
Inner rim 0
Outer rim 3/7

Description: In the hand specimen this 'calcified root' differs from 2258A in having a greyish central core of softer material surrounded by a cylinder of harder, cream coloured material. The grey colour of the core changed to white on heating to 1000°C for a few minutes, indicating the probable presence of organic matter.

In thin section the central portion of this specimen consists of about 20% of 0.1 mm subangular to irregular

quartz/

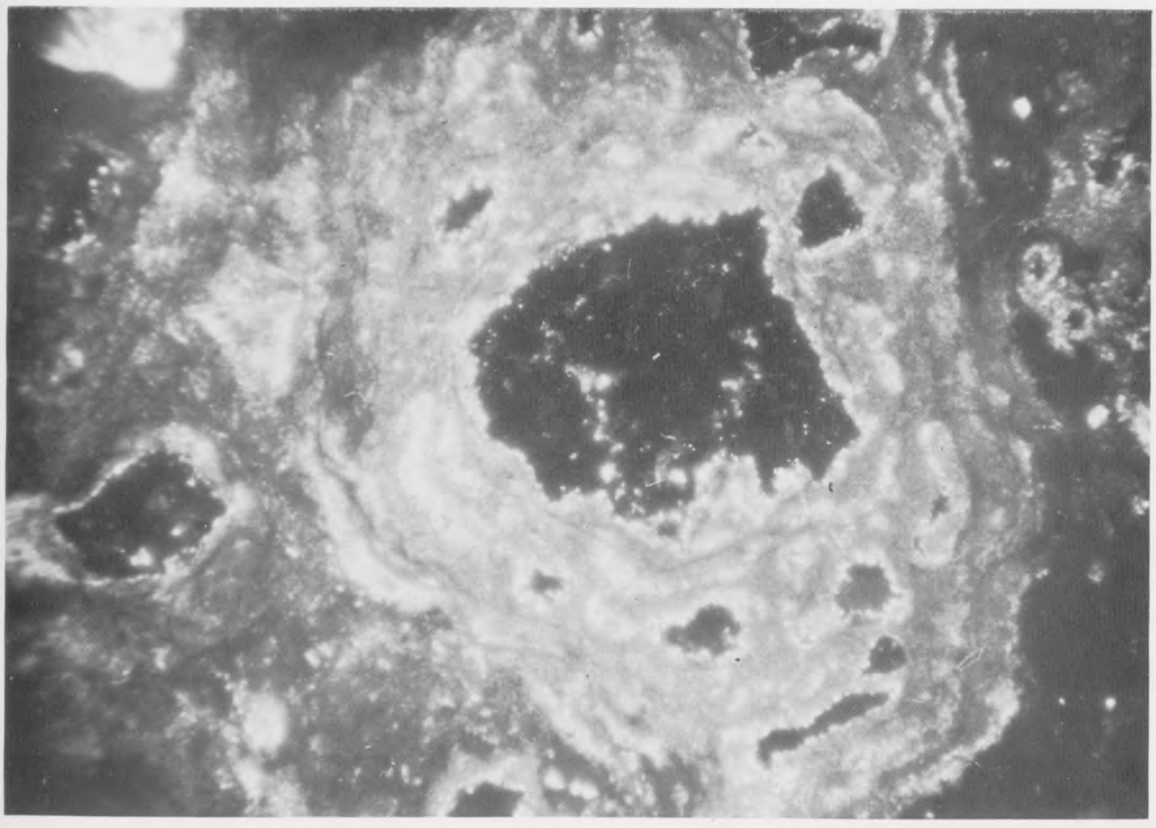


PLATE F.5

Thin section across Sample 2318, a calcified root-like object (pedotubule), showing the concentric fabric of the fine to coarse cryptocrystalline calcite (medium to light respectively) around the central channel (dark). Note the coarser crystalline calcite lining the voids. Crossed nicols, X70.

or whether the darker colour is merely obscuring the crystal size. The material lining cavities is invariably of the lighter, apparently coarser type. A few 0.1 mm subangular quartz grains float in the matrix. The central portion is about 7 mm in diameter.

Forming a rim around the central portion occurs a zone made up of densely packed, 0.1-0.3 mm, subrounded to rounded quartz grains in a calcite matrix of slightly lighter colour than that of the central portion. Several fossils said by Dr. K.A. Clauss to be of probably marine origin also occur in the outer rim. The contact between the inner portion and the outer rim is gradational over a short distance. The overall diameter of the "calcified root" is about 10 mm so that the rim is about 3 mm wide. Some of the quartz grains in one portion of the outer rim are severely shattered. One quartzite fragment was also noted.

2319: Calcrete pipe-like object

Chief minerals: Quartz 60%
Calcite 40%

M/C: Central portion 1/50
Outer rim 3/2

Description: Thin section through a calcified root-like object called by Mr. J. Wymer a "pipe" (Plate F.6.)

In thin section essentially similar to 2318 except only 4 mm in overall diameter and the radial width of the rim is greater than the radius of the central portion. No fossils were observed.

Air could be passed down the central hole of both 2318 and 2319.

2341: Calcareous sandstone

Chief minerals: Quartz 60%

Calcite/

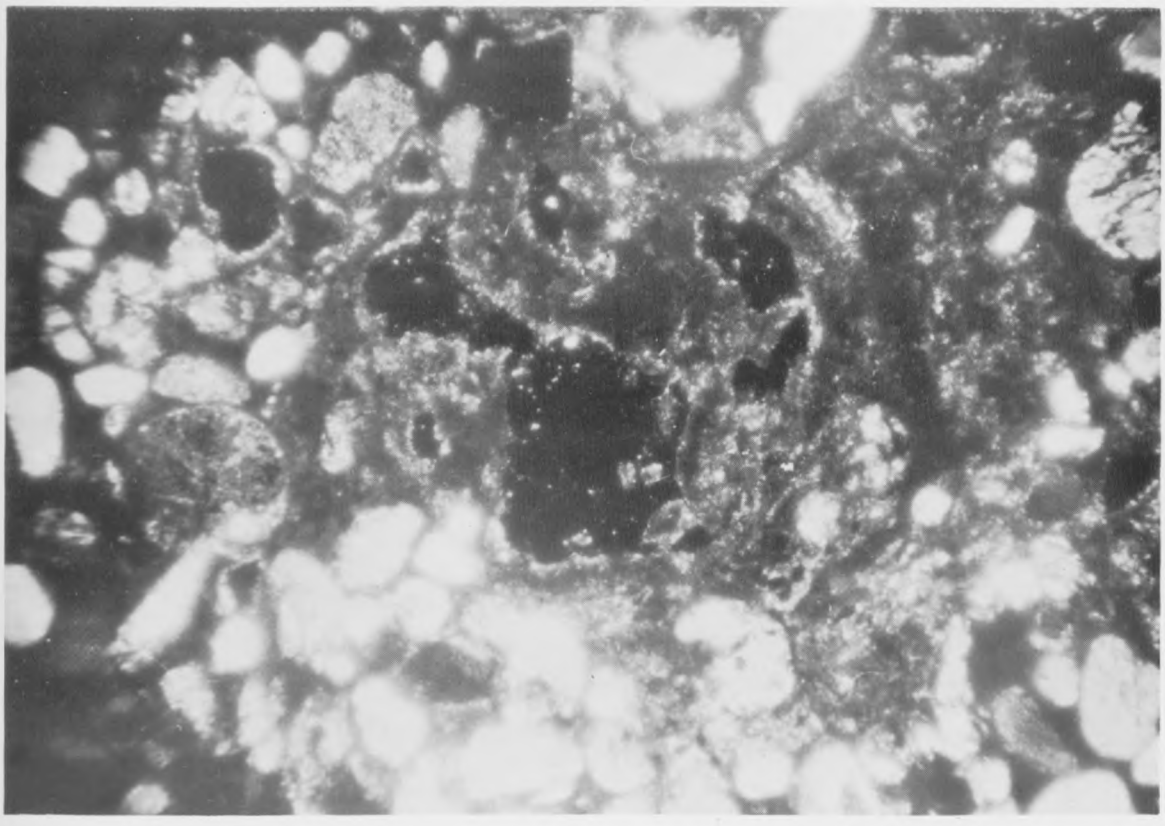


PLATE F.6

Thin section across Sample 2319, a pedotubule. Note the central channel (dark) surrounded by cryptocrystalline calcite (medium) and an outer rim of quartz grains (light). Crossed nicols, X70.

Calcite 30%
Glauconite 5%?

Accessories: Felspar (orthoclase(?) and plagioclase)

G/C: 7/3

Description: Angular to subrounded, equant, elongated and irregular quartz, quartzite and occasional felspar grains varying from 0.05 to 2 mm in size set in a dirty olive brown to opaque black cryptocrystalline calcite matrix. The dark colour of the matrix is probably due to glauconite, which could not be confirmed petrographically. One 0.3 mm subrounded, equant, strong brown, non-pleochroic grain with masked birefrigence was the only possible large glauconite grain. The grain was so vague in outline in the dark matrix that its relative refractive index could not even be determined. Many grains are cracked. Other accessory minerals probably occur, but are masked by the matrix. One or two of the quartzite fragments possess quartz overgrowths, but these may be inherited.

Another thin section cut at right angles to the first was little different in appearance except for a slightly lower grain matrix ratio. One or two probably heavy minerals were also noted.

The X-ray diffraction analysis indicates that up to 5% felspar may be present.

2516A, B: Calcrete nodule

Chief minerals: Calcite 97%
Quartz 3%

G/C: 5/19

Description: Dark grey, cryptocrystalline, calcite matrix containing scattered 0.05-0.1 mm subangular to subrounded

quartz/

Accessories: Ore
Other (not identified)

G/C: 3/2

Description: Mainly equant, subangular, 0.1-0.3 mm quartz grains well cemented by a cryptocrystalline (~5 μ) calcite matrix. One or two olive brown, non-pleochroic, unidentifiable grains as well as a few opaque black grains about 0.2 mm across. The latter may be ilmenite. No felspar could be positively identified, although the diffraction results indicated that about 10% was present in the powdered specimen X-rayed.

APPENDIX G

RADIOCARBON DATES

All known calcrete dates are listed in this appendix and commented on where possible. The dates were obtained by going through all the C^{14} laboratory date lists appearing in the issues of "Science" from 1951 to 1958 and in the issues of "Radiocarbon" from 1959 to 1967 and extracting all the calcrete dates. No calcrete dates were found in "Science". the vast majority of the world's C^{14} dates have been published in these two journals. Dates appearing in these journals are submitted by the laboratories doing the dating and not by the submitters, who usually publish them later elsewhere as part of other work. Reference to this is often made by the laboratory and, where possible, these other publications have also been examined as comments in the date lists are usually meagre (a small number of the dates shown may not even be calcretes). In most cases, however, when any check on the date was available it seems to have been mentioned. It should be noted then, that while Table G.1 probably represents practically all C^{14} dates so far performed on calcretes, the ensuring discussions are not always as complete as would be desirable. It was also not always clear whether the laboratory or the submitter was commenting and the names given are those of the laboratory workers. Reference to their comments should be made via Table G.1 as they are not included in the list of references at the end of Chapter 5. The comments are also to some extent those of this author's, especially where published comment was lacking or meagre. The apparent ages and C^{14} assays are mostly based on 95% of the activity of oxalic acid, but a few of the older ones may have used 19th century wood. No corrections appear to have been made for initial C^{14}/C^{12} ratios differing from this or for

isotopic/ ...

isotopic fractionation except in the case of Brinkmann et al (1960).

Some of the determinations were given as percent modern and some as an actual date. Relatively few determinations included both. Where only one was given the other has been kindly calculated by Dr. J.C. Vogel. The figures have also been checked by the author using a simple graph of the age equation. The original published figure can be distinguished in all cases where a finite age is shown by the fact that it has an error ascribed to it.

TABLE G.1 LIST OF KNOWN RADIOCARBON DATES ON CALCRETES. COMPILED FROM RADIOCARBON VOLS. 1-9 UNLESS OTHERWISE STATED

SAMPLE NUMBER	PORTION DATED	APPARENT AGE (YEARS B.P.)	C^{14} % MODERN	δC^{13} °/oo	VOL. NO.	PAGE NO.
L-347	Org. C from fat	20,400±1,200	7.9	-	1	22
?	Inorg. CO_3	23,500	5.4	-	1	22
W-787	" "	2,200± 250	76.0	-	2	159
W-790	" "	17,800± 450	10.9	-	2	159
W-788	" "	28,000±1,500	3.1	-	2	159
W-789	" "	>32,000	<1.9	-	2	159
W-791	" "	>29,000	<2.7	-	2	159
W-792	" "	11,730± 300	23.2	-	2	160
W-786	" "	11,900± 300	22.8	-	2	160
W-796	" "	20,300± 800	8.0	-	2	160
W-797	" "	>30,000	<2.4	-	2	160
L-483Y	" "	1,300± 150	85.0	-	3	156
LJ-510	" "	21,000± 600	7.3	-	5	264
A-296	" "	34,300	1.4 ± 0.6	-	5	295
A-224	" "	9,260	31.4 ± 0.8	-	5	297
A-222	" "	18,200	10.4 ± 0.6	-	5	297
A-223	" "	>28,000	<3.1	-	5	297

TABLE G.1 (CONTINUED)

SAMPLE NUMBER	PORTION DATED	APPARENT AGE (YEARS B.P.)	C^{14} % MODERN	δC^{13} °/oo	VOL. NO.	PAGE NO.
A-240	Inorg. CO_3	25,800	4.0 ±1.4	-	5	297
A-239	" "	28,200	3.0 ±0.5	-	5	297
A-251	" "	28,000	3.1 ±0.6	-	5	297
A-212	" "	13,200	19.4 ±1.3	-	5	297
A-218	" "	5,900	47.9 ±0.6	-	5	297
A-321	" "	12,800	20.4 ±0.4	-	5	298
A-308	" "	28,700	2.8 ±0.5	-	5	298
A-249	" "	12,600	20.9 ±1.2	-	5	298
A-248	" "	27,600	<3.2	-	5	298
A-265	" "	13,200	19.4 ±1.0	-	5	298
A-266	" "	12,800	20.2 ±0.6	-	5	298
A-262	" "	31,400	2.0 ±0.8	-	5	298
A-263	" "	>34,300	<1.4	-	5	298
A-259	" "	2,480	73.5 ±1.1	-	5	299
A-250	" "	2,700	71.5 ±1.1	-	5	299
A-272	" "	8,140	36.3 ±0.8	-	5	299
A-273	" "	17,000	12.1 ±0.8	-	5	299
A-271	" "	11,700	23.2 ±1.0	-	5	299
A-270	" "	15,800	14.0 ±0.8	-	5	299
A-285	" "	16,800	12.4 ±1.0	-	5	299
A-286	" "	15,500	14.5 ±1.0	-	5	299
A-287	" "	38,800	0.8 ±0.5	-	5	299
A-277	" "	6,900	42.5 ±1.0	-	5	300
A-278	" "	16,400	12.9 ±1.0	-	5	300
A-279	" "	18,800	9.6 ±1.0	-	5	300
A-291	" "	7,160	40.6 ±0.4	-	6	97
A-304	" "	3,660	63.4 ±3.8	-	6	97
A-397	" "	1,800	79.6 ±1.1	-	6	99
A-398	" "	9,800	29.6 ±0.4	-	6	99
A-399	" "	⩾32,000	0.88 ±0.45	-	6	99
LJ-601	" "	2,880± 150	69.9	-	7	101
LJ-602	" "	2,380± 150	74.4	-	7	101

TABLE G.1 (CONTINUED)

SAMPLE NUMBER	PORTION DATED	APPARENT AGE (YEARS B.P.)	C^{14} % MODERN	δC^{13} °/oo	VOL. NO.	PAGE NO.
A-468	Organic C	810 ± 70	90.4	-	8	8
A-467	"	1,085 ± 90	87.4	-	8	8
A-692	Inorg. CO_3	8,500	34.8±2.0	-	8	11
A-693	" " "	20,500	7.8±2.0	-	8	11
A-576	" "	7,000 ± 300	41.9	-	8	13
A-575	" "	10,250 ± 550	27.9	-	8	13
A-573	" "	15,450 ± 700	14.6	-	8	13
A-635	" "	17,760 ± 700	11.0	-	8	13
A-572	" "	>30,000	<2.4	-	8	13
I-423	" "	>35,500	<1.2	-	8	167
SI-270	" "	6,720 ± 80	43.4	-	8	420
SI-271	" "	8,140 ± 130	36.3	-	8	420
SI-272	" "	12,470 ± 150	21.2	-	8	420
SI-273	" "	12,860 ± 200	20.2	-	8	420
SI-274	" "	22,670 ± 200	6.0	-	8	421
SI-275	" "	5,000 ± 100	54.7	-	8	421
SI-276	" "	15,220 ± 250	15.0	-	8	421
A-472	Organic C	17,900 ±1,000	10.8	-	9	4
A-473	Inorg. CO_3	22,000 ± 600	6.5	-	9	4
A-787C	" "	13,200 ± 300	19.4	-	9	6
A-591	" "	3,320 ± 220	66.2	-	9	7
A-571	" "	>33,400	<1.6	-	9	8
A-746C	" "	5,960 ± 200	47.7	-	9	8
A-746A	Organic residue	11,000 ±1,100	25.4	-	9	8
A-746B	Humates	10,100 ± 700	28.4	-	9	8
A-715A	Organic residue	7,390 ± 400	39.8	-	9	8
A-715B	Humates (first)	7,990 ± 500	37.2	-	9	8
A-715BB	Humates (3rd)	7,890 ± 420	37.5	-	9	8
A-715C	Inorg. CO_3	7,070 ± 160	41.5	-	9	8
A-634	" "	7,580 ± 220	39.0	-	9	8

TABLE G.1 (CONTINUED)

SAMPLE NUMBER	PORTION DATED	APPARENT AGE (YEARS B.P.)	C^{14} % MODERN	δC^{13} ‰	REFERENCE
H513-494	Inorg. CO_3	9,360± 250	26.5±0.8	-8.1	Brinkman
H514-473	" "	>25,000	1.1±0.8	-7.8	et al
H511-487	" "	≈30,000	2.5±0.6	-3.8	(1960)
I-374	" "	5,725± 200	49.0	-	"
I-309	" "	10,226± 400	28.0	-	Gile et al
I-375	" "	4,575± 170	56.6	-	(1966)
I-392	" "	13,850± 600	17.8	-	"
I-616	Organic C	9,550± 300	30.4	-	"
I-391	Inorg. CO_3	18,300± 600	10.2	-	"
I-376	" "	15,300± 400	14.9	-	"
GaK-972	" "	>36,000	<1.1	-	This work
GaK-974	" "	14,500±1,700	16.4	-	" "
GaK-975	" "	13,340± 290	19.0	-	" "
GaK-976	" "	19,800± 450	8.5	-3.1	" "
GaK-979	" "	2,270± 100	75.4	-1.3	" "
GaK-980	" "	17,000± 400	12.0	-	" "
GaK-982	" "	34,700 +4,300 -2,800	1.3	-	" "
GaK-973	" "	16,700± 400	12.5	-2.3	" "
GaK-981	" "	18,200± 450	10.2	-	" "
GaK-981b	" "	25,200±1,000	4.3	-1.0	" "
GrN-5347	" "	4,440± 70	57.6	-2.1	Dr. J.C. Vogel (1968, personal comm.)

It may be worth plotting these dates on a histogram to see whether definite phases of calcrete formation are indicated. The dates should, however, first be classified on a continental or subcontinental basis.

L-347

The organic carbon in this caliche apparently resulted from the seepage of fats from the cooking of early man (in the American sense) into the caliche when it was used as a firebrick. Olson and Broecker (1959) stated that the apparent age of the carbonate itself was 23,500 years and that "since the initial C^{14} concentration in caliche is difficult to estimate and since the caliche may be contaminated with more recent calcium carbonate the caliche age is difficult to evaluate".

W-786-792, 796-797

Comment by Rubin and Alexander (1960): "The activity was measured as part of a program on caliche genesis". Age-corrected 1890 wood was used as the initial activity standard and no correction was made for isotopic fractionation.

787 was taken from the upper banded surface and 790 from 4 ft below in massive caliche of the conglomerate type. 788 was taken from the "wallrock of a solution kettle" (presumably a makondo or 'pothole') in pisolitic caliche (honeycomb calcrete?) while 789 came from 4 ft below in the pisolitic caliche. 791 came from a depth of 3'6" in massive caliche overlain by 10 inches of platey caliche and six inches of soil. 792 came from a thin layer of platey caliche under 10 inches of soil. 786 was dense "trowelled calcrete" capping 3 ft of massive caliche under 10 inches of weathered gravel. 796 consisted of stringers of $CaCO_3$ in the B horizon of a buried soil, the profile being one foot of outcropping "calichified gravel" overlying a buried A horizon which in turn overlay the buried B horizon dated. At the bottom of this B horizon a "basal layer of nodular caliche" occurred from which 797 was taken.

The/ ...

The only comment made on any of these results was that "if the C^{14} activity of W-796 was the same as in the sample "(797)", one could say that the two carbonates formed during the same cycle". It can,however,be seen that while all the dates appear reasonable and possible, the submitters either had no control checks on the ages or have not mentioned them. They do not appear to have published and discussed the dates elsewhere in the literature.

L-483Y

Comment by Olson and Broecker (1961): "Fine grained calcium carbonate from the carbonate-accumulation horizon (Cca horizon) of a buried paleosol (Toyeh soil) formed during the latter part of the Altithermal Age ... Although the C^{14} age appears somewhat low, the high C^{14} concentration in this soil strengthens the possibility of dating buried organic-free soils".

LJ-510

Comment by Osborne in Hubbs et al (1963): Caliche from 20-30 cm below the upper surface of a 100 cm thick caliche layer overlain by 180 cm of loess. Lower part of the caliche layer was dated at >35,500 years. "Activity of upper part, corresponding to an "age" of 21,000 years is in agreement with activities found in Wisconsin pluvial caliche layers from Arizona". This sample came from Colorado.

A-296

Comment by Damon et al (1963): "Carbonate nodules in laminated red clay ... The initial value "(activity)" for carbonate precipitated from ground water should lie between 50% and 100% modern".

Arizona/ ...

Arizona Radiocarbon dates from Vol. 5

Details from Damon et al (1963): The following Arizona C^{14} laboratory numbers from Vol. 5 were collected "mostly from Arizona, in order to compare C^{14} contents of caliche of different types and depths, and from different climatic environments. This was in connection with a study of the origin of caliche. Generally, they were found to be more radioactive nearer the surface of the ground, indicating formation by means of evaporation of meteoric water infiltrating through the unsaturated zone rather than evaporation of vadose water from the groundwater table. Also, the caliche found in presently more humid climates tended to contain more C^{14}, indicating a more rapid rate of formation in the grasslands than in the deserts". Results are as percent modern, i.e. 95% NBS oxalic acid.

A-224, 222, 223

"Caliche layer below soil zone, 1-5 ft thick, from recently excavated pit". 224 came from the top of the caliche, 222 from 9 inches below the top and 223 from 19.5 ft below the top.

A-240, 239

240 came from the top of a caliche layer 4 ft below the surface of the soil. 239 came from 10 ft depth.

A-251

This sample came from caliche encrusting Late Pleistocene bones at a depth of 10 ft.

A-212

Caliche from the surface of "wash bank" covering and forming the matrix of loose cobbles and boulders of gneiss.

A-218/ ...

A-218

Hard white caliche formed in crevice of weathered light gray basic tuff.

A-321

Caliche 6 inches deep from shallow drainage ditch, apparently in basic volcanic rock.

A-308

"Sample from out surface of thick caliche veneer observed on banks and extending into bottom of arroyo. The C^{14} content is consistent with formation during last pluvial episode".

A-249, 248

Caliche formed in limestone from road cut. 249 from land surface and 248 from 11 ft depth.

A-265, 266

Caliche samples from ground surface in drainage gully, 266 being downslope from 265.

A-262, 263

262 from 2 ft and 263 from 5 ft below surface of a road cut.

A-259, 250

Caliche covering a probably post-Pleistocene lava flow. 250 from surface and 259 from 9 inches. The "age" of the flow was thus dated at 5,600 years B.P., a "plausible number". Unless dates have been interchanged by mistake an inversion is present. They presumably calculated the "age" of the lava flow from the apparent rate of caliche

formation/ ...

formation. If they have done this the dates must be interchanged.

A-272, 273

272 came from the top of a caliche at a depth of 5 inches and 273 from the bottom at a depth of 20 inches in the same caliche overlying an older lava flow than the one mentioned above.

A-271

Sample from "6 to 10 inches below surface at top of the calichified zone in which the caliche was coating and cementing the cinders" of a still older lava flow.

A-270, 285, 286, 287

These samples came from caliche overlying the oldest flow of the series. 270 came from the top of the "calichified zone" 2 ft below the surface. 285 was from a 3/4" thick "boulder caliche plate" covering the bottom of a boulder. 286 came from the outer 1/4" of this layer and 287 from the inner 1/4".

A-277, 278, 279

These samples came from a section consisting of "two caliche zones apparently of different ages". The 18 inch thick lower zone is in an old soil profile in a flow (of the same stage as that mentioned in connection with A-270, etc.), buried by cinders. "the upper caliche zone is 2 inches thick in the cinder layer 2 ft below the land surface, 3.5 ft separate the two caliche zones".

It is apparent from these Arizona samples that they also hoped to obtain information useful in the dating of calcretes. The results seem to be all perfectly reasonable

and/ ...

and those on successive lava flows showed successive decreases in activity as would be expected. It is also apparent that they were hard pressed for samples of calcrete of known age, the best being on a post-Pleistocene lava flow and another encrusting Late Pleistocene bones. No comment was offered on the latter sample. The results in general certainly indicate that the possibility of caliche dating should be pursued further.

A-291, 304

Details from Damon et al (1964). Caliche from sand dunes presumed to have formed by "dissolution and re-deposition of loess", probably derived from the dried Willcox playa surface. 291 came from a large stabilized dune and 304 from an apparently young active dune.

A-397-399

Details mainly from Damon et al (1964) although the dates have also been published by Buol and Yesilsoy (1964) in connection with a pedogenesis study. The material dated was carbonate from a Mohave sandy loam profile. All three "caliches" contained less than 10% $CaCO_3$. 397 was from a depth of 38" - 44", 398 from 60" - 66" and 399 from 84" - 90". Assuming formation at 100% modern, the top one could still be forming and the age discontinuity at 60 inches is corroborated by petrographic and other work. They seem to consider the dates perfectly reasonable and that the "approximate rate of caliche formation, ca.1 inch/1,000 yr, in this locality is similar to the rate in the neighboring Santa Cruz Valley". They do not state how they derive this figure and using 397 and 398, simple calculation yields a rather different figure of 348 years per inch. There is, however, a discontinuity at 60", so that any rate of formation calculated on these dates should be regarded as a maximum figure.

LJ-601, 602

Details from Hubbs et al (1965): $CaCO_3$ from slightly calcified horizons in loess. "These measurements give only minimal estimates of age of caliche formation". The ages are apparently discussed further in a Californian archaeological report, the reference to which is given (not obtained).

A-468, 467

Details from Haynes et al (1966): 468 was an outcropping porous tufa transitional to caliche capping the top of a spring mound. The 0.14% organic carbon was dated after pyrolysing and decalcifying the material. 467 was the 0.1% organic C from 1 ft below the top of the same mound below a one foot thick layer of sandy silt. Soil humates from the same level yielded a result of 10.2 ± 2.1% modern. They regarded the dates as quite reasonable dates for the "final stage of mound accretion".

A-692, 693

Details from Haynes et al (1966): 692 came from the uppermost portion of a caliche bed 3 ft below ground surface while 693 came from the lowest portion of the bed, 5 ft below ground surface. The samples are part of a "chemical and radiometric study of caliche formation".

A-576, 575, 573, 635, 572

Details from Haynes et al (1966): Various caliches from the Lehner Ranch site in Arizona. 476 apparently overlay 575 which in turn overlay 573 which were believed to be pedogenic in origin. 635 was a nodular caliche in a paleosol. This date was considered too old and that it suggested deposition from ground water since another date

(not/ ...

(not a caliche?) on overlying material was younger. 573 was thought to be too young. 572 were caliche nodules in an apparently older horizon than "any of these other samples". Date is in accord with pre-Wisconsin age estimate "for the horizon from which it came".

I-423

Details from Trautman and Willis (1966): Caliche from the bottom of a Cca horizon developed over sandstone (and apparently overlain by soil?).

SI-270-276

Details from Long and Mielke (1966): Carbonate and caliches from Willcox Playa. 270 came from 25 cm below surface and above upper green clay. "Date is minimum age for host sediment". 271 came from 30 cm below 270 and 70 from above upper green clay. "Date is minimum age". 272 is the only sample dated described as "calcrete" and not as "caliche" found in the literature and it came from the "bottom of an ancient stream bed exposed in a lime pit". These samples occurred at successively lower levels and at least show a consistent increase in age with depth. 273 was from the top of a white marl. 274 came from 80 cm below 273. 275 was a caliche which occurred above the upper green clay some distance away from 270 and 271. 276 came from the top of the same white marl as 273, but apparently some distance away outside the playa.

The dates are discussed further by Long in an unpublished thesis on the chronologies of playa lakes in Arizona and New Mexico (not obtained). Here he merely stated that "care must be taken when comparing dates from fresh water carbonates and dates from wood or charcoal and that "certain carbonates, e.g. caliche were not formed in discrete events". It is apparent, however, that the dates are

at/ ...

at least consistent in relation to each other.

A-472

Details from Haynes et al (1967): "Wisconsin (?) caliche channeled into Illinoian (?) fan. Date confirms Wisconsin age for caliche".

A-473

Details from Haynes et al (1967): Caliche cementing Illinoian (?) conglomerate. Their comments are ambiguous to anyone unfamiliar with North American Pleistocene chronology, but they seem to accept this date.

A-787C

Details from Haynes et al (1967): CO_2 from soft carbonate layer 2 ft below surface.

A-591

Details from Haynes et al (1967): "CO_2 from secondary carbonates encrusting mammoth bone and as irregular nodules in clayey sand".

A-571

Details from Haynes et al (1967): Caliche nodules in red mudstone. "Date is in accord with pre-Wisconsin age estimate".

A-746A-C

Details from Haynes et al (1967): These samples appear to be different fractions of the same azonal A horizon of a black wet meadow paleosol. It would appear from the brief description of their stratigraphic position that the age of the horizon in which they occur was regarded as

about/ ...

about 10,410 ± 190 B.P. (A-33). The carbonate gave the youngest, but an apparently not impossible age.

A-715 A, B, BBB, C

Details from Haynes et al (1967). Apparently different fractions of the same possible A horizon of a truncated paleosol. The different fractions are in good agreement and also agree with A-576 from the same horizon in another trench.

A-634

Details from Haynes et al (1967): "Secondary calcium carbonate in clayey sand". The stratigraphic position of the Lehner Ranch samples appear to be as follows, from lowermost to upper layers: A-571 (>33,400); A-572 (>30,000); A-573 (15,450); A-574 (>28,800, apparently not a caliche); A-478 B (>11,600, apparently not a caliche); ≡ A-575 (10,250); A-33 (10,410, apparently not a caliche) ≡ A-746 series (5,960 - 11,000, only lowest one a caliche); A-576 (7,000) ≡ A 715 series (7,070 - 7,990, only lowest one a caliche).

It can be seen that on the whole the caliche series is reasonably consistant, only A-575 and A-746 C being slightly on the low side. Sometimes the caliches check with the organic dates and sometimes they differ, but on the whole the caliche dates appear reasonably satisfactory.

H 513-494, 514-473, 511-487

These three determinations were published and discussed by Brinkmann et al (1960) - see discussion in Section 5.3.5.

I-374, 309, 375, 392, 616, 391, 376

Discussed by Gile, Peterson and Grossman (1966) - see discussion in Section 5.3.5.

GaK-dates/ ...

GaK-dates

Discussed in detail in Section 5.3.5.

GrN-5347

This is an unpublished Groningen date kindly made available by Dr. J.C. Vogel. The calcrete apparently encrusted a Boskop (?) skeleton found on the farm Otjiseva in the Windhoek district of South West Africa. An age of the order of 20,000 years is thus called for in the case of the skeleton itself. It can plainly only be said that the encrusting calcrete must be younger than the skeleton and the date does in fact show this. Assuming an initial C^{14} content of 100% modern, a minimum age for the skeleton of 4,440 years is thus indicated. The sample received no special treatment unusual to the routine dating of carbonates by the Groningen laboratory. One of the laboratory's standard precautions is, however, not to use the first fraction of CO_2 evolved from any carbonate, thus excluding surface contamination.

TABLE G.2 VALUES OF δC^{14}, $\delta_o C^{14}$, Δ and Δo FOR TABLE 5.10

SAMPLE NUMBER	MEASURED δC^{14} °/oo	Δ °/oo	ESTIMATED $\delta_o C^{14}$ °/oo	Δo °/oo
1598A	-875	-881	-100	-141
1603B	-957	-959	-100	-143
1907	-915	-919	-150	-187
1961	-246	-282	-50	-95

APPENDIX H

SUMMARY OF ENGINEERING TEST RESULTS

Tables H.1 to H.4 show most of the engineering test results available on the calcretes tested in the course of this project grouped according to the calcrete classification outlined in Chapter 1. Further miscellaneous test results are given in Appendix J. The test methods and abbreviations used are given in Appendix I.

Most of the work on which Tables H.1 to H.4 were based was carried out by Mr. T.E. O'Connor, with some by Mr. F. Netterberg and a little by Mr. E. Nash, Miss D.Holton, Mrs. H. Ernyes and Mr.C Broadbent.

APPENDIX I

ENGINEERING TEST METHODS AND ABBREVIATIONS EMPLOYED

Table I.1 gives brief details of the test methods employed or a reference thereto. Sometimes more than one method was employed.

Where more than one symbol or abbreviation is shown, the first one represents the one normally employed in the text. The second one is, however, becoming more internationally accepted and is therefore also shown.

TABLE I.1 SUMMARY OF TEST METHODS EMPLOYED

TEST OR PROPERTY	SYMBOL OR ABBREVIATION	METHOD
Absorption limit	AL, w_A	Nascimento et al (1963)
Liquid limit	LL, w_L	NIRR (1966)
Plastic limit	PL, w_P	" "
Shrinkage limit	SL, w_S	Lambe (1951)* using G_s
Shrinkage ratio	SR, R	" "
Shrinkage limit	SL, w_S	ASTM D427
Plasticity index	PI, I_p	LL - PL
Shrinkage index	SI, I_s	PL - SL
Flow index	F, I_f	$2\ (w_{10\ blows} - w_{32\ blows})$
Toughness index	T, I_t	$\frac{PI}{F}$ (Casagrande, 1932)
Bar linear shrinkage	LS, L_S	NIRR (1966)
Petrifaction degree	PD	$\frac{SL}{AL}$ (Nascimento et al, 1963)

* This method is the same as the ASTM optional method

TABLE I.1 (CONTINUED)

TEST OR PROPERTY	SYMBOL OR ABBREVIATION	METHOD
		water: $\gamma_D = \frac{a}{b - c - \left(\frac{b-a}{G_{wax}}\right)}$ where a = specimen weight in air, b = weight of specimen plus wax in air, c = weight of specimen plus wax in water, G_{wax} = specific gravity of wax (about 0.90)
Bulk density (rapid method)	-	Normal specific gravity method by weighing in air and in water, but reading in water taken as soon as possible before much water absorption
Optimum moisture content	OMC, w_o	Dept. of Transport (1958), modified AASHO compaction unless otherwise stated
Maximum dry density	MDD	As above
California bearing ratio	CBR	As above
Grading modulus	GM	Cumulative percent retained on U.S 10, 40 and 200 sieves divided by 100 (Kleyn, 1955).
Effective size	ES, D_{10}	Max. size of the smallest 10% by weight (Woods, 1960)
Uniformity coefficient	UC, C_u	Max. size of the smallest 60% by weight divided by the effective size.
D.O.T. classification	G = gravel S = sand SSC = semi - sand clay SC = sand clay	Dept. of Transport (1958)

TABLE I.1 (CONTINUED)

TEST OR PROPERTY	SYMBOL OR ABBREVIATION	METHOD
Extended Casagrande classification	See reference	Road Research Laboratory (1952)
Revised PRA (HRB, AASHO) classification	See reference	Road Research Laboratory (1952)
Sulphate soundness	-	Dept. of Transport (1958)
Sound cycles	-	Number of completed cycles before onset of disintegration
Polished stone value (1965)	PSV (1965)	Maclean and Shergold (1966)
Detachment	-	Karius and Dalton (1964)
Flakiness	-	SABS 647: 1961
Weighted mean Mohs hardness	$\bar{H}_w$	Normal method using minerals (Dana, 1932) or pocket hardness tester (section 7.9.2) and weighting according to estimated percentage by volume of each hardness component.
Combined strength and roughness factor?	$\bar{H}_w + H_{MAX} - H_{MIN}$	Weighted mean hardness plus range of hardness (Section 8.10.11)

APPENDIX J

MISCELLANEOUS ENGINEERING TEST RESULTS

J.1 EFFECT OF DRYING TEMPERATURE ON SOIL CONSTANTS

J.2 COMPARISON OF BS AND ASTM LIQUID LIMIT DEVICES

J.3 SOME VARIABLES AFFECTING LOS ANGELES ABRASION RESULTS

J.4 COMPARISON OF SHRINKAGE LIMIT METHODS

J.5 AVERAGE SPECIFIC GRAVITY OF SOLIDS

J.6 VARIATION OF SPECIFIC GRAVITY AND WATER ABSORPTION WITH SIZE FRACTION

J.7 EFFECT OF DIATOMS ON SOIL CONSTANTS

J.8 VOLUMETRIC SHRINKAGE

J.9 MISCELLANEOUS SPECIFIC GRAVITIES AND WATER ABSORPTIONS

J.10 MISCELLANEOUS AGGREGATE CRUSHING TEST RESULTS

J.11 SURFACE AREA

J.12 LINEAR SHRINKAGE TIMES PERCENT PASSING 40 AND 200 MESH

J.1 EFFECTS OF DRYING TEMPERATURE ON SOIL CONSTANTS

The detailed results of an experiment described in Section 7.2.2 to determine the effect of drying temperature on calcrete soil constants are shown in Table J.1. It should be noted that all samples were soaked for 24 hours at a moisture content equal to about 1½ times the liquid limit after drying and before testing. The shrinkages shown were all from the liquid limit. The linear shrinkages shown were all by the direct bar method. The particle specific gravity employed in the shrinkage limit and volumetric shrinkage methods was determined on air dried material. The values used will be found in Appendix H.

TABLE J.1 EFFECT OF HEAT ON THE SOIL CONSTANTS OF FIVE CALCRETES

SAMPLE NUMBER	PROPERTY	HEAT TREATMENT					MAX. DEVIATION FROM AIR DRIED VALUE	
		AIR DRIED	DRY		WET			
			50°C	105°C	50°C	105°C	+	-
2114	w_L	36.4	35.0	35.0	34.7	34.7	None	1.7
	w_p	22.7	21.1	21.3	21.2	23.8	1.1	1.6
	I_p	13.7	13.9	13.7	13.5	10.9	0.2	2.8
	$Vs^{(1)}$	27.5	23.4	23.1	24.4	22.9	None	4.6
	$Vs^{(2)}$	23.0	25.6	25.5	29.7	25.1	6.7	None
	Ls	6.7	7.2	6.7	7.0	6.7	0.5	0.0
	$w_s^{(1)}$	20.5	21.3	21.4	20.6	21.3	0.9	None
	$w_s^{(2)}$	13.3	20.0	20.0	17.5	20.0	6.7	None
	R	1.73	1.71	1.70	1.73	1.71	0.00	0.03
	I_f	1.0	2.8	2.6	13.4	2.2	12.4	None
	I_t	13.7	5.0	5.3	1.0	5.0	None	12.7

TABLE J.1 (CONTINUED)

SAMPLE NUMBER	PROPERTY	HEAT TREATMENT					MAX. DEVIATION FROM AIR DRIED VALUE	
		AIR DRIED	DRY		WET			
			50°C	105°C	50°C	105°C	+	-
2114	w_A	36.9	40.4	43.0	36.8	36.7	6.1	0.2
	PD(1)	0.56	0.53	0.50	0.56	0.58	0.02	0.06
2116	w_L	26.2	25.5	24.4	25.7	24.3	None	1.9
	w_p	16.6	14.9	14.4	15.0	15.7	None	2.2
	I_p	9.6	10.6	10.0	10.7	8.6	2.1	1.0
	Vs(1)	20.2	19.7	17.3	21.0	14.3	0.8	5.9
	Vs(2)	27.0	21.9	-	25.4	15.4	None	11.6
	Ls	4.9	5.3	4.7	5.3	5.0	0.4	0.2
	w_s(1)	15.6	15.2	15.3	14.8	16.6	1.0	0.8
	w_s(2)	12.0	14.0	-	12.5	16.0	2.0	None
	R	1.90	1.91	1.91	1.93	1.86	0.03	0.04
	I_f	3.0	3.0	3.6	2.0	3.2	0.6	1.0
	I_t	3.2	3.5	2.8	5.4	2.7	2.2	0.5
	w_A	35.4	37.8	40.3	37.3	42.8	7.4	None
	PD	0.44	0.40	0.38	0.40	0.39	None	0.06
2223	w_L	23.6	22.9	23.8	23.3	22.6	0.2	1.0
	w_p	13.3	17.2	16.6	17.4	16.4	4.1	None
	I_p	10.3	5.7	7.2	5.9	6.2	None	4.6
	Vs(1)	4.7	5.1	4.8	5.4	2.1	0.7	2.6
	Vs(2)	8.0	8.6	-	7.5	-	0.6	0.5
	Ls	0.0	0.7	0.0	0.0	0.0	0.7	0.0
	w_s(1)	20.9	20.1	21.0	20.2	21.4	0.5	0.8
	w_s(2)	19.0	18.0	-	19.0	-	0.0	1.0

TABLE J.1 (CONTINUED)

SAMPLE NUMBER	PROPERTY	HEAT TREATMENT					MAX. DEVIATION FROM AIR DRIED VALUE	
		AIR DRIED	DRY		WET			
			50°C	105°C	50°C	105°C	+	-
2223	R	1.74	1.76	1.70	1.75	1.72	0.01	0.04
	I_f	3.6	2.0	4.0	2.0	1.8	0.4	1.8
	I_t	2.9	2.9	1.8	2.9	3.4	0.5	0.9
	w_A	43.9	41.9	43.7	42.4	41.2	None	2.7
	PD	0.48	0.48	0.48	0.48	0.52	0.04	0.00
2367	w_L	31.4	32.8	29.5	32.0	29.3	1.4	2.1
	w_p	16.0	16.1	15.7	16.4	15.1	0.4	0.9
	I_p	15.4	16.7	13.8	15.6	14.2	1.3	1.6
	$Vs^{(1)}$	19.6	20.3	16.5	18.8	17.5	0.7	3.1
	$Vs^{(2)}$	25.2	23.8	22.8	-	24.4	None	2.4
	Ls	6.0	6.0	5.7	6.0	5.3	0.0	0.7
	$w_s^{(1)}$	20.2	21.1	20.1	20.9	19.4	0.9	0.8
	$w_s^{(2)}$	17.0	19.0	16.5	-	15.5	2.0	1.5
	R	1.75	1.72	1.75	1.69	1.77	0.03	0.06
	I_f	1.8	2.2	1.6	2.6	2.0	0.8	0.2
	I_t	8.6	7.6	8.6	6.0	7.1	0.0	2.6
	w_A	42.5	48.0	39.2	33.3	51.6	9.1	9.2
	PD	0.48	0.44	0.51	0.63	0.38	0.15	0.10
2493	w_L	32.7	33.7	32.1	31.7	32.4	1.0	1.0
	w_p	17.8	21.0	20.2	18.1	19.4	3.2	None
	I_p	14.9	12.7	11.9	13.6	13.0	None	3.0
	$Vs^{(1)}$	15.7	16.2	12.8	14.0	15.1	0.5	2.9
	$Vs^{(2)}$	20.2	17.5	16.3	17.6	19.5	None	2.7

TABLE J.1 (CONTINUED)

SAMPLE NUMBER	PROPERTY	HEAT TREATMENT					MAX. DEVIATION FROM AIR DRIED VALUE	
		AIR DRIED	DRY		WET			
			50°C	105°C	50°C	105°C	+	-
2493	Ls	4.7	5.3	4.7	5.3	4.7	0.6	0.0
	w_s (1)	23.2	23.8	24.2	23.2	23.2	1.0	0.0
	w_s (2)	20.5	23.0	22.0	21.0	20.5	1.5	0.0
	R	1.65	1.64	1.62	1.65	1.64	0.00	0.03
	I_f	0.4	2.4	2.2	4.8	0.4	4.4	0.0
	I_t	37.2	4.9	5.4	2.8	32.5	None	34.4
	w_A	41.0	41.3	44.5	47.9	45.2	6.9	None
	PD	0.57	0.58	0.54	0.48	0.51	0.01	0.09

(1) Particle specific gravity (G_s) shrinkage limit method

(2) Volumetric shrinkage shrinkage limit method

Operators: Messrs. T.E. O'Connor and F. Netterberg.

J.2 COMPARISON OF BS AND ASTM LIQUID LIMIT DEVICES

In view of the facts that both BS and ASTM liquid limit devices are in use in South Africa and are known to yield somewhat different results (Norman, 1958) it was thought desirable to assess the affect of the two on calcretes. Seven calcretes were selected which represented all the known clay mineral combinations found in calcretes together with a range of liquid limit such as would be encountered in base and subbase construction. The results are shown in Table J.2. Details of the two devices are given in Table J.3. The two BS devices were used for all routine testing for this project. The ASTM device was kindly made available for the comparative study by Mr. W.H. Luwes.

TABLE/ ...

TABLE J.2 COMPARISON OF RESULTS YIELDED BY BS AND ASTM LIQUID LIMIT DEVICES

SAMPLE NUMBER	BS DEVICE*		ASTM DEVICE	
	w_L (%)	I_f (%)	w_L (%)	I_f (%)
1569	23.3	3.0	22.1	2.4
1602	29.7	2.6	29.0	4.8
2114	33.1	1.0	32.4	3.0
2116	25.0	5.6	23.8	2.8
2223	22.3	2.4	21.6	4.4
2367	34.2	1.2	32.2	3.0
2555	20.8	3.2	19.8	1.6

* Clockhouse No. 2522/2

Operator: Miss D. Holton and Mr. F. Netterberg

It can be seen that in every case the BS device used yielded liquid limits 1-2 percentage units higher than the ASTM device. The behaviour of the flow curves was erratic and may perhaps be within the experimental error for calcretes (not determined) in some cases.

Table J.3 shows that the hardness of the base of the ASTM device is much greater than those of the BS devices. The hardness of the base of the ASTM device used is also harder than that used by Casagrande (1958): Micarta 221A with a Rockwell M hardness of 113 - unless Casagrande meant Rockwell R. Neither the ASTM (ASTM D423), the AASHO (AASHO T89), nor the S.A. Department of Transport (1958) specify the hardness of the bases of their liquid limit devices. BS 1377 requires a British Standard hardness number of between 21 and 25.

It is also of interest to note that the hardness of the area where the bowl makes contact with the base

TABLE/ ...

TABLE J.3 HARDNESS OF LIQUID LIMIT DEVICE BASES

OWNER		NIRR	NIRR	W.H. LUWES
MAKE		Clockhouse Engineering	Clockhouse Engineering	W.H. Luwes
STANDARD		BS	BS	ASTM
MAKERS TYPE NO.		7001	7001	-
SERIAL NO.		2522/1	2522/2	-
CONTACT AREA	IRHD(1)	88	86	-
	BSD(2)	88	86	-
	BSHN(3)	23	26	-
	SHORE 'D'(4)	32	31	87
GENERAL AREA AROUND CONTACT POINT	IRHD(1)	90	89	-
	BSD(2)	90	89	-
	BSHN(3)	20	21	-
	SHORE 'D'(4)	35	34	88
	ROCKWELL R(5)	7	7	116
	ROCKWELL M(5)	-	-	(184)

(1) International Rubber Hardness Degrees (ISO R48, ASTM D1415-68).

(2) British Standard Degrees, equivalent to IRHD.

(3) British Standard Hardness Number, by tables from IRHD.

(4) By Shore durometer (ASTM D2240-64T).

(5) By the Rockwell test (ASTM D785).

Operators: SABS personnel and Mr. F. Netterberg.

decreases with use. Both BS devices have been in use for about 5 years while the ASTM device has virtually only been used for the comparative study. Device 2522/1 was apparently just too hard, but after use the contact area now falls within the BS1377 requirement. The contact area of device 2522/2 falls just outside the specification (too soft), but the general base area falls just within the specification. These differences are marginal and probably do not affect the liquid limit results.

A Rockwell hardness test result falling within the range 100 to 115 is regarded as undesirable and one greater than 115 as unreliable (ASTM D785). The Rockwell L range should therefore rather be used on the harder bases like that fitted to the ASTM device. The results, however, will not then be directly comparable with the results on the R scale, and it is quite likely that the BS device bases will prove too soft for testing on the L scale.

The figures shown in Table J.3 are the means of four or more results.

J.3 SOME VARIABLES AFFECTING LOS ANGELES ABRASION RESULTS

The results of a limited study of the effect of weight and grading of sample on the Los Angeles result are shown in Table J.4.

J.4 COMPARISON OF SHRINKAGE LIMIT METHODS

Table J.5 shows the shrinkage limits of some calcretes determined by the ordinary ASTM D427 method from the volumetic shrinkage in comparison with the optional method using the solid particle specific gravity (G_s) and the shrinkage ratio. The former method requires that the weight of the soil pat of which the volume is measured shall be closely equal to the weight of the pat before removing it from the mould (i.e. an

TABLE/ ...

TABLE J.4 EFFECT OF WEIGHT AND GRADING OF SAMPLE ON THE LOS ANGELES ABRASION VALUE

SAMPLE NUMBER	MATERIAL TYPE	WEIGHT grams	NUMBER OF SPHERES	GRADING (2)	LAA %	
					100 revs	500 revs
1658X	CRUSHED HARDPAN	2500	8	$\frac{1}{4}$"-$\frac{3}{8}$"	4.6	18.2
	"	5000	11	$\frac{3}{8}$"-$\frac{1}{2}$"	5.1(1)	21.6(1)
BOULDERS IN 2116	CRUSHED BOULDERS	2500	11	$\frac{3}{8}$"-$\frac{1}{2}$"	12.4	51.0
	"	5000	11	$\frac{3}{8}$"-$\frac{1}{2}$"	8.2	32.8
	"	5000	12	A	12.2	42.9
2114	NODULES	2500	11	$\frac{1}{2}$"-$\frac{3}{4}$"	21.8	64.1
	"	5000	11	$\frac{1}{2}$"-$\frac{3}{4}$"	18.0	50.0
	"	5000	12	A	23.8	56.3
2116	NODULES	2500	11	$\frac{1}{2}$"-$\frac{3}{4}$"	14.9	55.5
	"	5000	11	$\frac{1}{2}$"-$\frac{3}{4}$"	13.7	43.2
	"	5000	12	A	13.7	44.4
2588	NODULES	1250	12	$\frac{3}{8}$"-$\frac{1}{2}$"	22.1	67.8
	"	2500	11	$\frac{3}{8}$"-$\frac{1}{2}$"	18.9	55.2
	"	5000	11	$\frac{3}{8}$"-$\frac{1}{2}$"	13.9	42.9
	"	5000	12	A	19.2	45.9
2588	NODULES	1250	12	$\frac{3}{4}$"-1"	22.0	59.8

(1) One result only, all others in duplicate.

(2) See Calif. 211 or ASTM C131 for meaning of the grading code letters.

Operator: Mr. T.E. O'Connor.

unbroken pat as required). To achieve this it is usually necessary to grease the moulds before use. As ungreased moulds (though often plastic coated) had to be used to enable petrifaction determinations to be made on the pats, a maximum loss of 0.5 gm. from the pat was permitted. This corresponds to a tolerance of 2%, as the pats weighed 25-30 grams each.

It can be seen that considerable differences between the results of the two methods are possible. This may be due to departure of the shrinkage curve from the ideal shape. The shapes of calcrete shrinkage curves are unknown.

TABLE J.5 COMPARISON OF SHRINKAGE LIMITS OBTAINED BY THE VOLUMETRIC SHRINKAGE METHOD AND THE SPECIFIC GRAVITY METHOD

SAMPLE NUMBER	SHRINKAGE LIMIT (%)	
	VS METHOD	SG METHOD
895	22.0	22.3
902	24.5	26.0
1513	21.5	21.8
1514	23.5	21.5
1516	24.5	23.5
1557	20.0	18.9
1561	23.0*	23.2
1696	25.5	24.8
1980	19.5	19.3
1981	20.0	20.1
2114	13.3	20.5
2116	12.0	15.6
2223	19.0	20.9
2360	29.5	28.7
2367	19.5	21.7

TABLE J.5 (CONTINUED)

SAMPLE NUMBER	SHRINKAGE LIMIT (%)	
	VS METHOD	SG METHOD
2368	22.0*	21.7
2493	20.5	23.2
2588	37.0	44.0
2689	14.0	16.1

* One result only, all others in duplicate.

Operator: Mr. T.E. O'Connor.

J.5 AVERAGE SPECIFIC GRAVITY OF SOLIDS

The average specific gravities of the solid particles of some calcretes are shown in Table J.6. These were determined by crushing and grinding a riffled down portion of the whole sample to minus 40 mesh and using the NIRR (1966) particle specific gravity method. The specific gravity of the minus 40 mesh fraction is also shown for comparison.

It is apparent that the specific gravity of the minus 40 mesh fraction is by no means always the same as the average specific gravity of the whole sample. In the case of calcified sands, it would seem that the specific gravity of the minus 40 mesh fraction might prove to be usually the higher, while in the case of modular calcretes the average specific gravity of the whole sample seems to be the higher. This effect is probably largely due to the nature of the carbonate distribution with respect to particle size. Incomplete air removal may also be a factor in some cases.

Owing to their carbonate content, calcretes are slightly heavier than the average road material, for which a specific gravity of 2.65 is usually assumed.

TABLE/ ...

TABLE J.6 AVERAGE SPECIFIC GRAVITY OF SOLIDS (G_s) OF SOME CALCRETES

CALCRETE TYPE	SAMPLE NUMBER	SPECIFIC GRAVITY	
		WHOLE SAMPLE	MINUS 40 MESH FRACTION
CALCIFIED SAND	1567	2.625	2.650
" "	1625	2.709	2.729
POWDER CALCRETE	1696	2.591	2.498
" "	2223	2.708	2.709
" "	2360	2.636	2.638
NODULAR CALCRETE	2114	2.680	2.680
"	2116	2.694	2.694
"	2367	2.706	2.689
"	2368	2.622	2.616
"	2493	2.664	2.662
"	2566	2.682	2.656
"	2588	2.652	2.541
"	2689	2,678	2.504

Operators: Messrs. C. Broadbent and T.E. O'Connor.

J.6 VARIATION OF SPECIFIC GRAVITY AND WATER ABSORPTION WITH SIZE FRACTION

Tables J.7 - J.8 show that the variation of specific gravity and water absorption with size fraction is apparently considerable in the case of calcretes. Dry bulk specific gravity affects the validity of a grading curve by weight, the water absorption affects the soil constants, and the saturated surface dry specific gravity is probably the specific gravity that should really be used in hydrometer analyses. Standard ASTM methods were generally used down to 200 mesh. It was initially thought that the C128 method should yield reliable results down to this size, but inspection of the results and comparison

of/ ...

of the apparent specific gravity with the specific gravity of solids determined by the usual specific gravity bottle vacuum saturation technique suggests that it is in fact only reliable down to perhaps 20 mesh. The method is intended for use on fine aggregate for concrete which normally possesses little fines and no method was found in the literature intended for use on material with an appreciable amount passing 200 mesh. The determination of G_s presents no problem, but the determination of bulk specific gravity and water absorption requires the attainment of a saturated surface dry state. The ASTM C128 method employs a cone for this to determine the point at which cohesion is lost by drying. This is plainly not satisfactory on very fine or clayey materials. The BS 812 method assesses the saturated surface dry state visually, but again this is considered to be unreliable on fines (though microscopic examination might prove satisfactory). In the Calif 225-A method the material is shaken in a dry bottle and the saturated surface dry condition taken to be when the material just ceases to adhere to the inside. Very fine material always shows this tendency of course. In view of these difficulties, four other methods were also tried on the very fine fractions.

The wax method involved stirring a weighed amount of fines into molten wax in a mould, allowing it to solidify and then weighing in air and in water and applying the formula in Appendix I. This method should yield the dry bulk particle density. Another method tried was one of the standard methods, but employing petroleum ether instead of water to prevent the clay minerals becoming plastic. A third method was the ordinary NIRR (1966) particle specific gravity method using SAE 30 motor oil instead of water. This yielded dry bulk particle densities below 2.0 (results not shown), which were definitely too low. The last method tried is based on a suggestion of Dr. K.A. Clauss, who suggested that a

paraffin/ ...

paraffin saturated surface dry state could be attained by adding the paraffin-soaked material to water. This was in essence the method used, except that a water insoluble dye (iodine) was added to the paraffin to help judge when the surplus paraffin was removed. The soil/paraffin/water mixture was then thoroughly mixed, allowed to settle and the supernatant paraffin and water removed by decantation and pipetting. The surplus water was then removed by drying in a desiccator over silica gel. At this point the material was assumed to be in a surface dry paraffin saturated state. Use of a second, paraffin insoluble, water soluble dye of a different colour might have been a help here. Several different methods can be used from this point. The ASTM, BS, or Calif methods would then yield all specific gravity and absorption data (using paraffin instead of water) or the paraffin absorption could be calculated at this stage and the other data calculated from a knowledge of G_s. The surface dry paraffin saturated specific gravity could be found by using the usual specific gravity bottle technique. The surface dry water saturated specific gravity should be this multiplied by the specific gravity of paraffin. Time has so far precluded much experimentation, but some results by the latter technique are shown.

It is unfortunately impossible to say which of these methods (if any) has yielded the correct answer. In view of the importance of the variation of bulk specific gravity with size fraction in determining the maximum compacted density particle size distribution by weight, and the effect of water absorption on the soil constants, further work is definitely justified on a method for the determination of bulk particle specific gravity and water absorption of fine particles. Consideration should also be given to the suggestion that there is no such thing as a saturated surface dry state for a material consisting of a wide range of particle sizes, as the

suction/ ...

suction in and around the finer particles will tend to drain the larger particles. Surface area and mercury porosimeter measurements might be revealing.

TABLE J.7 VARIATION OF WATER ABSORPTION AND SPECIFIC GRAVITY WITH SIZE FRACTION IN POWDER CALCRETES

SAMPLE NUMBER	SIZE FRACTION (inches or U.S. sieves)	WATER ABSORPTION %	SPECIFIC GRAVITY			METHOD
			AP-PAR-ENT	BULK, DRY	BULK, SATURATED SURFACE DRY	
1020	$\frac{3}{4}$"-1"	7.6	2.69	2.23	2.40	ASTM C127-59
	$\frac{1}{2}$"-$\frac{3}{4}$"	7.9	2.72	2.24	2.41	"
	$\frac{3}{8}$"-$\frac{1}{2}$"	11.0	2.70	2.08	2.30	"
1557	$\frac{3}{4}$"-1"	6.8	2.59	2.20	2.34	ASTM C127-59
	$\frac{1}{2}$"-$\frac{3}{4}$"	7.0	2.60	2.21	2.36	"
	$\frac{3}{8}$"-$\frac{1}{2}$"	8.0	2.60	2.15	2.32	"
2223	$\frac{1}{4}$"-$\frac{1}{2}$"	7.4	2.73	2.27	2.44	ASTM C127-59
	4-$\frac{1}{4}$"	12.1	2.79	2.09	2.34	"
	10-4	5.4	2.54	2.23	2.35	ASTM C128-59
	20-10	8.9	2.60	2.11	2.30	"
	40-20	8.5	2.52	2.07	2.25	"
	60-40	7.5	2.57	2.16	2.32	"
	100-60	0.8	2.62	2.57	2.59	"
	200-100	0.3	2.65	2.63	2.64	"
	200-100	-	2.709	-	-	NIRR (G_s)
	200-100	-	-	2.42	-	Wax
	-200	0.4	2.58	2.56	2.57	Calif 225-A
	-200	0.3	2.56	2.54	2.55	ASTM C128-59
	-200	9.9	2.50	2.00	2.13	Petroleum ether (Calif)
	-200	-	2.701	-	-	NIRR

TABLE J.7 (CONTINUED)

SAMPLE NUMBER	SIZE FRACTION (inches or U.S. sieves)	WATER ABSORPTION %	APPARENT	SPECIFIC GRAVITY		METHOD
				BULK, DRY	BULK, SATURATED SURFACE DRY	
	-200	-	-	2.62	-	Wax
2360	$\frac{3}{4}$"-1"	13.1	2.64	1.96	2.21	ASTM C127-59
	$\frac{1}{2}$"-$\frac{3}{4}$"	16.1	2.58	1.83	2.11	"
	$\frac{3}{8}$"-$\frac{1}{2}$"	14.9	2.69	1.92	2.20	"
	$\frac{1}{4}$"-$\frac{1}{2}$"	-	-	-	-	"
	4-$\frac{1}{4}$"	9.6	2.71	2.15	2.35	"
	10-4	12.6	2.64	1.98	2.23	ASTM C128-59
	20-10	16.3	2.62	1.84	2.13	"
	40-20	12.2	2.49	1.91	2.14	"
	60-40	7.6	2.57	2.15	2.31	"
	100-60	4.1	2.32	2.12	2.21	"
	200-100	10.0	2.37	1.92	2.11	"
	200-100	-	2.612	-	-	NIRR (G_s)
	200-100	-	-	2.47	-	Wax
	-200	26.2	2.77	1.60	2.02	ASTM C128-59
	-200	-	2.654	-	-	NIRR

Operators: Mrs. H.Ernyes, Miss. D.Holton and Messrs. C. Broadbent and E. Nash.

TABLE/ ...

TABLE J.8 VARIATION OF WATER ABSORPTION AND SPECIFIC GRAVITY WITH SIZE FRACTION IN NODULAR CALCRETES

SAMPLE NUMBER	SIZE FRACTION (inches or U.S. sieves)	WATER ABSORPTION %	SPECIFIC GRAVITY			METHOD
			APPARENT	BULK, DRY	BULK, SATURATED SURFACE DRY	
978	¾"-1"	12.5	2.62	1.97	2.22	ASTM C127-59
	½"-¾"	15.0	2.66	1.90	2.18	" "
	⅜"-½"	15.9	2.64	1.86	2.15	" "
1024M	¾"-1"	6.4	2.64	2.26	2.40	ASTM C127-59
	½"-¾"	6.3	2.60	2.24	2.37	" "
	⅜"-½"	7.5	2.64	2.20	2.36	" "
1561	¾"-1"	21.0	2.46	1.62	1.95	ASTM C127-59
	½"-¾"	20.6	2.49	1.65	1.98	" "
	⅜"-½"	20.0	2.54	1.68	2.08	" "
1565	¾"-1"	7.7	2.66	2.21	2.37	ASTM C127-59
	½"-¾"	2.5	2.66	2.50	2.56	" "
	⅜"-½"	4.0	2.67	2.41	2.50	" "
1569	¾"-1"	4.8	2.61	2.32	2.43	ASTM C127-59
	½"-¾"	5.0	2.64	2.33	2.45	" "
	⅜"-½"	5.0	2.58	2.29	2.40	" "
1602	¾"-1"	2.8	2.68	2.49	2.56	ASTM C127-59
	½"-¾"	2.6	2.69	2.51	2.57	" "
	⅜"-½"	2.8	2.69	2.50	2.57	" "
1980	2"-3"	3.8	2.64	2.40	2.49	ASTM C127-59
	" "					
	1½-2 "	5.0	2.69	2.37	2.49	" "
	1" -1½	4.1	2.66	2.40	2.50	" "

TABLE J.8 (CONTINUED)

SAMPLE NUMBER	SIZE FRACTION (inches or U.S. sieves)	WATER ABSORPTION %	SPECIFIC GRAVITY			METHOD
			APPARENT	BULK, DRY	BULK, SATURATED SURFACE DRY	
1980	¾"- 1"	4.5	2.67	2.38	2.49	ASTM C127-59
	½"- ¾"	5.3	2.68	2.35	2.47	" "
	¼"- ½"	6.1	2.70	2.32	2.47	" "
	4"- ¼"	7.6	2.74	2.27	2.44	" "
	10- 4	8.9	2.77	2.22	2.42	ASTM C128-59
	20- 10	8.5	2.76	2.23	2.42	" "
	40- 20	6.2	2.52	2.19	2.32	" "
	60- 40	3.7	2.43	2.23	2.31	" "
	100-60	3.2	2.59	2.39	2.46	" "
	200-100	2.7	2.45	2.30	2.36	" "
	200-100	-	2.674	-	-	NIRR (G_s)
	200-100	-	-	2.47	-	Wax
	-200	4.2	2.42	2.20	2.29	Calif 225-A
	-200	1.8	2.37	2.27	2.31	BS 812
	-200	9.3	2.65	2.14	2.26	Petroleum ether
	-200	-	2.728	-	-	NIRR (G_s)
	-200	-	-	2.53		Wax
2114	1"-1½"	7.1	2.68	2.25	2.41	ASTM C127-59
	¾"-1"	7.1	2.63	2.22	2.38	" "
	½"-¾"	6.4	2.63	2.26	2.40	" "
	¼"-½"	7.1	2.63	2.21	2.37	" "
	4-¼"	8.5	2.66	2.17	2.36	" "
	10-4	6.4	2.61	2.24	2.38	ASTM C128-59

TABLE J.8 (CONTINUED)

SAMPLE NUMBER	SIZE FRACTION (inches or U.S. sieves)	WATER ABSORPTION %	SPECIFIC GRAVITY			METHOD
			APPARENT	BULK DRY	BULK, SATURATED, SURFACE DRY	
2114 (cont.)	20-10	10.3	2.66	2.09	2.30	ASTM C128-59
	40-20	8.8	2.50	2.05	2.23	" "
	60-40	10.7	2.42	1.92	2.13	" "
	100-60	8.8	2.34	1.94	2.11	" "
	100-60	-	2.669	-	-	" "
	100-60	-	-	2.659	-	NIRR
	200-100	5.0	2.40	2.14	2.25	ASTM C128-59
	200-100	-	2.639	-	-	NIRR (G_s)
	200-100	-	-	2.52	-	Wax
	200-100	-	-	-	1.955	NIRR (paraffin saturated)
	-200	12.6	2.43	1.86	2.10	ASTM C128-59
	-200	-	2.672	-	-	NIRR (G_s)
	-200	-	-	2.42	-	Wax
2116	2"-3"	3.2	2.64	2.44	2.51	ASTM C127-59
	$1\frac{1}{2}$"-2"	3.0	2.65	2.46	2.53	" "
	1"-$1\frac{1}{2}$"	3.2	2.65	2.44	2.52	" "
	$\frac{3}{4}$"-1"	3.4	2.66	2.43	2.52	" "
	$\frac{1}{2}$"-$\frac{3}{4}$"	3.7	2.66	2.42	2.51	" "
	$\frac{1}{4}$"-$\frac{1}{2}$"	4.5	2.67	2.38	2.49	" "
	4-$\frac{1}{4}$"	5.5	2.70	2.35	2.48	" "
	10-4	6.8	2.66	2.24	2.40	ASTM C128-59
	20-10	10.9	2.67	2.07	2.29	" "
	40-20	6.0	2.39	2.09	2.22	" "
	60-40	4.4	2.66	2.39	2.49	" "
	100-60	4.1	2.43	2.21	2.30	" "

TABLE J.8 (CONTINUED)

SAMPLE NUMBER	SIZE FRACTION (inches or U.S. sieves)	WATER ABSORPTION %	SPECIFIC GRAVITY			METHOD
			APPARENT	BULK, DRY	BULK, SATURATED SURFACE DRY	
2116 (cont.)	100-60	-	2.681	-	-	NIRR
	100-60	-	-	-	2.652	NIRR (paraffin saturated)
	200-100	2.5	2.57	2.41	2.47	ASTM C128-59
	200-100	-	2.667	-	-	NIRR (G_s)
	200-100	-	-	-	2.657	NIRR (paraffin saturated)
	200-100	-	-	2.40	-	Wax
	-200	1.2	2.55	2.48	2.50	Calif 225-A
	-200	3.9	2.49	2.27	-	ASTM C128-59
	-200	-	2.706	-	-	NIRR (G_s)
	-200	-	-	2.38	-	Wax
2588	2"-3"	19.9	2.61	1.72	2.06	ASTM C127-59
	1½"-2"	18.5	2.61	1.75	2.08	" "
	1"-1½"	13.5	2.65	1.95	2.22	" "
	¾"-1"	11.5	2.69	2.05	2.29	" "
	½"-¾"	12.7	2.69	2.01	2.26	" "
	¼"-½"	13.4	2.73	2.00	2.27	" "
	4-¼"	15.0	2.75	1.95	2.24	" "
	10-4	11.6	2.71	2.06	2.31	ASTM C128-59
	20-10	8.7	2.65	2.15	2.34	" "
	40-20	11.1	2.59	2.01	2.34	" "
	60-40	9.6	2.24	1.85	2.02	" "

TABLE J.8 (CONTINUED)

SAMPLE NUMBER	SIZE FRACTION (inches or U.S. sieves)	WATER ABSORPTION %	SPECIFIC GRAVITY			METHOD
			APPARENT	BULK DRY	BULK, SATURATED SURFACE DRY	
2588 (cont.)	100-60	7.7	2.62	2.18	2.35	ASTM C128-59
	200-100	5.5	2.39	2.11	2.23	Calif. 225-A
	200-100	-	2.659	-	-	NIRR (G_s)
	200-100	-	-	2.04	-	Wax
	-200	20.8	2.32	1.57	1.89	Calif 225-A
	-200	12.4	2.42	1.86	2.01	Petroleum ether (ASTM)
	-200	-	2.679	-	-	NIRR (G_s)
	-200	-	-	2.26	-	Wax
2689	½"-¾"	3.3	2.67	2.46	2.54	ASTM C127-59
	¼-½"	3.9	2.72	2.46	2.56	" "
	4-¼ "	5.3	2.67	2.33	2.46	" "
	10-4	10.5	2.58	2.03	2.25	ASTM C128-59
	20-10	9.8	2.58	2.06	2.26	" "
	40-20	3.8	2.63	2.39	2.48	" "
	60-40	6.1	2.61	2.25	2.39	" "
	100-60	7.4	2.63	2.20	2.36	ASTM C128-59
	200-100	6.7	2.32	2.00	2.15	" "
	200-100	-	2.653	-	-	NIRR (G_s)
	200-100	-	-	2.26	-	Wax
	-200	2.8	2.41	2.26	2.32	Calif 225-A
	-200	-	2.569	-	-	NIRR (G_s)

Operators: Mrs. H.Ernyes, Miss D.Holton and Messrs. E. Nash and C. Broadbent.

J.7 EFFECT OF DIATOMS ON SOIL CONSTANTS

Table J.9 shows the results of an experiment carried out to assess the effect of diatoms on the soil constants of calcretes. Samples 2114 & 2116 contained no diatoms in their natural state. The diatoms used were all minus 200 mesh and came from a commercial kieselguhr product. Their shrinkage limit was 109 by the SG method and 106 by the volumetric shrinkage method, their solid particle specific gravity 2.23, shrinkage ratio 0.66, absorption limit 177%, petrifaction degree 0.61, liquid limit over 100 and linear shrinkage 0.7.

TABLE J.9 EFFECT OF ADDED DIATOMS ON THE SOIL CONSTANTS

SAMPLE NUMBER	PROPERTY	PERCENT ADDED DIATOMS			
		0	2.5	5.0	10.0
2114	w_L	36.4	37.8	38.5	38.9
	w_p	22.7	24.1	25.0	25.7
	I_p	13.7	12.7	13.5	13.2
	$Vs^{(1)}$	27.5	25.0	22.7	24.8
	$Vs^{(2)}$	23.0	26.3	24.0	24.2
	I_s	6.7	6.0	6.7	6.7
	$w_s^{(1)}$	20.5	22.8	24.4	23.6
	$w_s^{(2)}$	13.3	22.0	23.5	24.0
	$I_s^{(1)}$	2.2	1.3	0.6	2.1
	$I_s^{(2)}$	9.4	2.1	1.5	1.7
	R	1.73	1.67	1.61	1.63
	I_f	1.0	3.6	6.0	3.0
	I_t	13.7	3.8	2.3	4.4
	w_A	36.9	40.1	44.0	40.6
	$PD^{(1)}$	0.56	0.57	0.55	0.58
	G_s	(2.680)	2.666	2.656	2.655

TABLE J.9 (CONTINUED)

SAMPLE NUMBER	PROPERTY	PERCENT ADDED DIATOMS			
		0	2.5	5.0	10.0
2116	w_L	26.2	29.7	27.4	33.4
	w_p	16.6	17.6	20.6	22.6
	I_p	9.6	12.1	6.8	10.8
	$Vs^{(1)}$	20.2	24.9	16.8	18.2
	$Vs^{(2)}$	27.0	27.1	19.5	20.5
	Ls	4.9	6.7	6.0	4.7
	$w_s^{(1)}$	15.6	16.3	18.0	22.5
	$w_s^{(2)}$	12.0	15.0	16.5	21.0
	$I_s^{(1)}$	1.0	1.3	2.6	0.1
	$I_s^{(2)}$	4.6	2.6	4.1	1.6
	R	1.90	1.86	1.80	1.66
	I_f	3.0	5.0	5.0	5.0
	I_t	3.2	2.4	1.4	2.2
	w_A	35.4	39.8	39.5	44.9
	PD	0.44	0.41	0.46	0.50
	G_s	(2.694)	2.680	2.667	2.655

(1) Specific gravity shrinkage limit method

(2) Volumetric shrinkage limit method.

Operators: Messrs. T.E. O'Connor and F. Netterberg.

J.8 VOLUMETRIC SHRINKAGE

Table J.10 shows some volumetric shrinkage results calculated from the liquid limit, shrinkage limit and shrinkage ratio in Tables H.1-H.2.

TABLE/ ...

TABLE J.10 VOLUMETRIC SHRINKAGE FROM THE LIQUID LIMIT

SAMPLE NUMBER	VOLUMETRIC SHRINKAGE(1) %
913	26.1
1024M	12.5
1026M	14.2
1513	20.4
1514	35.2
1516	12.6
1533	15.1
1561	4.0
1565	48.3
1569	8.7
1602	12.0
1624	37.1
1980	19.6
1981	46.3
2114	30.4
2116	22.2
2367	17.1
2493	16.0
2689	45.5
895	17.9

SAMPLE NUMBER	VOLUMETRIC SHRINKAGE(1) %
1625	30.0
902	52.1
1512	11.3
1557	14.4
1696	32.5
1881	12.0
2223	5.9
2360	28.5

(1) Using the specific gravity shrinkage limit.

Operator: Mr. T.E. O'Connor.

J.9 MISCELLANEOUS SPECIFIC GRAVITIES AND WATER ABSORPTIONS

Table J.11 shows some specific gravity and water absorption results on size fractions differing from those in Tables H.1-H.4

J.10 MISCELLANEOUS AGGREGATE CRUSHING TEST RESULTS

Table J.12 shows some aggregate crushing test results on size fractions differing from those in Tables H.1-H.4.

TABLE/ ...

TABLE J.11 MISCELLANEOUS SPECIFIC GRAVITIES AND WATER ABSORPTIONS ON SIZE FRACTIONS DIFFERING FROM THOSE IN TABLES H.1-H.4

SAMPLE NUMBER	SIZE FRACTION	WATER ABSORPTION %	SPECIFIC GRAVITY			METHOD
			APPARENT	BULK, DRY	BULK, SATURATED SURFACE DRY	
1028X	¼" - ⅜"	5.8	2.60	2.26	2.39	ASTM C127-59
1625	⅜" - ½"	8.1	2.70	2.22	2.40	" "
1642	¼" - ⅜"	20.7	2.50	1.65	1.99	" "
2228	¼" - ⅜"	2.4	2.68	2.52	2.58	" "

Operator: Mrs. H. Ernyes.

J.11 SURFACE AREA

Surface area determinations on the minus 40 mesh (0.42 mm) fractions of some calcretes are shown in Table J.13. The method used was the free glycol surface desorption method described by Van der Merwe, which is essentially that of Dyal and Hendricks (1950) modified by the inclusion of the free glycol surface of Martin (1955). The free surface method tends to yield higher surface areas than the Dyal and Hendricks method. The total surface area was obtained on air dried material, the external surface area on material which had been heated to 600°C for two hours and the internal area by difference. In this connection it should be noted that Jackson (1956) has stated that heating to 600°C also decreases the specific surface of amorphous materials.

The surface areas were calculated from the glycol retention by means of the formula:

Surface/ ...

TABLE J.12 MISCELLANEOUS AGGREGATE CRUSHING TEST RESULTS ON DIFFERENT SIZE FRACTIONS FROM THOSE IN TABLES H.1 - H.4.

SAMPLE NUMBER	SIZE FRACTION	10% F.A.C.T.(2)			ACV %	LAA(1)		A.P.T.	
		DRY tons	SOAKED			100 revs %	500 revs %	AFV %	APV %
			tons	MOISTURE %					
1557	$\frac{3}{8}$"-$\frac{1}{2}$"	~5	-	-	-	-	-	-	-
1557	$\frac{3}{4}$"-1"	~3	-	-	-	-	-	-	-
1561	$\frac{3}{8}$"-$\frac{1}{2}$"	1.2	-	-	-	-	-	-	-
1561	$\frac{3}{4}$"-1"	0.9	-	-	64.8	-	-	-	-
1565	$\frac{3}{4}$"-1"	8.8	-	-	-	-	-	-	-
1602	$\frac{3}{4}$"-1"	~12	-	-	-	-	-	-	-
2588	$\frac{3}{8}$"-$\frac{1}{2}$"	7.6	2.6	16.9	-	-	-	-	-
2588	$\frac{3}{4}$"-1"	-	-	14.3	-	-	-	81	56

(1) See also Table J.4

(2) The sign '~' means that the fines fell outside the range 7.5 - 12.5% and the calculated result at 10% may therefore be inaccurate.

Operators: Routine Test Section Staff and Mr. T.E. O'Connor.

$$\text{Surface area} = \frac{\text{Weight glycol retained}}{\text{Weight dry unheated soil} \times 3.1 \times 10^{-4}} \; m^2/g$$

where 3.1×10^{-4} is the weight of glycol required in grams to form a monomolecular layer one square meter in extent. The weight of dry unheated soil was obtained by drying to constant weight over calcium chloride.

TABLE/ ...

TABLE J.13 SURFACE AREA MEASUREMENTS ON THE SOIL FINES

MATERIAL TYPE	SAMPLE NUMBER	SURFACE AREA (m^2/g)	
		TOTAL	EXTERNAL
CALCIFIED SAND	1625	85	49
POWDER CALCRETES	1696	81	16
	2223	16	184
	2360	88	-
NODULAR CALCRETES	1533	54	<3
	1569	52	<3
	1601	62	<3
	1602	90	31
	1624	96	39
	2114	43	<3
	2116	45	39
	2367	67	135
	2368	96	194
	2493	65	105
	2555	33	52
	2566	31	72
	2588	88	65
NODULAR CALCRETES PLUS ADDED DIATOMS	2114+2.5%	46	28
	2114 + 5%	48	<3
	2114+10%	46	18
	2116+2.5%	42	48
	2116+5%	45	47
	2116+10%	45	50

Operator: Mr. J. Schultz.

It can be seen that the values supposedly representing the external surface area are in somecases higher than the values supposedly representing the total surface area. This is plainly impossible, but if experimental error can be excluded, the results suggest that the surface area of some calcretes increases on heating to 600°C. The results are given here because they are the only results on calcretes available. In view of the anomalous values the work should be repeated.

Specific/ ...

Specific surface and the equilibrium moisture content at 85% humidity has been related to the potential expansiveness of soils by De Bruyn et al (1956). Using only the total surface as a rough guide, it would appear from their results that values above about 120 m^2/g indicate a potentially expansive soil and values above about 150 m^2/g a badly expansive soil (see, however, also their conclusions). These conclusions are probably not applicable to soils containing palygorskite or sepiolite, as these clay minerals possess high surface areas, but are non-expansive.

Surface area has also been correlated with the cement content required to satisfy the freeze - thaw criteria for soil-cement. A figure relating surface area and cement requirement appears in Woods (1960, figure 21-20).

J.12 LINEAR SHRINKAGE TIMES PERCENT PASSING 40 AND 200 MESH

Table J.14 shows values of bar linear shrinkage times the percentage passing the U.S. 40 and 200 mesh sieves calculated from the data in Tables H.1-H.4.

TABLE J.14 VALUES OF BAR LINEAR SHRINKAGE TIMES WEIGHT PERCENTAGE PASSING 40 AND 200 MESH

MATERIAL TYPE	SAMPLE NUMBER	LS X % -40 MESH	LS X % -200 MESH
CALCIFIED SAND	895	375	160
	1015	72	31
	1625	400	282
POWDER CALCRETES	902	792	652
	1512	132	104
	1557	272	88
	1696	592	330
	1737	143	45

TABLE J.14 (CONTINUED)

MATERIAL TYPE	SAMPLE NUMBER	LS X % -40 MESH	LS X % -200 MESH
POWDER CALCRETES	1881	334	201
	2223	50	44
	2236	176	51
	2360	409	211
NODULAR CALCRETES	913	343	182
	976	569	138
	978	331	147
	1016	304	104
	1021M	307	84
	1024	254	122
	1024M	286	148
	1026	157	99
	1026M	302	180
	1513	260	174
	1514	392	312
	1516	100	78
	1561	168	57
	1565	300	140
	1569	109	46
	1601	138	43
	1602	224	108
	1624	214	120
	1876	250	105
	1980	119	79
	1981	377	200
	2114	344	192
	2116	204	138
	2234	65	14
	2367	289	107
	2368	78	24
	2493	207	74
	2555	48	16
	2566	0	0
	2588	88	40
	2689	221	98
CALCRETE MIXTURES	896	72	13
	900	188	56
	911	10	6
	912	8	5
	918	382	143
	1019	518	241
	1022	192	90

TABLE J.14 (CONTINUED)

MATERIAL TYPE	SAMPLE NUMBER	LS X % -40 MESH	LS X % -200 MESH
CALCAREOUS SOILS	891	924	480
	893	479	153
	894	1660	1060
	916	476	201
BLACK CLAY	892	1853	1621

APPENDIX K

TEST RESULTS ON SOME SOUTH AFRICAN CALCRETE BASED ROADS

K.1 BASE AND SUBBASE

Table K.1 shows detailed test results of five South African calcrete-based roads kindly made available by the Cape Provincial Roads Department and the Cape Town and Port Elizabeth Divisional Engineers. The test results originally appeared in letters from the Assistant Materials Engineer, Queenstown, to the Divisional Roads Engineer, Port Elizabeth in 1956 (file QL.7/2/7/1012) and from the Provincial Roads Engineer, Cape Town, to the Divisional Roads Engineer, Cape Town in 1960 (file R/P. 20/9). The Cape Roads Dept. follow the Dept. of Transport (1958) test methods.

Table K.2 shows an analysis of the grading and soil constant results according to the Texas and FAA caliche base specifications.

Table K.3 shows details of some calcrete wearing courses in the Western Transvaal kindly made available by the Transvaal Roads Department. These samples were taken from the roads themselves. The Transvaal Roads Dept. do not follow the Dept. of Transport (1958) methods exactly. Their usual technique is to dry sieve and only wash through the 40 mesh sieve. Only the dry sieved material is used for Atterberg limits. Table K.4 shows details of some borrow pit samples from the same area.

TABLE/ ...

TABLE K.1 TEST RESULTS ON FIVE ROADS EMPLOYING CALCRETES AS BASE AND SUBBASE

ROAD	SAMPLING POINT	ROAD PROFILE	SAMPLE DETAILS			PERCENTAGE PASSING (INCHES, MILLIMETRES, U.S. SIEVES									HYDROMETER ANALYSIS (mm)						CONSTANTS			DENSITY			MOD. AASHO OMC, CBR AND SWELL												GRADING MODULUS	GROUP INDEX	LINEAR SHRINKAGE X % PASSING 40 MESH	REVISED PRA CLASSIF.
															SAND				SILT	CLAY							OMC %	4 DAYS SOAKING			CURED 7 DAYS SOAKED 4 DAYS			CURED 28 DAYS SOAKED 4 DAYS								
															COARSE	FINE												CBR (%)(1)		SWELL (%)	CBR (%)(1)		SWELL (%)	CBR (%)(1)		SWELL (%)					
			C.P.A. No.	DEPTH inches	MATERIAL	2.0	1.5	1.05	0.742	0.525	0.185 4	0.078 & 10	0.0164 0.42 40	0.0021 0.05 270	<2.0 >0.42	<0.42 >0.246	<0.246 >0.147	<0.147 >0.05	<0.05 >0.005	<0.005	LL %	PI %	LS %	IN-SITU lbs/cu ft	M.AASHO lbs cu ft	RELATIVE %		0.1"	0.2"		0.1"	0.2"		0.1"	0.2"							
PORT ELIZABETH MARINE DRIVE	Opposite Noord-hoek quarry	?	DE.7400	Base	Calcrete	100/98/98	81	72	72	72	72	71	56	17	21	12	20	23	8	16	22	4	2.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.5	0.0	140	A-2-4 (0)
	"	"	DE.7401	"	"	100/60	46	46	46	45	44	44	42	15	5	12	30	19	14	20	23	5	2.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.9	0.0	105	A-1-, (0)
	"	"	DE.7402	"	"	100	67	62	60	59	55	50	45	16	10	17	25	15	13	20	23	5	2.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.8	0.0	112	A-1-' (0)
	"	"	DE.7403	"	"		100	90	90	86	80	75	55	19	27	10	24	14	9	16	21	5	2.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.5	0.0	137	A-2-4 (0)
	"	"	DE.7404	"	Mixture of 7400-7403	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	110	-	14.4	90	92	0.1	38	46	0.0	38	40	0.0				1.7	0.0	124	-
	Mile 5	?	DE.7415	Base	Calcrete	100	78	78	71	71	65	61	48	15	21	15	22	17	9	16	23	8	3.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.7	0.0	168	A-1- (0)
	" "	"	DE.7416	"	"	100/53	53	53	51	49	44	37	28	9	24	14	21	17	9	15	24	9	4.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2.2	0.0	112	A-2-4 (0)
	" "	"	DE.7417	"	"	100	73	61	59	57	54	50	41	14	18	15	20	20	11	17	23	8	3.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.8	0.0	143	A-2-4 (0)
	" "	"	DE.7418	"	"	100	79	75	74	74	65	58	33	9	43	10	18	13	6	10	20	6	2.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2.0	0.0	83	A-1- (0)
	" "	"	DE.7419	"	Mixture of 7415-7418	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	116	-	12.4	62	81	0.0	85		0.0	63	79	0.0				1.9	0.0	127	-
PORT ELIZABETH - ADDO	Mile 29.5	?	DE.7380	Base	Calcrete		100	87	85	83	79	70	56	23	20	8	11	29	20	12	28	12	5.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.4	0.4	308	A-2-6 (0)
	" "	"	DE.7381	"	"		100	93	93	86	71	67	55	18	18	8	13	34	18	9	31	14	6.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.4	0.5	330	A-2-6 (1)
	" "	"	DE.7382	"	"		100	85	79	77	68	61	49	16	20	10	13	31	16	11	31	11	5.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.7	0.2	270	A-2-6 (0)
	" "	"	DE.7383	"	"		100	96	96	93	82	79	56	21	29	8	11	25	17	9	28	12	5.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.4	0.3	308	A-2-6 (0)
	" "	"	DE.7384	"	Mixture of 7380-7383	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	116	-	12.2	66	83	0.2	75	87	0.0	68	79	0.1				1.5	0.4	304	-
	Mile 26	?	DE.7385	Base	Calcrete		100	93	93	88	76	66	39	13	41	10	11	19	10	9	32	14	6.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.8	0.2	254	A-2-6 (0)
	" "	"	DE.7386	"	"			100	97	95	84	73	42	13	43	10	10	19	10	8	33	15	6.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.7	0.3	273	A-2-6 (0)
	" "	"	DE.7387	"	"				100	99	90	80	52	17	35	9	12	23	11	10	31	13	6.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.5	0.3	312	A-2-6 (0)
	" "	"	DE.7388	"	"		100	94	94	94	83	72	53	17	26	12	12	26	12	12	31	13	6.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.5	0.3	318	A-2-6 (0)
	" "	"	DE.7389	"	Mixture of 7385-7388	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	117	-	13.1	47	61	0.1	29	33	0.0	19	25	0.05				1.6	0.3	289	-

(1) At Mod. AASHO compaction, but only nominally at Mod. AASHO OMC

TABLE K.1 (CONTINUED)

ROAD	SAMPLING POINT	ROAD PROFILE	SAMPLE DETAILS			PERCENTAGE PASSING (INCHES, MILLIMETRES, U.S. SIEVES										HYDROMETER ANALYSIS (mm)						CONSTANTS			DENSITY			MOD. AASHO OMC, CBR AND SWELL						GRADING MODULUS	GROUP INDEX	LINEAR SHRINKAGE X % PASSING 40 MESH	REVISED PRA CLASSIF.
			C.P.A. No.	DEPTH inches	MATERIAL	2.0	1.5	1.05	0.742	0.525	0.185 4	0.078 2 10	0.0164 0.42 40	0.0021 0.05 270		SAND				SILT	CLAY				IN - SITU lbs/ cu ft	M.AASHO lbs/ cu ft	RELA-TIVE %	OMC %	4 DAYS SOAKING			FIELD CBR %					
																COARSE	FINE			<0.05 >0.005	<0.005	LL	PI	LS					CBR (%)(1)		SWELL %	0.1"	0.2"			
																< 2.0 > 0.42	<0.42 >0.246	<0.246 >0.147	< 0.147 > 0.05										0.1"	0.2"					
LANDS-DOWNE ROAD, CAPE FLATS	Mile 0.1	0-24" Calcrete	D.9558	0-4½	Calcrete		100	96	90	88	75	68	55	21	19	16	15	19	11	20	19	7	3.0	121	121	100	-	-	-	-	95	114	1.5	0.0	165	A-2-4 (0)
	" "	24" + Sand	D.9559	4½-14	"	97	85	73	66	62	51	46	37	11	20	18	18	20	12	13	19	6	2.5	-	-	-	-	-	-	-	-	-	2.0	0.0	93	A-1-b (0)
	Mile 0.2	0-12" Calcrete	D.9561	0-4	"	100	98	93	90	88	78	71	56	20	21	16	17	19	11	17	19	6	3.0	123	121	102	-	-	-	-	112	142	1.5	0.0	168	A-2-4 (0)
	" "	12-17" Calcrete + Sand 17" + Sand + calcrete	D.9562	4-12	"	92	86	80	72	68	57	51	41	14	20	18	17	19	12	15	19	6	2.5	-	-	-	-	-	-	-	-	-	1.9	0.0	102	A-1-b (0)
	-	-	-	-	Mixture of 9558 & 9561	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	121	-	10.0	112	142	0.0	-	-	1.7	0.0	132	-
	Mile 0.4	0-17" Calcrete	D.9564	0-6	Calcrete	95	88	81	76	75	67	61	48	16	21	17	16	19	11	15	20	8	3.0	118	121	98	10.6	125	133	0.0	60	77	1.7	0.0	144	A-2-4 (0)
	" "	17" + Sand	D.9565	6-12	"	94	84	70	68	62	56	52	42	10	19	19	21	20	10	10	18	6	2.5	-	-	-	-	-	-	-	-	-	1.9	0.0	105	A-1-b (0)
	Mile 0.5	0-10½" Calcrete	D.9566	0-6	"	100	96	88	77	71	60	54	43	12	20	17	19	21	14	9	17	6	2.5	121	125	97	9.5	134	-	0.0	118	-	1.9	0.0	107	A-1-b (0)
	" "	10½"-18" Greyish soil	D.9567	6-10½	"	95	94	87	87	84	75	69	56	16	19	19	20	19	12	11	18	7	2.5	-	-	-	-	-	-	-	-	-	1.5	0.0	140	A-2-4 (0)
	Mile 0.6	0-13" Calcrete	D.9569	0-3	"	99	97	87	85	78	63	57	45	15	21	16	18	20	13	12	18	5	2.5	121	±122	±99	-	-	-	-	-	-	1.8	0.0	112	A-1-b (0)
	" "	13"+Greyish soil	D.9570	3-8	"	96	92	86	80	73	59	53	43	13	19	17	18	22	16	8	18	5	2.5	-	-	-	-	-	-	-	-	-	1.9	0.0	107	A-1-b (0)

(1) At Mod. AASHO compaction, but only nominally at Mod. AASHO OMC.

TABLE K.1 (CONTINUED)

ROAD	SAMPLING POINT	ROAD PROFILE	SAMPLE DETAILS: C.P.A. No.	DEPTH inches	MATERIAL	PERCENTAGE PASSING (INCHES, MILLIMETRES, U.S. SIEVES): 2.0	1.5	1.05	0.742	0.525	0.185 4	0.078 2	0.0164 0.42	0.0021 0.05
DUINE-FONTEIN ROAD	Mile 0.2	0-13" Calcrete	V.396	0-5	Calcrete	100	99	96	92	88	77	69	53	18
	" "	13"+ Sand	V.397	5-10	"	100	95	91	87	81	74	68	54	18
	Mile 0.6	0-14" Calcrete	V.400	0-6	Calcrete		100	93	90	87	74	66	52	17
	" "	14"+ Sand	V.401	6-14	"	81	79	75	71	69	62	58	46	16
	Mile 1.0	0-8" Calcrete	V.402	0-8	Calcrete	100	99	99	97	96	91	88	74	16
	" "	8"+ Sand	V.403	8-18	Sand							100	74	2
	Mile 1.4	0-13" Calcrete	V.404	0-4	Calcrete	97	91	88	83	77	67	61	48	16
	" "	13"-18" Sand	V.405	4-13	"		100	97	96	95	87	81	61	19
	Mile 1.8	0-14" Calcrete	V.406	0-4	Calcrete	100	95	95	86	82	72	65	52	18
	" "	14-18" Sand	V.407	4-14	"	100	98	91	81	81	71	64	49	14
WEL-TEVREDE ROAD	Mile 0.1	0-14" Calcrete	V.2327	0-4	Calcrete	100	98	90	88	82	66	59	44	15
			V.2328	4-14	"		100	94	89	85	76	69	52	17
	Mile 0.2	0-16" Calcrete	V.2329	0-4	Calcrete		100	94	90	84	68	59	44	15
			V.2330	4-16	"	90	87	78	75	70	57	51	37	13
	Mile 0.3	0-13" Calcrete	V.2331	0-5	Calcrete	98	90	84	76	72	61	55	40	14
	" "	13"+ sand	V.2332	5-13	"	100	98	98	91	89	78	71	54	18
	Mile 0.4	0-12" Calcrete	V.2333	0-3	Calcrete		100	95	88	82	70	63	46	15
	" "	12"+ sand	V.2334	3-12	"	100	94	94	88	76	66	59	44	15

ROAD	HYDROMETER ANALYSIS (mm): SAND COARSE <2.0 >0.42	SAND FINE <0.42 >0.246	SAND FINE <0.246 >0.147	SAND FINE <0.147 >0.05	SILT <0.05 >0.005	CLAY <0.005	CONSTANTS: LL	PI	LS	DENSITY: IN-SITU lbs/cu ft	M.AASHO lbs/cu ft	RELATIVE %
DUINE-FONTEIN ROAD	23	15	17	19	13	13	18	7	3.0	130	127	102
	21	15	17	21	14	13	21	8	3.0	-	-	-
	21	16	17	20	14	12	19	6	2.5	129	127	102
	21	15	16	21	14	13	20	7	3.5	-	-	-
	16	23	25	18	10	8	18	4	1.5	118	123	96
	26	34	30	7	1	1	-	NP	0.0	-	-	-
	21	16	16	20	13	13	18	5	2.5	132	127	104
	25	15	18	19	12	12	19	6	2.5	-	-	-
	20	15	18	21	14	13	20	6	2.5	128	127	101
	23	16	15	23	13	9	20	6	2.5	-	-	-
WEL-TEVREDE ROAD	25	17	17	16	11	14	21	6	2.5	123	124	99
	25	17	17	16	11	14	18	6	2.5	-	-	-
	25	16	16	16	11	15	18	6	2.5	118	±121	±98
	27	18	17	14	10	15	18	7	2.5	-	-	-
	27	18	17	14	10	15	19	7	2.5	112	118	95
	24	18	18	15	11	14	18	6	2.5	-	-	-
	27	16	17	16	10	14	19	5	2.5	118	±121	±98
	25	17	17	15	12	13	18	5	2.5	-	-	-

ROAD	MOD. AASHO OMC, CBR AND SWELL: OMC %	4 DAYS SOAKING CBR (%) (1) 0.1"	0.2"	SWELL %	FIELD CBR % 0.1"	0.2"	GRADING MODULUS	GROUP INDEX	LINEAR SHRINKAGE X % PASSING 40 MESH	REVISED PRA CLASSIF.
DUINE-FONTEIN ROAD	9.7	87	108	0.0	92	120	1.6	0.0	159	A-2-4 (0)
	-	-	-	-	-	-	1.6	0.0	162	A-2-4 (0)
	-	-	-	-	-	-	1.6	0.0	130	A-2-4 (0)
	-	-	-	-	-	-	1.7	0.0	161	A-2-4 (0)
	9.9	107	133	0.0	70	74	1.2	0.0	111	A-2-4 (0)
	-	-	-	-	-	-	1.2	0.0	0	A-3 (0)
	-	-	-	-	-	-	1.7	0.0	120	A-1-b (0)
	-	-	-	-	-	-	1.4	0.0	152	A-2-4 (0)
	-	-	-	-	-	-	1.7	0.0	130	A-2-4 (0)
	-	-	-	-	-	-	1.7	0.0	122	A-1-b (0)
WEL-TEVREDE ROAD	10.9	95	120	0.0	90	114	1.8	0.0	110	A-1-b (0)
	-	-	-	-	-	-	1.6	0.0	130	A-2-4 (0)
	-	-	-	-	-	-	1.8	0.0	110	A-1-b (0)
	-	-	-	-	-	-	1.9	0.0	93	A-2-4 (0)
	12.5	98	125	0.0	91	103	1.9	0.0	100	A-2-4 (0)
	-	-	-	-	-	-	1.5	0.0	135	A-2-4 (0)
	-	-	-	-	-	-	1.7	0.0	115	A-1-b (0)
	-	-	-	-	-	-	1.8	0.0	110	A-1-b (0)

(1) At Mod. AASHO compaction, but only nominally at Mod. AASHO OMC.

TABLE K.2 COMPARISON OF CALCRETE BASE TEST RESULTS WITH FAA AND TEXAS CALICHE BASE SPECIFICATIONS

ROAD	SAMPLE NO.	LAYER*	FAA SPECIFICATIONS		TEXAS SPECIFICATIONS	
			PASS/ FAIL	REASON FOR FAILING	PASS/ FAIL	REASON FOR FAILING
P.E. MARINE DRIVE	DE.7400	B	Fail	Max. size,-40, -200 mesh	Fail	Max.size,-40mesh
	DE.7401	B	Fail	Max.size,-40, -200 mesh	Fail	Max.size
	DE.7402	B	Fail	-40,-200 mesh	Fail	Max.size
	DE.7403	B	Fail	-40,-200 mesh	Fail	-40 mesh
	DE.7415	B	Fail	-40,-200 mesh	Fail	Max. size
	DE.7416	B	Fail	Max.size	Fail	Max.size
	DE.7417	B	Fail	-40 mesh	Fail	Max.size
	DE.7418	B	Pass	-	Fail	Max.size
P.E.- ADDO	DE.7380	B	Fail	-40, -200mesh, PI	Fail	-40 mesh
	DE.7381	B	Fail	-40, -200mesh, PI	Fail	-40 mesh, PI
	DE.7382	B	Fail	-40,-200mesh, PI	Pass	-
	DE.7383	B	Fail	-40,-200mesh, PI	Fail	-40 mesh
	DE.7385	B	Fail	-40 mesh, PI	Fail	PI
	DE.7386	B	Fail	-40 mesh, PI	Fail	PI
	DE.7387	B	Fail	-40,-200 mesh, PI	Fail	-40 mesh, PI
	DE.7388	B	Fail	-40,-200 mesh, PI	Fail	-40 mesh, PI
LANDS-DOWNE ROAD	D.9558	B	Fail	-40,-200 mesh	Fail	-40 mesh
	D.9559	S	Fail	Max.size, -40 mesh	Fail	Max.size,-40 mesh
	D.9561	B	Fail	-40,-200 mesh	Fail	Max.size,-40 mesh
	D.9562	S	Fail	-40 mesh	Fail	Max.size
	D.9564	B	Fail	Max.size,-40, -200 mesh	Fail	Max.size
	D.9565	S	Fail	Max.size,-40 mesh	Fail	Max.size
	D.9566	B	Fail	-40 mesh	Fail	Max.size
	D.9567	S	Fail	Max.size,-40, -200 mesh	Fail	Max.size,-40mesh

TABLE K.2 (CONTINUED)

ROAD	SAMPLE NO.	LAYER *	FAA SPECIFICATIONS		TEXAS SPECIFICATIONS	
			PASS/ FAIL	REASON FOR FAILING	PASS/ FAIL	REASON FOR FAILING
LANDS-DOWNE ROAD	D.9569	B	Fail	Max.size,-40 mesh	Fail	Max.size
	D.9570	S	Fail	Max.size,-40 mesh	Fail	Max.size
DUINE-FON-TEIN	V.396	B	Fail	-40,-200 mesh	Fail	Max.size,-40mesh
	V.397	S	Fail	-40,-200 mesh	Fail	Max.size,-40mesh
	V.400	B	Fail	-40,-200 mesh	Fail	-40 mesh
	V.401	S	Fail	Max.size,-40, -200 mesh	Fail	Max.size
	V.402	B	Fail	Max.size,-40, -200 mesh	Fail	Max.size,-40 mesh
	V.404	B	Fail	Max.size,-40, -200 mesh	Fail	Max.size
	V.405	S	Fail	-40,-200 mesh	Fail	-40 mesh
	V.406	B	Fail	-40,-200 mesh	Fail	Max.size,-40 mesh
	V.407	S	Fail	-40 mesh	Fail	Max.size
WELTE-VREDE ROAD	V.2327	B	Fail	-40 mesh	Fail	Max.size
	V.2328	S	Fail	-40,-200 mesh	Fail	-40 mesh
	V.2329	B	Fail	-40 mesh	Pass	-
	V.2330	S	Fail	Max.size, -40 mesh	Fail	Max.size
	V.2331	B	Fail	Max.size, -40 mesh	Fail	Max.size
	V.2332	S	Fail	-40,-200 mesh	Fail	Max.size,-40mesh
	V.2333	B	Fail	-40 mesh	Pass	-
	V.2334	S	Fail	-40 mesh	Fail	Max.size
TOTAL PASSING	BASE	1 out of 30 (3%)			3 out of 30 (10%)	
	SUBBASE	0 out of 13 (0%)			0 out of 13 (0%)	

* B = Base
S = Subbase

TABLE K.3 DETAILS OF SOME WESTERN TRANSVAAL CALCRETE WEARING COURSES OF KNOWN PERFORMANCE (ROAD SAMPLES)

GENERAL PERFORMANCE(1)	TPA SAMPLE NO.	TPA ROAD NO.	LL %	PI %	LS %	GM	% -10 MESH	% -40 MESH	% -200 MESH	LS x % -40 MESH	LS x % -200 MESH	AFV %	APV %	REVISED PRA CLASSIF.	GROUP INDEX	IN SITU CBR(2)	REMARKS
GOOD, ALL WEATHER	F183/69	1227	29	14	5.3	1.86	53	44	16	234	84	97	61	A-2-6	0	Mod.	Slightly loose & stony
	F179/69	611	40	23	7.7	1.42	69	61	28	469	215	46	19	A-2-6	2	Mod.	
	F191/69	1699	29	11	4.3	1.44	69	61	26	262	111	86	28	A-2-6	0	-	
	F188/69	168	29	13	5.0	1.68	65	47	20	235	94	90	41	A-2-6	0	High	
	F195/69	2054	36	12	4.7	1.36	76	65	22	305	103	43	4	A-2-6	0	High	
	F194/69	652	19	8	2.7	1.11	82	74	32	199	86	60	14	A-2-4	0	High	
	F178/69	510	43	20	7.0	2.34	32	24	10	168	70	90	41	A-2-7	0	High	
	RANGE	-	19-43	8-23	2.7-7.7	1.11-2.34	32-82	24-74	10-32	168-469	70-215	43-97	4-61	A-2-4 to A-2-7	0-2	Mod - High	
SATISFACTORY	F185/69	774	22	5	2.0	1.60	63	52	23	104	46	92	37	A-2-4	0	Mod.	Slightly loose & dusty
	F230/69	611	24	12	4.3	1.36	76	64	24	275	103	45	26	A-2-6	0	Mod.	Slightly dusty
	F190/69	1404	30	13	4.7	1.62	61	49	28	277	131	90	48	A-2-6	0	-	Slightly corrugated
	F192/69	167	32	22	8.0	1.59	63	52	24	416	192	88	26	A-2-6	1	-	
	F226/69	167	48	23	8.7	1.74	61	43	22	374	191	71	30	A-2-7	1	-	
	F193/69	1067	37	18	7.3	1.11	81	75	33	547	240	38	11	A-2-6	1	Mod.	Said to pothole
	F224/69	1067	35	15	6.0	1.18	78	71	34	426	204	28	13	A-2-6	1	Mod.	Said to pothole
	RANGE	-	22-48	5-23	2.0-8.7	1.11-1.74	61-81	43-75	22-34	104-547	46-240	28-92	11-48	A-2-4 to A-2-7	0-1	Mod.	
UNSATIS-FACTORY	F227/69	1057	44	27	10.0	0.65	97	93	45	930	450	8	1	A-7-6	7	-	Slippery
	F187/69	1456	36	15	6.0	1.15	86	66	32	396	192	41	12	A-2-6	1	Low	Ruts and slippery
	F225/69	1067	38	23	9.0	1.37	71	60	32	540	288	44	21	A-2-6	2	-	Slippery
	F198/69	030	31	16	6.3	1.61	66	54	19	340	120	62	31	A-2-6	0	High	Said to be slippery and to rut
	F184/69	1227	37	18	7.3	1.48	62	60	30	437	219	90	41	A-2-6	1	-	Ruts and slippery
	F181/69	155	33	17	6.7	1.29	80	65	26	435	174	50	18	A-2-6	1	Low	Said to be loose, corrugated, dusty and slippery
	RANGE	-	31-44	15-27	6.0-10.0	0.65-1.61	62-97	54-93	19-45	340-930	119-450	8-90	1-41	A-2-6 to A-7-6	0-7	Low-high	

Notes: (1) The samples have been grouped largely according to the local road inspector's experience of the performance of the sections of road from which they came, supplemented by the author's own observations.

(2) Estimated at natural moisture content by dynamic cone peretrometer.

TABLE K.4 DETAILS OF SAMPLES FROM SOME WESTERN TRANSVAAL CALCRETE WEARING COURSE BORROW PITS OF KNOWN PERFORMANCE

TPA SAMPLE NUMBER	TPA ROAD NO.	LL %	PI %	LS %	GM %	% -10 MESH	% -40 MESH	% -200 MESH	LS x % -40 MESH	LS x % -200 MESH	AFV %	APV %	REVISED PRA CLASSIF.	GROUP INDEX	PROBABLY EQUIVALENT ROAD SAMPLE	REMARKS
F222/69	628	22	7	2.7	1.66	55	49	30	132	81	89	45	A-2-4	0	-	Good
F196/69	2054	43	17	6.7	1.29	76	70	25	510	167	28	7	A-2-7	1	F195/69	Good
F180/69	611	29	13	5.0	1.29	76	66	30	330	150	86	37	A-2-6	0	F179/69	Good
F186/69	911	32	10	2.0	1.99	50	36	14	72	28	76	23	A-2-4	0	-	Satisfactory, bit loose
F223/69	028	35	11	3.7	.40	93	87	80	321	296	16	2	A-6	8	-	Powdered
F182/69	155	44	20	8.0	1.58	70	51	21	408	168	30	11	A-2-7	1	F181/69	Said to be loose, corrugated, dusty and slippery