ALKALI - AGGREGATE REACTION

1981

ALKALI - AGGREGAATREAKSIE

S252

CHARACTERISTICS AND SERVICE RECORD OF COMMONLY USED SOUTH AFRICAN AGGREGATES

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SYNOPSIS

Several rock types from which aggregates are commonly produced in South Africa appear among the list of materials that have potentially bad reactions with alkalis in cement. These are primarily forms of silica (strained quartz, chert and opal) and are found in quartzite, sandstone, granite, andesite, hornfels and carbonates.

All these rocks contain varying proportions of silica and/or phyllosilicate minerals. Several have been altered to varying degrees by deformation and metamorphism, as indicated by petrographical studies which show the presence of strained quartz. The selection of aggregates should not be judged solely on the presence of potentially reactive minerals. Of critical importance is the past history and service record of the aggregate.

SAMEVATTING

Verskeie rotstipes waarvan aggregate algemeen in Suid-Afrika vervaardig word, kom voor in die lys van materiale wat potensieel nadelig met die alkalië in sement reageer. Hierdie is primêr vorms van silika (vervormde kwarts, chert en opaal) en word aangetref in kwartsiet, sandsteen, graniet, andesiet, horingfels en karbonate.

Al hierdie rotstipes bevat wisselende hoeveelhede silika en/of fillosilikaatminerale. Verskeie is in wisselende mate verander deur vervorming en metamorfose, soos aangedui deur petrografiese ondersoeke wat die teenwoordigheid van vervormde kwarts aandui. Die selektering van aggregate behoort nie bloot op grond van die teenwoordigheid van potensieel reaktiewe minerale beoordeel te word nie. Die geskiedenis en gebruiksgedrag van die aggregaat is van kritiese belang.

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For example, if confidence limits ($\pm \Delta R$) are set at $\pm$ 10 per cent, N = 3 and confidence level derived is 90 per cent.

$$S = \frac{\sqrt{3} . 10\%}{2,92} \simeq 6\%$$

and Range $\simeq$ 10%

Example (1). Three thin sections are analyzed and the reactivity factors calculated:

Section (1)	8/12 showed potential reactivity
Section (2)	4/15 showed potential reactivity
Section (3)	6/10 showed potential reactivity

$$R_1 = 67\%\ R_2 = 27\%\ R_3 = 60\%\ \bar{R} = 51\%$$

$$\text{Range} = 40\%\quad S \simeq 24\%$$

$$\frac{ts}{\sqrt{n}} \simeq 86\%$$

and error limits are exceeded.

Example (2). Three sections are analyzed and the results listed:

Section (1)	9/13 show potential reactivity
Section (2)	10/15 show potential reactivity
Section (3)	7/9 show potential reactivity

$$R_1 = 69\%,\ R_2 = 67\%,\ R_3 = 78\%;\ \bar{R} = 71\%$$

$$\text{Range} = 11\%\quad S \simeq 6,5\%$$

$$\frac{ts}{\sqrt{n}} = 11\%$$

Error limits are close enough to those prescribed to lend statistical support to the judgement.

Table 2 could be used to express allowable values of reactivity factor ranges for $\pm$10 per cent confidence limits at confidence levels of 90, 95 and 99 per cent as a function of n > 3.

TABLE 2 : Range of reactivity factors permitted for a ±10% confidence limit at various confidence levels

N	Range at 90% confidence level	Range at 95% confidence level	Range at 99% confidence level
3	10,0	6,8	3,0
4	14,0	6,0	4,1
5	17,8	12,1	5,2
7	24,5	16,6	7,2
10	32,5	22,3	9,7

(At first glance one would expect that allowable range should increase as the confidence level increases from 90 to 95%, but it should be kept in mind that these are determined by a fixed confidence limit, $ts/\sqrt{n}$ and as t does increase with increasing probability s must necessarily decrease).

If the allowable reactivity range is exceeded for the minimum number of thin sections examined, one can increase the number of thin sections to be sampled from the sub-class. If this is not acceptable, the alternatives include expanding the confidence limit for the mean reactivity factor or, even better, refining the classification of classes and sub-classes in the preliminary examination.

e.g. For n = 3 Range in R values = 16% at 90% confidence level
(t = 2,92)
$S \simeq 0,59 \times 16 \simeq 9,4$

The minimum number of thin sections needs to be increased to 5 for this sub-class for the level of statistical significance required (assuming the range does not change).

Alternatively, if no additional thin sections are examined, ΔR can be re-defined.

e.g. $\Delta R = \frac{ts}{\sqrt{3}} = \frac{2,92 \times 9,4}{\sqrt{3}} \simeq 16\%$

1. INTRODUCTION

Examination of the geological map of South Africa shows that this country is in a very fortunate position regarding the availability of rock construction materials.

Large areas are underlain by hard igneous rocks and other older rocks of various kinds, which have undergone thorough metamorphism and diagenesis. Superficial sedimentary deposits of geologically recent (Recent and Tertiary) age consisting of aolian or glacial material, are absent over most of the country and the cover of weathered material is relatively thin due to the semi-arid climatic conditions[1].

2. QUARRY LOCATIONS AND AGGREGATE PRODUCTION

The distribution of aggregate quarries operating in South Africa is shown on the attached map, page 18, which was compiled by Oberholster[2] from information listed in the Minerals Bureau Directory on operating mines. An indication of the rock types quarried at these different mines can be obtained by comparing this location map with a geological map of South Africa.

The rock types most commonly crushed for aggregate production are given in Table 1 together with their percentage contribution to total aggregate production[2].

In addition to these rock types felsite, gabbro, norite and anorthosite are also used and to a lesser extent basalt.

Information given in Table 2, page 2, on rock types crushed and the estimated aggregate production in some of the larger growth areas for 1980, is based on figures obtained from major producers as well as figures reported by Oberholster[2].

At present the total aggregate production is fairly evenly divided between stone used in concrete manufacture and for road building. However, this trend is changing towards a greater demand for aggregate conforming to concrete-stone specifications. This is partly due to the increase in concrete roads presently being constructed and planned for the future. Over 300 km of these roads have already been constructed in South Africa.

3. SELECTION OF AGGREGATES

A high quality aggregate consists of particles that are strong, durable, clean, favourably graded and not flat or elongated. They should not slake when wetted and dried, have a fairly rough texture and not contain constituents that would interfere with cement hydration, or react chemically with the cement paste to cause excessive expansion. Some other properties, such as elasticity, thermal properties and skid resistance characteristics, may also be required in particular cases. The ideal aggregate is not always available. The problem is then to decide on the level of performance required in a given situation and select the aggregate with which it is economically attainable.

The selection of an aggregate should be based on the knowledge of its technically important properties. A service record, when available in sufficient detail, provides a most valuable guide to the behaviour of coarse and fine aggregates in concrete. Past performance records can add more to the knowledge of the concrete materials than many of the frequently performed laboratory tests. To be meaningful, the record should cover structures with concrete proportions and exposures similar to those anticipated for the proposed work. Petrographic and other suitable tests, should be used to determine whether the aggregate in the structure and that proposed for use, are sufficiently similar to make the service record meaningful for the aggregate evaluation. 'A structure completely sound after 10 years or more of representative service, can be assumed to constitute an 'endorsement' of all the materials used in it, including the aggregates'[3].

Where applicable service records of aggregates are sparse or not available, the selection of an aggregate should be based on the results of appropriate laboratory tests or petrographic examination. Not only is petrographic examination the best method by which potentially deleterious substances can be detected and determined quantitatively, but the method may be usefully employed to assist in the interpretation of other test results.

The economy of concrete also plays an important role in aggregate selection. For instance, an aggregate made up of chunky particles should be selected in preference to aggregates consisting of flaky, elongated particles. This applies specifically to fine aggregate (sand). Particle shape and texture especially, and to a lesser extent grading, are factors which significantly affect the water demand of aggregates. Any reduction in the water demand will make a substantial difference to the concrete's quality and economy[4].

TABLE 1 : Contribution of major rock types to aggregate production in South Africa.

Rock type	Major rock group	% Contribution
Quartzite	Metamorphic/Sedimentary	36
Dolerite	Basic Igneous	22
Granite	Acid Igneous	12
Hornfels/Greywacke	Metamorphic/Sedimentary	9
Tillite	Sedimentary	5
Sandstone	Sedimentary	4
Dolomite	Sedimentary	3
Andesite	Intermediate Igneous	2

TABLE 2 : Estimated aggregate production for 1980 in major growth areas

Growth area	Rock type	Aggregate production* x 10^6 tonnes per year	
Pretoria/Brits	Quartzite	1,40	2,65
	Dolomite	0,80	
	Granite	0,40	
	Gabbro/Norite	0,05	
Witbank/Middelburg	Felsite	1,0	1,0
Witwatersrand/ Vereeniging	Quartzite	4,9	6,9
	Andesite	1,0	
	Granite	0,6	
	Dolomite	0,4	
Durban	Quartzite	1,3	2,4
	Tillite	1,1	
Pietermaritzburg	Dolerite	0,6	0,7
	Tillite	0,1	
Natal Midlands	Dolerite	0,5	0,5
Port Elizabeth/Uitenhage/Plettenberg Bay George/East London/ King William's Town	Quartzite	-	5,0
	Dolerite	-	
Cape Peninsula	Hornfels/Greywacke		5,0
	Granite		
	Quartzite and Sandstone		

* Tonnes = m^3 x 1,4

The effects of aggregate properties on the properties of concrete are summarised in Table 3. Some act directly whereas others have an indirect effect. For instance, the strength of weak aggregates has a direct effect on concrete strength, whereas the aggregate grading with a given maximum particle size influences the concrete strength indirectly through the workability and water requirement of the fresh concrete. The influence of the maximum particle size on concrete is an example of the combination of direct and indirect effects.

4. AGGREGATE SPECIFICATIONS

In South Africa aggregates have to comply with the requirements laid down in SABS 1083 (amended 1979[5]). Standard test methods are referred to in this official document, which also specifies limiting values and gives guidelines for the various properties of aggregates to be used in concrete and road building.

A summary of some of the requirements and guidelines in SABS 1083 as drawn up by Oberholster[2], is given in Appendix A, page 16.

5. CHARACTERISTICS AND PROPERTIES OF AGGREGATES

The suitability of a rock as a construction material depends on its intrinsic properties, primarily on its mineral composition and secondarily on the size, shape and arrangement of, and bond between, the minerals, that is the texture of the rock. The larger-scale structural features are less important although they must not be neglected[6]. The texture and structural features (cleavage, laminations) inherent in certain rock types, also play an important role in the properties aggregates will acquire after crushing.

This applies especially to particle shape, an important property for both concrete and road building aggregates.

TABLE 3 : Effects of aggregate properties on the properties of concrete

Concrete property	Relevant aggregate property
Durability	Soundness Porosity Permeability Grading Maximum size
Strength	Grading Particle shape Cleanliness Maximum size
Shrinkage	Grading Cleanliness Presence of clay Modulus of elasticity Maximum size
Resistance to wetting and drying	Pore structure Modulus of elasticity
Resistance to heating and cooling	Coefficient of thermal expansion
Abrasion resistance	Hardness
Modulus of elasticity	Modulus of elasticity Poisson's ratio
Economy	Particle shape Surface texture Grading Maximum size Availability

Very fine-grained rocks such as felsite, andesite and hornfels and those which show marked cleavage, produce very flaky aggregates. Particle shape however, can be controlled through more sophisticated methods of crushing and screening.

It has been pointed out that the variation in the properties of aggregates quarried from sedimentary and metamorphosed sedimentary rocks, is greater than that of igneous rocks. The variation across bedding planes of the former two rock types is generally greater than that parallel to the bedding planes. It is important for the quarry operator to be aware of any variations in his operation and know how the properties of the aggregates he produces, are influenced by these variations. The aim is to produce an aggregate with properties which are acceptable to as many authorities as possible and suitable for as many purposes as possible[2].

A comprehensive assessment, of the physical properties of several hundred aggregates used in concrete construction in South Africa and produced from many different rock types, has been carried out by Davis et al[7]. Their data, classified both geographically and geologically, enables the interested person to find out the likely range of materials available for use in a particular area and also assess their concrete-making properties.

A classification of natural road building materials occurring in South Africa has been drawn up by Weinert[6], who grouped them according to their potential durability and technical properties.

The significant characteristics of aggregates produced in the major growth areas are described below.

6. WITWATERSRAND/PRETORIA/WITBANK AREA

The properties of the more commonly produced aggregates in this area are given in Tables 4, page 4 and 5, page 5.

6.1 Quartzites

Quartzites and sandstones represent accumulations of detrital mineral and rock particles, transported mainly by the agencies of water and air to depositional sites. Mineralogically they consist dominantly of quartz grains and variable amounts of feldspars, mica and rock fragments. Sandstones become quartzites either by the process of recrystallisation of the separate detrital particles into an interlocking mosaic by metamorphism, or by the cementation of the grains by secondary quartz through diagenesis. As a result, friability and porosity generally decrease while crushing strength increases and the rock tends to acquire a glassy appearance[7].

6.1.1 *Witwatersrand quartzites.* The gold mining industry on the Witwatersrand and in the Orange Free State provides an abundant source of hard aggregate from the quartzite strata belonging to the Witwatersrand Supergroup, which are exploited for their gold content. These aggregates are used extensively for the manufacture of concrete and as surfacing chips, base-course and sub-base material for road construction and as railway ballast.

While composed predominantly of quartzites, which consist primarily of quartz and amorphous silica with small amounts of mica and some sulphides, the waste dumps also contain lesser quantities of other rock types, mainly shales, siltstone, lava and diabase. The Free State dumps often also contain lavas and the Far West Rand dumps dolomite[8].

Davis et al[7] recorded that the presence of high content of shale, siltstone and basic igneous rock did not necessarily imply high drying shrinkage characteristics. Mortar shrinkage tests carried out on specimens made with these materials, generally gave results of the same order as those obtained from tests conducted on quartzite. Sulphides mainly in the form of pyrite, frequently occur in the waste dump quartzite in very small quantities, seldom more than

TABLE 4 : Properties of Witwatersrand Quartzite aggregate[2]

		Values for				
		Q 13	Q 14	Q 11	Q 12	Q8
10% FACT value:						
Dry	kN	203	197	166	151	260
Wet	kN	153	141	100	109	200
Wet/dry	%	75	72	60	72	77
Los Angeles abrasion loss	%	-	-	-	-	-
Drying shrinkage	%	0,076	0,071	0,079	0,073	0,075
relative*	%	123	115	127	118	121
Water absorption	%	0,20	0,23	0,35	0,20	0,16
Relative density		2,68	2,72	2,71	2,68	2,70
Loose bulk density, kg/m³		1 322	1 398	1 400	1 322	1 404
Voids	%	51	49	48	51	48
Soundness, 15 cycles loss	%	2,3	1,5	3,3	2,3	2,1
Polished stone value		-	-	-	-	52

* These values are expressed relative to the drying shrinkage of mortar prisms made with norite aggregate.

one per cent[6]. These small quantities may give rise to unsightly stains and spalls on exposed aggregate surfaces due to their oxidation. For this reason there have been occasions when aggregates produced from these quartzites, have been rejected for aesthetic reasons. However, the amount of pyrite present in these aggregates is seldom sufficient to jeopardise the structural suitability of concrete in which it is used[7].

Base course aggregate produced at crushing operations working off the older waste dumps, often contain concentrations of sulphates which have resulted from the oxidation of pyrite in these dumps. Migration of soluble sulphate salts from the basecourse layer to the asphalt road surface, can lead to the formation of salt blisters. These blisters cause the asphalt surfacing to crack and lift[8].

At those crushing operations where concentrations of sulphates are known to occur, bulldozers are used to cut through the dump layers in order to blend materials of differing sulphate concentration. In addition, lime is added during the crushing operation, to bring the soluble salt content in the base course aggregates to within the limits specified in SABS-1083.

The gold mine waste dumps have been and are still a major source of reliable and high quality aggregates for the Witwatersrand and Free State Goldfield areas[7].

6.1.2 *Pretoria group quartzites.* Quartzites belonging to this group have been estimated to provide up to 80 per cent of the crushed coarse aggregate used in concrete in Pretoria. These quartzites generally provide aggregates that vary

TABLE 5 : Properties of aggregates produced in the Witwatersrand/Pretoria/Witbank area[2]

Property		Values for							
		Pretoria Quartzite	Gabbro	Anorthosite	Granite 5	Granite 3	Dolomite	Andesite	Felsite
10% FACT value:									
Dry	kN	222	170	89	132	164	268	470	238
Wet	kN	208	132	77	115	157	266	442	222
Wet/dry	%	94	87	87	87	96	99	94	93
Los Angeles abrasion loss	%	25	24	-	38	-	20	8	18
Drying shrinkage	%	0,057	0,062	0,067	0,062	0,058	0,051	0,070	0,073
relative*	%	92	100	108	100	95	82	113	118
Water absorption	%	0,54	0,13	0,16	0,36	0,22	0,12	0,28	1,00
Relative density		2,63	2,92	2,91	2,61	2,61	2,82	2,88	2,62
Loose bulk density kg/m³		1 456	1 538	1 562	1 389	1 404	1 498	1 492	1 281
Voids	%	45	47	48	47	46	47	48	51
Flakiness index		21	15	19	22	24	26	23	34
Soundness, 15 cycles loss	%	4,4	4,1	15,3	6,1	2,3	0,2	1,7	6,9
Polished stone value		37	52	-	48	-	50	38	44

* These values are expressed relative to the drying shrinkage of prisms made with norite aggregate.

in colour from pink through to deep purple, a quality that has been utilised in exposed aggregate surfaces. Davis et al[7] found no justification for claims that the purplish coloured fractions of the rock may be responsible for low-strength concrete. They reported also that although the 10 per cent fine aggregate crushing test (FACT) values on samples tested by them were slightly lower than those for Witwatersrand quartzites, the Pretoria quartzites are a satisfactory concrete aggregate.

Elastic modulus tests carried out on concrete made with this aggregate gave good results, consistent with those obtained from Witwatersrand quartzites[7].

6.2 Dolomite

Dolomitic limestone from the Transvaal supergroup, are quarried in several operations between Pretoria and Vereeniging and produce aggregates for both metallurgical and construction purposes. These aggregates are regarded as being very good concrete aggregates.

The findings of a large number of research workers show that by comparison with concretes made with other acceptable aggregates, concretes made with dolomite aggregate have, in general, the following properties[8]:

(a) a higher flexural strength
(b) an equal or greater compressive strength
(c) a more uniform resistance to wear
(d) a lower drying shrinkage
(e) a greater durability
(f) a lower thermal coefficient of expansion

Concrete made with dolomite aggregate will also have:

(g) a suitable resistance to freezing and thawing
(h) a comparatively high resistance to fire
(i) a satisfactory adhesion between the aggregate and the cement paste
(j) a comparatively high density
(k) a less variable modulus of elasticity than commonly expected.

Because of their neutralising properties dolomitic aggregates are extensively used in sewer pipe construction. Use of these aggregates prolongs the life of pipes subject to sewer corrosion, since sulphuric acid attacks the cement paste as well as the dolomite aggregate. By spreading the attack over a much larger area, the rate of deterioration of these pipes is significantly reduced[7].

Although there is good adhesion between dolomite and bitumen, it is not used as a road surfacing aggregate because it polishes evenly and easily. It is suitable for all classes of railway ballast[2].

6.3 Granite

Granites and granite-gneisses consist essentially of quartz and feldspar, together with variable amounts of mica, amphibole and some iron oxides. These crystalline igneous rocks have textures that vary from medium to coarse-grained. Weathering in them is manifested mainly in the replacement of the feldspars by clay minerals, illite and/or kaolinite[7].

Granite aggregates used in the Johannesburg and Pretoria areas are produced at crushing operations established on the Halfway House granite dome, part of the Basement Complex Granites.

Crushing tests show that these aggregates are suitable for concrete subject to surface abrasion. However, their crushing strength is insufficient for road surface dressings and rolled-in chips. Elastic modulus tests on concretes in which these aggregates were used, gave results slightly lower than average, the elastic modulus varying from normal down to about 15 per cent below average[7]. This they reported, could be due to varying degrees of weathering in the feldspar minerals.

These aggregates were used in the building of a section of the western by-pass concrete road, Sandton, and in the exposed aggregate surfaces of the Carlton complex, Johannesburg.

6.4 Andesite

Immediately south of Johannesburg, andesitic lavas of the Langgeleven Formation which forms part of the Ventersdorp Supergroup, are being crushed. Since quarrying began at this site in the early 1970's, large quantities of both fine and coarse aggregate have been produced. These aggregates, greenish-grey in colour, are extremely hard and durable, crushing strengths having been measured in excess of 460 kN (10 per cent FACT). A significant characteristic of this rock described by Davis et al[7], is its ability when used as a sand in concrete to provide an increase in compressive strength of 25 per cent and more, in mixes of low cement and high sand content. This rock type produces good concrete aggregates which are also used in the surfacing of roads, although it has a marginal polishing value.

Davis et al[7] have commented that although no long term performance records of this rock in concrete are available, there is no reason to believe that the material will not, in general, provide satisfactory behaviour in concrete over a long period of time.

6.5 Felsite

Felsite is a very fine-grained (cryptocrystalline) volcanic rock of granite composition which forms part of the Bushveld Complex. These rocks are extremely resistant to chemical decomposition owing to their very fine-grained texture and the presence of a large amount of quartz[8]. These latter properties which account for its extreme

toughness and abrasiveness, result in aggregate producers being faced with exceptional wear on their quarry and plant equipment. In addition, this rock type crushes to form very flaky aggregates and producers are now having to increase the number of crushing stages in their plants to improve the aggregate shape.

The felsite aggregates are very hard and durable, having a high crushing strength and low abrasion loss. Davis et al[7] note that a feature of concrete made with this aggregate, is the lack of adhesion at early stages between the aggregate and the cement paste, probably as a result of the cryptocrystalline texture of the felsite. They comment further that, whereas this characteristic is of no significance in normal structural concrete as the bond soon improves, it is a detrimental feature in the construction of concrete roads, where the sawing of joints is usually carried out within 24 hours of placing the concrete. The lack of bond during these early stages causes pieces of the aggregate to be torn out along the line of the joint during the sawing process.

Besides their use in concrete, these aggregates are also used as basecourse material for roads and railway ballast. They are used as well to a limited extent as road surfacing aggregate, but stripping of bitumen may occur and they polish excessively[2].

Felsite aggregates are presently being used in the construction of concrete roads and power stations in the Witbank area.

6.6 Gabbro, norite and anorthosite

These rocks outcrop to the north of Pretoria and form part of the Main Intrusive Phase of the Bushveld Complex. They are coarse-grained rocks composed essentially of feldspar and pyroxene and depending on the relative proportions of these minerals, the rocks are designated as gabbro, norite, anorthosite, etc[7].

Aggregates consisting of these rocks are either produced at operations crushing off waste rock dumps at platinum mines in the Rustenburg area, or at quarries generally established on prominent hills, such as the municipal quarry at Bon Accord immediately north of Pretoria.

Gabbro (norite) provided it is unweathered, is a good concrete aggregate and is known for its low drying shrinkage properties. In fresh concrete if used as both coarse aggregate and crusher sand, it is frequently found to be harsh and difficult to place.

These aggregates are used in road construction, especially as basecourse material. They are too soft for surface dressing and rolled-in chips, and also have a marginal polishing value[2].

7. NATAL

The properties of a limited number of aggregates from Natal have been determined by the NBRI. These results have been summarised by Oberholster[2] and are given in Table 6, page 8.

7.1 Quartzite

The Table Mountain Formation quarried in the Durban area consists of both felspathic sandstones and quartzites. Orogenic disturbances have resulted in many of these sandstones being converted into quartzites by recrystallisation. Cementation by secondary silica has also been responsible for the conversion of sandstones into quartzites, the latter phenomenon having taken place selectively so that glassy quartzite layers may alternate with more friable layers[7].

Gradations between sandstones and quartzites are frequent in the Natal exposures and this could possibly be the reason for the difference in crushing strengths (10 per cent FACT dry) reported by Oberholster of 170 kN in Table 6 and Davis et al of 230 kN, measured on these rocks. Quarry operators are aware of the variations in quality found in these deposits and selective mining is practised, whereby layers of varying quality are blended prior to crushing.

Aggregate produced from these quartzites in the Durban area are regarded as being good concrete aggregates and are suitable for railway ballast. They are also used as road surfacing material.

Over half (54 per cent) of the total aggregate used in the Durban area consists of this quartzite material.

7.2 Tillite

Tillite is the name given to material transported and then dumped by glaciers, once it has become consolidated. It consists of very poorly sorted coarse fragments of various rocks, set in a dense fine-grained matrix, consisting essentially of quartz, feldspars and phyllosilicates[7]. Aggregates produced from the unweathered 'blue' tillite variety are generally satisfactory for concrete aggregate. Crusher sand made from this material is erratic in quality and might lead to shrinkage problems. Investigations carried out by Weinert[6] show that tillite has been used as subbase, basecourse and surfacing material in road construction. It is used extensively as a road surfacing aggregate, provided it is not too water-absorbent and it complies with the relevant crushing strength value. It is characterised by its resistance to polishing.

7.3 Granite

The granite from the Richards Bay area is reported to make suitable concrete aggregate[2].

7.4 Dolerite

At Pietermaritzburg and in the Natal Midlands, aggregates are produced almost solely from dolerite. Dolerite is a basic igneous rock, dark-grey to black in colour and usually of medium to fine-grained texture. It is composed

(d) using an air entraining admixture if above methods are inadequate.

These aggregates are good concrete aggregates, they have been used for all applications in road construction and are acceptable as ballast[2].

Disintegration of apparently fresh dolerite aggregates over a short period (several months) has occurred at certain quarrying operations. This phenomenon is believed to result from swelling pressures generated during the hydration of clay minerals of the smectite group[10].

7.5 Basalt

In general, aggregates produced from this lava type are not very acceptable as concrete aggregate because of their variability, the presence of objectionable secondary minerals, high drying shrinkage and doubts about the long-term durability of concrete made with it. Disintegration of base course and blow ups in bitumen surfaces are known to have occurred where basalt from the Richards Bay/Empangeni area has been used[2].

8. EASTERN CAPE PROVINCE

The properties of some aggregates produced in this area are summarised in Table 7, page 10.

8.1 Quartzite

In East London quartzitic sandstones of the Beaufort Formation of the Karoo Supergroup are quarried for use as concrete aggregate. Aggregate produced from unweathered rock is bluish-grey in colour and in quality is inferior to quartzites of the Table Mountain Formation[7].

In the Port Elizabeth/Uitenhage and George areas quartzites of the Table Mountain Formation are quarried for aggregate[2].

Davis et al[7] report that these rocks compare favourably with the Witwatersrand quartzites and in some instances have given strength and elastic modulus results slightly superior to those of the Witwatersrand quartzites.

9. SOUTH WESTERN CAPE PROVINCE

9.1 *Malmesbury formation aggregates*

The main area of exposure of Malmesbury rocks lies between a point to the west of Citrusdal in the north and Cape Town in the south. These rocks have been folded and the intrusion of the younger Cape Granites has resulted in the formation of indurated rocks; fine-grained greywackes and slates being more common, with associated phyllites, quartzites and felspathic grits[11].

The major portion of construction aggregate used in the Cape Peninsula and surrounding areas, is obtained from several quarrying operations established on the indurated hornfels and greywacke horizons of the Tygerberg Formation of the Malmesbury Group. Generally these horizons dip steeply (± 40 degrees), are jointed and strongly cleaved. These features together with the fine-grained texture of the rocks, are responsible for the flaky nature of the aggregates produced. These aggregates which have a blue-black colour and are locally referred to as 'Malmesbury blue', possess good intrinsic physical properties of high strength and medium to high abrasion resistance for making concrete. They are also used as road aggregate and as railway ballast.

Table 8, page 11, lists the mean values of the properties of run of quarry aggregates and of selected rocks from quarries based on investigations done at the NBRI[2].

Problems have occurred however, in certain exposed concrete structures in which these aggregates have been used together with high alkali cements. In 1977, the cracking of a number of exposed structures alerted engineers to a problem which was soon identified as alkali-aggregate reaction[12].

Those minerals that are potentially reactive with high alkali cement are listed in Table 9, page 12. A total alkali content of 0,6 per cent Na_2O equivalent is given (ASTM C 150), as the upper limit for cement when used in combination with alkali reactive aggregates.

Table 9 shows that there are many rocks that are potentially alkali-reactive. As pointed out by Oberholster[14], the petrographer should have no trouble in identifying alkali-reactive minerals or their presence in rocks. In practice however, a problem may arise in identifying the presence of reactive forms of quartz, especially in those rocks where the alkali-reactivity can be attributed to their presence.

Figure 1, page 14, illustrates a thin-section of a typical hornfels (indurated siltstone) from the Tygerberg Formation of the Malmesbury Group. As can be seen it is a very fine-grained rock in which the individual minerals, chiefly quartz, feldspar and mica can be identified with difficulty. In order to examine and assess the form of the quartz grains it is necessary in very fine-grained rocks to make particle-mountings.

Figure 2, page 14, shows a thin section of an indurated greywacke from the Tygerberg Formation. Typical of these rock types, it is composed of a poorly sorted assemblage of mineral grains dominantly quartz with some feldspar. The following reactive forms of quartz are present, microcrystalline quartz in the matrix and larger grains of stressed quartz characterised by their undulating extinction, as seen under crossed nicols.

In dealing with rocks in which the alkali-reactivity can be attributed to the presence of reactive forms of quartz, the petrographer is, in practice faced with determining the following in rock thin sections[14]:

TABLE 6 : Properties of some aggregates produced in Natal. Where mean values are reported, the number of determinations is given in brackets[2]

Property		Values for				
		Quartzite	Tillite	Granite	Dolerite	Basalt
10% FACT value:						
Dry	kN	170	291(2)	167(2)	445(2)	333(2)
Wet	kN	111	243(2)	156(2)	429(2)	215(2)
Wet/dry	%	65	84(2)	95(2)	97(2)	64(2)
Los Angeles abrasion, loss	%	17	15	-	12	16
Drying shrinkage:						
Mortar	%	-	0,109	0,072	0,093	0,142
Concrete	%	-	0,033	0,024	0,023	0,042
Water absorbtion	%	-	0,52(2)	0,44(2)	0,48(3)	2,28
Relative density		-	2,69	2,62	2,88	2,75(2)
Loose bulk density, kg/m³		-	1 330	1 420	1 520	1 605
Voids	%	48	51	46	48	42
Flakiness index		35	43(2)	18(2)	23(3)	16(2)
Soundness, 15 cycles loss	%	5,1	11,7(2)	22,4(2)	3,4(3)	39,5(2)
Polished stone value		51	58	55	55	-

essentially of plagioclase feldspar and pyroxene (augite) which occur in roughly equal volumes[7]. Other minerals frequently present in dolerite are olivine and quartz, while small quantities of magnetite, ilmenite and sometimes a little biotite may also be present. Dolerite dykes and sills are widespread throughout South Africa. In those areas where rocks give rise to shrinkage aggregates, such as the sediments and basaltic lavas comprising the Karoo Supergroup, unweathered dolerite occurrences are quarried to provide a valuable alternative aggregate for concrete manufacture and road surfacing. It has been reported by Davis et al[7], that concrete mixes containing both coarse aggregate and crusher sand made from dolerite, often cause some degree of harshness and segregation in fresh concrete. Bleeding is also often pronounced and is aggravated by the high relative density of the rock. These phenomena can be prevented by:

(a) using better shaped aggregates, especially that of the crusher sand;
(b) ensuring adequate quantity of extreme fines (ie material passing 75 μm sieve) 8 to 10 per cent;
(c) blending in suitable natural sand if deficiency of fines in crusher sand cannot be produced through crushing;

TABLE 8 : Properties of aggregates produced from Malmesbury Group[2]

Property	Value for					
	Run of quarry aggregate			Selected crushed rock		
	Range	Mean	Number of determina-tions	Range	Mean	Number of determina-tions
10% FACT value: Dry kN Wet kN Wet/dry %	 351 - 230 340 - 206 97 - 90	 282 264 93	 9 9 9	 35 - 241 325 - 219 98 - 86	 290 263 91	 8 8 8
Aggregate crushing value: Dry % Wet %	 - -	 - -	 - -	 21,5 - 11,7 15,5 - 14,6	 13,6 15,1	 8 8
Los Angeles abrasion loss %	-	-	-	28 - 15	22	8
Drying shrinkage %	0,108 - 0,075	0,084	9	0,092 - 0,059	0,071	4
Water absorption %	0,40 - 0,20	0,23	9	0,89 - 0,24	0,48	8
Relative density	2,76 - 2,69	2,74	9	2,75 - 2,66	2,71	6
Loose bulk density kg/m^3	1 462 - 1 365	1 412	7	-	-	-
Voids %	50,0 - 43,2	47,9	7	-	-	-
Flakiness index	38,8 - 22,0	29,4	9	-	-	-
Soundness, 15 cycles loss %	35,1 - 1,6	9,8	9	-	-	-
Polished stone value	-	-	-	61 - 55	58	8
Riedel and Weber stripping value	-	-	-	0	0	8

TABLE 7 : Properties of some aggregates from the Eastern Cape Province[2]

Property	Values for							
	Table Mountain Quartzite							River gravel
	1,1	1,2	1,3	2,1	2,2	2,3	2,4	
10% FACT value: Dry kN Wet kN Wet/dry %	 233 205 88	 250 245 98	 178 178 100	 235 205 87	 148 145 98	 204 183 90	 162 152 94	 243 214 88
Aggregate crushing value: Dry % Wet %	- -	- -	- -	- -	- -	- -	- -	17,0 -
Los Angeles abrasion loss %	-	-	-	-	-	29	33	23
Drying shrinkage %	0,058	0,062	0,061	0,055	0,082	0,084	0,065	0,050
Water absorption %	0,55	0,70	0,67	0,28	0,61	0,34	0,42	0,42
Relative density	2,64	2,65	2,65	2,68	2,66	-	-	2,62
Loose bulk density kg/m^3	1 437	1 570	1 403	1 435	1 360	-	-	-
Voids %	46	41	47	47	49	-	-	-
Flakiness index	11	11	33	11	9	-	-	-
Soundness, 15 cycles loss %	37,3	31,3	31,3	16,6	28,5	9,8	13,3	-
Polished stone value	-	-	-	-	-	57	60	56

TABLE 10 : Aggregate properties of granite from the South Western Cape Province[2]

Property		Value		Number of determinations
		Mean	Range	
10% FACT value:				
Dry	kN	215	355 - 175	35
Wet	kN	195	322 - 110	35
Wet/dry	%	90	100 - 70	35
Aggregate crushing value:				
Dry	%	19,4	24,4 - 15,2	10
Wet	%	20,8	25,3 - 16,3	2
Los Angeles abrasion, loss	%	23	33 - 16	18
Drying shrinkage	%	0,066	0,076 - 0,051	34
Water absorption	%	0,35	0,89 - 0,12	34
Relative density		2,66	2,75 - 2,60	26
Loose bulk density, kg/m^3		1 420	-	1
Voids	%	47,7	49,7 - 46,2	4
Flakiness index		26	31 - 16	3
Soundness, 15 cycles loss	%	6,2	22,0 - 0,0	26
Polished stone value		52	56 - 47	12
Detachment value, CC10		8	13,4	9
Riedel and Weber stripping Value		0	0	7

Nine of these samples are from quarries that are or were producing aggregate in the South Western Cape Province.

TABLE 9 : Minerals, rocks and other substances which are potentially deleteriously reactive with alkalis in cement[13]

MINERALS

Opal
Chalcedony
Tridymite
Cristobalite
Cryptocrystalline, microcrystalline or glassy quartz
Coarse-grained quartz which is intensely fractured, granulated and strained internally or filled with submicroscopic inclusions of which illite is one of the most common
Vein quartz

ROCKS

Rock	Reactive component
Igneous rocks	
Granites Granodiorites Charnockites	More than 30 per cent strained quartz as characterised by suturing and undulatory extinction.
Pumice Rhyolites Andesites Dacites Latites Perlites Obsidians Volcanic tuff	Silicic to intermediate silica rich volcanic glasses; devitrified glass; tridymite.
Basalts	Chalcedony; cristobalite; opal; palagonite; basic volcanic glass.
Metamorphic rocks	
Gneisses Schists	More than 30 per cent strained quartz as characterised by suturing and undulatory extinction.
Quartzites	Strained quartz as above: 5 per cent or more chert.
Hornfelses Phyllites Argillites	Possibly certain phyllosilicates eg vermiculite; strained quartz; cryptocrystalline quartz.
Sedimentary rocks	
Sandstones	Strained quartz; 5 per cent or more chert; opal.
Greywackes	Possibly certain phyllosilicates eg vermiculite; strained quartz.
Siltstones	Possibly certain phyllosilicates eg vermiculite; strained quartz; opal.
Shales	Possibly certain phyllosilicates eg vermiculite; strained quartz; opal.
Chert Flint	Cryptocrystalline quartz: chalcedony; opal.
Diatomite	Opal: cryptocrystalline quartz.
Carbonates	Phyllosilicates exposed by dedolomitization; opal; chalcedony.

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REFERENCES

1. VAN SCHALKWYK A *Geology and selection of quarry sites.* Institute of Quarrying of South Africa Conference, Kimberley, October 1980.

2. OBERHOLSTER R E *Aggregates in South Africa: Production, properties, testing and utilisation.* Institute of Quarrying of South Africa Conference, Kimberley, October 1980.

3. POPOVICS S *Concrete-making materials.* Washington, 1979.

4. DAVIS D E *Aggregate and the quality and economics of concrete.* Concrete Society Seminar, Portland Park, November 1980.

5. Council of the South African Bureau of Standards. SABS 1083-1976 (as amended 1979). *Standard specification for aggregates from natural sources.* Pretoria, 1976.

6. WEINERT H H *The natural road construction materials of Southern Africa.* Academica, Pretoria/Cape Town, 1980.

7. DAVIS D E McIVER J R and WOLHUTER C W *South African aggregates for concrete, Part 1 Coarse aggregate, Part 2 Fine aggregate.* The Civil Engineer in South Africa, June 1978 and May 1979.

8. BRINK A B A *Engineering geology of Southern Africa.* Volume I. Building Publications, Pretoria, 1979.

9. NETTERBERG F BLIGHT G E THERON P F and MARAIS G P *Salt damage to roads with bases of crusher run Witwatersrand quartzite.* CSIR RR 173.

10. ORR C M *Rapid weathering dolerites.* The Civil Engineer of South Africa, July 1979.

11. TRUSWELL J F *An introduction to the historical geology of South Africa.* Johannesburg: Purnell, 1970.

12. DONALDSON G W *Civil engineering in the decade ahead.* Symposium, Durban, September 1980.

13. NBRI *Alkali-aggregate reaction.* Information Sheet X/BOU 2-47, Pretoria, 1979.

14. OBERHOLSTER R E *Alkali-aggregaatreaksie: Die rol van reaktiewe kwarts.* Spesialislesing gelewer by die Departement Geologie, Universiteit van Pretoria, Augustus 1980.

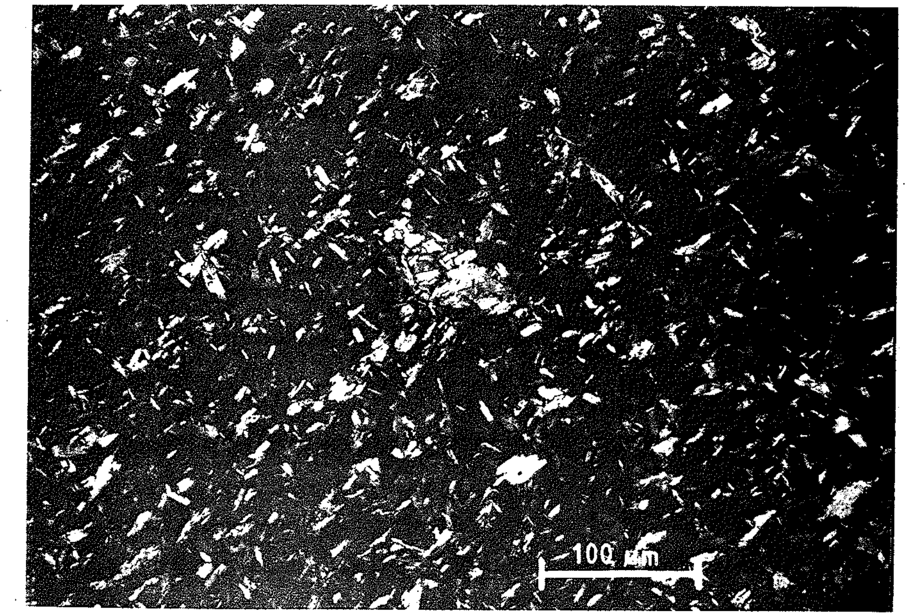

FIGURE 1 : Thin section of a hornfels, Tygerberg Formation, Malmesbury Group, showing the very fine-grained nature of these rocks (X nicols)

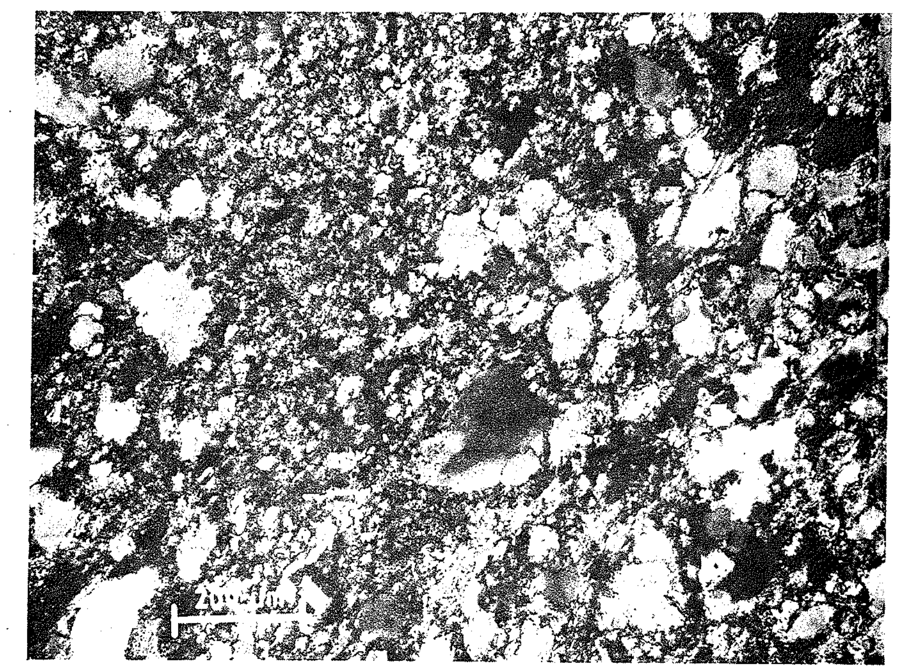

FIGURE 2 : Thin section of an indurated greywacke, Tygerberg Formation, Malmesbury Group. Reactive forms of quartz present, microcrystalline quartz (in matrix) and larger grains of stressed quartz (undulating extinction) (X nicols)

- the presence of strained quartz
- the amount of this quartz present
- the degree of stress in the quartz

9.2 Granite

The properties identified from tests carried out by the NBRI on various samples taken from quarries and also on borehole cores are given in Table 10, page 13.

Oberholster[2] comments that the granite aggregates produced in the South Western Cape Province are generally good concrete aggregates. Results obtained from various samples tested by the NBRI, indicate that there are adequate resources of granite with properties suitable for concrete and road aggregate. Of great importance is the fact that very few of the granite aggregates tested by the NBRI for potential alkali-reactivity, have been found to be deleteriously expansive[2].