THE GEOLOGY OF

A PORTION OF

NORTH – WESTERN

ALBANY

by

A.R.Wright, B.Sc.(HONS.)

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INTRODUCTION

FACTORS WHICH LEAD UP TO THE PROJECT:

During 1965 the author, in looking for a project for a thesis to be submitted for the degree of Master of Science in Geology, decided to map a suitable region in order to gain experience in geological field work. The exact nature of the region itself was of no great importance, but since this study was to be conducted through Rhodes University, it was decided that an area, as near to Grahamstown as possible, would be the most suitable.

With this in view, the geologist in charge of the Grahamstown Office of the Geological Survey was invited to suggest an area suitable for study, and, if possible, to obtain financial assistance. He indicated the region which has been mapped and which will eventually form part of the proposed sheet 143. It is immediately adjacent to, and to the west of the 1:125,000 sheet 136 of Grahamstown completed by Mountain in 1940. In addition, the Geological Survey generously offered the requested financial assistance.

THE PROJECT:

The field work was commenced in October 1965, and carried out during the following periods: October 1965 to March 1966; June 1966 to July 1966; October 1966 to March 1967; and June 1967 to July 1967 when the basic field work was completed. During the intervening periods, and when time was available from normal duties of employment, the author carried out laboratory and more theoretical research.

During the field work, and when the weather was suitable, approximately twelve miles per day were covered on foot. The region as a whole was covered thoroughly in this manner.

PREVIOUS WORK:

The region falls within that mapped and described as Cape Sheet 9 (Haughton 1928). This sheet, with its explanation, was extensively used in the project. Supplementary information was obtained from Johnson (1966), Meyer (1965), Loock (1967), and the various publications by Mountain specified in the references.

Part of the silcrete exposures, immediately to the northwest of Grahamstown, had previously been mapped by Mr. A. Ruddock.

ACKNOWLEDGEMENTS:

The author is particularly indebted to Prof. E. D. Mountain, Mr. A. Ruddock and Dr. H. V. Eales of the Rhodes University Department of Geology, under which this project was carried out; to the Geological Survey of South Africa for its financial assistance; and to the University College of Fort Hare for the use of its apparatus and equipment.

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N A T U R E   O F   T H E   I N V E S T I G A T I O N

FIELD WORK

The region was mapped by plotting field data on aerial photographs. These photgraphs were taken in 1956 and made available by the Trigonometrical Survey as Job 545. The information on the aerial photographs was transferred onto portions of the 1:50,000 sheets 3326 AA Riebeek East, 3326 AB Pigott's Bridge, 3326 AC Alicedale and 3326 AD Salem principally by means of proportionate dividers.

The closest possible examination was carried out on the macroscopic features of the strata, their structure, soil, topography and vegetation, and photographs taken of aspects of particular interest. The rock types themselves were examined and identified in the hand specimen and representative samples of the various suites in the region were collected for closer laboratory examination.

LABORATORY WORK

The various aspects are described separately:

Colour: The colours, and colour data, of the various hand specimens were obtained by comparing them with a rock colour chart (Rock Colour Committee, 1963). The freshest available samples were used, but in most instances, a fair degree of weathering had taken place, a process which tends to lighten the colour of the various rocks.

Grain-Size Distributions: These were obtained by measuring the maximum grain diameters of the quartz fraction. As far as possible, these measurements were limited to detrital grains. Due to the large number of quartz grains, it was necessary to devise a system of selection. The method used was first to lock the microscope stage to ensure that the orientations of the various grains in the respective thin sections remained constant relative to the plane of polarisation of the bottom nicol. The slide was moved about by means of a mechanical stage in order to measure the various grains. A gypsum plate was then inserted into the microscope with the nicols crossed, and all the grains registering blue or yellow under these conditions were measured. Approximately 150 grains were measured from each sample.

The actual measurements were carried out by means of a graticule eyepiece. The scale of the eyepiece was obtained by comparing it with a two millimetre micrometer slide for each objective.

The grain measurements were treated statistically by grouping them according to the Udden $\sqrt{2}$ grade scale given in Pettijohn (1957, p.26) in which each class was subdivided into two subclasses. These size frequency distributions were then plotted graphically as frequency curves from which the modal grain size was obtained, and as "less than" cumulative curves from which the median, the first and third quartile and the ten and ninety percentile grain sizes were obtained. The above data was substituted in various formulae in order to obtain the sorting coefficients, the logs of the coefficients of geometrical quartile skewnesses, the quartile kurtoses and the arithmetic means.

The following formulae were used to compute these characteristics:

Sorting coefficient

$$So = \frac{Q3}{Q1}$$

$$(Q3 > Q1)$$

where So is the sorting coefficient, Q1 the first quartile grain size and Q3 the third quartile grain size.

Log of the coefficient of geometrical quartile skewness

$$\text{Log}_{10}\ Sk = \frac{Q1.Q3}{(Md)^2}$$

where $\log_{10}$ Sk is the log of the coefficient of geometrical quartile skewness

Quartile Kurtosis

$$K = \frac{(Q3 - Q1)}{2\ (P90 - P10)}$$

where K is the quartile kortosis, P90 is the ninety percentile grain size and P10 the ten percentile grain size.

Arithmetic mean

$$M = \frac{\Sigma nd}{n}\ \varnothing$$

where M is the arithmetic mean, Σnd the total of the first moment, n the total frequency and $\varnothing$ indicating that the phi scale was used in this calculation.

Mo is the modal grain size.

Henceforth these symbols will be used without explanation.

The first three formulae were obtained from Twenhofel and Tyler (1941) and the last from Tickell (1965).

The size characteristics, specifically the first and third quartiles, were plotted against each other on the diagram of textural classification of sediments, modified from Niggli (1938), given in Pettijohn (1957, p.26), in order to classify these sediments according to the grain sizes of their quartz fractions.

In a number of instances secondary alteration of the primary quartz grain characteristics may well influence the grain size distributions.

The most important characteristics of the quartz grain size distributions are the median and quartile grain sizes. The other parameters are included mainly for interest and completeness.

Sphericity and Roundness: Sphericities and roundnesses of detrital grains of the quartz fraction in the various thin sections examined were determined by comparison with the visual chart in Krumbein and Sloss (1951, p.81).

Since sphericity and roundness are both functions of grain size (Pettijohn 1957, p.60), they were determined from median size grains in each sample. In order to limit (in an objective manner) the number of grains to be measured, a gypsum plate was used in the microscope in a similar way to that described above as having been employed in the measurement of grain diameters.

MINERAL COMPOSITION

The percentage mineral compositions of the various rocks were obtained by clamping the microscope stage, orienting the graticule eyepiece used for grain size diameter measurements parallel to the east-west microscope direction and counting the number of divisions falling on each mineral grain. By moving the mechanical stage, ten complete lateral traverses were made on each thin section, and the percentage mineral composition was obtained by averaging the ten groups of percentage compositions obtained from the respective traverses.

In order to classify the rocks according to their mineral compositions, their percentage mineral contents were recalculated as quartz, felspar and clay (the sericitic matrix and muscovite were grouped together as clay). Iron oxides, which occur mainly in the matrix and in veinlets were assumed to be authigenic. These and the sparse accessory minerals were ignored.

These data were plotted on the triangular diagram between these three components given in Krumbein and Sloss (1951, p.130). Although this triangular diagram is designated a "classification of sandstones" it includes a compartment designated "shale". It is clear therefore that this diagram may be applied to rocks differing widely in texture. In order to give fuller expression to the textural differences between the various rocks examined, the name derived mineralogically from this diagram, based on mineral content, was prefixed by the term denoting the textural classification, derived from Pettijohn's diagram (1957, p.26).

STRUCTURAL GEOLOGY

The techniques and methods of description employed in this section are explained in the chapter "Structural Geology".

T E R M I N O L O G Y

STRATIGRAPHICAL CLASSIFICATION

Following the classification employed and described by Johnson (1966) and by Loock (1967), the strata have been subdivided into the following lithostratigraphic units:

Supergroup
Group
Formation
Member.

BEDDING

In keeping with that used by Johnson (1966), the classification of bedding given by Ingram (1954; reproduced in Dunbar and Rogers, 1957, p.97) has been used as far as possible.

	Very thick bedded	
		100 cm
	Thick bedded	
		30 cm
Beds	Medium bedded	
		10 cm
	Thin bedded	
		3 cm
	Very thin bedded	
		1 cm
	Laminated	
Laminae		0.3 cm
	Thinly Laminated	

P H Y S I C A L   F E A T U R E S

LOCATION:

The region mapped lies in northwestern Albany immediately to the northwest of Grahamstown. It is bound by longitudes 26 degrees 10 minutes east and 26 degrees 30 minutes east, and by the latitudes 33 degrees 10 minutes south and 33 degrees 20 minutes south. Its location is illustrated diagrammatically by Diag. 1.

COMMUNICATIONS:

The area is well supplied with roads of all types among which are the Grahamstown/Port Elizabeth, Grahamstown/Alicedale, Grahamstown/Riebeek East and Grahamstown/Cradock roads. The Grahamstown/Alicedale railway line passes along the southern edge of the region.

HABITATION:

Apart from the small village of Riebeek East in the extreme east, the area is entirely populated by farming families and their staff. Cattle and sheep farming predominate.

CLIMATE:

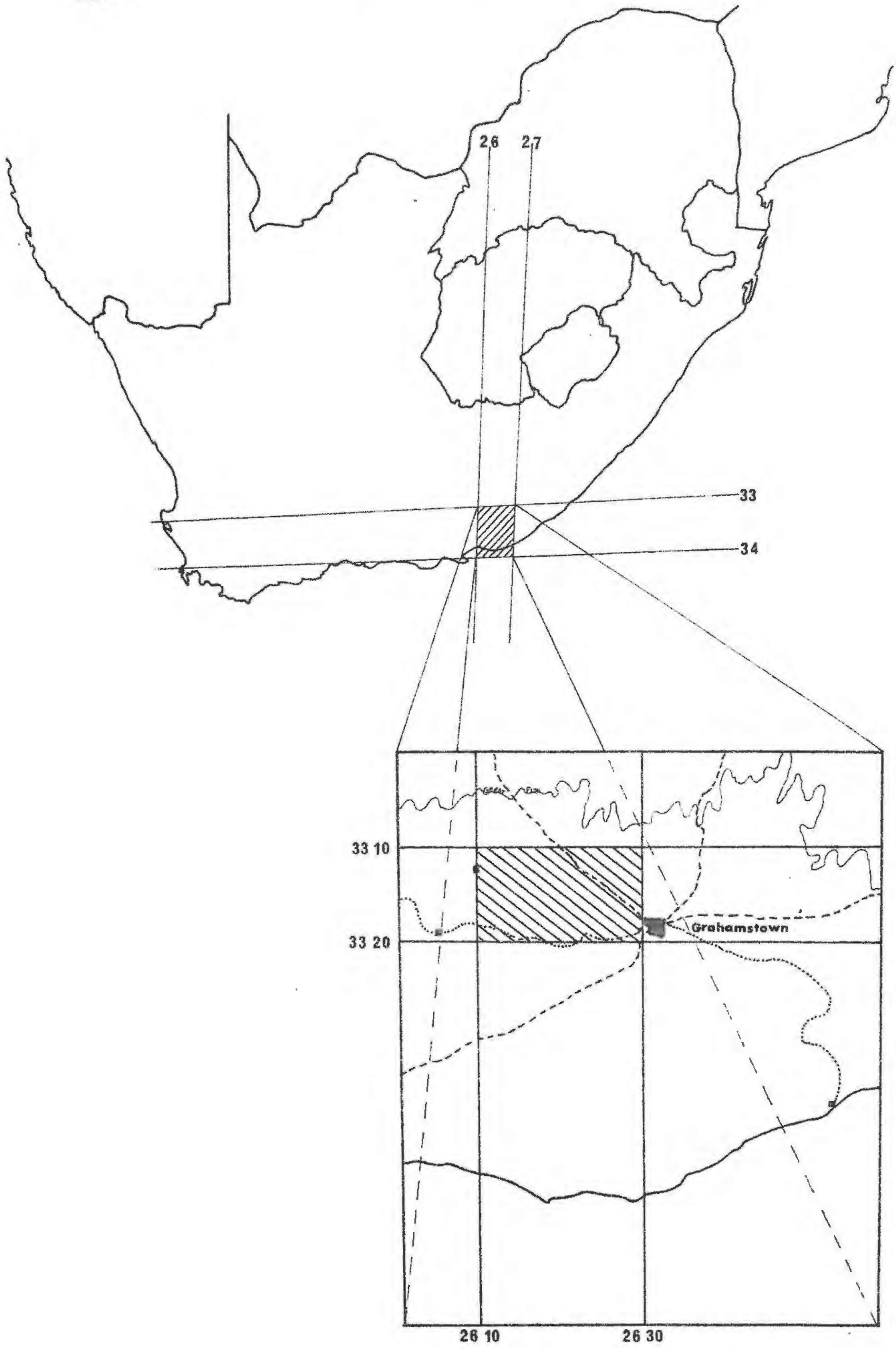
The climate is temperate with predominant summer rain-fall. The temperature in some of the valleys has been known to exceed the 100 degree mark during the summer months. The best times for field work are during Spring and Autumn.

TOPOGRAPHY:

As a whole, the relief of the region is a somewhat rugged one with changes in altitude between about 1,200 feet and 2,800 feet above sea-level. The region is

LOCALITY

DIAG 1



divided into elongate and en echelon basins, running more or less east-west, divided by ridges built up of strong Witteberg Quartzite rocks. The region is drained by the following rivers and their tributaries: the New Years, Bothas, Great Fish, Gxetu, Palmiet and Broekhuizenspoort rivers.

The main topographical basin in the region is the Riebeek East/Grahamstown basin. It enters the region around, and to the north of, Grahamstown, and passes through the region in a west-northwesterly direction to leave its western boundary around Riebeek East. This basin is about nine miles wide (from ridge to ridge) at Grahamstown, and about five miles wide at Riebeek East. The basin is drained from the west by the Gxetu River, a tributary of the New Years River, and from the east by the New Years River. The New Years River leaves the Riebeek East/Grahamstown basin on the farm Hilton where it cuts southward through the bounding Witteberg Quartzite ridge to form the Hilton Poort. The valley floor is at its lowest elevation of about 1,600 feet above sea-level at this point. The basin floor is a gently rolling one with relatively high ground running along its middle. In the west it rises to a fairly constant elevation of approximately 2,100 feet above sea-level on the more or less flat topped remnants of the peneplain around Grahamstown. Minor remnants of this same peneplain occur as scarps along the valley sides, and as a capping on the conical Leeukop, at an elevation of between 2,200 and 2,300 feet above sea-level, around Riebeek East.

In the northeastern corner of the region, immediately north of the ridge forming the northern boundary of the Riebeek East/Grahamstown basin, the country drops gradually northward towards the Great Fish River valley. This slope is interrupted by a few narrow, more or less east-west trending valleys, and is drained by the Botha's River and its tributaries.

A fairly deep basin occurs in the west, approximately five miles south of Riebeek East across the southern ridge of the Riebeek East/Grahamstown basin. It is approximately five miles in width at its widest. It enters the region on the farm Meyers Kraal and runs eastward for approximately six miles where, on the farm Rockdale, it bifurcates into two valleys. The northernmost of these two valleys provides a drainage way for the New Years River and passes upwards into the Hilton Poort; the other persists as a narrow steep-walled valley as far as Highlands in the south-central part of the region. Remnants of two high-level plains occur in this Rockdale/Meyers Kraal basin. One minor remnant of a silcrete-capped peneplain occurs on the farm Spits Kop on the crest of the southern ridge of the basin. Numerous remnants of a gravel and boulder capped valley-floor plain, varying between altitudes of approximately 1,200 and 1,500 feet above sea-level, occur in the basin proper.

A minor valley, running more or less east-west occurs in the extreme southwest of the region.

The southern and southeastern parts of the region are made up, for the most part, of moderately high ground dissected by steep-walled river valleys. A fairly deep valley occurs on the farms Geelhoutboom and Fir Glen near Atherstone station. In the extreme southeastern corner of the region, about one mile south of Grahamstown, there is a fairly abrupt drop in the land level where the Palmiet River flows down to Howison's Poort.

REGIONAL GEOLOGY

The regional geology is illustrated by Diag. 2 (pocket). It consists for the most part of the concordant Cape and Karroo supergroups, which, as a result of the Cape folding, are folded into successive east-west trending synclinoria and anticlinoria (p.104). These strata are moderately broken by strike faults.

They are overlain unconformably by isolated remnants of more or less horizontal, consolidated and unconsolidated Cainozoic sediments.

Igneous rocks do not occur.

G E N E R A L   M I N E R A L O G Y

The common features of the mineralogy of the various rocks encountered in the region are described under this heading.

QUARTZ

Quartz, if not always predominant, is the most prominent mineral occurring in the various suites of rocks in the region. It occurs in a limited variety of forms.

(a) Allogenic quartz: This is the most abundant variety and was used in grain size measurements on the rocks. The boundaries of the detrital grains are frequently obliterated by recrystallisation and by the formation of secondary quartz overgrowths in optical continuity with the original core. The latter phenomenon is often recognised from the occurrence of thin veneers of sericitic clay about the detrital core (Plates 2A and 5F) and, rarely, by rutile needles in the detrital grain being cut off at its boundary with the secondary quartz. The larger allogenic grains are, for the most part, fairly spherical and well-rounded indicating a fair amount of predepositional abrasion. The smaller quartz grains occurring in the finer-grained rocks are generally angular. Whether these grains are allogenic or authigenic is problematical. Since the finer grained rocks appear to have suffered less recrystallisation and introduction of authigenic material, it is assumed that these grains are allogenic. In addition, it is unlikely, by virtue of their small size, that they would be subjected to abrasion in an aqueous transporting medium.

A few examples of secondary veinlets passing though rounded quartz grains were observed.

The quartz grains frequently have inclusions in them - predominantly in the form of rutile needles. The grains in the Dwyka Tillite display the greatest variety of inclusions.

(b) Authigenic and recrystallised quartz: Although both these types of quartz do probably occur, it was impossible to differentiate between them in thin section. They occur predominantly as optically oriented crystalline overgrowths about detrital grains and as secondary quartz grains. In Plate 5F, pressure shadows may be observed at various points near the margin of a quartz grain where clots of clay have been caught up between two growing grains (Carozzi 1960, p.23). The secondary quartz grains sometimes show crystal boundaries (Plates 3G and 5D). This quartz, and sericite, frequently occur as intimate intergrowths.

Plate 5D displays evidences of at least two ages in the formation of a quartz coating about an irregular grain.

MUSCOVITE

Muscovite is fairly widepsread among the rocks in the area. It is usually observed in the form of abundant shiny flakes on the bedding planes of the more fissile rocks. In thin section, it is seen to occur predominantly as minute platelets in the groundmass, more often than not broken and twisted between adjacent quartz grains, a phenomenon due probably to diagenic pressures. It often occurs in minor secondary iron-oxide veinlets.

Carozzi (1960, p.58), in his description of felspathic sandstones with a primary matrix, states that mica occurs as flakes from two to fifty times larger than the average grain size of the other constituents. This is very seldom the case in the examples examined. Perhaps this mineral was deposited under quieter conditions than those prevailing during the deposition of the other constituents. A feature suggesting that the muscovite is allogenic is the occasional occurrence of a muscovite grain penetrating secondary quartz, a phenomenon suggesting that the muscovite was present in the rocks before the advent of secondary quartz.

SERICITE AND CLAY MINERALS

Sericite and clay minerals occur in a finely divided and intergrown state and, together, form the dominant constituent of the matrix of the various rocks. They have therefore been grouped together as the matrix. This matrix frequently contains appreciable amounts of cryptocrystalline secondary quartz which is more apparent in the coarser grained rocks. It is therefore interesting to note that the decrease in matrix silica more or less parallels the decrease in the incidence of secondary quartz overgrowths from the coarser to the finer grained rocks. Fine disseminations of rutile, iron-oxides and carbon frequently make up a fairly large proportion of the matrix and in some instances, give the whole rock characteristic colours, such as shades of red in the case of the iron-oxides, and dark greys and black in the case of carbon. Recrystallisation under pressure has at times caused a fine cleavage in the matrix (Plate 2D).

FELSPAR

Felspar in the form of orthoclase and plagioclase forms a somewhat rare constituent of the rocks in the area. Its occurrence is, for the most part, limited to the more heterogeneous rocks, and occurs in appreciable quantities only in the Ecca. Their habit is similar to that of the detrital quartz grains without secondary overgrowths. Grains are frequently somewhat saussuritised and sericitised.

ALLOGENIC HEAVY MINERALS

It is apparent from Loock (1967) that a fairly large variety of heavy minerals occur in the majority of the rock types occurring in the area. These are, however, rarely encountered in thin section.

Those which were encountered are pleochroic tourmaline, zoned and unzoned zircon, and rutile. They all show limited evidences of abrasion and tend to occur grouped together parallel to the bedding (Plates 4A and 4B). Plate 1H is a photomicrograph of a zoned grain of zircon.

Rutile occurs in a number of forms - as rounded detrital grains (Plate 4B), as crystalline secondary grains, and as the acicular crystals within quartz grains already described (Plate 4A).

IRON OXIDES

These occur as fine disseminations and in minor secondary veinlets predominantly in weathered and finer grained rocks, imparting red to yellow colours to them. It was impossible to determine whether or not these oxides are crystalline.

CALCITE

Small quantities of fine grained calcite were observed in a few thin sections of the Ecca rocks.

S T R A T I G R A P H Y

THE CAPE SUPERGROUP

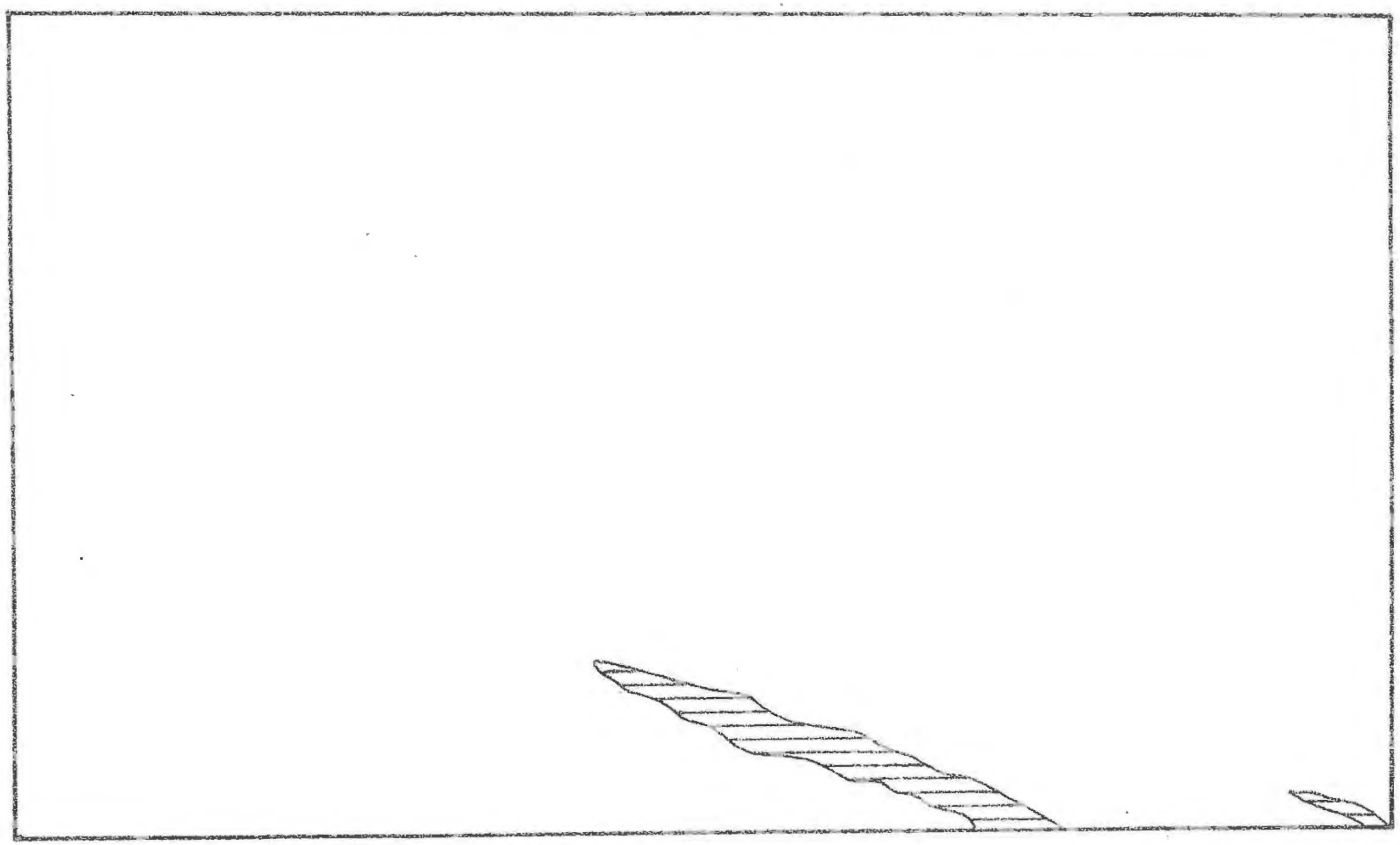
THE BOKKEVELD GROUP

DISTRIBUTION AND MODE OF OCCURRENCE

Rocks belonging to this group occur in two elongate strips parallel to the general strike of the region, in the southern and southeastern portions of the tract of land mapped (Diag. 3).

One occurrence, the larger, extends from the intersection of the Rockdale/Oakdale boundary fence with the road to the former farm for a distance of about seven miles on an approximate bearing of 105 degrees to and past the southern boundary of the region. The width of this outcrop is, at its greatest, about one mile. The topography of the country underlain by the Bokkeveld in this locality is of two contrasting types. Between the northwestern tip (the Rockdale/Oakdale boundary) and where the Grahamstown/Highlands railway line crosses these exposures of the Bokkeveld at Atherstone station, the land surface is that of a shallow valley with a gently rolling and well-grassed floor surrounded all about by hills of the stronger and overlying Witteberg Quartzite. A minor tributary of the Mill River incises part of the valley floor, exposing a few poor outcrops of Bokkeveld rocks. Southeastwards from Atherstone the topography is one of marked relief where tributaries of the Broekhuizenspoort River have incised themselves deeply into the relatively weak Bokkeveld rocks. Exposures in this valley are still poor but the Bokkeveld/Witteberg contact can be quite easily determined both in the field and on aerial photographs. The only good exposures encountered are

DIAG 3



in the railway cuttings near Atherstone station.

The smaller occurrence extends from near the railway tunnel on the farm Coldsprings, just to the west of Grahamstown, parallel to the larger occurrence, for a distance of about two miles to the southeastern corner of the region. This exposure of the Bokkeveld is at most about a quarter of a mile wide. The topography of the country underlain by this occurrence of the Bokkeveld is similar to the southern portion of the larger occurrence with tributaries of the Palmiet River (which flows down Howison's Poort) incising it deeply and forming the western tip of Featherstones Kloof which passes eastwards into the region mapped by Mountain. This valley contains the most luxuriant vegetation encountered in the mapped area, and is covered by long grasses more typical of the coastal plain towards the south and southeast than of the region above the Highlands/Grahamstown escarpment where the rest of the mapped area lies. Scenically this valley is quite beautiful mainly as the result of pine tree plantations.

Exposures are once again largely absent apart from a few cuttings in both the old and new Grahamstown/Port Elizabeth roads, and along the Grahamstown/Alicedale railway line.

FIELD OBSERVATIONS AND NOMENCLATURE

The rocks of the Bokkeveld are for the most part well weathered even in fairly recently opened cuttings so that the description of these strata is based on only a few fresh exposures. Mountain (1946) has described the fresh, sandy, micaceous shales as frequently carbonaceous, and the fresh sandstones as tending to be somewhat dark in colour.

The rocks exposed in the Howison's Poort road cuttings appear in the hand specimen to vary between a laminated, micaceous siltstone and a quartzitic sandstone which varies considerably in bedding thickness. These two rocks grade into each other by change in fissility and mica content rather than by a marked change in grain size. Some beds, even massive ones, display fine bands resembling varves. The overall competency of any part of these rocks is dependent on the proportion of massive quartzitic sandstone bands occurring in it. A typical occurrence of these rocks is given in Plate 1B. The bedding in these strata is very regular and no evidence of other primary structures, fossils or concretions was observed.

Perhaps the most striking feature of the Howison's Poort exposures is the overall maroonish to brick red colouration of all the rocks present. This colour is derived from iron-oxides in the more fissile bands and is only superficial on the more massive bands.

The fissile bands are definitely more susceptible to weathering and leaching than the more massive bands. If these were originally dark in colour as suggested by Mountain (1946), then they change to the shades of red due to the formation of iron-oxides when exposed to oxidising agents. A coarse colour-banding was observed between deep red and light maroonish red in the weathered laminated micaceous siltstones.

Two railcuttings within a short distance of each other comprise the Atherstone station exposures. In the northern cutting two main groups of rocks occur separated by a sharp boundary. These rocks occupy a stratigraphically lower position than those in the southern cutting. The lower group has a general deep red colouration, and breaks into small fragments due to the intersection of jointing, cleavage and bedding planes. It is largely similar to the rocks occurring in the Howison's Poort exposures except that the more massive bands are thinner and red on the fresh surface, have more definite boundaries, and occur less frequently. Red to grey shales and irregularly bedded siltstones occur locally. Plates 1A and 1D are good illustrations of these rocks. The upper group of strata in this cutting consists of well stratified micaceous siltstones which have been leached to a white sandy clay parted approximately every four to six feet by one or a few narrow, extremely hard, orange-white weathering bands of quartzitic sandstone. These features are well illustrated by Plate 1E. The leached sandy clays occurring here frequently contain small spherical ferruginous concretions often arranged in rows parallel to the bedding (Plate 1F).

The stratigraphically higher Bokkeveld rocks exposed in the southern cutting display a greater frequency of massive bands tham is encountered anywhere else. Red colourations in the rocks are largely absent with both the fissile and massive rocks weathering to a buff or grayish-buff colour. The contacts between the quartzitic sandstones and the more fissile or finer grained rocks, though frequently sharp, are more often than not gradational as is the case in the Howison's Poort exposures. The massive bands apparently have an extremely hard core - probably of quartzitic sandstone which perceptibly grades out either way through sandstone to the laminated micaceous siltstone and sometimes to a narrow band of shale.

Once more, apart from the true shales, the difference in grain-size between the laminated and more massive rocks is apparently small with the most notable difference being an affluence of mica flakes in the more laminated rocks.

It is obvious from the above descriptions that Bokkeveld rocks are of every type ranging from the fine shales, through laminated micaceous siltstones to quartzitic sandstones.

The author therefore selected seven representative samples of Bokkeveld rocks in order to study and classify them in greater detail. Table 1. indicates the serial numbers allocated to these samples, their field descriptions, and the localities in which they were collected.

TABLE 1

Sample serial numbers

Serial number	Field description	Sample locality
Bkv 1	Shale	Atherstone
Bkv 2	Silty mudstone	"
Bkv 3	Laminated micaceous siltstone	"
Bkv 4	Siltstone	"
Bkv 5	Very thin bedded quartzitic sandstone	Howison's Poort
Bkv 6	Very thin bedded quartzitic sandstone	Atherstone
Bkv 7	Quartzitic sandstone	"

PHYSICAL PROPERTIES

The following is an account of the physical properties of the Bokkeveld rocks as represented by samples Bkv 1 to Bkv 7.

Colour:

Colour data of the hand specimens, expressed in terms of a colour chart (Rock Colour Committee, 1963) are given in Table 2.

TABLE 2

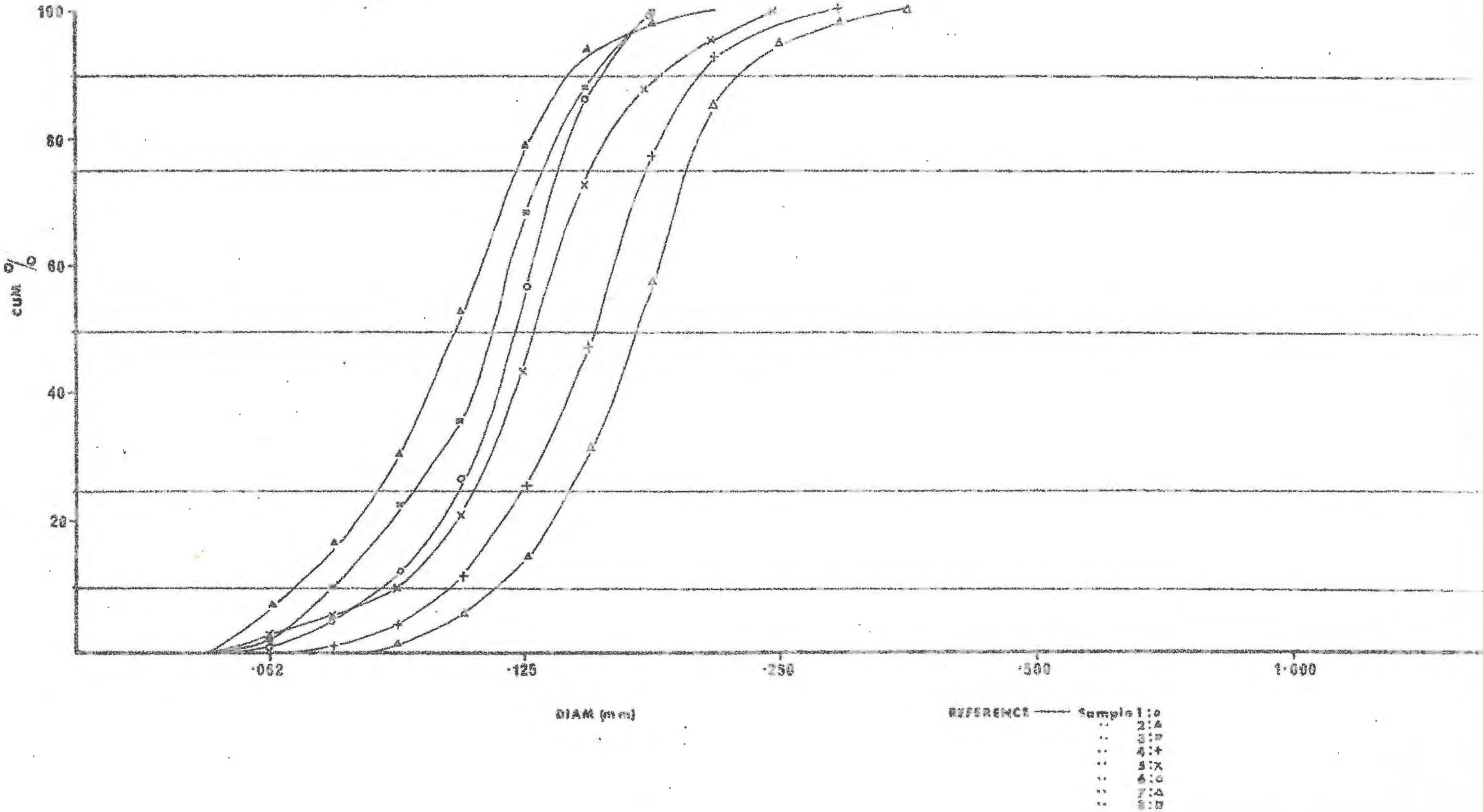
Hand specimen colours

Specimen	Colour	Hue	Value	Chroma
Bkv 1	Grayish Red	10 Red	4	2
Bkv 2 (Mixed)	Medium gray	Neutral	5	0
	Light brown	5 Yellow Red	6	4
Bkv 3	Grayish red	10 Red	4	2
Bkv 4	Grayish orange-pink	5 Yellow Red	7	2
Bkv 5	Yellowish gray	5 Yellow	7	2
Bkv 6	Light gray	Neutral	7	0
Bkv 7	Light gray	Neutral	7	0

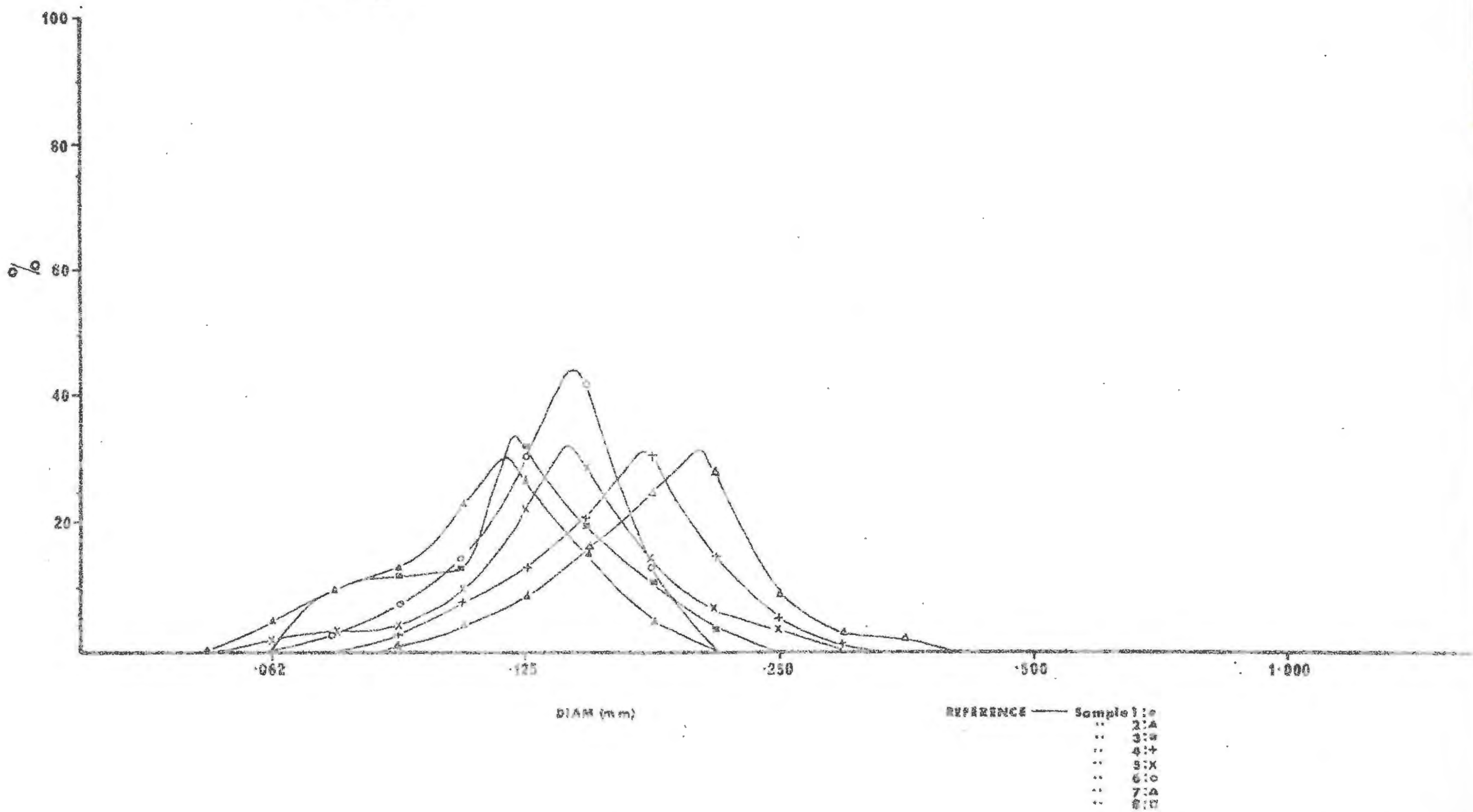
Grain-size Distributions:

The measured distributions of maximum diameters of the more rounded quartz grains in these samples are illustrated graphically by the cumulative frequency curves in Diag. 4 and the percentage frequency curves in Diag. 5. The Md., M., Mo., So., $\text{Log.}_{10}\text{Sk.}$, and K of these distributions computed from data obtained from the respective graphs are tabulated in Table 3.

Diag 4


100
80
60
40
20
CUM %
·062
·125
·250
·500
1·000
DIAM (mm)
REFERENCE —— Sample 1: o
" 2: ▲
" 3: ▫
" 4: +
" 5: X
" 6: o
" 7: △
" 8: ▫

Diag 5



100
80
%
60
40
20
·062
·125
·250
·500
1·000
DIAM (mm)
REFERENCE —— Sample 1 :
" 2 :
" 3 :
" 4 : +
" 5 : X
" 6 : o
" 7 :
" 8 :

TABLE 3

Grain-size distribution data

Sample	Md(mm)	M(mm)	Mo(mm)	So	$Log_{10}Sk$	K
Bkv 1	-	-	-	-	-	-
Bkv 2	0.081	0.103	0.094	1.203	$\bar{1}.977$	0.253
Bkv 3	0.112	0.113	0.120	1.196	$\bar{1}.994$	0.270
Bkv 4	0.151	0.149	0.175	1.187	$\bar{1}.978$	0.268
Bkv 5	0.130	0.130	0.140	1.156	0.004	0.202
Bkv 6	0.120	0.120	0.146	1.142	$\bar{1}.996$	0.258
Bkv 7	0.182	0.173	0.208	1.182	$\bar{1}.924$	0.272

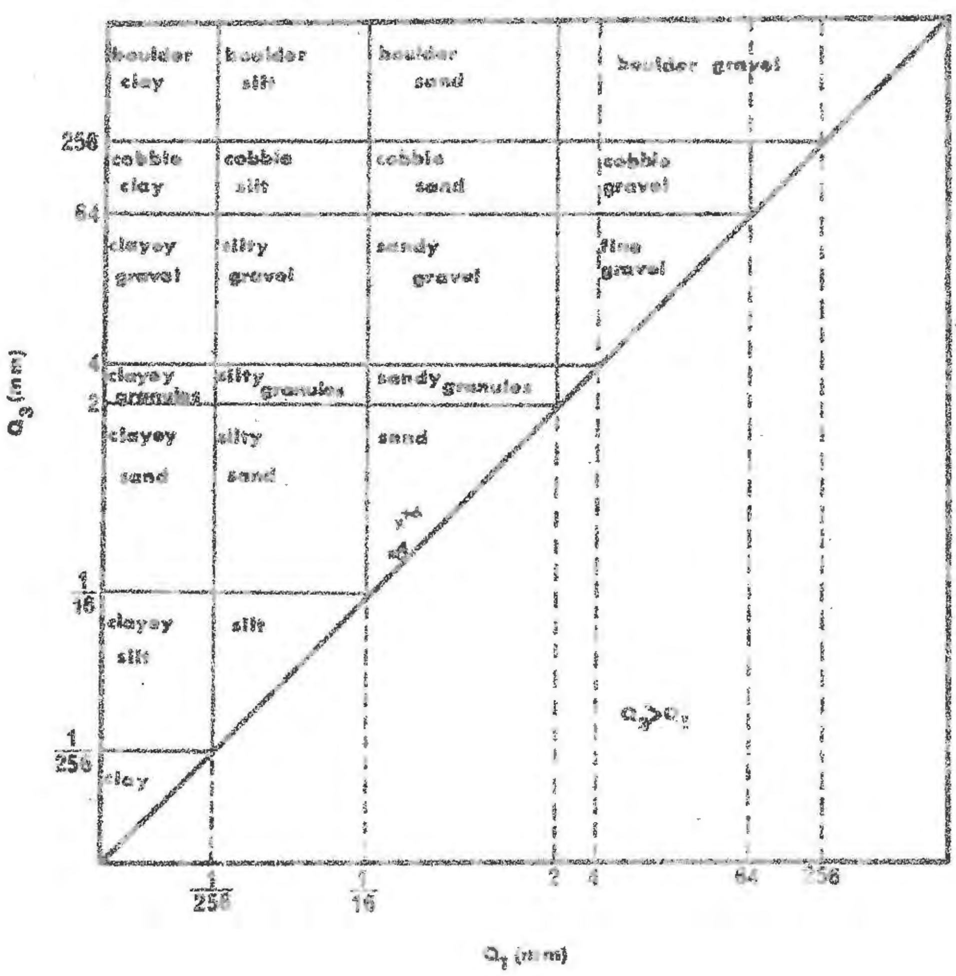
It is obvious from these data, and even from a rough appraisal of the graphs in diagrams 4 and 5, that apart from the actual sizes measured, the distributional characteristics of the respective samples closely resemble each other. Exceptions to this are the percentage frequency distribution curves of the samples Bkv 2 and Bkv 3, the two finest grained rocks measured, which have admixtures of fine grains.

These distributions all show a high degree of sorting, the So. values as tabulated in Table 3 varying between 1.142 and 1.203. Trask (1932), as quoted by a number of authors, has stated that any value of So. less than 2.5 indicates a well sorted sediment.

They are all moderately negatively skewed, with the exception of sample Bkv 5 in which finer admixtures exceed the coarse (Pettijohn 1957, p.37). Kurtosis values are included here for completeness.

In Diag. 6 the first and third quartiles of these distributions are plotted against each other according

Diag 6



REFERENCE

Sample 1 : ●
" 2 : ▲
" 3 : ■
" 4 : ▼
" 5 : ✕
" 6 : ○
" 7 : △
" 8 : □

to the method given in Pettijohn (1957, p.26). It is seen that they all fall within the sand grade.

Sphericity and Roundness:

The sphericities and roundnesses of median size quartz grains in the respective samples are given in Table 4.

TABLE 4

Sphericity and roundness

Sample	Median grain sphericity	Medium grain roundness
Bkv 1	-	-
Bkv 2	0.60	0.40
Bkv 3	0.68	0.36
Bkv 4	0.78	0.66
Bkv 5	0.78	0.58
Bkv 6	0.68	0.58
Bkv 7	0.62	0.79

Whereas the sphericities remain fairly constant, there is a general increase in roundness of the quartz grains with increase in the grain size of the sample. Zircon and tourmaline both exhibit low to moderate sphericities and roundnesses while the few grains of felspar observed in the samples appeared to resemble quartz in this respect.

Mineralogy:

Quantitative mineralogy:

The percentage mineral compositions of the various samples studied are tabulated in Table 5.

TABLE 5

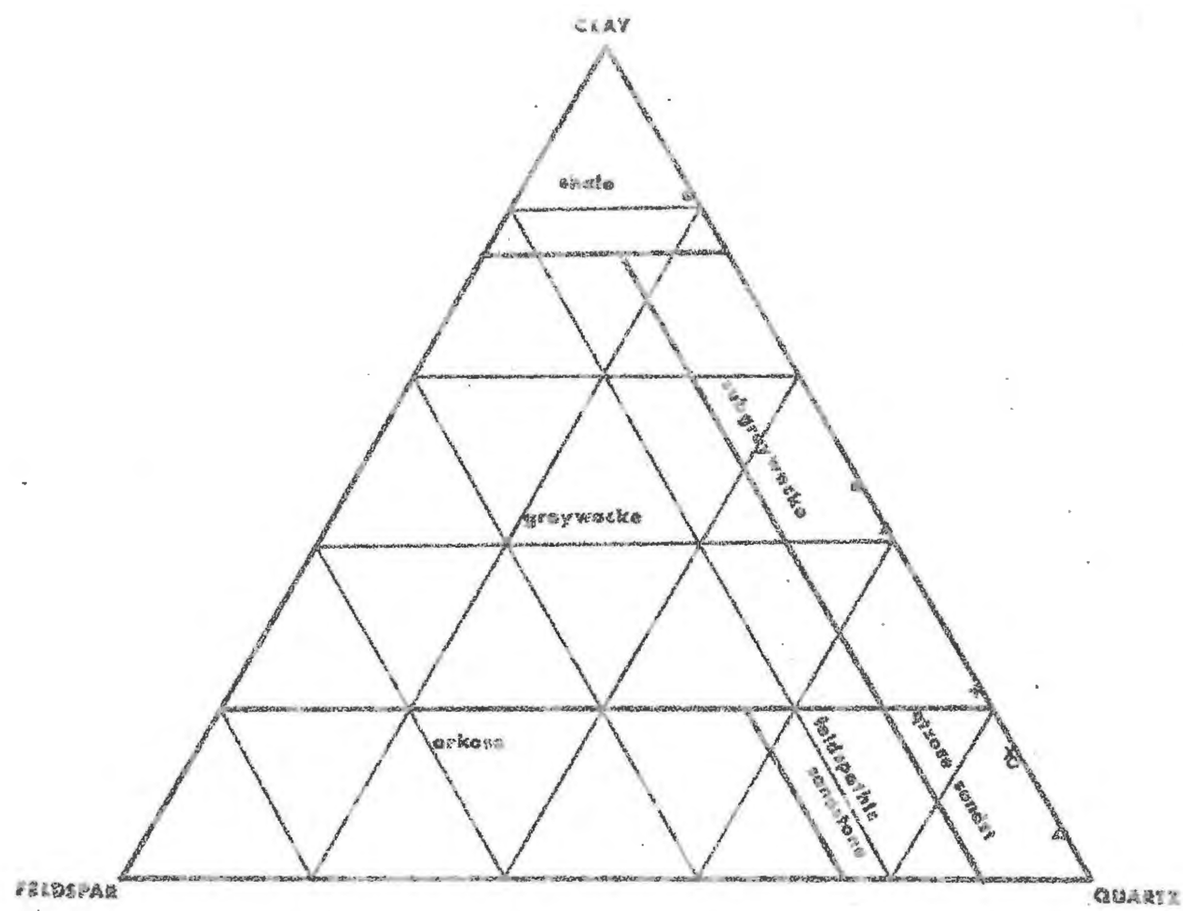
Percentage mineral composition

Sample	Qtz	Mat	Musc	Rut	FeOx	Tour	Felsp	Zir	Ind
Bkv 1	8.0	67.0	7.0	-	5.0	-	-	-	13.0
Bkv 2	35.0	24.0	1.0	-	26.0	-	-	-	14.0
Bkv 3	39.7	27.4	9.5	t	23.7	-	-	-	t
Bkv 4	73.5	15.1	4.8	t	3.8	t	-	t	3.1
Bkv 5	78.1	13.1	2.6	t	4.0	-	t	-	2.2
Bkv 6	81.1	11.9	1.8	t	1.9	t	-	-	3.3
Bkv 7	92.6	7.1	0.3	t	t	-	-	-	t

t refers to trace; Qtz to quartz; Mat to the fine grained matrix which consists predominantly of sericite and clay minerals, plus carbon in the dark coloured rocks; Musc to muscovite; Rut to rutile: FeOx to iron oxides; TOUR to tourmaline; Felsp to felspar; Zir to zircon; and Ind to an indeterminate yellowish, amorphous material, possibly silica.

In order to classify these rocks in the triangular diagram given in Krumbein and Sloss (1951, p.130) their percentage mineral contents were recalculated between quartz, matrix and muscovite (grouped together as clay), and felspar. The recalculated percentage compositions are given in Table 6, and the plots on the diagram itself appear in Diag. 7.

Diag 7



REFERENCE

Sample 1 : ◆
" 2 : △
" 3 : ●
" 4 : +
" 5 : ×
" 6 : ○
" 7 : ▲
" 8 : □

TABLE 6

Recalculated percentage compositions for use in diagram 7

Sample	Quartz	Clay	Felspar
Bkv 1	9.7	91.3	-
Bkv 2	59.3	40.7	-
Bkv 3	51.8	48.2	-
Bkv 4	78.7	21.3	-
Bkv 5	83.3	16.7	t
Bkv 6	85.4	14.6	-
Bkv 7	92.6	7.4	-

Descriptive mineralogy:

The mineralogy of the Bokkeveld suite of rocks is largely similar throughout, apart from variations in size and abundance. The textures are typically fragmental apart from recrystallisation, secondary enlargement, replacement and introduction of authigenic material. Qualitatively the samples Bkv 2 to Bkv 7 may be described as similar to Carozzi's "quartzitic, pure quartz sandstones", which have mosaic textures (1960, p.13). They resemble the variants between the two end members, that is, between those that contain quartz whose grains, with secondary overgrowth (where this occurs), in spite of their volume increase, do not come in contact and those quartzites in which they do.

With increase in quartz grain content there is a gradual increase in the degree of sorting and a decrease in the skewness (Table 3). This is accompanied by a decrease in the matrix content (Table 5). An irregular banding composed of successive quartz-rich and matrix-rich layers occurs in the sample Bkv 2 (Plate 1G).

This appears as a colour banding in the hand specimen. It is interesting to note that the decrease in quartz content in the samples examined generally accompanies a decrease in the incidence of quartz overgrowths.

Rutile and iron oxides, more often than not amorphous, but occasionally crystalline, occur in their greatest quantities in the finer grained rocks to which they impart a red colouration.

CLASSIFICATION OF THE ROCKS

Taking into account the information recorded above, and following the procedure described on p. 7, the author suggests the classification for these rocks to be that given in Table 7.

TABLE 7

Classification of the Bokkeveld suite of rocks

Sample	
Bkv 1	Shale
Bkv 2	Sand subgraywacke
Bkv 3	Laminated micaceous sand subgraywacke
Bkv 4	Sand subgraywacke
Bkv 5	Very thin bedded quartzose sandstone
Bkv 6	Very thin bedded quartzose sandstone
Bkv 7	Quartzose sandstone

STRATIGRAPHICAL FEATURES:

Stratigraphically these rocks are the lowest, and hence the oldest, encountered in the region mapped. Only the uppermost strata of this group are exposed and they form a conformable sequence underlying the Witteberg Group. There is no unconformity between the two groups.

As has already been stated the contact between these two groups is nowhere exposed in the region, and this contact, for the most part, was taken as a topographical one where the generally gentle, outcrop-free and red-soiled country overlying the Bokkeveld gave way to the rugged, white-soiled and boulder-strewn country overlying the Witteberg. The stratigraphy of the lower portion of the Witteberg will be dealt with in greater detail under the heading "The Witteberg Group".

Although a limited amount of information was obtained from the various cuttings already described, it must be noted that in all these instances the strata were observed to be in a highly contorted condition, such that the exact stratigraphical positions of these various exposures was impossible to determine. Estimates based on the inclinations of the adjacent and regular dipping Witteberg Quartzite would place the Howison's Poort exposures in what Johnson (1966) called the Erekroons or fifth shale of the Bokkeveld Group, which embraces the uppermost 600 feet of the group. In the same way the Atherstone station exposures would either fall into the Upper Red Shale or the Adolf's Kraal or fourth shale, which lies between 800 and 2,200 feet below the Witteberg Quartzite, and immediately underlies the Driekuilen or fourth sandstone formation. In view of the high frequency of quartzose sandstones in the northern cutting near Atherstone the rocks there may well be an exposure of the Driekuilen Sandstone itself.

THE WITTEBERG GROUP

THE WITTEBERG QUARTZITE FORMATION

THE BOKKEVELD/WITTEBERG QUARTZITE BOUNDARY

It has already been stated that the selected boundary between the Bokkeveld and Witteberg groups is nowhere exposed in the region under consideration. The decision to take the base of the Witteberg, (in accordance with Mountain, Meyer and other workers), at the point where the softer Bokkeveld shales give way to the first thick occurrences of massive bluish quartzites, is an obvious one. This boundary is an easy one to follow, not only in the field and from aerial photographs, but also topographically and lithologically. It represents the greatest change of depositional conditions recognisable within that thickness of rock in which this boundary must be placed. The author is, however, aware that this division might not be so easily placed in the light of detailed stratigraphical work since bands of quartzitic sandstone, like those in the Witteberg Quartzite, definitely occur in the parts of the Bokkeveld within the region mapped. The term "thick" used with reference to the development of quartzites at the base of the Witteberg, is also a comparative one and would obviously give rise to much confusion as to its meaning for different investigators. It would perhaps therefore be better in regional mapping if this boundary was selected from a broader point of view, for example from aerial photographs, taking it as a line in a photograph where the change from the Bokkeveld features to Witteberg Quartzite features is most conspicuous.

It is with interest that the author noted that

Theron (1964[2], p.365) in his description of this boundary, west of Willowmore, took the bottom of the Witteberg to be at the base of two "closely similar and parallel trending pinkish-cream, siliceous sandstone horizons" within the main mass of the Witteberg. These occur in the same stratigraphical position in the Grahamstown region. In practice the base plotted from aerial photographs falls very close to that of Theron. Theron cited as one of his reasons for selecting this boundary that it is conspicuous in the field.

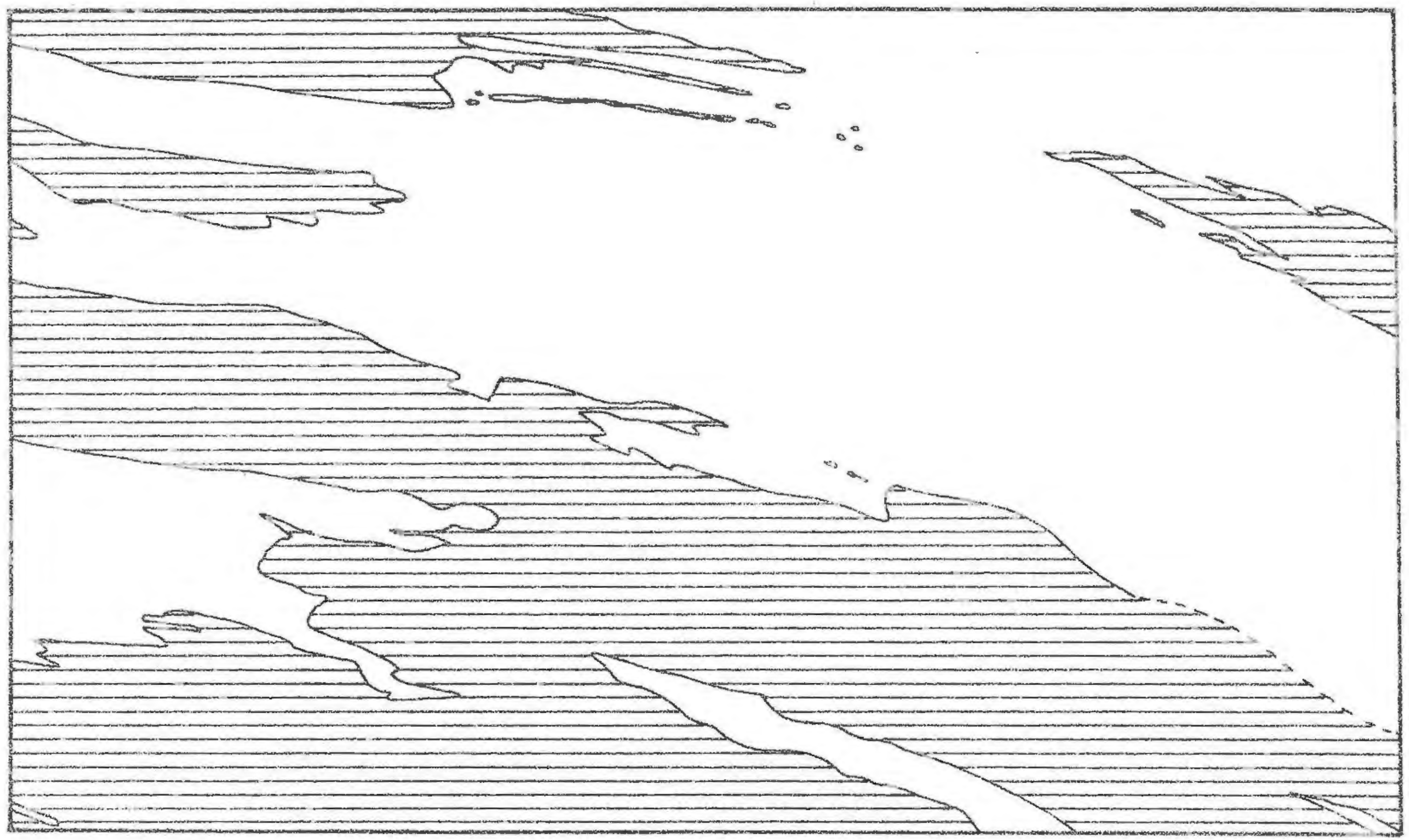
In addition, the author is in full agreement with Haughton (1935), and later Johnson (1966, p.26), where he states "the shales below the sandstone mass should be placed in the Bokkeveld group everywhere", especially in the Grahamstown region, because the general similarity between Johnson's description of the Steytlerville Shales and the characteristics of the upper parts of the Bokkeveld in the area mapped by the author suggest them to be one and the same taking into account a certain amount of facies - change along strike.

DISTRIBUTION AND MODE OF OCCURRENCE:

The Witteberg Quartzite is the dominant group of rocks encountered in this region, and, like the other strata caught up in the Cape Fold Belt, it crops out in generally continuous, en echelon strips parallel to the regional strike (Diag 8.).

These rocks are very resistant to weathering and erosion and govern the relief of the region. They tend to form highlands which often tower hundreds of feet above adjacent valleys incised into the softer rocks. These hills tend to be irregular. Their slopes are characteristically covered with

DIAG 8



angular boulders and free faces are common.

The majority of the rivers in this region arise in these highlands and they are obsequent and resequent, flowing directly down the slopes of steep-sided valleys; on occasion, they make use of bands of softer material, fault planes or fold axes in the quartzites as avenues of flow.

The Witteberg Quartzite is well covered with long grasses and reeds. Although trees and bushes do occur along the watercourses, they are more noticeable by their absence in contrast to the country where other rocks crop out. The soils derived from the quartzites are sandy and grey to white in colour and may be easily recognised in aerial photographs where they have distinctly lighter grey tones (Plate 2E). Plate 2F illustrates the typical soil profile with ill-defined layers of coarse angular quartzite fragments and finer, rounded - often red-stained - quartzite pebbles in the B - horizon.

For the most part, the Witteberg Quartzite crops out in the cores of anticlinoria (p.104) with the topography closely following the pattern of folding. The macroscopic folds (p.106) in these anticlinoria frequently become complex - clearly visible in the zigzag folding in Plate 2E - and the minor anticlines often became overfolded (Plate 2G). This will be discussed in greater detail under the heading "Structural Geology". The effect of the complexity of these folds is to make the outcrop of the quartzitic sandstones irregular, especially where minor folds in them plunge beneath overlying strata and where only their crests penetrate the surface of the land. This is particularly the case on the farms Palmietfonteyn, Vaalė Krans, Van der Merwes Kraal, Rietfontain and Burnt Kraal in the north (Plate 2E).

The southern half of the region is underlain almost exclusively by Witteberg Quartzite. The northern boundary of the southern region enters the area immediately south of Grahamstown, where it strikes in a west-northwesterly direction, and leaves the region a short distance to the south of Riebeek East. Other exposures within this part of the region are the four by six miles Meyers Kraal/Rockdale outlier of Lake Mentz Shale with their overlying gravel beds, the two Bokkeveld exposures in the south and southeast, and sporadic occurrences of silcrete throughout.

In the west, two minor exposures in the form of anticlines plunging towards the east enter the region on either side of Riebeek East. The southern occurrence is only about half a mile wide and penetrates the area for a mile, while the northern one attains a width of about two miles and extends eastwards for a distance of five miles, before disappearing beneath the overlying Lake Mentz Shale at a large dam on the farm Palmietfonteyn.

To the north of these occurrences, a fairly narrow anticlinorium exposing Witteberg Quartzite enters the region in its northwest corner as the eastward continuation of the Riebeek East mountains. The quartzites attain a maximum width of outcrop of about three miles and extend right across the region in the direction of the regional strike except for about five miles on Van der Merwes Kraal, where they plunge beneath the Lake Mentz Shale. They leave the area on Burnt Kraal. The anticlinorium provides the northernmost exposures of the Witteberg Quartzite in this part of the Cape Fold Belt.

Continuous exposures, both natural and man made, are surprisingly few. Although many river courses do traverse the Witteberg Quartzite, they expose only the more resistant strata for study. Roads and railway lines tend to avoid the more mountainous Witteberg Quartzite country and are routed along sinuous paths on the valley floors. Where they do traverse the Witteberg Quartzite, it is along strike, such as the Grahamstown/Highlands/Alicedale railway line, in order to maintain a constant elevation and thus their cuttings render little useful data for the study of the stratigraphic succession. The information on the following pages has therefore been drawn from isolated exposures throughout the region.

FIELD OBSERVATIONS AND NOMENCLATURE

Apart from a few minor exceptions, the Witteberg Quartzite represents a petrologically uniform group of rocks which as a whole are easily distinguishable from those which occur above and below. They were therefore probably formed during a stage of steady deposition in an aquatic environment which experienced slight fluctuations in depth. Due to the presence of black carbonaceous shales, du Toit (1954, p.560), described this as a brackish water environment.

Throughout the succession of the Witteberg Quartzite there is a continual variation between quartzitic sandstones, sandstones, micaceous flaggy sandstones, and more rarely, black carbonaceous shales.

The generally bluish to grey-white and sometimes pinkish quartzitic sandstones crop out prominently, and are thickly bedded. They are often seen to be recrystallised even in hand specimens, and are, for the most part, devoid of primary sedimentary structures apart from stratification and cross-bedding. Boulders and outcrops of these rocks tend to become rounded by exfoliation and weather to a yellowish-brown colour. At times, these outcrops were observed to take on a hard glazed appearance. It was noted, however, that this phenomenon tended to occur predominantly in areas closely associated with silcrete (p.94).

Interbedded with the quartzitic sandstones are layers - usually up to three feet in thickness - of very thinly to thinly-bedded sandstones which weather and erode more easily than the adjacent quartzitic sandstones. They are white on the fresh surface and tend to weather to orange and reddish crusts, due probably to the formation of iron oxides. These layers are prolifically cross-bedded and sometimes ripplemarked, in seemingly haphazard orientation. Although in the first stages of the field work the author spent considerable time and effort in recording the orientations of these current structures, he later abandoned it when the conviction crystallised that only a detailed systematic and statistical approach to this problem would yield reliable results. Examples of cross-bedding are illustrated by Plates 3A and 3B. In the latter illustration the cross-bedding is overturned and is obviously of the type described by Mountain (1962, p.203).

At irregular intervals in the succession, the rocks gradually change into softer and thin to medium-bedded, flaggy micaceous sandstones which rarely crop out. They are easily distinguished on aerial photographs for they form strips of land which are well grassed and frequently bushy between the adjacent outcrop-ridden country overlying the quartzitic sandstones. Good examples of these white weathering and somewhat friable rocks may be seen in the overflow channel of the Grahamstown municipal dam near the southwestern boundary of Cold Stream (Plate 3C).

Occasional bands of irregularly laminated black carbonaceous shale, containing abundant fragments of a fossil plant, form the antipode to the quartzitic sandstones in the gradation through the micaceous sandstones. The only good exposure of this rock type in the area mapped is in the overflow channel of the municipal dam. A good example may, however, be observed in the national road cuttings at the foot of Howison's Poort in the area mapped by Mountain (Plate 3D). A notable difference between these two exposures is that the shale at the municipal dam is bounded by flaggy micaceous sandstones which grade outward into quartzitic sandstones while those in Howison's Poort are immediately flanked by massive quartzitic sandstones. Fragments of red shale, used by the local Bantu for red pigmentation, and locally referred to as "rooiklip", were frequently observed in the soils underlain by the Witteberg Quartzite. This and the occurrence of fairly large circular goethite concretions in bedding planes of the micaceous sandstones, a few inches beneath their contact with the black carbonaceous shales at the municipal dam (Mountain - verbal communication), suggest that these shales have a fairly high iron content. Although no further examples of shale were observed, it was noted that Meyer (1965) and Mountain (1946) mention that shales are common in the Witteberg Quartzite, and that they rarely exceed twenty to forty feet in thickness, and that they grade into sandy, micaceous and carbonaceous types.

In order to name and classify the suite of rocks in the Witteberg Quartzite, five hand specimens were collected for more detailed work. Table 8 indicates the serial numbers allocated to these samples, their field description, and the localities in which they were collected.

TABLE 8

Sample serial numbers

Serial No.	Field description	Sample Locality
W Q 1	Black carbonaceous shale	Howison's Poort
W Q 2	Micaceous sandstone	Municipal Dam
W Q 3	Sandstone	Rockdale
W Q 4	Quartzitic sandstone	Howison's Poort
W Q 5	Quartzitic sandstone	Witteklip

Plates 3E and 3F are photographs of the samples W Q 2 and W Q 5 respectively.

PHYSICAL PROPERTIES:

The following is an account of the physical properties of the Witteberg Quartzite suite of rocks as represented by the samples W Q 1 to W Q 5.

Colour:

Colour data, obtained by comparing the hand specimens with a colour chart (Rock Colour Committee, 1963), are given in Table 9.

TABLE 9

Hand specimen colours

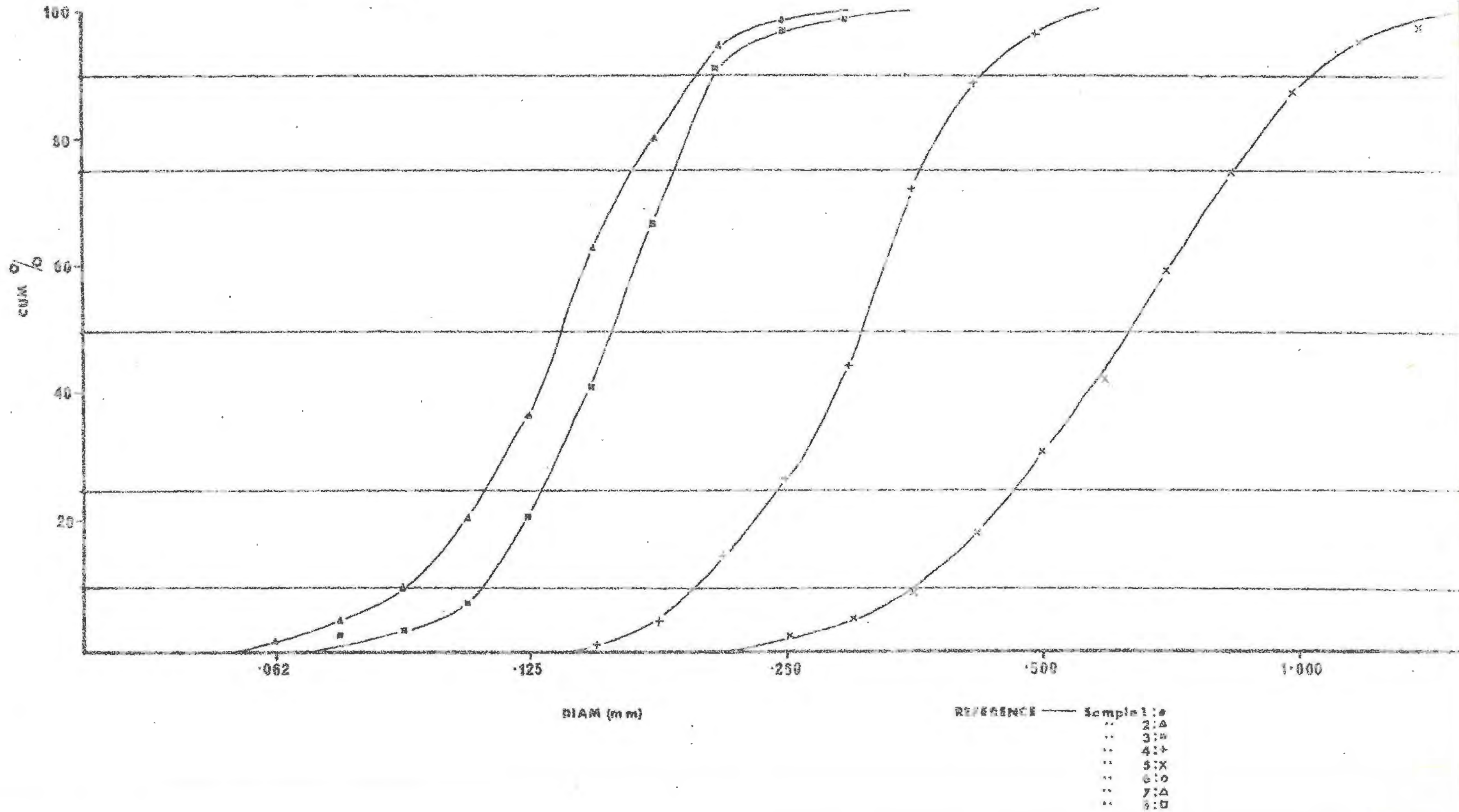
Specimen	Colour	Hue	Value	Chrome
W Q 1	Medium dark gray	Neutral	4	0
W Q 2	Yellowish gray	5 yellow	8	2
W Q 3	Pinkish gray	5 yellow red	8	1
W Q 4	Light gray	Neutral	7.5	0
	Medium gray	Neutral	5	0
W .Q. 5	Light gray	Neutral	7	0
	Pinkish gray	5 yellow red	8	1

The two colour evaluations given to samples W Q 4 and W Q 5 indicate that they vary in colour in the field. Samples were collected to represent the opposite extremes of their colour variations.

Grain-size distributions:

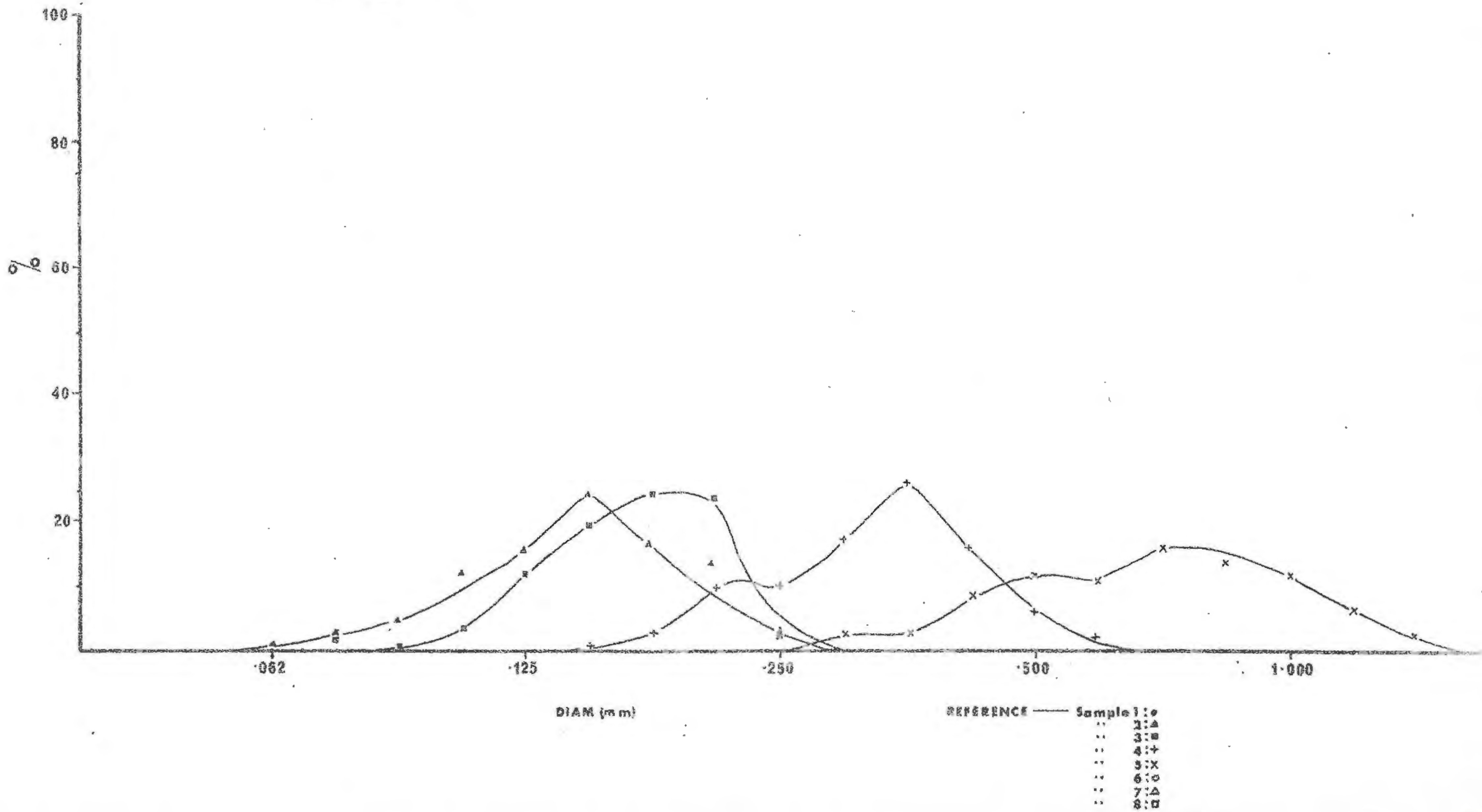
The measured distribution of maximum diameters of the quartz grains in these samples is illustrated graphically by the cumulative frequency curves in Diag. 9 and the percentage frequency curves in Diag. 10. The Md, M, Mo, So, $Log_{10}Sk$ and the K of these distributions computed from data obtained from the respective graphs are tabulated in Table 10.

Diag 9



100
80
60
40
20
CUM %
·062
·125
·250
·500
1·000
DIAM (mm)
REFERENCE —— Sample 1 : ●
" 2 : △
" 3 : ■
" 4 : +
" 5 : X
" 6 : o
" 7 : △
" 8 : ◻

Diag 10



100
80
% 60
40
20
·062
·125
·250
·500
1·000
DIAM (mm)
REFERENCE —— Sample 1 : o
" 2 : ▲
" 3 : ■
" 4 : +
" 5 : X
" 6 : o
" 7 : △
" 8 : □

TABLE 10

Grain-size distribution data

Sample	Md(mm)	M(mm)	Mo(mm)	So	$Log_{10}Sk$	K
W Q 1	-	-	-	-	-	-
W Q 2	0.140	0.135	0.143	1.237	$\bar{1}.999$	0.273
W Q 3	0.155	0.158	0.205	1.179	$\bar{1}.997$	0.236
W Q 4	0.310	0.455	0.370	1.135	0.021	0.174
			0.225			
W Q 5	0.640	0.540	0.530	1.353	$\bar{1}.994$	0.279
			0.500			

Note: The grain-size distributions of samples W Q 4 and W Q 5 are bimodal. Both modes are given in the above table for each distribution. The lower figure is the secondary maximum.

Apart from the differences in grain-size and a lesser slope in the coarser grain-sizes, the cumulative frequency curves in Diag. 9 appear to be approximately similar. The percentage frequency curves in Diag. 10, however, illustrate an increasing complexity in the distributions with increase in grain-size. The samples W Q 4 and W Q 5 have a definite bimodal or even polymodal character.

These sediments are all well sorted as the So values tabulated in Table 10 vary between 1.135 and 1.353 (see p.23). The grain-size distributions of the measured samples may be described as having little or no skewness. Their $Log_{10}Sk$ values vary between $\bar{1}.994$ and 0.021 whereas perfectly symmetrical curves yield a value of zero (Pettijohn 1957, p.37). Kurtosis values are included here for completeness.

In Diag. 11 the first and third quartiles of these quartz grain-size distributions are plotted against each other according to the method given in Pettijohn (1957, p.26). It is seen that they all fall within the sand grade. In fact, very few of the grains measured were less than one-sixteenth of a millimetre in size, and none greater than two millimetres.

Sphericity and Roundness:

The sphericities and roundnesses of median size quartz grains in the respective samples are given in Table 11.

TABLE 11

Sphericity and roundness

Sample	Median grain sphericity	Median grain roundness
W Q 1	-	-
W Q 2	0.56	0.46
W Q 3	0.74	0.46
W Q 4	0.72	0.52
W Q 5	0.69	0.52

Due to the presence of secondary quartz overgrowths and recrystallisation, considerable difficulty was experiencedin obtaining these readings.

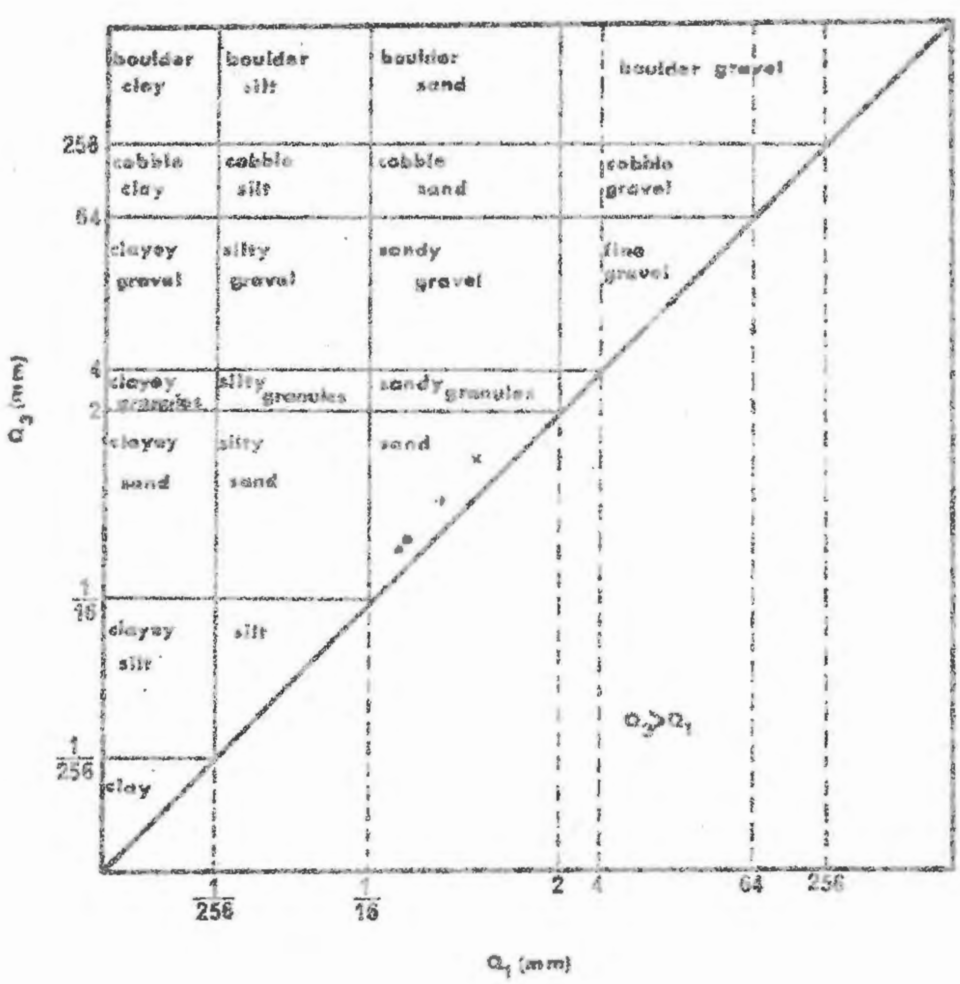
The few heavy minerals encountered are, for the most part, well rounded with a high degree of sphericity.

Mineralogy:

Quantitative mineralogy:

The percentage compositions of the various samples

Diag 11



REFERENCE

Sample 1 : ●
" 2 : ▲
" 3 : ■
" 4 : +
" 5 : ×
" 6 : ○
" 7 : △
" 8 : □

studied are tabulated in Table 12.

TABLE 12

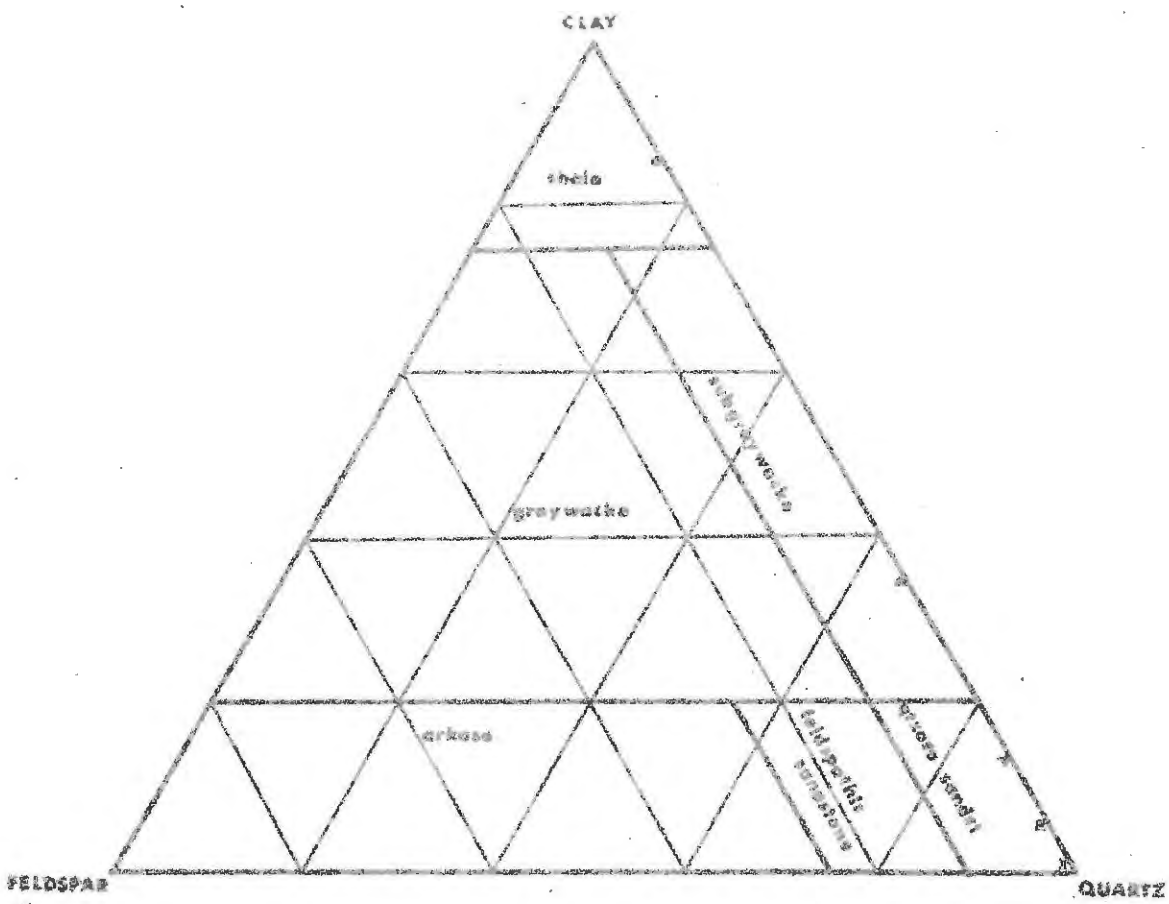
Percentage mineral composition

Sample	Qtz	Mat	Musc	Rut	FeOx	Tour	Felsp	Zir	Ind
W Q 1	7.0	93.0	t	t	t	-	-	-	-
W Q 2	63.5	28.0	3.5	t	5.0	-	-	t	-
W Q 3	88.0	4.5	0.5	t	3.5	t	-	1.5	t
W Q 4	85.0	7.5	5.5	t	t	t	t	t	t
W Q 5	98.0	1.0	1.0	t	t	t	t	t	-

t refers to trace: Qtz to quartz; Mat to the fine grained matrix which consists predominantly of sericite and clay minerals, plus carbon in the dark coloured rocks: Musc to muscovite; Rut to rutile; FeOx to iron oxides; Tour to tourmaline; Felsp to felspar; Zir to zircon; and Ind to an indeterminate yellowish, amorphous material, possibly silica.

In order to classify these rocks in the triangular diagram given in Krumbein and Sloss (1951, p.130) their percentage mineral contents were recalculated between quartz, matrix and muscovite (grouped together as clay), and felspar. The recalculated percentage compositions are given in Table 13, and the plots on the diagram itself appear in Diag. 12.

Diag 12



REFERENCE

Sample 1 : ⊕
" 2 : △
" 3 : ■
" 4 : +
" 5 : X
" 6 : ○
" 7 : ▲
" 8 : □

TABLE 13

Recalculated percentage compositions for use in Diag. 12

Sample	Quartz	Clay	Felspar
W Q 1	7.0	93.0	-
W Q 2	66.8	33.2	-
W Q 3	94.1	5.9	-
W Q 4	86.7	13.3	t
W Q 5	98.0	2.0	t

Descriptive Mineralogy:

As in the Bokkeveld, the mineralogy of the Witteberg Quartzite suite of rocks is largely similar throughout, apart from variations in size and abundance. Once again, the textures are typically fragmental apart from recrystallisation, secondary enlargement, replacement and introduction of authigenic material. Qualitatively the samples W Q 2 to W Q 5 may be described as similar to Carrozzi's "quartzitic pure quartz sandstones", which have mosaic textures (1960, p.13). Under the microscope the samples show many of the characteristics described by Carozzi. The sample W Q 1 is a carbonaceous shale which contains a scattering of small angular quartz fragments. Plates 3G and 3H are photomicrographs of the samples W Q 5 and W Q 2 respectively.

Quartz grains show a fairly high degree of recrystallisation. Boundaries between grains are both regular and irregular (Plate 3G). The regular boundaries are probably the result of crystal face formation. It is therefore obvious that the sedimentological use of the measured distributions is not great, although it should be noted that the size of the quartz has not appreciably altered with recrystallisation. Pressure phenomena such as pitting and an orientated columnar habit among finer grains are common. Whether or not these finer grains are secondary is problematical. It is observed, however, that Carozzi (1960, p.24) states that dissolution of the finer detrital grains in a sediment is often the origin of secondary silica cement. This may well be the case in the Witteberg Quartzite since there is frequently a marked absence of finer grains. It must be noted, however, that in this suite of rocks the finer grained sediments appear to be recrystallised to a lesser extent.

Rutile, zircon and tourmaline comprise the other detrital constituents and occur as generally well rounded fragments frequently arranged parallel to the bedding. Plate 4B is a photomicrograph taken by oblique illumination of a natural concentration of a few of these minerals. Felspar is a rare constituent and occurs in much the same manner as quartz.

Muscovite, although never present in great quantity, occurs in most of the samples examined, generally as flakes between and parallel to the bedding.

Sericite is far less abundant in the Witteberg Quartzite than it is in the Bokkeveld rocks. It is, in fact, noticeable by its rarity in the samples W Q 3 to W Q 5 which, under the microscope, differ from each other only in grain size. Sericite does, however, form a large proportion of the sample W Q 2 and it is the dominant constituent of the carbonaceous shale sample W Q 1. Where it does occur, its characteristics are much the same as described previously.

Authigenic rutile and iron oxides occur throughout, but predominantly in the finer grained rocks. They are particularly abundant in rocks which have been weathered. Rutile needles frequently occur in quartz grains (Plate 4A).

CLASSIFICATION OF THE ROCKS:

Taking into account the information recorded above, the author suggests the classification of these rocks to be that given in Table 14.

TABLE 14

Classification of the Witteberg Quartzite suite of rocks

Sample	Classification
W Q 1	Black carbonaceous shale
W Q 2	Thin bedded micaceous sand subgraywacke
W Q 3	Quartzose sandstone
W Q 4	Quartzose sandstone
W Q 5	Quartzose sandstone

STRATIGRAPHICAL FEATURES:

The structural complexity of the Witteberg Quartzite made accurate computation of its thickness extremely difficult. In one instance where a determination was possible on the farm Stoneham, a thickness of approximately 2,900 feet was obtained over a distance of 21,000 feet along the strike of the axis of an anticline with an approximate plunge of 10 degrees. The drop in land elevation between the lower and upper contacts is approximately 800 feet. This agrees closely with the figure of 2,800 feet derived by Meyer immediately to the southwest of the area mapped (1965,p.10).

Taking into account the work done by other authors, the Witteberg Quartzite may be described as an essentially arenaceous series of rocks consisting predominantly of thickly to very thickly bedded grey to white quartzose sandstones. These are parted at irregular intervals by variable thicknesses, seldom greater than 40 feet, of thin bedded white micaceous sand subgraywackes and laminated black carbonaceous shales. The boundaries between the carbonaceous shales and the quartzose sandstones are both sharp and transitional through sand subgraywackes. The presence of the sand subgraywackes and carbonaceous shales is easily recognised on aerial photographs where they form elongated elements of negative topography between the strong outcroppings of quartzose sandstones.

The base of the Witteberg in the Grahamstown area is characterised by two fairly thick bands of quartzose sandstone parted by a thickness of sand subgraywacke. The roof of the Witteberg Quartzite immediately underlying the Lake Mentz Shale is formed by the "white streak" (Johnson 1966, p.26) which is a rather coarse grained white quartzose sandstone. W Q 5 is a sample from this band.

THE LAKE MENTZ SHALE FORMATION

THE WITTEBERG QUARTZITE/LAKE MENTZ SHALE BOUNDARY

The boundary between the Witteberg Quartzite and the Lake Mentz Shale is an abrupt and easily definable one. It is taken to be at the top of the uppermost massive quartzose sandstone band (in this case the white streak) where it is in contact with the base of a fairly large thickness of thinly laminated carbonaceous shales.

This boundary is fairly easy to map - both in the field and in aerial photographs - more by the cessation of quartzose sandstone outcroppings than by the presence of the carbonaceous shales which are generally well covered by soils and vegetation. It is merely necessary to establish the presence of these shales at isolated points in order to determine which boundary of the Witteberg Quartzite is being dealt with. Needless to say, there is a great topographical change between the country underlain by the lower portions of the Lake Mentz Shale and that underlain by the Witteberg Quartzite.

The carbonaceous shales themselves are easily distinguished from both the Bokkeveld shales and the carbonaceous shales occurring in the Witteberg Quartzite. Those of the Lake Mentz Shale are very much thicker. They are finer in bedding and texture than the micaceous Bokkeveld shales.

Problematical ridges of Witteberg quartzose sandstone, occurring as inliers in the Lake Mentz Shales and penetrating them from larger quartzose sandstone exposures (p.108), at first suggested that this boundary was a gradational one, with bands of quartzose sandstone of the Witteberg Quartzite fingering out into the adjacent and overlying Lake Mentz Shale.

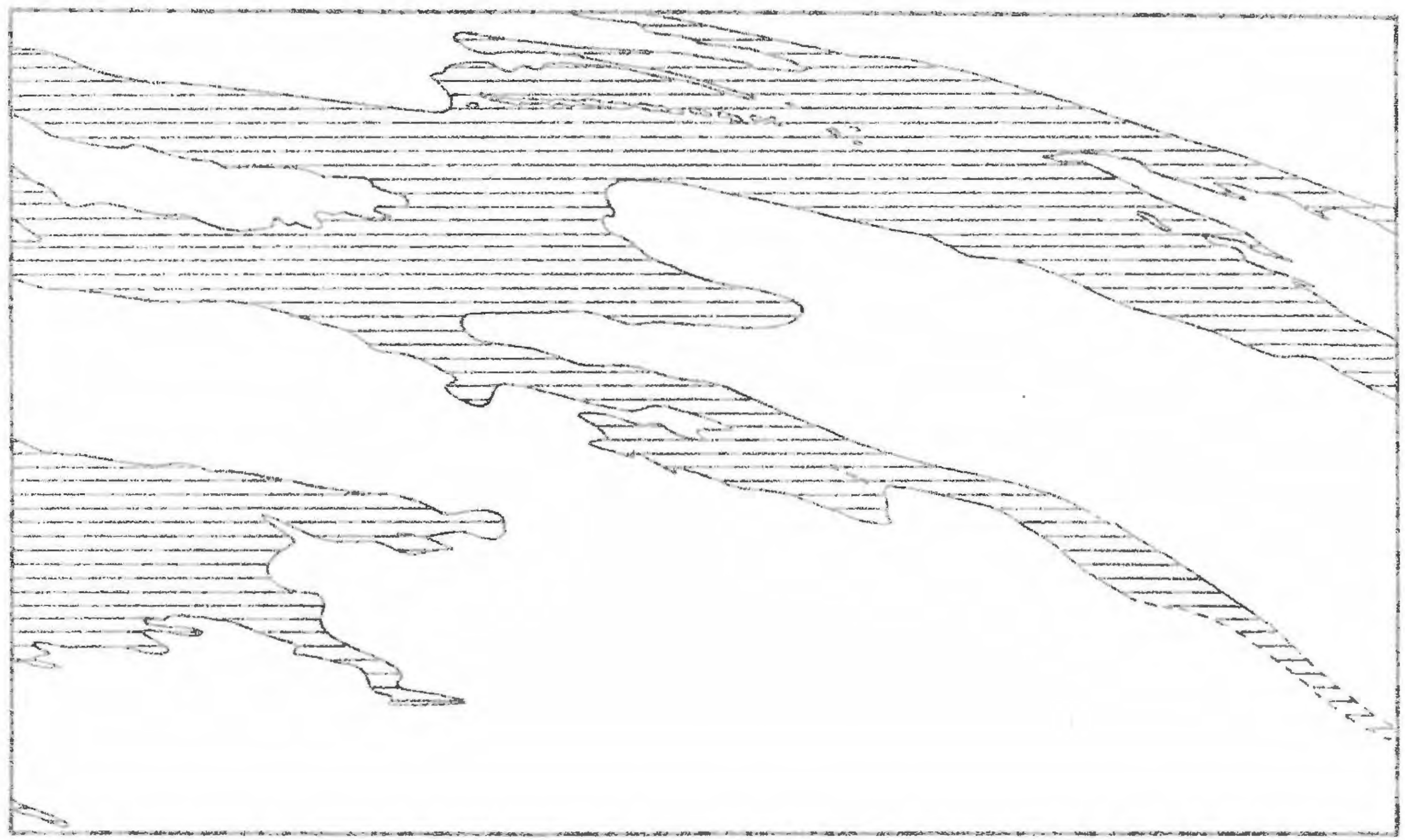
DISTRIBUTION AND MODE OF OCCURRENCE:

The Lake Mentz Shale occupies a large proportion of the tract of land mapped. Its exposure is largely controlled by the structural arrangements of the underlying competent Witteberg Quartzite and, like the latter, its outcrop patterns take the form of elongate and en echelon strips parallel to the regional strike (Diag. 13).

The Lake Mentz Shale underlies flat-floored lowlands bounded on either side by rugged Witteberg Quartzite ridges or more gentle Dwyka Tillite hills. They therefore resemble the Bokkeveld in that, by virtue of their erodibility, they provide drainage ways for streams and rivers rising in the adjacent highlands. When examined in greater detail it may be seen that the Lake Mentz Shale valleys are themselves divided by moderately high ground between rivers that tend to flow immediately adjacent to the Witteberg Quartzite and Dwyka Tillite highlands. The reason for this is the presence of more arenaceous strata approximately in the middle of the Lake Mentz Shale succession. These features will be commented on in greater detail under the headings"Field observations and nomenclature", and "Stratigraphical features".

The soils deriving from the Lake Mentz Shale, like the strata themselves, are somewhat variable. Broadly, those deriving from the more arenaceous strata tend to be coarse and sandy not unlike those derived from the Witteberg Quartzite, while those derived from the argillaceous strata tend to be loamy and are frequently

DIAG 13



red in colour. The vegetation on them is also largely controlled by the variability in rock and soil type. Rows of trees, bushes and shrubs, arranged parallel to strike, are common and characteristic features easily discernible on aerial photographs. Fairly high up in the stratigraphic sequence strips of olive green shales and mudstones are frequently exposed, even in flat country, without any soil or vegetation cover whatever.

On the whole good exposures of the Lake Mentz Shale are limited to river courses and road cuttings.

The northern half of the region mapped is largely underlain by these rocks. The southern boundary of this sub-region is the Riebeek East/Grahamstown boundary already described under the heading "The Witteberg Quartzite" (p.32). This boundary is a fairly complex one, corresponding to overfolds over part of its length and in places being extremely irregular due to ridges of Witteberg quartzose sandstone penetrating the Lake Mentz Shale land surface. These features will be commented on in greater detail under the heading "Structural Geology". The northern boundary of the sub-region, at the contact with Dwyka Tillite, is a regular one and easy to follow from the farm Rietfontain in the east to the farm Bergplaats in the north. The Lake Mentz Shale occupies a broad valley in which are highlands formed by Witteberg Quartzite inliers and an elongate two by ten mile Dwyka Tillite outlier which enters the region immediately to the north of Grahamstown. The entire sequence of the Lake Mentz Shale is exposed here, but subject to a limited amount of repetition due to folding. This sub-region is drained by the Brak, Bothas, Gxetu and New Years rivers - flowing either northward toward the Fish River valley or toward the west and southwest.

Three exposures of the Lake Mentz Shale occur in the southern half of the region as outliers in the Witteberg Quartzite.

The largest of these is the Rockdale/Meyers Kraal outlier already referred to under the heading "The Witteberg Quartzite". It takes the form of a fairly complex westward plunging synclinorium which attains a maximum width of about three miles. It penetrates the area from the west for a distance of approximately six miles and then bifurcates into separate synclinoria which nose out within a short distance. This exposure forms a deep valley surrounded by impressive dip slopes of Witteberg quartzose sandstone. It provides the drainage way for the New Years River which flows westward towards Alicedale. Although well exposed along the river, only the lower half of the Lake Mentz Shale sequence occurs in this valley.

An additional small outlier occurs in the extreme southwest (Diag. 13) of the region.

In the region mapped no fossils were observed in the Lake Mentz Shale.

FIELD OBSERVATIONS AND NOMENCLATURE:

Petrologically the Lake Mentz Shale is the most diverse sequence of rocks encountered in the area, varying from exceedingly fine-grained carbonaceous shales to coarse-grained sandstones, like those in the Witteberg Quartzite. They may be subdivided into three main members as suggested by Marais (1963), and comprising a Lower Carbonaceous, a Middle Arenaceous, and an Upper Shale member.

The Carbonaceous Member is a fairly uniform one consisting almost exclusively of thinly laminated to laminated black carbonaceous shales which are easily erodible, seldom crop out, and characteristically weather to buff or sometimes purple and red colours. These carbonaceous shales are easily distinguished from those occurring in the Witteberg Quartzite by virtue of their fineness of grain, which is very apparent when samples are handled, and by the regularity and closeness of their bedding planes. Locally on the farm Roodekrantz, on the Rockdale/ Meyers Kraal Lake Mentz Shale outlier, a band of the slightly coarser, micaceous and more heterogeneous carbonaceous shale, like those in the Witteberg Quartzite, was observed. Thin bands of flaggy, micaceous and buff-coloured siltstones sometimes occur near the top of this member. These rocks originated in a fairly deep-water environment which, by virtue of its depth and anaerobic nature, represents a fairly drastic change of environment from that in which the Witteberg Quartzite rocks originated. As a whole this member is an extremely incompetent one, with the result that its dominant manner of secondary deformation is by plastic flow whereby it fits itself into the structures determined by adjacent competent rocks. Slaty cleavage is generally well developed and, where the primary bedding is not entirely obliterated by metamorphic processes, the rocks tend to break up into long pencil-like fragments formed by the intersection of bedding and slaty cleavage planes. Slickensiding rarely occurs in it. Quartz veins up to an inch in width trending perpendicular to strike, were observed near Hell's Poort on the Grahamstown/Carlisle Bridge road. Plate 4C is a photograph of these carbonaceous shales.

The Arenaceous Member is characteristically coarse-grained and micaceous and, in fact, mica may almost be regarded as a diagnostic mineral of this subdivision of the Lake Mentz Shale. Petrologically the rocks consist predominantly of bands of grey to greenish and khaki siltstones, flaggy siltstones, micaceous siltstones, sandstones and quartzitic sandstones parted by narrow bands of sandy micaceous shales (Plates 4D and 4F). The shales are not unlike those encountered in the upper part of the Bokkeveld where, in the transition from an adjacent sandstone, or siltstone, to shale, an increase in fissility and mica content is more conspicuous than the decrease in grain size. This member is subject to facies-change along strike. This conclusion was drawn from the fact that, although good sections of these rocks were exposed at a number of localities throughout the area, Witteberg Quartzite-like quartzose sandstones were only encountered in three instances and in stratigraphic positions elsewhere occupied by dark sandstones or siltstones. The greatest development of grey to white quartzitic sandstone was observed on the farm Meyers Kraal in the Meyers Kraal/Rockdale outlier where a/massive to medium bedded band of quartzitic sandstone, approximately 30 feet thick, occupies two limbs of an anticline (Plate 4E). This band could only be traced with certainty for a few miles. The other two occurrences of this type of rock are on the farm Van der Merwes Kraal approximately 15 miles from the Rockdale/Meyers Kraal outlier in the northeast of the mapped region. One of these is a narrow and apparently local band of pastel-pink quartzitic sandstone, while the other, a few miles to the east, is represented by a number of large angular boulders of purple and white banded and highly silicified quartzite. The latter contain an abundance of white quartz veins (Plate 5B).

Primary current structures are not uncommon in this member. Numerous cross-beds and, in one or two instances, ripplemarks, were observed. The cross-beds tend to occur in specific bands.

In the Rockdale/Meyers Kraal valley these strong rocks form high cliffs along the New Years River but this is the result of undercutting by the river rather than the resistance to erosion offered by these rocks (Plates 4E, 4F). They are also fairly competent and generally deform into gentle flexures which vary in size (Plate 4D). They are, for the most part, well jointed, but only rarely exhibit cleavage. As a whole this member was probably laid down in a shallower and more oxygenated aqueous environment than the underlying carbonaceous member.

The Shale Member is a somewhat mixed one, consisting predominantly of fine-grained olive green shales (Plate 5A) with numerous intercalated layers of siltstone, flaggy and shaley siltstones and mudstones. These rocks are sometimes micaceous. They occur in continuous bands subject to little or no facies-change. The more arenaceous bands within this member resemble those present in the Arenaceous Member, and probably represents relatively short reversions to the environmental conditions which existed during the deposition of that member. At most places at the contact with the Dwyka Tillite there is a buff-coloured, fine-grained, massive mudstone which in places is finely cross-bedded. However, olive green shales occasionally occur at the contact and in one instance, a coarse friable khaki sandstone occurs in this position. This sandstone may, however, be faulted against the tillite (Plate 4G). Many ferruginous concretions occur in the lower parts of the mudstone band. The smaller concretions are apparently richer in iron oxides for they tend to be redder than the larger varieties. Plate 4H is a photograph of one of the larger concretions. In the field it was frequently possible to predict the close proximity of the Dwyka Tillite contact in areas of poor exposure, from the presence of large numbers of these ferruginous concretions in the soil. The Shale Member behaves in much the same way as the Carbonaceous Member when structurally deformed.

In areas which are, or have recently been capped by silcrete, or for some other reason underlie a fairly static land surface and have therefore been subjected to prolonged weathering, the~~y~~ argillaceous strata tend to become converted to generally white clays which are often stained red by iron oxides. In these, original primary and secondary structures are easily recognisable. The arenaceous rocks offer a greater resistance to these processes than do the argillaceous rocks and they are usually converted to white friable sandstones while the argillaceous rocks form true clays. These clays were not studied in any detail because they have already been fairly fully dealt with by previous authors and by the firms exploiting them. The most promising prospecting areas for these clays would be those embracing the Carbonaceous Member.

Eight samples representative of the various rocks occurring in the Lake Mentz Shale were selected for closer study in the laboratory. Table 15 indicates the serial numbers given these samples, the nomenclature adopted in the field, and the locality from which each sample was obtained.

TABLE 15

Sample serial numbers

Serial No.	Field description	Sample Locality
L M S 1	Carbonaceous shale	Hells Poort
L M S 2	Olive green shale	Meyers Kraal
L M S 3	Siltstone	Meyers Kraal
L M S 4	Siltstone	Hilton
L M S 5	Flaggy Siltstone	Meyers Kraal
L M S 6	Flaggy Micaceous Sandstone	Vaale Krans
L M S 7	Quartzitic Sandstone	Van der Merwes Kraal
L M S 8	Quartzite	Van der Merwes Kraal

Plate 5B is a photograph of the sample L M S 8.

PHYSICAL PROPERTIES:

The following is an account of the physical properties of the Lake Mentz Shale suite of rocks as represented by the samples L M S 1 to L M S 8.

Colour:

Colour data, obtained by comparing the hand specimens with a colour chart (Rock Colour Committee, 1963) are given in Table 16.

TABLE 16

Hand specimen colours

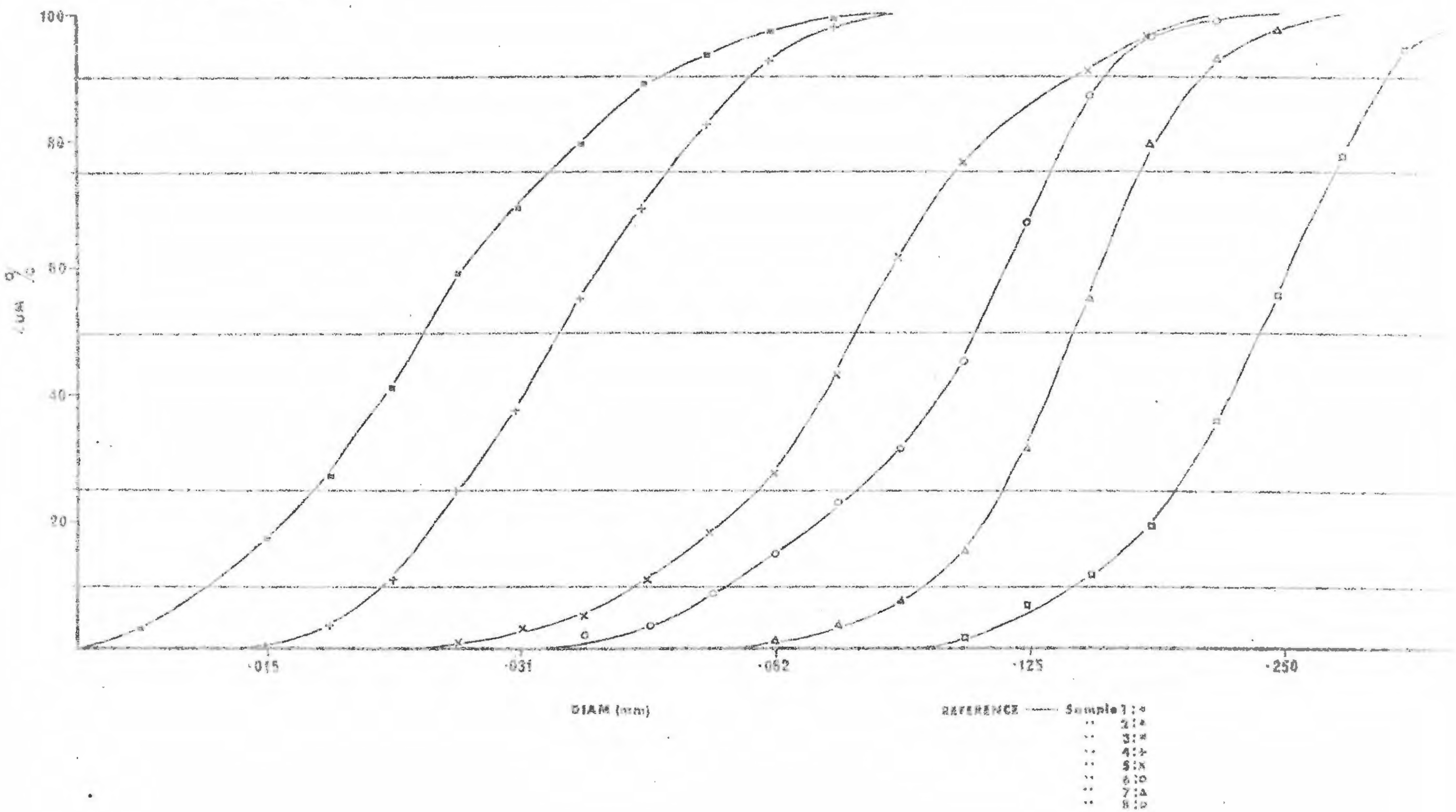
Specimen	Colour	Hue	Value	Chroma
L M S 1	Black	Neutral	1	0
L M S 2	Dark greenish gray	5 Yellow gray	4	1
L M S 3	Olive gray	5 Yellow	4	1
L M S 4	Light olive gray	5 Yellow	5	2
L M S 5	Light olive brown	5 Yellow	5	6
L M S 6	Olive gray	5 Yellow	4	1
L M S 7	Grayish orange pink	5 Yellow red	7	2
L M S 8	Grayish red	5 Red	4	2
	Light gray	Neutral	7	0

Sample L M S 8 is a banded rock containing definite bands of the two colours given in Table 15 (Plate 5B).

Grain-size distributions:

The measured distributions of maximum diameters of the more rounded quartz grains in these samples are illustrated graphically by the cumulative frequency curves in Diag. 14 and the percentage frequency curves in Diag. 15. The Md, M, Mo, So, $Log_{10}Sk$, and the K of these distributions computed from data obtained from the respective graphs are tabulated in Table 17.

Diag14



100
80
60
40
20
% CUM
·015
·031
·062
·125
·250
DIAM (mm)
REFERENCE —— Sample 1 :
" 2 :
" 3 :
" 4 :
" 5 : x
" 6 : o
" 7 : Δ
" 8 : □

Diag15

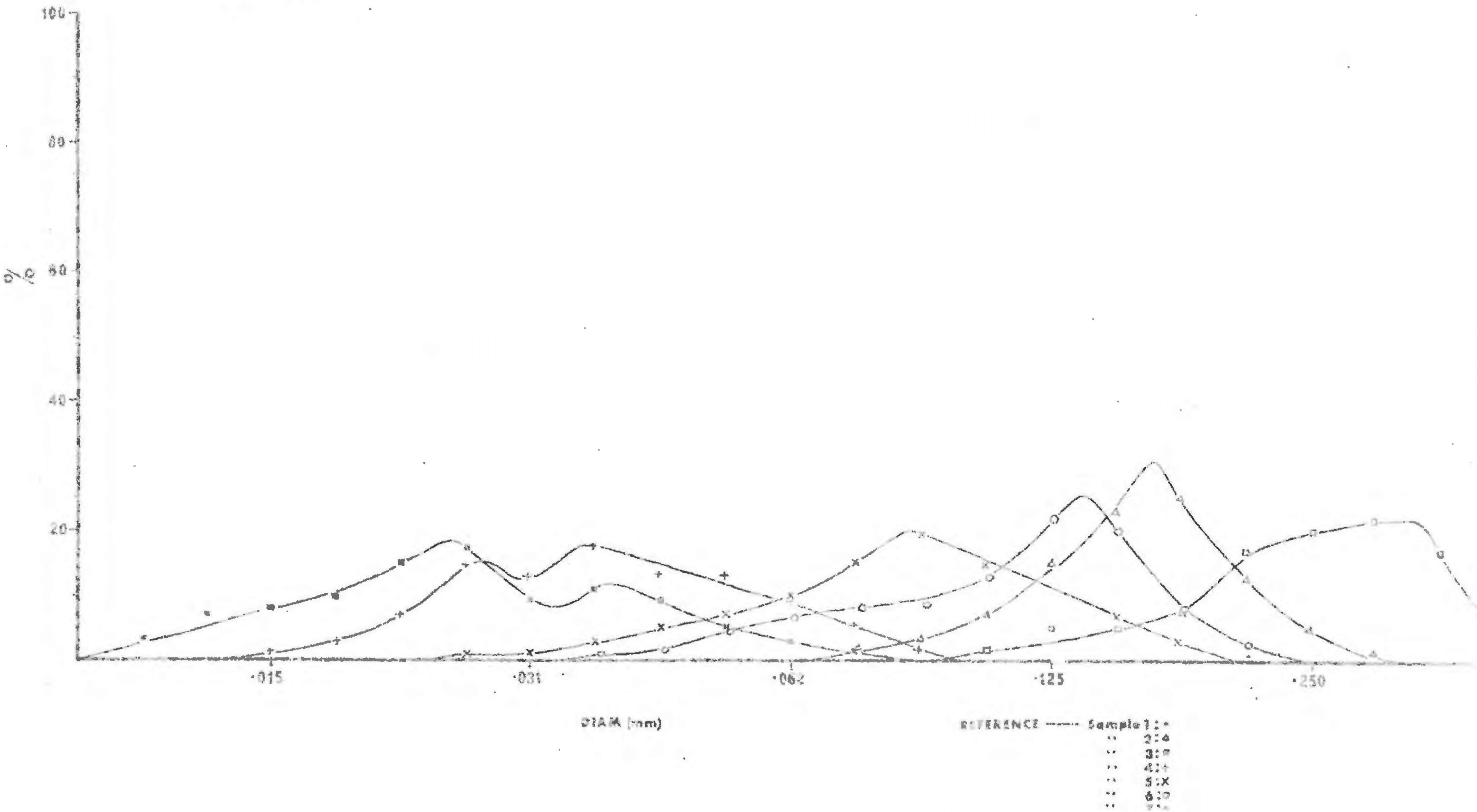


TABLE 17

Grain-size distribution data

Sample	Md(mm)	M(mm)	Mo(mm)	So	$Log_{10}Sk$	K
L M S 1	-	-	-	-	-	-
L M S 2	-	-	-	-	-	-
L M S 3	0.024	0.027	0.026 0.038	1.363	0.027	0.242
L M S 4	0.035	0.036	0.037 0.027	1.352	0.030	0.285
L M S 5	0.080	0.081	0.090	1.307	0.004	0.204
L M S 6	0.110	0.102	0.136	1.306	$\bar{1}.933$	0.264
L M S 7	0.148	0.142	0.170	1.218	$\bar{1}.989$	0.259
L M S 8	0.245	0.233	0.320	1.237	$\bar{1}.991$	0.272

The grain-size distributions of samples L M S 3 and L M S 4 are bimodal. Both modes are given in the above table for each distribution, the lower figure being the secondary maxim~~a~~um.

The quartz grain-size distributions of the Lake Mentz Shale samples, as illustrated by the cumulative frequency curves in Diag. 14, are, apart from differing in average grain-size, broadly similar. When the data are plotted in the form of the percentage frequency curves (Diag. 15) however, a number of differences are brought to light. The finer grained samples L M S 3 and L M S 4 are distinctly bimodal and the coarsest sample, L M S 8, is markedly asymetrical in contrast to the curves of the intermediate grained samples L M S 5, L M S 6 and L M S 7. In the case of the sample L M S 8, it was noted in the hand specimen (Plate 5B) and in thin section (Plate 5C) that the rock is both highly recrystallised and silicified. This was often the case in the Witteberg Quartzite and peculiarities in the grain-size distributions can be expected. The arithmetic mean grain-sizes of the finer grained samples L M S 3 and L M S 4 (Table 17), are well beneath the upper limit of the clay grade (1/16 mm). Twenhofel and Tyler (1941, p.63) state that little of sedimentary significance is to be gained if analyses are extended below the upper limit of the clay-size particle. Therefore, as in the Witteberg Quartzite, a number of factors decrease the sedimentological value of the measured distributions.

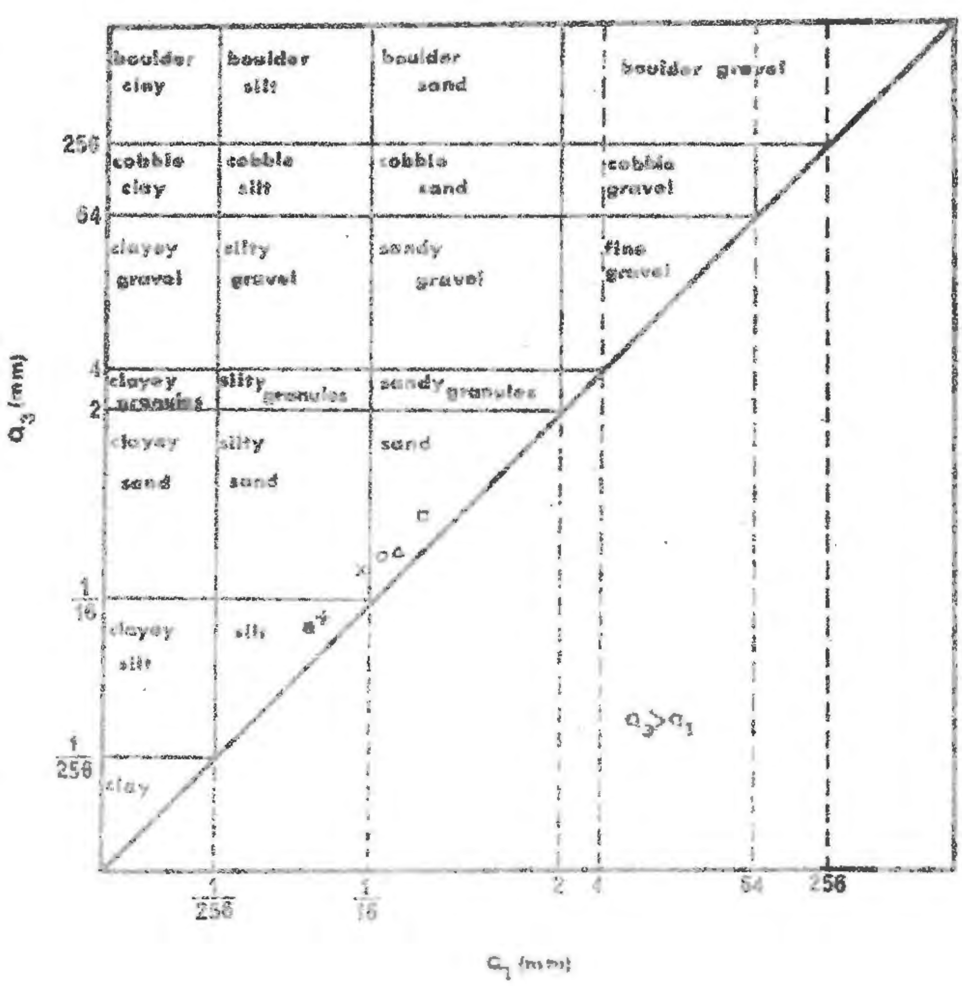
The So values tabulated in Table 16 vary between 1.218 and 1.363 so that the original sediments are well sorted (p.23). The distributions may be described as having little or no skewness. Their $\mathrm{Log}_{10}\mathrm{Sk}$ values vary between $\bar{1}.933$ and 0.030 and therefore closely approximate the zero value appropriate to a perfectly symmetrical curve (Pettijohn 1957, p.37). Kurtosis values are included here for completeness.

In Diag. 16, the first and third quartiles of these distributions are plotted against each other according to the method given in Pettijohn (1957, p.26). It may be seen from this diagram that the rocks L M S 3 and L M S 4 fall within the silt grade, the rock L M S 5 within the silty sand grade, and the rocks L M S 6, L M S 7 and L M S 8 within the sand grade.

Sphericity and roundness:

The sphericities and roundnesses of median-size quartz grains in the respective samples are given in Table 18.

Diag 16



REFERENCE

Sample 1 : ●
" 2 : ▲
" 3 : ✱
" 4 : +
" 5 : ×
" 6 : ○
" 7 : △
" 8 : □

TABLE 18

Sphericity and roundness

Sample	Median grain sphericity	Median grain roundness
L M S 1	-	-
L M S 2	-	-
L M S 3	0.56	0.14
L M S 4	0.62	0.17
L M S 5	0.80	0.48
L M S 6	0.65	0.46
L M S 7	0.78	0.54
L M S 8	0.80	0.70

The variation in sphericity and roundness between the finer and coarser grained rocks of the Lake Mentz Shale is apparent even without measurement. This may be seen by comparing Plate 5E, a photomicrograph of the sample L M S 3, and Plate 5F, a photomicrograph of the sample L M S 7.

The few heavy minerals encountered are, for the most part, well rounded with a high degree of sphericity. Exceptions occur, as in recently shattered grains, or in minerals such as zircon, in which the original crystal shape deviates greatly from the spherical.

Mineralogy:

Quantitative mineralogy:

The percentage compositions of the various samples studied are tabulated in Table 19.

TABLE 19

Percentage mineral composition

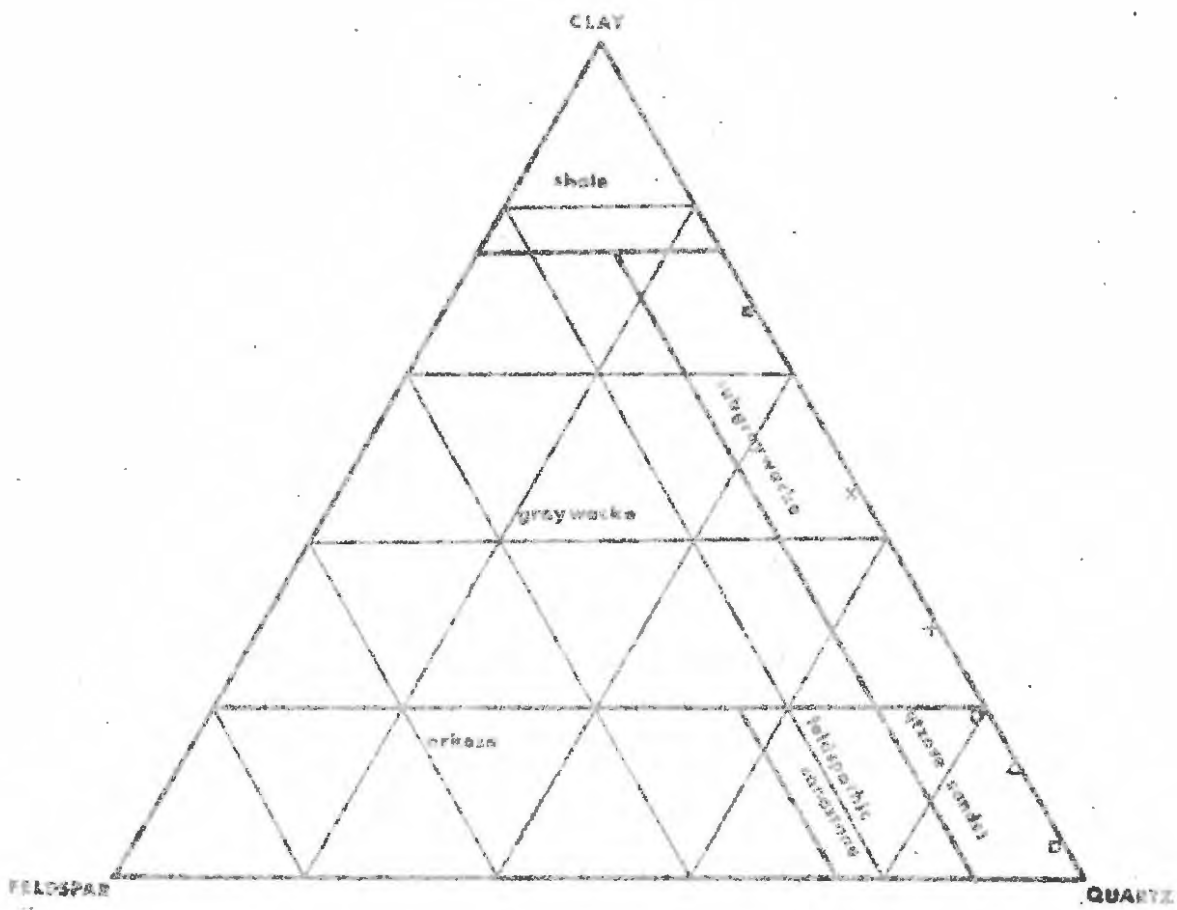
Sample	Qtz	Mat	Musc	Rut	FeOx	Tour	Felsp	Zir	Ind
L M S 1	-	-	-	-	-	-	-	-	-
L M S 2	-	-	-	-	-	-	-	-	-
L M S 3	33.6	-63.2-		-	1.2	-	-	-	3.0
L M S 4	64.0	-29.0-		-	t	-	t	-	7.0
L M S 5	55.2	-44.8-		t	t	-	t	-	t
L M S 6	75.0	13.0	5.0	t	6.0	t	t	1.0	t
L M S 7	86.5	12.5	1.0	t	t	t	t	t	t
L M S 8	96.0	1.0	1.0	t	t	t	2.0	t	t

t refers to trace; Qtz to quartz; Mat to the fine-grained matrix which consists predominantly of sericite and clay minerals, plus carbon in the dark-coloured rocks; Musc to muscovite; Rut to rutile; FeOx to iron oxides; Tour to tourmaline; Felsp to felspar; Zir to zircon and Ind to an indeterminate yellowish, amorphous material, possibly silica.

In the case of samples L M S 3 to L M S 5, the muscovite is very fine-grained and difficult to distinguish in the matrix. In these finer grained samples they were therefore counted together.

In order to classify these rocks according to the scheme in the triangular diagram in Krumbein and Sloss (1951, p.130), their percentage mineral compositions were recalculated between quartz, sericite and muscovite (grouped together as clay), and felspar. The recalculated percentage compositions are given in Table 20, and the plots on the diagram itself appear in Diag. 17.

Diag 17



REFERENCE

Sample 1 : ●
" 2 : ▲
" 3 : ■
" 4 : +
" 5 : X
" 6 : ○
" 7 : △
" 8 : □

TABLE 20

Recalculated percentage compositions for use in Diag. 17

Sample	Quartz	Clay	Felspar
L M S 1	-	-	-
L M S 2	-	-	-
L M S 3	34.6	65.4	-
L M S 4	69.2	30.8	t
L M S 5	55.2	44.8	t
L M S 6	80.7	19.3	t
L M S 7	86.5	13.5	t
L M S 8	96.0	2.0	2.0

Descriptive mineralogy:

The mineralogy of the various rocks in the Lake Mentz Shale is similar to that of other rock suites already described.

The textures are typically fragmental apart from recrystallisation, secondary enlargement, replacement and introduction of authigenic material. However, these latter phenomena occur to a lesser degree than in the Witteberg Quartzite. Petrologically the Lake Mentz Shale suite is not unlike that of the Bokkeveld. The samples L M S 3 to L M S 8 may all be classified under Carozzi's (1960) quartzitic pure quartz sandstones. They vary between the two end members, namely, sandstones in which allogenic quartz grains, displaying secondary overgrowth, do not come in contact with one another and sandstones in which the quartz grains are closely packed and, through their secondary overgrowth, are in contact with one another. Transition from the one end member to the other is accompanied by an increase in quartz content and grain-size. Because of their grain-size, samples L M S 3 to L M S 5 may not be strictly termed sandstones. The variations in the proportions of quartz and matrix material through the series L M S 3 to L M S 8 are given in Table 20. The samples L M S 1 and L M S 2 are both fine-grained shales containing a majority of clay minerals with scatterings of angular quartz fragments and a few heavy minerals. The essential difference between them is the carbon content which renders the sample L M S 1 black in colour.

CLASSIFICATION OF THE ROCKS:

Taking into account the information recorded above, the author suggests the classification tabulated in Table 21/for these rocks.

TABLE 21

Classification of the Lake Mentz Shale Suite of Rocks

Sample	Classification
L M S 1	Carbonaceous shale
L M S 2	Shale
L M S 3	Silt subgraywacke
L M S 4	Silt subgraywacke
L M S 5	Silty sand subgraywacke
L M S 6	Quartzose sandstone
L M S 7	Quartzose sandstone
L M S 8	Quartzose sandstone

STRATIGRAPHICAL FEATURES:

The Lake Mentz Shale sequence is a conformable one and, although no single section exhibits the entire succession, it was possible to piece it together by correllating exposures throughout the area. Accurate determination of thicknesses of these strata is extremely difficult due to the generally poor nature of exposures and the high degree of contortion existing in these incompetent strata. This is borne out by the variation in figures quoted by previous authors in localities not far from Grahamstown. A few of these are as follows: 2,965 feet by Loock (1967) at Bergplaas near Kommadagga; 1,800 feet by Mountain (1946) to the east of Grahamstown; and 1,350 feet by Marais (1963) at Lake Mentz. The thickness attributed to Loock is the sum of the thicknesses of his Kommadagga and Lake Mentz Shale formations. The other quoted authors regarded these together as one formation. On the boundary of the farms Rietfontain and Burnt Kraal, in the northeastern part of the region, the Lake Mentz Shale crops out across an extremely narrow strip of land where the maximum thickness of these strata is approximately 1,500 feet. They dip more or less perpendicular to the land surface. As there is no apparent evidence of faulting in this locality, the figure of 1,500 feet was taken to be the thickness of the formation in the Grahamstown area.

The sequence is subdivided into the Shale Member, the Arenaceous Member and the Carbonaceous Member, following the system used by Marais (1963). Proponents of the modern methods of nomenclature advise against the use of the terms "upper", "middle", and "lower", since a threefold subdivision cannot always be recognised. It is preferable to assign specific names to the various members such as those suggested by Loock (1967). However, Loock (1967) calls the

Upper Shale Member of Marais (1963) the Kommadagga Formation and assigns it to the Dwyka Group. Although the author agrees with the arguments put forward by Loock (1967) for this procedure, especially with regard to the pro-glacial nature of the sediments immediately preceding the Dwyka Tillite, he prefers to assign all the strata occurring between the top of the Witteberg Quartzite and the bottom of the Dwyka Tillite to one formation, falling within the Cape Supergroup. The reason for this preference is that the generally poorly outcropping strata between the Witteberg Quartzite and Dwyka Tillite would render mapping more difficult and inaccurate. Moreover, if there is any facies-change, this may well lead to the same sort of confusion between authors as has arisen over the Witteberg Quartzite/Bokkeveld boundary. The author has therefore chosen to regard all the strata described in this chapter as belonging to the Lake Mentz Shale Formation, and to regard them, as a whole, as having been layed down during a period of transition between the periods in which the Witteberg Quartzite and Dwyka Tillite were deposited. Loock himself (1967) suggests that difficulty may be experienced in regional mapping using his subdivision. It is suggested that Loock's (1967) nomenclature be applied. In this way, the Upper Shale Member of Marais would become the Kommadagga Member; the Middle Arenaceous Member the Swartwaterspoort Member; and the Lower Carbonaceous Member the Bergplaas Shale Member.

(a) The Bergplaas Shale Member: This is approximately 350 feet thick and consists exclusively of thinly laminated to laminated black carbonaceous shales.

(b) The Swartwaterspoort Member: This is approximately 500 feet thick and is characterised by numerous bands of quartzose sandstone, individually up to 30 feet in thickness, together with silty sand subgraywacke, and susceptible to facies-change. Interbedded are bands of finer grained rocks such as black carbonaceous shale (more typical of the lower carbonaceous member); bands of silt subgraywacke, which frequently contain numerous muscovite flakes on their bedding planes toward the middle; and bands of olive green shales (more characteristic of the upper shale member).

(c) The Kommadagga Member: This is approximately 650 feet thick. The lower 400 feet is made up predominantly of olive green shales which tend locally to become flaggy and which are occasionally separated by beds of silty sand subgraywacke and silt subgraywacke. The upper 200 feet, which underlies the Dwyka Tillite consists of alternating finely cross-bedded mudstone, silt subgraywacke and silty sand subgraywacke.

Sometimes olive green shales occur at this level. This may be the result of facies-change, local absence of the mudstones and subgraywackes elsewhere present at this level, or due to faulting.

It will be noted that the relative thicknesses of the various members are different from those cited by Marais (1963). This may be due to facies-change, the upper portions of the Bergplaas Shale Member being perhaps more arenaceous in the Grahamstown area than at Lake Mentz, and grouped therefore with the Swartwaterspoort Member.

THE KARROO SUPERGROUP

THE DWYKA GROUP

THE DWYKA TILLITE FORMATION

THE LAKE MENTZ SHALE/DWYKA TILLITE BOUNDARY

This boundary was taken to be that level at which included fragments started to occur in the rock. Where good exposures of this contact were examined, it appeared to be definite and not gradational. While the character of the tillite remains unchanged along the contact, the upper beds of the Lake Mentz Shale are subject to facies-change (p.63).

On aerial photographs the country underlain by the Dwyka Tillite and the Lake Mentz Shale can usually be distinguished by virtue of a darker photographic grey tone exhibited by that country overlying the Dwyka Tillite, and by the greater lithological control of the vegetation exercised by the Lake Mentz Shale. In addition, the country underlain by the Dwyka Tillite tends to occupy higher ground than that underlain by the Lake Mentz Shale. This change in elevation is, for the most part, a gentle one.

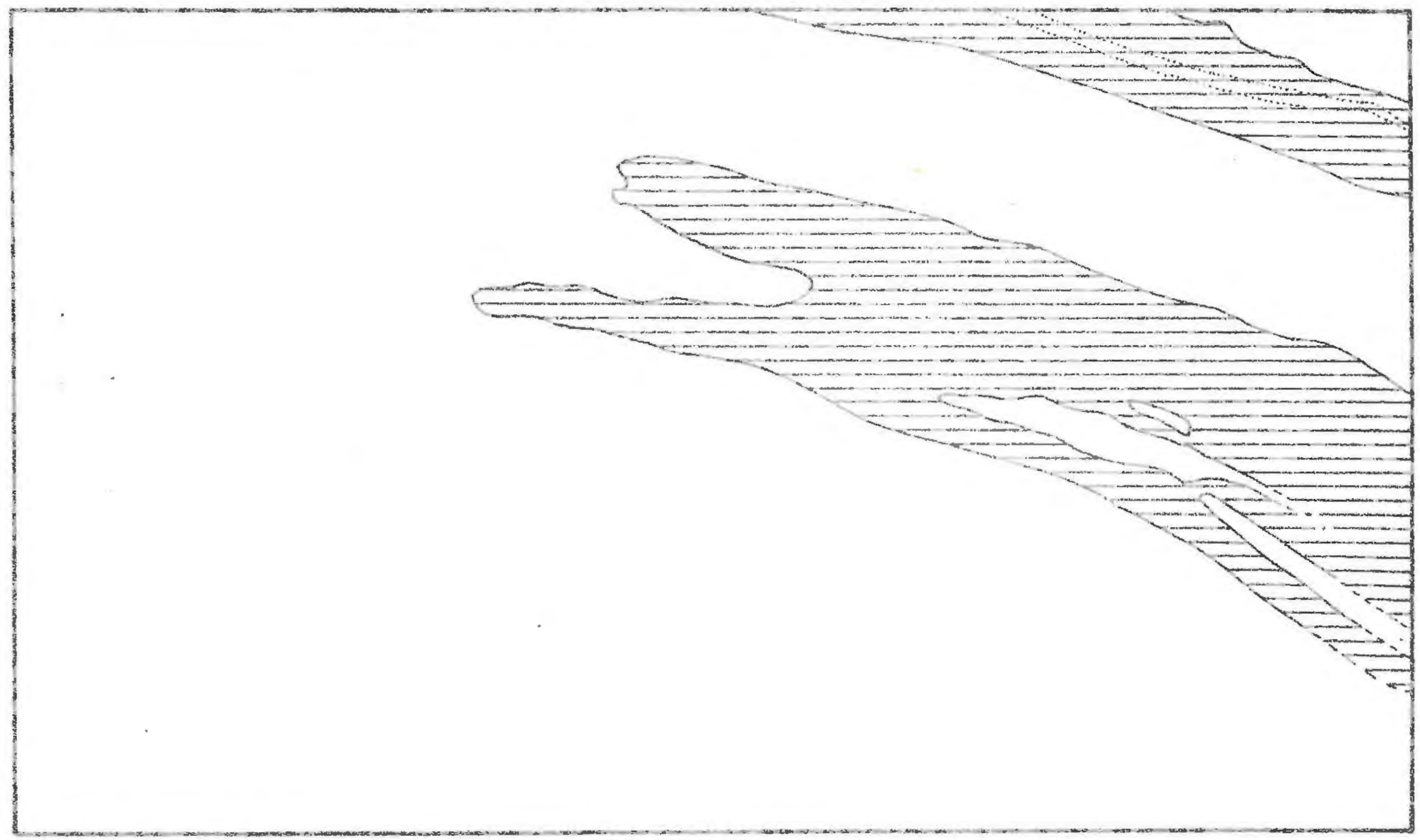
Nevertheless, the exact position of the contact itself can only be located with precision in the field.

DISTRIBUTION AND MODE OF OCCURRENCE:

Rocks belonging to the Dwyka Tillite occur in two localities within the tract of land mapped (Diag. 18).

The larger occurrence is a synclinorium occupying the east and central portion of the region and is surrounded by the underlying Lake Mentz Shale. The

DIAG18



southern contact of this outlier enters the region at Grahamstown in the east and runs parallel to the regional strike in a west-northwesterly direction. The formation maintains a fairly constant width of outcrop of approximately three and a half miles and penetrates the area for a distance of about nine miles to near the Vaale Krans homestead where, on the farm Vaale Krans, it divides into two parallel-trending synclines which nose out after a few miles on the same farm.

The smaller occurrence, in the northeastern corner of the map, is a strip dipping in a northerly direction and trending parallel to the regional strike between the Lake Mentz Shale and the Upper Dwyka Shale. It enters the eastern boundary of the region on the farm Burnt Kraal and maintains a fairly constant width of outcrop of approximately one and a half miles before leaving the northern boundary of the region on the farm Bergplaats.

The soils deriving from the tillite are generally buff to red in colour, usually loamy, but on occasion sandy or gritty. The ground is generally well covered by grasses and pasture land with numerous thorn trees which tend to abound along stream courses.

The Dwyka tillite generally crops out well, especially along river courses. Fairly thick bands of apparently massive tillite, trending parallel to strike, and separated by strips of outcrop-free veld, tend to occur frequently (Plate 5G). These outcrops often take the form of the so-called Bushman tombstones (Plate 5H) which are the result of differential weathering along intersecting joints and cleavage planes. This phenomenon has been commented on by a number of authors.

FIELD OBSERVATIONS:

The petrology of the Dwyka Tillite has not been tackled in any detail in the course of this investigation. The formation has been examined in the field, as well as a few hand specimens and thin sections in the laboratory.

The author cannot therefore enlarge much on the descriptions of the rock types occurring in the Dwyka Tillite given by earlier workers. Mountain (1946) has described the tillite, when fresh, to consist of "a massive bluish-grey siltstone" carrying "unsorted angular fragments, and rounded boulders sometimes over a foot across". du Toit (1954) described the matrix as "argillaceous". When examined beneath the microscope (Plate 6C) and compared qualitatively with thin sections of other rock types which were examined in greater detail, it was observed that the matrix tends to resemble that of the shales and mudstones rather than that of the siltstones.

It may perhaps be described best as a clayey silt matrix using the textural classification of sediments modified from Niggli in Pettijohn (1957, p.26). The included fragments vary in size from approximately the silt grade up to the figure of 10 feet across quoted by du Toit (1954) but the largest encountered in this region by the author was approximately 3 feet long. The smaller fragments are angular and the larger show a certain amount of rounding at the edges (du Toit 1954). The converse does, however, occur and length of transport, fluvioglacial action and the resistance to fracturing of the particular fragment must play a part (Plate 6A). The assemblage of rock types observed among the fragments deviated in no way from that described by other authors, and includes quartzite, gneiss, grit, sandstone, argillaceous rock, lydianite, micaceous and basic schist, granitic rocks, porphyry, felsite and various types of diabase (Mountain 1946). On Table Farm a few large fragments of yellowish white quartzose sandstones with current structures in them,/like the sandstones in the Lake Mentz Shale, were encountered, the largest of which measured approximately eight feet across. It may well be that these are either contemporaneous lenses of quartzitic sandstone or inclusions of quartzitic sandstone derived from the Lake Mentz Shales such as those described by Haughton and others (1953, p.20) which occur near the Kareiga River and southwest of Heuningskop not far from Willowmore. The author observed, as did Mountain (1946), that the larger inclusions tend to be more abundant high up in the succession.

On the whole, the tillite is well-jointed and cleaved in fairly definite planes - the majority of which appear to strike parallel to the regional strike of the area. The included fragments are also well cleaved. This feature is commented on by Haughton (1935).

As has already been stated, the colour of fresh Dwyka tillite is bluish-grey. Well-weathered tillite is buff brown in colour (a feature often noticed along joint planes in the fresh tillite), and it may even weather to a pure white clay in which the inclusions can still be recognised. This clay is frequently stained by iron oxides and owes its origin to the same environmental conditions which existed during the formation of similar clay from the Lake Mentz Shales (p.52). These clays, however, are sandy and therefore not as useful as those formed from the Bergplaas Shale Member of the Lake Mentz Shale. The fresh tillite has also been referred to as greenish in colour by other authors, and it was with interest that the author noted that in the Grahamstown area this colour is limited to those portions of the tillite which are highly cleaved, and that, in fact, this colour closely resembles that of the olive green shales in the Kommadagga Member of the Lake Mentz Shales, and the olive green shales occurring within the Dwyka Tillite itself. The cleavage in the tillite is a secondary feature and it is very probable that the green colour is also secondary, that is, it belongs to a stage in the lightening of colour of the tillite between the dark blue grey and the white with increased weathering. The reason why this colour is limited to fissile rocks is that this fissility provides avenues for the agents of weathering. Green tillite or green fissile shale frequently occur adjacent to massive grey-blue tillite.

The other rock type occurring within the Dwyka Tillite is an olive green shale usually laminated to thinly bedded, but sometimes flaggy. It closely resembles in every way the olive green shale occurring in the Lake Mentz Shale and frequently fractures into pencil-like fragments due to the intersection of cleavage and bedding planes. As a rule, however, the original bedding has been completely obliterated by metamorphic processes although the original bedding is still sometimes discernible. This obliteration of the bedding rendered the measurement of primary structures quite impossible. The only exposure of these shales observed in the area is in the form of a fairly thick band in the northern tillite occurrence. It was possible to conclude with certainty that this shale is interbedded with the tillite and not a Lake Mentz Shale inlier by thickness estimates (p.71).

It is very probable that many other perhaps narrower intercallated bands of shale occur within the tillite since a number of shale bands were observed to occur during borehole studies carried out in other areas by Haughton and others (1953), and Blignaut and others (1948), and observed by Mountain (1945 and 1946). This would agree with the environmental conditions postulated to have existed during the formation of the Dwyka Tillite, namely, that of an ice-front discharging into fairly deep water (du Toit 1954).

Two samples were collected for hand specimen study, one of the massive grey-blue Dwyka tillite and one of the olive green shales. Table 21 indicates the serial numbers allotted to these samples and the localities in which they were collected.

TABLE 21

Sample serial numbers

Serial No.	Field description	Sample locality
D T 1	tillite	Grahamstown
D T 2	shale	Rietfontain

Plate 6B is a photomicrograph of a thin section of sample D T 1.

Colour data of the hand specimens, expressed in terms of a colour chart (Rock Colour Committee 1963), are given in Table 22.

TABLE 22

Hand specimen colours

Specimen	Colour	Hue	Value	Chroma
D T 1	Medium dark grey	Neutral	4	0
D T 2	Dark greenish gray	5 Yellow gray	4	1

DESCRIPTIVE MINERALOGY:

The textures as a whole are fragmental. There is very little evidence of recrystallisation or the introduction of authigenic material. These samples are both very poorly sorted.

The most abundant allogenic constituent in the thin sections examined is quartz whose grains vary greatly in size and display no sorting whatever. Although the majority of the grains, particularly the small ones, show very low degrees of roundness and sphericity, some of the larger grains show evidence thereof.

This may well be due to some previous sedimentary cycle, for those grains showing evidence of rounding are often raggedly broken on one side. The newly broken areas show no rounding whatever. This suggests the shattering to have taken place during the collection and deposition of the moraine. In one instance, a grain of perfectly rounded and spherical quartz was observed with an encrustation of secondary quartz in optical continuity with it. The overall shape and nature of this grain, however, indicates this to have been a pre-Dwyka tillite feature. In some instances the larger grains display flattened faces which may well be due to faceting. The nature of the quartz forming these grains varies considerably in that a few have a dirty appearance due to the presence of abundant inclusions.

A few fragments of sericite and clay or shale were observed to occur. They appear almost to grade into the matrix. In fact, the only way in which they can be distinguished from the matrix is that they themselves are inclusion-free and sometimes have iron oxides in them.

A few fragments of chert also occur.

The mineralogy of the matrix and the olive green shales is very similar to that described in previous chapters for the finer grained rocks in that it is sericitic and extremely fine-grained.

STRATIGRAPHICAL FEATURES:

On the whole, the Dwyka Tillite sequence is made up of a number of bands of massive tillite separated by bands of cleaved tillite, and a few minor shale beds.

The author was unable to determine its thickness in the area because of the inability to determine dips in the northeastern exposure which is the only place in which the entire succession occurs. Mountain (1946) cites a thickness of 2,000 feet for the region. The shale band which occurs in this northwestern exposure is estimated to be about 200 feet in thickness and to be about 1,300 feet from the base of the formation.

THE UPPER DWYKA SHALE FORMATION

THE DWYKA TILLITE/UPPER DWYKA SHALE BOUNDARY

This boundary, like all the others in the area, is a conformable one. It was taken to be at that level at which inclusions cease to occur.

It was always necessary to fix the exact location of this boundary in the field, but at the same time possible to determine its approximate position on aerial photographs by virtue of a drop in elevation along the tillite boundary. Erosion in the northern exposure, by tributaries of the Bothas and Fish rivers, has caused the Upper Dwyka Shale to crop out on a fairly steep scarp slope above the Dwyka Tillite.

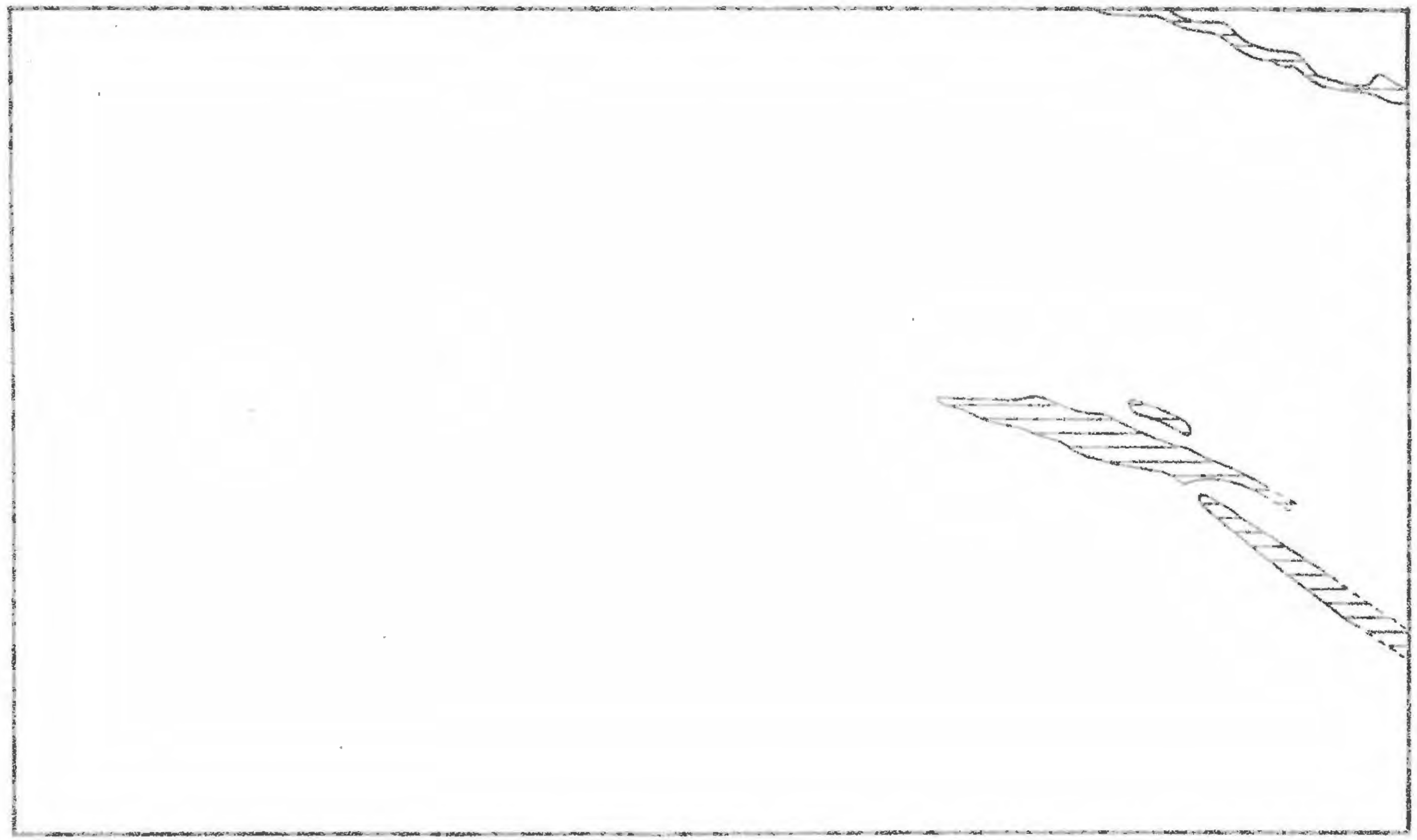
DISTRIBUTION AND MODE OF OCCURRENCE:

The Upper Dwyka Shale formation does not occur extensively, and is exposed in only two localities in the region (Diag. 19).

In the southeast an elongate synclinal outlier, trending parallel to the regional strike, enters the area at Grahamstown where it emerges from beneath the silcrete. It attains a maximum width of about four thousand feet and penetrates the area for a distance of about nine miles before nosing out over the Dwyka Tillite on Table Farm. On the farm Zyferfontein, the outcrop pattern is interrupted for about a quarter of a mile due to a fault. A small synclinal outlier occurs immediately to the north of the main outlier. It extends for only a matter of a mile and is traversed by the main Grahamstown/Cradock road.

In the northeast a dip sequence of the formation is exposed beneath the younger Ecca. It crops out parallel to the northern exposure of the Dwyka Tillite

DIAG 19



(p.64) on which it rests. In this instance, its outcrop on the map is very narrow because it occurs on a steep scarp slope overlooking the tillite.

On the whole, the Upper Dwyka Shale Formation is composed of easily erodible rocks and hence tends to occupy low ground. This is particularly the case in the northeastern exposure where they are bounded by higher ground on Dwyka Tillite to the south and Ecca to the north. In the southeast, these rocks do not occur in particularly low ground, probably as the result of having been, until recently, overlain by silcrete. In this instance they conform to the Dwyka Tillite topography - a feature which rendered them difficult to map.

In respect of vegetation and soils, the Upper Dwyka Shale closely resembles the Dwyka Tillite although, in some instances, on aerial photographs a difference in grey tone may be observed between country overlain by these two types of rock. Exposures are few. In the southeastern outliers a few poor exposures occur along the banks of the New Years River and in three small quarries dug for road metal along the Grahamstown/Cradock road. On the farm Zyferfontein and on the Grahamstown western commonage, two clay quarries have been excavated into the Upper Dwyka Shale. It may be inferred from the above that no complete sections of the Upper Dwyka Shale occurs so that it is impossible to work out a full stratigraphic sequence.

FIELD OBSERVATIONS AND NOMENCLATURE

As has already been stated, exposures of the Upper Dwyka Shale Formation are rare and occur in the outliers near Grahamstown. These expose only the lower portions of the succession. This study has therefore been limited to the lower portions of these shales and information about the upper portions was obtained from the work of others in neighbouring regions.

The base of the shales, which is exposed along the New Years River on Table Farm, is composed of massive green to khaki mudstones, parted by laminated black and olive green shales. These rocks are occasionally micaceous along their bedding planes and contain, in places, black nodules of chert which weather white. Other concretions which have been described as phosphatic by du Toit (1954) were observed throughout the succession, although Haughton and others (1953) found these to be rare in the lower portions. The mudstones and shales characteristically weather to a buff colour, frequently stained red and green. Further up in the succession, massive khaki rocks, weathering buff, and designated sandstones in the field, make their appearance in bands two inches to six feet in thickness. They are irregularly spaced between the mudstones and shales. These rocks are well jointed, subject to snuff-box weathering, and sometimes take on a dark graphite-grey coating on the weathered outer surface. Where they occur regularly and closely spaced, they tend to form minor elements of positive topography. The primary bedding of the argillaceous rocks has been largely obliterated by slaty cleavage, and they tend to break into elongate fragments (Plate 6E). The sandstones also take on a good cleavage in places (Plate 6D). The obliteration of primary bedding renders the accurate determination of dips and strikes extremely difficult at most localities.

The only evidences of the occurrence of the upper portion of the Upper Dwyka Shale observed in the area was a scattering of white weathered chert fragments in a kloof on the farm Rietfontain in the northeast of the region. The part of the succession from which these fragments are derived is known as the White Band - a prominent marker horizon. Mountain (1946) has described the White Band as the upper 40 or 50 feet of the Upper Dwyka Shale and as being black and carbonaceous at depth. Exogenetic processes have caused this cherty horizon to take on a white and multicoloured appearance. It is highly contorted within itself.

Two samples were collected from the Upper Dwyka Shale for closer laboratory examination. Table 23 indicates the serial numbers allocated to these samples, their field descriptions and the localities from which they were collected.

TABLE 23

Sample serial numbers

Serial No.	Field description	Sample locality
U D S 1	Mudstone	Table Farm
U D S 2	Sandstone-like rock	Table Farm

Colour data of the hand specimens, expressed in terms of a colour chart (Rock Colour Committee, 1963) are given in Table 24.

TABLE 24

Hand specimen colours

Specimen	Colour	Hue	Value	Chroma
U D S 1	Light Olive Gray	5 Yellow	5	2
U D S 2	Moderate Olive brown	5 Yellow	4	4

In thin section, the mudstone, sample U D S 1 (Plate 6F), was found to be extremely fine-grained, consisting predominantly of sericite and clay with a smattering of iron oxides, a few grains of heavy minerals and approximately two percent of small angular quartz grains. The sandstone, sample U D S 2 (Plate 6G), however, presented a somewhat unexpected picture. It can immediately be seen that this rock is in fact a true mudstone. Its resemblance to sandstone is created by an abundance of small, subspherical particles resembling concretions and varying between 0.05 and 0.30 millimetres in diameter. In the hand specimen, these particles are lighter in colour than the matrix giving the impression of mineral grains of the sand grade set in a mud matrix. Although the cores of the majority of these particles were plucked out during the preparation of the thin section, it is apparent that they are composed of sericite and clay minerals like the matrix itself, but they tend to transmit light more readily. The reason for this is that outside the core iron oxides permiate the entire rock and inhibit the passage of light through the thin section. In the spherical particles, however, the iron oxides appear to have migrated to the edges to leave an internal iron oxide free groundmass. The discontinuous spherical layer of iron oxide determines the size and shape of the particle. They appear to be secondary features in the rock, but the fact that they are limited to specific layers suggest that they may well be penecontemporaneous with the rock in origin. It is also significant that these particles are limited to the mudstones and do not occur in adjacent shales. The rock does not react with dilute hydrochloric acid.

It would make an interesting study to determine how and when these concretions were formed.

DESCRIPTIVE MINERALOGY:

There is not much that can be written about these rocks in so far as the qualitative mineralogy is concerned. As a whole, they consist of a few larger grains of heavy minerals and muscovite in a ferruginous matrix of sericite and clay.

CLASSIFICATION OF THE ROCKS:

Taking into account the information recorded above, the author suggests the classification of these rocks to be that given in Table 25.

TABLE 25

Classification of the Upper Dwyka Shale suite of rocks

Sample	Classification
U D S 1	Mudstone
U D S 2	Mudstone

STRATIGRAPHICAL FEATURES:

On the farm Rietfontain, in the northeastern region, the Upper Dwyka Shale was estimated to be approximately 400 feet thick using the upper limit of white chert fragments in the soil as the top of the sequence.

Stratigraphically, these rocks may be described as consisting of a lower 350 feet of soft, buff weathering shales and mudstones, which vary in colour from dark green to khaki, and contain small concretions (p. 76). The upper 50 feet comprise the White Band as it is understood in this region.

THE ECCA GROUP

THE ECCA PASS FORMATION

THE UPPER DWYKA SHALE/ECCA BOUNDARY

This boundary was taken to be the upper surface of the White Band. No exposures of the actual contact were observed in the area.

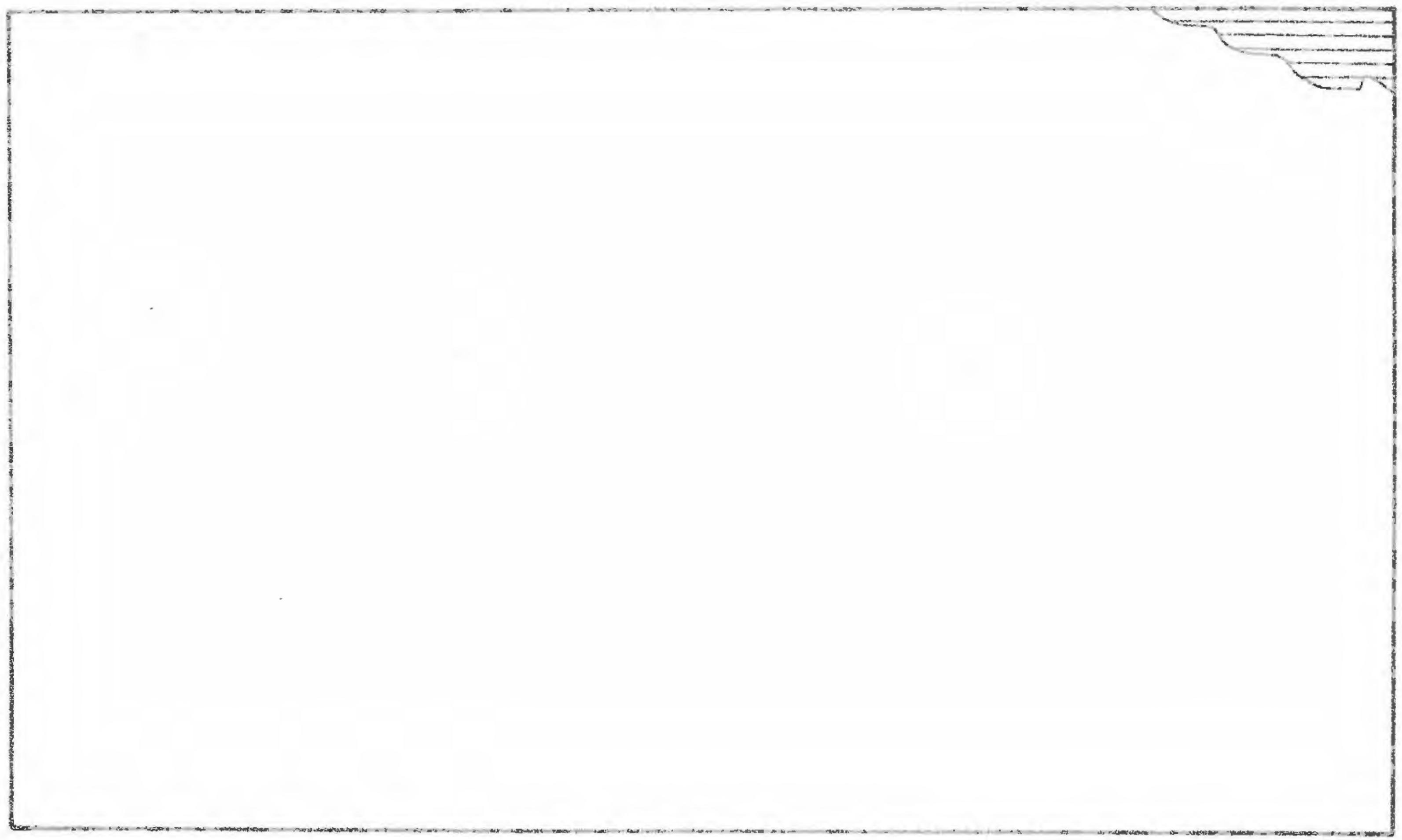
It has been described by other authors to be a conformable one outside this region, easily followed in the southern Karroo due to the prominence of the White Band. This may even be traced on aerial photographs. It can always be found approximately, owing to its occurring only 500 feet or so above the tillite (Mountain 1946). The only place in the area where this boundary could be approximately fixed was in a kloof where scatterings of white-weathered cherty fragments, presumed to have derived from the White Band, occur in the soil. Thickness measurements verified this assumption in that these fragments lie approximately 500 feet above the tillite.

DISTRIBUTION AND MODE OF OCCURRENCE:

Apart from overlying unconformable Cainozoic formations, the Ecca is the youngest group of rocks in the area. It occupies the extreme northeast corner of the area on the farms Kromme Krans, Krans Drift and Rietfontain and dips gently toward the north (Diag. 20).

Topographically the Ecca rocks occupy moderately high ground. These uplands are dissected by northward flowing tributaries of the Fish and Bothas rivers which expose fairly good sections of the more massive strata in the Ecca Pass Formation, the name applied to

DIAG 20



the lowest subdivision of the group by Johnson (1966).

The soils deriving from these rocks are, for the most part, buff and loamy with an occasional reddish strip, the latter, presumably, above more argillaceous horizons. The ground is well covered by small trees and bushes almost to the exclusion of grasses. This vegetation shows marked stratigraphic control which is very apparent on aerial photographs.

FIELD OBSERVATIONS AND NOMENCLATURE

Only strata in the Ecca Pass Formation (Johnson 1966), are exposed in this region. The description of the petrology of these rocks will be dealt with in the chronological order of the subdivisions of this formation recognised by Johnson. He distinguished a basal shale member, a member consisting mainly of sandstone, and an upper shale and sandstone member.

The basal shale member is poorly exposed as it usually crops out on a fairly steep scarp slope capped by sandstone. It was, in fact, difficult to establish with certainty where to place the boundary between the Upper Dwyka Shale and the Ecca Pass Formation. The surface overlying these rocks is strewn with fragments of a dark grey shale. In an adjacent kloof, exposures of a fine-grained flaggy rock were observed. In both instances, the weathered surfaces are buff to reddish. Very similar rocks are well exposed in the Ecca Pass, not far beyond the northeastern corner of this region, in Johnson's basal member of the Ecca Pass Formation.

The middle predominantly sandstone member is well exposed on the farm Kromme Krans, forming cliffs between 75 and 100 feet high along the Bothas River. Here it forms a gentle monoclinal flexture with increasing dips toward the north. The land surface tends to follow this monocline since the overlying and more easily denuded upper shale and sandstone member has been eroded away down dip towards the north. The middle member itself consists of massive, thick to very thick bedded bands of bluish grey to greenish mudstones, siltstones and sandstones separated by thin partings of more fissile argillaceous strata. The massive sandstones themselves tend to become more arenaceous higher up in the succession where they take on a white speckled appearance. The arenaceous strata generally weather to a khaki buff colour while the argillaceous strata are frequently tinted red. The positions of the shales in the sequence are, for the most part, easily discernible both in the field and on aerial photographs as they form minor negative elements of topography. The arenaceous rocks vary in character and include clay pellet conglomerates and sandstones with shale fragments in them (Mountain 1946, p.21), Numerous concretions resembling those described by Johnson (1966, p.36) were observed. The upper surface of this formation was taken to be a flaggy sandstone overlain by a thick development of blue to greenish fissile shales (Plate 7B).

Only the lowermost strata of the upper shale and sandstone member are present in the region. Although poorly exposed beneath alluvium of the Bothas River, they include dark grey to blue and green shales and mudstones (Plate 6H).which are incompetent to folding stresses. Due to the intersection of cleavage and bedding planes these rocks tend to break up into elongate pencil-like fragments. This intersection of cleavage and bedding planes is well illustrated in Plate 6H.

These rocks all weather to reddish and buff colours.

Seven samples were selected for detailed study in the laboratory. Thin sections of the shales and mudstones were not prepared.

The serial numbers of these samples, the description given them in the field and the localities where they were collected are given in Table 26.

TABLE 26

Sample serial numbers

Serial No.	Field description	Sample locality
E 1	Shale	Rietfontain
E 2	Shale	Kromme Krans
E 3	Mudstone	Rietfontain
E 4	Flaggy mudstone	Kromme Krans
E 5	Siltstone	Kromme Krans
E 6	Sandstone	Kromme Krans
E 7	Sandstone	Kromme Krans

Samples E 1 and E 2 are shale specimens collected from the basal member and the upper shale and sandstone member respectively.

PHYSICAL PROPERTIES:

The following is an account of the physical properties of the Ecca Pass rocks as represented by samples E 1 to E 7.

Colour:

Colour data obtained from the hand specimens, by comparison with a rock colour chart (Rock Colour Committee, 1963) are given in Table 27.

TABLE 27

Hand specimen colours

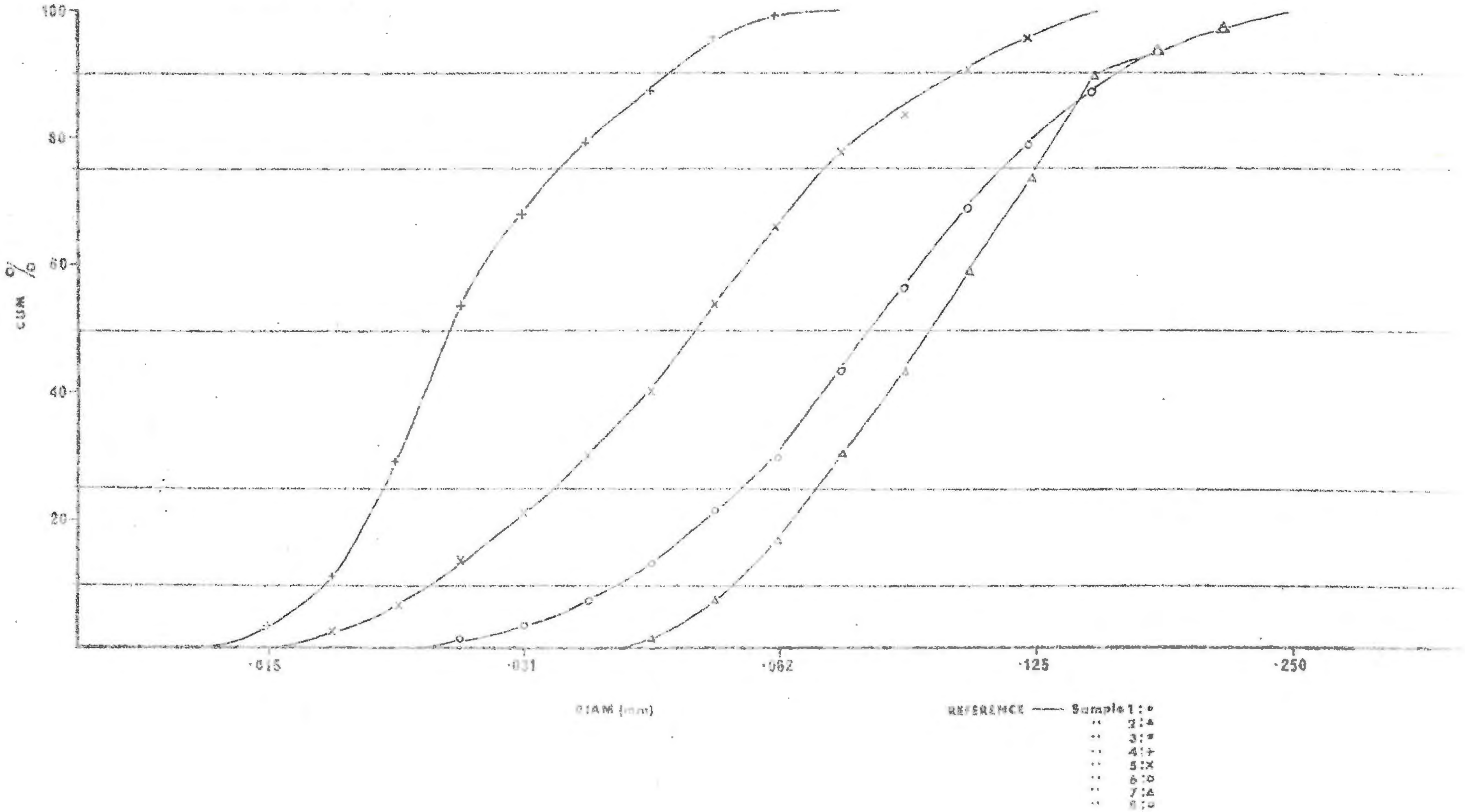
Specimen	Colour	Hue	Value	Chroma
E 1	Dark greenish gray	5 Green Yellow	6	1
E 2	Dark greenish gray	5 Green Yellow	6	1
E 3	Light Olive gray	5 Yellow	5	2
E 4	Dark gray	Neutral	3	0
E 5	Light olive gray	5 Yellow	5	2
E 6	Olive gray	5 Yellow	4	1
E 7	Olive gray	5 Yellow	4	1

Considerable difficulty was experienced in obtaining perfectly fresh specimens due to the absence of any man-made cuttings in the Ecca in this region. A cursory examination of the same rocks in the Ecca pass suggests that the colours of fresh specimens are somewhat darker.

Grain-size distributions:

The measured distributions of maximum diameters of the more rounded quartz grains in these samples are illustrated graphically by the cumulative frequency curves in Diag. 21 and the percentage frequency curves in Diag. 22. The Md, M, Mo, So, $Log_{10}Sk$, and the K of these distributions, computed from data obtained from the respective graphs, are tabulated in Table 28.

Diag 21



100
80
60
40
20
CUM %
·015
·031
·062
·125
·250
DIAM (mm)
REFERENCE —— Sample 1
" 2
" 3
" 4 : +
" 5 : X
" 6 : O
" 7 : Δ
" 8

TABLE 28

Grain-size distribution data

Sample	Md(mm)	M(mm)	Mo(mm)	So	$Log_{10}Sk$	K
E 1	-	-	-	-	-	-
E 2	-	-	-	-	-	-
E 3	-	-	-	-	-	-
E 4	0.026	0.028	0.026	1.276	0.060	0.230
E 5	0.051	0.051	0.056	1.475	$\bar{1}.986$	0.250
E 6	0.082	0.082	0.085	1.396	$\bar{1}.989$	0.255
E 7	0.094	0.096	0.150	1.346	0.003	0.306
			0.107			

Note: The distribution of the sample E 7 is bimodal. The secondary mode is tabulated beneath the primary mode.

Although the quartz grains in the Ecca samples differ in average grain-size, the patterns of their distributions are broadly the same (Diag. 21). A few differences appear in the percentage frequency curves in Diag. 22. The finest grained sample, E 4, is seen to be markedly better sorted than the others. The samples E 5, E 6, and E 7 have distinctly greater spreads of quartz grain-sizes than most of the samples previously examined.

These quartz grain distributions all show a moderate degree of sorting, the So values varying between 1.276 and 1.475 (p.23).

These distributions may be described as having little skewness, apart from minor coarse grain admixtures in the samples E 4 and E 7. Their $Log_{10}Sk$ values vary between $\bar{1}.986$ and 0.060. A perfectly symmetrical distribution has a value of zero (Pettijohn, 1957, p.37). Kurtosis values are included here for completeness.

In Diag. 23, the first and third quartiles of these distributions are plotted against each other according to the method given in Pettijohn (1957, p.26). It may be seen from this diagram that the more rounded quartz grains of the rock E 4 fall within the silt grade, those of the rocks E 5 and E 6 within the silty sand grade, and those of the rock E 7 within the sand grade.

Sphericity and Roundness:

The sphericities and roundnesses of median size quartz grains in the respective samples are given in Table 29.

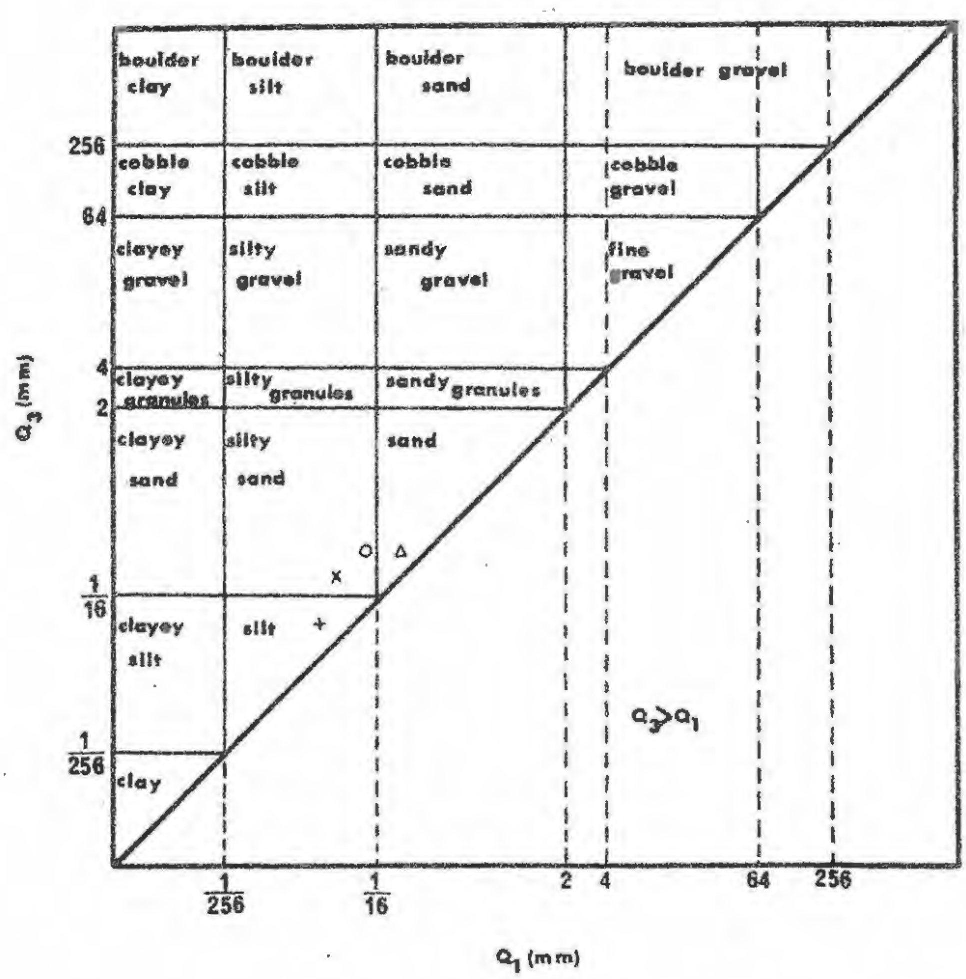
TABLE 29

Sphericity and roundness

Sample	Median grain sphericity	Median grain roundness
E 1	-	-
E 2	-	-
E 3	-	-
E 4	0.50	0.10
E 5	0.50	0.10
E 6	0.66	0.14
E 7	0.60	0.40

It can be seen from Table 29 that both the sphericities and roundnesses tend to increase with the median grain-size of the samples. The qualitative observation of the Ecca rocks in thin section gives the viewer a definite impression of general angularity of quartz particles (Plate 7A).

Diag 23



REFERENCE

Sample 1 : ●
" 2 : ▲
" 3 : ■
" 4 : +
" 5 : ×
" 6 : ○
" 7 : △
" 8 : □

The few heavy minerals encountered are, for the most part, well rounded with a high degree of sphericity. Exceptions occur where recent shattering of the grains has occurred, and in the case of minerals such as zircon, in which the original crystal-shape deviates greatly from the spherical.

Mineralogy:

Quantitative Mineralogy:

The percentage mineral compositions of the various samples are tabulated in Table 30.

TABLE 30

Percentage mineral compositions

Sample	Qtz	Felsp	Mat	Musc	Rut	FeOx	Zir	Cal	Ind.
E 1	-	-	-	-	-	-	-	-	-
E 2	-	-	-	-	-	-	-	-	-
E 3	16.0		84.0		-	t	-	-	t
E 4	24.0		76.0		-	t	-	-	t
E 5	31.9	6.6	48.1	2.4	-	5.0	t	-	6.0
E 6	40.7	20.8	29.7	3.8	t	3.0	t	t	2.0
E 7	20.8	27.3	44.6	1.0	t	2.0	t	t	4.3

t refers to trace; Qtz to quartz; Mat to the fine-grained matrix which consists predominantly of sericite and clay minerals, plus carbon in the dark coloured rocks; Musc to muscovite; Rut to rutile; FeOx to iron oxides; Felsp to felspar; Zir to zircon; Cal to calcite; and Ind to an indeterminate yellowish, amorphous material, possibly silica.

In the case of samples E 3 and E 4, which are fine-grained, it is impossible to differentiate between quartz and felspar, and between the sericitic matrix and muscovite. These pairs of minerals are therefore grouped together in the above table.

In order to classify these rocks in the triangular diagram of Krumbein and Sloss (1951, p.130), the percentage mineral compositions were recalculated between quartz, sericitic matrix and muscovite (grouped together as clay) and felspar. This information is tabulated in Table 30, and the plots on the diagram itself in Diag. 24.

TABLE 31

Recalculated percentage compositions

Sample	Quartz	Clay	Felspar
E 1	-	-	-
E 2	-	-	-
E 3	8.0	84.0	8.0
E 4	12.0	76.0	12.0
E 5	36.7	55.7	7.6
E 6	42.8	35.3	21.9
E 7	22.2	48.7	29.1

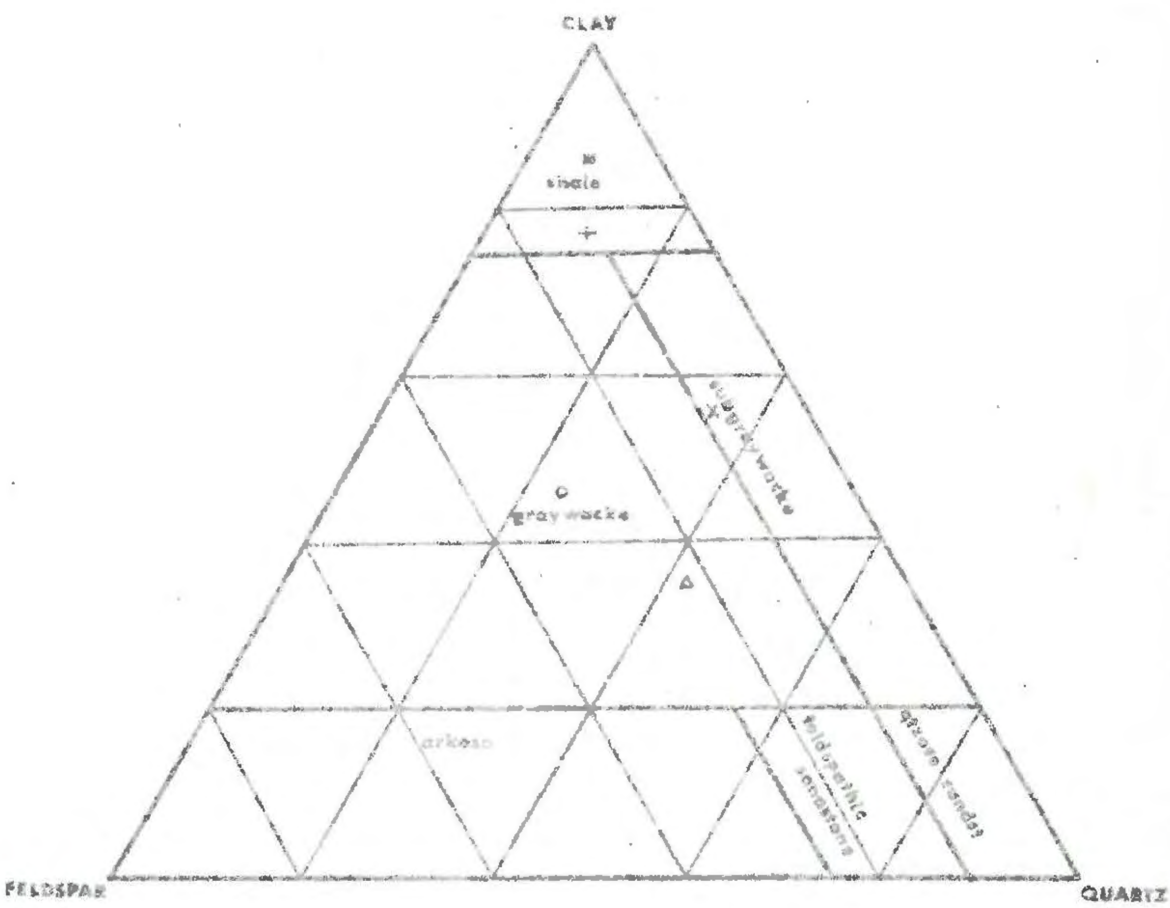
Descriptive mineralogy:

The mineralogy of the suite of rocks from the Ecca Pass Formation is largely similar throughout, apart from variations in size and abundance.

The textures are typically fragmental. Recrystallisation and silification are not very apparent.

Mineralogically, the rocks as a whole resemble the "Feldspathic Sandstones with a Primary Matrix" described by Carozzi (1960 p.57) in which the grains of the coarse fraction are fairly angular and consist predominantly of sericite, clay minerals and a scattering

Diag 24



REFERENCE

Sample 1 : ●
" 2 : ▲
" 3 : ■
" 4 : +
" 5 : X
" 6 : O
" 7 : Δ
" 8 : □

of muscovite grains. This matrix is sometimes lightly tinted by iron oxides. The argillaceous rocks have a greater proportion of matrix material, with the fewer coarse grains being smaller and generally more angular.

A remarkable feature of the rocks of the Ecca Pass Formation, as compared with those of the underlying formations, is the relatively abrupt increase in the proportion of felspars. This is especially true of the influx of plagioclase which is more readily recognised than orthoclase in thin sections of sedimentary rocks.

The other minerals occur in much the same manner as they do in the other rock suites.

CLASSIFICATION OF THE ROCKS:

Taking into account the information recorded above, the classification tabulated in Table 32 is suggested for these rocks.

TABLE 32

Classification of the Rocks

Sample	
E 1	(Shale)
E 2	(Shale)
E 3	(Mudstone)
E 4	Silty mudstone
E 5	Silty sand subgraywacke
E 6	Silty sand graywacke
E 7	Sand graywacke

STRATIGRAPHICAL FEATURES

Stratigraphically these rocks are the highest and youngest of the stratified rocks encountered in this region. Only strata of the lowermost member of the Ecca group are exposed. They form a conformable sequence.

The system of subdivision used by Johnson (1966) has been adopted. Approximately 2,000 feet of Johnson's lowermost formation, the Ecca Pass Formation, is present. In the Grahamstown region, this formation is subdivided into an upper shale and sandstone member, a member consisting mainly of sandstone, and a basal shale member.

The basal shale member is poorly exposed in the region, but from the information available, its thickness is very close to the figure of 100 feet quoted by Johnson (1966). It consists predominantly of dark grey to green shales which tend to become flaggy. The colour suggests the possible presence of carbon. These shales take on a buff to yellow colour on weathering.

The middle member, consisting mainly of sandstone, attains a thickness of approximately 1,000 feet. It consists predominantly of massive, medium to very thickly bedded bands of light to dark olive-grey silty sand subgraywacke and silty sand graywacke, which sometimes becomes flaggy, separated by fairly narrow bands of olive gray to dark silty mudstones, mudstones and shales. Mud pellets were observed in some of the massive bands, and large concretions are fairly common. Toward the top of the sequence, massive bands of a white speckled, blue to olive gray, sand graywacke tend to predominate. The shale bands usually break into elongate, pencil-like fragments due to the intersection of bedding and cleavage planes. All these rocks weather to shades of buff.

Only the lowest part of the upper shale and sandstone member occurs in the region and it appears to consist exclusively of argillaceous rocks such as silt mudstones, mudstones and shales which either alternate rapidly with one another or form thick bands. The base of this member consists of a highly fissile dark grey shale resting on a flaggy silty sand subgraywacke (Plate 7B) with worm tracks on its upper surface. The predominant colours of these rocks are dark grey to olive grey, becoming buff to red or yellow on weathering.

The lower part of the Ecca, like the Lake Mentz Shale, was probably deposited during less uniform conditions than the Witteberg Quartzite.

CAINOZOIC DEPOSITS

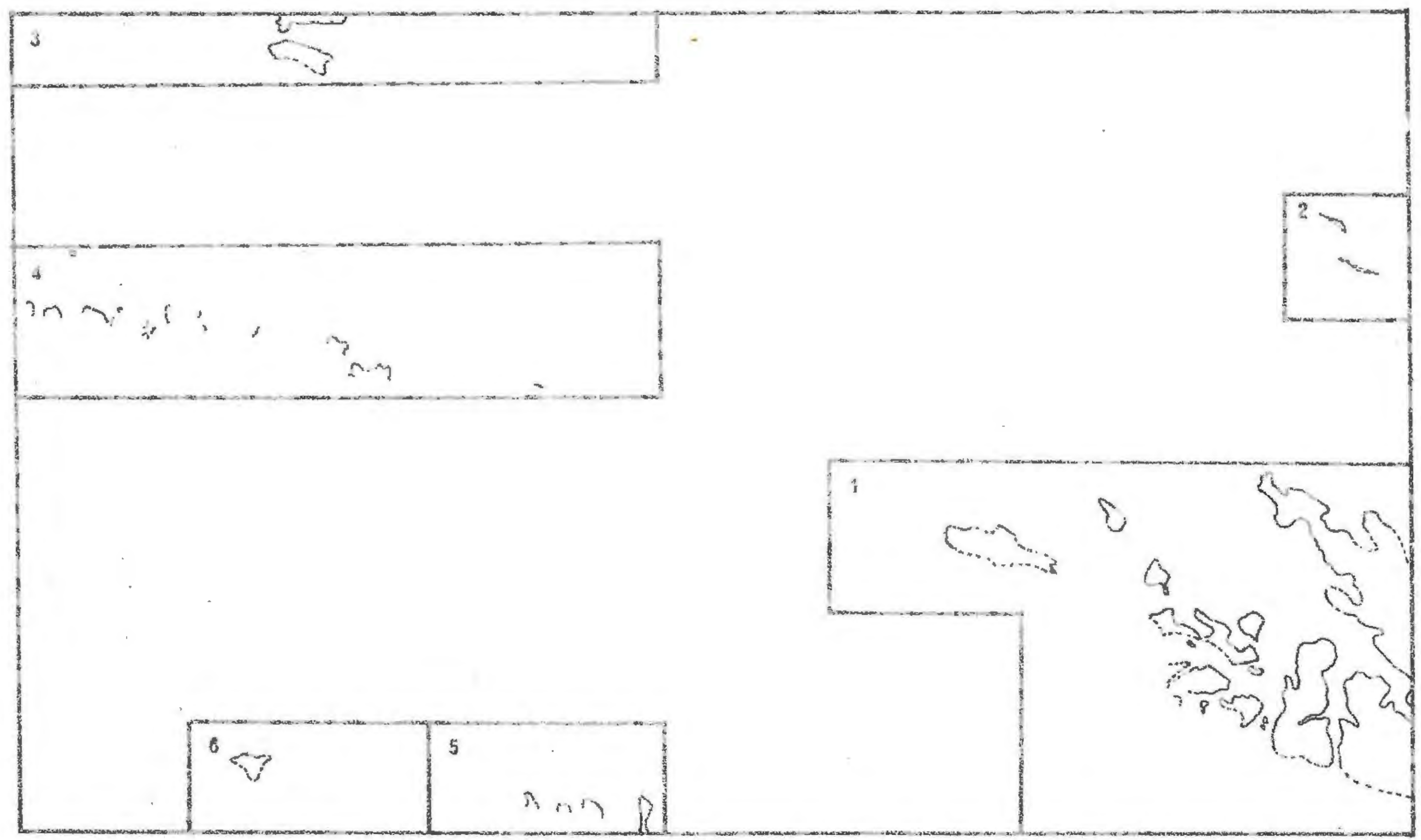
SILCRETE

DISTRIBUTION AND MODE OF OCCURRENCE:

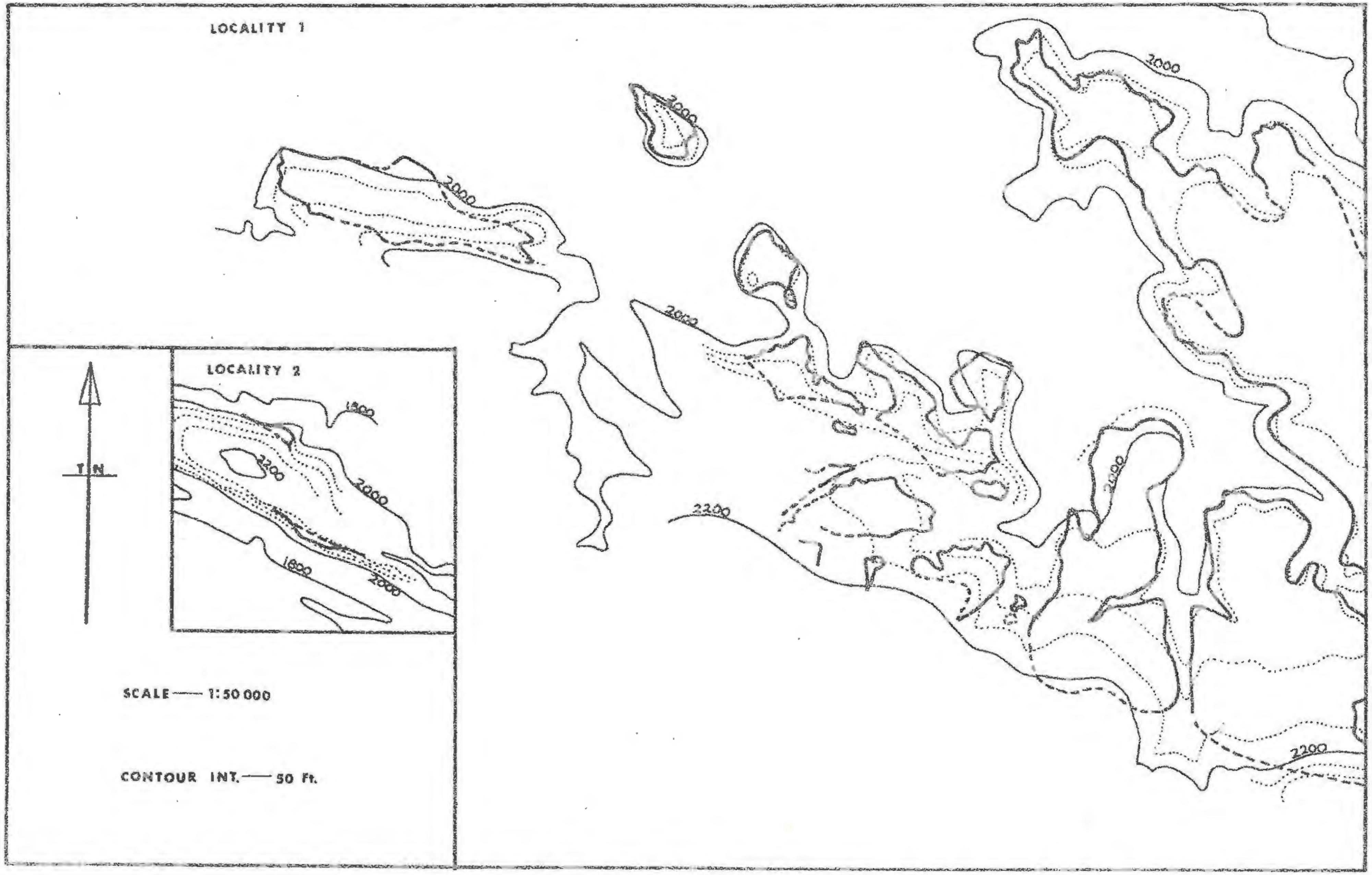
Silcrete forms irregular outcrop patterns distributed throughout the entire region as remnants of what must have been a more extensive deposit upon an ancient undulating plain which, near Grahamstown, has been called the Grahamstown peneplain. The silcretes may be described as unstratified surface rocks, generally horizontal, and unconformably overlying all older strata. Their thickness is variable, but seldom more than a few feet. There are no good sections, natural or man-made, through the silcrete. It occurs in six main localities in this region (Diag. 25).

The occurrences in the first two localities in the eastern half of the mapped area, will be described together (Diag. 26). They occur on the western continuation of the Grahamstown peneplain (Mountain 1946), the first locality immediately to the northwest of Grahamstown, and the second on the slopes of the westward continuation of Bothas Hill. These occurrences are remnants after dissection by the westerly and northwesterly flowing tributaries of the New Years and Bothas rivers. The Grahamstown silcrete occurs at a local watershed separating drainage towards the northwest, mentioned above, and towards the east and southeast via the Blaukrantz River. The remnants of the silcrete are remarkably flat (Plate 7D and Diag. 26). The silcrete in the southeastern part of the region of the present investigation, is inclined very gently towards the axis of the neighbouring headwater tributaries of the New Years River (Diag. 26). Its highest point is

DIAG 25



DIAG 26


LOCALITY 1
2000
2000
2000
2000
2000
2000
2200
2200
LOCALITY 2
1800
2200
2000
1800
2000
T N
SCALE —— 1:50 000
CONTOUR INT. —— 50 Ft.

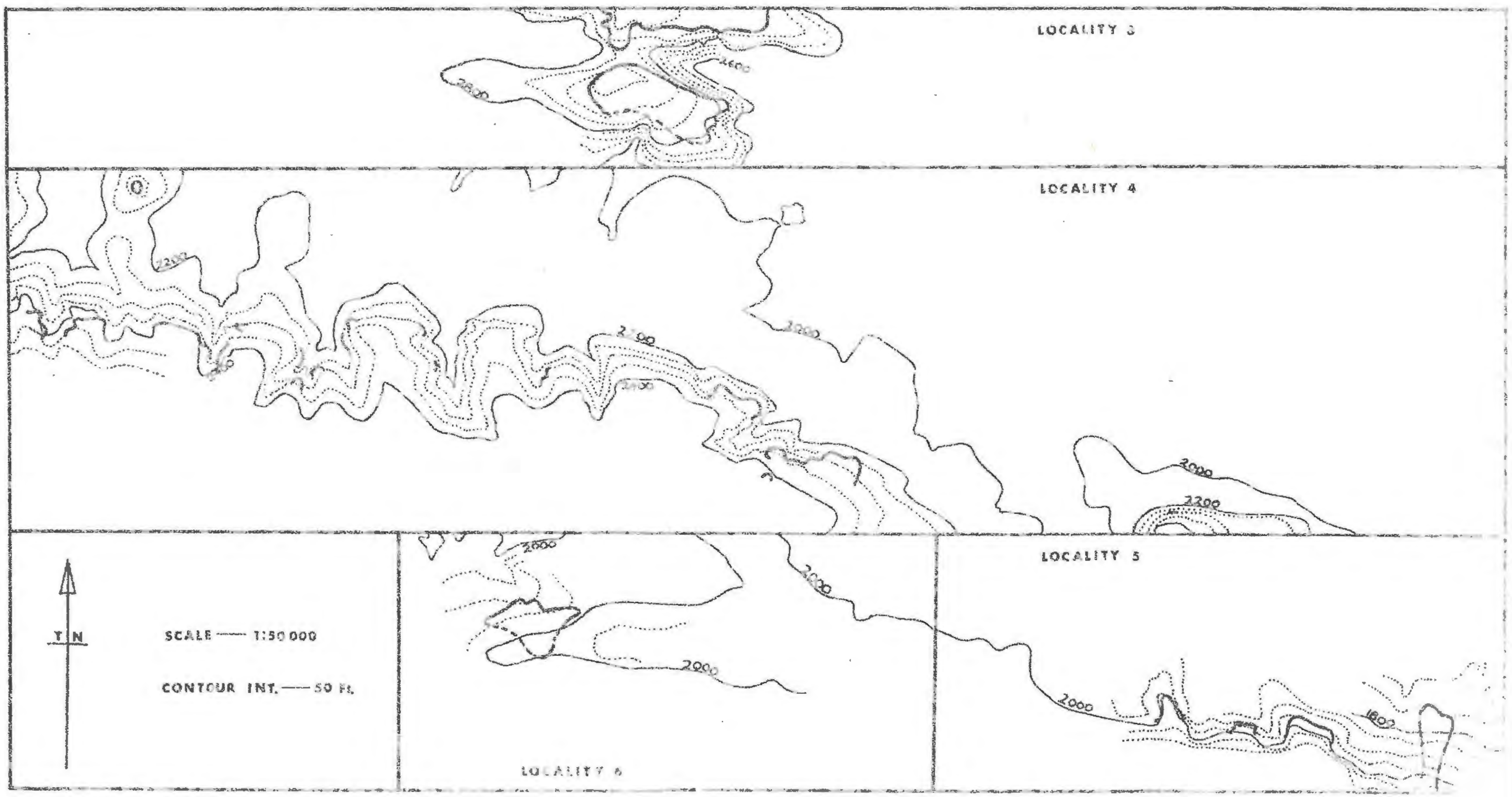
approximately 2,200 feet above sea-level where it shelves up against the bordering Quartzite ranges on its southern side. Its lowest point, on Zyferfontein, is approximately 2,000 feet above sea-level. The silcrete was not observed to rise up the bounding slope at locality 2 (Diag. 26). It occurs at 2,100 feet at this locality.

The westernmost silcrete exposure, near the southern boundary of the Grahamstown peneplain, shelves down as much as 200 feet over a distance of only 2,500 feet - a gradient of two in twenty five. There is very little lateral variation in the elevation of the peneplain along the valley axis. Mountain (1946) recognised an altitude variation in this direction of only 30 feet.

Locality 1, immediately northwest of Grahamstown, is the only one in which the land surface capped with silcrete survives extensively. This surface may be described as gently undulating. Due to the more extensive preservation of silcrete in this region, it occurs on weak rocks to a much greater extent than anywhere else. At all other localities it survives only on the borders of the ancient valleys and, therefore, generally on the quartzose sandstones of the Witteberg Quartzite.

Locality 3 (Diag. 27) is situated towards the west on the northern boundary of the region on the highest point of the Riebeek East mountains. Two outliers of silcrete, occupying approximately one square mile, occur at the unexpectedly high elevation of 2,900 feet above sea-level (Plate 7F). Assuming these outliers to have been continuous with one another, it may be seen (Diag. 27, locality 3) that from being almost horizontal in the extreme north,

DIAG 27


LOCALITY 3
2800
2600
LOCALITY 4
2200
2100
2000
2400
2000
2200
TN
SCALE — 1:50 000
CONTOUR INT. — 50 Ft.
2600
2000
2000
LOCALITY 6
LOCALITY 5
2000
1800

their upper surface displays an increasing downward inclination towards the southeast, attaining a gradient of one in ten. This suggests that silicification was not restricted to the valley-floor plains or the lower slopes of uplands bordering these. These ridge-top silcretes are the highest recorded in this part of the Fold Belt.

Locality 4 (Diag. 27) is an elongate one, embracing scattered silcrete remnants over a distance of approximately seven miles and extending eastward from a point about two miles south of Riebeek East. These silcrete remnants occur along the southern edge of a valley whose floor was perhaps continuous with the Grahamstown peneplain throughout the Riebeek East/Grahamstown basin. For the most part, they make minor scarps at the crests of the valley sides of insequent tributaries of the Gxetu River which flow off the bordering Witteberg Quartzite ranges. Sometimes the scarps face north towards the Gxetu itself. Over the seven miles of intermittent exposure these silcrete scarps display a fairly constant elevation of 2,300 feet above sea-level, which is similar to that of the silcrete on the southern margin of the Grahamstown peneplain. Farther away from the bordering mountains a small remnant of silcrete caps the hill "Leeukop", southeast of Riebeek East village (Plate 7E). The elevation of this small outlier is 2,388 feet above sea-level, about the same height as the other occurrences of silcrete in this locality.

Localities 5 and 6 occur within a fairly short distance of each other on the southern slopes of the Rockdale/Meyers Kraal basin (Diag. 27). The four outliers in locality 5 occur on the southern boundary of the area around and to the west of Highlands station. They form silcrete scarps similar to those described in locality 4, but at a constant elevation of approximately 2,000 feet above sea-level. The specific outlier at Highlands station is a narrow and elongate outcrop of silcrete extending northwards towards the adjacent valley for a distance of approximately two-thirds of a mile from the southern boundary of the area. Over this distance it drops in elevation almost 400 feet, from 2,150 to 1,750 feet above sea-level, and has an average gradient of one in six. There is only one half-mile square silcrete remnant in locality 6, at Stoneham railway siding on the farm Spitskop. It occupies much the same elevation, 2,000 feet above sea-level, as the Highlands outliers. It displays a downward inclination to the north. It resembles the outliers at locality 3 in that it crosses a ridge. Although in a sense this is a ridge-top silcrete, it occurs at the general level of the original valley floor plain in this region at the point where that plain skirts the end of the declining Witteberg Quartzite ridge that forms the southern margin of the Rockdale/Meyers Kraal basin from this point to Highlands. As Meyer (1965, Map 4) finds silcrete at 2,000 feet on the southern side of this ridge in the region of the coastal peneplain, it appears that the Rockdale/Meyers Kraal silcretes are an extension of the coastal peneplain silcretes. A distinct possibility exists of a link between the Riebeek East/Grahamstown silcretes and the coastal peneplain silcretes via the Hilton poort summit plain and the silcrete of the Rockdale/Meyers Kraal basin.

No definite evidence was found at any one locality that the silcrete occurs at more than one horizon.

Very common throughout this region, especially on gently sloping surfaces, are outcrops of what may be described as glazed quartzite. At such places, the exposed surfaces of the Witteberg quartzose sandstones are smooth, generally convex, and perhaps originally exfoliated. These surfaces have a dull gloss such as would arise if they had been wind-polished or superficially silicified. The cause of this feature is not, however, known.

Glazed quartzites are common near silcrete outcrops, but also occur far from them. They were never observed to occur well below the level of the lowermost parts of the regional surface carrying the silcrete. However, at locality 3, where the silcrete is abnormally high, they do occur at a lower altitude than the local silcrete.

At the westernmost outlier in locality 1, silcrete crusts occur sporadically on glazed quartzites, but it is not possible at this stage to conclude that all such surfaces formerly carried silcrete.

The soils overlying the silcrete are generally sandy and greyish white in colour, although they are very frequently stained red by iron oxides. The occurrence of small, rounded to angular, frequently red-tinted fragments of silcrete in these soils is characteristic. The vegetation is predominantly fairly lush grass with sporadic thorn trees. There is no evidence of structural control over the vegetation. Where the silcrete bedrock is exposed through the cover, it is in the form of hummocky, rounded, exfoliated surfaces. The upper surface of the silcrete crops out most conspicuously near the edges of silcrete remnants. The vegetation on the gently rolling and rounded hills adjacent to the silcrete exposures is very similar to that on the silcrete plain itself, but displays patterns due to structural control.

Little mention has been made of secondary structures in the silcrete apart from the joints described by Mountain (1952). Frankel and Kent (1937) cite the presence of vuggy cavities in the silcrete as evidence of the lack of any secondary compression. In contrast, Meyer (1965) describes the presence of conical structures in the silcrete that may well be the result of the release of lateral pressure perhaps manifested in immediate post-silicification times. A paper is to be published by the Bernard Price Institute on shatter cones formed experimentally by such a process (Nicollayson - verbal communication).

PETROLOGICAL FEATURES:

The nature of the silcrete in the region varies considerably. As a whole, it was found to match the description given by Mountain (1946). He says that it is most commonly "a fine-grained massive grey or creamy rock with tiny angular grains of quartz and occasionally small pitted hollows, but, especially near the margin of the original peneplain, passes into a rubble of smaller or larger subangular blocks of Witteberg quartzite, cemented with the same fine-grained material". Plate 7G is a photograph of silicified rubble, and Plate 7H one of the finer grained, rubble-free silcrete that exfoliates to a smooth sub-spherical surface. It was frequently difficult to distinguish this type of silcrete from glazed quartzose sandstones. Frankel and Kent (1937) attribute the sometimes brown to buff colour of the silcretes to an external concentration of iron and remark on the fact that the silcretes take on a good polish.

Silicified rubble occurs predominantly on the slopes of fairly high Witteberg Quartzite hills in this region but is known to occur on level surfaces in neighbouring regions. Also, even within this area, silicified rubble occurs on the more or less level summit in locality 3. It seems very likely that these silicified rubbles were originally subsoils in which resistant Witteberg quartzose sandstone has survived. Silcretes on weak rocks tend to be rubble-free due to the more rapid decomposition of rock fragments in the soil profile.

Both the silicified rubble and the cleaner silcretes frequently take on a deep red colouration due to iron staining. Mountain (1946) found this iron-stained silcrete to predominate in localities overlying the Dwyka Tillite. This was found to be the case on the farm Burnt Kraal, a few miles to the northwest of Grahamstown. In addition, however, the majority of the silcrete outliers occurring in the western half of the region in localities 3 to 6, are stained red, some of them to a deep maroon colour resembling ferricrete rather than silcrete.

Not much information about the vertical variations in the silcrete layer is available. Mountain (1952) remarks on the absence of stratification apart from isolated layers of water-worn pebbles and has described silcrete grading imperceptibly into underlying Witteberg Quartzite or other bed rocks, and passing into clays and soils. Frankel and Kent (1937) observed silcrete grading downwards through a silcrete conglomerate.

Three hand specimens of silcrete were collected for examination in the laboratory. Table 33 indicates the serial numbers allocated to these samples, their field description and the localities in which they were collected.

TABLE 33

Sample serial numbers

Serial No.	Field description	Sample locality
S 1	Silcrete	Zyferfontein
S 2	Silcrete	Zyferfontein
S 3	Silcrete	Palmietfonteyn

Colour data, obtained by comparing the hand specimens with a colour chart (Rock Colour Committee 1963) are given in Table 34.

TABLE 34

Hand specimen colours

Specimen		Hue	Value	Chroma
S 1	Grayish orange	10 Yellow red	8	2
S 2	Yellowish gray	5 Yellow	7	2
S 3	Dark reddish brown	10 Red	3	4

Sample S 3 is iron oxide-stained silcrete.

Although thin sections were examined, no quantitative studies were carried out on these specimens. Like the Dwyka tillite, they are not suitable in any way to the type of petrological work which has been applied to most of the other rocks encountered in the area.

The silcretes may be described as extremely poorly sorted sediments, containing fragments which vary little in shape (sphericity and roundness) from those occurring in the immediately underlying rocks (Frankel and Kent, 1937).

DESCRIPTION OF THE SAMPLES IN THIN SECTION

This aspect of the silcretes has been very fully described by previous authors, notably Mountain, and Frankel and Kent.

Plates 8A and 8B are photomicrographs of thin sections of samples S 2 and S 3 respectively. The thin sections revealed three types of silcrete which differ mainly in the mutual relationships of the various minerals. As a whole, they are typical of what may be expected in such a surface deposit. Two of the samples show large numbers of angular to subangular quartz grains varying greatly in size. There is little evidence of secondary enlargement or recrystallisation of these grains. Pressure phenomena are absent. The two samples differ in the nature of the matrix. In one, this consists almost exclusively of cryptocrystalline silica, while the matrix in the other is composed of an exceedingly fine-grained silica which is yellow in colour and paste-like.

Sample S 3 presents a somewhat different picture. It is composed mainly of relatively large, irregularly shaped quartz grains, coated with red iron oxide.

No attempt was made to isolate heavy minerals. A study of the heavy mineral assemblage in the Grahamstown silcretes was made by Frankel and Kent (1937).

TERRACE GRAVELS

DISTRIBUTION AND MODE OF OCCURRENCE

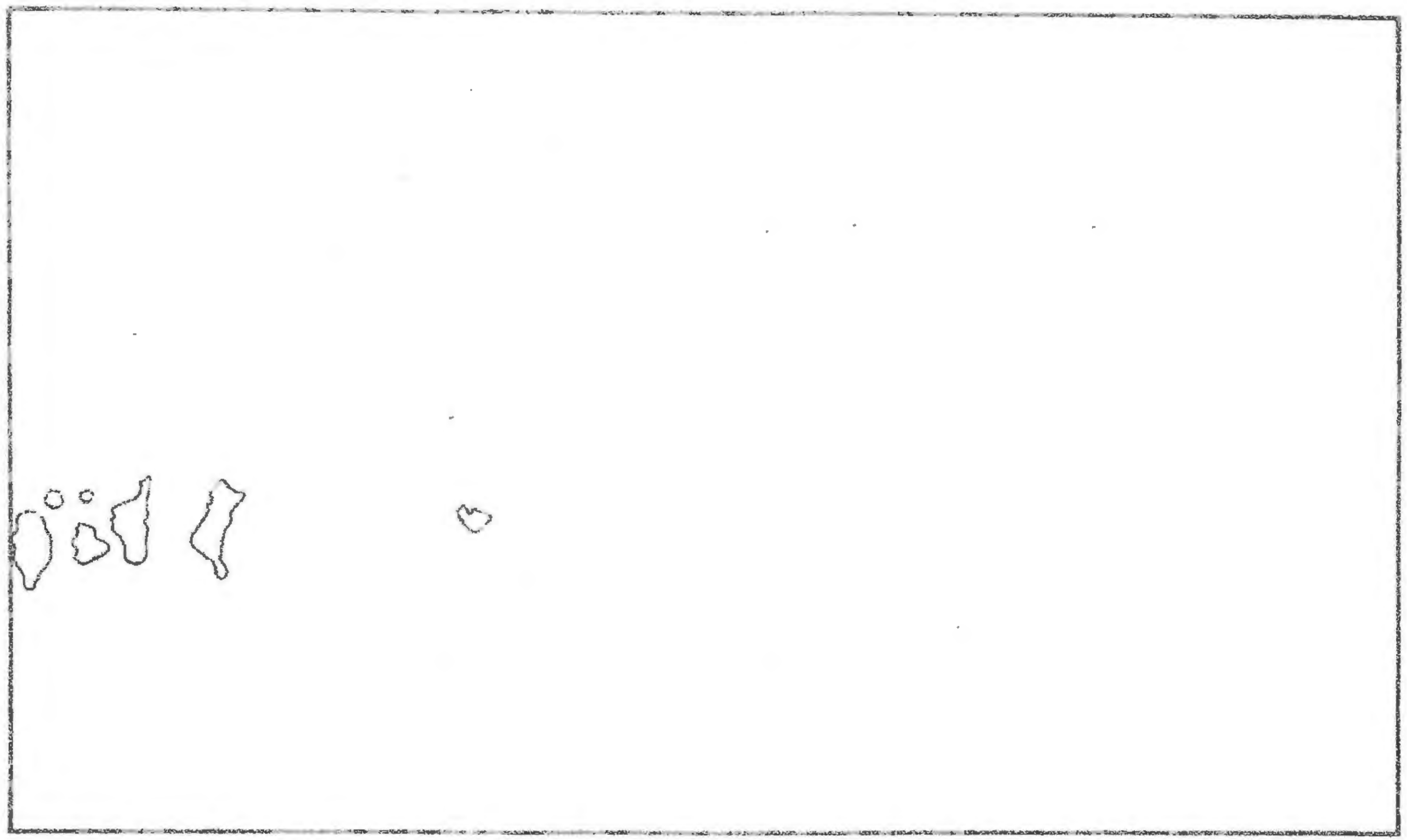
Seven isolated remnants of a dissected valley-floor plain occur in the Rockdale/Meyers Kraal basin (Diag. 28). These remnants are capped by unconsolidated beds of pebbles and boulders (Pettijohn 1957, p.19 - Table of size limits of common grade and rock terms).

The surface of this plain is fairly smooth, and drops in elevation from a maximum height of 1,550 feet above sea-level on the easternmost remnant to a low point of about 1,150 feet above sea-level at the southern extremity of the westernmost remnant - a total change in elevation of 400 feet (Diag. 29). The foregoing applies to the inclination of this plain towards the west in the direction of flow of the New Years River. However, it declines most steeply from north to south, across the basin, at an approximate gradient of 1 in 19. This configuration suggests that the New Years River flowed westward along the southern boundary of the Rockdale/Meyers Kraal basin at the time of deposition of the gravel beds. At some subsequent time, this river and its tributaries were rejuvenated resulting in the dissection of the basin to its present form.

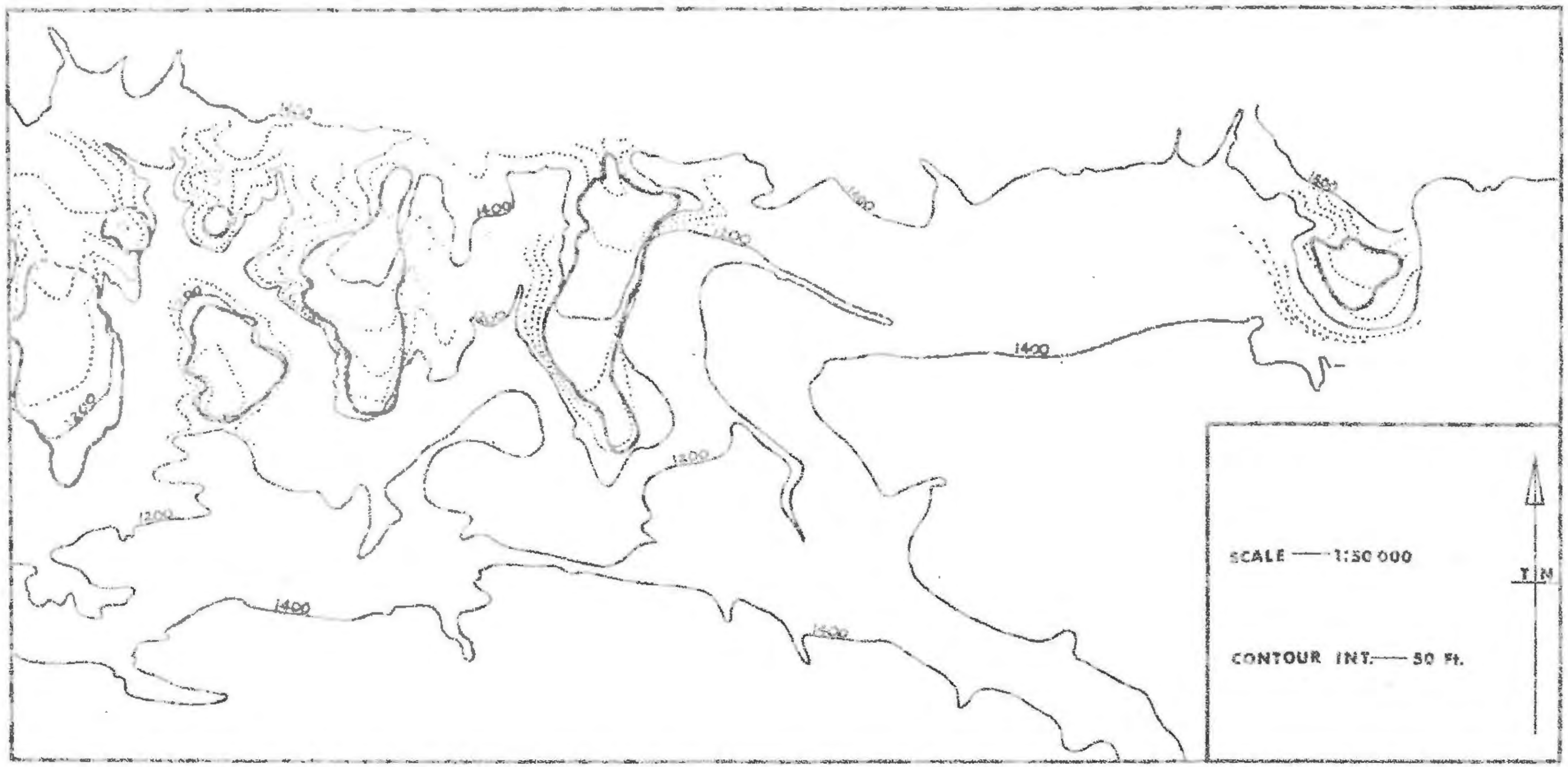
The extent of the gravel plain remnants is fairly easily discernible on both aerial photographs and contoured maps. The boundaries of this plain are characterised by the cropping out of layers of waterworn boulders and pebbles (Plate 8C).

The vegetation on this plain is fairly thick bush that shows no structural control.

DIAG 28



DIAG 29


1400
1400
1300
1200
1400
1400
SCALE —— 1:50 000
CONTOUR INT.—— 50 Ft.
T N

COMPOSITION AND STRATIGRAPHICAL FEATURES

The gravels themselves consist of rounded to subangular boulders and pebbles of a variety of rocks set in a coarse quartzose sand. The rocks comprising the larger fragments are: quartzose sandstone, glazed quartzite and iron oxide stained quartzose sandstone, all derived from the Witteberg Quartzite and a few fragments of the coarser grained rocks from the Lake Mentz Shale and numerous fragments of silcrete. Small limonitic nodules also occur. The fragments generally become smaller upward (Plate 8C). No artifacts were observed. Chattermarking is a fairly common feature on the surfaces of the fragments.

At this stage, little is known about the depth and vertical variations of the gravels. On the borders of one remnant a number of steps were observed extending down to approximately 120 feet below the level of the surface surmounting the gravels (Plate 8D). A few minor steps were also observed in the surface of the gravel-plain itself.

The boulders and pebbles forming the gravels were probably derived from the course of the New Years River. This river and its tributaries contain abundant boulders along their courses of similar nature to those in the gravel beds at the present time.

With the information at hand, the author is unable to comment on the origin of the Rockdale/Meyers Kraal valley-floor plain, or on the processes involved in the accumulation of its alluvial capping.

It is very probable that further remnants of this gravel plain occur to the south and west of the mapped area in the main basin above the Alicedale Poort.

FERRICRETE AND CALCRETE

These surface deposits occur sporadically throughout the area.

Ferricrete tends to occur mainly along the courses of minor streams in discontinuous bands in the banks or across the beds (Plate 8F). It was also observed as horizons in the profile of fairly thickly developed soil (Plate 8E). The rock itself is extremely ragged. It is essentially a gravel and frequently contains an abundance of angular to subangular boulders which vary greatly in size (Plate 8F), and which have been cemented into a hard rock by iron oxides. It is invariably coloured deep red although shades of orange do occur.

Calcrete occurs rarely. It is usually seen as white patches at the surface which, on closer inspection, are found to be due to the occurrence of soft, sandy nodules of calcium carbonate.

SOILS AND MODERN ALLUVIUM AND GRAVELS

The soils of the region have been briefly described with the rocks over which they lie.

Present day alluvium and alluvial gravels are not widespread, and are limited to the usually narrow stream beds. The alluvium itself is generally white to grey in colour and consists predominantly of quartzose sand. Local concentrations of mud give the alluvium a brown loamy character. Mudbanks are fairly common. The modern alluvial gravels consist of rounded to angular fragments of the more massive types of rock. They are limited to stream beds.

S T R U C T U R A L   G E O L O G Y

REGIONAL STRUCTURE

The Grahamstown region lies near the northern extremity of the area affected by the Cape Fold Belt deformation. Approximately twenty miles to the north of Grahamstown all evidences of folding cease to exist. In the area of this present investigation, the intensity of deformation falls off rapidly northwards in the extreme north of the area, from a position corresponding approximately with the trace of the contact of the Cape and Karroo supergroups.

Throughout the area the strata are folded about axes trending a few degrees south of east. Overfolding towards the north is fairly common. Three mappable faults occur in the region.

No tectonic structures were observed in the Cainozoic and younger formations.

Diag. 2(pocket) shows the pattern of deformation in this region in its regional setting.

REGIONAL STRIKE AND OUTCROP PATTERNS

From the description of the outcrop patterns of the various stratigraphic units given under their respective headings, it will be obvious that the principal feature of these patterns is their elongation parallel to the regional strike. However, the outcrop pattern is strongly influenced in detail by fold plunges, the variable intensity of folding from place to place, and topography.

The regional strike was derived in the first instance by plotting on a stereogram the poles of bedding planes from measurements at widely separated points throughout the area (Diag. 33). Poles of bedding in the vicinity of fold crests and troughs were omitted from this diagram. The girdle of poles, so obtained, indicates a regional strike of 108 degrees from true north.

Diag. 34 is a plot of the poles of cleavage planes and it indicates a regional strike of 115 degrees. Since this is presumably independent of fold plunges, it probably gives a more reliable indication of the regional strike.

Diag. 30 (pocket) indicates the positions and orientations of the traces of macroscopic fold axial planes and faults in the region.

FOLDING

Terminology

The area is characterised by a series of macroscopic anticlines and synclines whose style is typified by the Witteberg Quartzite. The enveloping surface (Turner and Weiss 1963, p.111) of these folds, constructed at the level of the top ~~and~~ or bottom of the Witteberg Quartzite, also displays an alternating synclinal and anticlinal form defining, respectively, what may be called, for convenience of description, synclinoria and anticlinoria. The axial planes of individual folds in these synclinoria and anticlinoria, as defined above, are not arranged in regular fan-form in this region.

Incompetent strata locally display folds of mesoscopic dimensions not individually mappable, and these will be described under a separate heading.

Synclinoria and anticlinoria

The distribution of synclinoria and anticlinoria is represented in Diag. 32. Close to the northern margin of the area is a persistent, relatively narrow anticlinorial zone. For the most part, this corresponds in the field to a ridge on the site of the northernmost outcrop of the Witteberg Quartzite in this part of the Fold Belt. The changing direction of plunge on the macroscopic folds in this anticlinorium carries the Witteberg Quartzite beneath the Lake Mentz Shale which crops out in the relatively low-lying central part of it on Van der Merwes Kraal. The structure remains anticlinorial despite the converging plunges of macroscopic folds.

Folding rapidly diminishes in intensity in the Karroo rocks north of this anticlinorium, and thereafter, for some distance, overall dips are northward.

The Riebeek East/Grahamstown basin occurs on the site of a relatively broad synclinorium with an overall east-southeasterly plunge so that the Witteberg Quartzite crops out in the extreme west and Dwyka Tillite and Upper Dwyka Shale in the east.

Along the southern boundary of the Riebeek East/Grahamstown basin is a prominent anticlinorial ridge of Witteberg Quartzite. South of this, in turn, on the site of the Rockdale/Meyers Kraal basin is another synclinorium, and beyond this, to the south, a small portion of a minor anticlinorial structure. In an east-southeasterly direction, the Rockdale/Meyers Kraal synclinorium becomes an anticlinorium across a transitional zone. This change, from synclinorium to anticlinorium, is independent of overall plunge which remains west-northwesterly throughout. The same independence of overall plunge is illustrated by the Riebeek East/Grahamstown synclinorium which becomes an anticlinorium west of Riebeek East and outside the region covered by the present survey. A transitional zone must exist immediately west of Riebeek East. The change from synclinorium to anticlinorium in the direction of regional strike is associated with a change in the relative magnitude of individual synclines and anticlines.

The overall west-northwesterly plunge in the southern part of the region is responsible for the outcrop of Lake Mentz Shale on Rockdale, Roode Krantz and Meyers Kraal and of Witteberg Quartzite and Bokkeveld in the south central and southeastern region.

Macroscopic folds

Macroscopic folds are the mappable folds whose troughs and crests define the envelopes of the anticlinoria and synclinoria.

The outcrops of mappable axial plane traces are shown in Diag. 30 (pocket) and the style of folding illustrated in the cross sections in Diag. 42 (pocket). The variation in the magnitude of individual folds is illustrated by both diagrams. A point of special interest is the fact that close spacing of axial planes of macroscopic folds, such as occurs in the Lake Mentz Shale in the southern part of Meyers Kraal, is not a phenomenon restricted to the incompetent strata, for several of the axial plane traces in this region can be traced along strike into the Witteberg Quartzite on the southern part of Roode Krantz. A similar close spacing of axial planes may be observed in the Witteberg Quartzite on the eastern part of Stoneham. Even the crestal regions of these folds are smoothly rounded and this suggests that they are concentric folds (Plates 8G, 2G). An even closer spacing of fold axial planes is to be observed in the north-eastern region, on the farm Rietfontain where, however, the folding in the Witteberg Quartzite is definitely of the concertina type with angular crests (Plate 2E).

Diag. 30 (pocket) shows also the varying degrees of persistence of folds along strike and it will be observed that in a general way the most persistent folds are those whose axial planes are the most widely separated from those of adjacent folds. Very often the more closely spaced axial planes converge at one or both ends. These converging axial planes are on the whole aligned with the regional strike, except near the points of convergence. Occasionally, converging fold axial planes depart from this rule, for example, on Hilton in the centre of the region.

Along strike the direction of plunge remains, on the whole, strikingly uniform, though in opposite directions in the Riebeek East/Grahamstown synclinorium and the southern part of the map. At two localities however, there is a notable change in the direction of plunge in the north centre on Van der Merwes Kraal and in the central region on Hilton.

Reference to the sections of Diag. 42 (pocket) shows that the folds are frequently inequant. Folds are either upright or inclined. In the latter case, axial planes dip towards the south. Overfolding is concentrated in two main areas, namely in the eastern half of the northern anticlinorium, and the eastern half of the northern part of the southern anticlinorium.

In both instances, the overfolding appears to be linked genetically with a deep synclinal structure on the northern flank.

The structure of Witteberg Quartzite and Lake Mentz Shale in the northern anticlinorium on Vaale Krantz and Van der Merwes Kraal is difficult to interpret. These long ridges of Witteberg Quartzite crop out, sometimes discontinuously, between Lake Mentz Shale, without a recognisable reversal of dip. This does not apply to the wider ridges which are clearly anticlinal.

Where these ridges are crossed by minor kloofs, outcrops show no widening with diminishing altitude on the sides of the kloof as would be expected in an anticlinal structure. The outcrops in the kloofs generally behave as though the beds were dipping towards the south only. The persistence of these narrow ridges over a distance of approximately six miles is remarkable, suggesting that they are associated with faulting. Section EF in Diag. 42 (pocket) and the drawing in Diag. 31A illustrates a possible interpretation along these lines. However, explanation of the detailed patterns of outcrops in the southern ridge requires something more than strike faulting along its northern margin. It is possible that this ridge is intersected transversely by numerous small wrench faults (Diag. 31B).

More specific interpretation would involve a much more detailed investigation in the field than was possible during this regional survey. However, the nature of the outcrops is such that the structural relationship between the Witteberg Quartzite and the surrounding Lake Mentz Shale is likely to remain uncertain.

FAULTING

Very little quantitative data is available from the faults within the area. No actual fault plane was observed. The positions and occurrences of the various faults were inferred from field relationships of adjacent strata and the approximate thicknesses of the various lithological units. Three major faults occur. Besides appearing on the geological map (Diag. 41, pocket), they are also shown on Diag. 30 (pocket).

One of these occurs in the extreme southeast of the area where the upthrown southern block has exposed a fairly narrow and elongate ~~out~~inlier of Bokkeveld rocks. Tributaries of the Broekhuizenspoort river have incised themselves into these rocks forming a deep valley (pp. 11, 17). This fault enters the area on the farm Geelhoutboom, and penetrates for a distance of about four and one half miles past Atherstone station before dying out and passing into Bokkeveld in an anticlinal structure on the farm Palmietfontein. The presence of this fault in the Geelhoutboom valley was inferred from the fact that the Witteberg Quartzite dips towards the Bokkeveld at the contact between the two - an arrangement which can only be the result of faulting. It is probably the continuation of a fault plotted by Mountain in the region immediately to the southeast. It was not possible to determine the hade of this fault.

In the east, a fault on Lot A truncates an Upper Dwyka Shale outlier in Dwyka Tillite for approximately 800 feet where it crosses it oblique to the strike. It does not affect the overlying silcrete.

There is an oblique fault on the boundary between Rockdale and Doorntjes with a westerly downthrow. It is followed by a prominent faultline scarp on Doorntjes.

MESOSCOPIC FOLDING

Mesoscopic folding is common in the less competent, finer grained rocks in the region. Such folds are poorly exposed except in the railway cuttings through Bokkeveld strata near Atherstone railway station. Special attention was paid to these as they afforded an opportunity to discover whether or not the orientations of these mesoscopic folds/were the same as that of the larger structures.

The orientation of a number of the minor structures of the mesoscopic folds was measured and plotted stereographically on southern hemisphere projections. These stereograms are reproduced in Diags. 35, 36, 37 and 38. Diags. 33 and 34 are plots of the poles of bedding planes and cleavage planes based on data obtained from measurements on macroscopic folds throughout the area, and serve to indicate the regional strike. The bearings of regional strike obtained from these diagrams are 108 degrees and 115 degrees, respectively (p.104).

The poles of bedding of mesoscopic folds at Atherstone appear in Diag. 35. The direction of strike is at right angles to the girdle of poles and is on a bearing of 108 degrees. This girdle provides an estimate of the mean value of the plunge which is 8 degrees on a bearing of 108 degrees.

Poles of the axes of mesoscopic folds are plotted in Diag. 36. They display a fair amount of spread corresponding to a mean direction of plunge comparable with that derived from bedding planes.

Diag. 37 is a plot of poles of axial planes of mesoscopic folds and it indicates a mean strike of 112 degrees. It will be seen also that the average inclination of these axial planes is nearly 90 degrees but it may be as much as 55 degrees.

It is clear from these data that the mesoscopic folds at Atherstone are of tectonic origin and originated during the macroscopic folding. Comparison of Diags. 33 and 35 show that the mean plunge of mesoscopic and macroscopic folds is very much the same.

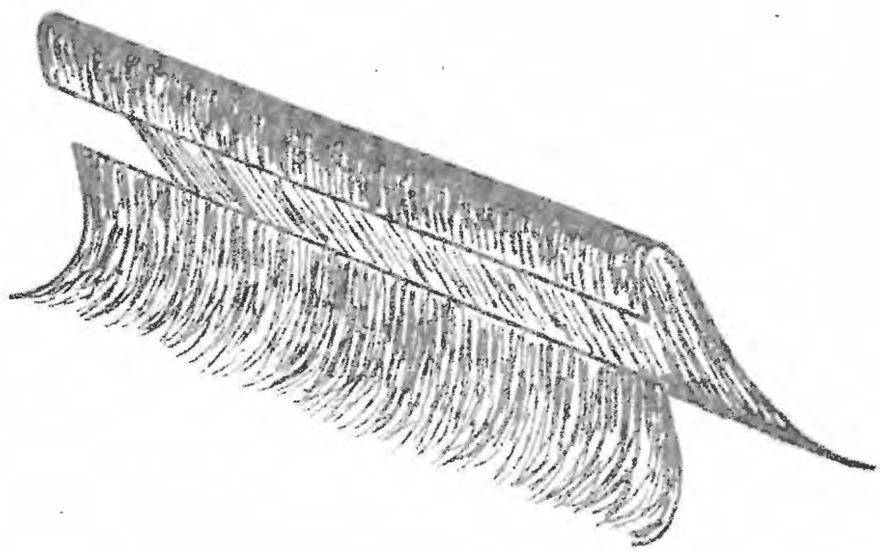
Cleavage is not plotted. It was clear in the field that this was not always parallel to the axial planes in mesoscopic folds but was usually fan-form.

In Diag. 38, minor faults at Atherstone are plotted (dots) and they are shown to be mainly strike faults with considerable variation in dip. Even individual faults may vary in dip. All the faults are upthrust or thrust faults. The poles of slickensiding on these faults are also plotted in Diag. 38 (circles) and indicate that these are, for all practical purposes, dip-slip faults.

Jointing in these mesoscopic folds was not measured as it was not considered to be relevant to the problem in hand.

Diag 31

A



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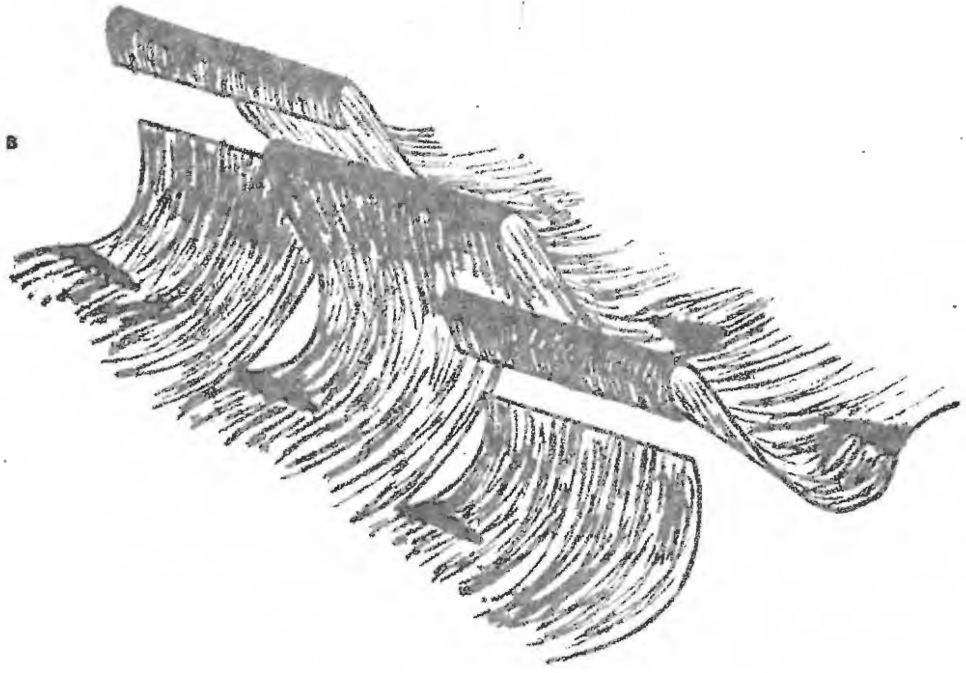
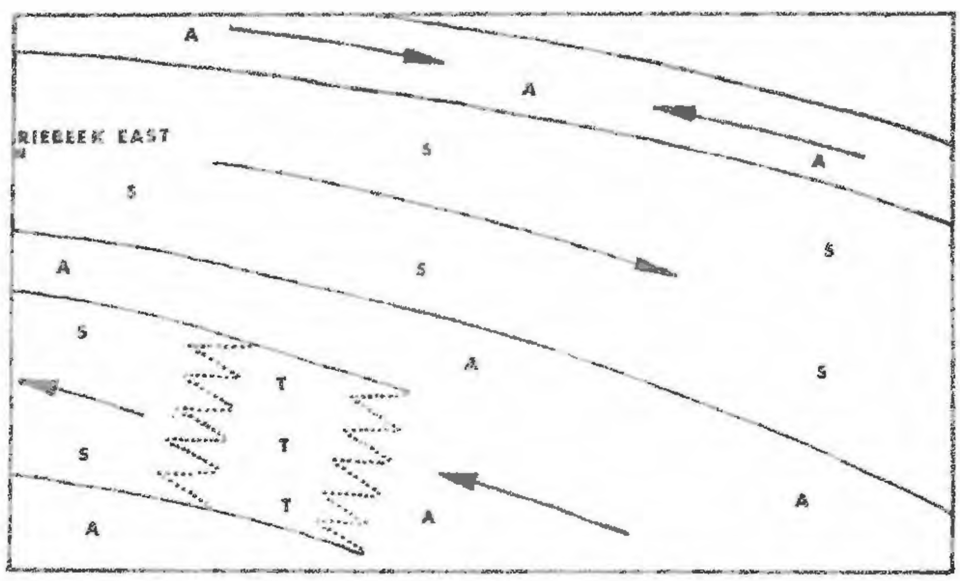


DIAG 32



REFERENCE

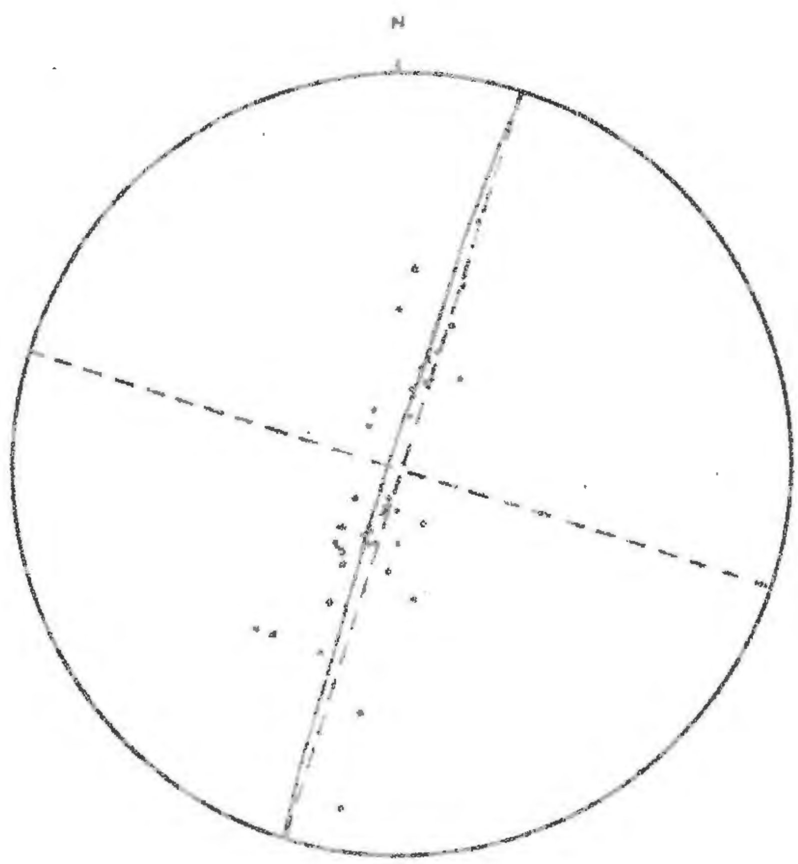
A ANTICLINORIUM

S SYNCLINORIUM

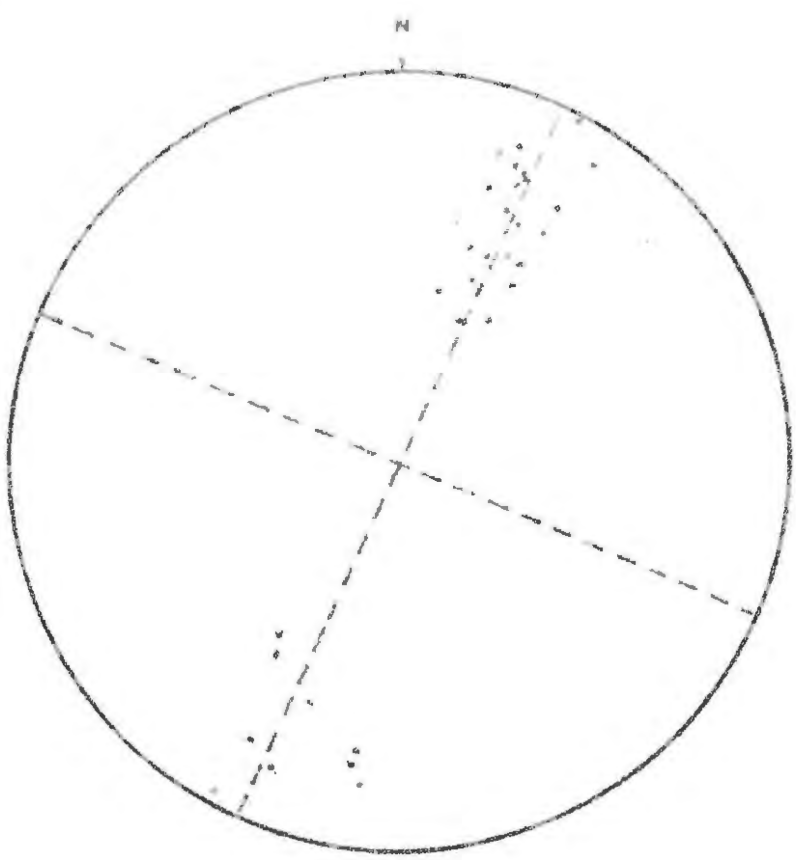
T TRANSITION

PLUNGE

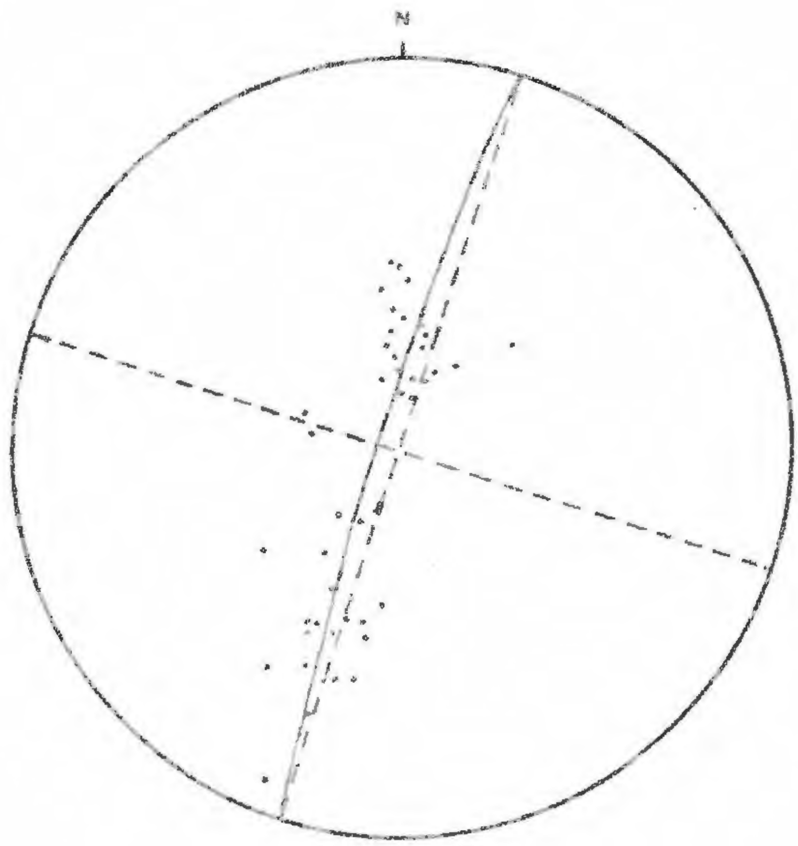
DIAG 33



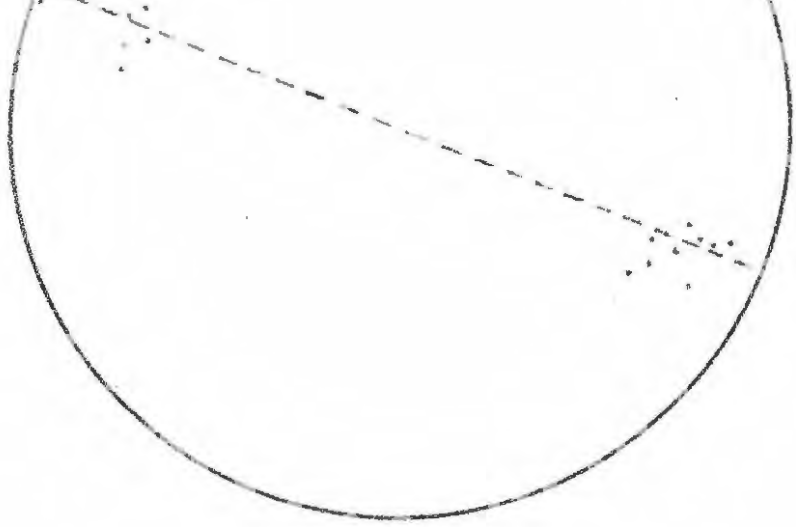
DIAG 34



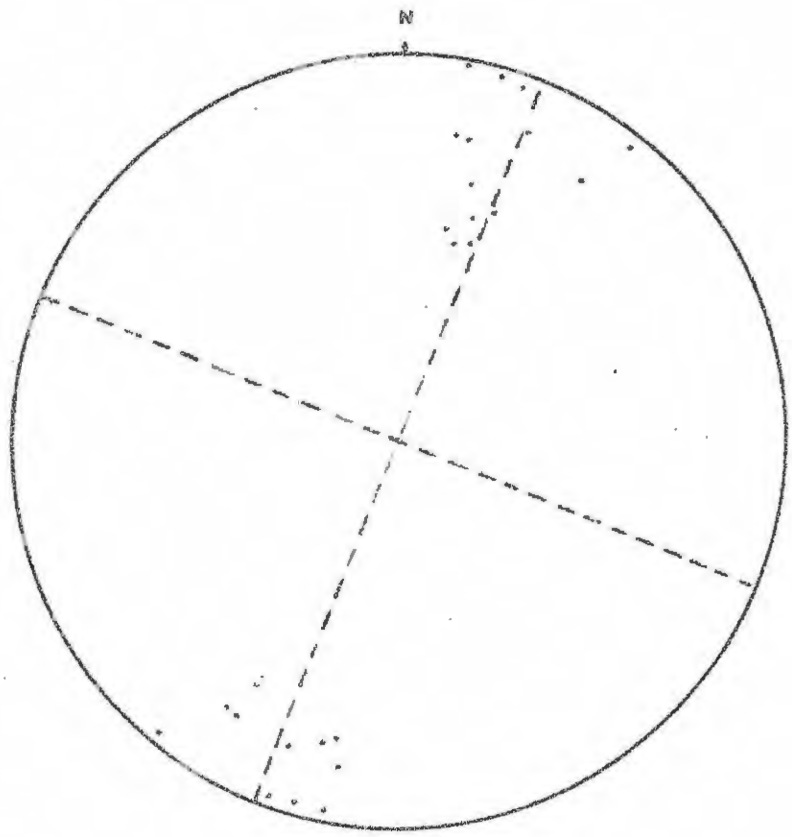
DIAG 35



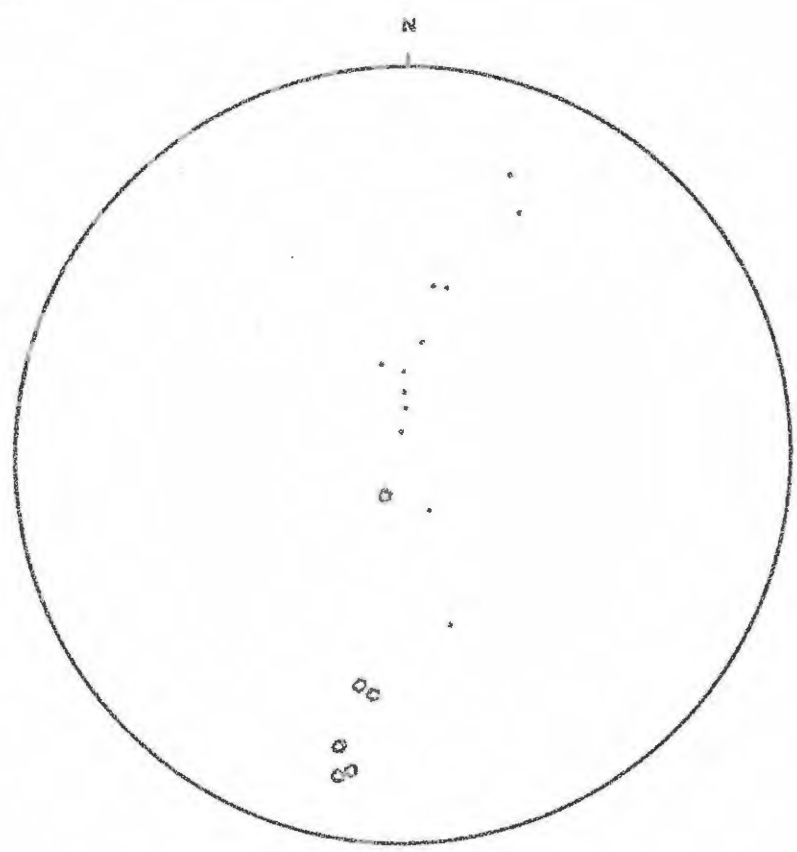
DIAG 36



DIAG 37



DIAG 36



GEOLOGICAL HISTORY

The examination of this area has added little to what is known about the history of Cape and Karroo deposits in the Eastern Cape, that is, the sequence shows no significant differences from that observed by other workers in this and surrounding regions.

Among the younger formations, the most significant feature which arises is the possibility that the Grahamstown peneplain was continuous with the coastal peneplain via the Hilton Poort and the Suurberge/ Highlands range gap near Alicedale (Alicedale Poort). Neither the Grahamstown nor the coastal peneplain silcretes have been reliably dated as yet.

The gravels in the Rockdale/Meyers Kraal basin represent a younger phase of deposition than the silcretes and, as they stand only about 100 feet above the present bed of the New Years River, are probably of comparatively recent age.

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PLATE 1

A. Inclined mesoscopic folds in red quartzose sandstones and sand subgraywackes; the Bokkeveld Group. Locality: northern railway cutting near Atherstone station.

B. Kink-plane in a mesoscopic anticline in predominantly quartzose sandstone bands in the Bokkeveld Group. Locality: Howison's Poort, Grahamstown.

C. A mesoscopic thrust plane in contorted, thinly bedded sand subgraywackes in the Bokkeveld Group. Locality: Howison's Poort, Grahamstown.

D. Undulations in the limb of a mesoscopic fold in predominantly quartzose sandstone in the Bokkeveld Group. Locality: northern railway cutting near Atherstone station.

E. Leached, white sandy clay separated by unleached fairly thin, massive bands of quartzose sandstone; Bokkeveld Group. Locality: northern railway cutting near Atherstone station.

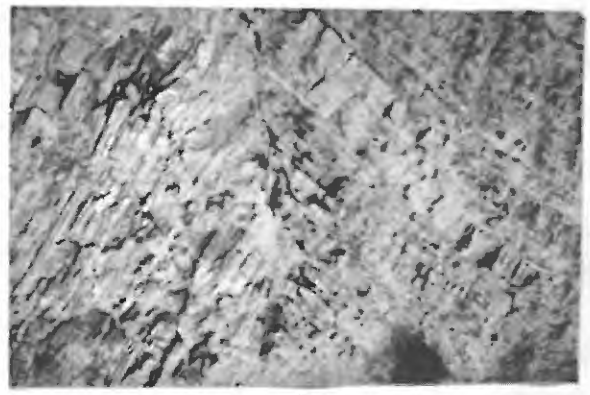
F. Small spheroidal ferruginous concretions, usually arranged parallel to the bedding, in the leached sandy clays in the Bokkeveld strata of Plate 1E.

G. Photomicrograph of the rock Bkv 2 (p.21) to illustrate its characteristic banding (p.26) Notice the general angularity of the detrital quartz grains and the absence of secondary quartz in this fairly fine-grained rock (X250; crossed nicols).

H. Photomicrograph of zoned zircon in the rock Bkv 4 (p.21). This grain shows only slight abrasion (X1,250; uncrossed nicols).

PLATE I

A



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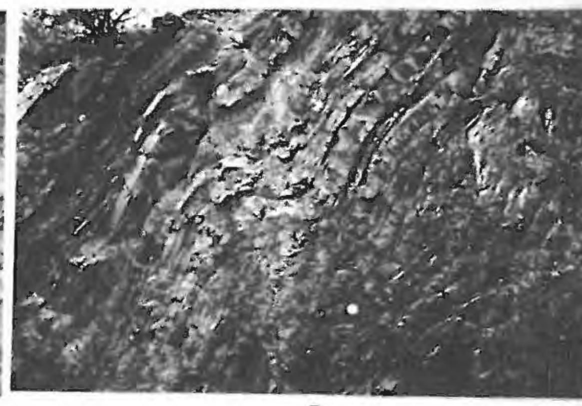

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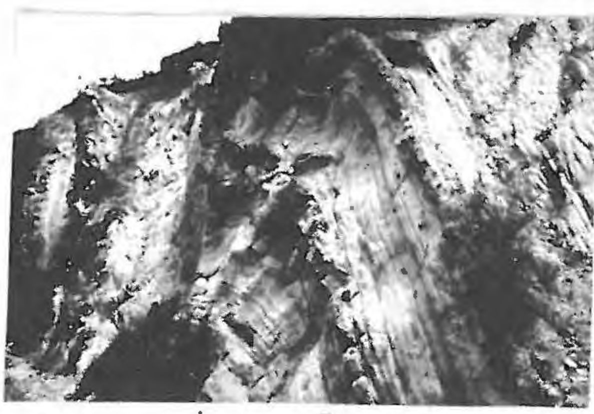

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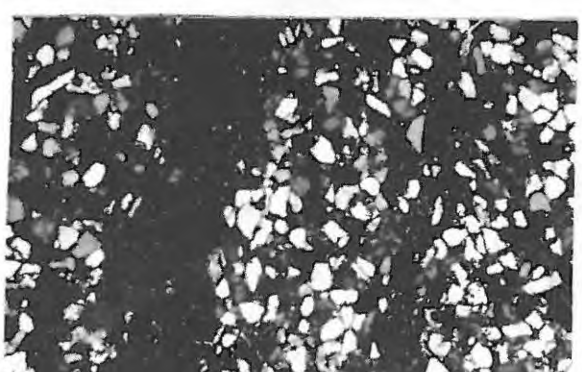

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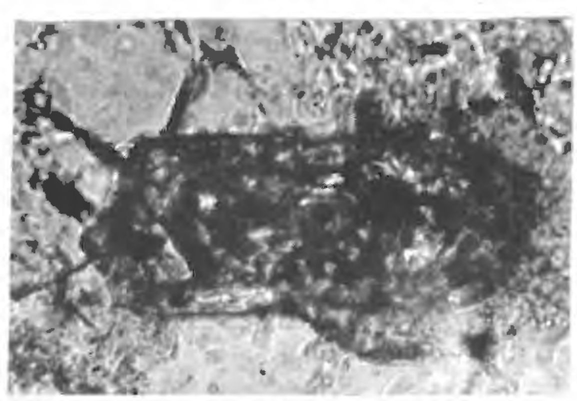

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PLATE 2

A. Photomicrograph of the rock Bkv 6 (p.21). The detrital core of the central quartz grain is separated from a secondary overgrowth in optical continuity with the core, by a thin veneer of matrix material. The remainder consists of anhedral quartz grains with coatings of matrix material, and a twisted muscovite flake (X250; crossed nicols).

B. Photomicrograph of a typical Bokkeveld sand sub-graywacke made up predominantly of quartz grains set in a matrix of sericite and clay minerals (X250; crossed nicols).

C. Photomicrograph taken with reflected light of part of a Bokkeveld thin section showing a rounded grain of detrital rutile, and a few anhedral grains of an indeterminate mineral (X250; uncrossed nicols).

D. Photomicrograph of part of a Bokkeveld thin section showing the development of fine cleavage in the matrix as the result of recrystallisation under stress (X1,250; uncrossed nicols).

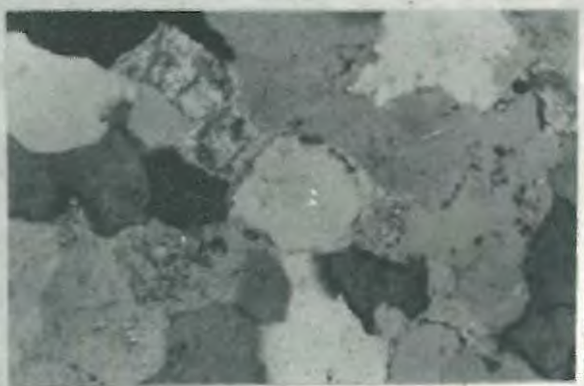
E. Concertina (zig-zag) folding in the Witteberg Quartzite and infolded, elongated outliers of the overlying Lake Mentz Shale. Notice the darker grey-tone of the country overlying the Lake Mentz Shale. The low ground in the middle distance comprises Lake Mentz Shale and Dwyka Tillite and the high ground beyond, Ecca rocks. View towards the northeast on the farm Rietfontain where a tributary of the Brack River cuts through a Witteberg Quartzite ridge.

F. A typical profile of residual soil overlying the Witteberg Quartzite. Notice the ill-defined layers of coarse angular quartzose sandstone fragments, and finer rounded and often red stained quartzite pebbles in the B-horizon. Locality: Grahamstown/Highlands road.

G. An overfolded macroscopic fold in the Witteberg Quartzite with a smooth rounded crest. Locality: Doorn Kloof.

H. View towards the west on Van der Merwes Kraal. The ridge of Witteberg Quartzite in the middle distance is flanked both on its northern and southern sides by the Lake Mentz Shale but dips in the Witteberg Quartzite are all to the south.

PLATE 2



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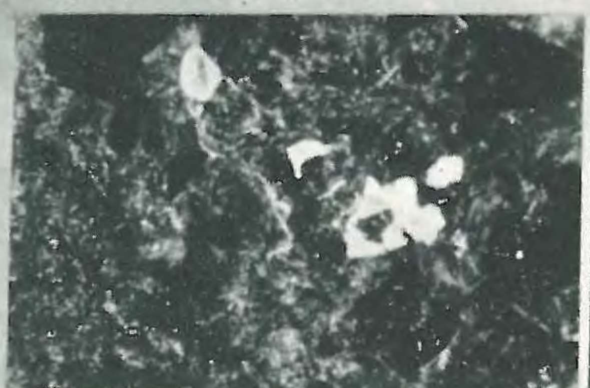

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PLATE 3

A. Cross-bedding in the Witteberg Quartzite. Locality: Grahamstown/Highlands railway line on the farm Geelhoutboom.

B. Overturned cross-bedding in the Witteberg Quartzite. Locality: Grahamstown/Highlands railway line on the farm Geelhoutbocm.

C. Thin to thickly bedded quartzose sandstone and micaceous sand subgraywacke in the Witteberg Quartzite. These well bedded rocks form part of the gradation from massive quartzose sandstone to black carbonaceous shale. Locality: overflow channel, Grahamstown municipal dam, near the boundary of farm Cold Stream.

D. A bed of fossiliferous black carbonaceous shale in the Witteberg Quartzite abruptly flanked by massive quartzose sandstones. Locality: Howison's Poort, Grahamstown.

E. Micaceous sand subgraywacke from the Witteberg Quartzite (sample W Q 2). Locality: Grahamstown municipal dam, near boundary of farm Cold Stream.

F. Quartzose sandstone (sample W Q 5) from the "white streak" (p. 44), Witteberg Quartzite. Locality: Witteklip.

G. Photomicrograph of quartzose sandstone (sample W Q 5) from the Witteberg Quartzite, showing a mosaic of recrystallised quartz grains with both regular and irregular boundaries (X80; crossed nicols).

H. Photomicrograph of micaceous sand subgraywacke from the Witteberg Quartzite showing quartz grains, muscovite and minor matrix (X250; crossed nicols).

PLATE 3

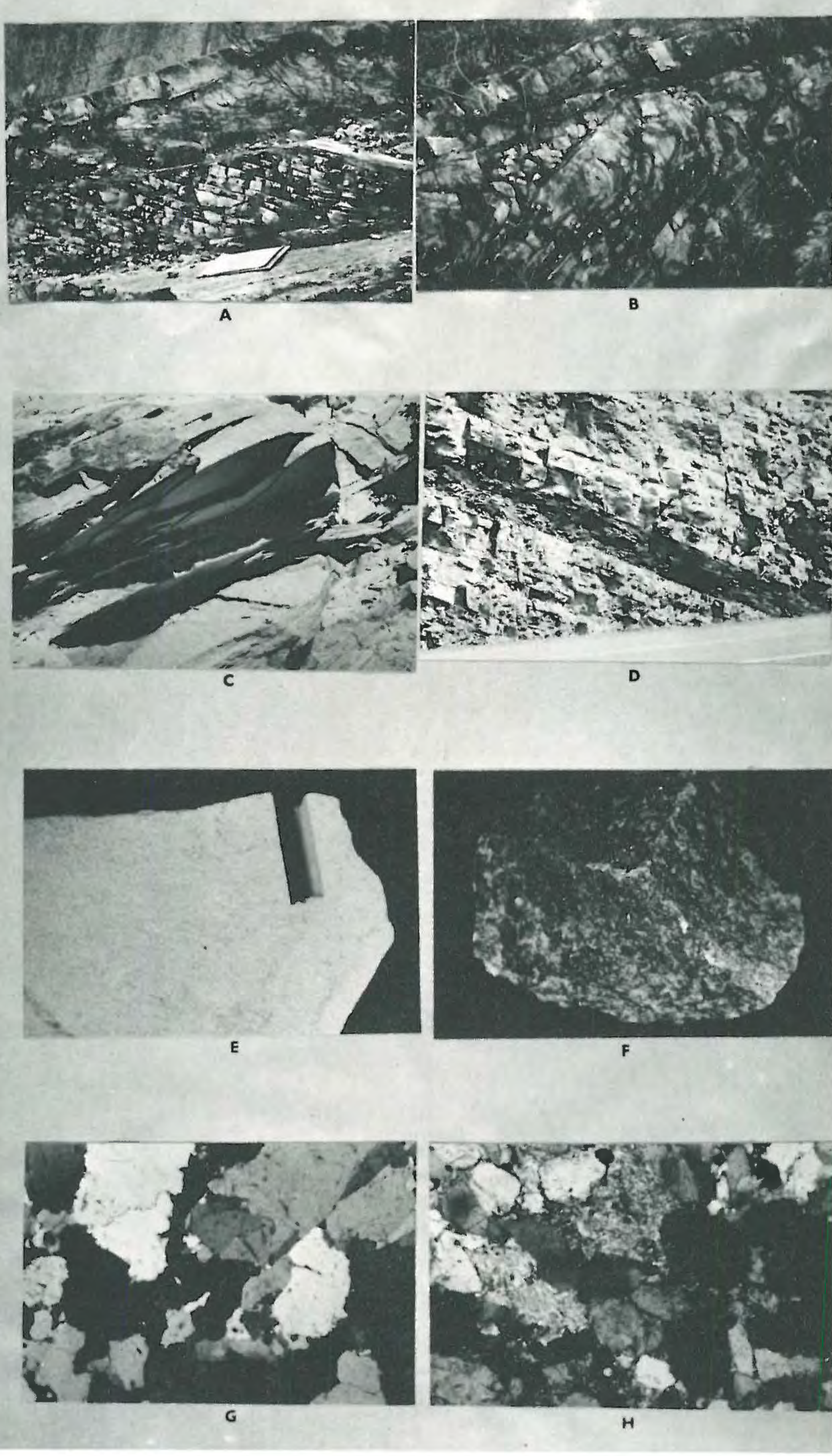

PLATE 4

A. Photomicrograph showing a fragment of a rounded zircon grain in the rock sample W Q 3 from the Witteberg Quartzite. Rutile needles occur in the surrounding quartz (X1,250; uncrossed nicols).

B. Photomicrograph taken by reflected light of an accummulation of heavy minerals (tourmaline, zircon and rutile) showing evidences of abrasion. Rock sample W Q 3, from the Witteberg Quartzite. (X250; uncrossed nicols).

C. Black, laminated carbonaceous shales typical of the Bergplaas Shale Member of the Lake Mentz Shale. Locality: Grahamstown/Cradock road near Hells Poort.

D. Quartzose sandstone and silty sand subgraywacke in a synclinal flexture in the Swartwaterspoort Member of the Lake Mentz Shale. Locality: Hilton.

E. Cliff formed by stream migration and cut into northerly dipping quartzose sandstone of the Lake Mentz Shale. View towards the west. Locality: Meyers Kraal.

F. Quartzose sandstones and silty sand subgraywackes of the Swartwaterspoort Member of the Lake Mentz Shale, exposed in a stream cliff. Locality: Meyers Kraal.

G. Coarse, friable sandstone at the top of the Lake Mentz Shale (left) in contact with Dwyka Tillite (right). This may be a fault contact. Locality: Hells Poort.

H. A fairly large ferruginous concretion in a buff-coloured mudstone not far below the top of the Lake Mentz Shale. Locality: Grahamstown/Cradock road, near the Riebeek East turn-out.

PLATE 4

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PLATE 5

A. Laminated, sometimes flaggy, olive green shales, typical of the Kommadagga Member of the Lake Mentz Shale. Locality: Hells Poort.

B. Highly silicified quartzose sandstone from the Swartwaterspoort Member of the Lake Mentz Shale. Notice the variations in colour, parallel to the bedding, and the white quartz veins. Locality: Van der Merwes Kraal.

C. Photomicrograph of quartzose sandstone from the rock sample L M S 8 from the Lake Mentz Shale. It shows a mosaic of quartz grains. Locality: Van der Merwes Kraal (X250; crossed nicols).

D. Photomicrograph of another part of the thin section in Plate 5C. It shows two stages of growth of secondary quartz. (X250; uncrossed nicols).

E. Photomicrograph of a silt subgraywacke rock sample L M S 3 from the Lake Mentz Shale. Small detrital quartz grains are set in a sericitic clay matrix. Quartz grains are generally angular and secondary quartz is generally lacking. Locality: Meyers Kraal (X250; crossed nicols).

F. Photomicrograph of quartzose sandstone (rock sample L M S 7) from the Lake Mentz Shale. The central quartz grain is a massive detrital grain with a vein of secondary quartz in optical continuity with the core. Strain shadows occur in places at the boundary of the enlarged grain due to clots of clay caught up between the adjacent growing grains. The abundance of secondary quartz, and the well rounded nature of the detrital grains in this coarse-grained rock are points of contrast with the fine-grained rock in Plate 5E. Locality: Van der Merwes Kraal (X250; crossed nicols).

G. View north across strong Dwyka tillite cropping out between depressions of weaker tillite. Locality: Zyferfontein.

H. "Bushman tombstones" in Dwyka tillite. Locality: Brack Kloof.

PLATE 5

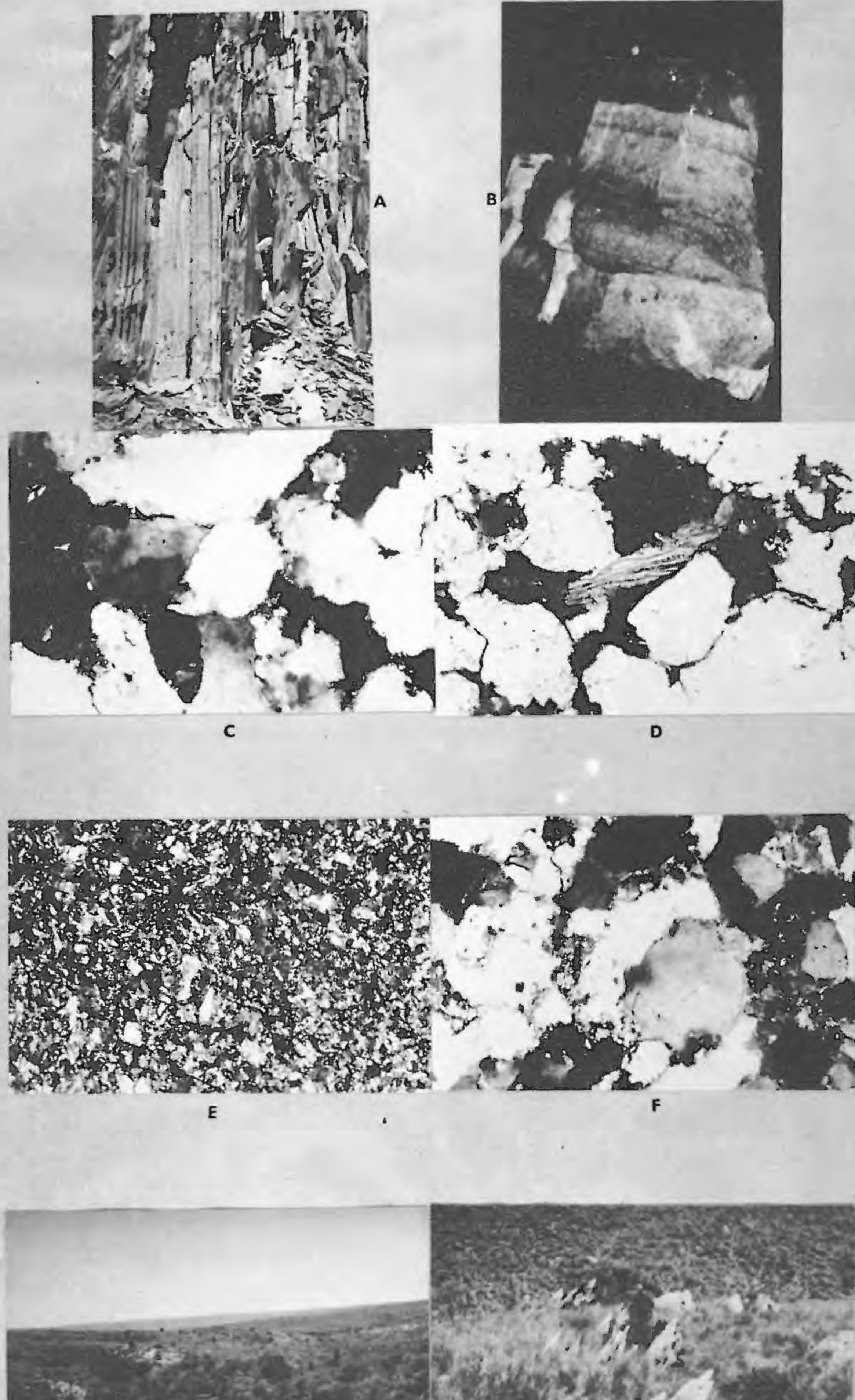


PLATE 6

A. Massive Dwyka tillite. In contrast to this example the larger inclusions usually display the greater sphericity. Locality: Burnt Kraal.

B. Hand specimen of Dwyka tillite. The lowest fragments display characteristic cleavage.

C. Photomicrograph of typical Dwyka tillite. The rock is poorly sorted and the mineral grains comprising it generally angular. (X250; crossed nicols).

D. Concretionary mudstones, resembling sandstones in texture, in the Upper Dwyka Shale. Cleavage dipping south. Locality: Table Farm.

E. Typical cleaved mudstone in the Upper Dwyka Shale. Locality: outlier on Lot A, traversed by the Grahamstown/Cradock road.

F. Photomicrograph of typical shale from the Upper Dwyka Shale. It consists predominantly of sericite, clay minerals and iron oxides. Small angular quartz grains occur. (X250; uncrossed nicols).

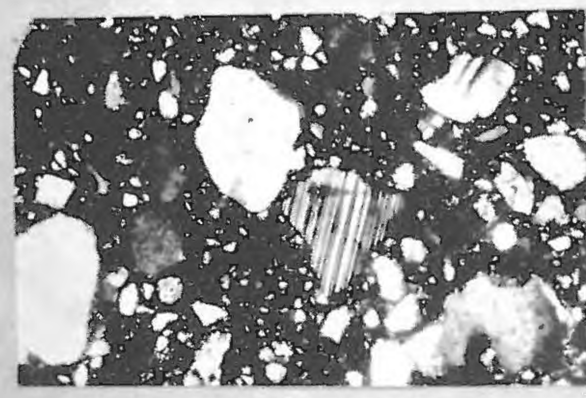
G. Photomicrograph of concretionary mudstone (rock sample U D S 2) from the Upper Dwyka Shale. Iron oxides (opaque) have migrated outward and crystallised along the outer boundaries of the spheroidal concretions, leaving a relatively iron oxide-free, translucent interior. Locality: Table Farm (X250; uncrossed nicols).

H. Plunging mesoscopic syncline in mudstones and shales of the Ecca Pass Formation. The slaty cleavage in the lower part of the photograph is parallel to the axial plane. Note: the rocks in the foreground crop out on a nearly horizontal surface. Locality: Krans Drift.

PLATE 6

A

B



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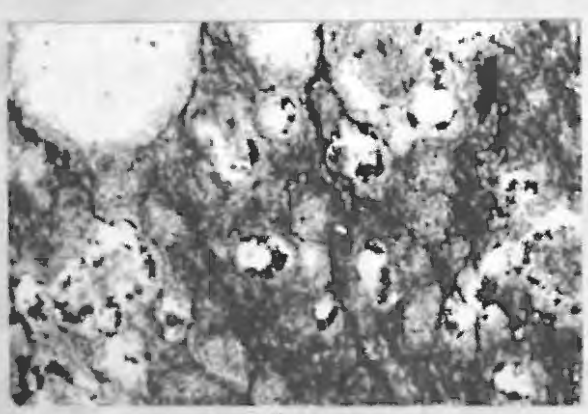

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PLATE 7

A. Photomicrograph of a mudstone (rock sample E C 3) from the Ecca Pass Formation. The constituents are poorly sorted and the grain generally angular. Quartz, orthoclase and plagioclase are set in a fine-grained matrix of sericite and clay minerals. Locality: Rietfontain (X250; crossed nicols).

B. Upper contact of the middle arenaceous member of the Ecca Pass Formation. View from the west. Locality: Kromma Krans.

C. Ledge of relatively rubble-free silcrete, approximately fifteen feet high. Locality: Burnt Kraal.

D. View towards the north across the Grahamstown/ Riebeek East basin from its southern bounding ridge of Witteberg Quartzite on Fancutts. Flat-topped remnants of the silcrete-capped, Grahamstown peneplain occur in the middle distance.

E. View towards the south of Leeukop and its capping of silcrete, near Riebeek East.

F. View towards the east from the summit of the Riebeek East Mountains on ALY.Q.3.21. Silcretes reach 2,900 feet above sea-level on the distant sky-line.

G. A photograph of silcrete rubble consisting of fragments of Witteberg Quartzite quartzose sandstone in a silicified matrix.

H. Rubble-free silcrete showing the characteristic hummocky form of its outer exfoliated surfaces.

PLATE 7

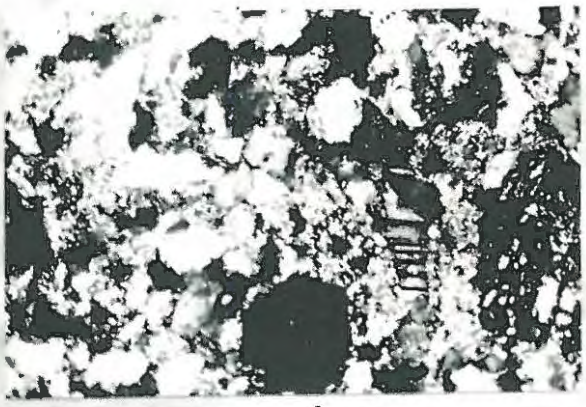

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PLATE 8

A. Photomicrograph of typical buff-coloured silcrete. It consists of generally angular grains of various minerals, predominantly quartz, set in a matrix of cryptocrystalline silica (X250; crossed nicols).

B. Photomicrograph of ferruginous silcrete (rock sample S 3). It consists of fairly large, irregular grains of quartz cemented by iron oxides (X250; crossed nicols).

C. Terrace gravels in the Meyers Kraal/Rockdale basin. Composed mainly of quartzose sandstone fragments displaying various degrees of abrasion and tending to diminish in size upwards. The matrix consists predominantly of grey to white sand. Locality: Roode Krantz.

D. Gravel steps in the ascent to the main gravel-capped terrace in the Meyers Kraal/Rockdale basin. Locality: Meyers Kraal.

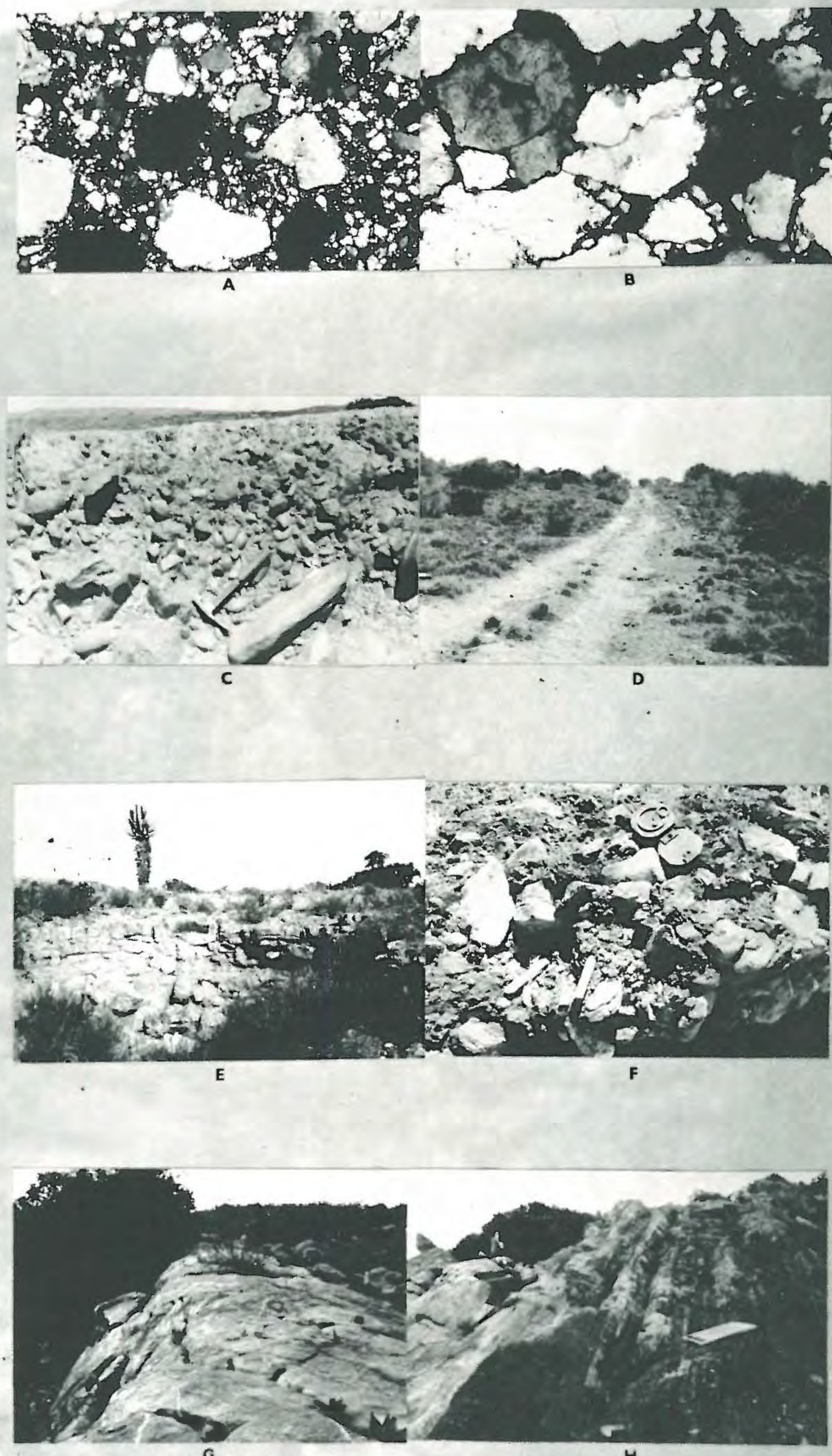
E. Ferricrete on Doorntjes.

F. Ferricrete rubble, occurring frequently along water courses. Included fragments of predominantly Witteberg Quartzite quartzose sandstone usually show evidence of abrasion.

G. The smoothly rounded crest of a macroscopic anticline. Quartz veins trend predominantly parallel to the strike. Locality: Stoneham.

H. Deeply grooved and slickensided bedding plane in quartzose sandstone of the Witteberg Quartzite. Dip towards the observer. Locality: Doorn Kloof.

PLATE 8



A B C D E F G H