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A COMPARATIVE PETROLOGICAL STUDY
OF SOME SEDIMENTARY ROCKS FROM SOUTH
AFRICA AND THE SURROUNDING CONTINENTS
AND THE SIGNIFICANCE OF THEIR HEAVY
MINERAL CONTENTS

by

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(1960)

This thesis is presented in partial fulfilment of the requirements for the degree Magister Scientiae in the Faculty of Science at the University of the Orange Free State.

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A COMPARATIVE PETROLOGICAL STUDY OF
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A B S T R A C T

The heavy residues, the light constituents and grain size of 150 samples of Devonian to Jurassic sandstones, conglomerates, tillites and siltstones were studied. Most of the samples were collected in South Africa but a number were obtained from Australia, Tasmania, Brazil, Antarctica and the Falkland Islands. The South African Cape System (Devonian to Carboniferous) residues were found to be quite different from those of the Karroo System, but the residues of the two groups are remarkably uniform in composition. The Cape System is characterised by an essentially simple assemblage of heavy minerals, the Table Mountain and Witteberg Series usually containing small percentages of red zircon. The Karroo System, on the other hand, is characterised by the presence of garnet, a rare mineral in other South African

sedimentary rocks. The concentrates of these two systems resemble the concentrates of the equivalent Brazilian, Antarctica and Falkland Island rocks. Especially close is the resemblance between the South African and the Falkland Island samples, indicating similar source rocks, tectonism and conditions of sedimentation. Whether the two regions once formed part of the same sedimentation basin cannot be deduced from the evidence available at present. The technique used is fully described and discussed.

INTRODUCTION

The remarkable sedimentary assemblage, known as the Gondwana System, occurs in all the continents of the Southern Hemisphere as well as in India, Madagascar and the Falkland Islands. It was deposited mainly in a continental environment during Carboniferous to Jurassic times and the lithological resemblance between the various parts is so striking that many geologists believe that the continents once formed part of a single continental mass, which Suess (1885) named Gondwanaland.

Certain features of the Gondwana System, such as lithology, palaeontology, palaeoclimatology and

tectonism, have been studied in detail, but information on the heavy mineral content is extremely scanty. In this study, heavy minerals as well as the significant light minerals of a large number of sandstones, conglomerates, tillites and siltstones have been examined. Samples were collected in all the provinces of the Union of South Africa and South West Africa. The overseas samples were obtained from various organisations and individuals.

Very little has been published about heavy mineral investigations in South Africa. Heavy minerals have been recorded in Cape and Karroo sedimentary rocks and isolated studies were conducted by Swiegers (1939), Conradie and Rabie (1944), Uys and Reitz (1944), van Coppenhagen (1944), Strydom (1944), Potgieter (1944), Swart (1950) and McIver (1957). The most comprehensive investigation up to date was made by Koen (1955).

As the area, from which the South African samples were obtained, is so vast (fig.1) my aim was to determine only the main characteristics of the systems. Once these are known, future studies of particular series or stages can be oriented within the broad framework of the large-scale investigation.

TECHNIQUE

One or more thin sections were cut from the sample. Another portion of the sample, weighing approximately 50 grams, was carefully crushed in an iron mortar and frequently sieved (0.42-mm sieve) until the whole of this portion had passed through the sieve.

This crushed sample was then weighed. The dust was removed by panning and, at the same time, slightly more than one half of the light fraction was carefully panned off. The material retained in the pan was dried and separated into light and heavy fractions by means of bromoform (s.g. 2.9).

Four funnels (5 cm in diameter), each fitted with a small length of rubber tubing and a pinchcock, were used for the separation. Approximately 6 gm of panned concentrate was separated in each funnel. The contents of each funnel were well stirred and the heavy minerals were then allowed to settle. The stirring was repeated ten times.

The heavy minerals were drained off into a 50-ml beaker and left to settle. The clear bromoform above the heavy minerals was carefully decanted into the bromoform stock bottle and alcohol was added to the remaining bromoform in the beaker. The resultant

lighter liquid was decanted into the bromoform residue bottle. The bromoform bearing the light fraction in the separating funnel was then drained through filter paper into the stock bottle. The bromoform still adhering to the light mineral grains and in the filter paper was washed out with alcohol and the washings collected in the residue bottle. The light fraction was discarded, as thin sections were used, in preference, for the study of the light minerals.

The heavy mineral concentrate was then dried and the metallic iron grains removed with a hand magnet. The metallic iron grains were acquired from crushing in the iron mortar. The weight of the concentrate was then determined and the heavy mineral content was computed as a percentage of the sample used.

Quartered portions of the heavy mineral fraction were mounted in various refractive index liquids and the minerals present were identified under the microscope. Another quartered portion was mounted in canada balsam on a microscope slide. The grains in this slide (usually more than one slide was necessary) were counted in the following way.

Several fields were selected and all the grains in each field counted until a total of about 500 grains had been counted. The information obtained is given as the number of grains percent. (tables 1 to 5). The percentages were recorded in whole numbers, since fractional percentages suggest an accuracy that did not exist. The slides were kept for reference purposes. The portions of the heavy mineral concentrate used for the solid and liquid mounts were obtained by quartering the concentrate with a sharp knife.

It is not only the heavy concentrates that are of importance in the study of provenance of sediments; the light fractions are equally significant. For instance, feldspar, mica and detrital graphite that occur in the South African Karroo System provide valuable and indispensable information on the history of the system.

The light fraction was studied mainly in thin section and in refractive index liquid mounts of the original sample. The point counter method of Chayes (1949) was used for the micrometric analysis of the thin sections. Since quartz and feldspar are sometimes difficult to distinguish in thin sections of sedimentary rocks, the percentages

were recorded to the nearest multiple of five percent. Only quartz, feldspar and rock fragments were counted. Carbonates, chloritic and sericitic material and mica were noted, but were not taken into account in the nomenclature unless they represented a very large proportion of the rock. The nomenclature used (tables 6-8) is that proposed by Pettijohn (1957, p.291). Hand samples were examined to ascertain the presence of graphite and clay pellets.

The average roundness of the light and heavy mineral grains was determined by the visual method, using the scale (letters A to E) described by Pettijohn (1957, p.59) and Heinrich (1956, p.103) namely:- A, angular; B, subangular; C, subrounded; D, rounded and E, well rounded. The presence of idiomorphic grains were also recorded in the tables.

The mean diameters of 50 grains were measured to determine the average grain size of each rock. The same procedure was followed to determine the average grain size of the individual heavy minerals.

DISCUSSION OF THE TECHNIQUE

An investigation was made to determine the most suitable technique to be followed for the study of heavy minerals in rocks of the Cape and Karroo Systems.

Problems relating to: (1) the weight of sample, (2) the crushing and sieving method, (3) the panning procedure, (4) the bromoform separation, (5) the recovery of bromoform, (6) the heavy mineral counts, (7) the use of statistical methods for the presentation of the results, and (8) the variation of the heavy mineral concentrates within one sandstone stratum, were investigated and the results are discussed below.

For the following investigations a large (3 kg) sample of Middle Beaufort sandstone (sample 39) was crushed to minus 0.42 mm and quartered portions of this sample were used.

(1) Weight of sample

To determine the most satisfactory weight of sample for study, three portions of the sample (A, 20 gm; B, 50 gm; C, 646.5 gm) were used. Dust was removed from all the samples by washing. Samples B and C were further panned to one half and one twentieth, respectively, of their original weight.

The samples were then separated by means of bromoform. Approximately 6 grams of washed or panned concentrate was used per funnel and stirred 10 times.

The total percentages of heavy minerals recovered were 1.4620 per cent, 1.4588 per cent and 0.2945 per cent, respectively. The heavy mineral contents of A and B were the same (within experimental error), whilst that of C was appreciably less. This marked difference in content is due to the greater degree of panning in the case of C (See Panning procedure below).

This sample (No. 39) yielded a very large concentrate. The percentages of heavy minerals obtained usually range between 0.05 and 0.50 percent. A 60-gm sample normally yields a sufficient concentrate for study and this weight was therefore used in the study.

In cases where the concentrates were found to be too small, a 100-gm sample was used, panned to a half, and separated in eight funnels.

(2) Crushing and sieving method

Careful crushing and frequent sieving is necessary to avoid an excess of rock flour and possible breakage of the heavy mineral grains.

This procedure was kept as uniform as possible for all the samples, so that the results would be comparable. (Tyler and Marsden, 1937. pp. 3-9).

The use of various size fractions has been advocated by some petrologists in order to eliminate the effects of granular variation and to restrict the grades used to those which can be examined conveniently under the microscope. Van Andel (1950) uses the whole 0.5 to 0.06-mm fraction whilst Sindowsky (1949) examines the grade containing the largest amount of sand and the two successive finer grades. Rubey (1933) again would consider it advantageous to use the whole heavy concentrate, if sorting were the only factor that affected the size distribution of the minerals, but for practical reasons he selects two fractions, one representing the same actual grain size and the other representing the same relative grain size in each sample. In the present study it was found that the average grain size of all the heavy residues, except those of the river sands, was much smaller than 0.5 mm, which is the size of the largest grains which can be examined conveniently under the microscope. The whole of the concentrate could therefore be studied.

To determine whether the study of a finer size grade would yield a result truly representative of the sample used, a portion of the sample (No. 39) was further sieved through a 0.074-mm sieve. The two fractions (D, 0.42 - 0.074 mm; E, minus 0.074-mm) were separated in an identical manner. Fraction D yielded a concentrate which represented 1.1160 per cent of the original sample whilst fraction E yielded a concentrate representing 0.2873 per cent of the same sample. It can thus be noted that the heavy minerals are not necessarily concentrated in the smaller size grades as postulated by Koen (1955).

In addition to the great differences in the heavy mineral percentages obtained from D and E, these two concentrates also differed greatly in composition. The concentrate obtained from D consisted of garnet and small percentages of apatite, zircon, rutile and tourmaline whilst the concentrate from E consisted of anatase with a small percentage of zircon.

The results obtained from the use of a size grade smaller than about 0.35 mm would not be comparable unless the size distribution of the different heavy minerals was identical in all the samples studied.

Crushing the whole sample to minus 0.42 mm would result in the breakage of a certain proportion of the heavy mineral grains but it was observed that this proportion was always small. In thin section it was noticed that some of the grains were already cracked in the rock, and these grains would be broken, whatever procedure was used.

The tillite samples are extremely tough and their disintegration could only be effected by crushing the whole sample to a predetermined fineness. The other more friable samples therefore had to be treated in the same way for the sake of uniformity. The coarse river sands were likewise crushed to minus 0.42 mm. This treatment of the coarse river sands alters the mineral percentage values but the results are sufficiently accurate for the requirements of this investigation.

Size analyses of heavy residues are sometimes carried out in order to solve certain problems relating to the history of the sediments. Thus Doeglas (1946, 1950) has been able to show whether a sediment has originated by the mixing of two components or by differentiation. This technique seems to be of value mainly in determining small

scale features and not in regional studies, and it has therefore not been used in the present investigation. Van Andel (1950) states: "Sedimentary petrological research can be carried out perfectly well with the aid of normal analysis. Special problems may in some cases be solved advantageously by means of fraction analysis."

(3) Panning procedure

Panning to half the original weight is justified by experiment, (See Weight of sample above), and is in accordance with the method of Holmes (1930, pp.69-70). As the method of separation of samples A, B and C was similar in all respects, with the exception of the degree of panning (A, dust removed; B, panned to one half; and C, panned to one twentieth), the differences in their respective heavy mineral contents (A, 1.4620 per cent; B, 1.4588 per cent; and C, 0.2945 per cent) could only be ascribed to the degree of panning.

Panning to a one half is thus permissible as the heavy mineral content is the same as for the unpanned sample (A). Ewig (1931, p.140) agrees that the loss of heavy minerals by panning is negligible if continued only to one half or even one third of the original weight. The panning procedure was kept as

uniform as possible so as to comply with the factors discussed by Smithson (1930, p.136).

(4) Bromoform separation

Four funnels (5 cm in diameter) are employed for the separation since one 500-gm bottle of bromoform adequately fills them.

The following investigation was made to determine the weight of sample that can be separated efficiently in one funnel. Two portions (F and G) of the sample (No. 39) were divided (by quartering) between 8 funnels for each sample. Different weights of sample were introduced into each funnel. Sample F was stirred three times and sample G ten times. The results obtained are graphically represented in figure 2. From the figure it can be seen that samples up to 6 grams can be separated in one funnel, if stirred ten times, and still retain the same degree of accuracy as 3 grams of sample per funnel stirred three times.

If about 6 grams of sample per funnel (stirred ten times) were used, the percentage error (difference between the absolute experimental heavy mineral content and that obtained) would be less than one percent per funnel. Greater errors could be expected

from other sources such as sampling, crushing, sieving, quartering of the concentrates for microscopic slides and grain counting.

The method of separation for sample G (stirring ten times) is time consuming. For the separation of the same amount of sample stirred three times however, approximately twice the number of funnels would be necessary in order to retain the same degree of accuracy. The use of more funnels increases the time necessary to complete the separation as well as the amount of bromoform used.

(5) The recovery of bromoform

The bromoform mixed with the alcohol in the residue bottle is recovered by means of the method used by Ross (1926, p. 456) and Twenhofel and Tyler (1941, p.71). This method entails the addition of a large volume of water to the bromoform-alcohol mixture and shaking well. The water mixes with the alcohol in all proportions to form a light liquid. The bromoform can thus be drained off in a separating funnel. Water still dispersed within the bromoform is removed by filtration through several thicknesses of filter paper and the bromoform is returned to

the stock bottle. Discoloration of the bromoform is removed by the addition of solid potassium hydroxide (KOH), shaking well and filtering off the resultant yellow precipitate.

Twenhofel and Tyler (1941, p.81) judge the losses of bromoform in one separation to be between 3 and 10 per cent. In this study the average loss of bromoform in one separation was found to be 5 per cent.

(6) Heavy mineral counts

The portions of the heavy mineral concentrate used for the solid and liquid mounts were obtained by quartering the concentrate with a sharp knife. Otto (1933, pp. 30-39) criticises this method severely. In order to lessen the error a number of mounts were made for the counting of one sample.

According to Dryden (1931, p.233) the accuracy of the counts increases as the square root of the number of grains counted. He advocated the counting of 300 grains, but on account of the possible error in the quartering of the heavy mineral concentrate, 500 grains were counted in this study.

Some authors use other methods of counting the

grains and presenting the results. Petrologists of the Dutch School (Doeglas, van Andel and others) count the grains by moving the slide along parallel lines by means of a mechanical stage and noting the grains which touch the crosshairs. The results obtained by this method will not be percentages by number, as the value for large grains will be increased and that for small grains decreased. As the numbers obtained have no precise meaning, the method of the Dutch authors has not been used.

Grains smaller than 0.03 mm are not easily identified under the microscope and are therefore not included in the heavy mineral counts. Many of these grains are probably removed by panning as only a small number were encountered.

(7) Statistical methods of presentation of the results

In order to compare heavy mineral analyses, some authors use statistical methods. Examples of such statistical methods are Eisenhart's (1935) chi-square test for homogeneity and Dryden's (1935) co-efficient of correlation. Refinements of these methods and other methods have also been used by Pettijohn (1931), Cogen (1935) Smithson (1939), Rittenhouse (1943), Manning (1953), Kellager and Flanagan (1956), Carrol (1957) and Poole (1958).

These methods are time consuming and although they may be of value in the study of suitable problems they have not been attempted in the present investigation for the following reasons: (1) Granular variation amongst samples of varying grain size would make comparison by statistical methods of little value. (2) Variations of composition cannot be studied quantitatively unless the stratigraphical as well as the geographical position of each sample is accurately known. In collecting samples for the present study it was often impossible to determine the precise stratigraphical horizon of an outcrop, due to poor exposures in the area. (3) Differences in the composition of the samples may be caused by differences in the degree of weathering and this factor cannot be evaluated quantitatively. Although relatively unweathered samples have been collected wherever possible, in some localities only somewhat weathered ones were available. The concentrates of the weathered samples usually carry a relatively large proportion of opaque grains consisting of iron and manganese oxides, and other undefinable minerals.

In practice it has usually not proved difficult to draw conclusions from mineralogical data, sometimes with the aid of simple graphs and diagrams.

(8) Treatment of the concentrates with acid

A further question which had to be settled in connection with the procedure, was the advisability or otherwise of treating the heavy minerals with acids. Acid treatment cleans the grains and facilitates their identification but it destroys certain diagnostic minerals such as apatite. As no particular difficulty was encountered in identifying the minerals present, acid treatment was not used.

(9) Variations of the heavy mineral concentrate within one sandstone stratum

An investigation was made to determine to what extent the heavy mineral concentrates vary horizontally and vertically in one sandstone stratum.

For this purpose six samples (Nos. 46 to 51) were studied. Samples 49, 50, 46 and 51 were taken at intervals of one mile along the strike of the outcrop whilst samples 47 and 48 were taken 20 feet above and 10 feet below sample 46 respectively. The results are given in table 2.

The total percentages of heavy minerals in the samples differed rather greatly (0.06 - 0.30 per cent). These differences could not be ascribed to experimental error though it may have played a subordinate role. The source of this discrepancy

is thought to be due to natural conditions during the deposition of the sediments.

The composition of the heavy mineral concentrates have a remarkable qualitative similarity and although they differ quantitatively to a small degree, these differences do not appear to show any special relationship to their relative positions in the stratum.

The differences encountered in the composition of the heavy mineral concentrates are of the same order of magnitude as those found among samples from the same stratigraphic horizon over long distances.

This test shows that differences in heavy mineral composition can be expected for sandstones from widely separated localities although they may have been derived from the same source rocks. Similar concentrates are indicative of similar source rocks, although differing concentrates may be derived from the same source rocks. These differences are ascribed to a number of factors such as weathering, conditions of transportation and sedimentation, intrastratal solution, and depth of burial.

DESCRIPTION OF HEAVY MINERALS

(1) Apatite

Apatite appears in small quantities in most of the Karroo samples and in three Bokkeveld samples and the Nama (Cambrian) sample. The apatite grains are usually clear and colourless, though some grains appear turbid as a result of minute inclusions. The grains are either rounded, elongated, idiomorphic or egg-shaped. Sometimes they contain small inclusions which are parallel or perpendicular to the crystallographic c axis, or clustered about the centre of the grains. Grains exhibiting definite prismatic faces with rounded terminations are plentiful in some concentrates.

(2) Garnet

With the exception of five samples (Nos. 19, 26, 30, 35 and 69), garnet occurs throughout the Karroo succession in varying quantities. It appears as a very small percentage in some Recent river sands (Nos. 3 to 5) and has been encountered in only one Cape System sample, the tillite band in the Table Mountain Series (No. 96).

Most of the grains appear colourless to pink

under the microscope, some grains showing signs of staining and superficial deposits of weakly anisotropic material. The grains are commonly angular, often fractured, and rarely well rounded. Rounded grains are sometimes present in samples of the Cave Sandstone Stage.

Distinctive surface features such as pitting, grooving and hillocks, reminiscent of etch patterns, are plentiful. Similar surface features have been noted by Sauer (1900, pp 42-46), Bosworth (1913, p. 57), Meckie (1925, pp.147-148), Brammall (1928, p. 36), Bramlette (1929, pp. 336-337), Wilgus (1933, p. 86), Buckley (1951, pp.319-321) and Koen (1955).

Bramlette ascribes the hillocks to etching, Buckley and Koen to growth, whilst Bosworth considers that the patterning is due to the effect of abrasion by transportation in water. Partially decomposed grains have been found in thin section. These grains have well-defined shells (possibly of chloritic matter) which still contain portions of the original grain. Such portions mostly exhibit patterning which is undoubtedly the result of etching rather than growth.

Inclusions with no apparent preferred orientation are fairly common. Most of the inclusions tend to be

weakly anisotropic.

The refractive indices of 21 samples, (containing the highest percentages of garnet) were examined (fig 3). The immersion method was employed using phenyl diodo arsine mixed with methylene iodide to give liquids with refractive indices 1.78, 1.80, 1.82 and 1.84. With the exception of sample 61, most of the garnet grains were found to have refractive indices between 1.78 and 1.80 with lesser proportions between 1.76 - 1.78 and 1.80 - 1.82. These indices correspond to those of almandite. In sample 61 most of the grains have a refractive index between 1.80 and 1.82. As the refractive indices of garnet were determined in only 21 samples it is impossible to form a definite opinion as to the significance of the distribution of the refractive indices in this sample (No. 61).

(3) Zircon

Zircon was found in most of the samples investigated, varying from a trace to more than 60 percent of the whole heavy mineral suite.

It occurs as idiomorphic, rounded or angular transparent grains. Generally colourless under the microscope, a small percentage of red zircon grains

were encountered in samples from the Witteberg and Table Mountain Series. A trace of red zircon was found in only two Karroo System samples (Nos. 33 and 34 of the Molteno Stage). The presence of a trace of red zircon in these samples can be explained on the assumption that the Cape System, particularly the Witteberg Series, once formed part of the source area of the Molteno Beds (Taljaard and Rust 1957). One percent and a trace respectively were also noted in a Waterberg sample (No.98) and in an Enon sample (No.9).

Idiomorphic grains have well-developed prismatic faces (100) and less frequently (110), terminated by pyramidal faces, slightly rounded in many cases.

Inclusions are common and tend to segregate in the centres or lie parallel to the crystallographic c axis. Some grains appear quite dark as a result of many small inclusions.

For the purposes of this study the zircon grains were subdivided into rounded, idiomorphic and angular grains. The red zircons are noted and are also included in the above subdivisions. Zoned or strained grains are also fairly common but their proportion to unzoned grains was not determined.

(4) Rutile

Rutile was found in most of the samples investigated and could be separated into two colour types, namely a dark reddish-brown and an amber to yellow type. Both colour types may be pleochroic.

The grains are mostly elongated (exhibiting parallel and extinction), and generally subangular to subrounded. Prismatic grains with rounded terminations were sometimes found, whilst a geniculate twin was encountered in one sample (No. 14). Apart from longitudinal striae a few of the idiomorphic grains show striae running diagonally across the prism edge, due to polysynthetic twinning.

(5) Tourmaline

Different varieties of tourmaline were found in most of the samples investigated, differing mainly in colour and pleochroism. Idiomorphic grains, (prismatic with rounded terminations) were found together with well-rounded and subangular grains. The rounded shape is by far the most common.

Practically all the grains are pleochroic in a variety of colours. The predominant colours are brown (ranging in shades from yellow-brown to red-brown) and green. A few blue and colourless grains were encountered.

Inclusions are common. No tourmaline overgrowths were encountered.

(6) Monazite

Monazite usually occurs as exceptionally well-rounded, colourless to pale yellow grains. Some grains (particularly the largest ones are weakly pleochroic in light shades of yellow. The grains are usually translucent and contain only a few or no inclusions. Idiomorphic grains were not encountered.

(7) Epidote

This mineral appears as irregular, subangular, colourless to light yellow grains. Pleochroism, when present, is weak. Subrounded grains were encountered in the Cave Sandstone Stage. The grains are not always perfectly clear, due perhaps to small inclusions or decomposition on the surface of the grains. Authigenic epidote (clinosoizitic) was found in samples (Nos. 145 - 150) from Queen Maud Land, Antarctica.

(8) Chlorite

The name chlorite, as used in this paper, is given to a group of crystalline green minerals including greenish undetermined "chloritic matter" (Milner, 1940 p.264). These minerals are sometimes

weakly pleochroic but lacking any definite crystal form. They are usually present as dirty, ragged, subangular grains. Between crossed nicols the grains exhibit anomolous (ultra blue) colours. Numerous inclusions were often encountered.

(9) Pyroxene

On account of the limited occurrence of pyroxene minerals in the heavy mineral suites, all the pyroxenes were grouped together under this heading. The pyroxenes in samples 1 to 4 consisted mainly of hypersthene characterised by the pinkish pleochroism and parallel extinction. The average grain sizes of the pyroxenes in table 1 represents the grain size in the crushed concentrate. The actual grain sizes of the pyroxenes in these samples was in excess of 0.42 mm (sieve opening).

In sample 5 the pyroxenes were mainly diopside.

(10) Amphibole

In this study all the amphibole minerals have been grouped together. The amphiboles in samples 3, 4, 5 and 111 were mainly green hornblende exhibiting the typical pleochroism and ragged prismatic form.

(11) Staurolite

Staurolite appears as reddish-yellow to light-yellow, pleochroic grains. The grains are usually subrounded and contain inclusions.

(12) Carbonate

Carbonate grains have the extreme birefringence of calcite. The minerals are generally cleavage fragments, but may be ragged or subangular. The grains are cloudy to colourless and exhibit characteristic "twinkling" effects upon rotation of the microscope stage.

(13) Anatase

The dominant colour of the anatase is brown in tints from pale yellow-brown to dark brown. The grains are usually square tabular and sometimes octahedral in form. Parallel intergrowths and striations were often noted. The most common type of inclusion is a dark irregular smudge due to an aggregate of dust particles. Only a few slightly rounded grains were encountered. Anatase was probably formed at the expense of ilmenite or other titaniferous minerals. In thin section the anatase grains tend to be clustered together around a core which could possibly once have been a

titaniferous mineral. The average grain size of the anatase found in this study was 0.05 mm and smaller. The identification of an almost pure anatase concentrate from sample 35 was confirmed by X-ray, spectrographic and chemical tests.

(14) Brookite

This mineral has a very limited occurrence in the heavy mineral concentrates. It appears as yellowish-brown, tabular, striated grains showing the characteristic dispersion of this mineral. The brookite probably has an authigenic origin (decomposition of other titaniferous minerals) as the grains are usually small and highly angular. Only in one instance was a rounded brookite grain encountered (No.14).

(15) Titanite

Titanite is pale brown to almost colourless and sometimes weakly pleochroic. The grains are usually angular to subangular, possibly representing grains broken during the crushing process, as they were found to be cracked in thin section. In some thin sections the titanite exhibits a very dark core, possibly the remains of a previous titaniferous mineral that has remained unaltered, whilst its

circumference has been altered to titanite. In sample 59 a few grains were found exhibiting the characteristic wedge-shaped form.

(16) Andalusite

This mineral appears as irregular, angular to subangular, colourless to light-pink grains. The light-pink grains are weakly pleochroic.

(17) Spinel

This mineral is characterised by a deep green colour, high refractive index and isotropism. Only two angular grains were encountered.

(18) Biotite

Biotite occurs as brown or yellow cleavage flakes, seldom worn and always lying with (001) in the plane of the slide, thus appearing non-pleochroic. It is identified by its colour, cleavage and almost uniaxial interference figure.

(19) Chloritoid

This mineral occurs as dirty subangular flakes, pleochroic in light green and blue.

(20) Cassiterite

Cassiterite appears as yellow-brown grains with high refractive indices. It is distinguished from

zircon by its lower birefringence. These few grains were angular.

(21) Xenotime

This mineral was only found in one sample (No.81) from the Witteberg Series. It had a slightly flattened, subrounded appearance and was light brown in colour. The refractive indices determined were $\omega=1.71$ and $\epsilon=1.82$. The low index, $\omega=1.71$, could possibly be due to some degree of alteration of the mineral. The mineral is uniaxial positive.

(22) Kyanite

Kyanite appears as colourless cleavage grains, devoid of inclusions. It is biaxial negative with an oblique extinction.

(23) Margarite

Only one flaky grain of margarite was encountered (Sample 124). Margarite is a brittle mica, resembling biotite in form.

(24) Leucoxene

Leucoxene has a white colour in reflected light, with a dull porcelainous lustre. The presence of titanium was determined by a chemical test (potassium

bisulphite melt). This mineral is included under the opaque heavy minerals.

(25) Ilmenite

Ilmenite appears black under the microscope and remains dark in reflected light. It was chemically tested for titanium (potassium bisulphite melt) and is included under the opaque heavy minerals in the counts.

(26) Opaque minerals

Under opaque heavy minerals are included all the dark undifferentiated minerals of unknown composition. In several cases a large proportion of the opaque minerals was identified as ilmenite or leucoxene by optical and chemical tests. The presence of ilmenite and leucoxene is recorded in tables 1 to 5.

The opaque minerals are generally angular to subangular, and on the whole tend to be larger than the rest of the heavy minerals in one particular concentrate. Rounded opaque minerals were found in samples from the Cave Sandstone Stage and in the Kalahari sands. This group of minerals corresponds to the "alterites" described by van Andel (1950, pp. 45-6).

POSSIBLE SOURCES OF DERIVATION OF HEAVY MINERALS

Apatite, according to Milner (1940, p.244), is especially common in granites and syenites, whilst Dana (1955, p.705) mentions crystalline metamorphic rocks as a further possible source. Sindowsky (1949, p.7) maintains that apatite weathers readily and therefore its presence could indicate a rapid erosion of the source area.

Schists and other crystalline rocks are the main sources of almandite garnet.

Zircon is such a ubiquitous mineral that no definite opinion can be expressed as to its origin without a more detailed study of the mineral grains. (elongation indices, etc.). Rounded grains of zircon, tourmaline and rutile are either indicative of long distances of transportation or second-cycle deposition (Pettijohn 1957, p.513).

Most of the tourmalines found in this study were yellow-brown to red-brown and green in colour. According to the classification of Krynine (1946, p.65-87) these varieties are derived from granites and pegmatized injected areas. The blue tourmaline is a pegmatitic variety. No outgrowths were encountered on the tourmaline, and this excludes its possible authigenic origin.

Monazite is an accessory mineral in acid igneous rocks especially granites.

Some heavy minerals such as brookite, anatase and titanite are probably formed by secondary processes (Pettijohn 1957, p.669). These minerals have therefore not been taken into account in the comparison of the heavy mineral data in the tables.

Judging by the compositions of the heavy concentrates, the source rocks of the Karroo sediments were primarily high grade metamorphic rocks and granite.

The concentrates of the Cape System are essentially composed of stable heavy minerals which are indicative of acid source rocks.

GEOLOGY AND RESULTS

Strata of Devonian to Carboniferous age, known as the Cape System, occur as a fringe around the South African coast (du Toit 1954). The lowest and highest members of this system, the Table Mountain Series and the Witteberg Series, respectively, are predominantly arenaceous whilst the intermediate member, the Bokkeveld Series, is predominantly argillaceous. The sediments of the Cape System were apparently deposited mainly in shallow water, the Bokkeveld Series representing deposition during a deeper water interlude.

The Karroo System (Gondwana) conformably overlies this assemblage in the Southern Cape Province and the strata here have been intensely folded to form the Cape folded ranges. In the northern Cape Province and the Transvaal, the Karroo System rests directly on the pre-Cambrian basement rocks, the attitude of the strata being approximately horizontal. Karroo sedimentation commenced with the formation of glacial deposits (the Dwyka Series) followed by a thick succession of fresh water and continental sediments (Ecca, Beaufort and Stormberg Series). The topmost beds consist of a deposit of wind-blown sand and sedimentation terminated with the outpouring

of a great thickness of basaltic lava.

The heavy residues of the three members of the Cape System are poor in mineral species and appear to be fairly uniform in composition throughout the area studied (Western Cape to Natal). The concentrates of the Table Mountain Series (Nos. 89-96) are characterised by the presence of a small proportion of red zircon whilst the Witteberg Series (Nos. 80-84) also usually carries traces of this variety of zircon. The Bokkeveld Series (Nos. 85-88) does not carry red zircon but small amounts of apatite are usually present.

The transition from the Witteberg to the Dwyka Series (Nos. 72-79) is marked by a complete change in the composition of the heavy residues. Garnet becomes the characteristic heavy mineral but there appears to be a break in the garnet content of the sediments in the Lower Ecca Stage and again in the Molteno Stage of the Stormberg Series. In the Cave Sandstone Stage, epidote becomes a conspicuous constituent of the concentrates.

The two Dwyka Series samples (Nos. 77 and 78) and the three Stormberg Series samples (Nos. 19, 27 and 35) from South West Africa (included under

the samples from the Union of South Africa) correspond closely to their Union equivalents. The garnet content however does seem to be slightly lower than in the Union samples.

No Karroo samples were studied from other localities in Africa. However in an Annual Report by Dixey (1930, p.11) information is given concerning heavy minerals of sediments of Karroo age of the Lower Shire, Nyasaland. He states: "Sediments, chiefly Upper Sandstones (Karoo) give garnet, rutile, zircon, epidote and barytes, with inconspicuous iron ores and ferromagnesian minerals."

The presence of garnet in the Karroo System is of particular significance as garnet is a rare mineral in other South African sedimentary rocks. With the exception of this formation it was found only in the tillite band of the Table Mountain Series. Koen (1955) has studied the heavy residues of Karroo rocks in certain Transvaal and Northern Free State boreholes. As he only examined the minus-0.074-mm fraction, his results are not comparable with those obtained in this study.

Two Tasmanian samples (Nos.122-123) and ten Australian samples (Nos. 124-131) were examined, and

the results are given in tables 4 and 5. The residues are simple, and red zircon is absent from the Devonian to Carboniferous samples. Apart from the presence of very small amounts in four samples (Nos. 124, 128, 130 and 131), garnet is moreover absent from the Gondwana samples. It can thus be deduced that there is no significant resemblance between the South African and the Australian samples.

The Devonian to Triassic succession in Brazil resembles that in South Africa. Descriptions of the stratigraphy, palaeontology, etc., are given elsewhere (du Toit 1927, 1937; Caster and Mendes 1948; Caster 1952; Maack 1950-1951, 1952, 1953; Barbosa 1952) and the particulars will therefore not be repeated here. The Furnas Sandstone is correlated with the Table Mountain Series and it is followed by the Santa Rosa Group (which includes the Ponta Grossa Shale and the Tibagi Sandstone) and the Barreiro Sandstone which are closely comparable with the Bokkeveld and Witteberg Series, respectively. The Gondwana System unconformably overlies the Devonian to Carboniferous assemblage, the lowest member being a glacial deposit, the Itararé Series. A succession

of continental, deltaic and estuarine strata (the Tubarão, Passa-Dois and São Bento Series) follows, and like the corresponding South African strata, the highest beds in the stratigraphical column (the Rio do Rasto or Botucatu Beds) are of aeolian origin. The Serra Geral eruptives crown this assemblage.

Ten samples from Brazil (Nos. 112-121) were examined and the results are given in table 4. The Furnas residues resemble those of the Table Mountain Series to some extent but they carry a higher percentage of tourmaline. The Tibagi and the Barreiro residues, however, are remarkably similar to the Bokkeveld and Witteberg concentrates respectively. The transition between the Devonian to Carboniferous and the Gondwana Systems furthermore shows some degree of resemblance to that between the Cape and Karroo Systems. The correspondence between the Gondwana residues of the two regions does not seem to be close but, as only a few samples were available for study, a definite opinion cannot be expressed. Of particular interest is the occurrence of staurolite in the intra-trappean sample (No. 112). This mineral may have originated in shales which were metamorphosed by the intrusion of the trap magma.

Samples from four localities in Antarctica (fig.4) were examined, namely, from South Victoria Land (Nos. 132-134); Mac Robertson Land (No.135) The Horlick Mountains (Nos. 136 - 144) and Queen Maud Land (Nos. 145-150). In the Horlick Mountains the Gondwana (or presumed Gondwana) strata conformably overlie a Devonian to Carboniferous assemblage whilst in the other localities these sediments (Gondwana) rest on pre-Cambrian basement rocks.

The sedimentary rocks of Queen Maud Land have suffered slight to moderate metamorphism and the epidote, amphibole and chlorite given in table 5 are not original constituents of the sediments. Most of the samples from this locality were moreover received in a partially or completely concentrated state before they were further examined in this study. The figures given for the heavy mineral percentages are therefore not quantitatively comparable with those given in the other tables.

The residues of the Antarctica Devonian to Carboniferous rocks are quite different from those of the South African Cape System but the Gondwana residues resemble their South African equivalents to some extent. In Antarctica the transition from

pre-Gondwana strata is not marked by a complete change in the composition of the heavy residues as it is in South Africa. The resemblance between the Gondwana residues of the two regions may thus be due merely to the fortuitous similarity of the conditions of sedimentation and not to any physical connection between the two regions (as is postulated by the hypothesis that all the southern continents once formed part of a supercontinent).

The sedimentary rocks of the Falkland Islands (Nos. 101 - 110) closely resemble those of the southern Cape Province. They have been described by Baker (1922) and Adie (1952a, 1952b). The Devonian to Carboniferous assemblage can be subdivided into three parts. The Port Stephens Beds, the Fox Bay and Port Philomel Beds, and the Port Stanley Beds. These groups are correlated with the Table Mountain Series, the Bokkeveld Series and the Witteberg Series respectively. They are followed by the strata of the Gondwana System which consist of a basal tillite (Lafonian Tillite) and a thick succession of terrestrial sandstones and shales (Lafonian Sandstone, Choiseul Sound and Brenton Lock Beds, Bay of Harbours and West Lafonian Beds) .

A palaeobotanical study has shown that the highest beds in the Falkland Islands stratigraphical column should be correlated with the Molteno Stage of the Stormberg Series. The Cave Sandstone and Drakensberg basalts are thus absent either because they have not been deposited or because they have been destroyed by erosion. The strata in both islands have been strongly folded, resulting in the formation of folded ranges which trend in two directions, one striking north-east and the other crossing it nearly at right angles.

Like the stratigraphical features, the heavy residues of the South African and Falkland Island rocks closely resemble each other. The similarity between the Table Mountain Series and the Port Stephens Beds residues, as well as that between the residues of the Witteberg Series and the Port Stanley Beds is practically complete. The transition between the Devonian to Carboniferous and the Gondwana rocks is furthermore precisely similar to that between the Cape and the Karroo Systems, a high percentage of garnet appearing in the Lafonian Tillite. Only a few samples of upper Gondwana strata were available for study but these seem to indicate that the break in the

garnet content of the Lower Ecca Beds is duplicated in the Falkland Islands. It was found that one Falkland Islands concentrate differs completely from its South African equivalent. The Port Philomel Beds residue (No.109) resembles the concentrates from the tillite horizon rather than those from the other Devonian to Carboniferous sandstones. It is therefore concluded that the sample was probably mislabelled in the laboratory and that it was actually obtained from the tillite horizon.

DISCUSSION OF RESULTS

The sediments of the Cape System become coarser as one goes northwards and it is generally accepted that they were derived from a northern source. That is, the source rocks for the most part are the same as those at present exposed in Southern Africa (with the exception of the younger Karroo rocks). Du Toit (1937) is of the opinion that the Devonian to Carboniferous sediments of South America also have a northern provenance. The composition of the heavy residues shows that the rocks of these two areas and also of the source area of the Falkland Islands Devonian to Carboniferous closely resemble one another.

The advent of the Gondwana era ushered in profound geological and climatic changes in the Southern Hemisphere. Much of the land surface of the hemisphere became glaciated. In Southern Africa a long period of erosion came to an end and sediments began to accumulate on a large part of the country—at first glacial deposits and later continental sands and muds. The study of the Karroo rocks has shown that:

- (1) the deposition was rapid, that is, the

sediments were derived from a region that was being rapidly elevated and denuded. This deduction is supported by the presence of unstable heavy minerals (andalusite, epidote, staurolite, apatite) which would disappear with protracted erosion.

- (2) the source of the sediments was for the most part crystalline rocks. From the discussion of the possible sources of derivation it follows that the common heavy minerals present in concentrates from rocks of the Karroo System were mainly derived from crystalline metamorphic rocks, granites and pegmatites. The light minerals (cf. feldspar, quartz and detrital graphite, tables 6 and 7) are also indicative of such a source.
- (3) the source rocks of the Karroo System differed from those of the Cape System. In order to determine whether or not the Basement rocks of South Africa would yield garnetiferous sediments, a number of sands from rivers which drain regions

composed of such rocks, were examined and the results are given in table 1, Nos. 1-5. Even if the pyroxenes were destroyed before deposition of the sediments, these Basement rocks could not have yielded some of the garnet-rich bands or even the graphite-bearing rocks in the Karroo System. If the sediments of the Cape System came from the north then (as the Karroo geosyncline is a linear east-west feature and as the source rocks of the two systems differ) the Karroo sediments were most probably derived from the south (Haughton 1952, King 1958). This region lay to the south of the present African continent and was composed of rocks similar to those which are today found in parts of Antarctica, namely garnet-hornblende-microperthite gneiss in Kemp Land and graphitic micaschists in South Victoria Land, (Fairbridge, 1952); garnetiferous gneisses in Queen Maud Land, (Roots, 1953); garnetiferous quartzite in Mac Robertson Land, (Crohn 1959).

It is probable that the Devonian to Carboniferous sediments of the Falkland Islands were derived from source rocks similar to those of the Cape System and that the Gondwana sediments (of the same region) came from a different source similar to that of the Karroo sediments. There may thus have been a close connection between the two regions in Devonian to Carboniferous to Triassic times, but on the other hand the resemblance may be due to other controlling factors such as climate and topography. More detailed study, preferably with the aid of size analysis, will have to be made before a definite opinion on the Palaeozoic and Mesozoic relationship between Africa and the Falkland Islands can be expressed.

Sediments derived from Karroo rocks are characterised by the presence of a large proportion of ilmenite (emanating from the dolerite) in the concentrates (see sand from the vicinity of Bloemfontein and Kalahari sand, table 1, Nos. 6 and 7). During the present cycle of erosion and redeposition of the Karroo sediments, garnet is apparently completely (or practically completely) destroyed.

Whilst it is not yet known what the reason is for the apparent break in the garnet content of the Lower Ecca Series, the absence of this mineral from certain Molteno Beds can be readily explained on the assumption that the rising Cape ranges cut off the supply of sediments from the crystalline source area to the south. Taljaard and Rust (1957) have found that pebbles of Ecca, Dwyka and Witteberg rocks occur as inclusions in the Molteno Beds at successively higher stratigraphical levels. They conclude that, as the mountains rose in the south, Ecca Beds were first eroded and at a later stage the streams cut down into Dwyka and Witteberg Beds.

The lower garnet percentages in the samples from South West Africa, may be due either to the great distance from the southern source area or the scarcity of garnet in a possible northern source area.

Finally, a few observations may be made on the value of heavy mineral analysis in sedimentation studies. Pettijohn (1941, 1957) has expressed the opinion that the heavy mineral assemblages of all sediments are originally practically the same but that age and depth of burial result in the destruction

of some mineral species. Heavy mineral zones are thus considered to be essentially stability zones. Van Andel (1959) however does not consider the effects of intrastratal solution important but assigns the dominant role to tectonic factors.

Van Andel (1959) finds that sediments deposited in orogenic regions are rich in mineral species whilst those which are laid down under stable shelf conditions are characterised by impoverished heavy concentrates. The present study has shown that age is indeed an important factor in determining the variety of mineral species present in heavy residues. The Recent sands and river sediments examined contain a relatively large proportion of the unstable minerals whilst these minerals are absent from Palaeozoic and Mesozoic rocks. On the other hand, there are major differences in composition amongst sandstones of the same age.

The appearance of a relatively large proportion of garnet in the Dwyka rocks (the underlying Witteberg rocks contain no garnet) is certainly not due to age, as specimens from a much lower horizon in the Table Mountain Series also contains

a small amount of this mineral. The reason for the absence in the Cape System, of garnet in all but the tillite of the Table Mountain Series is that the sandstones of the Cape System were deposited on a stable platform whilst glaciation afforded ideal conditions for the preservation of garnet. The composition of heavy residues is undoubtedly determined by a large number of factors, such as composition of the source rocks, conditions of sedimentation, age, degree of metamorphism and weathering.

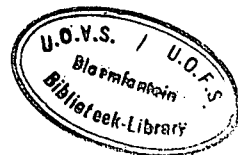
In order to prove (or disprove) the hypothesis that sediments derived from orogenic regions are richer in heavy mineral species than those produced by South African shield areas, a sample of sand from the Mendoza River (No.111) at the foot of the Andes Mountains was examined. This sample is not richer in heavy mineral species than the South African sands but no conclusions can be drawn from the study of only one sample and more samples must be examined before an opinion can be expressed.

The results of the present study show that the heavy mineral concentrates of the major South African stratigraphical units are usually fairly uniform and characteristic for that unit. It has

thus been possible to obtain useful results by the analysis of only a limited number of specimens. The significance of the similarity between South African and the Falkland Island concentrates, as well as the correspondence between other sedimentary groups, may be a fruitful field of sedimentary petrological study in the future.

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TABLE I: HEAVY MINERAL COMPOSITION (PERCENTAGES BY NUMBER), AVERAGE GRAIN SIZE (Gm.) AND ROUNDNESS (LETTERS A-E, PETTIJOHN).

(O INDICATES PRESENCE OF IDIOMORPHIC GRAINS.)

SAMPLE NO.	APATITE	GARNET	ZIRCON	ANGULAR, IDIOMORPHIC, ROUND, RED.	RUTILE	TOURMALINE	MONAZITE	EPIDOTE	CHLORITE	PYROXENE	AMPHIBOLE	CARBONATE	STAUROLITE	ANATASE	TITANITE	OPPOSITE MINERALS	WEIGHT PERCENT	
1.			20-10 B	2	tr.			10-10 B		46-050 C	tr.					51-030 C	1-77	
2.			20-10 B	2	tr.			tr.		50-050 B	20-10 C					4 ANDULSITITE	42-040 C	0-81
3.	20-10 C	tr.	tr.	tr.	tr.			10-15 C		42-050 B	17-030 B		tr.				38-040 C	0-98
4.	10-10 B	20-15 B						30-15 B		40-040 B	13-030 B						41-025 B	1-29
5.	tr.	tr.	tr.	tr.	tr.			tr.		60-020 B	14-015 C					tr. OLIVINE	26-035 C	5-19
6.			11-015 C	4 1 6	30-10 C	30-15 D		tr.					5-015 D			ILMENITE	78-020 D	0-28
7.			9-010 B	2 1 6	20-05 C	tr.	tr.	10-05 C		20-10 B			tr.			ILMENITE	86-010 D	0-60
8.			tr.	tr.	tr.											LEUCOFENE	100-025 C	0-61
9.			21-010 B	tr 7 3 11	4-010 B	6-010 C	tr.									LEUCOFENE	69-015 C	0-14
10.	10-05 C	20-010 B	9-010 C	3 1 6	10-05 C	15-015 D	tr.	14-010 C			4-010 B						36-010 B	0-06
11.	20-10 B	20-10 A	16-010 C	6 4 6	8-010 C	13-010 D		15-005 C		10-10 B			tr.				43-010 B	0-05
12.	tr.	27-010 B	30-010 C	14 6 10	6-010 C	5-010 D	10-10 D	11-005 C		10-05 B			tr.		tr.		19-015 C	0-27
13.		4-015 C	20-010 C	9 1 10	30-10 C	19-010 E	10-10 E	10-005 C							tr.		43-015 D	0-03
14.	tr.	38-025 C	24-020 D	16 1 7	20-15 C	10-005 D		3-005 C							tr. BROOKITE	ILMENITE	23-020 D	0-05
15.		18-010 B	24-010 C	12 3 9	5-010 C	20-15 C	10-05 D							tr.			50-010 B	0-09
16.		7-005 B	80-010 C	35 9 36	10-10 B	tr.											12-010 B	0-03
17.		26-010 D	28-010 D	16 3 9	30-10 C	11-010 E	tr.										32-015 D	0-09
18.		8-010 B	36-010 D	23 2 11	8-010 D	14-010 D	10-10 C										33-015 D	0-09
19.	tr.		24-015 D	13 2 9	20-15 C												74-015 B	0-07
20.	tr.	32-025 B	10-010 C	4 2 4	7-010 C	10-10 C	10-10 D	tr.	4-030 B					6-005 B	tr. BROOKITE		39-020 B	0-15
21.		10-010 B	27-005 C	12 4 11	3-005 C	tr.	tr.							4-005 A			56-010 D	0-41
22.		33-015 B	11-015 C	5 1 5	13-015 C	30-10 D	20-10 D							3-005 A			35-015 C	0-16
23.		5-015 B	14-010 C	6 2 6	20-015 C	4-015 C	30-15 E	tr.									54-015 C	0-11
24.	tr.	19-015 B	24-010 D	12 3 9	20-1 C	tr.	4-010 E						tr.		tr.		33-015 C	0-08
25.		tr.	20-010 D	10 3 7	31-015 C	20-10 C	4-010 E							5-005 A			38-015 C	0-28
26.	tr.		38-010 C	13 3 22	13-010 C	30-05 D	20-10 D	10-05 C						4-005 A	tr.		39-010 B	0-12
27.	5-020 C	7-015 B	4-010 B	1 tr 3	2-015 C	10-020 C	20-15 D					2-015 B					68-025 C	0-14
28.	30-10 C	10-10 B	14-020 B	4 2 8	14-020 B	4-015 C	tr.	10-020 B		tr.			10-15 C			ILMENITE	62-025 B	0-07
29.	10-10 B	tr.			16-015 C	6 4 6	14-020 C	6-010 D	4-010 E	10-10 B			tr.				58-020 B	0-07
30.			29-015 C	12 2 15	6-015 C	5-010 D	30-10 E							25-005 A		tr. SPINEL	32-015 B	0-02
31.		10-05 B	28-010 C	13 2 13	16-015 B	2-015 B	30-10 C							11-005 A			39-025 B	0-05
32.	30-15 B	7-020 B	37-010 C	15 7 15	tr.	3-010 C	10-10 D			10-10 B			tr.	10-005 A	10-10 C		46-015 C	0-08
33.	5-010 C	49-010 C	14-010 B	4 2 8	5-010 C	20-05 D			6-015 B					tr.	tr.		19-015 C	0-19
34.	8-010 D	14-010 C	26-010 C	tr 10 4 12	8-010 C	2-010 D	10-10 E	10-10 C						tr.	tr.		40-015 D	0-08
35.			39-010 D	tr 28 2 9	10-10 C	10-10 C						10-10 B					58-010 C	0-05

CRETACEOUS TO RECENT

UTERHAGE SERIES

DIVED SANDS

KALAHARI SAND ENON STAGE

CAVE SANDSTONE STAGE

STORMBERG SERIES

RED BEDS STAGE

MOLTENO STAGE

KARROO SYSTEM

TABLE 2: HEAVY MINERAL COMPOSITION (PERCENTAGES BY NUMBER), AVERAGE GRAIN SIZE (Gm) AND ROUNDNESS (LETTERS A-E, PETTILJOHN).

(O INDICATES PRESENCE OF ISOMORPHIC GRAINS)

SAMPLE No.	APATITE	GARNET	ZIRCON	ANGULAR IDOMORPHIC ROUND HED.	RUTILE	TURALINE	MONAZITE	EPIDOTE	CHLORITE	PYROXENE	AMPHIBOLE	CARBONATE	STAUROLITE	ANATASE	TITANITE	OPAQUE MINERALS	WEIGHT PERCENT		
36.	90-10D	480-15B	100-10B	2 2 6	60-10C	20-10D	tr			10-10C			10-10C			23020C	0.37	UPPER	
37.	110-10B	230-15B	140-10C	3 5 6	6005C	3005C		1005C		tr						42015C	0.03	BEAUFORT	
38.		12025C	20020C	10 2 8	13020C	3020D	10-15E									51020C	0.05	STAGE	
39.	30-15C	38025A	70-10C	3 1 3	20-15C	1020D	10-10E							42005A		6020B	1.78		
40.	180-15C	22020A	210-15C	5 8 8	20-10C	20-10D	tr	20-10C		tr			tr			33020B	0.08		
41.	70-10D	530-15B	80-10C	2 2 4	50-15C	20-15D	tr	tr		tr			tr			25015C	0.39	LOWER	
42.	190-10D	240-15B	100-10C	2 4 4	40-10C	2005C	tr	tr	30-15B	tr					ANALUSITE	37015B	0.28	BEAUFORT	
43.	100-15C	38020B	60-10C	1 2 3	30-15C	20-15D			10-15C							40020C	0.20	STAGE	
44.	220-10C	160-10C	90-10C	3 1 5	tr	40-10C	tr	10-10C	10-10B	40-10B			tr	tr		430-15B	0.46		
45.	4005B	tr	2005B	1 1 1	tr	tr										94010A	0.07		
46.	200-15C	190-15B	250-10B	6 9 10	50-10B	20-10D	10-10D	10-10C	20-15B	10-10B						24020B	0.09		
47.	260-15C	180-15A	170-10C	6 4 7	50-10C	30-10B	tr	tr	10-10B	10-10B						29020B	0.16		
48.	210-10C	280-15A	110-10C	2 5 4	50-10A	40-10C	tr	tr	20-15B	10-10B		tr				28020B	0.06		
49.	150-10C	220-15A	110-10C	3 3 5	10-10B	20-15C		tr	tr	10-10B			10-10B		10-10C	46020B	0.33		
50.	110-10C	42020A	10020B	3 2 5	4020A	10-15C	tr	tr	tr	20-10B			tr			30020B	0.19		
51.	110-10C	150-15B	260-10B	5 5 16	20-10C	10-10D	10-10D	10-10C	tr	20-10A			tr			41015A	0.18	LOWER	
52.	30-10C	48025B	60-15B	1 1 4	30-15B	20-15C		tr	tr	tr			tr	30-10A		35020B	0.19	BEAUFORT	
53.	130-10C	350-10B	90-10C	2 3 4	20-10C	20-10D	tr	tr	tr	tr					30-10E	360-15C	0.27	STAGE	
54.	170-10C	160-15B	170-10B	3 6 8	40-10D	10-10C	10-10D	10-10B		tr			tr	tr	60-10B	ANALUSITE	360-15C	0.07	
55.	5005C	120-10B	500-10C	18 14 18	10-10C	tr	tr	tr	tr	tr			tr			320-10B	0.03		
56.	20-10C	40035B	60-15C	2 1 3	20-10B	tr		10-10C					tr	tr		49030B	3.78		
57.	210-10C	320-15B	230-15B	6 6 11	50-10B	tr		tr								19015C	0.12		
58.	180-10C	480-15B	70-15C	2 2 3	40-10B	20-15B	20-10C	10-10C		tr				1005B	tr BROOKITE	170-15B	0.34		
59.	60-10C	530-15B	70-15C	3 1 3	40-10C	20-10D	20-10E	tr						9005A		170-15B	0.50		
60.	40-15D	60-10B	100-10C	3 4 3	20-15C	10-10C	tr		tr							670-15B	0.67		
61.	tr	530-40B	50-10B	1 1 3	tr		tr			tr						42025C	0.16		
62.	11005C	24005B	16005B	3 6 7		2005C	1005D	10005B							60-10C	300-10B	0.03		
63.	120-10C	32005B	2005C	1 tr 1	2005B	tr	1005D									510-10B	0.19	UPPER	
64.	20-15C	400-15B	40-10B	1 tr 3	4020C	tr				tr						50025B	0.07	ECCA	
65.	10-10C	550-10B	20005B	6 1 13	1005B	10-10C		1005C							1005B	200-10B	0.40	STAGE	
66.	20-10C	54025B	30-15B	1 tr 2	tr		20-10D							20-10B	2005C	350-15B	0.45	MIDDLE	
67.	20-10C	62020B	30-15B	1 tr 2	10-10C	10-15C	tr				2020B	10-10C			tr CHLORITE	28020C	0.66	ECCA	
68.	9005C	1005B	66005C	18 19 29	20-10B	20-10D	tr		tr					10-10A	tr	190-10C	0.04	STAGE	
69.			5020C	2 1 2			tr				46030A			tr		49025B	0.59	LOWER	
70.	8005B	1005B	7005C	2 2 3			tr								5005B	790-10B	0.06	ECCA	
71.	tr	10-10B	20-10C	1 1 1				tr								97035B	0.23	STAGE	

BEAUFORT SERIES
 KARROO SYSTEM
 ECCA SERIES

TABLE 3: HEAVY MINERAL COMPOSITION (PERCENTAGES BY NUMBER), AVERAGE GRAIN SIZE (mm.) AND ROUNDNESS (LETTERS A-E, PETTIJOHN)
(O INDICATES PRESENCE OF IDIOMORPHIC GRAINS)

SAMPLE No.	APATITE	GARNET	ZIRCON	ANDALUSITE BROOKITE RUTILE	RUTILE	TOURMALINE	MONAZITE	EPIDOTE	CHLORITE	PYROXENE	AMPHIBOLE	CARBONATE	STAUROLITE	ANATASE	TITANITE	OPAQUE MINERALS	WEIGHT PERCENT	
72	20-15 B	57-020 B	50-15 B	1 1 3	10-10 B	30-10 C	20-10 D	30-05 B	10-05 B	20-10 B		10-10 A		10-10 A	10-10 C	tr ANDRUSITE 21-0-15 C	0-29	
73	30-10 C	42-0-10 B	110-10 B	3 2 6		10-10 B	10-10 D	80-15 B	60-20 B							28-0-15 B	0-51	
74	30-10 C	80-15 B	30-10 C	1 1 1	tr	10-10 C		20-10 D	31-0-10 B							52-0-30 B	0-27	
75	20-15 C	63-0-25 C	20-10 C	1 1 1				30-10 C	20-20 B					20-05 A		26-0-20 C	0-55	
76	60-15 D	45-0-30 B	30-10 C	1 2	30-15 C	20-10 D								30-05 A		38-0-30 C	0-27	
77	40-10 D	25-0-15 B	50-15 C	2 tr 3	20-10 C	40-10 D	tr									60-0-20 D	0-30	
78	90-15 C	24-0-15 B	50-10 C	2 1 2	10-10 D	40-10 C										57-0-15 C	0-58	
79	tr	79-0-20 B	110-10 B	4 1 6	10-10 C	10-10 C		tr							tr	80-15 C	0-18	
80		40-0-10 C	tr	19 7 14	23-0-10 B	tr	50-10 D							10-05 A	3 BROOKITE	28-0-10 C	0-44	
81		37-0-15 C	2	14 6 17	19-0-10 C	10-10 C	10-05 D	tr						50-10 C	3 BROOKITE	tr KENOTIME	34-0-15 C	0-03
82		200-10 C	9	1 10	200-10 B	20-10 D	10-05 D									57-0-25 C	0-25	
83		200-10 C	tr	8 1 11	80-15 C	20-10 D	70-10 D							70-05 A	tr BROOKITE	56-0-20 C	0-20	
84		45-0-10 B	tr	18 2 25	80-05 C	20-05 C										45-0-15 C	0-06	
85	40-10 C	35-0-10 B	14	2 19	110-10 D	50-10 C	10-05 D							30-05 A		41-0-15 C	0-04	
86		19-0-05 C	8	2 9	40-05 C	70-05 C										70-0-10 C	0-06	
87	30-10 C	80-0-10 B	26	6 48	20-05 C	10-10 C	tr									14-0-10 C	0-05	
88	10-10 C	75-0-10 B	20	11 44	20-05 C	20-05 C	20-05 D									18-0-10 B	0-06	
89		18-0-15 C	3	8 4 6	20-10 C	70-15 D	20-10 D									ILMENITE	71-0-25 C	0-05
90		70-10 C	1	3 2 2	80-10 C	10-05 C	10-05 D				tr			tr		83-0-20 C	0-85	
91		600-10 C	3	26 10 24	30-10 C		30-15 E								tr	tr CASSITERITE	34-0-10 C	0-02
92		22-0-10 C	8	5 9	50-15 B	50-10 C	10-10 D	tr								tr KYANITE	67-0-20 C	0-05
93		45-0-15 B	2	18 4 23	50-15 B	110-15 D	10-10 E		tr							38-0-20 C	0-12	
94		63-0-15 C	tr	28 2 33	10-10 C	60-15 D	10-10 E									29-0-15 D	0-11	
95		65-0-15 B	1	25 2 38	20-10 B	10-10 C	20-05 D									30-0-20 C	0-06	
96		10-10 B	15	0-10 C	7	1 7	40-05 C	30-10 D	tr					tr		77-0-15 C	0-09	
97	21-0-05 C		30-05 B	1	tr 2	10-10 C	70-05 C		110-10 C							57-0-10 C	0-02	
98			60-10 C	1	2 1 3	tr								30-05 B		LEUCOXENE	91-0-25 B	0-25
99			40-10 D	4	tr		30-10 D									93-0-20 C	0-06	
100			20-10 C	1	tr		20-15 C									96-0-35 B	0-67	

KARROO SYSTEM
DWARVA SERIES

WITTEBERG SERIES
BOKKEVELD SERIES

CAPE SYSTEM
TABLE MOUNTAIN SERIES

TILLITE

NAAVA WATERBERG SYSTEM
NEUWERUST MATSAD BEDS

GAMAGARA SERIES
KLIPHEUVEL BEDS

TABLE 4: HEAVY MINERAL COMPOSITION (PERCENTAGES BY NUMBER), AVERAGE GRAIN SIZE (mm.) AND ROUNDNESS (LETTERS A-E, PETTIJOHN).

(O INDICATES PRESENCE OF IDIOMORPHIC GRAINS.)

SAMPLE No.	APATITE	GARNET	ZIRCON	ANGULAR IDIOMORPHIC HOWARD R.D.	RUTILE	TOURMALINE	MONAZITE	EPIDOTE	CHLORITE	PYROXENE	AMPHIBOLE	CARBONATE	STAUROLITE	ANATASE	TITANITE	OPAQUE MINERALS	WEIGHT PERCENT	
FALKLAND ISLANDS																		
101.	7.0-10C	5.0-10B	10.0-10B	2, 2, 6		2.0-10C		tr	5.0-10B						5.0-10B	20.0-10B	0.40	UPPER PART
102.	12.0-05B	1.0-10B	19.0-10B	1, 5, 7, 7	3.0-10C	5.0-05C										60.0-10C	0.08	UPPER LAFONIAN BEDS
103.	8.0-05B	tr	44.0-05B	11, 11, 22	3.0-05B	2.0-10C								1.0-05A		42.0-10C	0.02	LOWER PART
104.	4.0-10D	17.5-15B	1.0-10C	1, tr, tr, tr	tr	tr	tr	tr		5.0-10B					2.0-10B	13.0-15B	1.85	BLACK ROCK BEDS
105.		7.8-025B	2.0-10C	1, tr, 1	5.0-15B	tr		tr		tr						15.0-15B	1.80	LAFONIAN TILLITE
106.	tr	9.0-15A	3.0-10D	2, 1	3.0-15C	2.0-05D										2.0-15C	0.97	SANDS BAND IN LAETLITE
107.			34.0-15C	1, 10, 3, 21	14.0-15C	4.0-15C	1.0-10D								2 BROOKITE	45.0-20B	0.06	PORT STANLEY BEDS
108.			39.0-25C	1, 16, 7, 16	9.0-20C	tr	4.0-15D									48.0-20C	0.04	PORT PHILMEL BEDS
109.		7.9-020A	tr		3.0-15C	tr		2.0-15B		tr					1.0-10B	15.0-15B	0.73	PORT PHILMEL BEDS
110.			35.0-15C	tr, 18, 3, 14	4.0-15C	6.0-25D	tr							1.0-10A	1 BROOKITE	54.0-15B	0.02	PORT ALBEMARLE BEDS
SOUTH AMERICA																		
111.	tr	tr	1.0-10C	tr, tr, tr	tr	tr		3.0-15C	3.0-20B	13.0-25B	6.0-20B	4 GREEN, 2 BROWN				74.0-20C	2.33	MENDOZA RIVER SAND
112.			13.0-15D	1, 7, 1, 5	2.0-10C	5.0-15D							17.0-10B			63.0-15D	0.33	
113.			11.0-10C	tr, 6, tr, 5	1.0-10B	11.0-10D							tr			77.0-10D	0.10	BUCATU SANDSTONE
114.			39.0-10D	tr, 23, 1, 15	3.0-10C	10.0-15D	1.0-10D									47.0-15C	0.26	
115.	8.0-20C	16.0-25B	6.0-10C	3, 1, 2	1.0-10C	2.0-15C	tr		10.0-15B						9 BROOKITE	48.0-25C	0.88	ITABARE TILLITE
116.	12.0-10D	tr	18.0-10C	tr, 8, 1, 9	3.0-15C	8.0-10C	1.0-10D	tr				tr		1.0-05A	5 ANCALUSITE	52.0-15B	0.14	ITABARE TILLITE
117.			25.0-10C	1, 12, 3, 10	3.0-10B	tr	tr							18.0-05A		54.0-15C	0.15	BARREIRO SANDSTONE
118.			19.0-10C	tr, 9, tr, 10	3.0-10C	5.0-15D	1.0-10D							2.0-05A		70.0-15C	0.24	BARREIRO SANDSTONE
119.			19.0-10B	8, 1, 10	5.0-10B	4.0-25C	tr							11.0-05A		61.0-30A	0.15	SANTA ROSA SANDSTONE
120.			14.0-10C	tr, 6, 1, 7	1.0-15B	18.0-15C	tr					6.0-20B		1.0-03A		60.0-20C	0.01	FURNAS SANDSTONE
121.			4.0-10C	tr, 2, tr, 2	tr	4.9-025C	1.0-15D									46.0-30C	0.12	FURNAS SANDSTONE
TASMANIA																		
122.			1.0-05C	tr, tr, 1		13.0-10C	tr							3.0-05A		83.0-15C	0.07	KEEL QUARTZITE
123.			4.0-10C	2, tr, 2	3.0-10C	7.0-10D										86.0-15	0.35	CROTTY QUARTZITE

TABLE 5: HEAVY MINERAL COMPOSITION (PERCENTAGES BY NUMBER), AVERAGE GRAIN SIZE (mm.) AND ROUNDNESS (LETTERS A-E, PETTIJOHN).

(O INDICATES PRESENCE OF IDIOMORPHIC GRAINS.)

SAMPLE No.	APATITE	GARNET	ZIRCON	ANGULAR IDIOMORPHIC ROUND REO	RUTILE	TOURMALINE	MONAZITE	EPIDOTE	CHLORITE	PYROXENE	AMPHIBOLE	CARBONATE	STAUROLITE	ANATASE	TITANITE	OPAQUE MINERALS	WEIGHT PERCENT		
AUSTRALIA																			
124	3 0-10 C	2 0-15 B	4 0-20 C	1 1 2	tr.	1 0-10 C	tr.		1 0-15 B							SWARGARITE	84 0-20 C	0-10	WIANAMATTA GROUP
125			14 0-15 C	6 2 6	12 0-10 C	8 0-15 D											66 0-20 C	0-05	HAWKESBURY SANDSTONE
126			25 0-05 B	6 4 15	2 0-05 B	3 0-10 B	tr.							tr.			70 0-10 B	0-05	NARRABEEN FORMATION
127			tr.									98 0-30 B					2 0-30 B	2-04	NEWCASTLE COAL MEASURES
128		tr.	tr.		tr.							90 0-20 B					10 0-20 B	0-16	TOMAGO COAL MEASURES
129			tr.		tr.							85 0-25 B					15 0-20 B	0-38	BASE OF UPPER MARINE SERIES
130		tr.	tr.			tr.						98 0-25 B		tr.			2 0-20 B	1-52	GRETA COAL MEASURES
131	5 0-10 C	1 0-10 B	14 0-10 C	1 1 12		tr.	tr.	4 0-20 B	2 0-15 B			32 0-20 B			tr.		42 0-25 B	0-15	UPPER CARBONIFEROUS TILLITE
ANTARCTICA																			
132	tr.	51 0-25 B	2 0-10 B	tr.	2 tr.	1 0-10 C	tr.					3 0-15 B					42 0-20 C	1-59	BEACON SANDSTONE
133	1 0-05 C	25 0-10 B	21 0-10 B	7 4 10	6 0-05 C	4 0-05 C	2 0-05 E	9 0-05 B				4 0-10 B			tr.		28 0-10 C	0-08	
134		69 0-30 B	1 0-10 C	tr.	tr.	1 0-10 C	2 0-10 C	tr.				8 0-15 C					18 0-15 C	0-75	AMERY SANDSTONE
135		2 0-20 B	1 0-10 B	tr.	tr.	1 0-10 C		1 0-10 D									95 0-35 B	2-58	
136	tr.		2 0-05 D	1 tr.	tr.	tr.										3 BROOKITE	94 0-15 A	1-18	PERMO-CARBONIFEROUS
137	8 0-15 C		2 0-10 C	1 1 1	1 0-10 B	4 0-15 B			3 0-20 B								82 0-20 C	0-11	CARBONIFEROUS
138	11 0-20 C		8 0-10 C	3 1 4	1 0-15 B	3 0-10 C						43 0-20 A					34 0-15 B	0-10	
139	15 0-10 C		12 0-10 C	6 1 5	2 0-10 C	3 0-10 C											67 0-20 B	0-27	
140	16 0-10 C	1 0-10 A	13 0-05 C	6 2 5	2 0-10 C	2 0-05 B											65 0-15 B	0-18	DEVONIAN
141	7 0-15 B	1 0-10 B	6 0-10 C	3 1 2	3 0-15 C	3 0-15 C						2 0-10 B		2 0-10 B			72 0-20 C	0-10	
142	9 0-20 C		8 0-15 C	3 2 3	3 0-20 C	4 0-15 C								1 0-10 B			65 0-15 C	0-10	
143	tr.	3 0-20 C	1 0-10 D	1 tr.	tr.	1 0-15 C	tr.					tr.					94 0-25 B	9-21	LOWER DEVONIAN
144	2 0-10 C		9 0-10 C	3 2 4	tr.	2 0-10 C	tr.							2 0-05 B			12 0-10 B	0-45	
145	1 0-10 C		tr.	tr.				89 AUTHIGENIC MINERALS (CLINOZOISITIC EPIDOTE)								10 0-15 B			
146	2 0-15 C		1 0-10 C	1				91 AUTHIGENIC MINERALS (EPIDOTE, CHLORITE AND AMPHIBOLE)								6 0-20 B			
147	tr.		2 0-10 C	1				88 AUTHIGENIC MINERALS (CLINOZOISITIC EPIDOTE, CHLORITE AND AMPHIBOLE)								10 0-20 B			
148	12 0-10 C	1 0-10 B	8 0-10 B	3 1 4	tr.			12 AUTHIGENIC MINERALS (CHLORITE)								67 0-15 B			
149	1 0-15 C	2 0-15 B	4 0-10 B	1	3	1 0-10 D		22 AUTHIGENIC MINERALS (CHLORITE AND AMPHIBOLE)								70 0-20 B			
150	1 0-15 C	3 0-20 B	tr.		tr.			66 AUTHIGENIC MINERALS (CHLORITE AND EPIDOTE)								30 0-15 B			

"SEDIMENTARY ROCKS"
GONDWANA

TABLE 6. COMPOSITION AND LOCALITY OF SAMPLES.

SAMPLE No.	ROCK FRAGMENTS			NAME	AV. GRAIN SIZE (mm)	ROUNDNESS	CARBONATE	CHLORITE	SERICITE	MICA	GRAPHITE	CLAY PELLETS	LOCALITY								
	QUARTZ	FELDSPAR																			
1	nd.	15	nd.	SAND	0.80								CROCODILE RIVER, THABAZIMBI.	RIVER SANDS							
2	nd.	15	nd.	SAND	0.90								CROCODILE RIVER, THABAZIMBI.								
3	nd.	10	nd.	SAND	0.60								LIMPOPO RIVER, MESSINA.								
4	nd.	10	nd.	SAND	1.00								LIMPOPO RIVER, MESSINA.								
5	nd.	15	nd.	SAND	0.30								ORANGE RIVER, ALEXANDER BAY.								
6	nd.	5	nd.	SAND	0.60								HOTAZËL, KURUMAN, C.P.	KALAHARI SAND							
7	nd.	nd.	nd.	SAND	nd.								BLOEMFONTEIN.								
8	20	10	70	SUBGRAWACKE	0.15 B		X						NUY, C.P.	ENON STAGE							
9	80	15	5	SUBARKOSE	0.10 A				X				OUTDSHOORN.								
10	50	35	15	ARKOSE	0.10 C		X	X					LADY GREY.	CAVE SANDSTONE STAGE							
11	65	35	tr.	ARKOSE	0.10 C								12m. WEST OF BETHLEHEM.								
12	65	25	10	ARKOSE	0.10 B								JAMESTOWN.								
13	65	25	10	ARKOSE	0.15 C		X	X					MASERU, BASUTOLAND.								
14	55	35	10	ARKOSE	0.25 C				X				MASERU, BASUTOLAND.								
15	30	60	10	ARKOSE	0.10 B								ZASTRON.								
16	50	40	10	ARKOSE	0.10 B								ZASTRON.								
17	65	30	5	ARKOSE	0.20 C					X			HARRISMITH.								
18	70	25	5	ARKOSE	0.10 B					X			HARRISMITH.								
19	70	25	5	ARKOSE	0.30 C								ETJO MOUNTAIN, SWA.								
20	40	35	25	ARKOSE	0.30 B		X	X	X				ZASTRON	RED BEDS STAGE							
21	55	40	5	ARKOSE	0.20 C								ZASTRON.								
22	60	25	15	ARKOSE	0.30 C		X	X					LOTENI, NATAL.								
23	55	30	15	ARKOSE	0.30 B		X	X					LOTENI, NATAL.								
24	65	20	15	ARKOSE	0.20 C		X	X					40m. NORTH OF QUEENSTOWN.								
25	40	35	25	ARKOSE	0.20 C		X	X					THABA'NCHU.								
26	70	25	5	ARKOSE	0.15 B					X			THABA'NCHU.								
27	65	25	10	ARKOSE	1.50 B	X				X			OMBUROKO MOUNTAIN, SWA.								
28	80	15	5	SUBARKOSE	0.35 C		X						PAUL ROUX.					MOLTENO STAGE			
29	95	5	tr.	ORTHOQUARTZITE	0.30 C				X				10m. WEST OF KESTELL.								
30	70	25	5	ARKOSE	0.80 C		X						ZASTRON.								
31	65	20	15	ARKOSE	0.25 C					X			ZASTRON.								
32	65	30	5	ARKOSE	0.30 C				X	X			29m. NORTH OF QUEENSTOWN.								
33	30	25	45	SUBGRAYWACKE	0.10 B		X	X		X			THABA'NCHU.								
34	35	25	40	SUBGRAYWACKE	0.20 C	X	X	X		X			THABA'NCHU.								
35	95	5	tr.	ORTHOQUARTZITE	0.30 C					X			OMBUROKO MOUNTAIN, SWA.								
36	45	25	30	SUBGRAYWACKE	0.15 B		X	X		X			10m. EAST OF SENEKAL.	UPPER BEAUFORT STAGE							
37	50	15	35	SUBGRAYWACKE	0.20 B		X						KESTELL.								
38	35	15	50	SUBGRAYWACKE	0.25 B		X			X	X		HIMEVILLE.	MIDDLE BEAUFORT STAGE							
39	30	65	5	ARKOSE	0.25 C	X	X				X		10m. WEST OF WINBURG.								
40	20	50	30	ARKOSE	0.20 B		X	X		X			20m. WEST OF SENEKAL.	LOWER BEAUFORT STAGE							
41	60	10	30	SUBGRAYWACKE	0.15 B								4m. WEST OF HARRISMITH.								
42	20	35	45	SUBGRAYWACKE	0.20 B		X	X	X				ESTCOURT.								
43	25	30	45	SUBGRAYWACKE	0.20 C	X	X	X		X			ESTCOURT.								
44	50	35	15	ARKOSE	0.45 C		X	X	X				15m. N.E. OF BEAUFORT WEST.								
45	35	40	25	ARKOSE	0.10 B		X	X	X				10m. NORTH OF COLESBURG.								
46	55	15	30	SUBGRAYWACKE	0.20 B		X	X		X			7m. NORTH OF BLOEMFONTEIN.								
47	50	15	35	SUBGRAYWACKE	0.15 B		X	X		X			20ft. ABOVE SAMPLE No. 46.								
48	50	20	30	SUBGRAYWACKE	0.20 B		X	X		X			10ft. BELOW SAMPLE No. 46.								
49	30	30	40	SUBGRAYWACKE	0.20 B		X	X		X			5m. NORTH OF BLOEMFONTEIN.								
50	45	20	35	SUBGRAYWACKE	0.25 B		X	X		X			6m. NORTH OF BLOEMFONTEIN.								
51	40	20	40	SUBGRAYWACKE	0.20 B	X	X	X		X			8m. NORTH OF BLOEMFONTEIN.								
52	55	25	20	ARKOSE	0.25 B	X	X	X		X			SWINBURNE.								
53	55	25	20	ARKOSE	0.10 B		X	X	X	X			VAN REENEN.								

CRETACEOUS TO RECENT

UTENHAGE SERIES

KARROO SYSTEM

TRIASSIC

TABLE 7: COMPOSITION AND LOCALITY OF SAMPLES.

SAMPLE No.	QUARTZ	FELDSPAR	ROCK FRAGMENTS	NAME	AV. GRAIN SIZE (mm.)	ROUNDNESS	CARBONATE	CHLORITE	SERICITE	MICA	GRAPHITE	CLAY PELLETS	LOCALITY		
54.	50	30	20	ARKOSE	0.15	B		X		X			5m. SE. OF VAN REENEN.	LOWER BEAUFORT STAGE	KARROO SYSTEM
55.	55	35	10	ARKOSE	0.10	B	X						EAST LONDON.		
56.	65	30	15	ARKOSIC GRIT	2.00	A	X			X			KERELAW. OFS.		
57.	55	30	15	ARKOSE	0.10	B			X	X			BLOEMFONTEIN.		
58.	55	40	5	ARKOSE	0.20	C		X		X			5m. SOUTH OF LADYSMITH.	UPPER ECCA STAGE	
59.	30	65	5	ARKOSE	0.35	B	X		X	X			10m. SOUTH OF LADYSMITH.		
60.	30	30	40	SUBGRAYWACKE	0.15	C		X		X			7m. SOUTH OF MOOI RIVER.		
61.	30	55	15	ARKOSE	0.30	D		X					DE BRUG. OFS.	MIDDLE ECCA STAGE	
62.	65	15	20	SUBGRAYWACKE	0.10	B	X	X	X				LAINGSBURG.		
63.	50	50	nd.	SHALE WITH ARKOSE	0.15	B	X	X	X	X	X		BLOEMFONTEIN.		
64.	55	45	nd.	SHALE WITH ARKOSE	0.40	C	X	X		X			WEENEN.	LOWER ECCA STAGE	
65.	60	25	15	ARKOSE	0.20	C				X			KOUP. C.P.		
66.	55	40	5	ARKOSE	0.35	C							7m. SOUTH OF KINROSS. TVL.		
67.	85	10	5	SUBARKOSE	0.25	B	X		X				COAL MINE, SASOLBURG.	LOWER ECCA STAGE	
68.	55	20	25	SILTSTONE	0.05	B		X					FISH RIVER, SW. OF PEDDIE, C.P.		
69.	50	45	5	ARKOSE	0.45	C	X		X	X			PIETERMARITZBURG.		
70.	65	30	5	ARKOSE	0.10	B	X	X	X				DE BRUG. OFS.	DNYKA SERIES	
71.	nd.	nd.	nd.	SILTSTONE	0.03	A	X	X					15m. NE. OF LAINGSBURG.		
72.	nd.	nd.	nd.	TILLITE	nd.		X						FISH RIVER, E. OF GRAHAMSTOWN.		
73.	nd.	nd.	nd.	TILLITE	nd.		X						DURBAN	WITTEBERG SERIES	
74.	nd.	nd.	nd.	TILLITE	nd.		X	X					BARKLY WEST.		
75.	nd.	nd.	nd.	TILLITE	nd.		X	X					ST MICHAELS-ON-SEA.		
76.	nd.	nd.	nd.	TILLITE	nd.		X						GENADENDAL, C.P.	BOKKEVELD SERIES	
77.	nd.	nd.	nd.	TILLITE	nd.		X						GIBEON, SWA.		
78.	65	30	5	ARKOSE	0.20	B	X			X			GIBEON, SWA.		
79.	nd.	nd.	nd.	TILLITE	nd.		X						MATJIESFONTEIN, CP.	TABLE MOUNTAIN SERIES	
80.	95	0	5	ORTHOQUARTZITE	0.20	B			X	X			20m. SW. OF GRAHAMSTOWN.		
81.	100	0	tr.	ORTHOQUARTZITE	0.10	C				X			19m. EAST OF GRAHAMSTOWN.		
82.	95	0	5	ORTHOQUARTZITE	0.15	C				X			10m. NORTH OF WILLOWMORE.	BOKKEVELD SERIES	
83.	95	tr.	5	ORTHOQUARTZITE	0.30	B				X			CALEDON. CP.		
84.	95	0	5	ORTHOQUARTZITE	0.20	C							KONSTABEL, C.P.		
85.	95	5	tr.	ORTHOQUARTZITE	0.10	C				X			20m. NE. OF PORT ELIZABETH.	BOKKEVELD SERIES	
86.	nd.	nd.	nd.	MICACEOUS SILTSTONE	0.03	A		X		X			GRAHAMSTOWN.		
87.	95	0	5	ORTHOQUARTZITE	0.20	C				X			TOUWS RIVER.		
88.	75	5	20	PROTOQUARTZITE	0.20	C			X				HEX RIVER PASS.	TABLE MOUNTAIN SERIES	
89.	95	0	5	ORTHOQUARTZITE	0.30	B							14m. N.W. OF DURBAN.		
90.	65	25	10	ARKOSE	0.35	C	X	X	X				10m. N.W. OF DURBAN.		
91.	100	0	tr.	ORTHOQUARTZITE	0.70	B							PORT ELIZABETH.	TABLE MOUNTAIN SERIES	
92.	95	0	5	ORTHOQUARTZITE	1.80	C				X			NIEUWOUDTVILLE.		
93.	100	0	tr.	ORTHOQUARTZITE	0.20	C				X			GORDONS BAY.		
94.	100	0	tr.	ORTHOQUARTZITE	0.40	C							PRINCE ALBERT.	TABLE MOUNTAIN SERIES	
95.	95	0	5	ORTHOQUARTZITE	0.35	D							GORDONS BAY.		
96.	nd.	nd.	nd.	TILLITE	nd.			X	X	X			CLANWILLIAM.		
97.	55	15	30	SILTSTONE	0.05	A		X		X			NIEUWOUDTVILLE.	MATSAP NEUWERUST SERIES	
98.	nd.	nd.	nd.	CONGLOMERATE	nd.								WOLWEKRANS, TVL.		
99.	100	0	tr.	ORTHOQUARTZITE	0.30	D				X			POSTMASBURG.		
100.	95	tr.	5	ORTHOQUARTZITE	0.45	C			X	X			GORDONS BAY.	GAMAGARA SERIES	

KARROO SYSTEM
 PERMIAN
 CARBONIFEROUS
 CAPE SYSTEM
 DEVONO-CARBONIFEROUS
 PRE-CAMBRIAN
 WATERBERG NAMA SYSTEM

TABLE 8: COMPOSITION AND LOCALITY OF SAMPLES.

SAMPLE No.	QUARTZ	FELDSPAR	ROCK FRAGMENTS	NAME	AV. GRAIN SIZE (mm.)	ROUNDNESS	CARBONATE	CHLORITE	SERICITE	MICA	GRAPHITE	CLAY PELLETS	LOCALITY	
FALKLAND ISLANDS.														
101.	50	30	20	ARKOSE	0.15	C	X	X	X				DOS LOMAS.	TRIASSIC TO PERMIAN
102.	20	20	60	SUBGRAYWACKE	0.10	B	X	X	X				DARWIN JETTY.	
103.	90	10	n.d.	SHALE WITH SUBARKOSE	0.10	B	X	X	X				DARWIN JETTY.	UPPER CARBONIFEROUS
104.	n.d.	n.d.	n.d.	TILLITE	n.d.								MOUNT PLEASANT.	
105.	n.d.	n.d.	n.d.	TILLITE	n.d.								HILL COVE.	DEVONO-CARBONIFEROUS
106.	80	15	5	SUBARKOSE	0.30	D							HILL COVE.	
107.	95	0	5	ORTHOQUARTZITE	0.40	B			X				PORT STANLEY.	DEVONO-CARBONIFEROUS
108.	95	0	5	ORTHOQUARTZITE	0.50	B			X				MOUNT PLEASANT.	
109.	65	30	5	ARKOSE	0.30	B			X				DUNNOSE HEAD.	
110.	95	5	tr.	ORTHOQUARTZITE	0.35	D	X						PORT ALBEMARLE.	
SOUTH AMERICA.														
111.	n.d.	50	n.d.	SAND	0.20								MENDOZA RIVER, ARGENTINA.	RECENT TRIASSIC TO PERMIAN
112.	95	0	5	ORTHOQUARTZITE	0.20	D							FAXINA, BRAZIL.	
113.	95	tr.	5	ORTHOQUARTZITE	0.20	D	X						ARARUVA, BRAZIL.	TRIASSIC
114.	80	15	5	SUBARKOSE	0.10	C	X						JACARÉZINHO, BRAZIL.	
115.	n.d.	n.d.	n.d.	TILLITE	n.d.		X	X	X				MAFRA, BRAZIL.	UPPER CARBONIFEROUS
116.	n.d.	n.d.	n.d.	TILLITE	n.d.				X				PALMEIRA, BRAZIL.	
117.	95	5	tr.	ORTHOQUARTZITE	0.35	C	X						TIBAGÍ, BRAZIL.	DEVONIAN
118.	95	tr.	5	ORTHOQUARTZITE	0.20	C	X						TIBAGÍ, BRAZIL.	
119.	85	10	5	MICACEOUS SUBARKOSE	0.05	B			X				TIBAGÍ, BRAZIL.	LOWER DEVONIAN
120.	75	20	5	ARKOSE	1.00	B	X	X					CAMPO LARGO, BRAZIL.	
121.	95	0	5	ORTHOQUARTZITE	0.03	C				X			CAMPO LARGO, BRAZIL.	
TASMANIA.														
122.	20	60	20	ARKOSE	0.15	B		X					1m. SOUTH OF ZEEHAN PO.	UPPER SILURIAN DEV.
123.	15	70	15	ARKOSE	0.25	B							1m. S.S.W. OF ZEEHAN PO.	
AUSTRALIA.														
124.	20	tr.	80	SUBGRAYWACKE	0.35	B	X	X					MINCHINBURY, NSW.	UPPER TRIASSIC
125.	55	40	5	ARKOSE	0.35	B							SPRINGWOOD, NSW.	
126.	20	15	65	SUBARKOSE	0.10	B	X						NARRABEEN, NSW.	LOWER TRIASSIC
127.	10	tr.	90	LITHIC GRAYWACKE	0.70	A	X						MORRISSET, NSW.	
128.	15	10	75	LITHIC GRAYWACKE	0.20	A	X						LIDDELL, NSW.	UPPER PERMIAN
129.	10	5	85	LITHIC GRAYWACKE	0.25	A	X						CESSNOCK, NSW.	
130.	5	15	80	LITHIC GRAYWACKE	0.45	A	X						CESSNOCK, NSW.	LOWER PERMIAN
131.	n.d.	n.d.	n.d.	TILLITE	n.d.		X	X					SEAHAM, NSW.	
ANTARCTICA														
132.	65	10	25	SUBGRAYWACKE	0.30	C				X			PRIESTLEY GLACIER, S VICTORIA LAND.	GONDWANA
133.	95	5	tr.	ORTHOQUARTZITE	0.10	B		X	X				PRIESTLEY GLACIER, S VICTORIA LAND.	
134.	60	15	25	SUBGRAYWACKE	0.50	B	X	X	X				PRIESTLEY GLACIER, S VICTORIA LAND.	PERMIAN
135.	85	10	5	SUBARKOSE	0.80	C		X					MAC ROBERTSON LAND.	
136.	55	25	20	ARKOSIC GRIT	3.00	C	X							PERMO-CARBONIFEROUS
137.	65	20	15	ARKOSE	0.20	C	X	X						
138.	80	15	5	SUBARKOSE	0.15	C	X							CARBONIFEROUS
139.	30	20	50	SILTSTONE	0.05	B	X		X	X				
140.	40	10	50	SILTSTONE	0.05	B	X		X	X			HORLICK MOUNTAINS. 84°S. 114°W.	DEVONIAN
141.	60	10	30	SUBGRAYWACKE	0.30	A			X					
142.	55	15	30	SUBGRAYWACKE	0.20	B			X					LOWER DEVONIAN
143.	60	25	15	ARKOSE	0.30	B	X		X					
144.	50	40	10	ARKOSE	0.45	C		X	X					
145.	n.d.	n.d.	n.d.	CONGLOMERATE	n.d.									"SEDIMENTARY ROCKS" GONDWANA?
146.														
147.														
148.														
149.														
150.														
PARTIALLY CONCENTRATED SAMPLES RECEIVED.													QUEEN MAUD LAND.	

FIGURE I: SKETCH MAP SHOWING THE LOCALITIES OF THE SOUTH AFRICAN SAMPLES.

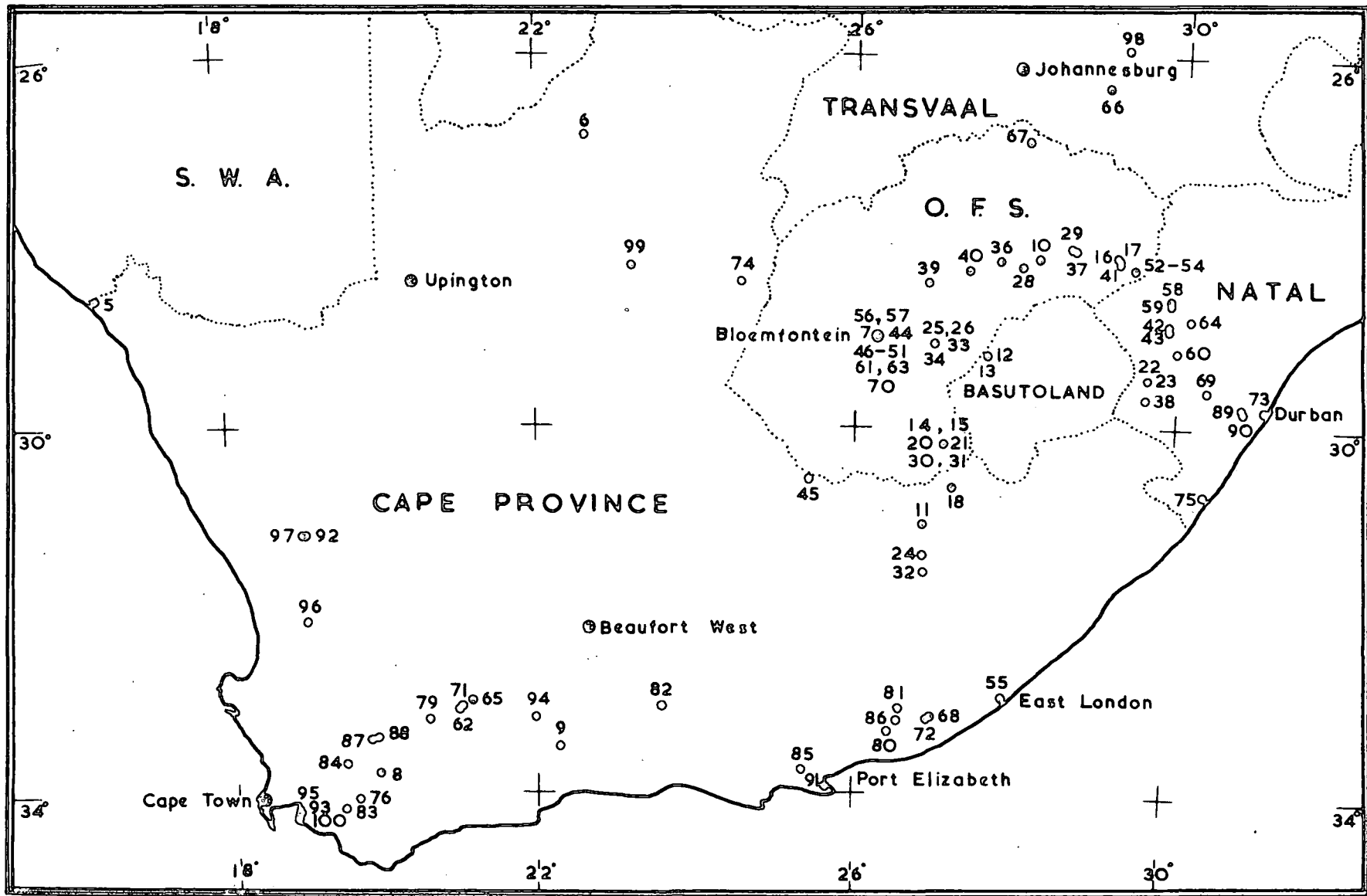


FIGURE 2: GRAPHIC REPRESENTATION OF THE DIFFERENCE IN EFFICIENCY
OF TWO METHODS OF BROMOFORM SEPARATION.

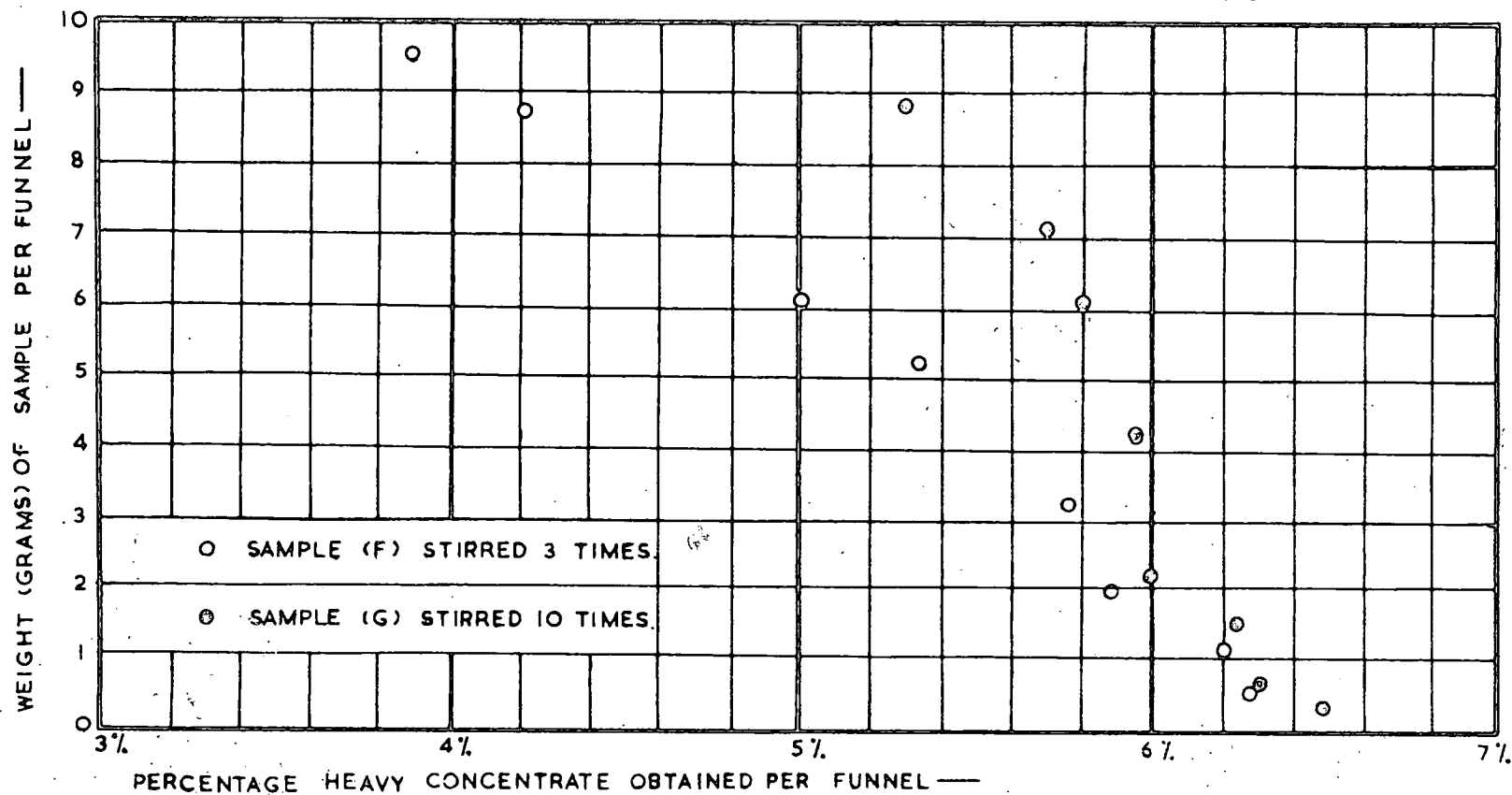


FIGURE 3: HISTOGRAMS OF THE REFRACTIVE INDEX DISTRIBUTION OF GARNET IN SELECTED SAMPLES.

(Numbers refer to samples in tables 1 to 8)

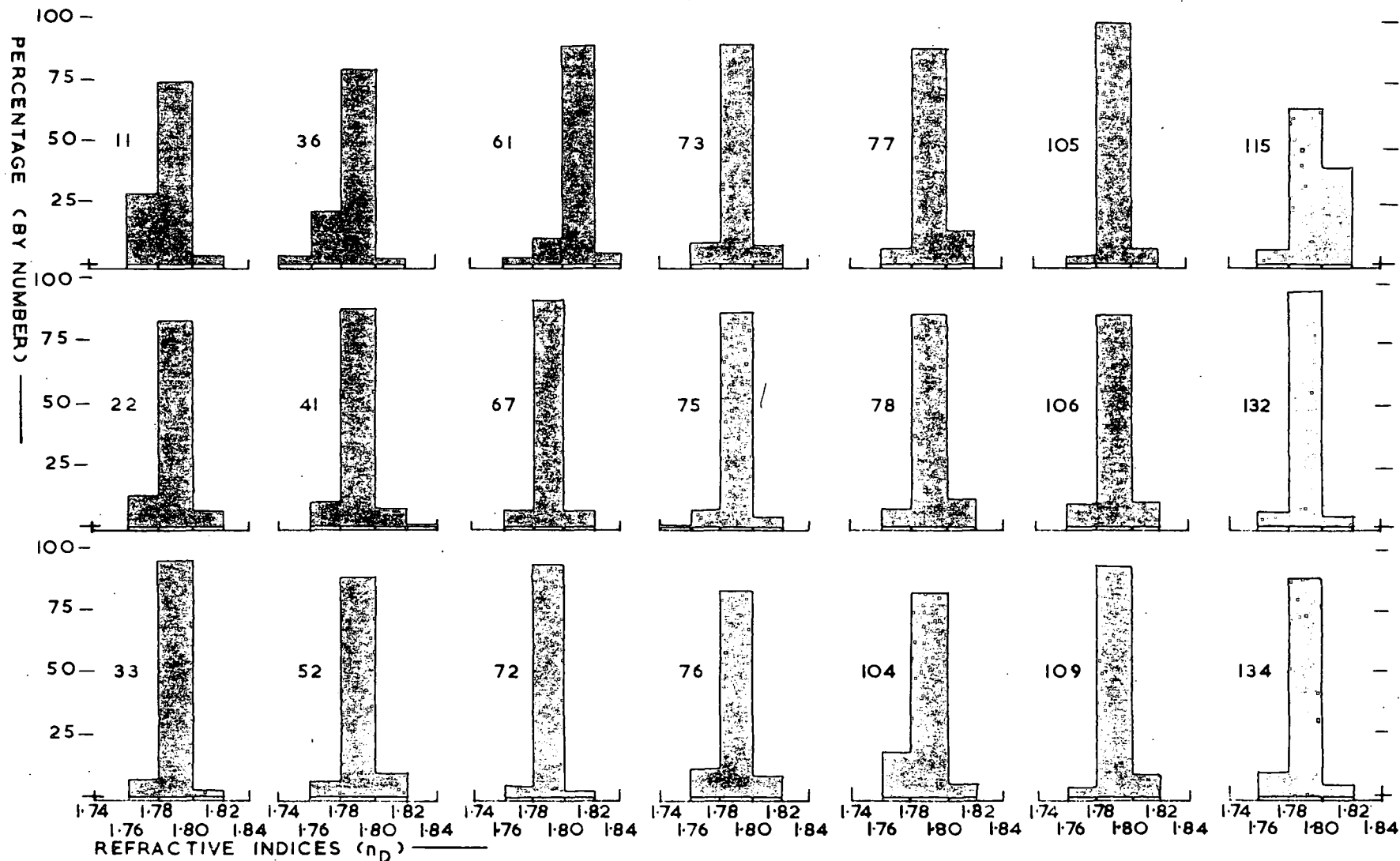


FIGURE 4: SKETCH MAP SHOWING THE LOCALITIES OF THE ANTARCTICA SAMPLES.

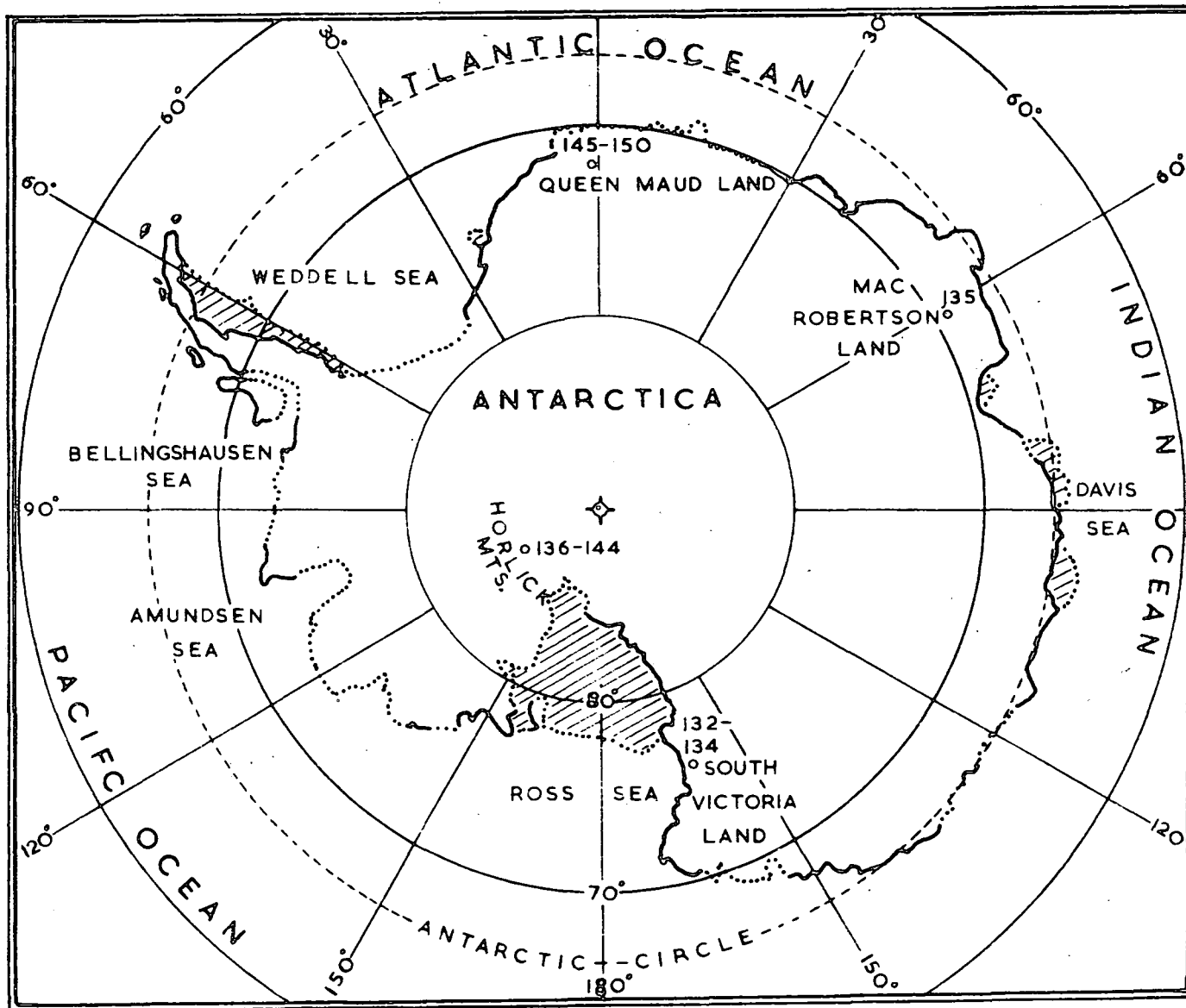
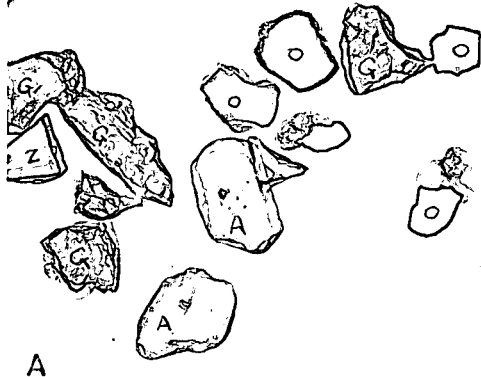


PLATE I.

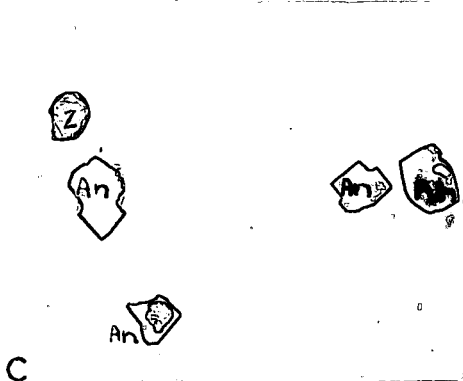
SAMPLE No 50.



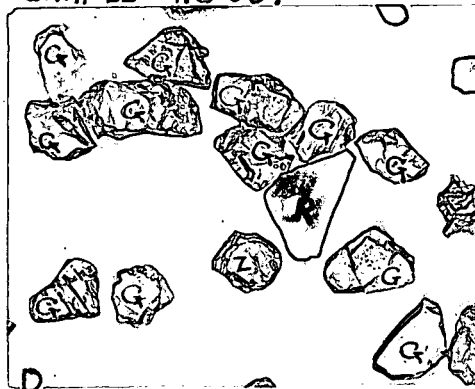
SAMPLE No 6.



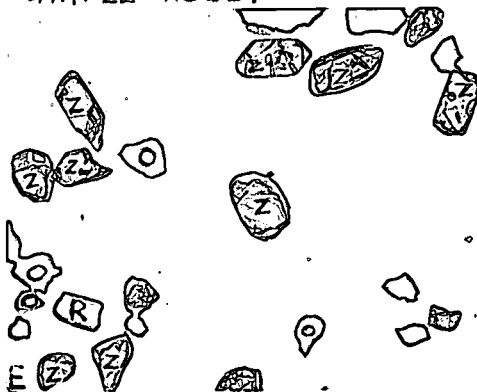
SAMPLE No 30.



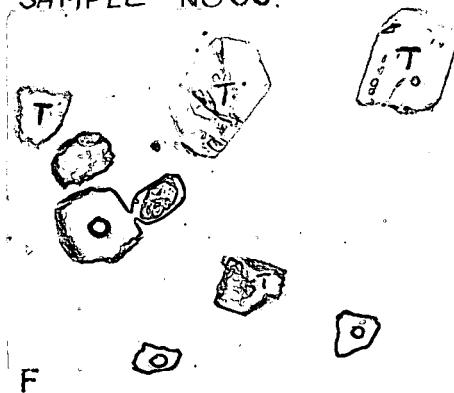
SAMPLE No 59.



SAMPLE No 93.



SAMPLE No 93.



G - GARNET, Z - ZIRCON, A - APATITE, An - ANATASE,
 R - RUTILE, T - TOURMALINE, I - ILMENITE, O - OPAQUE

