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THE STRATIGRAPHY OF THE WITTEBERG - DWYKA CONTACT BEDS

by

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A B S T R A C T

Effective use is made of a multiple system to subdivide the portion of the Cape-Karroo stratigraphical column investigated into rock-, time- and in a lesser degree, biostratigraphic units.

Heavy mineral studies reveal that distinct vertical variation trends exist for tourmaline. The steady increase in the frequency of brown tourmaline over other types makes this mineral specially suited for correlation, even over long distances. Garnet is indicative of the Dwyka Group.

In the southern outcrop areas the Cape and Karroo Supergroups are structurally conformable to each other. Continuity in deposition was the rule.

The sandstones of the Wittepoort Formation are interpreted as stable shelf deposits. The mixed sediments of the Lake Mentz Formation mark the rapid transition to a large interior basin with more restricted circulation. The fine-grained proglacial sediments of the Kommadagga Formation were deposited in a basin inherited from the Witteberg Epoch. The overlying tillites were deposited in a marine environment. An interpretation of the tectonic history of the Cape-Karroo sequence indicates that a peneplanation stage was present up to the end of the Witteberg Epoch. A geosynclinal stage then set in.

It is convenient to divide the sequence into two major time-stratigraphic units of system rank. The base of the Karroo System is chosen in view of historical, lithological, geographical and paleontological considerations.

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CHAPTER I

INTRODUCTION

A. SCOPE OF PROBLEM

The Cape and Karroo Supergroups formerly covered and still cover the major part of Southern Africa. Except for an isolated occurrence of the Table Mountain Group in Natal, the Cape Supergroup is found in the southwestern and southern parts of the Cape Province. The Karroo Supergroup follows in structural conformity on the Cape Supergroup all along the total length of the southern outcrop area of the two supergroups. For a certain distance to the north of Karoo-poort in the Western Karroo this conformable relation holds good. Northwards the basal group of the Karroo Supergroup, the Dwyka Group, oversteps the three groups of the Cape Supergroup.

Although the two supergroups have attracted the attention of many geologists, comparatively little is known of all the various aspects of the stratigraphy of the sequence as a whole; various investigators having confined their studies to a single group or a sub-division of one and frequently in one geographic locality only.

At the suggestion of Professor M.S. Taljaard the present research, the results of which are presented in this paper, was undertaken, the major objects of the investigation being the following:

(i) To establish the nature of the contact between the Witteberg and Dwyka Groups.

(ii) To determine the nature of the contact beds.

(iii) To establish field and laboratory criteria to be used when mapping this contact.

(iv) To clear up the old controversy of the exact position of the contact.

(v) To establish the stratigraphic relationship between the Cape and Karroo Supergroups.

The fieldwork was done during the university holidays spread over the period 1961 - 1964.

B. METHODS OF INVESTIGATION

A continuous length of outcrop of Witteberg - Dwyka contact rocks commences north of Elandsvlei in the Western Karroo and terminates near the mouth of the Great Fish River between Port Alfred and East London. Owing to folding and faulting a few scattered outliers are preserved in the southern and southwestern folded belt.

Generally speaking,the rocks are well exposed in the sparsely vegetated arid regions of the Southern Karroo. In the Grahamstown area and farther east, however, there is a thicker cover of vegetation on the more deeply-weathered rocks. In the Western Karroo, Tertiary gravels at the base of the Swartruggens Mountains, as well as recent water- and windborne sediments, constitute a natural hazard when mapping. Many miles of contact rocks are obscured in this way.

It was decided to investigate in detail only certain localities distributed over the length of the outcrop area. Particular attention was given to a few outliers. Wherever it was deemed necessary, mapping was done by telescopic alidade and plane table. Use was made of base maps supplied by the Trigonometrical Survey Office in Mowbray. In some areas only stratigraphic profiles were considered to be sufficient. In certain localities only peculiar or interesting phenomena were investigated.

Outcrops of the Witteberg and Dwyka Groups are shown on the locality map. (Fig. 1).

The work was divided into two parts:

(i) A field study of the rocks in question. It entailed mode of occurrence, lithology, control of local relief, weathering, colour, primary structures and fossil content.

(ii) Laboratory work on selected samples to study the microscopic characteristics and the heavy mineral content. Partial qualitative chemical analyses were made of a few samples.

In this paper the fundamental principles embodied in the "Code of Stratigraphic Nomenclature" of the American Commission on Stratigraphic Nomenclature (1961) as well as those described in the "Statement of Principles of Stratigraphic Classification and Terminology" by the International Subcommission on Stratigraphic Terminology" (1961) are used as a guide. The author is of opinion that the multiple system

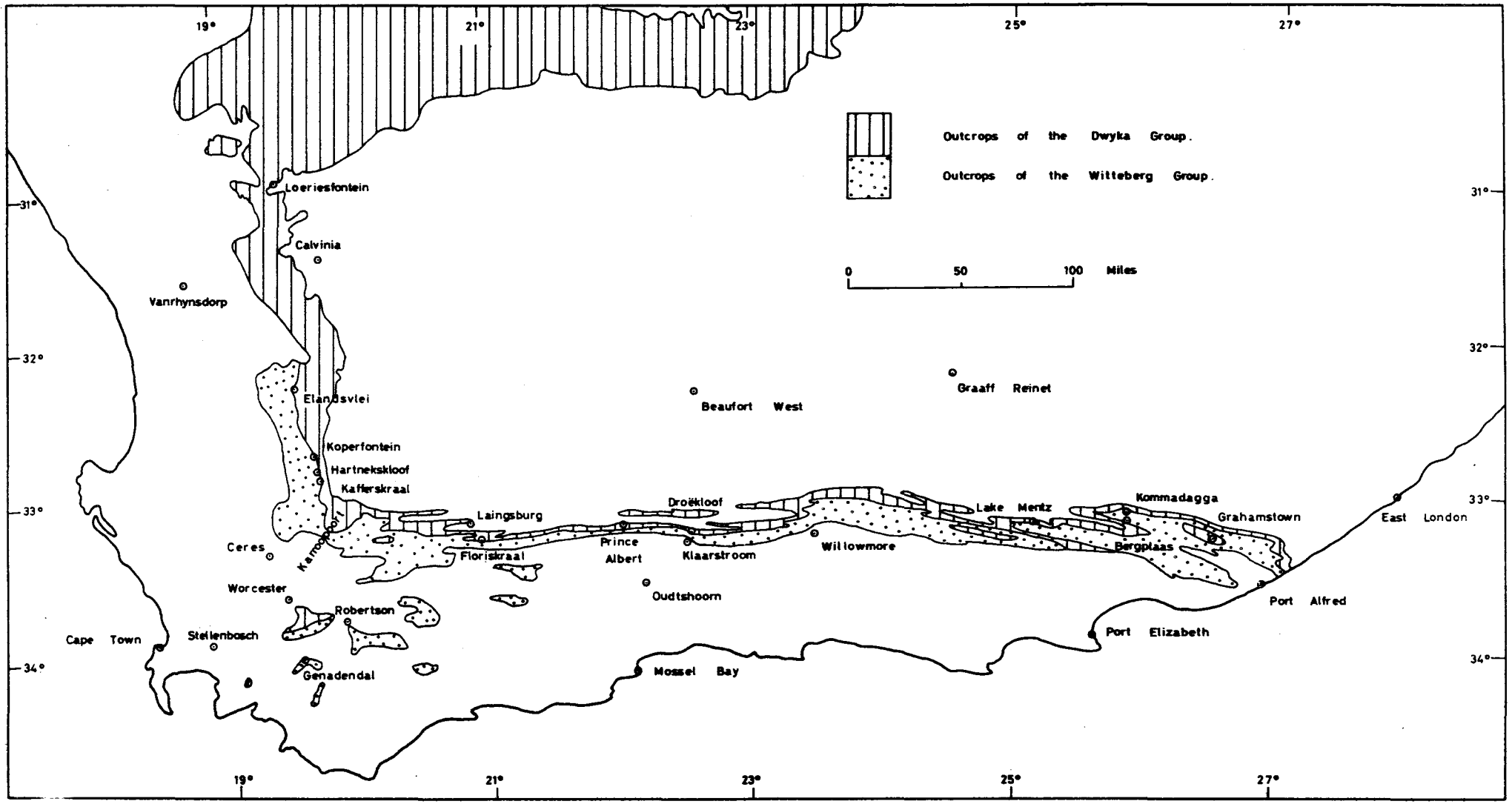

Fig. 1. Locality map.

as advocated by the ACSN and the ISST can be applied with great success in Southern Africa. The present rigid system used in this country does not permit the more detailed subdivision and classification of the various units of the stratigraphic column.

The use of the multiple system would ensure that our stratigraphic methods and terminology conform with the proven and accepted international practice. (At the twenty-first session of the International Geological Congress held in Copenhagen, 53 members of the ISST accepted the "Statement of Principles" while only three expressed disapproval).

To describe the thickness of stratification, the scheme of R.L. Ingram (1954, p. 938) is used.

When describing the lithology of sedimentary rocks, one is confronted by the lack of an accepted system of terminology. The classification system for sandstones by F.J. Pettijohn (1957, p. 291) is used here. For the more fine-grained rocks the scheme of C.O. Dunbar and J. Rodgers (1957, p. 166) is used.

To describe the roundness of sedimentary particles the roundness scale of M.C. Powers (1953, p. 118) is used.

The colour of certain rocks is, wherever necessary, accurately described in terms of the rock-colour chart distributed by the Geological Society of America (1951).

To describe the vegetation in certain selected areas, the classification scheme of J.P.H. Acocks (1953) is used.

C. HISTORICAL REVIEW

The geology of the Cape Province has attracted the attention of various writers throughout the years. Before the advent of trained geologists, various travellers observed and described certain aspects of the geology. Since the latter half of the nineteenth century the accumulation of facts took place in a more organized and scientific way.

Two controversies namely the one over the sequence of the pre-Karroo rocks and that over the origin of the Dwyka Tillite, retarded the accumulation of facts relating to the Cape and Karroo Supergroups.

These two controversies as well as other aspects of the history of stratigraphic investigation in Southern Africa, are treated in detail by G.S. Corstorphine (1904).

It is necessary to describe the long line of investigation which led up to our present knowledge of the geology of the Cape-Karroo contact rocks.

Sir John Barrow who travelled extensively through Southern Africa during the years 1797-1798, observed, inter alia, aspects of the geology and geography of the region. In the vicinity of Brandvlei near Worcester he saw Witteberg rocks. He recognized the separate character of the "...long range of hills.....composed of quarts, sand-stone and iron" (1807, p. 73), although he did so through faulty reasoning. (V.S. Forbes, 1965, p. 138).

Near the present day Prince Albert he observed Dwyka Tillite and noticed the ".....rounded pebbles, embedded in this argillaceous matrix ...." (Op. cit., p. 101). He mistook it for an intrusive igneous rock. (V.S. Forbes, Op. cit., p. 137).

The first clear outline of the geology of the Cape Colony was given by Andrew Geddes Bain (1856) in two papers submitted to the Geological Society of London in 1845 and 1852 respectively. The second paper was supplemented with a map showing the geology of the Southern and Western Karroo. Bain, a road-maker by profession and a "self-taught individual", carried out his observations in the western, southern and eastern parts of the Cape Colony, in part in an "uncivilized and dangerous region". He travelled extensively and found time to determine the nature of the various groups of beds and their succession and to draw a rough map. Unfortunately he left a gap in the Baviaanskloof area, thus failing to link up the western and eastern occurrences of the present-day Cape Supergroup. From his writings it is clear that Bain did not always distinguish between the white sandstones from the Table Mountain and Witteberg Groups. In the western region he did not differentiate between the Bokkeveld and Witteberg Groups, but mapped them as "Upper Silurian". To the east of the Baviaanskloof gap the same beds were called "Carboniferous", in this way indicating that he recognized the separate character of the Witteberg Group. The Bokkeveld Group was here taken as the lower division of the Witteberg Group. According to Bain the Claystone Porphyry (Dwyka Tillite) thus overlies the Upper Silurian beds in the west and the Carboniferous beds in the east. Although he traced the Claystone Porphyry for some hundreds of miles, he omits any reference to shales underlying it. Bain believed the Claystone Porphyry to be of igneous origin.

In 1859 Andrew Wyley published the results of his investigations during his journey across the Cape Colony. He encountered the Table Mountain, Bokkeveld and Witteberg Groups and confirmed Bain's generalized order of the succession. During his journey he found that the Karoopoort and Witteberg sandstones, which were the same as the Suurberg sandstones, constitute a separate series. Wyley encountered Bain's Claystone Porphyry and renamed it "Trap Conglomerate", thus indicating that he thought it to be of igneous origin. He observed that the Dwyka Tillite is conformable to the shales below and above it. He mentions black, brownish and gray shales below the tillite but omits any reference to the nature of the contact between it and the underlying Witteberg sandstones. He called the shales the "Lower Karoo Shale".

Dr. P.C. Sutherland, Surveyor General of Natal, investigated field occurrences of the "boulder clay" at the base of the Karroo Supergroup. He observed the stratification and on this and other evidence believed it to be of aqueous origin (1868, p. 19). The presence of boulders of many different shapes and sizes greatly intrigued him and he noticed the similarity in "mechanical composition" between the "boulder clay" and the "Scandinavian drift" which he knew to be of glacial origin (Ibid., p. 20). Sutherland thus proposed a glacial origin for the Dwyka Tillite of Natal.

R. Pinchin (1875), while completely ignoring the work of most of his predecessors, regarded the conglomerates above the Witteberg sandstones as a metamorphic rock, separated from it by some shales.

On the first edition of his geological map (1873), E.J. Dunn preferred to use the term "Trap Conglomerate" for the Dwyka Tillite. On his second map (1875) he introduced the name "Dwyka Conglomerate" for the Dwyka Tillite of the Southern Karroo. By 1879 he was convinced of its sedimentary character although he did not believe it to be of glacial origin like the so-called "Glacial Conglomerate" of the northern parts of the Cape Colony. To Dunn the tillite appeared conformable to the underlying sandstones. Dunn's map of 1886 show all the then known outcrops of the glacial conglomerates. He proved them to be of the same age and continuous in outcrop and assigned to all of them the name "Dwyka Conglomerate". He knew them to be of glacial origin and mapped them as a separate unit. He realized that the conglomerate formed the "rim and bottom of a vast basin of Karroo beds".

During field trips to the Southern Karroo, Professor A.H. Green (1888) collected evidence which led him to believe that an unconformity existed at the base of the Dwyka Conglomerate. Green's views have since been disproved.

In 1888 Dr. A. Schenck introduced the term "Cape Formation" to

include the three groups of the Cape Supergroup. He also applied the term "Karroo Formation" to what is now known as the Karroo Supergroup. In this respect he was preceded by earlier writers who had used the terms "Karroo" to denote either the whole supergroup or subdivisions thereof. In a second paper (1889) he maintained that the Dwyka Conglomerate was of glacial origin.

Between the years 1895-1911 the geologists G.S. Corstorphine, A.W. Rogers, E.H.L. Schwarz and A.L. du Toit, who were at one time or another attached to the Geological Commission of the Cape of Good Hope, made valuable contributions to the knowledge concerning the geology of the Cape Colony. They used the term "System" in preference to Schenck's "Formation". To denote a subdivision of a System, they used the term "Series". Although they divided the Cape-Karroo sequence into two systems, they were aware of the conformity between them, such as to be seen in the Southern Karroo. Their subdivision of the sequence is strange to understand in view of G.S. Corstorphine's observations published in an annual report to the Cape Government (1899). He admits that "....there is a perfectly continuous passage from the Witteberg Beds, through the Dwyka, to the Ecca sandstones and shales; that is to say a conformable succession through several thousands of feet of strata, implying continuity of deposition, marked, however, by one peculiar phase, when in addition to the normal sediments, glaciated boulders were carried far south and dropped irregularly among the accumulating muds".

The Dwyka Series was in 1902 subdivided into the Lower Shales, the Dwyka Conglomerate and the Upper Shales. Later the name "Dwyka Tillite" was used instead of "Dwyka Conglomerate". The "Witteberg Series" was seen to include several shaly bands in addition to the normal white sandstones. Previous writers had emphasized the sandstones only. The choice of the upper limit of the series was entirely arbitrary and based on convenience only. Wherever a continuous bed of white sandstone was found to occur in the midst of the shales intervening between the main body of Witteberg sandstones and the Dwyka Tillite, its top was taken as the boundary. Wherever no such continuous sandstone bed was present, the upper limit of the main body of white Witteberg sandstones was defined as the top of that series. All beds intervening between the arbitrary boundary and the overlying Dwyka Tillite, were grouped together as "Lower Dwyka Shales". It should now be noted that, years before, Andrew Wyley had considered the shales to belong to the "Karroo beds". As could be expected, this practice did not lead to a satisfactory solution of the problem. In a report to the Cape Government, A.W. Rogers and A.L. du Toit (1903, p. 19) described the Lower Dwyka Shales from near Karoopoort and observe that "...they are evidently 'passage beds' between the Witteberg and Dwyka Series, the lowest part

resembling those belonging to the former rather than the latter, while the reverse is the case in the higher beds."

The Lower Dwyka Shales were traced northwards from Karoopoort to the farms De Vallei and Kafferskraal. The disapperance of the shales was thought to be "....evidently connected with the unconformity..." which extended on from a as yet undetermined point more to the north.

In 1905 A.W. Rogers published his text "An Introduction to the Geology of Cape Colony" in which he presented the then known facts. He also strove to construct the geological history of the Cape Colony.

In the same year F.H. Hatch and G.S. Corstorphine published the first edition of their text "The Geology of South Africa". Although recognizing the separate character of the Dwyka Tillite, they preferred to consider it, as well as the shales below, as being part of the Ecca Series.

After studying the Dwyka rocks all over Southern Africa since 1903, A.L. du Toit published his widely-known work "The Carboniferous Glaciation of South Africa" (1921). This work is a major contribution to our knowledge of the Dwyka Glaciation. Du Toit picture the Dwyka ice-sheet as a "compound body.... formed by the coalescing of ice radiating from several distinct centres, namely, Namaland, Griqualand West, Transvaal and Natal". The continental ice moved in a general southerly direction into a sea which formerly covered what is now known as the southern part of the Cape Province. In this way the northern ground-moraine tillite grades into the southern marine facies which rests conformably on the Witteberg beds. Using evidence collected from all over Southern Africa, Du Toit compiled a map showing the radiation of the Dwyka ice-sheet.

In 1937 A.L. du Toit published his "Our Wandering Continents, an hypothesis of Continental Drifting", in which he saw the broader outline of the World's geology. He also explains how the sedimentational history of the Cape-Karroo sequence fits into the general picture.

In his review of the Cape Orogeny, J. de Villiers (1944) outlines the depositional and orogenic history of the Cape and Karroo Systems.

The first attempt to unravel the sedimentational history of a particular group of beds using more modern stratigraphic methods, was by B. Swart (1950). He investigated the Bokkeveld Series in the vicinity of Wuppertal. This work is a valuable addition to our ever-increasing amount of knowledge concerning the geological history of the Cape System.

Since its formation, geologists attached to the Geological Survey of South Africa have at various times investigated and mapped extensive

areas of the Cape Province. Regional maps together with explanations were published through the years. The outbreak of the Second World War in 1939 led to renewed attempts to find petroleum in Southern Africa. Although being totally unsuccessful in their original quest, the Geological Survey made a major contribution to the knowledge of the stratigraphy of the Southern Karroo. The results of their investigations were published in 1953 by S.H. Haughton et al.

An important change in the delimitation of the Cape System was instituted. All the beds between the uppermost white sandstone of the Witteberg Series and the base of the Dwyka Tillite which had previously been known as the Lower Dwyka Shales, were renamed "Upper Witteberg shales", in this way making the base of the tillite the base of the Dwyka Series. This practice conforms with that in use in the northern parts where no shales intervene between the terrestrial tillite and the floor on which it rests unconformably. As far back as 1925, A.W. Rogers, then director of the Geological Survey, had already remarked on the convenience of mapping the base of the tillite as the base of the Karroo System. By them, as in 1953, it had already been known that the beds in the lowermost part of the Lower Dwyka Shales closely resemble true Witteberg beds while the upper portion was, lithologically speaking, of a more "Karroo" type.

In a later paper J. de Villiers (1956) discussed the structure of the south-western Cape Province and makes certain observations on the sedimentational and orogenic history of the Cape-Karroo sequence.

In a thesis submitted in 1959 and subsequently published in 1962, I.W. Hälbich presents the results of a study of the morphology of the Dwyka Series in the vicinity of Loeriesfontein. After detailed field work which included fabric analyses, he was able to draw certain conclusions about the mode of transportation and deposition of the Dwyka Tillite. Hälbich also gave a review of the pre-glacial history of the western part of the Cape Province.

In a thesis submitted in 1960 and published in 1962, J.N. Theron analyses the Cape Folding in the district of Willowmore. His section includes all three series of the Cape System as well as the Dwyka Series of the Karroo System. He also records primary structures which he uses to evaluate certain aspects of the sedimentational history of the beds in question. Theron introduced a three-fold subdivision of the Witteberg Series, namely, into a Lower, Main and Upper Stage. The upper limit of the Main Witteberg Stage was taken at the top of the conspicuous white-weathering main sandstone. All beds intervening between it and the Dwyka Tillite constitute the Upper Witteberg Stage.

During January, 1960 an outlier of Dwyka Tillite was discovered by J.E. de Villiers in the vicinity of Genadendal. This outlier represents the most southerly occurrence of any Karroo rocks known up to the present. It was mapped and described by L.C. Gouws (1961). Subsequently a paper was jointly written by J.E. de Villiers and L.C. Gouws and read by the senior author at the C.C.T.A. Congres in Pretoria during September, 1961. The authors submit evidence to prove that the tillite is a terrestrial deposit resting unconformably on eroded Witteberg sandstones. The authors query the accepted view that the "southern" tillite is of marine origin.

The observations presented in the two papers as well as some of the conclusions drawn therefrom, is critically examined in Chapter III of this paper.

In January 1966 M.R. Johnson submitted a thesis on the stratigraphy of the Cape-Karroo sequence in the Eastern Cape Province. His work is primarily concerned with the division of the geological column into lithostratigraphic units and the description thereof. He touches on the sedimentational history only very briefly. Johnson clearly shows how the multiple system of the ACSN and the ISST can be applied to the Cape-Karroo sequence. Consequently we find that the traditional names for lithostratigraphic units as used have to be rejected in favour of the new terms. The old terms are retained, though in a different sense. Thus, for example, the old "Cape System" becomes the Cape Supergroup, a lithostratigraphic unit. The name Cape System is retained when referring to the time-stratigraphic unit. Likewise the old "Witteberg Series" becomes the Witteberg Group. The "Upper Witteberg Stage" is renamed by Johnson the Lake Mentz Shales, taking the name from their occurrence at Lake Mentz as described by J.A.H. Marais (1963).

In 1967 E.P. Plumstead published a well-illustrated paper on the flora of the Cape Supergroup.

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CHAPTER II

STRUCTURAL AND PHYSIOGRAPHICAL FEATURES

A. GENERAL STRUCTURE AND PHYSIOGRAPHY OF THE SOUTHERN AND WESTERN CAPE PROVINCE

A detailed discussion of the structure and physiography falls outside the scope of this paper. The subject is extensively treated by F. Dixey (1938), J. de Villiers (1944), (1956), L.C. King (1947), (1963), M.S. Taljaard (1949) and A.L. du Toit (1954), as well as in publications of the Geological Survey dealing with the area. It will suffice to describe here only the general outline of the structure and physiography only in so far as they have a bearing on the distribution of the beds of the Witteberg and Dwyka Groups and their mode of occurrence in the field.

The Cape and Karroo Supergroups are usually affected by folding in the western, southern and eastern regions of the Cape Province. The older Cedarberg or western folds trend slightly west of north. Towards the north the degree of folding is less intense. The southern or Swartberg folds occupy a wide belt in the southern and eastern areas. The strike of the folded belt is roughly east-west. However, individual folds tend to be concave to the south. Towards the interior and away from the last anticlinal mountain range, the degree of folding gets less intense. The area of syntaxis of the two fold systems runs diagonally across the strike-line of both, from Karoopoort, through Ceres and down to Cape Hangklip on the coast.

Mid-Cretaceous faulting, supposedly associated with the fracturing of Gondwanaland occurred on a widespread scale. Generally the parallel faults occur along the southern flanks of the fold ranges, the downthrow side being on the south as well. Thrust-faulting of the same age as the folding, is less common and when present, the fault-planes are invariably along the northern flanks of the anticlinal ranges. Folding, faulting and sometimes a combination of both led to the distribution of isolated occurrences of the Witteberg and Dwyka Groups well away from the continuous line of outcrop.

The marked lithological differences between the three groups of the Cape Supergroup coupled with folding and faulting, led to the birth of many parallel mountain ranges and subsequent intermontane valleys.

The Table Mountain Group, consisting mostly of sandstone, builds the major mountain ranges. The Bokkeveld Group by nature of its easily eroded shales and siltstones, is found in synclinal valleys or else on the southern side of ranges formed by Witteberg beds. The Witteberg Group consisting mainly of resistant sandstones as well as a few subordinate more argillaceous beds, builds less impressive fold mountains than the Table Mountain Group.

In the Western Karroo low-dipping beds of the Witteberg Group form a series of low hills in the vicinity of Elandsvlei. Towards the south the Swartruggens Mountains extend as far as Karoopoort where there is a right-angle junction with the Bonteberg Mountains. Commencing near Laingsburg the Witteberg Mountains, from where the group gets its name, extend towards Klaarstroom, where the name changes to the Witberg Mountains which merge with the Great River Heights near Steytlerville. Farther east the Suurberg curves slightly to the coast. In the Grahamstown area the Witteberg Group forms less impressive topographic features.

The fairly level plains studded with low hills, extending from the base of the fold ranges to the base of the Great Escarpment, are cut in beds of the Karroo Supergroup. In the Western Karroo the Dwyka Group occupies the flat river-cut area at the foot of the Swartruggens Mountains. In the Southern Karroo the Dwyka Group is to be found in the flat areas immediately north of the ranges or else it constitutes the low foot-hills such as near Laingsburg.

In the Western Karroo Tertiary and younger deposits cover most of the rocks along the base of the Swartruggens. Owing to the steep dip of the beds of the Wittepoort Formation in the Southern Karroo the Lake Mentz and Kommadagga Formations consisting of less resistant beds, occur all along the slope of the ranges or else along the base. Invariably scree and other unconsolidated sediments cover portions of the outcrops. The best sections are displayed at the northern entrances of the river gorges or "poorts" breaching the fold ranges.

Owing to the low annual rainfall, the vegetation in the Western and Southern Karroo is sparse. East of Kommadagga, however, the nature and thickness of the vegetal cover changes rapidly, corresponding to a higher rainfall and deeper weathering of the rocks.

B. STRUCTURE AND PHYSIOGRAPHY OF SELECTED AREAS

(1) Bergplaas, Kommadagga

The Bergplaas homestead lies 5.7 miles south of the new Kommadagga railway station. The area mapped (Fig. 2), occurs in the tract of country shown on Cape Sheet 9 of the Geological Survey. A wide strip of country to the north of Bergplaas is occupied by a few minor folds in beds of the Witteberg Group. A low anticlinal range having a low westerly plunge, attains a height of 2298 feet above sea-level in the Wittepoortkop 2.3 miles to the northeast of the Bergplaas homestead. Two miles to the east of Wittepoortkop, the Bushmans River flows through the Swartwaterspoort which is cut in the same anticlinal range. At the homestead the range is traversed by the Wittepoort through which a tributary of the Bushmans River flows towards the south. The Wittepoort owes its origin to the river having exploited the relatively weaker zone of a minor cross-flexure and having thus progressed from the south by headward erosion.

To the west of the southern entrance of the Wittepoort the remnants of a once more extensive terrace covered with superficial deposits, can be seen. Near the homestead and farther to the south, extensive patches of alluvium occur. It is in places utilized for agricultural purposes.

In the area south of the anticlinal range, the soft-weathering beds of the Lake Mentz and Kommadagga Formations constitute a few low rounded hills separated by subsequent valleys.

The average elevation of the Bergplaas area is 1600 feet above sea-level. In the area open exposures of the inclined beds are the rule. The poorly-developed soil supports typical short bushes, taller shrubs and occasional trees which constitute the False Karroid Broken Veld.

(2) Droëkloof, Klaarstroom

The Droëkloof homestead lies next to the Klaarstroom-Beaufort West road. (Fig. 3). It is also shown on maps incorporated with the Geological Survey Memoir 45. The farm lies on the northern side of the northernmost fold range of white sandstones of the Wittepoort Formation, the Witteberg. To the north the level plain of the Southern Karroo extends up to the Nuweveld Escarpment. In the Droëkloof area the fold axes have easterly plunges, in this way producing anticlinal ranges arranged en echelon. Owing to the low annual rainfall, the vegetal cover subsists on poorly-developed soil. Except where scree and elluvium are

present, the bedrock is well exposed.

Succulents, low shrubs and typical Karroo bushes constitute the Karroid Broken Veld.

(3) Floriskraal, Laingsburg

The area mapped (Fig. 4) is situated around the Floriskraal homestead. The farm lies at the northern entrance to Leeukloofpoort, the gorge of the Buffels River through the Witteberg Mountains.

In his textbook of geomorphology, "South African Scenery", L.C. King (1963) includes a photograph (Plate 25), taken by A.W. Rogers, of the northern entrance to Leeukloofpoort. Unfortunately he erroneously thought it to be the poort through the Klein Swartberg which lies, in fact, a few miles farther south.

The asymmetric anticline with internal overfolding forms the southern boundary of the area. Towards the north parallel strike-line ridges separated by the tributaries of the Buffels River, form the low foot - hills of the Witteberg range. The present-day topography is the result of the dissection of the Tertiary terrace which formerly extended along the northern slope of the Witteberg Mountains. Four remnants of this formerly large terrace are to be seen just to the west of the area mapped. Owing to the folded nature of the rocks, a subsequent drainage pattern is now firmly established.

In the area mapped, the bedrock is in places obscured by scree and elluvium. Extensive deposits of alluvium, utilized for agricultural purposes, are developed along the banks of the Buffels River.

Small shrubs and Karroo bushes dominated by succulents, constitute the sparse vegetation of the Succulent Karroo Veld.

(4) The Western Karroo

The Western Karroo is the tract of country to the north of Karoopoort. It is bounded by the Swartruggens Mountains in the West and the Roggeveld Escarpment in the east. Originally the names Tanqua Karroo and Ceres Karroo were applied to the northern and southern portions respectively. These names are still used by the local inhabitants of this sparsely populated area. However, certain writers used the name Tanqua Karroo whenever they had the whole of the Western Karroo in mind. To avoid any confusion, the name Western Karroo is used in this paper.

Sandstones of the Wittepoort Formation form the Swartruggens Mountains which attain their greatest height in the Karoopoort area. Northwards the height of the range as well as the easterly dip of the beds decreases.

Beds of the Floriskraal Sandstone Member cap the discontinuous line of low hills at the base of the Swartruggens between Karoopoort and Hartnekskloof. The remnants of a Tertiary terrace extend intermittently from the Karoopoort area towards Koperfontein and beyond. These remnants slope away fromthe mountain. Rounded boulders, gravels and clay rest unconformably on the bevelled surface cut in inclined beds of the Lake Mentz Formation and the Dwyka Group.

Numerous small tributaries of the Doorn River drain the Swartruggens and adjacent areas. The Doorn River flows northwards more or less parallel to the mountain until its confluence with the Tanqua River near Elandsvlei is reached.

In the Western Karroo with its low rainfall of less than six inches per annum, semi-desert conditions prevail. Low shrubs, typical Karroo bushes and succulents constitute the Succulent Karroo Veld. The sparse vegetal cover causes no natural hazard to the field geologist. As already stated, the Tertiary and recent sediments present a more serious problem.

C. PHYSIOGRAPHICAL EVOLUTION

For the purpose of the present paper only certain important events which have led directly to the present distribution and type of physiographic features, need to be briefly discussed.

In the western and southern areas of the Cape Province the Cape Supergroup was deposited with no apparent break in the continuity of deposition. The geosyncline had its deepest part in the south. Before the advent of the Dwyka sediments, minor folding and pre-glacial erosion of the Witteberg Group took place in the Elandsvlei area in the Western Karroo and also to the north. Nevertheless the Dwyka Group followed structurally conformable on the Witteberg Group for the greater part of the outcrop area of the latter. The area of deepest subsidence of the Karroo geosyncline more or less coincides with the same of the Cape geosyncline. Up to the time of deposition of the Stormberg Group, the main areas of deposition gradually shifted towards the north and northeast. Meanwhile the major phase of the Cape Orogeny had rapidly been gaining in impetus. The western Cedarberg folds are either slightly older or else practically contemporaneous with the southern Swartberg folds.

After studying the morphology of the Molteno Beds in the vicinity of Molteno, I.C. Rust (1962) concluded that folding, orogeny and erosion

of the older beds were instituted some time prior to the sedimentation of the Stormberg Group. Consequently the exposed Witteberg beds of the south had acted as provenance rock for the Molteno Beds. This is indicated by the profusion of inclusions of Witteberg sandstones in the Molteno Beds. It is clear that the southwestern and western fold ranges were by now also exposed; to what degree is not known.

The sedimentational history of the Karroo Period ceased with the extrusion of immense volumes of the basaltic Drakensberg Lavas and the intrusion of the Karroo Dolerites. Thus, during the late Triassic Period the huge dome-like mass of lavas, centred around the present Lesotho, was bordered on the south and west by fold ranges. From then onwards erosion and denudation of the southern Cape Province, aided by various periods of uplift, crustal warping and faulting, was dominant, interrupted at times by minor periods of deposition. These Cretaceous, Tertiary and Quaternary deposits are to be seen along the continental fringes and in a few intermontane valleys.

The rough radial drainage pattern which was initiated on the dome of basalt (F. Dixey, 1938, p. 158) was to have a continued influence on the later physiographic history of Southern Africa. The "Jurassic Surface" formed first was slowly attacked and ultimately destroyed by the "Gondwana" cycle of erosion which acted over vast areas of Southern Africa. Remnants of the "Gondwana" surface are still visible in the southern fold ranges. (L.C. King, 1963, p. 207). According to King the rupturing of Gondwanaland, presumably during the early Cretaceous Period, led to the new and active "African" cycle of erosion which was initiated on the steepened flanks of the continental margins. This gave birth to the Great Escarpment which retreated inland to its present position.

The breaching of the mountain ranges by the major rivers through the process of headward erosion, took place at various times ranging from late in the Cretaceous Period onwards into the Tertiary. During times of heavier rainfall in the Tertiary, bevelled surfaces along the base of some fold ranges were covered with conglomerates and finer sediments. Although subsequent erosion has destroyed many Tertiary surfaces, remnants are still to be seen.

At present erosion is progressing at a retarded rate in the Western and Southern Karroo, owing to the semi-desert conditions.

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CHAPTER III

FIELD GEOLOGY OF SELECTED AREAS

The portion of the geological column described in this paper (Table 1), is divided into four basic rock units:

(i) The Wittepoort Formation

J.N. Theron (1962) subdivided the "Witteberg Series" into the Lower, Main and Upper Stages. The "Main Witteberg Stage" of Theron is called the "Witteberg Quartzites" by M.R. Johnson (1966, p. 23). The present author favours a geographic name such as is advised by the ACSN. The name "Wittepoort Formation" is now formally proposed as the rock-stratigraphic name for the dominantly sandstone succession. The upper beds of this formation are well exposed in the Wittepoort, near Bergplaas, Kommadagga. In this paper the descriptions pertaining to the Wittepoort Formation will be applicable only to the upper beds of the unit. Later investigators may subdivide the formation into two or more members. For various reasons it is now convenient to use the term "formation" where in reality only what may be the upper member, is referred to.

(ii) The Lake Mentz Formation

The "Upper Witteberg Stage" of J.N. Theron (op. cit.) is given the formal rock-stratigraphic name of "Lake Mentz Formation", taking the name from their occurrence at Lake Mentz as described by J.A.H. Marais (1963). M.R. Johnson (op. cit., p. 23) uses the name "Lake Mentz Shales".

(iii) The Kommadagga Formation

This is the name formally proposed for the rock unit which on lithologic grounds is considered to be part of the Dwyka Group. The type area is to the south of Kommadagga. Up to now no rock unit occurring below the Dwyka Tillite and belonging to the Dwyka Group, has been recognized. In this paper various reasons for introducing the formation are given.

TABLE 1

STRATIGRAPHIC COLUMNS FOR SELECTED

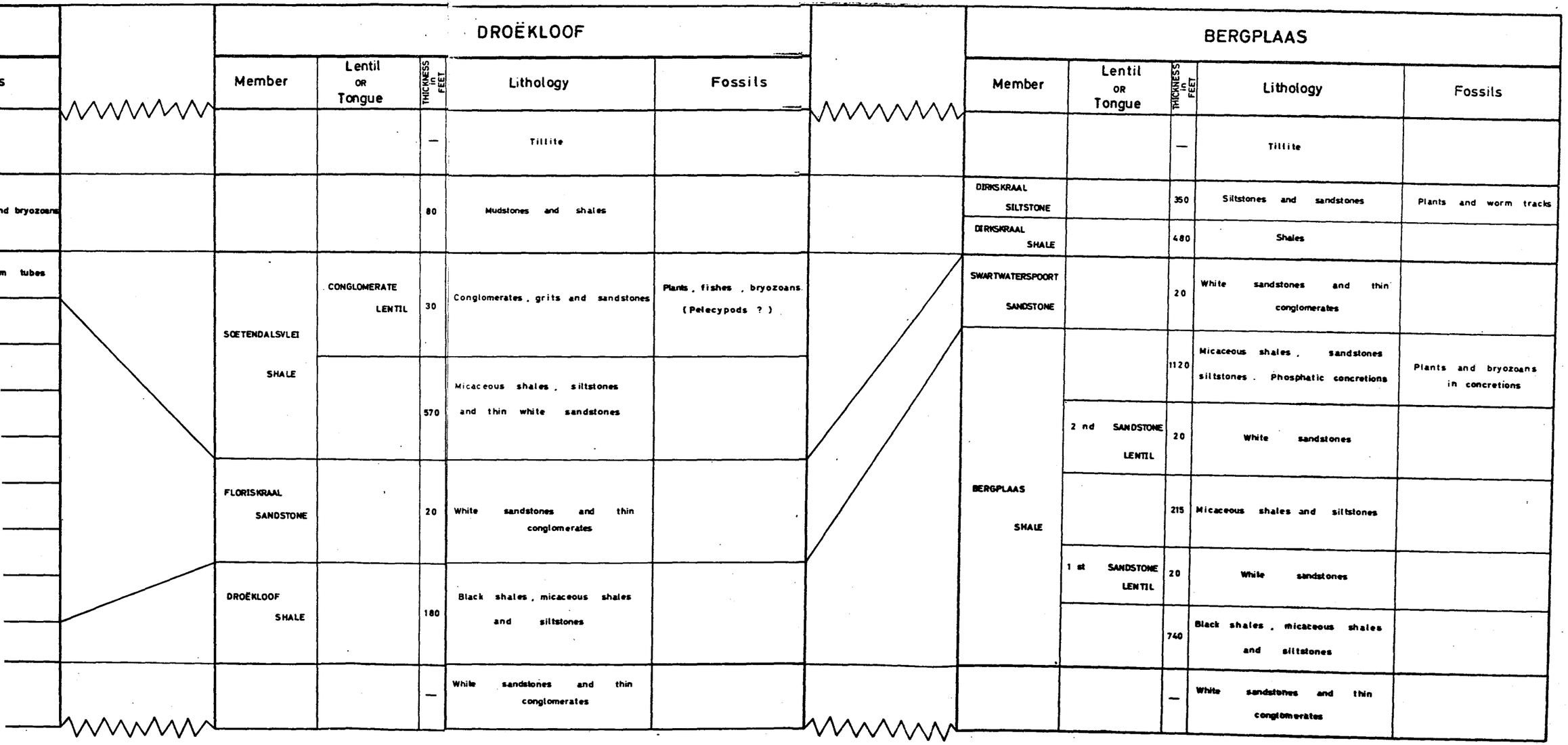
ROCK UNITS			WESTERN KARROO					FLORISKRAAL				
SUPERGROUP	Group	Formation	Member	Lentil OR Tongue	THICKNESS in FEET	Lithology	Fossils	Member	Lentil OR Tongue	THICKNESS in FEET	Lithology	Fossils
KARROO	Dwyka	Dwyka Tillite				Tillite				—	Tillite	
		Kommadagga				Mudstones, shales and siltstones				338	Mudstones and siltstones	Plants, fishes and b
CAPE	Witteberg	Lake Mentz	KAFFERSKRAAL SHALE			Micaceous shales, siltstones and sandstones	Plants (Kafferskraal)	BUFFELS RIVER SHALE		488	Mudstones, micaceous shales siltstones and sandstones	Plants and worm
								FLORISKRAAL SANDSTONE	4 th SANDSTONE LENTIL F.S.	40	White sandstones and thin conglomerates	
									4 th SHALE TONGUE L.S.	80	Micaceous shales and siltstones	
			FLORISKRAAL SANDSTONE			White sandstones			3 rd SANDSTONE LENTIL F.S.	40	White sandstones and thin conglomerates	
									3 rd SHALE TONGUE L.S.	110	Micaceous shales and siltstones	Plants
									2 nd SANDSTONE LENTIL F.S.	30	White sandstones and thin conglomerates	
			KATBAKKIES SHALE			Micaceous shales and siltstones		LEEUKLOOFPOORT SHALE	2 nd SHALE TONGUE L.S.	70	Micaceous shales and siltstones	Plants
									1 st SANDSTONE LENTIL F.S.	30	White sandstones	
									1 st SHALE TONGUE L.S.	480	Micaceous shales and siltstones	
		Wittepoort				White sandstones				—	White sandstones	

TABLE 1

STRATIGRAPHIC COLUMNS FOR SELECTED LOCALITIES.

KARROO		FLORISKRAAL					DROËKLOOF				
Lithology	Fossils	Member	Lentil or Tongue	Thickness in Feet	Lithology	Fossils	Member	Lentil or Tongue	Thickness in Feet	Lithology	Fossil
Tillite				—	Tillite				—	Tillite	
shales and siltstones				338	Mudstones and siltstones	Plants, fishes and bryozoans			80	Mudstones and shales	
shales, siltstones nd sandstones	Plants (Kafferskraal)	BUFFELS RIVER SHALE		488	Mudstones, micaceous shales siltstones and sandstones	Plants and worm tubes	SOETENDALSVLEI SHALE	CONGLOMERATE LENTIL	30	Conglomerates, grits and sandstones	Plants, fishes, b (Pelecypods
		FLORISKRAAL SANDSTONE	4 th SANDSTONE LENTIL F.S.	40	White sandstones and thin conglomerates				570	Micaceous shales, siltstones and thin white sandstones	
ite sandstones			4 th SHALE TONGUE L.S.	80	Micaceous shales and siltstones						
			3 rd SANDSTONE LENTIL F.S.	40	White sandstones and thin conglomerates						
			3 rd SHALE TONGUE L.S.	110	Micaceous shales and siltstones	Plants					
			2 nd SANDSTONE LENTIL F.S.	30	White sandstones and thin conglomerates		FLORISKRAAL SANDSTONE		20	White sandstones and thin conglomerates	
shales and silstones		LEEUKLOOFPOORT SHALE	2 nd SHALE TONGUE L.S.	70	Micaceous shales and silstones	Plants					
			1 st SANDSTONE LENTIL F.S.	30	White sandstones		DROËKLOOF SHALE		180	Black shales, micaceous shales and siltstones	
sandstones			1 st SHALE TONGUE L.S.	480	Micaceous shales and siltstones						
				—	White sandstones				—	White sandstones and thin conglomerates	

ED LOCALITIES .



DROËKLOOF

Member	Lentil or Tongue	Thickness in Feet	Lithology	Fossils
		—	Tillite	
		80	Mudstones and shales	
SOETENDALSVLEI SHALE	CONGLOMERATE LENTIL	30	Conglomerates, grits and sandstones	Plants, fishes, bryozoans (Pelecypods ?)
		570	Micaceous shales, siltstones and thin white sandstones	
FLORISKRAAL SANDSTONE		20	White sandstones and thin conglomerates	
DROËKLOOF SHALE		180	Black shales, micaceous shales and siltstones	
		—	White sandstones and thin conglomerates	

BERGPLAAS

Member	Lentil or Tongue	Thickness in Feet	Lithology	Fossils
		—	Tillite	
DIRKSKRAAL SILTSTONE		350	Siltstones and sandstones	Plants and worm tracks
DIRKSKRAAL SHALE		480	Shales	
SWARTWATERSPOORT SANDSTONE		20	White sandstones and thin conglomerates	
BERGPLAAS SHALE		1120	Micaceous shales, sandstones siltstones. Phosphatic concretions	Plants and bryozoans in concretions
	2 nd SANDSTONE LENTIL	20	White sandstones	
		215	Micaceous shales and siltstones	
	1 st SANDSTONE LENTIL	20	White sandstones	
		740	Black shales, micaceous shales and siltstones	
		—	White sandstones and thin conglomerates	

(iv) The Dwyka Tillite Formation

The name "Dwyka Tillite Formation" is proposed for the rock unit consisting of tillites. In this paper the descriptions of the Dwyka Tillite are valid only for the lower beds of the formation.

The stratigraphic columns for certain selected localities are shown in Table 1. Table 15 should also be referred to.

A. BERGPLAAS

(1) Wittepoort Formation (Witteberg Group)

The thickly bedded white to gray sandstones of the formation are easily accessible in the Wittepoort and the Swartwaterspoort. The upper member of the formation colloquially known as the "White Streak" is characterized by its white appearance when weathered. Found as a member of varying thickness everywhere in the Southern Karroo, it was responsible for the name of the Witteberg and Witberg Mountains.

Except for occasional gritty layers and thin pebble-conglomerates, good sorting is the rule. The small inclusions, usually less than one inch in diameter, consist of well-rounded ovaloid and disc-like pebbles of white and colourless quartz and black and gray chert. One red jasper was found. The more argillaceous beds are usually more micaceous than the well-sorted sandstones.

Cross-stratification is almost entirely absent in the Wittepoort. As a result the necessary studies and measurements of this important primary structure were made in the Swartwaterspoort.

On the eastern side of the river-bed in the Wittepoort, big interference ripple-marks occur, more than 200 feet from the top of the formation. (Plate 2, photo B).

The sole of a lithic graywacke on the western side of the Wittepoort displays load casts.

No fossils were found.

(2) Lake Mentz Formation (Witteberg Group)

(a) Bergplaas Shale Member

The lower contact of the member is usually obscured. Where seen, it was a 25 feet thick alteration of sand-

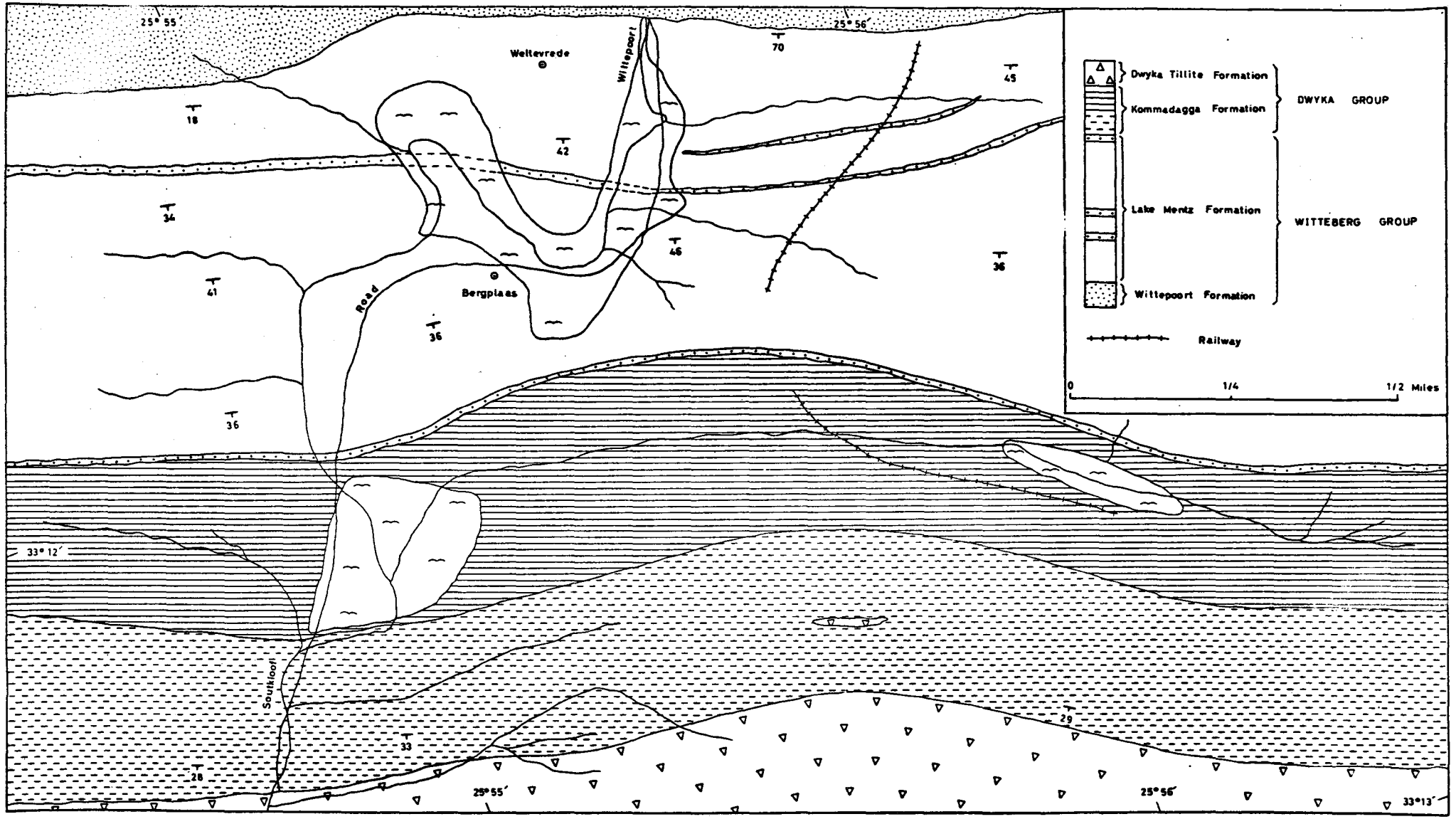


Fig. 2. Geological map of an area around Bergplaas, Kommadagga.

(See Table 1 for a more detailed stratigraphical column.)

stones, siltstones and micaceous shales. The exposed outcrops of the shales and siltstones are usually weathered to brown colours. At the tunnel entrance east of Wittepoort, the fresh shales were seen to be black. Subsequent qualitative analyses showed an excess of ferrous sulphide. No carbon or phosphate was found during qualitative chemical tests.

Towards the First Sandstone Lentil siltstones become more common. Occasional thin sandstones of a few yards in length are also met with.

Ripple-marks appear in all the beds. Cross-stratification, whenever present, is confined to the sandstones.

First Sandstone Lentil

The lentil consisting of sandstones and a few intercalated micaceous shales, forms a low ridge. Its contacts are not well defined.

Cross-stratification is present in some strata.

Well stratified micaceous shales and siltstones, frequently ripple-marked, occur above the lentil.

Second Sandstone Lentil

This lentil also forms a low ridge. In the east its thickness averages 20 feet. Towards the west it thickens progressively, at the same time forming a more prominant topographic feature. The contacts are ill-defined; being usually a zone of alternating shales, siltstones and sandstones.

Although cross-stratification is frequently met with, the characteristic primary structures of the lentil are interference as well as parallel ripple-marks.

The strata above the Second Sandstone Lentil can be conveniently subdivided into a lower argillaceous and an upper arenaceous division. Mudstones, shales and siltstones occur above the Second Sandstone Lentil.

Their colours are varying shades of gray. Micro-cross-lamination and ripple-marking becomes common. Load casts, confined to a narrow zone, were seen on Bergplaas, as well as in a cutting at Saltaire Station, 6 miles to the north.

Black concretions of up to ten inches in length occur in a zone 90 feet above the Second Sandstone Lentil. These concretions having their shortest axes perpendicular to the bedding, are flattened ellipsoids with a ratio of 2 to 1 for the longest to the shortest axes. The contacts between the surrounding shales and siltstones and the concretions, vary from very sharp to transgressive over the space of 1 inch. The bedding and in one example, micro-cross-lamination, seem to continue from the surrounding rocks right through the concretions.

Indeterminable plant stems and the fragmentary cast of a bryozoan were found in them. Concretions from Bergplaas and from the same zone at the Saltaire Station, contain a small percentage of phosphate. No carbon was found during qualitative chemical tests. It is interesting to note that S.H. Haughton et al. (1953, folder 3) record phosphate nodules from the Lake Mentz Formation near Prince Albert.

Thickly laminated shales, 180 feet above the Second Sandstone Lentil, are exposed in a ditch 500 yards east of the homestead. These shales, olive gray (5Y4/1) in colour, display numerous worm tracks.

The upper division becomes more arenaceous with the domination of siltstones and fine-grained sandstones. Ripple-marking and micro-cross-lamination is seen in many beds. All the rocks remain distinctly micaceous.

(b) Swartwaterspoort Sandstone Member

This member consisting of clean white sandstone forms a distinct topographic feature on Bergplaas as well as at the northern entrance to the Swartwaterspoort. The lithology of the member closely resembles that of the upper beds of the Wittepoort Formation. It has the same white colour when weathered. Pebble-conglomerates, frequently confined to a single bedding-plane, are common. The sub- to well-rounded pebbles are usually less than ½ inch in diameter.

Light gray (N7),grayish blue (5PB/2) and black chert together with light gray to dark gray (N3) quartz pebbles dominate. A few clear to white quartz pebbles also occur. Two brown pebbles of fine-grained sandstone, one of which was 2 inches in length, were also seen.

The contacts of the member are usually well-defined. On Bergplaas the member shows a variation of 10 to 50 feet in thickness.

Owing to the folding, the beds adjacent to the member, as well as the member itself is in places very much crumpled and contorted. As a result, the measurements of cross-stratification, a primary structure which is anyhow very scarce in the member, were not considered to be trustworthy and ultimately rejected.

No fossils were found.

(3) Kommadagga Formation (Dwyka Group)

(a) Dirkskraal Shale Member.

The member consists of medium dark gray (N4) to dark gray (N3) shales and mudstones with subordinate siltstones. A sudden decrease in the size and quantity of the sericite flakes visible to the naked eye, is apparent. A few intercalated calcareous beds were found. The shales are thinly- to thickly laminated. Micro-cross-lamination occurs in the thin siltstones.

(b) Dirkskraal Siltstone Member

The rocks of this member build a range of rounded hills of which the most prominent one is ¾ mile southeast of the homestead. A little more than ½ mile southwest of the homestead the lower beds of the member form prominent cliffs near the road.

The member consists primarily of silt- and sandstones. Interbedded shales are found at the lower contact and again near the top of the member. As with the shale member, the rocks are not distinctly micaceous.

Apart from stratification, the characteristic primary structure present, is micro-cross-lamination. Whenever it is absent the rocks are either well-stratified or massive.

In a bed 250 feet from the top, thickly cross-stratified rocks were seen.

Dense, hard, olive gray (5Y3/2) siltstones stratigraphically situated near the base of the member, are exposed next to the river bed 150 yards east of the old railway bridge. Ripple-marks and worm tracks occur in the siltstones (Plate 2, Photo H). A contemporaneous erosion channel is cut in the siltstones.

Twenty feet above the worm tracks, concretions of up to 1½ feet in size, contain fragmentary plant impressions. The concretions are distinctly calcareous whereas the surrounding rocks are not. Small concretions stained brown by ferric iron oxide occur in rocks higher up.

A single fragmentary imprint of a leaf was found 320 feet below the upper contact of the member.

The upper beds of the member are siltstones and fine-grained sandstones light olive gray (5Y5/2) to olive gray (5Y3/2) when weathered.

The upper contact of the member with the overlying Dwyka Tillite Formation forms no recognizable topographic feature as the rocks on both sides of the contact weather in much the same way. The actual contact is a transition zone from 1 inch to 1 foot in width, between the siltstones and the tillites. An interesting contact zone is exposed in a cutting along the national road a few miles north of Bergplaas. The zone is a 29 feet wide alternation of siltstones, shales, mudstones and tillites. The shales and mudstones are outwash material from the tillite itself.

Tillite Lentil

A few Dwyka-type erratics were found a few yards south of the crest of the rounded hill ¾ mile southeast of the homestead. A subsequent search for the origin revealed the presence of a tillite lentil 480 feet in length with a maximum width of 35 feet. The ends of the lentil terminate rather bluntly against the surrounding siltstones and fine-grained sandstones. The tillite weathers in the same way as the surrounding rocks i.e. flush with the rounded surface of the hill. Most of the contacts as well as

much of the lentil itself, is covered by soil. The outline of the lentil can, however, be fairly accurately traced by observing that Pteronia incana, known to the local farmers as Steenbokkaroo, occurs as a few stunted plants on the tillite whereas it abounds on the surrounding rocks, reaching up to 2 feet in height. In contrast the upper contact of the Kommadagga Formation with the Dwyka Tillite Formation was not seen to exhibit the same control over the vegetation.

The lentil occurs 200 feet from the top of the member. In texture and composition the tillite of the lentil resembles that of the Dwyka Tillite Formation. A few gritty layers representing winnowed tillite were seen.

The Kommadagga Formation was initially instituted as a separate formation solely on lithological grounds. At the time of the field work no laboratory evidence such as the result of heavy mineral analyses were yet available. The Kommadagga Formation with its "Karroo" appearance can be distinguished from the Lake Mentz Formation by its rocks having a better sorting and less mica and by its tendency to remain darker when weathered. The micaceous "Witteberg-type" rocks of the Lake Mentz Formation change to various shades of brown when weathered. The presence of the Tillite Lentil serves as further justification for the institution of a separate formation and its assignment to the Dwyka Group.

(4) Dwyka Tillite Formation (Dwyka Group)

The tillite builds low rounded hills near the southern border of Bergplaas. For a complete and more detailed description of the whole of the formation, the works of A.L. du Toit and the publications of the Geological Survey should be consulted. A short general description of the basal beds of the formation would suffice here.

The tillite is a dense hard rock, medium dark gray (N4) in colour, turning light olive gray (5Y5/2) and softer on weathering. A wide range of erratics, the majority of which is less than 6 inches in diameter is set in an argillaceous and sometimes arenaceous matrix. Occasional erratics measure a few feet across. Porphyritic and equigranular granites of various texture-types, quarts porphyries, dark basic rocks and Ventersdorp lavas occur as erratics. Sedimentary rocks are likewise well represented by various types of shale, chert, conglomerate, black and white quartzite, the latter being the most common. Granite gneisses and various schists represent the most common metamorphic rocks. A.L. du Toit

(1921, p. 198) notes that Campbellrand limestone and dolomite and Griquatown jaspers are absent to the east of the Traka River. E.D. Mountain (1946, p. 17) also records the absence of dolomite and banded ironstone in the Grahamstown area. The present author has discovered only one erratic of banded ironstone east of Droëkloof. It was picked up north of Botha's Ridge near Grahamstown.

While some erratics are facetted and sometimes striated, the majority is distinctly rounded. At first sight the tillite appears to be without stratification. On closer examination it could be classified as being very thickly bedded. Beds containing tillite which had been slightly reworked by bottom currents during or immediately after deposition from a floating ice-shelf or ice-bergs, are traceable for short distances in the field. Very thinly bedded shale with the characteristic dark greenish gray colour (5GY4/1) of shale seen within the Dwyka Tillite Formation, are sometimes associated with conglomerate. In strongly folded areas cleavage planes give rise to the pointed "Bushman's tombstones" or gravestone weathering.

B. DROËKLOOF

(1) Wittepoort Formation (Witteberg Group)

The upper beds of the Formation form a conspicuous white marker along the upper slopes of the Witberg. (Plate 1, Photo A) Colloquially known as the "White Streak" the weathered sandstone is considerably whiter than the rocks lower down which often tend to be stained by ferric iron. S.H. Haughton et al. (Op. cit., p. 15) found a variation in thickness of from 115 feet near the Gamka Poort to 180 feet near Willowmore.

The rocks are clean white sandstone with occasional gritty layers and thin pebble-conglomerates. The inclusions are white to dark pebbles of quartz and chert. A single pebble of banded chert was found. The thickly bedded strata are in places cross-stratified. A few small ripple-marks were seen 20 feet from the top.

No fossils were seen.

The contact with the Droëkloof Shale Member appears sharp. Its precise nature could not be determined as it is usually covered with loose material.

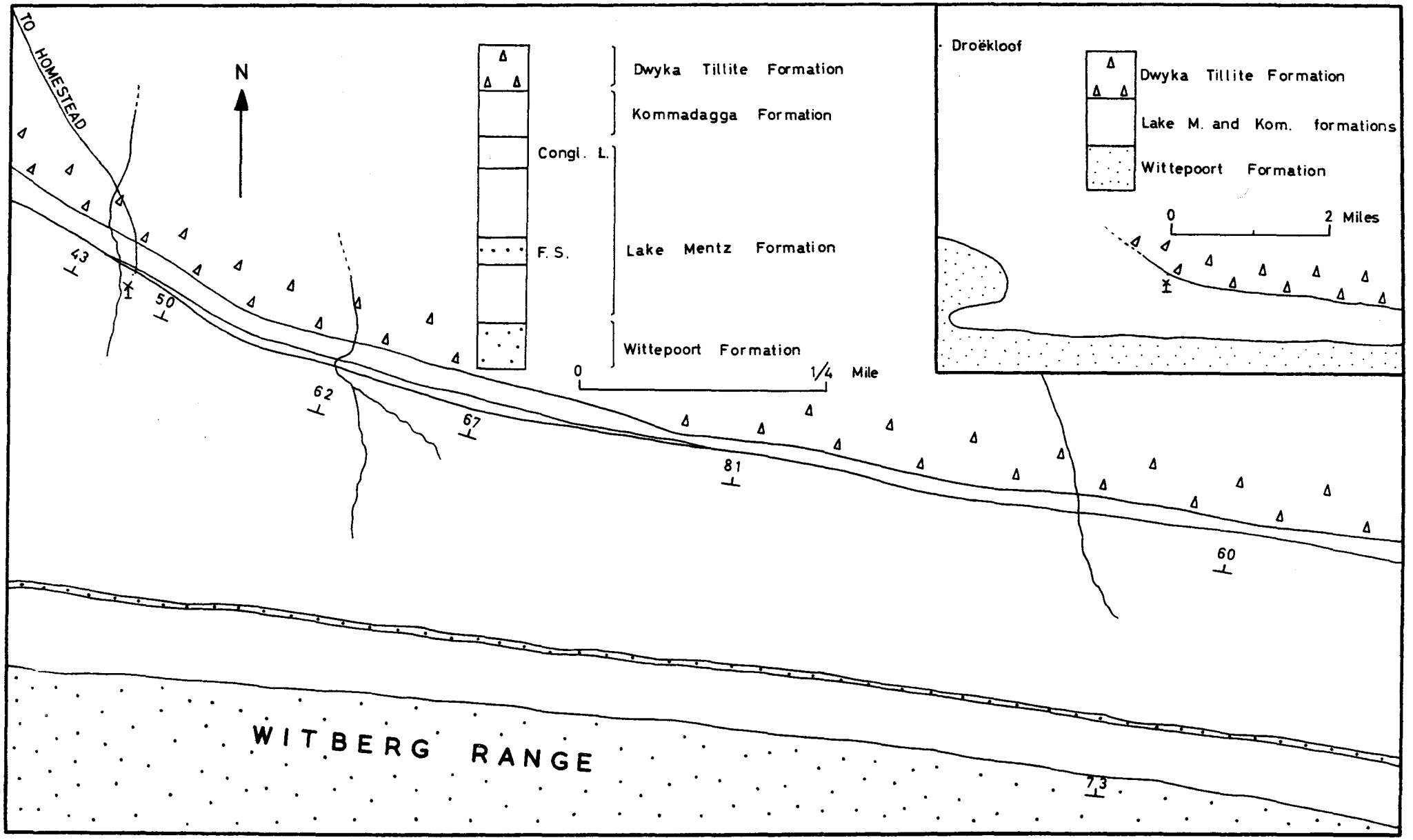


FIG. 3. GEOLOGICAL MAP OF AN AREA AROUND DROËKLOOF, KLAARSTROOM

(2) Lake Mentz Formation (Witteberg Group)

(a) Droëkloof Shale Member

The lower rocks are well-laminated dark micaceous shales. Higher up thin siltstones increase in frequency until the upper beds are almost entirely siltstones. Micro-cross-lamination and ripple-marks also become common in the siltstones.

(b) Floriskraal Sandstone Member

Although being tentatively correlated with the Floriskraal Sandstone Member, the Swartwaterspoort Sandstone Member is given a separate name until such time the correlation is definitely established in the field.

The Floriskraal Sandstone Member is seen as a continuous streak high up on the flank of the Witberg range, some distance below the precipitous outcrops of the Wittepoort Formation. The member can be traced for many miles to the east and west of Droëkloof.

Although containing a few siltstones, the sandstones of the member closely resemble the same from the Wittepoort Formation. A peculiar feature of some beds is the presence of reversed graded bedding whereby a siltstone grades upward into a sandstone which in turn grades into a coarse grit. Frequently pebble-conglomerates occur in the upper few inches of a bed. Some grits are distinctly feldspatic. The grains of microcline may be seen without a lens. Freshly broken surfaces of the rocks display cellular cavities filled with porous material consisting of limonite and/or weathered feldspatic material. The inclusions in the conglomerate consist of clear, white and bluish pebbles of quartz up to 1 inch in diameter. In his area of study, J.N. Theron (Op. cit., p. 375) also recorded shale and limestone pebbles. S.H. Haughton et al. (Op. cit., p. 16) mention sandstone pebbles. Of great interest is the presence of angular and rounded pebbles of microcline, sometimes up to ¾ inch in diameter.

Cross-stratification is developed to such an extent that this primary structure serves as a distinct characteristic. Contemporaneous erosion channels ranging from 1 to 8 feet in width occur at intervals along the line of outcrop.

Big interference ripple-marks of the same type as those found in the Wittepoort, Bergplaas, were seen. Load casting sometimes occurs towards the lower contact of the member.

(c) Soetendalsvlei Shale Member

The rocks of this member form the lower northern slopes of the Witberg and part of the plain immediately next to the mountain. Although consisting of a great number of beds of great diversity in lithologic character, the member was mapped as a single entity.

The lower rocks are micaceous shales, siltstones and thin white sandstones. Some shales are black when fresh. All beds may show ripple-marks and micro-cross-lamination. J.N. Theron (Op. cit., p. 375) briefly mentions the presence of mud cracks. The present author failed to find this important primary structure.

Load casts occur in some beds.

Towards the top of the member siltstones dominate. When weathered, they are light olive gray (5Y5/2) in colour, or to use a common term, rather "yellowish". All beds are distinctly micaceous. The main primary structures are ordinary stratification and micro-cross-lamination. Ripple-marks are also present.

No fossils were found at Droëkloof. This member is by no means devoid of any. Plant fossils and fishes are described by J.N. Theron (Op. cit., pp. 376-378). S.H. Haughton (Op. cit., p. 19) record phosphatic nodules.

Conglomerate Lentil

The lentil is a most complex and interesting unit. It forms a continuous and conspicuous outcrop over a distance of 1200 yards along the base of the Witberg. (Plate 1, Photo D). It attains a thickness of 30 feet in the west. Towards the east it thins out and disappears. Farther on it crops out intermittently in the form of thin lenticular bodies, over a distance of 1500 yards. The four major rock-types present in the lentil, do not occur everywhere;

(i) In the west light olive gray (5Y5/2) siltstones showing little or no stratification, occur at

the base of the lentil.

(ii) The bulk of the lentil consists of thickly-bedded grits. These are quite unlike any other seen anywhere in the Witteberg Group. The grains are of clear and white quartz and white to gray chert. All are set in a matrix of fine sand and sometimes grayish olive green (5GY3/2) mudstone. In addition the rocks are heavily ferruginized.

Cross-stratification is present in places. Imprints of stems and leaves were seen.

(iii) The conglomerates are found at the top only where the lentil is thickly developed. The matrix consists of quartz, chert and mudstone. Quartz pebbles range up to 1 inch in diameter. Of much interest are the numerous inclusions originally having a sedimentary and/or chemical origin. Hard grayish black (N2) argillaceous inclusions show a size distribution of from small pebbles to cobbles measuring 9 x 7 x 2 inches. Some are well rounded while others are angular and barely show signs of attrition. Some resemble the black concretions found elsewhere in the formation. One cobble was of a black crystalline limestone.

The imprints of plants occur throughout the conglomerates. These occur singly or in places in densely packed masses. Furthermore the same types of plants occur within some black inclusions. Three fragmentary imprints of pelecypods were found together with fragmentary remains of a fish and a bryozoan.

This petromictic conglomerate owes its origin to cannibalistic processes operating during the time of deposition. The cobbles of sedimentary origin had clearly suffered only a short distance of transport.

As in the case with the grits, the conglomerates are very ferruginous, appearing very dark in the field.

(iv) Both to the east and west the lentil is composed of a thin bed of dark calcareous and argillaceous material containing numerous imprints of plants. The scattered outcrops to the east are a few inches thick and only a few feet in length. These beds were evidently deposited over a large area for they also crop out near the Droëkloof homestead.

J.N. Theron found plants in the Vondeling area at various stratigraphic levels. (Op. cit., Table 1).

(3) Kommadagga Formation (Dwyka Group)

The shales and mudstones of the formation overlie the Conglomerate Lentil in the west of the area mapped. Towards the east it overlies the siltstones of the Soetendalsvlei Shale Member. There the scattered outcrops of the Conglomerate Lentil actually occur a few feet below the upper contact of the member.

The medium dark gray (N4) to dark gray (N3) shales of the formation are thinly to thickly laminated. The mudstones occurring in the upper few feet only, tend to have more "greenish" colours such as grayish olive green (5GY3/2). The mudstones contain numerous small angular to rounded inclusions of quartz and feldspar as well as small pebbles resembling those seen in the tillite itself. Furthermore the mudstones resemble those found interstratified with the Dwyka Tillite Formation.

The rocks of the Kommadagga Formation differ from those of the Lake Mentz Formation in that they are non-micaceous, better sorted and have more "greenish" colours, especially the mudstones. The colours due to ferric iron oxide are never seen upon weathering. These rocks with their distinct "Dwyka" or "Karroo" appearance were therefore mapped as a separate formation and included in the Dwyka Group.

(4) Dwyka Tillite Formation (Dwyka Group)

Being less resistant than the white sandstones of the Wittepoort Formation, the Dwyka Tillite forms the southern plains of the Southern Karroo. Although it may escape notice in small outcrops, the formation is distinctly stratified when seen as a whole. Two parallel sets of low hills occur some distance away from the Witberg range.

The tillites have very much the same appearance as at Bergplaas. The usual array of erratic types are encountered. Griquatown jaspers are now more frequently observed. Enough time was not available to determine the frequency of the various types of erratics. However, when walking about on the erratic-strewn tillite surface, the author gained the impression that Ventersdorp lavas are now by far more common than at Bergplaas.

The basal contact of the formation

Near the homestead shales of the Kommadagga Formation occur below the Dwyka Tillite, the mudstones either being entirely absent or else represented by thin layers of outwash material from the tillite. Near the contact the shales acquire small inclusions. Frequently big Dwyka erratics are confined to the upper 2 feet of shale. The laminae of the shale are then curved below and around the sides of the erratic, indicating that it had been dropped onto unconsolidated muds. Undisturbed laminae above an erratic indicate a short period of deposition of muds before the deposition of the main tillite.

Whenever mudstone do occur, their contact with the Dwyka Tillite is usually less sharp. It is sometimes gradational over a few feet with the erratics increasing in size and frequency towards the tillite. In places the contact is a complex alternation of mudstones, gritty shales, stratified and ordinary tillite.

C. FLORISKRAAL

(1) Wittepoort Formation (Witteberg Group)

The white sandstones of the formation are very conspicuous along the northern slopes of the Witteberg range. The well-exposed outcrops at the northern entrance to the Leeukloofpoort were examined (Plate 1, Photo B). There the white-weathering upper division of the formation ("White Streak") consists of various sandstones as well as a few more micaceous and argillaceous rocks. The sandstones are from mediumly to very thickly bedded. Cross-stratification is also present in places. Deformed cross-stratification occurs about 100 feet from the top. Primary current lineation occurs in the sandstones 60 feet from the upper contact. Big interference ripple-marks of the same type previously seen in the Wittepoort Formation of Bergplaas and the Floriskraal Sandstone Member of Droëkloof, are found near the primary current lineation. The

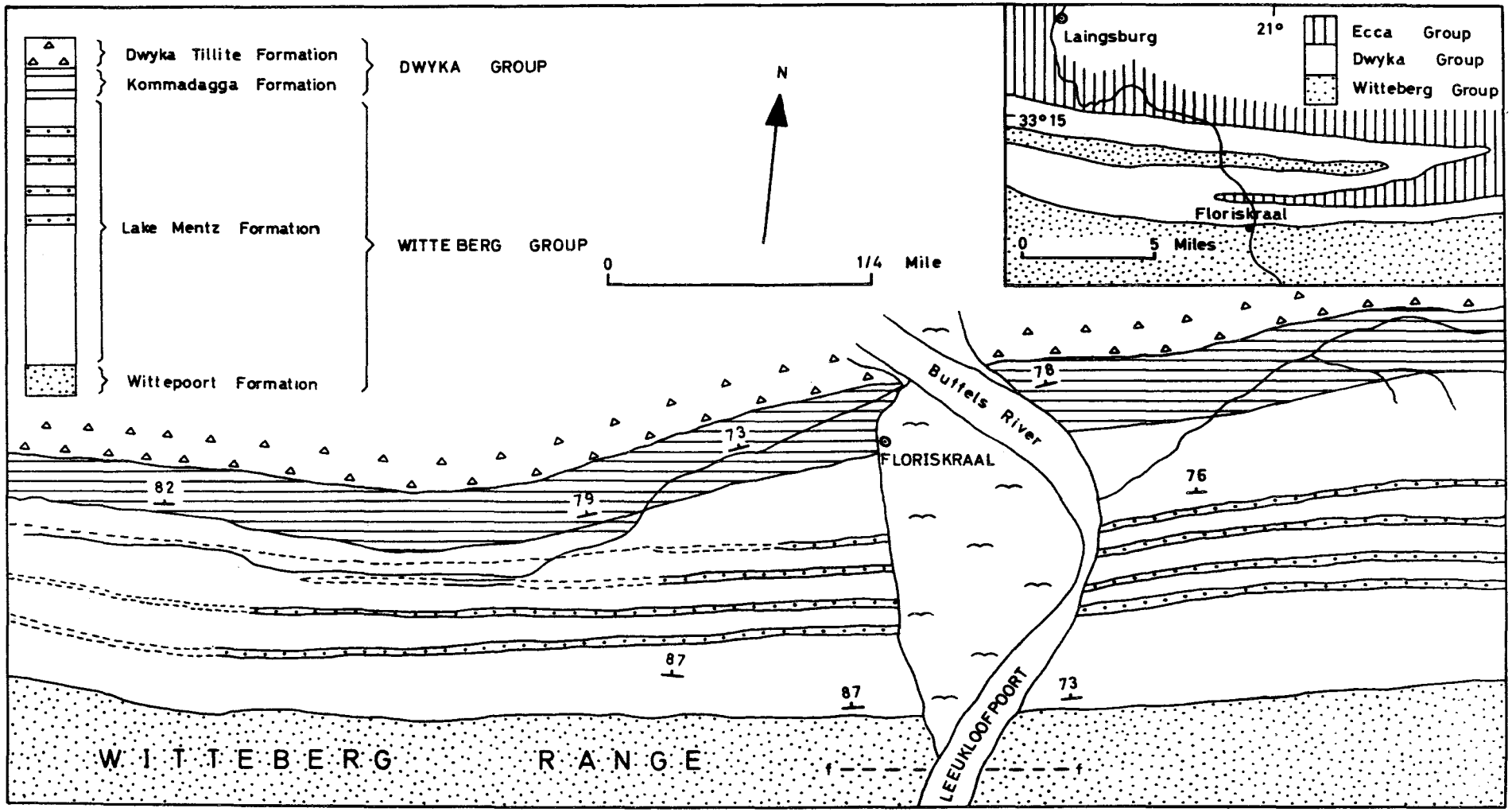


Fig. 4. Geological map of an area around Floriskraal, Laingsburg.

(See Table 1 for a more detailed stratigraphical column.)

primary structures are fully described in Chapter IV.

The contact between the formation and the overlying First Shale Tongue of the Leeukloofpoort Shale Member is everywhere obscured by surface material (Plate 1, Photo B). It does, however, appear to be fairly sharp.

(2) Lake Mentz Formation (Witteberg Group)

(a) Leeukloofpoort Shale Member

This member is composed of a mixed and varied number of different rocks ranging from true shales to siltstones, all being distinctly micaceous. The more arenaceous beds are not well-sorted and the colloquial term "arenaceous shale" can well be applied to many. Stratification can be described as ranging from thinly laminated to thinly bedded. Apart from stratification the other characteristic primary structures are ripple-marks and micro-cross-lamination.

First Shale Tongue

Calcareous siltstones occur below the upper contact. These brown-weathering rocks appear in strong contrast with the rest. They are dark gray (N3) when fresh, turning moderate brown (5YR4/4) on weathered surfaces. The siltstones are thickly laminated.

Second Shale Tongue

Thin lenticular beds of white siltstones and sandstones, the latter sometimes carrying small quartz pebbles, are to be seen. One black concretion resembling those from Bergplaas was found.

Fragmentary plant stems occur.

Third Shale Tongue

Thin lenticular beds of white sandstone occur. Load casts appear in some mudstones. Plant stems were seen.

Fourth Shale Tongue

A thin calcareous siltstone was found.

(b) Floriskraal Sandstone Member

This member is represented by four lentils which are alike in field appearance, lithology and primary structures. Field work as well as an examination of aerial photographs show that the four lentils are not continuous over many miles. Their number may dwindle to one. Either the third or the fourth lentil can be taken as the main one.

The rocks are much the same as the sandstones of the Wittepoort Formation viz. white-weathering clean sandstones with gritty layers. Pebble-conglomerates, when present, are usually confined to the upper surface of a single bed and then only in beds at the top of the lentil. The gritty layers likewise are to be seen near the top. The stratification can be described as being from thinly to thickly bedded. Cross-stratification is better developed towards the top of the lentils. Big interference ripple-marks as well as the ordinary smaller types occur in the lentils and then usually in the lower division. The reversed graded bedding of the lentils is reminiscent of the Floriskraal Sandstone Member of Droëkloof. Micaceous and arenaceous rocks are present in all four lentils.

First Sandstone Lentil

The sandstones appear to be slightly darker than those from the Wittepoort Formation. Some are light olive gray (5Y5/2)

They too, turn whiter when weathered.

Second Sandstone Lentil

One thin calcereous siltstone is present. A gritty layer towards the top contains small feldspar inclusions. This layer is full of small cellular cavities partially filled with porous material, in this way closely resembling rocks from the same formation at Droëkloof. Pebbles of clear and white quartz and greenish chert are up to one inch in diameter. A single chert was 1½ inches in diameter. One pebble of microcline perthite was found.

Third Sandstone Lentil

In the conglomerate pebbles of white quartz range up to 1½ inches in length. Other types are even larger. The three biggest cobbles were 4½, 4 and 3½ inches in diameter.

One pebble of granite was found. A few rather flattened pebbles are of fine-grained sandstone olive gray (5Y4/1) in colour. Metamorphic rocks are represented by pebbles of phyllite, muscovite granite gneiss and metaquartzites. Small pebbles of microcline and albite are numerous. Two small inclusions 1/5 inch in diameter were likewise later identified as black tourmaline.

Fourth Sandstone Lentil

A pebble-conglomerate contains inclusions of quartz and sandstone.

(c) Buffels River Shale Member

A.W. Rogers and E.H.L. Schwarz (1902, p. 106) describe the sequence between the Fourth Sandstone Lentil of the Floriskraal Sandstone Member and the Dwyka Tillite Formation as "Lower Shales". They found the thickness to be 700 feet. Initially the present author had some difficulty in trying to subdivide the sequence. The lower rocks have a distinct "Witteberg" appearance while the rocks in the upper division have more "Dwyka" or "Karroo" characteristics. Consequently a traverse was made near the eastern bank of the Buffels River in order to determine various features of the rocks and to find the upper contact of the Buffels River Shale Member. The stratigraphic column is given in Table 2. The Buffels River Shale Member is seen to be of typical "Witteberg" appearance; being distinctly micaceous and thinly laminated. Ripple-marks are numerous. Faint and indistinct structures near the base may be plant stems.

The upper contact with the Kommadagga Formation is not always very definite. To the west the contact is more gradational and it is extremely difficult to decide on its exact position.

(3) Kommadagga Formation (Dwyka Group)

Table 2 demonstrates how the formation differs from the Buffels River Shale Member. It is not apparent from the table, but the rocks of the formation tend to remain darker upon weathering. The brown colours due to ferric iron oxide are rarely seen as in the case with the "Witteberg" type rocks. Better sorting is also seen. The siltstones marker bed

TABLE 2

Stratigraphic column showing the beds between the Floriskraal Sandstone Member and the Dwyka Tillite Formation.

ROCK UNITS		THICKNESS in feet	LITHOLOGY	PRIMARY STRUCTURES					MICA content		COLOUR	
				Stratification		Laminae per inch	Ripple-marks	Micro-cross-lamination	Distinctly micaceous	Poorly or non-micaceous	Fresh	Weathered
FORM.	MEMBER			Distinct	Indistinct							
DWYKA TILLITE		——	Tillite		X					X	5GY4/1 N3	5Y5/2 10Y4/2
KOMMADAGGA		17	Mudstone		X					X		
		50	Mudstone		X					X		5Y6/4
		44	Siltstones and mudstones	X		0-10		X		X		
		36	Siltstones and mudstones. Black concretions		X	0-5				X		
		2	Siltstone (marker bed)		X	0-3				X		5Y6/4 5Y5/2
		93	Mudstones, siltstones, black concretions, calcareous concretions		X	0-3				X	5Y3/2 N3	
		96	Mudstones and siltstones		X	0-5				X	N4	5Y5/2
LAKE MENTZ	BUFFELS RIVER SHALE	13	Mudstones and siltstones	X		0-30	X		X			5Y5/2
		9	Siltstones	X		1-15	X		X			5Y5/2
		3	Siltstone with worm tubes		X				X			5Y5/2
		15	Siltstones. Calcareous concretions	X		5-30	X		X			5Y5/2 5Y6/4
		212	Siltstones, shales and thin white sandstones. Concretions.	X		10-30	X		X			5Y5/2 5Y6/4
		30	Siltstones and shales	X		10-30	X		X			5Y5/2
		30	Siltstones and mudstones	X		5-30	X		X			5Y5/2 5Y6/4
		176	Siltstones, shales and thin white sandstones	X		10-40	X		X			5Y6/4 10Y4/2

can be traced for a few hundred yards to the west of the homestead. Some silt- and mudstones resemble others seen in the Dirkskraal Siltstone Member at Bergplaas; being similar in colour, texture and field appearance.

The mudstones from directly below the Dwyka Tillite Formation are like those found within the tillite itself. The contact varies from a sharp line to a transition zone of one foot. The lower few feet of tillite contain small inclusions before grading upwards into normal tillite.

Fossiliferous Rocks

Thin lenticular bodies of calcareous silt- and sandstone with numerous imprints of plants crop out intermittently over a distance of 600 yards to the west of the homestead. The stratigraphic distance below the tillite varies from 40-60 feet in the east to 30 feet in the west. The weathered surfaces of the rock are grayish brown (5YR3/2). The rocks are very similar to those representing the eastern facies of the Conglomerate lentil on Droëkloof.

The rocks from near the homestead also contain imprints of fishes and bryozoans. A more detailed description is given in Chapter IV.

(4) Dwyka Tillite Formation (Dwyka Group)

The tillites form conspicuous outcrops in the Floriskraal area. Stratification of the formation is made apparent by the presence of beds of conglomerates and greenish mudstones and shales.

Erratics show a size distribution of from grit-size inclusions to huge boulders a few feet across. The usual erratic types are present. A.W. Rogers (1925, p. 16) observes that "Several of these rocks can be identified with formations that crop out north of the Karroo area, such as the Campbell Rand - Griquatown Series, and the Ventersdorp and Matsap beds."

Cleavage planes within the tillite dip southwards. They are parallel to the fold axis of the east-west anticline in the Witteberg Group and nearly perpendicular to the stratification of the tillite. The resulting Bushman's tombstones incline northwards. Many of the erratics seen in situ in the well-exposed outcrops near the homestead, are traversed by a set of narrowly-spaced parallel cracks. These cracks are approximately perpendicular to the cleavage of the tillite itself and approximately parallel to the stratification.

D. THE WESTERN KARROO

In this area the Witteberg Group displays regression and offlap from north to south. The Dwyka Group oversteps the three units of the Cape Supergroup before it finally rests unconformably on the Basement Complex to the north of the Western Karroo. It was already previously known that the contact between the Witteberg and Dwyka groups is conformable for some distance northwards of Karoopoort. The exact extent of this conformity was not determined by previous investigators nor by the present one. Evidence is submitted further on to show that the conformable junction is traceable at least to the farm Koperfontein.

It must finally be borne in mind that well-exposed outcrops and more specifically contacts, are rarely seen along the base of the Swartruggens Mountains.

(1) General Description of Formations

(a) Wittepoort Formation (Witteberg Group)

The resistant rocks of this formation form the eastern flank of the Swartruggens Mountains as well as the north-eastern entrance to the Karoopoort. The white-weathering sandstone and some more micaceous and arenaceous rocks are well exposed by the many resequent streams incised into the bare slopes. The formation consists of the usual array of well-stratified clean sandstones, sometimes having small inclusions of quartz. Cross-stratification is also present.

(b) Lake Mentz Formation (Witteberg Group)

Katbakkies Shale Member.

In the vicinity of the Skitterykop the Katbakkies road connecting the Cold Bokkeveld with the Western Karroo, is for some distance cut in the micaceous shales and siltstones of the member. Ripple-marking and micro-cross-lamination is present.

Floriskraal Sandstone Member

The resistant sandstone of this member forms the crests of the low hills parallel to the base of the Swartruggens. These hills are to be seen in the vicinity of Karoopoort and on the farms Kafferskraal, Nuwardouw and Hartnekskloof.

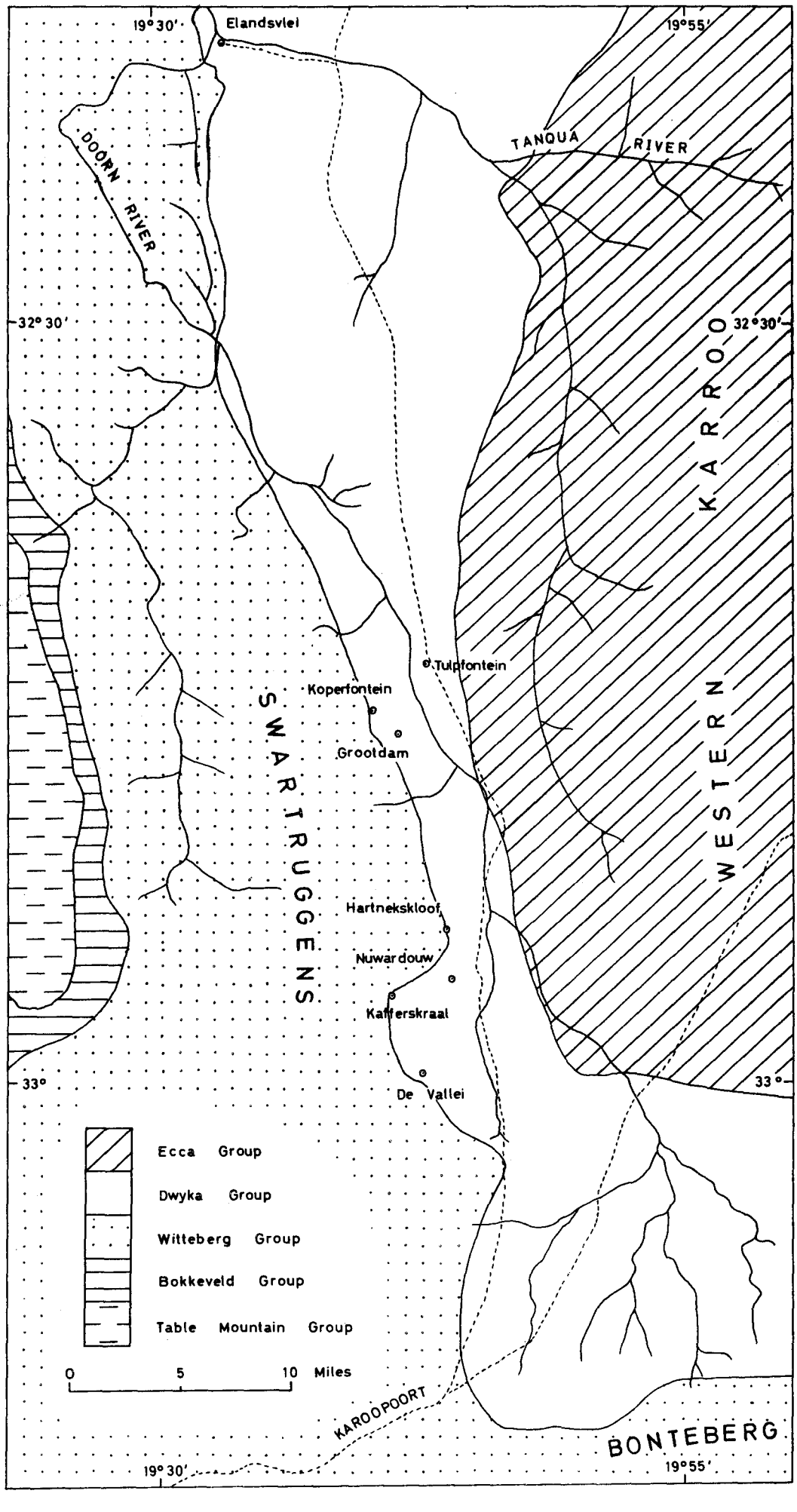


FIG. 5. Locality map, Western Karroo.

Some rocks are well-stratified flagstones while others are cross-stratified sandstones. Gritty layers and thin pebble-conglomerates containing inclusions of quartz, chert and feldspar are common. Big interference ripple-marks are present. In field appearance, lithology and primary structures, this member closely resembles the same from the Floriskraal area.

Kafferskraal Shale Member.

This member forms no conspicuous or important topographic feature. Micaceous shales and siltstones with distinct "Witteberg" characteristics occur together with a few sandstones. The lower contact with the Floriskraal Sandstone Member is not clearly defined.

(c) Kommadagga Formation (Dwyka Group)

Mudstones, shales and siltstones are in places to be seen below the Dwyka Tillite. These generally darker and non-micaceous rocks are unmistakably "Dwyka-type". Exposures of the formation are scarce. From the vicinity of Karoopoort, the formation ranges northwards towards Nuwardouw where it probably terminates under loose material somewhere on that farm. It is already absent near the northern boundary of the farm with the adjoining Hartnekskloof.

The "Lower Shales" of A.W. Rogers and A.L. du Toit (1903, p. 19) probably comprise both the Kafferskraal Shale Member and the Kommadagga Formation of the present usage. They were, however, aware of the "Witteberg" characteristics of the lower rocks and the more "Dwyka" appearance of the upper portion. They use the term "passage beds", in this way tentatively suggesting the mixing of sedimentary material and continuity of deposition.

(d) Dwyka Tillite Formation (Dwyka Group)

Many types of erratics are strewn about on the surface in the tract of country underlain by Dwyka Tillite. Griquatown jaspers are more common than in the area to the east of Floriskraal. An uncommon sandstone erratic was found in the basal tillite on Koperfontein. This dark yellowish green (10GY4/4) pebble is said to come from Rehoboth in South West Africa.

(2) Description of Selected Localities

(a) Kafferskraal

This farm was visited to investigate certain rocks only. Near the upper contact of the Kafferskraal Shale Member a few indeterminable plant stems were seen.

The lower contact of the Kommadagga Formation is obscured. The approximately 125 feet of mudstones, shales and siltstones clearly belong to the Dwyka Group. Some dusky yellow (5Y6/4) siltstones are reminiscent of similar rocks seen on Floriskraal and Bergplaas. Shales and mudstones from directly below the Dwyka Tillite Formation resemble those seen interstratified with the basal tillite itself.

(b) Hartnekskloof

This farm lies immediately north of Nuwardouw which in turn borders on Kafferskraal. As shown in Table 3, the Kommadagga Formation is absent on Hartnekskloof.

TABLE 3

STRATIGRAPHIC COLUMN FOR HARTNEKSKLOOF

Group	Formation	Member	Thickness in feet	Lithology	Fossils
Dwyka	Dwyka Tillite		-	Tillite	
Witteberg	Lake Mentz	Kafferskraal	170	Micaceous shales, siltstones and sandstones	Worm tracks
		Floriskraal Sandstone	210	White sandstones	
		Katbakkies Shale	380	Micaceous shales and siltstones	
	Wittepoort		-	White sandstones	

The contact between the Kafferskraal Shale Member and the Dwyka Tillite Formation is well exposed on Hartnekskloof and the northern portion of Nuwardouw. The actual contact between the tillite and the underlying rocks of unmistakably

"Witteberg type", varies from a sharp one to a zone a few inches wide. A further proof of the water-saturated and unconsolidated condition of the underlying sediments prior to the deposition of the tillites is the presence of Dwyka erratics in the upper one foot of mudstones and shales.

Some erratics are completely enclosed. The presence of curved laminae below the erratics indicate that they were dropped onto the muds from ice-bergs or a floating ice-sheet.

No evidence of a period of erosion prior to the deposition of the tillite could be found. The Dwyka Tillite Formation is structurally conformable to the underlying rocks.

(c) Koperfontein

The Wittepoort Formation consists of stratified and cross-stratified white sandstones. Pebble-conglomerates are now absent. However, very small quartz pebbles occur singly. Near the southern border of the farm, a small re-sequent stream which eventually flows past the homestead of the bordering Grootdam, is incised into the resistant sandstones. There the exposed rocks display deformed cross-stratification in a zone approximately 12 feet from the top of the formation. This, as well as other occurrences of this primary structure is described in Chapter IV and further discussed in Chapters VI and VII.

Both the Lake Mentz and Kommadagga Formations are absent. This means that almost 800 feet of the stratigraphic column thins down and disappears over a distance of 10 miles.

Immediately to the north of the small incised stream mentioned above, the upper sandstone bed of the Wittepoort Formation has been completely stripped of its former cover of Dwyka Tillite. (Plate 2, Photo C). On the upper surface of the sandstone numerous hollows are to be seen which on closer inspection prove to have been left by the weathering out of former inclusions (Plate 2, Photo D). A map of a portion of the surface shows the distribution of the original inclusions (Fig. 7). Unfortunately only a few inclusions, all sedimentary rocks, were discovered in situ. One is a light gray (N7) banded chert. Others are very light gray (N8) sandstones. A few very light gray arkosic sandstones were

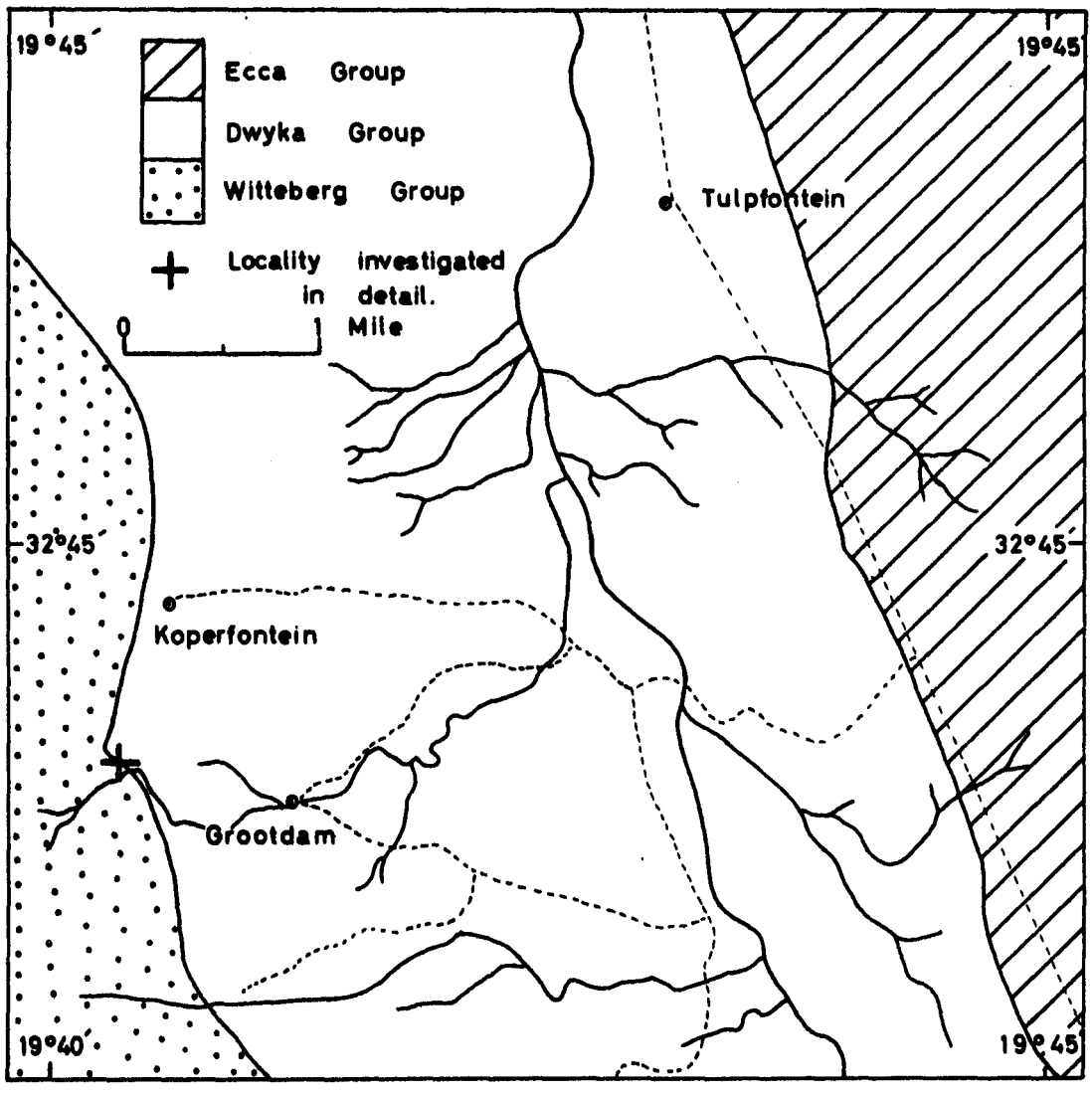


Fig. 6. Geological map of an area around Koperfontein.

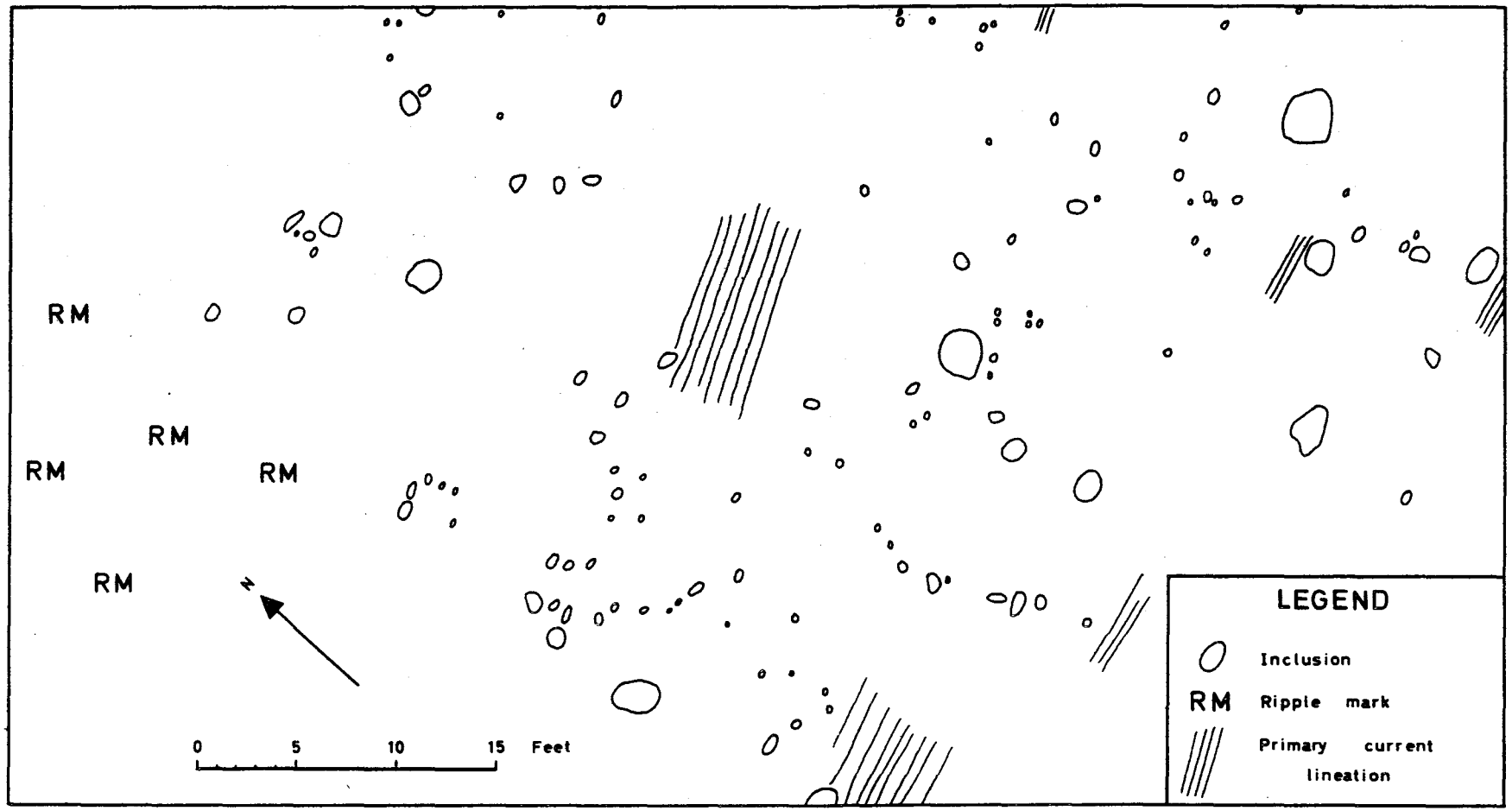


Fig. 7. Bedding plane. Wittepoort Formation, Koperfontein, Western Karroo.

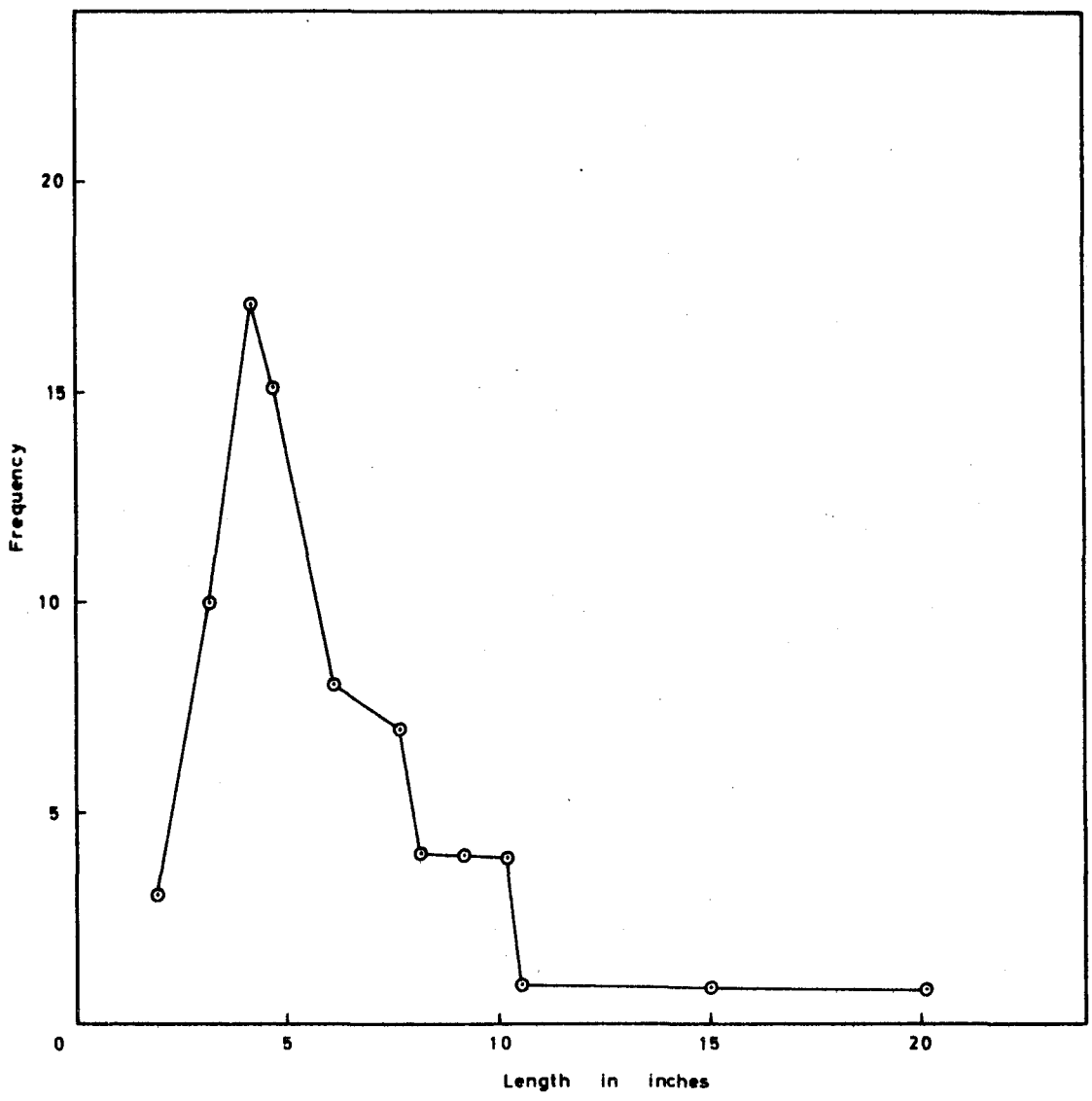


Fig. 8. Frequency distribution of the long axes of 75 inclusions in the uppermost bed of the Wittepoort Formation, Koperfontein.

also collected. The latter with their pock-marked weathered surfaces are frequently seen as erratics in the Dwyka Tillite of the Western Karroo. In colour, texture and macroscopic mineral content the inclusions of arkosic sandstone closely resemble certain rocks from the base of the Nama Supergroup at the Roodewal occurrence of monazite to the north of Vanrhynsdorp. It is shown in Chapter V that the heavy minerals of the inclusions and the Roodewal Nama rocks are not comparable. The Cape Supergroup as a possible provenance seems improbable for the chert inclusions as no chert is known to be present in it.

We are then left with the straightforward explanation that the inclusions are Dwyka erratics. In this area the Dwyka Tillite Formation immediately overlies the Wittepoort Formation. Further proof that the inclusions are of Dwyka origin is given by the hollow left by one specimen displaying glacial striations. (Plate 2, Photo E).

Measurements were made of the orientation of 22 hollows. (Fig. 13). The longest axes of 75 inclusions (hollows) were measured to determine the size-distribution. (Fig. 8) Primary current lineation and big interference ripple-marks are also present on the upper surface of the sandstone bed.

The Koperfontein exposure is further discussed and evaluated in Chapters IV, VI and VII.

(d) Elandsvlei

At Elandsvlei the Kommadagga and Lake Mentz formations are missing and possibly much of the Wittepoort Formation as well. The exact stratigraphical position of the sandstones underlying the Dwyka Tillite was not determined. However, the writer suspects that the upper beds of the Wittepoort Formation are absent. This is evident from the impressions of a Spirophyton and a Haplostigma (formerly known as Bothrodendron) found 20 feet below the tillite. From the work of J.N. Theron (Op. cit., Table 1) it is clear that the upper limit of the range zone for the Spirophyton and the Haplostigma is well below the upper contact of the Wittepoort Formation. The present author has neither found the abovementioned fossils in the upper beds of the formation, nor heard of their discovery in that stratigraphical position.

Prior to the deposition of the Dwyka Tillite, small-scale folding and subsequent erosion of the sandstones took place. The pre-glacial surface is undulatory with the small anticlinal ridges sometimes at right angles to the later structural trend of the Swartruggens. In contrast the overlying beds of the Dwyka Tillite Formation are relatively undisturbed; retaining a very low easterly dip. The exact contact between the Witteberg and Dwyka Groups is usually obscured. The nature of the angular unconformity is further indicated by the observation of A.W. Rogers and A.L. du Toit that fragments of sandstone are sometimes to be seen in the lowest six inches of tillite (Op. cit., p. 21).

The glacial pavement

The Elandsvlei pavement is described by A.W. Rogers and A.L. du Toit (Ibid., pp. 21-22). The present author paid a visit only to the portion of the pavement exposed at the Kruidfontein homestead on the southern bank of the Doorn River. A full description of the pavement is beyond the scope of this paper. Only certain aspects which have a direct bearing on this paper are mentioned below. Placed at more than 70 feet from the base of the tillite, the pavement has the appearance of a cobbled street owing to weathering. Small unweathered portions of the pavement display parallel glacial striations. Striations are also present on the planed-down surfaces of some erratics inbedded in the tillite of the pavement. Measurement of the bearing of the striations and observation of the crescent-shaped cracks on the stoss side of some erratics protruding slightly from the pavement indicate that the direction of movement of the ice was S86E. The pavement is overlain by one foot of normal tillite. This is followed by 10 feet of stratified tillite and mudstones containing small inclusions.

The origin of the pavement is ascribed to the grounded portion of an ice-shelf moving eastwards. The consistency in direction of the striations and the long and sustained period of grinding necessary to produce the facets on the big erratics in the pavement, would rule out a free-drifting ice-berg.

The Elandsvlei pavement is referred to and its importance discussed in Chapter VI.

E. GRAHAMSTOWN

A very brief visit was paid to the Grahamstown area in order to investigate certain aspects of the geology of certain formations.

Lake Mentz Formation

This Formation is described by E.D. Mountain (Op. cit.) at the time of his investigation the name "Lower Dwyka Shales" was still in use. From his description (pp. 13-16) it seems that he was not entirely convinced of the justification of the use of that name. He admits that the top of the "main quartzite" (i.e. the Wittepoort Formation) forms a more logical boundary for the lower limit of the "Lower Dwyka Shales", instead of the frequently-appearing sandstone lentils near the upper contact with the Dwyka Tillite. The use of such a sandstone would mean that the "Lower Dwyka Shales" would be eliminated completely. Mountain estimates the formation to be 1800 feet in thickness.

The "Lower Dwyka Shales" were later given the name of "Upper Witteberg Stage" by the Geological Survey. It is clear that the assignment of the formation to the Witteberg Group is correct. The rocks have the typical "Witteberg" appearance. In texture and lithology the sandstone lentils of the Coombs Valley resemble the white sandstones from the Wittepoort Formation. The results of a heavy mineral analysis as presented in Chapter V clearly indicate that the assignment of the lentils and consequently the formation to the Witteberg Group, is correct.

Kommadagga Formation

On the farm Uniondale, 8 miles ENE of Grahamstown, mudstones, shales and siltstones of typical "Dwyka" appearance occur below the Dwyka Tillite. A few erratics imbedded in the siltstone, were seen a few feet below the tillite contact. The lateral extent and thickness of the formation was not determined.

F. ROBERTSON

In the Worcester-Robertson area the outcrops of the Dwyka Group are separated from the continuous line of outcrop. The Witteberg-Dwyka contact rocks were examined along the flank of the Rooiberg on the farm Onder Noree. The Dwyka Tillite Formation rests on a 260 feet sequence of shales, silt- and sandstones. Below that 40 feet of sandstones in turn overlies 230 feet of shales, siltstones and white sandstones.

Below alternating silt- and sandstones occur. The rocks underlying the Dwyka Tillite have distinct "Witteberg" characteristics. They are distinctly micaceous, and have the distinct colours owing to ferric iron oxide when weathered. Micro-cross-lamination and ripple-marking occurs in places; the latter primary structure being of smaller size than encountered elsewhere.

Impressions of the Spirophyton occur in great numbers in all rocks below the Dwyka Tillite, sometimes to within inches of the tillite itself. The Witteberg-Dwyka sequence in the Robertson area has not yet been worked out in detail. The author did not do regional mapping of the area.

However, the rocks below the tillite do not seem to belong to the Lake Mentz Formation. Nor were the white sandstone of the "White Streak", i.e. the upper beds of the Wittepoort Formation recognized. It then seems that the rocks directly underlying the tillite occur in a stratigraphic position some distance below the upper limit of the Wittepoort Formation. Wherever the Witteberg sequence has been clearly established as in the Willowmore area, (J.N. Theron Op. cit.) it is found that the range zone for the fossil Spirophyton extends upwards to some position well below the upper limit of the Wittepoort Formation. Assuming that this is correct for all geographic areas, it would further justify the view that the whole of the Lake Mentz Formation and the upper portion of the Wittepoort Formation is missing in the Robertson area.

The results of a heavy mineral analysis as presented in Chapter IV also suggests that the sandstones underlying the Dwyka Tillite, is from a stratigraphic position below the upper beds of the Wittepoort Formation.

Regional mapping and a heavy mineral investigation of the whole of the Witteberg Group in the western areas should be done in the future.

The Kommadagga Formation is also absent. The Dwyka Tillite is conformable to the underlying rocks. A transition zone of a few inches is sometimes present.

G. DROËHOEK, CERES

Faulted-down rocks of the Dwyka Tillite Formation occur in the Droëhoek area, 17 miles NNE of Ceres. A normal sedimentary contact with the Witteberg Group is to be seen on the farm Witklippies. The Wittepoort Formation consists of the usual white sandstones and a few pebble-conglomerates. The Lake Mentz Formation is restricted to the Katbakkies Shale and the Floriskraal Sandstone Members. Their respective thicknesses is given as 100 and 140 feet by J.N. Theron. (Personal communication). The Dwyka Tillite rests confor-

mably on the sandstones of the Floriskraal Sandstone Member. The contact is gradational with a zone varying from a few inches to a few feet.

In the vicinity of Karoopoort A.W. Rogers and A.L. du Toit (Op. cit., p.19) found 350 to 400 feet of "Lower Shales" (i.e. the Lake Mentz and Kommadagga Formations) intervening between what is known in the present paper as the Floriskraal Sandstone and Dwyka Tillite Formations. This means that a thickness of 350 to 400 feet thins down and eventually disappears over the distance of 15 miles from Karoopoort to the Droëhoek area.

This same phenomenon is present from south to north in the Western Karroo. In the Droëhoek area all the upper divisions of the Witteberg Group suffer a decrease in thickness from east to west. (J.N. Theron, personal communication).

H. GENADENDAL

The outcrops from Genadendal represent the most southern known occurrence of Dwyka Tillite. It was mapped and described by L.C. Gouws (1960).

The tillite is underlain by 30 feet of sandstones, siltstones and shales, which in turn rests on a 300 feet zone of argillaceous rocks with a few sandstones. As in the Robertson area, the Kommadagga and Lake Mentz Formations as well as the upper beds of the Wittepoort Formation were not recognized. Impressions of Spirophyton occur to within 8 feet of the Dwyka Tillite. As was explained previously, this indicates that the stratigraphic position of the rocks underlying the tillite is some distance below the upper contact of the Wittepoort Formation. This is confirmed by the results of a heavy mineral investigation given in Chapter V.

The basal contact of the Dwyka Tillite Formation is usually obscured. The best exposures are found in the southwestern outcrop area. Because he found the contact too ill-exposed, L.C. Gouws dug a short trench in order to examine the contact phenomena more closely. (Ibid., Plate II, fig. 2) He found a boulder of granite imbedded in the rocks just below the contact and described it as an erratic which had been forced into it by the superincumbent pressure of terrestrial ice. (pp. 19-20) He proposes that pre-glacial erosion of the Witteberg rocks had taken place and that the boulder was pressed into weathered material and acquired a facet in the process. Gouws also undertook a heavy mineral analysis which show that part of the stratigraphic column is missing. On the strength of this and

the one granite boulder, he then proposes that a disconformity exists between the Witteberg and Dwyka Groups. (pp. 20, 22-24) Gouws' observations and deductions are critically discussed below and alternative views are given:

The granite boulder is an ordinary erratic which had been dropped onto wet and unconsolidated muds. It is merely by coincidence that a flat surface occurs on top. This surface is much too weathered to be identified as a glacial facet which was formed with the boulder in situ. The rocks in the trench are much too weathered to show curved laminae below the erratic.

For a distance of 40 yards to the north of the trench the contact is exposed intermittently. A few other erratics also occur partially or fully imbedded in the Witteberg rocks just below the contact. The curved laminae around the sides and below an erratic are not clear in a photo (Plate 1, Photo E) but are very distinct in the field. Towards the north on the slope leading towards the river, a contact zone of 2 feet is exposed. The transition from Witteberg mudstones and siltstones to Dwyka Tillite is clearly seen.

Gouws invokes pre-glacial erosion by terrestrial ice and consequently has to call the basal rocks of the Dwyka Tillite Formation a ground moraine tillite. He does not find any other indications of the presence of terrestrial ice such as roches moutonnées, glacial striae, glacial pavements or any other signs of disturbance of the floor. From field observations as well as from Gouws' map it is clear that the same beds underlie the Dwyka Tillite everywhere in the area. It is indeed remarkable that the terrestrial ice of Gouws had stripped off the weakly resistant and weathered rocks down to the same stratigraphic level everywhere. Gouws' "disconformity" (p. 19) can be described more correctly as a paraconformity indicative of a hiatus in deposition.

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CHAPTER IV

PRIMARY STRUCTURES

A. PRIMARY STRUCTURES OF MECHANICAL ORIGIN

In the field much attention was paid to primary structures since knowledge of their origin is a prerequisite in the study of the mode and environment of deposition of the rocks.

(1) Ripple-marks

(a) Symmetric ripple-marks

These are very common in the rocks of the Lake Mentz Formation and less so in the Wittepoort and Kommadagga Formations. Ripple-marks from localities as far apart as Kommadagga and the Western Karroo are remarkably similar in appearance.

Two types are present:

(i) Interference ripples showing a haphazard distribution of crests and troughs.

(ii) Oscillation ripples.

The latter are not of the type usually seen to have straight parallel crests over long distances, but are composed of a series of sinuous crests, often bifurcating. (plate 2, Photo H). All ripple-marks are distinctly rounded. Their orientation was not measured as this structure is not a good indicator of the direction of the currents which transported the sediments. The usual measurements of amplitude and wave-length were made of some in order to determine the size-variation and range. These together with the calculated indices are presented in Table 4.

While some ripple-marks are confined to a single surface, the outlines of others can, in a section, be seen to occur throughout several inches of rock. These were formed during the continuous settling of sediments onto ripple-marked surfaces. Since E.M. Kindle and W.H. Bucher instigated interest with their

TABLE 4

SYMMETRIC RIPPLE-MARKS IN THE LAKE MENTZ FORMATION

Wave-length in inches	Amplitude in inches	Index
Second Sandstone Lentil Bergplaas		
7.5	0.25	30
6.0	0.75	8
5.0	0.3	16.7
4.75	0.3	15.8
4.5	0.25	18
4.5	0.5	9
14.5	1.5	9.3
9.5	0.75	12.7
8	0.75	10.7
8	1	8
5.5	0.5	11
10.5	1.0	10.5
7.5	0.5	15
6.5	0.75	8.7
6	0.75	8
5	0.5	10
2.75	0.13	21.1
2.75	0.13	21.1
2.5	0.25	10
2.5	0.25	10
2	0.25	8
2	0.2	10
2	0.2	10
1.25	0.25	5
Soetendalsvlei Shale Member, Droëkloof		
7	0.35	20
6	0.48	12.5
5.5	0.3	18.3
5	0.4	12.5
4.5	0.28	16.1
4.5	0.6	7.4
3	0.3	10
3	0.25	12
Buffels River Shale Member, Floriskraal		
10	1.1	9.1
9	0.7	12.9
7	0.8	8.7
7	0.6	11.7
6.5	0.7	9.3
6	0.7	8.6
5.5	0.7	7.9
4	0.5	8
13	0.9	14.4
10	0.8	12.5
8.5	0.7	12.1
6	0.5	12
6	0.5	12
6	0.4	15
5.5	0.5	11
5	0.6	8.3
4.5	0.6	7.5
4.5	0.5	9

publications, the environmental conditions which favour the formation of ripples, is still the object of research and discussion. The size and form of ripple-marks depend on a number of variable factors such as the depth of the

water, the size of the waves and the presence and nature of currents. Field observations of modern ripples have led geologists to believe that small-size examples with a wave-length of only a few inches, can form in any depth of water from very shallow to many fathoms in depth. The larger ripples have a limited depth range.

The observations of E.M. Kindle (1917, p. 29) led him to believe that the symmetrical types, such as occur in the Lake Mentz Formation, can only form in water deeper than 20 feet. The lower limit for the formation of symmetrical ripples coincides with the greatest depth to which an oscillatory movement due to wave action could extend. Kindly gives a "conservative estimate" of 300 feet. (p. 42) He warns that the presence of ripple-marks in rocks does not necessarily mean shallow-water deposition. (p. 39)

In the Lake Mentz Formation the ripple-marks display a size-variation in the same bed as well as between beds spaced a few feet apart. The presence of ripple-marks in conjunction with cross-stratified beds indicate relatively quiet conditions which were frequently interrupted by periods of stronger current-flow.

(b) Big interference ripple-marks

This type was found in the Wittepoort Formation at Bergplaas, Floriskraal and Koperfontein. In the Floriskraal Sandstone Member of the Lake Mentz Formation, they were seen at Droë-kloof, Floriskraal and in the Western Karroo. These ripples appear as an apparently haphazard distribution of crests and troughs. (Plate 2, Photo B) The measurements of the crest-to crest distance (wave-length) and the depth of the troughs (amplitude) are given in Table 5.

In no place were big current-ripples, termed "para-ripples" by W.H. Bucher (1919, p. 263), found.

Owing to lack of data the big interference ripple-marks cannot be used as a criterion of absolute depth. Taking the size into account, it is improbable that it can originate in water only a few feet in depth. In the Wittepoort Formation the ripple-marks are associated with ordinary stratification as well as cross-stratification and in two cases with primary current lineation. (Floriskraal and Koperfontein). In the

TABLE 5

BIG INTERFERENCE RIPPLE-MARKS IN THE FLORISKRAAL SANDSTONE MEMBER

DROËKLOOF			FLORISKRAAL		
Wave-length in inches	Amplitude in inches	Index	Wave-length in inches	Amplitude in inches	Index
68	4.5	15.1	34	2.25	15.1
56	4	14	31	3.5	8.6
49	5	9.8	31	2	15.5
49	3.5	14			
37	4.5	8.2			

Floriskraal Sandstone Member of Floriskraal the small symmetrical ripples sometimes occur together with the big interference types.

While skin-diving in 20-30 feet of water at the Robberg, Plettenberg Bay, the author has frequently observed similar-looking mounds and depressions on the sandy bed of the bay. There the structures are due to the interference between the swells advancing nearly parallel to the rocky coast, and a secondary refracted set crossing the former diagonally. It is therefore conceived that the big interference ripple-marks can develop in any shallow sea subjected to two sets of swells.

(2) Primary Current Lineation

Under suitable conditions the upper surface of a bed of sand acquires faint lines, the strike of which is parallel to the direction of flow of the current. W.L. Stokes (1947, p. 54) attributes its origin to laminar flow of shallow water at a moderate velocity. This primary structure is to be seen in the near-vertical cliffs at the northern entrance to Leeukloofpoort on the farm Floriskraal. There the Wittepoort Formation consists of well- and cross-stratified sandstones. The lineation is confined to the upper surfaces of the beds whose thickness varies from 4 to 18 inches. Cross-stratified beds occur amongst them.

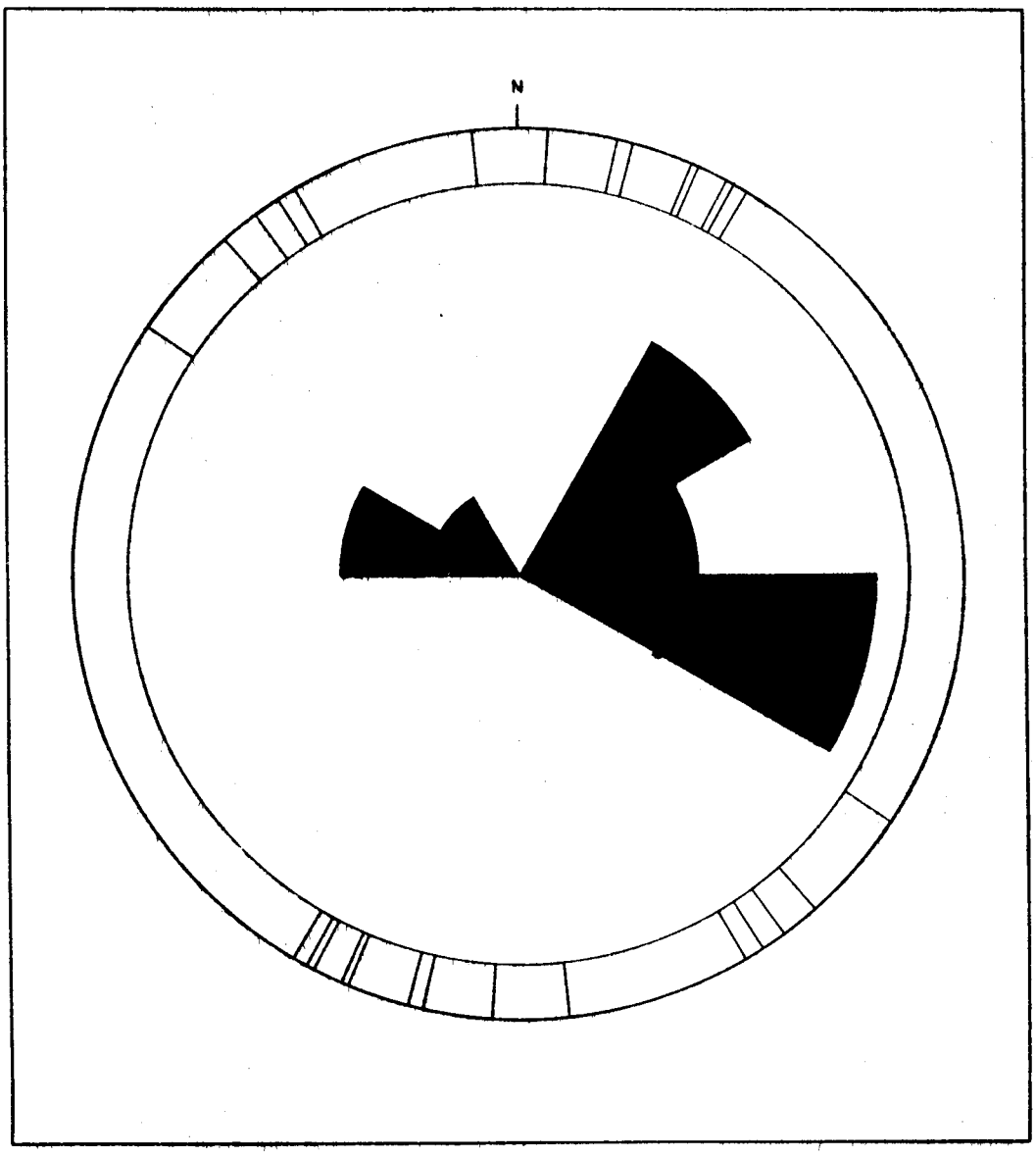

Fig. 9. Compass diagram of cross-stratification. The strike of 14 primary current lineations is shown on the outer circles.

From the Wittepoort Formation, Floriskraal.

It was hoped that measurements of the cross-stratification which is associated with the lineated beds, would indicate the direction of flow of the laminar paleocurrents. The results of measurements of both primary structures are combined in Fig. 9. Folding has been corrected for. It is rather disappointing that no distinct relationship exists.

(3) Load Casts

The soles of sandstone beds are sometimes seen to display a structure attributed to post-depositional settling of sand into water-logged and unconsolidated mud. R.R. Shrock (1948, p. 158) gives a photograph of the structure and uses the term "flow cast" to describe it. Subsequently Ph. H. Kuenen (1953, P. 1058) proposed the term "load cast". Load casting is present on the sole of a lithic graywacke interstratified with the sandstones of the Wittepoort Formation in the Wittepoort, Bergplaas. Shrock's photograph also show "curvilinear grooves" on the sole. He interprets it as "shear fractures produced in the sand when it could no longer flow". The Wittepoort examples display the same types of grooves. It also occurs on the soles of thin siltstone beds only ½ inch thick. The grooves are the casts of structures which appear as minute oscillation ripple-marks with a wave-length of from 1/10 to 1/5 inch.

Load casting is mentioned in Chapter III to occur in some of the more argillaceous divisions of the Lake Mentz Formation.

(4) Stratification

It is the most characteristic primary structure. In the field it is usually made more clear by the effect of differential weathering of the various lithologic units. Stratification is formed during the deposition of sedimentary material on an originally horizontal surface or one nearly so. The study of this primary structure is important when determining the environment and mode of deposition of the sediments. The terms "bed" and "lamina" each imply an individual layer of sedimentary rock within certain fixed thickness boundaries. Each layer would be of uniform thickness, lithology and colour and would be indicative of a single act of deposition. The term "bed" as used in this paper means a group of two or more "beds" and/or "laminae" as used by R.L. Ingram (1954). A bed as seen in the field would then constitute a clearly-recognizable lithologic unit, indicative of a

number of nearly-similar acts of deposition. The term "lamination" is in this way not restricted to its usual application to shales.

(a) The Witteberg Group

The rocks of the Wittepoort Formation show a complete stratification range of from being thinly laminated to thickly bedded. Lamination is often present in beds which are described in this and other papers as "well-stratified".

The sandstone beds are separated from others above or below either by a more argillaceous bed or else a distinct dividing surface. These dividing surfaces are of two main types:

(i) Surfaces of non-erosion and temporary non-deposition.

(ii) Surfaces of erosion and temporary non-deposition.

The thickness of individual beds range up to several feet; the average being less than 3 feet.

As is described in Chapter III, the rocks of the Lake Mentz Formation are also well stratified.

(b) The Dwyka Group

Although it is apparently absent in hand specimens and in small isolated outcrops, stratification is clearly seen in bigger outcrops of the Dwyka Tillite Formation and on aerial photographs. In places it may be partially obscured by secondary cleavage and joints. Most of the tillite can be classified as being very thickly bedded. However, distinctly thinly to thickly bedded tillite sometimes occurs in association with beds of mudstone, shale or conglomerate.

(5) Cross-stratification

Colloquially known as "cross-bedding", this primary structure is frequently mentioned in description of the Witteberg Group.

(a) Large-scale cross-stratification

In Chapter III it is mentioned to occur in the more arenaceous rocks of the Wittepoort and Lake Mentz formations where it is usually associated with ordinary stratification. The nature of the surface on which a cross-stratified bed rests, cannot

always be determined. In places it is clearly a surface of erosion. A cross-stratified bed may show truncation of its upper portion. The cross-stratification of the Witteberg Group may be described as being from thickly cross-laminated to very thinly cross-bedded. The length of the cross-strata, usually never exceeding 3 feet, depends on the thickness of the bed. In the Wittepoort Formation some units exceed 10 feet with a very low inclination angle of less than 10°. Some units are concave with a resulting tangential lower contact. Cross-stratification frequently occurs continuous over a distance of many yards. The "simple cross-stratification" and "planar cross-stratification" of E.D. McKee and G.W. Weir (1953, p. 387) are both to be seen.

The origin of cross-stratification is attributed by some as due to the deposition of sand as foresets on inclined slopes. F.J. Pettijohn (1962, p. 1472) believes it to originate due to the migration of traverse sand waves. In any case the direction of inclination of a plane of cross-stratification coincides with the general direction of the paleocurrent. which deposited the sand.

The 20-30 readings required for each rock unit were made with a Brunton compass and the results plotted on a Wulff net. To compensate for the effect of folding and tilting, the standard procedure was used viz. to bring the pole of the bed back to the centre of the net; the pole of the cross-stratification plane then moves along a small circle. The subsequent position of the latter pole then indicates both the direction of transport as well as the inclination angle. This method is based on the assumption that:

(i) The original attitude of the beds were horizontal or nearly so.

(ii) The fold axis is horizontal.

In this way inclination angles varying from 14° to 26° were found. The above cannot be taken as average values since low-angle examples are overlooked.

The directions of the paleocurrents are shown in the compass diagrams, Fig. 10 and Fig. 11. In view of the small number of readings in localities spaced widely apart, the present work should be considered to be a reconnaissance study.

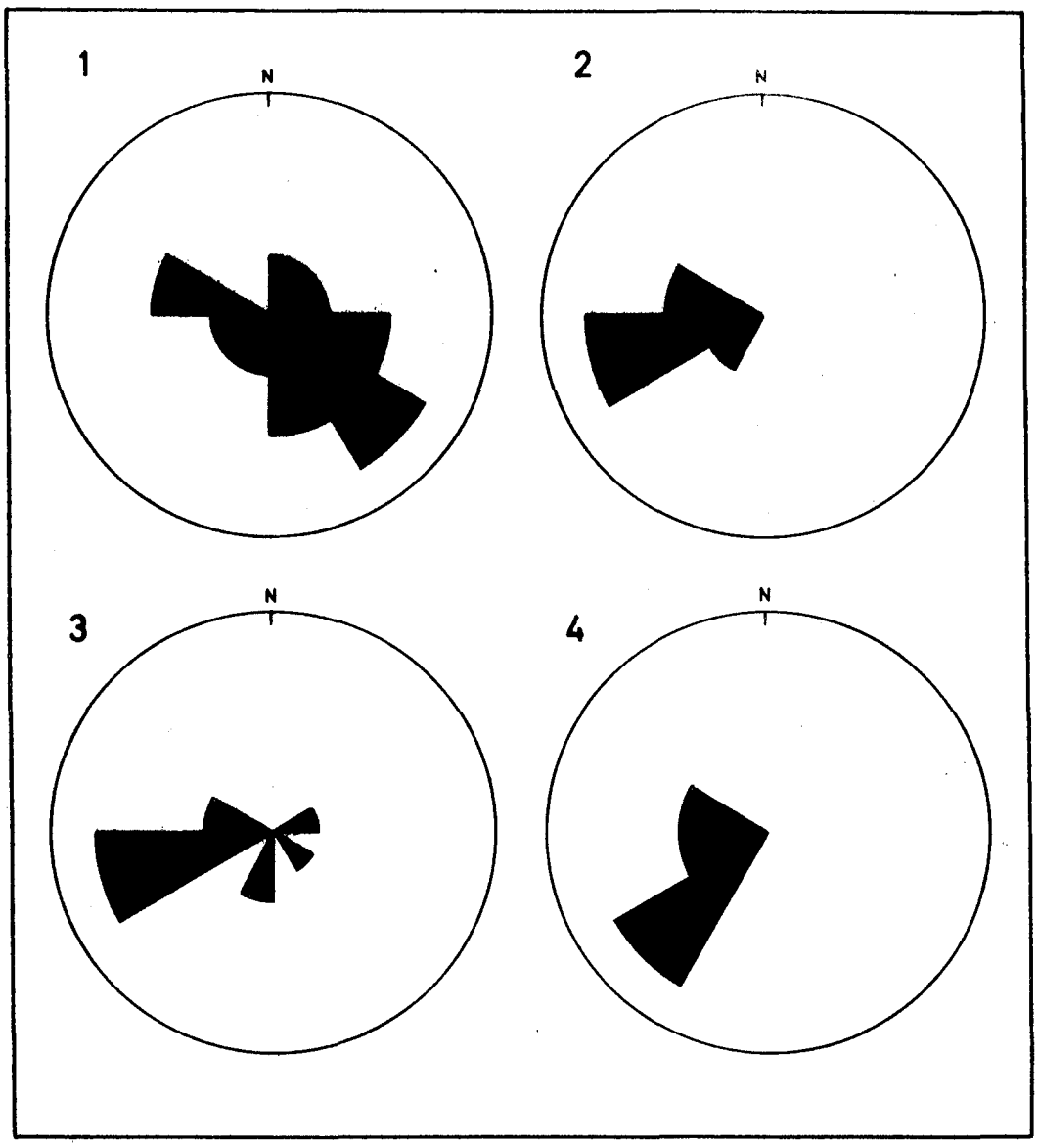

Fig. 10. Compass diagrams of cross-stratification in the Witteepoort Formation.

1. Swartwaterspoort, Kommadagga.
2. Droëkloof, Klaarstroom.
3. Floriskraal, Laingsburg.
4. Koperfontein, Western Karroo.

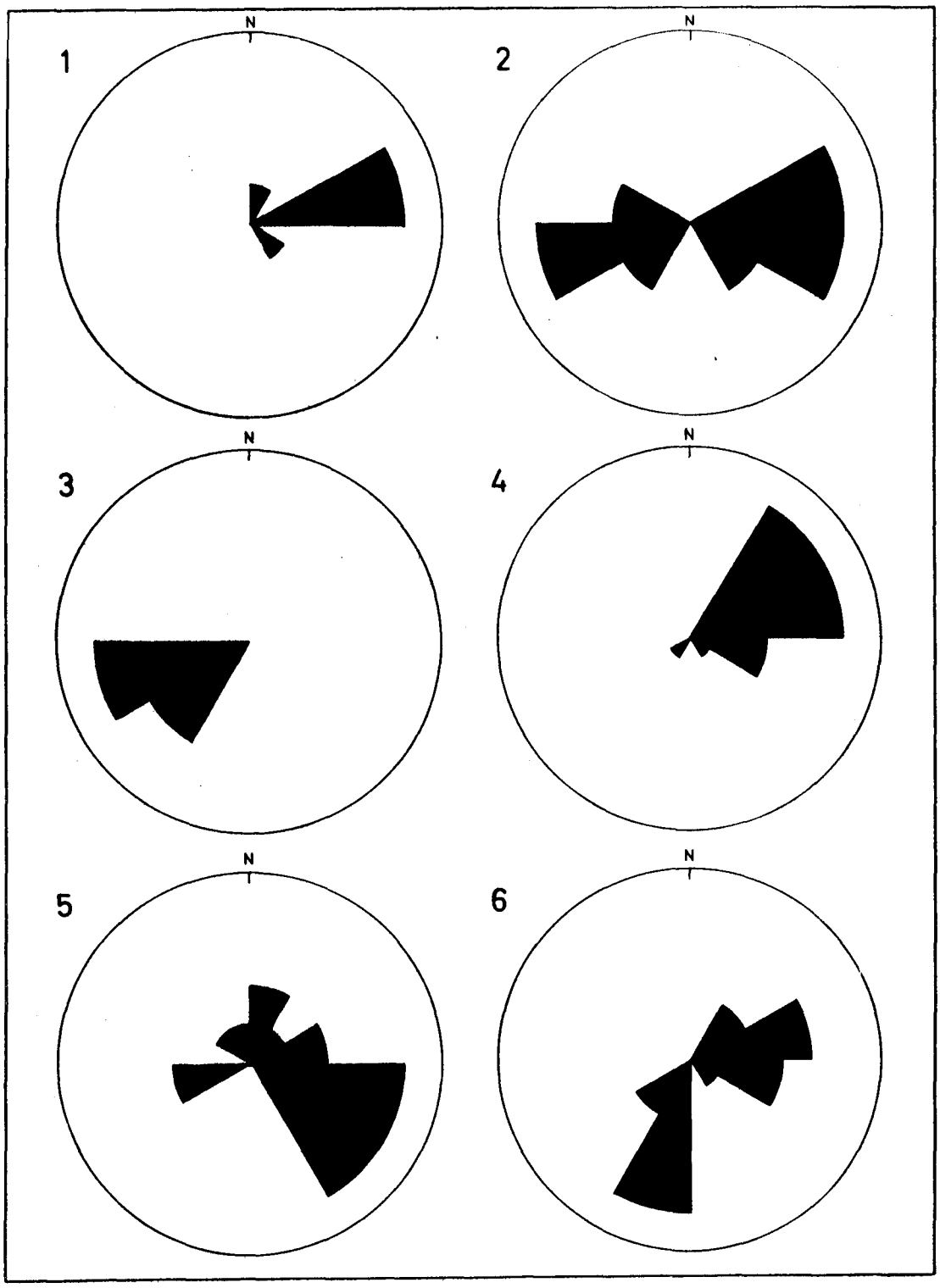

Fig. 11. Compass diagrams of cross-stratification in the Lake Mentz Formation.

1. 1 st Lentil.
2. 2 nd Lentil.
3. 3 rd Lentil.
4. 4 th Lentil.

From the Floriskraal Sandstone Member, Floriskraal.

5. Conglomerate Lentil, Soetendalsvlei Shale Member, Droëkloof.
6. Floriskraal Sandstone Member, Hartnekskloof, Western Karroo.

When constructing a paleocurrent map of the whole of the Witteberg Group, many readings should be taken at more closely-spaced localities.

(b) Micro-cross-lamination

A type of small-scale cross-lamination recognized as a distinct species and termed "micro-cross-lamination" by W.M.K. Hamblin (1961, pp. 390-401), is sometimes found in fine-grained arenaceous rocks. Hamblin gives a description of this structure in his well-illustrated paper. From its association with other sedimentary features he concludes that it forms under shallow water conditions when cusp ripple-marks migrate. It also indicates the direction of the paleocurrent. He adds that it is not only indicative of shallow or subaerial conditions of sedimentation but also of a deeper environment.

In ripple-marked rocks another type of cross-lamination is to be seen. It results from the gradual lateral migration of a ripple during slow sedimentation from above.

(6) Deformed Cross-stratification

On Floriskraal deformed cross-stratification occurs nearly 100 feet from the top of the Wittepoort Formation. Of more interest are the better examples on Koperfontein where it is found 12 feet below the upper contact of the same formation. (Plate 2, Photo A). The structures appear over a distance of 40 yards. The bed containing the structures also contains a small reverse fault with a displacement of ¾ inch. The faulting, associated with the slumping of the sand, took place before deposition of the beds above. The fault-plane shows the characteristic blurred edges, a criterion listed by R.E. Rettger (1935, p. 2911) as being typical of soft-rock deformation.

E.D. Mountain (1964) describes deformed cross-stratification from seven localities in and around Grahamstown. They are all from the same stratigraphic horizon 100 feet below the top of the Wittepoort Formation. Mountain discusses various causes of its formation.

G.P. Jones (1962) describes the same structure from the top of the Bima Sandstone of Nigeria. He lists five possible causes viz. differential compaction, surface thrusting, overloading, falling water level and earth tremors. Jones leads evidence to conclude that the latter, associated with nearby volcanic activity, may well

have been responsible for the slumping. (p. 238)

When applying the five possible causes, as listed above, to the deformed cross-stratification of the Wittepoort Formation, we find that:

(i) Differential compaction would be very rare indeed in well-sorted sand and if present, not confined to one stratigraphic horizon only.

(ii) Surface thrusting can be ruled out because no undercutting of sediments is to be seen.

(iii) Overloading may be a possible cause but then it would also be present in other beds deposited in the same environment. Overloading would not suddenly take place over a distance of 400 miles.

(iv) A falling water level and exposure of the sand to subaerial conditions does not seem possible. On the contrary, all available evidence tend to point to a neritic environment for the deposition of the Wittepoort Formation.

(v) Earth tremors may well be responsible for the subaqueous slumping of metastable sand. This is linked with slight tilting which accompanies the change from a stable depositional platform to one less so. The restriction of deformed cross-stratification to one stratigraphic horizon over a distance of 400 miles, justifies the invocation of external causes.

A search would probably lead to the discovery of more examples of the structure. Deformed cross-stratification is further discussed and its importance evaluated in Chapters VI and VII.

(7) Contemporaneous Erosion Channels

These features are present in the Dirkskraal Siltstone Member of Bergplaas and the Floriskraal Sandstone Member of Droëkloof. The channels originate when sedimentation is interrupted by a period of more torrential flow of currents, in this way leading to the erosion of sediments deposited previously. The strike of two channels on Droëkloof coincides with the direction of inclination of the planes of cross-stratification associated with it. This

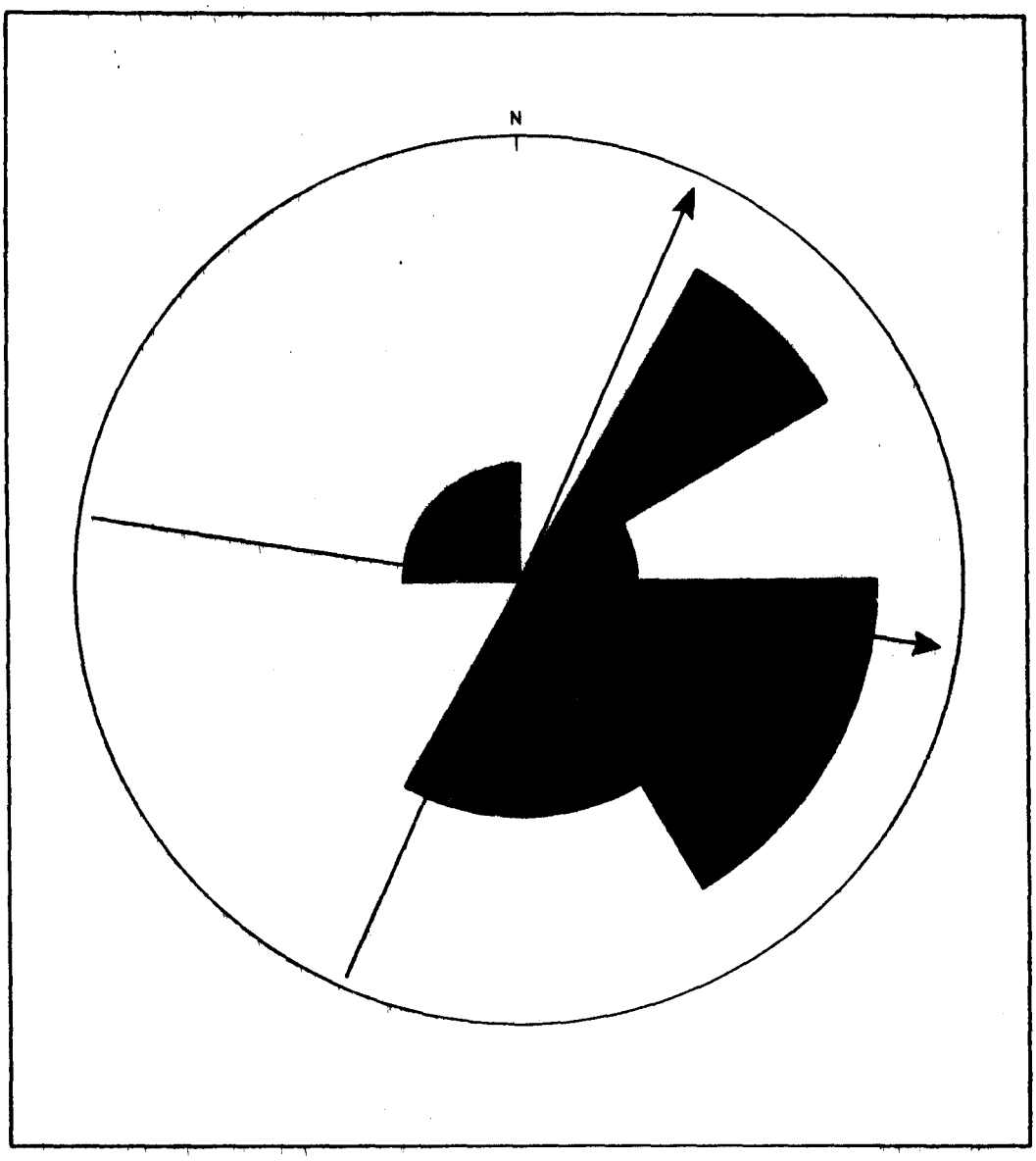

Fig. 12. Compass diagram of cross-stratification shown together with the directions of two contemporaneous erosion channels.

From the Floriskraal Sandstone Member, Droëkloof, Klaarstroom.

is to be expected. (Fig. 12).

(8) Reversed Graded Stratification

This structure is present in the Floriskraal Sandstone Member of Droëkloof and Floriskraal. Beds displaying it were deposited by currents which gradually increased in velocity and competency.

(9) Deformation of Stratification by Rafted Erratics

On Droëkloof Dwyka erratics are sometimes present in the upper few feet of the Kommadagga Formation. On Hartnekskloof and near Genadendal the erratics occur within rocks of the Witteberg Group. In all cases the curved laminae below and around the sides of an erratic indicate that it settled into the wet and unconsolidated sediments after it had been released from a floating ice-berg or ice-shelf.

(10) The Orientated Erratics of Koperfontein

The occurrence of Dwyka erratics in the upper sandstone bed of the Wittepoort Formation is described in Chapter III. The few erratics remaining in situ as well as the hollows left by their removal through erosion, indicate a preferred orientation as shown in Fig. 13. The erratics had once been almost totally buried, leaving only the upper portion visible. The longest axes of all the erratics plunge towards the west. W.A. Johnston (1922, p. 387) points out that a rock resting on sand and affected by a current, is orientated with its longest axis parallel to the current and dipping upstream. The Koperfontein erratics were thus orientated by an eastward-flowing current. The presence of this paleocurrent is further indicated by the primary current lineation on the surface of the sandstone bed. The lineation sometimes curves around an erratic. The current apparently soon waned for the lower beds of the Dwyka Tillite Formation, wherever seen, do not appear to be clearly stratified.

The Witteberg-Dwyka contact on Koperfontein can be regarded as a paraconformity marked by a hiatus or short period of non-deposition which preceded the advent of the Dwyka Tillite. During this interval the Lake Mentz and Kommadagga Formations were deposited to the south. At Koperfontein there is no evidence of pre-Dwyka erosion of the upper beds of the Wittepoort Formation. Nor are there signs of direct deposition of the tillite under extremely

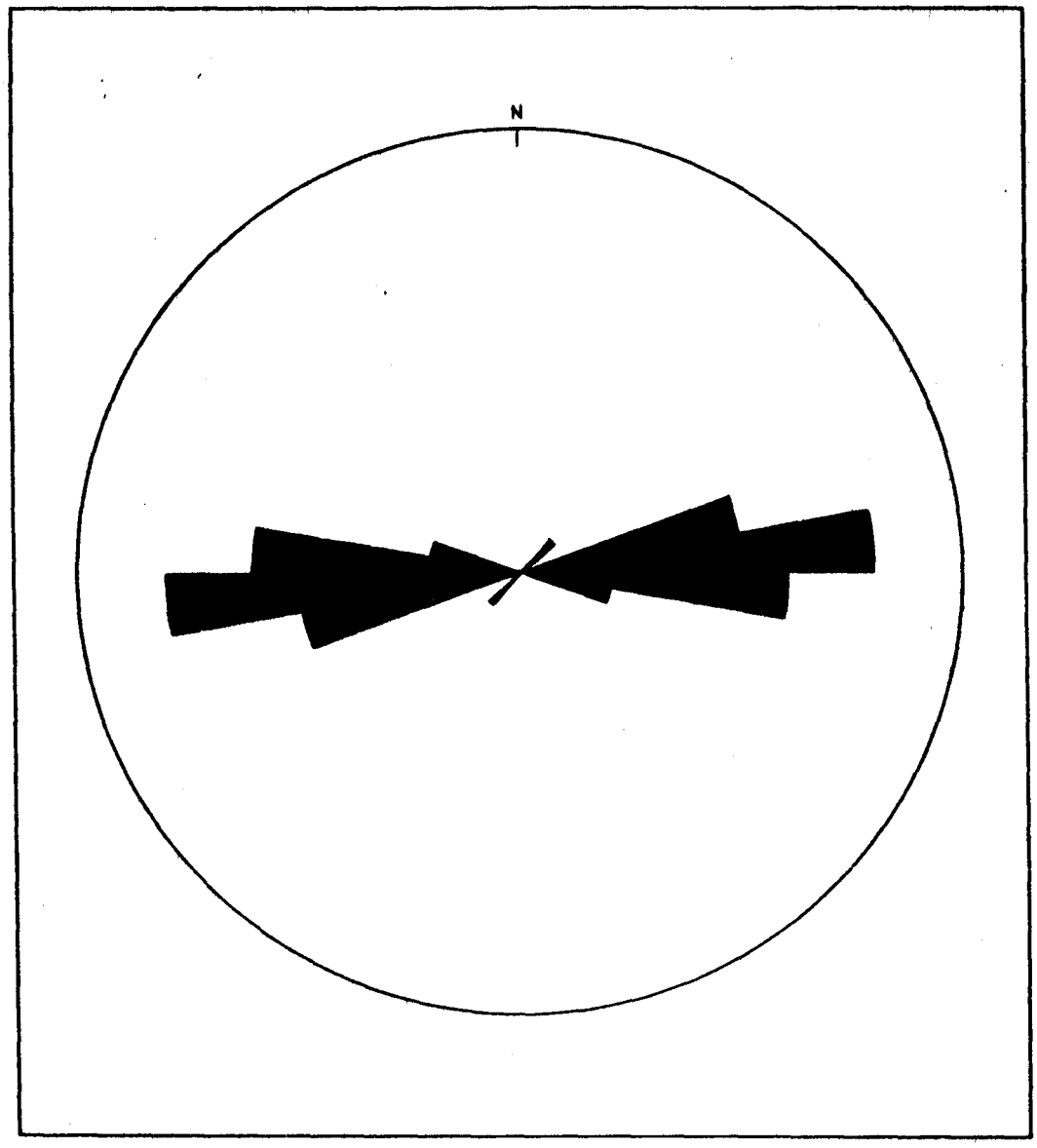

Fig. 13. Compass diagram showing the orientation of the longest axes of 22 inclusions in the Wittepoort Formation, Koperfontein, Western Karroo.

shallow aquatic or subaerial conditions. The presence of the big interference ripple-marks rules that out. The sandstones as well as the tillite show no signs of deformation by a grounded ice-berg or ice-shelf.

The Koperfontein erratics are further discussed and their significance commented on in Chapter VI.

B. FOSSILS

Faunal and floral remains are scarce in the Witteberg Group and almost entirely absent in the Dwyka Group. Hence the relevant literature contain very few descriptions of fossils. Then only vague reference to the place of occurrence is made and the exact stratigraphic position not given. Furthermore many fossils are fragmentary and incomplete, rendering positive identification impossible.

The floral remains found by the writer were submitted to Dr. Edna P. Plumstead of the University of the Witwatersrand, who was able to identify some in spite of their fragmentary condition.

The occurrence of fossils is given in Table 1 and sometimes also briefly mentioned in the text of Chapter III.

(1) Wittepoort Formation

The work of J.N. Theron (1962, Table 1) is valuable since he gives the true stratigraphic position of fossils. He records the presence of lycopods in the upper beds of the formation. He finds that the range zone for the Spirophyton extends from the upper beds of the Bokkeveld Group to the lower beds of the Wittepoort Formation. It is completely absent from the upper white-weathering sandstones ("White Streak") of the formation. Theron briefly treats the history of the controversy over the origin of Spirophyton impressions (p. 373).

In a recent publication E.P. Plumstead (1967, pp. 65-73) gives a brief history and summary of the controversy. She believes the Spirophyton to be of plant origin.

It is now also worthwhile to consider the views of A. Seilacher (1967). He favours an animal origin for Spirophyton-like impressions. His photograph (p. 79) of a fossil from the Tertiary Period resembles that

of a Spirophyton from the Cape Supergroup. He calls his fossil a burrow left by the worm Zoophycos when foraging through the sediment.

Faunal remains seem to be either scarce or absent in the Wittepoort Formation. In 1939 a chonetes was found in "Witteberg sandstones" near Robertson. (Personal communication, Professor M.S. Taljaard). The precise stratigraphic position is not known. The author suspects that it came from either the lower beds of the formation or the rocks from lower divisions of the Witteberg Group.

(2) Lake Mentz Formation

The occurrence of plants are given in Table 1. Only two specimens from the Conglomerate Lentil of Droëkloof could be identified. They appear to be the lycopods Protolepidodendron and Archaeosigillaria.

Small fragmental remains of fish were found in the Conglomerate Lentil of Droëkloof. The fish evidently had a widespread distribution for they are found from Laingsburg to Lake Mentz, a distance of 250 miles. All are from the rocks between the Floriskraal Sandstone Member and the Dwyka Tillite Formation. For a more detailed description the work of J.N. Theron (Ibid.) and J.A.H. Marais (1963) should be consulted.

Fragmental remains of bryozoans are to be seen in some black concretions from the Bergplaas Shale Member of Bergplaas. Another type is from the Conglomerate Lentil of Droëkloof. It resembles a specimen mentioned by I.W. Hälbich (1962, Plate 1, Photo H).

Three broken specimens which appear to be pelecypods are from the same Conglomerate Lentil. (Plate 2, Photo F).

(3) Kommadagga Formation

The broken and incomplete plant impressions closely resemble those from the Conglomerate Lentil of the Lake Mentz Formation of Droëkloof.

The numerous remains of fishes (Plate 2, Photo G) are unfortunately very fragmental and incomplete. When comparing the appearance of their scales, some fish closely resemble species "A" and "B" described by J.A.H. Marais (Op. cit., Plate IIIb and Plate IVc). Marais found his specimens in the Lake Mentz Formation from near Lake Mentz.

Bryozoans occur with the fishes.

Other fragmentary plants and worm tracks occur at Bergplaas.

(4) Dwyka Tillite Formation

No fossils have yet been discovered in the basal beds of this formation.

The occurrence of fossils are important since they reflect the environment and mode of deposition of the rocks studies. Certain fossils are referred to in Chapters VI and VII where their bearing on certain aspects of the stratigraphy is discussed.

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CHAPTER V

MICROSCOPIC INVESTIGATIONS

A. HEAVY MINERAL STUDIES

In this paper much attention is given to the description of the heavy minerals and their distribution in the rocks studied. The techniques of sampling, separation, counts, classification etc., are fully described in the Appendix.

(1) Description of Species.

(a) Tourmaline

When determining the nature of provenance beds, tourmaline is of more value than zircon because of a more widespread occurrence in different types of provenance rocks. P.D. Krynine (1946, p. 65) realized that the tourmaline group possesses "... a series of very sensitive morphological characteristics which reflect very closely both the ontogeny and phylogeny of each grain and thus can act as excellent guides to the origin and history of each tourmaline grain..."

He recognized five major types of provenance rocks (p. 68-77) and the different types of tourmaline grains which are characteristic of specific source areas.

Krynine's genetic scheme of classification is used in this paper. The nature of inclusions, colour, pleochroism and external form are taken as criteria. A random survey was conducted using one thousand tourmaline grains to obtain insight into the types of inclusions present. Slides were selected to represent different beds from widely-scattered localities. The combined results are presented in Table 6.

Type 1. Granitic tourmaline

Small prismatic crystals displaying $\{10\bar{1}0\}$ and $\{11\bar{2}0\}$, terminated by the trigonal pyramid $\{10\bar{1}1\}$ were studied. Unbroken crystals invariably have length-breadth ratios of 3:1 to 3:2. Most grains are well- to sub-rounded, but some

TABLE 6

RANDOM SURVEY OF TYPES OF INCLUSIONS IN 1000 TOURMALINES

Colour group of tourmaline	Brown			Green			Blue			Colourless		
Type of inclusions	Bubbles and/ or foreign crystals	Black spots	No inclu-sions	Bubbles	Black Spots	No Inclu-sions	Bubbles	Dusty Spots	No inclu-sions	Bubbles	Black Spots	No inclu-sions
Totals	127	158	212	85	97	195	9	32	66	1	16	2
Percentage distribution for each colour	25	32	43	22	26	52	8	30	62	5	84	11
Percentage distribution for all tourmalines	13	16	21	8	10	19	1	3	7	-	2	-

crystals are angular. Terminal flat surfaces of broken crystals, as well as cracks in some of the others, are sub-parallel to (0001). This basal parting is also mentioned by Krynine. (Ibid. p. 67). in some grains discontinuous zoning is revealed. Such zones are parallel to prismatic and pyramidal faces, differing in colour as well as intensity of pleochroism. Examples of continuous zoning are very rare. In other grains zoning is revealed by the presence of a crowding of bubble-like inclusions in the central part, the mantle being entirely free of inclusions.

Bubble-like inclusions seen in some crystals, are usually orientated at random. In a few cases they are elongated parallel to the c-axis. Small euhedral opaque and nono-paque foreign crystals are sometimes to be seen. In one isolated case two small inclusions believed to be zircon, are surrounded by pleochroic halos visible only when ϵ is perpendicular to the plane of polarization of the light. In two crystals many long transparent needles orientated parallel to the c-axis were seen. In a third the needles

are in the plane of $\{0001\}$.

Pleochroism:

ω	ϵ	ω	ϵ
dark brown	pale brown	dark green	pale green
dark brown	yellowish brown	dark green	pale purple
brown	pale yellow	dark green	pale brown
reddish brown	yellow		

Owing to strong absorption, $\omega > \epsilon$, the colour of some crystals can only be determined with difficulty.

Type 2. Pegmatitic tourmaline

The habit is very angular to sub-angular, with grains commonly exhibiting sharp, wedge-like edges. Such grains must have been derived from larger crystals.

Zoning is rare, being observed only as continuous zoning from dark green to dark blue, in a few specimens.

Inclusions when present, are dust-like, quite unlike the black spots of the Type 3 tourmaline. Bubble-like inclusions are less common. Krynine (Ibid., p. 68) states that the typical colour is blue with pleochroism in shades of mauve and lavender. Southern African pegmatites and pegmatitic segregations in igneous rocks carry a wide range of tourmaline types. The present author includes angular fragments of green tourmalines in the Type 2 group. This is done because zoning and a blue to green colour-range is frequently observed.

Pleochroism:

ω	ϵ	ω	ϵ
pale blue	colourless	pale green	colourless
dark blue	colourless	dark green	colourless
dark blue	pale blue	pale green	pale pink
dark blue	pale purple	dark green	pale pink

Type 3. Tourmaline from pegmatized-injected metamorphic terrains.

The habit and degree of rounding corresponds fairly closely to that of the Type 1 tourmaline, although acicular crystals

are more common. An extreme length-breadth ratio of 6:1 was found.

Zoning is seen in a few crystals as faint lines parallel to the faces of the prism and the pyramid. Discontinuous zoning in a few crystals is shown by a difference in colour and intensity of pleochroism of the various zones. In other grains zoning is revealed by a crowding of black inclusions along planes parallel to the prism and pyramid faces.

Inclusions, whenever present, are mostly black. In a few grains they occur together with dusty spots. In a few isolated cases bubbles are also present. Inclusions are sometimes confined to the core of a crystal, leaving the mantle entirely free. In other crystals the inclusions are scattered at random. In some crystals, generally the colourless and non-pleochroic types, the inclusion are so numerous as to render them almost opaque.

Pleochroism:

ω	ϵ	ω	ϵ
dark brown	pale brown	dark green	colourless
pale brown	colourless	dark green	pale purple
reddish brown	colourless	dark green	pale brown
reddish brown	yellow	colourless	colourless
brown	pale yellow		

Type 4. Sedimentary authigenic tourmaline

No tourmaline belonging to this type were recognized.

Type 5. Reworked tourmaline from older sediments

These well-rounded grains are characterized by a high degree of sphericity. Some grains have slightly pitted surfaces while others are perfectly smooth.

The Type 5 tourmalines are scant.

(b) Zircon.

Owing to a dearth of information on the distribution of various types of zircon in Southern African rocks, a genetic scheme of classification is not yet possible. G.M. Koen (1955) and L.A. Hardie (1958) used descriptive schemes with

success. In order to facilitate counts the present author adopted a simple scheme whereby only three easily recognizable types are counted. The scheme is, broadly speaking, also a genetic one, since the three types represent zircons from different primary sources.

Colourless zircon

This group includes many diverse types of zircon; all being colourless and unzoned. A full range of grain types are present, from the very rare perfectly euhedral crystals to well rounded and sometimes even spherical grains. The majority appear to be rounded to well-rounded elongated grains. Irregular flakes and fragments of once rounded grains are also present.

Euhedral crystals display $\{110\}$ and $\{111\}$. In rounded grains the faces of $\{111\}$ are absent. Occasionally $\{311\}$ is also present. $\{100\}$ and $\{331\}$ are very rare.

Crystals with very faint traces of zoning are grouped with the colourless zircon.

A wide variety of inclusions are present. Acicular, rounded or irregular types ranging from colourless to opaque, as well as dusty spots, may be arranged centrally, marginally, in zones or in an apparent haphazardly way.

A few cored grains were seen. In some cases the core only is zoned while the reverse is true in other examples.

Parallel growths of two crystals are rare.

Most zircons are characterized by smooth polished surfaces while some display minute pits.

Pink zircon

These rounded to well-rounded grains, with a high sphericity, are pleochroic in shades of pink to purple. Inclusions are not common.

Zoned and dusty zircons

A few varieties are included in this group.

Distinctly and sometimes delicately zoned crystals display discontinuous zoning either parallel to the faces $\{110\}$

and {111} or else as concentric ellipses. The latter grains are usually devoid of crystal faces.

The usual array of inclusions is present. Some crystals are rendered nearly opaque by the numerous dusty inclusions. Sometimes closely-spaced zoning has the same effect, in which case strong convergent light is necessary for determining colour and pleochroism. Some grains are pleochroic:

ω = shades of pink
ϵ = shades of light brown.

Other crystals are nearly opaque owing to numerous cracks and to a light brown colour. All zircons distinctly pleochroic in brown are also included in this group, whether they contain dusty inclusions and are zoned, or not.

Closely zoned and dusty grains appear to have shagreen surfaces.

(c) Rutile

For rapid counts and easy comparison with the results of previous investigators, rutile is divided into three groups according to colour. It is, however, sometimes difficult to classify certain grains such as the "brown" types. The opaque appearance of some strongly coloured grains, resulting from smooth exteriors and a high refractive index, necessitates the use of convergent light for determining the true colour.

Red rutile.

The grains are pleochroic in various shades of red and brown. Typical pleochroic formulae are:

ω	ϵ	ω	ϵ
foxy red	dark foxy red	dark red	reddish brown
brown	dark blood red	brownish red	pale brown
reddish brown	dark blood red	reddish brown	red
brownish red	blood red	brown	red

Many are rounded to well-rounded elongated grains with polished surfaces. Others are pitted. Irregular fragments and broken crystals are also common. A few crystals display {110} or a combination of {110} and {100}. Pyramidal faces are always absent.

A few dusty inclusions are to be seen in some grains.

Brown rutile

The grains are pleochroic in shades of brown:

ω	ϵ
Yellowish brown	yellowish brown
yellowish brown	brown
light brown	brown
light brown	reddish brown.

Many are irregular fragments, broken crystals and sub-rounded grains. $\{110\}$ and $\{100\}$ occur alone or in conbination. In one isolated example $\{111\}$ occurs in combination with $\{100\}$.

Dusty inclusions are scant.

Yellow rutile

Pleochroism and colour are less intense. Many are either non-pleochroic or else feebly so.

ω	ϵ
light yellow	light yellow
yellow	yellow
brownish yellow	brownish yellow
light yellow	yellow
light yellow	dark yellow
light yellow	light brownish yellow
yellow	brownish yellow
brownish yellow	brownish red

The majority appear to be sub-rounded to rounded grains, sometimes smooth or else with pitted surfaces. Angular fragments and broken crystals are also present.

Prism faces are often seen on crystals.

Twinning

A random survey was made to determine the distribution of the three types of twinning amongst the three colour groups. Polysynthetic twinning parallel to one or more faces of $\{011\}$ are frequent. Eight hundred grains were counted to

determine the percentage distribution.

Two types of contact twins were found:

(i) Geniculate twins on {011}.
(ii) Cordate twins on {031}.

Only 18 of these were found during exmination of dozens of slides containing a few thousand rutile grains.

Although the number of contact twins is admittedly very low, the information presented in Table 7 would nevertheless appear to be significant, corroborating the classification of rutile into three types.

TABLE 7

TWINNING IN RUTILE

Colour	Polysynthetic Twinning		Contact Twinning		
	Percentage distribution		Pleochroism	Number observed	
	Twinned	No twinning		Geniculate	Cordate
Red	23	77	-	-	-
Brown	58	42	ω = light brown ϵ = brown	2	-
			ω = light brown ϵ = reddish brown	1	-
			ω = yellowish brown ϵ = light brown	1	-
			ω = yellowish brown ϵ = brown	1	-
Yellow	41	59	Feebly pleochroic in yellow	3	5
			ω = yellow ϵ = yellowish brown	1	-
			ω = yellow ϵ = light brown	3	1

(d) Garnet

Garnet is an unimportant heavy mineral in rocks of the Witteberg Group. In the Dwyka Tillite Formation it suddenly assumes predominant proportions.

Colourless garnet

It is the only type found in rocks of the Witteberg Group. The grains are very angular to sub-rounded. Many are characterized by etched and pitted surfaces, a phenomenon that cannot be caused by abrasion. A few grains have smooth surfaces.

Small euhedral, acicular or tabular inclusions occur in some.

The garnets from the Dwyka Tillite Formation are larger, on the average. As garnet grains can sometimes be seen in hand specimens of tillite, it is conceivable that the crushing of the rock can lead to an increase in the garnet frequency. This seems to be proved by the presence of many very angular fragments with sharp edges. Secondary dodecahedral overgrowth was seen on a few grains. Study of abrasion along crystal edges indicates that this feature had developed before original transport.

Pink garnet

Garnets having colours in various shades of pink, are restricted to the Dwyka Group. Although very angular grains are common, better rounding is apparent than in the case of colourless garnets. Some grains have a high sphericity. Pitted as well as smooth grains occur. Euhedral, acicular and tabular inclusions may be present. Secondary dodecahedral overgrowth with the same signs of later abrasion was seen on a few specimens.

(e) Brookite

The distribution of this mineral is rather erratic, as is shown in Table 8. In order to recognize all the grains, it is advisable to view the same field under crossed nicols and ordinary lighting alternately.

Two types were observed:

Yellow, blue and green brookite

The grains are very angular to sub-rounded. Some display traces of abrasion at the edges.

Up to five different crystal forms may be seen on some grains.

The orientation of C. Palache et al. (1946, p. 588) corresponds with the crystal structure as determined by X-Ray crystallography. With an axial ratio of a:b:c = 0.5941 : 1 : 0.5611, the various forms are the following:

$\{001\}, \{010\}, \{120\}, \{403\}, \{201\}, \{101\}$.

Being tabular the vertically-striated $\{010\}$ of all the grains lies horizontal in the slides. Owing to this the pleochroism along the a- and c-axes were exclusively determined.

// a-axis	// c-axis
pale olive green	pale bluish green
very pale blue	pale blue
colourless to pale yellow	colourless to pale yellow

The colourless to pale yellow crystals may be feebly pleochroic. Larger grains are invariably multicoloured, being either yellow and blue, or yellow and green. In a few crystals the different colour zones are haphazardly distributed. A common type of zoning can be described as an hourglass of yellow extending across the crystal parallel to the a-axis. Different colours in zones always correspond with differences in birefringence. In one example numerous and thin faint zones in the green, parallel to (001), could be seen in light vibrating parallel to the a-axis.

Yellow brookite

Yellow brookite is more strongly coloured and of smaller average size than the previous type. Pleochroism, if present, is very feeble. The grains appear corroded and sometimes marginally altered to black material. Only the striated faces of $\{010\}$ are present.

(f) Monazite

Monazite is recognized by its colour and pleochroism, pitted surfaces and a birefringence and refractive index lower than

that of zircon. The grains are sub-angular to rounded with a low sphericity. A few grains are well-rounded and nearly spherical.

The colour and pleochroism depend on the orientation. Pleochroic colours vary from colourless to pale greenish yellow. Cleavage is seen in the more angular grains. Foreign crystals, dustlike and vermicular inclusions occur in some grains.

(g) Apatite

Apatite is a scarce heavy mineral in rocks of the Witteberg Group. It does however occur in important quantities in certain beds on Bergplaas.

Many crystals contain dusty spots and/or acicular inclusions, sometimes arranged zonally parallel to the c-axis. The apatite from the upper beds of the Bergplaas Shale Member of Bergplaas is in the form of angular to sub-rounded grains and basal flakes.

Small angular to sub-rounded flakes occur in the lower beds of the Dirkskraal Siltstone Member. The upper beds contain rounded to well-rounded spherical or elongated grains with slightly pitted surfaces.

(h) Anatase

The only anatase recognized were seven crystals in a slide of the heavy mineral crop of the Swartwaterspoort Sandstone Member of Bergplaas and one crystal from the Wittepoort Formation of Droëkloof. The crystals show light traces of abrasion on some edges. The crystal faces are horizontally striated.

With the axial ratio of a : c = 1 : 2.5133 as given by C. Palache et al. (Ibid., p. 583) the only form present was determined as $\{011\}$ by measurement of interfacial angles and use of a stereogram. Before the results of X-ray analyses became available, the axial ratio was given as a : c = 1 : 1.7771, in which case the form would be $\{111\}$.

Owing to the extreme refractive index and adamantine luster, the crystals appear nearly opaque. In convergent light the central zone differs from the rest:

central zone : ω = yellowish brown
ϵ = light yellowish brown
the rest ω = pale greenish yellow or pale blue
ϵ = very pale blue

(i) Opaque Minerals

Opaque grains are common in all slides. Reflected light was used to observe and identify them.

Ilmenite

Angular to rounded grains of various sizes appear in most slides. Their colour is bluish black. Broken grains show conchoidal fracture. Abraded surfaces are either smooth or slightly pitted.

Leucoxene

Large numbers of irregular grains appear in all slides. Their colour is a dull white but sometimes yellow or brown owing to staining by ferric oxides, and on the minutely pitted surfaces they resemble unglazed porcelain. Some quarts grains are partially covered by a thin film of leucoxene.

Magnetite

Small black octahedral crystals are sometimes seen.

Secondary Iron Minerals

Irregular aggregates and limonitic coatings abound in slides containing heavy minerals which were not treated extensively with hydrochloric acid.

Broken spherulitic grains with radiating translucent fibres sometimes occur.

(j) Ottrelite

This mineral has a limited distribution. It is recognized by its basal cleavage, flaky habit, colour and pleochroism. Some angular to sub-rounded grains show signs of abrasion along the edges. The pleochroism is pale olive green to pale bluish green.

(k) Muscovite

It occurs as irregular basal flakes in most slides. Some

flakes have jagged edges while others display rounding, owing to abrasion.

(l) Biotite

It occurs as irregular flakes in some slides.

(m) Chloritic Material

This occurs as irregular basal flakes with green to greenish blue colours.

(2) Application to Problems of Correlation

(a) Floriskraal - Droëkloof - Bergplaas

In order to ensure accuracy, separate counts were made of zircon, rutile and tourmaline, counting the types of each species. Two to three hundred grains of each species were counted. During the fourth count the relative frequencies of seven species were determined. The results are presented in Table 8. The frequencies are based on one hundred zircons. We could expect that sorting would lead to an erratic distribution of the relative frequencies of the three major constituents, owing to a difference in size, shape and specific gravity. The various types of a single heavy mineral species were therefore plotted on a ternary diagram. The trends of tourmaline, zircon and rutile are shown in Fig. 14.

Tourmaline

The correlation based on field evidence as explained in Chapter III and shown in Table 1 is now corroborated by the distribution of the tourmaline types as shown in Table 9. The ternary diagram, Fig. 14, also shows similar trends for all three localities.

The author strongly advocates the use of tourmaline as a reference mineral for future stratigraphic investigations.

Zircon

Zircon is of little value for correlating between the three localities. Table 8 and Fig. 14 does, however, show distinct trends for a specific locality. It is conceived that zircon may be useful when correlating over short distances.

TABLE 8

Quantitative heavy mineral content based on 100 zircons

FLORISKRAAL

ROCK UNITS		ZIRCON			RUTILE			TOURMALINE	GARNET		BROOKITE	MONAZITE	APATITE	OTHERS
		Colourless	Zoned	Pink	Red	Brown	Yellow		Colourless	Pink				
DWYKA TILLITE FORMATION		25	71	4	2	18	4	18	162	24	—	2	—	Epidote
KOMMADAGGA FORMATION		58	41	1	18	16	13	15	1	—	—	3	Tr.	
LAKE MENTZ FORMATION	Buffels River Shale Member	73	24	3	23	11	18	10	3	—	—	1	—	
		50	48	2	2	5	6	5	6	—	2	5	—	
	Floriskraal Sandstone Member 4 th Lentil	61	32	7	4	2	4	22	—	—	15	Tr.	Tr.	
	3 rd Lentil F.S.	64	31	5	4	6	8	11	1	—	1	10	—	
	Leeuwloofpoort Shale Member 2 nd Lentil F.S.	61	38	1	4	10	10	25	—	—	3	—	—	
	1 st Lentil F.S.	61	38	1	3	4	3	18	1	—	—	1	Tr.	Ottrelite
WITTEPOORT FORMATION		72	26	2	9	8	6	8	Tr.	—	2	2	Tr.	

DROËKLOOF

	ZIRCON			RUTILE			TOURMALINE	GARNET		BROOKITE	MONAZITE	APATITE	OTHERS
	Colourless	Zoned	Pink	Red	Brown	Yellow		Colourless	Pink				
Conglomerate Lentil	64	36	—	18	11	1	8	13	—	14	—	—	
Sootendalsvlei Shale Member													
Floriskraal Sandstone Member	47	51	2	4	8	13	16	Tr.	—	2	—	—	Anatase Ottrelite
Droëkloof Shale Member	67	31	2	33	24	15	6	233	13	—	—	—	
	51	48	1	13	8	13	10	—	—	—	11	—	

BERGPLAAS

	ZIRCON			RUTILE			TOURMALINE	GARNET		BROOKITE	MONAZITE	APATITE	OTHERS
	Colourless	Zoned	Pink	Red	Brown	Yellow		Colourless	Pink				
	46	54	—	—	—	—	7	808	54	—	—	Tr	Epidote
Dirkskraal Siltstone Member	74	21	5	—	—	—	3	2	—	—	—	25	
	41	52	7	—	—	—	28	41	—	—	—	22	
Swartwaterspoort Sandstone Member	70	24	6	10	7	7	19	Tr.	—	3	1	—	Anatase
	76	24	—	17	14	13	3	Tr.	—	—	—	17	
	72	28	—	9	8	19	8	1	—	—	—	—	
Bergplaas Shale Member 2 nd Lentil B.S.													
1 st Lentil													
	80	17	3	2	7	4	7	Tr	—	7	Tr.	—	
	87	10	3	21	17	11	13	Tr	—	—	—	—	Ottrelite

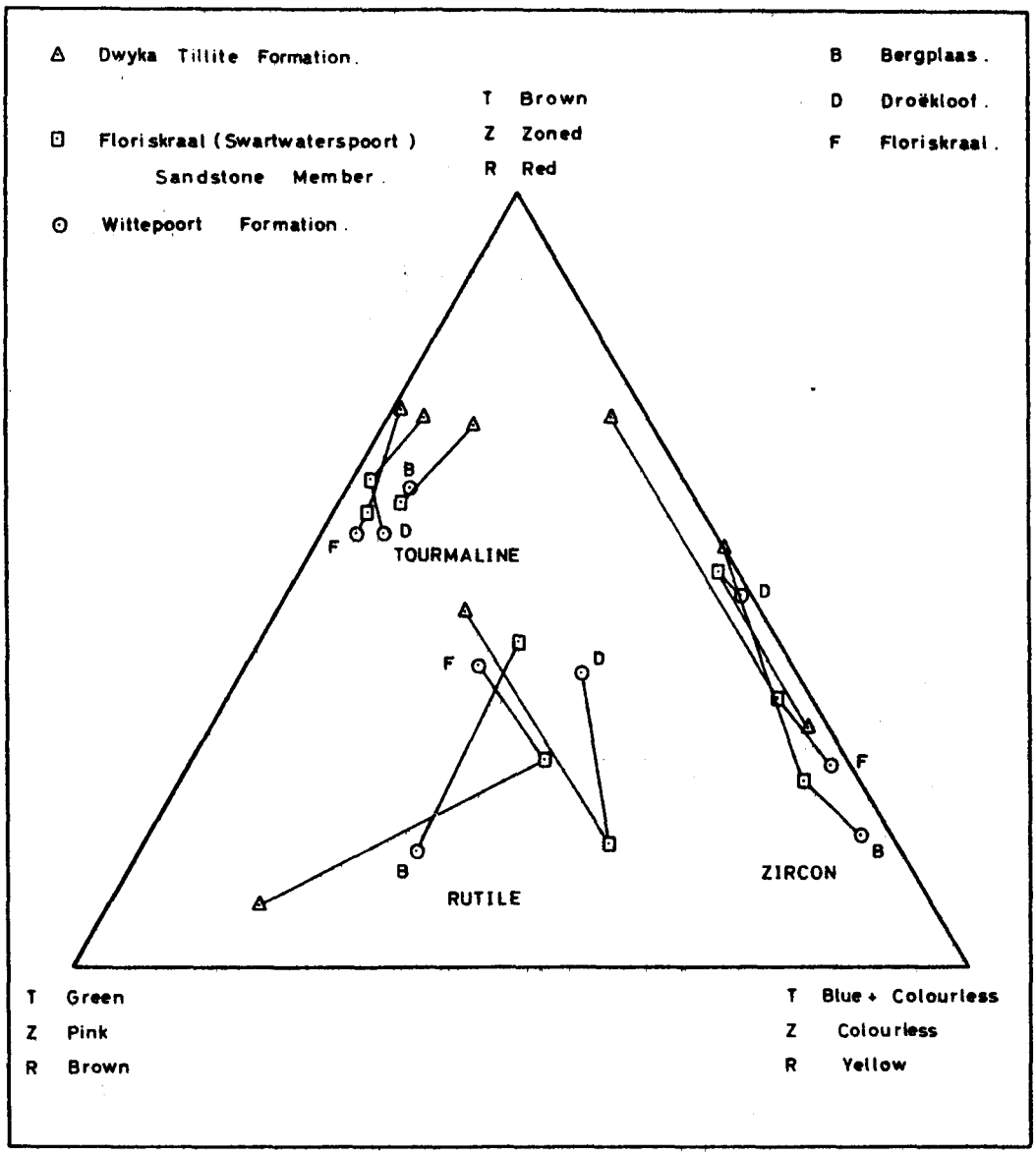


Fig. 14. Ternary diagram showing the distribution trends of the three most important heavy minerals.

T - Tourmaline, Z - Zircon, R - Rutile.

TABLE 9

Percentage subdivision of tourmaline content according to colour.

ROCK UNITS		FLORISKRAAL					DROËKLOOF					BERGPLAAS				
		Brown	Green	Blue	Colourless		Brown	Green	Blue	Colourless		Brown	Green	Blue	Colourless	
Dwyka Tillite Formation		72	27	1	—		71	25	2	2		70	20	5	5	
Kommadagga Formation		67	28	3	2						Dirkskraal Siltstone Member	59	32	7	2	
												58	39	3	—	
Lake Mentz Formation	Buffels River Shale Member	65	31	3	1	Conglomerate Lentil	67	24	7	2	Swartwaterspoort Sandstone Member	60	33	7	—	
		65	31	4	—	Soetendalsvlei Shale Member										
	Floriskraal Sandstone Member — 4 th Lentil	59	36	4	1							67	23	7	3	
	4 th Tongue											71	29	—	—	
	3 rd Lentil F.S.	58	38	4	—											
	3 rd Tongue					Floriskraal Sandstone Member	63	35	2	—	Bergplaas Shale Member — 2 nd Lentil					
	Leeukloofpoort Shale Member — 2 nd Lentil F.S.	60	35	5	—											
	2 nd Tongue															
	1 st Lentil F.S.	58	40	2	—	Droëkloof Shale Member					1 st Lentil					
	1 st Tongue															
Wittepoort Formation		56	40	3	1		56	37	7	—		62	31	7	—	
												72	23	4	1	

Rutile

Table 8 and Fig. 14 show no apparent trends. The absence of rutile in the lower bed of the Dwyka Tillite Formation of Bergplaas, should be seen as a very local phenomenon.

Rutile has very little correlative value. This is rather disappointing in view of the genetic classification employed.

Garnet

The paucity of garnet in rocks of the Witteberg Group is in strong contrast to those of the Dwyka Group. In Table 8 it is shown that this mineral is indicative of the Dwyka Group.

In Chapter III it is explained why the Kommadagga Formation is assigned to the Dwyka Group. The high garnet content of the former corroborates the field classification.

J.N. Theron (1962, Table 4, p. 367) shows a high garnet content for the Lake Mentz Formation ("Upper Witteberg Stage"). This apparent anomaly can be explained by the possibility that his compound sample may have accidentally included a few chips from beds which should actually be mapped as Kommadagga Formation. Theron mapped all beds between the top of the Wittepoort Formation and the base of the Dwyka Tillite Formation as "Upper Witteberg Stage" (i.e. the Lake Mentz Formation).

Other minerals

Brookite, monazite, apatite, epidote, ottrelite and anatase occur in small quantities and are unsuitable for correlation. They are, however, of other interest.

(b) Rocks of Special Interest

Koperfontein, Western Karroo

The origin of inclusions in the upper bed of the Wittepoort Formation is of much interest. The results of a heavy mineral investigation are presented in Table 10 and a ternary diagram. (Fig. 15). Two inclusions are compared with the upper bed of the Wittepoort Formation in which they occur. An analysis of a sample from the basal beds of the Nama Group of Roodewal, Vanrhynsdorp is also given. Rutile is not shown in Fig. 15 owing to the low number of grains found.

From the results it is clear that the two inclusions cannot be

TABLE 10

Quantitative heavy mineral content based on 100 zircons.

	ZIRCON			RUTILE			TOURMALINE	MONAZITE	GARNET	OTHERS	TOURMALINE as Percentages			
	Colourless	Zoned	Pink	Red	Brown	Yellow					Brown	Green	Blue	Colourless
Wittepoort Formation, Grahamstown.	80	19	1	8	5	14	8	1	—		66	25	9	—
Wittepoort Formation, Coombs Valley.	83	14	3	28	14	29	18	4	2		68	23	8	1
Sandstone Lentil, Coombs Valley.	81	12	7	26	11	24	16	1	1	Anatase	65	24	10	1
Wittepoort Formation, Koperfontein.	76	19	5	1	5	8	21	3	Traces	Anatase	48	45	7	—
Nama Supergroup, Roodewal, Vanrhynsdorp.	29	69	2	—	1	—	2	1	1		80	20	—	—
Inclusion No. 1	42	40	18	—	1	4	11	—	—	Octahedral Magnetite	56	43	1	—
Inclusion No. 2	22	24	54	—	5	—	—	—	2		—	—	—	—

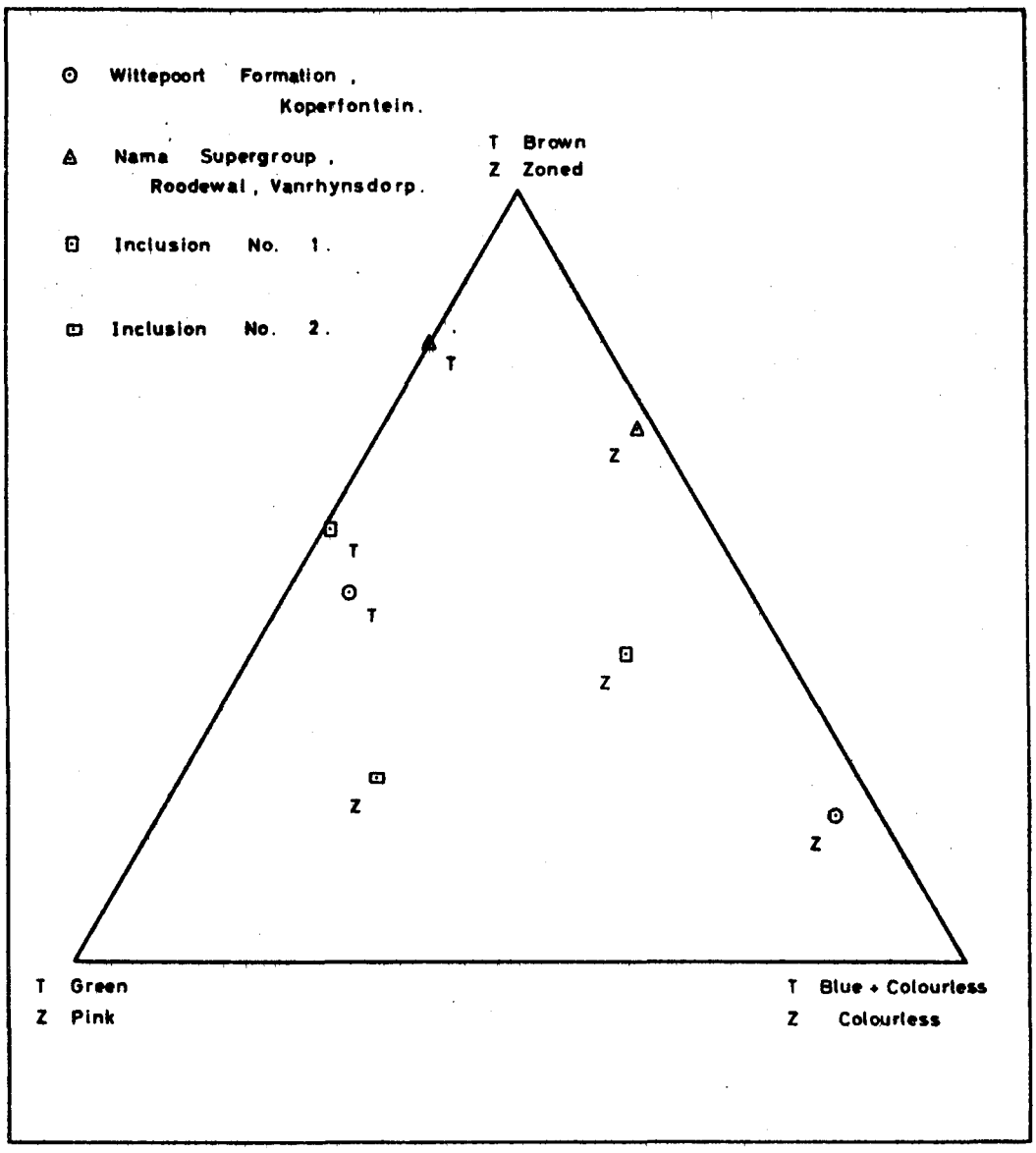


Fig. 15. Ternary diagram showing the distribution of the two most important heavy minerals .

T - Tourmaline , Z - Zircon .

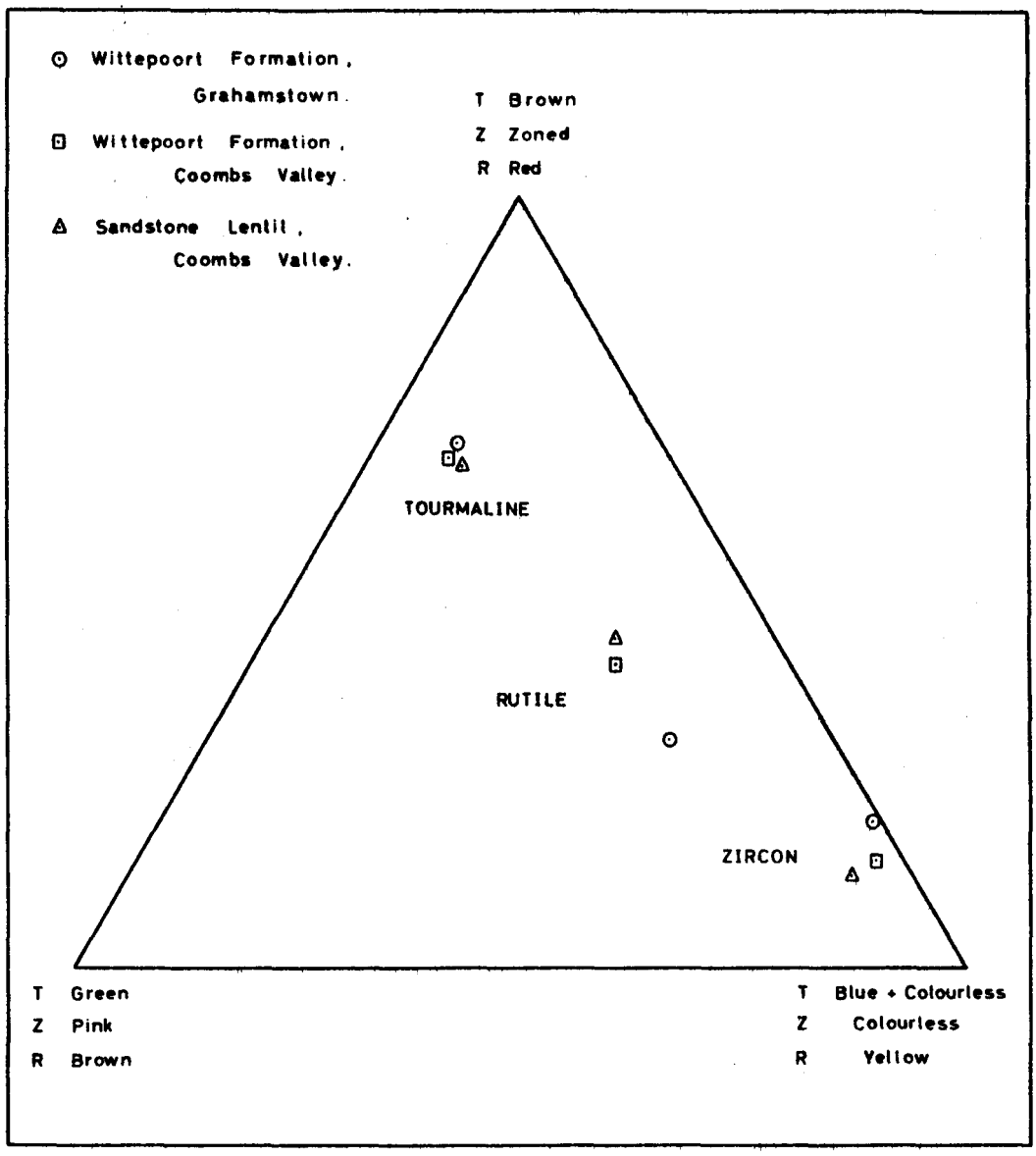


Fig. 16. Ternary diagram showing the distribution of the three most important heavy minerals.

T - Tourmaline, Z - Zircon, R - Rutile.

compared with the rocks of the Wittepoort Formation. In Chapter III it is mentioned that the inclusions resemble certain beds of the Nama Supergroup of Roodewal. The results of the heavy mineral analyses show that on this basis no correlation between the two inclusions and the sample from Roodewal is possible.

B. Swart (1950, Table III, p. 438) and J.N. Theron (1962, Table 4, p. 367) give analyses of beds from the Table Mountain and Bokkeveld groups. Their results show a high preponderance of colourless zircon over pink and zoned and of brown tourmaline over green and blue.

The Cape Supergroup as a possible provenance for the inclusions can also be ruled out.

Coombs Valley, Grahamstown.

A heavy mineral analysis of a sample from a sandstone lentil, Coombs Valley, is compared with the same from the upper beds of the Wittepoort Formation close by, as well as with a sample from Grahamstown. See Table 10 and Fig. 16.

It is clear that the sandstone lentil belongs to the Witteberg Group.

Robertson

In order to establish the stratigraphic position of the rocks underlying the Dwyka Tillite, a heavy mineral analysis of a sandstone as given in Table 11 may be of value. It is also compared with a sample from below the tillite of Genadendal. The analyses of Floriskraal (Tables 8 and 9), the area nearest to Robertson for which figures of the complete sequence is available, show that:

(i) The frequencies of the zircon types of Robertson as given in Table 11 do not fit into the Floriskraal sequence and more specifically, compare unfavourably with the figures for the Wittepoort Formation.

(ii) Rutile is scarce at Robertson in this way suggesting that the sandstones do not belong to the upper beds of the Wittepoort Formation. It should be noted, however, that rutile has a very erratic distribution as is evident from Table 8.

TABLE II

QUANTITATIVE HEAVY MINERAL CONTENT OF TWO SAMPLES FROM BELOW THE DWYKA TILLITE

Locality	Zircon			Rutile			Tourmaline	Monazite	Garnet	Brookite	Tourmaline as percentages			
	Colourless	Zoned	Pink	Red	Brown	Yellow					Brown	Green	Blue	Colourless
Robertson	58	42	-	-	3	3	36	2	2	4	45	49	5	1
Genadendal	54	46	-	-	1	3	20	3	-	-	53	38	8	1

(iii) The figures for the percentage distribution of tourmaline from Robertson do not correspond with the figures for the upper beds of the Wittepoort Formation. Table 9 shows that tourmaline is well suited for lateral correlation as well as for determining the stratigraphic position of an unknown sample. The figures for the Floriskraal sequence suggest that the Robertson sample occurs well below the upper contact of the Wittepoort Formation.

In Chapter III it is shown how paleontological evidence supports the above deduction.

Genadendal

An analysis of a sandstone underlying the Dwyka Tillite is compared with the same from Robertson. (Fig. 11). The same remarks and arguments pertaining to the Robertson sample as given above, also hold good for Genadendal. The stratigraphic position of the Genadendal sample is probably well below the upper beds of the Wittepoort Formation.

B. THIN SECTION STUDIES

The results of thin section studies are given below. It is not implied that one or more thin sections are representative of that bed or member or even of whole formations. Nevertheless the selected examples convey the general impression of the rocks under consideration.

(1) Minerals Present

(a) Quartz

The most abundant mineral appears as single grains of varying roundness and sphericity. In some sandstones the grains have mantles of secondary quartz in optical continuity. The original boundary of a grain then appears as a line of dust-like inclusions. Acicular crystals of foreign minerals appear in some grains. Many grains show varying degrees of undulatory extinction and a small optic axial angle. This is more apparent in the sandstones of folded regions. Some grains set in a more argillaceous matrix may also exhibit a small angle. The latter apparently acquired this property in the provenance area. Curved Boehm lamellae are to be seen in grains

from folded sandstones.

Chert grains are scarce.

(b) Feldspar

Feldspar grains are usually more angular than quartz. Plagioclase is represented by sodic varieties viz. albite - oligoclase - andesine. That this mineral is not very abundant is clear from Table 12.

Orthoclase and microcline are sometimes seen, often in a much weathered state.

(c) Heavy minerals

As accessory minerals, they are seldom seen in thin sections.

(d) Micaceous minerals

Big flakes of muscovite, sometimes twisted and bent may be present along the stratification planes. In addition to the allogenic micas, secondary sericite and other greenish to brown micaceous minerals constitute an important part of the matrix of some rocks.

(e) Calcite

Calcite is seen as small interstitial crystals in fine-grained calcareous rocks. It also appears interstitially in some unweathered samples of the Swartwaterspoort Sandstone Member. Calcite constitutes the matrix of the calcareous siltstone from the First Shale Tongue of the Leeukloofpoort Shale Member on Floriskraal.

(2) Descriptions of Certain Rocks

(a) Wittepoort Formation

The volume-percentage of matrix in white sandstone as determined by using a Leitz integrating stage, may vary from as little as 4 per cent in an orthoquartzite from Droëkloof to 20 per cent in a feldspatic sandstone from Floriskraal. Quartz grains of high to low sphericity display different degrees of average roundness, depending on the sample chosen. The majority of quartz grains in a lithic graywacke with 38

per cent matrix from Bergplaas, can be described as ranging from very angular to sub-rounded. In sandstones the grains are more rounded.

Most orthoquartzites show interstitial quartz as well as secondary growth around grains. In more argillaceous rocks the grains are usually unaffected. Acicular crystals, bubbles and dusty spots occur as inclusions in some grains. Chert grains are scarce. The matrix of the sandstones consists of smaller quartz grains, sericite and occasional limonitic stains.

(b) Lake Mentz Formation

The sandstones

These rocks closely resemble those from the upper division of the Wittepoort Formation. The main characteristics can be summarized as follow:

Quartz grains appear to be better rounded, being from angular to well rounded. The percentage and type of matrix depend on the sample and the locality. In the same way, the degree of recrystallisation and amount of secondary quartz vary. The rocks from the four lentils of the Floriskraal Sandstone Member of Floriskraal show these phenomena to such an extent that determinations of roundness and original size of the grains become very difficult.

The type of quartz remains the same, viz. clear grains and specimens containing the usual inclusions. Plagioclase grains are often seen. Microcline, sometimes almost unrecognizably weathered, is seen in some samples from the Floriskraal Sandstone Member of Droëkloof and Floriskraal.

The more argillaceous rocks

The siltstones are seen to be comprised of very angular to sub-angular quartz grains set in a brown to almost black matrix, which, in one sample from Bergplaas, constitutes 43 per cent of the rock. The maximum diameter of the well-sorted grains is usually below 0.06 mm. Mica flakes are common along the easily recognizable planes of stratification. Fresh plagioclase grains are occasionally to be seen.

All true shales show small quartz grains scattered through a dark micaceous matrix.

(c) Kommadagga Formation

The worm-tracked siltstone (Plate 2, Photo H) of the Dirkskraal Siltstone Member of Bergplaas shows very angular to sub-rounded quartz grains set in a brown micaceous matrix. The well-sorted quartz grains (Plate 1, Photo G) have an average diameter of 0.035 mm. Plagioclase grains are present.

The siltstones immediately underlying the Dwyka Tillite are much the same. The same type of grains are set in a matrix which may constitute as much as 52 per cent of the volume. Without actually doing any counting, it is clear that Plagioclase is more plentiful than in rocks of the Lake Mentz Formation.

The shales of the Dirkskraal Shale Member of Bergplaas have small angular quartz grains set in a dark matrix. Small black spots are sometimes present.

(d) Dwyka Tillite Formation

The Dwyka Tillite can be readily recognized in thin section. (Plate 1, Photo H). Very angular to well-rounded grains are set in a matrix which may vary from 40 to 70 per cent, according to the sample. The grains represent a wide variety of rocks and minerals. Fragments of sandstone, chert, gneiss etc. are common. Clear quartz grains as well as examples containing bubbles or solid inclusions occur together with various feldspar types viz. orthoclase, microcline, perthite and sodic plagioclases. The most common heavy minerals seen are zircon and garnet.

(e) Rocks of Specific Interest

Concretions from Bergplaas

Black concretions sometimes containing phosphate and bryozoans, are found in the Bergplaas Shale Member. Very small quartz grains and muscovite flakes, the latter along the distinct stratification planes, are set in a dark greenish micaceous matrix. Elongated opaque patches may be ferrous sulphide.

The Conglomerate Lentil of Droëkloof.

A thin section was made of a sample containing many imprints and casts of leaves and stems. Very angular to sub-angular quartz grains are set in a matrix of calcite and a little micaceous material. Nearly all the grains show corrosion by calcite. Of more interest are the brown and black remains of plants, appearing as streaks along the planes of stratification. Fibrous masses are also present.

A calcareous siltstone from Floriskraal

This rock is found in the upper division of the First Shale Tongue of the Leeukloofpoort Shale Member. Well-sorted very angular to sub-angular quartz grains together with muscovite flakes are set in a finely crystalline matrix of calcite. All the quartz grains show corrosion. Fibrous calcite occurs in narrow veins. Limonitic stains and a few opaque spots are also present in the matrix.

(3) Plagioclase Counts

Thin sections of certain samples were selected for plagioclase counts. It should be noted that a small percentage of grains were not counted, i.e. specimens lying with (010) in the plane of the thin section; in this way obscuring the albite twinning, thus rendering rapid recognition, when viewing the slide under crossed nicols, impossible.

From 300 to 800 grains of quartz and plagioclase per thin section were counted in a number of randomly-selected fields of view. The number of plagioclase grains per 100 of quartz was calculated. The results are presented in Table 12.

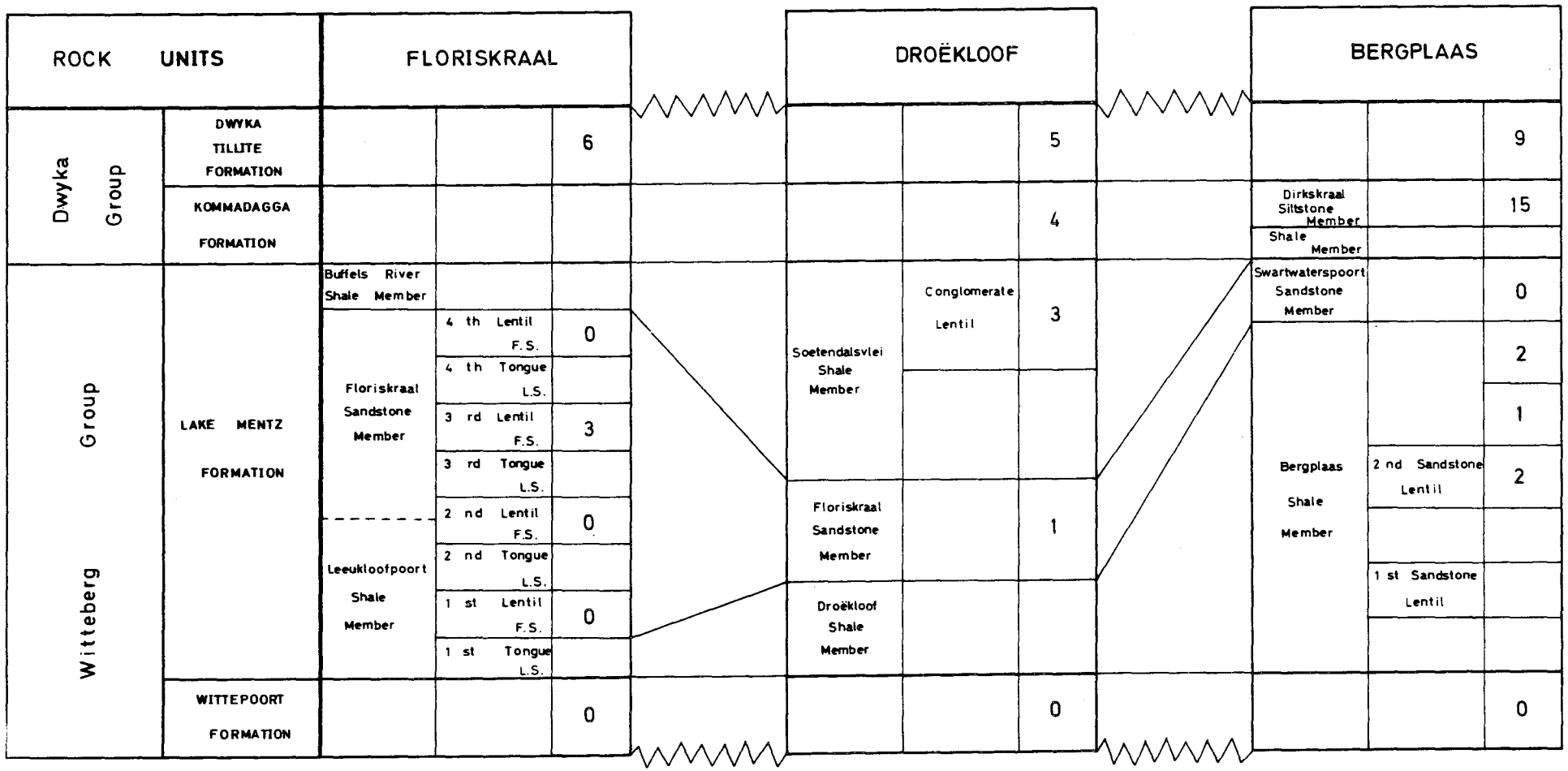
Two facts are clear from the table:

(i) The "clean" white sandstones are usually devoid of plagioclase.

(ii) The plagioclase content increases stratigraphically upwards. Spearman's rank correlation coefficient was calculated for the plagioclase sequences of Bergplaas and Droëkloof. A value of 0.775 for the former and 1.000 for the latter (i.e. high positive correlation in both cases) indicates a strong upward trend. The

TABLE 12

Quantitative plagioclase feldspar content based on 100 quartz grains.



coefficient for the Floriskraal sequence was not calculated as any value would be meaningless in view of the fact that although feldspar was not seen in thin sections of samples from three of the four lentils of the Floriskraal Sandstone Member, this mineral is indeed visible in the pebble-conglomerates.

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CHAPTER VI

THE SEDIMENTATIONAL HISTORY OF THE CAPE - KARROO CONTACT ROCKS

The history of sediments is a continuous drama which should not be subdivided into three separate acts, viz. origin, transportation and accumulation. It is, however, convenient to do so for descriptive purposes.

A. THE PROVENANCE ROCKS

(1) Direct Determination Using Inclusions or Erratics

In Chapter III reference is made to the presence of various inclusions and erratics found. Their distribution is now given in Table 13. The nature of the provenance rocks from which they had been derived, can therefore be determined at a glance. The inclusions found in rocks of the Witteberg Group cannot yet be possitively linked with any possible provenance rocks. On the other hand, many of the erratics found in the Dwyka Tillite Formation can easily be compared with outcrops of older rocks in the areas north of the present-day occurrences of the tillite. This is shown by A.L. du Toit. (1921, p. 189).

(2) Inferred Determination Using Specific Minerals

(a) Quartz

This mineral is described in Chapter V in the relevant section dealing with thin section studies. Quartz can be genetically classified on the basis of inclusions (W. Mackie, 1897 as quoted by A.W. Grabau, 1924, p. 716), undulose extinction and Boehm lamellae; features which all indicate the nature of the provenance rocks.

The quartz as found would then be derived from granitic rocks, quartz-bearing metamorphic rocks, metaquartzites and other older sandstones.

(b) Feldspar

Grains of K-feldspar and sodic plagioclase are found in certain rocks. (Tables 12 and 13). The K-feldspars are derived from acid igneous rocks and gneisses whilst the

TABLE 13

ROCKS AND MINERALS FOUND AS INCLUSIONS OR ERRATICS
(MACROSCOPIC SAMPLES)

ROCK UNIT	IGNEOUS	SEDIMENTARY	METAMORPHIC
Dwyka Tillite Formation	granite granite pegmatite quartz porphyry andesite (Ventersdorp) dolerite quartz K-feldspar Na-feldspar	conglomerate orthoquartzite shale limestone banded ironstone jasper chert	dolomite metaquartzite schist gneiss breccia vein quartz
Kommadagga Formation	-	-	-
Lake Mentz Formation.	granite quartz K-feldspar Na-feldspar Fe-tourmaline	orthoquartzite shale limestone chert	metaquartzite phyllite gneiss vein quartz
Wittepoort Formation	quartz	jasper chert	vein quartz

sodic plagioclases have acid to intermediate igneous rocks as well as certain metamorphic types as provenance rocks. Basic igneous rocks should not be excluded. The absence of calcic plagioclase is probably due to their low resistance to weathering. The pebbles of feldspar seen in the Floriskraal Sandstone Member of Droëkloof and Floriskraal indicate porphyritic granites or pegmatites as source rocks.

(c) Heavy minerals

The distribution of heavy minerals among various possible types of provenance rocks is presented in Table 14. With the exception of apatite, ottrelite and biotite all are stable enough to survive more than one cycle of erosion and hence could also be derived from older sedimentary rocks. Certain heavy minerals such as tourmaline, zircon and rutile can be classified according to a genetic scheme. It is

TABLE 14

POSSIBLE PROVENANCE ROCKS OF CERTAIN HEAVY MINERALS

HEAVY MINERALS	IGNEOUS					METAMORPHIC			
	Acid	Alkaline	Intermediate	Basic	Pegmatites and veins	Hornfelsic, Slaty and phyllitic	Schistose	Gneissose	Granular
Tourmaline	X				X		X	X	
Zircon	X	X	X						
Rutile	X	X	X	X	X		X	X	X
Garnet	X						X	X	X
Brookite	X				X			X	X
Monazite	X							X	
Apatite	X	X	X	X			X	X	
Anatase	X		X	X	X				
Ilmenite			X	X					
Ottrelite						X	X		
Muscovite	X				X		X	X	
Biotite	X		X	X			X	X	X

therefore even more unfortunate that very little is known of the heavy mineral content of possible provenance rocks of the Witteberg Group.

When considering the inclusions, erratics and heavy minerals present, it becomes clear that many rock types were present in the provenance area, with granitic rocks being dominant.

(3) The Provenance Area

Further on in this chapter a northerly provenance is advocated for the Witteberg Group. For the Dwyka Group the same provenance area is apparent. The frequencies of tourmaline and zircon types show constant trends from the upper Wittepoort right up to the Dwyka Tillite Formation. This is interpreted not as a gradual change in provenance area but as a constantly changing provenance type as weathering and erosion uncovered deeper rocks. The marked garnet content of the rocks of the Dwyka Group is not an indication of a

sudden and total switch in provenance area, but as a natural consequence of the nature of the rocks themselves. The rocks of the Witteberg Group are monomictic sediments having resulted from prolonged periods of erosion and transport before final deposition. In contrast the rocks of the Dwyka Group and more specifically the tillites, are polymictic sediments constituted of unstable rock particles and minerals. In view of the low relative stability of garnet (F.J. Pettijohn, 1957, pp. 504-506) its presence in the Dwyka Group is therefore not altogether unexpected and unnatural.

B. THE DISTANCE OF TRANSPORTATION

In the past various attempts have been made to give quantitative values, for the distance of transportation. The calculations are based on the size and degree of roundness of sedimentary particles. Ph. H. Kuenen (1959, pp. 14-21) criticizes these calculations and points out that too many non-determinable factors, including the little-known affect of chemical attack, are present.

The roundness of grains is described in Chapter V. The quartz grains of the Witteberg Group are not too well rounded. The grains of the Dwyka Group show the full range of roundness. This is to be expected of glacial sediments. The only thing which can be safely stated is that a few heavy minerals can be described as first cycle sediments viz. certain zircons, tourmalines, brookites and possibly also anatase.

The study of pebble-size should be more rewarding. American and European writers have published the results of studies of the decrease in pebble-size as seen in river and flood-plain deposits. In South Africa I.C. Rust (1962) successfully applied roundness and size of boulders and pebbles to determine the mode and distance of transport of certain sediments of the Stormberg Group. When considering the marine environment of deposition and all the variable factors involved, no estimate of the distance of transport of pebbles found in the Wittepoort and Lake Mentz formations, will be made at present.

C. THE ENVIRONMENT OF DEPOSITION

(1) A Brief Review of the Sedimentational History of the Cape Supergroup.

A brief description of the sequence of events which led up to the time of deposition of the Wittepoort Formation is necessary in order to

understand and appreciate the later sedimentational history outlined in this chapter. The various writers on the subject are listed in Chapter I. Their work should also be consulted.

The sediments of the Table Mountain Group with their dominantly northerly provenance, were deposited under shallow marine and sometimes subaerial conditions. Slow sinking and contemporaneous sedimentation took place. The northern limit of sedimentation was probably not far from present-day outcrops and suboutcrops of the group.

The sediments of the Bokkeveld Group were deposited in a deeper neritic environment. Milder conditions led to the prolific development of Devonian marine fauna. This is in strong contrast to the almost barren rocks of the Table Mountain Group. The shoreline was to the north. Numerous fossils are to be found in the northern outcrop area. In contrast the more argillaceous rocks south of the fold ranges are almost devoid of any fossils. For the latter rocks a deeper environment is apparent. The number of fossils decreases towards the top of the group.

The more arenaceous sediments of the Witteberg Group were deposited in roughly the same depositional area as those of the Table Mountain and Bokkeveld Groups. As in the case of the Bokkeveld Group, the rocks to the south of the fold ranges are more argillaceous. The marine environment probably became shallower than before. The development of fauna was restricted. Only the Spirophyton (Zoophycos?), known also from the upper beds of the Bokkeveld Group, becomes abundant, especially in the lower divisions of the group. This fossil decreases and completely disappears when the Wittepoort Formation is reached. Towards the top of this formation the rock becomes more arenaceous.

Finally attention should be drawn to the fact that each group displays remarkably little variation in lithology and primary structures over the east-west outcrop area of 500 miles. The environment of deposition for each single formation of a group was very much the same over thousands of square miles.

(2) The Environment of Deposition of the Cape - Karroo Contact Beds

(a) The Wittepoort Formation

The lithology and primary structures reveal the mode and environment of deposition of the sediments. The rocks are generally well-sorted clean sandstones with occasional grits and pebble-conglomerates and subordinate siltstones.

Towards the upper division of the formation the rocks are more arenaceous. Unstable minerals such as feldspars are conspicuously absent or else very scarce. Likewise the assemblage of heavy minerals is a stable one. When examining the rocks from east to west, the most remarkable feature is the constancy in lithology over many miles. Ordinary, as well as cross-stratification is the most common primary structure. Some well stratified beds were originally deposited over many square miles, sometimes retaining the same thickness over long distances. It is thought that a single bed was deposited in a relatively short space of time. Likewise a cross-stratified bed showing foresets inclined in the same general direction, is the result of fairly rapid deposition. This type of cross-stratification had its origin through a subaqueous deltaic sheet of sand advancing through the addition of foresets. The continuity in direction of the foresets over long distances can be seen in the field. Field observations and subsequent presentation of measurements by means of compass diagrams (Fig. 10) indicate an essentially monomodal distribution for the paleocurrents. However, in certain beds the direction may be diametrically opposed to those of beds a few feet lower in the succession. It is interesting to note that for the four localities represented in Fig. 10, viz. Bergplaas, Droëkloof, Floriskraal and Koperfontein, the paleocurrents are shown to be either to the east or to the west. In the vicinity of Grahamstown the directions are towards the northwest (E.D. Mountain, 1964, p. 203). In Chapter IV it is stated that the present study of cross-stratification should be regarded as a reconnaisance study in view of the few localities spread out along the line of outcrop. Too many major deductions should not be attempted at this stage. The east-west lineation of the currents would nevertheless seem to indicate that these paleocurrents may have well been parallel to an east-west shoreline (Fig. 17). It should be borne in mind that the directions as shown in Fig. 10 indicate only the final phase of transport before permanent deposition. These directions do not indicate the direction in which the area of provenance lay.

Conditions of laminar flow of water also prevailed. This is shown by the sandstones having parallel laminae. Another indication of sheet flow is the primary current lineation such as occurs at Floriskraal.

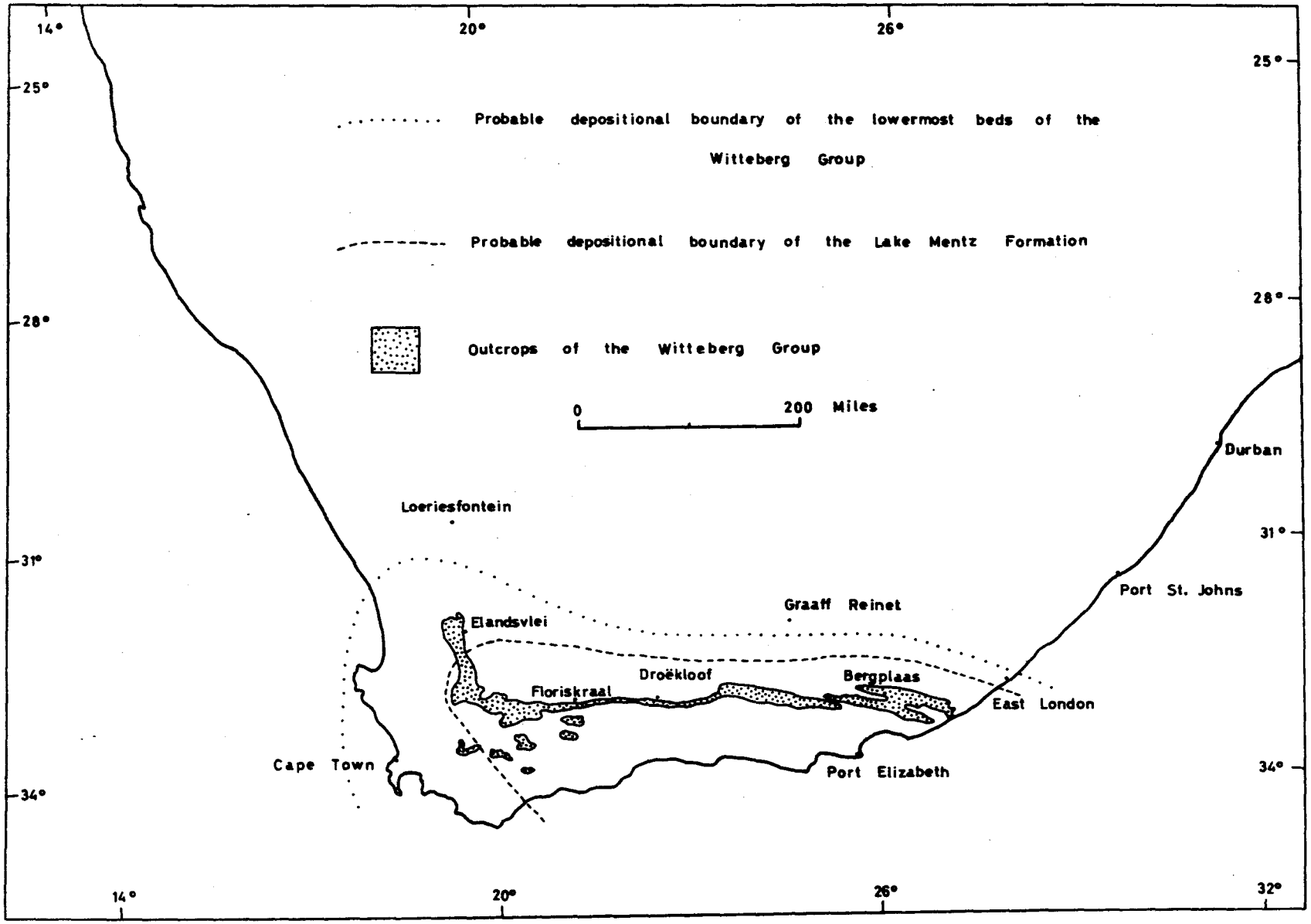

Fig. 17. Stratigraphic map showing the distribution of the Lake Mentz Formation

Deposition did not take place continuously. The contacts between beds represent periods of temporary non-deposition. It is impossible to estimate the relative amount of time lost. However, by taking into account the long span of time during which a succession of beds were laid down and the fact that individual beds had been deposited rather rapidly, it is safe to state that more geological time is represented by the contact between beds than by the beds themselves.

In the shallow marine environment periods of non-deposition sometimes favoured the formation of big interference ripple-marks such as are to be seen at Bergplaas, Floriskraal and Koperfontein. Their occurrence at localities miles apart serve to accentuate further the phenomenon of the uniformity of the environment of deposition which prevailed over a large area.

Deformed cross-stratification, apparently confined to one zone, is present from Grahamstown to Koperfontein. This primary structure is fully described in Chapter IV. Its importance is further discussed in Chapter VII.

For the area of deposition of the Wittepoort Formation the following is postulated: a broad stable shelf bordering on a cratonic area.

The above will now be described in both a geographic and a tectonic sense.

The cratonic area i.e. the geographic area to the north of the present day outcrops and suboutcrops of the Witteberg Group, was subjected to a cycle of peneplanation which had already begun before the time of deposition of the Table Mountain Group. Presumably this cratonic area also extended towards the northwest and west. The existence of this presumed western craton is advocated further on in this chapter. The pre-Karroo topography west of longitude 26°E shows that the provenance area immediately adjacent to the area of deposition had very little relief. Tectonically the cratonic area was stable with slow but continuous uplift. No rapid orogeny is reflected in the petrography of the sediments.

A geological map of Southern Africa shows the nature of the

northern provenance area. A host of rock types are present with the granitic rocks of the Basement Complex being dominant. The nature of the provenance rocks as deduced previously by using the inclusions, quartz, feldspar and heavy minerals as evidence, is in agreement with the above observation. Slow peneplanation explains the thorough mixing of the sedimentary material as well as the resulting absence of unstable minerals such as feldspar and certain heavy minerals.

In the neritic environment of deposition the sediments were subjected to sorting processes by wave and current action prior to final deposition. The east-west paleocurrents are longshore currents aligned parallel to the east-west shoreline. Owing to the appreciable distance from the shoreline, a generally southward trend for the paleocurrents is not expected.

Primary structures show that the environment of deposition was remarkably uniform over many thousands of square miles. With so much transportation and mixing of sedimentary material from different geographic regions of the provenance area, we would expect to find:

(i) A stable assemblage of heavy minerals over the whole area;

(ii) Very little variation in the heavy mineral suites for the various localities; and

(iii) Very little variation in lithology for the rocks.

This is indeed found to be so.

The present outcrop and suboutcrop area of the Witteberg Group can be regarded as only a portion of the former area of deposition. This leads us to the problem of the missing argillaceous sediments which were surely produced together with the more arenaceous types which we see today. The argillaceous facies of the group should therefore be towards the south i.e. south of the fold ranges and even beyond the present southern coastline. The depositional area of the group used to extend far to the south; the exact limit of which is unknown. The process of sedimentary by-passing was in force whereby the finer sediments were transported beyond the limits of the sand and deposited in presumably

deeper water. This calls for a marine environment of considerable areal extent. In it would be present currents, evidence of which is seen in the field today.

(b) The Lake Mentz Formation

The sedimentational history of the Wittepoort Formation ended very abrubtly. Dark shales of the lowest division of the Lake Mentz Formation overlie the white sandstones over the greatest part of the area. We therefore find a rapid transition from the high-energy sedimentation type to one indicative of a quiet environment.

Black shales are usually attributed to a restricted marine basin in which active currents were absent. It is clear that the shales were deposited under quiet conditions by gentle currents and the slow settling of fine material. Poor circulation of the water and generally anaerobic conditions were the rule. This is indicated by the presence of ferrous sulphide and occasional phosphates in the shales. The quiet and anaerobic conditions were in force over a considerable length of time as is shown by the considerable thickness of black shales found everywhere except in the western areas.

Gradually stronger currents became active, resulting in a progressive increase in grain size of the sediments. Thin silt- and sandstones were now deposited together with shales. Ripple-marking becomes more common, in this way indicating minor pauses in sedimentation. As in the case of ripple-marks higher in the formation, many show that at times slow settling of material onto the bottom took place simultaneously with the process of ripple-marking.

White sandstone lentils or members occur at nearly all localities. Three are present at Bergplaas, one at Droëkloof, four at Floriskraal and one in the Western Karroo. In the Grahamstown area none may be present in certain outcrops while thick lentils occur elsewhere as at the Coombs Valley. Regional mapping should reveal the exact correlation. Here, their very presence is of more importance. The sandstones are the result of more rapid deposition of coarser material. This is in strong contrast to the underlying rocks. The mode of deposition is the same as previous described for the upper beds of the Wittepoort Formation i.e. deposition

of well-sorted sand by swifter currents. Cross-stratification becomes the rule. Grits and pebble-conglomerates occur once again. These pebbles are evident of the strong currents which deposited the four lentils of the Floriskraal Sandstone Member of Floriskraal. These sometimes torrential conditions even led to the formation of contemporaneous erosion channels such as at Droëkloof. Temporary cessations of deposition, marked by the formation of big interference ripple-marks, took place at times.

The directions of paleocurrents are once again remarkable in that the same east-west trend is present. Both the mono- and bimodal distributions are to be expected. The compass diagrams for the four successive sandstone lentils of the Floriskraal Sandstone Member of Floriskraal show that a reversal of the paleocurrent is sometimes present from one lentil to another. The similarity in lithology of the rocks of the member as seen in various areas, is described in Chapter III. The results of the heavy mineral analyses and especially the distribution of the colour types of tourmaline, likewise prove that mixing of sedimentary material prior to final deposition was the rule.

To the west of Bergplaas the rocks overlying the Floriskraal Sandstone Member usually resemble those from below the member. They consist of silt- and sandstone with a few shales. Apart from a few thin sandstones, the rocks are not well sorted. The finer texture of the rocks as well as the well-developed ripple-marking indicate deposition by gentle currents interspaced with periods of non-deposition. The similarity between ripple-marks from localities far apart indicate the similarity in environmental conditions. The ripple-marks are of the types found in a neritic environment.

The present author found no evidence of any period during which the sediments were exposed to the air. J.N. Theron (1962, p. 375), however, records mud-cracks, in this way indicating at least one short period of subaerial conditions.

The environmental conditions seem favourable for the development of marine life. It is then rather disappointing that so few floral and faunal remains are found. The occurrence of fish intermittently over a distance of 250 miles from Lake Mentz to Laingsburg, is described in Chapters III and IV.

The fossiliferous rocks i.e. concretions or calcareous lenses, mark the sudden death of large numbers of fishes under conditions which extended over a large area. J.N. Theron (Ibid., p. 377) attributes the cause of their death to anaerobic conditions or a sudden change in temperature or salinity. J.A.H. Marais (1963, p. 198) thinks that it was due to the decrease in temperature prior to the Dwyka glaciation. Whatever the cause of their death, their preservation as fossils is evidently connected with the generally quiet and sometimes anaerobic conditions of sedimentation.

Seen as a whole, the Lake Mentz Formation differs markedly from the Wittepoort. It consists of sandstones, occasional thin pebble-conglomerates, micaceous siltstones and shales, black shales, black concretions and calcareous concretions. Feldspar is common in some beds. Ordinary, as well as cross-stratification, and ripple-marks are the main primary structures. The above fits the description given by W.C. Krumbein and L.L. Sloss (1963, pp. 425-426 and pp. 505-507) for sediments typical of an environment ranging from an unstable shelf to an interior basin. Such a stratigraphic model explains the lithology as described as well as the cyclic occurrence of certain rock-types as for example the sandstones. The greater rate of subsidence explains the badly sorted sediments as well as the generally more angular appearance of the quartz grains. The better rounding seen in the sandstones is, however, a contrast. We would expect that an unstable area would be subjected to a differential rate of subsidence, in this way leading to much variation in thickness of the formation. This is indeed seen to be so.

It is now necessary to comment upon the presence of feldspar in certain rocks, as mentioned in Chapter III and shown in Table 12. A steady increase in feldspar content is apparent. More feldspar would be expected in the generally unsorted sediments typical of an unstable shelf or interior basin subjected to rapid deposition. Feldspar is stable under conditions of extreme cold. It is also found in a sediment whenever rapid mechanical weathering exceeds chemical decay, irrespective of climate. It is here only fair to state that, with all things being equal, the gradual lowering of temperature

prior to the Dwyka glaciation would also cause an increase in feldspar content.

Summary

Towards the end of the Witteberg Epoch there existed an unstable depositional area with a shallow marine environment. The limits of the depositional area is a matter of deduction, interpolation and speculation. (Fig. 17).

The Witteberg sea was soon to receive sediments of a different nature.

(c) The Kommadagga Formation

The Cape Period was brought to a close by the climatic changes associated with the Dwyka Glaciation. This glaciation effected vast changes in the nature of the sedimentary material produced. It is therefore necessary to give a short description of the distribution and nature of the Dwyka ice-sheets.

At the onset of the Karroo Period falling temperatures led to the formation of ice-caps on highland areas. (Fig. 18). A.L. du Toit (1954, p. 277) visializes four highlands from whence the ice radiated. From the work of H. Martin (1961) it is evident that a fifth highland was in existence in northern South West Africa. It can be called the Ovambo Land ice-centre. (Not shown in Fig. 18). The existence of a sixth highland, the Atlantic ice-centre, is now postulated. Supporting evidence for this view is given below:

(i) B. Swart (1950, pp. 463-475) deduces that a westerly provenance existed, amongst others, for the rocks of the Cape Supergroup.

(ii) H. Martin, who studied continental drift, shows that the direction of ice movement in the Paraná Basin of South America is from the east. (Op. Cit., pp. 18-30). Martin favours the existence of a highland which once lay between the present South American and Southern African coasts.

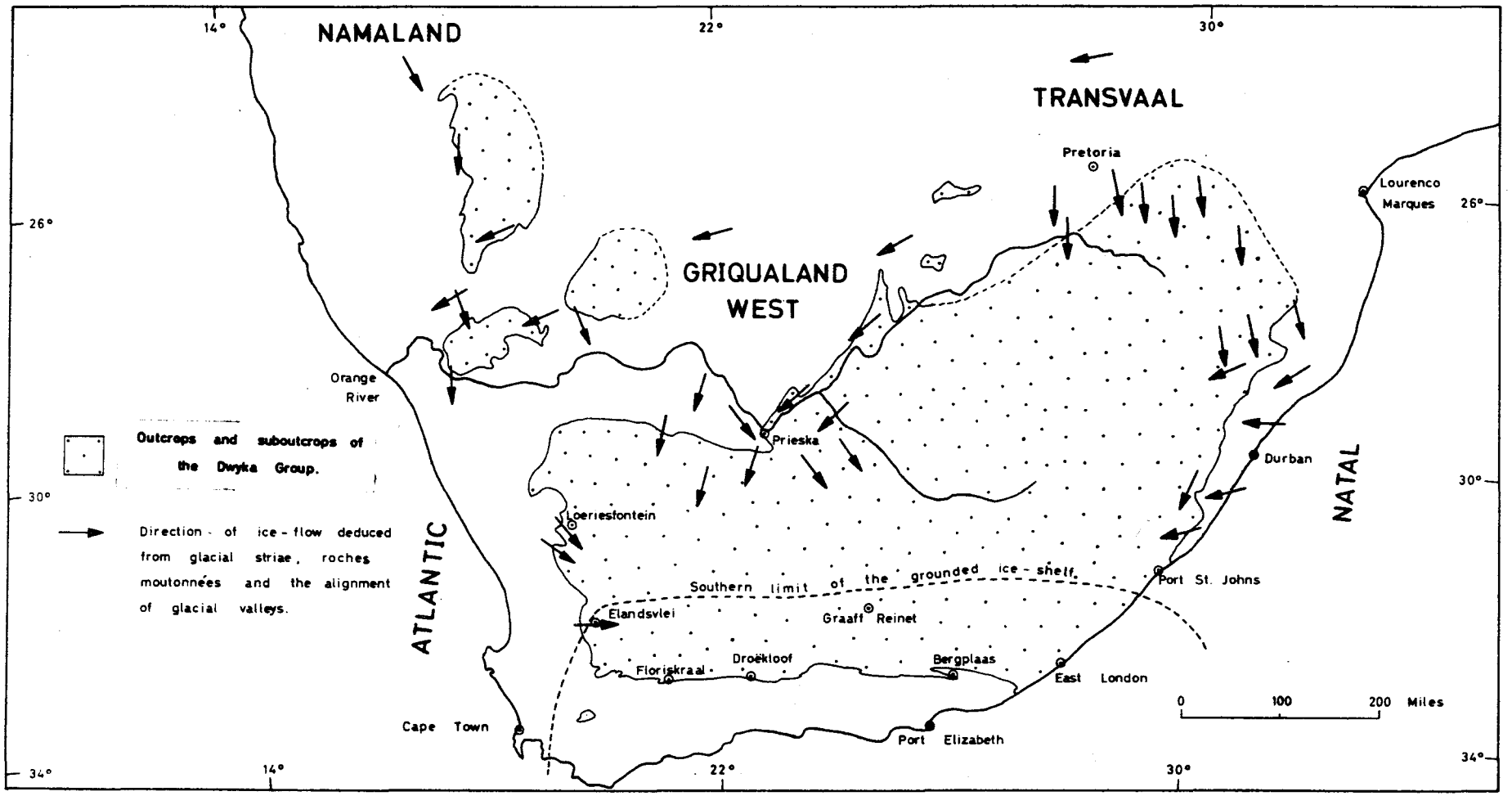

Fig. 18. Map showing the inferred radiation of the Dwyka Ice-sheets from various ice-centres.

Compiled in part from Alex. L. du Toit (1954), J.W. von Backström (1960) and H. Martin (1961).

(iii) In Chapter III it is shown how the upper divisions of the Witteberg Group as well as the Kommadagga Formation of the Dwyka Group decrease in thickness towards the western outcrop areas, in this way indicating a gradual approach to a western shoreline.

(iv) The glacial pavements near Nieuwoudtville show directions of movement of the ice from the northwest. (J.W. von Backström, 1960, p. 19).

(v) The glacial pavement at Elandsvlei shows a direction from the west.

(vi) The Koperfontein exposure shows the existence of a paleocurrent which was responsible for the orientation of the inclusions. This current was from the west. If the early Dwyka glaciers and ice-shelves were wet-base, then the sub-glacial melt-water current would have flowed from the presumed Atlantic highland towards the east in the same way as the modern Antarctic cold waters sink and flow outwards and away from the continent. If, on the other hand, the glaciers and ice-shelves were dry-base, then the paleocurrent would have been a high-density salinity current flowing in the same course and direction as a melt-water current.

The different northern ice bodies gradually coalesced and spread in a generally southward direction. The Atlantic ice linked up with that of the Namaland ice-centre and spread towards the southeast and east. The ice-sheet eventually became a floating ice-shelf calving ice-bergs.

It is also necessary to establish whether the Dwyka glaciers and ice-shelves were wet- or dry-base, according to the definition of S.W. Carey and N. Ahmad (1961, p. 867). Their studies convince them that each type produces characteristic proglacial sediments. They report that till is found in the

ground shelf zone of a wet-base glacier and clay, silt and sand in the floating shelf and ice-berg zones (pp. 886 and 892). A few scattered erratics are also present. The dry-base glacier produces only mudstones with erratics in the floating shelf and ice-berg zones (pp. 886 and 893). Although enough convincing evidence is admittedly not yet available, the present author thus deduces that the Dwyka glaciers were wet-base.

The mud-, silt- and sandstones of the Kommadagga Formation are therefore interpreted as proglacial sediments produced during the initial stages of glaciation. Many would then be the deposits of the ice-berg zone and beyond. These proglacial sediments were carried into and deposited in a marine environment inherited from a former age, and which was characterized by unequal subsidence of an unstable depositional area. The presence of unstable minerals such as feldspar, apatite and garnet in the rocks can be ascribed to low rates of chemical decay owing to the cold climate and also the shorter period of transport before the final rapid burial.

When the first of the proglacial sediments were transported into the "Witteberg" sea, some mixing of material must have taken place. This explains why the exact contact between the Lake Mentz and Kommadagga Formations is in places difficult to place. The "Witteberg" appearance of the lower division of the old "Lower Dwyka Shales" and gradual change into the "Dwyka" appearance of the upper division, was noted by the early investigators.

The above remarks also explain why fishes and plants appear in the upper beds of the Lake Mentz Formation in the Droëkloof - Lake Mentz area while they are present in the lower beds of the Kommadagga Formation at Floriskraal. It was explained in Chapter IV that the fish are found all along a synchronous surface.

The origin of the Tillite Lentil, occurring in the Dirkskraal Siltstone Member of Bergplaas, is a problem. It may represent a submarine till flow originating through the slumping of foreset deposits of till which, at that stage, lay to the north, i.e. towards the grounded shelf zone of the glaciers. A till flow can erode and occupy channels in proglacial se-

diments (S.W. Carey and N. Ahmad, Ibid., pp. 884-885 and 892). Its thickness in relation to its width suggest that the lentil may well be a till flow occupying an erosion channel. Further investigation should be undertaken.

(d) The Dwyka Tillite Formation

The mode of deposition of the Dwyka Tillite is described by A.L. du Toit (1921 and 1954) as well as by I.W. Hälbich (1962). Only certain aspects are referred to below.

Fig. 18 shows the radiation of the Dwyka glaciers and the presumed southern limit of the grounded ice-shelf. The extent of the floating shelf and the southern limit of the ice-bergs are obviously unknown.

From the descriptions of the basal contact of the formation it is clear that the deposition of the till took place on to wet and unconsolidated material. South of the southern limit of the grounded ice-shelf the floating shelf and ice-bergs were the transporting media. There is nowhere any indication that the southern tillite is a ground moraine. L.C. Gouws (1960, pp. 38-44) challenges the traditional belief that the southern tillite is marine. On the basis of his discovery of a "disconformity" at Genadendal and the rather dubious method of comparing isolated samples of the southern tillite with the northern occurrences with respect grade and fabric analyses as well as direct comparisons, he declares that all the Dwyka tillites are of terrestrial origin.

It is obvious that more work should be done on the Dwyka Group. The possibility that some tillite beds may represent submarine till flows, should not be overlooked.

The southern tillites were deposited in a relatively quiet environment. A few spasmodic currents did, however, lead to the winnowing of material and the subsequent deposition of conglomerates, silts and muds.

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CHAPTER VII

STRATIGRAPHIC RELATIONSHIPS AND SUBDIVISION OF THE STRATIGRAPHIC COLUMN

A. THE STRATIGRAPHIC RELATIONSHIP BETWEEN THE CAPE AND KARROO SUPERGROUPS

A stratigraphical map is given to show the hypothetical distribution of the Witteberg Group. (Fig. 17). During the Upper Witteberg Age the area of deepest subsidence was towards the Eastern Province. It is interesting to note that the Cape Supergroup as a whole also attains its thickest development there. The same holds good for the Dwyka, Ecca and Beaufort Groups. (M.R. Johnson, 1966, p. 69).

The Relationship between Tectonic Activity and Sedimentation

This relationship is best illustrated by means of a few sections along the 23°E meridian. The first (Fig. 19a) shows the craton and the stable shelf characterized by slow uplift and slow subsidence respectively.

The deformed cross-stratification seen in the upper division of the Wittepoort Formation heralded the tectonic disturbance resulting in the sudden influx of generally unsorted sediments into a more rapidly subsiding basin. (Fig. 19b). In the meantime slight uplift and erosion of the Cape Supergroup had taken place in the northwestern areas. The contact between the Witteberg and Dwyka Groups ranges from a disconformity to a slight angular unconformity. For a short distance to the south of Elandsvlei, relative stability of the depositional area is evident. Over a long period of time little or no deposition took place in this stable belt in which Koperfontein is situated. Here the paraconformity marks the hiatus in deposition. During this time interval spanning the Upper Witteberg and Lower Dwyka Ages, the sediments of the Lake Mentz and Kommadagga Formations respectively, were deposited towards the south. The Witteberg Group thus displays regression and offlap from north to south.

During the Dwyka Epoch a slow but continuous northward migration of the depositional basin took place. (Fig. 19c). Towards the end of this epoch the depositional area was further enlarged with the continued migration of the northern edge.

During the Ecca Epoch further slow negative epeirogenesis took place. (Fig. 19d). Meanwhile the area of slight uplift in the south had shown a corresponding shift towards the north. Orogeny and folding in depth increased in intensity. It led to the present southern fold areas.

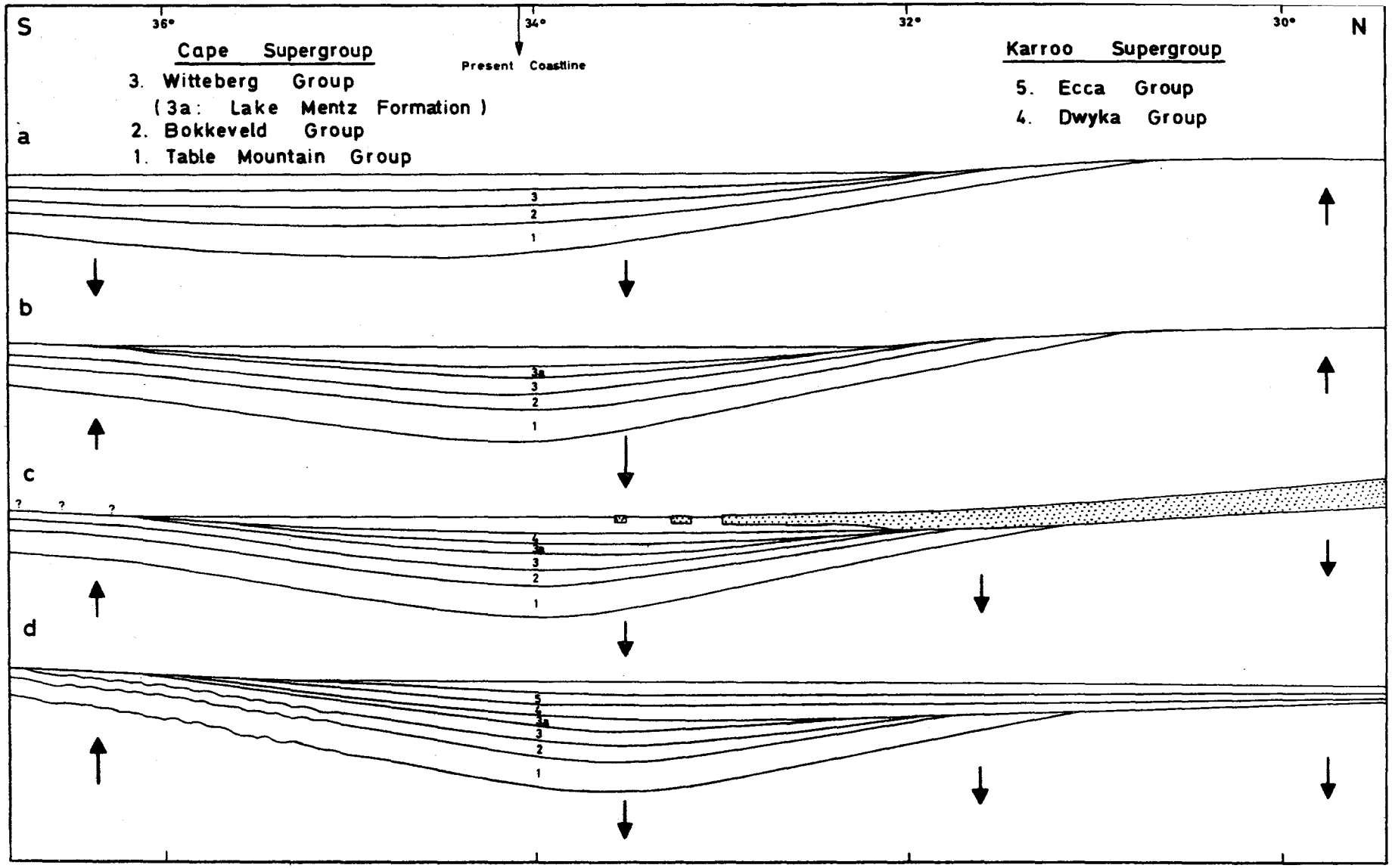

Fig. 19. Successive stages in the evolution of the Cape - Karroo geosyncline.

a. Middle Witteberg Age, b. Upper Witteberg Age, c. Dwyka Epoch, d. Middle Ecca Age.

From all the above the following is clear:

(i) In the south the Cape and Karroo Supergroups are conformable to each other.

(ii) The tectonic disturbances which eventually led to the Cape Orogeny, started at the end of the Middle Witteberg Age with the sudden transition from a slowly-subsiding stable shelf to an unstable basin subjected to unequal and more rapid subsidence. The depositional area migrated northwards corresponding with a slow shift of the area of folding and uplift in the same direction.

(iii) The Cape Orogeny with its intense folding and uplift attained its climax in the southern areas where the Cape and Karroo Supergroups show maximum development.

(iv) The later history of the Karroo Supergroup shows that the uplift and erosion of the southern orogenic region supplied sedimentary material for the upper division. (The Stormberg Group).

The facts given (iii) and (iv) are natural phenomena occurring as integral parts of the history of a geosyncline.

B. THE SUBDIVISION OF THE STRATIGRAPHIC COLUMN

The division of the stratigraphic column into time-stratigraphic and rock-stratigraphic units as proposed and used in this paper, is shown in Table 15. Various methods of subdividing the stratigraphic column into distinct units are discussed below.

(1) Rock-stratigraphic Units

Only clearly-observable features of the sedimentary rocks are used to recognize a number of distinct units. Fossils, geological history and age play no part. The four formations and subdivisions thereof described in this paper all have distinct lithological characteristics. The groupings of higher rank can likewise be distinguished from each other.

J.N. Theron (1962, p. 406) suggests that the "Upper Witteberg Stage" (i.e. the Lake Mentz and Kommadagga Formations) should be assigned to the Dwyka Group because the Lower Carboniferous age of the fossil fish.

TABLE 15

Time - stratigraphic and rock - stratigraphic column.

TIME - STRATIGRAPHIC UNITS				ROCK UNITS		
European equivalent	South Africa					
SYSTEM	SYSTEM	Series	STAGE	SUPERGROUP	Group	FORMATION
CARBONIFEROUS	KARROO	Dwyka	MIDDLE DWYKA	KARROO	Dwyka	DWYKA TILLITE
			LOWER DWYKA			KOMMADAGGA
? ?	CAPE	Witteberg	UPPER WITTEBERG	CAPE	Witteberg	LAKE MENTZ
DEVONIAN			MIDDLE WITTEBERG			WITTEPOORT

M.R. Johnson (Op. Cit., p. 27) correctly points out that this practice should not be followed as age considerations play no part in rock-stratigraphic classifications.

(2) Biostratigraphic Units

The scarcity of fossils in some rock-stratigraphic units and their absence in others, rules out the division of the stratigraphic column into biostratigraphic units at present. Distinct assemblage and range zones are few. J.N. Theron (Op. Cit., Table 1) gives the range zone for a plant fossil as well as an assemblage zone for fish types in the Vondeling area. Elsewhere the fishes are restricted to a single bed. The fish-bearing bed of Lake Mentz, Droëkloof and Floriskraal can be regarded as a synchronous surface. At Vondeling the precise position of this surface is not known. From Lake Mentz in the east to Floriskraal in the west this synchronous surface ranges from the upper beds of the Lake Mentz Formation to the lower beds of the Kommadagga Formation.

(3) Time-stratigraphic Units

In Europe and North America the subdivision of the stratigraphic record is based on natural phenomena such as fossil content and/or unconformities. The South African time-stratigraphic column cannot be made to fit the European time-scale. Our breaks in the record do not coincide with the boundaries between the European systems. We are also confronted with the unique Cape-Karroo sequence which shows continuous deposition, although not always in the same place, from the Silurian Period to the Triassic. It is then necessary to use a time-scale adapted to the Southern African geological column. Originally the names "Cape System" and "Karroo System" were given to what are clearly major rock-stratigraphic units. In this paper in which the threefold system of the ACSN is used, the above two units are referred to as the "Cape Supergroup" and the "Karroo Supergroup". The old name of "system" was clearly used in a lithologic context. Because of historical considerations the names "Cape" and "Karroo" are now retained. The names "Cape System" and "Karroo System" as used in this paper, refer to time-stratigraphic units. This nomenclature is, however, somewhat incorrect. The Code of Stratigraphic Nomenclature of the ACSN states that names for time-stratigraphic units should not duplicate those used for rock-stratigraphic units (Article 32d). New names would have to be coined if the terms "Cape" and "Karroo" as used here in conjunction with "system" are to be rejected. This is beyond the scope of the present paper.

Aspects of the basis of the subdivision of the Cape-Karroo sequence into two major time-stratigraphic units with the rank of system, are discussed below.

(a) Historical considerations

The early investigators found that, although being conformable to each other in the southern regions, the Cape and Karroo Supergroups occur in two distinct areas when seen on a regional scale. They were also aware of the distinct difference between the "Cape" and "Karroo" type rocks. The sequence was thus divided into the "Cape System" and the "Karroo System".

All rocks intervening between the Floriskraal Sandstone Member and the Dwyka Tillite Formation were originally known as the "Lower Dwyka Shales" and thus considered to be part of the "Karroo System". The Cape-Karroo boundary was thus taken at the top of the Floriskraal Sandstone Member.

Years later, in 1953, the Geological Survey fixed the Cape-Karroo boundary at the easily-recognizable base of the Dwyka Tillite Formation. This practice ensures that small-scale or regional mapping becomes easy and practicable. The "Lower Dwyka Shales" were now renamed the "Upper Witteberg shales" and taken as the upper division of the "Upper Witteberg Stage" which extends from the top of the Wittepoort Formation to the base of the Dwyka Tillite Formation.

This practice is open to criticism because it excludes the proglacial sediments of the Kommadagga Formation which are genetically related to the Dwyka Tillite Formation and which also show distinct "Karroo" lithologic traits.

(b) Lithology

On the basis of lithology the Cape-Karroo sequence can be subdivided into two distinct rock-stratigraphic units viz. the Cape Supergroup and the Karroo Supergroup. It therefore seems logical that a boundary between two time-stratigraphic units should coincide with the above one.

(c) Geographical aspects

The Cape Supergroup occurs in the southwestern and southern areas of the Cape Province. Outcrops of more limited extent are found in Natal. The Karroo Supergroup on the other hand once covered the major portion of Southern Africa. If a

subdivision of the sequence into two major time-stratigraphic units is necessary, the boundary between the Cape and Karroo systems must then coincide with the boundary between the Cape and Karroo Supergroups.

(d) Paleontological criteria

In the south a marine environment of deposition is evident for the Cape Supergroup as well as the Dwyka Group and the major portion of the Ecca Group. From there upwards to the top of the Karroo Supergroup a terrestrial environment with appropriate fauna and flora is present. The Dwyka Tillite Formation represents a big gap in the faunal and floral succession. The boundary between the Cape and Karroo Systems should not be fixed at the base of that formation as seems logical but rather some distance lower down so as to coincide with the synchronous surface that marks the death of the fishes. This surface also represents the upper limit of the "Witteberg flora". In the absence of fossils the exact position of this surface cannot be determined in all localities. For practical purposes the boundary between the Cape and Karroo Systems should then be placed at the base of the Kommadagga Formation.

(e) Climatological factors

If one prefers to make use of an external basis for subdivision, the Dwyka Glaciation with its major change in climate serves as a good reason for placing the boundary at the base of the Kommadagga Formation.

(f) Tectonism

Whenever fossils are scarce or absent an ulterior basis for the subdivision of the stratigraphic record is favoured by some. Tectonism is then taken because it can be argued that its effects changes in the area of deposition, lithology, environment and fossil content of the rocks. In the second edition of their textbook, W.C. Krumbein and L.L. Sloss (1963) review the history and development of stratigraphic thought with respect to tectonic activity and sedimentation. The modern tendency is to reject the catastrophist concept and to recognize that tectonic activity and sedimentation is

a continuous process (p. 414). Krumbein and Sloss also include a figure illustrating Krynine's tectonic cycle (p. 410). If we apply this cycle to an analysis of the Cape-Karroo sequence, we find that a "peneplanation stage" is evident up to the end of the Middle Witteberg Age. From then on more rapid and unequal subsidence accompanied by the incursion of unsorted sediments is evident. This is the "geosynclinal stage" of Krynine.

When reviewing the whole of the history of Cape-Karroo sequence, we find that the deposition of the sediments of the Cape and Karroo Supergroups fits into only one cycle of tectonism and deposition. The conformable relation between the two supergroups in the south, the continuity of deposition, the slow shift of the main area of deposition with the resulting unconformities towards the edges of the area, the folding and the cannibalism, are all inherent characteristics of a geosyncline. It then follows that the subdivision of the sequence into two major time-stratigraphic units would be entirely artificial and arbitrary. If, however, a subdivision has to be made on the basis of tectonism, it should be done with reference to Krynine's tectonic cycle. The boundary between the two systems should then be placed at the top of the Wittepoort Formation.

(g) Comparison with the European time-scale

The boundaries between the European systems do not coincide with natural boundaries in Southern Africa. On the evidence of the fossil fishes J.N. Theron (Op. Cit., Table 1) believes that the contact between the Wittepoort and the Lake Mentz Formations corresponds with the Devonian-Carboniferous boundary. On the other hand, Dr. Edna P. Plumstead, who examined the fossil flora submitted to her by the author, states that "..... the general age impression is of Upper Devonian rather than Lower Carboniferous". (Personal communication, 22/11/1963). When bearing in mind the extended vertical range of certain flora, the presence of the fishes was considered to be of more importance in the placing of the Devonian-Carboniferous boundary. The position as shown in Table 15 is that given by J.N. Theron (Op. Cit., Table 1).

The present author admits that the position of the border can and should be revised in future. He suspects that it

can be placed at an as yet undetermined position some distance below the top of the Lake Mentz Formation. To do so will be a better compromise between the apparently conflicting evidence provided by the fauna and the flora.

Summary

It is shown that the rocks of the Cape Karroo sequence are the result of deposition spread over a very long span of geological time from probably the Lower Silurian Period to the Upper Triassic. Subdivision of the stratigraphic column, which is the record of continuous deposition, into two major time-stratigraphic units should not be made. It is, however, convenient to do so for a number of reasons outlined above in the discussion of the basis for the subdivision of the sequence.

The position of the boundary between the two systems as shown in Table 15, is chosen in view of the arguments and proposals given in the above discussion.

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CHAPTER VIII

SUMMARY

The rocks of the Cape Supergroup occur in the western and southern regions of the Cape Province. In the south the Cape Supergroup is conformably overlain by the vast and spread-out Karroo Supergroup. The sedimentational history of the contact rocks has not been studied in detail in the past nor has the exact position of the contact ever been placed with any degree of certainty. Consequently a field study in a few localities along the line of contact was undertaken. This was supplemented with laboratory work.

Fieldwork shows that a multiple system such as advocated by the ISST can be successfully applied to the portion of the geological column studied. The Wittepoort and Lake Mentz Formations are assigned to the Witteberg Group. The Dwyka Tillite and Kommadagga Formations are included in the Dwyka Group. Previously there was some confusion over what is called in this paper the Lake Mentz and Kommadagga Formations. The four formations can readily be recognized in the field. The Wittepoort Formation consists of well-and cross-stratified white sandstones and subordinate siltstones. The Lake Mentz Formation consists of shales, mud- and siltstones. The Kommadagga Formation is comprised of non-micaceous and better sorted silt- and mudstones. Darker colours prevail, even upon weathering. The tillites of the Dwyka Tillite Formation are easily recognizable owing to a profusion of various erratic-types set in a dark matrix.

Heavy mineral studies indicate that tourmaline can be used for correlative purposes even over long distances. Zircon should be of value over short distances only. Garnet was found to be a good indicator of Dwyka rocks.

The petrography of the rocks, as well as the heavy mineral content, indicates a mixed array of provenance rocks, dominated by granitic types. The provenance area was towards the north, northwest and west.

The primary structures of rocks of the Wittepoort Formation are typical of a shallow marine environment. These, together with the uniformity of the stable sediments as found over a large depositional area, indicate a stable shelf environment. With the sudden transition to a more unstable environment at the beginning of the Upper Witteberg Age, the sediments change to generally more unsorted types deposited under more complex conditions.

In the meantime the gradual decrease in temperature during the onset of the glaciation led to the growth of the Dwyka ice-sheets in the western, northern and eastern provenance areas. The proglacial sediments of the Kommadagga Formation were deposited in a marine environment inherited from the Witteberg Epoch. The great mass of tillites followed soon after. The northern terrestrial tillite grades into the southern marine tillites which were deposited by a floating ice-shelf and free-drifting ice-bergs.

In the southern areas the Karroo Supergroup follows structurally conformable on the Cape. Continuity in sedimentation is evident. Towards the edges of the old Cape geosynclinical area, this conformity changes to a paraconformity and thence into a disconformity and even local angular unconformities before the basal beds of the Karroo Supergroup rests on all pre-Cape rocks with a non-conformity.

The Cape and Karroo Supergroups occur in two distinct geographic areas. This together with the distinct difference in lithology induced the early geologists to divide the Cape Karroo sequence into two major units. This sequence is the outcome of one cycle of tectonism and deposition. A critical study of the theoretical aspects of the basis of subdivision of a stratigraphic column reveals that the Cape-Karroo sequence should not be divided into two time-stratigraphic units of system rank. It is, however, convenient to do so. The placing of the boundary between the Cape and Karroo Systems as shown in this paper, satisfies historical, lithological, geographical and paleontological considerations.

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****

PLATE 1

Photo

A — Typical topography in parts of the Southern Karroo. View looking east, Droëkloof. The outcrops of the Wittepoort, Lake Mentz and Dwyka Tillite formations are shown. The mountain is the Witberg Range.

B — View of the eastern bank of the Buffels River at the entrance to the Leeukloofpoort, Floriskraal.

(a) Wittepoort Formation.

(b) First Shale Tongue, Leeukloofpoort Shale Member.

(c) First Sandstone Lentil, Floriskraal Sandstone Member.

(d) Second Shale Tongue, Leeukloofpoort Shale Member.

(e) Second Sandstone Lentil, Floriskraal Sandstone Member.

C — Outcrops of Dwyka Tillite showing cleavage and the resulting tombstone weathering. The stratification is indicated. Floriskraal.

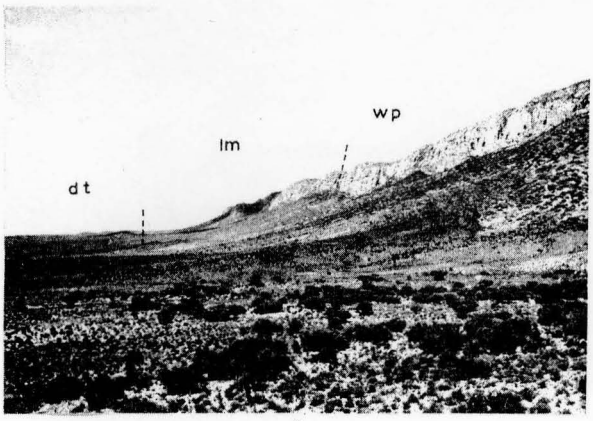
D — Outcrop of the Conglomerate Lentil, Droëkloof.

E — Dwyka erratic imbedded in Witteberg rocks, below the contact. The contact between the Witteberg rocks and the Dwyka Tillite is stippled. Genadendal.

F — Sandstone of the Wittepoort Formation, Floriskraal, under crossed nicols. Some quartz grains show secondary overgrowths.

G — Siltstone of the Dirkskraal Siltstone Member, Kommadagga Formation, Bergplaas, under crossed nicols. Three plagioclase grains are present.

H — Dwyka Tillite, Bergplaas.



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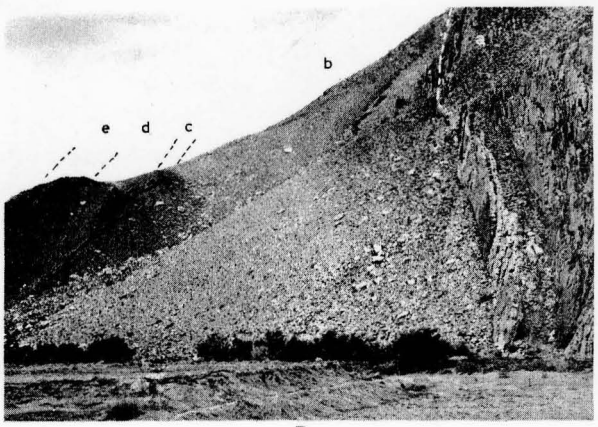

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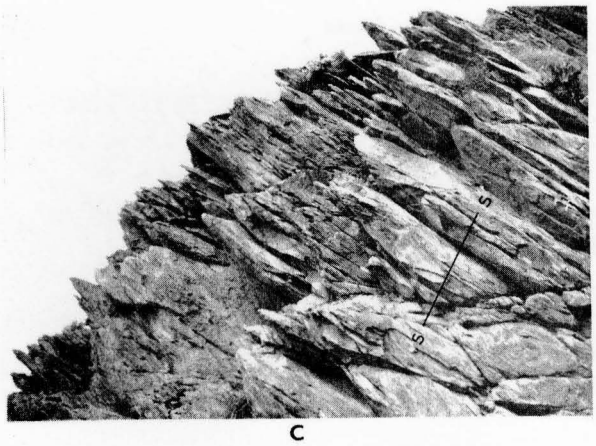

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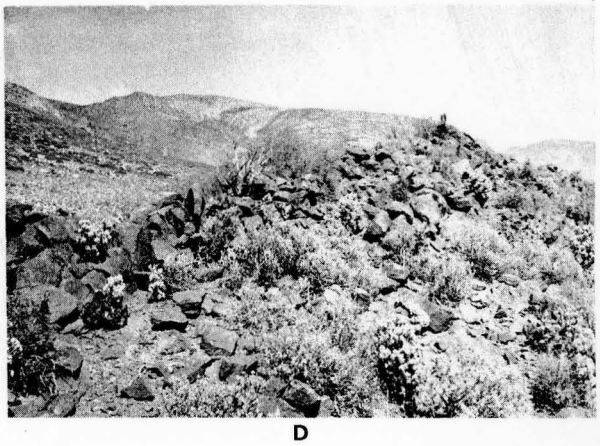

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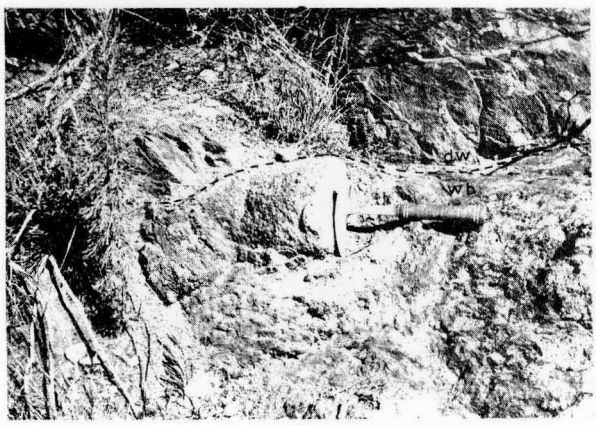

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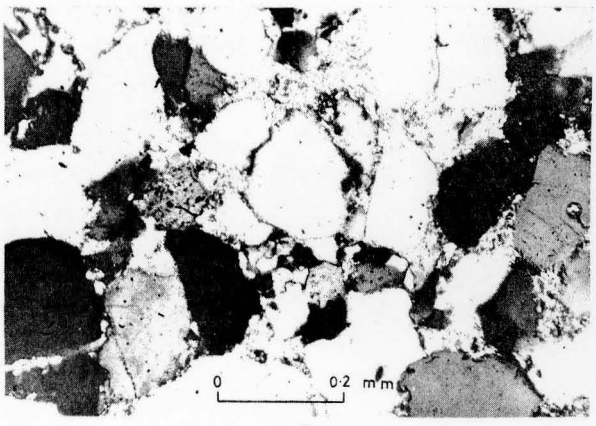

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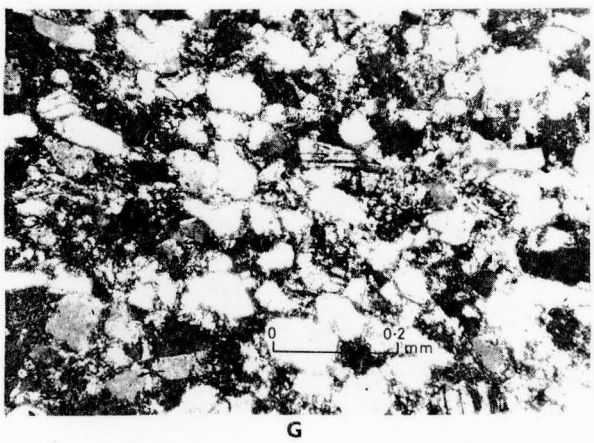

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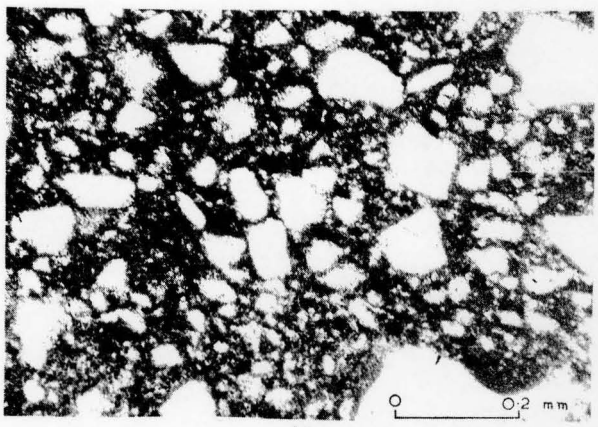

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PLATE 2

Photo

A — Deformed cross-stratification in upper Wittepoort Formation, Koperfontein, Western Karroo.

B — Big interference ripple-marks, upper Wittepoort Formation, Bergplaas, Kommadagga. The crests are stippled.

C — General view, looking south, of the low-dipping sandstone bed showing hollows left by former erratics. Note the Tertiary surface in the background. Koperfontein.

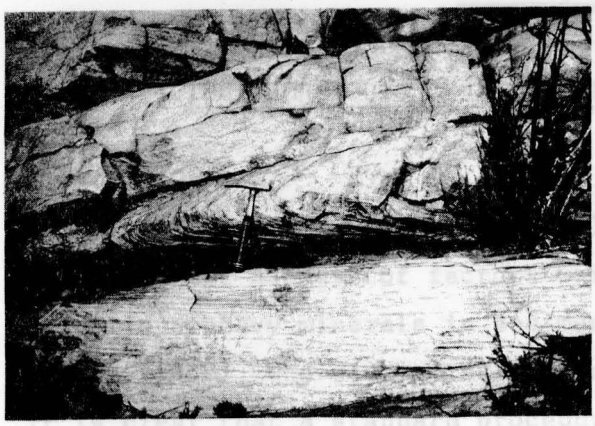
D — Orientated hollows previously occupied by erratics. Koperfontein.

E — Hollow formerly occupied by a striated erratic. Koperfontein.

F — Two imprints of Brachiopods (?), Conglomerate Lentil, Lake Mentz Formation, Droëkloof.

G — Imprints of plants and fishes, Kommadagga Formation, Floriskraal.

H — Worm tracks (?) on ripple-marks, Dirkskraal Siltstone Member, Kommadagga Formation, Bergplaas.



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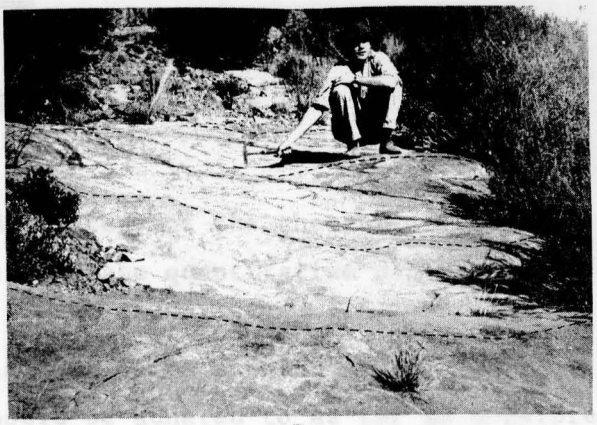

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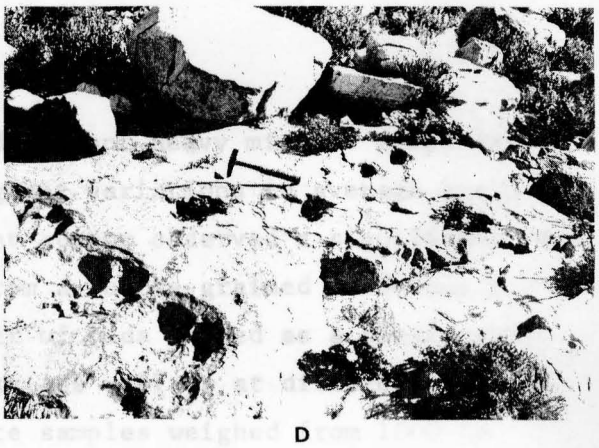

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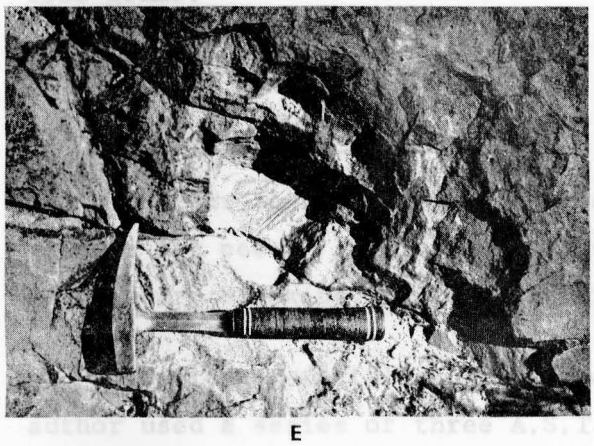

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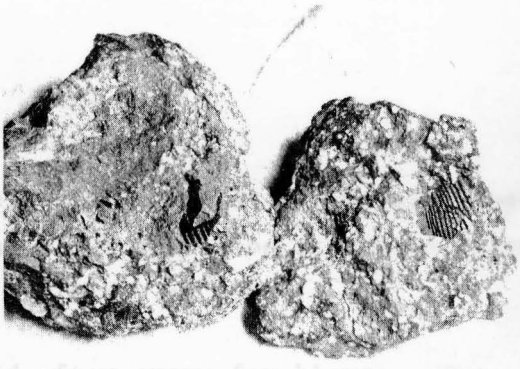

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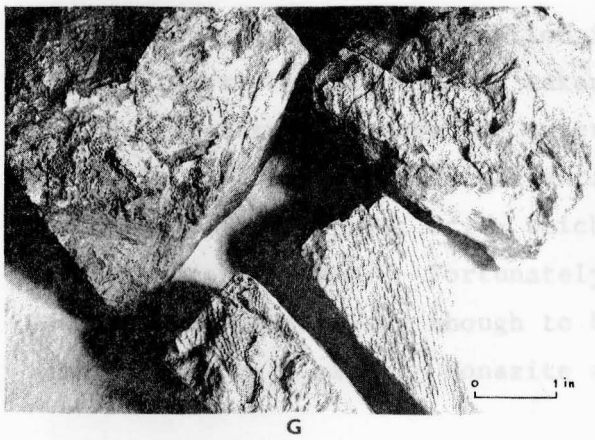

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H

A P P E N D I X

THE TECHNIQUES OF HEAVY MINERAL INVESTIGATION.

G.M. Koen (1955, pp. 286 - 297) made a study of the theoretical and practical aspects of factors which affect the quantitative distribution of various heavy minerals in sediments. From his work and that of L.A. Hardie (1958), who studied heavy minerals from certain South African rocks, it is clear that a standard procedure should be adhered to as far as possible, and that a description of it should be given for the benefit of others.

1. Sampling technique

Koen (Op. cit., p. 290) shows how different heavy mineral crops can be obtained from samples which exhibit great variations in average grain size and degree of sorting. The present author observed a significant variation in zircon grains, respectively from a coarse-grained sandstone and a siltstone both of which occur in a number of beds mapped as a single unit. Chips were taken along the line of strike, as well as at different stratigraphic levels. The resulting composite samples weighed from 1000 to 1500 grams.

2. Preparations of samples

In order to disaggregate the sample, a few chips at a time are crushed, using a big pestle and mortar. Straight blows should be struck to prevent unnecessary breaking of mineral grains. (Ibid., p. 294).

The finer material should be removed after every few blows. The author used a series of three A.S.T.M. sieves of 10, 60 and 100 mesh to obtain the minus 100-mesh fraction which was then reduced in bulk using a sample splitter. This fraction is now washed to remove the rock flour and clay particles, care being taken not to pan the sample in any way. It is now necessary to remove the superficial coatings of ferric iron on mineral grains in order to facilitate identification. For this the author used hot diluted hydrochloric acid, which treatment destroyed any apatite which may have been present. Fortunately apatite is a rare heavy mineral. However, whenever it was though to be present in any quantity untreated samples were also used. Monazite survived the acid treatment.

3. Separation of heavy minerals

The author used a battery of six glass funnels fitted with short lengths of

transparent rubber tubing and pinch-cocks, above a similar set of six funnels. Koen (Ibid., p. 285) advises that 2 grams of minus 200-mesh (Tyler) should be used with bromoform with a circular surface 5 centimeters in diameter. The present author used twelve grams of dried sediment for six simultaneous separations. The sediment is strewn on to the surface of the bromoform and stirred repeatedly with a thin copper wire. After ensuring that the separation is as complete as possible, the heavy minerals are run off on to filter papers in the lower set of funnels. The filter papers are now removed and the heavy minerals are washed off into a small glass dish, using a directed jet of alcohol. Most of the alcohol wash is now decanted and the grains left to dry before transfer to a storage bottle using a camel hair brush.

The alcohol wash can be used to extract most of the bromoform remaining in the light fraction after it has been filtered.

All filter papers, light fraction and alcohol-bromoform mixtures should be kept for the eventual recovery of the bromoform.

The method is described by W.C. Krumbein and F.J. Pettijohn (1938, p. 343).

4. Preparation of slides

Standard petrographic slides and cover glasses were used with "Arachlor" resin as a mounting medium. Use a microsplitter to obtain the required amount of heavy mineral grains. The author found that 0.02 - 0.03 grams minerals, together with 0.25 grams of resin are sufficient for one slide. The slide is now gently heated and the molten resin uniformly spread over the required surface using a clean matchstick while ensuring that the grains are evenly distributed. Quickly draw a Bunsen flame over the surface of the resin to destroy air bubbles before attaching the cover glass. To ensure better results, two or more slides should be made of every heavy mineral crop.

5. The Classification of heavy minerals, for microscopic counts

The reasons for studying heavy minerals must be borne in mind when selecting a scheme of classification. This scheme should be chosen in order that:-

(i) The nature of the provenance rocks can be deduced with ease.

(ii) Well-defined criteria can be used when dividing a heavy mineral species into different types. The number of types should be kept as low as possible.

Theoretically a genetic scheme of classification should be ideal as it affords a direct picture of the grains from different types of provenance rocks. In practice, however, we find that most of the common heavy minerals cannot easily be divided into different genetic types. Furthermore, whenever different types are present, all the grains cannot be classified with a reasonable degree of accuracy, with the result that the work might not be duplicated by others.

We are usually forced to adopt a descriptive scheme whereby a given heavy mineral species is divided into different types on the basis of colour and pleochroism, zoning, inclusions, degree of rounding and shape.

A descriptive scheme was used with success by Koen in solving problems of correlation of Karroo beds. (Op. cit., p. 1955).

6. Microscopic counts

A Leitz mechanical stage fitted to the microscope table is used to carry out the counts. Parallel traverses are made over the slide covering the entire area containing grains. The spacing of the traverses is adjusted to suit the density of distribution of the grains as well as the number of grains to be counted. All the grains passing through the field of view are counted.

In order to increase the reliability of the counts, the results of two or more duplicate slides of each sample should be combined.

Separate counts are made to determine the relative frequencies of the types of a single heavy mineral species. During the final count the relative frequencies of the species are determined. In this way approximately 300 grains are counted during each individual count.

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