STRATIGRAPHIC AND PALEOCURRENT ANALYSIS OF THE ECCA SERIES AND LOWERMOST BEAUFORT BEDS IN THE KARROO BASIN OF SOUTH AFRICA

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STRATIGRAPHIC AND PALAEOCURRENT ANALYSIS OF THE ECCA SERIES AND LOWERMOST BEAUFORT BEDS IN THE KARROO BASIN OF SOUTH AFRICA

by

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ABSTRACT

Over 7,000 measurements of primary sedimentary structures were recorded in the Ecca and Lowermost Beaufort Beds (Permian) in the Karroo Basin of South Africa. These were taken with a view to reconstructing the regional paleocurrent patterns, the tectonic framework of sedimentation and the paleogeography.

A regional study was made of the Ecca and Lowermost Beaufort litho-stratigraphy within the Karroo Basin and particular emphasis was placed on determining the areal distribution of the various facies and their relationship to paleocurrent trends. The Ecca Series has been subdivided into four distinct facies known as the Northern, Southern, Western and Central Facies.

Sediments of the Northern Facies are confined to the northern one-third of the basin, and are composed of bluish-black shale, coarse arkose, conglomerate and coal seams. Sediments constituting the lower and upper portions of this facies were deposited in a relatively deep water continental sea environment, while the middle portion was deposited under fluvial-deltaic conditions on a slowly subsiding cratonic shelf. The major source of these sediments lay to the east and north-east of the present Natal coast. These source rocks were predominantly granitic in composition as revealed by the heavy minerals and abundance of microcline felspars.

The Southern Ecca Facies is confined to the Karroo Trough and outcrops along the southern structural margins of

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the basin as well as along the Transkei coast. It is composed of a thick sequence of greenish-grey and bluish-black shale, graywacke and sub-graywacke sandstone. Sedimentary structures indicate that the lower portion of the succession was deposited under deep water conditions and that turbidity currents were active. Progressively shallower water conditions prevailed during deposition of the upper portion of the succession and the facies as a whole was deposited in a rapidly subsiding trough which forms part of the Cape-Karroo Geosyncline. Although the majority of the sediments were derived from a source lying south of the Southern Cape Folded Belt, transport also took place in an easterly direction along the axial portions of the Karroo Trough. Heavy mineral studies and thin section examination of these sandstones indicates that the source rocks were predominantly granitic, but that sedimentary, metamorphic and basic igneous rocks also occurred.

The Western Ecca Facies occurs in the south-western portion of the basin and is composed of bluish-black shale, sub-graywacke and graywacke sandstone. These sediments were deposited partly in the western portion of the Karroo Trough and partly on the unstable shelf areas around the western margins of this feature. Sediments constituting the lower one-third of this succession were deposited under relatively deep water conditions while the remaining two-thirds of the succession was deposited under fluvial-deltaic conditions. The source of these sediments lay to the west and south-west and was composed mainly of granitic rocks.

Rocks constituting the Central Ecca Facies are confined to the central portions of the basin and were deposited in an extensive, relatively deep, inland sea. These rocks actually constitute an inter-mixture of the fine-grained facies equivalents of the other three facies, derived from three different source areas.

The Lowermost Beaufort Beds are composed of fine to coarse-grained sandstone interbedded with blue, green and occasionally maroon and purple shale and mudstone. Three distinct facies, derived from separate source areas composed mainly of granitic rocks, are recognised within these beds. These have more or less the same distribution as the Southern, Western and Northern Facies within the Ecca Series, except that they do not grade into a facies composed entirely of shale. Instead the different lithological units constituting the various facies interfinger with each other towards the central portions of the basin. These sediments were derived from more or less the same source areas as occurred during the Ecca period and were mainly deposited in an aqueous continental environment.

Paleogeographical reconstructions indicate that the present African sub-continent was more extensive during deposition of the Ecca and Lowermost Beaufort Beds. In Lower Ecca times, the Karroo Basin was probably connected to the oceans by means of two narrow openings situated in the south-eastern portion of the basin as well as in the vicinity of the Orange River Mouth.

Economically important mineral deposits are discussed in the light of conclusions drawn from the present research. Certain sedimentological, paleotectonic and paleogeographical controls are pointed out and recommendations made for future exploration.

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I. INTRODUCTION

The Karroo System, or the African equivalent of the so called Gondwana systems of the southern hemisphere, covers vast areas of the Republic of South Africa. In addition, the system occurs in South West Africa, Botswana, Rhodesia, Malawi, Zambia, Congo and East Africa. In the Republic, the largest and best preserved occurrence constitutes the Great Karroo Basin and covers an area of approximately 2[illegible]5,000 square miles (see fig. 1). This feature is bounded in the south and south-west by the east-west and north-south trending Cape Folded Belts respectively. Karroo strata extend seawards below the Indian Ocean to the east and the northern and north-western margins are partly structural and partly erosional.

The system was first studied and defined in the provinces of the Cape and Natal, where the Dwyka Tillite forms the base and the basaltic lavas of the Drakensberg the top. The intervening beds, many thousands of feet thick, have been divided up partly on palaeontological, but mainly on lithological criteria into the Ecca, Beaufort and Stormberg Series (see table 1). These rocks are represented by an estimated maximum thickness of at least 30,000 feet in the east-west trending Karroo Trough, lying immediately north of the Southern Cape Folded Belt. A considerable thickness of strata was also deposited in a second trough, the axis of which more or less parallels the Natal coast. Inland from these linear downwarps the sediments become progressively thinner.

- Rocks -

Rocks of the Karroo System rest conformably on the older Cape System strata in the central portions of the Karroo Trough but transgress onto progressively older Cape System rocks in a northerly direction and ultimately come to rest unconformably on Basement granite. Outside the troughs and on the shelf areas, the Karroo strata are not only represented by abbreviated sequences, but stratigraphic disconformities are common, resulting in the absence of considerable thicknesses of strata. Two large disconformities have been described by Du Toit (1956), one at the top of the Dwyka Tillite and the other at the base of the Stormberg Series.

Dwyka, Ecca and Lower Beaufort strata have been intensely folded along the southern margins of the basin, but the folding gradually dies out northwards. The first major foldings are thought to have commenced in Upper Permian times and been more or less continuous through to Upper Triassic times (De Villiers 1944).

During Jurassic times the Karroo Strata were flexed into a monoclinal fold along the eastern margins of the basin and subsequent normal faulting has greatly modified this structure. However, over the remainder of the basin the beds dip inwards at low angles towards the centre.

Intrusive into the Karroo strata are numerous dolerite sills and dykes. Only in the south where the beds are folded are the dolerites absent. Du Toit (1956) believed that the dolerites were intruded at more or less the same time as the Drakensberg Lavas were being extruded and that intrusion at depth continued for some time after vulcanicity at the surface had ceased.

- Table 1 -

Table 1 summarizes the stratigraphy of the Karroo System and also lists the accepted correlations with equivalent European Systems. Following the outpouring of the Drakensberg Lavas, at the end of the Karroo period, isostatic uplift of the Southern African sub-continent resulted in the superimposition of a radial drainage system upon an essentially horizontal, lava capped succession of strata. Successive uplifts and minor downward movements, together with erosion, have resulted in vast quantities of Karroo strata being removed and transported radially outwards into the oceans since Jurassic times. Thus at the present, rocks constituting the different stratigraphic sub-divisions of the Karroo System outcrop as a series of concentric belts within the basin. The Dwyka forms the margins and the Drakensberg Lavas the centre (see fig. 1).

The present study was confined to the Ecca and Lowermost Beaufort Beds occurring within the present structural and erosional limits of the Karroo Basin. The most important coal deposits in South Africa occur in these rocks and recently the Ecca Series in particular has attracted considerable interest as a potential source of oil and gas. Consequently it was of the utmost importance, from an exploration point of view and as an overall objective of this study to reconstruct the history of sedimentation of the Ecca and Lowermost Beaufort Beds. It is believed that a better understanding of the mode of origin and localization of known coal deposits in their basinal setting will enable more accurate predictions to be made regarding future exploration for further deposits. Similarly, reconstructions of the paleogeography, tectonic framework of sedimentation and the depositional environments would be of considerable value in any exploration programme for oil and gas.

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TABLE 1

STRATIGRAPHY OF THE KARROO SYSTEM

Series	Group	Representative Rocks	Characteristic Fossils	European Equivalent
4. Stormberg	Drakensberg Volcanics	Basaltic lava, pyroclastics, minor sandstone	"Dinosaurs"	Lower Jurassic (Rhaetic - Lias)
	Cave Sandstone	Aeolian Sandstone		
	Red Beds	Red coloured mudstone, shale and sandstone		Triassic
	Molteno	Felspathic sandstone, shale, minor coal seams		
3. Beaufort	Upper	Red, purple and maroon mudstone, felspathic sandstone	Cynognathus Procolophon	
	Middle	Red, purple and maroon mudstone, felspathic mudstone	Lystrosaurus	
	Lower	Bluish-grey sandstone, felspathic sandstone, purple and green mudstone	Cistecephalus Endothiodon Tapinocephalus	Permian
2. Ecca	Upper	Grey shale, graywacke, sub-graywacke	Gangamopteris Glossopteris Cyclodendron	
	Middle	Bluish-grey shale, arkose, siltstone, coal seams		
	Lower	Grey shale, graywacke, sub-graywacke, siltstone		
1. Dwyka	Upper Shales	Greenish-grey shale	Mesosaurus, Eurydesma found only in S.W.A.	
	Tillite	Tillite, shale		Upper Carboniferous

Taking the above considerations into account, the following were the main objectives of the study -

1. To reconstruct the regional paleocurrent patterns within the Ecca and Lowermost Beaufort Beds, and to relate these to regional facies changes in order to gain a better understanding of the stratigraphy.
2. To relate regional paleocurrent directions to paleoslope and consequently to reconstruct the position and nature of the source areas and paleogeography.
3. To reconstruct the tectonic framework of sedimentation and the paleotectonic history by a study of Ecca and Lowermost Beaufort lithofacies.
4. To reconstruct the various depositional environments which existed within the Ecca and Lowermost Beaufort Beds.

In view of the above objectives the following investigations were carried out -

1. Fourteen months were spent in the field examining primary sedimentary structures, particular emphasis being placed on the measurement of directional structures such as cross-bedding, ripple marks, sole structures, parting lineations, etc.
2. Average current directions were determined for each outcrop locality, after correction of the directional data for tectonic tilt. These current trends were then represented on paleocurrent maps covering the complete extent of the Ecca and Lowermost Beaufort outcrop belts.
3. Average thickness of planar cross-bedding and average ripple index (wave length divided by amplitude) were determined for different outcrops and represented on maps in order to determine areal variations which may be related to paleocurrent trends and other sedimentological properties.
4. Using Wentworth's visual size chart, average grain size of Ecca Sandstone was determined for each outcrop locality investigated. The data were plotted on a map and related to paleocurrent trends, and also used to delineate the extent of different facies within the Ecca.
5. At each outcrop of conglomerate encountered in the field both mean pebble size and composition were determined and related to the regional paleocurrent patterns. Pebble compositions were used to determine the position and nature of the source rocks.

6. Stratigraphic sections were studied in the field, and available borehole logs and measured sections were examined in the office. From this information it was possible to form a clearer picture of Ecca and Lowermost Beaufort stratigraphy as well as the areal distribution of facies and sedimentary overlaps.

7. An isopach map of the total Ecca plus underlying Upper Dwyka Shale was constructed for the major portion of the Karroo Basin, from which it was possible to obtain useful information concerning the tectonic framework and paleogeography during Lower Karroo times. In addition the areal relationship between thickness of Lower Karroo strata and published gravity data were compared.

8. Geological sections across the Karroo Basin at the time of sedimentation were constructed to elucidate the stratigraphy, paleogeography and sedimentary tectonics.

9. Texture and composition of Ecca Sandstones belonging to different facies were examined in thin sections, and point counts made to determine percentage compositions and to classify the sandstones. In addition, useful information concerning the nature of the source rocks and the depositional environment were obtained. Major petrological differences were used to differentiate between facies.

10. Heavy minerals were extracted from sandstones belonging to different facies, and point counts made in order to detect any quantitative and qualitative differences between facies; and to determine the nature of the source rocks

11. Coal and other mineral deposits were examined in the light of the new information. Certain sedimentological controls were pointed out, and recommendations for future exploration made.

The thesis is composed of two volumes. Volume I contains the written portion and Volume II contains the appendices and the illustrations referred to in Volume I. The appendices record the geographic location of each outcrop measured, together with the types of sedimentary structures and relevant statistical data. In addition, borehole and measured stratigraphic sections used in the construction of subsurface geological maps are listed.

II. STRATIGRAPHY

The purpose of this chapter is to provide a basic stratigraphic framework for the Ecca and Lowermost Beaufort Beds within the confines of the Great Karroo Basin from an analysis of their facies distribution, thickness and inter-relationships of their component parts. Previous attempts to recognise and define time-stratigraphic units within these beds have so far been largely unsuccessful due to paucity of fossils and the lack of subsurface control. In addition, the lithology is discussed and mention is made of the various sedimentary structures and fossils found in these beds.

STRATIGRAPHY OF THE ECCA SERIES

A. GENERAL

Extensive geological investigations have been carried out on the Ecca and Lowermost Beaufort rocks since 1896 by numerous different geologists. In this study, no separate review of previous stratigraphic work will be given, as most of the important works are cited in the following text.

The Ecca Series rests conformably on the Upper Dwyka Shale in the Karroo Trough to the north of the Cape Folded Belt, the contact being taken at the top of a very distinctive and persistent carbonaceous zone, known as the "White Band", (see fig. 2). Farther north it becomes increasingly difficult to recognise this contact in the field so that ultimately north of a line joining Port St. John's and Hopetown, there is virtually no way of differentiating between shale of Upper Dwyka age and

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that of the succeeding Lower Ecca (see fig. 1).

Following retreat of the Dwyka glaciation vast areas of Southern Africa were covered with tillite, and in the succeeding period subsidence and sedimentation continued uninterruptedly in the Karroo Trough, portions of the Natal Trough and large areas of what is today the Cape Province. However, over much of the north-eastern portion of the basin, extensive areas of tillite were subjected to erosion and reworking. It is quite possible that much of the material constituting the Upper Dwyka Shale was derived from reworked older glacial beds in the north. This extensive area of non-deposition, in the northern part of the basin, has resulted in a very large disconformity between the Dwyka Tillite and the Ecca Series. The Upper Dwyka Shale is thought to thin out gradually northwards and, therefore, the magnitude of the disconformity increases in this direction as well.

In that part of the basin where the White Band is no longer recognisable it becomes necessary to include the Upper Dwyka Shale as part of the Ecca Series. In this study the Dwyka-Ecca contact is taken to be where rocks of the Ecca Series rest conformably or disconformably on the highest definite bed belonging to the Dwyka Series. In portions of the Transvaal and Natal the original tillite has been removed, and here the Ecca rests unconformably on pre-Karroo formations.

The upper limit of the Ecca Series is even more difficult to define on lithological grounds. In the Karroo Trough, where sedimentation was more or less continuous throughout Ecca and Lowermost Beaufort times, the Geological Survey of South Africa has taken the Ecca-Beaufort contact at the base of the first purple shale zone (Mountain 1946, Haughton et al. 1953).

The first appearance of purple shale above the Ecca Series does not always occur at the exact stratigraphic position over hundreds of miles but is found within a zone of limited thickness. This contact is easily recognised in the field and can be traced for a distance of nearly four hundred miles, from Verlaten Kloof south of Sutherland to the Indian Ocean in the east.

North of Verlaten Kloof and along the Roggeveld escarpment, the first purple shale zone occurs at progressively higher stratigraphic levels and may, therefore, no longer be used as a marker. Rogers and Du Toit (1903) mapped the area between Matjiesfontein and Calvinia and took the Ecca-Beaufort contact as the base of a very thick, massively bedded, reddish-yellow sandstone, which they were able to trace as far north as the outliers of Beaufort Sandstone, known as Roep My Nie Berg, Kriet Berg and Tafel Kop in the Calvinia district.

The stratigraphic relationship between the massive reddish-yellow sandstone used by Rogers and Du Toit (1903) as the contact and the first zone of purple shale was examined during the present study at a number of localities in the Little Roggeveld, Tanqua Valley and in the Verlaten Kloof. It was found that over the greater part of this area the first purple shale zone occurs at approximately the same stratigraphic position as the massive sandstone used by Rogers and Du Toit.

Eastwards from Calvinia and over the remainder of the basin the upper part of the Ecca Series is composed of shale and

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the contact with the Beaufort is taken on lithological grounds at the occurrence of the first well-defined bed of Beaufort Sandstone. It should be realised at the outset that this contact is certainly not time-stratigraphic and that considerable transgression of geological time does occur.

Recognition of the Ecca-Beaufort contact in borehole cores towards the centre of the basin has proved to be an even more difficult task.

Plant macrofossils occur in both the Ecca and Lowermost Beaufort, but it has not yet been possible to fix the contact accurately over the whole basin mainly because these fossils are fairly rare.

Attempts have been made to fix the Ecca-Beaufort contact at the incoming of the first fossil reptiles, such as *Pareiasaurus* (Rogers and Schwarz, 1902, p. 112), but it was concluded that these fossils were too rare in the Lowermost Beaufort Beds to enable the contact to be mapped accurately.

Therefore, at the present time, it is only possible to fix the upper and lower limits of the Ecca Series over the whole basin on the basis of lithological boundaries. While it is fully appreciated that the lower and upper boundaries of the Ecca are not isochronous surfaces and, therefore, strictly speaking, it should not be termed a series, it is nevertheless recommended that this term be retained as it is already so deeply ingrained in the literature.

The Ecca Series forms an outcrop belt 10 to 100 miles wide around the Karroo Basin, except in the south-east where it

- lies -

lies below the Indian Ocean. An isopach map showing total thickness of Ecca plus Upper Dwyka Shale was constructed using thickness data from boreholes and measured stratigraphic sections (see folder 1). The Ecca Series and the Upper Dwyka Shale were taken as one sedimentary unit because -

1. They are genetically related.
2. In areas where the White Band is absent the two units cannot be distinguished from each other.
3. It is difficult to recognise the White Band in borehole cores.

From folder 1, it may be seen that the Ecca plus Upper Dwyka Shale reaches a maximum thickness of about 11,000 feet in the Karroo Trough south-west of East London, and thins out in a northerly and westerly direction. The succession also thins westwards and north-westwards from the Natal Trough where it reaches an estimated maximum thickness of about 4,000 feet. In the north central portions of the basin, there is an extensive oval-shaped area where the succession is less than 1,000 feet thick, suggesting the presence of a broad topographically high-lying area on the pre-Karroo surface. Information concerning actual thicknesses used in the construction of the isopach map are given in appendices 19 and 20.

Du Toit (1956) recognised three different facies within the Great Karroo Basin. These he referred to as -

1. The Southern or Green Ecca Facies.
2. The Central or Blue Ecca Facies.
3. The Coal Measure Facies.

Their distribution was, however, never clearly defined by him.

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On the basis of lithology and paleocurrent directions the Ecca Series has here been subdivided into four distinct facies. These are as follows -

1. The Southern Ecca Facies.
2. The Western Ecca Facies.
3. The Northern Ecca Facies.
4. The Central Ecca Facies.

Sandstone and shale constitute the dominant rock types in the first three, while the Central Ecca Facies is composed almost entirely of shale. Folder 2 illustrates the distribution of these facies within the Karroo Basin. It has been possible on lithological grounds to subdivide the strata constituting the Southern, Western and Northern Ecca Facies into three well defined groups, but due to the lithologically homogeneous nature of the Central Ecca Facies it has not yet been possible to subdivide these beds into smaller units.

B. STRATIGRAPHIC NOMENCLATURE

Truswell (in press) has pointed out the drawbacks to the code of stratigraphic nomenclature currently used in South Africa, and has recommended that the proposals of the International Subcommission on Stratigraphic Nomenclature be adopted. The writer agrees with these recommendations in principle and throughout this chapter an attempt has been made to avoid the use of chronostratigraphic terms in describing the lithostratigraphy of the Ecca and Lowermost Beaufort Beds.

It is felt that to completely change the present stratigraphic nomenclature would be to destroy much of what has already been built up, at a time when more than half the Ecca and Lowermost Beaufort outcrop belts have only been mapped on a reconnaissance scale, and less than a dozen boreholes have penetrated the complete succession of these beds in the southern half of the basin.

Use of the terms Lower, Middle and Upper Ecca Stages to define various lithostratigraphic units within different facies of the Ecca Series implies that these are all chronostratigraphic. This is certainly not the case and therefore it is suggested that the Lower, Middle and Upper Ecca Stages within the different facies be changed to Lower, Middle and Upper Ecca Groups, thereby implying a lithostratigraphic meaning. It should also be realised that although the terms Lower, Middle and Upper are normally used in chronostratigraphy, they are retained here to avoid confusion.

By definition, "a group consists of two or more formations" and a formation is "the fundamental unit in rock stratigraphic classification. A formation is a body of rock characterised by lithologic homogeneity, it is prevailingly but not necessarily tabular and is mappable at the earth's surface or traceable in the subsurface". (American Commission on Stratigraphic Nomenclature 1961).

It may be argued that certain lithostratigraphic units within the Ecca should be termed formations rather than groups, as they are composed of a homogeneous lithology. An example is the Lower Ecca Shale of the Northern Ecca Facies. However, it has already been shown by King (1948) that this unit is subdivisible into two distinct formations in the vicinity of Pietermaritzburg and it is felt that more detailed mapping will

- reveal -

reveal the presence of two or more formations within this sequence over wide areas. According to the American Commission on Stratigraphic Nomenclature (1961) the term group may be applied to stratigraphic units "that appear to be divisible into formations but which have not yet been so divided". It was not within the scope of this study to recognise and define every possible mappable formation within the Ecca Series and Lowermost Beaufort Beds, but rather to gain an understanding of the generalised stratigraphy and then to consider whether a gross reclassification of the present stratigraphic nomenclature was in fact necessary at this stage.

The wedge-out of a component formation or formations within a group may justify the reduction of the group to the rank of formation, but retaining the same name. For example, in southern Natal it may become impossible to recognise more than one formation within the Middle Ecca Group and therefore this unit should be referred to as the Middle Ecca Formation in this area.

Normally a group and a formation are prefixed by a geographic name, as for example the Vryheid Group and the Tugela Formation, but it was considered preferable at this stage of our knowledge to retain the terms Lower, Middle and Upper until such time as the entire basin has been mapped in more detail and additional information exists regarding the detailed stratigraphy. In this respect it should be realised that the stratigraphic nomenclature and correlations within certain North American Systems has become highly confusing through the uncontrolled application of locality names to various formations within

- relatively -

relatively small areas. This has seriously hindered the development of a unified and accurate stratigraphic and paleogeographic framework for certain extensive sedimentary basins. An outstanding example is the Permian System of the Colorado Plateau (Baars 1962).

The important point is that the term stage must be dropped and replaced by the term group. When the stratigraphy is more fully understood it is then recommended that the various groups be prefixed by appropriate locality names in order to bring this terminology into keeping with international usage.

C. THE SOUTHERN ECCA FACIES

Rocks belonging to the Southern Ecca Facies outcrop along the southern structural margins of the basin and form an outcrop belt 10 to 15 miles wide, extending from Matjiesfontein in the west to the Indian Ocean in the east, a distance of nearly four hundred miles (see folder 3). Deep drilling by the Southern Oil Exploration Corporation in the districts of Laingsburg, Fraserburg, Beaufort West and Murraysburg has revealed that these rocks occur at depth below the Beaufort Series to the north of the outcrop belt. Between the Bashee and Umtata rivers in the Transkei, there is a narrow outcrop belt of rocks which are believed to form part of the Southern Ecca Facies.

The boundary of the Southern Ecca Facies with that of the Central Ecca Facies to the north (folder 2) is taken at the estimated limit of the Southern Ecca sandstones which wedge out in a northerly direction. The contact with the Western Ecca Facies is gradational and a considerable amount of overlapping and interfingering takes place.

This facies is confined to the Karroo Trough and reaches a maximum thickness of about 10,500 feet in the axial portions north of Grahamstown. The succession becomes progressively thinner towards the margins as well as in a general westerly direction (see folders 1 and 2).

In the southern outcrop belt, this facies may be subdivided on lithological grounds into the Lower, Middle and Upper Ecca Groups.

1. <u>The Lower Ecca Group</u>

This group of rocks rests conformably on the White Band which forms the top of the Upper Dwyka Shale in this area. The group may be further sub-divided into a Lower Argillaceous Formation, containing scattered sandstone beds and an Upper Arenaceous Formation composed mainly of sandstone and siltstone.

Near Matjiesfontein in the west, the Lower Argillaceous Formation is over 2,000 feet thick (Kingston et al. 1961), but becomes thinner towards the east. Near Klipplaat it is about 400 feet thick (Haughton et al. 1953) and at Ecca pass, north of Grahamstown, is only about 100 feet thick. The progressive thinning of the Lower Argillaceous Formation towards the east may best be explained by non-deposition of sandstone in the upper portion of this Formation in the west and the progressive increase in sandstone deposition towards the east.

Rocks of the Upper Arenaceous Formation partly overlie and partly interfinger with rocks of the Lower Argillaceous Formation and occur at progressively lower stratigraphic horizons towards the east (Haughton et al. 1953). North-west of Matjiesfontein these sandstone beds wedge out completely. Along the southern outcrop belt the Lower Ecca Group increases in thickness from west to east as shown in table 2.

TABLE 2

THICKNESS OF LOWER ECCA GROUP

Locality		Average thickness	No. of Measurements
Dwyka River - Strydomsvlei	+	1,9[illegible] feet	32
Strydomsvlei - Korenkraal	+	2,6[illegible]5 feet	5
Volstruisleegte - Klipplaat	+	2,150 feet	-
North-west of Wolwefontein Station	+	2,200 feet	10
North of Grahamstown	•	3,[illegible] feet	-

• Information supplied by M. Johnson of the Geological Survey.

\+ Haughton et al. (1953).

The Lower Argillaceous Formation is composed of a basal succession of greenish-grey shale, rhythmically interbedded with beds of yellow illitic clay and strongly resembling the beds immediately below the White Band. Hard, black, cherty shales occur near the base and display sharp contacts with associated beds of illitic clay. Phosphatic nodules occur in these beds. According to Haughton et al (1953, p. 25) this basal succession has an average thickness of 150 feet. These beds grade upwards into a succession composed of bluish-green indurated shale, which on exposure disintegrates into masses of elongate fragments, and fine-grained bluish-grey sandstone. These sandstone beds display sharp contacts with the underlying shales and usually grade upwards into shale. Lateral continuity of bedding is well developed and these sandstones maintain an even thickness over considerable distances.

Sole casts, graded bedding and asymmetrical ripple marks occur in the Lower Argillaceous Formation. Fossil plant fragments and invertebrate trails and tracks are fairly common.

Rocks of the Upper Arenaceous Formation partly overlie and partly interfinger with rocks of the Lower Argillaceous Formation and occur at progressively lower stratigraphic horizons towards the east (Haughton et al 1953). North-west of Matjiesfontein these sandstone beds wedge out completely. This formation is composed of fine-grained mottled sandstone, siltstone and shale. The sandstone is usually dark grey, very compacted, and often resembles quartzite. Shale pebble conglomerate and isolated fragments of shale occur locally. Shale within the formation is greenish-grey, very indurated and breaks up into splintery fragments. The sandstones display sharp contacts with the underlying shales and grade upwards into shale. Lateral continuity of bedding is well developed and even thicknesses are maintained over considerable distances.

Sole casts, ripple marks, graded bedding, slump structures, load structures, ball-and-pillow structures, convolute laminations and sandstone dykes are the most abundant primary sedimentary structures. Turbidity structures are more abundant in the central and eastern portions of the basin indicating that much of the sediment in this area was deposited by means of turbidity currents. Fossil leaf impressions and silicified wood have been found at a number of localities (Haughton et al 1953).

- Recently -

Recently completed SOEKOR boreholes 49, 61, 62 and 63 (see folder 1) have shown that the Lower Ecca Group is composed almost entirely of shale north of the southern outcrop belt, indicating that a facies change has taken place from south to north and that the source of the sediments lay to the south. The greater abundance of sandstone in the succession to the east suggests that uplift and subsidence of source and depositional areas was probably more active in this area.

Due to the gradation of Lower Ecca Sandstone into shale towards the north, it becomes very difficult to determine the upper limit of this group on lithological grounds and, therefore, accurate thickness measurements are virtually impossible (see folder 4).

Good exposures of what may be the equivalent of the Lower Ecca Group occur as cliffs along the Wild Coast at places such as Umtata Mouth, Coffee Bay and "Hole in the Wall". In these areas the Ecca is composed of dark-grey fine-grained sandstone, siltstone and shale. Thin beds of chert occur locally. Sole casts, small-scale cross-bedding, slump structures, load structures and remarkable exposures of sandstone dykes and sills occur in these rocks. North of the Umtata River, sandstones of this group wedge out fairly rapidly in a northerly direction indicating a southerly source for these sediments.

2. The Middle Ecca Group

The Middle Ecca Group is composed mainly of a thick succession of bluish-black shale resting conformably on and

locally -

locally interfingering with rocks of the Lower Ecca Group (see folder 4). Those sediments normally give rise to a flat-lying belt of country between parallel ranges of hills formed by the more resistant sandstones of the Lower and Upper Ecca Groups. Sandstone zones occur at varying positions in the succession and become particularly abundant near the top to the east of Klipplaat. The upper contact of this group is taken at the base of the first prominent sandstone zone, above which the succession becomes predominantly arenaceous.

Table 3 shows that the group thickens in an easterly direction. Johnson (personal communication) reports an average thickness of 3,000 feet for the area north of Grahamstown and Kingston et al ([illegible]) measured [illegible] feet at more or less the same area.

It is believed that the decrease in thickness between Angora and the area north of Grahamstown is probably only apparent and is due to the deposition of Upper Ecca Sandstone at a relatively lower stratigraphic level in this area.

TABLE 3

THICKNESS OF MIDDLE ECCA GROUP

Locality		Average thickness	Maximum thickness
Western Portion	+	2,740 feet	3,735 feet
Hops River	+	4,[illegible]30 feet	-
Angora	+	4,700 feet	-
North of Grahamstown	*	3,000 feet	[illegible],900 feet

+ Haughton et al (1953).

* Johnson (personal communication)

- Ripple -

Ripple marks with large wave lengths relative to their amplitude occur throughout this group, and Haughton et al (1953) report the presence of silicified wood and indeterminate plant fragments near the top. Invertebrate tracks and trails are fairly common, but the most interesting feature is a series of parallel, regularly sinuous scratch markings first described by Haughton (1928) and thought by him to have been caused by the ventral fins of fishes (see fig. 50). Similar markings were observed in bluish-grey shales at Five Kings bridge on the Bashee River in the Transkei.

Due to correlation difficulties outlined above it was not possible to determine thicknesses of this group in bore-holes north of the outcrop belt.

3. The Upper Ecca Group

Rocks constituting the Upper Ecca Group rest conformably on and interfinger locally with the Middle Ecca Group (see folder 4). It consists of a succession of greenish-grey fine to medium-grained sandstone, and dark-grey to blue-grey shale and mudstone. As a rule lateral continuity of individual beds is not well developed.

The sandstones are usually mottled and contain dark lenses and bands of marl and ferruginous limestone. The shale in the lower portion of the succession strongly resembles that of the Lower Ecca Group but can always be identified by the abundance of ripple marks. In fact it is usually possible to find ripple marks at almost every outcrop of this shale. Large-scale planar cross-bedding, scour channels, slump structures, shale pebble conglomerate and parting lineations, are common.

-- Medium --

Medium-scale planar cross-bedding, scour channels and parting lineations, are distinctive of this unit.

Table 4 illustrates that the change in thickness of the group from west to east, along the outcrop belt, is variable, but that a general thickening in an easterly direction takes place.

TABLE 4

THICKNESS OF UPPER ECCA GROUP

Locality		Average thickness
Dwyka River	+	1,950 feet
Gamka River	+	2,[illegible] feet
Prince Albert	+	1,280 feet
Zwart Kraal	+	2,100 feet
As Kop	+	1,450 feet
North of Miller Station	+	2,680 feet
South of Saxony	+	3,125 feet
South of Jansenville	+	2,600 feet
North of Grahamstown	•	4,100 feet

\+ Haughton et al (1953)

• Johnson (personal communication)

A thickness of 2,620 feet for the Upper Ecca Group in the Sambokkraal borehole (see borehole number 40, folder 1) compared to 1,950 feet at the Dwyka River in the outcrop belt to the south suggests that the group thickens northwards in this area. However, deep drilling north of the outcrop belt clearly indicates that the sandstones of the Upper Ecca Group, as was the case in the preceding two groups, wedge out in a northerly direction from the axis of the Karroo Trough.

- Sandstones -

Sandstones of this group extend farther north than any of the preceding sandstones, and indicate a northward advance of the depositional trough, or rapid uplift of the source area, or a combination of the two (see folder 4). The upper contact of this group, as already stated, is taken at the base of the first purple shale zone.

D. THE WESTERN ECCA FACIES

Rocks constituting the Western Ecca Facies outcrop along a belt five to twenty miles wide, between Matjiesfontein in the south and Calvinia in the north (see folder 2 and 3).

In the southern part of the outcrop belt, the beds are somewhat folded and have an east-west strike, but farther north the strike changes to more or less north-south, and the beds have gentle dips towards the east. These features can be explained in terms of the regional tectonics of this area.

The Roggeveld escarpment, which is capped by beds belonging to the Beaufort Series, constitutes an outstanding physiographical feature and in places rises over 3,000 feet above the plains to the west. The escarpment is more sharply defined north of the Tanqua River, a feature which Rogers and Du Toit (1903) believe to be due to the protective effects of the dolerite sills in this area. South of this river, and beyond the extent of the dolerites, the escarpment becomes deeply dissected by the Tanqua, Ongeluks, Groot and Smits Winkel rivers, resulting in the highly dissected country forming the Koedoesberg and Little Roggeveld mountains.

On the farm Klip Drift twenty miles south-west of

- Sutherland -

Sutherland, the thickness of this facies as revealed by the deep borehole is about 5,000 feet (see borehole No. 60, folder 1). The facies thins out fairly rapidly towards the north and west from this locality, but thickens in an easterly direction along the axis of the Karroo Trough (see folders 1 and 2).

This facies may be subdivided on lithological grounds into the Lower, Middle and Upper Ecca Groups. Due to a fairly rapid facies change from sandstone into shale towards the north-east and east, it becomes increasingly difficult to recognize these three groups as one proceeds northwards along the Roggeveld escarpment.

The eastern boundary of this facies with that of the Southern Ecca is transitional (folder [illegible]), and it is only by the careful consideration of relative stratigraphic positions of sandstone formations, facies changes and palaeocurrent directions that a distinction may be made. The estimated boundary with the Central Ecca Facies to the north and north-east is taken where sandstones of this facies are predicted to wedge out.

1. The Lower Ecca Group

Between Laingsburg and Matjiesfontein, the Upper Arenaceous Formation of the Southern Ecca Facies becomes thinner in a westerly direction. At the same time the Lower Argillaceous Formation becomes progressively thicker. About twelve miles north-west of Matjiesfontein, and along the valley of the Groot River, the Upper Arenaceous Formation is only represented by a few thin zones of fine-grained sandstone and siltstone. Still farther to the west, the Lower Ecca is composed almost entirely of shale.

- At -

At first sight it would appear that the Upper Arenaceous sandstones were derived from a source lying to the east or south-east and that they grade progressively into shales towards the west and north-west. However, paleocurrent measurements in this area have shown that the sandstones of the Upper Arenaceous Formation were derived mainly from a southerly source and that the underlying and overlying predominantly argillaceous sediments were mainly derived from a source lying to the west and south-west. It is therefore possible on the basis of paleocurrent measurements to distinguish the Upper Arenaceous Formation of the Southern Ecca Facies from the Lower Ecca Shales of the Western Ecca Facies. Eastwards from Matjies-fontein the exact amount of overlapping and interfingering of shales belonging to the two facies is not yet fully understood, but detailed paleocurrent studies may throw more light on this problem.

The succession immediately above the White Band is composed of hard bluish-black shales interbedded with thin beds of yellow illitic clay. Impersistent chert beds are also present. Lying conformably above this is a few hundred feet of softer bluish-black shale often weathering to a khaki colour. Calcareous nodules with diameters of up to 18 inches are abundant in this shale and thin beds of limestone also occur. Both the limestone beds and the calcareous nodules exhibit well developed cone-in-cone structures, good examples of which can be seen on Bovenste Wagen Drift, about thirty two miles west of Sutherland. Rogers and Du Toit (1903) found fossilized leaves and wood in these beds.

- The -

The general lithological character of the rocks constituting this group remains more or less unchanged from the valley of the Groot River in the south to beyond Calvinia in the north. The outcrop belt formed by this group is usually represented by a broad plain in the west, but forms the lower flanks of some of the higher mountains in the east, such as the Koedoesberg, Schoorsteenberg and the Roggeveld escarpment.

Rogers and Du Toit (1903) measured 1,400 feet of Lower Ecca shale in the vicinity of Schoorsteenberg about eight miles west of the Koedoesberg mountains. Due to a rapid facies change, the overlying basal sandstones of the Middle Ecca Group grade rapidly into bluish-black shale towards the east and north-east, thereby making it virtually impossible on lithological grounds to recognise the boundary between these two groups towards the east and north-east.

2. The Middle Ecca Group

Rocks of this group rest conformably on and interfinger locally with shales of the Lower Ecca Group. It is composed of hard bluish-grey shale (± 60%), siltstone, fine-grained thinly-bedded sandstone and thick massive-bedded sandstone.

The massive sandstones are usually light-grey, fine-grained and reach maximum thicknesses of 100 to 200 feet at Schoorsteenberg. From this locality they thin out rapidly along the flanks of the Koedoesberg and finally grade into shale towards the north-east. Vertical jointing is very well developed in these sandstones and large rectangular blocks often strew

- the -

the hillslopes, below cliffs composed of this rock (see fig. 3). Good exposures of massive sandstone also occur along the southern flanks of the Little Roggeveld mountains and may be traced eastwards to Dwars-in-die-weg, about twelve miles north of Matjiesfontein. Farther east the sandstones of this group gradually wedge out and grade into shale, so that ultimately it is only possible on the basis of paleocurrent directions to distinguish rocks of this group from those of the Middle Ecca Group of the Southern Facies.

Various types of ripple marks are abundant in the siltstones and thinly-bedded sandstones. In the southern part of the outcrop belt interference ripple marks are fairly abundant and good examples were found on the farms Bantamsfontein and Waterval. A significant feature of the thinly-bedded sandstones in the southern part of the area is the tendency for successive beds to contain ripple-marked surfaces. Furthermore, the average strikes of ripples in succeeding beds tend to be at appreciable angles to each other, the predominant directions being approximately north-south and northwest-southeast. This is evidence of a depositional environment wherein the current directions fluctuated with considerable frequency.

During the present study fossilised wood was found in these beds on the farm Vogelstruisfontein, about twelve miles northwest of Matjiesfontein and worm trails and tracks are abundant, as for example at outcrops in the Tanqua River on the farm Waterval. Rogers and Du Toit (1903) report the occurrence of indistinct plant remains in these beds.

3. The Upper Ecca Group

Sediments of the Upper Ecca Group rest conformably on, and interfinger locally with, rocks of the Middle Ecca Group. This unit is composed of hard grey shale, thinly-bedded sandstone and siltstone and thick massively-bedded sandstone. The sandstone is usually fine-grained, grey and mottled. Various types of ripple marks are abundant in this group, particularly in the thinly-bedded sandstone and siltstone.

Good exposures of this group may be seen in the Koedoesberg, where massive sandstones form lofty cliffs capped by a thin succession of Lowermost Beaufort (see fig. 4). These massive sandstones grade into thinly-bedded sandstones and shales towards the east and north-east, as they are followed from the Koedoesberg into the Tanqua Valley, and then northwards along the Roggeveld escarpment. Ultimately all the sandstone of this group grades into shale and at this point the Western Ecca Facies is composed entirely of shale, and passes into the Central Ecca Facies. The northernmost sandstones of this group may be seen in the Hantamsberg north of the town of Calvinia. Good outcrops of this group also occur along the rugged south-facing slopes of the Little Roggeveld mountains, where it is possible to see massive beds of sandstone thinning out towards the east and north-east, in which directions the succession becomes more argillaceous. Farther to the east beds of this group are thought to interfinger with those of the Upper Ecca Group of the Southern Ecca Facies.

Local disconformities, contemporaneous erosion channels, shale pebble conglomerates, parting lineations and

- compaction -

compaction structures occur in these beds. Rogers and Du Toit (1903) record the presence of *Gangamopteris*, *Glossopteris*, *Schizoneura* and *Phyllotheca*. In addition, trails and tracks are fairly common.

E. THE NORTHERN ECCA FACIES

Rocks of this facies are confined to the northern part of the basin and form an outcrop belt ten to a hundred miles wide. This belt extends from north of Bloemfontein in the west to Witbank in the north and then southwards as far as the Umtamvuna River, a total outcrop length of about 600 miles (see folders 5 to 8). The Natal Monocline and associated faulting has caused rocks belonging to this facies to occur at various localities along the Natal coast as well as northwards into Zululand and Swaziland, where they outcrop as a narrow belt 5 to 10 miles wide (see folders 6 and 7).

The entire western part of the outcrop belt forms a featureless plain, the monotony of which is only broken by shallow depressions known as pans, and also by valleys formed by the major rivers, along which outcrops are occasionally encountered. The topographical relief of the outcrop belt, in the north and east, varies from gently undulating to mountainous, and exposures are good.

The estimated boundary of this facies with that of the Central Ecca Facies is taken at the southernmost limit at which sandstone occurs. This facies is thought to have reached a maximum thickness of about 4,000 feet in the Natal Trough, from where it thins out in a northerly and north-westerly direction (see folders 1 and 2). This feature may be partly explained by the lapping out of individual beds against a broad topographically high-lying area on the pre-Karroo surface and partly by the thinning of individual beds. A number of large stratigraphic disconformities are known to occur in this area.

Looked at in regional terms, sandstones within this facies are coarser-grained, thicker and more numerous towards the north-east, in which direction is thought to have lain the source. In addition, these sandstones are coarser-grained, relatively better sorted and less indurated than sandstones in the Southern and Western Ecca Facies. On lithological grounds the Northern Ecca Facies may be divided into the Lower, Middle and Upper Ecca Groups. The Lower and Upper Ecca Groups are composed mainly of shale while the Middle Ecca is composed of sandstone, grit, conglomerate, shale and coal seams.

Far more is known about the stratigraphy of this facies, for it is in these rocks that the economically important coal deposits occur.

1. The Lower Ecca Group

In southern Natal this group is composed entirely of bluish-black, micaceous shale and flagstone (see fig. 5). It occurs as a regular belt six to ten miles wide extending northwards from the Umtamvuna River, where the Middle Ecca Sandstones of the Northern Facies make their first appearance. The time-stratigraphic equivalents of this group are undoubtedly represented in the Central Ecca Facies, but to date it has not

- been -

been possible to recognise the upper boundary of this unit in the field. King (1948) found that in the vicinity of Pietermaritzburg it was possible to sub-divide this group into an 800 foot thick "Lower Zone", composed of a monotonous succession of shale and flagstone, and a 300 feet thick "Upper Zone" composed of micaceous clayey shale. During the present study, it was possible to trace the "Upper Zone" more or less continuously along the main outcrop belt between Greytown and the Umtamvuna River. Throughout northern Natal this group is composed entirely of bluish-black shale, and north of the Natal border these rocks outcrop along the base of a belt of highly dissected country constituting the Eastern Escarpment. Outcrops have been found as far as the Taaibos River, latitude 26°54'. North of this point sedimentary overlap takes place and the Middle Ecca comes to rest directly on either the pre-Karroo surface or the Dwyka Tillite (see folder 9). In the vicinity of the Assegaai and Taaibos rivers, only isolated occurrences of these rocks are found resting unconformably on Basement granite and rocks of the Swaziland System. These occurrences apparently represent localized pre-Karroo depressions wherein shales of this group were deposited. The Lower Ecca Shale of the south-eastern Transvaal is slightly different in appearance to the typical bluish-black variety found in Natal, in that it weathers to a brown or buff colour and is more arenaceous near the top.

Drilling has revealed that rocks of this group extend westwards from the outcrop belt, but wedge out against the pre-Karroo surface at about longitude 28° where they are overlapped by rocks of the Middle Ecca Group. In the western part of the basin, between Brandfort and the Orange Free State Goldfields shale closely resembling that of the Lower Ecca is found lying between Dwyka Tillite and typical Middle Ecca Sandstone. It is uncertain whether this shale is -

1. The fine-grained facies equivalent of the Middle Ecca Group.
2. The time-stratigraphic equivalent of the Upper Dwyka Shale.
3. The time-stratigraphic equivalent of the Lower Ecca Shale of northern Natal.
4. A combination of these possibilities.

Lower Ecca Shale outcrops at a number of localities along the Natal coast, for example at Port Shepstone, Ifafa Beach Scottburgh, Umgababa and in a more or less continuous belt from the Umgeni River in the south to the Tugela River in the north.

In the Lebombo Belt of Swaziland, outcrops of typical Lower Ecca Shale are mainly found in the south (Scogings 1957) and none have been reported north of the Great Usutu River. It is, therefore, possible that north of this area sedimentary overlap takes place and the Middle Ecca Group comes to rest unconformably on pre-Karroo formations or disconformably on the Dwyka Tillite. Unfortunately, the precise relationship is complicated by faulting.

Over most of southern Natal, the Lower Ecca Shale rests directly on typically massive Dwyka Tillite or stratified fluvio-glacial sediments with a sharp contact. In this respect, it is of importance to note that the Upper Dwyka Shale found in the Karroo Trough is apparently not represented. The contact is everywhere an even and regular surface giving the impression of continuous sedimentation. Du Toit (1920) regards the apparent absence of the Upper Dwyka Shale as evidence of a hiatus, which becomes more apparent farther north. Krige (1932) found exposures of what he considered to be Lower Ecca shale resting unconformably on Dwyka Tillite and Table Mountain Sandstone nine miles north-west of Durban. On the other hand Kent (193[illegible]) found that the fluvio-glacial sediments at the top of the Dwyka Series, 25 miles north of Durban, grade imperceptibly into typical Lower Ecca Shale.

Throughout northern Natal the Lower Ecca Shale rests disconformably on Dwyka Tillite or unconformably on pre-Karroo rocks where the Dwyka is not represented. In the belt of country at the foot of the Escarpment, between the Natal border and Sheepmore, the Dwyka Tillite is absent and the Lower Ecca Shale rests unconformably on pre-Karroo formations. Farther east, and along the Swaziland-Transvaal border, the tillite again intervenes between the Lower Ecca and the pre-Karroo surface. In view of the evidence of a hiatus between the Dwyka Tillite and the Lower Ecca Group, it is thought that this north-easterly trending belt may be a pre-Karroo ridge from which the unstratified glacial material was eroded in the time interval which followed retreat of the glaciation and preceded deposition of the Lower Ecca Shale.

Throughout the entire extent of the Lower Ecca Group, its upper contact with the Middle Ecca Group is gradational and is usually taken at the base of the first prominent sandstone above which the succession becomes predominantly arenaceous.

- In -

In southern Natal this group thins in a northerly direction as indicated by the following thicknesses -

Harding	1,400 feet
Pietermaritzburg	1,100 feet
Greytown	1.000 feet
Tugela Valley	[illegible]00 feet

In the vicinity of Durban the group reaches a maximum thickness of between 1,500 and 1,900 feet (Krige 1932, Kent 193[illegible]) and at [illegible] the total thickness is 1,100 feet (Du Toit 1918). This indicates that maximum sediment accumulation took place in the Natal Trough.

North of the Tugela River this group varies considerably in thickness, but there is a general thinning to the north. In the vicinity of the Natal-Transvaal border it averages 150 feet and becomes progressively thinner towards the Assegaai River. In southern Swaziland the average thickness of this group is approximately 2[illegible] feet ([illegible] 1952).

[illegible] (194[illegible]) records the presence of indistinct leaf impressions in the vicinity of Pietermaritzburg but macrofossils are generally rare in this group. Du Toit (1931) found a unique occurrence of carbonaceous shales interbedded with thin coal layers, immediately above the Dwyka Tillite south-east of [illegible].

2. The Middle Ecca Group

Rocks of the Middle Ecca Group are known to outcrop as a continuous belt between the Umtamvuna and Tugela rivers. North

- of -

of this, the group spreads out to cover large areas of northern Natal. It also extends north-eastwards into Zululand and then northwards along the Lebombo [illegible] into Swaziland and beyond. Down-faulted blocks of Middle Ecca strata occur at various points along the Natal coast as for example at Port Shepstone and [illegible]. In the south-eastern Transvaal rocks of this group are well exposed along the Eastern Escarpment and extend westwards over extensive areas of the Highveld. The group is poorly exposed over large areas of the northern and central Orange Free State and drilling has indicated that rocks of this group [illegible] of the position of a line joining Bloemfontein and [illegible].

The type area of the Middle Ecca is in northern Natal, where it occurs as a wedge of predominantly coarse clastics sandwiched between the argillaceous Lower and Upper Ecca Groups. It lies conformably on the Lower Ecca Shale and is composed mainly of coarse-grained sandstone, micaceous siltstone, carbonaceous shale, coal seams and occasional beds of limestone.

Blignault and Furter (1947) mapped extensive areas in the vicinity of Vryheid and Utrecht and were able to recognise the following lithological units within this group -

	Maximum thickness
5. Upper Transition Beds	-
4. Upper Sandstones	350 feet
3. Coal Zone	700 feet
2. Basal Sandstones	[illegible]50 feet
1. Lower Transition Beds	350 feet

In this study, these same names are retained with minor variations but are termed formations in order to denote their lithostratigraphic character. Normally a formation is given a locality name, but in this case it is considered preferable to retain the old names as these are already in general use.

The Lower Transition Formation

This formation rests conformably on the Lower Ecca Shale, and is composed of 150 to 350 feet of alternating beds of sandstone and shale (Blignaut and Furter 1940). The lower contact is taken at the base of the lowermost bed of sandstone.

In general, the shales of this formation are bluish-grey and become more carbonaceous near the top. Sandstone beds are thicker and more abundant near the top and sometimes contain cross-bedding.

The Basal Sandstone Formation

Over large areas of northern Natal this formation is composed of thick beds of coarse sandstone, which form prominent cliffs and rest conformably on the Upper Transition Formation.

The thickness varies from 250 to 350 feet and good exposures occur in the Vryheid district. Cross-bedding is a common feature.

The Coal Formation

Blignaut and Furter (1940) defined the Coal Zone as

- "the -

"The coal-bearing series of shales and sandstones occurring between the lowest coal seam situated near the top of the basal sandstones, and the topmost seam, contained in most instances in the base of the Upper Sandstones". However, in this study the Coal Formation is defined as the coal bearing strata between the top of the Basal Sandstone Formation and the base of the Upper Sandstone Formation.

Reasons for making this change are -

1. The Basal and Upper Sandstone formations are easily identified and mapped in the field, and therefore the upper and lower limits of the intervening beds are automatically demarcated.

2. The thin seams (a few inches thick) interbedded with the Basal and Upper sandstones are very local in their extent and therefore do not form good stratigraphic reference.

3. There is no vertical overlap of the three formations as was the case with the old definition.

Resting conformably on the Basal Sandstone Formation is a succession of coarse sandstones and shales. Higher up in the succession lenticular beds of conglomerate, of fluvial origin, become more abundant. The economically important coal seams occur over a vertical distance of 100 to 150 feet, and in ascending order are the Swaine, Dundas, Gus and Alfred seams. The sediments associated with the coal seams are coarse sandstones and micaceous shales. Planar cross-bedding is very well developed in the coarse clastics of this formation.

The Upper Sandstone Formation

This formation is mainly composed of about 300 feet of white sandstone forming prominent cliffs at many points along

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the Escarpment. The Eland seam occurs locally in the basal portion of this sandstone, and at the top there is an oil shale not always well developed but extending over wide areas. The contact with the Upper Transition Formation is gradational. Various types of trough cross-bedding are abundant in these sandstones.

Upper Transition Formation

Lying conformably above the Upper Sandstone Formation is about 50 feet of alternating sandstones and shales which grade upwards into typical bluish-black shale of the Upper Ecca Group.

In the south-eastern Transvaal the plateau or highveld is largely built up of rocks of the Middle Ecca. The best exposures are found along the highly dissected and mountainous country constituting the Great Escarpment, and forming the eastern edge of the Transvaal plateau. Inliers of Middle Ecca are found below the Upper Ecca shale at a number of localities on the plateau, especially where larger tributaries of the Vaal have cut deep valleys. Examples are the Schulpspruit, near Amersfoort, and the Sandspruit about ten miles west of Volksrust. Numerous outliers occur east of the Escarpment, such as Tafelberg, [illegible], [illegible] mountain and around the town of Amsterdam. North of the northern erosion limit of the Karroo Basin there are a number of detached outliers of Middle Ecca, for example around Belfast, and north of Middelburg and Bronkhorstspruit.

Due to the well exposed nature of the Middle Ecca

Group along the Eastern escarpment in the south-eastern Transvaal, it has been possible to recognise the same five subdivisions of the Middle Ecca as recognised by Blignaut and Furter (1940) for the Vryheid area of Northern Natal.

The five sub-divisions are -

		Thickness
5.	Upper Transition Formation	50 feet
4.	Upper Sandstone Formation	250 feet
3.	Coal Formation	450 feet
2.	Lower Sandstone Formation	300 feet
1.	Lower Transition Formation	50 feet
	Total	1,100 feet

It is important to note that, although the succession in the south-eastern Transvaal is essentially the same as in Natal, the following variations exist -

1. The various formations constituting this group are thinner than in northern Natal.
2. The Lower Transition Formation only occurs where the Lower Ecca Shale is present (see Folder 1).

Coarse grits and pebble masses form an integral part of most sandstones, especially in the Coal Formation. Pebble types found are felspar, granite, quartz, dark and light-coloured quartzites, sheared quartzites, Waterberg quartzites, chert and rocks from the metamorphic aureole of the Bushveld Igneous Complex.

East of Ermelo, the escarpment again affords a good section of the Middle Ecca, where once again it is possible to

- recognise -

recognise the same stratigraphic succession as occurs near Vryheid.

In the area between Lake Chrissie and Middelburg only the lowermost portion of the Middle Ecca has not been denuded, and it is interesting to note that over most of this area the lowest coal seam lies less than 100 feet above the average elevation of the pre-Karroo floor. This indicates a considerable rise in the latter at the expense of the Lower Ecca Shale, Lower Transition Formation and lowermost portion of the Basal Sandstone Formation (see folder 9).

On the Highveld Plateau, to the west of the Escarpment, drilling has shown the stratigraphy of the Middle Ecca to be essentially the same as along the Eastern Escarpment but it becomes increasingly difficult to recognise the various formations within this group the farther one goes to the south-west. In the vicinity of Witbank and Middelburg the Number 1, or lowermost coal seam, lies only a few feet above the Dwyka Tillite, and the Basal Sandstone is absent, once again indicating progressive sedimentary transgression in a northerly direction (see folder 9).

In the high ground along the northern margins of the basin where the upper levels of the Middle Ecca are still preserved, drilling has shown a zone of massive white sandstone, over 70 feet thick, above the Number 5 or top coal seam. It is almost certain that this zone represents the Upper Sandstone Formation. Abundant trough and scoop cross-bedding were observed in these beds.

- Continued -

[illegible] ([illegible]) reports that the lower portion of the Middle Ecca Group was not deposited over large areas of the north-western Orange Free State, and in some places the entire group is absent, so that the Upper Ecca Shale rests directly on reworked Dwyka tillite or pre-Karroo formations. [illegible] believes that the undulating nature of the pre-Karroo landsurface in this area is the reason for the non-deposition of certain portions of the Ecca.

In Swaziland, outcrops of Middle Ecca are more abundant in the south and are normally found in streams, road and railway cuttings. It is strikingly similar in lithology to that along the Escarpment. The same five sub-divisions established by Blignaut and Furter ([illegible]) in the Vryheid area are also clearly recognisable in Swaziland (see table [illegible]). The main differences are -

1. A total of [illegible] seams are known to occur in the Coal Formation.
2. The sandstones and grits are considerably coarser-grained and more angular.
3. Conglomerates and pebble bands are more abundant than elsewhere.
4. The Upper Transition Formation contains thin limestone beds.

The five formations recognised by Blignaut and Furter ([illegible]) in northern Natal, and traceable over wide areas of the south-eastern Transvaal and Swaziland, are not clearly recognised in the highly dissected country around the Tugela Valley and farther south.

In the Tugela and Mooi valleys the Middle Ecca Group constitutes large flat-topped mountains, on the flanks of which

- are -

[illegible]

[illegible]

Group		Lithology	Average thickness
	Zone 8	Carbonaceous shales and coals	65 feet
	Zone 7	Grey-white sandstone	32 feet
	Zone 6	Carbonaceous shales and coals	56 feet
	Zone 5	Sandstone	30 feet
Upper Ecca Group	Zone 4	Carbonaceous shales and coal seams of workable thickness	90 feet
	Zone 3	Sandstone	35 feet
	Zone 2	Carbonaceous shales and coals	77 feet
	Zone 1	Sandstone with narrow carbonaceous partings	45 feet
	Upper Transition Formation	Alternation of grey shales and sandstones, with intercalations of limestone	310 feet
	Upper Sandstone Formation	Grey sandstone characterized by presence of irregular carbonaceous wisps	230 feet
Middle Ecca Group	Coal Formation	Grey sandstones, grits and gritty sandstones with carbonaceous shales and coal seams	670 feet
	Basal Sandstone Formation	Sandstones and grits with white [illegible] sandstone at the base	200 feet
	Lower Transition Formation	Grey shales and sandstones	650 feet
Lower Ecca Group		Grey-black shales	200 feet

are characteristic benches or cliffs composed of Middle Ecca Sandstone (see fig. 7). At the base, and above the typical Lower Ecca Shale, is the massive "First Sandstone Formation". This unit is approximately [illegible] feet thick and is composed of medium to coarse-grained micaceous sandstone, containing abundant planar cross-bedding. [illegible] and fossil worm burrows are abundant.

Above this sandstone is about 400 feet of soft micaceous sandy shale followed by the massive medium to coarse-grained "Second Sandstone Formation", 150 feet thick and containing abundant planar cross-bedding. It is followed by 250 feet of dark micaceous shale and arenaceous mudstone with thin sandstone beds. Within this formation (see fig. [illegible]), occur the coal seams of [illegible], on the northern side of the Basin (du Toit [illegible]). This formation was examined at a few localities near [illegible] and although no coal seams were encountered, some of the shales were found to be highly carbonaceous.

Next in the succession is the "Third Sandstone Formation"; a medium to coarse-grained [illegible]-bedded felspathic sandstone about 100 feet thick and containing abundant planar cross-bedding.

This formation is followed by [illegible] feet of arenaceous shale and thin beds of sandstone. Lying on these sediments is the "Fourth Sandstone Formation" composed of [illegible] feet of medium to coarse-grained felspathic sandstone and subordinate shaley layers, followed by a bed of coarse grit containing abundant planar cross-bedding. Above this, the sediments become progressively more argillaceous and grade upwards into typical Upper Ecca Shale.

- The -

The Middle Ecca sediments in association with thick dolerite sills, constitute a north-north-easterly trending escarpment from Greytown in the [illegible] to the [illegible] River (see Fig. [illegible]). In this belt of broken country outcrops usually occur at elevations between [illegible] and [illegible],000 feet.

In the belt of country between Greytown and the [illegible] Valley good sections of Middle Ecca are rare, mainly due to the [illegible] and [illegible] of weathering. However, it would appear that the main change in the lithology is a progressive grading of coarse [illegible] into [illegible] shales towards the south-west. These [illegible] [illegible] a characteristic [illegible] or buff-colour and sometimes grade into beds of kaolinite, as for example on the farm [illegible] [illegible], about [illegible] miles north-west of [illegible]. The four sandstone formations so clearly defined in the [illegible] and [illegible] valleys are probably still represented but greatly reduced in thickness.

In the [illegible] Valley and around Pietermaritzburg exposures are more common [illegible] ([illegible]) was able to recognise five different sandstone formations, of which only the third outcrops [illegible] as a prominent [illegible]. This sandstone is [illegible] medium to coarse-grained and contains abundant planar cross-bedding.

Between Pietermaritzburg and the [illegible], good outcrops only occur at a few localities, as for example, the Lovu Valley [illegible], [illegible], in the valley of the [illegible] and in the [illegible] Valley. Here again there is a general thinning of individual sandstone beds and a progressive grading into [illegible] shales towards the south. At a number of localities closely [illegible] were observed, as for example in the road cutting on [illegible] about [illegible] miles west-southwest of [illegible], and about 300 yards below Crystal Range siding, five miles north-east of [illegible]. These become altered to [illegible] in the vicinity of dolerites. The interesting feature of these beds is that they strongly resemble similar beds occurring between the second and third sandstone formations in the [illegible] and [illegible] Valleys, and may be the stratigraphic equivalents of the [illegible] beds. Should this prove to be the case they would act as good lithologic markers in future studies in the area.

It was seen that the coarse clastics of the Middle Ecca Group grade progressively into shale towards the south-east, so that south of the [illegible] River the Middle Ecca is only represented by [illegible] beds of fine-grained sandstone and the Ecca Series as a whole is composed almost entirely of bluish-black shale and siltstone. This does not mean that the time-stratigraphic equivalents of the Middle Ecca were not deposited in this area, but that the fine-grained clastics were transported farther into the depositional basin and deposited in deeper and quieter water conditions (see [illegible]). Thus it follows that the [illegible] occurring above and below the Middle Ecca and [illegible] Upper and Lower Ecca Beds respectively, belongs to the Middle Ecca [illegible] shale. In this respect it is interesting to note that this shale contains a high percentage of kaolin and is probably the result of sedimentary differentiation of detritus rich in kaolin formed from the decomposition of felspars. Some Middle Ecca sandstones in the Transvaal and [illegible] contain over [illegible] per cent felspar.

- Middle -

Middle Ecca sandstone occurs at Port Shepstone, [illegible] and [illegible] a more or less continuous belt running parallel to the coast between the [illegible] and Tugela Rivers. The Middle Ecca sediments are fairly typical in the belt of outcrops along the coast, and it is interesting to note that thin coal seams occur [illegible] miles north-west of Durban ([illegible]) and between [illegible] and [illegible] ([illegible]). In this respect it must be stated that no economically important coal occurrences have so far been reported south of the Tugela River in the main outcrop belt. Cross-bedding is common particularly in the coarse felspathic grits, such as at [illegible] and [illegible] Mouth. Contemporaneous [illegible] folds and slump structures are abundant in the sandstones at [illegible] Mouth.

The Middle Ecca group reaches a maximum thickness of 1,900 feet in [illegible] ([illegible]). It is 1,700 feet in the Tugela Valley ([illegible]) from where it thins out in a northerly direction as is evident from the following average thicknesses:-

Tugela Valley	1,700 feet
Dundee	1,300 feet
Vryheid	1,250 feet
Natal-Transvaal Border	1,100 feet
[illegible]	900 feet

In the northern portions of the basin only the basal portion of the Middle Ecca has not been denuded and therefore it has not been possible to obtain thickness measurements.

Just north of the [illegible] this group is about 100 feet thick and increases rapidly towards the north-east, till

It reaches a maximum of [illegible] feet at [illegible] in the Tugela Valley (see Table 6).

Table 6

Locality	Thickness	Measured by
North of [illegible]	± [illegible] feet	[illegible]
[illegible]	[illegible] feet	Du Toit (1918)
[illegible]	600 feet	Du Toit (1918)
[illegible]	[illegible] feet	[illegible]
South of [illegible]	[illegible] feet	Du Toit (1918)
[illegible]	1,[illegible] feet	Du Toit (1918)
Durban	± [illegible] feet	[illegible]
North of Durban	± [illegible] feet	[illegible]

In the north-eastern Orange Free State the Ecca thins in a general westerly direction as can be seen from the following thicknesses -

Locality	Average Thickness
Near [illegible]	300 feet
Near [illegible]	[illegible] feet
Between [illegible] and Virginia	300 feet
10 miles east of [illegible]	[illegible] feet
[illegible]	[illegible]0 feet

Near [illegible] the Ecca series is composed entirely of shale ([illegible] 1950).

Thus it is apparent that maximum sedimentation took place in the [illegible] trough. It is also apparent that an east-

- west -

[illegible] in the vicinity of the [illegible] Group (see [illegible]).

[illegible] of the [illegible] conventional [illegible] at the top of the [illegible] from which the succession [illegible].

5. [illegible]

The [illegible] composed of [illegible] of [illegible]. [illegible], however, this [illegible].

[illegible]. The [illegible] also [illegible] of the [illegible]. In addition, drilling [illegible] the Lower Beaufort [illegible] Orange Free State.

In [illegible], [illegible] are rare and [illegible] River. However, [illegible] succession [illegible]. [illegible] have been used [illegible] Table 1[illegible]).

It is interesting to note the following differences in the Upper Ecca of Swaziland -

1. Coal seams are present.
2. The coals are characterised by an abundance of pyrite, and by interbedded shale bands and lenses.
3. Sandstones are in greater abundance than elsewhere.
4. The stratigraphy is characterised by a form of cyclic sedimentation.

Except for a small area north of Tugela Mouth these rocks do not occur along the coast. The time-stratigraphic equivalents of this group are undoubtedly represented south of the Umtamvuna River but their lower contact can not be recognized in the field due to the absence of the Middle Ecca sandstones in this area.

Throughout Natal this group maintains a fairly constant thickness. In the vicinity of the Umtamvuna River, the group is 800 feet thick and thins very gradually to about 700 feet in the Tugela Valley. From here the unit thins gradually to about 500 feet between Wakkerstroom and Piet Retief (Du Toit, 1918).

In the vicinity of longitude 27°30' the group is 600 to 700 feet thick and is thought to have originally thickened to an estimated 1,[illegible]00 feet in the Natal Trough. It also thickens westwards to an estimated 1,000 feet in what may have been a subsidiary basin in the western Orange Free State. A general thinning towards the north also occurs. The group is 400 feet thick near Stegi in Swaziland.

- Thickness -

Thickness variations within this group follow more or less the same pattern as those of the Lower and Middle Ecca Groups, although both regional and local variations are less pronounced. This may be explained, firstly by the limited effect of the pre-Karroo topography and, secondly by the relatively slower rates of subsidence within the Natal Trough.

No more were directional sedimentary structures observed in these rocks during the present investigations, but [illegible] recorded the presence of small-scale cross-bedding in fine-grained sandstone on the Volksrust commonage. Nodules and lenses of calcium phosphate are common in these beds particularly near Dundee in Natal. Lenses and nodules of calcium carbonate are also abundant in this group as for example in the Klip River Valley north of [illegible]rton. A further characteristic of the Upper Ecca shale is the presence of ferruginous shale nodules and lenses which sometimes contain fossilised plant remains as for example in outcrops along the Biggersberg in northern Natal.

F. [illegible]

As the name implies, this facies occurs mainly in the central portions of the Karroo Basin (see folder 2). From earlier descriptions of the other facies it must be clear that this facies has a composite provenance. Interfingering deposits from these three different source areas are unified solely by their lithology, being composed almost entirely of bluish-black shale and flagstone. Due to the homogeneous lithology of these beds it has not yet been possible to subdivide this facies up

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into groups of strata. However, the most promising approach towards establishing time-stratigraphic units within the Ecca Series appears to be the use of palynology. Hart (1966) was able to extract well preserved spore and pollen grains from sediments of the Middle Ecca Group of the Northern Facies in the northern and north-western portions of the basin but found that over extensive areas of the Southern Karroo and northern Natal the spore and pollen grains were unrecognisable due to the effects of metamorphism. Davey (personal communication) has recently had considerable success in extracting identifiable spore and pollen grains from cuttings of Ecca Shale from borehole No. 63 (folder 1) in the Southern Ecca Facies. It would, therefore, seem that a micropalaeontological study of the Central Ecca Facies may enable this succession to be subdivided into a number of bio-stratigraphic units.

The Central Ecca Facies rests conformably or disconformably on the Dwyka Series and the upper limit is taken at the base of the first prominent Beaufort sandstone.

In the western portions of the basin, rocks of this facies give rise to flat-lying country intersected by low dolerite ridges. Silicified wood is fairly common near the top and foot prints of small four toed creatures have been found in outcrops of flagstone in the Sak River, Williston district. Excellent examples of parallel scratch marks, thought to have been caused by fishes, occur in flagstones on the farms Hodenbeck and Lower Zwartrand in the Carnarvon district, and good examples of worm burrows were observed in beds near the top of the Ecca on L[illegible]bukop in the Britstown district. Crustacean tracks were found in shales near the base of the Ecca, on the farm Blauwbanks Drift in the Jacobsdal district.

Ripple marks are fairly common near the top of this facies, and impressions of what appear to be plant stems may be found at almost every outcrop. Du Toit (1956) refers to these markings as "fucoid-like structures".

Much of the Central Ecca facies lies beneath a cover of younger rocks in the central portions of the basin, but is again exposed at a number of localities in the Transkei. Here pyrite nodules up to 1½ inches in diameter are fairly common in these beds, as for example in the cliffs along the coast at Umgazi Mouth. Highly carbonaceous shales are also occasionally encountered, as for example near the Wild Coast Inn about 5 1/2 miles north-east of Port St. John's. Thin beds of dark lime-stone and chert were found interbedded with typical bluish-black shale in the road cuttings on the Mlengana Pass about 18 miles west of Port St. John's. Parting lineations are some-times found in flagstones and shales north of Port St. John's.

This facies reaches an estimated maximum thickness of about 4,000 feet along the northern margins of the Karroo Trough and thins out fairly rapidly towards the north where it is only about 1,300 feet in some areas (see folders 1 and 2). On the basis of evidence obtained from borehole number 48, it would appear that the Ecca series thickens towards the north-west, and it is possible that there may have been a deepening of the basin in this direction.

STRATIGRAPHY OF THE LOWERMOST BEAUFORT BEDS

A. GENERAL

It was considered to be advantageous and also justified in a regional study of this type to include the Lowermost Beaufort Beds.

The most complete stratigraphic succession of the Lower Beaufort is confined to the Karroo Trough. North of this area sedimentary overlap takes place, so that progressively younger Beaufort Beds come to rest disconformably on what is taken on lithological grounds to be Upper Ecca. Therefore on a basin scale, these beds should not be looked upon as isochronous. Palaeontological evidence confirms this, as progressively younger vertebrate fossils are found in these beds the farther north one proceeds from the Karroo Trough.

In this study the Lowermost Beaufort Beds are defined on lithological grounds, and taken to mean those rocks lying immediately above the top of the Ecca Series.

On the basis of palaeocurrent directions and lithology three distinct facies can be recognised within these beds and will be referred to as the Southern, Western and Northern Facies. These three facies are composed of sandstone, mudstone and shale and have more or less the same distribution as the Southern, Western and Northern Facies within the Ecca Series except that they do not grade into a facies composed entirely of shale. Instead, the different lithological units constituting the various facies interfinger with each other towards the centre of the basin and only by the detailed mapping of paleocurrent directions would it be possible to distinguish between rocks belonging to different facies. Towards the southern, south-western and north-eastern margins of the basin sandstones of the Lowermost Beaufort Beds become coarser-grained and more numerous.

Although isopach maps have not been constructed for the Lower Beaufort, available thickness measurements indicate that these beds follow more or less the same thickness distribution pattern as the Ecca Series (see folder 1), except that the axes of the Karroo and Natal Troughs have moved towards the north and west during this period, thus indicating a shrinking sedimentary basin.

The basal portion of the Lowermost Beaufort Beds becomes progressively more argillaceous towards the central portions of the basin, and as the Ecca Series is composed entirely of shale in this area it becomes virtually impossible on lithological grounds to distinguish between the fine-grained facies equivalent of the basal portion of the Lowermost Beaufort Beds and the top of the Upper Ecca. As already stated, the Ecca-Beaufort contact in this area is taken at the base of the first well defined bed of Beaufort sandstone. It is therefore to be expected that the topmost beds of the Ecca Series, in the northern Cape Province, are the time-stratigraphic equivalents of the Lowermost Beaufort Beds in the outcrop belt to the south, and that the so called Lowermost Beaufort Beds of the northern Cape are in fact the time-stratigraphic equivalent of a higher sequence of strata in the south.

- Kitching -

Kitching, of the Bernard Price Institute for Palaeontological Research, found a typical Cistecephalus fauna (uppermost palaeontological zone in the Lower Beaufort) in Lowermost Beaufort rocks in the vicinity of the Van der kloof Dam site on the Orange River.

It is the view of the writer that a combination of facies change and sedimentary overlap offers the most likely explanation of differences in the stratigraphic successions of the Lowermost Beaufort in the Karroo Trough and in the northern Cape and southern Orange Free State. Furthermore it is believed that the reason why Tapinocephalus and Endothiodon faunas are not found in the so called Upper Ecca of the northern Cape, is because these shales were deposited in a fairly extensive body of water wherein it was impossible for these land-dwelling reptiles to live.

It is important to mention that the Ecca-Beaufort contact, as indicated on the 1 : 1,000,000 geological map of the Republic of South Africa, was drawn in over large parts of the Orange Free State and northern Cape Province, as a result of reconnaissance mapping by the Geological Survey. As was to be expected, the present investigations revealed that in those parts of the country where only reconnaissance mapping had been carried out, the contact was considerably misplaced in certain areas.

Mapping of the Ecca-Beaufort contact did not lie within the scope of this study and therefore the same contact as shown by the Geological Survey is used, except where results of

- recent -

recent mapping were available for inclusion. However, in the Fouriesmith district the contact was so inaccurate that an attempt was made to remap its position on a reconnaissance basis.

B. THE SOUTHERN FACIES

Rocks belonging to this facies outcrop along the southern structural margins of the Beaufort Basin and also occur in isolated, tightly folded synclines farther to the south (see folder 3).

Good outcrops also occur along the coast, both north and south of East London, where due to normal faulting they are often found abutting against very coarse-grained Middle Beaufort Sandstone.

These beds are composed of fine to medium-grained massively bedded grey sandstone, blue, green, grey, purple and maroon coloured shale and mudstone and occasional thin lenticular beds of chert and limestone. Discontinuity of sandstone beds is a marked feature.

Contemporaneous erosion channels, planar and trough cross-bedding, shale-pebble conglomerates, ripple marks, parting lineations and compaction structures are abundant. Fossil plants and reptiles have been found in these beds at a number of localities (Rossouw et al 1964).

C. THE WESTERN FACIES

Good outcrops of this facies may be seen along the grained felspathic sandstone, siltstone and mudstone. The sandstone resembles that of the Middle Ecca Group, but the mudstone is normally a light grey, green or purple colour. Planar and trough cross-bedding are abundant in the medium-grained sandstones.

In northern Natal good outcrops of this facies occur along the Eastern Escarpment, Biggarsberg and Belelasberg. In these areas the succession is composed of coarse sandstone, grit, conglomerate, carbonaceous shale and coal seams.

Rocks of this facies also occur in the districts of Volksrust and Wakkerstroom in the south-eastern Transvaal, as well as over wide areas of the northern and central Orange Free State. Along the Escarpment near Volksrust, these beds occur at elevations above 6,000 feet, but westwards from this area outcrops are found at progressively lower altitudes, as a result of a regional westerly dip. In the south-eastern Transvaal and Orange Free State the Lowermost Beaufort Beds are composed of coarse- to fine-grained sandstone and grit, together with brown and buff coloured shale and mudstone. Occasionally coal seams occur, as for example on the flanks of Majuba Mountain south of Volksrust. The sandstones strongly resemble those of the Middle Ecca, being mainly arkosic in composition and containing abundant medium- to large-scale planar cross-bedding, similar in appearance to that found in the Coal Formation. Slump structures and intra-formational recumbent folds also occur.

According to Visser et al (1958) the Lower Beaufort

Group near Volksrust can be subdivided into a 300 feet thick "Lower Zone" where sandstones predominate and a 600 feet thick "Upper Zone", where shales and mudstones predominate. Rocks of this facies are not as brightly coloured as the other two facies in the Cape Province.

In Swaziland, drilling has proved the existence of 130 feet of blue-grey micaceous shale overlying the Upper Ecca. A narrow clay pellet conglomerate occurs at the contact. It must, however, be emphasized that the correlation of this shale with the Beaufort Series is based purely on lithological grounds and until confirmatory fossil evidence is obtained, such a correlation should be treated with caution. It is indeed strange that the so called Beaufort of Swaziland is composed almost entirely of shale, when the Lowermost Beaufort Beds are known to become progressively more arenaceous towards the north-east. On this basis it would be logical to expect the Lowermost Beaufort Beds of Swaziland to be composed of coarse clastics. It is thus possible that either these beds are not represented in Swaziland or else the present stratigraphic correlation is incorrect.

The Lower Beaufort Beds thin in a north-easterly direction as shown by the following thicknesses -

Central Transkei	+ 4,500 - 5,000 feet
Mount Currie	+ 2,500 feet
Bulwer-Deepdale	+ 1,900 feet
Van Reenen's Pass	+ 1,600 feet
Newcastle	+ 1,200 feet
Inkwelo	+ 1,100 feet

+ Du Toit (1918)

III. PETROLOGY

At each outcrop of conglomerate encountered in the field, both composition and mean pebble size were determined. In addition, variations in grain size of sandstones encountered were visually estimated using a Wentworth size chart. Representative sandstone samples from different facies within the Ecca were studied in thin section, and heavy minerals were extracted and examined under the microscope.

Generalized petrological studies of Ecca sediments were carried out with the following aims in mind -

1. To obtain information regarding the nature of the source rocks.
2. To detect any evidence of the depositional environment.
3. To determine any mineralogical differences between sandstones belonging to the different facies.

A. PEBBLE SIZE AND COMPOSITION

1. Pebble Size

Lengths of long axes of the ten largest pebbles were measured at each outcrop of Middle Ecca conglomerate encountered (Pelletier 1958). From this data, the average pebble lengths were calculated for the different sample localities and summarized in appendix 18. The results are plotted on the outcrop map (folder 11) from which the following deductions may be made -

1. Middle Ecca conglomerates are confined to the northern and north-eastern portions of the basin.
2. The largest mean pebble sizes occur along the northern margins of the basin.

- 3. -

3. There are no clearly defined directional decreases in mean pebble size, a feature which may be due to the limited number of sampling localities.

In northern Natal, Swaziland and the south-eastern Transvaal, pebbles within the Middle Ecca conglomerates are generally well rounded and sorted, suggesting that they have been transported a considerable distance from their source. However, along the northern margins of the basin, the pebbles usually display poor sorting and are sub-angular to sub-rounded, indicating that they were derived from a near-by source.

2. Pebble Composition

Compositions were recorded for the 30 largest pebbles as each outcrop of Middle Ecca conglomerate examined. These are expressed in terms of percentage compositions in table 7, from which the following conclusions may be drawn -

1. Quartz, or quartzite, usually constitutes the dominant pebble type.
2. Quartzite is usually the most abundant pebble type in the northern portions of the basin.
3. Granitic pebbles occur in minor amounts (2.8 - 16.8 percent), in northern Natal, south-eastern Transvaal and Swaziland, but are rare or absent along the northern margins of the basin.
4. Pebbles of felspar, up to 2 inches in length, are fairly abundant in the north-eastern and eastern portions of the basin, but are completely absent along the northern margins.
5. Pebble compositions indicate that the source rocks for most of the Middle Ecca Conglomerate, in the north-eastern portions of the basin, were more granitic in composition than along the northern margins.
6. Chert pebbles, probably derived from the Dolomite Series, occur mainly along the northern margins.
7. Pebbles falling into the group of "other rock types" are mainly found in the north.

- Before -

Roggeveld Escarpment and in the rugged country forming the Karreeberge between Williston and Carnarvon.

The beds are composed of massive medium-grained sandstone, greyish-green siltstone, hard green mudstone and green and purple shale. The sandstones in this succession are generally coarser-grained than the Southern Facies, and small granite pebbles are occasionally encountered (Rogers and Du Toit 1903).

Rocks of this facies become progressively more argillaceous in a north-easterly direction and good examples of sandstone beds wedging out in this direction may be seen in the Karreeberge north and west of Carnarvon. In the central portions of the basin rocks of this facies may be seen interfingering with those of the Southern Facies.

Planar and trough cross-bedding, various types of ripple marks, shale-pebble conglomerate, contemporaneous erosion channels, parting lineations and compaction structures are abundant. Glossopteris, Schizoneura Africana and Phyllotheca have been found in these beds. In addition, fresh-water lamellibranchs and fish scales are reported to occur on the farm Knechts Bank, about 12 miles north-west of Middelpos. Fossil reptiles are not as abundant as in the Southern Facies (Rogers and Du Toit 1903).

D. THE NORTHERN FACIES

In the northern Transkei and southern Natal the Lowermost Beaufort Beds are composed mainly of fine- to medium-

- grained -

TABLE 7

PERCENTAGE PEBBLE COMPOSITIONS OF MIDDLE ECCA CONGLOMERATES

Outcrop No.	District	Farm	Outcrop Description	Quartzite	Quartz	Granitic Rocks	Felspar	Chert	* Other
98	Dundee	Matatana 13024	In stream	9.1	36.4	-	54.5	-	-
99	Dundee	Overton 3315	In stream	6.2	84.6	2.8	6.4	-	-
87	Dundee	Van Rooyan 4252	In Sandspruit	68.1	27.3	-	4.6	-	-
52	Dundee	Lyell 2398	In stream	62.3	35.5	-	2.2	-	-
198	Utrecht	Schuilklip 109	Side of hill	50.3	21.2	3.3	25.2	-	-
196	Utrecht	Witklip 98	In stream	42.6	30.9	4.3	22.2	-	-
110	Utrecht	Nooitgedacht 60	In stream	45.8	20.9	16.8	4.3	12.2	-
142	Utrecht	Novembersdrift 87	In donga	62.8	16.2	11.6	9.4	-	-
227	Paulpietersburg	Trek drift [illegible]9	Near bridge	82.4	17.6	-	-	-	-
221	Paulpietersburg	Makateeskop 59	Side of hill	72.3	27.7	-	-	-	-
262	Vryheid	Vaalkrans 306	Cutting	71.7	20.5	7.8	-	-	-
265	Vryheid	Langkrans 367	Side of mountain	95.9	2.3	-	-	-	1.8
230	Vryheid	Erfstuk 4	In stream	81.8	13.7	-	4.5	-	-

TABLE 7 contd.

Outcrop No.	District	Farm	Outcrop Description	Quartzite	Quartz	Granitic Rocks	Felspar	Chert	Other
268	Vryheid	Riversdale 75	Side of mountain	30.2	23.7	15.8	-	-	30.3
277	Piet Retief	Pongola 160	Sititulu Hill	89.4	6.1	4.5	-	-	-
281	Nongoma	Native Reserve No. 12	In donga	66.7	33.3	-	-	-	-
165	Wakkerstroom	Nauwgevonden 369	Cliff	6.8	93.2	-	-	-	-
212	Wakkerstroom	Klipspruit 461	In donga	50.3	41.4	-	-	-	8.3
133	Bethal	Uitmelkaar 126	Cutting	85.7	7.1	-	-	7.2	-
64	Ermelo	Nooitgedacht	Quarry	54.1	28.6	-	17.3	-	-
-	Middelburg	Uitkyk 290	Quarry	89.4	7.0	-	-	-	3.6
179	Witbank	Honingkranz	Old Mine	97.5	2.5	-	-	-	-
184	Manzini	-	Rail cutting	63.6	10.7	6.1	5.5	-	14.1
188	Hlatikulu	-	In stream	28.9	16.1	10.5	44.5	-	-
-	Ermelo	Bellevue 176	Cutting	81.2	18.8	-	-	-	-
100	Carolina	Onbekend 172	Side of hill	86.6	10.7	3.7	-	-	-
99	Carolina	Kleinbuffelsspruit 111	Side of hill	35.7	7.9	-	-	10.3	46.1

TABLE 7 contd.

Outcrop No.	District	Farm	Outcrop Description	Quartzite	Quartz	Granitic Rocks	Felspar	Chert	Other
167	Balfour	Malanskraal 562	Ledges	85.7	12.2	-	-	-	2.1
169	Balfour	Modderfontein 562	Side of pan	83.1	9.8	-	-	-	7.1
-	Vereeniging	Klipplaatdrift	North bank of	64.4	-	-	-	25.6	10.0

* Basic igneous rocks, banded ironstones, dolomite, and metamorphic rocks associated with the Bushveld Igneous Complex.

Before offering any explanation for the various size and compositional characteristics of the Middle Ecca conglomerates, it is necessary to stress that the Lower Ecca Shale intervenes between the Dwyka Tillite or pre-Karroo surface, over the whole of northern Natal, southern Swaziland, and the south-eastern Transvaal. This fact excludes the possibility of the pebbles being derived locally from reworked Dwyka Tillite or pre-Karroo formations. In some areas pre-Karroo hills project through the Lower Ecca Shale, but this is the exception rather than the rule. However, along the northern margins of the basin, the Middle Ecca rests disconformably on genuine Dwyka Tillite, reworked tillite, or pre-Karroo formations, and vast quantities of reworked tillite and coarse clastic material from the surrounding pre-Karroo ridges were incorporated in the Middle Ecca Group. Therefore, it is believed that the pebble constituents of the Middle Ecca conglomerates in the northern portions of the basin were mainly derived locally from the reworking of older Dwyka deposits. In contrast, pebbles constituting the conglomerates in the north-eastern portions of the basin were derived from a more distant source.

5. SIZE VARIATIONS IN SANDSTONES OF THE ECCA SERIES

At each outcrop of sandstone investigated, estimates of the average grain size were made visually using a Wentworth grade scale (see fig. 13). The results are presented on folder 10, where a visual size scale is used to illustrate average grain size at each outcrop, rather than a strictly quantitative approach.

From folder 10 the following conclusions may be drawn-

-- 1. -

1. The coarsest sandstones occur in the north-eastern portions of the basin.

2. The sandstones of the Northern Ecca Facies become finer-grained in a south-westerly direction.

3. The sandstones of the Northern Ecca Facies grade into shales fairly rapidly towards the south-west.

4. The sandstones of the Southern and Western Ecca Facies are clearly much finer-grained and probably represent a distal facies.

5. The apparent lack of any major grain size variation along the southern outcrop, suggests that this belt probably trends more or less parallel to the sedimentary strike. Furthermore, it has already been shown that the sandstones in this belt grade rapidly northwards into shale.

Reasons for not applying a more quantitative method, such as moving averages, for treating the data are as follows -

1. On a basin scale, the outcrop belt is too narrow to favour the contouring of numerical data.

2. Sandstones of varying average grain size occur at different stratigraphic levels, and are duplicated on outcrop by folding etc.

3. Sedimentary overlaps and disconformities have excluded certain portions of the succession from different parts of the basin.

C. PETROGRAPHY OF THE SANDSTONES

Microscopic examination was carried out on a total of 70 representative sandstone samples from the Northern, Southern and Western Ecca Facies. Of these, percentage compositions by means of counting five hundred points, were determined for 30 thin sections using a graduated eye-piece. The results are listed in tables 8, 9 and 10.

The classification used by Krumbein and Sloss (1959) and modified from Pettijohn (1957) was used in the classification of sandstones. The various types are defined as follows -

Quartzose Sandstone "has a simple mineralogical composition, with a dominance of quartz (at least 90%) and a minor amount of matrix".

Felspathic Sandstone "has from 10 to 25 percent felspar and less than 20 percent matrix".

Arkose "contains more than 25 percent felspar and less than 20 percent matrix. The matrix is commonly kaolinitic".

Graywacke "is a poorly sorted sandstone with more than 20 percent matrix. The particles include angular rock fragments, quartz, and detrital chert, with more than 10 percent felspar. The matrix is composed mainly of clay minerals, chlorite, and sericite".

Sub-graywacke "is a sandstone which resembles a true graywacke, except that it contains less than 10 percent of felspar, and chlorite may be less prominent".

1. The Northern Ecca Facies

(a) Texture and Grain Size

The majority of the sandstones examined are medium- to very coarse-grained (¼ - 2 mm) and display poor sorting. Individual grains vary from sub-angular to rounded and in general the felspars, particularly microcline, are larger and show better rounding than the other minerals.

(b) Mineral Composition

Fifty percent of the sandstones examined were found to be arkoses (see Table 8 and fig. 9) and the remainder were

- more -

more varied and include sub-graywackes, quartzose sandstones or felspathic sandstones.

Quartz is usually the most abundant mineral present and constitutes 30 - [illegible]5 percent of the rock. Individual grains usually show undulose extinction and contain liquid and gas bubble trains, as well as needle-like inclusions and fracture cracks.

Fragments of quartzite and chert were found in sandstones along the northern margin of the basin and were probably derived locally from pre-Karroo formations in this area.

Felspar constitutes between 5 and 45 percent of the rocks (see Table 6). Individual grains are either completely or marginally altered to kaolin. The fine-grained sandstones have more matrix material than the coarser varieties usually at the expense of the percentage felspar, suggesting that certain of the detrital felspars have been altered to matrix material and are now only recognisable as such. Microcline is the most abundant felspar present (over 90%), and the remaining percentage is usually albite. In certain sandstones perthite was found to occur in small amounts.

The matrix material varies between 5 and 50 percent. Clay is the most abundant [illegible] matrix material. Calcite and secondary silica were occasionally seen acting as a cementing medium.

Detrital muscovite occurred in all the sandstones examined except x 9775 and x 9776, the constituents of which are thought to have been derived from local source areas. This mineral usually occurs in fairly large flakes lying along bedding planes, or bent around other detrital grains (see fig.10).

TABLE 8

PERCENTAGE MODAL ANALYSES OF MIDDLE ECCA SANDSTONES FROM THE NORTHERN ECCA FACIES

Slide No.	Outcrop No.	Farm	District	Quartz, Quartzite Chert	Felspar	Clay, Muscovite Chlorite etc.
x 7561	299	Nietgedacht 1192	Umvoti	30.4	28.2	41.4
x 7563	38	Sea Park	Port Shepstone	41.6	43.0	15.4
x 7565	23	Tongaat Beach	Inanda	42.0	8.0	50.0
x 7566	17	Roselands 13833	Richmond	41.6	31.8	26.6
x 7572	29	Umnini Location 1788	Umlazi	46.8	33.2	20.0
x 6862	289	Mpofana Location 4677	Msinga	40.6	39.6	19.8
x 6740	253	Native Reserve No. 18	Nqutu	46.0	34.0	20.0
x 9772	22	Zandspruit 103	Ermelo	62.6	25.8	11.6
x 9773	184	-	Manzini	60.2	28.6	11.2
x 9778	187	-	Hlatikulu	55.2	26.8	18.0
x 9774	188	-	Hlatikulu	33.6	45.4	21.0
x 9775	174	Varkensfontein 169	Nigel	78.5	-	21.5
x 9776	113	Nooitgedacht 300	Witbank	95.0	-	5.0
x 7176	Borehole	Schuilplaats 4267	Dundee	49.6	31.6	18.8
x 7178	70	Boschfontein 3307	Dundee	35.4	25.2	39.4

TABLE 8 contd.

Slide No.	Outcrop No.	Farm	District	Quartz, Quartzite Chert	Felspar	Clay, Muscovite Chlorite etc.
x 7180	Borehole	Schuilplaats 4267	Dundee	49.2	34.5	16.2
x 7181	Borehole	Balmoral 30	Amersfoort	50.4	30.3	19.3
x 7182	70	Boschfontein 3307	Dundee	48.8	38.4	12.8
x 7183	70	Boschfontein 3307	Dundee	43.2	26.6	30.2
x 7192	70	Boschfontein 3307	Dundee	36.0	27.5	36.5

In addition the following accessory minerals were observed (less than 1%) biotite, garnet, zircon, tourmaline, pyrite, spinel, apatite, epidote and ore minerals.

2. The Southern Ecca Facies

(a) Texture and Grain Size

These sandstones are very fine to fine-grained (1/16 to ¼ mm), angular to sub-angular and poorly sorted. The felspars are lath-shaped and larger than the quartz grains, which have irregular shapes, particularly sharp pointed slivers (see fig. 11). Nel (1962) also observed this feature in his petrographic work on the Upper Ecca Sandstones from the Laingsburg district. Graded bedding is common on a microscopic scale (see fig. 39).

(b) Mineral Composition

Seventy five percent of the sandstones examined from the Southern Ecca Facies were found to be graywackes, while the remainder are sub-graywackes (see Table 9 and fig. 9).

Quartz normally constitutes between 21 and 46 percent of the rock. Individual grains show undulose extinction, liquid and gas bubble trains, needle-like inclusions and fracturing. Chert sometimes occurs in amounts of up to 5 percent and is more abundant in these sandstones than in the Northern Ecca Facies. Quartzite fragments are rare.

Felspar constitutes 2 - 18 percent of the sandstones, and in contrast to the Northern Ecca Sandstones albite is by far the most abundant felspar. Orthoclase occurs in minor

- amounts -

TABLE 9

PERCENTAGE MODAL ANALYSES OF SANDSTONES FROM THE SOUTHERN ECCA FACIES

Slide No.	Outcrop No.	Farm	District	Stratigraphic position	Quartz Quartzite, Chert	Felspar	Clay, Muscovite, Chlorite etc.
x 9768	106	Wind Heuwel Su.Q.4-10	Sutherland	Upper Ecca	46.8	13.6	39.6
x 9769	-	Vischkuil Wor.Q.12-51	Laingsburg	Lower Ecca	33.0	6.4	60.6
x 9770	-	De Wolvefontein Uit.Q.2-70	Uitenhage	Lower Ecca	26.6	12.4	61.0
x 9771	13	Lot AH Aly.Q.12-14	Albany	Lower Ecca	21.4	2.0	76.6
x 9754	-	Lower Nenga Location No. 19	Mquanduli	Upper Ecca?	34.2	17.8	48.0
x 9757	14	Lot Al. Aly.Q.12-15	Albany	Lower Ecca	30.0	12.0	58.0
x 9756	30	Middleton Som.Q.16-12	Somerset East	Upper Ecca	37.0	17.4	45.6
x 9758	92	Doornkloof Wor.Q.15-8	Laingsburg	Lower Ecca	43.8	10.8	45.4

amounts, and microcline which is so abundant in the Northern Ecca Facies is rare in the south. Some felspar grains have been kaolinized to such an extent that it is difficult to distinguish them from matrix material. Many of the albite grains show bent twinning lamellae.

Matrix material and accessory minerals constitute 40 to 77 percent of the rock. Clay is the most abundant matrix constituent. Chlorite is fairly abundant in some rocks and is always more copious than in the Northern Ecca Sandstones.

Muscovite is not as abundant as in the north, while the reverse holds true for biotite. The following accessory minerals were identified; zircon, garnet, tourmaline, epidote and ore minerals.

3. The Western Ecca Facies

(a) Texture and Grain Size

Like the Southern Ecca Facies these sandstones are fine-grained. Individual particles are sub-angular to angular and poorly sorted (see fig. 12). Felspars are larger and lath shaped, in contrast to the quartz grains which have irregular shapes.

(b) Mineral Composition

On the basis of the eight thin sections examined and the two modal analyses carried out it has been found that these rocks are either graywackes or sub-graywackes (see table 10 and fig. 9) and therefore are similar in composition to the sandstones of the Southern Ecca Facies, but different in composition

TABLE 10

PERCENTAGE MODAL ANALYSES OF SANDSTONES FROM THE WESTERN ECCA FACIES

Slide No.	Outcrop No.	Farm	District	Stratigraphic position	Quartz Quartzite, Chert	Felspar	Clay, Muscovite, Chlorite etc.
x 9760	124	Kleinfontein Clv.Q.9-2	Calvinia	Upper Ecca	38.6	19.0	42.4
x 9761	108	Bloemfontein Su.Q.31-5	Ceres	Middle Ecca	47.4	8.0	44.6

to most sandstones in the Northern Ecca Facies.

Quartz is the most abundant framework mineral (39 - 47 percent) and appears to be petrologically similar to quartz grains of the Southern Ecca Facies.

Felspars constitute [illegible] - 19 percent of the rocks and their average size is slightly larger than the associated quartz grains. Albite is the predominant felspar (± 90%), as is the case in the Southern Ecca Facies, and orthoclase makes up the remaining percentage. Microcline and perthite were not found in the sections examined.

Matrix material and accessory minerals constitute 42 - 45 percent. Clay and chlorite are the most common matrix constituents, while muscovite, biotite, zircon, garnet, tourmaline and ore minerals occur in minor amounts.

D. HEAVY MINERALS

Koen (1956), Rust (1962) and De Villiers and Wardough (1962) studied heavy mineral suites from Ecca sandstones. In this study, additional data is presented from the Amersfoort area and the Western Ecca Facies.

This data will now be reviewed in the light of the different facies, in order to detect any major qualitative and quantitative differences. Certain of the earlier analyses have been recalculated in order that all the results may be uniformly expressed on a percentage basis. The results obtained by previous investigators are simplified and summarized in tables 11 and 12.

The assemblage of heavy minerals is similar in each of the three facies and indicates a predominantly granitic source for each of them. Although the data is scanty, there do appear to be certain quantitative distinctions between different facies. Sandstones constituting the Northern Ecca Facies have less zircon and more garnet in their heavy mineral suites than sandstones of the Southern Ecca Facies. On the other hand, there are apparently no major quantitative differences between the heavy mineral suites of the Southern and Western Ecca Facies, except that the percentage zircon is usually slightly higher in the Southern Ecca Facies (see table 11).

TABLE 11

PERCENTAGE HEAVY MINERAL DATA OF ECCA SANDSTONES

Sample No.	Locality	Investigator	Zircon	Garnet	Tourmaline	Rutile	Apatite	Other Minerals	Strati-graphic position
NORTHERN ECCA FACIES									
68	Sasolburg	De Villiers and Wardaugh (1962)	3.0	62.0	1.0	1.0	2.0	31.0	Coal zone
67	Kinross	De Villiers and Wardaugh (1962)	3.0	54.0	-	Tr.	2.0	41.0	Above coal zone
14	Witbank Coalfield Blaauwkrans 62	Koen (1956)	33.4	51.8	1.1	5.9	6.1	1.7	Coal zone
39	Kestell, Brakfontein 953	Koen (1956)	9.2	54.2	0.6	1.9	1.4	32.7	Coal zone?
See Table	Amersfoort, Balmoral 30	Ryan	5.2	66.9	1.3	2.9	4.1	19.6	Coal zone
SOUTHERN ECCA FACIES									
Land 2	N. of Grahamstown	Rust (1962)	42.7	14.1	3.4	0.5	Not stated	39.3	Lower & Upper Ecca
66	Koup, Cape Province	De Villiers and Wardaugh (1962)	20.0	55.0	1.0	1.0	1.0	22.0	Upper Ecca
69	Fish River S.W. of Pedi	De Villiers and Wardaugh (1962)	66.0	1.0	2.0	2.0	9.0	20.0	Lower Ecca

TABLE 11 contd.

Sample No.	Locality	Investigator	Zircon	Garnet	Tourmaline	Rutile	Apatite	Other minerals	Strati-graphic position
72	15 miles N.E. of Laingsburg	De Villiers and Wardaugh (1962)	2.0	1.0	-	-		97.0	Lower Ecca
63	Laingsburg	De Villiers and	16.0	24.0	2.0	-	11.0	47.0	Upper Ecca
			WESTERN ECCA FACIES						
Y 1	Calvinia, Kleinfontein Clv. Q.9-2	Ryan	12.0	15.7	2.0	1.7	13.6	55.0	Upper Ecca
Y 2	Calvinia, Kleinfontein Clv. Q.9-2	Ryan	27.0	30.5	2.8	5.7	3.5	30.5	Upper Ecca
Y 3	Calvinia, Kleinfontein Clv. Q.9-2	Ryan	11.7	22.6	2.7	1.6	21.6	39.8	Upper Ecca

TABLE 12

PERCENTAGE HEAVY MINERAL COMPOSITION OF MIDDLE ECCA SANDSTONES IN THE AMERSFOORT DISTRICT

Sample No.	Locality	Zircon	Garnet	Tourmaline	Rutile	Apatite	Other Minerals	Stratigraphic position
A 1	Balmoral 30 Amersfoort	4.8	51.0	0.8	3.8	6.0	33.6	Coal zone of Middle Ecca (N. Facies)
A 2	Balmoral 30 Amersfoort	5.6	67.6	1.0	.6	2.6	20.6	Coal zone of Middle Ecca (N. Facies)
B 1	Balmoral 30 Amersfoort	7.8	77.4	1.0	3.4	2.5	8.2	Coal zone of Middle Ecca (N. Facies)
B 4	Balmoral 30 Amersfoort	2.6	71.8	2.5	1.8	5.6	16.0	Coal zone of Middle Ecca (N. Facies)

IV. SEDIMENTARY STRUCTURES

Fundamental to the study of any sedimentary unit is an understanding of its provenance and environment of deposition. In this respect, the qualitative and quantitative study of primary sedimentary structures enables valuable information to be gained towards solving these problems. Many sedimentary structures such as cross-bedding have directional significance and may, therefore, be used in the reconstruction of the paleocurrent patterns. Similarly, various sedimentary structures are indicators of the depositional environment, particularly when considered as an assemblage.

In this chapter sedimentary structures in the Ecca Series and Lowermost Beaufort Beds are described. The environmental significance of sedimentary structures is discussed and measurement techniques are outlined for those structures which have directional significance.

Brief references to sedimentary structures have been made in previous stratigraphic descriptions of certain areas, but in general little was known about the type and availability of directional sedimentary structures prior to the commencement of the fieldwork. It was fully appreciated that in order to achieve the objectives of this study within a period of 3 years, an efficient sampling technique had to be developed. It was decided to commence work in northern Natal, as good outcrops of cross-bedding were known to occur, the area had been geologically surveyed on a scale of 1 : 125,000 and the stratigraphy was fairly clearly defined. Due to correlation difficulties it was decided to classify sedimentary structures according to groups within the different facies, except in northern Natal and the south-eastern Transvaal where it was possible to distinguish between structures occurring above, below or within the Coal Formation.

To ensure an even distribution of sampling localities a grid 30' longitude by 30' latitude was used for the entire basin and an attempt was made to obtain a sample locality every three to six miles within each grid square. This procedure worked well in northern Natal and the south-eastern Transvaal (see folder 7), where the Middle Ecca Group is well exposed and cross-bedding is a ubiquitous feature of these rocks. However, in other portions of the basin, particularly where the Ecca is composed entirely of shale, this method was found to be impractical and outcrops were sampled wherever they could be located. Occasionally it was necessary to go underground at collieries in order to obtain exposures.

Due to the enormous distances which had to be covered in a limited period of time, sampling was confined to the existing road network as far as possible. However, in areas of poor exposure or where there were no roads, traverses were made on foot. Maximum sampling effort was given to the Ecca Series, but an attempt was also made to obtain some idea of the regional transport directions within the Lowermost Beaufort Beds as well. In those areas where the Ecca Series is composed almost entirely of shale and outcrops are rare, more effort was given to sampling the Lowermost Beaufort Beds which are usually better exposed and contain abundant sedimentary structures.

This procedure proved to be very useful as an aid to the interpretation of regional palaeocurrent trends within the Ecca, in portions of the basin where exposures are poor. In the south-eastern corner of the Karroo Basin where the Ecca Series is not exposed, a few outcrops of Middle and Lower Beaufort were sampled with a view to gaining some idea of the transport trends within the underlying Ecca Series.

Outcrop localities were plotted on small-scale maps together with the outcrop number and these points were later transferred to large-scale maps on completion of the fieldwork. At each outcrop locality measured, the following information was always recorded:

1. The stratigraphic position of the outcrop.
2. The dip and strike of true bedding where it exceeded 5 degrees.
3. The mean grain size of incorporated particles.
4. Associated primary sedimentary structures and fossils.

Additional information pertaining to particular sedimentary structures, was also recorded and will be discussed in the succeeding text.

A. CROSS-BEDDING.

Excellent examples of various types of cross-bedding were found in the Ecca Series and Lowermost Beaufort Beds, therefore it is important to describe these in considerable detail, as they indicate the depositional environment.

The most widely used code of cross-bedding terminology is that proposed by McKee and Weir (1953). Three main types are recognised (see fig. 14), and the following definitions are given -

Simple Cross-bedding is represented by sets whose lower bounding surfaces are non-erosional or of abrupt change in character.

Planar Cross-bedding is represented by sets whose lower bounding surfaces are planar surfaces of erosion.

Trough Cross-bedding is represented by sets whose lower bounding surfaces are curved surfaces of erosion.

Potter and Pettijohn (1963, p. 71) recognised two main types of cross-bedding based on the nature of the upper and lower bounding surfaces and is a modification of McKee's classification. These two types are -

1. Tabular Cross-bedding, which consists of units with essentially planar contacts and,
2. Trough Cross-bedding, which consists of units that have curved basal contacts.

Allen (1963) proposed a descriptive classification of cross-bedded units, based on the following criteria -

1. Whether a cross-stratified unit is a single set, or a coset composed of two or more similar sets.
2. The physical size (thickness) of the set of cross-strata.
3. The character of the lower bounding surface of the set of cross-strata.
4. The shape of the lower bounding surface.
5. The angular relationship between the cross-strata in the set and the lower bounding surface.

6. The degree of lithological homogenuity of the cross-strata within a set.

Using the above criteria Allen was able to recognise fifteen distinct types of cross-bedding.

Throughout this study, the terms <u>planar</u> and <u>trough cross-bedding</u>, as defined by McKee and Weir (1933) will be used when referring to these two major types in general terms. However, for detailed description and classification it is necessary to use Allen's code of terminology. Although the present study is of a regional nature, many of Allen's specific types may be matched to examples from the Ecca and Lowermost Beaufort Beds. These will now be discussed with a view to reconstructing the depositional environments.

<u>Alpha-Cross-bedding</u>.

This type is represented by the following -

1. Large-scale solitary sets (see fig. 15).
2. The lower bounding surface is non-erosional and essentially planar.
3. The cross-strata bear a discordant relationship to the lower bounding surface.
4. The cross-strata are lithologically homogeneous.
5. In vertical sections parallel to the dip of the cross-strata, they are straight or concave-upward.
6. In plan the cross-strata vary from straight in one set to curved in another.

This type of cross-bedding is fairly common in the Coal Formation of the Northern Ecca Facies and is also found in the Upper Ecca Group of the Southern Ecca Facies. It is

- best -

best observed where large-scale foresets overlie coal seams or beds of carbonaceous shale with a non-erosional contact (see fig. 16). Coarse sandstone and grit constitute the dominant lithological type in these units. Good examples may be seen at outcrops 3 and 10 (see folder 7) as well as in the Hlobane Colliery near Vryheid.

The origin of these structures is best explained by the forward building of large fan-shaped bodies of sand. Deposition must have taken place in fairly extensive swamps and lakes, where water depths of a few feet prevailed. This type of sedimentation explains the remarkable preservation of coal seams below coarse clastic material in many parts of northern Natal.

Beta-Cross-bedding.

Beta-cross-bedding has the following properties -

1. Large-scale solitary sets (see fig. 15).
2. The lower bounding surface is a planar surface of erosion.
3. The cross-strata are discordantly related to the lower bounding surface.
4. The cross-strata are lithologically homogeneous.
5. In plan view, the cross-strata vary from curved in one set, to straight in another (see fig. 15).

This type is fairly common in the Northern Facies of both the Middle Ecca and Lowermost Beaufort (see fig. 17). The constituent material is usually coarse sandstone and grit and the scale varies from 6 inches to over 20 feet (see fig. 18). When well exposed, these structures may cover an area of over

- 2,500 -

2,500 square yards. Good examples were observed at outcrops 60 and 145 (see folder 7). This type is thought to have formed by the forward building of large, solitary sand-banks. The eroded nature of the base indicates that either the bank advanced swiftly and erosively over the preceding deposit, or bevelling took place prior to deposition.

<u>Gamma-Cross-bedding</u>.

This type is represented by the following -

1. Large-scale solitary sets.
2. The lower bounding surface of each set is an irregular surface of erosion.
3. The cross-strata of each set are discordant with respect to the lower bounding surface.
4. The cross-strata are lithologically homogeneous.
5. In plan, the strata vary from straight in one set to curved in another (see fig. 15).

This type is rare and was only observed in the Middle Ecca Group and Lowermost Beaufort Beds in the north-eastern portion of the basin. These structures are usually found where coarse sandstone and grit rest on an irregular erosional surface composed of fine sandstone, shale or an incompletely eroded cross-bedded unit (see fig. 19). Examples were found at outcrop 204 (see folder 7). Thickness of individual units varies from 1 to 4 feet.

The depositional surface was certainly eroded prior to the forward building of a cross-bedded sand-bank and suggests a changeable, shallow water sedimentary regime.

- <u>Epsilon</u> -

Epsilon-Cross-bedding.

Epsilon-cross-bedding is characterised by the following -

1. Found as solitary sets which are usually large in scale.
2. The lower bounding surface is a planar surface of erosion.
3. The cross-strata are discordantly related to the lower bounding surface.
4. The cross-strata are lithologically heterogeneous, usually consisting of alternate layers of clayey silt and sand (see fig. 15).
5. In vertical sections parallel to the maximum dip direction the cross-strata vary from straight in a few units to convex-upward in the majority.
6. In plan the cross-strata are often curved.

This type of cross-bedding is found in fine-grained sandstone of the Middle Ecca Group of the Northern Facies. It also occurs in the Upper Ecca Groups of the Southern and Western Facies and in the Lowermost Beaufort Beds in the southern portions of the basin. Unit thicknesses vary from 5 to 18 inches. Allen (1963) reports the presence of Epsilon-cross-bedding associated with point bars.

Zeta-Cross-bedding.

This type of cross-bedding is characterised by the following -

1. Large-scale solitary sets.
2. The lower bounding surface is erosional and trough-shaped (see fig. 15).
3. The axis of the trough-shaped lower surface is approximately horizontal.

4. The cross-strata within the unit are concordant with the lower bounding surface and are lithologically homogeneous.

This type of cross-bedding is associated with the contemporaneous erosion channels so common in the Upper Ecca Group and Lowermost Beaufort Beds in the southern and south-western portions of the basin. These structures also occur in the Middle Ecca Group and Lowermost Beaufort Beds in the northern part of the basin.

McKee (1957a) found by experimentation, that this type of cross-bedding is formed where a semicircular-shaped channel is cut by a submerged current and then filled with sediment either from a second submerged current, flowing down the axis of the channel, or from sediment settling from above into quiet water. In both cases the stratification conforms to the general shape of the channel, but in the first case, the cross-strata thicken towards the base of the channel, while in the second they remain uniformly thick. The majority of channels in the Ecca and Lowermost Beaufort were filled with sediment discharged by a submerged current flowing parallel to the axis, in that the cross-strata mainly conform to the first case.

Contemporaneous erosion channels vary in depth from 6 inches to over 20 feet and good examples occur at Verlaten Kloof south of Sutherland (see fig. 20). These structures are best observed in outcrop sections parallel to the sedimentary strike, as they are usually orientated parallel to the regional paleocurrent trends.

<u>Eta-Cross-bedding</u>

- Eta -

Eta-cross-bedding is characterised by the following -

1. Solitary sets, mostly of a large scale.
2. A scoop-shaped erosional surface underlies each unit.
3. The cross-strata are discordantly related to the lower bounding surface (see fig. 1[illegible]).
4. The cross-strata are composed of lithologically heterogeneous material.

This type is occasionally found associated with fine-grained micaceous sandstones in the Middle Ecca Group of the Northern Facies. The thickness of these structures is seldom greater than 6 inches. Sykes (1937) described structures of this type from the Colorado River Delta.

Theta-Cross-bedding

The following properties characterise this type of cross-bedding -

1. Large-scale solitary sets.
2. The lower bounding surface is trough-shaped, plunging inwards at both ends.
3. The cross-strata within the set are lithologically homogeneous.
4. The cross-strata are discordant to the lower bounding surface, a feature which is more easily observed in longitudinal sections than in those at right angles to the long-axes (see fig. 1[illegible]).

This type of cross-bedding is the equivalent of what is usually referred to as trough cross-bedding. It is found associated with nearly every arenaceous formation within the Ecca and Lowermost Beaufort, but is most abundant in the Basal and Upper Sandstone formations of the Northern Ecca Facies (see fig. 21). The depth of these structures is usually between 6 and 18 inches and the axis of the lower bounding surface plunges at angles varying between 3 and 12 degrees. They are oval-shaped in plan, with length : breadth ratios averaging 2.5. The upper bounding surface is usually a planar surface of erosion. This structure appears to form as a result of two distinct events, firstly the scouring of a trough-shaped depression by a submerged current and, secondly the filling of the depression by the forward building of a bank of sand. Subsequent levelling, has the effect of only slightly modifying the already existing structure. In general these structures are a response to a turbulent shallow water environment. Excellent examples may be observed in good exposures of the Basal and Upper Sandstone Formations.

<u>Iota-Cross-bedding</u>

This type of cross-bedding is characterised by the following -

1. Large-scale solitary units.
2. The lower bounding surface is spoon-shaped with the axis plunging inwards at both ends.
3. The cross-strata are concordant with respect to the lower bounding surface, a relationship which may be observed in sections parallel and perpendicular to the axis of the trough (see fig. 1[*]).
4. The cross-strata forming the set are lithologically homogeneous.

This type of cross-bedding was only observed in the Upper Sandstone Formation, where it is fairly common (see folder 9). Good examples may be observed at outcrop 27 (see folder 6).

- The -

The depth of the spoon-shaped depression is usually 6-10 inches (see fig. 22). In plan they are oval-shaped with the length of the long axis varying between 1 foot 6 inches and 10 foot 6 inches, with an average length : breadth ratio of 2.1. The upper bounding surface is usually a planar surface of erosion and the constituent material is coarse sandstone and grit.

Kappa-Cross-bedding.

This type is recognised by the following properties -

1. Occurs as cosets formed by individually small-scale units (see fig. 24).

2. The upper and lower bounding surfaces of each set, are imaginary irregular, gradational surfaces, defined by pronounced changes in the attitude of the cross-strata.

3. The cross-strata are generally continuous across these ill-defined surfaces from one set to another.

4. The cross-strata are usually discordantly related to the bounding surfaces.

5. In one section, cross-strata are seen to have steep dips, but in the perpendicular section they pinch and swell in a pattern of interlocking lenses identical to flazer bedding (see fig. 23).

6. This type is characterised by lithologically homogeneous cross-strata (Allen, 1963), but the writer has found heterogeneous cross-strata to be equally common.

This type is occasionally found in the arenaceous formations of the Southern and Western Ecca Facies as well as in the Coal Formation. These structures are usually found associated with fine-grained sandstone and siltstone. Individual units vary from 1 - 8 centimetres and cosets are usually in excess of 12 centimetres. Cross-bedding of this type is thought to have formed by the under-water migration of small-scale asymmetrical linguoid ripples commonly associated with a shallow water fluviatile environment.

<u>Lambda-Cross-bedding</u>.

This kind of cross-bedding is characterised by the following -

1. Found as cosets composed of individually small-scale sets (see fig. 24).

2. The upper and lower bounding surfaces of individual sets are imaginary gradational planar surfaces, defined by pronounced changes in the attitude of the cross-strata.

3. The cross-strata pass from one set to the next across these imaginary surfaces with which they are discordantly related.

4. In certain sections the cross-strata are steeply inclined, but in sections perpendicular to this strata are essentially horizontal (see fig. 24).

5. The cross-strata are composed of lithologically heterogeneous sediment.

Lambda-cross-bedding is occasionally found associated with arenaceous formations of the Southern and Western Ecca Facies and also occurs in the Coal Formation of Natal. The constituent material is fine-grained sandstone and the scale of the sets and cosets is comparable with that of Kappa - cross-bedding.

Allen believes that this structure is formed by the under-water migration of small-scale ripples with approximately straight crests.

<u>Mu-Cross-bedding</u>.

- Cross-bedding -

Cross-bedding of this type constitutes the following -

1. A coset composed of individual sets which are small in scale.

2. The lower bounding surface of each set is a planar surface of erosion (see fig. 24).

3. The cross-strata in each set are discordantly related to the lower bounding surface.

4. In sections perpendicular to the strike, the cross-strata dip steeply in a constant direction, but in sections parallel to the strike, they are seen as essentially horizontal, parallel layers.

5. The cross-strata are lithologically homogeneous.

Mu-cross-bedding is fairly common in fine-grained sandstones of the Coal Formation and also occurs in the Lower Ecca Group of the Southern Ecca Facies. The scale of individual sets varies from 2 to 5 centimetres and cosets are usually 12 to 30 centimetres thick. In some sets, the cross-strata have been deformed by slumping. This type is thought to have been formed by the subaqueous migration of small-scale asymmetrical ripples with approximately straight crests. Each set is separated from the succeeding one by a period of bevelling. Shallow water conditions are the most likely environment under which this type of structure formed, but Dzulynski and Walton (1965) believe that this type of cross-bedding may also be produced by subaqueous turbidity flows in a deep water environment.

Nu-Cross-bedding.

This type has the following properties -

1. Cosets composed of small-scale sets.
2. The lower bounding surface of each set is a scoop-shaped surface of erosion, plunging at one end only (see fig. 24).
3. The cross-strata constituting each set are curved, symmetrical and discordantly related to the lower bounding surface.
4. As was the case with theta-cross-bedding, it is only possible to see the discordant relationship in sections parallel to the axes of the scoops.

This type is abundant in the Lower Ecca Group of the Southern Facies as for example at Ecca Pass. It also occurs associated with fine-grained sandstones of the Middle Ecca Group of the Northern Facies.

Individual units rarely exceed 5 centimetres in thickness, and cosets are usually less than 20 centimetres. In certain units the cross-strata have been considerably deformed as a result of slumping. Hamblin (1961) believes that this type of cross-bedding is formed by the subaqueous migration of trains of small-scale, asymmetrical linguoid ripples, in a shallow water environment. These same structures may equally well be produced by turbidity currents under deep water conditions.

Xi-Cross-bedding.

Xi-cross-bedding is characterised by the following -

1. Cosets of sets which are individually large in scale.
2. The lower bounding surface of each set is a non-erosional planar surface (see fig. 24).
3. The cross-strata are discordant to the lower bounding surfaces in all sections.

- 4. -

4. The constituent material is lithologically homogeneous.

Exposures of what appear to be Xi-cross-bedding were found in the Middle Ecca Sandstone along the Vaal River in the north-western part of the basin at outcrops 61, 62 and 66. Individual units vary in scale from 6 to 18 inches and are composed of medium- to coarse-grained sandstone. McKee (1957b) has shown that this type of structure occurs in the backshore deposits of some beaches.

Omikron-Cross-bedding.

Cross-bedding of this type is characterised by the following -

1. Cosets composed of large-scale sets (see fig. 24).
2. The lower bounding surface of each set is a planar surface of erosion.
3. The cross-strata are discordant with respect to the lower bounding surface, a feature which can only be seen in sections parallel to the dip of the strata.
4. The cross-strata in individual sets of a coset all have more or less the same orientation.
5. The constituent material is lithologically homogeneous.

Omikron cross-bedding is by far the most abundant type found in the Middle Ecca Group and Lowermost Beaufort Beds of the Northern Facies. Good examples occur at outcrops 79, 131 and 202 (see folder 7).

Individual units vary in size from 6 inches to over 4 feet, and cosets may be as thick as 20 feet. Considerable thickness variations often exist between sets, within cosets,

- and -

and the constituent material is usually coarse sandstone (see fig. 25).

Two schools of thought exist regarding the origin of this type of cross-bedding. The first believes that individual sets were formed by the forward building of extensive banks of sand in shallow water (Jopling 1963), while the second postulate the forward migration of large-scale asymmetrical ripple marks, with approximately straight crests as the most likely explanation for the origin of this structure. The first possibility is considered to best explain the conditions under which this type of cross-bedding was formed in the northern part of the Karroo Basin.

Pi-Cross-bedding.

Cross-bedding of this type constitutes the following -

1. Composed of interfingering large-scale sets (see fig. 24).
2. The lower bounding surface of each set is a scoop-shaped surface of erosion, plunging at one end only.
3. Each set is composed of curved, approximately symmetrical cross-strata.
4. The cross-strata are discordantly related to the lower bounding surface, a feature which is usually only seen in sections parallel to the axes of the sets.

This type is the equivalent of "festoon cross-bedding" and is very common in the Basal Sandstone Formation, Upper Sandstone Formation and Lowermost Beaufort Beds, in the northern part of the basin. It also occurs abundantly in the Lowermost Beaufort Beds of the Southern and Western Facies.

- Thicknesses -

Thicknesses of individual sets vary from 4 to 10 inches, while lengths of scoop-shaped erosional surfaces vary from 1 to 16 feet. Length : breadth ratios average 1.9

A number of explanations have been put forward to explain the origin of this structure, but the writer believes that each set is formed, firstly by the scouring of a scoop-shaped depression by subaqueous currents and secondly, the filling of the depression with a bank of sand under less turbulent conditions. The formation of a group of these sets would be achieved by repetition of this process. McKee (1962), believes that this type of structure is usually formed under fluviatile conditions.

Measurement Technique.

A total of 4,598 cross-bedding measurements from 616 outcrops were taken in the Ecca and Lowermost Beaufort Beds. Appendix 21 summarises the number of readings recorded in different parts of the basin. Previous experience (Ryan, 1963), had shown that care should be taken not to confuse portions of trough cross-bedded units with planar cross-bedding, when measuring the orientation of these structures, as this may lead to spurious results. Therefore, the only structures recorded were those which could be established with a fair degree of certainty as belonging to either the planar or trough types of cross-bedding as defined by McKee and Weir (1953). In the case of planar cross-bedding, dip and strike of foresets were recorded using a Brunton compass and clinometer, while in trough cross-bedding orientation and plunge of trough axes

- were -

were measured. Only one measurement per cross-bedded unit was taken and an attempt was made to measure 5 - 10 different units at each exposure. Reasons for adopting this procedure will become more apparent when discussing the statistical treatment of data.

At each outcrop locality investigated all or portion of the following information was recorded -

1. The type of cross-bedding measured.
2. The thickness of each cross-bedded unit measured.
3. The dip and strike of one fore-set from each planar cross-bedded unit and the orientation and angle of plunge of the axis of each trough cross-bedded unit.
4. The length and breadth dimensions of units exposed in plan.
5. The attitude of the upper bounding surface of cross-bedded units.
6. The nature of fore-set beds where observable in three dimensions.

Although small-scale cross-bedding is a common feature of the flysch sequences within the Lower Ecca Group of the Southern Facies, it was seldom measured due to the difficulty experienced in distinguishing between planar and trough types of cross-bedding.

B. RIPPLE MARKS

Ripple marks are the most abundant primary sedimentary structures in the Southern and Western Ecca Facies, and are also common in the Lowermost Beaufort Beds. However, they are seldom found in coarse sandstones of the Middle Ecca Group in the northern part of the basin. The various types of ripple marks encountered will now be described.

- Symmetrical -

Symmetrical Ripple Marks

Symmetrical ripple marks constitute about 90 percent of the types found and occur in the following stratigraphic units; Middle Ecca Group of the Northern Ecca Facies, Lower, Middle and Upper Ecca Groups of the Southern and Western Ecca Facies, and the Lowermost Beaufort Beds throughout its outcrop. These structures are mainly found in fine-grained sandstone and siltstone.

The crests vary from gently convex to fairly sharp. They are usually relatively straight in plan, but sometimes branch in a haphazard fashion. At outcrops 7, 36 and 94 (see folder 3 and fig. [illegible]6), single beds containing ripple marked surfaces of over 600 square feet in extent were found. Wave lengths vary from 0.5 to 48.[illegible] inches and amplitudes from 0.1 to 2.3 inches.

Mudcracks were found associated with these structures in siltstones of the Lowermost Beaufort, at outcrop 8 (see folder 5), and worm burrows occur in ripple marked sandstone of the Middle Ecca Group at outcrop 53 in the north-western portion of the basin (see folder 5).

A common feature of ripple marked surfaces of this type, in the Southern and Western Ecca Facies, is that they often contain trails, tracks and fragmental plant material. A characteristic of ripple marks in the northern portion of the basin, is that relatively larger sand grains often accumulate in the ripple troughs.

From the areal extent of these ripple marked

- surfaces -

surfaces it is apparent that they were formed in an extensive, relatively shallow, body of water.

Asymmetrical Ripple Marks

Asymmetrical ripple marks only constitute about 10 percent of the types found. They occur mainly in the Lower and Middle Ecca Groups of the Southern Facies and are occasionally found in the Middle Ecca Group of the Western Facies (see outcrop 120, folder 3). These structures are rare in the Middle Ecca Group of the Northern Facies and were seldom encountered in the Lowermost Beaufort Beds.

This type may be sub-divided into -

1. Those with relatively straight parallel crests and,
2. Those with curved non-parallel crests.

The latter are usually referred to as linguoid or cuspate ripples.

Asymmetrical ripples with approximately straight crests have wave lengths which vary from 2.5 to 30.4 inches and amplitudes varying from 0.2 to 1.6 inches. They are occasionally found occurring over wide areas on the surface of a single bed, as at outcrop 90 (see folder 3 and fig. 27).

Many of the crests are only slightly asymmetrical and may easily be misinterpreted as being symmetrical in shape. These structures occur in fine sandstone, argillaceous siltstone or shale. Their surfaces often contain trails, tracks and fragments of plant material. In section, asymmetrical ripple marks are cross-stratified (see fig. 28).

- This -

This type of structure is usually formed in relatively shallow water by sheet-like currents, with the asymmetry defining the direction of current movement, but has also been recorded in turbidite sequences, which are considered to have accumulated in deep water.

Exposures of linguoid ripple marks were found in fine sandstone at outcrops 21 and 57 (see folder 3). McKee (1957b) reported ripple marks of this type in channels of concentrated water movement, on present day tidal flats. They are also a common feature of flysch sequences in geosynclinal belts.

Interference Ripple Marks

This type is abundant in fine sandstone and siltstone of the Middle and Upper Ecca Groups, in the south-western corner of the basin (see fig. 29). These structures are thought to result when two sets of symmetrical ripples, formed at different times, intersect each other at approximately right angles.

Sand Waves

There is no standard definition delineating the lower size limits of sand waves (Potter and Pettijohn 1963, p. 99), and consequently it was decided to accept any rippled surface with wave lengths greater than three feet as being a set of sand waves.

Such structures only occur in the Middle Ecca Group of the Northern Facies (see fig. 30). Wave lengths vary from 3 to 5 feet and amplitudes from 12 to 20 inches. Crests are fairly straight in plan and symmetrical or asymmetrical in section. The large linear sandstone ridges on the floor of the number 2 seam in the Witbank Coalfield are probably sand waves.

Structures of this type have been reported from shallow marine shelves, but are most commonly found in a fluviatile environment.

Measurement Technique

A total of 1,077 ripple marks from 210 outcrops were collected in the Ecca and Lowermost Beaufort Beds. A summary of the number of measurements and outcrops from different parts of the basin is given in appendix 21.

At each outcrop of ripple marks, all or portion of the following information was recorded -

1. The type of ripple marks i.e. symmetrical, asymmetrical, etc.
2. The strike of ripple marked sets.
3. The wave length and amplitude of ripples on a set in order to calculate the ripple index at each outcrop.
4. The areal extent of ripple marked surfaces.

Only one measurement per set was taken and 2 to 10 different sets were recorded from as many different beds as possible within the same outcrop. There is usually very little angular difference in the strike of ripple marked sets at a single outcrop. However, in the south-eastern corner of the basin, strikes of ripple marks lie at large angles to each other in successive beds within an outcrop.

C. SOLE MARKS

Sole marks of various types are fairly common on the undersides of many sandstone and siltstone beds in the Lower Ecca Group of the Southern Ecca Facies, particularly in the eastern and central portions of the Karroo Trough. Structures of this type are usually found associated with the flysch facies of geosynclinal sequences and are now generally accepted as being indicative of turbidity currents (Kuenen 1957). These structures are always developed at the interface between sand and the underlying mud.

Groove Casts

Groove casts are most abundant in the Upper Arenaceous Formation, but also occur in the Lower Argillaceous Formation. Found on the undersurfaces of sandstone and siltstone beds, they rest on shale with a sharp contact and are obviously the casts of original grooves and striations which once existed in the underlying shale. The casts range in size (figs. 31-34) from faint hairlike ridges to long linear ribs, over 4 feet in length, ½ an inch high and over an inch wide. Spacing between individual grooves is variable. Two or more sets of different ages with slightly different trends may be observed on the same sole (fig. 31), but in general a marked parallelism exists on any one surface. The sides of casts are usually clean-cut and show no marked dimensional changes within a single exposure. Minor striations often occur on the surfaces of large casts, and usually trend parallel to the axis of the latter (see fig. 32).

- Nowhere -

Nowhere were the original tools, responsible for producing the groove and striations, found at the down-current end of these structures, but it is presumed that they were angular shale fragments so common in these beds.

Groove casts in the Ecca Series are thought to have formed by the dragging of sedimentary debris over the underlying shale surface, by the transporting currents, at the time of sedimentation. Dzulynski and Walton (1965), attribute the linear nature of these structures to the longitudinal transport conditions prevalent during turbidity flows.

Bounce and Prod Casts

These structures occur as narrow discontinuous ridges on the under surfaces of fine sandstone and siltstone beds, in the Lower Ecca Group of the Southern Facies. They are more numerous in the eastern portions of the Karroo Trough and are usually found in association with groove casts. Bounce and Prod casts appear to be genetically related in that they are considered by Potter and Pettijohn (1963) to have both been formed by objects intermittently striking the depositional floor, as they were transported by the current.

Bounce casts vary in length from a few millimetres to over 2 centimetres and thin out to sharp points at either end (see figs. 33 and 34). They usually lie approximately parallel to the groove casts where they occur on the same sole (see fig. 34). Due to their symmetrical shape, these structures only indicate a line of sediment transport and not a sense of current movement.

- Prod -

Prod casts vary in length from 0.5 to 2 centimetres. They are asymmetrical in longitudinal profile and fairly straight in plan. The one end is blunt, and the upcurrent end tapers to a sharp point (see fig. 33). Prod casts usually lie approximately parallel to groove and bounce casts on the same sole and according to Spotts and Weser (1964), may be used as reliable indicators of current direction.

Flute Casts

Flute casts occur infrequently and were only found in the Upper Arenaceous Formation, in the eastern portions of the Karroo Trough. These structures are tongue-shaped bulges on the under surfaces of fine sandstone; polished sections of which usually reveal the presence of graded bedding. Lengths of casts vary from a ½ to 1 inch. Depths vary from 1/10 to ¼ inch and breadths from ¼ to ½ inch. Flute casts are occasionally found on the same soles as groove casts where a marked parallelism usually exists between the two.

On the basis of experimental studies, reviewed by Dzulynski and Walton (1965), it has been shown that these structures are formed by the erosive action of vortices impinging on an unconsolidated mud floor.

Chevron Marks

Examples of what are considered to be chevron marks (Dunbar and Rogers, 1957, p. 195), were found in the Upper Arenaceous Formation at outcrop 63 (see fig. 35).

In plan these structures are V-shaped and according to Dzulynski and Walton (1965, p. 102) their convexities point in the downstream direction.

They are always related to groove casts and occasionally half-chevron ridges are found only on the one side of a groove (see Fig. 35). These structures are thought to have formed by the wrinkling up of coherent mud on the sides of grooves during their initial cutting (Dzulynski and Walton, 1965).

Measurement Technique

Groove casts are the most abundant substratal lineations recorded (see appendix 21). These structures only give a line of movement, but associated flute and prod casts on the same soles were used to obtain a direction of current flow. Groove casts and other substratal lineations are usually so well orientated on a particular sole that one or two measurements are sufficient. An attempt was made to measure sole markings from different beds at each exposure. In general, the orientation of sole structures is fairly constant for different beds within the same outcrop, but may differ considerably between widely spaced outcrops.

The following information was recorded at each exposure of sole markings -

1. The azimuth of the sole markings, as for example groove casts.
2. The current direction where possible, as indicated by associated structures such as flute and prod casts.

D. FUCOID STRUCTURES

The term fucoid structure is generally used in a non-specific way to describe burrows, roots, trails etc. (Pettijohn and Potter, 1964, p. 308). However, in this dissertation it is used to describe linear casts, of what were probably originally the impressions of plant stems lying on the sea floor (see fig. 37).

Fucoid structures are common in the bluish-black shale throughout the Central Ecca Facies and also occur in the Lower and Upper Ecca Groups of the Northern Facies. They are occasionally encountered in the Lower Ecca Shales of the Western Facies. Fucoids most commonly occur as slightly raised, linear or gently curved casts on bedding plane surfaces. Lengths of individual structures vary from 3 to over 36 inches, and widths from a ½ to 3 inches. In transverse section the casts are lenticular in shape and have maximum thicknesses varying between 0.1 and 0.5 of an inch. The constituent material is usually clay or fine silt.

Occasionally fucoids are seen lying across each other and individuals may display bifurcations and semicircular terminations (see fig. 38). The surface is usually smooth, but small crescentric ridges resembling casts of leaf attachments sometimes pattern the exterior.

In those portions of the basin where the Ecca Series is composed almost entirely of shale and good exposures are confined to the major drainage lines, it became exceedingly difficult to find directional structures. Initially it was thought that the abundant fucoid structures present in these rocks had no preferred trend, but further examination revealed that they usually display a bimodal orientation and were

- probably -

probably aligned either parallel or at right angles to the prevailing current at the time of deposition. While it is admitted that fucoid structures are certainly not the best indicators of palaeocurrent direction, it was decided to measure their orientation in view of the rarity of other more reliable directional structures.

An attempt was made to measure the orientation of at least 40 fucoids at each exposure, although this was seldom possible. An effort was also made to measure fucoids from different beds within the same exposure. Appendix 21 summarises the number of readings recorded in different portions of the outcrop belt. The following information was recorded at each exposure -

1. The orientation of the largest fucoids.
2. The lengths of exposed portions of fucoids in order to calculate the mean length for each outcrop.

E. PARTING LINEATIONS

Certain uniformly bedded sandstones contain delicate, elongated ridges and furrows with an irregular outline on their bedding surfaces. These features are usually about a millimetre thick and are most easily seen in oblique lighting (see fig. 36).

Yeakel (1962, p. 1,525) found a close relationship between the trend of parting lineations and internal grain fabric, thereby showing that these structures are of primary sedimentary origin.

- Parting -

Parting lineations occur in fine-grained sandstones of the Upper Ecca Groups in the Southern and Western Facies. They are fairly common in the Lowermost Beaufort Beds and are occasionally found in flagstones of the Central Ecca Facies, as for example at outcrop 53 (see Folder 8). These structures usually occur in association with cross-bedding, ripple marks and contemporaneous erosion channels, thereby suggesting that they were mainly formed in a shallow water environment.

Although parting lineations only indicate a line of current movement, they were measured wherever encountered in the field. A total of 61 measurements from 12 outcrops were recorded (see Appendix 21). These structures are strongly orientated on a single bedding plane surface and therefore only one measurement of azimuth, is sufficient. An attempt was made to measure parting lineations on at least three different bedding planes per outcrop.

F. GRADED BEDDING

Graded bedding (Pettijohn and Potter 1964, p. 310) is a common sedimentary structure in most graywacke sandstones of the Lower Ecca Group of the Southern Facies (see fig. 39). However, due to the fine-grained nature of these rocks it is not always easily observed, except in fresh or polished surfaces. Grading is easily recognised in thin beds of sandstone which grade rapidly into shale.

Graded bedding is now thought to form during the down-slope movement of a turbidity current (Dzulynski and Walton 1965). The heavier coarser grains tend to collect in the fore of the current while the lighter and smaller particles remain above and behind. With a decrease in velocity the grains begin settling out at any one point, according to size; and are derived from positions progressively further to the rear of the current.

C. SHALE - PEBBLE CONGLOMERATE

Shale-pebble conglomerate occurs in the Lower and Upper Ecca Groups of the Southern Facies, and the Upper Ecca Group of the Western Facies. It is also a ubiquitous feature of the Lowermost Beaufort Beds in the southern half of the basin.

Conglomerates vary in thickness from a few inches to over a foot. They are usually lenticular in section and may outcrop over a strike length of a few yards. The shale pebbles are usually disc-shaped and well rounded (see fig. 40), but conglomerates composed almost entirely of angular fragments also occur. Pebbles vary in size from one to 7 centimetres and the matrix material is fine sandstone.

Shale-pebble conglomerates form by penecontemporaneous fragmentation and redeposition during the laying down of a sandstone formation. Sedimentation of this type may result from several different processes, of which the following are considered to be the most common -

1. Mud-cracked layers develop under widespread conditions of dessication. Subsequent flooding, reworking and redeposition of the mud-cracked fragments results in the formation of a thin but fairly extensive shale-pebble conglomerate.

2. During deposition of interbedded greywacke-shale sequences, characteristic of flysch deposits, sub-aqueous fragmentation of shale beds by turbidity currents is thought to take place (Kuenen and Natland, cited by Pettijohn 1957, p. 277).

The first type of process is thought to best explain the majority of the shale-pebble conglomerates in the Lowermost Beaufort Beds and Upper Ecca Group of the Western Facies, while the second process is considered to have been operative during deposition of the flysch sequences in the Lower Ecca Group of the Southern Facies.

H. GAS PITS

Spherical gas pits are very abundant in fine-grained sandstone at outcrop 145 (see folder 3). The cavities have diameters of 1 to 3 millimetres (see fig. 41) and occur throughout an outcrop length of about 50 yards.

These structures are found associated with ripple marks, trough cross-bedding and fossil plants, and are thought to have been produced by escaping gas in a shallow water environment. The gas was probably generated during the decay of organic material in the unconsolidated sand floor.

I. CONE-IN-CONE STRUCTURES

Excellent examples of cone-in-cone structure were observed in the calcareous nodules and thin beds of limestone of the Lower Ecca Group, Western Facies. These structures occur as inverted cones with their axes normal to the bedding.

J. DEFORMATIONAL STRUCTURES

This section deals with primary sedimentary structures and bedding which have been deformed contemporaneously, or shortly after deposition of the sediments.

Load Structures

The term "load structure" has recently been proposed by Dzulynski and Walton (1965), in preference to "load cast". These features are not in fact casts, and therefore the term structure is preferred. Load structures always occur as irregularly shaped projections at the base of sandstone beds, where these rest conformably or disconformably on shale (see fig. 42). They are common in successions of alternating sandstone and shale beds in the Southern, Western and Northern Facies of the Ecca Series and occur extensively within the lowermost Beaufort. In general they show no preferred orientation.

The depth of these features varies from a few inches to over 3 feet and the constituent material varies from fine to very coarse sandstone and grit. The shales immediately underlying these structures are bent and deformed (see fig. 42).

Kuenen (196[illegible]), was the first to draw attention to the presence of flame structures in the Lower Ecca Group near Laingsburg and these features have since been found to occur extensively within this unit, both in the southern outcrop belt and along the Wild Coast. Flame structures are complementary to load structures and are always found closely

- related -

related to the latter. They represent mud plumes separating the load casts at the sand-shale interface.

Load structures are generally accepted as having been formed by the unequal loading of hydroplastic muds with coarse clastic material. These structures are commonly found associated with turbidite sequences (Kuenen 1964), but are not characteristic of any particular environment. A few examples of flute and groove casts displaying the effects of loading were observed at outcrops 66 and 68 (folder 3), but in general most sole marks examined showed no sign of deformation prior to consolidation.

Ball-and-Pillow Structure

Ball-and-pillow structures occur in the Northern, Southern and Western Ecca Facies as for example at outcrop 125 (see folder 3). They occur in the basal portions of certain fine-grained sandstone beds, where these rest on shale. Ball-and-pillow structures are usually hemispherical or kidney-shaped, and range in size from 6 inches to over three feet. Occasionally pillows are seen completely isolated in a matrix of shale (see fig. 43). Potter and Pettijohn (1963) have reviewed the various theories relating to the origin of this structure and conclude that if a violent shock is applied to an unconsolidated layer of sand, resting on a hydroplastic layer of mud, then the sand layer will plunge into the mud and break up into isolated spherical and kidney-shaped bodies. Earthquakes are visualized as having provided the "violent shock" in nature.

- Convolute -

Convolute Lamination

Convolute laminations (Sanders 1960) are characterized by contorted and folded patterns within a bed of fine sandstone or siltstone. These units are usually 2 - 5 inches thick and can be traced for considerable distances in outcrop. Such structures occur in the Lower Ecca Group of the Southern Facies and good examples occur in the cliffs along the Wild Coast, both north and south of Coffee Bay.

Prior to compaction the convolutions were underlain by undisturbed laminae and merge upwards into approximately horizontal bedding. The axial planes of individual anticlines and synclines are usually approximately horizontal to the bedding. In the exposures examined, there does not appear to be any periodicity between the crests of convolutions.

Dzulynski and Walton (1965, p. 188) have reviewed current thinking on the origin of convolute lamination and conclude that this structure may be formed in a number of different ways, but is largely a response to vertical stresses acting on a hydroplastic sediment. Convolute lamination has been reported mainly from turbidite sequences (Wood and Smith, 1958, McBride, 1962, and Dzulynski and Walton 1965). The presence of other typical turbidity structures, such as sole marks, in close association with convolute lamination further suggests that the Lower Ecca Group of the Southern Facies is a typical turbidite or flysch sequence within the Cape-Karroo Geosyncline. The trend of these structures seldom bears any relationship to the paleocurrent direction.

- Slump -

Slump Structures

Potter and Pettijohn (1963, p. 155) apply the term "slump structure", to sediments which have undergone lateral movements, generated by the force of gravity. A variety of slump structures occur in the Ecca and Lowermost Beaufort Beds. Penecontemporaneous recumbent folds (see fig. 44) were observed in coarse- to medium-grained sandstone of the Middle Ecca and Lowermost Beaufort Beds in the north-eastern portion of the basin, as for example at outcrop 24 (see folder 8). The axes of these structures appear to be orientated parallel to the sedimentary strike and many were probably formed by the overturning of cross-bedded strata.

Slump structures do not characterise any particular depositional environment, but are found associated with tectonically unstable areas, such as geosynclinal basins and rapidly subsiding troughs. A delta front is also an area where slumping is likely to occur.

Slump structures are fairly common in the Lower and Upper Ecca Groups of the Southern Facies and also occur in the Middle and Upper Ecca Groups of the Western Facies. Along the Wild Coast, numerous examples of incoherent slumping exist. These structures are composed of a chaotic mixture of fine-grained sandstone and shale (see fig. 45), probably formed during subaqueous turbidity flows.

Sandstone Dykes and Sills

Sandstone dykes are crumpled sheets of sandstone contained in cross-cutting fissures. They are formed by the injection of quicksand during the deposition of a sedimentary succession. These structures are fairly common in the Lower Ecca Group of the Southern Facies and as already stated, excellent examples occur at Coffee Bay in the Transkei (see fig. 46). They vary in thickness from ¼ inch to over 2 feet and have vertical extents of 1 to 10 feet. Compaction wrinkles occur in most steeply dipping or vertical dykes indicating that they were injected into soft, hydroplastic sediments prior to compaction (see fig. 47).

In the exposures at Coffee Bay, sandstone dykes either show cross-cutting relationships to, or originate from, excellent examples of sandstone sills (see fig. 46). The margins of dykes and sills are smooth and sharply defined. Exposures of sandstone sills at Coffee Bay varied in thickness from ½ inch to over 4 feet and thickness variations within individual sills is a common feature. The origin of most sandstone dykes and sills has been ascribed to earthquake shocks (Dzulynski and Walton, 1965). These structures are most commonly found associated with flysch sequences in rapidly subsiding geosynclinal basins.

K. MARKINGS OF ORGANIC ORIGIN (TRACE FOSSILS)

The apparent rarity of invertebrate fossils in the Ecca Series makes it important to obtain as much information about the type of animal life that existed in this basin, from a study of the available burrows, tracks, trails and impressions preserved in these rocks. Collectively these are referred to as trace fossils (Häntzschel 1962).

Worm Burrows

Worm burrows are the most abundant trace fossils in the Ecca and were encountered in all four facies. They are most common throughout the Middle Ecca Group of the Northern Facies where they are found associated with shallow water structures such as large-scale planar cross-bedding and ripple marks. In general they become progressively less abundant towards the south-west of this facies and are rarely encountered in the Central Ecca Facies. Worm burrows associated with the Northern Ecca Facies are very characteristic. They are seen in plan as light-coloured circular structures, usually containing a central core, (see fig. 52). The constituent material within the casts is fine even-grained sand and is usually devoid of organic matter, although they often occur in carbonaceous sandstone and siltstone. In section, they usually lie normal to the bedding and vary in length from 1 to 16 centimetres (see fig. 53). Most burrows taper slightly towards the base.

Peculiar bifurcating structures which may be worm burrows were found in the Lower Ecca Group half a mile south of Umtata Mouth in the Transkei. They are characterised by a lateral groove and the tendency to lie approximately horizontal to the bedding (see fig. 54).

Tracks

This term is applied to spoor made by various animals. The most common type found in the Ecca Series are considered to be crustacean tracks. These are represented by twin parallel lines of claw marks, which occasionally extend across the entire outcrop of a bedding plane surface (see fig. 48).

- They -

They also occur in cherty shales near the base of the Central Ecca Facies, as for example at outcrop 37 (see folder 5), and similar tracks occur on bedding plane surfaces in the road cuttings near Laingsburg. These tracks closely resemble the genus copeza (Häntzschel, 1962, p.w. 191).

Parallel crescent-shaped ridges and depressions, aligned in rows about three to five inches long and ¼ of an inch wide are occasionally found in the Central Ecca Facies and in the Upper Ecca Group of the Northern Facies (see fig. 49). The origin of these features is uncertain, but they may have been produced by some creature which used its crescent-shaped tail to propel it along the mud floor of the basin. On the other hand these markings may represent the resting place of a segmented animal.

Trails

The most interesting trails found in the Ecca Series are the parallel regularly sinuous grooves first described by Haughton (1928, p. 15) from the Middle Ecca Group, north of Grahamstown. During the present investigations these same trails were found to occur abundantly at different stratigraphic levels over extensive areas of the Southern and Central Ecca Facies. Grooves are usually about 1 millimetre deep and widths between pairs vary from 9 to 18 millimetres (see fig. 50). Wave lengths vary from 5.8 to 12.0 centimetres and amplitudes from 12 to 18 millimetres. Individual groove pairs cross each other in a haphazard fashion and show no preferred trend.

From the periodicity of these trails it was

- concluded -

concluded that they were formed by the ventral fins of fishes as they swam along the floor of the sea. A linear relationship always exists between width of track, wave length and amplitude, and it was concluded that the frequency of body movement was less in the larger fish.

Irregular, curved grooves about 0.5 millimetre deep and 5 to 20 millimetres long are abundant on the surfaces of many shale and flagstone bedding planes in the Southern, Western and Central Ecca Facies (see fig. 51). Occasionally casts of these same features are encountered. The majority of these structures were probably formed by small worms, but a few closely resemble the trails left by small gastropods.

V. METHODS OF STUDYING DIRECTIONAL STRUCTURES AND PALEOCURRENT ANALYSIS

On the basis of lithology and paleocurrent directions the Ecca Series has been subdivided into the Southern, Western, Northern and Central Facies. Furthermore, it has been pointed out that the sandstone formations within the first three facies grade into a succession composed almost entirely of shale within the central portions of the basin. Additional evidence will now be presented to show that these three facies - in which sandstones are abundant - were derived from separate source areas and have distinct paleocurrent patterns. Other sedimentary properties, such as facies changes and average grain size of sandstones will be discussed in relation to these paleocurrent patterns. Regional sediment transport directions and provenance of the Lowermost Beaufort Beds will also be discussed.

A. PREVIOUS INVESTIGATIONS

A comprehensive review of previous paleocurrent work done in the Karroo Beds of South Africa and South West Africa has been given by Ryan (1967) and therefore only a summary of the most important contributions pertaining to the Ecca and Beaufort Series is given here. The subject will be dealt with in stratigraphic sequence and in chronological order.

Du Toit (1918), in an important contribution dealing with the stratigraphy of the Karroo System believed that the source of the Ecca sediments north of the Cape Folded Belt -

between Matjiesfontein and Grahamstown - lay well to the south. Referring to the Middle Ecca Group of northern Natal he stated: "An important point is the universal false-bedded nature of the grits, the dip of the planes being regular over a great area directed west or south-west, indicating for the sediments a source lying within what is now the Indian Ocean".

Wybergh (1924), Kent (1938), King (1948) and Blignaut (1951) all confirmed Du Toit's original observation viz. that the Middle Ecca sandstones in Natal were derived from a source area lying to the east and north-east.

More recently, Koen (1956), on the basis of heavy mineral studies, suggested that the Archaean granite-gneiss of the northern and eastern Transvaal and Rhodesia, constituted the most likely source for the isolated occurrences of Karroo sediments in the northern Transvaal. Visser et al (1958) believe that the Middle Ecca sediments north-east of Volksrust in the Transvaal, were derived from a general easterly direction.

Dealing with the hypothesis of continental drift in the light of recent advances of geological knowledge in Brazil and in South West Africa, Martin (1961), believes that the Great Karroo Basin was probably closed in the west during Permian times, and that the Windhoek Highlands formed an effective barrier between the Kalahari or Great Karroo Basin and the Huab Basin in the Kaokoveld north of the Windhoek Highlands.

On the basis of cross-bedding studies in the Middle

Ecca Sandstone of the north-western Orange Free State, Behr (1962) concluded that the sediments were derived from a general northerly source. De Villiers and Wardough (1962) studied heavy-mineral suites from the Ecca Series of the main Karroo Basin, with a view to determining the provenance and nature of the source rocks. They concluded that the present pre-Karroo basement rocks of South Africa could not have provided the consistently garnetiferous Karroo sediments, and on this basis, postulated an extra-continental source. In a paper dealing with turbidites in South Africa, Kuenen (1963) believed that the direction of transport in the Lower Ecca sediments near Laingsburg was variable, but mainly from the south.

Mountain (1945), in his presidential address to the Geological Society of South Africa stated that cross-bedding dip directions in rocks of the Middle Beaufort Series north and south of East London indicated a source area to the south-east. Visser et al (1958) believed that the majority of the cross-bedded units in the Lowermost Beaufort sandstones in the vicinity of Volksrust dipped to the west and south-west, thus indicating a source for the sediments lying to the east and north-east. Recently, Kingsley and Theron (1966) concluded that the Lowermost Beaufort Beds of the central and southern Orange Free State were shed from a southerly source, and that associated arkosic material was derived from sedimentary and granitic rocks in the north.

B. CORRECTION OF DATA FOR TECTONIC TILT AND APPLIED STATISTICS

In the previous chapter, the field measurement of

- directional -

directional structures was described in considerable detail. The methods used to correct this data for tectonic tilt and the application of statistics will now be discussed.

1. Correction of Data for Tectonic Tilt

Prior to the statistical treatment of directional structures the necessary corrections for tectonic tilt have to be made in order to restore the beds back to their original position at the time of sedimentation. The Southern Folded Belt and the Natal Monocline are the main areas where the Ecca and Lowermost Beaufort Beds have been subjected to tectonic disturbance.

Ramsay (1961), has discussed the effects of folding on the orientation of sedimentary structures and has dealt with various methods of compensating for tectonic tilt using a stereonet. In the case of cross-bedding readings, the method described by Potter and Pettijohn (1963; p. 260) was used to correct for tectonic tilt in beds with structural dips in excess of 5^{o}.

The Ecca and Lowermost Beaufort Beds have been affected by flexure or concentric folding in the south and individual folds have gentle angles of plunge. Therefore it was seldom necessary to make any correction for plunge, and the various linear primary sedimentary structures such as groove casts were untilted about horizontal axes. Ramsay (1961), found that azimuths of bedding plane lineations, such as groove casts, are only appreciably affected in strata dipping at angles in excess of 25^{o}. Therefore, linear sedimentary structures were only corrected for tectonic tilt in strata which had structural dips in excess of this figure.

2. Applied Statistics

Cross-bedding

Due to the fact that cross-bedding azimuths at a particular outcrop often have a wide scatter, it is preferable to calculate the vectoral mean orientation rather than the arithmetic mean (Pincus 1956). Therefore, at each outcrop locality the vectoral mean cross-bedding azimuth was determined. Where planar and trough cross-bedding occur at the same exposure, the directional data were grouped together and the mean determined. Throughout northern Natal, the vectoral mean was calculated using the mathematical method described by Curray (1956), but this procedure was too time consuming and therefore the graphical method first described by Reiche (1938) was adopted to determine the vectoral means for the remaining outcrops. In both methods, each cross-bedding measurement was given unit vector and the results obtained using the graphical method seldom differed significantly from those derived mathematically, except where the number of measurements became large. Therefore, the graphical method was not applied to outcrops with more than 10 measurements.

In the case of the mathematical method, the north-south and east-west components of each cross-bedding vector are computed by multiplying the magnitude by the cosine and sine of the azimuth respectively. These components are then summed to give the components of the resultant vector, which has a direction and a magnitude. Reiche (1938) used the vector magnitude divided by the number of observations (consistency ratio), as an index of dispersion; a parameter which may also be determined graphically. The calculation procedure is outlined below:

$$N - S \text{ component} = \Sigma_n \cos \theta$$

$$E - W \text{ component} = \Sigma_n \sin \theta$$

$$\tan \bar{\theta} = \frac{\Sigma_n \sin \theta}{\Sigma_n \cos \theta}$$

$$\bar{\theta} = \arctan \frac{\Sigma_n \sin \theta}{\Sigma_n \cos \theta}$$

$$r = \sqrt{(\Sigma_n \sin\theta)^2 + (\Sigma_n \cos\theta)^2}$$

$$L = \frac{r}{\Sigma_n}$$

Where: θ = azimuth from $0^\circ - 360^\circ$ of each observation or group of observations

$\bar{\theta}$ = azimuth of resultant vector

n = observation vector magnitude or, in the case of grouped data of unit vectors, it is the number of observations in each group

r = magnitude of resultant vector

L = consistency ratio

Both vectoral mean and consistency ratio were determined for each outcrop and the results summarised in appendices 2, 6, 10, 14 and 16.

A number of investigators have measured standard deviation or its square the sample variance, as an index of the dispersion or variability of cross-bedding directional data. Curray (1956, p. 120) has pointed out that variance may

- only -

only be calculated for directional data on the assumption that the measurements bear a linear normal distribution with respect to the mean. In the majority of outcrops investigated, too few readings were recorded to be certain that the data have in fact a normal distribution and therefore it was decided to determine the consistency ratio in preference to the sample variance.

On commencement of the fieldwork in the north-eastern portion of the basin, an attempt was made to determine the degree of variability of planar and trough cross-bedding at different levels of sub-sampling, in order to gain some idea at what level maximum sampling effort should be directed. Sample variance is calculated using the formula given by Potter and Pettijohn (1963, p. 254).

$$S_x^2 = \sum_{i=1}^{n} (x_i - \bar{x})^2 / (n - 1)$$

Where: x_i = individual cross-bedding azimuths

$\bar{x}$ = vector mean of all the observations

n = number of observations

TABLE 13

SAMPLE VARIANCE FOR DIFFERENT LEVELS OF SUB-SAMPLING

A. PLANAR CROSS-BEDDING IN MIDDLE ECCA SANDSTONES

Sub-sampling level	Sub-sample variance
Within a single cross-bedded unit	128
Between cross-bedded units within the same outcrop (one measurement per unit and 40 units per outcrop)	1,483
Between outcrops spaced 3 to 6 miles apart (10 measurements per outcrop and 20 outcrops)	2,735

- B. -

B. TROUGH CROSS-BEDDING IN THE UPPER SANDSTONE FORMATION

Sub-sampling level	Sub-sample variance
Within a single trough cross-bedded unit	Nil
Between cross-bedded units within the same outcrop (one measurement per unit and 30 units per outcrop)	324
Between outcrops spaced 10 to 20 miles apart (10 measurements per outcrop and 15 outcrops)	1,544

From table 13 it is possible to draw the following conclusions -

1. Both planar and trough cross-bedding have fairly low variances between outcrops.
2. Variance between sedimentation units within outcrops is low for both planar and trough cross-bedding, but particularly so for the latter.
3. Variance within a planar cross-bedded unit is very small and for axes of troughs is nil.

By comparing variability of cross-bedding data in the Ecca Series with results obtained by Potter and Olson (1954) and Potter and Siever (1956) it was concluded that one measurement per unit, 5 to 10 units per outcrop and one outcrop every 3 to 6 miles would be more than adequate for the objectives of this study.

In order to determine the degree of vertical variability of paleocurrent trends within the Ecca and Lowermost Beaufort Beds, cross-bedding measurements were recorded at different stratigraphic levels in the Biggersberg and Elandsberg sections of northern Natal. The data were grouped according to stratigraphic position as shown in table

14 and the vectoral mean cross-bedding direction calculated for each stratigraphic group and compared to the vector mean of the entire section. The results are presented in table 14 from which it may be seen that the deviation of the sub-sample means from the mean for the entire section is less than 68° in the Biggersberg section and 53° in the Elandsberg section.

TABLE 14

VERTICAL VARIATION OF CROSS-BEDDING AZIMUTHS

BIGGERSBERG SECTION

Stratigraphic Unit	Vectoral Mean of Sub-sample	Vectoral Mean of Section	Difference
Lowermost Beaufort Beds	209°	210°	1°
Above coal formation	* 261°	210°	51°
Within coal formation	214°	210°	4°
Below coal formation	157°	210°	53°

ELANDSBERG SECTION

Stratigraphic Unit	Vectoral Mean of Sub-sample	Vectoral Mean of Section	Difference
Lowermost Beaufort Beds	218°	216°	2°
Above coal formation	* 148°	216°	68°
Within coal formation	233°	216°	17°
Below coal formation	254°	216°	38°

* Planar and trough cross-bedding grouped together

- From -

From the above results it was concluded that cross-bedding directions of partial sections are fairly reliable indicators of current trends within the entire Ecca-Lowermost Beaufort section of northern Natal. Except in those portions of the basin where more than one current direction prevailed, the sampling procedure used always gave results comparable to those obtained for the entire Ecca-Lowermost Beaufort succession. Numerous investigators have employed two dimensional moving averages to show the areal variation in cross-bedding orientation (Potter and Siever 1956, Pelletier 1958 and Ryan 1963). In this study an interpretive paleocurrent map based on all available directional evidence was used to summarise paleo - current patterns on a basin scale. It was decided to apply this technique for the following reasons -

1. The density of outcrop localities is variable and in some areas cross-bedding was completely absent.
2. In certain portions of the basin more than one transport direction prevails, and therefore the application of a moving average would give a meaningless result.
3. The regional nature of this study and the lack of precise stratigraphic control.

Pelletier (1958) found an increase in the variability of planar cross-bedding data in the down current direction. In this study no attempt was made to investigate regional changes in consistency ratios of cross-bedding for the following reasons -

1. At each outcrop locality the vector mean is derived from either planar or trough cross-bedding, or varying proportions of the two. Because these types seldom display the same degree of consistency a comparison is not justified.

2. The pre-Karroo topography has a greater effect on the current trends in the Middle Ecca Group in the northern portions of the basin, than farther south where considerable thicknesses of Dwyka Tillite and Lower Ecca Shale intervene.

3. The lack of precise stratigraphic control may involve an additional number of variables which would further complicate the issue and lead to a misinterpretation of the facts.

Linear Structures

In the case of ripple marks, parting lineations and groove casts, the mean orientation direction was calculated arithmetically, as the spread of data is usually small.

The azimuths of fucoid structures at each outcrop, were plotted on rose diagrams (see folder 12), from which it can be seen that a preferred bimodal orientation exists for most localities. The arithmetic mean for each mode was calculated (see appendices 3 and 9). At 75 percent of the outcrops the fucoids were either orientated approximately N.E. - S.W. or N.W. - S.E., thereby suggesting that the original plant stems tended to align themselves parallel and at right angles to a preferred current direction.

At outcrops 27 and 28 (see folder 5) where 40 and 70 readings were recorded, the scatter or dispersion about the two means was calculated. Standard deviations were 9° and 37°, thereby indicating that these structures are fairly well orientated with respect to the two means (see appendices 3 and 9). The bimodal orientation of these structures at outcrops 27 and 28 is further illustrated in figures 55, 56, 57 and 58.

- C. -

C. PRESENTATION OF RESULTS

At each outcrop, the mean orientation for a particular directional structure is given. The data are presented on a series of maps covering the entire outcrop belts of the Ecca and Lowermost Beaufort Beds (see folders 3, 5, 6, 7 and 8). These maps were originally constructed on a scale of 1 : 500,000 and then photographically reduced to a scale of 1 : 1 million. Various symbols have been used to distinguish between different sedimentary structures and a distinction is also made between structures occurring in different stratigraphic units. All cross-bedding arrows were given the same length; as the vector magnitudes were consistently high for the majority of outcrops.

Each outcrop locality is given a reference number on the map and all the relevant statistical data are tabulated in the appendices 1 to 17. An interpretive paleocurrent map based on all available sedimentalogical evidence summarises the regional paleocurrent trends within the Ecca Series (see folder 13).

Mean thickness of planar cross-bedding and mean ripple index are also recorded in the appendices. Areal variations of these two parameters are illustrated in folders 14 and 15, where a visual size scale was used in preference to a more quantitative approach. Reasons for adopting this method have already been discussed in chapter III.

D. PALEOCURRENT ANALYSIS OF THE ECCA SERIES

1. The Northern Ecca Facies

- Due -

Due to the limited distribution, poorly exposed nature and rarity of sedimentary structures, very little paleocurrent data was obtained from the Lower and Upper Ecca Shale. Instead, most of the conclusions drawn regarding the current directions in the Northern Ecca Facies had to be gained from the abundant cross-bedding measurements taken in the Middle Ecca Group. In addition, the paleocurrent reconstructions for the Lowermost Beaufort Beds and the paleo-ice-flow directions, determined by Du Toit (1956, p. 277) and Stratten (in press) for the underlying Dwyka Tillite, were used as an additional aid in the interpretation.

Folders 5 - 8 illustrate the average flow directions at each outcrop measured in the Northern Ecca Facies, from which it may be deduced that apart from a few anomalous areas the general dispersal pattern was towards the south-west and west. However, in portions of Natal there is substantial evidence of a south-easterly trend in sediment transport particularly in the sandstones below the Coal Formation. It is believed that the relatively faster rates of subsidence in the Natal Trough had the effect of causing considerable quantities of south-westerly trending sediment to be diverted towards this major structural feature. Regional transport directions within the Natal Trough were mainly in a general south-westerly direction and approximately parallel to the axis, but a certain amount of westerly flow also took place.

Along the northern margins of the basin there is evidence for a southerly current trend. This feature is probably best explained by the fact that the Middle Ecca

Group rests directly on the pre-Karroo surface over wide areas in this part of the basin. Therefore the effect of the pre-Karroo topography with its large north-south trending valleys (Wybergh 1922), exercised a major control on the flow trends of sedimentary detritus. Along the Vaal River in the north-western Orange Free State cross-bedding measurements indicate a south-southeasterly transport direction, thereby indicating a possible local source area towards the north-northwest. However, this is not borne out by any major change in the composition of the sandstones in this area and therefore, this abnormal transport trend may have been controlled by the local effects of the pre-Karroo topography. Cross-bedding vector means in sediments above the Coal Formation indicate a pronounced westerly transport direction over a fairly wide area (see folders 6 and 7), compared to the remaining Middle Ecca strata, thereby suggesting that the paleoslope had a more westerly dip during deposition of the upper portion of the Middle Ecca. This feature may be accounted for by one or more of the following possibilities -

1. Subsidence rates in the Natal Trough may have been less marked during this period, thereby reducing the volume of sediment transported down the axis of this feature.

2. The effects of the pre-Karroo topography on the trend of sediment transport had been greatly reduced during deposition of sediments above the Coal Formation due to the blanketing effect of the underlying strata.

3. A slight re-adjustment in the basin tectonics may have resulted in a corresponding change in the dip direction of the paleoslope.

The strikes of symmetrical and asymmetrical ripple marks usually lie approximately at right angles to the paleocurrent trend as indicated by the cross-bedding.

Essentially the same dispersal patterns as obtained for the Middle Ecca Group were also found to occur in the Lowermost Beaufort Beds, and Du Toit (1956, p. 237) found similar trends in his study of the Dwyka ice-flow directions. It may therefore be assumed with a fair degree of certainty that the regional dispersal patterns displayed by the Middle Ecca Group are a reliable representation of the sediment transport directions for the whole of the Northern Ecca Facies. The generalised flow pattern for this facies is illustrated in folder 13.

2. The Southern Ecca Facies

Evidence of paleocurrent trends in the Lower Ecca Group is mainly derived from sole casts, asymmetrical and symmetrical ripple marks (see folder 3). Although groove and bounce casts do not indicate a sense of current flow, it was, however, possible to infer the probable current direction with a considerable degree of certainty from the current direction as indicated by associated flute casts, prod casts and asymmetrical ripple marks. One of the most striking features of the paleocurrent map (see folder 3), is the tendency for the majority of directional structures in the Lower Ecca Group to lie essentially parallel or at right angles to the regional strike of the southern outcrop belt. It has already been demonstrated that this outcrop belt lies approximately parallel to what was an easterly plunging depositional trough. It is therefore concluded that during Lower Ecca times, sediment transport was predominantly northwards and into this elongate basin but a considerable amount of flow also took place eastwards and parallel to its direction of plunge.

Current thinking on palcocurrent systems in turbidite basins has been reviewed by McBride (1962), Potter and Pettijohn (1963) and Dzulynski and Walton (1965). All conclude that sediment transport may take place both down the marginal slopes, as well as longitudinally along the axis of the depositional trough. Controversy exists as to whether the longitudinal current pattern was caused by the introduction of sediment by a large river entering the trough at one end, or whether it was caused by currents bringing in sediments from the margins of the trough and then subsequently altering direction in the axial portions. In this respect there appears to be very little doubt that sediment was mainly derived from beyond the southern margins of the Cape-Karroo Geosyncline, as the amount of coarse clastic material in the Lower Ecca Group decreases rather than increases towards the west.

In the vicinity of Coffee Bay in the Transkei, rocks which may be the time-stratigraphic equivalents of the Lower Ecca Group contain groove casts which have either a north-south or north-west south-east orientation. In addition, sandstones within this succession grade northwards into shale. This leads to the conclusion that the major transport direction was also northwards. However, the possibility of a certain amount of sediment transport in an easterly direction should not be discounted.

Ripple marks in the Middle Ecca Group mainly

- indicate -

indicate a northerly transport direction, but a certain amount of easterly flow may have occurred, as evidenced by the mean current direction at outcrop 21 (see folder 3) and the general thickening of the group towards the east. Cross-bedding in the Upper Ecca Group shows a pronounced northerly flow of sediment and the strikes of symmetrical ripple marks usually lie more or less parallel to the regional strike of the outcrop, except in the extreme western portion where they trend northwest-southeast (see folder 3). Analysing the regional current pattern during Upper Ecca times, in terms of available cross-bedding and symmetrical ripple marks, it may be deduced that the predominant transport direction was northwards, except in the western portions of the outcrop where a more north-easterly trend becomes predominant. As already pointed out, the axis of the Cape-Karroo Geosyncline advanced northwards in time. It is therefore not unlikely that although no sedimentological evidence exists to indicate an easterly transport of sediment during Upper Ecca times, this may be due to the fact that only the marginal facies is exposed in the southern outcrop belt, and that a longitudinal easterly flow may have occurred in the axial portions farther to the north. The writer is, however, inclined to the view that although rapid subsidence in the Karroo Trough continued throughout Upper Ecca times a shallower water environment prevailed, uplift of the source area to the south was greater and the paleoslope had a steeper inclination towards the north. These factors are thought to have contributed towards the stronger, northerly directed current trends found in the Upper Ecca Group. The generalised flow patterns within the Southern Ecca Facies are illustrated in folder 13.

- 3. -

3. The Western Ecca Facies

Directional current structures such as ripple marks, cross-bedding and parting lineations indicate that the paleocurrent pattern in the Western Ecca Facies was towards the east and north-east (see folder 3). Strikes of symmetrical ripple marks lie essentially parallel to the depositional strike of the facies as indicated by cross-bedding and current ripples, and therefore are of considerable value in reconstructing the paleoslope. Similar relationships have been observed by Greiner (1962, p. 232 - 233) in his study of the Albert Shale, New Brunswick. The regional palaeocurrent trends for this facies are illustrated in folder 13.

4. The Central Ecca Facies

One of the problems encountered in reconstructing the paleocurrent trends in the Central Ecca Facies, is the limited numbers of reliable directional current structures. From the paleocurrent maps (folders 3 and 5) it is possible to see that the easterly and north-easterly trends so well developed in the Western Ecca Facies are continued for some three hundred miles along the western outcrop belt of the Central Ecca Facies. Evidence of this trend is mainly indicated by the following -

(a) Strikes of symmetrical ripple marks near the top of the Ecca Series have a pronounced northerly and north-westerly orientation. They therefore lie more or less at right angles to the current direction as indicated by the limited number of cross-bedding measurements found in the very fine grained sandstones near the top of this series.

(b) Ripple marks and cross-bedding in the Lowermost Beaufort Beds indicate a general westerly and north-westerly transport direction.

In the valley of the Orange River and in the south-eastern Orange Free State, interpretation of the paleocurrent pattern is to a large extent based on the mean orientations of fucoid structures. As already pointed out, these features usually display a bimodal orientation at a particular outcrop. From the rose diagrams of these fucoids (see folder 12) and the paleocurrent maps (folders 3 and 5) it may be seen that at 70 percent of the outcrops the arithmetic mean orientations of the fucoids lie either approximately northwest-southeast or northeast-southwest. Thereby suggesting that the original plant stems aligned themselves approximately parallel and at right angles to the prevailing current. Interpreting this information in the light of regional paleocurrent trends within the Ecca, as well as the overlying Lowermost Beaufort Beds and the underlying paleo-ice-flow directions in the Dwyka Tillite (Du Toit 1956, p. 277 and Stratten (in press)), it was concluded that the general line of current movement was north-east-southwest. From the available paleocurrent evidence in the western outcrop belt of the Central Ecca Facies, it would appear that fine-grained clastic material was being transported in an easterly and north-easterly direction to somewhat north of the present position of the Orange River. While north of this, flow directions were towards the south-west. A considerable amount of overlapping and interfingering of sediment derived from these two sources took place where these directionally opposed currents met.

- Along -

Along the eastern outcrop belt of this facies, a limited number of parting lineations indicate a northeast-southwest current trend (see folder 8). This is fu[illegible] sub-stantiated by the fact that the average transport direction in the southern portion of the Northern Ecca Facies is towards the south-west, while in the Southern Ecca Facies near Coffee Bay, the generalised dispersal pattern is northwards. On the basis of the above evidence it has been concluded that the outcrop belt of the Central Ecca Facies in the eastern portions of the basin represents a zone of intermixing of fine-grained clastics derived from both the north-east and south.

E. PALEOCURRENT ANALYSIS OF THE LOWERMOST BEAUFORT BEDS

Although only limited numbers of directional structures were measured in the Lowermost Beaufort Beds, it has nevertheless been possible to draw certain conclusions regarding the regional sediment transport trends in this unit. From the palaeocurrent maps (see folders 5 to 8), it may be deduced that the generalised transport directions, along the northern and north-eastern portions of the Lowermost Beaufort outcrop, were towards the south-west and west. In the eastern portion of the outcrop belt (see folder 8). it is evident that two separate paleocurrent systems were operative. The first had a general south-westerly and westerly trend and is merely the southern extension of the dominant transport trend farther to the north. While the second has a general northerly trend and is obviously related to a completely separate current system. It may be assumed that where these directionally

- opposed -

opposed currents met, a considerable amount of overlapping and interfingering of sediments derived from different source areas took place. Attention must also be drawn to the two outcrops (Nos. 50 and 55) where the transport direction as indicated by cross-bedding showed a general easterly current trend. It is therefore probable that a certain amount of sediment transport also took place towards the east.

Along the southern margins of the basin, directional structures indicate a general northerly transport direction (see folder 3). While in the west, between the Fish and Orange Rivers, the regional paleocurrent patterns are towards the north-east and east.

In the north-western portions of the basin there is evidence of two major transport directions (see folder 5). These are -

1. A general south-westerly trend which is a continuation of the dispersal pattern encountered in the north-eastern portions of the basin.
2. A northerly current direction which is more pronounced in the southern Orange Free State.

It has therefore been concluded that a considerable amount of interfingering of sediments derived from these two source directions took place in the central and southern portions of the Orange Free State. In fact, this feature has been observed at a number of localities, as for example in the hills six miles north of Bloemfontein, where it is possible to see coarse and medium-grained arkoses from the north interfingering with fine-grained sub-graywackes derived from a general southerly source.

In summary, regional paleocurrent directions within the Lowermost Beaufort Beds are essentially the same as those of the Ecca Series. Three major and one minor dispersal patterns have been identified. These are as follows -

1. A general south-westerly trending pattern which occurs in the northern one-third of the basin.
2. A northerly trending pattern which is mainly found in the southern half of the basin.
3. An easterly and north-easterly orientated dispersal pattern, occurring in the south-western portions of the basin.
4. A smaller but significant easterly trending current pattern occurs south of Port St. John's in the eastern part of the basin.

A considerable amount of overlapping and interfingering of sedimentary detritus derived from different source areas, takes place in the central portions of the basin where these separate dispersal patterns meet.

F. OTHER SEDIMENTARY PROPERTIES AND THEIR RELATIONSHIP TO THE PALEOCURRENT PATTERN

Fundamental to any paleocurrent analysis of a stratigraphic unit is the examination of the relationships between regional transport trends, as indicated by primary directional structures, and other sedimentary properties of the unit, such as average grain size. These various relationships will now be discussed.

1. Facies Changes and their Relationship to Paleocurrent Directions

The examination of borehole and outcrop sections in the Northern Ecca Facies has revealed a marked increase in the percentage of coarse sandstones towards the north-east and east. Conversely the succession becomes predominantly shaley towards the south-west and west. The percentage shale in the Northern Ecca Facies is controlled by the distance from source, paleocurrent pattern, and energy level at the depositional interface. It is therefore interesting to note the regional relationships between sediment transport directions, paleoslope and trends in facies change (see folders 2, 4 and 13). Furthermore, the regional dispersal pattern lies essentially at right angles to the depositional strike.

The same regional relationships have been found in the Southern and Western Ecca Facies (see folders 2, 4 and 13). Similar patterns are also displayed by the various facies within the Lowermost Beaufort Beds.

2. Thickness changes and their relationship to the paleocurrent directions

A comparison between folders 1 and 13 reveals a close relationship between regional paleocurrent directions and thickness trends within the Ecca plus Upper Dwyka Shale sequence. A concordant relationship exists between trends in facies change and the isopach pattern (see folders 1 and 2). Pryor (1960), Potter (1962) and Forgotson (1963) observed parallel relationships between paleocurrent directions, thickness and lithofacies trends for different sedimentary basins in North America.

3. Average grain size of sandstones and their relationship to the paleocurrent directions

A comparison between folders 10 and 13 reveals the following -

(a) There is a marked parallelism between regional paleocurrent directions and trends in decreasing average grain size, for sandstones within the Northern Ecca Facies.

(b) No well-defined directional trends in mean grain size were detected along the southern or south-western outcrop belts. This is due to the fact that the regional trends of these two belts lie essentially parallel to the depositional strikes of the Southern and Western Ecca Facies respectively. However, drilling has shown that sandstones within the Southern Ecca Facies grade into shale towards the north, and that sandstones within the Western Ecca Facies grade into shale towards the east and north-east, thereby indicating that a concordant relationship exists between paleocurrent directions and regional trends in average grain size reduction.

4. Mean pebble sizes and their relationship to paleocurrent directions

Pelletier (1958) and Yeakel (1962) demonstrated a close relationship between mean paleocurrent direction and the trend in decreasing average pebble size, for deltaic and fluvial deposits respectively. A comparison between folders 11 and 13 reveals that average pebble sizes of Middle Ecca conglomerates do not become progressively smaller in the down current direction. Reasons for this feature have already been given in Chapter III. It is significant, however, that the Middle Ecca conglomerates are only confined to the northern and north-eastern portions of the basin.

5. Mean thickness of planar cross-bedded units and their relationship to paleocurrent directions

The thickness of planar cross-bedded units was measured where possible, and the average determined for each

- outcrop -

outcrop locality. These values are recorded in the appendices 2, 6, 10, 14 and 16 and presented in folder 14, where a visual size scale is used to indicate thickness variations. From folder 14 the following deductions may be drawn -

(a) The thickest planar cross-bedded units occur in the Northern Ecca Facies of northern Natal and the south-eastern Transvaal.

(b) Planar cross-bedded units in the Northern Ecca Facies appear to become progressively smaller towards the south-west, although there are local exceptions.

(c) In the outcrop belts of the Southern and Western Ecca Facies it is not possible to draw any definite conclusions regarding trends in average thicknesses of planar cross-bedded units, as the number of sample localities are too few and the outcrop belts are too narrow.

Folders 13 and 14 reveal that, with local exceptions planar cross-bedded units in the Northern Ecca Facies become progressively thicker towards the source. Similar relationships have been observed by Schwarzacher (1953) and Pelletier (1958).

6. Pre-Karroo valleys and their relationship to paleocurrent directions

Wybergh (1922), Cousins (1950) and Behr (1962) mapped the trends of large pre-Karroo valleys in the northern portions of the basin. Many of these have depths in excess of 100 feet. A particularly large valley in the vicinity of the Orange Free State Goldfield has a maximum depth of 1,890 feet (Cousins 1950). The majority of these valleys have a general north-south trend and therefore lie approximately parallel to the mean paleocurrent directions as indicated by sedimentary

.. structures -

structures within the basal portions of the Ecca Series. Du Toit (1956) showed that the paleo-ice-flow directions were southwards along the northern margins of the basin, thereby indicating a parallel relationship to the trend of pre-Karroo valleys. It is therefore probable that these entrenched channels were formed prior to, or during the Dwyka glaciation, and exercised a major control on the transport directions of Lower Karroo sediments. With the infilling of these valleys with sediment, their effect on the current patterns diminished.

7. Petrographic provinces and their relationship to paleocurrent directions

Siever and Potter (1956) studied the regional relationship between petrographic provinces and sedimentary dispersal patterns within the Eastern Interior Basin of the United States. They found that separate palaeocurrent systems, related to different source areas, were associated with distinct petrographic provinces. Within the Karroo Basin, the Southern, Western and Northern Ecca Facies each display a distinct current pattern relatable to three separate source areas. Petrographic investigations - at the reconnaissance level - have clearly indicated that the sandstones of the Northern Ecca Facies are considerably different in their mineralogical properties to both the Southern and Western Ecca Facies. On the other hand there appear to be no major mineralogical differences between the Southern and Western Ecca Facies.

G. POSITIONS AND NATURE OF THE SOURCE AREAS

The regional paleocurrent directions within the

- Northern -

Northern Ecca Facies clearly indicate a source area lying to the north-east and east. In addition, petrographic studies have demonstrated that the source rocks were predominantly granitic in composition. The actual location of the source area poses an interesting problem. The first possibility is that the source of these sediments was situated to the north-east and east of the present Natal coast. The second possibility is that the north-south trending belt of Basement granite exposed along the core of the Natal Monocline represented a rising portion of the craton at the time of sedimentation and therefore constituted a source area. A combination of these two possibilities must also be considered.

The exposures of Basement granite along the core of the Natal Monocline are not considered to have represented a source area, for the following reasons -

(a) Cross-bedding measurements in downfaulted blocks of Middle Ecca Sandstone along the Natal coast, as well as in eastern Swaziland, clearly indicate a source lying east and north-east of the present coast. These rocks contain no evidence to suggest that the north-south trending granite arch shed sediments eastwards.

(b) Isopach maps of the Ecca plus Upper Dwyka Shale succession indicate that the present exposures of Basement granite in the eastern portions of the basin were completely covered during this period.

(c) The abundance of detrital muscovite and small pebbles of microcline in the Middle Ecca sediments strongly suggests that such rock types as muscovite pegmatite, muscovite gneiss and granite constituted the dominant source-rock material. In this respect, it is interesting to note that the granites and gneisses exposed in the belt of pre-Karroo rocks along the eastern margins of the basin are mainly hornblende-biotite varieties. These rocks do contain muscovite pegmatite, but they are believed to be far too few in number to account for the abundance of muscovite in sediments of the Northern Ecca Facies.

- (d) -

(d) The Middle Ecca Sandstones appear to become progressively coarser-grained towards the north-east and east, which is what would be expected closer to the source.

(e) Over most of coastal Natal the Table Mountain Sandstone rests unconformably on a mature surface of Basement granite. In addition, no major orogenic movements took place until early Jurassic time. Therefore, the existence of a high coastal mountain range in this area may be discounted.

In view of the above evidence, it has been concluded that a major highland area, composed predominantly of granitic rocks, lay to the north-east and east of the present Natal coast. The north-south trending belt of pre-Karroo rocks in the eastern portions of the basin did not represent a major barrier to sediment transport. Judging from the abundance of angular to sub-angular felspar pebbles in eastern Swaziland and in Coastal Natal, it is thought that this highland area was situated fairly close to the present coastline. On the basis of paleocurrent directions and trends in average grain size of Middle Ecca Sandstones, together with changes in lithofacies, it may be deduced that relief in this source area probably decreased towards the south.

Along the northern margins of the basin, as for example in the vicinity of Witbank, paleocurrent directions, together with the compositions of sandstones and conglomerates have indicated that the pre-Karroo formations to the north of the present erosional limits shed minor amounts of sediment into the basin. This region therefore represented a subordinate source area.

During Lower Ecca times sedimentation in the northern portions of the basin was confined to the Natal

Trough and possibly also the western Orange Free State. The intervening portions of the craton, although only mildly positive, were subjected to erosion and therefore probably shed small quantities of predominantly fine-clastic material into the depositional areas.

The regional dispersal patterns within the Southern Ecca Facies together with petrographic evidence indicates the presence of a linear source area composed mainly of granitic rocks lying to the south of the African continent in its present form. Sedimentary, basic intrusive and metamorphic rocks probably also occurred in minor amounts. Stratigraphic successions indicate that relief in the source area was more pronounced in the east. Combined paleocurrent, stratigraphic and structural evidence indicates that the source area probably represented a rising geanticlinal ridge along the southern margins of the east-west trending Cape-Karroo Geosyncline. The coarse facies of the Ecca Series in this area was deposited closer to the source and has since been eroded away. Isopach maps of the Cape System (Kingston et al. 1961), and the Ecca Series (folder 1) indicate that the southern margins of the Cape-Karroo geosyncline lay some 150 miles south of the present Cape coast (see folder 4). It is therefore, conceivable that the source of the sediments constituting the Southern Ecca Facies lay some 200 miles to the south of the present outcrop belt.

Regional paleocurrent directions within the Western Ecca Facies clearly indicate that the source of these sediments lay to the west and south-west of the present outcrop belt. In addition, the petrography of the sandstones has shown that the source rocks were predominantly granitic in composition, although sedimentary, basic intrusive and metamorphic rocks probably also occurred in minor amounts. The western source area must have been situated beyond the present continental limits, as none of the rock types along the western and south-western margins of the Karroo Basin correspond to the requirements of a predominantly granitic provenance.

Isopach maps of the Cape System (Kingston et al. 1961) indicate that the outcrops of the Cape Granite along the present west coast were covered during the Permian and therefore could not have represented a source area. Structural, stratigraphic and sedimentological evidence suggests that the western source area had a general north-northwesterly trend. This highland area probably corresponded to a geanticlinal ridge bordering the south-western and western margins of the Cape-Karroo Geosyncline. The presence of "borderlands" outside the margins of the present configuration of Southern Africa is certainly not unique to this continent. For example it has been shown by numerous investigators that the North American continent was originally bordered in the east and west by highland linear belts known as Appalachia and Cascadia respectively.

VI. SEDIMENTARY TECTONICS

A. REGIONAL TECTONIC FRAMEWORK DURING ECCA AND LOWERMOST BEAUFORT TIMES

Lithofacies patterns and paleocurrent trends, together with isopachs and mineralogical compositions of sediments, have been used in the interpretation of the tectonic framework. The classification of paleotectonic elements used in this chapter is based on that of Krumbein and Sloss (1963) who in turn adopted a modified classification of the concepts developed by Kay (1947). No attempt is made to distinguish between miogeosynclinal and eugeosynclinal zones in this study. Instead the term geosyncline is applied to an orogenically active linear element of long continued subsidence and lying adjacent to the craton. Furthermore, it is inferred that geosynclines receive the bulk of their sedimentary fill from a linear actively rising geanticlinal ridge, paralleling their outer margins.

Folder 16 shows the average position and configuration of the various paleotectonic elements during the Ecca period, and a similar pattern prevailed during deposition of the Lowermost Beaufort Beds. These various tectonic elements will now be discussed.

The Eastern Highlands

The Eastern Highlands represented a strongly positive tectonic element extending southwards for a distance of some 500 miles from south-eastern Mocambique. This feature was probably situated about 100 miles to the east of the present

- Natal -

Natal coast. Litho-stratigraphic and paleocurrent evidence indicates that tectonic uplift in the southern portions of this feature was not as pronounced as in the northern and central parts. The enormous volume of coarse arkosic sediment shed westwards and south-westwards from this highland during Middle Ecca and Lowermost Beaufort times indicates that relief in this source was very high (± 15,000 feet). Based on the trend of isopachs in the Natal Trough and the paleocurrent patterns along the eastern margins of the basin, it has been concluded that the Eastern Highlands represented a large north-south trending granite horst (see folder 4). In this respect it is interesting to note the parallelism between the presumed trend of the Eastern Highlands, the axis of the Natal Monocline, and the shear zones in the Basement Complex of eastern Swaziland. Relief during Lower and Upper Ecca times was relatively low as evidenced by the predominance of shales in these two groups.

The Southern and Western Highlands

The Southern and Western Highlands constituted a more or less continuous belt of high ground, probably in the form of a linear geanticlinal ridge forming the southern and western margins of the Cape-Karroo geosyncline (see folders 16 and 4). Litho-stratigraphic and paleocurrent evidence indicates that tectonic uplift was more pronounced in the eastern portions of the Southern Highlands and that relief in the northern portions of the Western Highlands was not as pronounced as in the south. There is no evidence to suggest that a highland source existed along the south-eastern margins of the Karroo Basin during Permian times. It is therefore possible that relief in this

- area -

area was either low, or completely absent at this time.

Pronounced periods of tectonic uplift took place in the Southern Highlands during Lower Ecca, Upper Ecca and Lowermost Beaufort times. However, in Middle Ecca times relief was fairly low (see folder 4). In contrast, only limited tectonism took place in the Western Highlands during Lower Ecca times, but became progressively more intense during Middle Ecca, Upper Ecca and Lowermost Beaufort times.

The Witwatersrand Arch

The Witwatersrand Arch is a broad north-easterly trending palaeotectonic feature, composed of pre-Cambrian formations and occurring along the northern and north-western margins of the Karroo Basin (see folder 16). During Permian times, this feature was represented by a broad zone of relatively high hills. Field relationships have clearly indicated that most of the formations constituting the Middle Ecca Group wedge out against the flanks of this positive element. In contrast, the Upper Ecca and Lowermost Beaufort sediments were probably deposited over most of this tectonic element.

Petrographic and palaeocurrent studies have demonstrated that this feature constituted a subordinate source area during Lower and Middle Ecca times. However, the Waterberg and Bushveld Coal Basins represented localised areas, within the confines of this broad tectonic element, where sediment accumulation took place.

The Windhoek Highlands

The Windhoek Highlands constituted an east-north-easterly trending, mildly positive structural feature, extending across the central portions of South West Africa. According to Martin (1961), this mildly positive area formed an effective barrier between the Great Karroo Basin in the south and the smaller Huab Basin to the north. From this area, sediments were shed both southwards and northwards into these two basins.

The Clocolan Dome

The position and nature of this large sub-surface tectonic element can best be observed by comparing folders 1 and 17. From folder 1 it is possible to see that the isopachs of the Ecca Series plus Upper Dwyka Shale show a progressive thinning over what appears to be an extensive pre-Karroo structural feature, the centre of which lies immediately west of Lesotho. Similarly, the presence of an extensive gravity low anomaly in this area (- 180 milligals), suggests the presence of Basement granite fairly near the surface in this portion of the Karroo Basin (see folder 17). This is further substantiated by the presence of a granite inlier south of Verkeerdevlei (Ryan 1967), and the intersection of Basement granite below the Karroo System at a depth of [illegible],043 feet below surface in borehole No. 39 (see folder 1). Based on the above evidence it has been concluded that a large dome-shaped feature composed predominantly of Basement granite occurs below a relatively thin cover of Karroo rocks in the eastern Orange Free State. Although the Lower Beaufort Beds extend over this feature, the Dwyka Tillite, Lower Ecca Shale and Middle Ecca Sandstone wedge out against the flanks of this tectonic element.

- Conglomerates -

Conglomerates containing pebbles of granite and felspar have been observed in the lowermost Beaufort Beds near Brandfort and were probably derived from the Clocolan Dome.

The isopachs in folder 1 indicate the presence of two broad subsurface palaeotectonic arches. The axis of the first has an approximately north-easterly trend and passes through the town of De Aar, while the second has an essentially north-westerly trend and passes through Port St. John's. These two arches intersect at more or less the position of the Clocolan Dome (see folder 16). Available litho-stratigraphic evidence indicates that these two arches were probably covered with sediment throughout most of the Permian and therefore did not represent subordinate source areas.

The Karroo Trough

The Karroo Trough was the area of maximum sediment accumulation during the Permian. The axis of this linear downwarp parallels the trend of the later Southern Cape Folded Belt and has an easterly plunge (see folders 1 and 16). This structural feature lay within the site of the Cape-Karroo geosyncline (see folder 4) and a well defined hinge line marks its northern margin where it merges with the cratonic shelf. The Karroo Trough was at least 450 miles long, 150 miles wide and was probably bordered in the south and west by a relatively narrow unstable shelf lying to the north and east of the Southern and Western Highlands respectively. During Upper Permian times, the axis of this linear downwarp advanced northwards, a feature which was probably brought about by increased tectonism in the source area to the south.

The Natal Trough

The axis of this linear basin lay approximately parallel to the trend of the present east coast and plunged towards the south-southwest (see folder 1). Evidence as to the former existence of this feature is mainly deduced from the increased thicknesses of Ecca plus Upper Dwyka Shale along the eastern margins of the basin. A well defined hinge line occurs where this elongate basin merges with the cratonic shelf areas to the west. The Natal Trough was bordered in the east by the Eastern Highlands and available evidence suggests that this linear downwarp conforms to the structural and sedimentalogical requirements of a yoked basin.

Cutting transversely across the Natal Trough, is a smaller fault bounded basin known as the Tugela Trough. Lithostratigraphic and structural evidence suggests that this linear feature represented a fairly rapidly subsiding fragment of the craton, particularly during Middle Ecca times.

The earth's crust must have been very deeply depressed in the area where the Karroo and Natal Troughs met, and therefore formed an ideal area for inundation by the Permian seas.

The Cratonic Shelf

The Cratonic Shelf is represented by those neutral portions of the craton lying between the strongly negative and more positive tectonic elements. These areas underwent relatively small amounts of subsidence during the Permian. On the basis of isopachs and lithologic associations, it has been possible to

- subdivide -

subdivide the Cratonic Shelf into stable and unstable areas. These are shown in folder 16 and will be discussed shortly.

Apart from the tectonic elements already discussed the following additional structural features lie within the confines of this broad shelf area.

1. The Limpopo Trough

The Limpopo Trough constituted a shallow fault controlled linear basin, extending across Southern Africa in a general north-northeasterly direction. Truter (1945) has shown this feature to be a structural lineation of pre-Waterberg age.

2. The Kalahari Basin

On the basis of outcrop distributions and available thickness measurements (Green 1966), the writer has concluded that a slowly subsiding basin with a general south-westerly trending axis occurred in what is now the south-western part of Botswana.

3. The Namaqualand Basin

From thickness measurements obtained in borehole No. 48 (see folder 1), together with the present outcrop distributions of Upper Dwyka Shale, it would appear that a north-westerly trending basin occurred in what is now southern South West Africa and the north-western Cape. It is almost certain that this basin was connected to the oceans by means of a narrow sea-way in the vicinity of the Orange River Mouth. Evidence as to the position of this sea-way is indicated firstly

- by -

by the presence of Eurydesma, Conularia, Peruvispira and Echinoids in the Upper Dwyka Shale of southern South West Africa, and secondly by the directions of the Dwyka ice-flow. Immediately south of the Windhoek Highlands, the ice advanced southwards suggesting that it was confined in the west, but in the vicinity of the Orange River the flow directions change to south-west and indicate an opening in this direction (Martin, 1961).

B. TECTOTOPES AND LITHOLOGIC ASSOCIATIONS

Lithologic association is the term applied to groups of sedimentary rocks which were formed under a particular set of tectonic conditions (Krumbein and Sloss 1959). It must be stressed that the various tectonic conditions (tectotopes) thought to have prevailed in the Karroo Basin during Ecca and Lowermost Beaufort times have been largely inferred by a study of the rocks themselves.

Due to the enormous size of the Great Karroo Basin and the diversity of paleotectonic elements, this feature offers a unique opportunity for the study of the relationships between various tectonic elements and associated sedimentary rocks.

Stable Shelf Associations

The whole of the Northern Ecca Facies, except that portion deposited in and around the margins of the Natal Trough, was deposited on a fairly stable tectonic shelf (see folder 16). The predominant rock types are coarse arkose and shale. Conglomerate, coal seams and thin beds of limestone occur in minor

- amounts -

amounts. Disconformities are a characteristic feature of these sediments, particularly along the northern margins. The lithological associations of the Karroo Stable Shelf are summarized in table 15. The Middle Ecca and Lowermost Beaufort Beds are predominantly fluvial-deltaic in origin, while the Lower and Upper Ecca shales were probably deposited in a relatively deep continental sea. Subsidence in this portion of the basin was slow and the majority of the sediments were derived from the Eastern Highlands which was being actively uplifted and eroded.

Unstable Shelf Associations

The Karroo Stable Shelf grades imperceptibly into unstable shelf areas towards the south and east (see folder 16). The hinge line of the Karroo Trough forms the southern boundary of this tectonic element and the eastern margins are taken at approximately the position of the 3,000 foot isopach line (see folder 1). A relatively narrow area of unstable shelf probably also occurred around the western margins of the Karroo Trough. Bluish-black shale is the dominant rock type of the unstable shelf areas. Arkose, carbonaceous shale, subordinate limestones and occasional thin coal seams occur in and around the Natal Trough. There is evidence of cyclic repetition in these beds, as for example, in the valleys of the Mooi and Tugela rivers. Sub-graywacke sandstone and thin beds of chert and limestone occur in minor amounts on the unstable shelf areas to the north of the Karroo Trough. The majority of the Ecca sediments on the unstable shelf were deposited in a fairly deep continental sea environment, while the Lowermost Beaufort

- Beds -

Beds were mainly laid down under shallow water continental conditions. These sequences are slightly thicker than on the stable shelf. Lithologic associations of the unstable shelf are summarized in table 16.

Yoked Basin Associations

A yoked basin is defined as a subsiding linear basin on the cratonic platform and lying adjacent to a complimentary uplift which supplies the sedimentary detritus. The Natal Trough is considered to be a yoked basin and represents a subsiding area flanked in the east by the rapidly rising Eastern Highlands. This trough-like basin originally widened and deepened down the axial plunge to the south-southwest, in which direction it may have been open to the Permian seas. It grades into shelf conditions towards the west and north (see folder 16). Unfortunately the eastern portions of this basin are covered by the Indian Ocean, but available outcrops indicate that bluish-black shale and arkose are the dominant rock types and the succession probably becomes progressively more arkosic closer to the granitic Eastern Highlands.

Sedimentation in this basin was more continuous than on the shelf areas and the only major disconformity known to exist is that occurring at the top of the Dwyka Tillite. The coarse clastics are thought to have been mainly deposited under fluvial-deltaic conditions and the bluish-black shales in a relatively deep continental sea. The predominant sediment transport direction as shown by cross-bedding is south-westwards and westwards, indicating that sediment was being transported

- transversely -

transversely as well as longitudinally with respect to the axis of the basin. The coarse arkose within the Middle Ecca Group grades into shale in a general westerly and south-westerly direction. The paleocurrent patterns, facies changes and sediment thickness distributions are, therefore, all a natural response to the regional tectonic framework within the Natal Trough. Table 17 summarises the characteristic lithologic associations of the Natal Trough.

Geosynclinal Associations

The Karroo Trough is a deep linear basin, plunging eastwards, and containing an alternating succession of shales and sandstones, and forming an integral part of the Cape-Karroo geosyncline (see folder 4). The lower portion of this succession has been classified as a typical flysch sequence. Paleocurrent studies of these rocks have indicated that sediment transport took place northwards and into the Karroo Trough, as well as eastwards and parallel to the direction of axial plunge. Subaqueous turbidity currents were the principal agents of sediment distribution and deep water conditions prevailed. During Upper Permian times sediment transport was predominantly northwards and fluvial-deltaic conditions existed. The Southern Highlands represented the source of these sediments. Fine-grained graywackes, sub-graywackes and greenish-grey and bluish-black shales are the most abundant rock types. Sedimentation appears to have been continuous throughout the Permian in this rapidly subsiding basin. Characteristic lithologic associations are summarized in Table 18.

TABLE 15

LITHOLOGIC ASSOCIATIONS OF THE STABLE SHELF WITHIN THE KARROO BASIN

Unit	Ecca Series plus Lowermost Beaufort Beds (Permian)
Rock Types	Arkose, sub-graywacke, shale, conglomerate, coal seams, and thin limestones. Thin bands of glauconite occur fairly extensively.
Geometry	Broad shallow basin originally widening and deepening towards the south-west i.e. in the direction of axial plunge. Broad pre-Karroo dome-shaped structure in the central portions of the basin.
Sedimentary structures	Predominantly large-scale planar and trough cross-bedded units, ripple marks, scour channels, slump structures, compaction structures and parting lineations also occur.
Dispersal pattern	The regional dispersal pattern was towards the south-west and therefore parallel to the axis of the basin. Centripetal flow also took place along the northern and eastern margins of the basin.
Arrangement	Apart from the area around the Clocolan Dome, the succession thickens down the paleo-slope. Lithofacies changes take place in a general south-westerly direction and the predominantly fluvial-deltaic environment in the north-east grades into a relatively deeper water (continental sea) environment towards the south-west.
Fossils	Abundant plant fossils; planktonic micro-fossils preserved in certain thin shale beds within the Ecca Series. Fossil rep-tiles occur within the Lowermost Beaufort Beds.
Port-Depositional effects	Weathering of felspar to kaolin in certain arkoses.

TABLE 16

LITHOLOGIC ASSOCIATIONS OF THE UNSTABLE SHELF WITHIN THE KARROO BASIN

Unit	Ecca Series plus Lowermost Beaufort Beds (Permian)
Rock Types	Bluish-black shale, arkose, sub-graywacke, carbonaceous shale, subordinate limestone, chert and thin coal seams.
Geometry	The unstable shelf dips fairly gently towards the south in the central portions of the basin, while in the east the slope is inwards towards the axis of the Natal Trough.
Sedimentary Structures	Large-scale planar and trough cross-bedded units associated with the arkoses and sub-graywackes. Symmetrical ripple marks and fucoid structures associated with the bluish-black shales.
Dispersal pattern	The regional transport directions in the unstable shelf areas flanking the Natal Trough were mainly towards the south-west. Sediments deposited in the southern shelf areas were derived from the Western, Southern and Eastern Highlands.
Arrangement	The succession thickens southwards in the central portions of the basin. In those areas around the flanks of the Natal Trough, the succession expands inwards towards the axis and facies changes take place towards the south-west.
Fossils	Fish scales, fish trails and crustacean tracks in the bluish-black Ecca Shale. Plant and reptile fossils in Lowermost Beaufort Beds.
Post-Depositional effects	Weathering of felspar to kaolin in certain arkoses.

TABLE 17

LITHOLOGIC ASSOCIATIONS OF THE NATAL TROUGH (YOKED BASIN)

Unit	Ecca Series (Lowermost Beaufort Beds eroded away).
Rock Types	Bluish-black shale and arkose.
Geometry	Linear basin parallel to tectonic strike and probably bordered abruptly in the east by the Eastern Highlands.
Sedimentary structures	Predominantly large-scale planar and trough cross-bedded units. Slump and compaction structures also occur.
Dispersal pattern	Sediment transport, transverse and parallel to basin axis i.e. westwards and south-westwards.
Arrangement	Section thickens in the direction of axial plunge. Facies changes take place towards the south-west and west. Arkose deposited in fluvial-deltaic environment; bluish-black shale in fairly deep continental sea.
Fossils	Poorly preserved plant remains.
Post-Depositional effects	Weathering of kaolin to felspar in certain arkoses.

TABLE 18

LITHOLOGIC ASSOCIATIONS OF THE KARROO TROUGH (GEOSYNCLINE)

Unit	Ecca Series plus Lowermost Beaufort Beds.
Rock Types	Greenish-grey and bluish-black shale, graywacke, sub-graywacke, siltstone and thin beds of chert.
Geometry	Deep linear basin, elongated parallel to the tectonic strike and plunging eastwards.
Sedimentary Structures	LOWER ECCA Groove, prod, bounce and flute casts, graded bedding, small-scale cross-bedding, ripple marks, shale pebble conglomerate, load structures, ball-and-pillow structure, convolute lamination, slump structures and sandstone dykes and sills.
	MIDDLE ECCA Symmetrical and asymmetrical ripple marks.
UPPER ECCA AND LOWERMOST BEAUFORT	
	Large-scale cross-bedding, scour channels, parting lineation, ripple marks, shale pebble conglomerate, load structures, ball-and-pillow structures, slump structures.
Dispersal pattern	Paleocurrents trended both transverse and parallel to the basin axis during Lower and Middle Ecca times. In Upper Ecca and Lowermost Beaufort times sediment transport was mainly northwards and transverse to the basin axis.
Arrangement	Facies changes take place northwards and the section as a whole reaches a maximum thickness in the axial portions of the basin. Lower and Middle Ecca deposited in deep water environment. Upper Ecca and Lowermost Beaufort deposited in fluvial-deltaic environment.

TABLE 18 contd.

Fossils	Fragmental plant remains, fish trails and crustacean tracks in the Ecca Series. Plant, reptile and fresh water lamellibranch fossils occur in the Lowermost Beaufort Beds.
Post-Depositional effects	Subjected to regional metamorphism during the Cape Orogeny. Effects diminish away from the Folded Belt.

C. TECTONICS AND SEDIMENTATION

The various periods of tectonic activity are reflected in the lithologic nature of the sediments themselves. Due to the numerous uncertainties which must exist in any attempt to correlate the various litho-stratigraphic units in the Southern and Western Facies with those of the Northern Facies, it was deemed preferable to discuss the sequence of paleotectonic events in the southern and northern portions of the basin separately.

1. The Southern Portion of the Basin

The southern portion of the Karroo Basin is taken to mean those areas covered by the Karroo Trough and the unstable shelf areas to the north of this feature.

Upper Dwyka Tectonics and Sedimentation

Following retreat of the Dwyka glaciation, this portion of the basin continued to subside. Gentle epeirogenic uplift over large areas of the Transvaal and northern Natal resulted in the re-working of morainic debris in many areas. It seems very likely that certain of the fine clastic material constituting the Upper Dwyka Shale was derived from the re-working of these older glacial beds in the north.

Relief in the Southern and Western Highlands was probably relatively low, so that mainly fine clastic material was transported northwards and eastwards into the Karroo Trough and the more slowly subsiding shelf areas to the north. The coarse facies equivalents of the Upper Dwyka Shales were

- probably -

probably deposited farther to the south and west and have been subsequently uplifted and eroded away (see folder 4).

The presence of the White Band as far north as Port St. John's and Hopetown shows that sedimentary transgression had extended fairly far north by the beginning of Ecca sedimentation (see fig. 1). The southern portion of the basin was almost certainly connected to the Permian seas by means of two narrow accessways, situated in southern South West Africa and in the south-eastern portion of the basin.

Lower Ecca Tectonics and Sedimentation

The presence of thin beds of fine-grained sandstone and siltstone in the eastern portions of the outcrop belt of the Lower Argillaceous Formation, suggests that moderate tectonic uplift took place in the eastern portions of the Southern Highlands during this period. At the same time subsidence of the Karroo Trough continued fairly rapidly particularly in the eastern portions. Relief in the Western Highlands and in the western portions of the Southern Highlands was not as pronounced and therefore predominantly fine clastic material was shed into the Karroo Trough and unstable shelf areas to the north. Once again the coarse facies equivalents of this formation were deposited farther to the south and west.

During deposition of the Upper Arenaceous Formation a pronounced phase of tectonic uplift took place in the eastern portions of the Southern Highlands, resulting in an increased paleoslope and the rapid transport of vast quantities of coarse and fine-grained clastic material into the rapidly subsiding Karroo

- Trough -

Trough (see folder 4). Re-distribution of these sediments took place by means of subaqueous turbidity flows and paleocurrent directions were transverse and parallel to the axis of the basin. Relief in the Western Highlands, as well as in the western portions of the Southern Highlands was not very high at this time, and therefore smaller quantities of sandstone and greater amounts of shale were deposited in the south-western portions of the Karroo Basin. North of the present southern outcrop belt of the Ecca, the graywacke and sub-graywacke sandstones of the Lower Ecca Group grade rapidly into shale. Therefore, the time-stratigraphic equivalents of these rocks on the unstable shelf areas to the north are mainly represented by a shale sequence.

Middle Ecca Tectonics and Sedimentation

During deposition of the Middle Ecca Group, relief in the Southern Highlands was not as pronounced as during deposition of the Lower Ecca Group. The Karroo Trough continued to subside fairly rapidly during this period and 2,500 to 3,000 feet of bluish-black shale was deposited. In certain areas - particularly towards the east - fairly thick lenticular sandstones were laid down. Sediment transport took place northwards, as well as eastwards and parallel to the direction of axial plunge. Tectonic uplift in the eastern portions of the Southern Highlands was more marked. These shales originally graded into a coarse facies farther to the south, which has subsequently been uplifted and eroded away as a result of the Cape Orogeny.

In contrast to the relatively low relief in the Southern Highlands at this time, the Western Highlands were

- experiencing -

experiencing rapid tectonic uplift and erosion, so that thick deposits of sand were shed eastwards and north-eastwards into the Karroo Trough. These sandstones grade rapidly into shales towards the east and north-east. A considerable amount of overlapping and interfingering of sediments derived from the Western and Southern source areas takes place in the south-western portions of the Karroo Basin. On the shelf areas to the north of the Karroo Trough, the Middle Ecca Groups of both the Southern and Western Ecca Facies are represented by a reduced succession composed almost entirely of shale.

Upper Ecca Tectonics and Sedimentation

During this period pronounced tectonic uplift took place in both the Southern and Western Source Areas, resulting in an increase in the paleoslope and the rapid transport of vast quantities of coarse and fine clastic material into the Karroo Trough. Although this linear basin continued to subside fairly rapidly the greater rate of sedimentation resulted in the filling up of the basin and the introduction of fluvial-deltaic conditions of deposition. Sediment accumulation varied from 1,900 feet in the west to 4,100 feet in the east.

The coarse clastics of this group were transported almost across the entire width of the Karroo Trough and therefore tectonism in the southern source area must have been more pronounced during this period than at any previous time during Ecca sedimentation (see folder 4). Sediments deposited on the unstable shelf areas to the north of the Karroo Trough during this period are mainly represented by a markedly reduced succession of bluish-black shale. A considerable amount of

- overlapping -

overlapping and interfingering of sediments derived from the Southern and Western source areas took place in the western portions of the Karroo Trough.

Lowermost Beaufort Tectonics and Sedimentation

Uplift in the Southern and Western source areas during Lowermost Beaufort times was even more pronounced than during the Ecca period. The paleoslope dipped northwards and eastwards respectively from these two source areas. Subsidence of the Karroo Trough continued to be fairly rapid, but the increased rate at which coarse and fine-grained sediments were being transported into the basin, resulted in the accumulation of sediments above base level and typical shallow water continental conditions prevailed. During this period the axis of the Karroo Trough had advanced northwards. This marked period of tectonism and sedimentation resulted in coarse and fine-grained clastics being transported into the central portions of the Karroo Basin, where overlapping and interfingering of sediments derived from different source areas took place. On the unstable shelf areas to the north of the Karroo Trough, a finer-grained and greatly reduced succession, displaying a number of disconformities is represented.

2. The Northern Portion of the Basin

The northern portion of the Karroo Basin is taken to mean those areas covered by the cratonic shelf, and the Natal Trough lying to the east of this broad tectonic element.

Dwyka Tectonics and Sedimentation

Following withdrawal of the Dwyka glaciation in the

- northern -

northern portions of the basin, there followed a major break in sedimentation during which time the unconsolidated glacial till was subjected to a considerable amount of reworking. In certain deep, pre-Karroo valleys the original till was preserved, while in other areas the morainic debris was completely eroded away and redeposited as fluvial-glacial sediments. Kent (1938) noted that there is apparently no break in sedimentation between the Dwyka Tillite and the Lower Ecca shales north of Durban, thereby suggesting that subsidence and sedimentation were continuous during this time in certain portions of the Natal Trough.

Lower Ecca Tectonics and Sedimentation

During deposition of the Lower Ecca Group, the Natal Trough began slowly subsiding and fine clastic material was shed westwards and south-westwards from the slowly rising Eastern Highlands. A certain amount of fine sediment was probably also shed centripetally into the Natal Trough from the mildly positive areas flanking this feature in the west and north-west. Downwarping of this linear basin was more pronounced in the south and with time subsidence spread westwards and north-westwards onto the surrounding cratonic shelf areas. It is also possible that deposition took place during this time in certain large pre-Karroo valleys in the west rn Orange F ee State. The Lower Ecca Shale was not deposited over the mildly positive areas surrounding the Clocolan Dome as well as north of latitude 27°30' (see folder 1). Instead these mildly positive areas either acted as broad zones of sedimentary by-passing or subordinate source areas. These shales originally graded into a coarse sandstone facies towards the Eastern Highlands (see folder 4).

- Middle -

Middle Ecca Tectonics and Sedimentation

Rapid uplift and erosion of the granitic Eastern Highlands resulted in vast quantities of coarse arkosic material being shed south-westwards and westwards into the Natal Trough and the more slowly subsiding cratonic shelf areas to the west of this feature. Lithofacies and paleocurrent trends indicate that relief in the southern portions of the Eastern Highlands was not as pronounced as in the northern and central areas. With time, subsidence of the craton spread progressively northwards and what had been areas of sedimentary by-passing in Lower Ecca times now became areas of deposition (see folder 9). Sedimentation first occurred in the pre-Karroo valleys and subsequently spread over many of the pre-Karroo hills. The Witwatersrand Arch and the central portions of the Clocolan Dome were not completely covered during this period and therefore acted as mildly positive source areas.

Coarse morainic debris originally deposited in this area during Dwyka times was subjected to reworking and became incorporated with the Middle Ecca sediments as typical fluvial conglomerates. The predominantly coarse-grained Middle Ecca sandstones grade progressively into shales towards the south-west and ultimately the whole series is composed almost entirely of bluish-black shale (see folder 4). Lithostratigraphic and structural evidence has shown that the Tugela Trough represented a fault controlled basin which underwent fairly rapid subsidence during this period. At certain times during deposition of the Coal Formation subsidence rates were sufficiently slow over wide areas and for sufficiently long enough periods of

- time -

time to enable thick seams of coal to accumulate under shallow water lacustrine or swamp conditions.

Upper Ecca Tectonics and Sedimentation

The fact that the Upper Ecca Group is composed almost entirely of shale suggests that relief in the Eastern Source Area was not as pronounced as in Middle Ecca times. During this period the Natal Trough and the cratonic shelf to the west continued to subside at relatively slower rates. This unit maintains a fairly constant thickness of 600 - 800 feet over most of the cratonic shelf, a feature which may be explained by more even rates of subsidence and the limited effect played by the pre-Karroo topography. Although sandstone constitutes an insignificant percentage of the Upper Ecca succession within the present confines of the basin, these shales are thought to have originally graded into a predominantly coarse clastic facies towards the north-east (see folder 4). Deposition took place over most of the Witwatersrand Arch and the Clocolan Dome during this period.

Lowermost Beaufort Tectonics and Sedimentation

The presence of coarse sandstones and conglomerates in the Lowermost Beaufort Beds clearly indicates a sudden pulse of tectonic uplift in the eastern source area. This was accompanied by relatively slow rates of subsidence on the cratonic shelf areas and probably also in the Natal Trough. Sediments were shed south-westwards and westwards into the depositional basin. The continental sea which occupied most of the northern portion of the Karroo Basin during Upper Ecca

- times -

times had largely been replaced by fluvial-deltaic conditions during deposition of the Lowermost Beaufort Beds. Under favourable tectonic and paleogeographic conditions thin coal seams were laid down. The Lowermost Beaufort Beds must have originally extended over the entire Witwatersrand Arch.

VII. DEPOSITIONAL ENVIRONMENTS AND PALEOGEOGRAPHY

A. DEPOSITIONAL ENVIRONMENTS

Essential to any stratigraphic analysis is the reconstruction of the ancient depositional environments. Marked vertical and lateral variations in the depositional environments are a characteristic feature of the Ecca Series. Therefore, environmental evidence will be discussed according to the various facies constituting this series. The Lowermost Beaufort Beds were deposited under a more uniform environment of deposition and will be discussed as a single unit.

1. The Southern Ecca Facies

Du Toit (19[illegible]6) believes that the sediments constituting the Southern Ecca Facies were partly deposited as broad alluvial fans in a shallow water environment. However, the writer is of the opinion that more than half the sediments constituting this facies were deposited in a deep water environment and evidence for this will be presented below.

The presence of radiolaria in the Upper Dwyka Shales near Matjiesfontein (Strydom 1950), together with phosphatic nodules and thin beds of illitic clay strongly suggests that these beds were deposited in a marine environment. The fossil fauna in the Upper Dwyka Shales of southern South West Africa further supports the contention that marine conditions prevailed during Upper Dwyka times. Over wide areas of the Cape Province the Upper Dwyka shales pass conformably upwards into the Ecca Series, the contact being taken at the top of the

- White -

Band. Furthermore, the sediments constituting the Lower Argillaceous Formation strongly resemble the Upper Dwyka Shales. Therefore, although no marine fossils have so far been discovered in the Southern Ecca Facies its close genetic and stratigraphic relationship to the Upper Dwyka Shales leads to the suggestion that the Lower Ecca Group may have also been deposited in a marine environment. The well-developed lateral continuity of bedding in the Upper Dwyka Shales and the Lower Ecca Group suggests that these sediments were laid down in an extensive body of water. The White Band is a classic example of a thin zone of sediments deposited over an area some 80,000 square miles in extent. Thin beds of illitic clay and phosphatic nodules within the Lower Argillaceous Formation are indicative of a marine environment.

The abundance of typical turbidite structures such as groove, prod, bounce and flute casts, graded bedding, small scale cross-bedding, convolute lamination, slump structures and sandstone dykes, are indicative of a deep water turbidite succession. Directional structures show that sediment transport was mainly by currents flowing down a sub-aerial slope in a deep water environment. The absence of typical shallow water sedimentary structures such as large-scale cross-bedding, scour channels and mud cracks further supports the contention of a deep water environment.

The rapid wedging out of sandstones within the Lower Ecca Group into shale towards the north indirectly suggests the presence of an extensive and deep body of water occupying the site of the Karroo Trough during this period. It is interesting to note that nearly all generally accepted turbidite

- sequences -

sequences were deposited in flysch basins associated with geosynclinal zones. Furthermore, although fossils in a flysch sequence are relatively rare, they are generally pelagic or relatively deep-water benthonic organisms (Dzulynski and Walton, 1965). The depth of water in which the turbidite sequence of the Southern Ecca Facies was deposited has to be inferred from indirect evidence. Based on the palaeoecological interpretation of foraminfera, Sullwood (1960) concluded that turbidites of the Modelo Formation, California, were deposited in about 3,000 feet of water.

The presence of invertebrate trails and crustacean tracks indicates the presence of benthonic organisms living on the sea-floor at the time of deposition. Fragmental plant fossils and silicified wood occur in certain beds and are usually indicative of a terrestrial environment. However, it is also possible that the original plant material was transported into the Karroo Basin from the margins and therefore the possibility of a neritic environment for these beds should not be excluded.

The thick succession of bluish-black shale constituting the Middle Ecca Group was probably deposited in a relatively deep water environment. The dark colour and well-bedded nature of these sediments suggests deposition under entirely subaqueous conditions. Symmetrical and asymmetrical ripple marks are the only primary sedimentary structures occurring within these rocks. The absence of large-scale cross-bedding, scour channels and other typical shallow water structures indirectly supports the idea of a deep water environment. The enormous lateral extent of these shales suggests that they were deposited in an extensive body of water, probably in the form of a continental sea. The

- apparent -

apparent absence of typical marine fossils further supports the idea of a continental sea with only restricted openings to the oceans. Invertebrate tracks and trails and parallel scratch marks thought to have been produced by the ventral fins of fishes clearly indicates the presence of abundant animal life. However, euxinic bottom conditions may explain in part the apparent absence of their fossil remains. Silicified wood and indeterminate plant fragments near the top of this unit are compatible with the commencement of fluvial deltaic conditions towards the close of this depositional period.

In Upper Ecca times pronounced tectonic uplift in the source area to the south resulted in the rapid influx of coarse clastic material into the Karroo Trough. The paleoslope was inclined towards the north and subsidence of this surface was more rapid in the axial portions of the trough. This marked period of tectonism in the source area was responsible for the northward displacement of the shoreline and the change from deep water conditions during Lower and Middle Ecca times into fluvial-deltaic conditions during Upper Ecca times. Lateral continuity of bedding is poorly developed in this group and the presence of large-scale planar cross-bedding, abundant symmetrical ripple marks, scour channels, slump structures, shale pebble conglomerates and parting lineations points towards a fluvial-deltaic environment in the area of the southern outcrop belt. This contention is further supported by the presence of silicified wood and plant fossils. North of the outcrop belt, drilling has shown that sandstones of this group grade progressively into shales towards the north (see folder 4), therefore, it would seem that the predominantly fluvial-deltaic conditions existing in the southern portions of the basin gradually merged into

- deeper -

deeper water conditions towards the central portions. Although little is known about the detailed stratigraphy and sedimentation of this group to the north of the outcrop belt, it is possible that off-shore bars and beach deposits may exist in those areas where the typical fluvial-deltaic sediments of this group reached the extensive body of water (continental sea) occupying the central portions of the Karroo Basin.

In summary, the Southern Ecca Facies records a change from a deep-water marine or continental sea environment into fluvial-deltaic conditions. At the same time a pronounced period of tectonic uplift in the source area to the south during Upper Ecca times, resulted in a major northward displacement of the shoreline (see folder 4).

2. The Western Ecca Facies

The basal shales within this facies are lithologically similar to the Upper Dwyka Shales. This fact together with the presence of thin beds of illite clay, phosphatic nodules and well developed lateral continuity of bedding, points to a marine origin for these beds. The lateral extent of the Lower Ecca Group, together with the abundance of calcareous nodules and thin beds of limestone is indicative of deposition in an extensive body of water. The only primary sedimentary structures observed in this group are a few ripple marks and well developed cone-in-cone structures occurring in the calcareous nodules and thin limestone beds. However, other typical shallow water sedimentary structures such as large-scale cross-bedding, scour channels and mud-cracks are completely absent. Therefore, from this negative evidence it has been concluded that the Lower Ecca Group was mainly deposited under relatively

- deep -

deep water conditions. The presence of fossil leaves and wood is indicative of a terrestrial environment, but taking the other evidence into account it is believed that the original plant material was transported into a deeper water environment from the marginal portions of the basin lying farther to the south-west and west.

During Middle and Upper Ecca times tectonic uplift in the Western Highlands and the western portions of the Southern Highlands resulted in vast amounts of coarse clastic material being shed eastwards and north-eastwards into the Karroo Basin. This period of tectonism caused an increase in the general eastwardly inclined paleoslope, which in turn resulted in a displacement of the shoreline to the east and a change in the depositional environment from fairly deep water conditions during Lower Ecca times to fluvial-deltaic conditions during Middle and Upper Ecca times. The presence of large-scale cross-bedding, abundant ripple marks, scour channels, local disconformities, shale pebble conglomerates, slump structures and parting lineations are all indicative of fluvial-deltaic conditions. The presence of fossilised wood and leaves as well as the abundance of worm burrows is in keeping with these environmental conditions. Eastwards and north-eastwards from the outcrop belt, the sandstones of this facies grade rapidly into shales, thereby indicating that progressively deeper water conditions existed in this direction.

5. The Central Ecca Facies

Du Toit (1956) believes that these beds were deposited in a deep water environment but does not specify whether marine conditions prevailed.

- The -

The enormous area over which this facies was deposited with so little lithological variation is thought to indicate deposition in an extensive body of water in the form of a continental sea which occupied the central portions of the Karroo Basin throughout the Ecca Period. The apparent absence of marine fossils leads to the conclusion that only narrow accessways connected this extensive body of water with the Permian Oceans. Therefore, restricted, de-oxygenated, still bottom conditions probably prevailed. The fact that sandstone formations within the other three facies grade rapidly into shale towards the central portions of the basin, clearly indicates that extensive, fairly deep water conditions occurred in this area. Parallel scratch marks thought to have been caused by fishes and the abundance of crustacean tracks in the basal beds of this facies indicates the presence of animal life. The rarity of shallow water sedimentary structures is an outstanding characteristic of this facies. Symmetrical and asymmetrical ripple marks and small-scale cross-bedding are only found in the uppermost beds and often occur in association with worm burrows and plant fossils, thereby indicating that shallow water conditions existed at this time. The abundance of fucoid structures (probably casts of plant stem impressions) indicates that a considerable amount of plant material was transported into the central portions of the basin and laid down under fairly deep water conditions. The preferred orientation displayed by most of these structures indicates that sufficient current movement took place on the sea-floor to align these structures parallel and at right angles to the prevailing current direction. Pyrite nodules and abundant carbonaceous material in these shales suggests that floor conditions were of a reducing nature. These toxic bottom conditions

- may -

may explain in part the apparent absence of fossil remains in these bluish-black shales.

4. The Northern Ecca Facies

During Lower Ecca times, the continental sea which occupied the central portions of the Karroo Basin transgressed northwards along the site of the Natal Trough and the deep pre-Karroo valleys in the western Orange Free State. Here, a fairly thick succession of well-bedded bluish-black shale was deposited under relatively deep water conditions. The abundance of carbonaceous material in these shales suggests that they were deposited under quiet water, reducing conditions. The absence of typical shallow water sedimentary structures further supports the idea that these sediments were deposited in a relatively deep water environment. Apart from the indistinct leaf impressions found by King (1948) in the vicinity of Pietermaritzburg, no identifiable macrofossils are known to occur in this unit.

In Middle Ecca times rapid uplift and erosion of the Eastern Highlands caused enormous quantities of sedimentary detritus to be transported south-westwards and westwards into the northern portion of the Karroo Basin. During this period the shoreline was displaced southwards and fluvial-deltaic conditions prevailed over most of the area covered by the Northern Ecca Facies. Large-scale planar and trough cross-bedding, ripple marks, fluvial conglomerates, scour channels and slump structures imply deposition by shifting variable currents in a shallow water environment. The relationships between the paleocurrent pattern and other sedimentary properties such as facies changes, thickness changes, decrease in average grain size of sandstones, mean thickness of planar cross-bedded units and pre-Karroo valleys,

- point -

point towards a predominantly fluvial-deltaic environment. The presence of coal seams and abundant plant fossils is compatible with the physiographical setting of a broad low lying delta plain. Towards the south, these predominantly fluvial-deltaic conditions grade into a deeper water continental sea environment. Within the Middle Ecca Group are a few thin beds of carbonaceous shale which on the basis of their microfossils are considered by Hart (1964) to be marine in origin. This indicates that at certain times marine transgressions took place from the south. Future micropalaeontological studies of the carbonaceous shales within the Central Ecca Facies may reveal the presence of further marine beds. Thin bands of glauconite have been found to occur extensively within the Middle Ecca Group. With few exceptions, this mineral is formed in a marine environment in depths of water ranging between 10 and 400 fathoms (Pettijohn 1957). The presence of annual growth rings in specimens of fossil wood, together with deciduous plant fossils and coal seams indicates that a cool moist climate prevailed during this period.

During Upper Ecca times, reduced relief in the Eastern Highlands, coupled with continued subsidence in the northern portions of the basin resulted in a second major northward transgression of the sea. As evidenced by the abundance of carbonaceous material, calcium phosphate and pyrite nodules, the Upper Ecca Shale must have been deposited in a quiet-water, reducing environment. The presence of thin beds of limestone indicates that at certain times the water was relatively shallow, but the absence of typical shallow water sedimentary structures excludes the possibility of turbulent shallow water conditions. The presence of fish remains in ferruginous shale nodules proves the presence of aquatic life during this period.

5. The Lowermost Beaufort Beds

The continental sea which had occupied the central portions of the Karroo Basin during Upper Ecca times had largely withdrawn during deposition of the Lowermost Beaufort Beds and shallow water continental environmental conditions became predominant over most of the basin. The presence of abundant large-scale planar and trough cross-bedding, scour channels disconformities, shale pebble conglomerates, and ripple marks implies deposition in shallow water by shifting variable currents. Mud-cracks and the abundance of red, maroon and purple mudstones suggests deposition on alluvial mud flats in an oxidizing environment. The abundance of fossil reptiles and plants is indisputable evidence of a continental environment. Coal seams and thin lenticular beds of limestone indicates that under favourable tectonic and paleogeographic conditions lacustrine and swamp environments prevailed. In certain of these lakes and swamps fresh water fish and lamellibranchs thrived (Du Toit 1956). Paleocurrent evidence has demonstrated that the Karroo Basin may have been open to the seas in the south-eastern portions of the basin and therefore deeper water conditions may have prevailed in those areas lying between the Kei and Umzimvubu rivers.

B. PALEOGEOGRAPHY

In addition to discussing the paleogeography of the Ecca and Lowermost Beaufort Beds, a brief account of the geological history of the Cape System will also be given.

1. The Cape System

During late Silurian times Southern Africa was represented by a broad shield area flanked in the south, south-west and east, by a rapidly subsiding arcuate trough. The outer margins of this more or less continuous linear downwarp were probably bordered by a rapidly rising belt of high ground. Prior to deposition of the Cape System, extensive areas of the southern Cape Province and coastal Natal were subjected to peneplanation (Du Toit 1956). In the north-central portions of the cratonic shield, there existed a number of mountains and high hills composed of pre-Cambrian formations.

Paleocurrent measurements at the reconnaissance level have shown that vast quantities of sediment were shed radially outwards from the central cratonic shield and deposited into the marginal geosyncline. Longitudinal transport also took place in the axial portions of the troughs. The rising linear belt of high ground thought to have bordered the outer margins of the periferal troughs is also believed to have represented a major source area during deposition of the Table Mountain Series. Haughton et al (1925) indicated the presence of a highland area lying to the west of the glacial deposits within the Table Mountain Series. The subsidence rates within the linear troughs appear to have kept pace with the rapid influx of coarse sedimentary detritus and shallow water conditions prevailed. Rust (1967) found marine fossils in the Table Mountain Series of the Western Folded Belt, thereby proving the existence of marine conditions during deposition of certain portions of this series.

Isopach maps of the Table Mountain Series (Kingston et al 1961) clearly indicate that the trough-like depressions along the eastern and south-western flanks of the craton plunged southwards, while the fore-deep lying to the south of the shield had an easterly plunge. The earth's crust must have been deeply

- depressed -

depressed where the southern and eastern marginal troughs met, and therefore formed an ideal area for inundation by the seas. Based on available lithostratigraphic correlations and thickness measurements, it may be deduced that sedimentary transgression spread inwards from the marginal troughs towards the central cratonic shelf areas during this period. During Bokkeveld times continued subsidence of the arcuate trough along the southern and south-western flanks of the central shield area caused this linear depression to be inundated by a shallow sea which extended westwards from an opening to the oceans in the east. The fact that the Bokkeveld sediments were only deposited in the axial portions of the southern and south-western troughs clearly points towards sedimentary regression during this period (De Villiers 1944). Sediments of Bokkeveld age may also have been deposited in the eastern trough, but unfortunately only the marginal portions of this feature are exposed, the central or structurally deepest portions being situated east of the present Natal coast. A few widely spaced cross-bedding measurements in the southern and western troughs were recorded during the study, and have indicated that sediment dispersal patterns during Bokkeveld times were essentially the same as during deposition of the Table Mountain Series. The finer-grained nature of these sediments suggests that relief in the source areas was not as pronounced as during deposition of the Table Mountain Sandstone.

During deposition of the Witteberg Series (Middle Devonian to Lower Carboniferous) subsidence within the southern and south-western troughs was mainly confined to the axial portions and further sedimentary regression took place (see folder 4). Mountain (1964) found that the Witteberg sediments in the vicinity of Grahamstown were mainly derived from a south-easterly source. Stratten (in press) has recently found that the Witteberg sediments in the south-western trough were mainly derived from a highland area lying to the west, while in the southern trough paleocurrent trends clearly indicate the presence of two source areas. The first lay to the south, and the second to the north. In the axial portions of this trough interfingering of sediments derived from these two source areas took place. The marine environment which prevailed in this area during Bokkeveld times appears to have lingered on in certain portions of these linear downwarps during Witteberg times, (Swart 1950). The abundance of cross-bedding (Stratten in press) and overturned cross-bedding (Mountain 1964) indicates the presence of shallow water conditions. The presence of plant fossils Spirophyton and fossil fish (Theron 1962) points towards a shallow marine or littoral environment. On the basis of palaeo-botanical evidence, Plumstead (1967 p. 15) concluded that the climate was cold and wet. Sediments of Witteberg age may also have been deposited in the eastern trough, but there is no evidence to prove this. Relief in the source areas was relatively high during this period, as evidenced by the abundance of coarse clastic material. From folder 4 it is possible to see that the axis of the southern geosyncline advanced northwards during Cape System times.

2. The Karroo System

On the basis of paleo-ice-flow directions, Du Toit (1956 p. 277), deduced that during the Dwyka Ice-Age (Carboniferous) there were four centres of glaciation. These are thought to have been situated 1) in the central portions of South West

Africa, 2) in the vicinity of Griqualand West, 3) in the central Transvaal and, 4) east and north-east of the Natal coast. In addition, Stratton (in press) has recently indicated the presence of a further two centres of glaciation. These are 1) a major centre lying to the west of the Western Cape Folded Belt and 2) a smaller but significant source lying to the south of the Southern Cape Folded Belt. Due to an increasingly cold climate these positive areas developed an extensive glaciation. From these centres the ice sheets spread basinwards and the central shield area, which up till this time had remained a broad positive area, now became depressed and started accumulating extensive deposits of glacial till. The marginal linear troughs continued to subside at relatively faster rates, and therefore greater thicknesses of tillite were accumulated in these areas compared to the deposits on the more stable central craton. Tillite was probably never deposited over some of the higher mountains in the western Orange Free State.

At the end of the Dwyka Ice-Age, extensive areas of Southern Africa were covered with tillite. In the succeeding period subsidence and sedimentation continued uninterruptedly over large parts of the Cape Province. However, extensive areas in the north-eastern portion of the basin were epeirogenically uplifted, and vast amounts of tillite were subjected to erosion and reworking. Therefore, it is very likely that much of the fine clastic material constituting the Upper Dwyka Shale was derived from the reworking of older glacial beds in the north. Relief in the major centres of glaciation had been greatly reduced following this extensive ice-age. The climate was cold and wet and the Upper Dwyka Shale is thought to have been

- deposited -

deposited in a deep-water marine environment. The sea which occupied large areas of the Cape Province and southern South West Africa is thought to have been connected to the oceans by means of two narrow accessways, situated in the south-eastern portion of the basin and near the present position of the Orange River Mouth. It must be realised that the accuracy of any attempt to reconstruct the paleogeography during Ecca times is limited by the uncertainties which exist in the present correlation of groups of strata between the various facies.

During Lower Ecca times the Southern Highlands were being actively uplifted and eroded, while relief in the Western and Eastern Highlands was relatively low. Sedimentation was mainly confined to the Karroo and Natal Troughs as well as large areas of the Cape Province and south-western Orange Free State. Deposition did not apparently take place north of latitude 27° and over the mildly positive areas surrounding the Clocolan Dome. Instead, these positive areas acted as subordinate source areas of Lower Ecca sediment. Very deep-water conditions prevailed in the Karroo Trough and fairly deep-water conditions are thought to have existed in the Natal Trough and over those portions of the cratonic shelf where Lower Ecca sediments were being deposited. During this period, the Karroo Basin was probably connected to the oceans by means of two narrow accessways and restricted, reducing, still bottom conditions prevailed. The climate was cool and wet and abundant vegetation flourished around the margins of this extensive continental sea.

During Middle Ecca times the Eastern and Western Highlands were being actively uplifted and eroded and vast quantities of sediment were shed into the basin. In contrast, relief in the Southern Highlands was relatively low and mainly fine clastic material was transported basinwards. With time, subsidence of the craton spread progressively northwards and what had been areas of sedimentary bypassing during Lower Ecca times became depositional areas during Middle Ecca times. The Witwatersrand Arch and the Clocolan Dome continued to act as subordinate source areas. Both the Karroo and Natal Troughs subsided at relatively faster rates than the cratonic shelf areas and therefore accumulated greater thicknesses of sediment. Deep-water, reducing conditions prevailed in the central portions of the basin, as well as in the eastern and central parts of the Karroo Trough. However, in the northern one-third of the basin, inflooding of vast amounts of coarse detritus, resulted in a southward displacement of the shoreline and the introduction of fluvial-deltaic conditions. Minor marine transgressions did, however, take place from the south during this period, as evidenced by the presence of thin beds of marine shale associated with these sediments. In those areas where favourable tectonic and paleogeographic conditions prevailed extensive coal swamps flourished and the climate was cool and wet. In the south-western portions of the basin coarse and fine clastic material was being shed eastwards and north-eastwards into the basin and fluvial-deltaic conditions are thought to have prevailed. Vegetation was fairly abundant and the climate was cool and wet.

In Upper Ecca times, tectonism in the Southern and Western Highlands was either more pronounced than during any other period of Ecca sedimentation or the source area lay closer to the depositary. Enormous volumes of coarse and fine clastic

- material -

material were shed into the rapidly subsiding Karroo Trough and the fine-grained facies equivalents of these sediments were deposited on the relatively stable shelf areas to the north of this linear downwarp. Relief in the Eastern Highlands was comparatively low during this time, and predominantly fine clastic material was shed into the basin. The Natal Trough and the cratonic shelf areas to the west and north-west of this feature continued to subside at a steady rate. Marked tectonism in the Southern and Western Highlands caused sediment to be shed rapidly into the Karroo Trough. This resulted in a northward displacement of the shoreline, and the establishment of fluvial-deltaic conditions in this portion of the basin. Northwards, and towards the central portions of the basin, the fluvial-deltaic conditions graded into a relatively deep-water, reducing, continental sea environment. Continued subsidence in the northern portions of the basin during Upper Ecca times, resulted in a major northward transgression of the continental sea which lay to the south. Comparatively deep-water, reducing, conditions were most common, except towards the end of Upper Ecca times when progressively shallow, oxygenated conditions became predominant. The climate was cool and wet, and vegetation was abundant.

The Southern, Western and Eastern Highlands were being rapidly uplifted and eroded during Lower Beaufort times and vast amounts of sediment were shed into the Karroo Basin. The axis of the Karroo Trough and probably also the Natal Trough advanced northwards and westwards respectively. While subsidence rates in these two troughs continued to be comparatively rapid, the cratonic shelf areas subsided at a slower rate. This feature resulted in an essentially continuous succession of sediments

- being -

being deposited in these linear downwarps, and the presence of disconformities and diatoms in the sedimentary successions deposited on the cratonic shelf areas.

The continental sea which occupied extensive areas of t Karroo Basin during Upper Ecca times had largely withdrawn during Lower Beaufort times and shallow water continental conditions prevailed over the major portion of the basin. The Lower Beaufort sediments were deposited over most of the pre-Karroo topographic highs, such as the Witwatersrand Arch and the Clocolan Dome. Minor marine transgressions may have taken place from the east during this period, but in general the Karroo became a closed continental basin.

In the Southern Cape Folded Belt, strata as young as the Lower Beaufort have been involved in the folding, indicating that the earliest tectonism could have commenced in this area was during Upper Permian times. Therefore, it is generally believed that towards the end of Lower Beaufort times, the first significant pulse of folding took place in the Southern and Western Cape Folded Belts. Further evidence of this major tectonic event is seen by the presence of coarse grits and conglomerates in the Middle Beaufort Beds near East London and elsewhere in the Eastern Province. Mountain (1945) showed from a study of the cross-bedding that the Middle Beaufort Sandstones in the Eastern Province were derived from a south-easterly source. Therefore, it may be concluded that this major phase of tectonism during the Upper Permian was more pronounced in the east and south-east. The abundance of felspar in the Middle Beaufort Sandstones in the eastern and north-eastern portions of the basin strongly indicates that a predominantly

- granitic -

granitic source area occurred along the eastern margins of the Karroo Basin. Towards the central portions of the basin a considerable amount of intermixing of sediments, derived from the Eastern, Southern and Western source areas took place and a typical shallow water continental environment prevailed.

During Upper Beaufort times continued tectonic uplift and erosion of the Eastern, Southern and Western source areas, resulted in a continuous supply of sedimentary detritus to be shed into the Karroo Basin. Subsidence rates within the basin continued to be slow and sedimentation took place in a shallow-water continental environment.

Although tectonism in the Southern and Western Cape Folded Belts is believed to have been more or less continuous during deposition of the Middle and Upper Beaufort Beds, De Villiers (1944) states that the major period of orogenesis within the Southern Cape Folded Belt took place during Molteno (Triassic) times. On the basis of heavy mineral studies Ryan (1963) confirmed the presence of Witteberg quartzite pebbles in the Molteno Beds, and by means of paleocurrent studies showed that the dominant source of these sediments lay to the south, thereby indicating that Witteberg quartzite of the Southern Cape Folded Belt was being actively eroded at this time and that sedimentary cannibalism was taking place i.e. older sedimentary deposits within the basin were being uplifted along the southern margins to provide the material for later deposits within the same basin. In addition, a secondary source composed predominantly of granitic rocks lay to the east and south-east of the present Transkei coast, indicating that tectonic uplift of Basement granite had taken place during this period.

- Deposit

Deposition took place under shallow water continental conditions. These sediments were not deposited as far north as the overlying Red Beds which overlap the Molteno Beds towards the north and come to rest disconformably on older Karroo strata or the pre-Karroo surface. The climate was temperate and wet, and abundant vegetation flourished.

In general the tectonic frame-work during deposition of the Red Beds and Cave Sandstone was essentially the same as during Molteno times. The red, maroon and purple muds of the Red Beds together with the abundance of dinosaurs points towards arid conditions. In addition, the abundance of large-scale cross-bedding in the Cave Sandstone together with the well sorted nature of the sand grains is indicative of a typical aeolian sandstone. Cross-bedding measurements in the Cave Sandstone of the Waterberg Coalfield Ryan (1965) indicates that the paleo-wind-directions in this area were north 69 degrees east.

Karroo sedimentation was finally brought to a close by the outpouring of vast quantities of basaltic lava during early Jurassic times.

VIII. ECONOMIC GEOLOGY

The present study, together with a detailed sedimentological study carried out on the Waterberg Coalfield (Ryan 1965), has led to a better understanding of the origin and localization of known coal deposits both in the main Karroo Basin and in the smaller basins to the north. Consequently it has been possible to make certain predictions regarding future exploration for further deposits. Similarly, reconstructions regarding the paleotectonic framework, paleoenvironmental conditions and paleogeography, within the main Karroo Basin during Ecca and Lowermost Beaufort times, have enabled valuable conclusions to be drawn regarding the possibilities of finding oil and gas.

COAL

Economically, coal is by far the most important mineral deposit found within the Karroo Basin. At present almost the entire production comes from the Coal Formation of the Middle Ecca Group, but potentially exploitable deposits are also known in the Upper Ecca Group of the Northern Facies, the Lowermost Beaufort Beds and the Molteno Beds. In addition, Martin (1961) drew attention to the presence of thin coal seams near the top of the White Band in South West Africa.

Before making any recommendations regarding future exploration, a brief summary is given of what are considered to be the most important geological factors controlling the localization of known deposits.

A. GEOLOGICAL FACTORS CONTROLLING THE LOCALISATION OF COAL DEPOSITS

In order to understand the geological conditions controlling the localisation of coal deposits within the Ecca and Lowermost Beaufort Beds it is essential to interpret the known coal bearing areas in their paleotectonic, paleoenvironmental and paleogeographic setting. The following factors should be taken into account -

1. The economically important coal deposits lie north of latitude 29°.

2. Sediments constituting the Middle Ecca Group and the Lowermost Beaufort Beds were mainly deposited under fluvial-deltaic conditions in the northern portions of the basin.

3. Except for those portions deposited in and around the margins of the Natal Trough the entire Middle Ecca Group of the Northern Facies was deposited on a relatively slowly subsiding stable shelf.

4. With time, subsidence of the craton spread northwards and progressively higher formations within the Middle Ecca Group come to rest uncomformably on the pre-Karroo surface. Similarly progressively higher coal seams within the Coal Formation lap out against the pre-Karroo surface in a general northerly direction.

5. The shape and extent of many of the original coal swamps along the northern margins of the basin was controlled by the pre-Karroo topography. The swamps and lakes wherein the original material was accumulating were confined to the valleys and basins on the pre-Karroo surface.

6. Certain of the topographically low-lying areas on the pre-Karroo surface were almost entirely surrounded by ranges of hills. Such areas undoubtedly constituted sheltered environments ideal for the accumulation of organic material. Examples of coalfields formed under these conditions are the Witbank, South Rand and Vereeniging fields.

7. With time the pre-Karroo valleys became filled with sediment and subsequently deposition took place over the pre-Karroo hills. However, due to differential compaction, the effects of the pre-Karroo topography are often perpetuated upwards for a few hundred feet into the overlying sediments. Therefore, topographically low-lying areas on the pre-Karroo surface may still exercise a certain amount of influence on the localisation of coal deposits even though this surface was completely blanketed with sediment.

8. The northern and north-western margins of the basin were bounded by the mildly positive area constituting the Witwatersrand Arch and the Eastern Highlands lay some 100 miles to the east and north-east of the present Natal coast.

9. South of latitude 29° the predominantly fluvial-deltaic conditions of the Middle Ecca Group grade into relatively deep water conditions as the extensive continental sea occupying the southern and central portions of the basin is approached.

10. The present distribution of the Karroo System outside the main basin and in parts of Southern and Central Africa is largely confined to those areas effected by post-Karroo graben faulting, as for example the Limpopo, Zambezi and Luangwa Troughs (see folder 18). Regional mapping by the various geological surveys, together with detailed sedimentological studies (Ryan 1965), has shown that the coal measures (Ecca Series) and their associated coalfields are mainly confined to the axial portions of the troughs, while outwards from these areas the Upper Karroo sediments such as the Cave Sandstone (Forest Sandstone) transgress the Ecca Series and come to rest directly on the pre-Karroo surface. Therefore, deposition of the coal measures in portions of Southern and Central Africa was confined to these structurally controlled linear basins (see folder 18).

11. Over large areas of the south-eastern Transvaal and northern Natal, considerable thicknesses of Lower Karroo strata (Lower Ecca Shale plus Dwyka Series) intervene between the pre-Karroo surface and the Coal Formation. Consequently it is unlikely that the pre-Karroo topography could have exercised any control on the localisation of these deposits. Instead, factors such as relatively slow rates of subsidence, depositional environment and paleogeographical setting, probably exercised a major control on the deposition of coal in this area. Similar factors probably also best explain the location of the coal deposits in the Lowermost Beaufort Beds in the north-eastern portion of the basin, as for example near Volksrust and along the Lebombo Belt of Zululand.

B. RECOMMENDATIONS FOR FUTURE COAL EXPLORATION

Taking into account the various factors controlling the distribution of coal both in the main Karroo Basin and in the smaller basins to the north, it has been possible to make certain recommendations regarding future exploration. These will now be discussed according to various lithological units within the Lower Karroo succession.

- The -

The Upper Dwyka Shale

During the present investigations a 1'9" thick bed of carbonaceous shale containing thin bands of bright coal was observed at Ntonjane Location near Hole-in-the-Wall, Transkei. In a similar occurrence, a bed of carbonaceous shale about four feet thick and containing less coal was observed in typical Upper Dwyka Shale at Mpame Location about 2 miles south of Mncwassa Mouth, Transkei.

Two weathered outcrop samples of these shale bands were analysed at the Transvaal Coal Owners Laboratory and the results are tabulated below -

Lab. No.	H_2O %	Ash %	Volatiles %	Fixed Carbon %	Calorific Value
756	12.8	80.1	6.7	0.4	Incombustible
757	3.7	88.9	5.8	1.6	Incombustible

Recently, thin coal seams interbedded with sandstone and lying 150 feet stratigraphically above the Dwyka Tillite were intersected in borehole 59 near Philippolis (see folder 1). Although these coal seams were originally logged as lying within the Ecca Series, the writer is inclined to the view that the seams do in fact lie within the upper portion of the Dwyka Series.

From a coal mining point of view the seams are worthless, but these occurrences are of major importance in that they indicate the presence of coal along the northern portions of the original Upper Dwyka Basin. Therefore, the possibility of finding economically important coal seams deposited under

- favourable -

favourable paleogeographic conditions and in the continental facies equivalent of the Upper Dwyka Shale should not be overlooked. The Upper Dwyka Shales over the remainder of the basin, with the possible exception of the south-western portion, are thought to have been deposited in a marine environment and, therefore, should not be prospected for coal.

The Lower Ecca Group

The bluish-black shales of the Lower Ecca Group of the Northern Facies are thought to have been deposited in an extensive inland sea environment. However, these environmental conditions must have ultimately graded into shallow water continental conditions along the northern, north-eastern and eastern margins of the basin. Consequently, if coal was ever formed during this period, then the most likely areas to look would be - (1) around the eastern and western flanks of the Clocolan Dome, (2) along a broad belt between Piet Retief and Vredefort and (3) along the Lebombo Belt of Swaziland and northern Natal. Elsewhere, within the present structural and erosional limits of the Great Karroo Basin sediments of the Lower Ecca Group are thought to have been deposited in a deep water environment and therefore there appears to be no possibility of coal deposits having been formed.

The Middle Ecca Group

The Middle Ecca Group of the Northern Facies is by far the most favourable area for future coal exploration. In general, it is known that economically exploitable coal deposits decrease in abundance away from the northern and north-eastern

- margins -

margins of the basin. This is because the paleogeographic, paleotectonic and paleoenvironmental conditions became less favourable for the formation of coal deposits in a general south-westerly direction. However, an exception to this general rule may exist in the vicinity of the Clocolan Dome. The presence of this broad paleotectonic element in the north-central portions of the basin may have produced suitable environmental conditions for the formation of coal deposits.

The Middle Ecca Group of the Northern Facies is not considered to be favourable for coal exploration in the south-central portions of the Natal Trough, as well as along its southern margins (see folder 2). Reasons for this are that the paleogeographic, paleotectonic and paleoenvironmental conditions are considered to have been unsuitable in these areas.

Conditions are thought and in many cases known to have been good for the accumulation of coal in the following areas -

1. The north-western, northern and north-eastern margins of the Great Karroo Basin.
2. Around the northern, western and eastern flanks of the Clocolan Dome, in the north-central portions of the Karroo Basin.
3. Along the Lebombo Belt of Zululand, Swaziland and the eastern Transvaal Lowveld.
4. In the Springbok Flats area of the central Bushveld.
5. In the Limpopo Trough and its westward extension into eastern Botswana (see folder 18).
6. In the Zambezi Trough and its south-westward extension into north-eastern Botswana.

During the present research three specific areas were recommended to the Anglo American Corporation as being favourable for coal exploration. Each of these three areas will now be discussed briefly.

Area I

This area lies about 10 miles east of Morgenzon in the Ermelo District of the Transvaal. It is bounded by latitudes 26°37' and 26°52' and longitudes 29°42' and 30°00' (see folder 6). This area was considered favourable for the following reasons -

1. At the time of sedimentation suitable geographical, tectonic and envirormental conditions are thought to have prevailed in this area.
2. The Coal Formation occurs at depths of less than 1,000 feet over a wide area.
3. Dolerite intrusions appeared on surface to be at a minimum.
4. The A or uppermost seam outcrops in this area.
5. Thick seams of coal occur at Camden about 18 miles to the north-east.
6. Water supplies are available.
7. Railway communications are 8 to 10 miles distant.

This area was drilled during the early part of 1965 and although seams up to 8 foot thick were encountered, the coal was of a high ash content and therefore economically unsuitable by present day standards.

Area II

This area lies some 30 to 70 miles west of Messina in the northernmost portion of the Transvaal and constitutes an area approximately 400 square miles in extent (see folder 18). This area was considered favourable for the following reasons -

1. Favourable geographic, tectonic and environmental conditions for the formation of coal seams are thought to have existed at the time of sedimentation.

2. Rocks of the Ecca Series outcrop over a wide area and thus if coal seams are present they would occur at shallow depths.

3. Regional geological mapping has yielded no evidence of major faulting in the Karroo strata on the south side of the Limpopo.

4. Post-Karroo intrusions are mainly in the form of east-west trending dolerite dykes which appear to be more numerous in the north.

5. Two workable seams of coking coal have been proved in the Tulifield on the north side of the Limpopo River, and an 8 foot thick seam of coking coal occurs in the Bubye Coalfield farther to the east (Swift 1961).

6. Coal seams containing coal of high swelling index (potential coking coal) are known to occur in nearly all the down-faulted blocks of Karroo strata in the vicinity of the Soutpansburg and northwards.

7. Water supplies are available from the Limpopo River.

Initial drilling results have established the presence of a zone composed of alternating beds of carbonaceous shale and coal. Individual coal seams are as thick as 6 feet.

Area III

This area is bounded in the south by the Vet River, in the east by longitude line 26°30' and in the north and west by the erosional margins of the Ecca Basin (see folder 5).

The following geological reasons were considered favourable from a coal exploration point of view -

1. The area is underlain by rocks of the Middle Ecca Group (Main coal-bearing unit in the northern portion of the basin).

2. Rocks closely resembling strata lying above the coal seams in the Vierfontein area have been observed at outcrops along the south bank of the Vaal River west of Bloemhof. Therefore, a considerable portion of the area under discussion is probably underlain by that portion of the Middle Ecca which is normally coal-bearing.

3. Coal seams have been intersected in boreholes west of Odendaalsrust (Coetzee 1960) and in the vicinity of Wesselsbron.

4. Favourable paleogeographic, palectectonic and paleo-environmental conditions are thought to have existed.

This area has not yet been prospected, and therefore the coal potential is still unknown. Elsewhere in the Karroo Basin sediments of the Middle Ecca Group are considered to be unfavourable from a coal exploration point of view, because they were deposited under unfavourable tectonic and environmental conditions.

The Upper Ecca Group

Rocks constituting the Upper Ecca Group of the Northern Facies were mainly deposited in a relatively deep water, inland sea environment. However, in the Stegi district of Swaziland, the Upper Ecca Group contains thick zones of sandstone and coal seams (Davies 1961). If in fact this correlation is correct, then it indicates that sediments of this group grade into a shallower water, continental facies towards the north-east. Therefore, the Upper Ecca Group should not be overlooked as a potential source of coal in the Lebombo Belt of Zululand, Swaziland and the eastern Transvaal Lowveld.

The Upper Ecca Groups of the Southern and Western Facies were mainly deposited under fluvial-deltaic conditions, but subsidence rates are thought to have been too rapid in these areas to favour the accumulation of coal seams. Relatively deep water continental sea conditions are thought to have prevailed in the central portions of the Karroo Basin throughout the Ecca Period, and therefore there is no possibility of coal having formed in this area.

The Lowermost Beaufort Beds

The Lowermost Beaufort Beds were mainly deposited under shallow water continental conditions. The thickest and best developed coal seams are found along the northern, stable shelf areas of the basin. On the basis of fossil plants, the coal seams at Somkele in Zululand are thougnt to be of Beaufort Age (Du Toit 1956). The writer believes that exploration for coal in the Lowermost Beaufort Beds should be confined to the northern and north-eastern margins of the main Karroo Basin as well as along the Lebombo Belt of Zululand, Swaziland and the eastern Transvaal. Elsewhere in the Karroo Basin thin, lenticular coal seams are known to occur in these beds (Rogers and Du Toit 1903), but in general paleotectonic and paleoenvironmental conditions are considered to have been unfavourable for the accumulation of thick coal seams.

OIL AND GAS

Prior to discussing specific regional areas suitable for oil and gas exploration it is necessary to point out certain general aspects of Karroo geology which have a bearing on the hydrocarbon prospects of the Karroo Basin as a whole -

1. The Upper Dwyka Shales and the Lower Ecca Group of the Southern and Western Facies, together with large portions of the Cape System are thought to have been deposited in a marine environment (Strydom 1950, Du Toit 1956 and Rust 1967).
2. Rocks constituting the entire Central Ecca Facies, as well as the Lower and Upper Ecca Shales of the Northern Facies were deposited in a restricted, continental sea environment and are generally considered to be suitable source rocks of hydrocarbons.
3. In general, good reservoir rocks are relatively rare in the Karroo Basin. However, certain sandstones in the Middle

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Ecca Group of the Northern Facies appear to have sufficient porosity and permeability to enable them to be classified as suitable reservoir rocks (Kingston et al 1961). In addition, sandstones with suitable reservoir properties were found in the Lowermost Beaufort Beds and in the Dwyka Tillite.

4. The Upper Ecca Group of the Southern Facies and the Lowermost Beaufort Beds may contain reservoir sandstones in the vicinity of the Karroo hinge-line.

5. The re-working of Dwyka Tillite, together with the shedding of a certain amount of coarse clastic material probably took place in the vicinity of the Clocolan Dome. Thus, conglomerates and sedimentary breccias with high porosities are expected to occur around the flanks of this major tectonic feature.

6. The Table Mountain Series probably contains conglomerates and coarse-grained sandstones with good reservoir properties where it laps out against the flanks of the craton north of the Southern Cape Folded Belt.

7. The Ecca and Lowermost Beaufort Beds are folded into numerous anticlines and synclines along the southern margins of the basin and the folding gradually dies out northwards. This has subjected the Lower Karroo sediments along the southern structural margins of the basin to the effects of regional metamorphism.

8. Normal faulting has effected the Karroo strata along the hinge-line of the Natal Trough, along the Lebombo Belt and in the area along the east coast between the Fish River Mouth and Port St. John's. Therefore, suitable fault-block traps may occur in this area.

9. Secondary structural folds are rare in the shelf areas of the Karroo Basin, but compaction structures are known to occur over many of the large pre-Karroo topographic highs on the cratonic shelf areas of the Karroo Basin.

10. Stratigraphic overlap and pinch-out sedimentary traps exist on the flanks of both the Natal and Karroo Troughs as well as on the flanks of the Clocolan Dome. A major sedimentary overlap occurs where the Table Mountain Sandstone is overlapped by the Dwyka Tillite along the northern margins of the Cape-Karroo Geosyncline, but it is possible that any oil which had accumulated in the Table Mountain and Bokkeveld Series may have been lost updip as a result of subsequent subsidence prior to deposition of the Dwyka Tillite.

11. Numerous shows of oil and gas occur in the Karroo Basin (Haughton et al 1953 and Kingston et al 1961).

12. The abundance of dolerite dykes and sills must have had a detrimental effect on the hydrocarbon possibilities of the Karroo Basin.

- 13. -

13. The vast amounts of Upper Karroo strata which have been removed by erosion has greatly reduced the cap rock potential
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of the Karroo Basin.

14. There is an apparent lack of hydrostatic pressure in the northern portions of the basin, but fairly good pressures have so far been encountered during drilling operations in the southern portion.

A. SPECIFIC REGIONAL PROSPECTS

1. The Hinge-line area of the Karroo Trough

It is a well-known fact that hinge-line and shelf provinces are usually the most favourable areas to look for oil (Knebel and Rodriguez-Eraso 1956). Thus one of the most obvious areas to look in the Karroo Basin is along a broad belt of country paralleling the hinge-line of the Karroo Trough (see folder 4).

Favourable Factors

1. Some 4,000-8,000 feet of shale, with definite source rock potential exists in this area.
2. Sandstones with reservoir properties may occur in the Dwyka Tillite, Upper Ecca Group of the Southern Facies (folder 4) and in the basal sandstones of the Lowermost Beaufort.
3. Sedimentary and structural traps are known to occur.
4. The trapping of oil and gas against vertical dykes and in fault-blocks may have taken place.
5. The regional metamorphic effects produced during the Cape Orogeny are not as pronounced in this area.
6. Suitable cap rock properties are thought to exist in this area.
7. In general, hydrostatic pressures are fairly good in this portion of the basin.

Unfavourable Factors

1. It may be difficult to locate suitable reservoir rocks in this area.

2. The effects of the regional metamorphism may have been detrimental to the accumulation of oil.

2. The Hinge-line area of the Natal Trough

The estimated position of the Natal Trough hinge-line is indicated in folder 1. This paleotectonic element has been greatly modified by the effects of the Natal monocline and its associated faulting, as well as subsequent erosion. However, there is a reasonable chance that some of the original hinge-line hydrocarbons still remain in certain of the fault traps along the main outcrop belt of the Ecca, between the Umtamvuna River in the south and latitude 27°30'.

Favourable Factors

1. Potential source rocks occur in this area.
2. Reservoir rocks are known to occur in the Middle Ecca Group and the Dwyka Series.
3. Fault-block structures are fairly common along this belt (Blignaut and Furter 1940).
4. It is possible that Ecca-generated hydrocarbons did not migrate until after the Drakensburg Lavas had been extruded. If this was the case, it would cause oil to become trapped against vertical dykes associated with the extrusion of the lavas.
5. Oil and gas shows are known to occur at a number of localities along this belt.
6. Possible trap structures occur at shallow depths and therefore drilling costs would be relatively low.

Unfavourable Factors

1. In general, the reservoir rock potential of the Middle Ecca Group and the Dwyka Series is only fair.
2. Intrusive into the Ecca beds are numerous dolerite dykes and sills.
3. The Upper Ecca Shales do not appear to have good cap rock properties in this area.

4. In general there appears to be a lack of hydrostatic pressure along this belt.

5. The chances of finding a large oil or gas field in this area do not appear to be good.

3. The Flanks of the Clocolan Dome

Beds of the Dwyka and Ecca Series are known to lap out against the flanks of this broad pre-Karroo topographic feature (see folders 1 and 4). Geophysical and borehole evidence has indicated that this feature is mainly composed of Basement granite.

Favourable Factors

1. Potential source rocks occur along the eastern, southern and western flanks of the Clocolan Dome.

2. Suitable reservoir rocks are thought to occur around the flanks of this feature.

3. Overlaps, updip-pinchouts and compaction structures over pre-Karroo topographic highs can be expected in this area.

4. A large surface dome structure is well exposed near Fouriesburg in the eastern Orange Free State. It is not known whether this structure is due to the effects of compaction over a pre-Karroo topographic high or the effects of large subsurface dolerite sills.

5. The eastern flanks of the Clocolan Dome are overlain by considerable thicknesses of protective strata.

6. Based on surface exposures dolerites appear to be at a minimum in this area.

7. Oil and gas shows are known to occur in this part of the basin.

Unfavourable Factors

1. Virtually no deep boreholes have been drilled around the southern and eastern flanks of the Clocolan Dome and thus there is a lack of subsurface geological information in this area.

2. Cap rock conditions appear to be poor on the western and northern sides of this feature.

4. The Northern Margins of the Cape-Karroo Geosyncline

Along the northern margins of the Cape-Karroo Geosyncline, rocks of the Dwyka Series come to rest disconformably and unconformably on progressively older rocks of the Cape System (see folder 4). The northern pinch-out zone of the Cape System rocks against the Dwyka unconformity is considered to be a favourable area for oil and gas accumulation.

Favourable Factors

1. Possible source rocks occur in the Bokkeveld Series.
2. The sandstones of the Bokkeveld and Table Mountain Series are predicted to become coarser-grained and more suitable as potential reservoir rocks along the northern margins of the geosyncline.
3. The intensity of folding and the regional metamorphism decreases northwards towards the predicted pinch-out zone.
4. Apart from broad anticlinal structures in this area there exists a fair possibility of oil and gas accumulations along the unconformity.
5. The pinch-out zone is thought to be relatively free of dolerites.
6. Cap rock conditions are good.
7. Hydrostatic pressures should be good.

Unfavourable Factors

1. Most of the hydrocarbons may have escaped prior to deposition of the Dwyka Tillite.
2. The effects of regional metamorphism may have been too severe.
3. The estimated depth to the Cape-Karroo unconformity from the top of the Ecca Series is thought to be about 10,000 feet.
4. Seismic methods would have to be used to determine the pinch-out zone of the Cape System.

5. The Distillation of Oil from Oil-Shale

Oil shales are known to occur fairly extensively in the Middle Ecca Group of the Northern Facies and have actually been mined in the districts of Ermelo, Wakkerstroom and Utrecht. Distillation tests have yielded between 8.5 and 79.0 gallons of oil per ton of oil-shale (Visser et al 1947 and Visser et al 1958).

Extensive deposits of carbonaceous shale containing as much as 14 percent of carbonaceous matter, together with some hydrocarbons, occur near the top of the Upper Dwyka Shale. Samples of these shales from the Orange River Station were found to yield some oil on distillation (D Toit 1956 p. 278).

The present investigations indicated that the most promising areas for investigating the Upper Dwyka Shales for exploitable deposits of oil-shale were around Port St. John's in the east and in a broad belt along the Orange River in the west, as carbonaceous shales appear to reach their maximum development in these areas.

B. SUMMARY OF OIL AND GAS POSSIBILITIES

In the writer's opinion, the overall prospects of finding economically exploitable deposits of oil and gas in the Karroo Basin are only fair. However, there appears to be a fairly good chance of finding commercial deposits of oil and gas in the four specific areas discussed above in order of their prospective worth. In these four areas, the unfavourable geological factors such as regional metamorphism, scarcity of good reservoir rocks, the effects of Karroo dolerites and a lack of sufficient cap rocks in certain areas, is outweighed by the favourable factors. It is, therefore, recommended that detailed geological and geophysical investigations, followed up by exploratory drilling be carried out in these four specific areas.

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