ECONOMIC GEOLOGY RESEARCH UNIT

University of the Witwatersrand
Johannesburg

BASIN ANALYSIS OF THE ECCA AND LOWERMOST BEAUFORT BEDS AND ASSOCIATED COAL, URANIUM AND HEAVY MINERAL BEACH SAND OCCURRENCES

P. J. RYAN and G. G. WHITFIELD

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ABSTRACT

The regional sediment transport directions, major provenance areas and the controlling palaeotectonic and palaeogeographic framework of sedimentation have been reconstructed for the Great Karoo Basin during the Permian. Analyses of this magnitude can be useful in regional exploration programmes for coal, uranium and fossil heavy mineral beach sand deposits.

The strong palaeogeographic control on coal deposition is demonstrated by the fact that some of the most important deposits accumulated in topographically low-lying areas on the pre-Karoo surface. Such areas formed sheltered environments ideal for the growth and accumulation of organic material. Elsewhere relatively slow rates of subsidence of a broad, protected, low-lying, delta plain controlled the deposition of coal. North of the main Karoo Basin many of the coal deposits are confined to structurally controlled linear basins.

Hundreds of sedimentary uranium occurrences of varying grade and size occur within a broad, discontinuous belt in the Lower Beaufort of the southwestern portion of the Karoo Basin. The uranium mineralization occurs in a variety of fluvial deposits usually rich in carbonaceous material. Minute tuffaceous fragments, reflecting contemporaneous vulcanism, form a minor but significant constituent in some of the uraniferous sandstones. The uranium occurrences are largely confined to the Southern and Western Facies of the Lower Beaufort, and occur mainly within the confines of the Karoo Trough. The original source of the uranium is not known but it is suggested that the predominantly granitic provenance areas lying to the south and west of the basin provided an adequate source. The uranium could also have been derived from the leaching of the fine-grained tuffaceous material found in these sediments.

Consolidated heavy mineral beach deposits have been found in the predominantly fluvio-deltaic Middle Ecca Group of the Northern Facies at a number of widely separated locations. These deposits were formed by shore line processes, such as the reworking of delta-front sands, during periods of temporary marine regression.

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BASIN ANALYSIS OF THE ECCA AND LOWERMOST BEAUFORT BEDS AND ASSOCIATED COAL, URANIUM AND HEAVY MINERAL BEACH SAND OCCURRENCES

I. INTRODUCTION

The purpose of this paper is to indicate the regional sediment transport directions, the controlling tectonic framework of sedimentation and the palaeogeography within the Karoo Basin during Ecca and Lowermost Beaufort times. Reconstructions of this magnitude have a direct bearing on the hypothesis of continental drift, and can be useful in regional exploration programmes for coal, uranium and fossil heavy mineral beach sands.

Particular emphasis was placed on the measurement of directional sedimentary structures such as cross-bedding and ripple marks. Average current directions were determined, for each outcrop locality, after correction of the data for tectonic tilt. Mean current trends were then represented on palaeocurrent maps covering the complete extent of the Ecca and Lowermost Beaufort outcrop belts. From these maps an interpretive palaeocurrent map showing regional sediment transport directions within the basin was constructed (Ryan, 1967). Conclusions regarding the positions and nature of the source areas, the tectonic framework of sedimentation and the palaeogeography are drawn from all available stratigraphic, petrographic and palaeocurrent evidence.

II. GEOLOGICAL SETTING AND FACIES DISTRIBUTION

The Karoo Supergroup, or the African equivalent of the so-called Gondwana Succession of the Southern Hemisphere, covers vast areas of southern Africa but is most extensive and best preserved in the Great Karoo Basin. This geographic region is bounded in the south and south-west by the Southern and Western Cape Folded Belts respectively. Karoo strata extend seawards into the Indian Ocean in the east, and the northern and north-western margins of the basin are controlled partly by structure and partly by erosion.

The Karoo Supergroup was first studied and defined in the Cape and Natal where the Dwyka Tillite forms the base, and the basaltic lavas of the Drakensberg cap the succession. The intervening beds, thousands of metres thick, have been subdivided, partly on palaeontological but mainly on lithological criteria, into the Ecca, Beaufort and Stormberg groups. These groups are represented by an alternating sequence of argillaceous and arenaceous rocks with an estimated maximum thickness of at least 9 000 m in the east-west-trending Karoo Trough, lying immediately north of the Southern Cape Folded Belt. A considerable thickness of strata also occurs in the Natal Trough, the axis of which approximately parallels the Natal coast.

In the Karoo Trough, where sedimentation was continuous, beds of the Karoo Supergroup rest conformably on rocks of the older Cape Supergroup. Outside the troughs, and on the shelf areas, the Karoo strata are not only represented by abbreviated sequences, but stratigraphic disconformities are common, resulting in the absence of considerable thicknesses of strata.

North of the east-west-trending Southern Cape Folded Belt, the Dwyka, Ecca and Lower Beaufort rocks were intensely deformed during the Cape orogeny, but the folding gradually dies out northwards. Along the Natal coast, Karoo strata dip seawards at angles between 5 and 30 degrees, but over the greater part of the basin the beds dip into the African subcontinent at low angles.

A. The Ecca Group

The Ecca sediments have an estimated maximum thickness of 3 000 and 1 200 m in the Karoo and Natal troughs respectively. Towards the north and west of these downwarps the strata become progressively thinner, through the gradual tapering of individual beds as well as sedimentary overlap (Figure 1). The Ecca Group lies conformably on the Upper Dwyka Shales (Lower Permian) in the Karoo Trough. However, northwards from this area the sequence rests disconformably and unconformably on rocks of widely different age. On the basis of lithology and provenance the Ecca Group has been subdivided into the Southern, Western, Northern and Central Facies (Figure 2).

1. *The Southern Ecca Facies*

The Southern Ecca Facies is mainly composed of fine-grained graywacke, subgraywacke sandstone, and greenish-grey and bluish-black shale. The Lower Ecca Group is represented by a typical flysch sequence found in association with a geosynclinal belt, and is thought to have been deposited mainly under deep water conditions (Truswell and Ryan, 1969). Sole casts, current ripple marks, graded

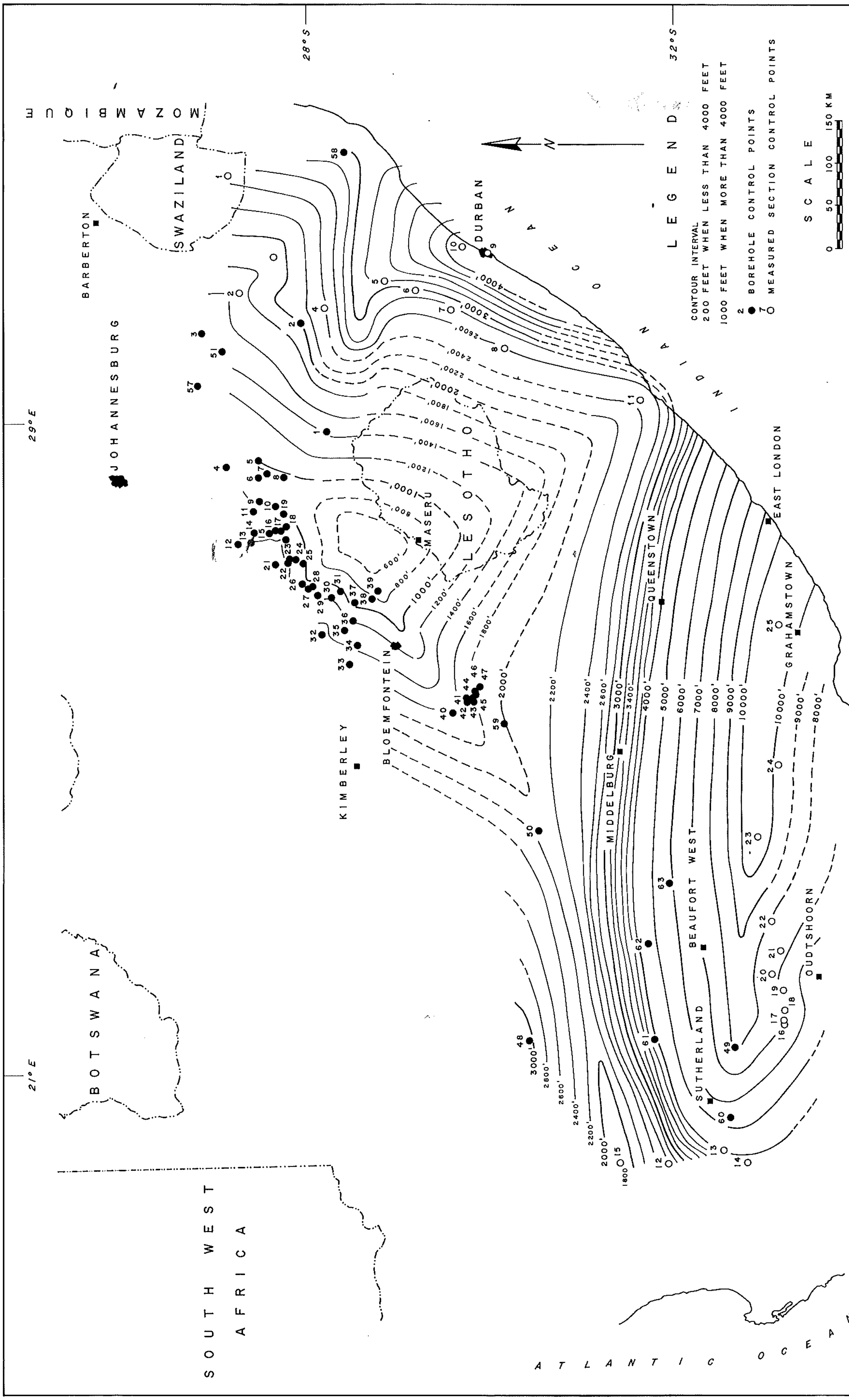


FIG. 1

ISOPACH MAP OF TOTAL ECCA PLUS UPPER DWYKA SHALE IN THE KAROO BASIN.

bedding, shale-pebble conglomerate, slump and load structures, convolute lamination, small-scale cross-bedding and sandstone dykes are the most abundant sedimentary structures. Haughton et al (1953) reported the presence of fossil leaf impressions, silicified wood, invertebrate trains, worm burrows and fish trails. The thick succession of bluish-black shale, constituting the middle portion, was probably also deposited in a fairly deep water environment. The dark colour, the well-bedded nature of these sediments, and their enormous lateral extent, suggest deposition in an extensive body of water. Symmetrical and asymmetrical ripple marks are the only primary sedimentary structures occurring within these rocks. Silicified wood and indeterminate plant fragments near the top are compatible with the commencement of fluvial-deltaic conditions towards the close of this depositional period. The upper portion of the Southern Ecca Facies consists mainly of fine-to-medium-grained graywackes and sub-graywackes deposited under shallow water fluvial-deltaic conditions with ripple marks, cross-bedding, scour channels, slump structures, shale-pebble conglomerate and parting lineations being the most common sedimentary structures. Drilling by SOEKOR has shown that sandstones within this facies grade rapidly into shale towards the north thereby indicating the presence of a once extensive and deep body of water in this direction (see Winter and Venter, 1970).

2. *The Western Ecca Facies*

This facies is composed of bluish-black shale, graywacke and subgraywacke sandstones, and thin beds of chert and limestone. It is possible, on lithological grounds, to divide this facies into Lower, Middle and Upper Ecca groups, but due to fairly rapid gradation of sandstone formations into shale towards the east and northeast they become increasingly difficult to recognise. The eastern boundary of this facies, with that of the Southern Ecca Facies, is transitional and it is only by careful examination of the relative stratigraphic positions of the sandstone formations and their related palaeo-current directions that a distinction can be made. The estimated boundary with the Central Ecca Facies is taken where the sandstones are predicted to wedge out.

The Lower Ecca Group of this facies consists of bluish-black shale, often weathering to a khaki colour, interbedded with thin, persistent, beds of yellow illitic clay and occasional chert beds. Calcareous nodules, with diameters of up to 40 cm, are abundant in the shale and thin limestone beds. Rogers and Du Toit (1930) found fossilised leaves and wood in these beds. The well-bedded nature and extensive lateral extent of these rocks, together with the abundance of calcareous nodules and thin beds of limestone indicate that deposition took place in an extensive, relatively deep body of water.

Rocks of the Middle Ecca Group rest conformably on, and locally interfinger with, shales of the Lower Ecca Group. Approximately 60 per cent of the succession is composed of hard, bluish-grey, shale, the balance consisting of siltstone, fine-grained thinly-bedded sandstone and thick massive-bedded fine-grained sandstone. The sandstones are all either graywackes or subgraywackes. Various types of ripple marks are abundant in the siltstones and thinly-bedded sandstones. Worm trails and tracks as well as fossilized wood occur in these beds.

Rocks of the Upper Ecca Group are composed of hard, grey, shale and siltstone together with thin and thick beds of graywacke and subgraywacke. The sandstones are usually fine-grained, grey and mottled. Various types of ripple marks are abundant, particularly in the thinly-bedded sandstone and siltstone.

Ultimately, all the sandstone in the Upper Ecca Group grades into shale, and at this point the Western Ecca Facies passes into the Central Ecca Facies. Local disconformities, contemporaneous erosion channels, shale-pebble conglomerates, parting lineations and compaction structures occur in these beds. In addition to plant fossils, trails and tracks are fairly common. Fluvial-deltaic conditions are thought to have prevailed throughout Middle and Upper Ecca times in the Western Facies.

3. *The Northern Ecca Facies*

Sediments constituting the Northern Ecca Facies are confined to the northern one-third of the basin and the estimated boundary with that of the Central Ecca Facies is taken as the southernmost limit at which sandstone occurs. The Northern Ecca Facies reaches a maximum thickness of about 1 200 m in the Natal Trough from where it thins out in a northerly and easterly direction.

The Lower Ecca Group is composed almost entirely of bluish-black micaceous shale and flagstone and has been traced along the eastern outcrop belt to as far north as the Taaibos River (latitude 26°54' south). North of this point, however, it is thought that sedimentary overlap takes place and the Middle Ecca comes to rest directly on either the pre-Karoo surface or the Dwyka Tillite.

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 southeast of Krantzkop. In general, these rocks are thought to have been mainly deposited under fairly deep water conditions in the continental sea which occupied the central portions of the basin during this period, and which also extended northwards along the site of the Natal Trough and the deep pre-Karoo valleys of the western Orange Free State.

The Middle Ecca Group occurs as a wedge of predominantly coarse clastic between the argillaceous Lower and Upper Ecca groups. The dominant rock types are coarse-grained arkose, conglomerate, micaceous siltstone, carbonaceous shale, coal seams and thin beds of limestone. 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, predominantly fluvial-deltaic, environment. Towards the south, these conditions grade into a deeper water continental sea environment. A thin bed of glauconite-rich sandstone immediately above the Number 4 coal seam can be traced over extensive areas in the southeastern Transvaal coalfields, thereby suggesting periods of extensive marine transgression. Hart (1964) also found marine microfossils in thin carbonaceous shale beds of this group. The Middle Ecca Group grades upwards into the Upper Ecca Group, the contact being taken at the top of the uppermost sandstone above which the succession becomes predominantly argillaceous.

The Upper Ecca Group is composed of bluish-black shale and mudstone with occasional argillaceous sandstone and limestone. In Swaziland, however, this unit is composed of carbonaceous shale, thick sandstones and coal seams (Davies, 1961). Nodules of calcium phosphate and calcium carbonate are common, and a further characteristic is the presence of ferruginous shale nodules and lenses which sometimes contain fossilized fish remains.

The Upper Ecca Group of the Northern Facies was mainly deposited in an extensive body of water in the form of a continental sea. Shallower water fluvial-deltaic conditions and coal swamps existed in the northermost extensions of the Natal Trough in the Lebombo Belt of Swaziland.

4. *The Central Ecca Facies*

This facies occurs mainly in the central portions of the Karoo Basin and is composed of an admixture of the fine-grained equivalents of the other three facies. The interfingering sediments derived from the three different source areas are grouped together purely on the basis of their lithology which consists almost entirely of bluish-black shale and flagstone.

Due to the complete lack of marker beds in this facies no attempt has been made to subdivide it on lithological grounds into groups of strata. The Central Ecca Facies rests conformably or disconformably on the Dwyka Group and the upper limit is taken at the base of the first prominent Beaufort sandstone. Fish tracks and worm burrows have been found at a number of localities and silicified wood is a common feature near the top of the succession. 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 Karoo basin throughout the Ecca period. The apparent absence of marine fossils leads to the conclusion that only narrow accessways connected this body of water with the Permian oceans. Consequently, restricted, de-oxygenated, still-bottom conditions probably prevailed.

B. The Lowermost Beaufort Beds

In the Karoo Trough the Lowermost Beaufort Beds follow conformably on the Ecca. However, north of this area sedimentary overlap takes place, so that progressively younger Beaufort Beds rest disconformably on what is taken, on lithological grounds, to be the Upper Ecca. Therefore, on a regional scale it should be clearly understood that these beds are not isochronous. Palaeontological evidence confirms this, as progressively younger vertebrate fossils are found in these beds the farther north one proceeds from the Karoo Trough. In this paper the Lowermost Beaufort Beds are defined on lithological grounds and are taken to mean the first few hundred metres of sediment lying immediately above the top of the Ecca.

Available thickness measurements of the Lower Beaufort indicate that these beds follow a similar distribution pattern to that of the Ecca (Figure 1), except that the axes of the Karoo and Natal troughs have moved towards the north and west during this period, thereby 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 Group is also 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 Upper Ecca. As already stated the Ecca-Beaufort contact in this area is taken at the base of the first well-developed sandstone above the Ecca shale. It is therefore to be expected that the topmost beds of the Ecca Group in the northern Cape and southern Orange Free State are the chronostratigraphic 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 chronostratigraphic equivalents of a higher Beaufort sequence of strata in the south.

Kitching (personal communication) found a typical *Cistecephalus* fauna (uppermost palaeontological zone in the Lower Beaufort) in the Lowermost Beaufort rocks in the vicinity of the Van der Kloof dam site on the Orange River.

The authors are of the opinion 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 Karoo 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 bluish-black shale which, on lithological grounds, is classified as the Upper Ecca Group 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.

On the basis of palaeocurrent directions and lithology, three distinct facies can be recognised. These are known as the Southern, Western and Northern facies and have a similar distribution and provenance as the Ecca, except that they do not grade into a central 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 palaeocurrent directions is it possible to distinguish between rocks belonging to the different facies.

1. *The Southern Facies*

These rocks outcrop along the southern structural margin of the basin and also occur in isolated, tightly folded synclines farther to the south. 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 coarse-grained Middle Beaufort Sandstone.

These beds are composed of fine- to medium-grained, massive 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 (Roussouw et al, 1964).

2. *The Western Facies*

Good outcrops of this facies occur along the 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 northeastwards and good examples of sandstone beds wedging out in this direction may be seen in the Kareeberge 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 have been reported. Fossil reptiles are not as abundant as in the Southern Facies (Rogers and Du Toit, 1903).

3. *The Northern Facies*

In northern Transkei and southern Natal the Lowermost Beaufort Beds are composed mainly of fine- to medium-grained felspathic sandstone, siltstone and mudstone. The sandstone resembles that of the Middle Ecca Group, but the mudstone is normally light grey, green or purple in 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 and in the Biggersberg and Belelasberg. In these areas the succession is composed of coarse arkosic sandstone, grit, conglomerate, carbonaceous shale and coal seams.

In the southeastern 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 Group of the Northern Ecca Facies being mainly arkosic in composition and containing an abundance of 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. Rocks of this facies are not as brightly coloured as the other two facies.

The continental sea which appears to have occupied the central portions of the Karoo Basin throughout Ecca times had largely withdrawn during deposition of the Lowermost Beaufort Beds when shallow water continental conditions became predominant. 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 mudflats in an oxidizing environment. The abundance of fossil reptiles and plants is indisputable evidence of a terrestrial environment. Coal seams and thin lenticular beds of limestone indicate that under favourable tectonic and palaeogeographic conditions, swamp and lacustrine environments prevailed.

III. PALAEOCURRENT ANALYSIS

A. The Ecca Group

Figures 2 and 3 show the regional palaeocurrent trends within the different facies of the Ecca. The generalised transport directions within the Northern Ecca Facies were towards the southwest and west. However, in portions of Natal there is substantial evidence of a southeasterly trend in sediment transport, particularly in the lower part of the succession. It is believed that the more rapid rates of subsidence in the Natal Trough had the effect of causing considerable quantities of southwesterly-trending sediment to be diverted towards this major structural feature. Regional transport directions within the Natal Trough were in a general south to southwesterly direction, and approximately parallel to the trough axis. Along the northern margin of the basin there is evidence of a southerly current trend. This feature is at least partly explained by the fact that the Ecca Group rests directly on the pre-Karoo surface over wide areas in this part of the basin. The effect of the pre-Karoo topography, with its large north-south-trending valleys (Wybergh, 1922), no doubt exercised a major control on the southerly flow-trends of sedimentary detritus.

Regional palaeocurrent directions within the Southern Ecca Facies clearly indicate that during Lower Ecca times sediment transport took place northwards towards the Karoo trough, as well as eastwards and parallel to the axial plunge of the trough. Sediment transport directions during Upper Ecca times were predominantly towards the north, except in the western portions of the outcrop where a more north-easterly trend becomes predominant.

The palaeocurrent pattern in the Western Ecca Facies is towards the east and northeast. From Figures 2 and 3 it is possible to see that the easterly and northeasterly trends, so well developed in the Western Ecca Facies, are continued for some 500 km along the western outcrop belt of the Central Ecca Facies, to somewhat north of the present position of the Orange River. North of this, flow directions were towards the southwest. A considerable amount of overlapping and interfingering of sediment, derived from two separate source directions, took place where these directionally opposed currents met. Similarly, palaeocurrent directions in the eastern outcrop belt of this facies indicate that a zone of intermixing of fine-grained clastics, derived from both the northeast and south, took place.

B. The Lowermost Beaufort Beds

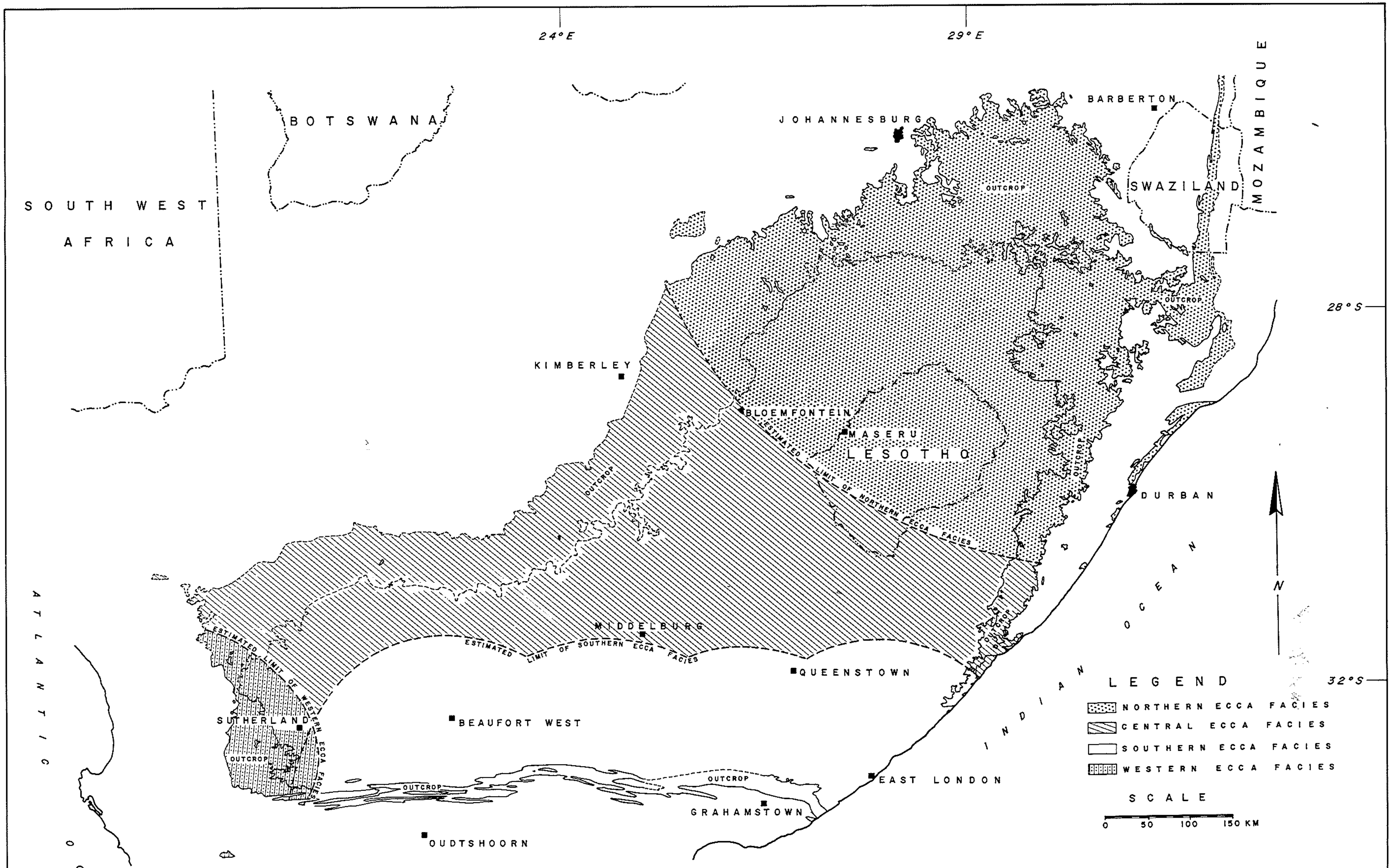
Although only limited numbers of directional structures were measured in the Lowermost Beaufort Beds, it has nevertheless been possible to draw certain conclusions regarding the regional sediment transport trends in these rocks. Three major, and one minor, dispersal patterns have been identified. These are as follows :

1. A general southwesterly-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 northeasterly pattern in the southwestern portions of the basin.
4. A smaller but significant easterly-trending current pattern occurring south of Port St. John's in the eastern part of the basin.

It may be assumed that 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. In general, therefore, the palaeocurrent directions within the Lowermost Beaufort Beds are very similar to those found in the underlying Ecca Group, indicating that the flow patterns initiated by the Ecca continued through into the Lower Beaufort, although under progressively shallower water conditions.

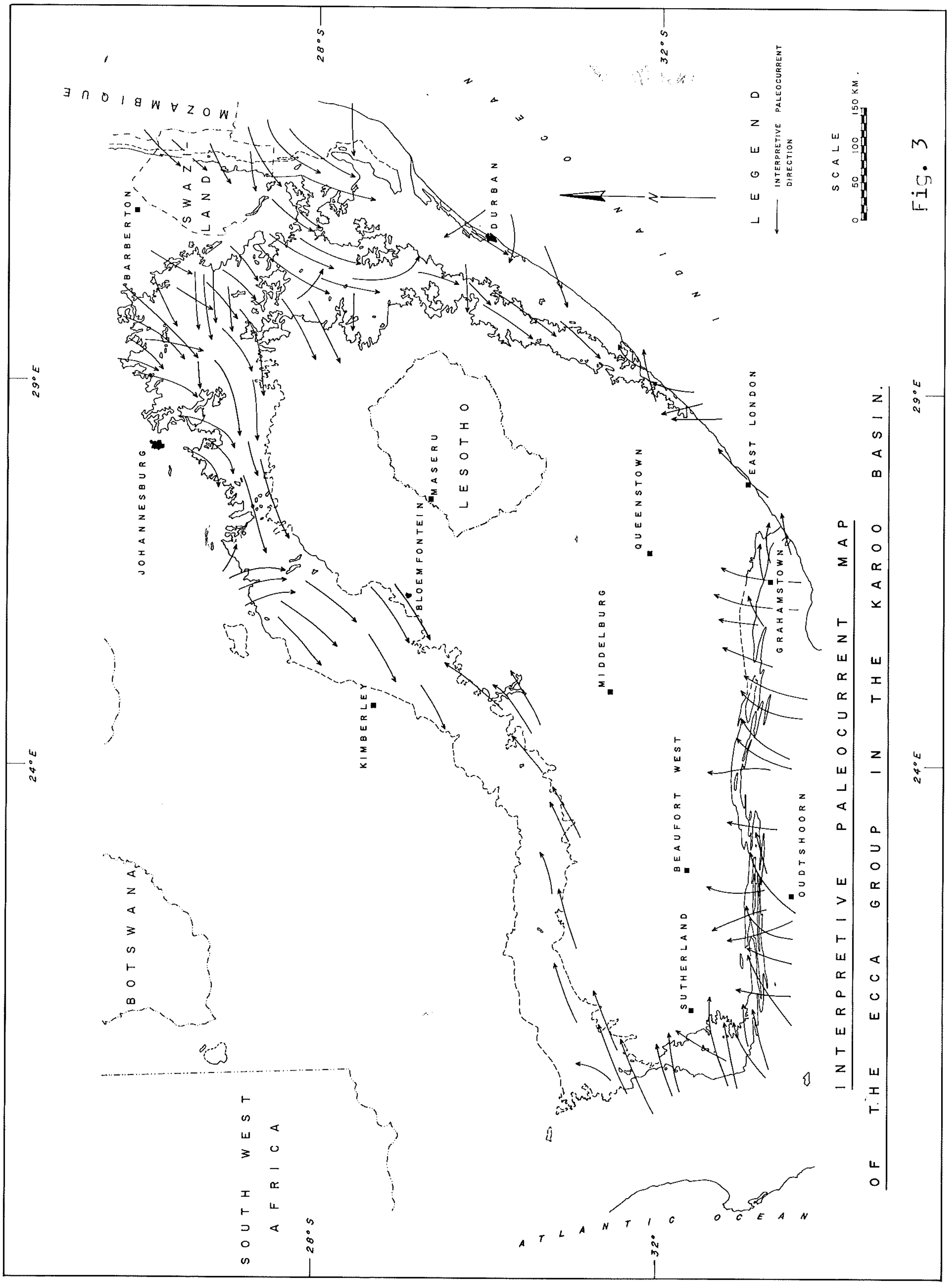
C. Positions and Nature of the Source Areas

The regional palaeocurrent directions within the Northern Ecca Facies clearly indicate a source area lying to the northeast and east. In addition, petrographic studies (Ryan, 1967) have revealed that the majority of the sandstones in this facies are medium- to coarse-grained arkoses. It has therefore been concluded that a major highland area, composed predominantly of granitic rocks, lay to the northeast and east of the present Natal coast (Figure 4). Judging from the abundance of angular to sub-angular felspar pebbles in eastern Swaziland and coastal Natal, it is believed that this highland area was situated fairly close to the present coastline. On the basis of palaeocurrent directions, and trends in average grain-size of sandstones, together with changes in lithofacies, it may be deduced that relief in this source area probably decreased towards the south.



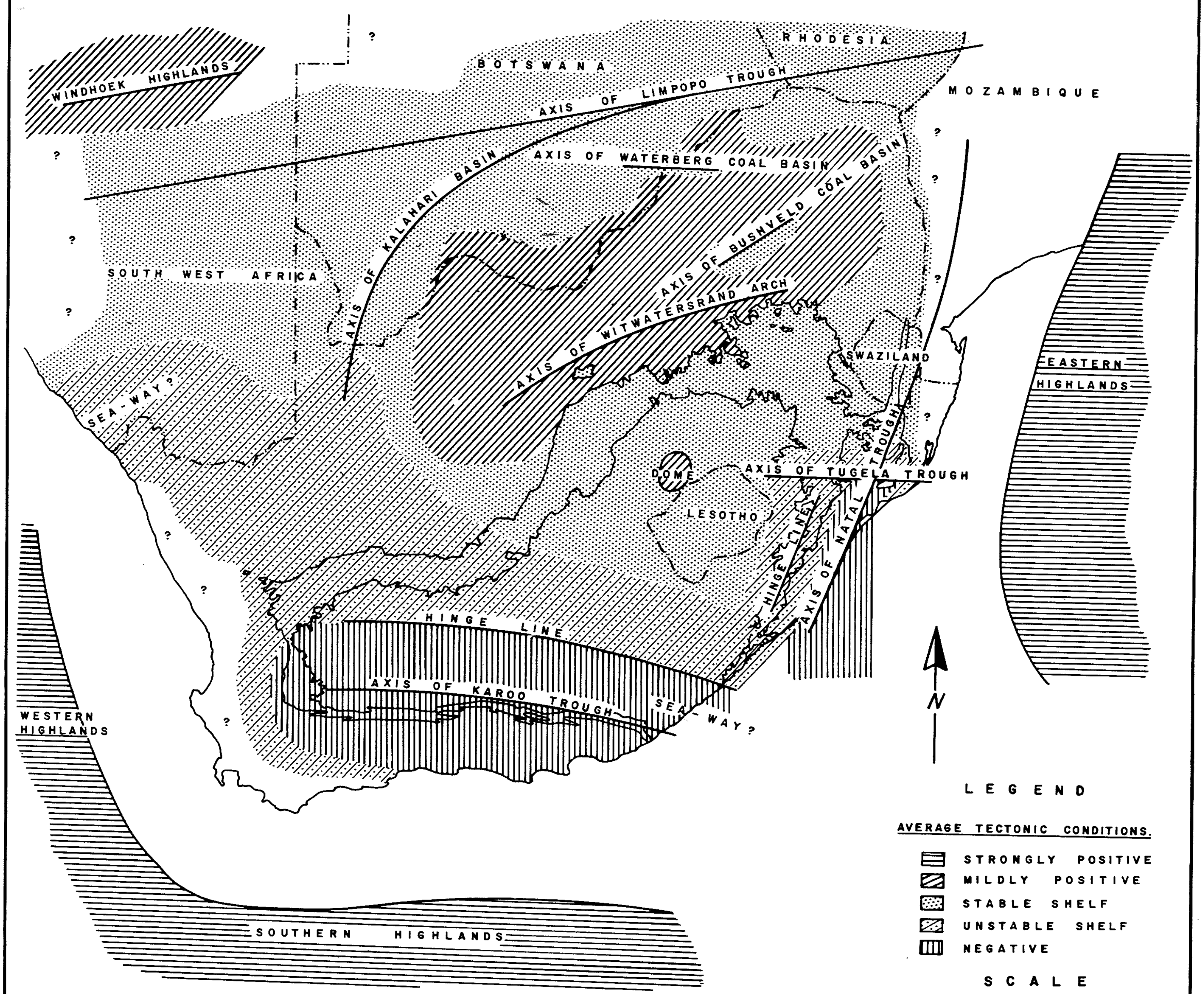
FACIES DISTRIBUTION MAP OF THE ECCA GROUP IN THE KAROO BASIN

FIG. 2



INTERPRETIVE PALEOCURRENT MAP OF THE ECCA GROUP IN THE KAROO BASIN.

Fig. 3



AVERAGE TECTONIC CONDITIONS WITHIN
THE KAROO BASIN DURING THE PERMIAN

FIG. 4

Along the northern erosional margins of the basin, as for example in the vicinity of Witbank, palaeocurrent directions, together with the compositions of sandstones and conglomerates, have clearly indicated that the pre-Karoo formations to the north of the present erosional limits shed significant amounts of sediment into the basin. This area, looked at in regional terms, therefore represented a significant, but subordinate, source area.

The regional dispersal patterns within the Southern Ecca Facies, together with the abundance of quartz and albite in the sandstones, indicate the presence of a linear source area composed largely of granitic rocks lying to the south of the African continent in its present form. Recent workers (Elliot and Watts, 1974; Martini, 1974; Lock and Johnson, 1974) have also presented irrefutable evidence for the presence of volcanic fragments and tuffaceous detritus in many of the rocks of the Southern Ecca Facies, and in the Lowermost Beaufort Beds of the southern Cape. It is becoming increasingly clear, therefore, that significant contemporaneous volcanism took place during the Permian in the southern source area. The volcanic components are probably intermediate to acidic in composition. Sedimentary, intrusive and metamorphic rocks probably also occurred in lesser amounts. The greater abundance of coarse clastics in litho-stratigraphic successions in the east indicates that relief in the source area was probably more pronounced in this section. Combined palaeocurrent, stratigraphic and structural evidence suggests that the source area probably represented a rising mountain mass to the south of the east-west-trending Cape-Karoo Geosyncline. The coarse-grained facies equivalent of the Ecca Group in this area was deposited closer to the source and has since been eroded away. In addition, isopachs of the Cape Supergroup and the Ecca Group indicate that the southern margins of the Cape-Karoo Geosyncline lay some distance south of the present Cape coast.

Regional palaeocurrent directions within the Western Ecca Facies clearly indicate that the source of these sediments lay to the west and southwest of the present outcrop belt. Again, the abundance of quartz and albite in the sandstones suggests that the source rocks were predominantly granitic in composition although sedimentary, volcanic, intrusive, and metamorphic, rocks also occurred in lesser amounts. The western source area must have been situated beyond the present continental limits, as none of the rock types along the western and southwestern margins of the continent correspond to the requirements of a predominantly granitic source. Isopach maps of the Cape Supergroup indicate that the outcrops of 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.

The presence of borderlands around the margins of southern Africa during the Permian period is certainly not unique to this continent. Numerous investigators have shown that the North American continent was originally bordered in the east and west by highland linear belts, known as Appalachia and Cascadia respectively.

IV. TECTONIC FRAMEWORK AND PALAEOGEOGRAPHY DURING SEDIMENTATION

On the basis of isopach, lithofacies and palaeocurrent maps (Ryan, 1967) it has been possible to reconstruct the broad regional tectonic framework within the Great Karoo Basin during the Permian. The greater portion of the southern part of the present African continent constituted a fairly stable cratonic block, flanked in the south and southeast by the tectonically negative Karoo and Natal troughs respectively. These linear downwarps contain well-defined hinge lines where they merge with the cratonic shelf (Figure 4).

Other well-defined structural elements include the Tugela Trough, Kalahari Basin, Limpopo Trough, Waterberg and Bushveld coal basins, Windhoek Highlands, Witwatersrand Arch and the Clocolan Dome. The Witwatersrand Arch and the Windhoek Highlands are thought to have been mildly positive during this period and therefore acted as subordinate source areas.

The Eastern, Southern and Western highlands represented strongly positive linear borderlands forming an arcuate belt of mountains around the southern portion of the sub-continent, except in the southeast where these highlands were either very low or completely absent (Figure 4). The earth's crust was probably deeply depressed where the Karoo and Natal troughs met and therefore formed an ideal area for inundation by the Permian seas.

In Permian times, tectonic uplift of the borderland source areas resulted in the erosion and transportation of vast quantities of sediment into the Great Karoo Basin. Significant but lesser amounts of sediment were also derived from the Windhoek Highlands and the Witwatersrand Arch. During the early Permian, deposition was restricted to the Karoo Trough but, with time, subsidence spread northwards along the Natal Trough and also onto the cratonic shelf.

V. COAL OCCURRENCES

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

In order to understand the geological conditions controlling the localization of coal deposits within the Ecca and Lowermost Beaufort Beds it is essential to interpret known coal-bearing areas in the light of their palaeotectonic, palaeoenvironmental and palaeogeographic setting.

A comparison of Figures 4 and 5 shows that the important coal deposits of the Ecca and Lowermost Beaufort Beds were deposited on a relatively slowly subsiding stable shelf. The associated sediments, derived mainly from the Eastern Highlands, were deposited primarily under fluvial-deltaic conditions, with periodic marine transgressions from the south. Conditions for coal deposition became progressively less favourable as the more unstable shelf conditions flanking the rapidly subsiding Karoo and Natal troughs were approached, and where deeper water marine conditions are thought to have predominated.

With time, subsidence of the craton spread northwards and progressively higher formations within the Middle Ecca Group of the Northern Facies came to rest unconformably on the pre-Karoo surface. In the same way progressively higher coal seams within the Coal Formation are known to lap out against pre-Karoo topographic ridges along the northern margins of the basin.

The strong palaeogeographic control on coal deposition is demonstrated by the fact that some of the best deposits in the Transvaal and Orange Free State are known to have accumulated in topographically low-lying areas on the pre-Karoo surface. Certain of the original coal swamps were almost entirely surrounded by ranges of pre-Karoo hills. Such areas undoubtedly constituted sheltered environments ideal for the accumulation of organic material. Examples of coalfields formed under these conditions are Witbank, South Rand, Vereeniging and North Bethal fields. With time the pre-Karoo valleys became filled with sediment and, subsequently, deposition took place over the pre-Karoo hills. However, due to differential compaction, the effects of the pre-Karoo topography were often perpetuated upwards for 60-70 m into the overlying sediments. Therefore, topographically low-lying areas on the pre-Karoo surface may have exercised a certain amount of influence on the localization of later coal deposits even though this surface had been blanketed with sediment.

During Ecca times the northern and northwestern margins of the main basin were bounded by a mildly positive area constituting the Witwatersrand Arch. However, within certain limited areas on this broad tectonic feature, graben faulting and subsequent sedimentation resulted in the formation of the Waterberg and Bushveld coal fields. It can also be seen from Figure 4 that on the northwestern flank of the Witwatersrand Arch favourable palaeotectonic and environmental conditions must have prevailed for the formation and preservation of coal deposits in eastern Botswana.

Still farther to the north of the main basin the present distribution of the Karoo sequence is mainly confined to those areas affected by contemporaneous and post-Karoo graben faulting, as for example the Limpopo, Zambezi and Luangwa troughs (Figure 6). In these areas, regional mapping by the various geological surveys, as well as detailed sedimentological studies, have shown that the Coal Measures (Ecca Group) and their associated coalfields are mainly confined to the axial portions of the troughs, while outwards from these areas the upper Karoo sediments such as the Cave Sandstone (Forest Sandstone) transgress the coal measures and come to rest directly on the pre-Karoo surface. Therefore, deposition of the coal measures in portions of Southern and Central Africa was confined to these structurally controlled linear basins.

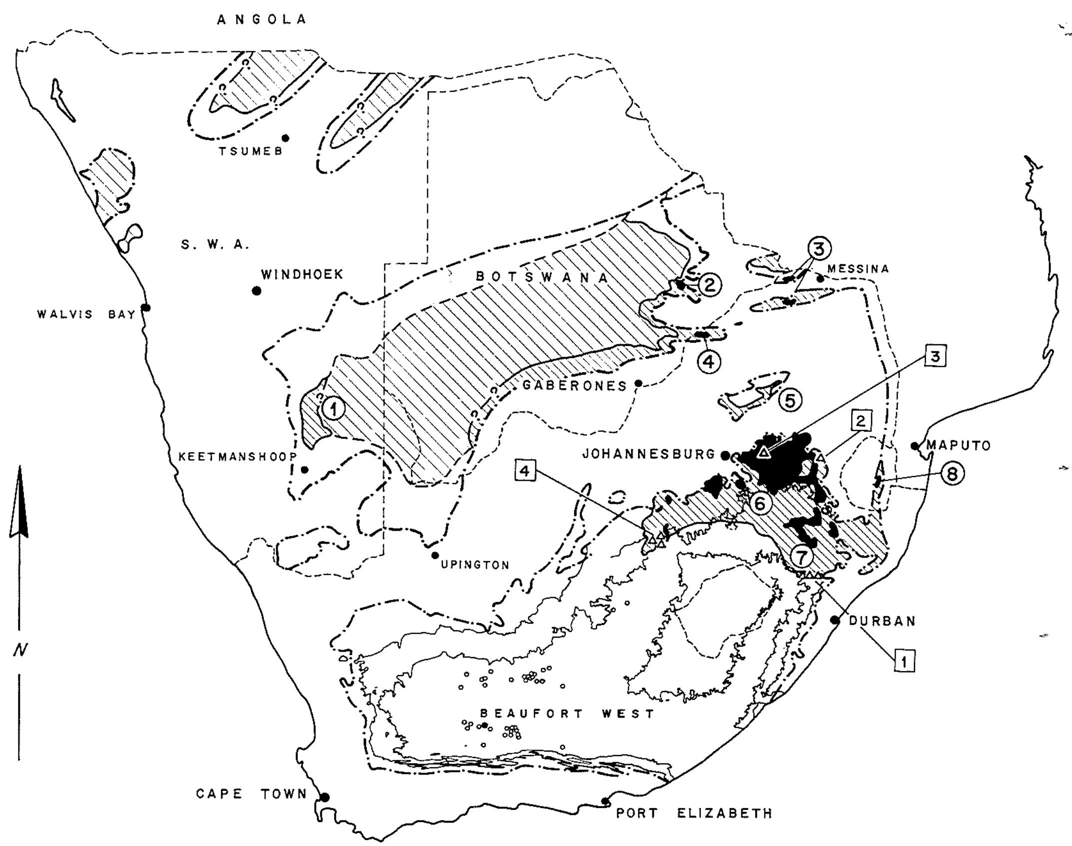
Over large areas of the southeastern Transvaal and northern Natal considerable thicknesses of Lower Karoo strata (viz. Dwyka Group plus Lower Ecca Shale) intervene between the pre-Karoo surface and the coal formation. It is, therefore, unlikely that the pre-Karoo topography exercised any control on the localization of the coal deposits. Instead, factors such as relatively slow rates of subsidence in the physiographical setting of a braod, low-lying delta plain, grading southwards into a shallow marine environment, were the factors which controlled the deposition of coal in these areas. Similar factors also probably best explain the localization of the coal deposits in the Lowermost Beaufort Beds in the northeastern portion of the basin as for example near Volksrust and along the Lebombo belt of Zululand.

VI. URANIUM OCCURRENCES

Uranium mineralization within the Lower Beaufort Beds of the Karoo Supergroup was first discovered near Beaufort West in 1969. Subsequent exploration has revealed hundreds of additional occurrences of varying size and grade, mainly in the Lower Beaufort sediments of the southwestern portion of the Karoo Basin (see Von Backström, 1974, and Moon, 1976, for preliminary studies).

The most important uranium occurrences are situated in the Beaufort West-Merweville area, in sediments of the Tapinocephalus biozone of the Lower Beaufort. Uranium occurrences are not restricted to the vicinity of this bio-stratigraphic zone as numerous locations have also been recorded at stratigraphically higher levels. In addition, Von Backström (1974) has also reported that similar-type uranium mineralization has been discovered in the lower members of the Karoo sequence in the Transvaal, Natal, South West Africa and Angola.

DISTRIBUTION OF SOUTHERN AFRICAN COAL FIELDS, URANIUM OCCURRENCES AND HEAVY - MINERAL BEACH SAND DEPOSITS OF THE PERMIAN.



LEGEND

SOUTHERN AFRICAN COAL FIELDS

- IN SITU COAL RESERVES
- IN SITU COAL RESERVES SPECULATIVE
- EXTRACTABLE COAL RESERVES i.e. THAT PART OF IN SITU RESERVES WHICH ARE CURRENTLY COMMERCIALLY EXTRACTABLE FROM IN SITU RESERVES GIVEN MARKET AVAILABILITY

FROM D.A.M. SMITH (1976)

1. S.W.A.
2. BOTSWANA
3. LIMPOPO - SOUTPANSBERG
4. WATERBERG
5. SPRINGBOK FLATS
6. S.&E. TRANSVAAL AND N.O.F.S.
7. NATAL
8. SWAZILAND

HEAVY - MINERAL BEACH SAND DEPOSITS

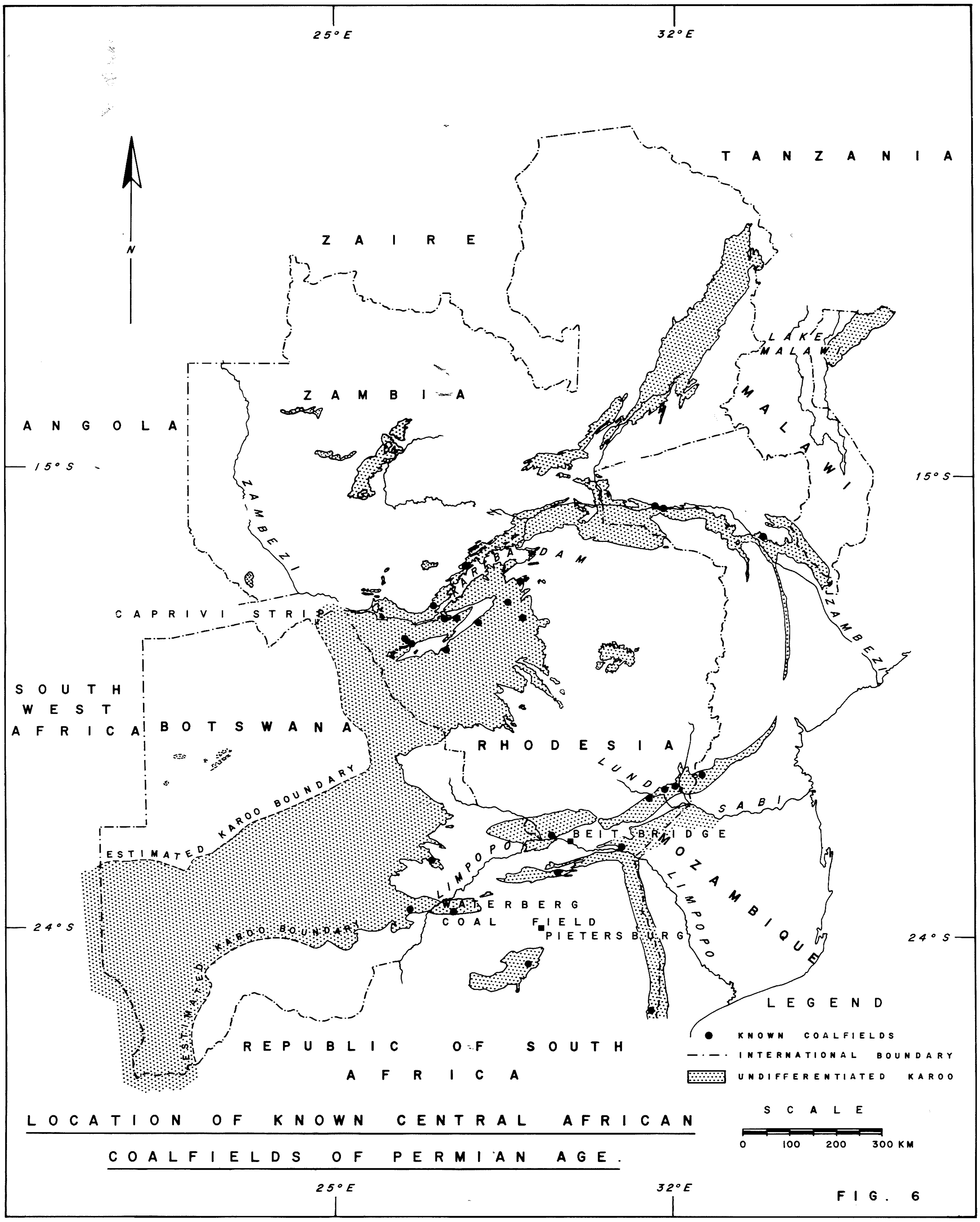
- ΔΔ LOCATION OF HEAVY MINERAL BEACH SAND DEPOSIT
- 1 MUDEN
- 2 CAROLINA
- 3 DELMAS
- 4 BOTHAVILLE / WOLMARANSSTAD

- KNOWN SEDIMENTARY URANIUM OCCURRENCE
- LIMIT OF KAROO STRATA

SCALE

100 0 100 200 400 700 KM

FIG. 5



LOCATION OF KNOWN CENTRAL AFRICAN COALFIELDS OF PERMIAN AGE.

FIG. 6

The known occurrences of uranium mineralization within the Beaufort Group are shown in Figure 5. In many instances, small single occurrences are clustered within a relatively small area and have not been indicated separately. It is realised that the map is far from complete but, owing to the confidentiality of recent exploration data, the localities of many uranium occurrences are not known. However, sufficient information is available to reveal that the majority of known occurrences lie within a broad discontinuous belt around the western portion of the Karoo Trough, where the Lower Beaufort Beds have their most complete development.

In general, the Lower Beaufort Beds of this area display crude features of upward-fining sedimentary cycles consisting typically of restricted intraformational shale or clay-pellet conglomerates at the base of the cycles, followed by medium- to fine-grained cross-bedded and horizontally-bedded sandstones, and finally siltstones and mudstones. In places, however, coarsening-upward cycles can also be recognised which may represent deposition under local swampy or lacustrine conditions. The overall environment of deposition is consistent with the formation and infilling of meandering stream and river channels and the formation of overbank deposits in the lower reaches of a flood plain. Deposition is regarded as having taken place under conditions of fairly rapid subsidence with periodic subaerial exposures.

Uranium mineralization occurs mainly in three related channel-fill deposits. These are :

(i) lenses and pods of fairly massive dark calcareous sandstone;

(ii) laterally more persistent beds of buff-coloured, well-bedded sandstone, often ferruginous; and

(iii) restricted intraformational horizons of clay pellet conglomerate.

All three rock types can occur within a single uranium occurrence, although the persistency and grade of the mineralization is very variable.

The host rocks themselves have been petrographically identified as varieties of immature, fine- to medium-grained sandstone, classified varyingly as feldspathic, lithic, and calcareous graywackes or subgraywackes, usually rich in carbonaceous material. A minor, but significant, constituent of some of the uraniferous sandstones are minute rounded rock fragments (usually < 0,2 mm in diameter) displaying felsitic or trachytic textures. These tuffaceous fragments probably reflect contemporaneous Permian volcanism which existed in the southern extension of Gondwana (Martini, 1974). Such volcanism has important implications when the origin of the Karoo uranium mineralization is discussed.

Both primary and secondary uranium mineralization has been recognised. The secondary mineralization, which is generally much more conspicuous in the lighter, well-bedded sandstone, occurs primarily as hydrated uranyl arsenates and phosphates, while primary uranium mineralization is found in the more calcareous sandstone as discrete grains of uraninite and coffinite (or their *in situ* alteration products), and also amorphous material associated with specks of cellular organic matter (Oosthuyzen, 1975).

At present no clear picture exists regarding the major factors controlling the deposition of the uranium. However, the presence of abundant plant material in the sandstones appears critical. Soluable uranium complexes were most likely precipitated under suitable Eh and pH conditions by the abundant carbonaceous and sulphidic material formed from the decaying organic material; uranium could also have been adsorped onto clay minerals (Turner, 1975). Sandstone diagenesis, resulting from compaction and deeper burial, eventually fixed the uranium in the form of discrete grains of uraninite and coffinite. Evidence clearly indicates that the primary uranium occurrences were formed both before the folding of the southern Karoo rocks, and also before the intrusion of the Jurassic Karoo dolerites. Redistribution of the mineralisation has taken place in much more recent times, primarily along fractures, joints, and bedding planes.

Two main possibilities exist regarding the origin of the uranium mineralisation. Firstly, it has been shown that the source of the Lowermost Beaufort Beds in the Karoo Trough was from the predominantly granitic Southern and Western provenance areas. These would have provided an adequate source from which the present uranium mineralization could have been derived. Secondly, contemporaneous Permian volcanism, thought to have been centred in the Southern source area, is the probable origin of the fine-grained tuff and volcanic debris found in the sediments of the southern Karoo. It is also possible, therefore, that the uranium was derived from the leaching of this material, both by weathering processes and during diagenesis.

Considering the regional distribution of the Permian uranium occurrences it is apparent that, as far as is presently known, they are primarily confined to the Southern and Western Facies of the Lower Beaufort, occurring within the tectonic confines of the Karoo Trough. The influence of basinal development and the provision of suitable provenance areas on the formation of these uranium occurrences is therefore well-illustrated. To date, none of the occurrences are being exploited although exploration interest is considerable.

VII. HEAVY MINERAL BEACH SANDS

Consolidated beach deposits, rich in heavy minerals, have been found in the Middle Ecca Group of the Northern Facies (Figure 5). Although at present they do not constitute viable orebodies these occurrences have, in the past, been prospected primarily for their nuclear raw materials and titanium content. They occur in the Bothaville area of the Orange Free State, the Wolmaransstad, Delmas, and Carolina, areas of the Transvaal (Behr, 1965) and, during the course of recent exploration, similar deposits have been found in the Muden area of Natal.

The Bothaville-Wolmaransstad deposits have been studied in greatest detail and occur within sandstones correlated with the lower portion of the Middle Ecca. Behr (1965) records that in this area the Middle Ecca rests directly on the Upper Dwyka (perhaps Lower Ecca) or, in its absence, on Dwyka Tillite or pre-Karoo rocks, and consists of sandstone, grit, shale (carbonaceous in part) and locally, coal. The heavy-mineral deposits of the Muden area are also located within the Middle Ecca sandstones, which are believed to represent mainly deltaic deposits (Hobday, 1973). The deposits of the Delmas and Carolina areas probably occupy a similar stratigraphic position.

The Bothaville-Wolmaransstad deposits are extremely rich in ilmenite, or its alteration products (mainly anatase, leucoxene, and goethite). Garnet, zircon, rutile and monazite are prominent in the heavy mineral suite. Preliminary work on the Muden deposits revealed a similar high ilmenite content, with abundant zircon and garnet, and a minor, yet significant, amount of monazite. The deposits of the Delmas and Carolina areas are also of a similar overall composition, but are noticeably devoid of monazite, while the Delmas deposit is particularly rich in garnet.

Behr (1965) has concluded that the deposits he studied were formed by littoral processes on a regressive shore-line and with fairly strong palaeotopographic control dominated by post-glacial valleys. Hobday (1973), in describing the Middle Ecca deltaic deposits from the Muden area, did not record evidence of the significant reworking of the outer delta margins by shoreline processes. However, the presence of the recently found heavy mineral deposits in this area now points to a significant process of shoreline reworking, although perhaps on a fairly local scale.

Seen in their regional context it is obvious that these heavy mineral deposits occur only within the predominantly fluvio-deltaic Middle Ecca Group of the Northern Facies. It is concluded that shoreline processes, such as the reworking of delta-front sands, were in operation at certain times during Middle Ecca deposition leading to the local formation of the heavy mineral beach deposits, probably during temporary periods of marine regression. As with the formation of the Ecca coal deposits these scattered, reworked, heavy mineral occurrences reflect overall palaeotectonic conditions consistent with deposition on a slowly subsiding stable platform. Once again, the palaeotectonic, palaeoenvironmental and palaeogeographic influence on the formation of ore deposits in this sedimentary basin is demonstrated.

* *

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