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**Falcon, Rosemary S**

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# PALYNO-STRATIGRAPHY OF THE LOWER KARROO SEQUENCE IN THE CENTRAL SEBUNGWE DISTRICT, MID-ZAMBEZI BASIN, RHODESIA

by

**Rosemary M. S. Falcon**


## ABSTRACT

Hart (1962) was the first to discuss seriously the subject "palynology—key to stratigraphy" with regard to Southern Africa. Since then a number of publications have appeared on African Karroo palynology. However, to date only one large scale microfloral zonation scheme has been proposed—that of Hart (1967). In this, four major palynofloristic zones were outlined for Lower Karroo (Permian) sequences, drawn from surface and sub-surface material in South and Central Africa. Another scheme, dividing the Permian into eight zones in S. Africa (Great Karroo Basin) is as yet unpublished (Anderson, in press).

In an attempt to apply palynology to the problems of geological correlation and relative age determinations, specifically in the field of coal exploration in Rhodesia, a standard section in the form of one borehole, the Matabola Flats borehole, well-sited, deep and with apparently continuous deposition was chosen for palynological biostratigraphic analysis. Fifty-five miospore genera and ninety-eight species have been recognised in this study. Their systematic descriptions and statistical analyses are published elsewhere. Falcon 1975 a, b. Detailed analysis of the forty-eight productive samples show large scale micro-floral changes up the stratigraphic column. Four major assemblage zones and eight assemblage sub-zones are herein proposed, thereby expanding by four the palynofloristic zones of Hart.


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## INTRODUCTION

Palynological research in Rhodesia was initially embarked upon by the author in 1969, on one borehole core situated in the Mid-Zambezi Basin, Rhodesia. This basin is one of a number of isolated troughs in Central and Southern Africa bearing thick Lower Karroo (Lower Gondwana) deposits of Permo-Carboniferous age. Due to mining exploration in search of coal in the Ecca Series of the Lower Karroo sequences, the stratigraphy is well known in certain areas such as the rich coalfields of Wankie. However, due to the widespread and undisturbed nature of these continental deposits, and the paucity of fossils in these thick and monotonous rock units, correlation within the basin and inter-regionally is difficult.

It was therefore considered necessary to seek a palynological basis for sub-dividing and correlating this series of strata. The initial study (Falcon, 1973) showed the miospore content to be of excellent quality and preservation, and broad age correlations were drawn between these sediments and those of other Lower Gondwanaland deposits in Africa, India, Antarctica and Australia.

Having established the potential of palynology in Rhodesia it is now considered necessary to describe in detail the taxonomic content of the borehole core, and to attempt a biostratigraphic sub-division of the sequences using a palynological basis for drawing the zonal boundaries.

Due to the ideal and relatively continuous nature of this core and its changing microfloras, it is ten-

tatively proposed (a) that the Matabola Flats borehole be regarded as a type section for Lower Karroo sediments in Rhodesia and (b) that the miospore assemblage zones found within this section be used as a standard reference on which to base future detailed regional correlation for the present.

*Previous Palynological Work*

No previous work has been published from Rhodesia, and those publications concerning Pre-Tertiary palynology from Zaire, Tanzania, Malagasy, Zambia, South West Africa and South Africa have been reviewed by Hart (1967), Falcon (1972, 1973), and Anderson (in prep.). Suffice it to say that of major stratigraphic importance only the four broad palynofloristic zones of Hart (1966, 1967, 1969, 1970) exist at present for Southern-Central Africa and these lack precise definition and type area. They are adequate to determine broad relative ages of miospore assemblages at regional levels, but are too generalised for local stratigraphic delineation.

Farther afield in Gondwana countries Goubin (1965) in Malagasy compiled a detailed stratigraphic scheme dividing the Middle and Upper Karroo sequences into four palynological zones. In Australia three zonal schemes exist to date — an original tripartite scheme of Balme (1964), further sub-divided into five units by Segroves (1969, 1970a,

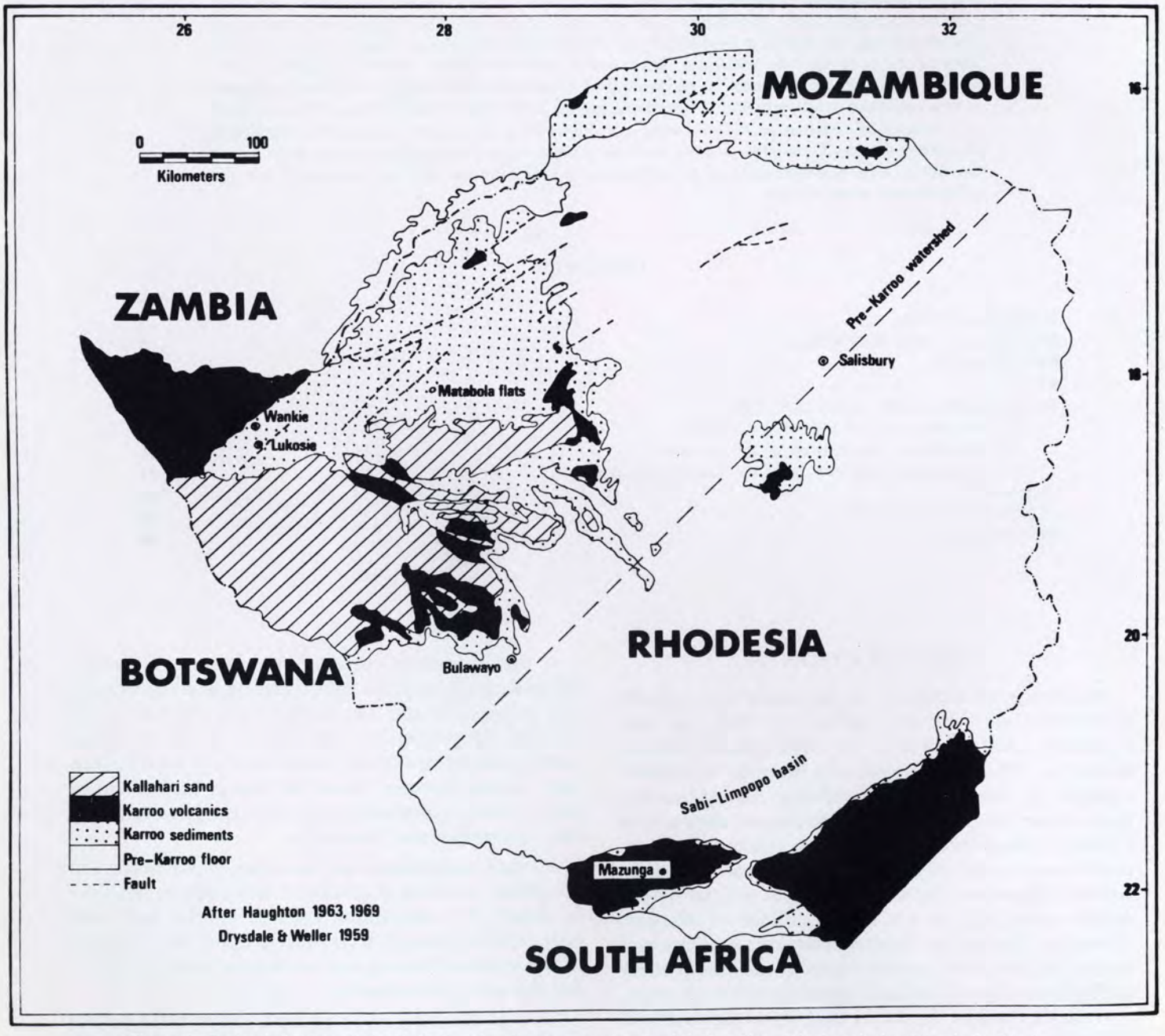



Figure 1. Geological Map of Rhodesia showing Karroo outcrops and the locality of the borehole. (Matabola Flats).

b) in the Perth Basin, Western Australia, and that of Evans (1967) in Eastern Australia. The last is extended into an *older* assemblage by Helby (1969). In India, only a very broad assemblage, related in general terms to Gondwana macrofloras, has been published (Bharadwaj, 1970).

In the Northern Hemisphere in Permo-Carboniferous times the micro- and macrofloras differ widely over the major floral provinces (as reviewed by Chaloner and Lacey, 1973) and large scale botanical and regional correlation by zonation is difficult. However, chronostratigraphic correlation is possible due to widespread marine intercalations. In contrast, in the Southern Hemisphere the macro- and microfloral Gondwanaland assemblages appear to be broadly similar but no widespread correlateable horizons exist in the dominantly continental deposits to confirm their relationships in time.

The palynological zonations so far offered in Gondwanaland may be regarded as generalisations in regional areas, as no true type-sections have been figured. These zonations serve to illustrate the common widespread microfloral changes occurring during these times, which in turn contribute to the evidence of the original composite landmass. However, due to the vast geographical extent of this supercontinent and the consequent variations of palaeolatitude, palaeoclimates and palaeoenvironments, close comparison of these microfloral zones at any one point in time would obviously show some degree of variation. In order to build up a more detailed understanding of the parent floras and their climates and environments during this long period of time finer analysis of regional areas is necessary. It is for this reason that the Matabola Flats assemblage zones are proposed as standard references for a future detailed analysis of the floral changes in Rhodesian and other Central African Basins.

## MATERIALS AND METHODS

The material initially selected for palynological study was from a borehole drilled in 1963 in the course of water exploration. This is sited in the centre of the Matabola Flats in the Central Sebungwe District of the Mid-Zambezi Valley (co-ordinates 18° 13′ S; 27°45′ E; 1960 edition of the 1/1 000 000 geological map of Rhodesia). (See Figure 1.)

The selection of this borehole core hinges on three main factors:

(a) the position relative to the Mid-Zambezi trough is virtually central;

(b) the lithological successions throughout the core are apparently conformable, thereby presenting a continuous sequence of Lower Gondwana (Karroo) sediments. In particular the core passes through an unusually thick succession of Dwyka, the thickest yet published in Rhodesia.

(c) the absence of intrusions in the vicinity of this core probably accounts for the excellent preservation of the miospores in productive horizons.

Bond and Stocklmayer (1967) describe in detail the lithology of the Dwyka Series, and record the younger Lower Karroo sediments found within the 0′—1 206′ limits of the core. The lithological units are those based on Bond's work in the Central and Eastern parts of the Mid-Zambezi region (Bond, 1952, 1967).

In the region of the Matabola Flats borehole, no economic coal seams are encountered. The sequences consist of conformable tillites, conglomerates and varved and non-varved shales at the base, overlain in succession by the Lower Wankie Sandstone (sandstone and conglomerates), Black Shales and Coals (carbonaceous shales and coals), Upper Wankie Sandstone (sandstones and shale) and finally by Madumabisa Mudstones (shales, siltstones, mudstones and limestones).

*Sampling and Preparation*

Of 105 samples collected in the 1 206 ft. of core, 48 samples were productive (See Figure 2.) Samples are labelled by depth in feet. Core samples are housed in the Department of Geology, University of Rhodesia, Salisbury, and the slides are to be found at the Bernard Price Institute of Palaeontology, University of the Witwatersrand, Johannesburg.

Sampling and preparation techniques are fully discussed in Falcon (1973). The extraction techniques involved a standardised sequence of seven stages through which all types of lithologies passed. Slides were made from material taken at intervals during the extraction procedures, i.e. after demineralisation, and after two periods of oxidation (ten minutes and one hour).

Briefly the extraction technique involved crushing two to five grams of sample to pass through a 35 tyler mesh. Carbonate dispersal was conducted by use of 50 per cent hydrochloric acid followed by demineralisation in 40 per cent hydrofluoric acid and removal of the silicofluorite compounds by means of 50 per cent hydrochloric acid. Oxidation was effected by Schultz solution for periods of ten minutes and one hour, and the resultant humic acids were dispersed by means of 10 per cent sodium carbonate. The organic residue was mixed with Cellosize or Clearcol and mounted on glass slides by means of Canada Balsam.

*Microscopy*

A Laborlux D. Leitz Microscope was used for general scanning and statistical counts. Magnification for this purpose was 500X but, in the case of detailed miospore study, it was 1 250X. A Zeiss photographic microscope was made available for limited photographic use.

In scanning the slides for analysis, the entire surfaces of two or more slides per sample (within the

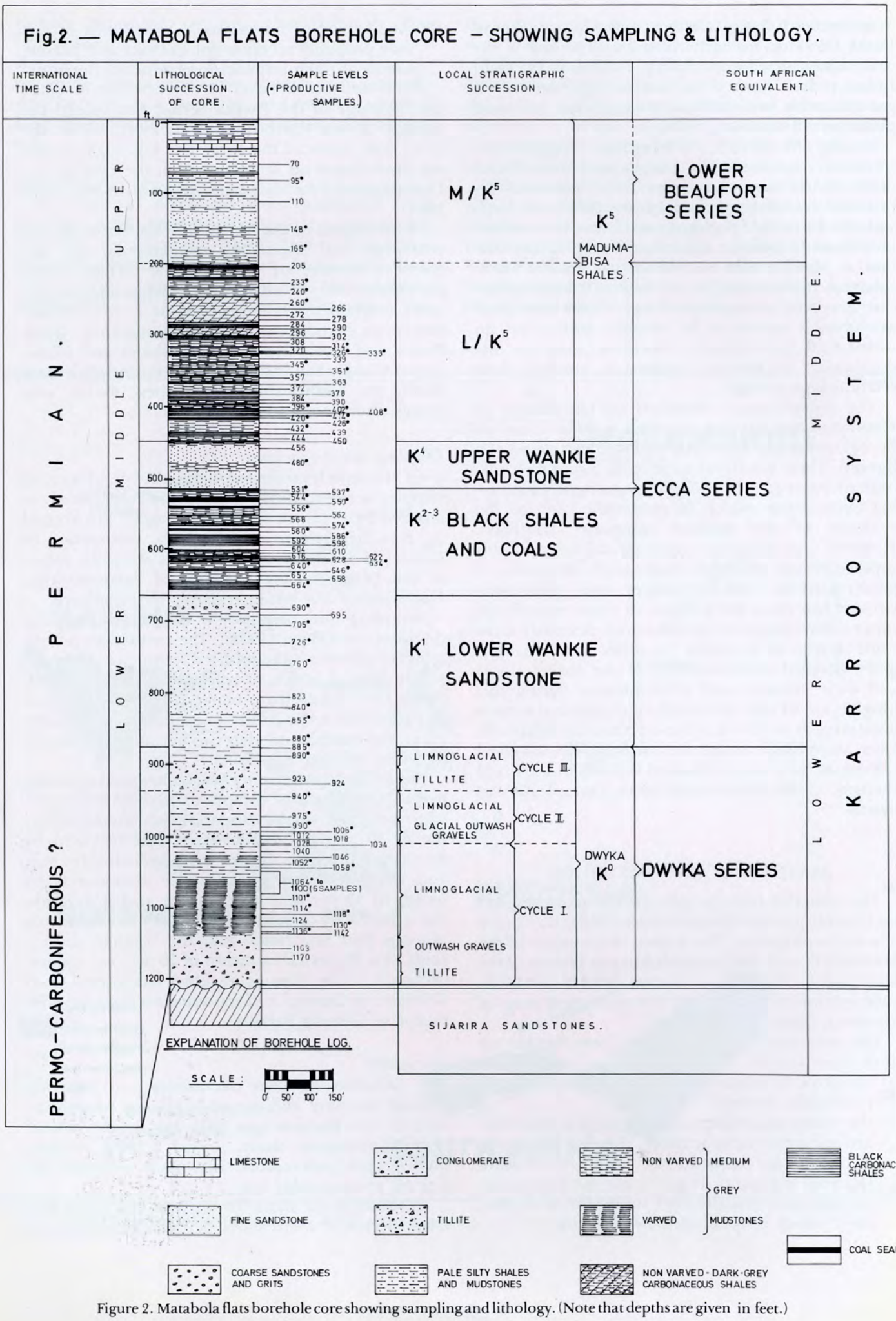



Figure 2. Matabola flats borehole core showing sampling and lithology. (Note that depths are given in feet.)

microspore co-ordinate range) was traversed for genera and species; whilst random traverses were scanned for the overall quantitative count.

*Counting Techniques*

Counting procedures were similar to those employed by Hart (1966), Segroves (1970a, b), and Balme (1970). Visual (as opposed to true statistical) counts of a minimum 250 and maximum 500 miospore specimens were conducted in the quantitative study and 2 000 or more in the qualitative study. Where preparation or preservation was too poor for reliable counts, a visual average was noted, and qualitative analysis pursued. Supra-generic analysis comprised straight percentage counts of the initial 250—500 miospores, whilst relative abundance of species involved absolute counts within the first 250—500, and thereafter, when noted during scanning, were recorded as 1 per cent on a presence/absence basis.

In relative abundance analysis five grades are used; very rare (not present in the 250—500 count but seen in scanning); rare (1 per cent or less): common (1—10 per cent); abundant (10—25 per cent); and dominant (more than 25 per cent).

Where Aletes dominate the assemblages, further percentage counts were taken disregarding the Alete content. Percentage counts thus obtained are seen in cross hatching in Figure 3.

*Analyses*

Analyses are (a) quantitative and (b) qualitative.

*Quantitative analysis.* The purpose of this analysis is to study the distribution throughout the borehole core of (i) the percentage relative abundance of the major supra-generic miospore taxa based on 250—500 miospores; and (ii) the relative abundance of species in each sample using the five grades of abundance as defined above.

*Qualitative analysis:* This represents the study of the generic and specific content of the microfloral assemblages of each sample. The purpose of this analysis is to plot the stratigraphic ranges of each species. These, combined with the relative abundance of each species at every productive level, are illustrated in Figures 4 and 5.

## SYSTEMATICS

*Approach to Systematics*

The systematic problems facing the palynologist in Africa at present have been adequately summarised (Utting (in press), Anderson (in prep.), and Falcon 1972, 1973). These problems involve the several schools of systematic thought already introduced into pre-Tertiary African palynology. These broadly defined are—the European School (Bose, Kar, Maheshwari, Gosh, Sen, with Hoeg and Pierart in collaboration); and the South African School (Hart (subsequently), Anderson (with an Australian background)).

The basic taxonomic schemes range from morphological to phylogenetic philosophies, whilst the different species concepts involve the use of morphological, chronological, phylogenetic or preservational criteria. Frequently ill-defined taxonomic forms have been published often with inadequate illustrations.

The systematic approach adopted in this study has been, of necessity, a practical morphological one, and one major taxonomic system has been followed, that of Hart (1964a, b; 1965b, c, d; 1966a, b; 1969a, b, c). In order to supplement this system in which very few photographs appear and in which there is inadequate coverage of some major taxa, six other important authors of taxonomic works were consulted—those of Jansonius (1962), Bharadwaj (1962), Balme and Hennelly (1955, 1956a, b), Balme (1970), Segroves (1967, 1969) and Goubin (1965). Other relevant papers were consulted for lists of synonymies, e.g. the publications issued on the Congo miospores.

The supra-generic system of classification is basically that compiled by Hart (1965b) based on the original classification of R. Potonié (1956, 1958), and the information collated by the International Commission for the Microflora of the Palaeozoic. The names attributed to the miospores are primarily based on previously described African material, but do include forms referred to in the major sources of reference. The layout and proposed names of the genera and species are such that they may be relatively easily combined to fit any future improved classification system.

*Terminology*

The terminology employed is based on the suggested terms from the I.C.M.P. and modified by Hart (1965b). Other terms employed are followed by their author in parentheses.

**List of Taxa**

*Triletes*

*Punctatisporites gretensis* Balme and Hennelly, 1956b.
*P. gretensis* forma *minor* Hart, 1965c.
*Deltoidospora directa* (Balme and Hennelly, 1956) Hart, 1965c.
*D. lukugaensis* Kar and Bose, 1967.
*Calamospora plicata* (Luber and Valtz, 1941) Hart, 1965c.
*Retusotriletes diversiformis* Balme and Hennelly, 1956b.
*Apiculatisporis levis* Balme and Hennelly, 1956b.
*A. filiformis* Balme and Hennelly, 1956b.
*A. cornutus* Balme and Hennelly, 1956b.
*A. minutus* sp. nov.
*Granulatisporites tentula* (Tiwari, 1965) nov. comb.
*Lophotriletes* sp. cf. *L. rarus* Bharadwaj and Salujha.

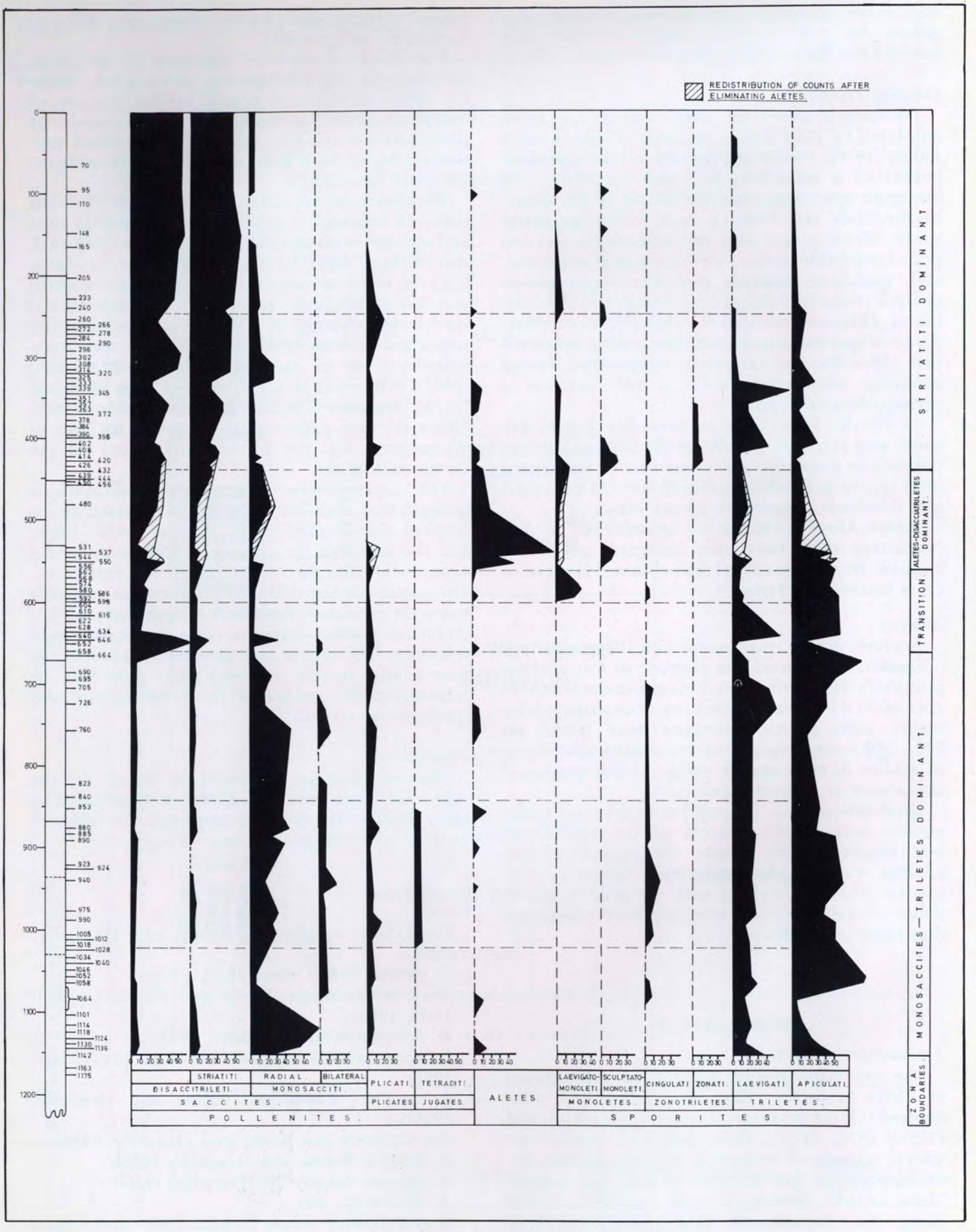



Figure 3. Quantitative Analysis of the Supra-Generic Taxa.

*Microbactulatispora micronodosus* (Balme and Hennelly, 1956b) nov. comb.
*A. tereteangulatus* Balme and Hennelly, 1956b
*Acanthotriletes tereteangulatus* Balme and Hennelly, 1956b. forma *minor* nov. comb.
*Reinschospora* sp.
*Neoraistrickia ramosa* (Balme and Hennelly, 1956) Hart, 1960.
*N.* sp. cf. *N. congoensis* Kar and Bose, 1967.
*Reticulatisporites compactus* (Luber and Valtz, 1941) Hart, 1965c.
*Baculatisporites bharadwaj* Hart, 1965c.
*Verrucosisporites parmatus* Balme and Hennelly, 1956b.
*V. naumovai* Hart, 1963.
*V.* sp. cf. *V. pseudoreticulatus* Balme and Hennelly, 1956b.
*V. pseudotrisectus* sp. nov.
*V. bondii* sp. nov.
*Cirratriradites africanensis* Hart, 1963.
*Zinjispora bullata* (Balme and Hennelly, 1956) Hart, 1965c.
*Z. zonalis* Hart, 1975c.
*Densoporites rotundus* sp. nov.
*Denscsporites rotundus* sp. nov.
*Gondispora vrystaatensis* Hart, 1965c.
*G. novus* sp. nov.

*Monoletes*
*Laevigatosporites colliensis* (Balme and Hennelly, 1956) Bharadwaj, 1962.
*L. perpendiculus* sp. nov.
*Punctatosporites granulatus* Imgrund, 1960.
*Spinosporites spinosus* sp. nov.
*Thymospora thiesseni* (Kosanke, 1943) Wilson and Venkatachala, 1963.
*T. pseudothiesseni* (Kosanke, 1950) Wilson and Venkatachala, 1963.

*Jugates*
*Quadrisporites horridus* Hennelly, 1958.

*Aletes*
*Pilaspora calculus* Balme and Hennelly, 1956a.
*Circulisporites magnus* sp. nov.
*Granulatasporites* sp.
*Verrucosphaera colliensis* Glickson, em.
*Tetraporina* sp.

*Plicates*
*Marsupipollenites triradiatus* Balme and Hennelly, 1956a.
*M. striatus* Balme and Hennelly, 1956a.
*M.* sp.
*Cycadopites cymbatus* Balme and Hennelly, 1956a.
*C. nevesi* (Hart, 1964) Hart, 1965c.

*Monosaccates*
*Plicatipollenites indicus* Lele, 1954.
*Virkkipollenites obscurus* Lele, 1964.
*V. radiatus* (Hennelly, 1958) Lele, 1964.
*V. mehtae* Lele, 1964.
*V. densus* Lele, 1964.
*Parasaccites diffusus* (Tiwari) Bose and Maheshwari, 1968.
*Elilasaccites elilaensis* Bose and Kar, 1966.
*Florinites eremus* Balme and Hennelly, 1956.
*Densipollenites indicus* Bharadwaj and Salujha, 1964.
*Striomonosaccites* sp.
*Potonieisporites novicus* Bharadwaj, 1962.
*P. hennellyi* (Hart, 1960) nov. comb.
*P. thomasi* (Pant, 1955) nov. comb.
*Vestigisporites* sp.
*Caheniasaccites ovatus* Bose and Kar, 1966.

*Disaccates* (Striatiti)
*Protohaploxypinus globus* (Hart, 1960) Hart, 1964b.
*P. diagonalis* Balme, 1966.
*P. micros* Hart, 1964b.
*P. amplus* (Balme and Hennelly) Hart em. Balme, 1970.
*P. goraiensis* R. Potonie and Lele, 1961.
*P. limpidus* (Balme and Hennelly, 1956) Segroves, 1969.
*P. sulcatus* sp. nov.
*P. acutus* sp. nov.
*Striatopodocarpites octostriatus* (Hart, 1960) em.
*S. rarus* (Bharadwaj and Salujha) Balme, 1970.
*S. communis* (Wilson, 1962) Hart, 1964b.
*S. cancellatus* (Balme and Hennelly, 1955) Hart, 1964b.
*Taeniaesporites noviaulensis* Leschik, 1956.
*Striatoabietites multistriatus* (Balme and Hennelly, 1955) Hart, 1964b.
*Lueckisporites nyakapendensis* (Hart, 1960) Hart, 1969b.
*Guttulapollenites hannonicus* Goubin, 1965.
*Hemiapollenites karrooensis* Hart, 1964b.
*H.* sp.
*Vittatina africana* Hart, 1966b.
*V. minima* Jansonius, 1962.

*(Non-Striate)*
*Platysaccus radialis* Leschik, Hart, 1965c nov. comb.

*P. leschiki* (Hart, 1960) Hart, 1965c.
*Alisporites plicatus* Jizba, 1962.
*A. gracilis* Segroves, 1969.
*A. tenuicorpus* Balme, 1970.
*Sulcatisporites ovatus* Balme and Hennelly, 1955.
*S. splendens* Leschik, 1956.
*S. potoniei* (Lakhanpal, Sah and Dube) Hart, 1965c.
*Vesicaspora* sp. A.
*V.* sp. B.
*Jugasporites* sp.
*Illinites unicus* Kosanke, 1950.
*Limitisporites monstruosus* (Luber and Valtz) Hart, 1965c.

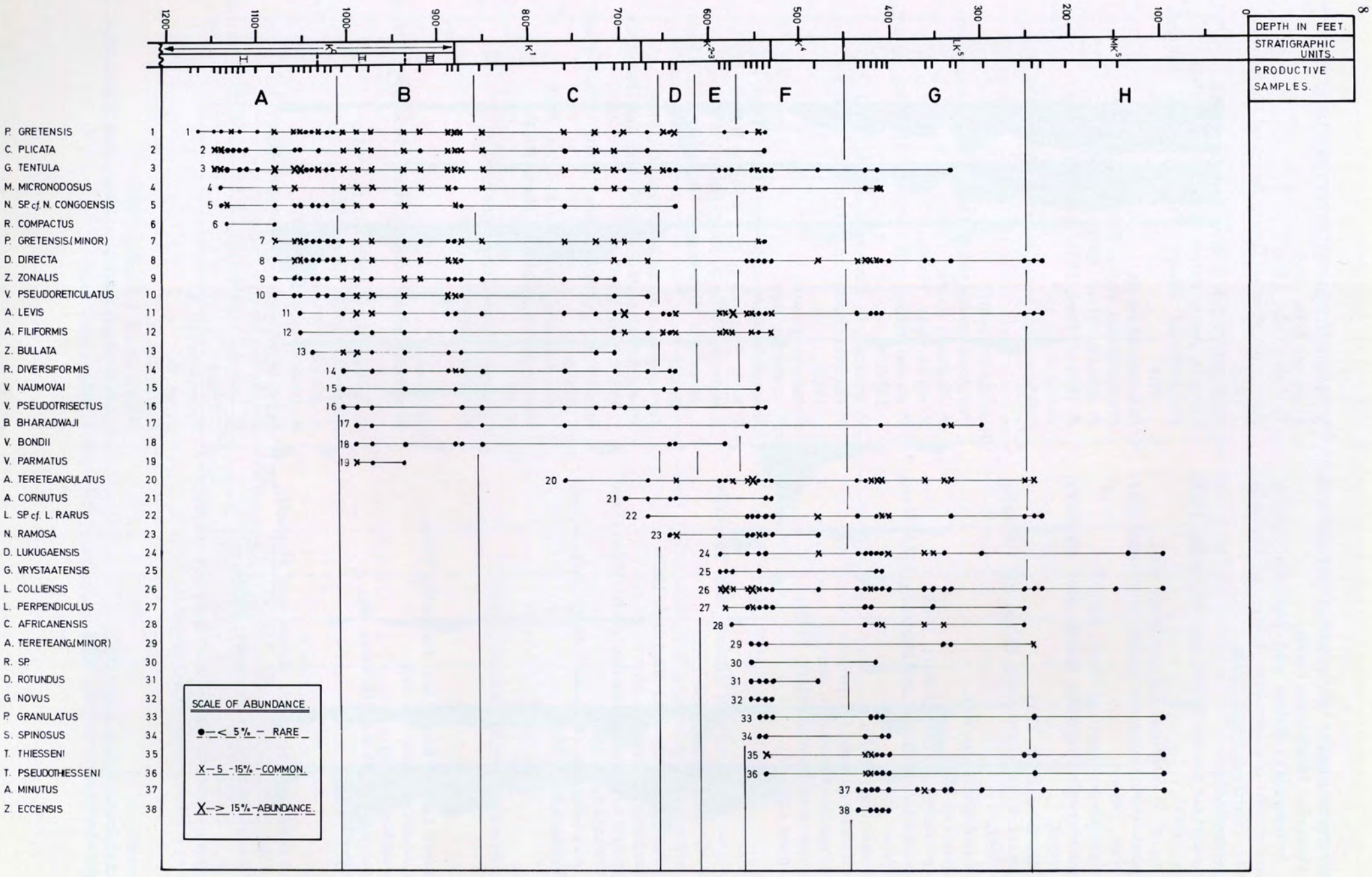



Figure 4. Qualitative Analysis and Range Chart for Sporites.

## RESULTS

The microfloral content of the Matabola Flats borehole core is summarised and illustrated in Figures 3, 4, 5 and 6.

*Quantitative Analysis*

The quantitative variations of the supra-generic categories of miospores are shown in Figure 3. The major trends are easily definable and, beginning in the oldest sediments, may be noted as:

(i) decreasing Monosaccites,
(ii) decreasing Triletes,
(iii) increasing Disaccites, and
(iv) increasing ratio of striate to non-striate pollen in the Disaccites.

Of particular interest is the existence of two major pollen groups, the Monosaccites (dominant in the lower half of the core), and the Disaccites (abundant in the upper half). A transitional zone may be noted midway, i.e. above sample 664′ in which Disaccites (striate and non-striate) consistently represent more than 10 per cent of the assemblage, whilst Monosaccites equally consistently represent less than 20 per cent. From sample 556′ upwards, non-striate forms of the Disaccites always total more than 20 per cent and striate forms more than 10 per cent (excluding the Alete counts), making a combined Disaccate total of greater than 30 per cent of the entire assemblages. Above 260′, striate and non-striate forms equal each other in proportion, and total more than 60 per cent, whilst the Monosaccates drop to below 10 per cent.

Boundaries based on this quantitative data may therefore be placed above 664′ and 556′ and arbitrarily above 260′.

The Triletes show a marked decrease in abundance up the stratigraphic column, but this group is regarded as unreliable zonal indicators. This is due to their possible pteridophytic origin and consequent fluctuations in their response to minor climatological and ecological factors. Also of little zonal value due to local influence is the abundance of Aletes at specific horizons. These forms exist at varying times over the region of sedimentation, depending on the necessary conditions for their existence (salinity or other mineral content of the water). The peak abundance of this group between samples 556′ and 408′ is particularly noteworthy, but only on a local regional basis.

Of further stratigraphic interest is the occurrence of a rare form of Jugates between samples 1 006′ and 853′, and bilateral Monosaccates between 1 006′ and 586′. The sudden appearance of Laevigatomonoleti at 586′ and Sculptatomonoleti at 556′, and the apparently restricted ranges of Zonati and Cingulati also serve as further diagnostic potential.

In summary, three major zones are indicated, over and above the minor fluctuations of the histograms. (See Figure 6.) In these histograms smooth and more stable results have been obtained by redistribution of associated spore/pollen types (Punctatisporites with Monosaccites) and recalculation of the major taxa excluding certain irrelevant taxa (Aletes).

(i) *samples 1 142′ to 664′:* Monosaccite and Trilete dominated assemblages. This may be further divided into three sub-stages on the basis of restricted ranges and peak abundance of Cingulati, Jugates, and bilateral Monosaccates.
(ii) *samples 646′ to 580′:* equally low proportions of Disaccates and Monosaccates, with abundant Triletes. This may be divided into three stages by the appearance of Zonati and Laevigatomonoleti.
(iii) *samples 556′ to 0′:* dominant Disaccates over Monosaccates. A further two divisions are possible on the grounds of equal proportions of striate over non-striate Disaccates, and the apparent termination of Zonati.

This method of analysis for vertical sub-division is treated with caution due to obvious factors influencing the proportions of major taxa after dispersal and prior to extraction. However, references to other Gondwana palynological assemblages show closely similar trends, indicating parallel major vegetational change over this period of time.

*Qualitative Analysis*

Figures 4 and 5 represent the range charts of the species encountered in the productive horizons, whilst Figure 8 illustrates the distribution of the genera and their species in the assemblage zones subsequently made. Figure 6 summarises the ranges of selected genera and species, together with the smoothed histograms of supra-generic taxa.

Briefly, on analysis of the range charts, three groups of genera and species may be noted:

(i) those of long range: i.e. apparently present in most productive samples to a greater or lesser degree, e.g. *Apiculatisporis*, *Protohaploxypinus*, and *Sulcatisporites* and species *A. levis*, *P. amplus*, *S. ovatus*, *R. diversiformis* and *P. calculus*. These miospores are termed general and are of little stratigraphic use.
(ii) those of medium range, showing finite points of appearance or disappearance at one end of their stratigraphic range but apparently extending beyond the range of this borehole at the other end, e.g. genera *Punctatisporites*, *Calamospora*, and *Virkkipollenites-Plicatipollenites* (up to $K^{2-3}$); *Marsupipollenites* and *Florinites* ($K^{1}$ onwards); *Striatopodocarpites*, *Laevigatosporites* and *Thymospora* ($K^{2-3}$ onwards) and *Vittatina* and *Hamiapollenites* ($LK^{5}$ onwards).
Examples of species noted for medium ranges, apart from forms attributed to the above genera are *Cycadopites cymbatus* (up to $K^{2-3}$) and *Acanthotriletes tereteangulatus* ($K^{1}$ onwards).
(iii) those of short restricted ranges with apparently finite points of appearance and disappearance,

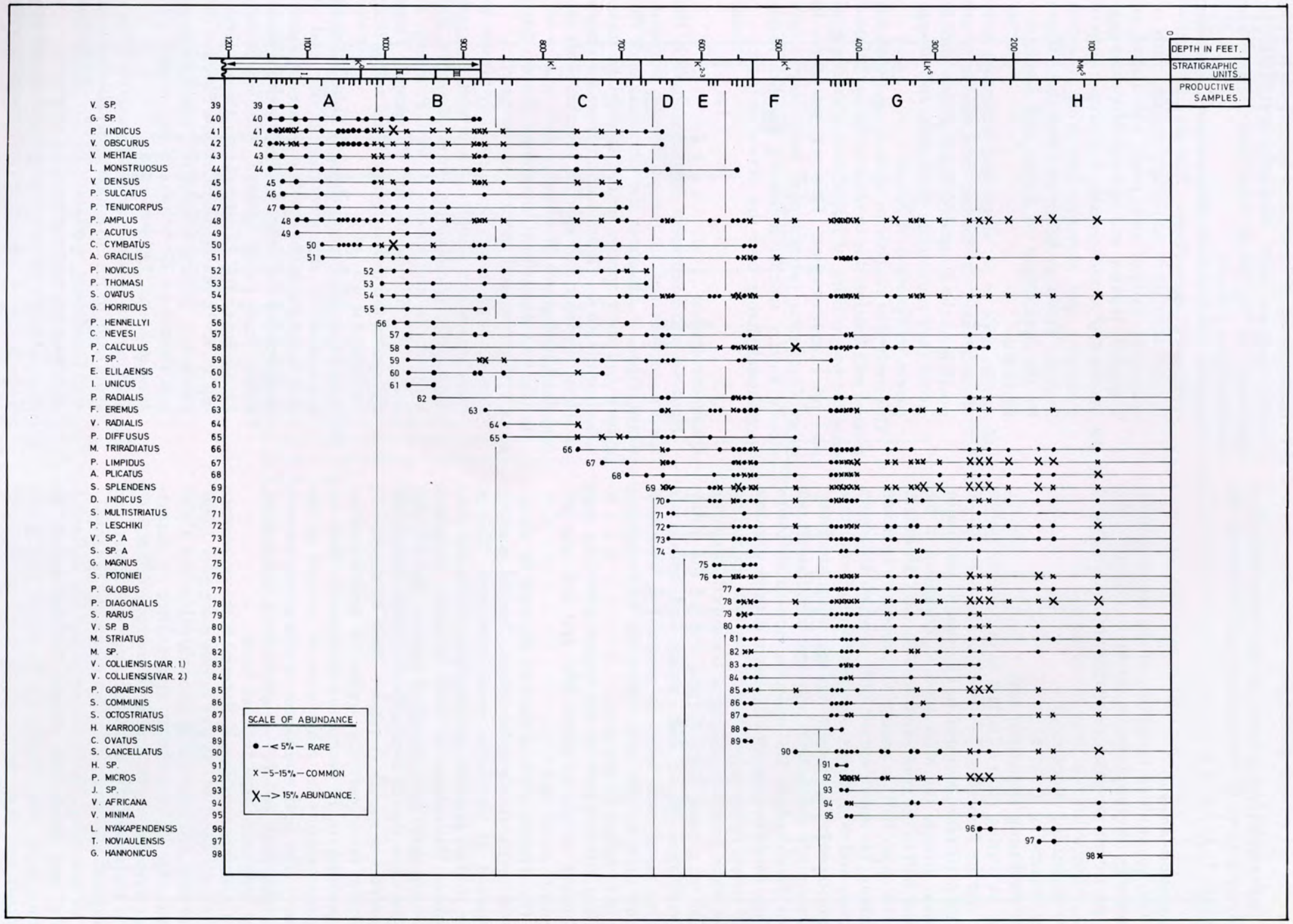



Figure 5. Qualitative Analysis and Range Chart for Pollenites and Aletes.

e.g. genera *Reticulatisporites*, *Quadrisporites*, *Potonieisporites*, *Cirratriradites* and *Guttulapollenites* and *Taeniaesporites*.
Examples of species are *P. acutus*, *V. parmatus*, *N. ramosa*, *C. novus*, *D. rotundus*, *Z. eccensis* and *L. nyakapendensis*.

From studying the proliferation of species and their relative abundance as seen on the range charts and in Figure 8, it becomes obvious that two major assemblages exist, overlapping between 646′ and 531′. Below this an abundance of Apiculate and Laevigate forms of Trilete spores are closely associated with an equal variety of Monosaccate pollen forms, a few early Disaccate striate and non-striate forms and two simple Monocolpate forms. Above the broad transition zone, the Sporites reduce in variation as well as number in favour of an overwhelming diversification in pollen forms, i.e. striate and non-striate Disaccates suffer an explosive evolution and so to a much less degree do Plicates and Aletes.

A further refinement of the study of species diversification may be seen in Figure 9. Here the total number of species counted per sample has been drawn in the form of a histogram in column 3. Data were collected on a presence-absence basis and only on samples bearing more than 200 specimens or more than 15 species. Species were presumed to be continuous (or potentially present) in samples between their oldest and youngest points of appearance. In column 1, account was taken of the number of new species occurring for the first time, and in column 2, the number of species disappearing.

Six distinct levels of increased species diversity are apparent, taking the arbitrary level at five species or more. In each case, several closely spaced samples are combined together to a period of change, during which time a large variety of miospore forms appear or disappear. Two major periods of species diversification occur, at 1 150′ to 1 140′ and 556′ to 544′, and four minor ones at the depths of 1 006′, 649′, 586′ and 432′,

Two significant periods of species disappearance or dying out occur, a major one at 556′ to 531′ reflecting the possible waning of the diverse older flora, evident in lower stratigraphic levels, and a minor one at 260′ to 240′.

## DISCUSSIONS AND CONCLUSIONS

### (a) Interpretations of Microfloral Trends

*Quantitative Analysis*

(a) The predominant trend is the swing from Monosaccate-Trilete dominance to Disaccate dominance. This is attributed to the large scale climatic and evolutionary factors which must have come into play during the long period of Lower Karroo sedimentation (Lacey, 1959, 1961, 1966). Fluctuations caused by local factors have not obliterated these trends to any marked degree.

(b) The high abundance and narrow stratigraphic occurrence of certain major taxa such as the very distinctive Alete group in Assemblage sub-zone F may be indicative of a specialised depositional environment, e.g. marine or brackish water conditions, or specific Eh/pH environment.

(c) Minor peaks and drops in the more or less continuous histograms are attributed to minor climatic fluctuations or changing depositional environments, or a combination of both. For example, in zone I inverse proportions of Monosaccites and Triletes coincide closely with tillitic and periglacial sedimentation. The presence of Striatiti and Cingulati are only noted in interglacial phases. In zone IV fluctuations gradually decrease until above 260′ the Disaccate-Striatiti flora appears to be constant, indicating little change in major conditions.

(d) The introduction of new major taxa may be considered as manifestations of climate amelioration and migration of these elements into the depositional area. Where the introduction is gradual, the possibility of evolution and natural selection of micro- and macrofloras must be considered, such an example being the slow introduction of striate Disaccate pollens. The more or less sudden occurrence of Sculptatomonoleti and Zonati may be considered as migrations from farther afield.

*Qualitative Analysis*

(a) From the range charts and Figure 8, it is possible to see the increase or decrease in diversification of the major evolving taxa, i.e. the Monosaccites and Disaccate Striatiti. In the oldest floral assemblage zone I, there are 12 species of Monosaccites but only three in zone IV, whilst in the Striatiti group, only four species occur in zone I but 18 in zone IV. Considerable evolutionary development assisted by climatic change is therefore interpreted throughout this period.

(b) By graphically illustrating the peaks of diversity and disappearance of miospore species (see Figure 9) further information may be noted regarding the gaps in time or apparent disconformities not hitherto realised in the stratigraphic sequence. Factors causing large scale qualitative rather than quantitative changes may be varied and interactive, and in particular are closely linked to the depositional history of the sediments. It is beyond the scope of the present paper to discuss at length the tectonic and

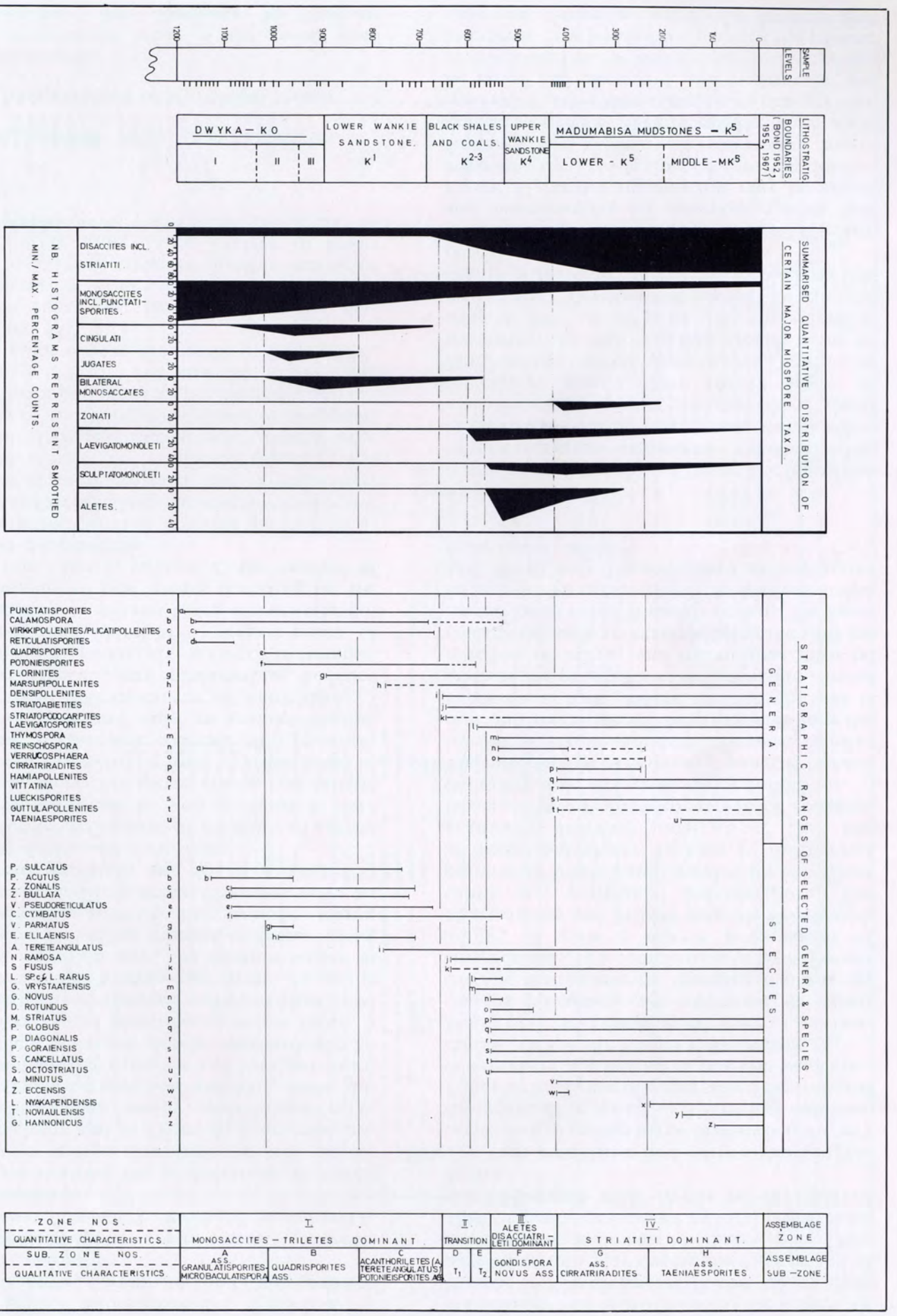



Figure 6. Summary of Significant Quantitative and Qualitative Data with Sub-division of the Borehole Core.

| Litho-stratigraphic Units (Bond *et al.*) | | Core samples | Bio-stratigraphic Units | Assemblage Characteristics | |
|---|---|---|---|---|---|
| | | | | Assemblage Zones | Assemblage Sub-Zones |
| Madumabisa Mudstones | M | | H | *Ass. Zone IV:*<br>**Vittatina-Lueckisporites Ass.**<br>*Notable Genera:*<br>Protophloxypinus<br>Striatopodocarpites<br>Vittatina<br>Hamiapollenites<br>Lueckisporites<br>Platysaccus<br>Sulcatisporites<br>Thymospora<br>Marsupipollenites<br>Rheinschospora | *Ass. Sub-Zone H:*<br>**Taeniaesporites-guttulapollenites Ass.**<br>*Introduction of:*<br>Taeniaesporites<br>Guttulapollenites<br>N.B. Striatiti dominant > 50% |
| | L | | G | *Notable Species:*<br>A. Cornutus<br>A. Minutus<br>*Quantitative Content*<br>Disaccites: 4C—75%<br>Striatiti: 25—60%<br>Monosacciti: < 5%<br>Triletes: 0—20%<br>Aletes: 0—15% | *Ass. Sub-Zone G:*<br>**Cirratriradites africanensis Ass.**<br>*Introduction of:* — *Restricted Species:*<br>Cirratriradites — C. africanensis<br>Hamiapollenites — Z. eccensis<br>Vittatina — P. micros<br>Lueckisporites — A. minutus |
| Upper Wankie Sandstone — $K^4$ | | | F | *Ass. Zone III:*<br>**Densosporites-Gondispora Ass.**<br>*Final Disappearance of:* Punctatisporites, Parasaccites, Calamospora; A. levis, A.filliormis, V.naumovai<br>*Restricted Species:* G. Novus, D. Sp.<br>*Introduction of:* Verrucospharera, Circulisporites, Thymospora; Rheinschospora, M.striatus, P.globus | *Ass. Sub-Zone F:*<br>*Quantitative content:*<br>Disacites 20—40%<br>Striatiti: 10—20%<br>Monosacciti: < 5%<br>Triletes: > 40%<br>Aletes: 10—30%<br>*P. Goraiensis*, *P. Diagonalis*, *S. Cancellatus*: S. octostriatus, Vesicaspora sp. A. and B., P. gracilis, etc. |
| Black Shales and coals — $K^{2-3}$ | | | E | *Ass. Zone II:*<br>*Transition Zone*<br>Miospore genera and species characteristic of both adjacent Assemblages. | *Ass. Sub-Zone E: T.II*<br>*Introduction of:*<br>Laevigatosporites spp., Lophotriletes sp. B., G. vrystaatensis, D. lukugaensis, S. potoniei |
| | | | D | *Quantitative content:*<br>Disaccites: 10—20% Monosacciti. < 10%<br>Striatiti: 5—20% Triletes: 40—50% | Ass. Sub-Zone D: T.I.<br>*Introduction of:*<br>Striatopodocarpites spp., Striatoabietities, Platysaccus, Marsupipollenites; Densipollenites, N. ramosa, S. splendens, P. leschiki |
| Lower Wankie Sandstone — $K^1$ | | | C | *Ass. Zone I:*<br>**Virkkipollenites-Plicatipollenites Ass.**<br>*Notable Genera:*<br>Granulatisporites<br>Microbaculispora<br>Punctatisporites<br>Calamospora<br>Zinjispora<br>Cycadopites<br>Protohaploxypinus<br>Apiculatisporis<br>Acanthotriletes<br>Lophotriletes<br>Retusotriletes<br>Potonieisporites | *Ass. Sub-Zone C:*<br>**Acanthotriletes tereteangulatus Ass.**<br>*Introduction of:*<br>Florinites eremus<br>Acanthotriletes tereteangulatus<br>*Notably Abundant:* Monosaccites, especially<br>Virkkipollenites<br>Plicatipollenites<br>Potonieisporites<br>Parasaccites |
| Dwyka — $K^0$ | III | | B | *Notable Species:*<br>S. ovatus<br>A. tenuicorpus<br>Granulatasporites sp. | *Ass. Sub-Zone B:*<br>**Quadrisporites Horridus Ass.**<br>*Introduction of:*<br>Potonieisporites<br>Elilasaccites<br>Verrucosisporites<br>Baculatisporites<br>*Restricted Species:*<br>Quadrisporites horridus |
| | II | | | | |
| | I | | A | *Quantitative Content*<br>Disaccites: 1—5%<br>Striatiti: 0—2%<br>Monosacciti: 10—60%<br>Triletes: 40—70% | *Ass. Sub-Zone A:*<br>**Granulatisporites-Microbaculispora tentula Ass.**<br>*Introduction of:*<br>Granulatisporites sp., Microbaculatispora tentula } Dominant<br>Punctatisporites<br>Calamospora<br>Cycadopites<br>Zinjispora<br>Plicatipollenites-Virkkipollenites<br>Protohaploxypinus<br>P. amplus, P. sp. A., P. sp. B. } Rare |

Figure 7. Proposed Assemblage Zone Characteristics.

depositional history of the basin in which these sediments were deposited. Suffice it to say that, if it may be assumed that the climate and vegetation continued to change relatively constantly (as is inferred from other palaeontological evidence from arctic floras to those supporting *Tapinocephalus* vertebrates in the youngest sediments), then any large scale changes in microfloral diversity or disappearance may possibly represent a gap in time often difficult to interpret otherwise in a borehole sequence.

Diversity periods I and II (with a possible third just above I) coincide with the advent of two periglacial phases, thereby indicating an earlier gap in time consistent with periods of glaciation. In these two cases, the non-fossiliferous deposition of glacigene sediments (occurring whilst the prevailing flora continued to flourish farther afield) followed by climatic amelioration during glacial retreat may well explain the sudden introduction of new floral elements that had evolved or been introduced during the intervening gap in time.

Diversity periods III, IV and V all occur during deposition of Black Shales and Coal. These sediments are predominantly barren of plant cuticles and spores (Watson, 1960, suggests that exposure, oxidation and possibly excessive transport may be the cause of this). The fact that miospores are found at all in these three periods illustrates a change in depositional environment, possibly a cyclic change in base-level or Eh-pH conditions. The introduction of new species at these points does not necessarily mean a sudden influx to the area, but rather a sudden accumulation and fossilisation of a number of species that had already evolved or migrated into the area of deposition since the previous miospore assemblage was deposited. This theory is consistent with the idea of fluctuating base-level during this period of deposition which has been suggested from other geological information (Bond, 1967). The greatest of these three periods of diversity indicating a larger gap in time occurs ten to fifteen feet below the top of the Black Shales and Coal beds, at the base of sub-zone F.

Diversity period VI represents a vegetation now markedly different in quantitative and qualitative character from older floras (cf. Figure 3). It appears after a peak in Alete abundance and after a period of renewed tectonic activity resulting in the deposition of about one hundred feet of sandstones. Whatever the rate of deposition or the gap of time involved, the climate or environment appears to have changed considerably and the evolution of the Disaccate Striatiti seems to have progressed rapidly. Above this point in the borehole the increase in floral diversity appears to be minimal, whereas the dominance of the Disaccate group becomes rapidly apparent.

Disappearances of large numbers of species is obvious during two periods. Period I, in the upper ten to fifteen feet of Black Shales and Coals, coincides with a large period of diversity (V). A combination of fifteen species disappear at this point in time, whilst twenty-one new species occur. This may indicate a longer gap in time since the previous assemblages were deposited, or a rapid change in climate or environment. All these factors may be true as there is a rapid and substantial waning of early cold temperate floras and an introduction to an Alete-rich environment.

In zones I and II miospores appear to have diversified well in interglacial periods with a gradual waning of species proliferation in Lower Wankie Sandstones.

A second period of large scale disappearance occurs between 240′ and 260′, the base of sub-zone H. This coincides with a minor climatic or environmental factor, and during this apparent gap in time the new species already introduced in zone III remain more or less constant, but a number of microfloral elements that were introduced in zones II and III disappear.

### (b) Microfloral Sub-Division of the Borehole

The problems of sub-division of sedimentary rock sequences by means of palynology have been discussed by such authors as Smith and Butterworth (1967) and Hart (1970), and general problems in stratigraphical procedure employing biostratigraphic methods have been enlarged upon by Eicher (1968) and Harland *et al.* (1972).

That broad floral changes occurred during these Lower Karroo times is obvious, when studying the quantitative analysis of the major supra-generic taxa. These major changes, gradual as they are, may be matched with those of Hart (the four florizones) and farther afield in Australia, India, Malagasy and Antarctica (Falcon, 1973). The causes of long term floral changes within the Gondwana sequences are postulated as rapid evolution and development of land plants after the Dwyka glaciation (Plumstead, 1968) and the broad climatic changes which must have occurred between the cold arctic conditions of the Dwyka and the ultimate hot, arid conditions of the Red Beds in the Stormberg Series (Bond , 1967; Lacey, 1967). Correlation is therefore possible on a broad developmental basis.

However, when finer biostratigraphic subdivision is required, an appreciation of local factors causing the minor microfloral fluctuations is necessary. These include, for example, the original amount of miospores produced by the parent plants, the climate and ecological niches affecting parent plants, the type of ultimate depositional environment of the miospores and the lithification and diagenetic process subsequently affecting the strata containing the miospores. These factors may be manifested in the miospore content in the form of fluctuations of relative abundances of different

| Assemblage Sub-Zones | I A | I B | I C | II D | II E | III F | IV G | IV H |
|---|---|---|---|---|---|---|---|---|
| *Punctatisporites gretensis* | + | + | + | + | + | + | | |
| *P. gretensis* forma minor | + | + | + | + | + | + | | |
| *Retusotriletes diversiformis* | | + | + | + | | | | |
| *Calamospora plicata* | + | + | + | + | + | + | | |
| *Deltoidospora directa* | + | + | + | + | + | + | + | |
| *D. lukugaensis* | | | | | + | + | + | + |
| *Apiculatisporis levis* | + | + | + | + | + | + | + | |
| *A. filiformis* | + | + | + | + | + | + | | |
| *A. cornutus* | | | + | + | + | + | | |
| *A. minutus* | | | | | | | + | + |
| *Reticulatisporites bharadwaji* | | + | + | + | + | + | + | |
| *Reticulatisporites compactus* | + | | | | | | | |
| *Granulatisporites tentula* | + | + | + | + | + | + | + | |
| *Microbaculatispora micronodosus* | + | + | + | + | + | + | + | |
| *Verrucosisporites pseudoreticulatus* | + | + | + | | | | | |
| *V. naumovai* | | + | + | + | + | + | | |
| *V. pseudotrisectus* | | + | + | + | + | + | | |
| *V. bondii* | | + | + | + | + | | | |
| *V. parmatus* | | + | | | | | | |
| *Lophotriletes* sp. cf. *L. rarus* | | | + | + | + | + | + | |
| *Neoraistrickia ramosa* | | | | + | + | + | | |
| *N.* sp. cf. *N. congoensis* | + | + | + | + | | | | |
| *Acanthotriletes tereteangulatus* | | | + | + | + | + | + | |
| *A. tereteangulatus* forma minor | | | | | | + | + | |
| *Reinschospora* sp. | | | | | | + | + | |
| *Cirratriradites africanensis* | | | | | | + | + | |
| *Zinjispora bullata* | + | + | + | | | | | |
| *Z. eccensis* | | | | | | | + | |
| *Z. zonalis* | + | + | + | | | | | |
| *Densosporites rotundus* | | | | | | + | | |
| *Gondispora vrystaatensis* | | | | | + | + | + | |
| *G. novus* | | | | | | + | | |
| *Laevigatosporites colliensis* | | | | | + | + | + | + |
| *L. perpendiculus* | | | | | + | + | + | |
| *Punctatosporites granulatus* | | | | | | + | + | + |
| *Spinosporites spinosus* | | | | | | + | + | + |
| *Thymospora thiesseni* | | | | | | + | + | + |
| *T. pseudothiesseni* | | | | | | + | + | + |
| *Pilaspora calculus* | | + | + | + | + | + | + | |
| *Circulisporites magnus* | | | | | + | + | | |
| *Tetraporina* sp. | | + | + | + | + | + | | |
| *Granulatasporites* sp. | + | + | | | | | | |
| *Verrucosphaera colliensis* | | | | | | | | |
| *Var. 1* | | | | | | + | + | |
| *Var. 2* | | | | | | + | + | |
| *Marsupipollenites triradiatus* | | | + | + | + | + | + | + |
| *M. striatus* | | | | | | + | + | + |
| *M.* sp. | | | | | | + | + | + |
| *Cycadopites cymbatus* | + | + | + | + | + | + | | |
| *C. nevesi* | | + | + | + | + | + | + | + |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| *Quadrisporites horridus* | | + | | | | | | |
| *Plicatipollenites indicus* | + | + | + | + | | | | |
| *Virkkipollenites obscurus* | + | + | + | + | | | | |
| *V. radialis* | | | + | | | | | |
| *V. mehtae* | + | + | + | | | | | |
| *V. densus* | + | + | + | | | | | |
| *Parasaccites diffusus* | | | + | + | + | + | | |
| *Elilasaccites elilaensis* | | + | + | | | | | |
| *Florinites eremus* | | | + | + | + | + | + | + |
| *Densipollenites indicus* | | | | | | + | + | + |
| *Striomonosaccites* sp. | | | | | | + | + | + |
| *Potonieisporites novicus* | | + | + | | | | | |
| *P. hennellyi* | | + | + | + | | | | |
| *P. thomasi* | | + | + | | | | | |
| *Vestigisporites* sp. | + | | | | | | | |
| *Caheniasaccites ovatus* | | | | | | | + | |
| *Protohaploxypinus globus* | | | | | | | + | + |
| *P. diagonalis* | | | | | | | + | + |
| *P. micros* | | | | | | | | + |
| *P. amplus* | + | + | + | + | + | + | + | + |
| *P. goraiensis* | | | | | | | + | + |
| *P. limpidus* | | | + | + | + | + | + | + |
| *P. sulcatus* | + | + | + | | | | | |
| *P. acutus* | + | + | | | | | | |
| *Striatopodocarpites cancellatus* | | | | | | | + | + |
| *S. octostriatus* | | | | | | | + | + |
| *S. rarus* | | | | | | | + | + |
| *S. communis* | | | | | | | + | + |
| *Taeniaesporites noviaulensis* | | | | | | | | + |
| *Striatoabietites multistriatus* | | | | | + | + | + | + |
| *Leuckisporites nyakapendensis* | | | | | | | | + |
| *Guttulapollenites hannonicus* | | | | | | | | + |
| *Hamiapollenites* sp. | | | | | | | | + |
| *H. karrooensis* | | | | | | | + | + |
| *Vittatina africana* | | | | | | | | + |
| *V. minima* | | | | | | | | + |
| *Platysaccus radialis* | | + | + | + | + | + | + | + |
| *P. leschiki* | | | | + | + | + | + | + |
| *Alisporites plicatus* | | | + | + | + | + | + | + |
| *A. gracilis* | + | + | + | + | + | + | + | + |
| *A. tenuicorpus* | + | + | + | | | | | |
| *Sulcatisporites ovatus* | | + | + | + | + | + | + | + |
| *S. splendens* | | | | + | + | + | + | + |
| *S. potoniei* | | | | | + | + | + | + |
| *Vesicaspora* sp-a | | | | + | + | + | + | + |
| *Vesicaspora* sp-b | | | | | | | + | + |
| *Jugasporites* sp. | | | | | | | | + |
| *Illinites unicus* | | + | | | | | | |
| *Limitisporites monstruosus* | + | + | + | + | + | + | | |

Figure 8. Qualitative Comparison of Assemblage Sub-Zones.

species, or the sudden dearth of a portion of or all the miospores, or a sudden influx of several new species. These changes occur within the broad gradually changing microfloral trends, and their uses in biozone delineation must be kept in perspective.

In terms of sub-dividing the present borehole core, these minor microfloral changes causing qualitative and quantitative differences in the miospore assemblages are very useful. However, these changes may not be synchronous chronostratigraphically with changes in other parts of the region, or in basins of sedimentation farther afield. Correlation on the basis of artificial changes is therefore somewhat suspect in anything other than restricted locality. It is for this reason that, in addition to the analysis of the minor changes for future local correlation, attention is paid to the qualitative analysis (local range charts) of the miospore assemblages in this borehole core, with particular reference to the development of the highly diagnostic new lineage, the Striate Disaccates. From the introduction of new and rapidly evolving genera and species in this infra-turma, as well as the association of other significant genera and species with them, a series of eight assemblage sub-zones are delineated, which it is hoped will prove more reliable for wider chronostratigraphic use. The ar-

tificial periods of maximum species influxes and disappearance as noted in Figure 9 coincide with the boundaries of six assemblage sub-zones.

Four major assemblage zones have been proposed, characterized by the presence of distinct genera and delineated by quantitative analysis of selected major supra-generic taxa showing in particular the distinctly evolving change from Monosaccate to non-striate and striate Disaccate dominated microfloras.

*Analysis of Assemblage Zones*

By definition (Harland *et al.*, 1972 and Eicher, 1968) a (bio)zone refers to all rocks deposited anywhere during the entire time a species existed. In order to provide the most accurate correlation, zones must be delineated by consistent boundaries and comprise the narrowest time stratigraphic sequence possible. The definition of the boundaries is therefore of prime importance, and must inherently rest on the bottoms and tops of species ranges, the positions of which can only be inferred from the actual distribution in the rocks. It has been proved (Oppel in Eicher, op. cit., p. 109) that greater precision results from overlapping ranges of several species than the range zone of one species alone and it is in this context that the present eight assemblage sub-zones have been defined. Although strictly known as *concurrent-range zones*, the term sub-zones has been retained in this paper to denote a rank subordinate to the four major assemblage zones which in turn may be defined as *acme zones* or epiboles (i.e. peak abundance) of selected major supra-generic taxa. The prefix *assemblage* to zone or sub-zone is adhered to in its original definition by Harland *et al.* (op. cit.) as referring to "a body of strata characterised by a certain assemblage of fossils without regard to their ranges". *Assemblage zones* therefore refer to biostratigraphic units bearing characteristic miospore genera associations and delineated by the acme zones of major taxa, whilst *assemblage sub-zones* are all composed of reliable time-stratigraphic fossils, delineated by the appearances of new species within evolving major miospore taxonomic groups (i.e. new lineages) and characterized by other selected species associations, not all of which need appear together. The sub-zones are named by selected species not always present or confined to that stratigraphic unit. The advantage of this type of concurrent-range sub-zone is that in terms of correlation, the characteristics and delineations can be carried into all depositional environments independent of facies change or thickness. This, however, applies typically to regional (provincial) correlation only, as factors affecting the minor changing microfloral assemblages may not be synchronous in other regions. Where larger changes occur, groups of zones or stages can be correlated between regions.

*Assemblage Zones*

From the peak abundances three major delineations are drawn, based on the arbitrary proportionate percentage levels of Monosaccates, Disaccates (striate and non-striate) and Aletes. The points of appearance, disappearance and periods of abundance of other major taxa (e.g. Jugates, Bilateral Monosaccates, Monoletes and Zonati) represent diagnostic parameters for further subdivision of the borehole core. In terms of chronostratigraphic correlation, the three primary epiboles may prove to be far reaching in Gondwanaland, although the abundance of Aletes is regarded as possibly only a local deep water (algal?) phase. The remaining epiboles would be of diagnostic interest in surrounding regions where the climate and ecology would suit the major parent floras, provided this abundance was recorded everywhere in the strata containing it. It may also be that maximum abundance may be found in some localities and not others, and where found they may not necessarily be entirely synchronous.

Therefore the interpretation of peak abundance of major taxa may be regarded as useful in dividing the stratigraphic sequence, and of great value in local and regional correlation, but only of broad, less chronostratigraphic value in correlation farther afield.

The associated genera within each assemblage are listed in Figure 7.

*Assemblage Sub-Zones*

By definition the ranges of the species as seen in Figures 4, 5 and 6 are termed local range (bio)zones (Harland *et al.*, op. cit.). They represent the total appearance of the individual taxa in this one locality, which in turn may be only a part of each life span, assuming that the ranges may extend into younger or older sediments elsewhere. Therefore in sub-dividing the biostratigraphic units appearances and disappearances of new miospore forms are of relative importance in one locality, but in terms of correlation their appearance and disappearance in other areas may not be contemporaneous due to a number of factors discussed earlier. Range zones may be said to fluctuate with environment in a province and are not therefore true chronostratigraphic units. For detailed local palaeoecological and palaeoclimatological interpretation this may well prove of interest, but in terms of age in a province, total ranges must be obtained from all the local ranges.

Of the length of ranges encountered within the borehole core, those of short restricted duration are particularly diagnostic in the assemblage zones and may prove of interest in correlation if the parent plant possessed a particularly low ecological or climatic tolerance. Such an example may well be *Quadrisporites horridus*, which has been seen equally rarely and at correlateable horizons in the Perth

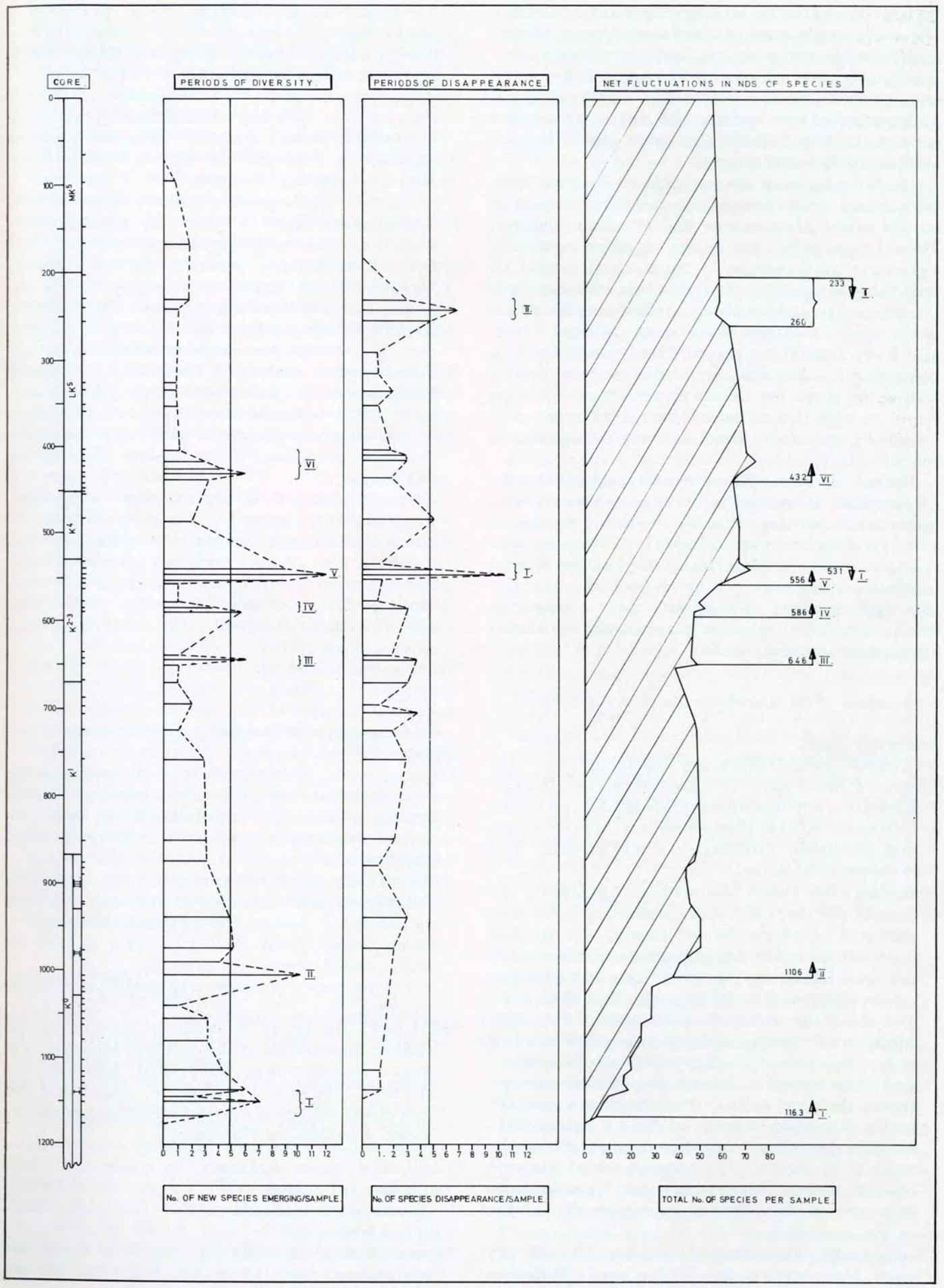



Figure 9. Periods of Apparent Miospore Diversification and Disappearance.

Basin, Western Australia (Segroves, 1970a). However, single lines of fossil evidence are subject to greater error than several lines interpreted collectively, so assemblage sub-zones have been characterized by the combined information of appearances of new species, disappearances of older species and the notably abundant associations of selected species and genera.

The boundaries of the assemblage sub-zones have been drawn at the introduction of major genera and species in the Monosaccate and Disaccate lineages. These major pollen forms are regarded as usually significant components in most samples and of possessing a rapidly evolving and diversifying array of species. The introductions of these new forms are fairly rapid, sometimes showing intermediate forms, all of which may at a future date be included in a phylogenetic classification (Anderson, in prep.). Within the above limitations these introductions are therefore regarded as natural events (as opposed to artificial ones) at which to place the boundaries in this locality.

The sub-division of the assemblages, based on the six horizons of miospore diversity and two of disappearance, although feasible obviously represents some ecological, climatological or depositional changes. However, these factors may only be of local importance. It remains to be seen whether correlation farther afield also reflects these changes in which case the cause of the changes may be termed chronostratigraphic events.

*Summary of the Assemblage Zones and Sub-Zones*

*Assemblage Zone I:*
*Virkkipollenites-Plicatipollenites* Assemblage.

Limits: 1 163′—664′, i.e. Dwyka, Lower Wankie Sandstone and lowermost Black Shales and Coals. Sediments include glacigenes, inter-glacial varves and siltstones, sandstones, conglomerates and carbonaceous shales.

Boundary: the lower boundary is marked by the base of the core; the upper boundary is taken at the level at which the prominent Monosaccate group drops in average abundance to less than 10 per cent, whilst the previously rare Disaccites increase to more than 10 per cent. This level, 646′, also shows the virtual disappearance of the major Monosaccate genera and species so prolific below (e.g. *Virkkipollenites*, *Plicatipollenites*, *Elilasaccites*, and *Caheniasaccites*). Within the Striatiti lineage, two of the three early *Protohaploxypinus* species (*P. acutus, P. sulcatus*) appear to die out before 664′, and a new species (*P. limpidus*) appears within sub-zone C of Zone I. The appearance of the new Striatiti genera *Striatoabietites* and *Striatopodocarpites* (rare) is also taken to strengthen the validity of the boundary.

Characteristic assemblages: Triletes 10—80 per cent; Monosaccites 10—70 per cent; Disaccites 0—5 per cent (Striatiti 0—2 per cent); Monocolpate Plicates 0—10 per cent; Jugates 0—4 per cent; Aletes 0—10 per cent; Monoletes 0 per cent; Cingulate Zonales 0—10 per cent.

*Abundant species: Punctatisporites gretensis, Calamospora plicata, Deltoidospora directa, Granulatisporites tentula, Microbaculispora micronodosus, Plicatipollenites indicus, Virkkipollenites obscurus, V. mehtae, V. densus.*

*Associated species: Retusotriletes diversiformis, Apiculatisporis levis, A. filiformis, Baculatisporites bharadwaji, Verrucosisporites pseudoreticulatus, V. parmatus, V. naumovai, V. pseudotrisectus* and *V. bondii, Neoraistrickia* cf. *congoensis, Zinjispora bullata, Z. zonalis, Cycadopites cymbatus, C. nevesi, Quadrisporites horridus, Tetraporina* sp., *Pilaspora calculus, Parasaccites* sp., *Elilasaccites elilaensis, Florinites eremus, Potonieisporites novicus, P. hennellyi, P. thomasi, Vestigisporites* sp., *Caheniasaccites* sp. *Protopaploxypinus amplus, P. salcatus, P. acutus, Platysaccus radialis, Alisporites plicatus, A. gracilis, A. tenuicorpus, Sulcatisporites ovatus, Illinites unicus, Limitisporites monstruosus.*

*Restricted species: Reticulatisporites compactus, Verrucosisporites parmatus, Zinjispora bullata, Z. zonalis, Quadrisporites horridus, Granulatasporites* sp., *Virkkipollenites radialis, V. mehtae, V. densus, Elilasaccites elilaensis, Potonieisporites novicus, P. thomasi, Vestigisporites* sp., *Caheniasaccites* sp., *Protohaploxypinus sulcatus, P. acutus, Alisporites tenuicorpus, Illinites unicus.*

Three sub-divisions are made:

*Assemblage Sub-Zone A:*
*Granulatisporites-Microbaculispora* Assemblage.

Limit: 1 163′ — 1 030′,

Characteristics: This sub-zone is characterized by two dominant groups, the apiculate Trilete genera *Granulatisporites-Microbaculispora* and the radial Monosaccate forms *Virkkipollenites-Plicatipollenites.*

*Associated species: Punctatisporites gretensis, Calamospora plicata, Cycadopites cymbatus, Zinjispora bullata* and *Z. zonalis*, and *Granulatasporites* sp.

*Striate lineage:* Only *Protohaploxypinus sulcatus, P. acutus* and *P. amplus* are present.

Restricted species: *Vestigisporites* sp., and *Reticulatisporites compactus.*

Boundary: The upper boundary is marked by the sudden appearance of the bilateral Monosaccites genus *Potonieisporites*, the radial Monosaccites species *E. elilaensis, V. radialis, V. densus*, and the new apiculate Triletes *Verrucosisporites naumovai, V. bondii, Baculatispora bharadwaji.*

*Assemblage Sub-Zone B:*
*Quadrisporites* Assemblage.

Limit: 1 006′—853′.

Characteristics: Typically this sub-zone shows the appearance and increased diversity of the

bilateral Monosaccites (20 per cent) (i.e. *Potonieisporites novicus, P. hennellyi* and *P. thomasi),* and of the Cingulate Zonotriletes (10 per cent) (*Zinjispora bullata* and *Z. zonalis*). The rare turma Jugates *(Quadrisporites horridus)* appear to be restricted to this sub-zone.

*Associated species:* These are typical of sub-zone I, with the introduction of species *Verrucosisporites naumovai, V. pseudotrisectus, V. bondii, V. parmatus* and *Baculatisporites bharadwaji.*

*Species dying out*: *Granulatisporites* sp. and *Protohaploxypinus acutus.*

*Striatiti lineage:* No new striate Disaccites were noted, only two non-striate forms (*Platysaccus radialis* and *Sulcatisporites ovatus).*

*Restricted species:* Include *V. parmatus, Illinites unicus* and *Quadrisporites horridus.*

Boundary: The upper boundary is drawn at the point of disappearance of *Quadrisporites horridus* and at the approximate introduction of the Monosaccites forms *Florinites* and *Parasaccites,* and species *V. radialis.*

*Assemblage Sub-zone C:*

*Acanthotriletes tereteangulatus* Assemblage.

Limit: 840′—664′.

Characteristics: Monosaccites are abundant, both bilaterial and radial forms.

*Notable species:* These are typical of Sub-zone B, with the further introduction of *Acanthotriletes tereteangulatus, Apiculatisporis cornutus, Lophotriletes rarus* and *Marsupipollenites triradiatus.*

*Species dying out:* The Monosaccites forms *Virkkipollenites mehtae, V. densus, V. obscurus, Potonieisporites novicus, P. thomasi, Elilasaccites elilaensis, Caheniasaccites* sp., the Zonotriletes forms *Zinjispora bullata* and *Z. zonalis* and the Trilete form *Verrucosisporites pseudoreticulatus.*

*Striatiti lineage: Protohaploxypinus sulcatus* dies out, whilst *P. limpidus* emerges within the sub-zone. In the Disacciatrileti range, *Alisporites tenuicorpus* significantly dies out, whilst *A. plicatus* emerges.

Boundary: The upper boundary is drawn at the level where the Striatiti genera *Striatoabietites* and *Striatopodocarpites* appear.

*Assemblage Zone II:*

Transition Assemblages.

Limit: 646′—574′, i.e. Middle Black Shales and Coals. Sediments include shales, carbonaceous shales and shaley coals.

Boundary: The lower boundary is discussed above, but is summarised as the appearance of *Striatoabietites multistriatus, Platysaccus leschiki, Sulcatisporites splendens, Densipollenites indicus* and rare specimens of *Striatopodocarpites* and *Marsupipollenites* species. The upper boundary is marked by the consistent appearance of Disaccites in excess of 20 per cent (when discounting the presence of Aletes), of which Striatiti represent more than 10 per cent. Aletes suddenly predominate from 550′ to 480′. This coincides with the appearance of sculptured Monoletes. No marked disappearances occur at the upper boundary, but a sudden increase in new genera and species within the Aletes, Monoletes, Plicates (Praecolpates), and Striatiti are noted at and above 556′. More specifically the boundary is taken to be below 556′ and above 574′ based on the Striatiti lineage, i.e. the emergence of three new *Protohaploxypinus* species (*P. globus, P. diagonalis* and *P. goraiensis*) and four *Striatopodocarpites* species *(S. cancellatus, S. octostriatus, S. rarus* and *S. communis).*

Characteristic assemblages: Triletes 40—50 per cent; Monosaccites less than 10 per cent; Disaccites 10—20 per cent (Striatiti 5—10 per cent); Monocolpate and Praecolpate Plicates 2—8 per cent; Jugates 0 per cent; Aletes 0—2 per cent; Laevigate Monoletes 0—20 per cent; Cingulate Zonotriletes 0—2 per cent.

*Associated species: Punctatisporites gretensis, Retusotriletes diversiformis, Deltoidospora directa, Apiculatispora levis, A. filiformis, A. cornutus, Lophotriletes rarus, Baculatisporites bharadwaji, Granulatisporites tentula, Microbaculatispora micronodosus, Verrucosisporites naumovai, V. pseudotrisectus, V. bondii, Cycadopites nevesi, Pilaspora calculus, Tetraporina* species, *Plicatipollenites indicus, Parasaccites* sp., *Virkkipollenites obscurus, Florinites eremus, Potonieisporites hennellyi, Protohaploxypinus amplus, Platysaccus radialus, Alisporites plicatus, A. gracilus, Sulcatisporites ovatus* and *Limitisporites monstruosus.*

*Species dying out: Verrucosisporites bondii, Plicatipollenites indicus* and *Potonieisporites hennellyi. New species appearing: Deltoidospora lukugaensis, Neoraistrickia ramosa, Laevigatosporites colliensis, Gondispora vrystaatensis, Marsupipollenites triradiatus, Circulisporites magnus, Densipollenites indicus, Striomonosaccites* sp., *Protohaploxypinus limpidus, Striatoabietites multistriatus, Platysaccus leschiki, Sulcatisporites splendens, S. potoniei, Vesicaspora* sp. A. and sp. B. There are no restricted species.

Two sub-divisions are made:

*Assemblage Sub-Zone D:*

Transition assemblage I (TI)

Limit: 646′—634′.

Characteristics: The assemblage in this sub-zone represents the first transition phase between the older essentially Monosaccate-Trilete dominated assemblage in Zone I, to the Disaccate-Striatiti dominated ones above. In common with the older floras are such species as *Punctatisporites gretensis, Granulatisporites tentula, Microbaculatispora micronodosus, Calamospora plicata, Cycadopites cymbatus, Protogaploxypinus amplus, P. limpidus, Potonieisporites hennellyi,* etc. New species emerging in this sub-zone include *Neoraistrickia ramosa, Densipollenites indicus, Striatoabietites multistriatus,*

*Striatopodocarpites* sp(?), *Sulcatisporites splendens* and *Platysaccus leschiki.*

Boundary: The upper boundary is taken at the introduction of Laevigatomonoletes.

*Assemblage Sub-Zone E:*

Transition assemblage II(TII)

Limit: 586′—574′.

Characteristics: This assemblage represents the second transition phase in the change towards the Zone III flora. Quantitative and qualitative data are similar to Sub-zone D, but for the sudden and abundant appearance of new laevigate Monoletes (*Laevigatisporites colliensis, L. colliensis* forma minor) together with *Deltoidospora lukugaensis, Gondispora vrystaatensis, Circulisporites magnus, Striomonosaccites* sp., and *Sulcatisporites potoniei.* No new Striatiti forms appear.

Boundary: The upper boundary is marked by a large influx (at 550′) of sculptured Monoletes, abundant Aletes and the Striatiti species *Protohaploxypinus goraiensis, P. diagonalis* and *P. globus.*

*Assemblage Zone III:*

*Densosporites-Gondispora* Assemblage.

Limit: 556′—below 432′. i.e. Upper Black Shales and Coals, and Upper Wankie Sandstone, possibly lowermost Madumabisa Mudstones. Sediments include carbonaceous shales, gray shales and mudstones.

Boundary: The lower boundary is discussed briefly above, but may be briefly be summarised as the introduction of the Striatiti species *Protohaploxypinus globus, P. diagonalis, P. goraiensis, Striatopodocarpites cancellatus, S. rarus, S. octostriatus* and *S. communis*, with a marked increase in variety and abundance of Aletes, Praecolpate Plicates and the new appearance of sculptured Monoletes. The upper boundary is drawn at the level at which Zonati Zonotriletes are introduced *(Cirratriradites)*, Disaccites begin to average 40 per cent or more, with Striatiti representing 25 per cent or more of this amount. Aletes, which are abundant in this zone, drop to less than 10 per cent. A large number of species disappear (remnants of Assemblage Zones I and II), and many new species emerge. Within the Striatiti lineage the upper boundary is marked more specifically by the appearance of one new *Protophaploxypinus* species *(P. micros)* and four new genera — *Vittatina, Hamiapollenites* and more rarely *Lueckisporites* and *Guttulapollenites.*

Characteristic assemblages: (Count exclusive of the Aletes). Triletes 40 per cent; Monosaccites average 5 per cent; Disaccites 20—40 per cent (Striatiti 10—20 per cent); Plicates 0—8 per cent; Jugates 0 per cent; Aletes 10—80 per cent; Monoletes 0—20 per cent; Zonotriletes 0 per cent.

*Associated species: Deltoidospora directa, D. lukugaensis, Apiculatisporis levis, Granulatisporites tentula, Microbaculatispora micronodosus, Lophotriletes rarus, Acanthotriletes tereteangulatus, Laevigatosporites colliensis, Pilaspora calculus, Florinites eremus, Densipollenites indicus, Protohaploxypinus amplus, P. limpidus, P. radialis, Alisporites plicatus, A. gracilis, Sulcatisporites ovatus, S. splendens, S. potoniei.*

*Species disappearing: Punctatisporites gretensis, P. gretensis* forma *minor, Calamospora plicata, Apiculatispora filiformis, A. cornutus, Verrucosisporites naumovai, V. pseudotrisectus, Lophotriletes rarus, Neoraistrickia ramosa, Cycadopites cymbatus, Circulisporites magnus, Parasaccites* sp. and *Limitisporites monstruosus.*

*Species appearing: Acanthotriletes* forma minor, *Reinschospora* sp., *Punctatosporites granulatus, Spinosporites* sp., *Thymospora thiesseni, T. pseudothiesseni, Marsupipollenites striatus, M.* sp., *Verrucosphaera colliensis* (varieties 1 and 2), *Protohaploxypinus globus, P. diagonalis, P. goraiensis, Striatopodocarpites cancellatus, S. octostriatus, S. rarus, S. communis, Hamiapollenites karrooensis, Vesicaspora* sp. B.

*Restricted species: Densosporites rotundus, Gondispora novus.*

*Assemblage Zone IV:*

*Vittatina-Lueckisporites* Assemblage.

Limit: 432′—0′: i.e. Lower and Mid-Madumabisa Mudstones. Sediments include mudstones, siltstones, carbonaceous shales and limestones.

Boundary: The lower boundary is taken as the level of introduction of *Protohaploxypinus micros, Vittatina africana, V. minima, Hamiapollenites karrooensis, Lueckisporites nyakapendensis* (rare) and *Cirratriradites africanensis.* The upper boundary is taken to be the top of the borehole.

Characteristic assemblages: Triletes 20 per cent; Monosaccites average 5 per cent; Disaccites 40—75 per cent (Striatiti 25—60 per cent); Plicates 0—10 per cent; Jugates 0 per cent; Aletes 0—15 per cent; Monoletes 0—5 per cent; Zonotriletes (Zonati) 0—8 per cent.

*Abundant species: Acanthotriletes tereteangulatus, Cirratriradites africanensis, Florinites eremus, Densipollenites indicus, Protohaploxypinus diagonalis, P. amplus, P. goriensis, P. limpidus, P. micros, Sulcatisporites ovatus, S. splendens* and *S. poteniei.*

*Associated species: Deltoidospora directa, D. lukugaensis, Retusotriletes diversiformis, Apiculatisporis levis, Baculatisporites bharadwaji, Laevigatosporites colliensis, Punctatosporites granulatus, Thymospora thiesseni, T. pseudothiesseni, Marsupipollenites triradiatus, M. striatus M.* sp., *Cycadopites nevesi, Pilaspora calculus, Verrucosphaera colliensis* (varieties 1 and 2), *Striomonosaccites* sp., *Protohaploxypinus globus, Striatopodocarpites cancellatus, S. octostriatus, S. rarus, S. communis, Striatoabietites multistriatus, Platysaccus*

*radialis*, *P. leschiki*, *P. plicatus*, *P. gracilis* and *Vesicaspora* sp. A. and *V.* sp. B.

*Species disappearing: Granulatisporites tentula*, *Microbaculatispora micronodosus*, *Lophotriletes rarus*, *Reinschospora* sp., *Gondispora vrystaatensis*, *Tetraporina* sp., and *Verrucosphaera colliensis* (varieties 1 and 2).

*Species appearing:* i.e. restricted to Zone IV; *Apiculatisporis minutus*, *Zinjispora eccensis*, *Cirratriradites africanensis*, *Protohaploxypinus micros*, *Leuckisporites nyakapendensis*, *Vittatina africana*, *V. minima*, *Taeniaesporites noviaulensis*, *Guttulapollenites hannonicus* and *Jugasporites* sp.

Two divisions are made:

*Assemblage Sub-Zone G:*

*Cirratriradites africanensis* Assemblage.

Limit: 438′—240′.

Characteristics: Striate and non-striate Disaccites (40—60 per cent) are now beginning to dominate the assemblages, with Aletes (dominant in Zone III) much reduced in abundance. Monoletes and Triletes are still prominent constituents of the assemblages. Zonati Zonotriletes appear for the first time.

*Associated species:* These are predominantly similar to those found in the uppermost levels of Zone III, with the exception of the new species listed above, all of which appear in this sub-zone except *Taeniaesporites noviaulensis*. In comparison with Zone III the relative abundance of certain species is seen to change significantly. *Protohaploxypinus* and *Sulcatisporites* species now become the dominant constituents of the assemblages, in favour of the abundant Trilete, Alete, Monolete and non-striate Disaccites species. Above 240′ the trend towards Disaccites dominance continues.

*Striatiti lineage: Protohaploxypinus micros*, *Vittatina africanensis*, *V. minima* and *Jugasporites* occur at the base of this sub-zone followed by *Hamiapollenites karrooensis* and *Leuckisporites nyakapendensis* in rare quantities.

*Restricted species: Zinjispora eccensis* and *Cirratriradites africanensis*.

Boundary: The introduction of the above striate Disaccites with Zonati Zonotriletes (*Cirratriradites*) serves as the lower boundary of this zone and sub-zone. The upper boundary may be delineated by the disappearance of the Zonati and the following species: *Deltoidospora directa*, *Apiculatisporis levis*, *Lophotriletes rarus*, *Acanthotriletes tereteangulatus*, *Pilaspora calculus*, and *Verrucosphaera colliensis*. More specifically, the boundary is drawn at the appearance of the striate Disaccites *Taeniaesporites noviaulensis*, *Lueckisporites nyakapendensis* and *Guttulapollenites hannonicus* (the latter two species in excess of 1 per cent).

*Assemblage Sub-Zone H:*

*Taeniaesporites — Guttulapollenites* Assemblage.

Limit: 233′—0′.

Characteristics: Striate and non-striate Disaccites now dominate the entire assemblages (60—80 per cent). Triletes (5 per cent) are only represented by *Retusotriletes diversiformis*, *Deltoidospora lukugaensis* and *Apiculatisporis minutus*. Laevigate and sculptures Monoletes are present in a small minority, whilst Zonotriletes and Aletes are almost absent.

*Abundant species: Protohaploxypinus diagonalis*, *P. micros*, *P. amplus*, *P. goraiensis*, *P. limpidus*, *Striatopodocarpites cancellatus*, *S. octostriatus*, *S. rarus*, *Guttulapollenites hannonicus*, *Platysaccus leschiki*, *Alisporites plicata*, *A. gracilis*, *Sulcatisporites ovatus*, *S. splendens* and *S. potoniei*.

*Associated species: Laevigatosporites colliensis*, *Punctatosporites granulatus*, *Thymospora thiesseni*, *T. pseudothiesseni*, *Marsupipollenites triradiatus*, *M. striatus*, *M.* sp., *Florinites eremus*, *Densipollenites indicus*, *Striomonosaccites* sp., *Protohaploxypinus globus*, *Striatoabietites multistriatus*, *Vittatina africana*, *V. minima*, *Vesicaspora* sp. A. and *V.* sp. B.

Boundary: As defined above the lower boundary occurs at the introduction of the striate Disaccites *Taeniaesporites noviaulensis* and at the consistent appearance (1 per cent) of *Leuckisporites nyakapendensis* and *Guttulapollenites hannonicus*. The boundary is emphasized by the disappearance of Zonati form *Cirratriaradites* and certain Trilete and Alete species (see above in Sub-zone G).

### (c) Stratigraphic Correlation of the Assemblage Zones

Stratigraphic correlations have been considered previously (Falcon 1972, 1973), but are again summarised here in order to update some recent advances in Central African palynology. A point to emphasize in correlation of the coal sequences in South and Central Africa is the interest displayed currently in the exploration and age of the different coal-bearing strata. Basically three potential ages of coal are now noted—Lower to Middle Ecca, Upper Ecca, and Molteno (Stormberg) — and three distinct macrofloras are known to have flourished over this period (Plumstead, 1967).

Due to this rapidly changing vegetation throughout Lower Karroo times, the parent floras forming the original constituents of the coal must have varied and thereby to some degree the eventual organic constituents of the coal. Inversely, the recognition of particularly sought after coal sequences may be conducted by the spore / pollen-macroplant content. Further research is being conducted along these lines at present and will be published at a later date.

*Assemblage Zone I:*

Dwyka and Lower Wankie Sandstone ($K^0$ and $K^1$).

In terms of percentage abundance of the major miospore taxa, Zone I as seen in the Matabola Flats core is comparable to Hart's Cavati Zone in South Africa. Both zones possess dominant Trilete

miospores with abundant (±20 per cent) Monosaccites. Striatiti are present but are rare.

The comparison based on genera and species content is not as close. Hart (1967) selects sixteen representative genera to illustrate the Cavati Zone of which eleven are represented in the Matabola Flats Zone I sediments. Three of these are very rare and have not been included in the present microfloral lists: viz. *Grandispora*, *Gondispora* and *Lycospora*. Of particular interest is the fact that three elements exist in the South African Cavati Zone: (Hart, 1963); (i) the pre-Permian forms: *Grandispora, Lycospora, Endosporites*, *Reinschospora* and *Reticulatisporites*. Of these only *Reticulatisporites* (*R. compactus*) has been described and is very rare in Rhodesia. (ii) The Permian element, containing *Marsupipollenites*, *Plicatipollenites* (*Cordaitina*) and Striatiti genera; the latter two are present in Zone I. (iii) Forms restricted to Lower Permian times; of the eleven forms present in the South African Cavati Zone, six occur in the Rhodesian Zone I, viz. *Zinjispora*, *Verrucosisporites*, *Vestigisporites*, *Apiculatisporis*, *Punctatisporites* and *Cordaitina*.

Zone I (Rhodesia) also possesses four species characteristic of Hart's Cingulati Zone (Hart, 1966a), viz. *Cordaitina balmei*, *Vestigisporites thomasi*, *Cycadopites nevesi*, and *Reticulatisporites* sp.

In terms of correlation, the South African Cavati (Camerati) microfloral assemblage is regarded as somewhat heterogeneous and in need of revision and therefore it cannot represent an absolute standard of reference. The problem of age and wrong stratigraphic bases is a related problem. The sediments from which Hart (1963) extracted his Cavati assemblage may be regarded as Lower Ecca and not Dwyka (J. Anderson, in prep.). For the present purpose, the Rhodesian Zone I assemblage is regarded as possibly Upper Cavati Zone, on the basis of little pre-Permian miospore elements, abundant Lower Permian elements and the presence of Striatiti (although rare) from the base of the productive horizons.

The Rhodesian Zone I appears to be very similar to the lowest beds of the Lower Coal Measures in Tanzania (K2c) due to the common occurrence of *Punctatisporites*, *Zinjispora*, *Vesicaspora*, and *Cordaitina*. Due to the small representation of Striatiti, it may be further confined to Sub-zone C. Utting (in press) has recently shown a closely comparable sequence in the Upper Luangwa Valley in his Mukumba Siltstone Member. Sub-zone A may be correlated to the lower assemblages of these beds on the basis of overwhelming Monosaccate/Trilete dominance and lack of striate Disaccites, whilst the upper assemblages of this member become closely allied to Sub-zones B and C by the introduction of *S. ovatus*, *P. limpidus*, *Z. eccensis*, *N. congoensis*, *V. pseudoreticulatus* and *T. tereteangulatus*.

In Tanzania, Manum and Tien (1973) describe two spore/pollen assemblages from the Ketewaka coalfield, the oldest of which, the *Cordaitina-Zone*, occurs in sandstone coal sequences and is characteristic of Assemblage Zone I, Sub-zone B and C, with abundant Monosaccates and Triletes, two rare Striatiti forms, and a bilateral Monosaccate. Disaccates are rare. *N. ramosa* is typical of Zone II, Sub-zone D, but the Cordaitina-Zone, due to the high proportion of Monosaccates, is for the present purpose retained in Zone I. It is of particular interest to note that unlike other Zone I microfloras these assemblages occur in sandstone coal measures, thereby representing the oldest coal seams so far palynologically correlated in Southern and Central Africa. The two youngest samples in this Cordaitina-Zone (4 and 5) appear to represent a transition zone with high Disaccate content (22—74 per cent), and the appearance of Monoletes and the introduction of *P. amplus, P. sewardi (limpidus), S. cancellatus, V. ovata* and *V. potoniei*. These are forms typically found in Zone II, D and E and are therefore regarded as indicative of the transition phase seen in early Black Shales and Coals beds in Rhodesia.

In the Congo (Pierart, 1959; Hoeg and Bose, 1960; Bose and Kar, 1966), the generic content of the Assise de Schistes noirs de la Lukuga and Assise de Schistes noirs Walikale are both similar to the Rhodesian Zone I assemblage due to the presence of *Virkkipollenites*, *Plicatipollenites*, *Elilasaccites*, *Strotersporites (Protohaploxypinus)*, *Punctatisporites*, *Apicultatisporis*, *Ginkgocycadophytus (Cycadopites)*. On the basis of diversity of species, the Congo assemblages are far more varied and have many forms not yet encountered farther south. The Assise Periglaciaires et Glaciaires is represented by a very dominant Monosaccate assemblage unlike anything encountered elsewhere in Africa so far; the Assise Schiste noirs de Walikale has an equally high proportion of Disaccites, Monosaccites and Triletes, whilst the Assise de Schistes noirs de Lukuga assemblage is predominantly Trilete. The Rhodesian Zone I is tentatively correlated on the basis of the above common abundant genera and low percentage of Striatiti with the Assise des Schistes de Walikale and Assise des Schistes de Lukuga.

No parallel assemblages have as yet been described from Madagascar. In India, the Talchir Flora (Potonie and Lele, 1961) possess a very comparable Monosaccate-dominated flora (*Nuskoisporites* and *Potonieisporites*). Other genera are *Leiotriletes*, *Punctatisporites*, *Granulatisporites*, *Lophotriletes*, *Apiculatisporis*, *Quadrisporites*, *Lunatisporites* (*Protohaploxypinus*), *Pityosporites* and *Ginkgocycadophytus* (*Cycadopites*).

The presence of *Quadrisporites* in minor quantities, abundant *Botryococcus* and *Microbaculispora* (*M. tentula*) equate this miospore assemblage to zones Upper-1 and 2 of Segroves, Western Australia (1970) and Stage 2 of Evans, Eastern Australia (1967). Also Blame's (1964) lower *Nuskoisporites*-Complex $K^1$ would appear to be equivalent to the upper part of

this assemblage. These assemblages are characteristic of glacigene deposits and post-glacial shales in Australia and are represented by the Nangetty Formation-Holmwood Shale-Fossil Cliff Formation ($K^1$) of the Lochinvar-Allandale strata of the Sydney Basin (Evans, 1967).

Correlation on the basis of biostratigraphy (i.e. microfloral assemblages and percentage abundance patterns) is evident, but the *age relationship* or chronostratigraphic tally is somewhat problematic. The base of the Permian in Australia was taken by convention as being the introduction of the *Glossopteris-Gangamopteris* flora and striatitid disaccate pollen (Balme, 1964; Evans, 1967). In Western Australia, Balme assigns the lowermost glacials (containing striatitid pollen) as the base of the Permian, whilst Evans, in Eastern Australia, regards the glacials as starting earlier, but still regards the occurrence of *Glossopteris-Gangamopteris* and striate pollen as the introduction of the Permian.

Plumstead, however, is of the opinion that the mixed *Glossopteris-Gangamopteris* macroflora in Southern Africa began in Upper Carboniferous times (Plumstead, 1967), and that this flora, her Zone III, was introduced prior to the end of the glaciation in Africa. This implies a fair discrepancy in age.

Earlier microfloral assemblages are found and defined in Australia in Evans' Stage I (Seaham and Kuttung Series, Sydney Basin) and the lowest part of Segroves' Zone I (lower part of the Nangetty Formation, Perth Basin). In these assemblages, Disaccites are rare, no Striatiti are found, and a few Monosaccites appear in the uppermost beds. An abundance of Sporites occurs. This microfloral content may be equivalent to the early *Proto-Glossopterideae* and Lycopod Assemblages of Plumstead (Zone II, macrofloral), for which she gives a Middle Carboniferous age in Southern Africa.

These floral assemblages are not considered present in the Matabola Flats sediments as Striatiti Disaccites are represented from the base. Also Monosaccites are fairly abundant and diverse, and Plicates are present in significant numbers. This miospore content is thought to indicate a flora equivalent to Plumstead's early Zone III. It is relevant to note here that palaeomagnetism has inferred a Lower to Middle Carboniferous age for the Dwyka Series in Rhodesia. In the light of microfloral evidence taken from the Matabola Flats glacigene sediments, this dating would seem to be somewhat early.

If the South African Cavati florizone (in Dwyka sediments) is of Stephanian-Sakmarian age (Hart, 1967b) then the age of the Rhodesian Dwyka, based on comparable miospore assemblages, may be very similar. This agrees with Bond's proposals (1952, 1967) based on climatic and lithological evidence, i.e. the occurrence of glacial tillites and conglomerates and varved sediments.

*Assemblage Zone II:*

Lower Black Shales and Coals (lower $K^2$-$K^3$).

This portion of the Black shales and coals series is correlated with the Tanzanian $K2e_1$ beds in the Mchuchuma-Ketewaka coalfields on the grounds of quantitative and qualitative content (Hart, 1965, 1966, 1967). Manum and Tien (1973) illustrate the presence of this Transition Zone (Assemlage Sub-Zones D and E) very clearly in the Ketewaka Coalfield. In Zambia, the lowermost Mpwashi carbonaceous shales and coals, as in Rhodesia, are assigned to this assemblage zone. Bar minor variations, the introduction of Monoletes occurs at the top of these beds together with the gradual introduction of the Plicate infra-turma group Monocolpates (*Marsupipollenites*) from the base. There is a comparable decrease in Sporites, a rapid increase in Disaccites (to a higher percentage in Tanzania), gradually increasing Striatiti and reduction in Monosaccites.

Generic content is essentially similar, with reduction in *Zinjispora* and *Punctatisporites*, and the introduction of *Acanthotriletes* (*A. tereteangulatus*), *Laevigatosporites*, *Marsupipollenites*, *Striatopodocarpites* and new species of *Protohaploxypinus* (= *Striatopinites*). In particular, the appearance of *L. colliensis, S. plicatus, S. potoniei, V. saccata* (*S. multistriatus*), *P. limpidus* and *S. fusus* (*S. rarus*) are diagnostic.

On comparison with the miospore florizones of South Africa, Hart places his $K2e_1$ (and therefore the Rhodesian Zone II) on the border of the Cavati and Cingulati Zones. This, on South African standards, is in the Lower Ecca. Bond (pers. comm.) assigns these beds, together with $K^1$ (Lower Wankie Sandstone) to Lower Ecca on the grounds of *Glossopteris/Gangamopteris* occurrences.

On detailed comparison with Australian microfloral assemblages, this microflora would appear to be comparable to Balme's (1963) upper *Nuskoisporites* Complex, Segroves' lower *Acanthotriletes* Assemblage (= High Cliff Sandstone, Northern Perth Basin), and Evans' (1967) lower stage 3 (= Rutherford and Farley sequences, Sydney Basin).

*Assemblage Zone III:*

Upper Black Shales and Coals (Upper K2-3).

The palynological content of this sequence is closely comparable to $K2e_2$ (Shale-Coal Measures) in the Tanzanian stratigraphy, more on the basis of generic content (qualitative) than quantitative content (Hart, 1966, 1967a, b; Manum and Tien, 1973). In the Upper Luangwa Valley, Utting (in press) also describes assemblages occurring mid-way up his Mpwashi Carbonaceous Member (Luwumba Coal Formation) closely resembling Assemblage Zone III. In the Rhodesian material a noticeable increase (up to 35 per cent) in Alete forms tends to mar the closer tally between the Disaccites and Striatiti percentage abundances of the three regions.

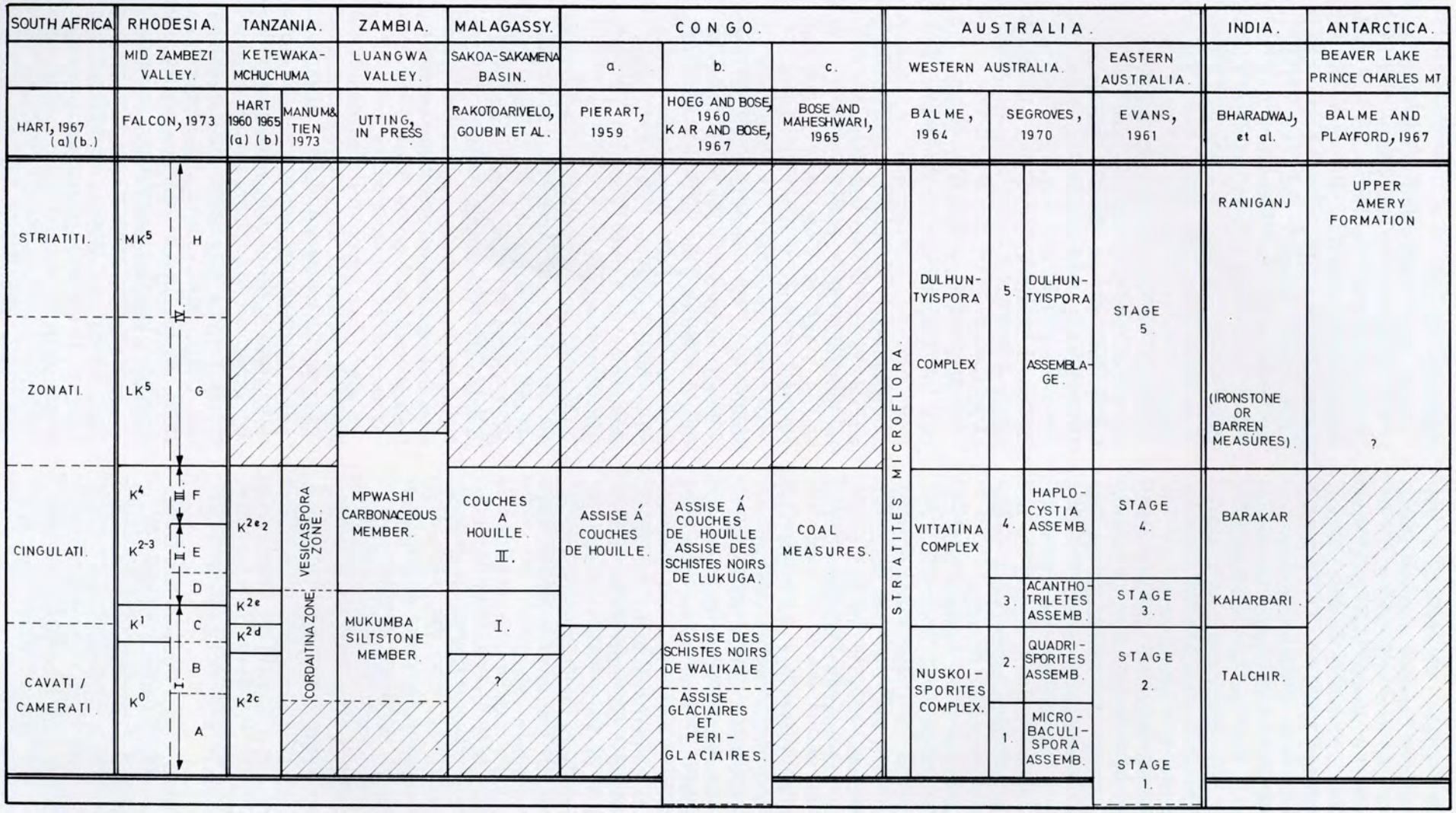



Figure 10. Broad Stratigraphic Correlations.

However, despite their reduction in abundance, both major miospore taxa continue to increase in the three areas under consideration, with Striatiti comprising roughly one third of the total Disaccites content. Monosaccites drop to 10 per cent or less in both regions, Monocolpates and Monoletes increase up to 8 per cent and 10 per cent and Sporites vary with samples, but are generally reduced.

Genera coincide markedly with the common abundance of *Acanthotriletes* (*A. tereteangulatus*), *Laevigatosporites*, *Marsupipollenites*, *Protohaploxypinus* species, *Striatopodocarpites*, *Sulcatisporites* and *Platysaccus*. *Circulisporites* (= *Chomotriletes*) and *Verrucosphaera* are amongst the diagnostic abundant Aletes. The introduction of *Striatoabietites*, *Vittatina*, *Florinites*, *Densipollenites* and *Cirratriradites* is apparent, but these genera are relatively rare in occurrence. In particular, the following species are diagnostic: *S. potoniei*, *S. rarus*, *M. striatus*, *S. communis* and *S. octostriatus*.

On the basis of the overall microfloral similarity to the Cingulati Zone, implying a South African lithostratigraphic equivalence of Middle Ecca, the correlateable $K2e_2$ beds in the Tanzanian Coal Measures and the Mid-Mpwashi Member of the Zambian Luwumba Coal Formation are also tentatively assigned to a Middle Ecca age. In Rhodesia, this confirms Bond's (pers. comm.) chronostratigraphic assignment of these beds on macrofloral and lithological (concretions) grounds. It is of interest to note that the Zone III microfloral assemblages have proved the existence of a facies change in the Ketewaka Coalfield ($K2e^2$). This is basically an arenaceous sequence and unlike the shale-coal units found elsewhere associated with this assemblage.

Australian comparisons illustrate differences due to marine incursions. However, basic quantitative and qualitative analyses of major taxa and genera are possible. $K^{2-3}$ (upper sequences) and $K^4$ appear to be equivalent to Balme's *Vittatina* Complex, Segroves' Upper *Acanthotriletes* Assemblage and *Haplocystia* Assemblage (Irwin Coals-Carynginia Sequences, Perth Basin) and Evans' (1967) Upper Stage 3 and Lower Stage 4 (Greta Coal Measures and Branxton Formation, Sydney Basin).

On the quantitative and qualitative information supplied by Rakatoarivelo (1970), the two zones of the Couches à Houille of the Sakoa-Sakamena Basin in Madagascar fit in very closely to the lower and upper $K^{2-3}$ beds and their characteristic assemblages. The Barakar microfloral assemblages in India (Tiwari, 1965), and the Assise à Couches de Houille of the Congo (Hoeg and Bose, 1960; Pierart, 1959) and Coal Measures South of Albertville near Lake Tanganyika, Congo (Bose and Maheshwari, 1968) are all considered equivalent to the Cingulati Zone.

*Assemblage Zone IV:*

Madumabisa Mudstones ($K^5$).

*Assemblage Sub-Zone G:*

Lower Madumabisa Mudstones ($LK^5$).

The Rhodesian Zone IV (Sub-zone G) appears to be very similar to the Upper Mpwashi Carbonaceous sequences in Zambia both quantitatively and qualitatively. Specifically there is in common the introduction of *P. micros*, *H. karrooensis* and the presence of other more prominent forms such as *V. africana*, *Striatoabietites*, *P. leschiki*, *V. saccata*, *L. lukugaensis*, *M. striatus*, *S. communis* and *S. cancellatus*. The uppermost beds encountered by Manum and Tien in the Tanzanian Ketewaka Coalfield (Bh II) are typically those of Sub-zone F, but they possibly grade into early Sub-zone G based on the quantitative comparisons. The typical and diagnostic genera of this sub-zone (*Lueckisporites* and *Cirratriradites*) are, however, missing.

The quantitative values of the Disaccites and Striatiti and the associated genera found in Subzone G do indicate a close resemblance to the South African Zonati Zone. Common genera to both assemblages in significant quantities are: *Vittatina*, *Striatoabietites*, new species of *Striatopodocarpites*, *Florinites*, *Densipollenites* and *Cirratriradites*. *Apiculatisporis* and *Marsupipollenites* are found in greater abundance. Minor variations within the Matabola Flats assemblage are the rare occurrences of *Hamiapollenites*, *Lueckisporites* and *Reinschospora*.

Hart places the Zonati florizone, and therefore by extrapolation the Lower Madumabisa Mudstones ($LK^5$) and Upper Mpwashi Member of the Luwumba Coal Formation, in South African Upper Ecca lithostratigraphy (Kazanian in age). Bond (pers. comm.) once again agrees with this on the basis of macrofloral evidence. *Gangamopteris* has now all but disappeared in the Mid-Zambezi Valley, whilst *Glossopteris* species continue. Plumstead's Zone IV (Transition Zone), with an abundance of *Glossopteris* and lack of *Gangamopteris* and abundance of swamp lovers (*Phyllotheca* and *Schizoneura*), is apparently equivalent and to this she assigns an Upper Ecca, Middle to Upper Permian dating.

The comparative Australian florizones are the lower *Dulhuntyispora* Complex of Balme (1963), the lower *Dulhuntyispora* Assemblage of Segroves (1970) (lower Wagina Sandstone, Perth Basin) and lower stage 5 of Evans (Muree Formation). The main features common to all these zones is the high percentage of Disaccites and Striatiti, and *Marsupipollenites*. A fair number of genera are common to the Rhodesian and South African microflora, but possibly marine incursions and ecological and climatic factors would have been the cause of a break away and development of different microfloral elements.

*Assemblage Sub-Zone H:*

Mid-Madumabisa Shales ($MK^5$).

The microfloral content of this sub-zone appears to be very closely allied to Hart's (1967) South

African Striatiti Zone. The percentage relative abundance of Sporites, total Disaccites, Striatiti, Monosaccites, Monocolpates and Monoletes are all closely comparable.

Generically, *Guttulapollenites* and *Taeniaesporites* are minor but significant introductions into the Matabola Flats MK[5] assemblage, while *Vittatina*, *Lueckisporites*, *Thymospora* and new species of *Striatopodocarpites* and *Platysaccus*—all of which are common to the Striatiti Zone—are in more substantial evidence.

As yet no other comparable Central African assemblages have been published.

Hart (op. cit.) assigns this zone to the Lower Beaufort in South Africa, whilst Bond (pers. comm.) proposes a Lower Beaufort correlation on the presence of *Tapinocephalus* Zone reptiles and other vertebrate and invertebrate macrofaunal fossils.

The MK[5] assemblages, via Hart's Striatiti Zone, is considered equivalent to the Raniganj Stage in India, and the *Dulhuntyispora* Assemblages in Australia (Wagina Sandstone, Perth Basin, and Newcastle-Tomago-Mulbring Formations, Sydney Basin). Hart (1967b) suggests the inclusion here of the dominantly striatitid assemblage reported by Balme and Playford (1967) from Beaver Lake, Prince Charles Mountains, Antarctica.

The Middle Madumabisa Shales, like the Lower Madumabisa Shales, are placed by Plumstead (1967) in her Zone IV, with a Middle to Upper Permian dating. The *Glossopteris* woodlands and equisetalians on the mudflats would seem to be even more pronounced in this zone (higher percentage of Striatiti) than in the lower one, probably creating an excellent environment for the fairly abundant reptilia and amphibia reported by Bond.

## SUMMARY

A detailed palynological analysis has been conducted on the microfloral assemblages encountered in the Matabola Flats borehole. This has included quantitative (major taxa) and qualitative (species and their relative abundancies) research, the establishment of an evolutionary sequence in the Disaccate Striatiti and the discovery of microfloral diversification and disappearance periods.

An attempt has been made to establish the major microfloral trends, throughout this Lower Karroo sequence, and to interpret, to some degree, the possible factors affecting these trends and their fluctuations.

Based on the above information, a number of sub-divisions of the microfloral assemblages have been investigated. This has resulted in the establishment of eight assemblage sub-zones which have been incorporated into four major assemblage zones.

Stratigraphic correlation of these assemblage zones, and in some cases sub-zones in South and Central Africa and in Gondwanaland has been attempted. This has illustrated the remarkably uniform parallel trends in changing microfloral patterns throughout this period of time. It has also been shown that lithofacies changes can be detected through assemblage correlation, and that the broad ages of the coal sequences may now be established. Further work is necessary before correlations can be refined to the point where coal seams or their intercalated sediments can be reliably linked.

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