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THE PALYNOLOGY OF LATE PALAEOZOIC GLACIAL DEPOSITS OF GONDWANALAND

by

E.M. KEMP

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Elizabeth M. Kemp*

Bureau of Mineral Resources, Geology & Geophysics, Canberra, A.C.T,
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ABSTRACT

Analysis of the palynology of the Late Palaeozoic glacial sequences of all Gondwanaland continents in terms of an Australian palynological zonal scheme has shown the following patterns: pre-Stage 1 microfloras are known to occur with probable glacial sediments only in the Paganzo Basin of western Argentina. Stage 1 microfloras have been positively identified only in Australia, where they are preserved in basins which may have been marginal to the main continental glaciation; they have, however, tentatively been reported from the Paraná Basin of Brazil. Stage 2 assemblages are most widespread, occurring in the lower parts of the examined sequence of Itararé Subgroup rocks in the Paraná Basin, in the Talchir Formation of the Salt Range and peninsular India, in diamictites in Victoria Land, Antarctica, and possibly, according to sketchy data, in the basal Dwyka Tillite in South Africa. Stage 3 assemblages characterize much of the Itararé and the Congo Basin sequences. In Australia microfloras of this category generally occur in post-glacial sequences, although evidence of iceberg activity persists into even younger sediments in some Tasman Geosyncline sections.

Preliminary interpretation confirms evidence from other sources in indicating that the oldest glacial deposits lie in west Gondwanaland, but it also suggests that the bulk of the glacial sediments are synchronous within the limits of resolution afforded by palynological means, which may be broad. Palynological evidence lends no support to suggestions that glaciation ceased at a relatively early date in much of South America and Africa.

INTRODUCTION

The idea that the Late Palaeozoic glacial deposits of different continental fragments of the Gondwana landmass might not be synchronous has its origins probably in the work of du Toit (1921). The idea was elaborated and further expressed by King (1962, p.44) thus ... 'The maximal centres of glaciation were, however, not contemporaneous in the several continents, but were sequential from west to east'. King visualized a west to east progression both in the commencement and in the termination of glaciation, so that the westernmost continents of the Gondwana complex, i.e. Africa and South America, were experiencing post-glacial warming at the same time that refrigeration was starting in the east in Antarctica and Australia. Such a movement of climatic zones was understood to have been brought about by either polar wandering from west to east, or by drift from east to west of the whole landmass across a fixed geographic pole.

The proposal for such a mechanism has drawn support from palaeomagnetic studies, recently summarized by Creer (1970, 1972), and by McElhinny (1973). Although the dating of many rock units on which measurement of pole positions are based is extremely broad, a general picture emerges which suggests wander of the south magnetic pole (and the south geographic pole, according to the axial dipole theory), from a broad scatter of positions in North Africa - northern South America in the early Palaeozoic, through a southern Africa pole position in the mid-Palaeozoic, to a Permo-Carboniferous grouping in the vicinity of the Ross Sea (Creer, 1972, fig. 7).

The suggested movement of the Gondwana landmass relative to palaeolatitude during the late Palaeozoic has been invoked as a mechanism to explain the initiation of glaciation and its progress across the supercontinent, by considering the possible effects on global circulation patterns (Frakes & Crowell, 1972). The same authors have recently suggested details of such a late phase of icecap migration (Crowell & Frakes, 1972). The evidence for an east-west migration in the commencement, culmination, and cessation of glaciation is, however, very meagre. Faunas of possible Early Carboniferous age in glacial marine sequences in Andean Basins of South America have been cited as evidence supporting an early westerly beginning. These faunas, however, have subsequently been referred to the Late Carboniferous (Amos & Rocha-Campos, 1972). An Early Carboniferous age for the base of the Dwyka Tillite in South Africa has also been suggested, on the basis of palaeobotanical, stratigraphic and palaeomagnetic data (Plumstead, 1969; McElhinny & Opdyke, 1968). The timing of the suggested migration of ice centres across the Antarctic continent rests on very little information, and that primarily stratigraphic (Frakes, Matthews & Crowell, 1971). An early westerly cessation, with glaciation essentially over in South America, Africa and India, while still of continental proportions in Antarctica and southern Australia (King, op. cit., Crowell & Frakes, 1972), is again based on interpretation of extremely meagre palaeontological data, although persistence of some ice into the Late Permian is suggested by large clasts in some eastern Australian basins.

Efforts to establish a chronological framework into which late Palaeozoic events might be set are hampered by the ephemeral nature of glacial deposits themselves, and by the restricted biota which could survive under rigorous physical conditions. Marine faunas which are demonstrably contemporaneous with glacial deposits are relatively rare throughout Gondwanaland, and are of a taxonomically restricted nature, factors which complicate their chronological interpretation. Quite commonly, however, glacial deposits contain plant microfossils, comprising spores and pollen produced by vegetation which must have existed in periglacial environments, and which expanded during phases of climatic warming and ice retreat. Although such a flora was equally as specialised as any fauna, it may offer some advantages as a correlative tool in that such remains are easily incorporated into both marine and non-marine sediments. The present study represents a preliminary attempt to see what, if any, light can be shed on the relative ages of glacial deposits from different continents on the basis of their contained microfloras.

Australia is as yet the only one of the Gondwana continents for which a sequence of microfloral assemblages has been established within late Palaeozoic strata. For eastern Australia, Evans (1969) outlined a series of palynological 'Stages' for the probable Late Carboniferous and Permian, which were based on the observed ranges of supra-generic spore groups, and on the ranges of individual form-species. The units are thus, in a broad sense, assemblage zones. They are as yet very imperfectly defined, but nonetheless offer the most valuable chronologic framework yet proposed on a palynological basis. One advantage offered by the Australian zonal scheme is that it has been erected largely in basins which appear to have been marginal to the main continental glaciation; hence the sequences can be expected to be most complete. Parallel palynological subdivisions have been recognized in Western Australian basins by Balme (1964) and Segroves (1972). The oldest assemblages, designated Stage 1 and Stage 2 by Evans, occur in stratigraphic units which carry a recognizable, though variable, glacial imprint in a number of eastern Australian sedimentary basins. Stage 1 microfloras appear to be associated with plant megafossils of the Gondwanidium type; those of Stage 2 coincide with the advent of a Glossopteris-dominated vegetation. Microfloras of Stage 3 occur, for the most part, in Australia in rock units which suggest that glaciation was waning or completely past, although there is evidence of ice-rafting in some Tasman geosyncline sequences bearing microfloras of this designation.

A further late Palaeozoic subdivision was identified by Helby (1970), who designated as the '<u>Grandispora</u>' microflora an assemblage lying stratigraphically below Evans' Stage 1 unit (referred to by Helby as the <u>Potonieisporites</u> microflora), and which occurs in pre-glacial strata in eastern Australia. Subsequently Helby (personal communication) has recognized an intermediate assemblage, informally designated the '<u>Anabaculites</u>' assemblage, which occupies an intermediate position between the <u>Grandispora</u> microflora and Stage 1 microfloras, and which has been recognized in both eastern and western Australian basins.

The present study has as its aim the classification of palynological data from glacial deposits of the Gondwanaland continents in terms of the Australian framework. Accepting, for the moment, that the Australian scheme is truly a chronological one, reflecting evolutionary changes in Late Palaeozoic floras, then this synthesis should give some guide to chronological relationships between glacial deposits in different regions of the Gondwana landmass. The fact that the Gondwana continents make up a single Late Palaeozoic floral province enables such comparisons to be made with relative ease. The age of the palynological units in Australia in terms of international time divisions remains problematic. It is sufficient here to mention that the base of Stage 1 in Australia may be as old as Westphalian, on the basis of its relationships with faunas in underlying sequences.

Text-figure 1 shows the locality of data sources against a background of Gondwanaland as reconstructed by Smith & Hallam (1970). Only those localities are shown for which data have been published concerning the palynology of glacial sediments: this excludes the wealth of data which is to be found only in oil company files. The quality of the palynological information available for such a synthesis varies widely.

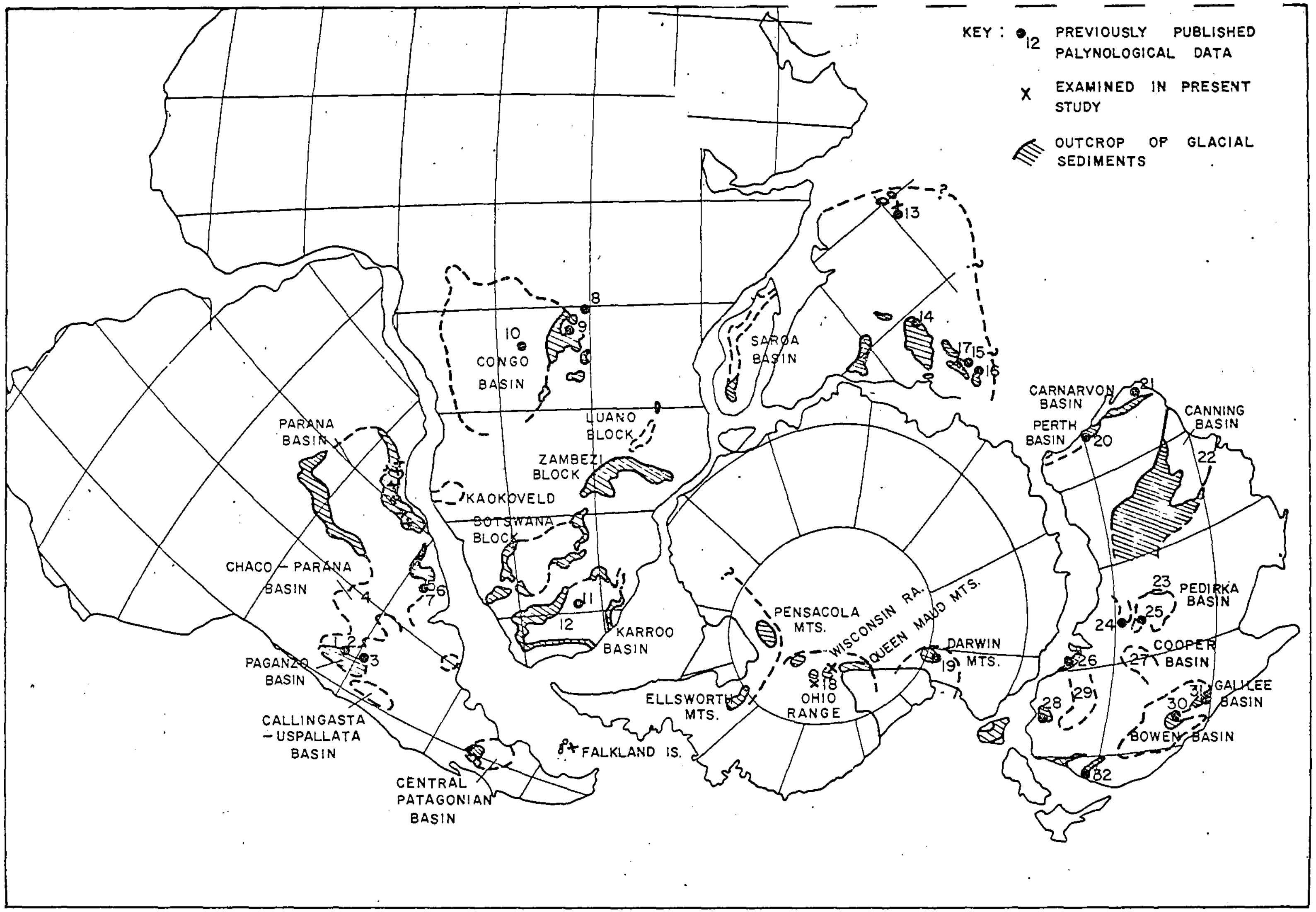

Figure 1: Gondwanaland reassembly according to Smith & Hallam (1970). with outcrop areas of Late Palaeozoic glacial sequences shown hachured. Localities from which published palynological information is available are numbered as follows: 1 - Menendez 1965, 1969; 2 - Menendez & Azcuy 1969, 1971; 3 - Menendez 1969; 4 - Padula & Mingramm 1969; 5, 6, 7 - Machiarello 1963, Bharadwaj 1969, Marques-Toigo 1970, Ybert & Marques-Toigo 1970; 8, 9, 10 - Bose 1971, Bose & Kar 1966, Bose & Maheshwari 1966; 11 - Hart 1963; 12 - Hart 1967, 1969; 13 - Virkki 1946; 14 - Potonie & Lele 1961; 15, 16, 17 - Lele 1966, Lele & Karim 1971, Surange & Lele 1956; 18 - Rigby & Schopf 1969; 19 - Barrett & Kyle, this symp.; 20 - Segroves 1972; 21, 22 - Balme 1964; 23 - Evans 1964; 24 - Balme 1957; 25 - McGowran & Harris 1967; 26 - Harris & McGowran 1971; 27 - Paten 1969; 28 - Douglas 1969, 29, 30, 31 - Evans 1969; 32 - Helby 1970 Localities from which samples have been examined in this study are also shown

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The published information ranges from fully illustrated microfloral assemblages, as in the Congo Basin, to mere mentions of ages obtained on the basis of palynology, as in the Chaco-Paraná Basin. Additionally, I have examined assemblages from glacigene sequences in the Paraná Basin, in the Salt Range of Pakistan, and in the Ohio and Wisconsin Ranges of Antarctica. These localities are also shown in Text-figure 1. The problems of comparing microfloras from widely separated areas are compounded by lack of a uniform taxonomy; to facilitate future comparisons the major forms discussed in this study are figured in Plates 1 and 2.

SOUTH AMERICA

In South America, the best known deposits of late Palaeozoic glacial rocks occur in the Paraná Basin, an intra-cratonic depression occupying large areas of southeastern Brazil, Uruguay and northeastern Argentina. Palaeozoic strata of the Paraná Basin extend westwards into the largely sub-surface Chaco-Paraná Basin (Padula & Mingramm, 1969), and thence even farther westward to connect with the Paganzo Basin and the Andean Geosyncline. Glacigene strata are best known from the Paraná Basin proper, where they are exposed along both eastern and western basin margins. Rocks of the eastern outcrop belt are referred to the Itararé Subgroup; this belt continues southward into Uruguay, where rocks of glacial origin are referred to the San Gregorio Formation. The distribution of outcrop areas and the localities mentioned in the text are shown in Text-figure 2. The distribution, nature, and thickness of the Itararé in the Paraná Basin has been reviewed by Frakes & Crowell (1969).

In the Chaco-Paraná Basin, glacial sediments are reported to occur rarely within the Sachoyaj Formation (of Late Mississippian age, according to Padula & Mingramm), but are abundantly represented within the overlying Charata Formation, which is equated at least in part with the

Itararé Subgroup. In the Paganzo Basin (the Rio Blanco Basin of Frakes & Crowell), the imprint of glaciation is slight. Strata containing diamictites and conglomerates of possible fluvioglacial origin occur in the lower section of the Paganzo Group, according to Azcuy & Morelli (1972), who reviewed the sedimentary characteristics of this basin. However, few details are yet available concerning the glacial nature of these deposits.

Palynological investigations have been carried out on late Palaeozoic strata throughout all three sections of the Paraná-Chaco-Paganzo Basin complex, but most are unpublished. In the Paganzo Basin, Menendez (1965, 1969) described microfloras from La Rioja province; these are from non-glacial strata probably equivalent to the lower section of the Paganzo Group. Menendez assigned a probable Westphalian age to the microflora, which is dominated by variously sculptured, acavate, trilete spore types, and is certainly older than Stage 1 of the Australian sequence. Subsequently, Menendez & Azcuy (1969, 1971) reported microfloras from the Lagares Formation, equivalent to the in-part glacigene lower section of the Paganzo Group. The spore-bearing formation is overlain by lavas dated isotopically at 295 million years, i.e. around the Westphalian-Stephanian boundary (Thompson & Mitchell, 1972). These microfloral assemblages are again older than Stage 1 types, although they are probably not as old as the '<u>Grandispora</u>' assemblage of the Sydney Basin.

A further locality within the general area of the Paganzo Basin is cited by Menendez (1969). This is at Bajo de Velis, where varve-like shales rest on crystalline basement. The shales have yielded a microflora which differs distinctly from those described above, containing monosaccate pollen types and rare disaccate striate forms, suggesting its equivalence with Stage 2 Australian microfloras, although data are presently somewhat sketchy. Within the Chaco-Paraná Basin, no details of palynological assemblages are yet available, although Padula & Mingram (loc.cit.) cite palynological evidence for the dating of both the Sachoyaj and Charata Formations.

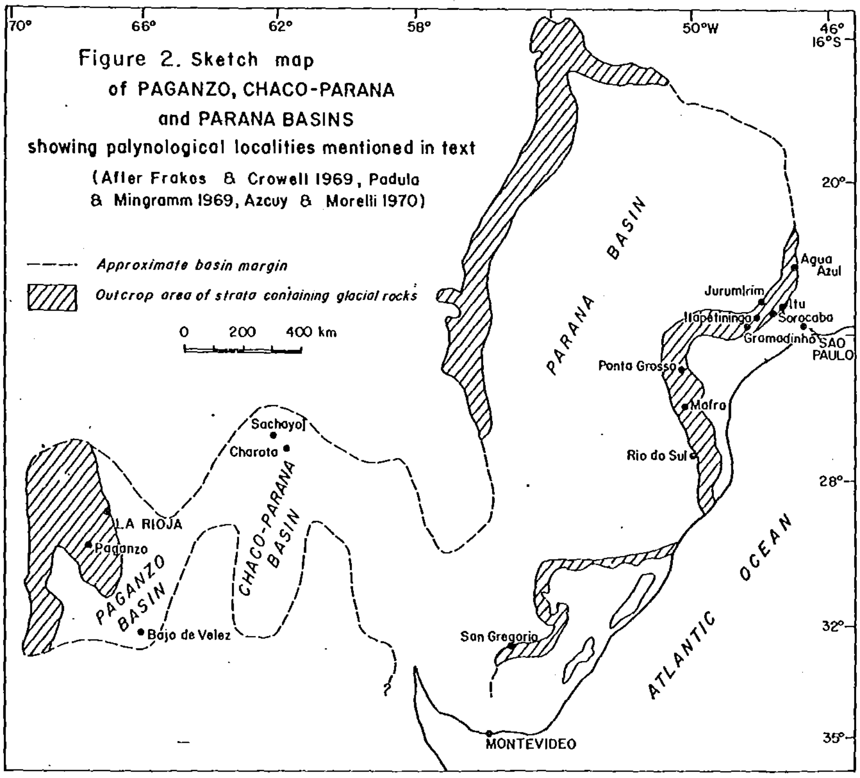

Figure 2. Sketch map of PAGANZO, CHACO-PARANA and PARANA BASINS showing palynological localities mentioned in text

(After Frakes & Crowell 1969, Padula & Mingramm 1969, Azcuy & Morelli 1970)

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In the Paraná Basin, published microfloral studies are concentrated in the Uruguayan sector of the eastern outcrop belt. Macchiavello (1963) recorded spores from the base of the glacial sequence near Tacuarembo in northeastern Uruguay. Bharadwaj (1969) in a general review of lower Gondwana formations, figured a microfloral assemblage from concretions in the San Gregorio Formation at an unspecified locality; the assemblage is a diverse one, with upward of twenty percent of disaccate, striate pollen types, a lower percentage of monosaccate types, abundant cavate, trilete spores, and, notably, a diversity and relatively high frequency of pollen of the Vittatina type. Such a composition suggests equivalence with Stage 3 microfloras in the Australian region. Detailed taxonomic treatment of individual form-species from the San Gregorio Formation is being undertaken by Marques-Toigo (1970) and Ybert & Marques-Toigo (1970).

For the present survey, productive samples were examined from seven localities in exposures of Itararé Subgroup rocks in Sao Paulo, Paraná and Santa Catarina states of southeastern Brazil. Stratigraphically, the samples range from the Itu Formation at the base of the sequence, through to the Itapetininga Formation at the top, although the relative stratigraphic position of many of the sampled sections is difficult to determine because of low regional dip and lack of detailed mapping in most areas. Lithologically, the samples examined included siltstones and diamictites, the latter frequently with sandy, recrystallized matrices. Sample rock types, with their stratigraphic positions, are listed in Appendix I.

Microfloras from the samples examined fall into two groups, although the number of samples studied to date is too small for this division to be more than tentative. Stratigraphically, the lowest sample examined came from quarries at Itu, where fine sandstones and siltstones, which have been termed varves (see Frakes & Crowell, 1969), rest on basement rocks. The microflora from this locality is dominated by trilete, cavate spore types (referable to the genera Densoisporites, Dentatispora and Indotriradites); monosaccate pollens make up about five percent of the assemblage, and striate disaccate pollens are present in very low frequencies. The presence of rare Striatiti suggests equivalence with Stage 2 of the eastern Australian sequence, or with its Western Australian correlate, the 'Microbaculispora' assemblage of Segroves (1972), which is known from the upper part of the glacial Nangetty Formation in the Perth Basin. Other localities where comparable assemblages occur are the Sorocaba - Itapetininga Road section (see Frakes & Figueiredo, 1967), where it occurs in a massive mudstone at the base of the sequence at 121 km, and from Gramadinho, where the assemblage is found in sediments of the Gramadinho Formation.

The remainder of the samples yielded a microflora which shows a considerable increase in diversity from that described above. This second assemblage was recovered from supposed mudflow units at 124 km and 165 km in the Sorocaba Road sequence (see Frakes & Figueiredo, 1967), from pebbly siltstone at Rio do Sul, from diamictites at Mafra, Agua Azul, and Jurumirim, and, in a poorly preserved state, from diamictites at Ponta Grossa. The microflora from all of these localities is characterized by a content of Striatiti ranging from five to fifteen percent; by comparable percentages of monosaccate pollens, and by a diversity of pollen of the Vittatina type. Cavate, trilete spore forms occur in quantities ranging from twelve to twenty five percent. This last group fluctuates widely in abundance throughout late Palaeozoic sediments in Australia, and its occurrence seems to be controlled by local factors; hence it is not considered to be of great stratigraphic import.

The abundance and diversity of Vittatina type pollens in these glacial sediments is of some interest. Included in the group in Paraná Basin assemblages is a species which bears transverse thickened bands on the distal face, at right-angles to the prominent proximal ribs, and which is closely similar to the species V. costabilis Wilson. Pollen of this type has previously been recorded only from the northern hemisphere; it occurs in Upper and Lower Permian rocks in the U.S.A. (Wilson, 1962; Tschudy & Kosanke, 1966), in Upper Permian rocks of the U.S.S.R. (Samoilovitch, 1961), and has recently been reported from strata of possible Pennsylvanian age in Canada (Barss, 1972). Other forms of stratigraphic interest occurring in the Itararé rocks include forms close to, but probably not conspecific with, the species Verrucosisporites pseudoreticulatus Balme & Hennelly, and Marsupipollenites triradiatus Balme & Hennelly. In Australia, these species are characteristic of Stage 3 microfloras, as these are defined by Evans (1969), although M. triradiatus appears late in Stage 2. The presence of closely related species in the Itararé sections, together with the high relative frequency and diversity of Vittatina species, and of striate bisaccate pollens, is compelling evidence for equating these assemblages with Stage 3.

Preliminary studies, then, suggest that Stage 2 microfloras may be present in the lower parts of the Itararé Subgroup, while Stage 3 assemblages occur in the higher parts of the sequence. A basic similarity with the Australian sequences seems indicated, although the distribution of assemblages remains tentative in view of the poor stratigraphic control. Further, Helby & Runnegar (pers. comm.) have indicated that Stage 1 assemblages might also be present within exposed Paraná Basin sequences.

PAKISTAN AND INDIA

In the Indian sub-continent, Palaeozoic glacial rocks occur in two distinct areas; in elongate depressions on the Precambrian shield of peninsular India, and lying unconformably on older sedimentary sequences in the Salt Range of Pakistan and in the Himalayas. The term Talchir Formation, or more informally, Talchir Stage, includes basal boulder beds and overlying shale units. In peninsular India, the Talchir Boulder beds which occur at the base of the sequence are now recognized as being probably heterochronous in the different basins in which they are known to occur (Ghosh & Mitra, 1972). In the Salt Range, the basal boulder beds (the 'Tobra Beds' of earlier usage) show marked variation in thickness between different areas. Teichert (1967) recognized three facies within the Salt Range boulder beds - an eastern tillitic facies grading upwards into marine sandstone, a freshwater silty facies with sparse boulders, characteristic of the central Salt Range, and, in the western Salt Range and Khisor Range, a mixed diamictite and sandstone facies, at least partly of marine origin.

Most of the spore and pollen assemblages described from the sub-continent have come from shale sequences overlying the boulder beds. In peninsular India palynological assemblages have been described from the Talchir 'Needle Shales', by Surange & Lele (1956) and Surange (1966), and from siltstones above the boulder beds by Lele (1966). Again, in the Salt Range, the major work of Virkki (1946) was based on the palynology of samples taken from above the boulder beds at Kathwai. However, Lele & Karim (1971) have recently described a diverse spore assemblage from the matrices of boulder beds in the Jayanti Coalfield, and Balme (in Teichert, 1967), briefly reported an assemblage from the boulder bed sequence at Zaluch Nala in the Salt Range.

In the present survey, two further samples from the Zaluch Nala sequence have been examined. One of these samples comes from the 'C member' of the section described by Teichert, the unit which also furnished the samples examined by Balme; the other comes from the basal or 'A unit' of the sequence. Text-figure 3 shows sampled horizons. Preservation of spores and pollen from the matrices of diamictites in this sequence is excellent, although only in the higher sample were they abundant enough to

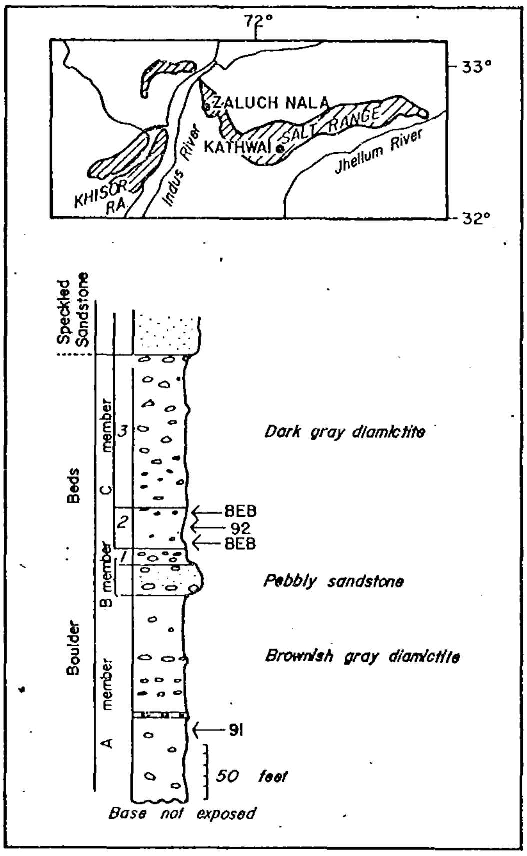

Figure 3: Sketch map of Salt Range area, Pakistan, and section at Zaluch Nala, with sampled horizons (after Teichert, 1967)

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allow quantitative estimates of relative frequencies. The 'C unit' assemblage is dominated by trilete spores, with cavate, cingulate forms referable to the genus Dentatispora, and acavate ornamented forms belonging to the genera Horridotriletes or Lophotriletes each making up roughly twenty five percent of the total assemblage. Monosaccate pollens make up some twelve to fifteen percent of the total, and striate disaccate forms approximately two percent. This frequency of disaccate Striatiti suggests correlation with Australian Stage 2 microfloras. The presence of acritarchs probably referable to the genus Cymatiosphaera in the boulder bed samples may be an indication of at least near-marine depositional conditions, since this form does not appear to have been recorded from non-marine strata.

Virkki's (1946) descriptions of microfloras from beds immediately overlying the boulder beds at Kathwai suggest rather poorly diversified assemblages from the 1½ ft and 4 ft horizons above the boulder bed datum, although no quantitative data were given. Monosaccate pollens are common, and there is a suggestion of a slightly greater abundance and diversity of Striatiti. Probably the assemblages are Stage 2 equivalents, but there are insufficient data for a definite assessment.

In the peninsula, the microfloras described by Lele & Karim (1971) from Jayanti Coalfield came from boulder beds which the authors claim may have been deposited under fluviatile conditions. Further, on the basis of local stratigraphy, they indicate that the beds may lie well above the base of the Talchir Formation. The microflora from the boulder bed is dominated by monosaccate pollens, and by disaccate forms which show considerable diversity. The content of Striatiti, however, is low, again suggesting correlation with Stage 2. From the South Rewa coal basin, the assemblage described by Potonié & Lele (1961), which represents a still higher horizon in the Talchir Formation, is basically similar to that from the Jayanti area. Both of the peninsula Talchir assemblages differ little from those of Zaluch Nala; they do, however, lack the component of cavate, trilete spore types, which may be of local significance only.

ANTARCTICA

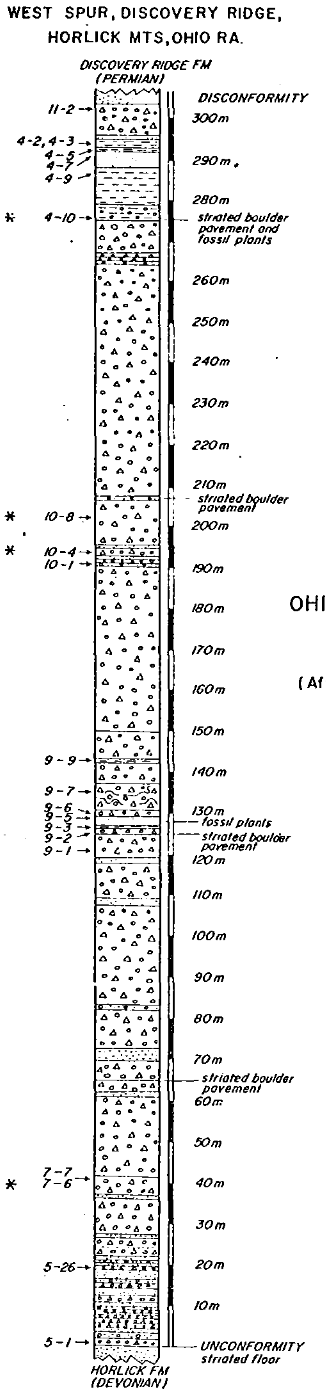
Late Palaeozoic rocks of glacial origin crop out across a wide region of Antarctica, occurring in the Transantarctic mountains from Victoria Land to the Pensacola Mountains. They are also known from the Ellsworth Mountains of West Antarctica. The distribution, nature, and thickness of these deposits were reviewed by Frakes, Matthews & Crowell (1971). In the West Antarctic basin - the Ellsworth and Pensacola Mountains - the sequences comprise thick, essentially unbedded diamictites of the Whiteout Conglomerate and the Gale Mudstone. In the Ohio and Wisconsin Ranges, the glacial deposits are thinner, and are referred to the Buckeye Formation, which is made up of relatively thin diamictite units alternating with shale, sandstone, and conglomerate. Striated boulder pavements and grooved sandstone beds occur at several levels within the glacial sequence at these localities, indicating interruption of deposition by periods of active erosion by ice.

Glacigene rocks also occur in southern Victoria Land (the Beardmore Basin of Frakes et al.), where sequences consisting of varying proportions of diamictite, sandstone, siltstone, and shale have been referred to the Pagoda, Darwin, and Metschel Tillites. Detailed descriptions of tillitic sequences in South Victoria Land and the Darwin Mountains are given by Barrett & Kyle (in press).

For the most part, the Palaeozoic glacigene rocks of Antarctica are unfossiliferous. Poor preservation characterises microfloras from the entire region of the Transantarctic Mountains, probably because of organic metamorphism resulting from intrusion of Ferrar Dolerites. However, Schopf (in Long, 1965) and Rigby & Schopf (1969) recorded the presence of rare spores in the middle of the Buckeye Formation in the Ohio Range, an assemblage dominated by monosaccate pollens referable to *Parasaccites triangularis* (Mehta). Of greater significance in the inter-continental correlation of the Antarctic glacials is the assemblage reported by Barrett & Kyle from the upper part of the Darwin Tillite at Colosseum Ridge in the Darwin Mountains. This microfossil suite is the most diverse yet recovered from Upper Palaeozoic strata in the Transantarctic Mountains, and includes a small proportion of disaccate striatitid pollens, in addition to a relatively high frequency of monosaccate types, both features which distinguish Stage 2 microfloras. The microflora also contains *Marsupipollenites triradiatus*, which occurs in the younger parts of the Stage 2 interval in Australia.

In the present study, nineteen samples were processed from the Buckeye Formation in the Ohio Range, and seven from outcrops in the Wisconsin Range (Text-figure 4). Only four samples in the former section and five in the latter were productive, and in these, preservation was extremely poor and only a limited number of sporomorph species could be identified.

In the Ohio Range, the Buckeye Formation disconformably overlies the marine Lower Devonian Horlick Formation, and is in turn overlain by the Discovery Ridge Formation. Palynologically, the most productive sample in the sequence came from a dark grey, recrystallized diamictite forty metres above the base. Monosaccate pollens dominate the assemblage recovered from this sample, including mostly types referable to *Parasaccites* and *Plicatipollenites*, but with rare specimens of a *Potonieisporites* species; trilete spores, including *Microbaculispora tentula* Tiwari and *Verrucosisporites* sp., are less common. No disaccate Striatiti were observed in this sample or in any throughout the sequence, but their absence may well be attributed to a preservation factor. The sample



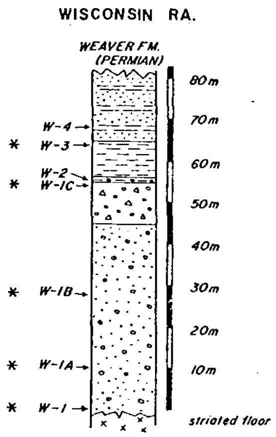
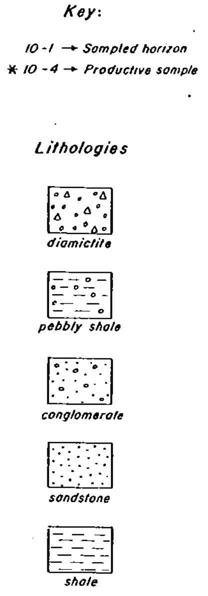


Figure 4.
BUCKEYE FORMATION,
OHIO AND WISCONSIN RANGES,
ANTARCTICA

(After Frakes, Matthews and Crowell, 1971)



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described above is notable for the abundance of recycled Early Devonian spores which it contains, deriving from erosion of the Horlick Formation or its equivalents, which contains a relatively diverse microflora (Kemp, 1972). Of particular interest in the diamictite is the presence of acanthomorph acritarchs, suggestive of a marine influence. It is not, however, possible at this stage to establish whether the acritarchs are in place or are recycled from older sediments, though they do not occur in the Horlick Formation. Most acritarchs in the Buckeye are referable to the genus Multiplicisphaeridium Staplin, which ranges from the Silurian to the Triassic. Within the Buckeye Formation, recognizable recycling is confined to the lower part of the unit. A further aspect of the Ohio Range microfloras which is of interest is that they reflect a parent vegetation which apparently flourished in short interglacial periods: the presence of striated pavements above the productive intervals confirms that the floras do not represent a post-glacial vegetation.

The present study provides the first record of spores from Buckeye Formation tillites of the Wisconsin Range. All samples from the basal units of diamictite and conglomerate yielded spores, although they were intensely carbonized and identified only with difficulty. Forms identified include an apparent diversity of Parasaccites and Plicatipollenites types, Potonieisporites, Puctatisporites gretensis, Cycadopites, Verrucosisporites, and rare non-striate bisaccates. No Striatiti were observed, nor is there any evidence of recycling.

In summary, microfloras from glacial deposits of the Ohio and Wisconsin Ranges are suggestive of Stage 2 of the Australian scheme. This designation is, however, inconclusive because of the poor preservation of the material recovered. The assemblage described from the Darwin Mountains by Barrett & Kyle appears to represent late Stage 2 microfloras.

As yet, none of the available palynological data from the Antarctic glacial deposits confirm the suggestion made by Rigby & Schopf (1969), that these might be younger than similar deposits on other continents, a suggestion which was based on the identification of species of Glossopteris and Gangamopteris in units conformably overlying the glacials.

AFRICA

No samples from southern Africa were examined directly during the present investigation. Published information from that continent is meagre; most comes from the Congo Basin, where Bose (1971) recently summarized the results of earlier investigations by Bose & Kar (1966), and Bose & Maheshwari (1966), concerning the palynology of the 'Assises glaciares et periglaciares' of Cahen (1954). The oldest assemblage from this series came from the Elila River area (see Text-figure 1). This microflora has some features in common with the Paraná Basin assemblages, notably in its diversity of Vittatina type pollens, which include the northern V. costabilis forms. The frequency of striate saccate pollen types (probably greater than six percent, according to Bose & Kar, p. 140) probably equates with lower Stage 3 assemblages in Australia, although most of the trilete spore species which distinguish that unit are missing.

Farther south in Africa, Hart (1963, 1967, 1969) has reported the palynological results of examination of Dwyka samples, although only in one case, the Salisbury borehole (Hart, 1963), are location and stratigraphic horizons given. At this locality, in the Orange Free State, striate saccate pollens are present in very low frequencies to the base of the sampled sequence, i.e. to the base of shales immediately above a tillitic unit. The presence of Marsupipollenites triradiatus, V. pseudoreticulatus, and Granulatisporites trisinus indicate equivalence with Stage 3 at this horizon. The precise relationship of the 'Camerati' florizone, to which Hart assigns most Dwyka sediments, with the Australian microfloral stages is not determinable; both Stages 1 and 2 could possibly be represented.

Recent unpublished studies by R. Falcon from a borehole in the mid-Zambezi Valley show the presence of Stage 2 microfloras in Dwyka varves and conglomerates in a pre-Karroo valley (R. Falcon, pers. comm., 1972).

FALKLAND ISLANDS

During the present investigation some fifteen samples from the Lafonian Diamictite and the overlying Port Sussex Formation of the late Palaeozoic Falkland Island sequence were examined palynologically. Lithologically, the samples included varve-like dark siltstone, diamictite, coaly shale, and fine grey sandstone, but all were barren of spores and pollen, although fine woody fragments were common. The reason for the apparent natural loss of any palynomorphs from the sequence is unknown.

SUMMARY AND CONCLUSIONS

The distribution of microfloras within the glaciated Gondwana area is summarized in Text-figure 5. Some of the most important features of this distribution are:

1. Only in one locality, that of the Paganzo Basin, are pre-Stage 1 microfloras recorded from the same stratigraphic horizon as glacially derived sediments. Broadly comparable microfloras in Australia are not associated with any traces of glacial conditions.

2. Stage 1 microfloras are presently known definitely only from Australia, although their possible presence in South America has been mentioned. Within Australia, they are recorded in the main from areas which were peripheral to the main continental glaciation. In at least three

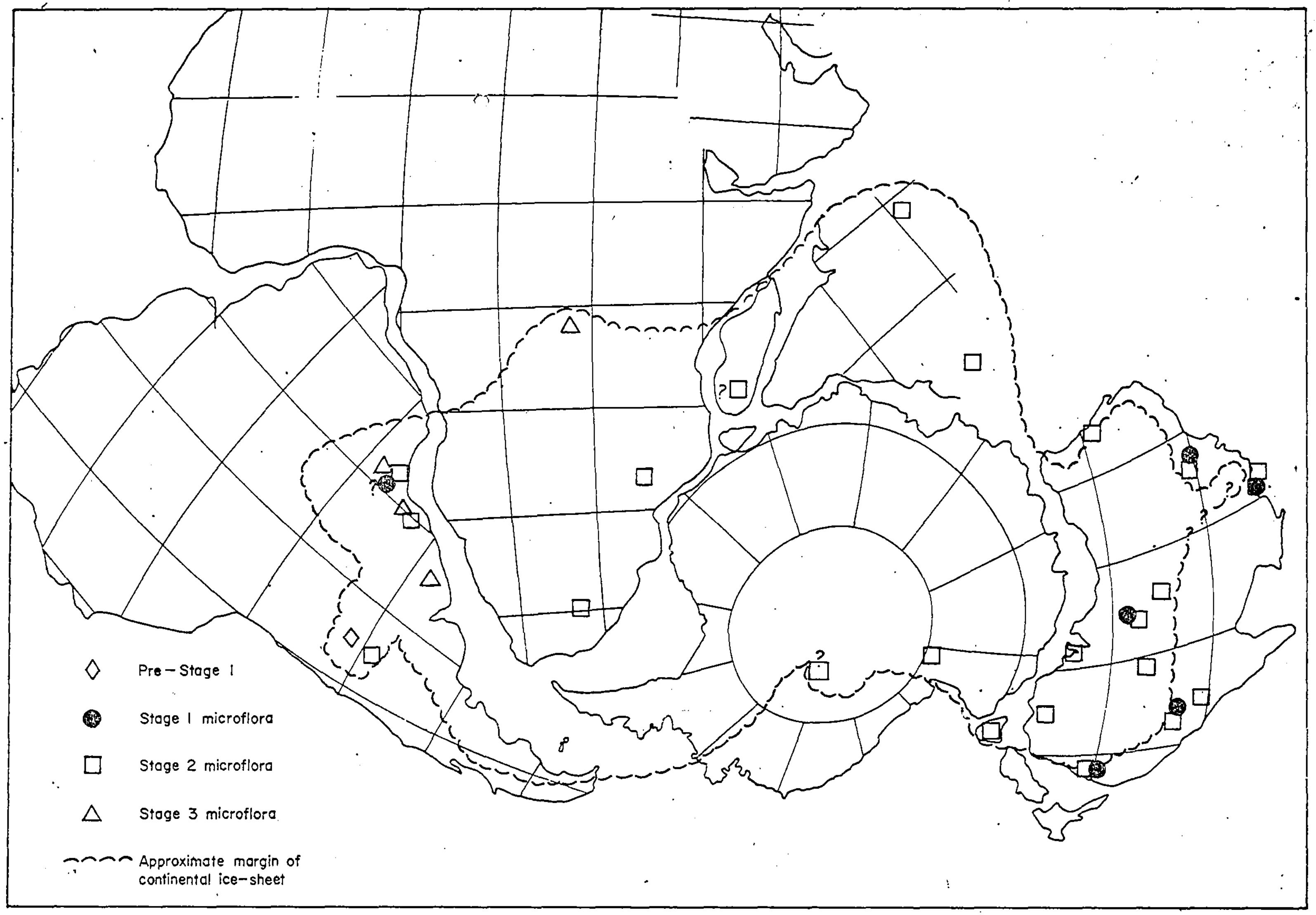

Figure 5: Gondwanaland reassembly showing localities of microfloras discussed.

basins, relatively thick, essentially non-glacial, older Carboniferous sequences underlie strata bearing the Stage 1 assemblages.

3. Microfloras of Stage 2 are the most widespread in their geographic distribution, occurring on all continents.

4. Stage 3 microfloras have been recovered from tillitic matrices in the Paraná Basin, and comparable microfloras occur in glacially derived sediments in the Congo Basin. In Australia, similar microfloras occur most commonly in strata which were deposited in post-glacial environments (Evans, 1969). The presence of Stage 3 microfloras at several localities within Itararé Subgroup rocks of the Paraná Basin is in agreement with other fossil evidence, i.e. the presence of Glossopteris (Rigby, 1972), and of marine invertebrates (Amos & Rocha-Campos, 1972), which suggests that at least part of the glacial sequence is relatively young.

Interpretation in terms of any model remains ambiguous, probably at least in part because of the sparseness of data points. However, some preliminary conclusions may be cautiously drawn. In terms of a glacial migration model, it might be expected that there would be a concentration of older microfloras in the western Gondwanaland sector, i.e. in South America and southern Africa. To date there has been recorded one occurrence of pre-Stage 1 microfloras in this region, which is that in the Paganzo Basin. This remains the oldest 'glacial' microflora yet recorded, although the nature of the glacial sediments with which it appears to be contemporaneous is obscure. It is conceivable that microfloras of the Sachoyaj and Charata Formations of the Chaco-Parana Basin are similar to these, and if so, they would reinforce the record of older microfloras in west Gondwanaland glacials, but as yet there is no information on their constitution.

Across the bulk of the Gondwanaland reassembly, most glacial sediments yield microfloras which suggest that, within the limits of palynological resolution at least, they are essentially synchronous.

The record indicates that tillitic sequences of the Talchirs in India, much of the Itararé in Brazil, the glacial sequences of the Transantarctic mountains, and possibly much of the Dwyka Tillite yield microfloras which are essentially similar to those which occur in glacial and near-glacial sediments in east and western Australian basins. The earliest phase of these microfloras, referred to Stage 1 of the Australian sequence, appears to have been preserved in areas which were essentially peripheral to the main continental glaciation in Australia. There is a suggestion that these occur in similar stratigraphic position in the Paraná Basin, but further work is required to establish the distribution there.

At the other end of the scale, it might be expected that glacial sediments in eastern Gondwanaland would show evidence of their comparative youth by their association with relatively young microfloras. This does not seem to be the case, since it is in the western sector, i.e. in the Paraná Basin, and in the Congo, that glacially derived sediments yield Stage 3 microfloras. In the Paraná Basin, these diverse assemblages have been extracted from the tillites themselves. In Australia, similar assemblages occur predominantly in sediments which are suggestive of deposition in post-glacial environments, although some glacial impress is present in Bowen Basin sequences of this age and younger, and Tasmanian sequences containing dropstones have not been investigated palynologically. There does not, however, seem to be anything in the palynological record to support the contention that glaciation was past in west Gondwana regions at an earlier date than the bulk of the Australian glaciation.

The palynological evidence, however, cannot be entirely used to negate the possibility of some migration of ice centres, for the following reasons. First, there is no certainty that the oldest microfloras have yet been recovered from the glacial sequences. Most of the data have come from the margins of basins, and it is possible that older microfloral material may yet be recovered from deeper basin centres. Second, the possibility that such movement has occurred must be considered, but too rapidly to be detected by current palaeontological means. The presence of probable Westphalian or Namurian faunas below and early Sakmarian faunas above the glacial sequences in Australia brackets those deposits as having been laid down through an interval which may be as long as forty million years. Currently, we can recognize two subdivisions within that interval on a palynological basis (Stages 1 & 2); we have no means of assessing the relative duration of each, but this could be as long as thirty million years, which is ample time for quite significant movement of continents.

One final point which warrants some comment concerns the extent to which the microfloral assemblages which have been defined in this Late Palaeozoic interval of time are influenced by environmental factors. There seems little doubt that such extreme environmental conditions have influenced the composition of the floras to a marked degree - whether or not the distinction between the microfloral Stages 1 and 2 is purely one of a change from a very rigorous to a slightly milder regime is presently not clear. The change is marked by an increase in diversity from Stage 1 to Stage 2, but there are species changes as well, and the microfloral change is marked by a change of some magnitude in the associated plant macrofossil assemblage, from a Rhacopteris flora (or a Gondwanidium flora in Australia, according to Rigby, 1973) into a Gangamopteris - Glossopteris assemblage, so significant evolutionary changes may also be involved.

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APPENDIX

LOCALITY AND LITHOLOGY OF SAMPLES EXAMINED FROM PARANÁ BASIN, BRAZIL

Sample No.	
205	Laminated light grey fine sandstone and interbedded dark grey siltstone. Quarry at Itu, near top of exposed section.
213	Massive dark grey mudstone. Sorocaba-Itapetininga Rd., 121.5 km, mudstone unit near base of sequence.
202	Greenish-grey massive siltstone. Sorocaba-Itapetingina Rd., 124 km.
212	Light brown sandy diamictite with sparse pebbles. Sorocaba-Itapetininga Rd., 155 km, mudflow near top of sequence.
204	Dark grey, massive, recrystallised mudstone 12 km E of Rio do Sul, within 50 m of base of Itararé section.
207	Dark grey calcareous siltstone with sparse pebbles. Ituporanga - Rio do Sul Rd., at 20 km.
203	Dark grey diamictite, sandy, recrystallised matrix. Highest diamictite in Mafra sequence; quarry 20 km west of Mafra on road to Coninhus.
201	Massive, dark grey recrystallised siltstone with rare small pebbles. Road metal quarry, slightly west of Agua Azul, on road to San Mateus do Sul.
215	Dark grey diamictite, some bedding. Gramadinho - Curitiba Rd., at 191 km.
210	Dark grey diamictite. 1 km SE Railway Stn. at Jurumirim.

PLATE 1

PALYNOMORPHS FROM THE ITARARÉ SUBGROUP, PARANÁ BASIN, BRAZIL

All magnifications X500. Localities of figured specimens are indicated.

Figure	
1	*Brevitriletes* sp. cf. *B. jhingurdahiensis*/Sinha, Itu.
2	*Microbaculispora tentula* Tiwari. Itu.
3, 4	*Lophotriletes* - *Horridotriletes* sp. Itu.
5	*Verrucosisporites* sp. Itu.
6	*Anapiculatisporites* sp. cf. *A. spinosus* (Kosanke). Itu.
7, 8	*Punctatosporites* sp. cf. *A. minutus* Ibrahim. Sorocaba Rd.
9	*Retusotriletes diversiformis* (Balme & Hennelly), Itu.
10	*Granulatisporites* sp. cf. *G. quadruplex* Segroves. Sorocaba Rd.
11	*Verrucosisporites* sp. cf. *V. pseudoreticulatus* Balme & Hennelly. Sorocaba Rd.
12, 13, 16	*Indotriradites* spp. Itu.
14	*Punctatisporites gretensis* Balme & Hennelly. Itu.
15, 17, 20	*Dentatispora* spp. Itu.
18, 19	*Spongocystia* sp. Gramadinho.
21	*Densoisporites* sp. Itu.
22	*Vittatina costabilis* Wilson. Sorocaba Rd.
23	*Vittatina* sp. cf. *V.* sp. *L.* Jansonius. Agua Azul.
24, 25	*Vittatina* spp. Gramadinho.
26, 29	*Vittatina* sp. cf. *V. subsaccata* Samoilovitch. Gramadinho.
27	*Taeniaesporites* sp. Mafra.
28	*Protohaploxypinus* sp. Gramadinho.
30	*Parasaccites* sp. cf. *P. mehtae* (Lele). Itu.
31	*Plicatipollenites* sp. cf. *P. indicus* Lele. Itu.
32	cf. *Deusilites* sp. Sorocaba Rd.


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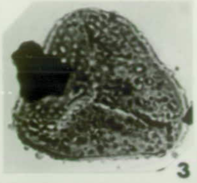
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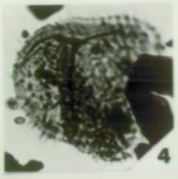
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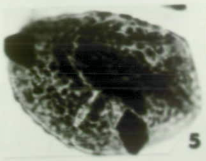
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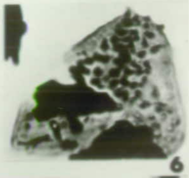
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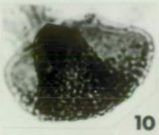
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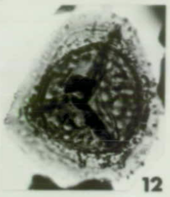
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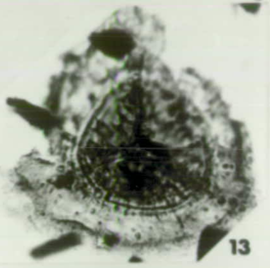
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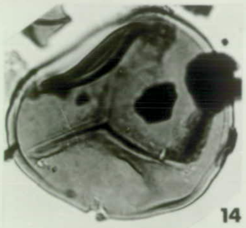
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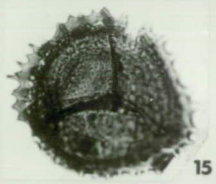
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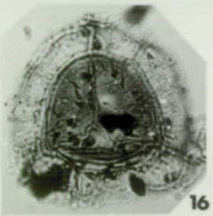
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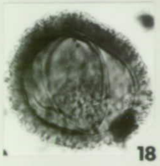
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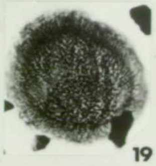
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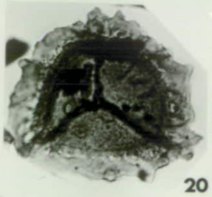
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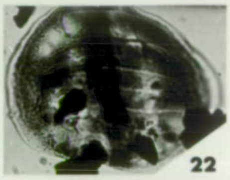
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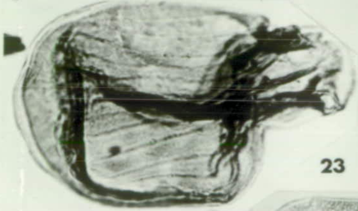
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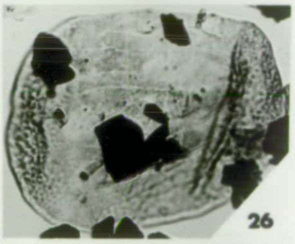
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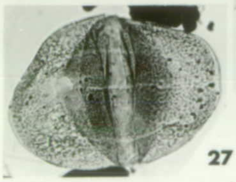
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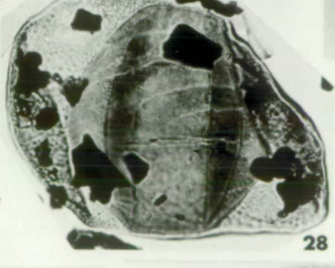
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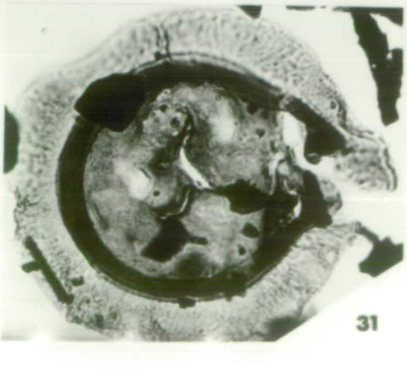
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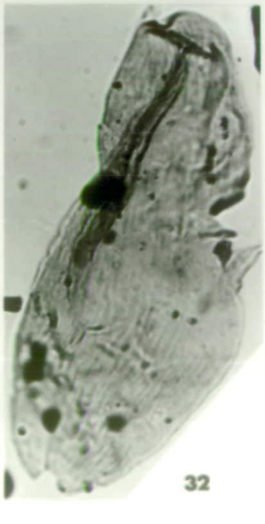
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PLATE 1

PLATE 2

PALYNOMORPHS FROM TALCHIR FORMATION, ZALUCH NALA (FIGS 1-15, SAMPLE 92) AND FROM BUCKEYE TILLITE, OHIO RANGE, ANTARCTICA (FIGS 16-24).

All magnifications X500.

Figure	
1	*Brevitriletes* sp. cf. *B. unicus* (Tiwari)
2	*Lophotriletes* sp. cf. *L. scotinus* Segroves
3, 4	*Horridotriletes* - *Lophotriletes* sp.
5	*Potonieisporites neglectus* Potonié & Lele
6, 7	*Dentatispora* sp.
8	?*Vesicaspora* sp.
9, 10	*Cymatiosphaera* sp.
11	*Protohaploxypinus* sp. cf. *P. goraiensis*
12	*Parasaccites* sp. cf. *P. mehtae* (Lele)
13	?*Schizosporis* sp.
14	*Caheniasaccites* sp. cf. *C. ovatus* Bose & Kar
15	*Plicatipollenites trigonalis* Lele
16	Acanthomorph acritarch indet.
17, 18	*Multiplicisphaeridium* sp.
19	*Microbaculispora* sp. cf. *M. tentula* Tiwari
20	*Verrucosisporites* sp.
21, 23	*Potonieisporites* sp.
22	*Plicatipollenites* sp.
24	?*Vestigisporites* sp.


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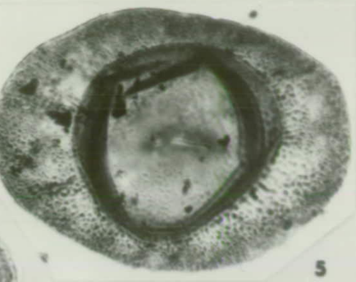
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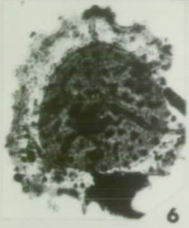
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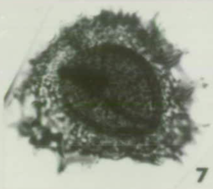
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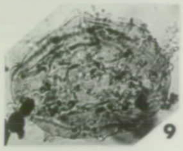
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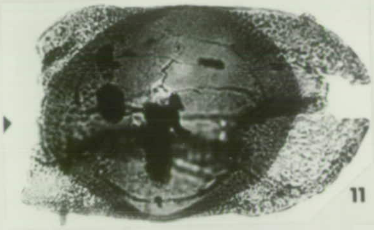
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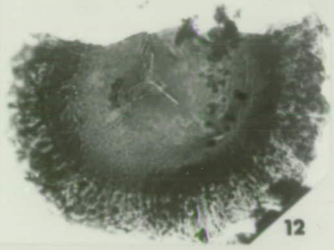
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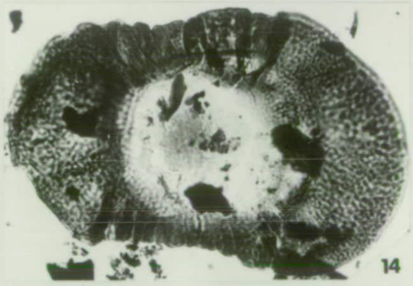
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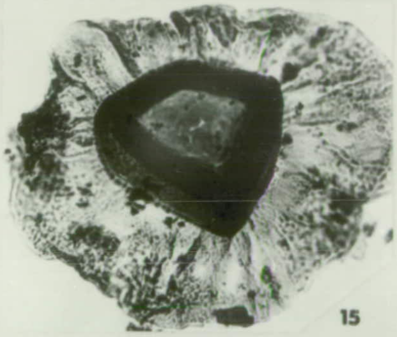
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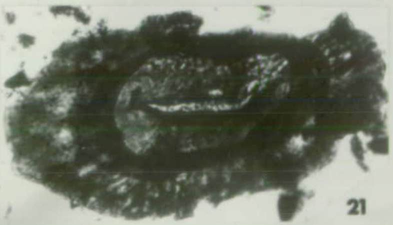
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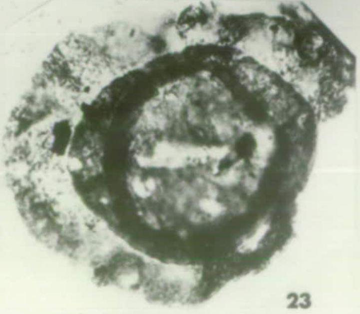
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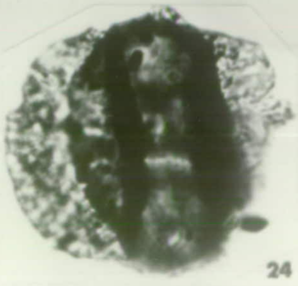
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PLATE 2

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Geology and Geophysics
Negative No. GA/8401