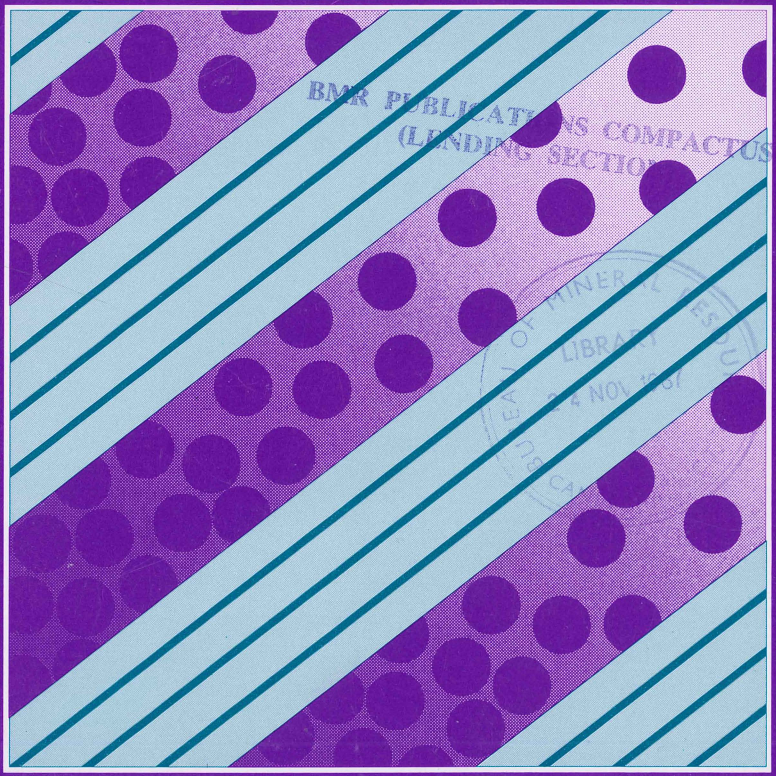
GROUNDWATER 2

Studies in Hydrogeology

RECONNAISSANCE PALYNOLOGY OF SELECTED BOREHOLES IN THE WESTERN MURRAY BASIN, NEW SOUTH WALES

ELIZABETH TRUSWELL



BUREAU OF MINERAL RESOURCES, GEOLOGY & GEOPHYSICS

DIVISION OF CONTINENTAL GEOLOGY

RECORD 1987/24

Record 1987/24

Reconnaissance palynology of selected boreholes in the central Murray Basin, New South Wales

Elizabeth M. Truswell

Record 1987/24

Reconnaissance palynology of selected boreholes in the central Murray Basin, New South Wales

Elizabeth M. Truswell

Division of Continental Geology
Bureau of Mineral Resources
Canberra

FOREWORD

In order to develop an understanding of groundwater movement in the Murray Basin, it is necessary to establish the geometry of the aquifers which act as the pathways for groundwater movement and of the aquitards which impede that movement. Understanding a groundwater system as complex as the Murray Basin requires application of all the techniques that we are able to bring to bear.

In this report, Dr E.M. Truswell clearly demonstrates how the study of spores and pollen can be used to put time lines through the basinal sequence and that these can then be used as the basis for defining changes in sedimentary patterns.

One of the most important features of the work is that it potentially provides a system for zoning the Renmark Group. There is increasing evidence that groundwater pressures in the Renmark Group, the deep aquifer system that underlies much of the basin, may exert a dominating influence on the behaviour of shallow water in the basin including areas where there are major salinity problems. Therefore the development of a better understanding of the Renmark Group may prove to be especially critical to overcoming the problems of salinization in the basin.

Peter J Cook
Chief
Division of Continental Geology

ABSTRACT

Preliminary palynological examination has been made of selected cuttings samples from six boreholes in the central Murray Basin, New South Wales. The methodology used combines standard zonal biostratigraphy with quantitative analyses of spore and pollen assemblages. Results of the study show; 1, the presence of Early Cretaceous (Neocomian to Albian) non-marine sediments in the Mitfords Corner borehole, at the northern end of the Wentworth Trough; 2, that sediments assigned lithologically to the Upper Renmark Group contain equivalents of the mid to late Miocene *Triporopollenites bellus* Zone, as demonstrated by sequences in the Mitfords Corner and Nambucurra boreholes; 3, that sediments identified lithologically as Lower Renmark Group can be assigned to the interval encompassing the Lower *Nothofagidites asperus* to Lower *Proteacidites tuberculatus* Zones, spanning the Middle Eocene to Early Oligocene; these zones have been identified in the Lake Garnpung, Arlington and Iona bores; 4, that sediments of probable Pliocene age, with relatively high frequencies of grass, chenopod and Asteraceae pollen, occur in the upper part of the sequence penetrated at Bramah.

Reconnaissance palynology of selected boreholes in the central Murray Basin, New South Wales

Introduction: This report documents preliminary palynological biostratigraphy of selected samples from six boreholes in the central part of the Murray Basin, New South Wales. The boreholes, at Mitfords Corner, Nambucurra, Lake Garnpung, Arlington, Iona and Bramah, (Figure 1), were drilled during 1986 as part of the Murray Basin Hydrogeological Project; this project, undertaken jointly by the Division of Continental Geology, BMR, and NSW Water Resources Commission, has as its aim the improved understanding of groundwater flow in the basin in the southwest regions of New South Wales.

Cuttings samples from the above boreholes were examined to provide reconnaissance biostratigraphy and time control during the early stage of the project. The data obtained complement more detailed analyses being undertaken of fully cored holes drilled during the project at Neckarboo Ridge, Manilla, Woodlands, Piangil and Hatfield.

The Murray Basin Hydrogeological Project has as its aim the development of an improved understanding of the groundwater regime of the basin, by elucidating the stratigraphic and structural controls on groundwater flow. The geometry of economically important aquifers and their hydrogeochemistry is clearly influenced both by the configuration of the underlying basement (see Brown & Stephenson, 1986) and by facies variations within the Cainozoic sediment sequence. While the influence of basement configuration has long been recognized as imposing significant boundary conditions on groundwater flow in the deeper aquifers, it is only recently that attention has been focussed on the role of aquitards in the basin's hydrodynamics. The most prominent aquitard in the central western part of the Murray Basin is the Geera Clay-Winnambool Formation which forms a permeability barrier to groundwater throughflow in the Renmark Group aquifers. The current drilling project is designed to improve the understanding of the spatial distribution of the Geera Clay in an area where data are presently insufficient, and to provide systematic data for preparation of 1:250 000 scale hydrogeological maps.

The Geera Clay and associated lithological units

The Geera Clay forms an arcuate band extending from southern, through southwest Victoria, into southwestern New South Wales and into northern South Australia. Its presence results in the stratigraphic thinning of the Renmark Group, which may be expressed at the landsurface by active discharge zones such as the salt lakes to the west of the Darling River in New South Wales; fossil discharge zones such as the gypsum playas of the Western Riverine Plain and the Willandra Lakes system occur around the perimeter of the Geera Clay.

Deposition of the Geera Clay probably reflects a sea-level rise commencing about the early Late Oligocene (Brown, 1983; Brown & Stephenson, 1986). This event is reflected in the deposition of shallow marine carbonates (Ettrick Formation, Gambier Limestone, Mannum Formation, Morgan Limestone, Duddo Limestone) in the west of the basin. These calcarenites grade, in the north and east, into a zone of calcareous glauconitic clay, the Winnambool Formation, deposited in restricted platform and lagoonal environments. Further east, these grade in turn into the black, carbonaceous, occasionally shelly and glauconitic or dolomitic clays of the Geera Clay. This unit seems likely (Brown, 1983) to have been deposited in a series of interdistributary bays and tidal flat environments. To the east and north it interfingers with fluvio-lacustrine sands, peats and clays of the Olney Formation of the Renmark Group. These stratigraphic relationships are shown in Figure 2.

The Geera Clay and contemporaneous units are separated by an erosional unconformity from the Late Miocene and Pliocene Bookpurnong Beds in the west, and the Calivil and Shepparton Formations to the east, deposited during the last major marine transgression into the basin.

Age control on the Geera Clay has been provided by foraminiferal determinations. Most recently, Lindsay (1983) examined the sequence in the SADME Oakvale 1 corehole in the northwestern Murray Basin, and was able to provide foraminiferally-based ages which enable some points within the sequence to be tied to international timescales, and to the sea-level curve of Vail et al. (1977).

The age determinations establish the base of the Geera Clay within the sequence at that locality as being probably of P21 (Late Oligocene, 28-32 Ma) age; the highest datable unit within the clay was identifiable in terms of the Australian Longfordian Stage (approximately N5, 19-22 Ma). Environmentally restricted faunas in the upper part of the unit make it difficult to place precise ages on that part of the sequence, and hence to date firmly the unconformity which bounds the top of this marine depositional phase. Lindsay, however considers that the unit extends into the early middle Miocene, although how much of the middle Miocene is represented is unknown. Palynological age determinations, which have a much coarser resolving power, confirm this upper age limit in a general way only (Truswell et al., 1985). The upper age limit of the Geera Clay thus remains undetermined.

The Miocene fluvial sediments which interfinger with the Geera Clay to the north and east are lithologically indistinguishable from the underlying Eocene sediments; all are included within the Olney Formation of the Renmark Group. A method independent of lithology is therefore required to distinguish between the Renmark Group aquifers. This is important because of the marked salinity stratification and significant head differentials which exist through the sequence. To the east of the Neckarboo Ridge the least saline groundwaters and highest potentials occur in the Eocene Renmark sediments; conversely the most saline waters and lowest potentials occur at the top of the Renmark sequence. Palynology may provide the necessary tool to unravel the depositional history and chemical genesis of groundwaters in the Renmark Group aquifers.

Previous palynological investigations in the Murray Basin Cainozoic: problems and methodology.

Cainozoic deposits in the Murray Basin, except where they have been subjected to weathering or to the prolonged percolation of groundwaters, are frequently rich in well-preserved spores and pollen. These assemblages, however, while not lacking diversity, tend to be dominated by a few major pollen types and it is difficult to find in them those species which are known to have a short time range, and which elsewhere provide good stratigraphic markers.

It may be that the relative lack of change in Murray Basin microfloras reflects a parent vegetation which underwent slow evolutionary change as a result of prolonged stability of habitat within the low-lying swamplands of the basin. There is too, no doubt, some bias introduced into the record both by preservation and sampling: pollen and spores are best preserved in lake and swamp depositional environments, so these are overrepresented in the record. Because of the strong possibility that lignites and other carbonaceous deposits will be pollen-bearing, they are the lithologies most frequently analysed palynologically. Thus it is that what may be the most stable habitats, in terms of vegetation change, are those most readily preserved, and most frequently examined for their fossil content - a situation which diminishes the usefulness of palynology in biostratigraphic applications.

In addition to the pollen and spores of land plants, dinoflagellates occur in the marine intervals of the Cainozoic sequence. These have received little study to date, with only one account published of the component species (Truswell et al., 1985) and their biostratigraphic potential remains unrealized.

The methodology used in earlier palynological investigations in the Cainozoic of the Murray Basin can be separated into three distinct categories:

1. The first approach utilizes the 'standard' type of zonal biostratigraphy, attempting to identify within the Murray Basin sequences zones which have been defined in other basins. Most commonly it has been the concurrent range/assemblage zones defined in the Gippsland Basin (Stover & Evans; 1973; Stover and Partridge, 1973;) which have been applied. Martin (1977) correlated spore and pollen assemblages from bores in the Hay-Balranald-Wakool districts in the eastern part of the basin with these units, recognizing there the Lower Nothofagidites asperus Zone, the Upper N. asperus Zone, the Proteacidites tuberculatus Zone, and the Triporopollenites bellus Zone, all of which were defined in the Gippsland Basin. The most recent interpretation of the position of these zones in terms of the international timescale is shown in Fig. 3, which is based on a recent BMR compilation.

   There are, however, distinct difficulties in applying the Gippsland Basin zonation in the Murray Basin. While identification of the mid to late Eocene Lower Nothofagidites asperus Zone presents few problems, the Upper N. asperus Zone cannot be recognized on the criteria given by Stover & Partridge (1973) for the Gippsland Basin, and there is difficulty separating this interval from the overlying Proteacidites tuberculatus Zone, which spans the Early Oligocene through Early Miocene. The species which characterize the Lower N. asperus Zone gradually disappear up-sequence. As the defining species of the P. tuberculatus Zone are not always present, the basal portions of this interval are frequently recognized only on the dubious criteria of the absence of those species which define the underlying zone.

   A further major difficulty is that the three subdivisions of the P. tuberculatus Zone which are recognized in the Gippsland Basin are rarely discernible in the Murray Basin owing to the sparseness of their indicator species. Problems commonly arise too with identifying the base of the Miocene T. bellus Zone, again because of the sparse occurrence of indicator species.

2. The problems outlined above have prompted the development of other methods of palynological subdivision, using quantitative rather than broadly qualitative approaches. Prominent among quantitative methods is Martin's (1984 a, b, c) 'ratio method', involving use of the presence of high frequencies of selected pollen types. The frequencies of the three pollen types selected have been expressed in terms of a ratio of these types to major botanical groups, viz. the pollen type Phyllocladidites mawsonii, a conifer akin to the extant Huon Pine, is expressed as a ratio of total gymnosperm pollen; the pollen Nothofagidites flemingii, a southern beech, is expressed as a ratio of total beech pollen; and lastly, pollen of Myrtaceae is compared to frequencies of beech pollen. The ratios have obvious ecological implications, a factor which may limit their biostratigraphic application; according to Martin the three taxa selected probably represent an ecological continuum, with abundant P. mawsonii reflecting the wettest habitats, abundant Myrtaceae the driest. In spite of the ecological constraints, the ratios appear to work as biostratigraphic tools, at least within limited geographic areas, as shown by Martin's studies in the Murrumbidgee and Lachlan fans. The interpreted relationships of the high ratios to the 'standard' zonal schemes are illustrated in Fig. 3.

3. The third method used in biostratigraphic subdivision is again quantitative. It utilizes the relative frequencies of all major taxa in assemblages. At the Oakvale-1 site in the northwestern part of the Murray Basin (Truswell et al., 1985), changes in relative frequencies were used to construct a zonation comprising two major zones and four subzones within the mid-Oligocene through mid-Miocene interval (Fig. 3). Boundaries between zones were statistically calculated by measuring degrees of similarity between adjacent pairs of pollen spectra. Again, the frequencies of pollen types within an assemblage depend on ecological factors affecting the parent vegetation, so it is unknown how geographically widespread are the events identified in any one sequence. The use of the Oakvale-1 sequence as a biostratigraphic reference section has yet to be tested elsewhere in the basin.

Quantitative analyses using total pollen frequencies were also applied by Martin (1973, 1977) to subdivide probable Pliocene-Pleistocene sequences, i.e. those apparently younger than the Triporopollenites bellus Zone in the upper Lachlan and the Murrumbidgee River areas. The four 'phases' recognized in this interval are shown in Fig. 3, but there is no independent age control and their position in time remains tentative.

In the present study, a combination of all the methods used in previous studies has been utilized. The Oakvale sequence has provided a measure of control in that it is dated in part by foraminifera; the ranges of individual spore and pollen taxa determined in that section have been extrapolated to date the sections studied here. Reference has also been made, where possible, to the Gippsland Basin zones, and, on occasion, to Martin's ratios and their relationship with those zones.

Palynological analysis of sampled sections

Samples submitted for analysis in this reconnaissance phase were mainly lignites. This, and the fact that samples were confined to a few intervals within the penetrated sections, has severely restricted biostratigraphic subdivision.

All were cuttings samples, which introduces the risk of downhole contamination of palynological material, a factor which is particularly significant in quantitative analyses of relative frequencies of pollen taxa. Contamination does not, however, appear to have been severe in the samples examined. The Early Cretaceouis assemblage encountered in Mitfords Corner provides a test of this; contamination from overlying Cainozoic assemblages in that section was minimal.

In the accounts of individual sections given below, all pollen frequency data are based on counts of 200 specimens per sample; taxon frequencies are shown in Table 1. Sample depths are shown in the lithological columns in Figs 4-10, which are based on preliminary, wellsite lithostratigraphy only. The preliminary cross sections shown in Fig. 11 were provided by J.R. Kellett.

1. Mitfords Corner

Latitude 33°06'13" Longitude 142°36'34"
RL 55.8 M

This borehole was drilled in the northern Wentworth Trough to provide depth control on the Nambucurra Seismic Line, to ascertain the hydrogeology of the northern Wentworth Trough and to determine whether there is hydraulic connection between the Wentworth and Blantyre Troughs.

Four lignite cuttings samples were examined from depths of 88-89 m, 168-169 m, 173-174 m and 332-333 m at this site (Fig. 4). All were highly productive of spores and pollen, although the long-ranging nature of most component species made reference to known biostratigraphic units difficult.

The deepest lignite sample, MFP8721, from 332-333m, yielded an Early Cretaceous assemblage of spores and pollen. Palynomorphs are sparse, however, and poorly preserved. The lack of stratigraphically short-ranging taxa makes it impossible to assign a precise age to the interval; the presence of several specimens of Dictyotosporites speciosus, however, in the sparse assemblage, suggests assignment to the zone of the same name. This implies an age range of late Neocomian through Early Albian (Dettmann, 1986). Lack of diagnostic taxa means that it is not possible to identify any of the sub-zones currently recognised within the D. speciosus Zone.

The interval is clearly non-marine. The sample examined is dominated by bisaccate or trisaccate pollen, with a lesser proportion of spores. It differs from the nearest known Cretaceous sequence in Wentworth No. 1 bore, which is marine in character (Evans & Hawkins, 1967) and possibly younger that the Mitfords Corner material. It has more in common with non-marine sequences in the Ivanhoe Trough, and with those recorded from the Murrumbidgee region by Martin (1984b).

The remaining samples are Cainozoic in age. The deepest examined, MFP 8720 at 173-174 m contains the species compared at Oakvale 1 to Perfotricolpites digitatus. In that reference section the species makes a first appearance in Subzone 1C, in the middle of the Geera

Clay section, an interval corresponding to low in the T. bellus Zone, of Middle Miocene age. Assuming that this is a reliable stratigraphic marker, then the sequence above 174 m at Mitfords Corner is equivalent

to Subzone 1C or younger intervals.

Pollen counts show that lignites at both 174-174 m and 168-169 m have high amounts of Nothofagidites, dominantly of the brassi morphotype. (20% in the deeper sample, 45% in the higher) which are somewhat higher than for Subzone C at Oakvale, although this is not sufficient grounds for excluding correlation with that subzone.

The uppermost sample at Mitfords Corner, MFP 8722 at 88-89 m, contains a spore-pollen suite which differs dramatically from those below. It is dominated by pollen of Myrtaceae (51%), including a substantial proportion of eucalyptoid types. In this it resembles the uppermost subzone 1A at Oakvale. There is nothing which definitely preclude the interval being younger than this; only the absence of pollen of Compositae and grasses can be used as negative evidence ruling against a Pliocene age. On this basis, the uppermost sampled sequence may best be referred to the Renmark Group, and is probably mid to Late Miocene in age.

2. Nambuccurra

Latitude 33°18'22" Longitude 142°56'54"
RL 65m

This drillsite is situated in a northeast-trending channel structure on the crest of the Neckarboo Ridge. It was drilled to ascertain whether Renmark Group sediments are occluded by the Neckarboo Ridge, as occurs further south.

Two lignite cuttings samples were examined, (Fig 5); MFP 8719 from 119-121 m, and MFP 8724 from 58.5-59.0 m. Both yielded palynomorphs, although recovery was sparse in the shallower sample.

The material from 119-121 m was well preserved, but poorly diversified, and stratigraphic assignment depends on a single pollen species, viz. Perfotricolpites sp. cf. P. digitatus. This species makes its first appearance in T. bellus Zone equivalents in the Oakvale reference section, so that it seems reasonable to assume that the section penetrated at Nambucurra is at least as young as this. The low diversity makes it impossible to constrain the age more precisely. The pollen suite is dominated by Casuarina (68 %) with a second dominance peak represented by the aquatic Sparganiaceae (15%). This combination suggests deposition in a swamp environment with locally derived pollen obscuring the regional vegetation contribution.

A number of hitherto unknown pollen types occur in this sample, whose stratigraphic value is as yet unassessed.

The younger sampled interval, 58.5-58.0 m, yielded a sparse assemblage of the same basic composition as MFP 8719. There is thus no reason to think that it is significantly younger, and it probably still represents the T. bellus Zone equivalent. Pollen frequencies differ from those of the deeper interval; there is a lower (45%) Casuarina frequency, higher Nothofagus and Myrtaceae.

3. Lake Garnpung

Latitude 33°29'27" Longitude 143°13'33"
RL 62.5 m

The hole was drilled in the Willandra Trough to provide control on the Garnpung-Gol Gol seismic line, to ascertain the thickness of Tertiary sediment in the trough, and to determine the southerly extent of good quality groundwaters in Lower Renmark aquifers.

Three lignite cuttings samples were examined from this hole, from depths of 54-54 m., 168-169 m. and 224-225 m (Fig. 6). All were productive of pollen and spores.

In the deepest sample (MFP 8721), residues were dominated by fragments of leaf cuticle. Some pollen was present, but it was too rare to be firmly diagnostic of age. Of the 23 pollen species recorded, only two, Proteacidites rectomarginis and Nothofagidites flemingii show any range restriction in the Oakvale-1 reference section. In that sequence, P. rectomarginis is confined to the lower part of the penetrated section, viz., the middle to upper P: tuberculatus Zone, identified in the Olney Formation and lower Geera Clay. N. flemingii is most common in, though not confined to that interval. Therefore, it seems likely that the base of the section at Lake Garnpung is at least as old as Late Oligocene; there is nothing to preclude an older age. No counts were possible because of sparse pollen recovery, but Nothofagidites was common, which is in keeping with correlation with Pollen Zone II at Oakvale. An attempt was made to obtain a date on the deeper part of the Lake Garnpung hole by processing lignitic cuttings from 275-276m; this interval yielded only sparse cuticle.

From sample MFP 8728 (168-169m), pollen and spores were recovered in abundance. The presence of P. rectomarginis again suggests an age equivalent to the lower part of the Oakvale section. The total dominance of pollen of Nothofagus accords with this: a correlation with Zone II at Oakvale and thus with the Middle P. tuberculatus Zone seems likely. Pollen species not previously reported from the Murray Basin include Dryadopollis retequetrus and an unknown pentacolpate species.

The uppermost lignite, MFP 8727 at 54-54 m, probably belongs to the interval which at Oakvale was designated Subzone 1C. It contains cf. Nuxpollenites sp., Perfotricolpites cf. digitatus, and a form close to, though not identical with, what was called Malvacearumpollis sp. in Oakvale. This combination means a probable placement within the T. bellus Zone, of Middle to Late Miocene age. The pollen assemblage contains a high (6.5%) frequency of Araucaria pollen, in keeping with subzone 1C. The frequency of Nothofagus pollen (2%) is much lower than for most of this zone at Oakvale, but this may be due to the fact that pollen of local swamp species is very high at the Lake Garnpung site. There, Restionaceae is around 25%, Cyperaceae 6%, and this local overdominance may be masking regional pollen influx.

4. Arlington

Latitude 33°29'47" Longitude 143°39'50"
RL 70.2m

The Arlington hole was drilled on the eastern flanks of the northern part of the Iona Ridge. The aims were to determine whether the Renmark Group aquifers extend over that ridge, and to assess whether this part of the ridge comprises a significant recharge zone for the Calivil and Renmark Aquifers.

A single lignite sample (MFP 8725) from the base of this hole at 212-216 m was macerated and yielded abundant, generally well-preserved spores and pollen (Fig. 7).

The assemblage was poorly diversified, and totally dominated by pollen of Nothofagus (75%). However, sufficient stratigraphically restricted species were present to assign the assemblage to the Lower Nothofagidites asperus Zone of Stover & Partridge (1973), although application of the Gippsland Basin zones is made tentatively.

Assignment of the zone is made on the basis of the following species: the presence of N. asperus, N. falcatus and Tricolporites leuros establishes that the sample is younger than the zone base; Proteacidites leightonii, Anacolosidites acutullus and Santalumidites cainozoicus, which terminate at the zone top, establish the age as not younger than the zone. The Lower N. asperus Zone is of Middle Eocene age.

The high Phyllocladidites mawsonii ratios, which Martin (1984a) identified as perhaps equating with the missing Upper N. asperus Zone, is not apparent. Whether this is stratigraphically significant or whether it has geographic connotations, is unknown.

5. Iona

Latitude 33°55'57" Longitude 143°26'36"
RL 60.6m

This section, drilled on the eastern flank of the southern part of the Iona Ridge, was designed to provide depth control for the Iona seismic line, and to investigate the extent of Pliocene channelling on the western side of the Balranald Trough.

Four samples of lignite from this site were examined for their palynomorph content. They were; MFP 8749, from 90-92 m, MFP 8750, from 196-198 m, MFP 8751 from 244-249 m, and MFP 1852, from 353-354 m (Fig. 8). All four yielded abundant and well-preserved palynomorphs, but low diversity assemblages of dominantly stratigraphically long-ranging taxa made age interpretation difficult.

The basal sample, MFP 8752 is referable to the Lower Nothofagidites asperus Zone of the Gippsland Basin (Stover & Evans, 1973), based on the rare presence of Anacolosiditis acutullus, which, in the Gippsland Basin at least, terminates its range within that zone. Proteacidites reticulatus is another taxon present which supports assignment to that zone. Numerically, the pollen spectrum is distinguished by very high frequencies of Nothofagidites (≏ 60%), anc by a gymnosperm component in which Phyllocladidites mawsonii is the most abundant taxon. This ratio of P. mawsonii to total gymnosperms (0.67) puts the sampled interval into the high P. mawsonii ratio interval of

Martin (1984a); such high frequencies were suggested by Martin to represent a level high in the Lower N. asperus Zone, or to the 'missing' Upper N. asperus Zone. If this equation is correct, the time interval involved is that of the latest Eocene - earliest Oligocene, i.e. between about 34-38 Ma.

The lignite sampled at 244-249 m yielded abundant, excellently preserved pollen. Diversity was low, however, and stratigraphically diagnostic taxa virtually absent. On somewhat shaky criteria, derived from comparison with the Oakvale section, the sample is assigned to the lower part of the Proteacidites tuberculatus Zone; the common occurrence of Proteacidites rectomarginis and the presence of Parvisaccites catastus are in accord with this assignment, although they do no exclude other intervals. Neither this sample, nor that above, contain Phyllocladidites mawsonii; both contain high frequencies (69, 55%) of Nothofagus pollen, but without the stratigraphically useful high frequencies of the N. flemingii type.

Sample MFP 8750 at 196-198 similarly has no firm criteria on which to base an age determination. It may belong to the upper units of the P. tuberculatus Zone, but assignment to the overlying T. bellus Zone cannot be ruled out.

The youngest sampled interval, MFP 8749 at 90-92m, represents a dramatic shift in vegetation from that reflected in the intervals below. Nothofagus, which is a temperate rainforest taxon, has all but disappeared; pollen of Casuarina type dominates (81%); the additional presence of rush and sedge pollen (Cyperaceaepollis, Milfordia, Sparganiaceaepollenites) suggests that the habitat represented by the lignite at this interval may have been a sheoak swamp, with little influx of pollen from the regional vegetation. Diversity of pollen types is low, and the assemblage non-diagnostic from a biostratigraphic point of view. On the negative criterion of the absence of dominantly Pliocene groups such as Asteraceae it is assigned to the Late Miocene, suggesting, identification with the Triporopollenites bellus Zone, or a Miocene interval younger than the zone limits.

6. Bramah

Latitude 34°25'04"   Longitude 143°18'08"
RL 61.8

This hole, drilled in the southwestern corner of the Balranald Trough, was intended to investigate the extent of the Miocene marine transgression within that trough, and to provide depth control for the Bramah seismic traverse.

Three lignites sampled in this section all came from high in the penetrated sequence. They are: Sample MFP 8726, from 44-45M., MFP 8723, from 59-60 m., and MFP 8718, from 70-72 m (see Fig 9). Additional samples were taken from 167-168 m and 199-200 m.

Minimum age control on the section was provided by the presence, at 70-72 m, of the angiosperm pollen Haloragacidites haloragoides. In the Oakvale reference section, this species was recovered as a rare component in the Upper Proteacidites tuberculatus Zone (Early Miocene): it was consistently present in the overlying

Triporopollenites bellus Zone. In the Gippsland Basin, Stover and Partridge (1973) reported it only from that zone. On this basis it is tentatively suggested that the lignite at 70-72m is most likely to represent the T. bellus Zone.

The restricted, poorly diversified assemblages recovered from both 70-72m and 59-60m allow little refinement in dating. Both are dominated by pollen of Casuarina, (68 and 88 %) with minor input from gymnosperms and from Nothofagus. The latter is represented mainly by brassi type pollen. High Casuarinaceae frequencies do occur in subzones 1B and upper 1C in Oakvale, high in the Geera Clay section there, but it is difficult to compare these lignite-derived assemblages from Bramah with the marine-based assemblages from further west, which give a better picture of regional vegetation changes. It is likely that the Bramah lignites represent swamps with a local dominance of Casuarina; the low frequencies of gymnosperms and Nothofagus probably represent rainforest elements in the regional vegetation.

The pollen spectra from the Bramah lignites at 59-60m and 70-72m differ too from those reported from a bore 16 km east of Hay by Martin (1973), again, mainly in their overdominance of Casuarina. Pollen frequencies at the two sites are compared in Fig. 10. Allowing for this local overdominance, however, it is apparent that they are closer in composition to those which Martin referred to the Miocene at Hay than to those she referred to the Pliocene. It should be noted here that the age control on all of the sequences is poorly constrained in terms of an international reference scale.

The uppermost lignite sampled at Bramah, from 44-45 m, differs considerably in its palynological composition from those below. Although Casuarinaceae pollen remains important at 64%, the minor components have changed. Gymosperms are less abundant and no Nothofagus were recorded, indicating that rainforest has all but disappeared from the pollen catchment. Myrtaceae is more abundant, and includes some pollen of Eucalyptus type. The presence of significant (4%) pollen of Asteraceae (daisy family) and some grass and saltbush (Graminidites, Chenopodopollis) attests to a much more open vegetation than before. The comparison is close to the unit which Martin (1973) tentatively referred to as Pliocene at Hay. The probability that this type of assemblage is in fact Pliocene is strengthened by the palaeomagnetic dating of sediments at Lake George which yield comparable assemblages (McEwen Mason, in prep.).

The two deeper samples prepared for examination, from 167-168m (MFP 8763) and 199-200m (MFP 8764) were intended to place age constraints on the marine incursion represented by the silty sands with shell fragments encountered between 173 and 200 m. In the Oakvale sequence, in the northwest of the basin, Lindsay (1983) identified few distinct marine 'pulses', and it would be of interest to determine which of these is represented in this more easterly section. However, the clays sampled between 167-168 yielded only rare, non- age-diagnostic pollen grains, too few to count, and the sample at 189-200 m was barren of palynomorphs.

Conclusions:

Sparseness of sampling, combined with the biostratigraphic problems outlined above, make generalizations tentative at this stage. Nevertheless, this reconnaissance study has provided some data pertinent to understanding the local geology of this part of the Murray Basin, and which may eventually find wider application.

Results of the palynological determinations are shown on the preliminary cross sections in Fig. 11, which shows basement configurations and lithologic subdivisions, including subdivisions of the Renmark Group proposed on the basis of variations in groundwater salinities indicated by electric logging and sampling at selected intervals. (J.R. Kellett, in prep). Fig. 11 also includes a number of sections not analysed in this study; the palynology of the cored sequence at Neckarboo Ridge is presently being examined in detail (E.M. Truswell), and palynological data are available from the NSW Water Resources Commission bore at Joulni (H.A. Martin, in press).

Palynological data obtained during this preliminary study has:

1. Established the presence of Early Cretaceous sediments in the northern end of the Wentworth Trough, as shown by the basal lignitic section in the Mitfords Corner bore. The non-marine character of these sediments, which can be identified only as being of Neocomian to Albian age, differs from the ? Albian marine sediments in Wentworth No. 1 bore to the southwest.

2. Provided the beginnings of a time-stratigraphic subdivision of the Renmark Group against which the log-based subdivisions can be measured. Within this framework, it is apparent, from reference to Fig. 11, that:

a. Upper Renmark Group sediments, wherever sampled, produced palynological assemblages that could be correlated, tentatively, with the mid to late Miocene Triporopollenites bellus Zone. This zone, on evidence from Mitfords Corner and Nambuccurra, extends down into the Middle Renmark; its boundary with the underlying Proteacidites tuberculatus Zone lies somewhere within that lithological unit.

b. There is some discrepancy between the sections at Mitfords Corner and Nambuccurra and that at Lake Garnpung, concerning the placement of the T. bellus and P. tuberculatus Zones. Horizons identified as belonging to T. bellus occur about the middle of beds identified as Middle Renmark in Mitfords Corner and Nambucurra: comparable horizons in Lake Garnpung yielded middle P. tuberculatus Zone assemblage. On face value, it appears that Middle Renmark Group sediments are younger towards the northwest. It should be borne in mind, however, that identification of the T. bellus Zone is insecure, being based only on a single species known to be confined to correlatives of that zone in the Oakvale-1 reference section. Closer sampling is needed to clarify the issue.

c. The determinations provided by Martin (in press) for the Joulni section are discordant with the tentative framework established here. According to her study, the Joulni section shows sediments, here identified as Upper Renmark, to contain the older, P. tuberculatus Zone, in contrast to most sections of that interval, which contain T. bellus. If the biostratigraphic identifications are correct, it suggests that Upper Renmark Group sediments may be absent from this section, due to erosion or non-deposition.

d. Sediments identified on log characters as Lower Renmark Group contain Lower Nothofagidites asperus Zone (middle to late Eocene) to Lower P. tuberculatus (early Oligocene) pollen assemblages. These have been identified tentatively in basal sequences in the Willandra Trough at Lake Garnpung, and, more confidently, on the slopes of the Iona Ridge, marginal to the Balranald Trough, at Arlington and Iona.

3. Shown the presence of sediments of probable Pliocene age in the section sampled at Bramah. These are broadly correlated, on a palynological basis, with sequences described from the Hay area by Martin (1973). It should be stressed that the age of these sediments, in terms of standard time scales, remains very poorly constrained.

Taxonomic and distributional notes on selected pollen species.

This section provides a brief note on new taxa, on taxa whch have not been recorded before from the Murray Basin, or those which have an emerging biostratigraphic role within the basin.

Genus Corsinipollenites Nakoman 1965
Type species: Corsinipollenites oculus noctis (Thiergart) Nakoman, 1965.

Corsinipollenites sp.
Fig 12, Q-T

These triporate pollen grains are appropriately assigned to Corsinipollenites on the basis of their complex pore structure. They are distinguished by an annulus formed from a thickening of the nexine - to 2.5 μ thick - in a pattern which characteristically shows some breakdown and granulation of that layer within the ora. This internal structure of the pore surrounds is overlapped by a rugulate, crumpled sexine.

The grains were frequently observed in tetrads. The species differs from C. oculus noctis, which has been reported from Queensland sediments by Hekel (1972) and Foster (1982), in being much smaller (individual grain diameter 53-57 μ), and in having a distinctively rugulate sexine. It differs too from specimens which Foster (1982, Pl. 9, fig. 2,3) referred to Triorites orbiculatus McIntyre in having more protruding, complexly thickened pores, as well as the rugulate sexine.

Affinities lie possibly with Onagraceae. Observed in probable Triporopollenites bellus Zone sediments at Nambucurra.

Genus Diporites van der Hammen 1954 ex Potonié 1960.
Type species: Diporites grandiporus van der Hammen 1954:
subsequent designation by Potonié, 1960.

Diporites aspis Pocknall & Mildenhall 1984
Fig 12, O,P

A single diporate grain, similar to those produced by Fuchsia (Onagraceae)

was observed at Mitfords Corner, and is reported here as there appear to be no previously published records of this grain type in Australia.

The grain is barrel-shaped, with vestibulate pores protruding some 10-11 μ beyond the grain ends. The pores are surrounded by an annulus 2-3 μ wide, developed in the nexine. There is evidence of nexine breakdown, giving a granulate appearance, within the ora. The sexine of the vestibulum is thinned, and across one of the pores it is infolded. On the body of the grain the stratification of the exine is obscure, but the sexine appears homogenous, 1.5-2.0 μ thick, the nexine much thinner. Structures which may be the bases of 3-4 broken viscin threads are visible on one face of the grain.

The grain is wider in relation to its length than Diporites aspis, from the Late Oligocene - Early Miocene of Southland, New Zealand (Pocknall & Mildenhall, 1984), but is otherwise morphologically close enough to place it in that species.

Genus Dryadopollis Srivastava 1975
Type species: Dryadopollis argus Srivastava 1975

Dryadopollis retequetrus (Partridge) Pocknall & Mildenhall, 1984
Fig.12, I-L

1973 Tricolporites retequetrus Partridge in Stover & Partridge, p. 260, pl. 19. fig. 8.9.

1984 Dryadopollis retequetrus (Partridge) Pocknall & Mildenhall, p. 32, pl. 13, fig. 8,9.

This species was tranferred to Dryadopollis on the basis of its possessing, in addition to the coarse reticulum in the mesocolpia, a very fine reticulum on the apocolpia and the colpi margins. This feature was clearly evident in the specimens observed here, from the Proteacidites tuberculatus Zone at Lake Garnpung. The exine in these regions is tectato-perforate, with lumina 0.2-0.3 μ evident. The specimens also showed clearly the structure of the sexine in the mesocolpia, where columellae 0.5 μ thick are paired or multiple, supporting a much thickened, apparently homogenous tectum. The exine in the mesocolpia reaches a thickness of 5 μ, more than half of which represents tectum.

The only other record of the species in Australia outside the Gippsland Basin is that of Owen (1975) who reported it from Early Miocene lake deposits at Kiandra.

Genus Lymingtonia Erdtman, 1960
Type species: Lymingtonia rhetor Erdtman, 1960

Lymingtonia sp.
Fig. 13, L-P

1973 Portulacaceae gen et sp. nov., Martin, p. 51, Pl. 1, fig. 10.11. In the gross features of its morphology, this species resembles that which Pocknall and Mildenhall (1984)assigned to their species Lymingtonia cenozoica: this taxon has 12 rugae or colpae arranged around 6 squares. However, there is a clear distinction between the Australian forms figured here, and those from New Zealand, relating to the nature of the exine surface. The Australian species surficially bears a fine, very regular reticulum bearing scattered low grana; in contrast, the New Zealand species has a non-reticulate, finely spinose surface.

The single specimen described by Martin (1973) had 15, rather than 12 rugae, but this may be a variable character, and the form here described is considered synonymous. Martin compared the fossil form to pollen of extant Montia (Portulacaceae): the New Zealand taxon was considered to have affinity with the Nyctaginaceae. Three grains were observed from Nambucurra, at 119-121 μ. Exine diameters were 51-60 μ.

Genua Malvacearumpollis Nagy 1962
Type Species: Malvacearumpollis bakonyensis Nagy 1962

Malvacearumpollis sp
Fig. 12, M,N

Specimens of Malvacearumpollis observed in this study were predominantly four-pored. They are characterised by a nexine around 4 μ thick, thicker in the annuli about the pores. The sexine is 1.5-2.0 μ thick, characteristically forming cushions under the spine bases. The spines are bulbous in shape, 3-4 μ diameter at their base, thickening to a maximum about halfway up their height, then tapering to an acute tip.

The bulbous shape of the spines, and their dense spacing, differs from specimens assigned by Wood (1986) to his species M. mannanensis. The spine density is greater than that in forms referred by Truswell et al. (1985) to Malvacearumpollis sp. Whether this variation is sufficient to warrant specific differentiation is at present uncertain.

Four specimens measured, from high in the section at Lake Garnpung, ranged in maximum diameter from 59-81 μ.

Genua Milfordia Endtman 1960
Type species: Milfordia hypolaenoides Erdtman 1960

Milfordia sp.
Fig. 12, E-H

This species is noted here as it represents an entity which has not previously been described from Australia. In the distribution chart, Table 1, it has been grouped within Milfordia homeopunctata, a broad category which includes all restionaceous pollen types with a graminioid pore, including both annulate and non-annulate types. Clearly, this approach, which follows that in most Australian literature, obscures potential stratigraphic application of distinct morphotypes.

The form figured here has a prominent annulus produced by a nexine thickening which is approximately double that of the thickness of that layer over the rest of the grain. The pore aperature is irregular, and small in relation to the total internal diameter of the pore. The exine stratification is distinct, with columellae discernible, and both fine scrobiculae and coarser punctae penetrate the sexine.

The total grain diameter ranges from 28-33 μ, based on 5 specimens from Iona, in lower P. tuberculatus Zone sediments, the only interval where the morphotype was observed.

Genus Nuxpollenites Elsik 1974 emend Frederiksen 1980
Type species: Nuxpollenites claibornensis Elsik 1974

Nuxpollenites sp.
Fig. 12, A-D

Specimens illustrated here show the diversity of form within individuals grouped within Nuxpollenites. Most common is the elongate form (Fig 12, A,B) in which the polar axis is about twice as long as the equatorial. A form with more squat dimensions is also present (Fig. 12, C,D), in which the ratio of polar to equational diameter is around 5/4.

In most specimens columellae are visible in the polar areas; the columellate layer is thin (0.5 μ), and supports a much thicker (±2.0 μ), homogenous outer sexine. Ora are distinct, lalongate, more so than in specimens assigned to aff. Diplopeltis by Kemp (1976).

Within the Murray Basin, the first appearance of pollen of the Nuxpollenites morphotype appears to have some stratigraphic value. In the Oakvale section (Truswell et al, 1985) it appears first in the Late Oligocene Upper Proteacidites tuberculatus interval (Foram Zone P 22) and was not observed outside that zone. In these more easterly localities, it appears to range into younger sediments.

Genus Propylipollis A.R.H. Martin & Harris 1974
Type species: Propylipollis reticuloscabratus (Harris) A.R.H. Martin & Harris, 1974 (by original designation).

Propylipollis biporus Dudgeon 1983
Fig. 13, E-G

These diporate pollen grains appear identical with P. diporus, which has hitherto been described only from the Yaamba Basin of central Queensland (Dudgeon, 1983). There, it occurs in spore and pollen assemblages equated with the Lower Nothofagidites asperus Zone of the Gippsland Basin (Middle to Late Eocene). In this Murray Basin study, it was seen only in sediments assigned to the same zone in the lower Renmark Group.

Genus Proteacidites Cookson ex Couper 1953 emend A.R.H. Martin & Harris 1974.
Type species: Proteacidites adenanthoides Cookson 1950,

subsequent designation by Couper, 1953.

Proteacidites rectomarginis Cookson 1950
Fig. 13, J,K

Well preserved specimens of P. rectomarginis were observed in the sequence at Iona. They show clearly the exine stratification with a slight but gradual thickening of the nexine towares the pore. There is frequently nexine breakdown in the pore area, with channelling leaving separated islands of exine. The grain surface characteristically shows punctate grooves separating irregular islands of tectum to form a negative reticulum. The species is most common in the Lower Proteacidites tuberculatus interval, decreasing in frequency upwards within that zone.

Proteacidites sp. cf. P. rhynthius Stover & Partridge, 1982
Fig. 13, H,I

Specimens observed from Eocene sediments at Arlington have a nexine which shows a slight thickening towards the pore. The sexine is tectate-perforate, with the muri of the reticulum clearly supported by more than one row of columellae. In this feature the form differs from P. rhynthius (Stover & Partridge, 1982, Pl. 4, fig. 5-7). It differs from P. pseudomoides Stover in having smaller luminae within the reticulum. The two specimens measured had maximum diameters of 42, 45 μ.

Genus Tetrapollis Pflug 1985
Type species: Tetrapollis validus (Pflug) Pflug 1953

Tetrapollis sp.
Fig. 13, D

Small grains with four pores in the plane of the equator were observed in probable Triporopollenites bellus Zone sediments at Mitfords Corner. They show a clear exine stratification, with sexine and nexine of roughly equal thickness, 0.5-0.6 μ. In some specimens the nexine thickens to 1.0 - 1.2μ at the pores, showing granulation and channelling about the aperture. The exine is often broadly folded. Grain diameters in the range 18-21 μ. The thickening about the pores is not so extreme as in Haloragacidites haloragoides Cookson & Pike.

Genus Triporopollenites Pflug & Thomson, 1985
Type species: Triporopollenites coryloides Pflug in Thomson & Pflug 1953.

Triporopollenites 'protrudens' n. sp.
Fig. 13, A-C

Triporate, spherical pollen grains, of circular to rounded-triangular amb, with protruding, thickened pores, were observed in the Lower T. bellus Zone at Mitfords Corner, and are here given the informal designation Triporopollenites 'protrudens'. The exine of the grains is thick (± 2.0μ), apparently without stratification, thickening further to 2.5μ in the apertural regions. The surface is made up of low, irregular verrucae separated by narrow (?perforate) channels which form a negative reticulum. The pores are elongate, almost colpate, and are surrounded externally by 6-10 verrucae. The verrucae may be irregularly joined or discrete; in profile they are hemispherical, sometimes bulbous and swelling from the base to a height of 2.0-2.5μ. Overall grain diameter 18-21μ.

There appear to be no previous reports of this grain type. It shows some similarity to a species which Frederikson (1979) described as Corsinipollenites sp. 1, from the Palaeocene of Virginia, but the Australian specimens are more spherical, and have more elongate apertures.

Acknowledgements: Samples were provided by J.R. Kellett, who also provided lithostratigraphic data. M.K. Macphail, G.E. Wilford and J.R. Kellett provided critical comment on a draft manuscript.

References:

Brown, C.M., 1983. Discussion: a Cainozoic history of Australia's southeast highlands. Journal of the Geological Society of Australia, 30, 483-486.

Brown, C.M. and Stephenson, A.E., 1986. Murray Basin, southeastern Australia: subsurface stratigraphic database. Bureau of Mineral Resources, Geology & Geophysics, Report 262, 1-60.

Couper, R.A., 1953. Upper Mesozoic and Cainozoic spores and pollen grains from New Zealand. New Zealand Geological Survey Palaeontological Bulletin 22, 1-77.

Dettmann, M.E., 1986. Early Cretaceous palynoflora of subsurface strata correlative with the Koonwarra Fossil Bed, Victoria. Memoirs of the Association of Australasian Palaeontologists, 3, 79-108.

Dudgeon, M.J., 1983. Eocene pollen of probable proteaceous affinity from the Yaamba Basin, central Queensland. Memoirs of the Association of Australasian Palaeontologists 1, 339-362.

Evans, P.R. and Hawkins, P.J., 1967. The Cretaceous below the Murray Basin. Bureau of Mineral Resources Record 1967/137.

Foster, C.B., 1982. Illustrations of Early Tertiary (Eocene) plant microfossils from the Yaamba Basin, Queensland. Geological Survey of Queensland Publication 381, 1-32.

Frederiksen, N.O., 1979. Paleogene sporomorph biostratigraphy, northeastern Virginia. Palynology 3, 129-167.

Hekel, H., 1972. Pollen and spore assemblages from Queensland Tertiary sediments. Geological Survey of Queensland Publication 355, 1-34.

Kemp, E.M., 1976. Early Tertiary pollen from Napperby, central Australia. BMR Journal of Australian Geology and Geophysics, 1, 109-114.

Lindsay, J.M., 1983. Oligo-Miocene trangressive events in Geera Clay, Oakvale 1, northern Murray Basin. Geological Survey of South Australia, Quarterly Notes 85, 5-12.

Martin, H.A., 1973. Upper Tertiary palynology in southern New South Wales. Geological Society of Australia Special Publication 4, 35-54.

Martin, H.A., 1977. The Tertiary stratigraphic palynology of the Murray Basin in New South Wales. 1. The Hay-Balranald - Wakool Districts. Journal and Proceedings, Royal Society of New South Wales 10, 41-47.

Martin, H.A., 1984a. The use of quantitative relationships and palaeoecology in stratigraphic palynology of the Murray Basin in New South Wales. Alcheringa 8, 253-272.

Martin, H.A., 1984b. The stratigraphic palynology of the Murray Basin in New South Wales. II. The Murrumbidgee area. Journal and Proceedings of the Royal Society of New South Wales, 117, 35-44.

Martin, H.A., 1984c. The stratigraphic palynology of the Murray Basin in New South Wales. III. The Lachlan area. Journal and Proceedings of the Royal Society of New South Wales, 117, 45-51.

Owen, J.A., 1975. Palynology of some Tertiary deposits from New South Wales. Ph.D. Thesis, Australian National University.

Pocknall, D.T. and Mildenhall, D.C., 1984. Late Oligocene - early Miocene spores and pollen from Southland, New Zealand. New Zealand Geological Survey Palaeontological Bulletin 51, 1-66.

Potonié, R., 1960. Synopsis der Gattungen der Sporae dispersae. III. Teil: Nachträge Sporites, fortsetzung Pollenites. Beihefte zum geologischen jahrbuch 39, 1-189.

Stover, L.E. and Evans, P.R., 1973. Upper Cretaceous spore-pollen zonation, offshore Gippsland Basin, Australia. Geological Society of Australia Special Publication 4, 55-72.

Stover, L.E. and Partridge, A.D., 1973. Tertiary and Late Cretaceous spores and pollen from the Gippsland Basin, Southeastern Australia.

Proceedings, Royal Society of Victoria, 85, 237-286.

Stover, L.E. and Partridge, A.D., 1982. Eocene spore-pollen from the Werillup Formation, Western Australia. Palynology 6, 69-95.

Truswell, E.M. Sluiter, I.R., and Harris, W.K., 1985. Palynology of the Oligo-Miocene sequence in the Oakvale-1 corehole, western Murray Basin, South Australia. BMR Journal of Australian Geology and Geophysics 9, 267-295.

Vail, P.R., Mitchum, R.M., and Thompson, S., 1977. Seismic stratigraphy and global changes of sea-level. Part 4: Global cycles of relative changes of sea-level. In Payton, C.E. (Editor), Seismic stratigraphy - application to hydrocarbon exploration. American Association of Petroleum Geologists, Memoirs, 26, 83-97.

Wood, G.R., 1986. Late Oligocene to Early Miocene palynomorphs from GSQ Sandy Cape 1-3R. Geological Survey of Queensland Publication 387, 1-27.

FIGURE EXPLANATIONS

Fig. 1 Murray Basin showing localities of boreholes discussed in text. Basement ridges are shown in outline. Fine stipple shows subsurface extent of the Geera clay (based on Brown & Stephenson, 1986).

Fig. 2 Suggested stratigraphic relationships of lithological units in the Murray Basin (from Brown & Stephenson, 1986).

Fig. 3 Palynological zones used in eastern Australian Tertiary sequences. Shown in the 3 right hand columns are Gippsland Basin assemblage zones (Stover & Evans, 1973; Stover & Partridge, 1973; Partridge, 1976), selected pollen ratios and younger 'phases' identified by Martin (1973, 1977, 1984) in the eastern Murray Basin, and the quantitative zonation developed at the Oakvale site by Truswell et al (1985). Left hand columns show international timescales and foraminiferal zonation.

Fig. 4 Preliminary lithostratigraphy of Mitfords Corner borehole. Palynological sample intervals on left. Tentative palynological zones on right.

Fig. 5 Preliminary lithostratigraphy of Nambucurra borehole. Palynological sample intervals on left. Tentative palynological zones on right.

Fig. 6 Preliminary lithostratigraphy of Lake Garnpung borehole. Palynological sample on left; tentative palynological zone on right.

Fig. 7 Preliminary lithostratigraphy of Arlington borehole. Palynological sample on left; tentative palynological zone on right.

Fig. 8 Preliminary lithostratigraphy of Iona borehole. Palynological sample intervals on left; tentative palynological zones on right.

Fig. 9 Preliminary lithostratigraphy of Bramah borehole. Palynological sample intervals on left; tentative palynological zones on right.

Fig. 10 Quantitative analysis (based on major taxa) of shallow samples in Bramah borehole, compared to similar analyses in Hay bore given by Martin (1973). Abbreviations are as follows: GYM - total gymnosperm pollen, MYRT - total Myrtaceae, CAS - Casuarinaceae, NOTH - _Nothofagus_ (m - _menziesii_, b - _brass;_, f - _fusca_ types), COMP - Compositeae, GRAM - Gramineae, CHENOPOD - Chenopodiaceae.

Fig. 11 Diagrammatic cross sections of lithostratigraphic units through sites shown in Fig. 1, showing relationship of sections to basement configurations. Subdivisions of the Renmark Group are based on electric log data from J.R. Kellett. Palynological samples are arrowed on the left of the lithological columns: abbreviated zonal determinations are: Tb - _Triporopollenites_

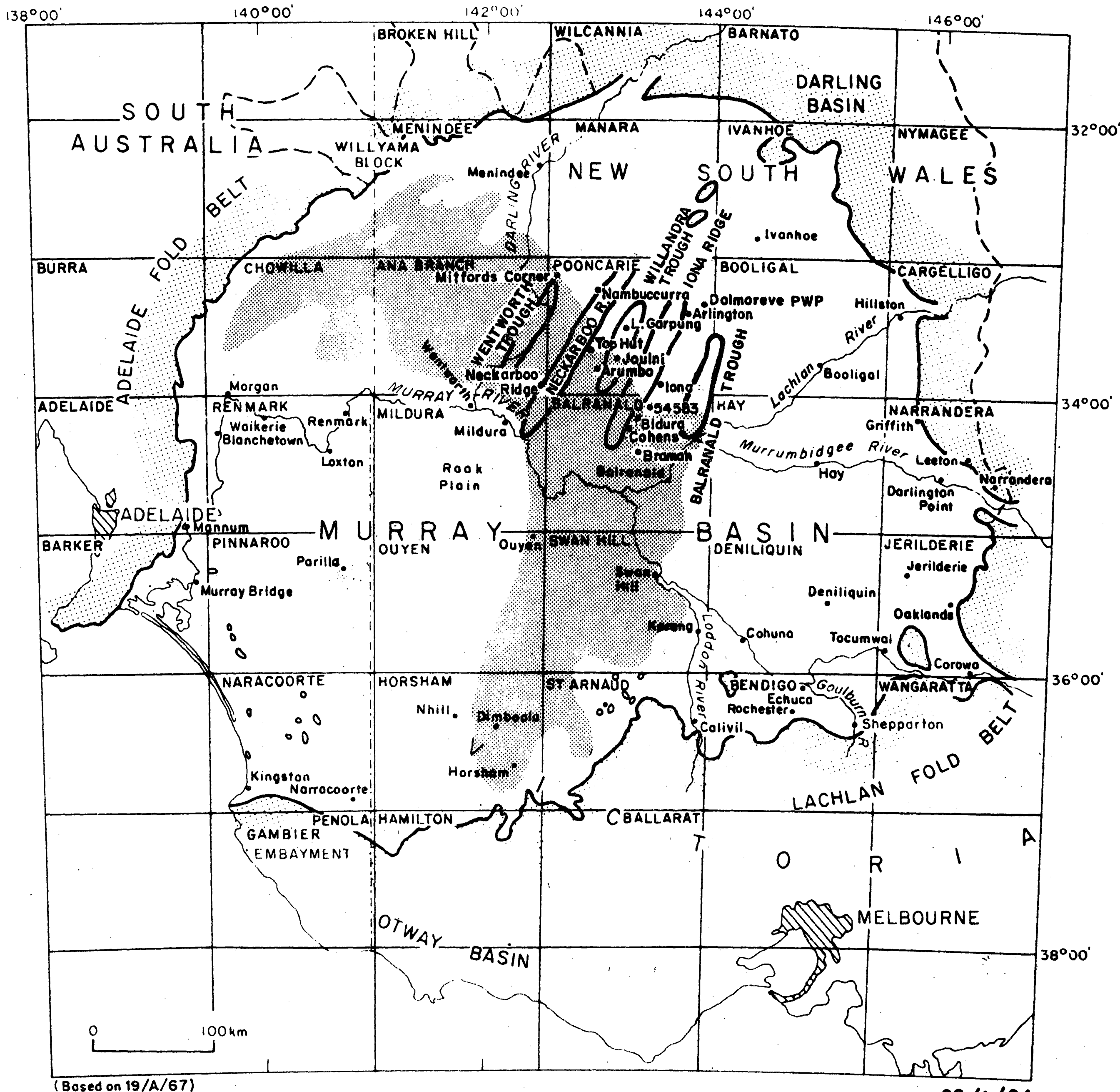


Fig. 1 Murray Basin showing localities of boreholes discussed in text. Basement ridges are shown in outline. Fine stipple shows subsurface extent of the Geera clay (based on Brown & Stephenson, 1986).

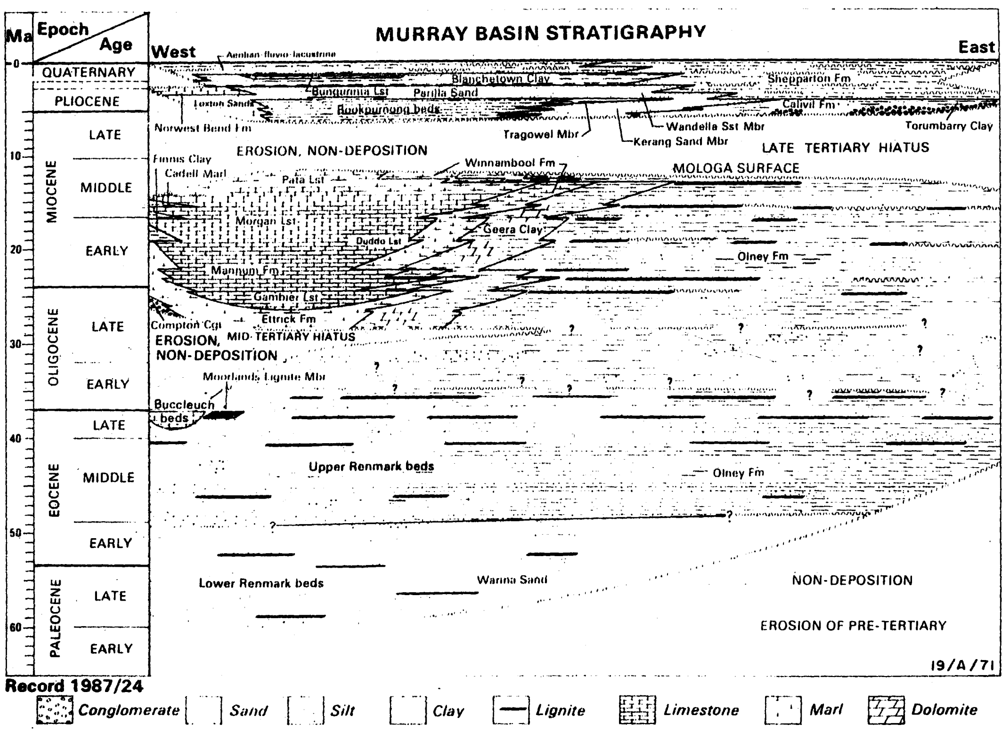
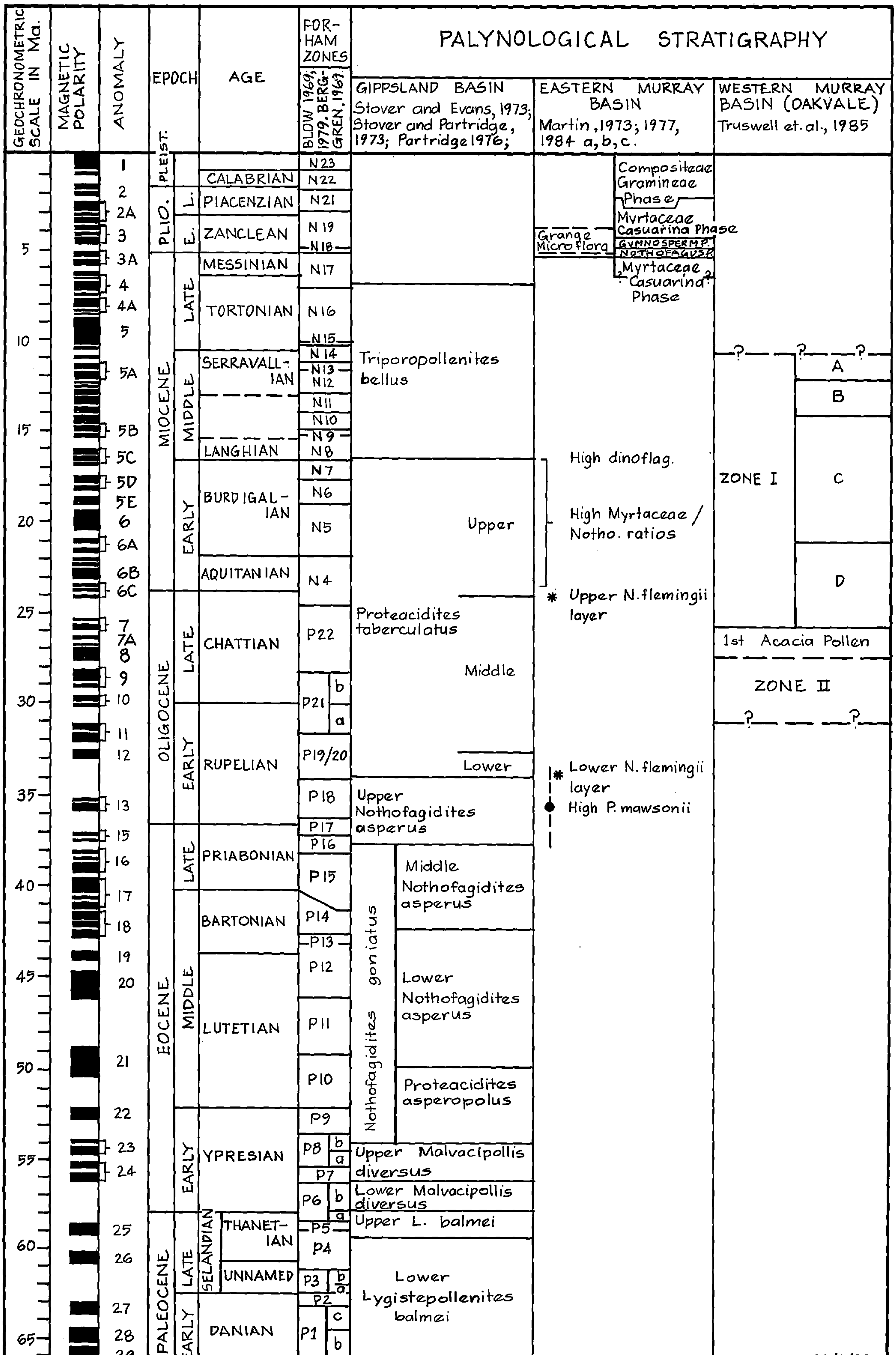


Fig. 2 Suggested stratigraphic relationships of lithological units in the Murray Basin (from Brown & Stephenson, 1986).

Fig. 3 Palynological zones used in eastern Australian Tertiary sequences. Shown in the 3 right hand columns are Gippsland Basin assemblage zones (Stover & Evans, 1973; Stover & Partridge, 1973; Partridge, 1976), selected pollen ratios and younger 'phases' identified by Martin (1973, 1977, 1984) in the eastern Murray Basin, and the quantitative zonation developed at the Oakvale site by Truswell et al (1985). Left hand columns show international timescales and foraminiferal zonation.



Record 1987/24

Fig. 3

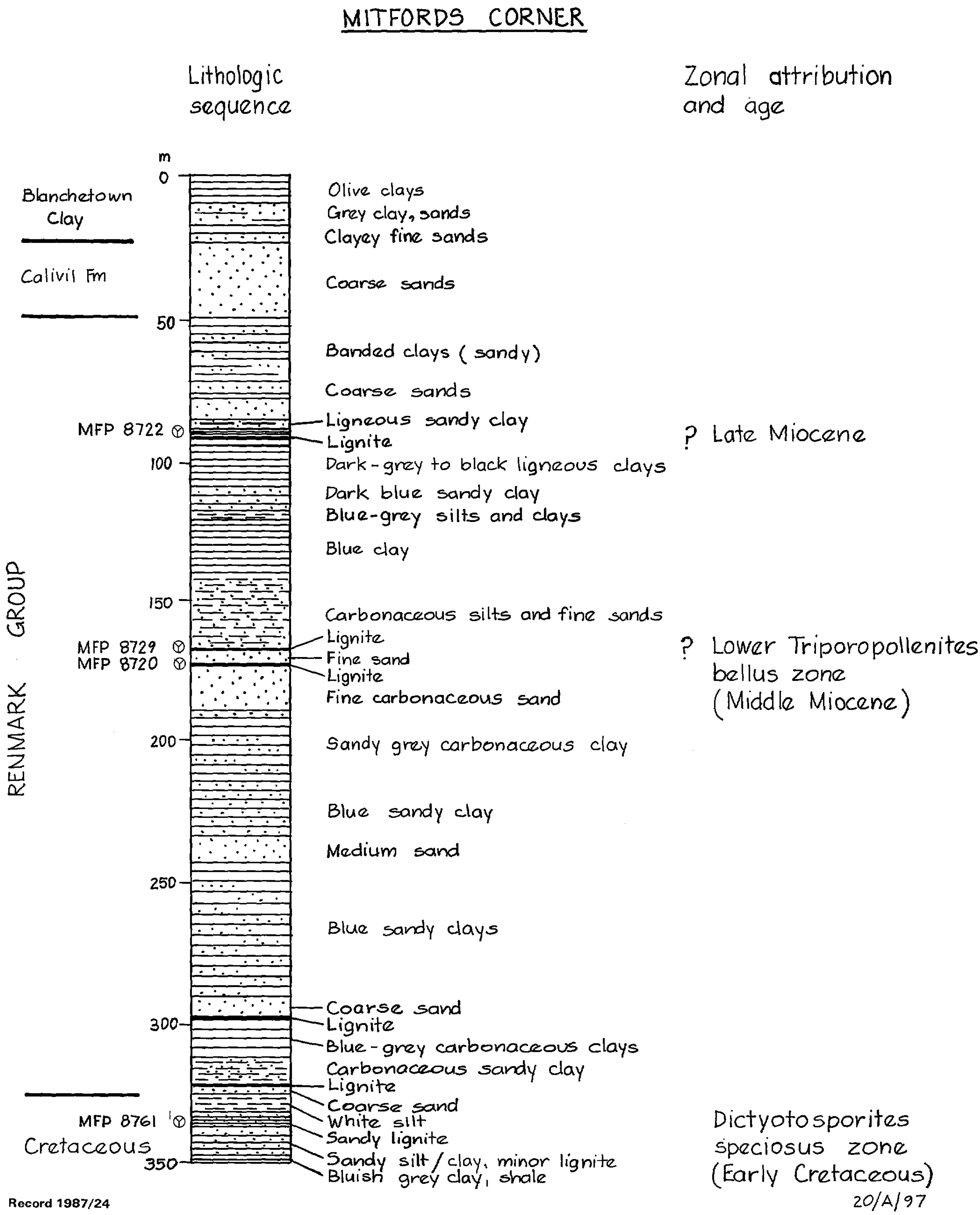


Fig. 4 Preliminary lithostratigraphy of Mitfords Corner borehole. Palynological sample intervals on left. Tentative palynological zones on right.

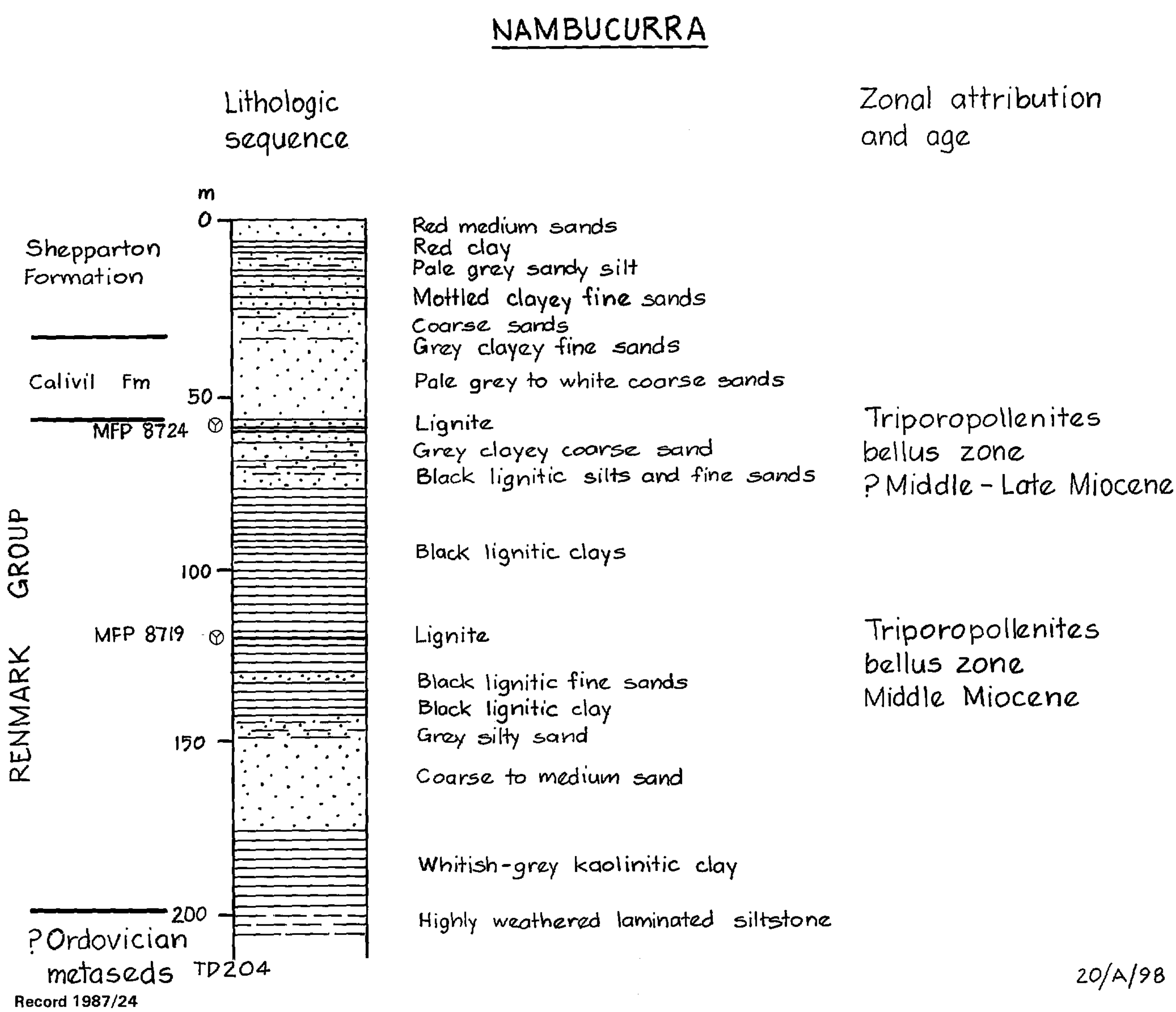


Fig. 5 Preliminary lithostratigraphy of Nambucurra borehole. Palynological sample intervals on left. Tentative palynological zones on right.

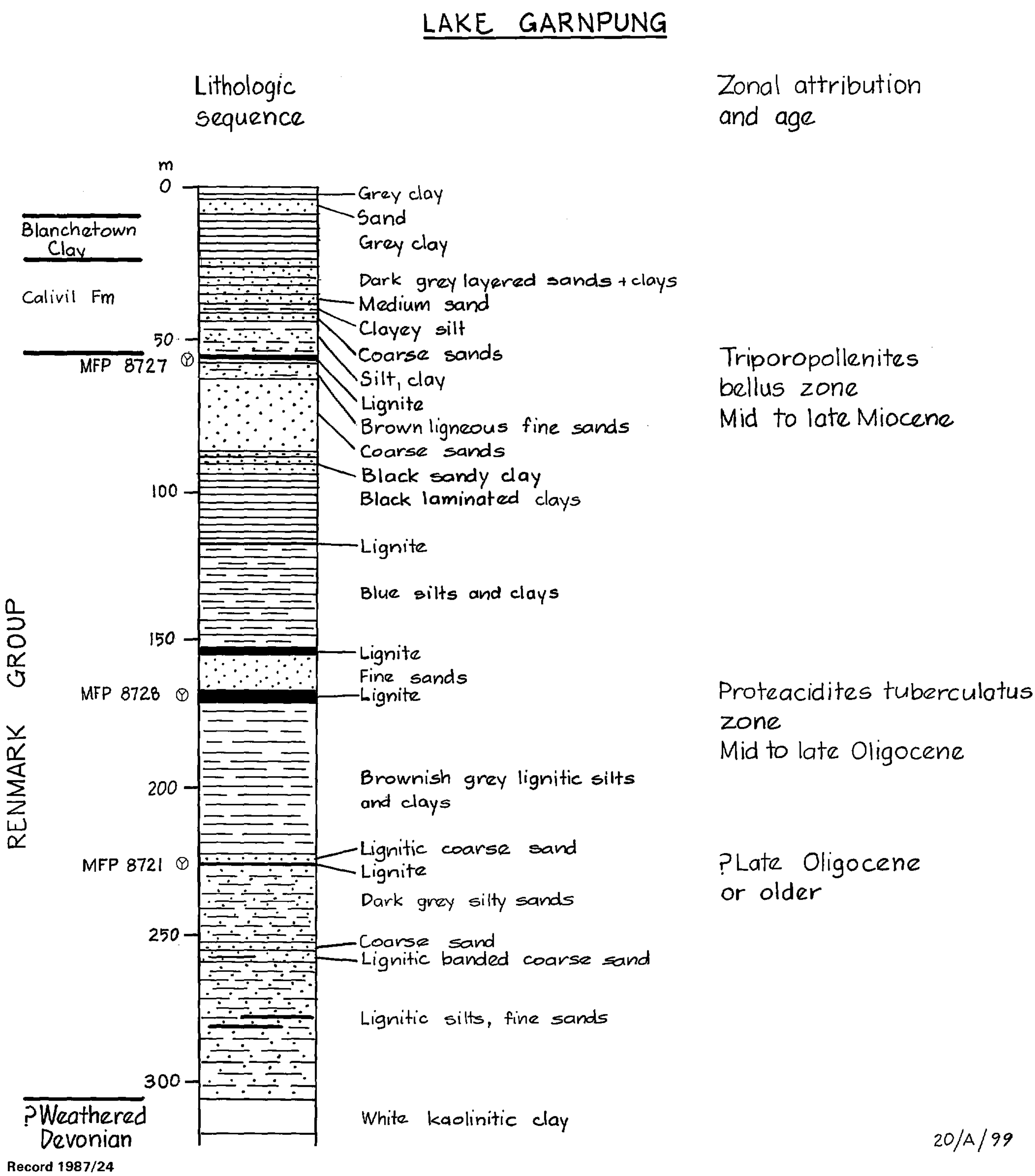
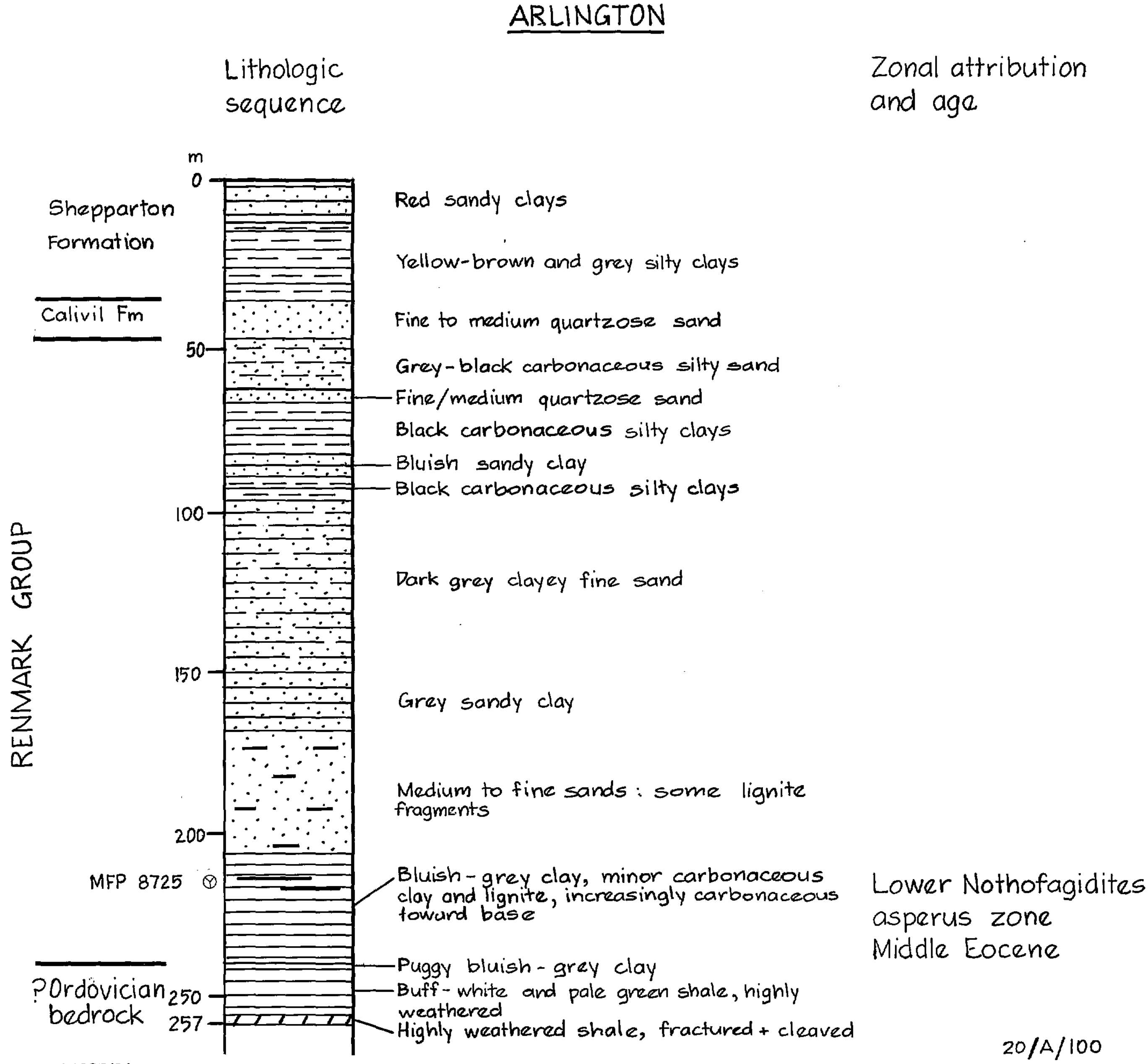
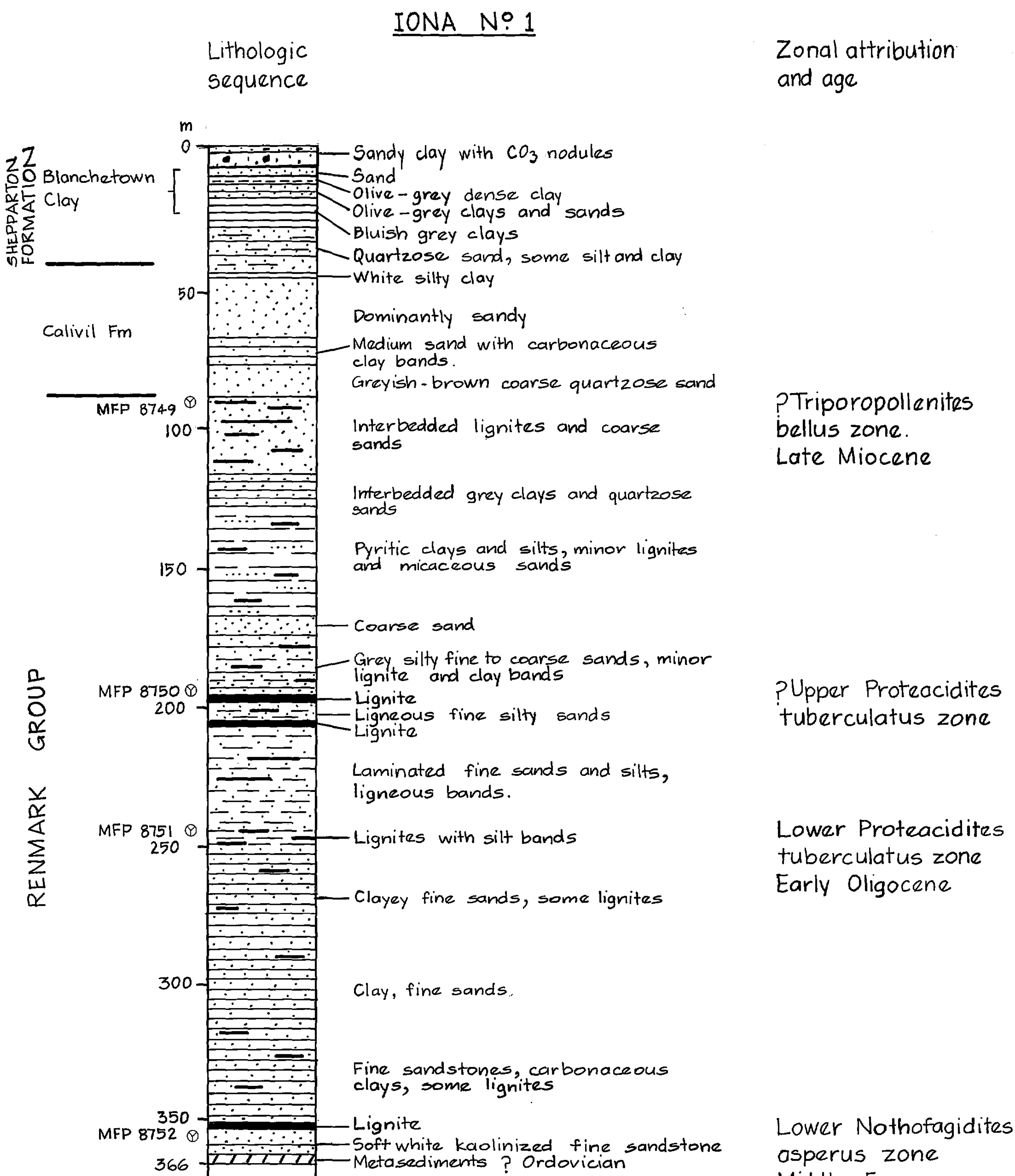


Fig. 6 Preliminary lithostratigraphy of Lake Garnpung borehole. Palynological sample on left; tentative palynological zone on right.



Record 1987/24

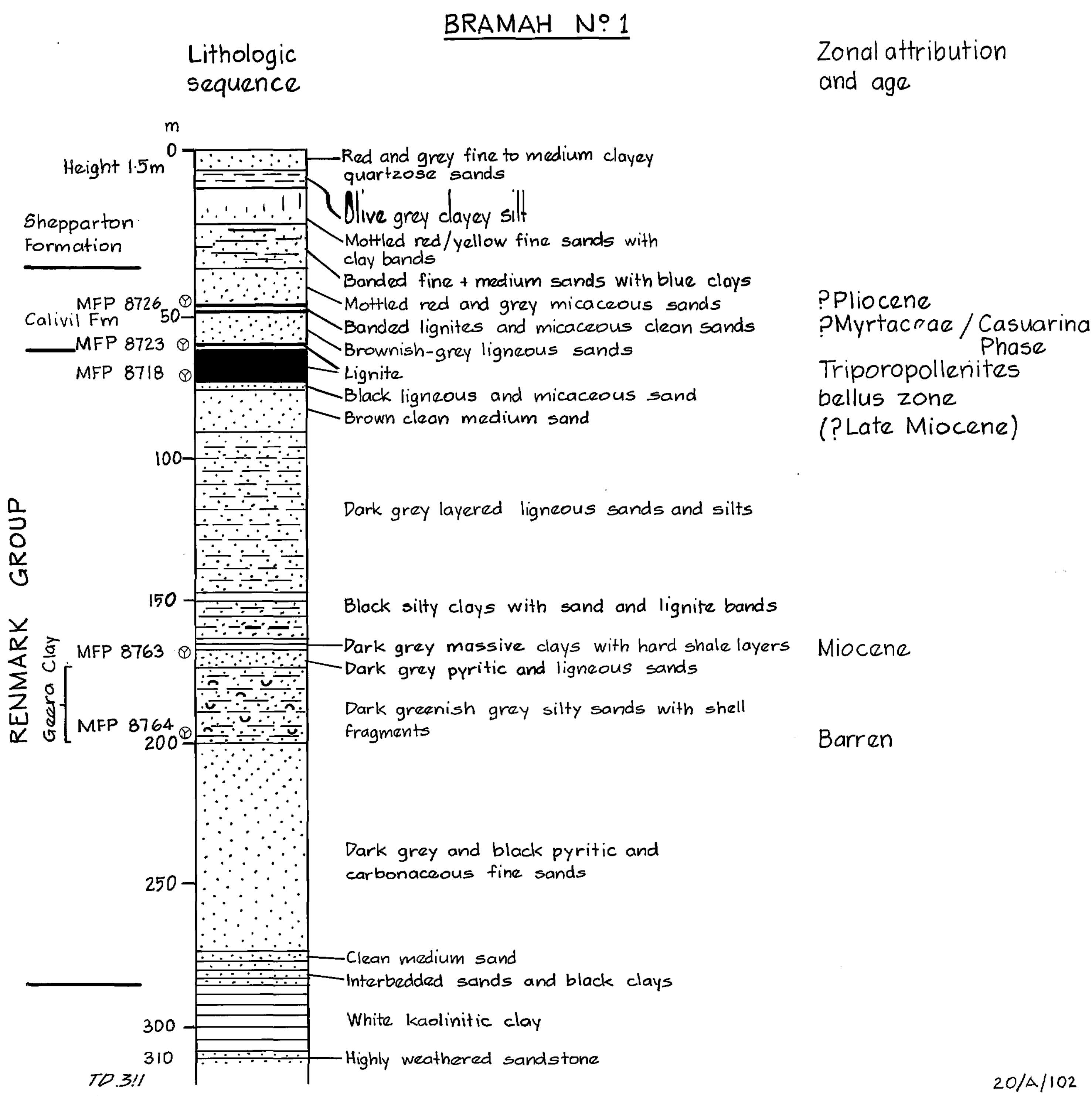
Fig. 7 Preliminary lithostratigraphy of Arlington borehole. Palynological sample on left; tentative palynological zone on right.



Record 1987/24

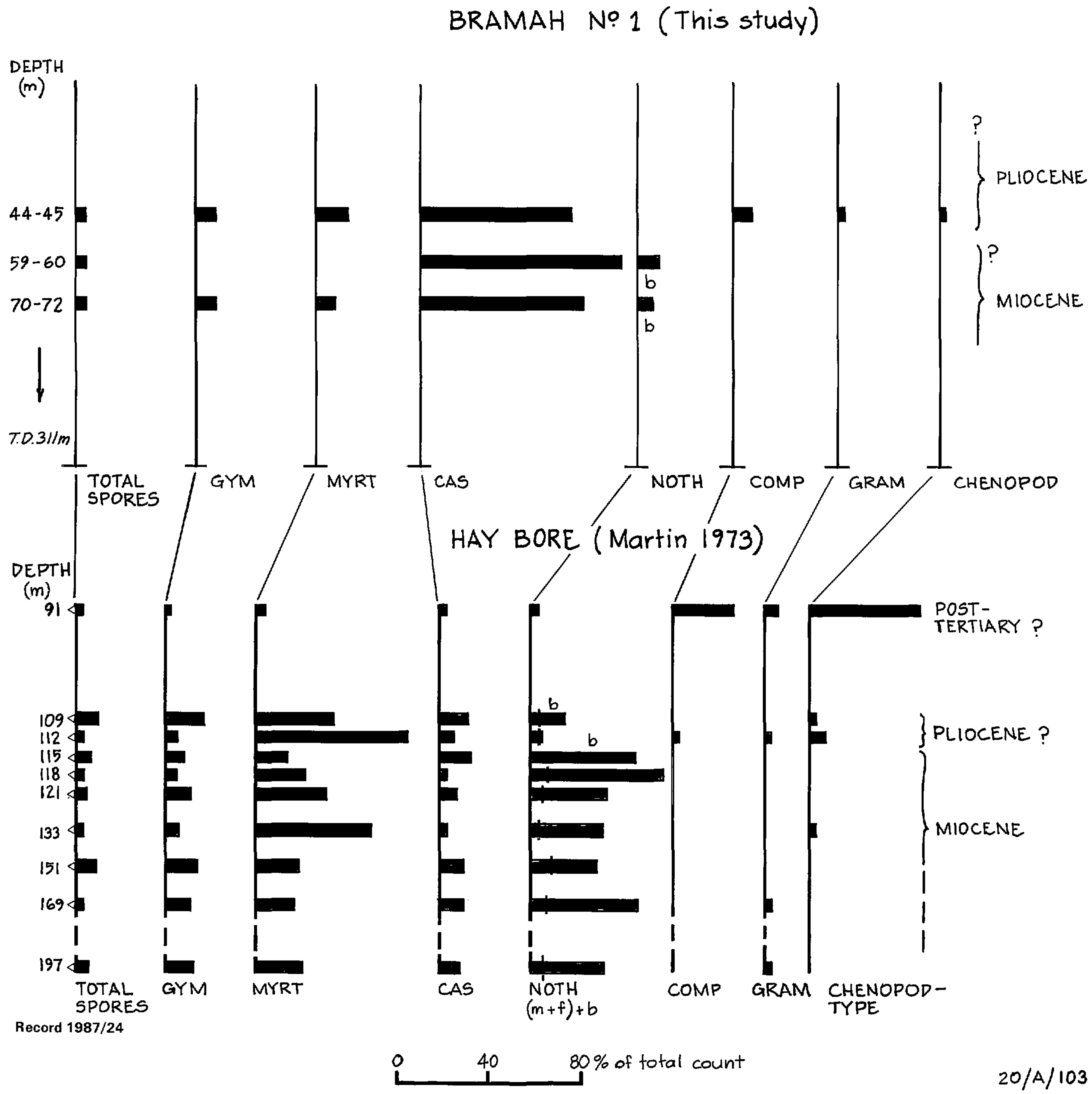
20/A/101

Fig. 8 Preliminary lithostratigraphy of Iona borehole. Palynological sample intervals on left; tentative palynological zones on right.



Record 1987/24

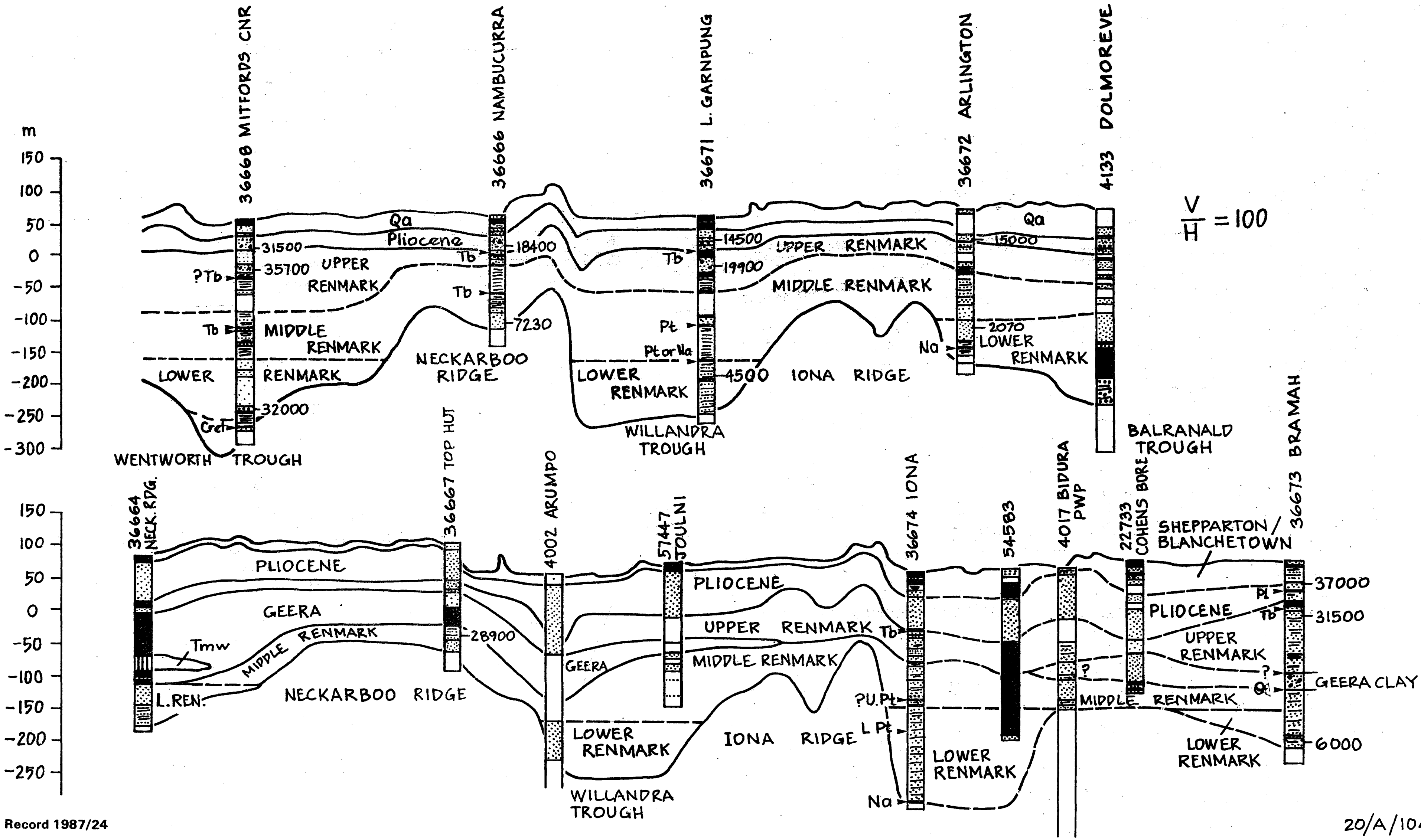
Fig. 9 Preliminary lithostratigraphy of Bramah borehole. Palynological sample intervals on left; tentative palynological zones on right.



Record 1987/24

20/A/103

Fig. 10 Quantitative analysis (based on major taxa) of shallow samples in Bramah borehole, compared to similar analyses in Hay bore given by Martin (1973). Abbreviations are as follows: GYM - total gymnosperm pollen, MYRT - total Myrtaceae, CAS - Casuarinaceae, NOTH - Nothofagus (m - menziesii, b - brass;, f - fusca types), COMP - Compositeae, GRAM - Gramineae, CHENOPOD - Chenopodiaceae.



20/A/104

Fig. 11 Diagrammatic cross sections of lithostratigraphic units through sites shown in Fig. 1, showing relationship of sections to basement configurations. Subdivisions of the Renmark Group are based on electric log data from J.R. Kellett. Palynological samples are arrowed on the left of the lithological columns: abbreviated zonal determinations are: Tb - Triporopollenites bellus, Pt - Proteacidites tuberculatus, Na - Nothofagidites asperus. Figures to right of columns represent salinities in parts per million.

Fig. 12 Selected pollen taxa from Murray Basin boreholes. All magnifications x 1000

A-D Nuxpollenites sp. A, B, elongate form. High and median foci, columellae visible. Mitfords Corner, MFP 8722/1: 100.1, 31.0. C, D, squat form, median and high focus on lalongate aperture, Nambucurra, MFP 8719/2: 101.7, 29.4.

E-H Milfordia sp. all from Iona. E, specimen with much thickened aperture, MFP 8752/2: 110.4, 43.9. F, G, median and high foci, MFP 8751/2: 98.0, 41.4. H, MFP 8751/3: 113.0, 48.2.

I-L Dryadopollis retequetrus (Partridge) Pocknall & Mildenhall. I, J, oblique polar view, high and median foci, Lake Garnpung, MFP 8728/3: 108.2, 37.4. K,L, equatorial view, median and high foci, Lake Garnpung, MFP 8728/1, 101.3, 44.3.

M,N Malvacearumpollis sp., Lake Garnpung. M, median focus showing sexine spines elevates on columellate cushions, MFP 8727/3: 97.2, 34.2. N, MFP 8737/3: 111.0, 38.5.

O,P Diporites aspis Pocknall & Mildenhall. Mitfords Corner, MFP 8720/1: 96.5, 37.9. O, focus on grain face with possible bases of viscin threads.

Q-T Corsinipollenites sp. All from Nambucurra. Q, MFP8719/2: 97.2, 41.3. R, Tetrad, focus on union between two individual grains, showing opposed pores, MFP 8719/2: 102.6, 44.5. S,T, foci showing wall, pores in section, MFP 8719/1: 109.7, 37.9.

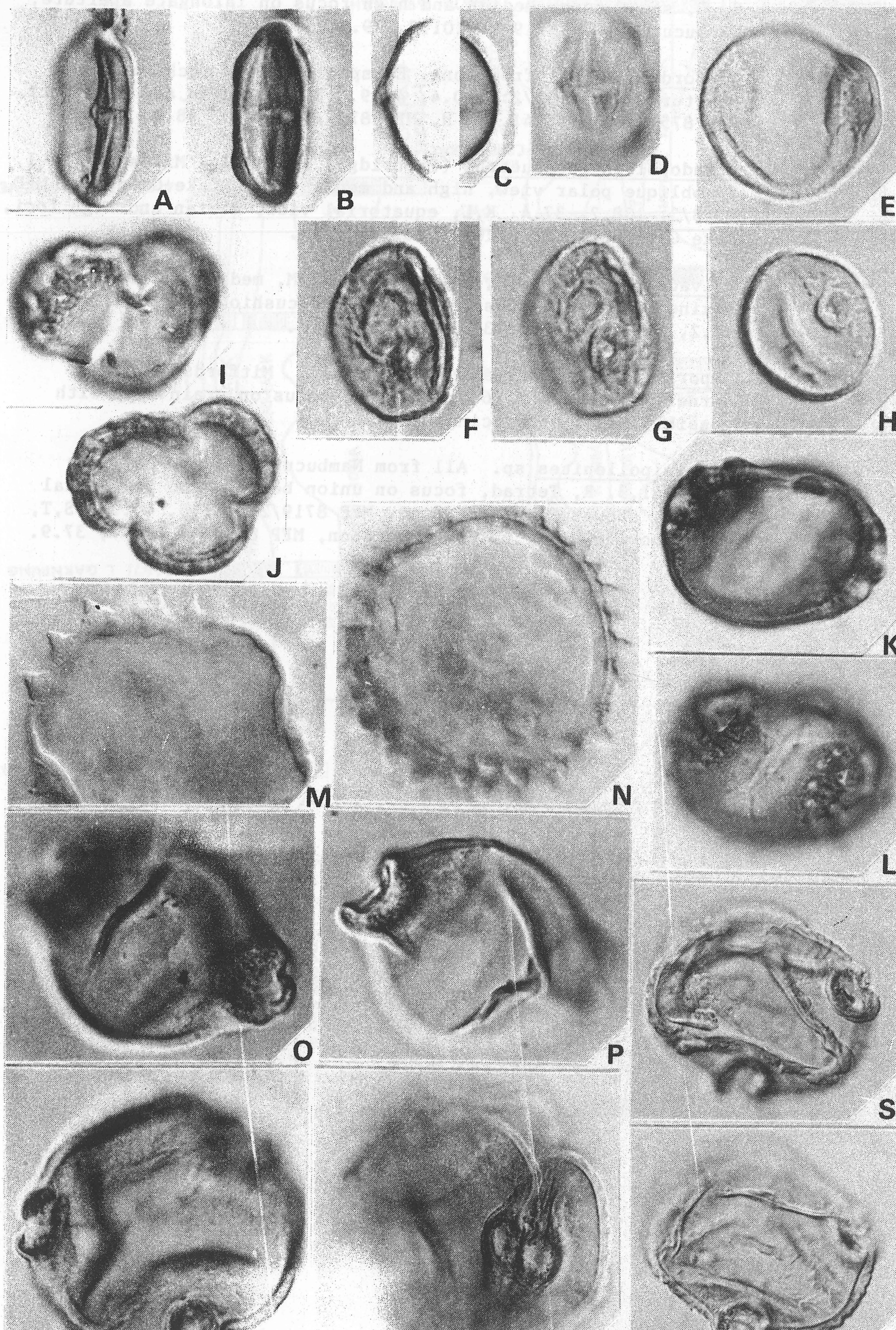

A
B
C
D
E
I
F
G
H
J
K
M
N
L
O
P
S
Q
R
T

Figure 13

Selected pollen taxa from Murray Basin boreholes. All magnifications x 1000.

A-C	Triporopollenites 'protrudens' A, median focus on pore protrusion, B,C, high and low foci on grain surfaces, each showing a pore surrounded by verrucate projections. Mitfords Corner, MFP 8729/2: 111.5, 47.5.
D	Tetrapollis sp. Mitfords Corner, MFP 8729/4 : 111.2, 29.6.
E-G	Propylipollis biporus Dudgeon. Arlington. E, MFP 8725/2: 97.5, 51.4. F,G, median and high foci. MFP 8725/3: 112.1, 46.0.
H,I	Proteacidites sp. cf. P. rhynthius Stover & Partridge. Arlington. High and median foci. MFP 8725/4: 94.2, 47.6.
J,K	Proteacidites rectomarginis Cookson. Iona, J, median focus on pore in section. K, high focus on surface. MFP 8751/2: 101.8, 44.5
L-P	Lymingtonia sp. Nambucurra. L, M, hgh and median focus, MFP 8719/1: 110.7, 44.0. N-P, MFP 8719/2: 109.2, 43.7. N clearly shows fine surface reticulum.

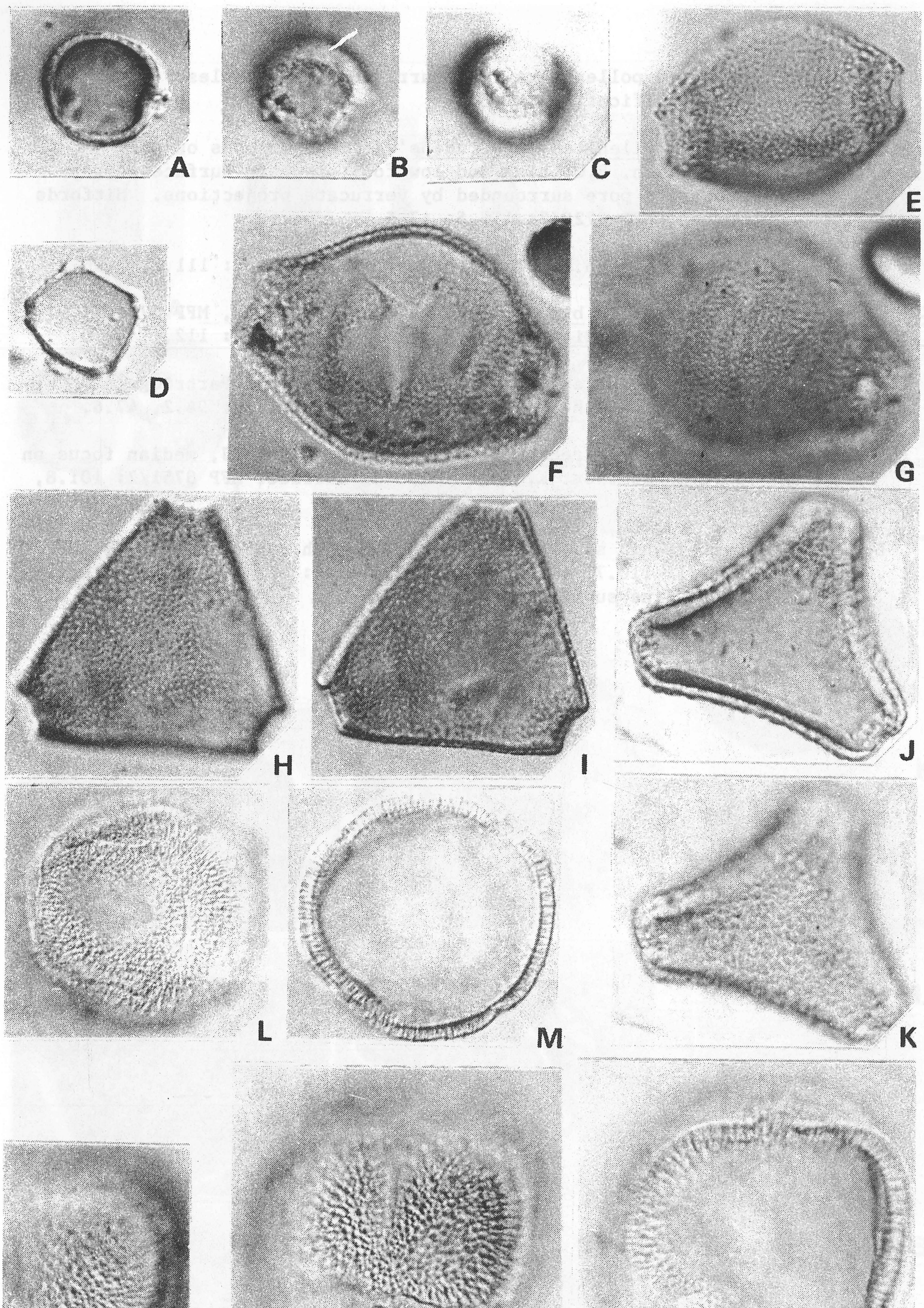

A
B
C
E
D
F
G
H
I
J
L
M
K
N
O
P

Table 1: Distribution of pollen and spore taxa in Murray Basin boreholes. Percentages based on a count of 200 specimens per sample (150 in Nambucurra at 58.5 - 59.0m). Asterisk indicates observed in sample but not in count.

	MITFORDS CORNER			NAMBUCURRA		LAKE GARNPUNG			ARLINGTON	IONA				BRAMAH		
BRYOPHYTA-LYCOPHYTA	88-89	168-169	173-174	58.5-59	119-121	52-54	168-169	224-225	212-216	90-92	196-198	244-249	353-354	44-45	59-60	70-72
Lycopodiumsporites sp.				1.3												
Stereisporites antiquasporites				1.3												
PTERIDOPHYTA																
Camarozonosporites sp.				1.3												
Cyathidites subtilis	0.5															
C. minor/australis	0.5				1.5	3.0		*				0.5				1.0
Gleicheniidites spp.				1.3	*	4.5										0.5
Laevigatosporites ovatus	1.5				0.5	3.0		*								
Matonisporites sp.	1.0															
Peromonolites sp. (cf. Paesia aff. scaberula)						*			*							
Polypodiisporites sp.									*							
Rugulatisporites sp. cf. R. trophus						*										
Verrucosisporites kopukuensis									*							
Verrucosisporites sp.				1.3												
GYMNOSPERMS																
Araucariacites australis	0.5		*			10.5					0.5	*	1.0			0.5
Cupressaceae						3.5										

	MITFORDS CORNER			NAMBUCURRA		LAKE GARNPUNG			ARLINGTON	IONA				BRAMAH		
	88-89	168-169	173-174	58.5-59	119-121	52-54	168.169	224-225	212-216	90-92	196-198	244-249	353-354	44-45	59-60	70-72
Dacrycarpites australiensis	0.5	6.5	13.0		0.5		3.0			1.0	3.5	2.5	0.5			1.0
Dacrydiumites florinii			*	1.3	0.5	1.0	*	*	3.0	2.5	0.5	1.0	4.0			4.0
Microcachryidites antarcticus									0.5			*		0.5		
Parvisaccites catastus												0.5				
Phyllocladidites mawsonii									*				14.5			
P. ovalis (MS)							0.5	*	*							
Podocarpidites ellipticus		1.0						*								
Podocarpidites spp.		2.0	5.5		1.0		0.5			0.5	1.0		1.5	3.0		1.5
ANGIOSPERMS																
Acaciapollenites myriosporites														0.5		
Anacolosidites acutullus									*				*			
Arecipites waitakiensis		1.0	7.0		0.5								0.5			
Banksieidites arcuatus						*						*				*
Banksieidites spp.									*		0.5					
Beaupreadites verrucosus			*						0.5				*			
Chenopodipollis chenopodiaceoides					*									1.0		
Corsinipollenites sp.					*											
Cupanieidites orthoteichus	1.0						*				*		0.5			0.5

	MITFORDS CORNER			NAMBUCURRA		LAKE GARNPUNG			ARLINGTON	IONA				BRAMAH		
	88-89	168-169	173-174	58.5-59	119-121	52-54	168-169	224-225	212-216	90-92	196-198	244-249	353-354	44-45	59-60	70-72
Dilwynites granulatus								*			*					
Dryadopollis retequetrus							*									
Echiperiporites sp.						*	*					*		*		1.5
cf. Elaeocarpaceae			4.0								*					
Ericipites crassiexinous		0.5							*			*	1.0	0.5		
E. scabratus													0.5			
Graminidites spp.		0.5		1.3	*			*						1.0		
?Geraniaceae											*					
cf. Gyrostemonaceae							*				*			0.5		
Haloragacidites haloragoides												*		4.0		
H. harrisii (Casuarinaceae)	19.5	22.0	13.0	45.3	68.0	27.5	7.5	*	6.0	81.0	22.0	17.0	1.5	64.5	88.0	68.0
H.sp. (four pored)											*					
Ilexpollenites spp.		*	1.0	1.3			1.5	*	2.5			*	1.0			
Liliacidites spp.		5.5	5.5		0.5	1.0	1.5		0.5	1.0	4.0	0.5	*			
Lymingtonia sp.					*											
Malvacearumpollis sp.					*	1.0				*						
Malvacipollis subtilis				2.6				*	2.0	*		*	1.0			

	MITFORDS CORNER			NAMBUCURRA LAKE		GARNPUNG			ARLINGTON	IONA				BRAMAH		
	88–89	168–169	173–174	58.5–59	119–121	52–54	168–169	224–225	212–216	90–92	196–198	244–249	353–354	44–45	59–60	70–72
M. diversus																0.5
Milfordia homeopunctata		0.5			0.5		*			0.5	0.5	1.0				
M. sp. cf. hypolaenoides						)25.5)				3.0		2.5				5.5
Myrtaceidites eucalyptoides	13.5								*		*	1.0		3.5	*	2.0
M. eugenioides	3.0			1.3							0.5					
M. mesonesus				2.6										0.5		
M. parvus	35.0	0.5		1.3	0.5	0.5	1.0		0.5		2.0	0.5	2.5	8.0		
Nothofagidites asperus		1.5	1.5				1.0	*	0.5			2.0	*		1.0	
N. brachyspinulos									*		3.0	1.5	11.5			
N. deminutus		1.0		5.3	1.0	0.5	12.5				6.0	11.5	4.0		2.0	0.5
N. emarcidus	2.5	27.0	14.5	13.3	3.5	0.5	44.5	*	57.0	1.5	32.0	30.5	17.0			1.5
N. falcatus		15.5	3.5	1.3	1.5	0.5	12.0	*	6.5	0.5	12.5	14.0	5.5		6.0	3.5
N. flemingii					*		*	*	0.5		0.5	0.5				
N. heterus		0.5	1.0		1.0		8.0	*	9.5		1.0	9.0	22.5			
Nuxpollenites sp.						0.5				1.0						
Onagraceae (diporate)			*													
Perfotricolpites sp. cf. P. digitatus	0.5		1.0		*	*										
Periporopollenites demarcatus							*	*	*							

	MITFORDS CORNER			NAMBUCURRA LAKE		GARNPUNG			ARLINGTON			IONA		BRAMAH		
	88-89	168-169	173-174	58-5-59	119-121	52-54	168-169	224-225	212-216	90-92	196-198	244-249	353-354	44-45	59-60	70-72
Periporopollenites spp.												0.5	1.0			
Polycopites reticulatus												*				
Polyorifices oblatus	3.0			6.6												0.5
Propylipollis sp. cf. P. annularis									1.0	0.5		0.5				1.0
P. sp. cf. P. latrobensis							*									
P. biporus									*							
Proteacidites angulatus									0.5							
P. pachypolus									*				*			
P. rectomarginis							*		*			0.5	*			
P. reticulatus									*				*			
P. sp. cf. P. symphonemoides						*										0.5
P. sp. cf. simplex													2.5			
P. spp.	4.0	*	*		*				3.5							
Psilodiporites sp. cf. P. redundantis			9.5													
Quintinia psilatispora			0.5										1.0			
Rhoipites alveolatus													0.5			*
R. sphaerica							*						*			
R. sp. C. of Foster							*									
Santalumidites cainozoicus									*							

	MITFORDS CORNER			NAMBUCURRA LAKE		GARNPUNG			ARLINGTON	IONA				BRAMAH		
	88-89	168-169	173-174	58.5-59	119-121	52-54	168-169	224-225	212-216	90-92	196-198	244-249	353-354	44-45	59-60	70-72
Sparganiaceaepollenites barungensis								*								
S. spp.	0.5	5.5	2.5	2.6	15.5	5.0	1.5			1.0		0.5			*	
Stephanocolpites oblatus	1.0	*			*			cf.							1.0	*
Tetrapollis sp.		*														
Tricolporopollenites protrudens		*														
Triporopollenites ambiguus													*			
Tricolporites spp.	3.0	3.0	5.0	6.6	1.0	3.0	2.0	*	5.5	0.5	2.0	1.5	3.0	9.5		4.0
Tricolporites leuros									*							
Tubulifloridites sp.														4.0		
Proteacidites asperopolis									*							
Proteacidites leightonii									*							
Proteacidites rynthius									*							
Unknowns	6.0	3.5	7.5		1.5	2.5		4.0		2.0	1.5	2.0	0.5	1.0		1.0
Tricolpites spp.	0.5	1.0	5.0								2.5		0.5			