# BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

## RECORD

RECORD 1981/32

# PALYNOLOGY OF THREE NERDDC STRATIGRAPHIC BORES IN THE EROMANGA BASIN: PRELIMINARY REPORT

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## SUMMARY

Palynological data from three NERDDC boreholes are briefly reviewed. BMR Augathella 6 and BMR Jericho 11 in Queensland intersect the Wallumbilla Formation (Coreena Member), Toolebuc Formation, and Allaru Mudstone; BMR Urisino 1 in New South Wales intersects the (upper) Bulldog Shale and the Oodnadatta Formation, including the Coorikiana, Wooldridge, and Mount Alexander Members.

The palynological sequence is of Albian age and represents the *Crybelosporites striatus, Coptospora paradoxa,* and *Phimopollenites pannosus* spore and pollen zones, and the *Pseudoceratium turneri* and (lower) *Endoceratium ludbrookiae* dinoflagellate zones. From their palynological associations, the Bulldog Shale and Coorikiana Member are correlated with the Coreena Member, the Wooldridge Limestone Member with the Toolebuc Formation, and the Mount Alexander Sandstone Member in all likeliness with the Allaru Mudstone.

Initially, palaeo-environments were chiefly brackish to non-marine, with local marine intercalations. The beginning of Toolebuc/Wooldridge deposition is the sign of a (shallow) marine episode, most likely of eustatic origin. The "Toolebuc Sea" stretched across Queensland, northwestern New South Wales, and northern South Australia. Dinoflagellate floras show restrictive (hypersaline?) characteristics, and confirm field evidence that northern connections with the open ocean were cut off at times.

## INTRODUCTION

As part of the NERDDC Oil Shale Methodology Project, 14 boreholes have been sunk along the eastern margin of the Eromanga Basin between Longreach and Charleville. This program aimed at obtaining continuously cored sections of the Toolebuc Formation for lithological, petrochemical, and palaeontological study of the oil shale. A fifteenth hole, BMR Urisino 1, had been drilled earlier, in order to check on a possible southern extension of the formation into northwestern New South Wales. The stratigraphy of these boreholes has been described by Ozimic (1980).

Palynological work on the Toolebuc Formation can contribute to the Project in two ways:

(1) by establishing more accurately than before the position of critical palynological zonal boundaries in the Albian sequence of the Eromanga Basin, thus contributing towards a better correlation of rock sequences within and outside the basin; and

(2) by assessing environments in which the Toolebuc Formation was deposited, and in this way making additional suggestions as to the conditions under which the oil shale formed.

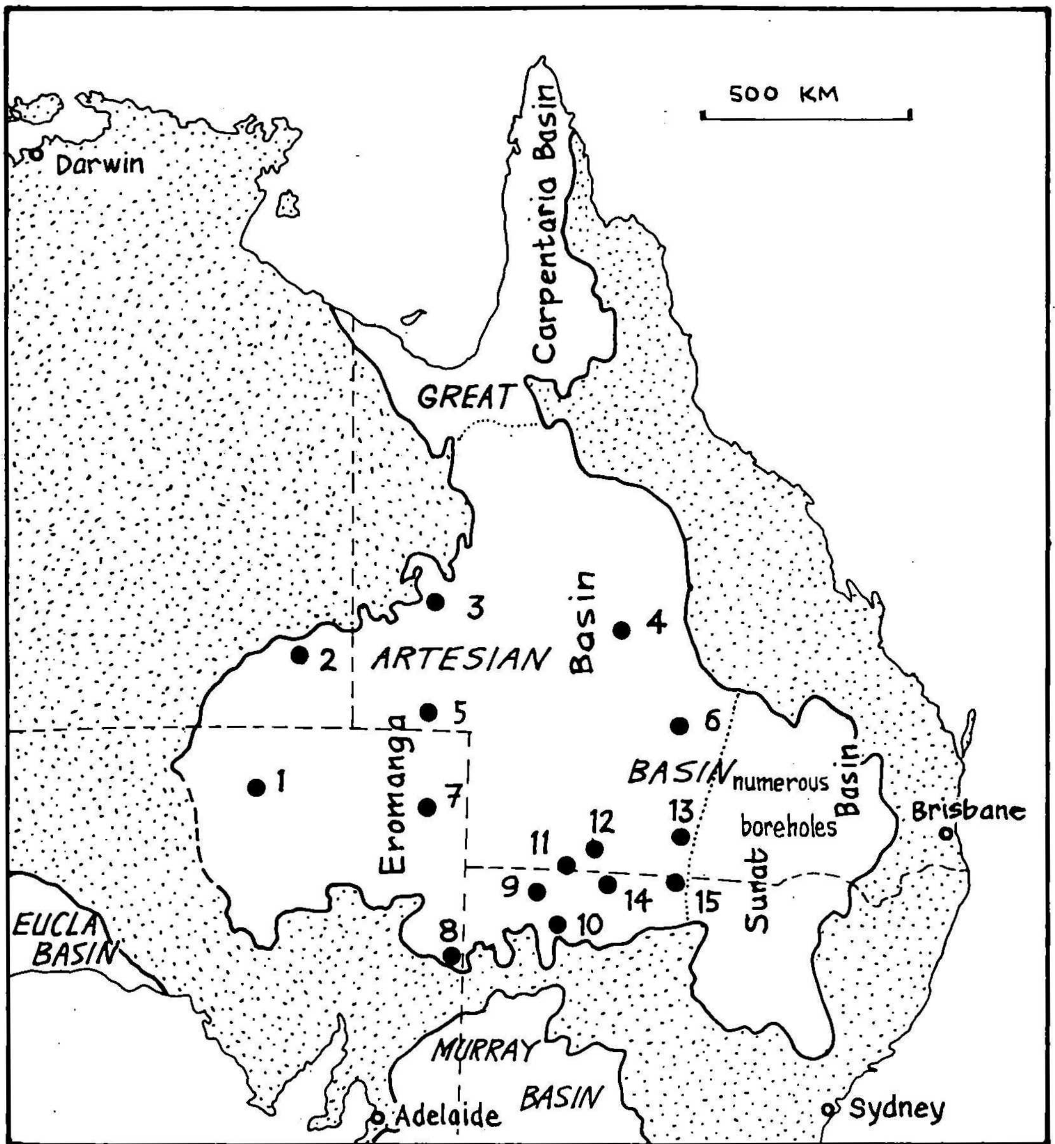
Earlier studies were hampered in investigating these aspects owing to a lack of suitable material, in particular from the critical areas of the central and northern Eromanga Basin. For a long time the Toolebuc Formation was thought to fall within the *Coptospora paradoxa* zone, and only recently new information from the Surat and Carpentaria Basins gave reason to doubt this. Evans & Hawkins (1967) touched on the problem of correlating Cretaceous rock sequences in Queensland and South Australia, as palynological and foraminiferal data seemed to disagree on this point. This made the acquisition of more accurate information highly desirable, in connection with the question as to whether, and how far, the Toolebuc Formation might extend into New South Wales and South Australia.

As a preliminary contribution to the NERDDC Project, three boreholes, BMR Urisino 1, BMR Augathella 6, and BMR Jericho 11, have been selected for an initial pilot study to investigate two problems, namely where the Toolebuc Formation fits in the palynological sequence, and how palynology may contribute effectively towards an assessment of the prevailing environments of deposition.

The first objective presented no difficulties, as selected samples from the boreholes yielded rich palynological residues. The fossils represent a section of the palynological sequence which is well known from studies in the Albian of the Otway Basin, the Eromanga Basin, and the Surat Basin (Dettmann, 1963; Dettmann & Playford, 1969; Dettmann & Douglas, 1976; Morgan, 1978; Burger, 1980a). The sequence of spores and pollen grains includes 4 intervals, and the concurrent sequence of dinoflagellates 6 intervals. These subdivisions and their interrelations in time, based on the studies of Morgan (1978), are shown in Figure 3. The geological ages of the subdivisions are derived from Day's (1969) study of shelly faunas from the associated sedimentary formations in outcrop along the eastern and northern margins of the basin.

To succeed with the second objective, microfloral assemblages from the NERDDC boreholes were subjected to statistical (numerical) analysis. Previous results with this type of analysis had been very encouraging, and the conclusions drawn from the present statistics are outlined in the section PALAEO-ENVIRONMENTS.

The locations of the NERDDC boreholes, and other drilled sections referred to in this report, are plotted in Figure 1, and specifications of samples analysed are listed in Table 1.




| | |
|---|---|
| 1 Santos Oodnadatta 1 | 9 BMR Urisino 1 |
| 2 BMR Hay River 4 | 10 DM Wanaaring DDH 1 |
| 3 BMR Boulia 3 | 11 BMR Bulloo 1 |
| 4 BMR Jericho 11 | 12 BMR Eulo 2 |
| 5 DFS Betoota 1 | 13 BMR Wyandra 1 |
| 6 BMR Augathella 6 | 14 DM Bellfield DDH 1 |
| 7 Kalladeina Water Bore | 15 DM Weilmoringle DDH 1 |
| 8 SADM Yalkalpo DDH 1 | |

Fig. 1 The Great Artesian Basin, and locations of boreholes used for reference in the text. Not referred to are 27 boreholes drilled in the Surat Basin

# PALYNOSTRATIGRAPHY OF BMR URISINO 1

This stratigraphic hole was drilled and logged by BMR about 29 km northwest of Urisino township, in the Bulloo Embayment of the basin in northwestern New South Wales. Palynological reports have been written by McMinn (1980) and Burger (1980b), and a brief recapitulation of the biostratigraphy follows here (Fig. 2).

The recovery of spores and pollen grains from selected depth intervals was satisfactory. The interval from 129 m to total depth is associated with the *Coptospora paradoxa* zone, and the interval from 50 m to 126 m with the *Phimopollenites pannosus* zone. A sample taken from 126.2-129 m yielded too few fossils to be dated, but lies probably within the *Phimopollenites pannosus* zone. The recovery of marine phytoplankton (dinoflagellates, certain acritarchs) was poor, but McMinn, who macerated a series of 18 samples at regular intervals, achieved better results. He considered the dinoflagellate assemblages from below 139.4 m to represent the *Pseudoceratium turneri* b zone, those from the 129.5-139.4 m interval the *Ps. turneri* b or c zones, and those from the 52-126 m interval the *Endoceratium ludbrookiae* a zone. Samples from between 124 m and 126.5 m were apparently barren of marine microfossils.

Scheibnerová (1980) examined benthic foraminifera from samples between 135 m and 58 m; she suggested that Urisino 1 may not have penetrated the Toolebuc Formation, but she observed that the section was "too short for any detailed stratigraphic analysis". The palynological age determinations prove that an interval equivalent in time to the Toolebuc Formation has been penetrated, which may be of interest for future search for oil shale in New South Wales. This interval is also lithologically very similar to the Toolebuc Formation, but referring it to this formation meets with problems, which flow in part from the different stratigraphic nomenclatures that geologists have developed in South Australia and Queensland. Burger (1980b) already briefly touched on this problem, and in the present report the South Australian nomenclature is used, as shown in Figure 2, for the following reasons:

(1) The presence of a mudstone seq ence within the *Coptospora paradoxa* zone at 144-149 m constitutes a lithological distinction from the sandstone of the Coreena Member (Wallumbilla Formation) in Queensland, which was deposited at the same time. However, the section falling within the zone can be equated without difficulty with Santos Oodnadatta 1 in South Australia, where the *Coptospora paradoxa* zone is associated with the upper part of the Bulldog Shale and the basal "greensand" interval known as the Coorikiana Member of the Oodnadatta Formation (Dettmann & Playford, 1969).

(2) The calcareous mudstone sequence in the 102-122 m interval corresponds both lithologically and in time to the Wooldridge Limestone Member of the Oodnadatta Formation; this member is associated with the lower part of the *Phimopollenites pannosus* zone in Santos Oodnadatta 1 (Playford et al., 1975).

(3) The silty and sandy interval between 53 m and 78 m is here regarded as being most logically the continuation into northern New South Wales of the Mount Alexander Sandstone Member of the Oodnadatta Formation in South Australia. As in Urisino 1, that member is associated with the *Phimopollenites pannosus* zone in Santos Oodnadatta 1 (Dettmann & Playford, op. cit.). Strata associated with the zone in Queensland are argillaceous (Allaru Mudstone), and the overlying sandston and siltstone (Mackunda Formation) are on palynological evidence younger.

## PALYNOSTRATIGRAPHY OF BMR AUGATHELLA 6

This borehole was drilled by Amalgamated Drillers Company, approximately 36 km northwest of Augathella, and logged by BMR. It penetrated superficial (Cainozoic) deposits, and continuously cored the Allaru Mudstone, the Toolebuc Formation, and the Coreena Member of the Wallumbilla Formation (Fig. 2).

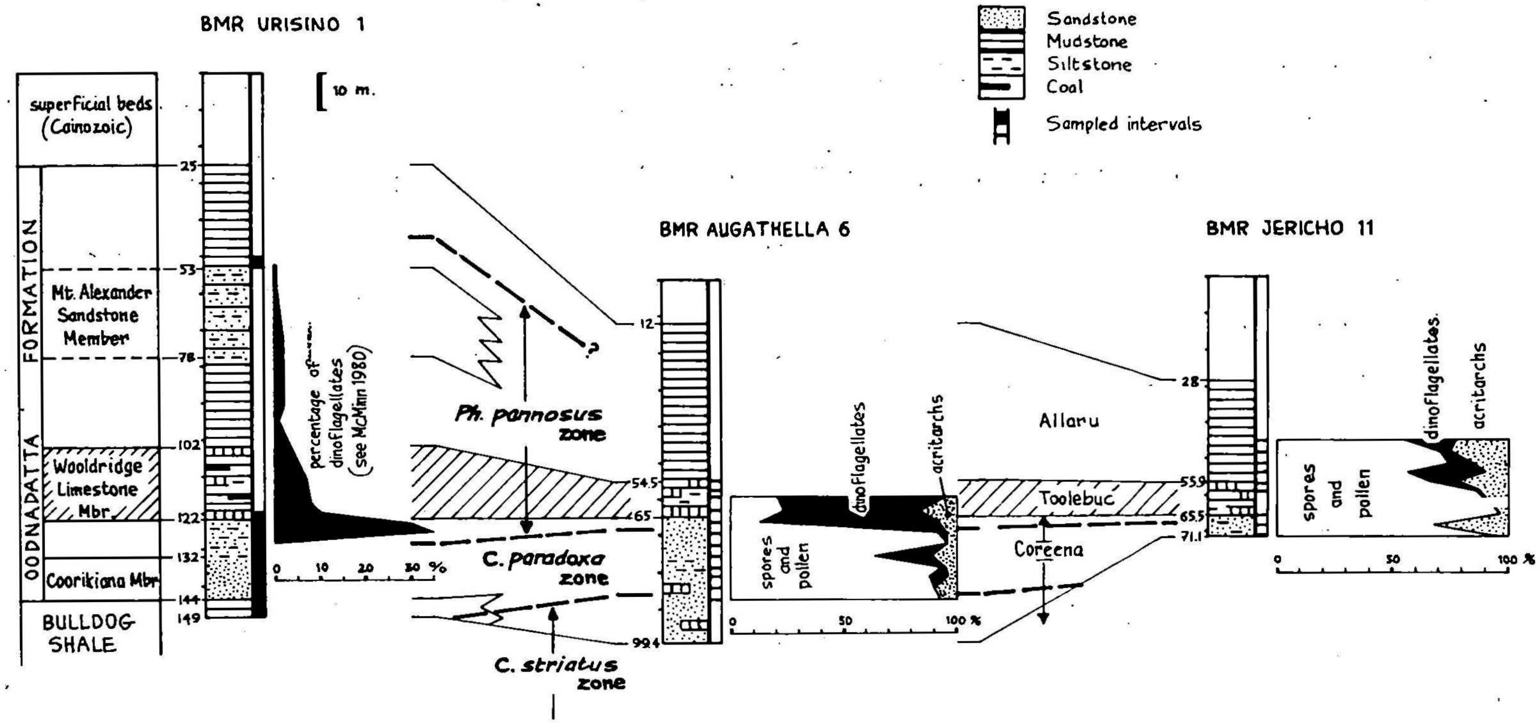



Fig. 2 Stratigraphy and correlation of NERDDC boreholes. For details of palynological statistical analyses see section Palaeoenvironments

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The recovery of spores and pollen grains was very good between 54.40 m and 87.40 m (the Allaru Mudstone will be studied later). The interval from 87.4 m to total depth falls within the *Crybelosporites striatus* zone, the interval from 69.1 m to 84.9 m within the *Coptospora paradoxa* zone, and the interval from 59.4 m to 66.4 m in the *Phimopollenites pannosus* zone.

The marine phytoplankton record is fragmentary, as several samples from the Coreena Member yielded few dinoflagellates. The assemblages from 75.40 m and 81.40 m are dominated by the genus *Diconodinium* and lack the appropriate guide species for accurate dating. The assemblage from 66.40 m, and those from the Toolebuc Formation at 63.40 m and 59.40 m are part of the *Endoceratium ludbrookiae* a zone. The samples taken from 54.40 m and 56.60 m yielded extremely rich marine floras and are undoubtedly part of the same zone, but the fossils are in extremely poor condition and need to be studied in much more detail.

## PALYNOSTRATIGRAPHY OF BMR JERICHO 11

This borehole was drilled by Amalgamated Drillers Company, about 25 km southeast of Barcaldine, and logged by BMR. It penetrated (below a cover of superficial sediments) the Allaru Mudstone, Toolebuc Formation, and the uppermost part of the Coreena Member of the Wallumbilla Formation (Fig. 2). Core samples at 3-m intervals from between 45.2 m and 70.8 m were analysed, and most yielded very abundant and species-diverse spore and pollen assemblages.

The interval from 68 m to total depth lies within the upper *Coptospora paradoxa* zone, and the interval between 45 m and 65.2 m within the *Phimopollenites pannosus* zone. The assemblage from 65.15 m lacks the index species *Ph. pannosus* of the upper zone but contains a small monolete species, *Microfoveolatosporis canaliculatus* Dettmann, which first appears in the sequence approximately at the same time as *Ph. pannosus*.

The marine microfossil record is rather poor in the lower interval. The dinoflagellate assemblage from 70.8 m is probably not older than the *Pseudoceratium turneri* c zone, and may represent the lower part of that zone. The assemblages from the 45-56 m interval are more diverse, and are recognised as part of the *Endoceratium ludbrookiae* a zone.

## CORRELATION OF BOREHOLES

### Correlation on spores and pollen grains

The correlation here made between the three NERDDC boreholes is shown in Figure 2. BMR Urisino 1 and BMR Jericho 11 reached a depth sufficient to penetrate the interval of the *Coptospora paradoxa* zone. BMR Augathella 6, which contains the thickest section of the Coreena Member (Wallumbilla Formation) so far drilled and cored in the NERDDC program, goes down into the upper part of the *Crybelosporites striatus* zone. This is important, because in view of its location this section can contribute towards the history of sedimentation on the west flank of the Nebine Ridge (which separates the Eromanga and Surat Basins), and perhaps verify possible movements of the ridge during the Albian, and their effects on the palaeo-environments of the Toolebuc Formation.

From the presence of the *Coptospora paradoxa* zone in BMR Urisino 1 it follows that the Coorikiana Member can be correlated with the uppermost part of the Coreena Member, and the upper part of the Bulldog Shale with the lower part of the member. The lower limit of the *Phimopollenites pannosus* zone is characterised by the first stratigraphic appearance of *Phimopollenites pannosus* (Dettmann), *Microfoveolatosporis canaliculatus* Dettmann, and possibly also *Tricolpites minutus* (Brenner). This boundary is of particular interest for the biostratigraphy of the Albian, because near this level a basin-wide change took place from sandy to argillaceous-calcareous environments, in which the oil shale was generated. In Santos Oodnadatta 1 this boundary lies at 124 m (407 feet), slightly below the Wooldridge Limestone Member (Playford et al., 1975).

Work in progress in the southern Carpentaria Basin has established that the beginning of the *Phimopollenites pannosus* zone lies slightly below, or at the base of, the Toolebuc Formation. Foraminiferal work by Haig (1973) indicated that the Toolebuc Formation should be correlated with the Wooldridge Limestone Member and not with the Coorikiana Member, as was suggested by Freytag (1966), and the present examination of the NERDDC boreholes confirms this.

The upper limit of the *Phimopollenites pannosus* zone, which is characterised by the upper range limit of *Coptospora paradoxa*, lies in Santos Oodnadatta 1 at 26.5 m (87 feet), slightly above the Mount Alexander Sandstone Member (Dettmann & Playford, 1969). In Queensland it lies probably in the upper part of the Allaru Mudstone, but the sections do not confirm this.

Correlation on dinoflagellates

Spores and pollen grains occur, in places abundantly, in sediments of both marine and non-marine origin. Dinoflagellates, on the other hand, being organisms closely bound to marine conditions, are often not present in sufficient quantity and diversity for proper biostratigraphic application, especially in marginal areas where salinity often falls below critical levels. The Toolebuc Formation and Allaru Mudstone in BMR Augathella 6 and BMR Jericho 11 yielded reasonably diverse marine assemblages of the *Endoceratium ludbrookiae* a zone. The Coreena Member yielded very few datable assemblages, but fossils from 70.8 m in BMR Jericho 11 are assigned to the *Pseudoceratium turneri* c zone, and a microflora from 66.4 m in BMR Augathella 6 is part of the *Endoceratium ludbrookiae* a zone. This means that the lower limit of that zone falls just below the Toolebuc Formation. It also lies slightly below the Wooldridge Limestone Member in BMR Urisino 1 (McMinn, 1980) and in Santos Oodnadatta 1 (Morgan, 1978), and thus coincides approximately with the lower limit of the *Phimopollenites pannosus* zone.

This is one of several instances of close parallelism between zonal boundaries; other instances have been documented, as is shown by the time relations of zonal intervals in Figure 3, which apply throughout the Great Artesian Basin. These observations are of fundamental interest to stratigraphic palynology, as zonal boundaries are characterised by stratigraphic first (or last) occurrences of organisms that phylogenetically are entirely unrelated. They demonstrate, in effect, that the boundaries in question are by approximation "time-planes" in the fossil sequence of the Great Artesian Basin, a conclusion that was reached also by Dettmann & Playford (1969) and Burger (1980a).

## STATISTICAL PALYNOLOGY

Palynology can contribute towards the study of past environments of deposition by statistical (numerical) analysis of the presence of fossils in microfloral assemblages. These assemblages may include organisms of both marine (dinoflagellates, certain acritarchs) and terrestrial origin (spores, pollen grains), and it is clear that the presence (be it abundant or rare) or absence of certain fossils very frequently reflects the conditions in which the associated sediment was formed.

On the basis of statistical analyses of Cretaceous assemblages in the Surat Basin, Burger (1980a) distinguished three broad palaeo-environmental complexes. The interpretations that flowed from this analysis closely agreed with the views held by Exon (1976) and Day (1969) on geological events in the basin, and it was therefore decided to carry out a similar analysis on the NERDDC boreholes.

The abundances of spores and pollen, acritarchs, and dinoflagellates (related to total assemblage counts of 400 specimens) are set out graphically for BMR Augathella 6 and BMR Jericho 11 in Figure 2. Percentage values of each of these groups are listed in Table 1. The dinoflagellate graph for BMR Urisino 1 is reproduced from McMinn (1980). Percentages of dinoflagellates are translated into three broad environmental subdivisions in the same manner as for the Surat Basin (see Burger, op. cit.):

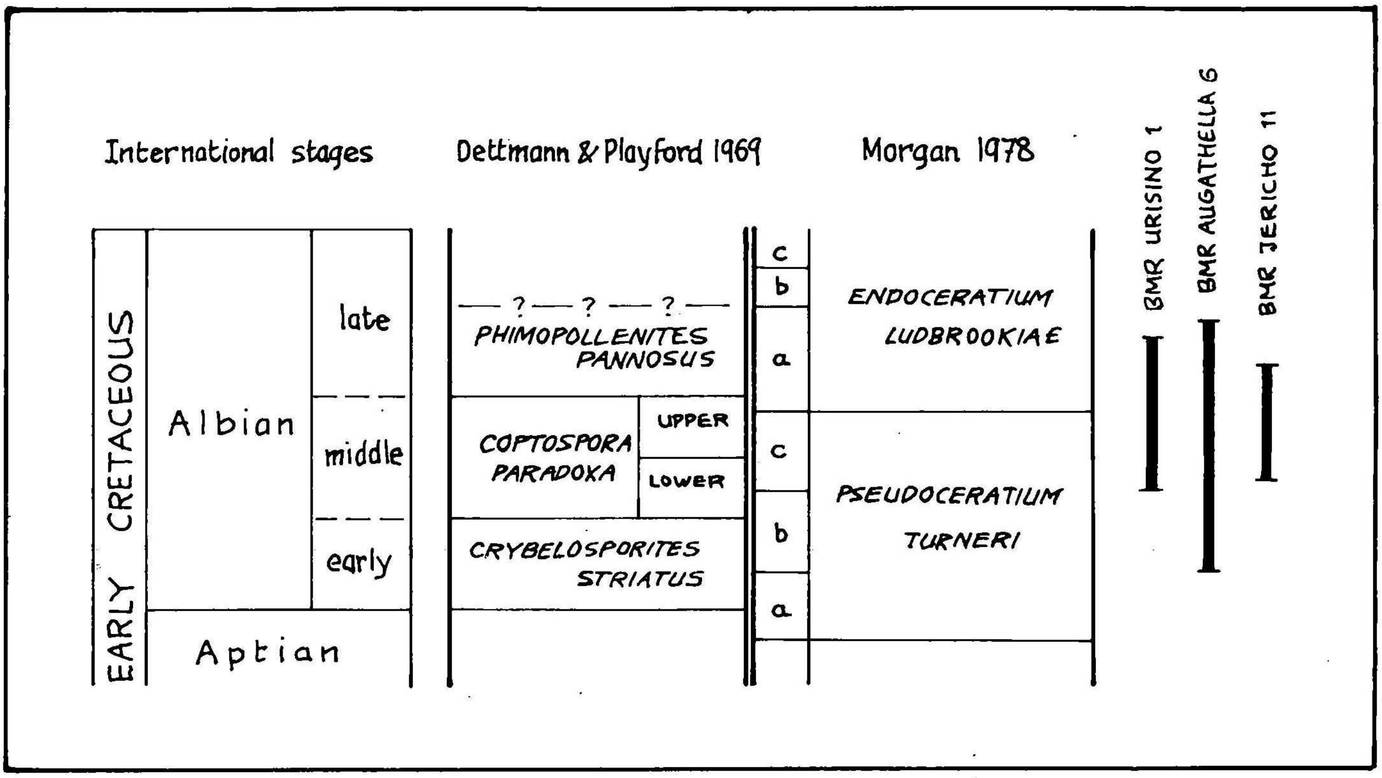


Fig. 3 Geological age of palynological zonations in the Great Artesian Basin

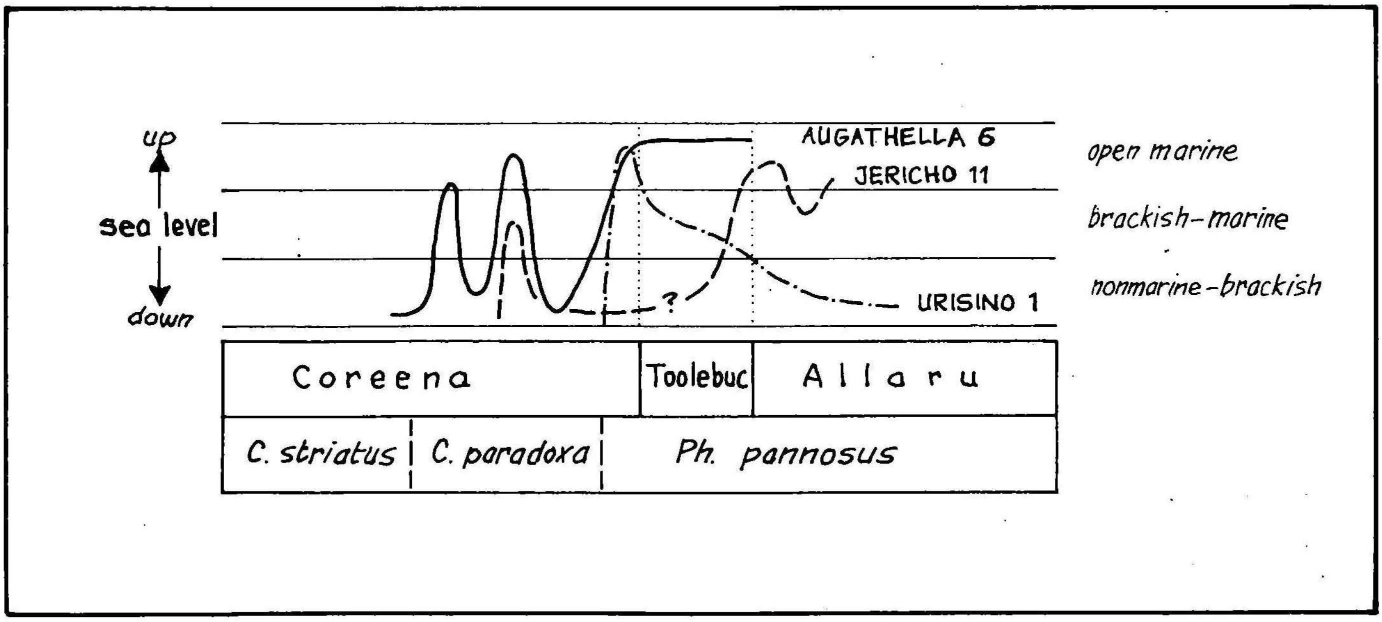


Fig.4 Palaeoenvironments of Albian strata in three NERDDC boreholes, as interpreted from statistical analysis of palynological assemblages

<u>0-3%</u>: non-marine to brackish conditions, such as occur in lower river courses and lakes.

<u>3-8%</u>: brackish-marine conditions, such as are found in littoral areas (beach deposits) and deltas.

<u>Above 8%</u>: open marine conditions of the epineritic and neritic zones (inner part of the Continental Shelf).

The associated samples, thus classified, illustrate how environments may have changed in time at the sites of the NERDDC boreholes.

## PALAEO-ENVIRONMENTS

The statistical analyses are set out in the way of an "environmental curve" for each borehole, in Figure 4. At the location of BMR Augathella 6 non-marine conditions prevailed, and were interrupted twice by probable brief incursions of the sea in the interval of the *Coptospora paradoxa* zone. The second incursion probably coincided with a brief brackish-marine episode at the location of BMR Jericho 11, as both episodes fall within the upper part of the zone.

Appreciable numbers (16-28%) of coniferous pollen, viz. *Alisporites* and *Microcachryidites*, have been registered in 6 of the 8 spore and pollen assemblages from the zone. The coniferous elements of the vegetation in the interior are therefore well represented in the local influx of pollen, which means that they probably grew nearby. This strengthens the impression that the marine intercalations were ephemeral and had little impact on the distribution of plant associations in that region.

The onset of the *Phimopollenites pannosus* zone coincides with the flooding of the locations of BMR Augathella 6 and BMR Urisino 1 by the Toolebuc sea. Apparently the sea then slowly receded from the latter site, and this eventually culminated in the deposition of the brackish to non-marine arenites of the Mount Alexander Sandstone Member.

At the site of BMR Jericho 11 fully marine conditions were not established before the beginning of Allaru Mudstone deposition; conditions of low salinity seem to have prevailed until then. On the whole, environments were typical of coastal regions, and this is reflected in the pollen sedimentation. Spore and pollen assemblages from the Augathella and Jericho sections include a low amount (4-7%) of coniferous elements, which indicates a low influx of pollen from the interior, and relatively high amounts of *Gleicheniidites* (26-36%) and *Baculatisporites-Osmundacidites* (6-10%), which point to the proximity of elements which Burger (op. cit.) considered to be characteristic of the coastal vegetation in the Surat Basin.

Albian sediments have been palynologically examined in boreholes from Queensland, New South Wales, the Northern Territory, and South Australia by BMR, the Geological Survey of New South Wales, and the University of Queensland. On the basis of those data available an attempt is made to fit the local events at the sites of the NERDDC boreholes into the regional development of the basin. A brief sketch is given of sedimentary and palaeogeographic events, based on data from the *Crybelosporites striatus, Coptospora paradoxa,* and *Phimopollenites pannosus* zones, which are plotted in three "palaeo-environmental" maps (Fig. 5).

The following boreholes are involved (numbering as in Fig. 1):

1. Santos Oodnadatta 1 (Dettmann, 1963; Dettmann & Playford, 1969; Playford et al., 1975; MOrgan, 1978).
2. BMR Hay River 4 (Burger & Mond, 1973).
3. BMR Boulia 3 (McMinn, pers. comm.).
4. BMR Jericho 11 (this report).
5. DFS Betoota 1 (unpublished data filed in the BMR).
6. BMR Augathella 6 (this report).
7. Kalladeina Water Bore (Morgan, 1978).
8. SADM Yalkalpo DDH 1 (Morgan, 1978).
9. BMR Urisino 1 (McMinn, 1980; Burger, 1980b; this report).

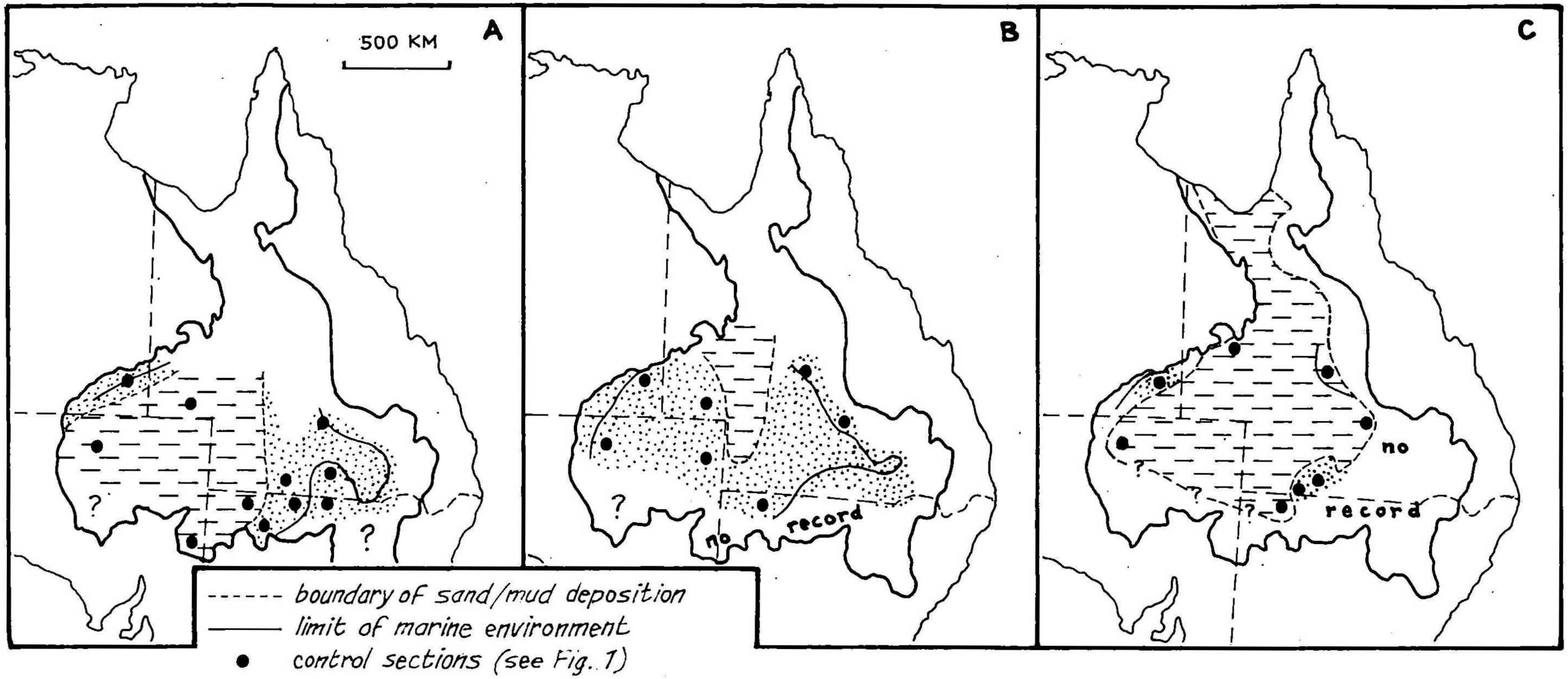


Fig. 5 Sedimentary provinces in the Albian of the Great Artesian Basin. Stippled areas sandstone, dashed areas mudstone.
A – During the early to middle Albian (lower Coptospora paradoxa zone)
B – During the middle Albian (upper Coptospora paradoxa zone)
C – During the late Albian (basal Phimopollenites pannosus zone)

10. DM Wanaaring DDH 1 (Morgan, 1978).

11. BMR Bulloo 1 (Terpstra & Burger, 1969).

12. BMR Eulo 2 (unpublished data filed in the BMR).

13. BMR Wyandra 1 (Burger, in Senior et al., 1969).

14. DM Bellfield DDH 1 (Burger, 1969; Morgan, 1978).

15. DM Weilmoringle DDH 1 (Morgan, 1978).

Upper *Crybelosporites striatus*/lower *Coptospora paradoxa* zone (Fig. 5A)

The period covered by these zonal intervals falls within the transition from early to middle Albian. Three broad sedimentary provinces can be distinguished. Towards the east is the sandstone of the Coreena Member (Wallumbilla Formation), and its slightly more silty counterpart in the Surat Basin, the Surat Siltstone. West of a line roughly along longitude 144$^{o}$ east, the Coreena Member is no longer recognised as such in the subsurface, and the Wallumbilla Formation represents an indivisible mudstone in many deep wells (Senior et al., 1978). This sequence merges with the Bulldog Shale (which was identified in Yalkalpo 1, Urisino 1, Betoota 1, Oodnadatta 1) and represents a large area of mudstone deposition, apparently in the deeper part of the basin, which reaches far into northeastern South Australia. At the northwestern margin, arenaceous deposits of similar age assigned to the Hooray Sandstone (Yeates, 1971) were drilled in BMR Hay River 4, Northern Territory. These marginal deposits do not contain the glauconite ("greensand") which Exon (1976) and Senior et al. (1978) described from the Coreena Member, and are probably derived locally from the Mount Isa Block.

Most of the control sections yielded marine palynological floras from this interval. Assemblages from BMR Wyandra 1 and DM Weilmoringle 1 include very few dinoflagellates, and they probably represent an area of low salinity, or even temporary non-marine sedimentation on the Cunnamulla Shelf. The sea formed an embayment in the Surat Basin (Burger, 1980a), and the amount of silt deposited there is presumably due to low-energy, stagnant environments.

Upper *Coptospora paradoxa* zone (Fig. 5B)

This period falls within the middle Albian. Outside the Surat Basin palynological data in New South Wales are available only from BMR Urisino 1, and strata from this age most probably have not been preserved in northern New South Wales outside the Bulloo Embayment. Broad environmental changes had taken place in the basin by this time. Deposition of arenites prevailed; a new "greensand" facies (the Coorikiana Member) is recognised in many boreholes and replaces much of the argillaceous province in the southwest. Towards the east it merges with the comparable glauconitic sandstone of the Coreena Member, and with its counterpart in the Surat Basin, the Griman Creek Formation. At the same time a different arenaceous province (Hooray Sandstone) persisted at the northwestern margin. Deposition of clays (upper Wallumbilla Formation) is now restricted to a corridor bounded to the east by a line roughly along longitude 144$^{o}$ east.

Apparently the sea did not diminish much in surface area, but the prevailing arenites indicate an increase in energy of deposition, and the occurrence of impoverished shelly faunas in the Coreena Member (Day, 1969) suggest an overall shallower water depth. There are also indications of non-deposition or erosion at the basin margins. McMinn (1980) commented on the thinness of the sedimentary interval associated with the *Pseudoceratium turneri* c zone in BMR Urisino 1, and suggested that it might include a hiatus. Palynological assemblages from 124.3-126.5 m contain no dinoflagellates, and Byrnes (1980) reported on desiccation cracks and plant roots from that interval. The rock section associated with the *Coptospora paradoxa* zone in BMR Augathella 6 (approximately 15-20 m thick) is unusually thin as compared with the overall thickness (100+ m) of the Coreena Member in that area. Although the palynological sequence does not show obvious gaps it seems likely that brief episodes of erosion and/or non-deposition have reduced the total amount of sediment laid down during the interval of the zone. Conglomeratic horizons have been cored at the Coreena/Toolebuc contact in several NERDDC boreholes, but these probably represent only a minor episode.

Lower *Phimopollenites pannosus* zone (Fig. 5C)

This period is dated (early) late Albian, and is of utmost importance for the NERDDC Project in that it includes a relatively uniform clayey and calcareous marine facies of the Toolebuc Formation in Queensland, and the correlative Wooldridge Limestone Member in South Australia and the Bulloo Embayment in northwestern New South Wales. Facies limits are indicated by simultaneous deposition of arenites (uppermost Coreena Member) on the Dynevor Shelf (BMR Bulloo 2, BMR Eulo 2), and at the northwestern margin (uppermost Hooray Sandstone) in Northern Territory. Developments in the Carpentaria Basin have been described by Smart et al. (1980), and the palynological aspects of this episode are being studied. Outside the Bulloo Embayment, strata of this age have not been preserved in northern New South Wales, or in the Surat Basin.

Palynological assemblages from mudstone and sandstone alike include dinoflagellates and reflect marine environments, except in BMR Jericho 11 (Fig. 4). The average depth of the sea may have increased slightly since the *Coptospora paradoxa* zone, and the spore and pollen assemblages from the Jericho and Augathella sections include relatively large numbers of "coastal" species, such as *Gleicheniidites* (20-35%) and the *Baculatisporites-Osmundacidites* group (5-10%), whereas the coniferous element of the interior is more sparsely represented (4-7%).

Northern connections of the Toolebuc Sea with the open ocean are apparent from the presence of contemporaneous strata bearing marine microfossils in the Carpentaria Basin. The situation to the south and southwest is not clear. Ingram (1968) reported a dinoflagellate assemblage from the western Eucla Basin, which Morgan (1978) recognised as being his *Pseudoceratium turneri* b zone. Sediments overlying these marine strata are probably non-marine, and suggest southwestern limits to the Toolebuc Sea north of the Eucla Basin.

During the Aptian the sea may well have penetrated into the Murray Basin (Evans & Hawkins, 1967; Morgan, 1978). Probable Albian foraminifera and spores and pollen of the *Coptospora paradoxa* zone have been reported in deep wells from what appears to be a pocket of Cretaceous sediments near Loxton (Evans & Hawkins, op. cit.). This meagre record adds little to the events during Toolebuc deposition in New South Wales. The sandy developments in BMR Bulloo 1 and BMR Eulo 2 suggest southeastern limits to the Toolebuc sea on the Dynevor Shelf, and if a connection to the south ever existed, evidence of it may have to be sought in contemporaneous strata across the Northwestern Fold Belt, southeast of BMR Urisino 1.

## CONCLUSIONS

(1) As part of the NERDDC Oil Shale Methodology Project, a brief summary is given of palynological work on BMR Jericho 11 and BMR Augathella 6 in Queensland, and BMR Urisino 1 in New South Wales. Albian spores and pollen grains were retrieved from all three sections. The *Crybelosporites striatus* zone is identified in BMR Augathella 6, and the *Coptospora paradoxa* and *Phimopollenites pannosus* zones in all three boreholes (Table 1).

(2) Part of the rock sequence in the boreholes has been deposited in marine environments, and many palynological assemblages include considerable amounts of Albian dinoflagellates. The *Pseudoceratium turneri* b zone is identified in BMR Urisino 1, the *Ps. turneri* c zone in BMR Jericho 11 and possibly in BMR Urisino 1, and the *Endoceratium ludbrookiae* a zone in all three boreholes (Table 1). Stratigraphic relations and age of fossil zonal intervals are shown in Figure 3.

(3) On the basis of the zonal intervals the Coreena Member of the Wallumbilla Formation is correlated with the upper part of the Bulldog Shale and the Coorikiana Member of the Oodnadatta Formation in South Australia. The Toolebuc Formation is correlated with the Wooldridge Limestone Member, and the Allaru Mudstone broadly with the upper part of Oodnadatta Formation, including the Mount Alexander Sandstone Member (Fig. 2).

The value of the palynological zones as a tool for correlation has been proven in many published and unpublished reports, and in this connection it is again pointed out that the zonal boundaries form effectively time-concordant horizons in the palynological sequence.

(4) The above correlations demonstrate that an interval equivalent in time to the Toolebuc Formation has been drilled in BMR Urisino 1 between 102 m and 122 m. That interval is here referred to as the Wooldridge Limestone Member of the Oodnadatta Formation. Arguments are put forward as to why the stratigraphic nomenclature used in South Australia is used for this borehole also.

(5) Statistical (numerical) analysis of palynological assemblages from the NERDDC boreholes indicates that there were several marine incursions in the Eromanga Basin during deposition of the Coreena Member (Fig. 4). They may have been of local extent only, since they coincide with a predominantly regressive episode in the *Coptospora paradoxa* zone (Morgan, 1978); the statistical data likewise suggest marginal-coastal conditions. A marine transgression at the beginning of the *Phimopollenites pannosus* zone, marking the onset of Toolebuc/Wooldridge deposition, was very likely of eustatic origin, since it coincides with a worldwide marine transgression during the early late Albian, which was mapped in North America, Europe, and Africa (Cooper, 1977).

(6) Shallow marine conditions prevailed at the time of Toolebuc/Wooldridge deposition (Fig. 5C). Overall sheltered (reducing) conditions have been suggested by Exon & Senior (1976). It is possible that the Toolebuc sea was cut off from the open ocean at intervals; dinoflagellate assemblages include over 50% of only a single species (*Diconodinium psilatum* Morgan), which is quite uncommon and points to restricted (hypersaline?) conditions.

The factors characteristic of the "Toolebuc facies" were apparently not operative everywhere. The suggestion was made by Ozimic (1980) that oil shale might be absent from the Toolebuc Formation south of a line joining Charleville and Bedourie. Detailed work will be needed to verify whether such a facies limit has had an effect on the palynological record, and whether such effects might be detected by qualitative or quantitative means.

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| Well | Depth | MFP | Rock unit | Palynological zone | | Percentage Fractions | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | Spores - pollen | dinoflagellates | acritarchs |
| BMR AUGATHELLA 6 | 59.40 | 7663 | Toolebuc | *P. pannosus?* | *E. ludbrookiae* a | 21.5 | 75 | 3.5 |
| | 63.40 | 7662 | Toolebuc | *P. pannosus* | *E. ludbrookiae* a | 24 | 60.5 | 15.5 |
| | 66.40 | 7661 | Coreena | *C. par/P. pann.* | *E. ludbrookiae* a | 13 | 79 | 8 |
| | 69.10 | 7705 | Coreena | *C. paradoxa (u.)* | insuff.recovery | 92.5 | 4 | 3.5 |
| | 72.40 | 7660 | Coreena | *C. paradoxa (u.)* | insuff.recovery | 96 | - | 4 |
| | 75.40 | 7659 | Coreena | *C. paradoxa* | ? | 65 | 25 | 10 |
| | 78.40 | 7658 | Coreena | *C. paradoxa* | insuff.recovery | 84 | 2 | 4 |
| | 81.40 | 7657 | Coreena | *C. paradoxa* | *P. turneri?* | 88 | 8.5 | 3.5 |
| | 84.40 | 7656 | Coreena | *C. paradoxa* | insuff.recovery | 91 | - | 9 |
| | 87.40 | 7655 | Coreena | *C. striatus* | insuff.recovery | 93.5 | - | 6.5 |
| BMR JERICHO 11 | 45.25 | 7650 | Allaru | *P. pannosus* | *E. ludbrookiae* a | 56.5 | 21.5 | 22 |
| | 48.25 | 7649 | Allaru | *P. pannosus* | insuff.recovery | 71 | 4.5 | 24.5 |
| | 51.25 | 7674 | Allaru | *P. pannosus* | ? | 75 | 10 | 15 |
| | 53.20 | 7675 | Allaru | *P. pannosus* | *E. ludbrookiae* a | 57 | 33.5 | 9.5 |
| | 56.15 | 7676 | Toolebuc | *P. pannosus* | *E. ludbrookiae?* | 67.5 | 11 | 21.5 |
| | 59.15 | 7645 | Toolebuc | *P. pannosus* | insuff.recovery | 86.5 | 1.5 | 12 |
| | 62.15 | 7677 | Toolebuc | insuff.recovery | insuff.recovery | | | |
| | 65.15 | 7643 | Toolebuc | *P. pannosus?* | insuff.recovery | 96.5 | 0.5 | 3 |
| | 68.15 | 7642 | Coreena | *C. paradoxa* | insuff.recovery | 68.5 | 2 | 29.5 |
| | 70.85 | 7704 | Coreena | *C. paradoxa (u.)* | *P. turneri* c | 95 | 1 | 4 |
| BMR URISINO 1 | 50-53 | 7522 | Oodnadatta | *P. pannosus* | *E. ludbrookiae* a* | | | |
| | 120-22 | 7524 | Oodnadatta | *P. pannosus* | *E. ludbrookiae* a* | | | |
| | 122-26 | 7539 | Oodnadatta | *P. pannosus?* | *P. turneri* b-c* | | | |
| | 129-32 | 7531 | Oodnadatta | *C. paradoxa* | *P. turneri* b-c* | | | |
| | 135-38 | 7529 | Oodnadatta | *C. paradoxa* | *P. turneri* b-c* | | | |
| | 146-49 | 7525 | Bulldog | *C. paradoxa* | *P. turneri* b* | | | |

*Zonal assignments of depth intervals done by McMinn (1980)

TABLE 1. Specifications of palynological samples and statistical data