APPENDIX

PALYNOLOGICAL ANALYSIS OF MANTA-1
(GIPPSLAND BASIN, PERMIT VIC/P19)

BY

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1. SUMMARY

DEPTH(M)	DINOFLAGELLATE ZONES	SPORE-POLLEN ZONES	AGE
1935-1954	-	-	post EOCENE
1980	(a mixture of mostly PALEOCENE and some EOCENE palynomorphs)		prob. EOCENE
1989	prob. D. WAIPAWAENSIS	-	Early EOCENE
2006-2040	prob. A. HYPERACANTHUM	M. DIVERSUS	(Late PALEOCENE)/ Early EOCENE
2084	A. HOMOMORPHUM	Upper L. BALMEI	Late PALEOCENE
2210-2296	Upper T.EVITTII/ E.CRASSITABULATA	Lower L. BALMEI	Early to Middle PALEOCENE
2311	T.EVITTII		Early PALEOCENE
2322-2538	-	T. LONGUS	MAASTRICHTIAN
2382-2442	I. DRUGGII	-	Late MAASTRICHTIAN
2564-2653	-	T. LONGUS or T. LILLIEI	MAASTRICHTIAN or CAMPANIAN
2700.5-3036	-	T. LILLIEI	CAMPANIAN
3051-3160	-	T. LILLIEI or N. SENECTUS	CAMPANIAN or SANTONIAN
3167-3437	-	N. SENECTUS	SANTONIAN-CAMPANIAN
3441-3572	-	prob. N. SENECTUS	prob. SANTONIAN-CAMPANIAN

(T.D. at 3572m, bdf)

SPORE COLOUR/DEGREE OF ORGANIC METAMORPHISM (D.O.M.)/ SOURCE ROCK QUALITY

Transmitted (white) light: from pale yellow (1935m) to deep yellow or light brown (3437m).

Incident U.V. light: bright yellowish-white to golden yellow and orange to dull light brown.

D.O.M.: from immature at 1935m to perhaps just reaching early mature near T.D. (3572m).

ENVIRONMENT OF DEPOSITION

1935-2311m:	(marginal) marine.
2322-3437m:	mostly non-marine (swamp, lake or fluvial deposits), with the exception of 2382-2442m, 2538m, 3036m, 3094.5m and 3167-3210m which are brackish-lagoonal or marginal marine.

2. INTRODUCTION AND METHODS

The interval examined palynologically ranged from 1935m down to 3572m (T.D. is at 3572m, bdf). A total of 2 conventional cores, 61 sidewall cores and 12 ditchcuttings were selected on the basis of lithology. Grey to black, fine-grained sediments (mudstones, shales) are generally richer in palynomorphs than sediments such as silts and sands deposited in higher energy environments. Where mudstones or shales were not available, siltstone samples were prepared. The quality of the sidewall cores was poor to fair. No sidewall cores were available over the deepest 135m and ditchcuttings had to be used instead.

Samples were prepared in Perth by Exploration Consultants Ltd (ECL) using the "standard" technique for siliciclastic sediments, i.e. hydrochloric and hydrofluoric acid treatment followed by heavy-liquid separation to remove mineral matter; controlled oxidation with nitric acid to reduce unwanted organic constituents and thus concentrate the palynomorphs; and finally washing with sodium hydroxide to remove humic acids. The resulting acid-insoluble residue was mounted in Elvacite to produce permanent microscope preparations. A slide of the non-oxidised residue was used for palynomaceral studies. Most of the oxidized preparations were stained using Bismarck Brown to enhance contrast of the palynomorphs.

All samples yielded an organic fraction but some proved to be poor to very poor in organic microfossils and did not contribute to the overall interpretation. Preservation was excellent to reasonable in most samples. Diversity of assemglages varied but was generally good in the Tertiary and good to poor in the Cretaceous part of the examined section.

The palynomorphs were recorded semi-quantitatively. To provide continuity with the work of Harris, 1983, the biostatigraphic interpretation of assemblages follows the zonal characteristics given in his "Biostratigraphic Summary" (Harris, undated). The range charts in this "Summary" are largely based on published and unpublished work of Stover and Evans (1974), Stover and Partridge (1973), Partridge (1975), (1976) and Helby, et al. ("in press").

Reworked palynomorphs were regularly encountered, mostly as single occurrences only. Most were Permo-Triassic in age, with an occasional Jurassic grain. It is not clear how to interpret the regular occurrences of Early and Mid Cretaceous Spores. They could be reworked, but, although found in younger sediments than their published ranges would indicate they may in fact belong.

Some contamination from the drilling mud was found in a few samples. Although all material used was carefully cleaned before preparation, a fractured or broken-up sidewall sample cannot always be fully trusted and some contamination with palynomorphs from the mud is unavoidable.

3. ANALYSIS OF ZONES

A. DINOFLAGELLATE ZONES

1935-1954m (2SWS): post EOCENE

A well preserved, rich and diverse assemblage, dominated by chorate cysts. Sporomorphs are present, but not common.

1980m (1 SWS): probably EOCENE

This assemblage is a mixture between common PALEOCENE and rather rare EOCENE markers. The original sample material could not be cleaned properly and was therefore suspect. On the strength of the interpretation at 1989m and below, the common PALEOCENE markers are regarded as reworked or as contaminants and the assemblage is therefore considered to be of EOCENE age.

1989m (1 SWS): probably DRACODINIUM WAIPAWAENSIS Zone, Early EOCENE

A number of cysts closely related to if not identical with D. waipawaensis together with Hafniasphaera septata and Ceratiopsis dartmooria form the basis of the zonal interpretation. The assemblage, although fairly rich in specimens (mostly proximate dinoflagellate cysts) was not diverse and contained few sporomorphs.

2006-2040m (4 SWS): probably APECTODINIUM HYPERACANTHUM Zone, Early EOCENE

Both dinoflagellates and sporomorphs are common in these fairly diverse assemblages. Apectodinium hyperacanthum, A. homomorphum and chorate cysts were the most abundant; Deflandrea truncata occurred as a single specimen while Hafniasphaera septata, Muratodinimum cf. fimbriatum and Spiniferites sp. were present as well. Of interest was an unknown Glaphyrocysta with a very complex distal network of trabeculae between the processes. It was quite common at 2040m.

Several "microforams", chitinous inner linings of foraminifera, were present also.

2084m (1 SWS): APECTODINIUM HOMOMORPHUM Zone, Late PALEOCENE.

The nominate species was common, together with Spinidinium spp.. Ceratiopsis dartmooria and Paralecaniella indentata occurred also. A single specimen of Senegalinium dilwynensis was found.

(2116m: too poor in palynomorphs).

2210-2296m (3 SWS) Upper TRITHYRODINIUM EVITTII/EISENACKIA CRASSITABULATA Zone, Early to Mid PALEOCENE.

The most common dinoflagellate cysts were Spinidinium spp., followed by Palaeocystodinium sp. and Ceratiopsis speciosa. Also present: Senegalinium dilwynensis, a few specimens of Palaeoperidinium pyrophorum, Alisocysta cf. circumtabulata and Glaphyrocysta retiintexta. Of the 2 nominate species only a single fragment of Eisenackia crassitabulata was found.

2311m (1 SWS): TRITHYRODINIUM EVITTII Zone, Early PALEOCENE

The nominate species was commonly present, although, because of its fragile nature, often as broken specimens. An unknown Oligosphaeridium was the only other common cyst. A few specimens of Ceratiopsis speciosa and Paralecaniella indentata and one rather worn looking Palaeoperidinium pyrophorum complete this short list.

(2322m: No dinoflagellates present, sample rather poor).

2382-2442m (2 SWS): ISABELIDINIUM DRUGGII Zone, Late MAASTRICHTIAN.

Apart from I. druggii and related species only two other dinoglagellate species were present: Palaeocystodinium sp. and an unknown proximate cyst with an apical archeopyle. An acritarch, Nummus cf. similis, was found also.

(2479-2488m: no dinoflagellates present).

2538m (1 SWS): Several specimens of a simple, proximate cyst with an apical archeopyle were present, as were the acritarch Nummus cf similis and one specimen of a Pediastrum, a colonial algae of probable freshwater environments.

(2564-3000m: no dinoflagellates, although Nummus is present in several samples).

3036m (1 SWS): in addition to Nummus cf. similis this sample contained 3 specimens of Xenascus ceratioides and one of

Oligosphaeridium cf pulcherrimum. The sidewall core was, however, contaminated by mud.

(3051-3090m: no dinoflagellates).

3094m (1 SWS): two specimens of a Chatangiella, but too poorly preserved for a specific determination although they could well be C. victoriensis.

3167m (1 SWS): in addition to common leiospheres of the Nummus type the assemblage contained a number of a fairly small, thinwalled dinoflagellate cysts, remarkably like Morkallacysta pyramidalis (Harris, 1974) and described from the Renmarks Beds, Victoria, of Paleocene age. Because of its thinwalled nature, most cysts are folded and distorted, obscuring its morphology. In fact, more than one species or even genus may be present. M. pyramidalis is a non-marine dinoflagellate (Harris, 1974) and nothing in the present assemblage would seem to contradict this. It is quite possible that Nummus is another non-marine aquatic organism, as it occurs regularly in assemblages that lack marine indicators and have all the marks of a non-marine environment of deposition (See Section 5).

3205-3210m (2 SWS: two types of chorate cysts were present, of which only Oligosphaeridium aff. pulcherrimum could be determined.

(3215-3437m: no dinoflagellates present)

B. SPORE-POLLEN ZONES

1935-1954m (2 SWS): the assemblages are dominated by dinoflagellate cysts and sporomorphs are uncommon. Most noteworthy was a single specimen of "Psilodiporites pertritus" described by Partridge, 1971 from the Lakes Entrance Oil Shaft at 352 ft. According to his Table 1, P.pertritus was present in the PROTEACIDITES TUBERCULATUS and the TRIPOROPOLLENITES BELLUS Zones, OLIGOCENE and MIOCENE.

1980-2040m (6 SWS): MALVACIPOLLIS DIVERSUS Zone, Early EOCENE.

The base of this Zone was determined by the present of Proteacidites grandis, P.leightonii, P. incurvatus, Spinizonocolpites prominatus and Verrucosisporites kopukuensis. Pollen and spores were quite common in this interral and some of the other types present were Ischyosporites gremius, several species of Nothofagidites and the smaller Proteacidites, Malvacipollis diversus,and a reticulate megaspore. The top of the zone is not easily determined since it relies on the base of markers for the overlying zone. None were seen, and additional evidence comes from the dinoflagellates (See Section 3A).

2084m (1 SWS): Upper LYGISTEPOLLENITES BALMEI Zone, late PALEOCENE.

The combined presence of Malvacipollis diversus, Australopollis obscurus and Matonisporites gigantis indicates the presence of this zone at this level. Amongst the many other sporomorphs found were Gambierina edwardsii, G.rudata, Lygistepollenites balmei, Notofagidites spp, Proteacidites spp, a.o. P. annularis and many more.

(2116m: too poor, virtually no sporomorphs).

2210-2311m (4 SWS): Lower LYGISTEPOLLENITES BALMEI Zone, Early to Mid PALEOCENE.

Although this interval is not particularly poor in sporomorphs, characteristic markers are absent and its age has been largely determined by the dinoflagellates.

2322-2538m (6 SWS): TRICOLPITES LONGUS Zone, MAASTRICHTIAN.

Most samples are rich in sporomorphs although diversity is not high. Types present and important for a zonal determination were the nominate species and Triporopollenites sectilis, Tricolpites lilliei, Quadraplanus brossus and "Grapnelispora evansii". Nothofagidites spp. and Proteacidites spp. occurred commonly. The latter group includes P. "gemmatus", P."reticuloconcavus" and P. "otwayensis". Other common species were Tricolpites confessus, T. gillii, Phyllocladidites spp, Microcachryidites antarcticus, Ceratosporites equalis, Kraeuselisporites spp, Stereisporites regium and Lygistepollenites balmei"

2564-2653m TRICOLPITES LONGUS or TRICOLPITES LILLIEI Zone, MAASTRICHTIAN or CAMPANIAN.

The base of the T. LONGUS Zone is a.o. defined by the dominance of Gambierina specimens over Nothofagidites spp. In the interval under discussion dominance of G.spp. or N.spp. is not readily apparent because both tend to be poor.

Other useful markers such as T.longus, Q.brossus and Stereisporites (Tripunctisporis) sp. were absent. Tetracolpites verrucosus was present in the deepest sample but as a single specimen only. Evidence for either one or the other zone is therefore not strong and the interpretation given reflects this.

2700.5-3036m (14 SWS): TRICOLPITES LILLIEI Zone, CAMPANIAN.

Although 14 sidewall cores were available, only 7 were fully examined as the others proved too poor in palynomorphs to be of any use.

In all examined samples Nothofagidites spp. were much more common than Gambierina spp.. The nominate species (T. lilliei) and Triporopollenites sectilis were both present. Some of the other common sporomorphs: Proteacidites spp, Tricolpites gillii, T. confessus, Phyllocladidites spp, Microcachryidites antarcticus, Lygistepollenites balmei, Baculatisporites comaumensis and Ceratospora equalis. Less common, present in only a few, or single specimens: Proteacidites "reticuloconcavus", P. "clinei", P. palisadus, P. amolosexinus, P. scaboratus, Kraeuselisporites sp., Ornamentifera sentosa, Cicatricosisporites sp, Gephyrapollenites wahooensis, Cyclosporites hughesii, Tricolpites sabulosus and a reticulate megaspore. Of particular interest was a species of "Grapnelispora", not with anchor-shaped processes like "G. evansii" but with strongly curled tips. Permian reworking occurred in several samples, but as single specimens only. Several types of the list above are very likely reworked as well.

3051-3160m (7 SWS): TRICOLPITES LILLIEI or NOTHOFAGIDITES SENECTUS Zone, CAMPANIAN or SANTONIAN.

The boundary between these two zones relies on the absence of certain markers in the lower, N. SENECTUS, Zone. It was therefore unfortunate that only one (at 30494m) out of 7 samples proved to be rich enough to be reliable in this respect. And even here results proved to be ambiguous. It contained a single specimen of Triporopollenites sectilis, (which would indicate the T. LILLIEI Zone), but not the nominate species for that zone. Gephyrapollenites wahooensis and Proteacidites palisadum, both present at this level, have been used as accessory evidence for the base T. LILLIEI Zone. However, the evidence is considered to be too weak and the interval determined accordingly. In general composition the assemblage found is not sufficiently different to repeat the list of palynomorphs founds.

3167-3437m (2 core - and 9 SWS) NOTHOFAGIDITES SENECTUS Zone, SANTONIAN-CAMPANIAN.

Nothofagidites spp, including N. senectus are present throughout while both Tricolpites lilliei and Triporopollenites sectilis are absent. Many of the types present in the overlying zones, such as Ceratospora equalis, Tricolpites confessus, T. gillii, T. sabulosus, Proteacidites spp., Phyllocladidites spp., Microcachryidites antarcticus, Lygistepollenites balmei, Baculatisporites comaumensis and Lycopodiumsporites circiniidites are present in this zone as well. Uncommon, and perhaps partly reworked, are Foraminisporis wonthaggiensis, Kraeuselisporites sp., Cicatricosisporites spp., Dictyotosporites speciosus, Gephyrapollenites wahooensis, Stereisporites viriosus, "Chomotriletes", Ornamentifera sentosa and Clavifera triplex. Of interest was a monosulcate pollengrain, very coarsely reticulate away from the sulcus. It seems closely related to, but not identical with Retimonocolpites peroreticulatus (Brenner) Doyle. It is unlikely to be reworked. It was also found in a stratigraphically similar position in Chimaera-1. A few Permian reworked grains were present in some of the samples.

3441-2572m (12 ditchcuttings) probably NOTHOFAGIDITES SENECTUS Zone, SANTONIAN-CAMPANIAN.

No sidewall cores being available, a series of ditchcuttings were prepared and examined over the deepest 130m. No indications of any of the older zones were found. N. senectus was present in all samples but of course these could have been caved from higher levels. The assemblages looked clean, however, and it seems not unlikely that the well bottomed in the NOTHOFAGIDITES SENECTUS Zone.

4. SPOROMORPH COLOUR, DEGREE OF ORGANIC METAMORPHISM (D.O.M.) AND SOURCE ROCK POTENTIAL

The colour of palynomorphs changes when subjected to the increasing or prolonged temperatures such as occur during burial. These changes in colour are irreversible and therefore indicate the maximum level of maturity reached. The different stages, yellow to golden-yellow through orange and brown to black can be correlated with changes in chemical composition as hydrocarbons are generated from the organic matter (see Fuchs, 1979; standard Legend, 23.5.10). The sporomorph colour scale is more subjective than the more commonly used vitrinite reflectance scale. Ideally, a long-ranging sporomorph type should be selected as different types of sporomorph within the same sedimentary section show variations in colour. As observed in transmitted white light the change in colour from light yellow to golden-yellow or orange corresponds with the onset of oil generation, whereas the onset of gas generation is associated with a change in colour from orange to brown. Post-mature source rocks contain black sporomorphs and organic fragments only.

In incident ultraviolet light palynomorphs (and some palynomacerals) exhibit fluorescence colours that no only help in their identification but also increase and decrease according to rank. Fluorescence is maximal at the threshold of the "oil window", decreases with increasing rank and disappears at the end of the "oil window" (1-1.3% R_o, see Robert, 1981).

In MANTA-1 sporomorph-colour in transmitted (white) light ranged from pale-yellow at 1935m to yellow at 3437m. Over the same interval fluorescence-colours of sporomorphs ranged from light yellow to golden yellow or orange and dull light brown. Both estimates (and that is all they are) seem to indicate immature conditions over most of the section studied. It is possible that from about 3200m early mature conditions existed. Palynomaceral determination was carried out on a sieved, non-oxidised preparation. The sieving (with a 10 micrometer mesh sieve) was necessary to concentrate the large palynomacerals that otherwise would be diluted by fine, amorphous organic matter. This fine fraction is undoubtedly important for source rock characterisation but its nature and origin cannot be determined by ordinary means.

In MANTA-1 a rough estimate during preparation (i.e., after the acid treatment but before oxidation) showed that between 1935 and 2311m total organic matter varied from 0.1 to 1.0 millilitre per 10 grams of sample, and from 2322 to 3437m from 01 to 6.0 millilitre per 10 grams of sample. It should be remembered that these estimates may not reflect the true picture, as they are based on samples selected for palnology (e.g. disregarding coarser grained sediments on the one hand and coals on the other). The interval 1935m to 2311m is rich in inertinite while plant tissues, pollen, spores and dinoflagellates are present in various amounts, but the low estimates for total amount of organic matter per 10 grams of sample classifies them as poor source rocks. The interval 2322m-3437m (again, considering the palynological samples only) shows higher organic matter estimates and probably contains good source rocks. The types of palynomacerals present suggest gas-prone rather than oil-prone sourcerocks.

5. ENVIRONMENT OF DEPOSITION/PALYNOFACIES

The relationship between organic matter and grainsize of the sediments has been well-documented and is used to deduce depositional environment (palynofacies) from the type of palynomorphs and palynomacerals present.

The palynomorphs can be divided into marine organisms such as dinoflagellates and Tasmanites (both algae) and foraminiferal test linings; fresh and brackish water organisms such as Botryococcus and acritarchs; and land derived pollen and spores (sporomorphs).

Breakdown products of plants (woody fragments, epidermal tissues, cork cells, resin), algal and bacterial remains, animal tissue and many indeterminate organic fragments are collectively known as palynomacerals.

Although wind transport is an important aspect of the initial dispersal of sporomorphs, water transport then carries the sporomorphs and palynomacerals until they settle out of the water column. A continuous process of mechanical abrasion, biological degradation and wave and current action sorts and grades the particles during this transportation phase. Less buoyant, heavy or larger organic particles tend to characterise environments close to source while lighter, more buoyant and smaller particles are carried further afield. Very low sporomorph diversity indicates authochthonous environments (marsh, swamps); allochthonous environments are characterised by more diverse assemblages. Marine microplankton diversity increases in an offshore direction (Whitaker, 1979).

In MANTA-1 the interval 1935-2311m is clearly marine because dinoflagellates, reasonably diverse, are present in almost all samples;

a fairly rich and diverse pollen flora, together with plant tissues indicate an environment near a source of land-derived organic matter. Between 2322m and 3437m only a few intervals with dinoflagellates occurred, namely: 2382-2442m; 2538m; 3036m; 3094m; 3167m and 3205-3210m. Low diversity and high content of land-derived material makes it unlikely that any of these intervals are open marine. At least one interval (3167m) contains dinoflagellates that could well be of freshwater origin. See Section 3A: Dinoflagellates zones, for more details.

From 2322 to 3437m, and excepting the depths mentioned above, assemblages are considered to be non-marine. Not only are marine indicators lacking, but the variety and size range of the plant tissues indicates limited water transport and size-sorting. Swamp, lake or some fluvial deposits are suggested.

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