APPENDIX 6.1
PALYNOLOGICAL ANALYSIS OF VOLADOR-1
(GIPPSLAND BASIN, PERMIT VIC/P19)

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I. SUMMARY

Depth		Dinoflagellate Zones	Spore-pollen Zones	Age
2941-2970m	:	W. ORNATUM or W. "THOMPSONAE"	Upper M. DIVERSUS	Early Eocene
2990m	:	W. ORNATUM	"	"
3000-3019.5m	:	A. HYPERACANTHUM to W. ORNATUM, probably W. ORNATUM	"	"
3030-3116m	:	(no dinoflagellates)	T. LONGUS	Maastrichtian
3122-3125m	:	I. DRUGGII	"	"
3133-3735m	:	(no dinoflagellates)	"	"
3896-4253m	:	(" ")	T. LONGUS or T. LILLIEI	Maastrichtian or Campanian
4265-4442m	:	(" ")	T. LILLIEI	Campanian
4526m	:	(" ")	No older than N. SENECTUS, probably T. LILLIEI	Probably Campanian

Sporomorph-colour, Organic Maturity and Source Rock Qualities

Transmitted (white) light	:	From pale yellow (2941m) to yellow/orange-brown (4526m)
Incident ultraviolet light	:	From bright yellow to yellowish brown
Organic Maturity	:	Immature at 2941m to Early Mature for oil generation at 4526m
Source Rock Qualitities	:	Sediments are moderate to very rich in organic matter, especially below 3300m, indicating good source rock qualities. Type of palynomacerals suggests that they are gas-prone.

Environment of Deposition (palynofacies)

2941-3019.5m	:	Marine - near shore
3030-3133m	:	Shore face, marine incursions
3283-4526m	:	Non-marine, low energy fluvial/swamp environment

II. INTRODUCTION AND METHODS

The interval examined palynologically ranged from 2941m down to 4526m (TD is at 4611m, bdf). A total of 49 sidewall cores and 8 cutting samples were selected on the basis of lithology. Grey to black mudstones and shales are generally richer in palynomorphs than silts and sands deposited in higher-energy environments. Where mudstones or shale samples were not available, siltstone samples were prepared. The quality of the sidewall cores was poor to fair.

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.

All samples yielded an organic fraction and almost all were productive, although from about 3800m down preservation deteriorated rapidly while assemblages were often poor in palynomorphs and lacked diversity. Consequently specific determination became almost impossible and this affected the picking of the T. LONGUS/T. LILLIEI zonal boundary.

The palynomorphs were recorded semi-quantitatively. To provide continuity with the work of Harris, 1983, the stratigraphic 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) and Partridge (1976).

Reworked palynomorphs were found throughout the interval studied, but in very low percentages only. They ranged in ages from ?Devonian-Carboniferous and Permo-Triassic to Jurassic and Early Cretaceous. Contamination from the mud was present in many samples. Although all samples were carefully cleaned before preparation, a fractured or broken-up sidewall sample cannot always be fully trusted as some contamination with palynomorphs from the mud is unavoidable.

III. ANALYSIS OF ZONES

A. Dinoflagellate Zones:

2941-2970m (3 samples): "W. THOMPSONAE" or W. ORNATUM Zone (Early Eocene)

Based on the presence of Apectodinium hyperacanthum and Muratodinium fimbriatum which have their top-occurrence in the "W. THOMPSONAE" Zone. Other dinoflagellates present: Apectodinium homomorphum (common), Ceratiopsis obliquipes (single), Renidinium spp., Cordosphaeridium ssp., Hystrichokolpoma spp., Adnatosphaeridium spp. and Deflandrea spp. (all common).

2990m (1 sample): W. ORNATUM Zone (Early Eocene).

Although the nominate species was absent several specimens of Wetzeliella articulata, which has the same vertical restricted range, were found. The types mentioned from the overlying interval were present in this sample as well.

3000-3019.5 (4 samples): Probably W. ORNATUM Zone, but may be as old as the A. HYPERACANTHUM Zone (Early Eocene).

W. ornatum was absent and W. articulata occurred only as a doubtful specimen. The interpretation is therefore largely based on the presence of A. hyperacanthum and single specimens of Deflandrea truncata and M. fimbriatum. A. homomorphum and Achomosphaera spp. were common. A few specimens of Palaeocystodinium australinum and fragmented (indet.) Deflandrea ssp. were present also. A sample at 3010m was quite rich in dinoflagellates including a number of unknown generic affinity.

3030-3116m (7 samples): Non-diagnostic; only a few long-ranging types are present.

3122-3125m (2 samples): I. DRUGGII Zone (late Maastrichtian). Both Isabelidinium druggii and Eurydinium conoratum were present. In addition a single specimen of I. acuminatum, several of Nummus cf. N. monoculatus and fragmented (indet.) Deflandrea spp. were found.

3129-4526m (40 samples): No dinoflagellates found.

B. Spore-pollen zones: 2941-3019.5m (8 samples): Upper M. DIVERSUS Zone (Early Eocene). Well preserved, diverse and fairly rich assemblages. Amongst the many species present were: Ischyosporites gremius, Proteacidites pachypolus, P. grandis, P. beddoesii, Kuylisporites waterbolki, Cupanieidites orthoteichus, Tiliaepollenites notabilis, Verrucosisporites kopukuensis, Gephyrapollenites cranwellae, and Triporopollenites ambiguus.

The boundary between the upper M. DIVERSUS Zone and the overlying P. ASPEROPOLUS zone is apparently not easily definable (see Harris, undated, Figure 2). In Volador-1 evidence from dinoflagellates has been taken into account to restrict the interval under discussion to the upper M. DIVERSUS Zone.

3030-3735m (22 samples): T. LONGUS Zone (Maastrichtian). Both Tricolporites lilliei and Triporopollenites sectilis were present in the highest sample indicating that at this level the section is no younger than the T. LONGUS Zone. The nominate species was present as well but not in the highest samples. Proteacidites spp were common to abundant while Nothofagidites spp were not, at least down to 3288m. From this level down to the deepest sample examined (4526m) both groups of pollen are present in roughly equal proportions. While most samples yielded pollen and spores their concentration was generally low in respect to the abundant organic material (mostly plant tissues and inertinite) and preservation starts to deteriorate in the lower part of the zone.

In addition to Proteacidites spp. and Nothofagidites spp., Gambierina rudata, Tricolpites gillii, T. waiparaensis, Triporopollenites sectilis, Tricolporites lilliei, T. waiparaensis, Dacrydium spp., N. endurus, P. angulatus, are all present in varying amounts but types such as Gephyrapollenites wahooensis, Dilwynites granulatus, Tetracolpites verrucosus, Stereisporites regium and Camarozonosporites ohaiensis occur singly only. In general, the assemblages lacked diversity.

3896-4253m (15 samples): T. LONGUS or T. LILLIEI Zone
(Maastrichtian or Campanian)

Most samples were very poor in pollen, only 2 out of 15 samples gave a workable assemblage. Furthermore, preservation deteriorated to the point that specific determination in many cases is impossible.

A sample at 4253m still contained Proteacidites angulatus, which has its base-occurrence at the boundary of the T. LONGUS and T. LILLIEI Zones. As this is regarded as insufficient evidence (none of the other zonal markers could be found) it seems better to leave the question of which zone is represented open.

4265-4442m (11 samples): T. LILLIEI Zone (Campanian).

Again, assemblages are very poor, badly preserved and lack diversity. Only 2 samples yielded a reasonable number of specimens. Markers for the T. LONGUS Zone are absent but T. lilliei and T. sectilis are both present. Smallish proteaceous pollen and Nothofagidites spp are fairly regularly present but too badly worn for identification at species level.

4526m (1 sample): Probably T. LILLIEI Zone (probably Campanian).

Deepest sidewall core available. Nothofagidites was still present, indicating that the base of the examined section is no older than the N. SENECTUS Zone (Senonian). However, a single specimen of T. lilliei (admittedly badly preserved) suggests that the T. LILLIEI Zone extends down to (at least) this level.

IV. 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, 1969; Shell Standard Legend, Section 23.51.10). The sporomorph colour scale is more subjective than the vitrinite reflectance scale. Ideally, a long-ranging sporomorph type should be selected as different types of sporomorphs within the same sedimentary section show variations in colour. The change in colour from light yellow to golden-yellow or orange when observed in transmitted white light corresponds to 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 not 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% Ro, see Robert, 1981).

In Volador-1 sporomorph-colour in transmitted light ranged from pale-yellow at 2941m to yellow and yellow-orange to light brown at 4526m. Over the same interval fluorescence colours of sporomorphs ranged from golden yellow to yellowish-brown. Both estimates seem to indicate immature conditions at 2941m., changing into early mature towards 4526m.

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 Volador-1 the total organic content after sieving in the interval 2941-3019.5m contained on average 30-40% Liptinite (spores, pollen, dinoflagellates, cutinite, alginite, all hydrogen-rich precursors of oil and gas), 50-60% Vitrinite (relatively hydrogen-poor) and 10% Inertinite (hydrogen-poor, no precursor of either oil or gas).
From 3030-3133m: a much higher percentage of Inertinite was present (50-80%), Vitrinite 10-40% and less than 10% Liptinite.
From 3288-4526m: 60-70% Vitrinite, 10-20% Liptinite and 10-30% Inertinite was found.

Although no accurate figures are available, a rough estimate during preparation showed that especially below about 3300-3500m the sediments were very rich in organic matter (1.0-3.0 millilitre per 10 grams of sample); between 2941 and 3288m sediments were less rich, averaging 0.25-1.0 millilitre per 10 grams.

V. ENVIRONMENT OF DEPOSITION AND 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 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 Volador-1 interval 2941-3019.5m is clearly marine: dinoflagellates are common and fairly diverse. Sporomorphs are common as well and so is landplant material (small to medium sized). This suggests a near source, near shore, environment.

Between 3030-3133m a marked increase in Inertinite is evident and sporomorphs and plant fragments are common. The latter are occasionally large to very large, indicating limited water transport. Dinoflagellates are present between 3122 and 3125m. A shore face environment is most likely.

No marine or brackish water indicators were present between 3288-4526m. Plant tissues predominate, varying in size from small to very large. Sporomorphs were found in all samples but often in low percentage in respect to the abundant organic matter. Inertinite was present as a "background" in all samples. A low to intermediate-energy, fluvial/swamp environment is suggested.

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