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GNS SCIENCE CONSULTANCY REPORT 2006/185

GNS Science - Esso Australia Pty Ltd Gippsland Basin Study: Final Report

C.P. Strong



October 2006





1 Fairway Drive
Avalon
PO Box 30 368
Lower Hutt
New Zealand
T +64-4-570 1444
F +64-4-570 4600
www.gns.cri.nz

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INTRODUCTION

The Gippsland Basin Study, conducted over the years 2004 to 2006, was undertaken by the Institute of Geological and Nuclear Sciences (GNS Science) in collaboration with Esso Australia Pty Ltd, for several complementary purposes. The primary purpose was to determine the potential for correlating and applying Taranaki Basin (and New Zealand) biostratigraphy in the Gippsland Basin, and, in the process, to begin to develop our own knowledge of the Gippsland Basin. Further, the project was considered an opportunity to demonstrate our biostratigraphic capabilities to the Australian petroleum exploration community and to improve our historically rather low level of trans-Tasman contact. One of the most important results of the project was establishing cordial personal relationships and dialogues with numerous Australian biostratigraphers, exploration geologists and potential clients/users for future collaboration on either side of the Tasman Sea.

PROJECT HISTORY

GNS Science interest in the Gippsland Basin developed partly through recognition of deep water exploration targets, far offshore, in the Taranaki Basin, which had potential Gippsland Basin analogues and partly from the realisation that GNS Science needed to broaden its market for biostratigraphic services. This project got under way in early 2004, when Chris McKeown (then GNS Science Commercial Manager), identified the opportunity for a collaborative project with Esso Australia. This resulted in conference calls between Jill Stevens, from Esso Australia, and Richard Cook, Erica Crouch, Ian Raine, and me, from GNS Science, and definition of a project.

In mid-July, 2004, Richard Cook and I spent a week Melbourne, where we visited Esso Australia, the Victoria Department of Primary Industries (offices and Werribee core store), and The University of Melbourne. During this week, we collected the materials for the Gippsland biostratigraphy project, Richard and I presented a seminar for Esso Australia, Richard gave a luncheon talk for PESA, I gave a talk at a micropaleontology workshop at the University, and we joined in several social events.

In the latter part of 2004, 65 samples of washed cuttings from Blackback-1, East Pilchard-1, Tuna-4, Angler-1, Archer-1, and Anemone-1 were processed at GNS Science, examined for foraminifera, and the results reported (Strong 2004).

In 2005, Erica Crouch took maternity leave, and Graeme Wilson joined the project. He examined and reported on dinoflagellates from existing prepared Anemone-1 palynological samples (Wilson 2005).

In April, 2006, Richard Cook presented a report on project results, including comparisons of petroleum systems in the Gippsland Basin and major New Zealand basins (Cook et al. 2006), at the APPEA Conference in Brisbane. This effectively marked the conclusion of the project.

PROJECT DOCUMENTS

Project outputs comprise four documents, which are included as Appendices 1 to 4:

Appendix 1 is a chart showing the correlation of New Zealand and Australian palynological zonations to selected Gippsland Basin Wells. Erica Crouch prepared the chart in an early phase of the project,

Appendix 2 provides foraminiferal results for Blackback-1, East Pilchard-1, Tuna-4, Angler-1, Archer-1, and Anemone-1 (Strong 2004). The first three wells, in the northern basin, were barren of foraminifera. In the latter three, only sporadic, sparse assemblages, unlikely to be biostratigraphically useful, but suggestive of innermost shelf to lagoonal environments, were recovered. It was concluded that foraminifera could potentially be of value if drilling progressed southeast from Anemone-1, into more marine-influenced environments.

Appendix 3 discusses the dinoflagellate sequence in Anemone-1, and notes that the studied section can be correlated with the Haumurian and Piripauan stages in New Zealand (Wilson 2005).

Appendix 4 is the text for Richard Cook's presentation at the 2006 APPEA Conference, Brisbane, which summarises work done for the Gippsland Basin Project and provides an overview of biostratigraphic capabilities and petroleum systems around the Tasman Sea.

ACKNOWLEDGMENTS

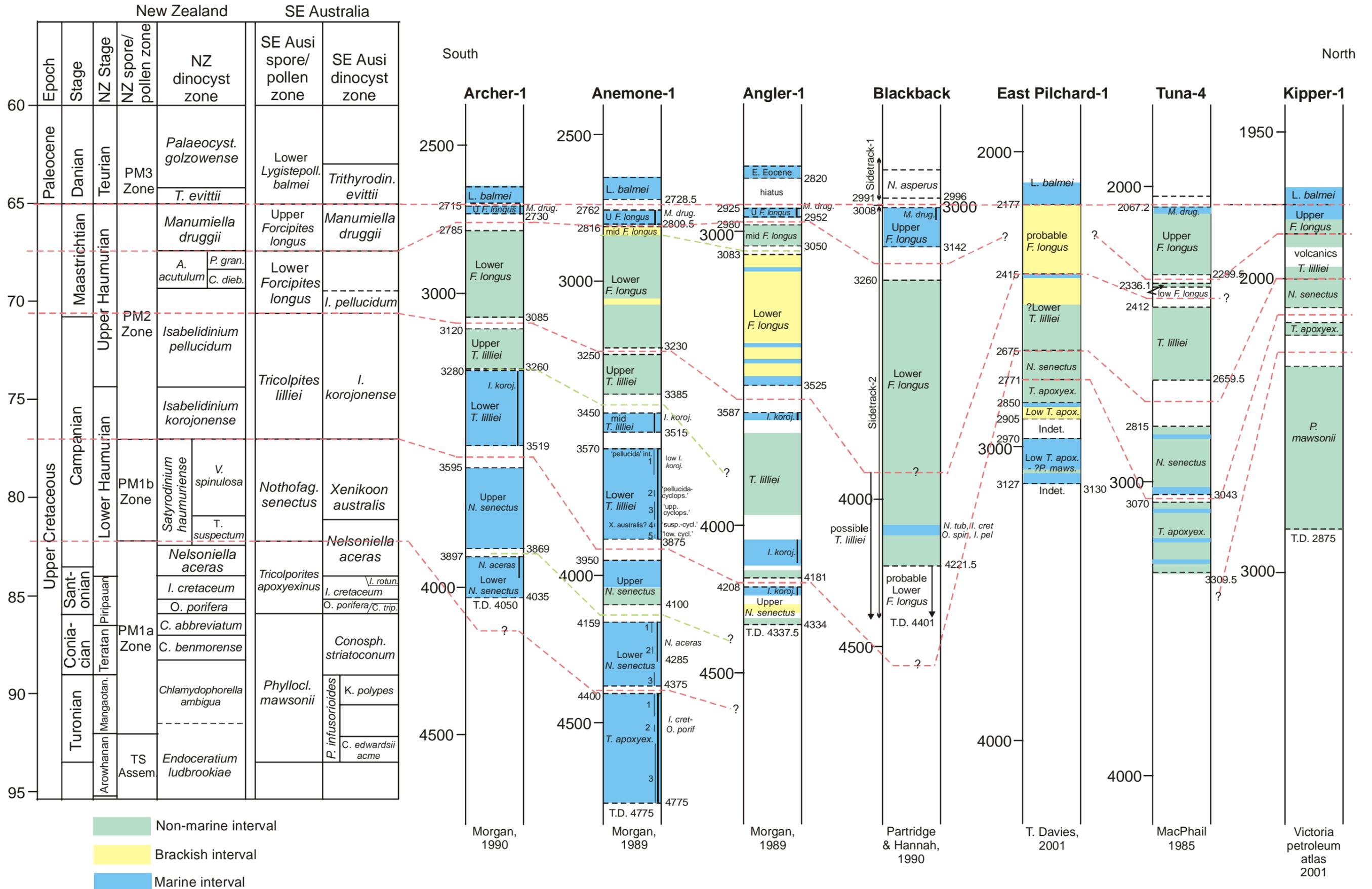
Grateful acknowledgment is made of the following: Financial support for the project through the GNS Science Capability Fund; encouragement, advice, and technical assistance from Jill Stevens and other staff at Esso Australia; core store access and general support from the Victoria Department of Primary Industries; the courteous hospitality and interest of numerous geological colleagues in Melbourne; assistance with proof reading and producing this report from, respectively, Graeme Wilson and Kirsty Hunt.

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- Strong, C.P. 2004: Gippsland Biostratigraphy Project Part A: provisional foram report. *Institute of Geological & Nuclear Sciences Client Report 2004/173*: 11 p.
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APPENDIX 1

Correlation Chart: New Zealand and Australian palynological zones in selected Gippsland Basin wells.



APPENDIX 2

Report of foraminiferal study



Institute of
**GEOLOGICAL
& NUCLEAR
SCIENCES**
Limited

Gippsland Basin Cretaceous Biostratigraphy Project

Part A: Provisional Foram Report

Percy Strong

Prepared for

ESSO AUSTRALIA PTY LTD

CONFIDENTIAL

**Institute of Geological & Nuclear Sciences client report 2006/173
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1. PURPOSE

This Institute of Geological & Nuclear Sciences (GNS) study was undertaken in collaboration with Esso Australia to assess similarities between the Gippsland and Taranaki Basins, and the extent to which New Zealand biostratigraphic knowledge could be applied in a trans-Tasman setting. Six Gippsland Basin wells, providing a paleo-onshore to offshore transect, were designated by Esso Australia for study of a part of their upper Cretaceous sequence. The wells chosen were Anemone-1, 1A, Angler-1, Archer-1, Blackback-1, East Pilchard-1 and Tuna-4.

The main achievements of work to date are:

1. This study is the first investigation of foraminiferal faunas from Cretaceous sections of these wells. However, Cenozoic foraminifers have been previously recovered from Anemone-1 and Angler-1 and mounted on assemblage slides. Caved Cenozoic foraminifera were also noted from the other studied wells.
2. The potential utility of foraminifera for age/environment and correlation assessments in future drillholes was evaluated.
3. Foraminiferal biostratigraphy has, at best, only very modest potential in wells examined in this study, but foraminifera may have some utility in paleoenvironmental interpretation. Overall utility is likely to improve in the more offshore sections of the basin, south of Anemone and nearby wells.
4. The project served as showcase for GNS capabilities and products.
5. Establishing relationships with staff at Esso Australia, Victoria Department of Primary Industries, and other individuals and organisations.

2. MATERIALS AND METHODS

A suite of 128 samples of washed/dried cuttings from selected upper Cretaceous intervals within the Anemone-1/1A, Angler-1, Archer-1, Blackback-1, East Pilchard-1 and Tuna-4 offshore petroleum wells was collected at the Victoria DPI Core Store, Werribee, and at Esso Australia headquarters in downtown Melbourne. Sample depths were pre-selected at GNS, using logs and well biostratigraphic reports provided by Esso Australia. This collecting programme was followed closely, as available time did not permit on-site inspection of material for sample selection. However, where cuttings were stored in transparent plastic bags, some minor depth adjustments were made. The amount of cuttings taken was limited by us to no more than one-half of the material available, and sample weights consequently ranged from c. 6 g to c. 85 g.

All bulk samples were examined individually at GNS, Lower Hutt, and 65 of them, considered from their lithology to be the most likely to be fossiliferous, were selected for further work. These samples were then processed using standard GNS techniques, and wet-sieved on a 75-micron screen. Residue >75 microns was retained for examination, finer material comprising the silt-clay fraction was lost during processing.

Because this project is intended to be a feasibility test for foraminiferal well servicing in Gippsland Basin drillholes, sample examination was done to "well biostratigraphy"

commercial standards. From our experience, examination to this level will generally produce useful results, if they are to be had at all, and within a reasonable time span. Before examination, residue is sieved into >500 micron, >212 micron and <212 (pan) fractions. The entire >500 micron fraction usually is scanned for large specimens. The >212 micron fraction, which typically contains most adult foraminiferal specimens is split by the cone-and-quarter method (fast, sufficiently accurate), to provide enough representative sample for c. 2 standard picking trays. Pan fraction was scanned for c. 1-2 minutes for small specimens. Normally, this procedure can easily stay abreast of 20 m samples when the ROP is c. 6-10 m/hr.

3. FORAMINIFERAL RESULTS

The main finding of this study is that foraminifera are of very limited biostratigraphic, but some paleoenvironmental, utility, in three of the chosen wells. Their value could increase for drilling farther south however. Foraminifera are sparse to common in 16 of the 65 samples examined, with all productive samples coming from marine shales/siltstones in the southernmost wells, Anemone-1/1A, Angler-1, and Archer-1. Only one significant calcareous fauna was recovered, with other assemblages consisting mainly or wholly of agglutinated taxa. Table 1 lists the foraminiferal taxa recorded during this study.

Haplophragmoides is the most common foraminifer seen, and appears to be represented by at least 6 species. The genus is taxonomically difficult, as its typically non-descript morphology and apparently considerable intra-specific variability is complicated by variable deformation individuals during burial. However, there are exceptions, and a *Haplophragmoides* species, tentatively referred to *H.wilgunyaensis*, is distinctive enough that its highest and lowest occurrences could provide readily recognisable bioevents. This species was originally described by Crespin (1963, Australian Min. Res. Geol. Geophys. Bull 66) from the Lower Cretaceous of western Queensland, and is distinguished by its incised sutures and high number of chambers.

Calcareous foraminifera, which tend to have more biostratigraphic utility, had significant representation in only one sample, from Anemone-1, and rare occurrences in a couple of others. It is considered that their general absence is due to unfavourable paleoenvironments, rather than to post-depositional dissolution. Calcareous faunas could become more prominent seaward of Anemone.

Foraminiferal occurrences were confined to shales and siltstones. Coarser sandstones were unfailingly barren of foraminifers and after a number of these were examined initially, further processing of this lithology was considered to be without merit. These sandstones constituted a substantial part of the lithofacies associations penetrated by the 6 drillholes, resulting in a very discontinuous foraminiferal record in the three wells where fossils occurred.

PALYNOLOGICAL ZONE	Anemone -1	Anemone-1A								Angler-1				Archer-1		
	Ir T lilliei	Ir Nothofagidites senectus					Tricolporites apoxyexinus				Ir Tricolporites lilliei				Ir N senectus	Ir N senectus
DEPTH	3730	4170	4195	4320	4350	4375	4410	4475	4500	4520	4050	4110	4140	4170	3930	4050
SPECIES																
<i>Astacolus</i>							X									
<i>Gavelinella?</i> sp.	X															
<i>Haplophragmoides</i> sp. 1		X	X												X	
<i>Haplophragmoides</i> sp. 2		X	X													
<i>Haplophragmoides</i> sp. 3								X								
<i>Haplophragmoides</i> sp. 4								X				X		X	X	
<i>Haplophragmoides</i> sp. 5									X			X				
<i>Haplophragmoides</i> , small, disk		X			X											
<i>Haplophragmoides</i> cf. <i>wilgunyaensis</i>			X				X	X	X	X		X	X	X	X	
<i>Haplophragmoides</i> spp.		X	X	X				X	X	X	X	X		X	X	X
<i>Lenticulina</i> sp.							X	X								
<i>Marginulinopsis</i> cf. <i>collinsi</i>							X									
<i>Melonis</i> sp.								cv								
Nodosarids, various						X										
<i>Praebulimina</i> sp.												cv				
<i>Psammosphaera</i> sp.					?		X	X	X	X	X				X	
<i>Pyrulinoidea</i> sp.						X										
<i>Saccammina</i> sp.			X			X	X								X	
<i>Trochammina</i> cf. <i>inflata</i>		X	X													
<i>Trochammina</i> sp.						?	?								X	
Echinoderm plates		X				X										
<i>Inoceramus</i> prisms						X										
Ostracods		X														
cv = probably caved																

From what was observed, foraminiferal biostratigraphy potentially could provide worthwhile results if drilling continued to move offshore, southward of Anemone, Angler, and Archer. Presumably, continuously fossiliferous section would increase with increasingly fine terrigenous sediment, and biostratigraphically significant taxa, commonly shelf or slope-dwellers, would become more common and persistent.

Well-by-well results are provided in the following sections. The three numbers separated by forward slashes indicate total samples taken for the well, the number prepared for study, and the number with foraminifera.

3.1 ANEMONE-1/1A (SEE TABLE 1 AND 2)

Samples collected/prepared/fossiliferous: 45/22/10

Comments

General:

Table 1 lists foraminifera recorded in Anemone-1/1A, and Table 2 provides sample examination information.

Colour indices for agglutinated foraminifers are in the 5 to 7 range, indicating fully mature sediments but also moderately obscuring morphological details of the individual specimens.

Age:

Although the overall fauna has a Cretaceous character, no age-diagnostic species were recorded in the well.

Paleoenvironment:

Nine of the 10 faunas recovered consist entirely of agglutinated foraminifers, or are strongly dominated by them. Haplophragmoides, Saccamina and Trochammina, in that order, are most commonly encountered, with the first of these characteristically overwhelmingly dominant. Diversity is typically low, suggesting restricted conditions, probably subnormal salinity. A lagoonal to marine marsh setting is inferred, implying that barrier beaches may have lain farther to the south.

The tenth sample, from 4410 m, contains a substantial proportion of calcareous foraminifers, mostly Lagenids. No planktics were found. This fauna suggests a normal marine, (mid?) shelf environment, with neritic surface waters fully sheltered from oceanic circulation.

In sequence stratigraphic terms, the 4410 m sample reflects the maximum transgression at the site (within the studied interval) and a marine highstand.

Table 2. Anemone-1/1A: foram samples (9/22/45)

Anemone-1					
DEPTH	WEIGHT	RESIDUE	FORAMS	NOTES ON RESIDUE	BIOSTRAT
3500	23.24	18.59	No	Snd, med to crse, angular; zst, dark grey; coal chips.	Mid T. lilliei
3535	19.97			Not processed	
3565	17.37			Not processed	
3600	17.20	9.00	No	Snd, med to crse, angular; zst, dark grey; coal chips, rare glauconite.	Lower T. lilliei
3635	27.33			Not processed	
3660	14.78			Not processed	
3690	39.53			Not processed	
3730	28.02	23.22	Yes	Snd, med to crse, angular; zst, dark grey; coal chips, pyrite, rare glauconite. Single pyritised probable foram, in place?	
3755	30.48			Not processed	
3780	25.74			Not processed	
3815	19.43			Not processed	
3835	35.84			Not processed	
3865	11.54	8.28	No	Snd, med to crse, angular; zst, brn, micaceous; coal chips, pyrite, occ'l glauconite.	
3890	17.23			Not processed	
3915	25.43			Not processed	
3950	19.14	10.65	No	Snd, med to v crse, ang; zst, brn, micaceous. Pyrite, rare glauc. Caved Cenozoic forams.	Upper N. senectus
3985	29.68	24.22	No	Snd, v crse to med, ang; zst, grey, occ'l glauc	
Anemone-1A					
3865	16.82	10.50	No	Snd, crse to med, ang to few subang; common zst, drk grey,	Lower T. lilliei
3900	49.45			Not processed	
3915	24.95			Not processed	
3950	22.62	14.56	No	Snd, v crse to med, ang; zst, dark grey, carb; rare glauc, coal chips	Upper N. senectus
3985	36.72	27.06		Snd, v crse to med, ang, few subang; zst, dark grey; pyrite	
4010	25.74	17.68	No	Snd, v crse to med, ang; zst, dark grey & brn; pyrite, coal chips	
4055	35.18			Not processed	
4080	26.60	22.25	No	Snd, v crse to med, ang; zst, minor, dark grey & tan; pyrite	
4115	39.12	32.49	No	Snd, v crse to med, ang; zst, dark grey & tan; pyrite, biotite, occ'l glauc. Rare, caved Cenozoic forams.	
4145	33.30			Not processed	
4170	6.06	1.60	Yes	Zst, grey; minor snd, med grain, ang. Few poorly preserved aggl forams, ostracods, echinoderm fragments	Lower N. senectus
4195	12.08	3.78	Yes	Zst, grey; minor snd, med grain, ang. Few poorly preserved aggl forams, echinoderm fragments	
4225	38.35	30.33	No	Snd, med to v crse; zst dark grey; pyrite	
4290	23.26	15.27	No	Snd, f grain, slightly calc, silty; zst dark grey; pyrite, rare glauc	

Anemone-1					
DEPTH	WEIGHT	RESIDUE	FORAMS	NOTES ON RESIDUE	BIOSTRAT
DEPTH	WEIGHT	RESIDUE	FORAMS	NOTES ON RESIDUE	BIOSTRAT
4320	29.43	14.55	Yes	Sst, f to med grain, calc.; zst, drk grey, non calc; pyrite. Very few poorly preserved aggl forams & rare caved Cenozoic forams.	
4350	14.07	5.37	Yes	Zst, drk grey; biotite, pyrite. Rare, poor aggl forams	
4375	22.32	8.98	Yes	Zst, drk grey, hard; pyrite. Rare forams, <i>Inoceramus</i> prisms.	
4410	52.15	18.82	Yes	Zst, drk grey, hard; pyrite, tr glauc. Few calc & aggl forams, <i>Inoceramus</i> prisms.	Tricolpites apoxyex.
4440	unsampled?			Pre-selected for sampling, but no sample taken	
4475	43.87	15.16	Yes	Zst, drk grey, hard; pyrite, tr glauc. Few aggl forams.	
4500	42.12	16.97	Yes	Zst, drk grey, hard; pyrite, tr glauc. Few aggl forams.	
4520	30.75	13.30	Yes	Zst, drk grey, hard; pyrite, tr glauc. Few aggl forams.	
4560	22.81			Not processed	
4625	25.73			Not processed	
4675	28.10			Not processed	
4710	24.26			Not processed	
4740	18.88			Not processed	
4770	21.2			Not processed	
TOTAL SAMPLES			45		
SAMPLES EXAMINED			22		

3.2 ANGLER-1 (SEE TABLES 1 AND 3)

Samples collected/prepared/fossiliferous: 12/12/4

Comments

General:

Although samples were examined from both the *Tricolpites lilliei* and *Nothofagidites senectus* Palynozones, only those from the *T. lilliei* Zone yielded foraminifera.

Age:

No age-diagnostic species were recovered.

Paleoenvironment:

With the exception of a single, probably caved, calcareous specimen at 4140 m, only agglutinated taxa were recovered. Foraminifera were sparse, except in the 4170 m sample, where they were moderately common. The low diversity, *Haplophragmoides*-dominated assemblages are suggestive of brackish water environments, perhaps lagoon or salt marsh, within the coastal complex.

Table 3. Angler-1: foram samples (4/12/12)

DEPTH	WEIGHT	RESIDUE	FORAMS	NOTES ON RESIDUE	BIOSTRAT
4050	46.31	10.14	Yes	Zst, grey, hard, rare glauc; minor sst, crse, ang; pyrite, coal chips. 1 foram recovered.	T. lillieii (I. koroj)
4080	35.84	11.57	No	Zst, grey, hard, rare carb chips; minor sst, med to crse, ang; pyrite, coal chips glauc.	
4110	46.58	12.50	Yes	Zst, grey-brn, hard, rare glauc; snd, vfg to fg, ang; coal chips, pyrite. Mod common forams; ostracods, echinoderm frags.	
4140	56.59	13.75	Yes	Zst, grey, carb chips; snd, crse, ang; pyrite, rare glauc. Sparse forams.	
4170	29.63	6.91	Yes	Zst to vfg sst, grey, carb chips; snd, med to crse, ang; mudstn, reddish, glauc. One foram found.	
4200	37.66	13.48	No	Zst, grey to brownish; sand, vfg, grey; coal chips, pyrite, rare glauc. Caved Cenozoic forams.	Upper N. senectus (I. koroj)
4240	63.86	55.98	No	Snd, med to crse, ang; sst, f to med grn, silty, ang; zst, grey & brn; pyrite, rare glauc	
4265	48.92	41.30	No	Snd, crse to med, ang; sst, fg, subang, poorly sorted; zst, grey; coal chips, pyrite.	
4275	84.43	69.38	No	Snd, crse to med, ang; sst, fg, subang, poorly sorted, some w/flaser? bedding; zst, grey; coal chips, pyrite.	
4290	58.75	45.26	No	Snd, crse to med, ang; sst, fg, subang, poorly sorted; zst, grey; coal chips, pyrite.	
4320	42.88	23.98	No	Snd, med to crse, ang; sst, f grn, silty, ang, calc; zst, grey; mudstn, salmon; pyrite.	
4330	55.30	20.17	No	Zst, grey; sst, white, fg to vfg, ang; snd, med to v crse, ang; pyrite	
TOTAL SAMPLES			12		
SAMPLES EXAMINED			12		

3.3 ARCHER-1 (SEE TABLES 1 AND 4)

Samples collected/prepared/fossiliferous: 24/9/2

Comments

General:

Sample processing had become much more selective by the time Archer was done, as it had become apparent that the sandier sediments were consistently non-productive. Consequently, only a few samples, mainly darker-coloured and finer-grained, were given further study.

Age:

No age-diagnostic species were encountered.

Paleoenvironment:

Foraminifera were moderately common at 3930 m, and rare at 4050 m. Only agglutinated taxa were recovered, and again they suggest brackish water lagoonal or salt marsh settings.

Table 4. Archer-1: foram samples

DEPTH	WEIGHT	RESIDUE	FORAMS	BIOSTRAT	NOTES ON RESIDUE
3320	20.23	2.40	No	Lower T lilliei	Zst, brn, sndy; pyrite, glauc. Caved Cenozoic forams common.
3350	33.51				Not processed
3380	38.68	3.23	No		Zst, brn, finely sndy; pyrite, glauc. Caved Cenozoic forams.
3400	40.06				Not processed
3430	42.31				Not processed
3460	42.93	36.74	No		Zst, brn-grey, v calc. Caved Cenozoic (Miocene?) forams.
3500	40.84				Not processed
3530	65.50	25.29	No		Mostly snd, v crse to med, ang to subang; minor zst, grey. Caved Cenozoic forams.
3555	52.04				Not processed
3595	73.91				Not processed
3625	57.48			Not processed	
3655	77.13	61.98	No	Upper N senectus	Mostly snd, v crse to med, ang to subang; minor zst, grey. Caved Cenozoic forams.
3680	65.58				Not processed
3705	56.73				Not processed
3730	41.23	34.49	No		Sst, v crse to med, ang; zst, brn; coal chips
3755	38.12				Not processed
3820	60.08	40.23	No		Sst, v crse to med, ang; zst, brn, carb; coal chips
3855	38.49				Not processed
3890	47.45			Lower N senectus	Not processed
3930	50.76	2.25	Yes		Mudstn, drk grey; zst, lt tan; minor snd, crse, ang; rare glauc. Aggl forams mod common.
3965	60.65				Not processed
4000	38.16				Not processed
4030	35.15				Not processed
4050	42.21	14.56	Yes		Zst, grey, hard. Rare aggl forams.
TOTAL SAMPLES			24		
SAMPLES EXAMINED			9		

3.4 BLACKBACK-1 (SEE TABLE 5)

Samples collected/prepared/fossiliferous: 27/10/0

Comments

General:

Although the finest-grained mainly were selected for processing, none were productive. It is likely that there was only very minor marine influence at the site during the Cretaceous.

Table 5. Blackback-1: foram samples (0/10/27)

DEPTH	WEIGHT	RESIDUE	FORAMS	NOTES ON RESIDUE	BIOSTRAT
3510	27.96			Not processed	Lower F. longus
3525	22.42	9.42	No	Zst, brn, mic; minor snd, qtz, ang; coal chips common, pyrite	
3535	39.72			Not processed	
3570	22.39	10.14	No	Zst, brn, mic, carb; minor qtz snd, ang; coal chips, pyrite, glauc??	
3615	26.39	13.06	No	Sst, flds, crse, ang; minor zst, brn, mic; coal chips	
3645	58.38			Not processed	
3680	37.76	25.36	No	Sst, flds, crse, ang; minor zst, brn, mic; coal chips, glauc (in place?)	
3710	37.03			Not processed	
3765	44.16			Not processed	
3800	32.04			Not processed	
3865	48.08	42.64	No	Sst, grey, fg, calc, silty, pyrite; minor snd, crse; minor zst, brn; coal chips, rare glauc	
3905	33.66			Not processed	
3935	44.80			Not processed	
3965	25.80	20.84	No	snd, med to crse; minor zst, brn; coal chips, rare glauc. Caved Cenozoic forams.	
4000	32.65			Not processed	
4060	36.21			Not processed	
4095	33.73			Not processed	
4110	23.65	15.30	No		
4140	21.58	8.89	No		
4170	28.20			Not processed	
4225	35.89	35.04	No		Probable Lower F. longus
4270	20.06			Not processed	
4315	32.29			Not processed	
4340	37.84			Not processed	
4365	22.20			Not processed	
4380	21.98			Not processed	
4390	17.71	12.92	No		
TOTAL SAMPLES			27		
SAMPLES EXAMINED			10		

3.5 EAST PILCHARD-1 (SEE TABLE 6)

Samples collected/prepared/fossiliferous: 17/12/0

Comments

General:

Although the section contained several siltstone intervals, which were extensively processed, none of the samples was productive. It is likely that there was only very minor marine influence at the site during the Cretaceous.

Table 6. East Pilchard-1: foram samples (0/12/17)

DEPTH	WEIGHT	RESIDUE	FORAMS	NOTES ON RESIDUES	BIOSTRAT
2525	24.93	11.86	No	Mafic Igneous fragments; snd, med to crse; zst, tan; pyrite. Caved Cenozoic forams.	?Lower T lilliei
2560	29.97			Not processed	
2595	33.34	11.55	No	Zst, grey, carb; sst, ylo-white, silty; pyrite. Caved Cenozoic forams.	
2635	37.85			Not processed	
2660	23.38	5.57	No	Zst, tan, sndy; zst, grey, carb; sst, med to crse, ang; pyrite.	N senectus
2695	50.24	33.35	No	Snd, med to crse, ang, rare subang; sst, fg, ang, silty; zst, grey; pyrite, coal chips grey chert.	
2735	51.54	9.61	No	Zst, grey & tan, carb; coal chips, pyrite	T. apoxyex
2810	44.57			Not processed	
2855	66.11	16.99	No	Zst, dark grey, hard, sndy; sst, ylo-brn, f to med grn, carb; snd, crse, ang; pyrite, coal chips.	Lower T. apoxyex. & ?P mawsoni
2905	45.82	32.05	No	Snd, med to v crse, ang; sst, fg, ang, silty, carb; zst, grey; pyrite, coal chips.	
2935	51.41	23.07	No	Snd, med to v crse, ang; sst, fg, ang, silty, carb; zst, grey; pyrite, coal chips. Caved Cenozoic forams.	
2985	39.44	11.82	No	Snd, med to v crse, ang; sst, fine to med, silty; zst, grey, carb.	
3010	48.71	22.92	No	Zst, grey, non-calc; minor snd, ang; v rare glauc, poss in place. Most marine-looking residue seen in sample suite.	
3050	56.35			Not processed	
3070	74.64	34.62	No	Zst, grey, carb; sst, f to med grn, white, silty; snd, med to crse grn, ang, rare rounded.	
3090	54.77			Not processed	
3125	84.38	68.04	No	Snd, v crse to med, ang; minor sst, fg, silty, ang, carb; minor zst grey; coal chips.	
TOTAL SAMPLES			17		
SAMPLES EXAMINED			12		

3.6 TUNA-4 (SEE TABLE 7)

Samples collected/prepared/fossiliferous: 3/3/0

Comments

General:

Tuna-4 is the most northerly well examined in this study, and the site presumably was closest to the paleoshoreline. Very few cuttings samples were available. There was good sidewall core coverage for the well, but it was deemed poor use of scarce material to attempt to recover foraminifers from the small sidewall samples. Further, results from other drillholes strongly suggested that this effort would be unsuccessful.

Table 7. Tuna-4: foram samples (0/3/3)*

DEPTH	WEIGHT	TYPE	RESIDUE	FORAMS	BIOSTRAT	COMMENT ON RESIDUES
2850	unsampled*	SWC			T lilliei	No sample taken
2965	unsampled	SWC				No sample taken
3025	unsampled	SWC				No sample taken
3045	unsampled	SWC				No sample taken
3100	unsampled	SWC			N senectus	No sample taken
3150	unsampled	SWC				No sample taken
3215	19.03	CTGS	15.44	No		Snd, v crse to med, ang, few subang to subround; sst, med to crse, silty; zst, grey; coal chips.
3265	34.57	CTGS	22.24	No		Zst, grey & brn; sst, f to med, silty; snd, crse, ang; coal chips, grey chert. 1 grain glauc seen.
3275	unsampled	SWC				No sample taken
3310	32.54	CTGS	20.89	No		Sst, ylo-brn, f to med, ang, silty; zst, grey; snd, crse, ang.
*Unsampled levels available only as SWCs						
TOTAL SAMPLES			3			
SAMPLES PROCESSED			3			

4. RECOMMENDATIONS

Foraminifera:

Work reported herein strongly suggests that Upper Cretaceous foraminifera are unlikely to be recovered at all from Gippsland Basin wells drilled north of Anemone-Angler-Archer, and foraminiferal studies in such wells is therefore not recommended. Although foraminifers make only a modest contribution to the biostratigraphic and paleoenvironmental interpretation of these three wells, increased marine influence is likely to the south (and also east). It is recommended that any well drilled in these areas include at least reconnaissance-level foraminiferal work.

APPENDIX 3

Report of dinoflagellate study



Institute of
**GEOLOGICAL
& NUCLEAR
SCIENCES**
Limited

Gippsland Basin Cretaceous Biostratigraphy Project
Part B: Provisional Dinoflagellate Report

Graeme J. Wilson

Prepared for

ESSO AUSTRALIA PTY LTD

CONFIDENTIAL

Institute of Geological & Nuclear Sciences client report 2006/165
Project Number: 54080010

November 2005

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The basis of this contract is that any and all work done on samples and slides viewed, taken or borrowed shall be properly documented and reported to the Petroleum Development Unit (DPI), Government of Victoria, and made available to the public.

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KEYWORDS

Gippsland Basin; Anemone-1/1A; Latrobe Group; Cretaceous; dinoflagellates.

INTRODUCTION

This report attempts to correlate previous biostratigraphic assessments of the economically important Upper Cretaceous Latrobe Group in the Gippsland Basin (Morgan 1989; Partridge 1999, 2003) with the New Zealand Stage and dinoflagellate zonal scheme (Cooper 2004; Figure 1). Several of the original palynological slides (on loan from DPI, Melbourne) were re-examined by the writer in order that a consistent taxonomic list could be obtained.

Petrofina Anemone-1/1A well, in the southern part of the basin, was selected for dinoflagellate assessment since it has a significantly greater marine aspect (and therefore more dinoflagellates) than other wells located particularly in northern parts of the basin, for which spore-pollen biostratigraphy is more useful (see Woollands & Wong 2001; Figure 2). The well tested gas in the Golden Beach Subgroup (lower part of the Latrobe Group).

The New Zealand Upper Cretaceous dinoflagellate zonal scheme was originally developed by Wilson (1984) using analyses of surface sections principally in the eastern basins of both North Island and South Island; the latest revision of this scheme is published in Cooper (2004). Effective application of this zonation to petroleum exploration wells in the Taranaki Basin is probably best demonstrated by Beggs et al. (1992) who recognized an earlier Late Cretaceous "Sequence K2" (Rakopi Formation) and a later Late Cretaceous "Sequence K1" (North Cape Formation). Outcrop sections of the Upper Cretaceous Pakawau Group, originally considered non-marine, occur in northwest Nelson and have been shown to contain marine dinoflagellates, principally in the North Cape Formation (Wizevitch et al. 1992).

ANEMONE-1/1A WELL: DINOFLAGELLATE BIOSTRATIGRAPHY

2728.5 m (swc)

Dinoflagellates are relatively abundant and include *Isabelidium cingulatum* in association with *Eisenackia cf. crassitabulata*. This represents the lower to middle part of the Paleocene *Palaeocystodinium golzowense* Zone in terms of the New Zealand zonation. The interval was correlated with the Australian *Eisenackia crassitabulata* dinoflagellate Zone and the lower part of the *Lygistepollenites balmei* spore/pollen Zone by Morgan (1989). At this level the indicated environment is offshore marine.

2750 m (swc)

Indeterminate. Very little organic matter present including a few scattered pollen grains.

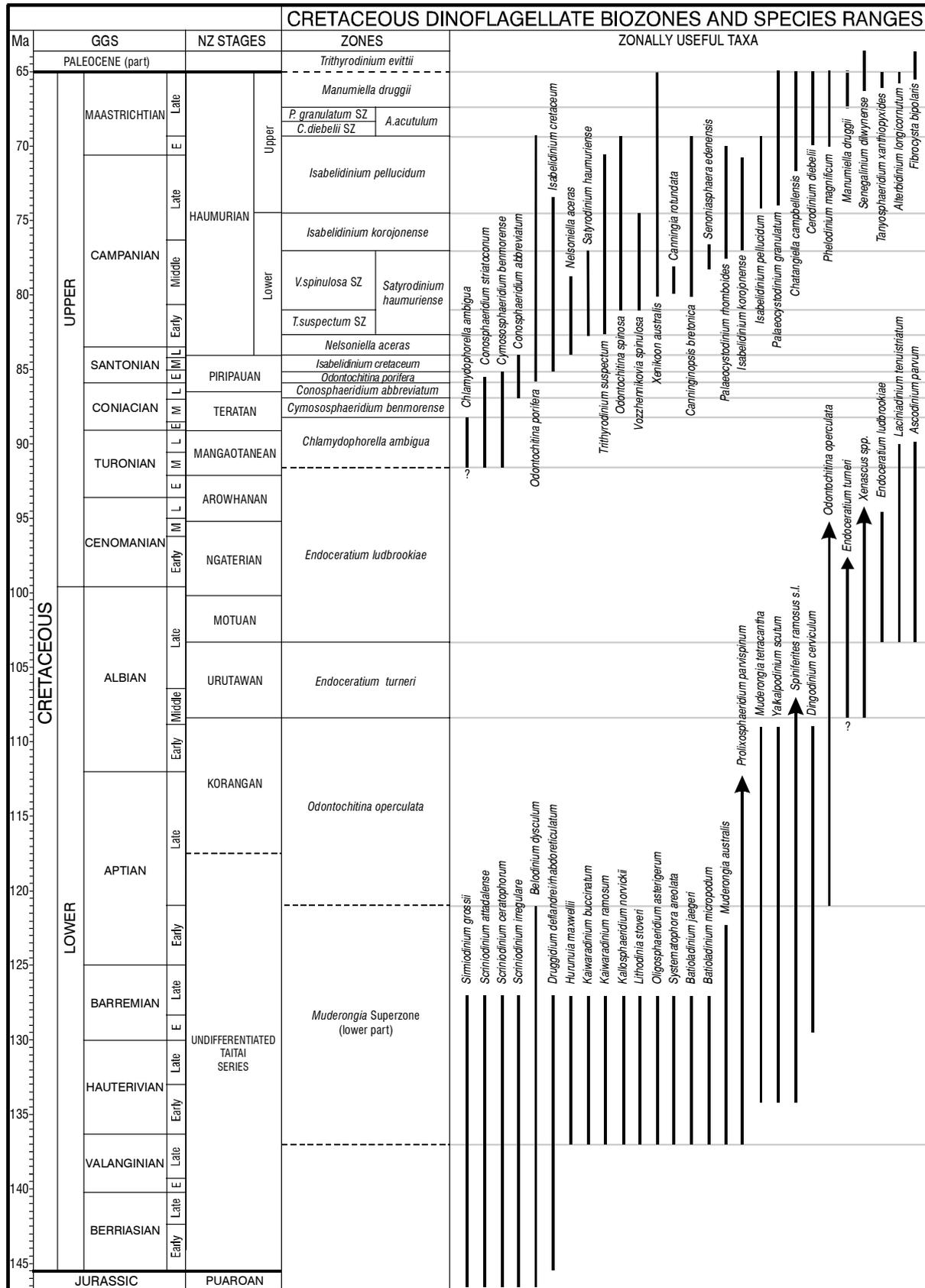


Figure 1. Stratigraphic ranges of the biostratigraphically most useful Cretaceous dinoflagellates, after Wilson (1984a); Schiøler and Wilson (1998); Roncaglia *et al.* (1999); Crampton *et al.* (2000, 2001, 2004); Schiøler *et al.* (2001), Cooper (2004).

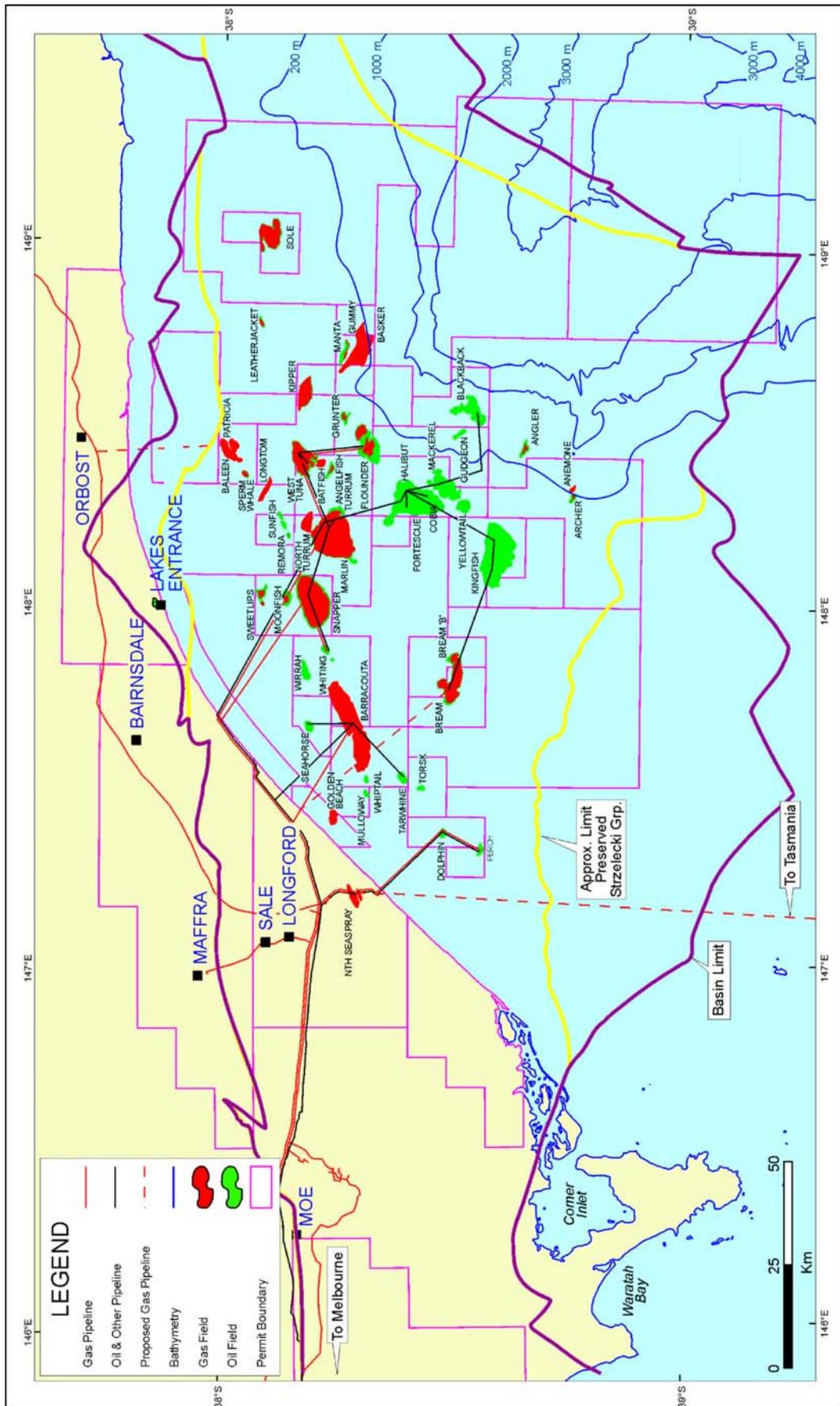


Figure 2. Oil and gas fields, Gippsland Basin (Woollands & Wong, 2001).

2762 m (swc), 2809.5 m (swc), 2816 m (swc)

Dinoflagellates are rare and include *Manumiella druggii*, indicating uppermost Cretaceous M. *druggii* Zone. This interval was correlated with the middle to upper *Forcipites longus* spore/pollen Zone by Morgan (1989) using the palynological zonal scheme documented by Helby et al. (1987). Environment is nearshore marine in the upper part and brackish in the lower part.

The Cretaceous/Tertiary boundary clearly lies between 2728.5 m and 2762 m and there is no clear evidence of the early Paleocene *Trithyrodinium evittii* Zone, indicating a possible hiatus.

2820 m (swc), 2825 m (swc), 2838 m (swc)

Dinoflagellates are extremely rare but appear to indicate M. *druggii* Zone, based on the presence of M. *druggii* or closely related forms. This interval was correlated with the lower to middle F. *longus* spore/pollen Zone by Morgan (1989). Environment brackish.

2850 m (swc), 2863 m (swc), 2958 m (swc), 3036 m (swc), 3063 m (swc)

Dinoflagellates are absent from this interval, which is considered non-marine. The interval was correlated with the lower F. *longus* spore/pollen Zone by Morgan (1989).

3075 m (ctgs)

Dinoflagellates occur in this sample, but are very pale and are likely to be caved.

3340 m (ctgs), 3450 m (ctgs)

Dinoflagellates are absent and the interval is considered non-marine. This interval was correlated with the middle to upper *Tricolporites lilliei* spore/pollen zone by Morgan (1989).

3575 m (ctgs), 3660 m (ctgs), 3875 m (ctgs)

Moderately rich dinoflagellates are present, including *Isabelidium pellucidum*, and apparently belong to the New Zealand I. *pellucidum* Zone. Some evidence of caving is suggested and it is possible that the lower part could be older. This interval was correlated with the lower T. *lilliei* spore-pollen Zone by Morgan (1989). The depositional environment is nearshore marine or brackish.

3960 m (ctgs)

Rare dinoflagellates including I. *pellucidum*, indicating apparent I. *pellucidum* Zone. The interval was placed in the upper *Nothofagidites senectus* spore/pollen Zone by Morgan (1989). Environment marginal marine.

4159 m (core catcher)

A relatively rich dinoflagellate assemblage includes *Satyrodinium haumuriense* and is indicative of the lower Haumurian S. *haumuriense* Zone. Other taxa include *Xenikoon* sp., *Nelsoniella* sp., *Chatangiella* cf. *victoriensis* and *Odontochitina* cf. *porifera*. The interval was correlated with the lower N. *senectus* spore/pollen Zone by Morgan (1989). Environment nearshore marine.

4375 m (ctgs), 4400 m (ctgs), 4620 m (ctgs), 4775 m (ctgs; TD)

All samples yielded moderate dinoflagellate assemblages and, in New Zealand terms, appear to be of earliest Haumurian to Piripauan age, no older than *Odontochitina porifera* Zone, on account of the association of O. *porifera*, *Cyclonephelium* cf. *compactum* and relatively abundant *Chatangiella* cf. *victoriensis*. The interval was correlated with the

Nelsoniella aceras to Odontochitina porifera Australian dinoflagellate zones and the lower N. senectus to Tricolpites apoxyxinus spore/pollen Zone by Morgan (1989). A nearshore to offshore marine environment is indicated. As noted by Morgan, the lowest part of the sequence (4620 m and 4775 m) contains brown palynomorph specimens indicating maturity for hydrocarbons, whereas palynomorphs from the sequence above indicate only marginal maturity or, above 3570 m, immaturity for hydrocarbons.

DISCUSSION

The above summary indicates that the Upper Cretaceous mainly marine section in Anemone-1/1A has a thickness of over 2000 m, from c.2762 m to TD at 4775 m, and ranges from the uppermost Haumurian *Manumiella druggii* Zone down to the *Odontochitina porifera* Zone of Piripauan age, in terms of the New Zealand stage and dinoflagellate zonal schemes. This represents a latest Maastrichtian to Santonian interval according to the latest version of the New Zealand timescale (Cooper 2004) and demonstrates that the New Zealand stages and dinoflagellate zones, all based on well-dated surface outcrops, can be applied to the subsurface Gippsland Basin sequences.

A dinoflagellate species list, with age interpretations, is given in Table 1.

Unlike most other wells in the Gippsland Basin, particularly in the northern part, open marine or marginal marine deposition appears to have been predominant in Anemone-1/1A, apart from the obvious substantial non-marine interval between 2850 m and 3400 m. A figure showing the full interpreted depositional environment for the well is provided by Woollands & Wong (2001, p.101; Figure 3).

Although a close correlation with the New Zealand dinoflagellate zonal scheme has been achieved, a major gap is present in the Late Haumurian where there is no indication of the *Alterbidinium acutulum* Zone. It seems most likely that this period of time is represented in the Gippsland Basin by the substantial non-marine interval discussed above, which has been correlated with the greater part of the *T. lilliei* and *F. longus* spore/pollen zones.

Relatively few New Zealand oil exploration wells in the Taranaki basin have a significantly thick marine Upper Cretaceous section comparable with Anemone-1/1A. The most complete sections appear to be in Arika-1, Tane-1 and Wainui-1, where the *M. druggii* to at least the *I. pellucidum* Zones (including *A. acutulum*) are represented and the thickness of the Upper Cretaceous (Mata Series) is up to 500 m (Beggs et al.1992). An apparently more complete marine Cretaceous/Tertiary transition interval, including the basal Paleocene *Trithyrodinium evittii* Zone, is present in the New Zealand wells, compared with Anemone-1/1A (Beggs et al. 1992).

Outcrops of the North Cape Formation (upper part of the Pakawau Group) in northwest Nelson have yielded dinoflagellates which are indicative of the *M. druggii* and *A. acutulum* Zones (Wizevitch et al. 1992) and confirm a marine depositional environment for at least part of the formation in this area.

Table 1. Anemone-1/1A Well, Gippsland Basin – Dinoflagellate Species List.

DEPTH (m)	2728.5	2750	2762	2809.5	2816	2820	2825	2838	2850	2863	2958	3036	3063	3075	3340	3450	3575	3660	3875	3960	4159	4375	4400	4620	4775
TYPE	SWC 24	SWC 23	SWC 22	SWC 18	SWC 17	SWC 16	SWC 15	SWC 14	SWC 13	SWC 11	SWC 6	SWC 2	SWC 1	ctgs	ctgs	ctgs	ctgs	ctgs	ctgs	core	ctgs	ctgs	ctgs	ctgs	
AGE	PALEOC.	nd	CRET.	CRET.	CRET.	CRET.	nd	CRET.	nd	nd	nd	nd	nd	nd	nd	nd	CRET.								
ZONE	P.gol.	nd	M.dr	M.dr	M.dr	M.dr	nd	M.dr	nd	nd	nd	nd	nd	nd	nd	nd	l.pe	lpe	lpe	lpe	Sha	?Opo	?Opo	?Opo	?Opo
SPECIES																									
Areoligera spp.	x													cvgs?											
Spiniferites ramosus	x																								
Chlamydothorea sp.	x																								
Fibrocysta cf. bipolaris	x																								
Glaphyrocysta retiintexta	x																								
Spinidinium densispinatum	x																								
Senegalium dilwynense	x																								
Isabelidium cingulatum	x																								
Palaeocystodinium golzowense	x																								
Eisenackia cf. crassitabulata	x		x																						
Manumiella conorata			x																						
Manumiella druggii			x	x	x			x																	
Manumiella seelandica			x																						
Impagidinium sp.			x																						
Pyxidiniopsis spp.			x																x						
Hystrichosphaeridium sp.				x																					
Impagidinium sp.					x																				
Manumiella sp.					x																				
Batiacasphaera spp.					x															x		x	x	x	x
Senegalium sp.					x																				
Manumiella cf. druggii						x																			
Operculodinium sp.							x							x											
Spiniferites sp.														x								x			
Glaphyrocysta sp.														x											
Cribroperidinium spp.														x											
Alterbidinium cf. longicornutum																									
Chatangiella spp																									
Isabelidium pellucidum																									
Odontochitina spinosa																									x
Alterbidinium cf. acutulum																									
Oligosphaeridium cf. complex																									x
Odontochitina porifera																									
Cleistosphaeridium sp.																									
Isabelidium marshallii																									
Isabelidium spp.																									
?Xenikoon sp.																									
Hystrichodinium spp.																									
Isabelidium cf. pellucidum																									
Circulodinium cf. distinctum																									x
Odontochitina cf. porifera																									
Alterbidinium spp.																									
Chatangiella cf. victoriensis																									
Satyrodinium cf. haumuriense																									
Nelsoniella spp.																									
Trithyrodinium cf. suspectum																									
Odontochitina operculata																									
Isabelidium cooksoniae																									
Cyclonephelium cf. compactum																									
Dingymnium spp.																									
Amphidiadema spp.																									
Vozzhennikovia cf. spinulosa																									
Xenascus cf. ceratioides																									x

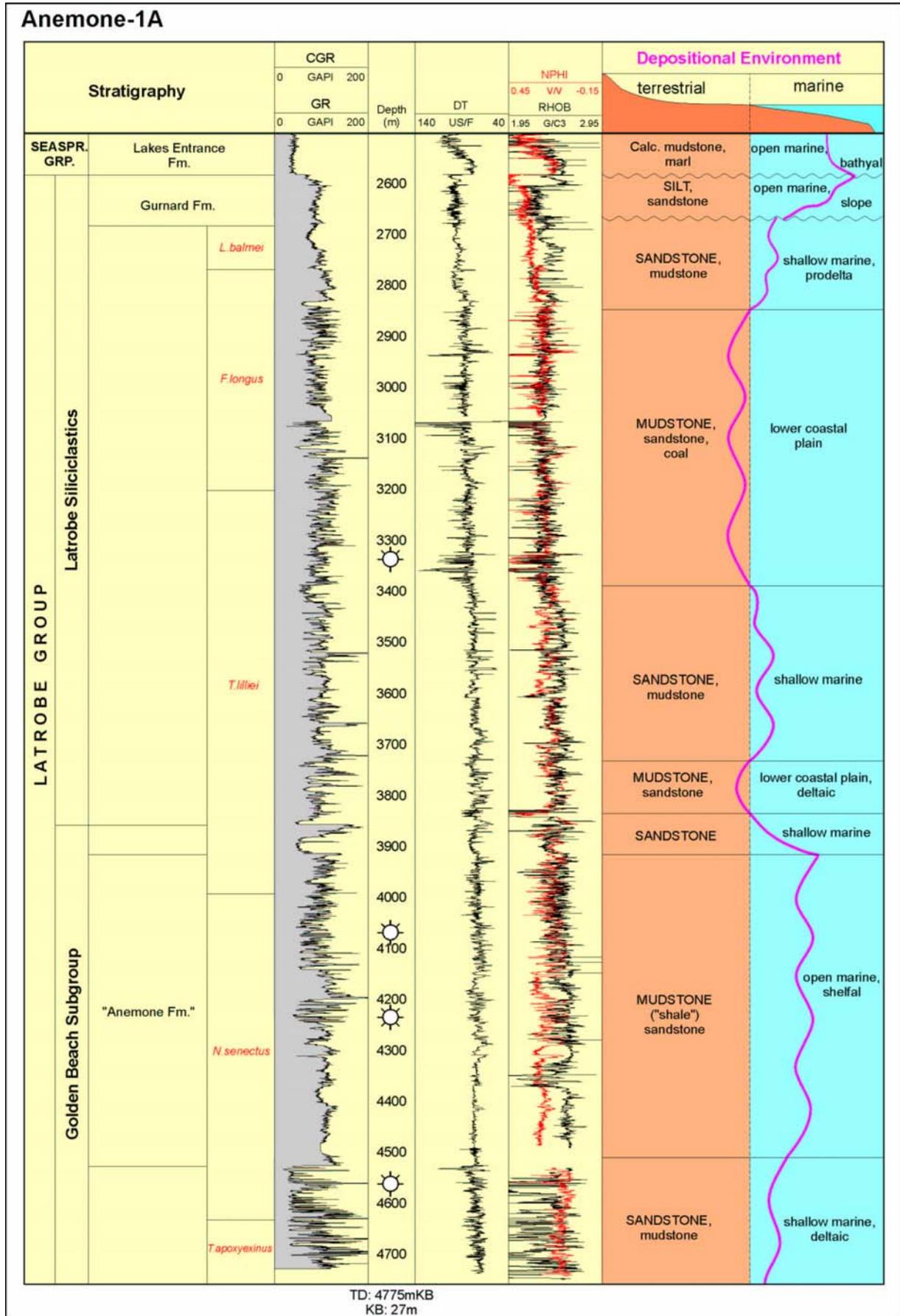


Figure 3. Anemone 1/A Well, Gippsland Basin, showing inferred depositional environment (Woollands & Wong, 2001)

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APPENDIX 4

Summary presentation at 2006 APPEA Conference, Brisbane

INITIAL REVIEW OF THE BIOSTRATIGRAPHY AND PETROLEUM SYSTEMS AROUND THE TASMAN SEA HYDROCARBON-PRODUCING BASINS

R.A. Cook, E.M. Crouch, J.I. Raine, C.P. Strong,
C.I. Uruski and G.J. Wilson

GNS Science
PO Box 30 368
Lower Hutt
New Zealand 6008
r.cook@gns.cri.nz
e.crouch@gns.cri.nz
i.raine@gns.cri.nz
p.strong@gns.cri.nz
c.uruski@gns.cri.nz
graeme.wilson@gns.cri.nz

INTRODUCTION

Paleontology is undergoing a renaissance in oil and gas exploration. After many years of having been overshadowed by geophysics and lithostratigraphy, paleontology has again been recognised as a major tool for understanding the high-resolution, detailed geology that is the essence of petroleum systems and sequence stratigraphy.

A recent study in Houston showed that companies still using paleontology within their exploration programs had a finding cost US\$1 a barrel less than others. With hundreds of millions of barrels in larger fields, this provides an extraordinary return on the relatively small investment into paleontology (Farley and Armentrout, 2000). In NZ the costs for a basic well evaluation are typically around NZ\$25,000.

In NZ the vast amount of paleontological data that defines the geological timescale has recently been synthesised into a comprehensive monograph (Cooper, 2004). The timescale is based on detailed studies of many well-dated outcrop sections, in which the NZ stage boundaries and microfossil and macrofossil zones are defined. This NZ timescale is routinely and successfully used to date and correlate drillhole samples from offshore and onshore Taranaki, Great South Basin and East Coast exploration well sequences. The aim of this project is to test the application of the NZ-defined timescale to the subsurface Gippsland Basin sedimentary succession and this paper is an initial report of the first aspects of the work.

The key to many of the paleontological advances in NZ in recent years has been the multi-disciplinary approach that has linked improved zonation of specific floral and faunal groups, along with data mining, absolute age dating and statistical procedures with close integration into sedimentology and organic geochemistry. These studies and techniques have provided a quantum leap in resolution of biostratigraphic absolute ages and discrimination of different paleoenvironments. Advances in modelling of hydrocarbon generation and migration require high resolution absolute ages to calibrate geophysical interpretations, particularly within the upper part of the sequence when the thermal effect on deeply buried sediments is greatest. Moreover, the models need good paleobathymetry for both thermal control and migration models, especially where compaction can alter the original structure. If the NZ geological timescale is widely applicable to the Gippsland Basin then there is a bridge to use these advances in exploration on either side of the Tasman Sea, particularly as exploration begins to focus on more offshore drill-sites.

ABSTRACT

Understanding the genesis and habitat of hydrocarbons in a sedimentary basin takes knowledge of that basin at many levels, from basic infill geology to petroleum systems, plays, prospects and detailed sequence stratigraphy. While geophysics can define the basins and their internal structures, biostratigraphy and paleogeography provide greater understanding of basin geology. Micropaleontology and palynology are the chief tools that we need to define both the environment and dimension of time.

As an example, the reconstruction of the Tasman Sea region to the mid-Cretaceous (ca 120 Ma) shows that the hydrocarbon-producing Gippsland and Taranaki petroleum basins developed at similar latitudes and in similar geological contexts. Other basins within the region have been lightly explored and need evaluation as to the value of further exploration.

As paleontology has developed separately in Australia and New Zealand, comparison of biostratigraphic zones and their chronostratigraphy is critical to understand the similarity or otherwise of the sedimentary record of the two regions. Recent refinement of the NZ timescale and comparative studies on Gippsland Basin wells by NZ paleontologists have provided some key insights that enable us to compare the geological history of both regions more closely, and to recognise similarities in petroleum systems that may enhance petroleum prospects on both sides of the Tasman Sea.

KEYWORDS

Taranaki, Gippsland, biostratigraphy, hydrocarbons, exploration, Tasman Sea, Australia, New Zealand.

ADVANCES

In the last decade major advances in NZ biostratigraphy have resulted in improved correlation of multiple faunal and floral zones, integrated with absolute age dating. Nowhere has this been more significant than in the Upper Cretaceous where dinoflagellate zones have improved resolution dramatically together with links to absolute ages (Cooper, 2004)

The latest NZ Geological Timescale (Cooper, 2004) provides the first fully integrated, comprehensive geological timescale for NZ from Cambrian to Holocene. The monograph synthesises information used for calibrating NZ strata and correlating them with the Global Geochronological Scale (GGS). NZ geological stages, definition of stage boundaries and boundary-defining events, numerical ages and their uncertainty limits for stage boundaries are documented.

High precision age correlation is derived from integrating: magnetostratigraphy; isotopic records; radiometric dating and planktic biostratigraphy from nearby Ocean Drilling Programme cores, in which NZ stages can be recognised; and, from onshore. Uncertainty intervals on stage boundary ages have been calculated and can be built in to physical models of basin history. Compared with the Australian Phanerozoic Timescale (Young and Laurie, 1996) there is more emphasis on the Late Cretaceous and Cenozoic, reflecting the predominance and importance of rocks spanning this period in NZ.

Data collection and data mining

NZ has long had the distinct advantage of a single fossil database with the majority of exploration biostratigraphy being carried out by one organisation, GNS Science. This NZ Fossil Record File is now a major source of data that is being fed back to the petroleum exploration industry through special well record and correlation projects where detailed knowledge of sedimentation history is crucial for reservoir and field evaluation, regional correlation and modelling. Two quantitative techniques developed at GNS Science—Biolog and CONOP—also provide both local and regional correlation with resolution virtually unique for a tectonically active region.

Fossil record file

To make best use of the systematic collection, identification and interpretation of the fossils, the NZ Fossil Record File (FRF) was established in 1946 as a national system for recording geographic location, geological context, and collection details of fossils. The location records are linked to paleontological fossil identifications, and age and paleoenvironment interpretations. The FRF is now an electronic database holding some 86,000 localities and over one million fossil occurrences.

The FRF database has provided extensive compilations of field and exploration data to NZ research individuals or organisations. There are now several international initia-

tives of similar data collation that may soon be linked to the NZ database, which will provide a huge resource for the future in many aspects of biostratigraphy and paleobiology. They include the following.

1. Commission for the Management and Application of Geoscience Information (Commission of the International Union of Geological Sciences) (http://www.bgs.ac.uk/cgi_web).
2. Chronos—a NSF-funded geoinformatics initiative that is developing a network of stratigraphic databases, tools and information (<http://www.chronos.org>).
3. The Paleobiology Database—a NSF-funded initiative that aims to provide global, collection-based occurrence and taxonomic data for fossils, as well as web-based software for statistical analysis of the data. The project's wider, long-term goal is to encourage collaborative efforts to answer large-scale paleobiological questions by developing a useful database infrastructure and bringing together large data sets (<http://paleodatabase.org>).
4. International Working Group on Taxonomic Database—working group of the International Union of Biological Sciences (<http://www.tdwg.org/>).
5. Indo-Pacific Pollen Database—part of the World Pollen Database project, which aims to provide regional fossil vegetation data for Quaternary paleoclimate research (<http://www.ngdc.noaa.gov/paleo/pollen.html>).

Biologs

Biologs are a quantitative graphic presentation of fossil occurrences and ratios in well section depth to provide a comparative graphic to electric logs (Scott and Crundwell, 1994). These biologs use census and specimen abundance data from pre-determined intervals through the well section to reveal potentially correlatable events (e.g. peak abundances) beyond presence or absence of index fossils. Biologs are valuable for regional studies and also for resolving correlation problems between closely spaced wells, as encountered during field development.

Some examples of outputs from census data, whether as biologs or other graphic signatures, follow.

- Oceanic setting—relative to benthic foraminifera species, planktonic taxa are rare in inshore, neritic water but their productivity is higher than benthic species in oceanic water. The relative abundance of the two groups enables upper water mass type to be specified and the position of the site relative to principal marine features, such as shoreline and shelf break, to be inferred.
- Paleodepth—interpreted from the abundance of depth-sensitive taxa, and providing a resolution of <100 m on shelf and upper slope. Trends in paleodepth are identified.
- Bottom environment—using modern analogs, bottom energy, relative dysoxia, temperature, water mass type, biotic productivity and stress are interpreted from assemblage composition and structure.
- Sediment flux—from the inception of sequence stratigraphic studies, microfossil abundances have been used

to identify condensed intervals. This is just one scenario of a general dilution model, in which abundances of benthic and planktonic foraminiferal specimens are interpreted as an inverse measure of detrital flux. Changes in specimen productivity are detected by analysis of co-variance between benthic and planktonic signatures.

- Facies classifications—groupings of stratigraphically contiguous localities based on multivariate analysis of species data provide biofacies classifications that can be compared with the distribution of lithofacies units, such as systems tracts. Unconformities and potential sequence boundaries are identified. High-resolution biofacies classifications are obtained, particularly from prograding complexes, due to the correlation of many species distributions with depth. In studies of basin architecture, foraminiferal populations provide a basic dataset for the recognition and evolution of depositional systems.

CONOP

Another quantitative technique is CONOP (short for CONstrained OPTimisation) (Cooper et al, 2001). This is an automated graphic correlation technique that uses a statistical/graphic system to define a best-fit sequence of all fossil ranges present and other stratigraphic events (ash layers, seismic horizons, etc). CONOP can handle enormous datasets, and provide vastly improved correlation precision, detailed intra-basin biostratigraphic time scales, and precise age/depth curves. A recent confidential CONOP study of 10 wells provided 750 independently correlatable levels from 1,800 biostratigraphic events for input into both a 3D seismic interpretation and modelling run (J. Crampton, GNS Science, pers comm, 2005).

CONOP uses constrained optimisation to derive a best-fit composite sequence of biostratigraphic events and to locate the true position of all events in all sections. The second main task undertaken by CONOP is the spacing of events in the composite sequence to create a composite section, and the placement of all events in all sections so as to honour the composite sequence and achieve a correlation.

CONOP will not detect global changes in depositional rate that affect all sections in the dataset and it should be noted also that when locating composite events in the sections CONOP will only place events at sampled horizons; the program will not interpolate between sampled levels. Therefore, the closer the sampling the better the final outcome. From several projects we have found CONOP-identified unconformities that were previously unrecognised and have provided important solutions to seismic stratigraphic problems.

TASMAN SEA COMPARISONS

Several sedimentary basins around the Tasman Sea (Fig. 1) now produce commercial hydrocarbons (Gippsland, Otway, Bass and Taranaki) and hydrocarbons have been found

in others, such as Great South, Canterbury, and Northland basins (Fig. 1). Modern basin development of this region started in the latest Jurassic with the precursor extension of this margin as the continental breakup began. This is recorded in the oldest sediments of the Gippsland Basin (Wollands and Wong, 2001), although extension is not seen in the main Taranaki basin until the late Early Cretaceous (120–110 my) (King and Thrasher, 1996).

Many reconstructions of the Tasman Sea for the last 120 million years have been published and show that the productive basins of the Tasman Sea were originally part of a contiguous eastern continental margin of Gondwanaland (e.g. Sutherland et al, 2001). During the Jurassic and for much of the Cretaceous this eastern margin was the site of subduction along what is now part of Australia, NZ and Antarctica (Mortimer et al, 1999). The basins were only a few hundred kilometres apart and at similar latitudes (Fig. 2), which would suggest similar geographies, sediment source hinterland, and floral and faunal assemblages.

Gippsland Basin

The Gippsland Basin is presently an east–west trending basin off the southeast coast of Victoria, Australia (Fig. 3). It is Australia's most productive basin with total original reserves of approximately one trillion (10^{12}) cubic feet (tcf) of gas and four billion (10^9) barrels of oil.

The basin comprises a deep central depression symmetrically bounded by faulted terraces and platforms to the north and south (Woollands and Wong, 2001). The oldest sediments are Jurassic coal measures and lacustrine beds deposited in extensional basins during the early stages of the Otway Rift Phase (Figs 4 and 5). This rift phase continued through the Early Cretaceous when the predominantly volcanoclastic Strzelecki Group was deposited in the east–west rift extending east of the Otway and Bass basins (Bradshaw, 1993). A regional unconformity of Cenomanian age (100–95Ma) was followed by deposition of the Emperor Subgroup fault-bounded units of lacustrine and alluvial sediments in the Cenomanian and Turonian. Following a depositional hiatus, the Golden Beach Subgroup was deposited in marine and marginal marine environments in the Santonian and Campanian (Bernecker and Partridge, 2001).

Effective petroleum systems involving elements of the Emperor and Golden Beach subgroups are now widely accepted (Woollands and Wong, 2001), (Fig. 6). The bulk of the hydrocarbons is derived from coals and related carbonaceous mudstones that were deposited in the lower coastal plain. The distribution of these facies intervals is poorly defined due to the limited well control. Marine shale is also recognised as a potential source rock, as Gorter (2001) concluded that the condensate recovered from the Anemone–1/1A well in the southeast part of the basin has biomarker evidence of marine organic source. This evidence supports Bernecker and Partridge (2001) who suggest that source rock distribution for the Emperor and Golden Beach Subgroups may extend further east than the non-marine facies.

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Figure 1. Present-day geography of the Tasman Sea region (after Sutherland et al, 2001). OB Otway Basin, BB Bass Basin, GB Gippsland Basin, CP Challenger Plateau, TB Taranaki Basin, CB Canterbury Basin, GSB Great South Basin, NCB New Caledonia Basin.

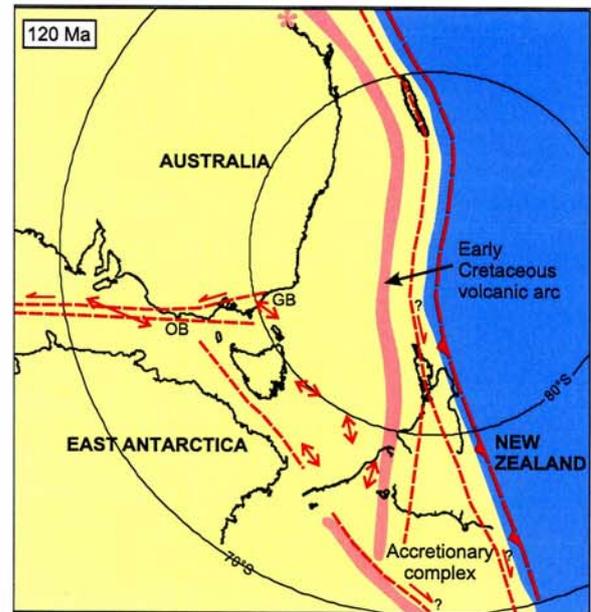


Figure 2. Tectonic and paleo-latitude reconstruction for the Early Otway Rift phase (120Ma) of Tasman Sea Development (after Sutherland et al, 2001). GB Gippsland Basin, OB Otway Basin.

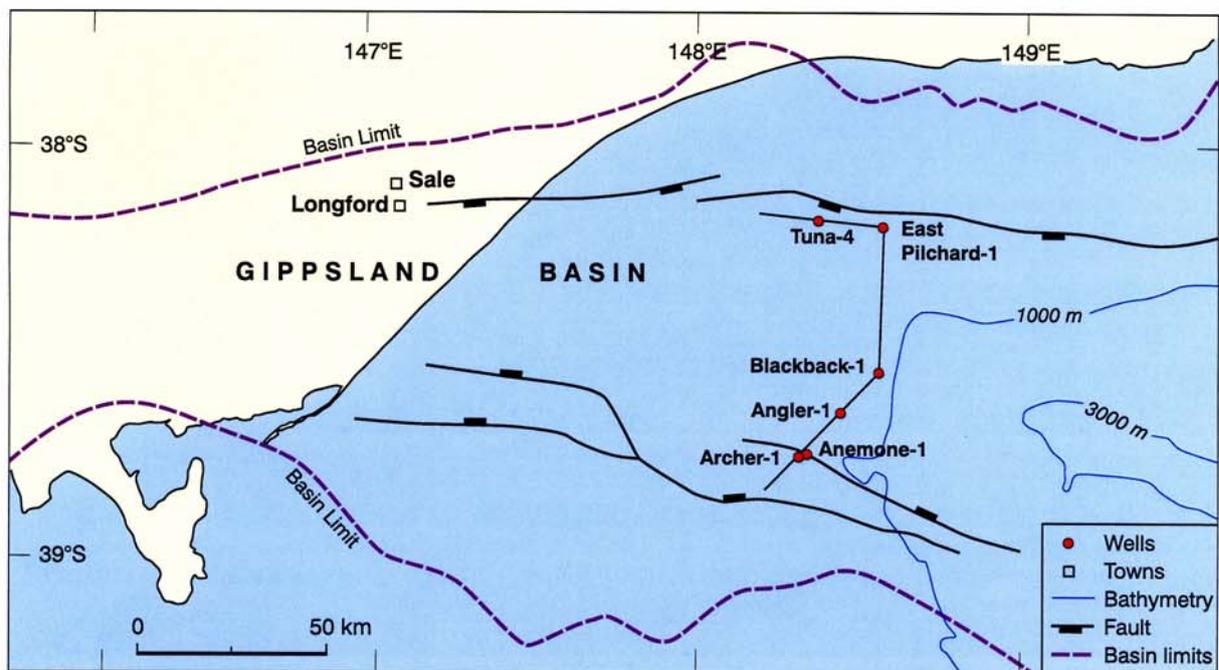


Figure 3. Map of the Gippsland Basin showing the location of the wells used in the study (after Woollands and Wong, 2001).

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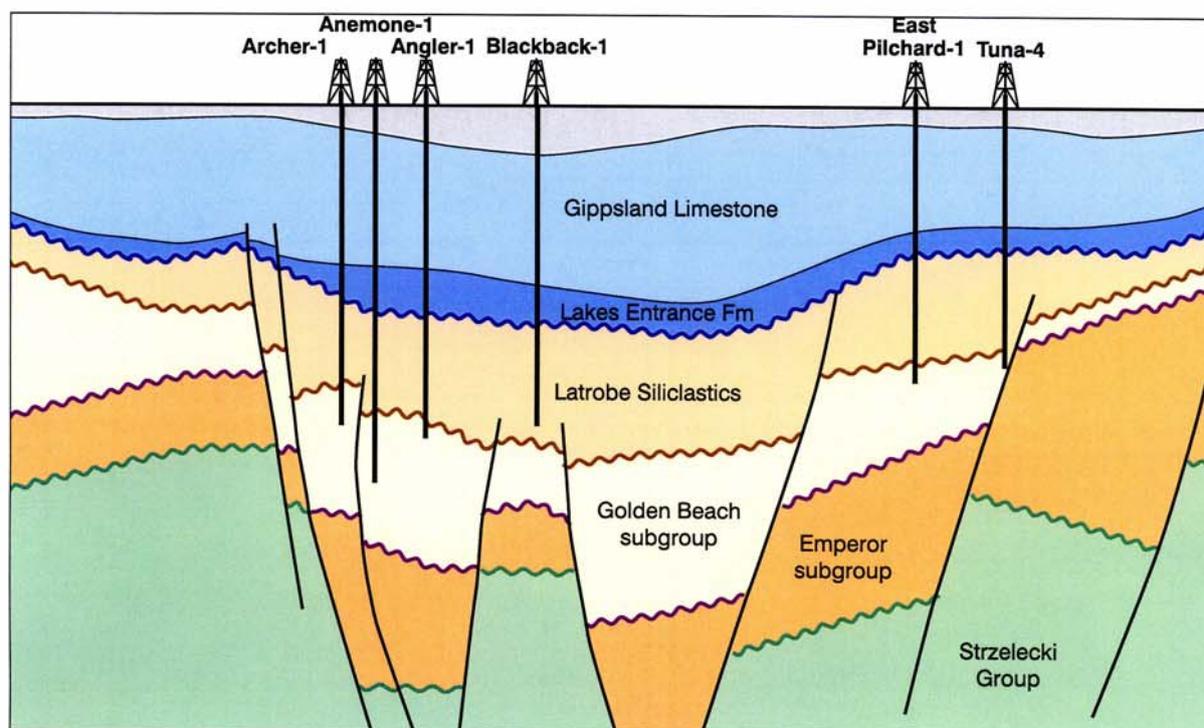


Figure 4. Cross-section of the Gippsland Basin (after Woollands and Wong, 2001).

The primary reservoirs for the basin are the Latrobe braided fluvial coarse clastics and the marine sandstones of the Golden Beach in the less explored eastern deepwater Gippsland Basin.

Taranaki Basin

Taranaki Basin is the only basin with commercially produced hydrocarbons in NZ. It has initial reserves estimated at around 500 mmbbl (10^6) of oil and condensate and 6.5 tcf (10^{12}) of gas (Crown Minerals, 2004).

The main Taranaki Basin covers the onshore Taranaki Peninsula and the adjacent shelf area extending north into the offshore Northland Basin and south into north-west Nelson (Fig. 7). The oldest sediments drilled to date are mid-Cretaceous (100my) (Fig. 5) and the sedimentary succession corresponds to a 100-million-year, first-order transgressive/regressive cycle that comprises a Cretaceous to Eocene transgressive systems tract, an Oligocene condensed section and a Neogene regressive and high-stand systems tract. Like most basins of NZ it has a composite structure resulting from multiple tectonic and sedimentary phases. Basin evolution can generally be divided (from oldest to youngest) into rifted margin, passive margin, and convergent margin episodes that reflect the broad plate tectonic development of the NZ subcontinent (Fig. 5).

Sources for NZ hydrocarbons are principally lower coastal plain to marginal marine coaly sediments. Geochemical analyses of oils and source rocks show that most of the oils

are derived from Cretaceous-Paleogene coaly source rocks and where they are higher in maturity they generate gas by secondary cracking of oils (King and Thrasher, 1996). The oil generative capability is enhanced by the presence of marine sulphur. Most of the hydrocarbons found to date are in fluvial and marine sandstone and subsidiary carbonate reservoirs of Eocene to Miocene age. Understanding paleoenvironmental distribution is therefore critical for efficient exploration. Moreover, there is also increasing evidence to suggest the presence of Mesozoic (Cretaceous and Jurassic) petroleum systems away from the traditional basins, and this is where the linkages to Australia and the Gippsland region are important.

Deepwater Taranaki Basin

To the west of the Taranaki Basin, a deepwater region extends from the shelf edge at about 200 m water depth into the head of the New Caledonia Basin at approximately 1,800 m (Fig. 7). It has not previously been explored for any significant distance beyond the shelf edge.

In 1997 a deepwater research seismic line was shot over the region and identified thick Cretaceous sediments (Fig. 8). This led to the subsequent *Astrolabe* seismic survey that was tied to eight wells on the shelf and to the deepwater Wakanui-1 well in the adjacent Northland Basin (Baillie and Uruski, 2004). The survey indicated more than 10,000 m of sedimentary section in the deeper water off the shelf and revealed a new play unknown from the Taranaki Basin. A

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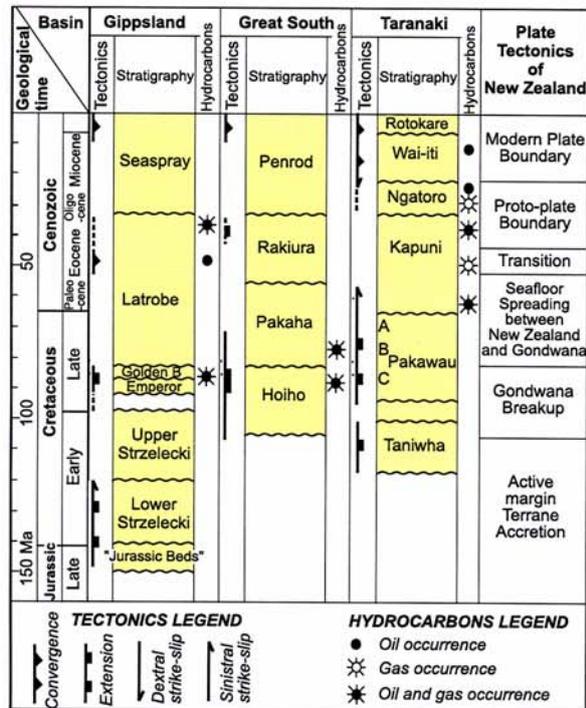


Figure 5. Stratigraphy of the Gippsland, Taranaki and Great South basins (after Baillie and Uruski, 2004).

mainly Late Cretaceous delta has been mapped, prograding into the head of the New Caledonia Basin (Fig. 6). The delta, in common with many deltas around the world, is believed to contain large volumes of petroleum source rocks, culminating with deposition of coal measures equivalent to the Rakopi Formation, Pakawau Group (Late Cretaceous) (A, B, C, Fig. 5). These sediments are possible correlatives of the Golden Beach and Emperor subgroups of Gippsland Basin.

A working petroleum system of the same age has been demonstrated in the Great South Basin, which was probably near the Taranaki Basin when the delta was being built (Figs 2 and 6). Relative ages and character of the sedimentary fill, together with considerations of basin and reflector geometry, allow comparisons to be made with the productive Gippsland Basin of southeast Australia (Cook et al, 1999).

To the north of the Taranaki Basin, the Northland Basin was drilled for the first time in the last decade and the Wakanui-1 well also extended the petroleum systems of NZ. Here again the correlation to Gippsland is important in that the well intersected Jurassic sediments with potential source rock coal present. The Jurassic age and lithology of these sediments correlates well with the Strzelecki group of Gippsland (Baillie and Uruski, 2004).

THE REGIONAL PALEONTOLOGICAL STRENGTHS WE CAN BUILD ON

The comparison of the paleontology of the Gippsland Basin with the Taranaki Basin/NZ area requires not just a comparison of the two zonal schemes (Fig. 9) of the region,

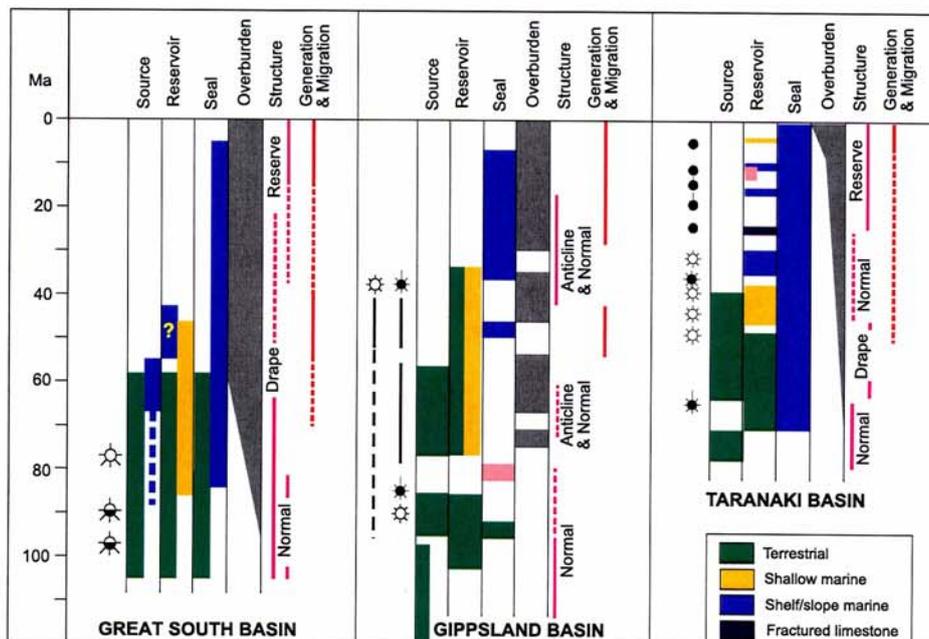


Figure 6. Petroleum systems of the Taranaki, Great South and Gippsland basins (after Cook et al, 1999; King and Thrasher, 1996; Woollands and Wong, 2001).

but also the comparison of the actual specimens and species present. GNS Science has borrowed the palynology slides and samples from some of the wells in the Gippsland basin and completed a NZ-type study of the foraminifera and dinoflagellates. Because the two regions have differing dominant facies, the initial foraminifera study was carried out using a transect of six wells from Tuna-4 to the Anemone-1/1A and Archer-1 region (Fig. 3). The dinoflagellate study consisted of a single well study on one of the more marine-influenced wells, Anemone-1/1A. While the detailed outcomes of these studies are reported elsewhere (Strong, 2004; Wilson, 2005) we have found the microfossil systematics to be very comparable and useful across the two regions. This allows the NZ timescale (Cooper, 2004) to be easily applied to Gippsland wells.

Foraminifera study

This study was undertaken to assess the extent to which NZ foraminiferal biostratigraphy could be applied in a trans-Tasman setting. Six wells, providing a paleo-onshore to offshore transect, were used for the study of a part of their Cretaceous sequence. The wells chosen were Anemone-1/1A, Angler-1, Archer-1, Blackback-1, East Pilchard-1 and Tuna-4 (Fig. 3). The study concentrated on the Cretaceous sequences as a zone of potential interest for future exploration. (Strong, 2004).

The main finding of this study is that foraminifera are of very limited biostratigraphic, but some paleoenvironmental, utility, being poorly represented in the three southernmost of the chosen wells and absent in the northern three wells (Fig. 3). Their value would potentially increase for drilling in more marine-influenced settings farther south. Foraminifera were generally sparse in 16 of the 65 samples examined, with all productive samples coming from marine shales/siltstones in the southernmost wells, Anemone-1/1A, Angler-1, and Archer-1. Only one significant calcareous fauna was recovered, with other assemblages consisting mainly or wholly of agglutinated taxa.

Calcareous foraminifera, which tend to have more biostratigraphic utility in NZ, had significant representation in only one sample, from Anemone-1/1A, and rare occurrences in a couple of others. It is considered that their general absence is due to unfavourable paleoenvironments, rather than to post-depositional dissolution. Calcareous faunas could become more prominent paleoseaward of Anemone-1/1A.

Foraminiferal biostratigraphy potentially could provide worthwhile results if drilling continued to move offshore, southward of Anemone, Angler, and Archer. Presumably, continuously fossiliferous section would grow with increasingly fine terrigenous sediment, and biostratigraphically significant taxa, commonly shelf or slope-dwellers, would become more common and persistent. Furthermore, Cenozoic foraminifera are present as sloughed material in at least some of the studied wells. Although these were outside the scope of the present

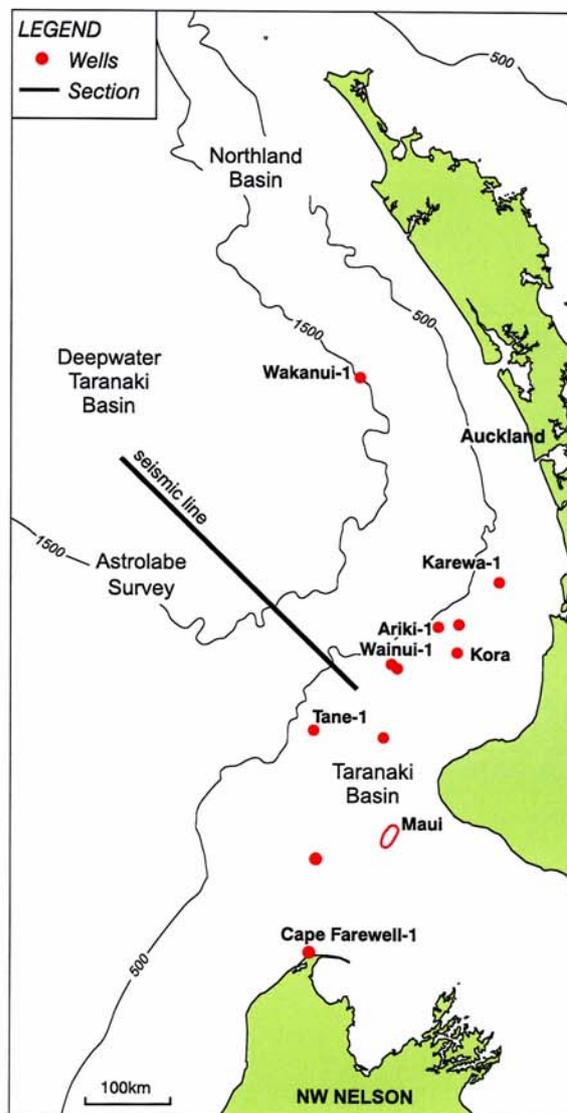


Figure 7. Regional map of greater Taranaki Basin showing location of the *Astrolabe* line (Fig. 8) (after Baillie and Uruski, 2004).

work, and were only noted in passing, they might also have applications in some future wells.

Dinoflagellate study

The dinoflagellate study of Anemone-1/1A indicates that the Upper Cretaceous is mainly a marine section and has a thickness of over 2,000 m, from c.2,762 m to TD at 4,775 m. It ranges from the *Manumiella druggii* Zone (uppermost Haumurian) to the *Odontochitina porifera* Zone (Piripauan), in terms of the NZ stage and dinoflagellate zonal schemes (Fig. 10). This represents a latest

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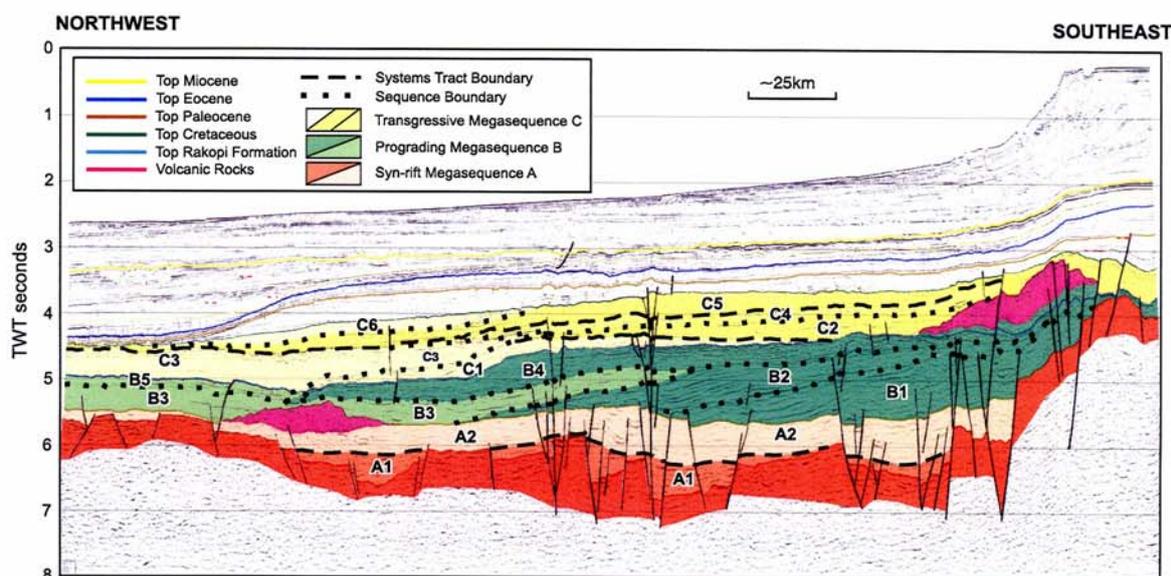


Figure 8. Regional seismic line from the *Astrolabe* survey, along the axis of the basin showing the deepwater Taranaki Cretaceous deltaic sequence (after Baillie and Uruski, 2004).

Maastrichtian to Santonian interval (Cooper, 2004) (Fig. 9) and demonstrates that the NZ stages and dinoflagellate zones, all based on well-dated NZ surface outcrops, can be applied to the subsurface Gippsland Basin sequences (Wilson 2005).

Unlike most other wells in the Gippsland Basin, particularly in the northern part, open marine or marginal marine deposition appears to have been predominant in Anemone-1/1A, apart from the obvious substantial non-marine interval between 2,850 m and 3,400 m (Fig. 10). This compares directly to the depositional environment for the well as provided by Woollands and Wong (2001).

A close correlation with the NZ dinoflagellate zonal scheme has been achieved, however a major correlation gap is present in the Late Haumurian (Maastrichtian equivalent (Fig. 9), where there was no indication of the *Alterbidinium acutulium* Zone. It seems most likely that this period of time is represented in the Gippsland Basin by the substantial non-marine interval discussed above, which has been correlated with the greater part of the *Tricolpites lillieii* and *Forcipites longus* spore/pollen zones.

Relatively few NZ oil exploration wells in the Taranaki Basin have a significantly thick marine Upper Cretaceous section comparable with Anemone-1/1A. The most complete section appear to be in wells near the present shelf edge such as Ariki-1, Tane-1 and Wainui-1, (Fig. 7) where the *M. druggii* to at least the *I. pellucidum* Zones (including *A. acutulium*) are represented and the thickness of the Upper Cretaceous (Mata Series) is up to 500 m (Beggs et al, 1992). An apparently more complete marine Cretaceous/Paleogene transition interval, including the basal Paleocene *Trithyrodinium evittii* Zone, is present in the NZ wells, when compared with Anemone-1/1A (Beggs

et al, 1992; Wilson, 2005).

Outcrops of the North Cape Formation, the upper part of the Pakawau Group, located in southernmost Taranaki and northwest Nelson (Figs 5 and 7) have yielded dinoflagellates that are indicative of the *M. druggii* and *A. acutulium* Zones (Wizevich et al, 1992), and confirm a marine depositional environment for at least part of the formation in this area.

The next phase of the research is to make a similar spore and pollen study of a well and then to attempt a three well CONOP study if sufficient well data is available.

RETURNS TO INDUSTRY

The biostratigraphic comparison between Gippsland and Taranaki has shown that there are geological and biostratigraphic similarities on both sides of the Tasman Sea for explorers in the Gippsland and Taranaki basins. The NZ, outcrop-based, geological timescale can be applied to Gippsland wells and, hence, explorers can consider using the techniques and services from either country to build the best understanding of sedimentary successions in both basins. The next stage is to test the same applicability to the non-marine successions using pollen and spores assemblages.

Another key issue for the long-term strategy of the industry is to continue the renaissance of paleontology by exposing the younger staff and potential graduates to values of paleontology in exploration. It is vital that the applications of detailed taxonomy/systematics are understood so that all fossil species can be used with confidence in exploration. Increasing the significance and understanding of paleontology could be promoted by secondments of paleontologists into exploration

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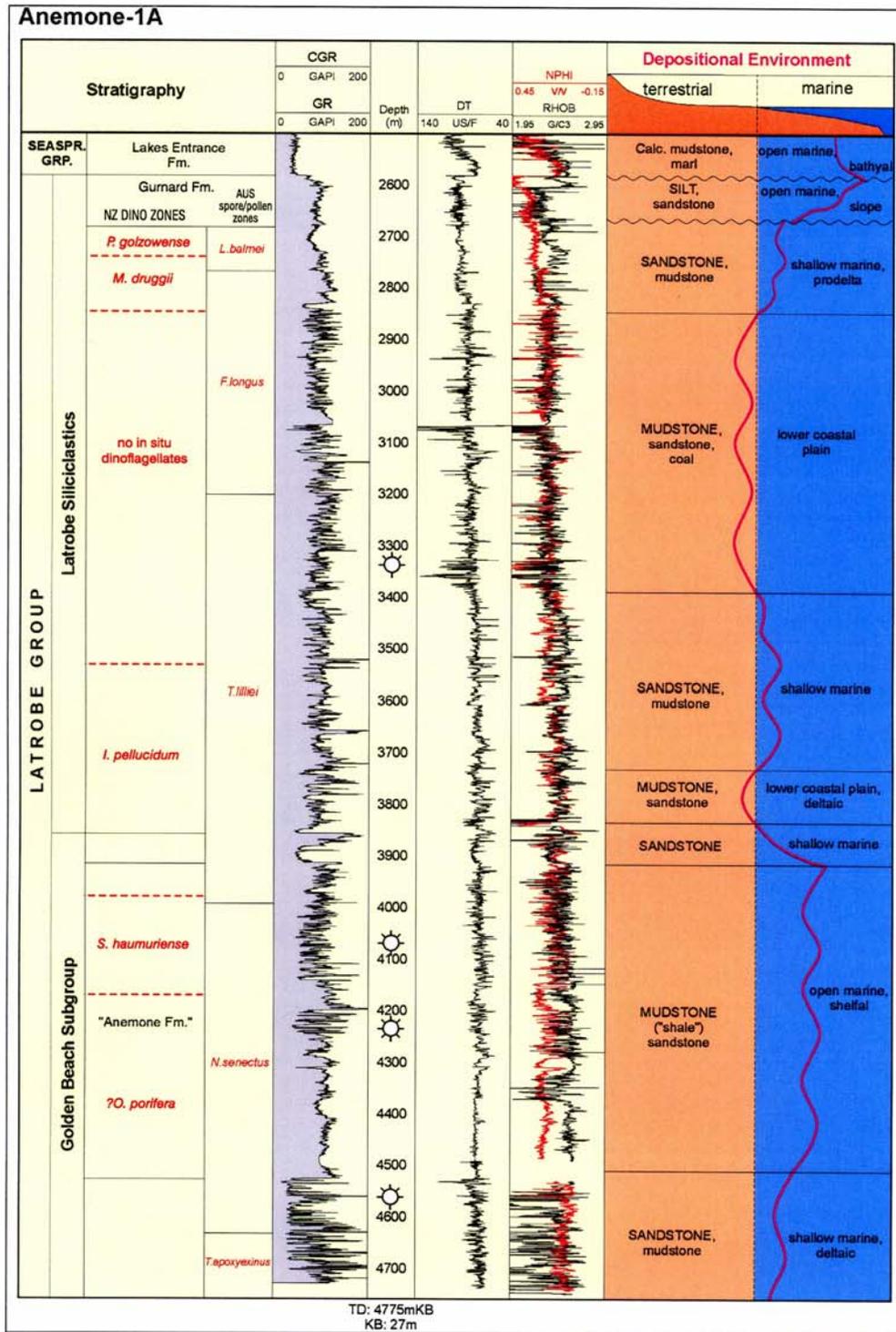


Figure 10. Anemone-1/1A composite well sheet (after Wollands and Wong, 2001) with NZ dinoflagellate zones added (Cooper, 2004; Wilson, 2005)

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teams and supporting multi-disciplinary paleontology groups in universities and research organisations so that they, in turn, understand the needs of the petroleum industry.

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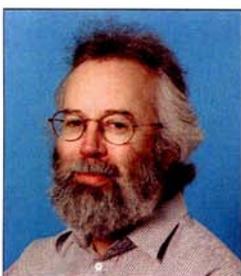


THE AUTHORS



Richard Cook is a Section Manager at GNS Science in Wellington. He began his career with Texaco Inc, working in the North Sea and internationally from Houston before returning to New Zealand to join the NZ Geological Survey in 1978. He completed his PhD at Victoria University of Wellington in 1987. Since then he has had several management roles

and has continued as a scientist, publishing numerous papers on basin studies, oil seeps, petroleum geochemistry, and resource evaluation in the New Zealand region.



Ian Raine is a Senior Scientist at GNS Science. Following a PhD in Quaternary vegetation history at Australian National University, in 1974 he moved to New Zealand where he has developed miospore zonation for Triassic to Paleogene strata and provided biostratigraphic services for regional geological mapping, sedimentary basin studies, and

petroleum and coalfield exploration. Projects now include taxonomic and biostratigraphic study of New Zealand Jurassic and Cretaceous palynomorphs, vegetation and climate change at the Cretaceous-Tertiary and Paleocene-Eocene boundaries, biogeography of Cenozoic Antarctic and southern high latitude floras, and management of the NZ Fossil Record File and Stratigraphic Lexicon databases.



Erica Crouch is a palynologist in the Geological Time Section at GNS Science, and specialises in the analysis of marine plankton (dinoflagellate cysts) and spores and pollen from land plants. Her research primarily focusses on the Paleogene (65–25 Ma), along with Late Cretaceous (80–65 Ma) and Quaternary (last two million years) intervals. Erica has

10 years experience as a palynologist. She completed her PhD from Utrecht University, The Netherlands, in 2001.



Percy Strong is a micropaleontologist and Senior Scientist at GNS Science. He received his BSc degree from the College of Wooster (Ohio) in 1964, and his PhD from University of Washington, Seattle, in 1969. From 1969 to 1975 he was Assistant Professor of Geology at Mt. Union College (Alliance, Ohio). In 1975, he joined the NZGS as

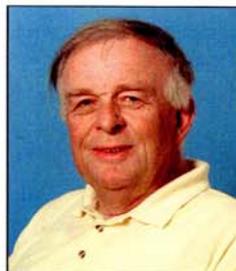
a micropaleontologist, and has continued in this position during the organisation's evolution into GNS Science. His main research interests are Late Cretaceous and early Paleogene foraminiferal biostratigraphy/paleoenvironments, Antarctic Cenozoic foraminifera and foraminiferal events at the Cretaceous-Tertiary boundary.

Initial review of the biostratigraphy and petroleum systems around the Tasman Sea hydrocarbon-producing basins



Chris Uruski is a petroleum geoscientist at GNS Science in New Zealand where he has worked since 1987. His main area of expertise is seismic interpretation and he is a co-author of two major GNS regional basin studies publications; the Western Southland and the East Coast monographs. He holds a BSc in geology from the

University College of Wales, Aberystwyth and has worked at Aberystwyth and Durham Universities and for ECL in various parts of the world before arriving in New Zealand. He was the lead author of major reports on the deepwater Taranaki and Northland basins. As well as conducting government-funded research, he has worked on contract for many, if not most of the exploration companies in New Zealand and he believes that our deepwater sedimentary basins contain large volumes of oil and gas.



Graeme Wilson is a research palynologist with GNS Science, specialising in dinoflagellate biostratigraphy and taxonomy. He has an MSc from Victoria University of Wellington and a PhD from Nottingham University; he began his career with the NZGS in 1964. During the past 40 years he has published over 200 scientific papers, as well as providing

biostratigraphic analyses for over 100 petroleum exploration wells, including projects in New Zealand, Antarctica, the South Pacific, Asia, northwest Europe and South America.