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Lower Oligocene Foraminiferal Fauna from CRP-3 Drillhole, Victoria Land Basin, Antarctica

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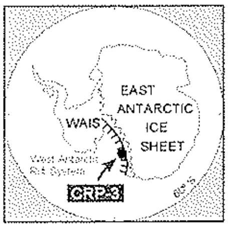

Abstract - A foraminiferal fauna comprising *c.* 33 genera and *c.* 53 species was recovered from a suite of 156 Lower Oligocene sediment samples, mostly muddy sandstone and siltstone, selected over the 2.80 - 823.11 mbsf depth range in the CRP-3 drillhole. All foraminifers, except for 2 isolated specimens, occurred above 340 mbsf, with 54 of 103 samples from above this depth being fossiliferous. At a generic and even a specific level, the fauna contains many components for the present-day Antarctic foraminiferal biota, indicating that its origin is at least as old as Early Oligocene.

Foraminiferal assemblages represent a single biofacies which is characterised by low diversity, and by dominant and persistent occurrences of *Cassidulinoides chapmani*, other *Cassidulinoides* and *Globocassidulina* species, and *Stainforthia* sp. These taxa are commonly accompanied by *Cibicides lobatulus*, *Epistominella exigua*, *Fissurina* spp., *Nonionella* spp. and *Oolina* spp. Large miliolids occur as isolated specimens at various levels. Planktic species are absent, and agglutinated taxa occur only rarely and sporadically. Preservation generally is fair to good, while absolute abundance is very low, with a maximum of *c.* 6 specimens/gram, and most samples containing <1 specimen/gram. These assemblages probably represent mid to outer shelf depths (50-200 m) in glacially influenced environments with a high sedimentation rate and poor oceanic connections.

Although the CRP-3 fauna closely resembles the one from Foraminiferal Unit III as defined in CRP-2/2A (CRP-2/2A Science Team, 1999; Strong & Webb, 2000), absence of some species, and the first records of others in the uppermost CRP-3 section, is consistent with an interpretation of minimal overlap between the CRP-2/2A and CRP-3 sediments. The fauna also appears correlative with the *Globocassidulina-Cassidulinoides-Trochoelphidiella* Assemblage Zone from lower DSDP-270, and with faunas from the lower, but not lowermost, section at CIROS-1.

INTRODUCTION

CRP-3, the third and final drillhole of the Cape Roberts Project, was drilled to a total depth of 939.42 mbsf (metres below sea floor) during October and November, 1999, achieving the deepest Antarctic bedrock penetration to date. This report documents the foraminiferal fauna from the drillhole, and provides palaeontological notes on its characteristic members. In CRP-3, the cored section from 2.80 mbsf (first core returns) to 823.11 mbsf consists of Early Oligocene to Late, or late Middle, Eocene diamictite, sandstone and muddy sandstone, sandy or muddy siltstone and conglomerate/breccia. These sediments rest unconformably on red-brown quartzose sandstone (Arena Sandstone) of the Beacon Supergroup, which constitutes the remainder of the lithological section (CRP-3 Science Team, 2000). No post-Oligocene sediments were recovered, and while palynological evidence suggests a Late, or Late Middle, Eocene age for the lowermost Palaeogene section, no foraminifers were recovered from pre-Oligocene strata.

Foraminifers discussed here come from a suite of 156 samples, selected over the interval from 3.12 to 823.11 mbsf. These include 30 "fast-track", 100 routine, and 20 macrofossil matrix samples (See Tabs. 1 & 2), together with 6 *in situ* observations of large miliolid specimens. The samples were selected, processed and initially examined at Crary Science and Engineering Center (CSEC), McMurdo Station. Foraminifers, represented by *c.* 33 genera and *c.* 53 species, were recorded from 56 samples. They occur with reasonable consistency only above *c.* 340 mbsf, and are recorded in 54 of the 103 samples above this level. The two other fossiliferous samples, from 705.97 mbsf and 763.40 mbsf, yielded only poorly preserved single specimens, identified respectively as *Globigerina* sp. indet. and *Cibicides?* sp. (Cape Roberts Science Team 2000). Due to their poor preservation, their occurrence is simply noted in this report. Samples are referred to the lithostratigraphical

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Tab 1 - Distribution and numerical abundance of foraminifers in CRP-3, and occurrence of other fossils. Only selected samples below 340 mbsf are shown; see table 2 for complete listing.

CRP-3 FORAM OCCURRENCES																																											
UNIT	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.3	1.3	1.3	1.3	1.3	1.3	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	2.1	2.1	2.2	2.2
TOP	3.12	6.70	6.80	10.65	10.88	13.54	15.53	17.72	18.97	22.23	23.34	25.92	27.88	27.92	33.06	35.53	38.45	38.46	41.01	41.01	41.86	44.12	44.18	45.72	49.14	54.42	55.86	59.59	60.56	62.95	65.91	70.87	73.73	76.57	78.27	80.49	81.58	82.29	82.89	87.15	88.29	101.53	106.08
BASE	3.20	6.78	6.88	10.73	10.99	13.62	15.61	17.80	19.05	22.33	23.42	26.00	27.96	27.95	33.14	35.61	-	38.53	41.02	41.09	-	44.18	44.27	45.80	49.22	54.43	55.94	59.60	60.64	63.09	65.99	70.95	73.81	76.65	78.34	80.57	81.66	82.39	82.95	87.23	88.30	101.59	106.16
No. species			5	5	2		3	1	1	2	1		0	1	3	1	1	2	1		1	5	6	6	9	1	1	1	1	2									1	8	1		26
No. specimens	NF	NF	13	9	2	NF	6	1	1	ND	1	NF	NF	1	3	1	1	3	2	4	1	7	20	14	29	1	1	1	1	2	NF	NF	NF	NF	NF	NF	NF	NF	1	16	1	NF	367
Preservation			F	G	G		G	F	F	G	G			P	G	G		F	P	G		F	F	G	P	F	G	P	G	G									G	G	F		F
Anomalina spp.																																											
Anomalinoides cf. *eoglabra*							2								1	1							6																				
Anomalinoides fasciatus																																											1
Anomalinoides globulosus																																											3
Anomalinoides miosuturalis			1																																								
Anomalinoides spp.																																											1
Astacolus spp.																																											1
Astrononion sp.																																								1			
Baggina cf. *brevior*																																											5
Bulimina sp.																							1																				
Cassidulinoides bradyi					1		1															2			7															2			28
Cassidulinoides braziliensis										?								1					4	2			1		1														12
Cassidulinoides chapmani			4	1			2																3	2	11					1										5			43
Cribroelphidium sp.																						1		2																			
Cibicides lobatulus																																											8
Cibicides cf. *temporatus*																																											
Cibicides spp.																																											
Cyclammina incisa																																											
Dentalina sp.																																											
Discorbis sp.			3	2	1																																						4
Epistominella exigua																								1																			9
Eponides bradyi																				1				2																			
Fissurina fimbriata																				1																							
Fissurina marginata																																											3
Fissurina spp.																																											5
Gavelinella spp.								1														1	1	2	1					1													
Globigerina sp. indet.																																											
Globocassidulina crassa																								3															1	4			2
Globocassidulina subglobosa				3											1			2							3																		7
Gyroidina orbicularis																																											1
Haplophragmoides spp.																																											
Hanzawaia sp.			2																																								11
Karreriulina sp.																				?1																							
Lenticulina spp.																									1																		
Melonis barleeanum																																											1
Melonis graniferum																																								1			
Melonis spp.																																											
Miliolidae (*in situ record*)																	?		X		X																				1		
Miliolidae, large									1					1					1							1		1															
Nodosaria spp.											1?																																
Nonionella bradii																									1																		
Nonionella iridea																									2															3			69
Nonionella magnalingua																									1																		10
Nonionella spp.																																											12
Oolina apiculata																									2																		3
Oolina aptopleura				2																																							6
Oolina globosa																																											9
Parafissurina lateralis.																																											2
Planularia sp.																																											2
Pullenia subcarinata																																											
Quniqueloculina spp.																																											
Reophax sp.																																											
Stainforthia sp.			3	1			1			?					1					2		2	5																				109
Textularia sp.																						1																					
Diatoms											X																																
Echinoderm spines/plates			X																			X															?						
Faecal pellets											X																																
Fish teeth, bones, etc.																																											
Indeterminate forams	X										X																																
Mollusc fragments			X								X		X							X		X																					
Ostracods																									X																		
Recycled Forams										X													1																				
Spicules																									X																		
Foraminifera *per* gram	0	0	0.26	2.72	0.24	0	0.12	0	0	0	0	0	0	0	1.28	0	0	0	0	0.12	0	2.16	0.29	3.52	1.13	0	0.03	0	0.24	0.06	0	0	0	0	0	0	0	0	0.02	0.27	0	0	6.22

Tab 1 - Continued.

CRP-3 FORAM OCCURRENCES																																						
UNIT	2.2	2.2	2.2	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	4.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.3	6.1	6.1	6.1	6.1	6.1	6.1	7.1	7.2	7.2	7.2	7.2	7.2
TOP	107.36	114.23	119.61	120.34	121.40	121.41	123.20	123.65	125.26	126.48	126.66	130.23	131.21	135.85	140.79	141.62	142.37	145.82	157.76	160.37	162.16	162.66	165.25	166.38	168.31	181.09	187.39	190.77	195.59	197.32	197.33	199.33	209.98	214.39	225.13	229.38	232.49	240.75
BASE	107.47	114.31	119.70	120.37	121.41	121.47	123.28	123.73	125.28	126.51	126.69	130.31	131.25	135.92	140.81	141.70	142.42	145.90	157.83	160.45	162.24	162.72	165.29	166.40	168.39	181.17	187.47	190.87	195.67	197.33	197.41	199.35	210.08	214.47	225.21	229.45	232.57	240.81
No. species	2	24	7	1	1	5			1	1	1	9	1	1	1				5	8	6	7	1	1	6	1				1	1	1						
No. specimens	2	236	14	1	1	7	NF	NF	1	2	1	18	1	1	1	NF	NF	NF	16	29	12	21	1	1	7	1	NF	NF	NF	1	1	1	NF	NF	NF	NF	NF	NF
Preservation	P	F	F	P	P	F			F	P	P	F	G	P	P				G	G	F	G	P	P	G	P				P	F	P						
Anomalina spp.		3																																				
Anomalinoides cf. *eoglabra*																																						
Anomalinoides fasciatus																																						
Anomalinoides globulosus																																						
Anomalinoides miosuturalis																																						
Anomalinoides spp.		2																																				
Astacolus spp.		2																																				
Astrononion sp.																																						
Buggina cf. *brevior*																																						
Bulimina sp.																																						
Cassidulinoides bradyi		19										3							3	4	3	1			1													
Cassidulinoides braziliensis		9																	2	7		11																
Cassidulinoides chapmani		14										7							7	6	2	2			2													
Cribroelphidium sp.																																						
Cibicides lobatulus		5	2																				1															
Cibicides cf. *temporatus*																															1							
Cibicides spp.		4																				1																
Cyclammina incisa													1																									
Dentalina sp.												1								1																		
Discorbis sp.			2			2						1								2					1													
Epistominella exigua	1	5																																				
Eponides bradyi																																						
Fissurina fimbriata																																						
Fissurina marginata		10																																				
Fissurina spp.		10																																				
Gavelinella spp.	1																			2																		
Globigerina sp. indet.																																						
Globocassidulina crassa		8	4			2															1																	
Globocassidulina subglobosa		11										2								3	1				1													
Gyroidina orbicularis																																						
Haplophragmoides spp.																																						
Hanzawaia sp.			1			1																3																
Karreriulina sp.																																						
Lenticulina spp.		1																																				
Melonis barleeanum																																						
Melonis graniferum																																						
Melonis spp.						1																																
Miliolidae (*in situ record*)					1																			1														
Miliolidae, large		1	1	1					1	2	1			1											1					1		1						
Nodosaria spp.																			1																			
Nonionella bradii		4																																				
Nonionella iridea		20										1										1																
Nonionella magnalingua		3																																				
Nonionella spp.		20																		1																		
Oolina apiculata												1																										
Oolina apiopleura		5																			1																	
Oolina globosa																																						
Parafissurina lateralis.		2																																				
Planularia sp.																																						
Pullenia subcarinata		2																																				
Quinqueloculina spp.		14																				1																
Reophax sp.			3			1																																
Stainforthia sp.		65	1									2							3	3	3	1			1													
Textularia sp.																					1																	
Diatoms																																						
Echinoderm spines/plates		X				X						X							X																			
Faecal pellets																																						
Fish teeth, bones, etc.																																						
Indeterminate forams																																						
Mollusc fragments		X	X													X			X	X	X							X			X							
Ostracods		X				X						X								X																		
Recycled Forams																																						
Spicules																																						
Foraminifera per gram	0.12	4.7	2.08	0	0	1.52	0	0	0	0	0	0.35	0	0	0	0	0	0	0.38	0.78	3.12	0.50	0	0	0.19	0	0	0	0	0	0.02	0	0	0	0	0	0	0

Tab 1 - Continued.

CRP-3 FORAM OCCURRENCES																																		
UNIT	7.2	7.2	7.2	7.3	7.3	7.4	7.4	7.4	7.4	8.1	8.1	8.1	8.1	8.1	8.1	8.1	8.1	8.1	9.1	9.1	9.1	9.1	9.1	9.1	10.1	12.1	12.3	12.5	13.1	13.1	13.1	13.1	13.2	17.1
TOP	242.39	257.10	264.34	267.48	268.73	275.42	278.50	285.84	288.60	310.63	311.14	312.96	314.59	315.57	319.95	321.51	321.92	324.72	325.00	330.54	332.00	338.46	342.58	345.54	406.36	457.42	500.28	564.45	621.80	690.62	705.97	747.33	788.65	903.35
BASE	242.47	257.25	264.42	267.56	268.81	275.5	278.60	285.92	288.68	310.71	311.24	313.04	314.67	315.61	319.96	321.52	322.00	324.78	325.08	330.62	332.10	338.54	342.66	345.62	406.44	457.57	500.39	564.60	621.95	690.70	706.05	747.41	788.69	903.35
No. species		3	1	1							1		1	1	1	1	9		1			3												
No. specimens	NF	6	1	1	NF	NF	NF	NF	NF	NF	1	NF	1	1	1	1	33	NF	1	NF		4	NF	NF	NF	NF	NF	NF	NF	NF		NF	NF	NF
Preservation		F	F	P							F		F	P	P	P	G		G			F									P			
Anomalina spp.																																		
Anomalinoides cf. *eoglabra*																																		
Anomalinoides fasciatus																																		
Anomalinoides globulosus																																		
Anomalinoides miosuturalis																																		
Anomalinoides spp.																	1																	
Astacolus spp.																																		
Astrononion sp.																																		
Baggina cf. *brevior*																																		
Bulimina sp.																																		
Cassidulinoides bradyi													1				8																	
Cassidulinoides braziliensis																	6																	
Cassidulinoides chapmani																	3					1												
Cribroelphidium sp.																						1												
Cibicides lobatulus		1																																
Cibicides cf. *temporatus*																																		
Cibicides spp.																																		
Cyclammina incisa																																		
Dentalina sp.																																		
Discorbis sp.		4															1																	
Epistominella exigua																																		
Eponides bradyi																																		
Fissurina fimbriata																	1																	
Fissurina marginata																																		
Fissurina spp.																																		
Gavelinella spp.																																		
Globigerina sp. indet.																															X			
Globocassidulina crassa											1											2												
Globocassidulina subglobosa																	3																	
Gyroidina orbicularis																																		
Haplophragmoides spp.			1																															
Hanzawaia sp.																																		
Karrerulina sp.																																		
Lenticulina spp.																																		
Melonis barleeanum																																		
Melonis graniferum																																		
Melonis spp.																																		
Miliolidae (*in situ record*)																																		
Miliolidae, large				1										1	1	1																		
Nodosaria spp.																	1																	
Nonionella bradii																	1																	
Nonionella iridea																																		
Nonionella magnalingua																																		
Nonionella spp.																																		
Oolina apiculata																	1																	
Oolina apiopleura																	1																	
Oolina globosa																	1		1															
Parafissurina lateralis.																																		
Planularia sp.																																		
Pullenia subcarinata																																		
Quniqueloculina spp.																																		
Reophax sp.																																		
Stainforthia sp.		1															5																	
Textularia sp.																																		
Diatoms																																		
Echinoderm spines/plates																																		
Faecal pellets																									X									
Fish teeth, bones, etc.																																		
Indeterminate forams																		X																
Mollusc fragments		X	X		X	X				X			X					X																
Ostracods																																		
Recycled Forams																																		
Spicules																		7																
Foraminifera *per* gram	0	0.12	0.32	0.02	0	0	0	0	0	0	0.23	0	0.32	0	0	0	0.48	0	0.32	0	0	0.08	0	0	0	0	0	0	0	0	0	0	0	0

Tab 2 - Sample levels from 340 mbsf to bottom of hole in CRP-3. Grey shading indicates fast track samples.

UNIT	TOP	BASE
9.1	342.58	342.66
9.1	345.54	345.62
9.1	354.09	354.17
9.1	359.95	360.03
9.1	359.21	359.31
9.1	363.13	363.21
9.1	363.86	363.91
9.1	388.37	388.45
10.1	406.36	406.44
10.1	408.63	408.73
10.1	410.38	410.46
12.1	457.42	457.57
12.2	459.21	459.29
12.2	462.05	462.13
12.3	500.28	500.39
12.5	564.45	564.60
12.6	584.49	584.60
13.1	621.80	621.95
13.1	632.63	32.71
13.1	636.15	636.24
13.1	638.30	638.30
13.1	640.74	640.86
13.1	656.59	656.75
13.1	662.12	662.20
13.1	664.31	664.39
13.1	670.59	670.67
13.1	690.62	690.70
13.1	697.38	697.48
13.1	701.40	701.48
13.1	705.97	706.05
13.1	709.11	709.19
13.1	710.73	710.81
13.1	712.72	712.80
13.1	716.30	716.38
13.1	722.58	722.66
13.1	725.70	725.78
13.1	726.00	726.08
13.1	727.37	727.45
	731.33	731.48
13.1	739.89	739.97
13.1	747.33	747.41
	751.38	751.48
13.1	756.70	756.81
13.1	763.40	763.48
13.1	765.40	765.48
13.1	766.69	766.73
13.2	776.70	776.75
13.2	781.12	781.20
13.2	781.29	781.34
13.2	781.41	781.48
13.2	781.52	781.57
13.2	788.65	788.69
	903.35	903.45

sub-units (LSU) adopted for classification of the CRP-3 rock succession (CRP-3 Science Team, 2000).

MATERIAL AND METHODS

Fine-grained sediments, mainly sandy or silty mudstone, considered the most likely to contain foraminifers, were preferentially sampled, with coarser sediments being taken only where mudstone was unavailable. The samples, most weighing 50-110 g (undried) and representing *c.* 5 cm of quarter-core, were processed using standard techniques, and wet-sieved into >1 mm, >500 µm, >125 µm, and >63 µm fractions. Residues were dried, weighed and examined for microfossils, and absolute abundance (specimens *per* gram of original sediment) determined for the fossiliferous samples. The <63 µm fraction from fast track samples, but not from routine samples, was also retained for study by other investigators. We recorded all fossil material observed, including sponge spicules, diatoms, and shell fragments, but refer here (See Tab. 1) to samples lacking foraminifers as "non-fossiliferous (NF)".

Systematic examination focussed on the >125 <500 µm residue fraction, where most foraminifera were found to occur. All observed specimens were removed to an assemblage slide for identification and counting for absolute abundance calculations. Residue volume, and the amount examined, vary from sample to sample. Some residues were picked entirely, but most were subdivided with a microsplitter, and usually about 1/8 to 1/16 of the available >125 <500 µm material was examined. Typically all of the >500 µm residue and a small amount of >63 µm residue (*c.* 5-minute scan) were also checked for large or minute specimens and macrofossil debris. The minimum criterion for determining a sample to be non-fossiliferous is the absence of specimens in two well-covered picking trays (9 x 5 cm) of >125 <500 µm residue and also in the scans of the other size fractions.

Absolute abundance is taken here as the number of foraminifers *per* gram of original sediment contained in the >125 µm fraction of the residue. This determination is of first-order accuracy only, as it was necessary to weigh and process samples without drying them beforehand, due both to limited time and facilities at CSEC, and to the tendency of some lithologies to set hard upon drying (PNW observation). Drying tests on a few samples, however, indicate the typical weight loss is *c.* 15 +/-3%. To compensate for incomplete sample disaggregation, weight of all >500 µm residue, which comprises rock chips large enough to conceal a typical foraminifer, was subtracted from the initial weight to give a more realistic weight of disaggregated sample.

Dried residue fractions were weighed in their storage pillboxes, using an "average" pillbox as a tare. Pillbox weight variation of *c.* 2% (*c.* 0.15 g for the smallest size) is negligible relative to the weight of most residues, and contributes little to the overall error. Because of extremely low foraminiferal abundance, weighing errors equate, in practical terms, to a maximum of about 1 specimen per gram of sediment!

FORAMINIFERAL FAUNA

Foraminifers occur consistently only in the upper *c.* 340 m of the CRP-3 stratigraphical section, with 54 of 103 samples (52.4%) proving fossiliferous.

Calcareous benthic forms are strongly dominant, while agglutinated taxa occur only as rare specimens in a few samples. No planktics were recovered from the upper 340 m of the drillhole. Specimen preservation ranges from very good to poor, with most samples (72%) judged as fair to good (See Strong & Webb, 2000 for criteria). Poor preservation results mainly from recrystallisation to coarse calcite, and/or decortication due to leaching. The general state of preservation suggests that most assemblages have suffered little, if any, leaching or other diagenesis, and therefore accurately represent the original *in situ* fauna. In some cases, preservation varies within a single assemblage, perhaps indicating partial reworking, or short-range preservation differences over the *c.* 5 cm standard sample interval.

Only two of the 49 samples collected from the thick sequence of sandstone and conglomerate below 340 mbsf (LSU 9.1-13.2) proved fossiliferous. As noted above, a sample from 705.97 mbsf yielded a single *Globigerina* sp. indet., and one from 763.40 mbsf, a possible specimen of *Cibicides* sp. These occurrences support the inferred marine origin for these sandstones, as interpreted from sedimentological data, but provide little evidence about their age or the palaeoenvironment.

FAUNAL CHARACTERISTICS

Foraminiferal assemblage composition in CRP-3 is relatively constant over the entire fossiliferous interval and faunas obtained are virtually identical to those from Foraminiferal Unit III in CRP-2/2A (Cape Roberts Science Team, 1999; Strong & Webb, 2000). The consistent occurrences of dominant *Cassidulinoides chapmani,* and other species of *Cassidulinoides* and *Globocassidulina*, together with *Stainforthia* sp. are the most prominent feature of the fauna. Other common taxa, which appear in many assemblages, include *Cibicides lobatulus, Epistominella exigua, Nonionella* spp., *Oolina* spp. and *Fissurina* spp.

Many generic *(e.g., Cassidulinoides, Fissurina)* and even specific *(Cibicides lobatulus, Epistominella exigua)* elements of this assemblage are also common in late Neogene and modern Antarctic assemblages (*e.g.* Ward & Webb, 1986; Bernhard, 1987; Violanti, 1996), showing that Antarctic foraminiferal faunas had begun to assume their modern characteristics by Early Oligocene time.

Non-foraminiferal fossil material in the residues includes relatively common molluscan fragments, and less common ostracods and echinoderm fragments. Siliceous fossils were notably rare, with only single records of both diatoms and sponge spicules.

Foraminiferal absolute abundance (see Tab. 1 and Fig. 1) ranges from low to very low, compared with typical marine sediments (*e.g.,* Murray, 1973; Sen Gupta, 1999). Most samples contain <1 specimen *per* gram of sediment, only 8 contain more than 1 specimen *per* gram. Maximum observed abundance is 6.2 specimens *per* gram, in residue from 106.08 mbsf. Thirty-one of the 54 samples classified as fossiliferous yielded but a single foraminifer, and had calculated absolute abundances of *c.* 0.02 to 0.5 specimens *per* gram of sediment. The largest assemblage recovered, also from the exhaustively picked 106.08 mbsf residue, comprised 367 specimens.

There appears to be little relationship between quality of preservation and abundance, indicating that dilution by rapid sedimentation, rather than loss of foraminifers through diagenesis or dissolution, is the primary cause of low specimen numbers.

ABSOLUTE ABUNDANCE AND STRATIGRAPHICAL DISTRIBUTION

Figure 1 shows foraminiferal abundance, plotted against the lithostratigraphy and sequence stratigraphic interpretation for the drillhole (Cape Roberts Science Team, 2000). Although foraminifers were recovered down to sequence 16, assemblages are developed best in sequences 1-4. Because sampling concentrated on selected lithologies rather than on sampling at fixed intervals, these results could be somewhat biased and may not be truly representative. Nonetheless, there is good overall sample coverage in sequences 1-4, and abundance maxima appear to lie in the middle to upper parts of the sedimentary sequences, probably reflecting glacial waning (CRP Science Team, 2000), with reduced sediment flux or increased foraminiferal productivity due to less inhospitable bottom conditions, or both.

The maximum abundance "peak" observed in CRP-3, of 4 - 6 specimens *per* gram, spans the interval from *c.* 106 to 115 mbsf, in the lower part of LSU 2.2, and the upper part of Sequence 3. Lesser abundance peaks of *c.* 2 – 3 specimens *per* gram occur at 10.65 mbsf (LSU 1.1), 44.12 mbsf (LSU 1.2), 45.72 mbsf (LSU 1.2) and 162.16 mbsf (LSU 5.1). Lithology in all cases consists of muddy sandstone or siltstone with dispersed clasts.

Species richness is generally low, with 6 or 7 taxa being typical for assemblages of *c.* 20 - 50 specimens. We observed that, beyond this number of specimens, in most cases diversity tended to increase only slowly, if at all, with additional picking, suggesting environmental limitations. An exception is the maximum diversity of 26 species (367 specimens), which coincides with the foraminiferal abundance maximum at *c.* 106-115 mbsf. Similar abundance peaks also have been observed within this interval for calcareous nannoplankton, dinoflagellates, and non-marine palynomorphs (See sections on Calcareous Nannofossils, Marine Palynology, and Terrestrial Palynology, this volume), suggesting that the interval may be condensed, and possibly represents the most

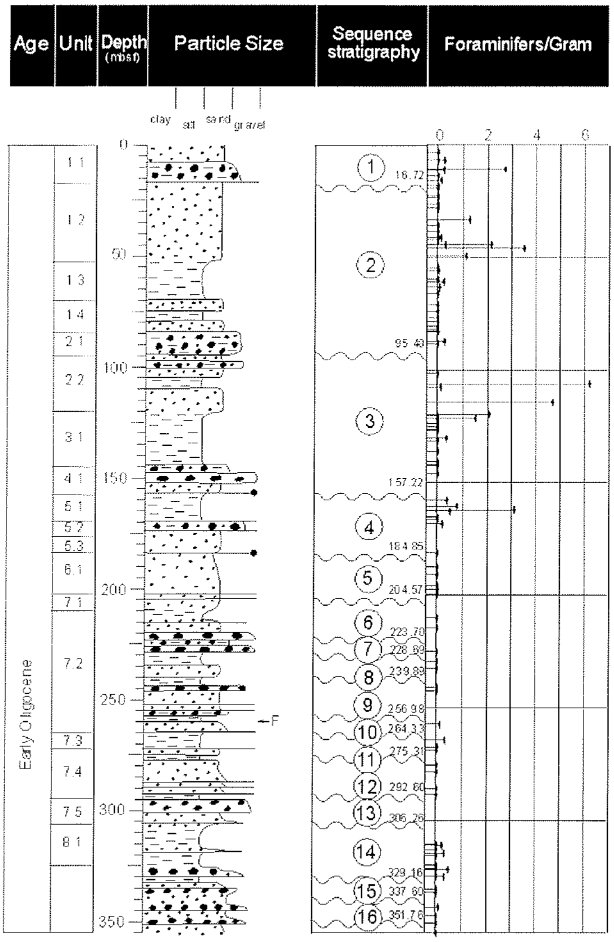

Fig. 1 - CRP-3 columnar section, 0-350 mbsf, showing lithology, lithostratigraphical units, sequence stratigraphy and foraminiferal sample levels and abundance.

optimal marine environment attained at the CRP-3 site during early Oligocene.

Major barren intervals, with consistently non-fossiliferous samples, occur at *c.* 65-82 mbsf (LSU 1.4), *c.* 210-250 mbsf (LSU 7.1 and 7.2) and *c.* 268-310 mbsf (lower LSU 7.3 - upper LSU 8.1). These intervals consist mainly of sandstone to muddy sandstone, with associated conglomerates, and probably reflect glacial maxima.

PALAEOENVIRONMENT

All foraminiferal assemblages observed consist mostly or entirely of perforate calcareous, benthic foraminifers, and have low-moderate to very low abundance and diversity. In overall aspect, these calcareous forms reflect many elements of the present-day Ross Sea fauna (*e.g.* Bernhard, 1987). Remaining benthics include a few large (up to 5 mm in diameter), biloculine miliolids (probably *Pyrgo* spp.), sprinkled throughout the section, and rare agglutinated taxa, represented by *Haplophragmoides*, *Cyclammina*, and *Textularia*. Planktics are absent except for the single specimen noted from 705.97 mbsf. It is most likely that the assemblages reflect various mid- to outer- shelf (50-200 m) benthic environments, with single-digit water temperatures (see further comments on large miliolids and *Stainforthia* in Palaeontological Notes) which were isolated from oceanic circulation and affected by high sedimentation rates, turbidity, and fresh-water influx. Various other glacially influenced events and processes, such as reduced or variable salinity, may have been important in limiting assemblage abundance and diversity.

AGE AND CORRELATION

All foraminifers recovered from CRP-3 have either long or poorly known ranges, and no age-diagnostic species were encountered to enable external correlation to high latitude foraminiferal zonation schemes (*e.g.*, Stott & Kennett, 1990). Scattered calcareous nannofossil and diatom occurrences yielded only early Oligocene ages for the more fossiliferous upper part of the section in CRP-3, while palynomorphs from near the base of the Cenozoic section provided the only evidence of Eocene penetration (CRP-3 Science Team, 2000).

CORRELATION WITH CRP-2/2A

Using foraminifers for correlation of the CRP-3 section with that of the nearby CRP-2/2A drillhole is problematical, due to the absence of distinctive foraminiferal bioevents. At one extreme, available data could be consistent with overlap of up to some 500 m between the drillholes, and at the other, no overlap at all. Diatom and calcareous nannofossil results, and also lithological correlations, show that the latter is the more likely, an interpretation somewhat supported by subtle foraminiferal evidence.

The CRP-3 foraminiferal fauna down to *c.* 340 mbsf, with persistent *Cassidulinoides chapmani*, *C.* spp., and *Stainforthia* sp., is virtually identical to Foraminiferal Unit III, as defined in CRP-2/2A (Cape Roberts Science Team, 1999; Strong & Webb, 2000). In CRP-2/2A, Unit III is *c.* 145 m thick, and occupies the interval from *c.* 342 to 486 mbsf. A major faunal change marks its upper boundary with Unit II, the latter containing common *Eponides bradyi* and *Cassidulinoides aequilatera.* This boundary is probably locally synchronous, and is the only known foraminiferal bioevent with potential for unambiguously correlating between the two drillholes. It is, however, not seen in CRP-3.

In CRP-2/2A, Unit III overlies the faunally impoverished Foraminiferal Unit IV (Strong & Webb, 2000), at least 138 m thick, which extends from 486 to 624.15 mbsf (Total Depth). The only foraminifers identified from Unit IV during drilling were scattered, *in situ* large miliolids, and a single specimen of *Stainforthia* sp. A post-drilling study (Galeotti et al., 2000), by dint of intensive sample processing, recovered 11 species from Unit IV, showing it to be a sparsely fossiliferous continuation of Foraminiferal Unit III. This result brings the minimum thickness of that unit to some 285 m, which is of the same order as the commonly fossiliferous portion of CRP-3.

Thus, if the foraminiferal succession in CRP-3 is "topless" Foraminiferal Unit III, it could correlate with CRP-2/2A at any level below *c.* 342 mbsf.

On the other hand, foraminiferal evidence favouring little overlap between the CRP-2/2A and CRP-3 sections depends upon rather minor faunal distinctions. These include the absence in the CRP-3 section of *Stainforthia (=Fursenkoina) schreibersiana* and *Ammoelphidiella uniforamina,* which occur, respectively, in Foraminiferal Units IV and III of CRP-2/2A and also the highest occurrences, near the top of the CRP-3 section, of *Hanzawaia* sp. and *Discorbis* sp., both distinctive, but not especially common, taxa not observed in CRP-2/2A.

In summary, there is no unambiguous foraminiferal correlation possible between CRP-3 and CRP-2/2A, but foraminiferal results are not inconsistent with diatom, calcareous nannoplankton and lithostratigraphical results, which suggest an underlap of the order of perhaps a few 10's of metres between the 2 drillholes (CRP-3 Science Team, 2000).

CORRELATION WITH OTHER ANTARCTIC DRILLHOLES

CRP-3 faunas, while less diverse and lacking planktic species, bear a general resemblance to Late Oligocene-Early Miocene faunas reported from lithostratigraphical Unit 2 (especially 2B to 2I) at DSDP Site 270 (Leckie & Webb, 1985). CRP-3 foraminiferal assemblages compare most closely with the *Globocassidulina-Cassidulinoides-Trochoelphidiella* Assemblage Zone from the lower part of DSDP 270. CRP-3 faunas also seem closely related to faunas in Sedimentary Units 8, 9, 15 and (perhaps) 18(Webb, 1989) and Assemblage C (Coccioni & Galeotti, 1997) in CIROS-1. Significantly, however, no fauna equivalent to the lowermost CIROS-1 fauna, (Unit 21, with *Alabamina dissonata* and other species) was encountered in CRP-3. This may indicate greater stratigraphic penetration by the earlier drillhole.

PALAEONTOLOGICAL NOTES

Species identified from CRP-3 are listed alphabetically below, and are briefly described and discussed where appropriate. Nondescript and/or poorly preserved specimens which are determined only to generic level, and listed in table 1 as "spp.", are not discussed. For brevity in discussions, only the top-of-sample depth is cited. Foraminiferal specimens, assemblage slides and residues are held at the Institute of Geological & Nuclear Sciences, Lower Hutt, New Zealand. Fossil Record Locality Number for CRP-3 is RS/f694, and foraminiferal curation number for residues and assemblage slides is F33518. Figured specimen curation numbers have the prefix "FP".

Anomalinoides cf. eoglabra Finlay

This small species (dia. 0.21 mm) is evolute dorsally and has a smoothly rounded periphery, with about 6 chambers in the outer whorl. Sutures are oblique and gently curved on the spiral side, straight and nearly radiate ventrally. It differs from *A. eoglabra* (Finlay, 1940) in its smaller size and more smoothly finished test. It occurs only rarely.

Anomalinoides globulosus (Chapman & Parr)

Anomalinoides globulosa (Chapman & Parr). Leckie & Webb, 1985, p. 1116, Pl. 14, figs. 13-16.

This species was recorded only from the relatively diverse assemblage at 106.08 mbsf.

Anomalinoides miosuturalis (Finlay)

Anomalina miosuturalis Finlay, 1940, p. 459, pl 65, figs. 128-131.

Anomalinoides fasciatus (Stache)

Plate 1, fig. 1

Rosalina fasciata Stache 1864, p. 281, Pl. 24, figs. 31a-c.

Anomalinoides fasciatus (Stache). Hornibrook et al., 1989, fig. 18: 7a, b.

A. fasciatus ranges from late Middle Eocene to Early Miocene in New Zealand (Hornibrook et al. 1989).

Astrononion sp.

A broken, single specimen was recovered from 87.15 mbsf.

Cassidulinoides bradyi Norman

Plate 1, figs. 2, 3

Cassidulina bradyi Norman 1881. *Fide* Ellis & Messina.

Specimens of *Cassidulinoides* having a small, compressed test are placed in this species.

Cassidulinoides braziliensis (Cushman)

Plate 1, fig. 4

Cassidulina braziliensis Cushman, 1932. *Fide* Ellis & Messina

Cassidulinoides braziliensis (Cushman). Leckie & Webb, 1985, p. 1112, Pl. 5, Fig. 13-14.

Leckie & Webb (1985) recorded the species in DSDP 270 from the lower half of Unit 2 (Late Oligocene to Early Miocene). It is a characteristic form through most of the fossiliferous section.

Cassidulinoides chapmani Parr

Plate 1, figs. 5, 6

Cassidulinoides chapmani Parr, 1931, p. 99, 100, figs. a-c; Carter, 1964, p. 70, Pl. 2, Figs. 37-39.

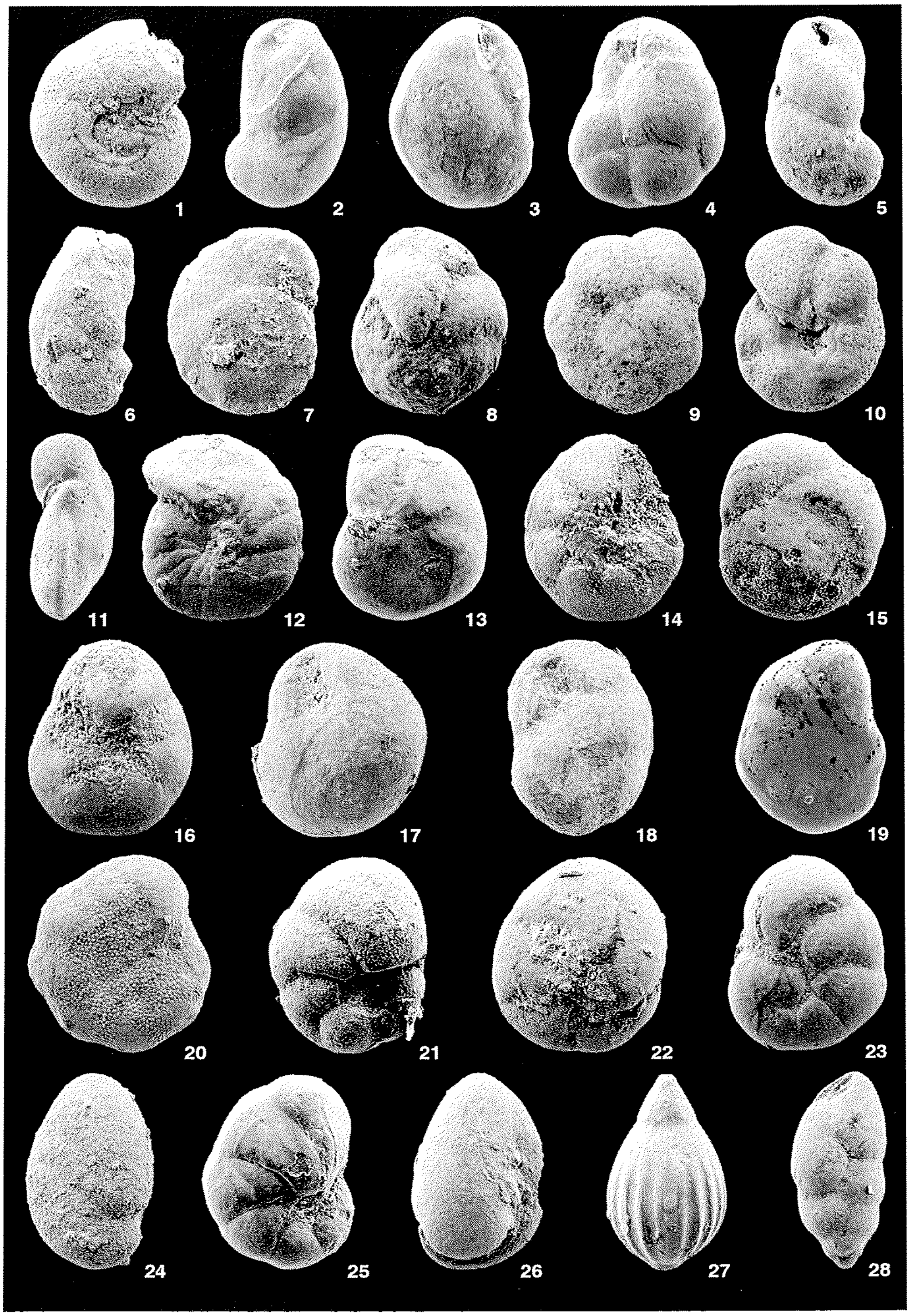

Plate 1

1. *Anomalinoides fasciatus*. FP4860, dorsal view, diameter 0.470 mm, 106.08 mbsf.
2, 3. *Cassidulinoides bradyi*. 2, FP4861, side view, length 0.440 mm, 87.15 mbsf.; 3, FP4862, side view, length 0.280 mm, 160.37 mbsf.
4. *Cassidulinoides braziliensis*. FP4863, side view, length 0.510 mm, 162.66 mbsf.
5, 6 *Cassidulinoides chapmani*. FP4864 side view, length 0.435 mm, 45.72 mbsf; 6, FP4865, Side view, length 0.440 mm, 106.08 mbsf.
7, 8. *Cibicides lobatulus*. 7, FP4866, dorsal view, diameter 0.280 mm, 106.08 mbsf.; 8, FP4867, ventral view, diameter 0.415 mm, 106.08 mbsf.
9-11. *Cibicides* sp. 9, FP4868, dorsal view, diameter 0.575 mm; 10, FP4869, ventral view, diameter 0.565 mm; 11, FP4870, apertural view, height 0.560 mm. All specimens 45.72 mbsf.
12. *Cyclammina incisa* Stache. FP4871, side view, diameter 2.55 mm, 131.21 mbsf.
13, 14. *Discorbis* sp. 13. FP4872, dorsal view, diameter 0.275 mm, 160.37 mbsf; 14, FP4873, ventral view, diameter 0.240 mm, 257.10 mbsf.
15, 16. *Epistominella exigua*. 15, FP4874, dorsal view, diameter 0.195 mm, 45.72 mbsf; 16, FP4875, ventral view, diameter 0.225 mm, 45.72 mbsf.
17. *Globocassidulina crassa*. FP4876, side view, diameter 0.260 mm, 45.72 mbsf.
18. *Globocassidulina subglobosa*. FP4877, side view, diameter 0.270 mm, 45.72 mbsf.
19, 20. *Hanzawaia* sp. 19, FP4878, dorsal view, diameter 0.501 mm, 162.66 mbsf; 20, FP4879, ventral view, diameter 0.375 mm, 106.08 mbsf.
21, 22. *Nonionella bradii*. 21. FP4880, dorsal view, diameter 0.280 mm, 106.08 mbsf; 22, FP4881, ventral view, diameter 0.220 mm, 106.08 mbsf.
23, 25. *Nonionella iridea*. 23. FP4882, dorsal view, diameter 0.260 mm, 87.15 mbsf; 25, FP4883, ventral view, diameter 0.275 mm, 87.15 mbsf.
24, 26. *Nonionella magnalingua*. 24, FP3884, dorsal view, diameter 0.350 mm, 106.08 mbsf; 26, FP4885, ventral view, diameter 0.405 mm, 106.08 mbsf.
27. *Oolina apiopleura*. FP4886, side view, diameter 0.485 mm, 324.92mbsf.
28. *Stainforthia* sp. FP4887, side view, length 0.495 mm, 45.72 mbsf.

This species is distinguished from *C. aequilatera*, a characteristic form of the CRP-2/2A succession, but not occurring in CRP-3, by its smaller size, thinner test wall and slightly compressed form. Carter (1964) notes that *C. chapmani* stratigraphically precedes *C. aequilatera;* this relationship is consistent with the inferred relationships of the sequences in the 2 drillholes. *C. chapmani* is characteristic of Foraminiferal Unit III in CRP-2/2A (Strong & Webb, in press) and occurs throughout the fossiliferous section in CRP-3.

Cibicides lobatulus (Walker & Jacob)
Plate 1, figs. 7, 8

Cibicides lobatulus (Walker & Jacob). Leckie & Webb, 1985, p. 1115, Pl. 11, Figs 10-12; Ward & Webb, 1986, p. 194, Pl. 6, Figs. 6, 7; Violanti, 1988, p.37, Pl. 10, Fig. 6.

C. lobatulus occurs mainly in the middle portion of the CRP-3 succession, and is relatively common in some samples. The species is a persistent component of Antarctic foraminiferal faunas, and ranges at least from early Oligocene to the Recent.

Cibicides cf. temporatus Vella

A single specimen from 197.32 mbsf is tentatively referred to Vella's (1957) species.

Cibicides sp.
Plate 1, figs. 9-11

This distinctive species is characterised by its moderate to large size, conical, evolute spiral side, and somewhat flattened, umbilicate ventral side. The test is coarsely perforate, and later chambers tend to become inflated on the dorsal side.

Cyclammina incisa (Stache)
Plate 1, fig. 12

Haplophragmium incisum Stache, 1864, p. 165, Pl. 21, fig. 1.

Cyclammina incisa Stache. Hornibrook, 1971, p. 34, Pl. 6, fig. 88-91.

A single, well preserved specimen was recovered from macrofossil matrix at 131.21 mbsf. Hayward (1986) suggests that the species is mainly a bathyal form, and ranges no shallower than the outer shelf.

Discorbis sp.
Plate 1, figs. 13,14

The species is moderately convex dorsally, and has about 6 chambers in the final whorl. Sutures are straight and nearly tangential dorsally; they are moderately curved ventrally, and radiate from a pustular umbonal mass. The aperture is a low, elongate, interiomarginal slit.

Epistominella exigua (Brady)
Plate 1, figs. 15, 16

Epistominella exigua (Brady). D'Agostino, 1980, p. 74, Pl. 4, Fig. 7, 8; Violanti 1996, Pl. 10, Fig. 5.; Mead, 1985, p. 230, Pl. 2, Fig. 1-4.

Epistominella vitrea Parker. Leckie & Webb, 1985, p. 1113, Pl. 6, Figs. 1-5; Ward & Webb 1986, p. 190, Pl. 4, Figs. 15-16.

Mead (1985) discusses the relationships of *E. exigua* and *E. vitrea*. The CRP-3 specimens are identical to reference specimens of *E. exigua* from DSDP Site 206, held in the GNS foraminiferal collections. The species occurs sporadically throughout much of the drillhole sequence, and is common in some assemblages. It is also recorded in CIROS-1, from *c.* 100- 500 mbsf.

Eponides bradyi Earland
Plate 1, figs. 17, 18

Eponides bradyi Earland. Boltovskoy, 1978, p. 15, Pl. 4. Figs. 1-3; Leckie & Webb, 1985, p.1115, Pl. 23, Figs. 11-13; Strong & Webb, 2000, p.409, Pl. 1, figs. 17, 18.

Specimens from CRP-3 closely resemble Leckie & Webb's (1985) figures, also Boltovskoy's figured specimen. They have a more lobulate periphery than Earland's specimens (*fide* Ellis & Messina), but his drawings appear to be somewhat diagrammatic. At DSDP 270, *E. bradyi* ranges down into Unit G, which is tentatively dated as early Miocene (Leckie & Webb 1985). In CRP 2/2A, *E. bradyi* is a characteristic species of Foraminiferal Unit II, and occurs rarely in Unit III (Strong & Webb, 2000).

Fissurina fimbriata (Brady)

Fissurina fimbriata (Brady). Leckie & Webb, 1985, p. 1112, Pl. 4, figs. 18-19.

Fissurina marginata (Montagu)

Fissurina marginata (Montagu). Leckie & Webb, 1985, p. 1112, Pl. 18, figs. 9-10.

Globocassidulina crassa (d'Orbigny)
Plate 1, fig. 17

Globocassidulina crassa (d'Orbigny). Leckie & Webb, 1985, p. 1115, Pl. 12, figs. 7-9.

G. crassa is distinguished from *G. subglobosa* by its larger, more robust test and more highly inflated chambers.

Globocassidulina subglobosa (Brady)
Plate 1, fig. 18

Globocassidulina crassa (d'Orbigny). Leckie & Webb, 1985, p. 1115, Pl. 12, figs. 4-6.

Gyroidina orbicularis d'Orbigny

Gyroidina orbicularis d'Orbigny. Leckie & Webb, 1985, p. 1116, Pl. 13, figs. 15-16.

G. orbicularis is recognisable by its straight, nearly radiate dorsal sutures, and numerous chambers per whorl. Although never formally described, this species has been recorded in numerous Oligocene and younger assemblages in New Zealand. Most of these assemblages are interpreted as upper bathyal (200-600 m) or deeper.

***Hanzawaia* sp.**

Plate 1, figs. 19, 20

This small species is compressed, convex dorsally and flattened ventrally, with a somewhat lobulate periphery.

***Melonis barleeanum* (Williamson)**

Melonis barleeanus (Williamson). D'Agostino, 1980, p. 88, Pl. 10, Fig. 5; Leckie & Webb, 1985, p. 1116, Pl. 14, Figs. 1-4.

M. barleeanum has a biumbilicate, involute, planispiral test with a broadly rounded periphery and about 8 chambers in the outer whorl. In New Zealand basins (temperate water mass) it is considered to represent depths of mid-upper bathyal or deeper (Hayward 1986).

Melonis graniferum (Terquem)

Nonion graniferum (Terquem). Galeotti & Coccioni, 1998, Pl. 1, fig. 1.

Large Miliolidae

Large miliolid foraminifers were recovered or observed *in situ* from several levels in the drillhole. They have biloculine coiling, and probably are referable to one or more *Pyrgo* species. The largest specimen observed was some 6 mm in diameter. A recent study (Gudmundsson, 1998) of twelve North Atlantic and Arctic *Pyrgo* species shows that their distribution is strongly linked to water depth and temperature. The genus shows a wide depth range, from *c.* 20 m to >2500 m, although many species occur only within more restricted depth limits. *Pyrgo lucernula* (Schwager), the largest species recorded in the study, attained a maximum length of 4.9 mm, comparable with some CRP-3 specimens. The species occurs in North Atlantic assemblages, and is most common between *c.* 100 and 1500 m, and over a temperature range of 3-7 ° C.

***Nonionella bradii* (Chapman)**

Plate 1, fig. 21, 22

Nonionella bradii (Chapman). Fillon, 1974, p. 118, Pl. 5, Fig. 42; D'Agostino, 1980, p. 86, Pl. 9, Figs. 1-3; Leckie & Webb, 1985, p. 1115, Pl. 13, Fig. 3-4, Pl. 23, Fig. 1-2.

***Nonionella iridea* Heron-Allen & Earland**

Plate 1, figs. 23, 25

Nonionella iridea Heron-Allen & Earland. Leckie & Webb, 1985, p. 1115, Pl. 13, Figs. 3-4, Pl. 23, Figs. 5-7; Ward & Webb, p. 198, Pl. 7, Fig. 4.

Melonis sp. B, Strong & Webb, 1998, p. 520, Pl. 1.10, 11.

N. iridea is characterised by its slightly asymmetrical test and curved, deeply incised sutures.

***Nonionella magnalingua* Finlay**

Plate 1, fig. 24, 26

Nonionella magnalingua Finlay. Leckie & Webb, 1985, p. 1115, Pl. 13, Fig. 5, Pl. 23, Figs. 3-4; Strong & Webb, 2000, Pl. 2, fig. 9.

***Oolina apiculata* Reuss**

Oolina apiculata Reuss. D'Agostino, 1980, p. 64; Leckie & Webb, 1985, p. 1112, Pl. 4, Fig. 11; Strong & Webb, 2000, p. 470, Pl. 2, fig. 10.

***Oolina apiopleura* (Loeblich & Tappan)**

Plate 1, fig. 27

Oolina apiopleura (Loeblich & Tappan). Leckie & Webb, 1985, p. 1112, Pl. 4, figs. 8-9.

***Oolina globosa* (Montagu)**

Oolina globosa (Montagu). D'Agostino, 1980, p. 65; Leckie & Webb, 1985, p.1112, Pl. 4, Fig. 10, Pl. 18, Fig. 17; Strong & Webb, 2000, Pl. 2, fig. 11.

***Parafissurina lateralis* (Cushman)**

Parafissurina lateralis (Cushman). Leckie & Webb, 1985, p. 1112, Pl. 18, Fig. 22-23.

Planularia sp.

Three moderately preserved specimens were encountered at 106.08 mbsf. They are flame-shaped, compressed, of medium size (*c.* 0.75 mm) for the genus, and are unornamented, with flush sutures.

***Pullenia subcarinata* (d'Orbigny)**

Pullenia subcarinata (d'Orbigny). Leckie & Webb, 1985, p. 1116, Pl. 13, Figs. 7-9.

Pullenia cf. subcarinata (d'Orbigny). Mead, 1985, p. 236, Pl. 4, Fig. 9-10.

Melonis sp. A. Strong & Webb, 1998, p. 520, Pl. 1.9.

These 6 to 7 chambered forms appear to be identical to those figured by Leckie & Webb (1985), but tend to have a more evenly rounded periphery, rather than the sharply compressed periphery as figured by d'Orbigny (*fide* Ellis & Messina) and Ward & Webb (1986).

Reophax sp.

Reophax is represented in 2 samples by large, coarsely agglutinated specimens.

***Stainforthia* sp.**

Plate 1, fig. 28

Stainforthia sp. Strong & Webb, 2000, p.472, Pl, 2, figs. 19, 20

In CRP 2/2A, *Stainforthia* sp. was one of the characteristic forms of Foraminiferal Unit III, and a single specimen was also observed in Foraminiferal Unit IV, and it also ranges through most of the fossilifeous CRP-3 section. The species has an elongate, fusiform test, the initial one-third consisting of a distinctly twisted, triserial early stage, and the remainder of biserial chambers. It lacks the apical spine often seen in the genus. *Stainforthia* sp. resembles the Pleistocene to Recent species *S. feylingi* Knudsen & Seidenkrantz (1994), but is more elongate, with a less rapid height increase in the later chambers. The latter species is widespread in Arctic and cold boreal environments (water temperature 8-9° C) at depths ranging from a few to several thousand metres (Knudsen & Seidenkrantz, 1994). At Saanich Inlet, British Columbia, it was recorded in mud and sand in low oxygen environments with slightly subnormal salinity, at a water depth of *c.* 90 m (Blais-Stevenson & Patterson, 1998).

Textularia sp.

The single specimen, recovered from 162.16 mbsf, consists of the final 4 chambers of a large, coarsely agglutinated, but smoothly finished, specimen.

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