Terra Antartica
Initial Report on CRP-3
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1 - Introduction

BACKGROUND AND GEOLOGICAL SETTING

BACKGROUND

In this third and final season of drilling by the Cape Roberts Project, the aim was to complete a coring transect from the lower Miocene (17 Ma) strata cored by CRP-1 on Roberts ridge to the Eocene (*c.* 40 Ma) strata expected to lie at relatively shallow depths on the western margin of the Victoria Land Basin (VLB). The project is named after Cape Roberts, the staging point for the offshore drilling and a small promontory 125 km northwest of McMurdo Station and Scott Base (Fig 1.1). The project was designed for two tasks:

- to investigate the early history of the Antarctic ice sheet and the record of Antarctic climate prior to its inception, around 35 million years ago;
- to date the history of rifting of the Antarctic continent as recorded by the uplift of the Transantarctic Mountains and formation of the Victoria Land Basin.

This volume records work carried out from the final drill hole, CRP-3, which completed coring the lowest part of the Cape Roberts sequence at a depth of 939.42 mbsf on 19 November 1999 (Tab. 1.1). This first section outlines the geological setting of the drill site, and then describes the operating environment (climate and sea ice) and drilling activity. Core management and sampling from drill site to the Crary Science & Engineering Center (CSEC) at McMurdo Station are also described. The remainder of the report presents the first results and preliminary interpretations of the data from both the core and logging within the hole itself.

GEOLOGICAL SETTING

The geological setting of the Cape Roberts drill sites has been reviewed previously in Barrett et al. (1995) and

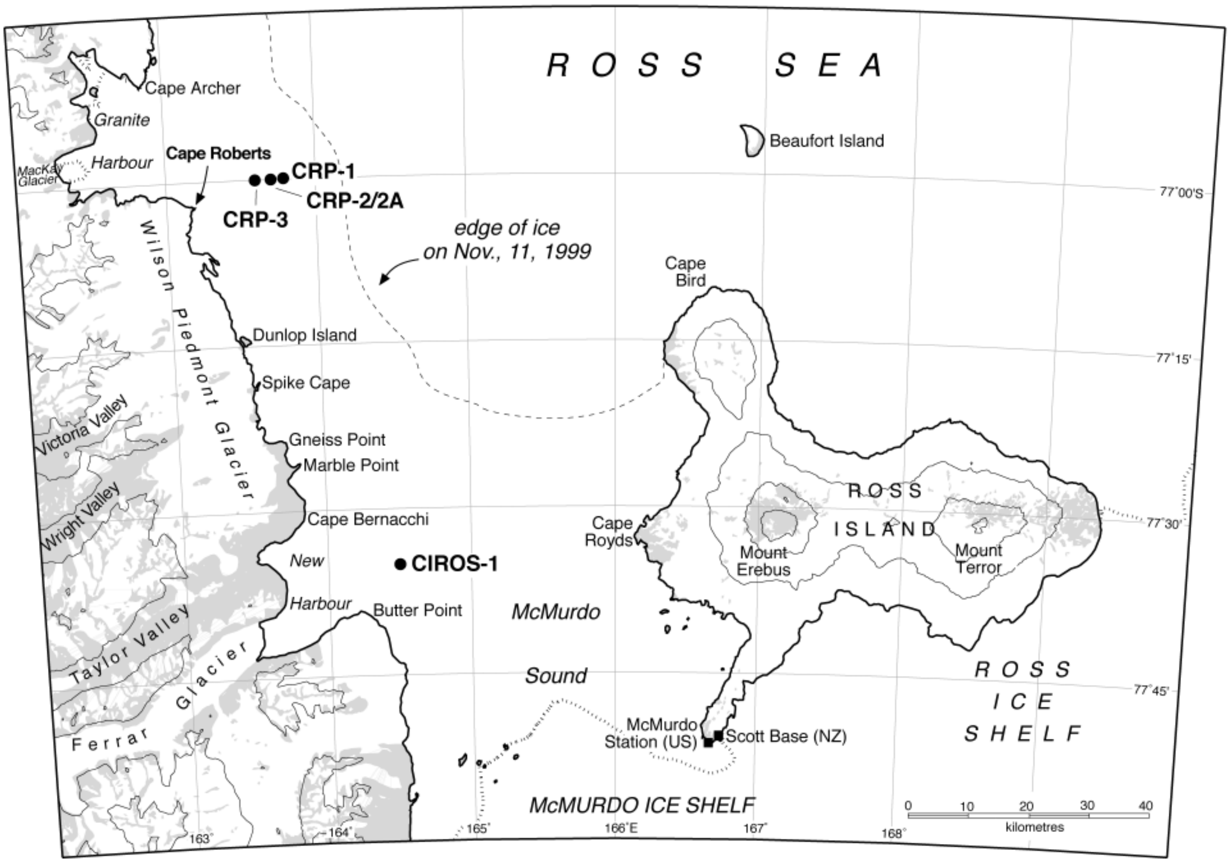


Fig. 1.1 - Map of the southwest corner of the Ross Sea, showing the locations of Cape Roberts, CRP-1, CRP-2/2A, CRP-3, and CIROS-1, and McMurdo Station/Scott Base, the main staging point for the project. The edge of the fast sea-ice, which provides the drilling platform, is also shown.

Tab. 1.1 - Site data for CRP-3.

Position:	11.76 km at 76° true from Cape Roberts	2.04 km at 255° true from CRP-2	
Latitude:	77.0106°S	Longitude:	163.6404°E
Water depth:	295 m	Fast ice thickness:	2.0-2.2 m
First core:	04.00 9 October 1999	Last core:	22.30 19 November 1999
Sea riser embedded to:	9.55 mbsf	Lateral ice movt from spudding:	5.0 m to 82° true
HQ core to:	345.85 mbsf	NQ core to:	939.42 mbsf
Recovery for hole:	97%	Phase 1 logging to:	345 mbsf
Phase 2 logging to:	773 mbsf	Phase 3 logging to:	918 mbsf
Deepest Cenozoic lithology & depth	Sandstone breccia from 822.87 to 823.11 mbsf	Age of oldest Cenozoic strata:	Earliest Oligocene or maybe latest Eocene
Deepest core lithology & depth	Light red-brown quartz-cemented quartz sandstone to 939.42 mbsf	Age of bedrock:	Devonian (probably mid Devonian)

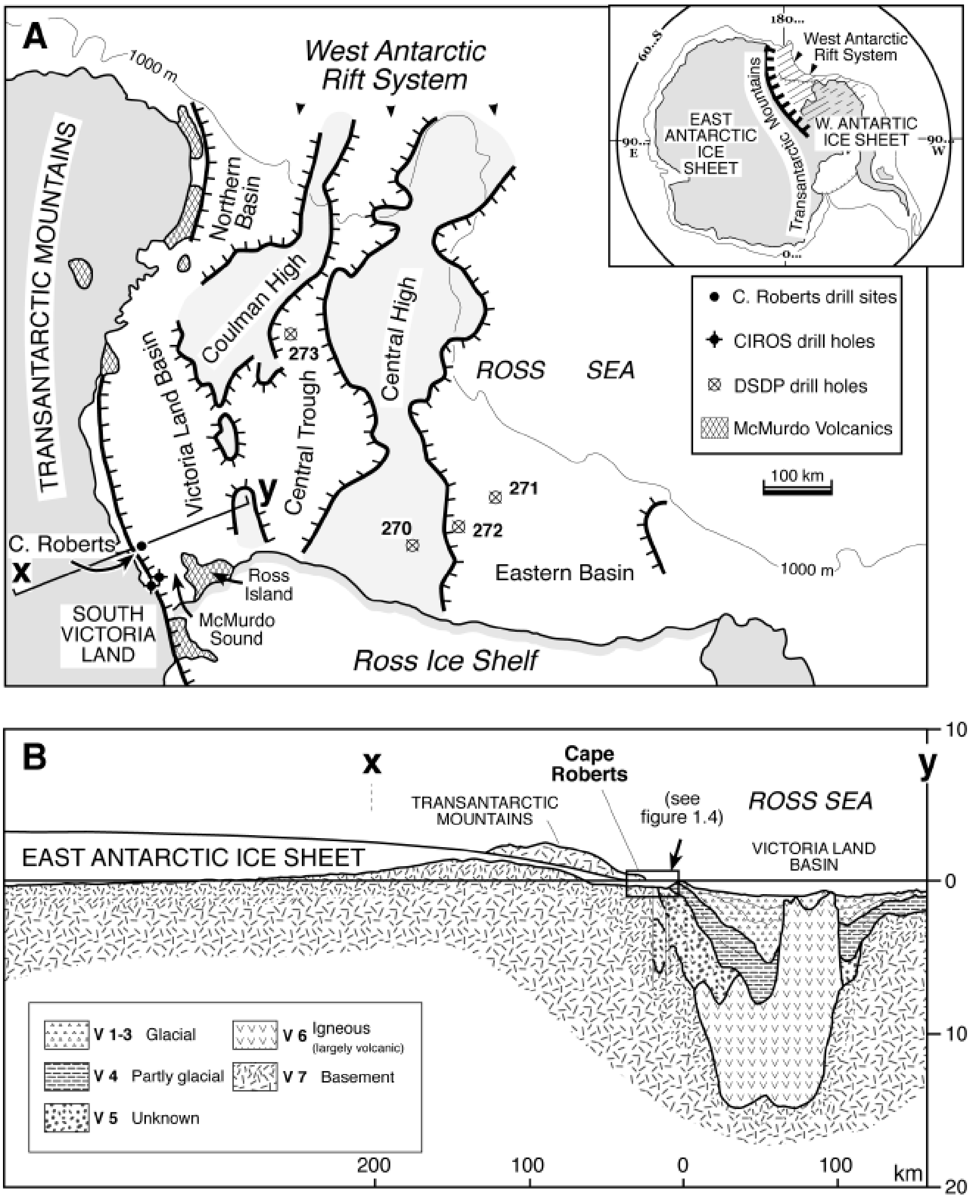


Fig. 1.2 - Map of the Ross continental shelf (A) and cross-section through the edge of the West Antarctic Rift System (B), showing the East Antarctic ice sheet, the Transantarctic Mountains and the Victoria Land Basin.

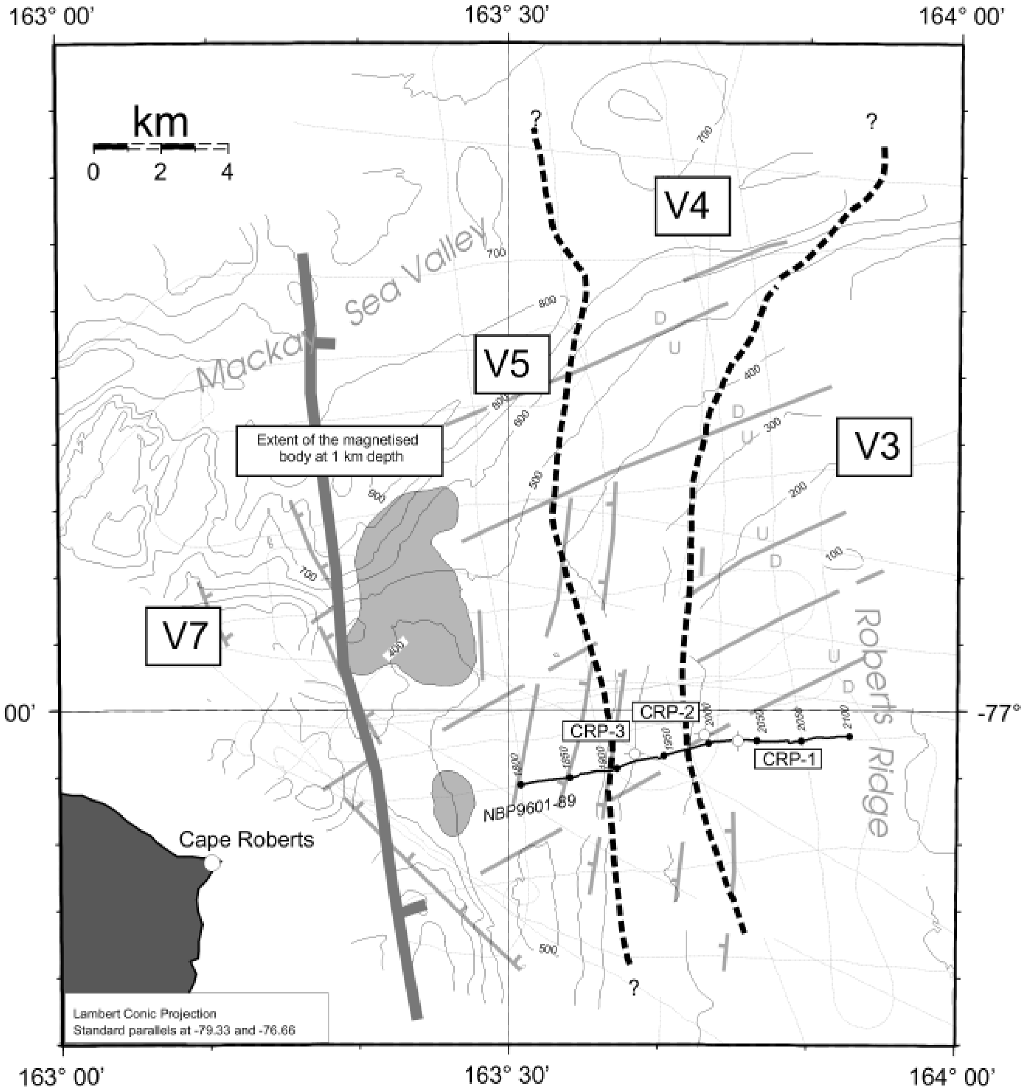


Fig. 1.3 - Map of the area off Cape Roberts (bathymetric contours in 50 metre intervals), showing the location of Roberts ridge, lines from key seismic surveys (dotted), the survey line on which the drill holes are based (solid, with drill sites) and the distribution of the older sedimentary sequences (V3, V4, V5) beneath the sea floor (dashed lines). The major fault inferred by Henrys et al. (1998) and the more complex fault systems interpreted by Hamilton et al. (1998) are also shown.

in last year's report on CRP-2/2A (Cape Roberts Science Team, 1999), and only a few brief comments are repeated here. Roberts ridge and CRP-3 (Fig. 1.2) lie on the western margin of the Victoria Land Basin, a trough at least 400 km long and *c.* 150 km wide filled with sediment of Cenozoic age, immediately seaward of the Transantarctic Mountains. Roberts ridge is separated from the early Palaeozoic basement rocks of the mountains by a major fault system, known as the Transantarctic Mountain Front, which parallels the present coast and represents the western edge of the VLB. Strata in the middle of the basin reach a thickness of 10-14 km, the oldest being interpreted as early rift-related volcanic rocks (Fig. 1.2, V6) (Cooper & Davey, 1987). Above these, lie the older sedimentary seismic sequences, V5 and V4. Through uplift and erosion along the basin margin, they now dip at between 10° and 15° eastward, and lie just beneath the sea floor on the western flank of Roberts ridge, a bathymetric high between 10 and 20 km off Cape Roberts. The younger sequences (V1-V3) are 5 km thick in the middle of the basin but thin to *c.* 300 m on Roberts ridge.

The main structural trend of the VLB is NNW, parallel to the axis of the Transantarctic Mountains. Northwest-trending, seismically defined faults demarcate presumed late Mesozoic half-grabens in the basin floor, and have been interpreted as terminating upward in the sedimentary section (Cooper & Davey, 1987). NNE- and ENE-trending faults have also been recognised in the mountains along the rift margin, and are interpreted to have formed, or have been reactivated, during transtension in more recent times (Wilson, 1995). Similar fault trends have been interpreted from seismic data from the basin margin off Cape Roberts (Hamilton et al., 1999) (Fig. 1.3).

Working backwards in time from the great eastfacing scarp of the present-day Transantarctic Mountains, we can deduce that the adjacent mountains were already deeply eroded and perhaps even approaching their present elevation by the earliest Miocene. This is evident from the dominance of basement lithologies as clasts in strata of this age in CRP-1 and the upper part of CRP-2A (Talarico et al., in press). Oligocene strata from the lower part of CRP-2A have also provided clast data, supported by sand provenance data (Smellie, in press), that suggest more extensive erosion of the cover beds (Beacon Supergroup and Ferrar Dolerite). Age constraints as well as sedimentary features hint at rapid contemporaneous basin subsidence. What did deeper drilling into the basin margin reveal?

OVERVIEW OF CRP-3

CRP-3 was drilled just 2 km west of CRP-2 and sited to overlap it stratigraphically by some 60 m (Fig. 1.4). Results from the hole are presented in the pages that follow, and a summary lithologic log is shown graphically in figure 1.5. The CRP-3 core down to 823 mbsf, where rift-margin bedrock was encountered, provides a continuation of the cold-climate story from CRP-2A back *c.* 34 Ma.Some glacio-eustatic cyclicity is evident, but becomes attenuated as the sediment record becomes increasingly coarser back in time. Despite the considerable thickness of sediment, the current judgement from a sparse microflora is that only 2 or 3 million years

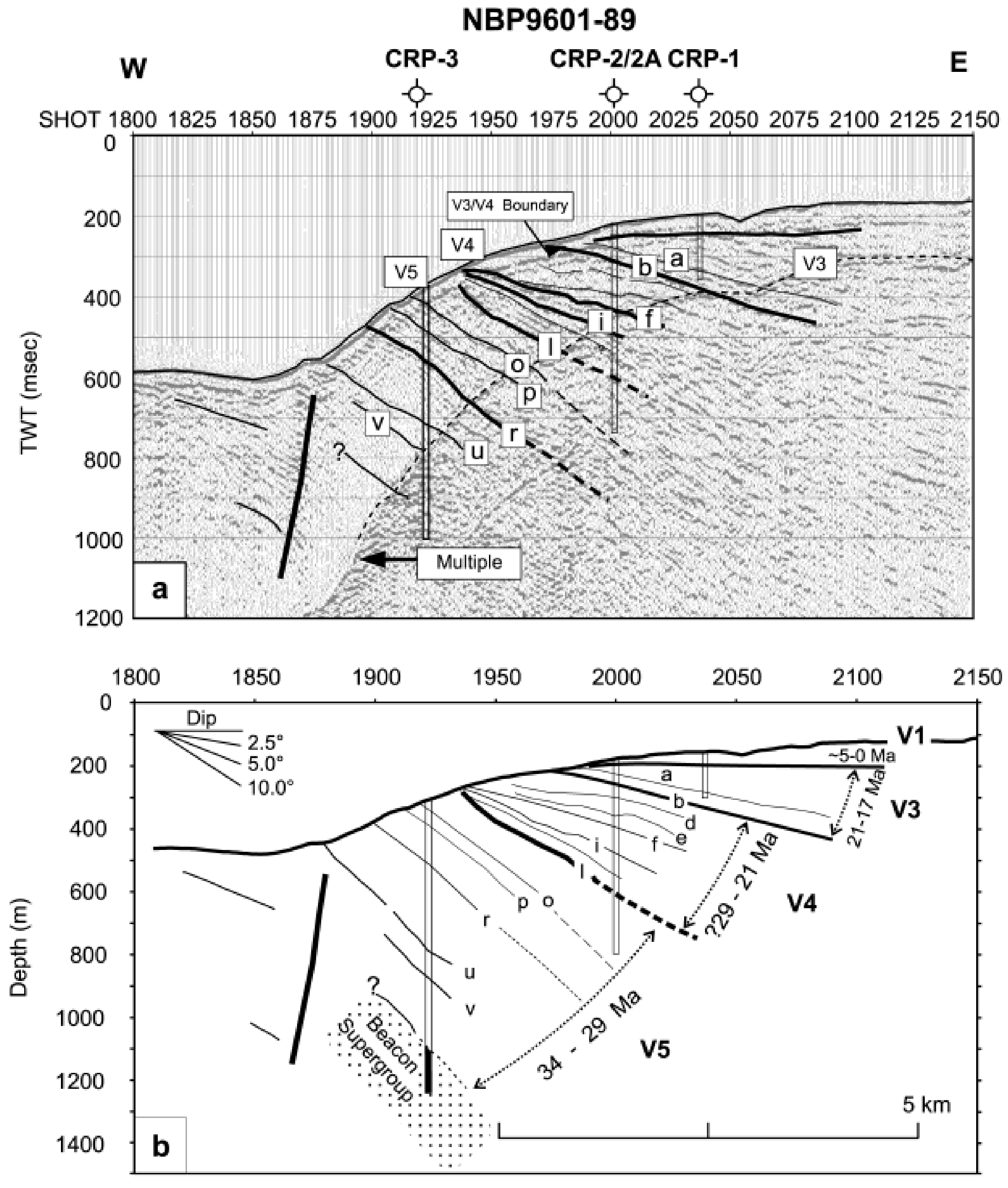


Fig. 1.4 - Geological section based on seismic data from NBP9601-89, showing CRP-1, CRP-2/2A and CRP-3, and ages obtained thus far by Wilson et al. (in press) and the Cape Roberts Science Team (this volume). The line is shown in bold on figure 1.3.

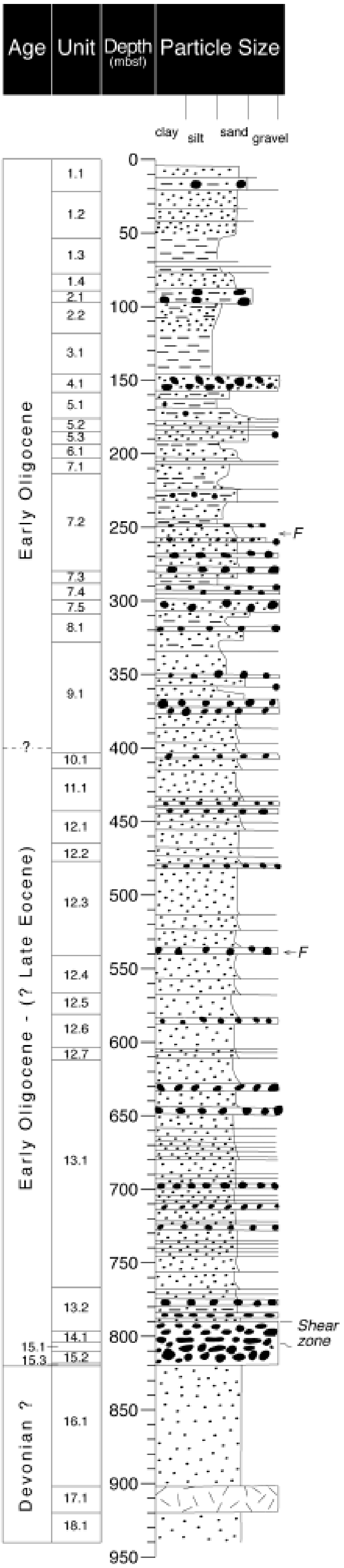


Fig. 1.5 - Stratigraphical column for CRP-3, showing the main lithological features and ages.

has been traversed. This is not enough to expect to reach back to warm middle Eocene times, nor is there any climatic indication of these times from the strata in CRP-3.

The rift margin bedrock described later in these pages is believed to be of mid Devonian sandstone of the Beacon Supergroup, around 3000 m below its stratigraphical position when projected eastward from the mountains to the west. Downhole logging has provided directional data on the attitudes of bedding and fault surfaces encountered in the drill hole so that a tectonic model for the behaviour of this rift margin can be attempted.

The piece-de-resistance for the drill hole is a body of rock 19 m thick that intruded the Beacon Supergroup near the base of the hole. Although it has a doleritic texture, it has other features, such as lack of graphic intergrowths and its pervasively altered state, that distinguish it from the widespread Ferrar Dolerite that intrudes the Beacon Supergroup throughout the length of the Transantarctic Mountains. Could it be a finger from the body causing the magnetic anomaly a few km west and northwest of the drill site (Fig. 1.3) that Bozzo et al. (1997) have modelled as a gently dipping broken slab? Or could it be a marginal facies of the volcanic rocks inferred to form Unit V6 (Cooper & Davey, 1987)? Or could the early stages of rifting be essentially free of magmatism, with all three features representing different phases of Jurassic Ferrar volcanism now preserved in the wall and floor of the West Antarctic Rift System? Do read on.

FAST ICE BEHAVIOUR, CURRENTS AND TIDES

INTRODUCTION

Knowledge of the history of the formation of fast ice in winter and its subsequent behaviour in the spring has been important for the safety and success of the Cape Roberts Project. The ice at any prospective drill site needs to be able to support around 55 tonnes of drilling and related equipment for a period of about 40 days. The pattern of ice growth for the previous two drilling seasons has been described in earlier reports (Cape Roberts Science Team, 1998, 1999). A similar but more complete set of observations follow, along with comments on techniques that have been adopted to ensure that the fast-ice platform is kept in the best possible condition throughout the drilling phase of the operation. Tides and currents also affect the drilling operation, the latter because of their influence on the sea riser, and are also discussed at the end of this section.

WINTER FAST ICE GROWTH

The growth, formation and breakout of fast ice in the south western Ross Sea was tracked from April through to

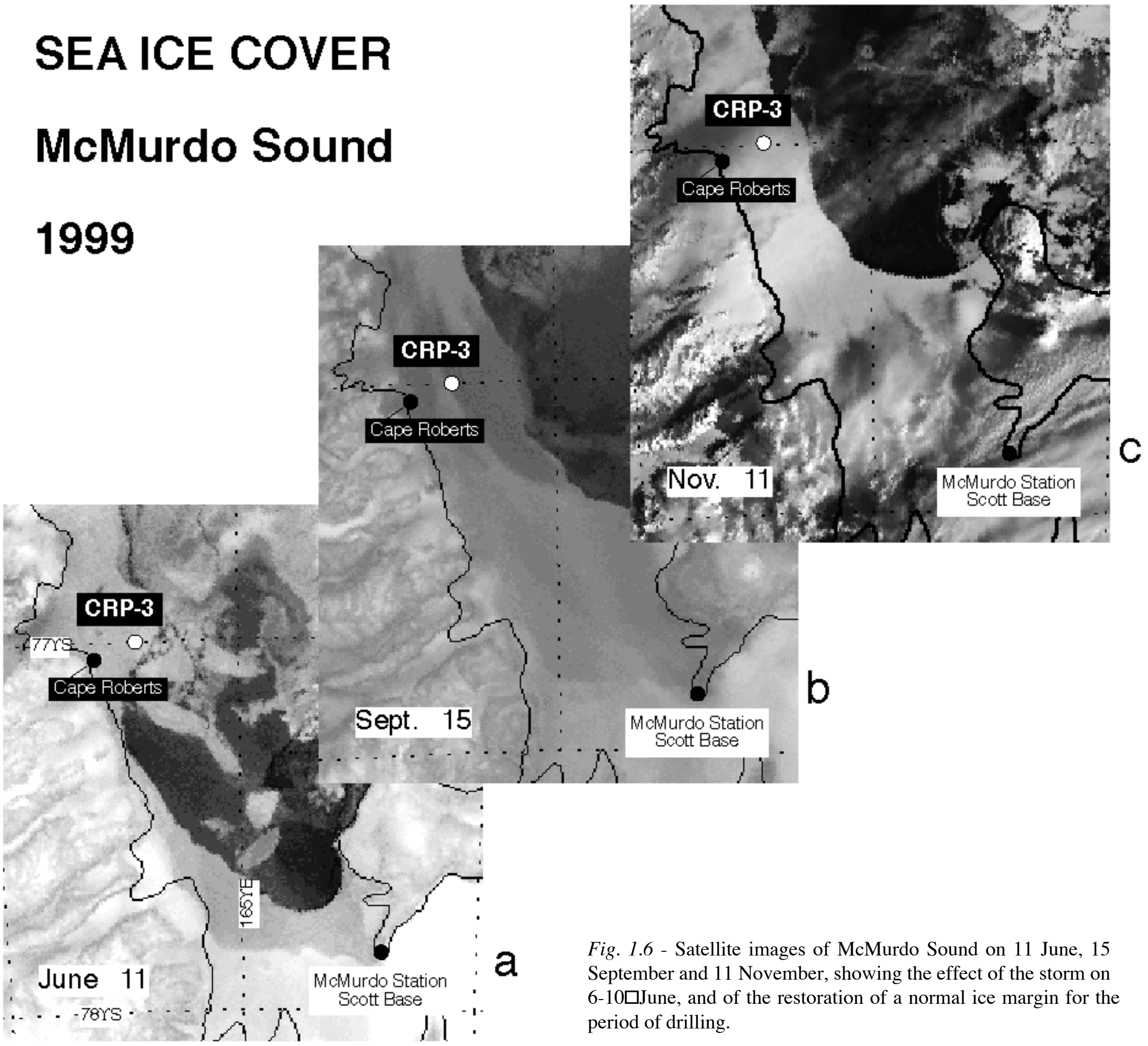


Fig. 1.6 - Satellite images of McMurdo Sound on 11 June, 15 September and 11 November, showing the effect of the storm on 6-10 June, and of the restoration of a normal ice margin for the period of drilling.

late September using weather satellite images (DMSP) downloaded at McMurdo Station and processed at ASA Headquarters in Denver. In the proposed area for drilling CRP-3 off Cape Roberts, fast ice had stabilised by mid April while in the southern part of McMurdo Sound, the fast ice continued to break out and did not stabilise until early July. Temperatures from mid April to mid May were 2°C cooler than the 18-year average (data source -Marble Point automatic weather station), promoting quick winter-ice growth in the drill site area. A compression event on 30 May caused northwest shearing of fast ice in the drill-site area and to the north in the offshore area of Granite Harbour. During 6-10 June, a storm event broke out fast ice along the Wilson Piedmont Glacier but did not appear to affect fast ice in the drill site area (Fig. 1.6).

The fast-ice history for 1999 was compared to winter fast-ice formation and break-out histories for the proceeding ten years (1988-1998) (Pyne, 1999) to determine whether the fast-ice sheet was again likely to provide a suitable platform for drilling as well as a surface resupply route through the southern and western part of McMurdo Sound. In the proposed drill site area, fast ice must stabilise in April-May to provide a guaranteed drilling platform in excess of 1.5 m thick by early October. In addition, post-June breakout events occurring in the fast ice either immediately north and/or south of the proposed drilling area are thought to reduce the protection for the fast ice, making it more susceptible to subsequent storms and possible break-out events. Resupply routes from McMurdo Station to Cape Roberts and out to the drill site must remain unaffected by break-out events from mid-June to ensure that sufficient ice thickness (1.2 m) is present for heavy vehicles.

In early July, the CRP International Steering Committee (ISC) met in Wellington to consider the fast-ice information and concluded that preparation for 1999 should proceed with a final confirmation to be made in early August, in line with the conclusions of the 10-year historical interpretation. The satellite image for August (Fig. 1.7) showed that the fast-ice margin and new ice that had formed after the 6-10 June storm event, remained stable. Growth rate predictions for the fast ice also indicated that the mandatory 1.5-m thickness should be exceeded by 1 October in the proposed drilling area, allowing the rig to be set up and operated safely. After considering all of the relevant data, the ISC decided that CRP-3 should proceed unless the Winfly reconnaissance indicated otherwise.

WINFLY RECONNAISSANCE

During the Winfly reconnaissance period (21-25 August), measurements of fast-ice thickness were made on route from Scott Base to Cape Roberts and in the drill-site area offshore of Cape Roberts. These included a survey of the Cape Roberts crack (Pyne, 1986), which is several metres wide and runs through the fast ice in a north-south direction several km off Cape Roberts. The shortest practicable route this year between Cape Roberts camp and the CRP-3 site involved bridging the crack 10 km to the south of the cape, and was 23 km long, compared with a straight line distance of 12 km (Fig. 1.7).

Most of the fast ice between Cape Roberts and the drill site area that stabilised in mid April was in excess of 1.6 m thick on 23 August, but some smaller areas that formed after the 30 May shear event were only 1.2 m thick. Detailed mapping of the smooth ice plates (*i.e.* those that formed in mid-April) indicated that five areas were potentially suitable as a drilling platform (areas CRP99-1-5, Fig. 1.7). A drilling position on area 3, chosen in consultation with the ISC, was 270 m north of shot point 1920 on seismic line NBP9601-89. Interpretation of the geometry from the single channel seismic record suggested that this site should give

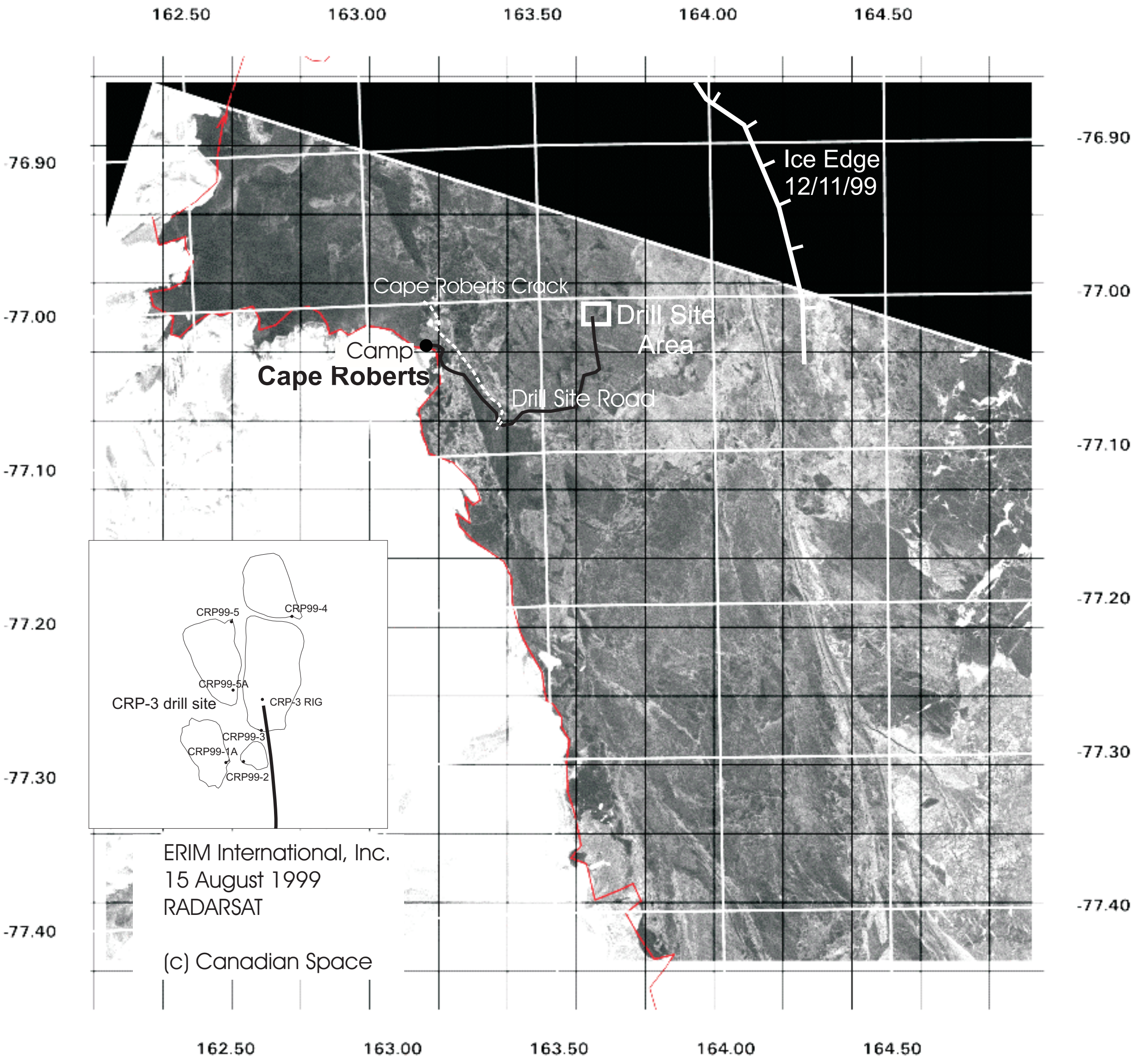


Fig. 1.7 - RADARSAT image for 15 August 1999, of the fast ice off Cape Roberts, showing the various plates and zones, with an inset showing the plates at and around the CRP-3 site. The Cape Roberts crack (dashed white line) and route from Cape Roberts to the drill site (solid black line) are also shown.

Tab. 1.2 - Summary of weather and fast-ice data collection.

Parameter	Position	Sampling frequency	Sampling period
Wind	Top of rig mast –12 m high	30-min avr.	16 Oct-22 Nov
Air temperature	3 m high	30-min avr.	16 Oct-22 Nov
Fast ice temp.	0.5 m below fast ice surface	30-min avr.	16 Oct-22 Nov
Fast ice lateral movt	4 sites close to drill site	6-10 days	10 Sept-14 Nov
Fast ice thickness	5 sites close to drill site	2 weeks	14 Oct-8 Nov
Freeboard	Under drill rig	Daily	3 Oct-15 Nov

approximately 60 m of overlap with the oldest strata cored in CRP-2.

FAST ICE MONITORING

During October, pack ice and refreeze ice obscured the position of the shear zone and fast-ice edge offshore of the drill site. Storm events in early November removed the pack, eroded some of the fast ice and established a ‘normal’ fast-ice edge 16 km NE and 14 km E of the drill site.

At the drill site, wind, air temperature, fast-ice temperature and fast-ice thickness have been measured throughout the drilling operation (Tab. 1.2) to monitor fast ice conditions. The rate of lateral movement (offset) of the fast ice was monitored as it affects the safe operation of the sea riser. Measurements were taken at three sites from 10 September, and also on the drill rig roof from 8 October, when the sea riser was spudded into the sea floor (Fig 1.7). Measurements were made by GPS and differentially post-processed against a base station at Cape Roberts 12 km away. The error ellipses of positions (95% precision) generally have axes less than 0.5 m.

At the drill site, relatively cool and settled weather was experienced during the month of October. However November was more unsettled with frequent storms with higher winds and warmer air temperatures (Fig. 1.8).

At the drill site, fast ice continued to grow through October and reached a thickness of 2.21 m by early November with ‘anchor ice’ forming on the sub-ice air bags to a depth of approximately 3 m below the base of the ice. Fast-ice temperature was measured by thermistor probe 0.5 m below the fast-ice surface in a shaded area behind the mud hut. It increased slowly from -12°C in early November to -8°C on 25 November when drilling activity ceased. Thus this year the ice did not become isothermal during the drilling phase of the operation in contrast to the fast ice in the latter stages of CRP-2A (Cape Roberts Science Team, 1999), when temperatures were warmer. Total lateral movement of the fast ice during the period of spud-in to cutting the sea riser at the sea floor was 6 m to the east (088°). Movement rates

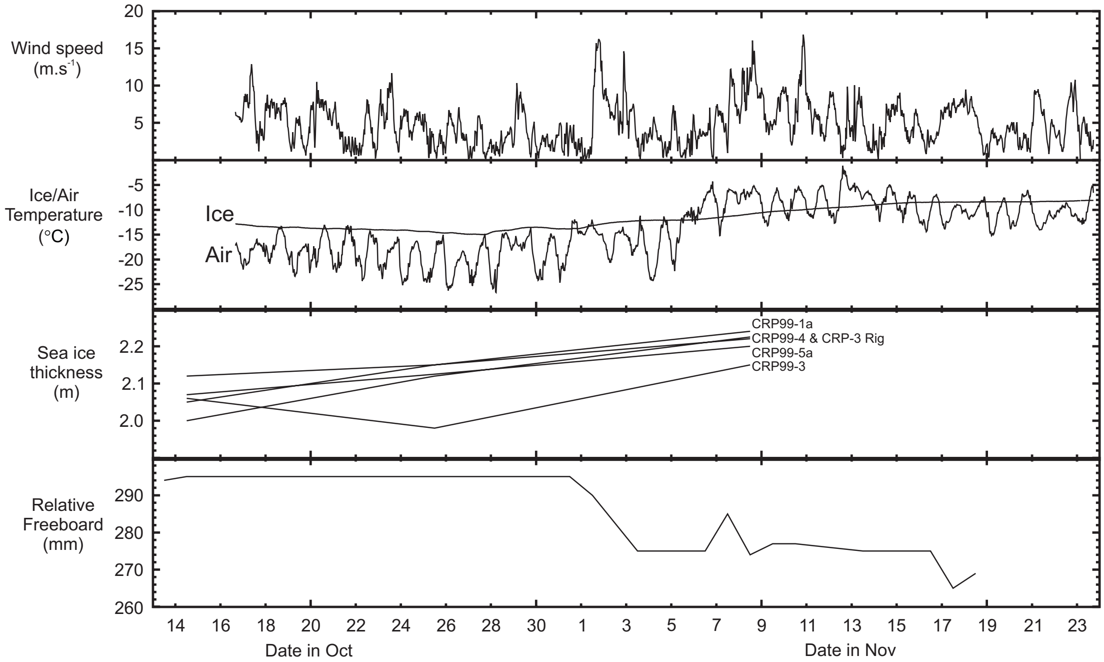
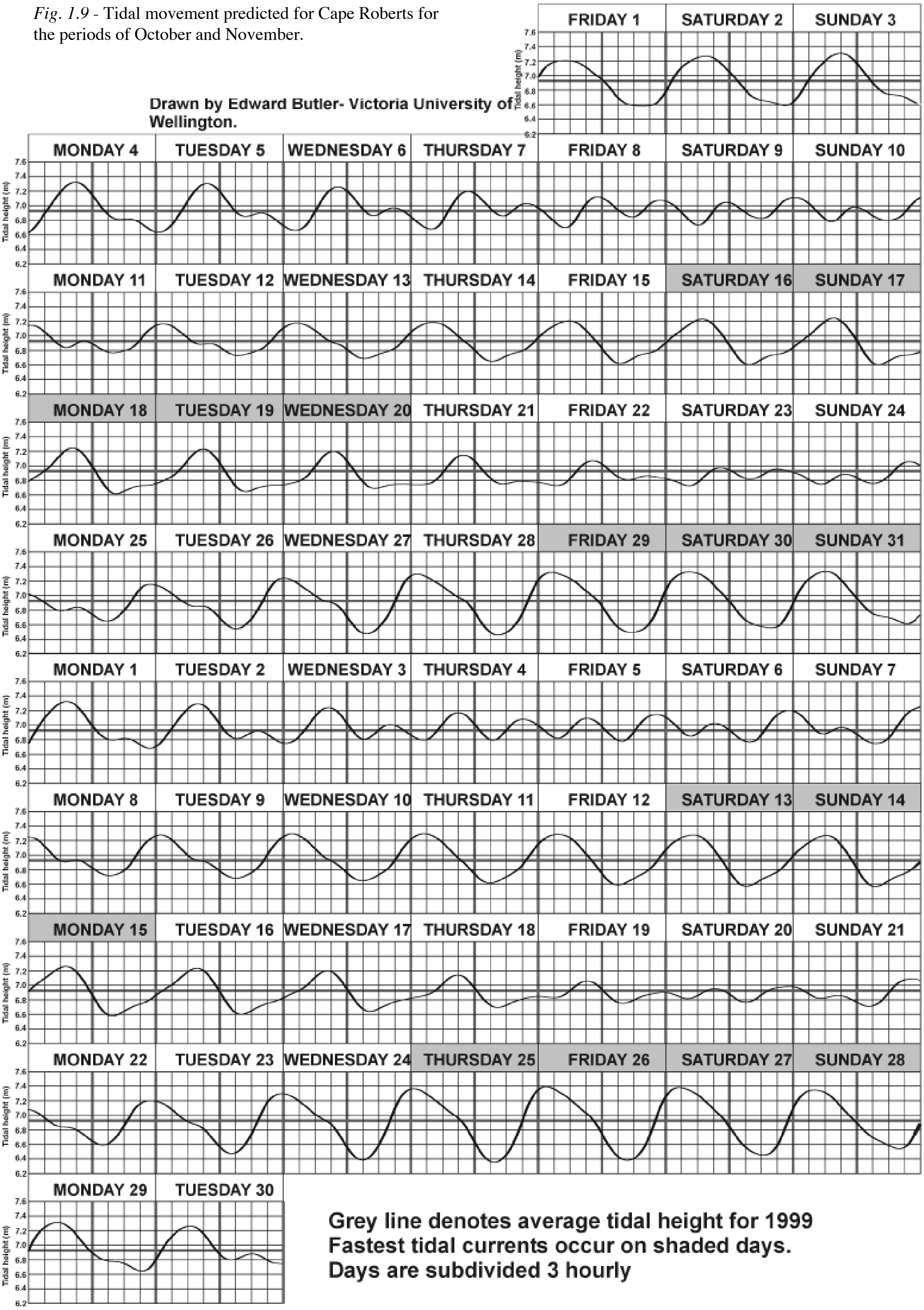


Fig. 1.8 - Weather and fast ice data plotted for the drilling period.

Fig. 1.9 - Tidal movement predicted for Cape Roberts for the periods of October and November.



Grey line denotes average tidal height for 1999
Fastest tidal currents occur on shaded days.
Days are subdivided 3 hourly

Tab. 1.3 - Summary of current meter deployments at proposed CRP-3 site.

File name	Deployment depth (m)	Deployment Period	Date	Period of spring-neap cycle
CRP3-98A.s4b	50	8 days	01-09/11/98	Neap-spring
CRP3-98B.s4b	55	3 weeks	10-27/11/98	Intermed. Neap-spring
CRP3VERT.s4b	Vertical	3-4 hours	28/11/98	Neap

during this period averaged 1.1 m/week, compared with 2.0 m/week during the drilling of CRP-2/2A in 1998.

Freeboard measurements were taken in the drilling and video hut fast-ice holes by measuring the distance from the water level to the top of a polythene ring, frozen into the fast ice and set 0.15 m above the fast-ice surface. Freeboard was largely maintained by deploying two air bags each with 5 tonnes of lift under the rig and mudroom. Losses in freeboard coincided with an increase in snow cover after storm events, but some recovery occurred after the snow was removed (Fig. 1.8). Freeboard under the drill rig was gradually lost as the ice warmed up. Freeboard at the mud huts was reduced to 95 mm by 15 November and remained stable.

On the fast-ice route to the drill site, the Cape Roberts crack was also monitored periodically (Fig. 1.6). The average weekly rate of spread was 0.3 m with the greatest spreading occurring during spring tides.

TIDE AND CURRENT MONITORING

The drilling operation is influenced not only by the lateral fast ice-movement but also by the vertical movement of the fast ice and the drag placed on the sea riser by tides and currents in the water column.

Tidal-height predictions for Cape Roberts were calculated on the basis of 12 months of records from the Cape Roberts tide gauge in 1998, using a tidal prediction program from the University of Hawaii Sea Level Centre. Tides are mixed (Fig. 1.9) with a maximum spring-tide and neap-tide range of *c.* 1.0 m and 0.3 m respectively. Spring tides are strongly diurnal (single cycle per day) while neap tides are characterised by two tidal cycles a day (semi-diurnal). Relative tidal heights measured on the rig floor this year show that tides are synchronous with the Cape Roberts tidal-height predictions (Fig. 1.9).

An investigation of currents was undertaken in November 1998, at the originally proposed CRP-3 site (located at 77.0151°S 163.6190°E and approximately 220 m west of the actual CRP-3 site) to establish a baseline for use in this year's drilling season. Water depth, current direction and current velocity were recorded using an S4 current meter. The instrument was deployed through a hole in the fast ice on three occasions during various stages of the spring-neap tidal cycle (Tab. 1.3). Vertical profiles were carried out to a water depth of 365□m, and longer-term static deployments were placed at elevations of 50 and 55 m water depth to measure mid-water current variations.

During spring tides, currents move in an anti-clockwise direction, through 360° over a 24-hr period with the larger flood tide of the day moving towards the northwest and continuing to swing around to the southeast for the subsequent low water (Fig. 1.10). At a water depth of 55 m during spring tides, current speeds reach a maximum of 0.3 ms^{-1} around low water and may remain above 0.2 ms^{-1} for up to 6 hrs on the largest of spring tides (Fig. 1.10). During neap tides, current speeds are mostly below 0.2 ms^{-1} throughout the water column, and at the sea floor, current speeds are <0.1□ms^{-1}. On only one occasion in October, during a

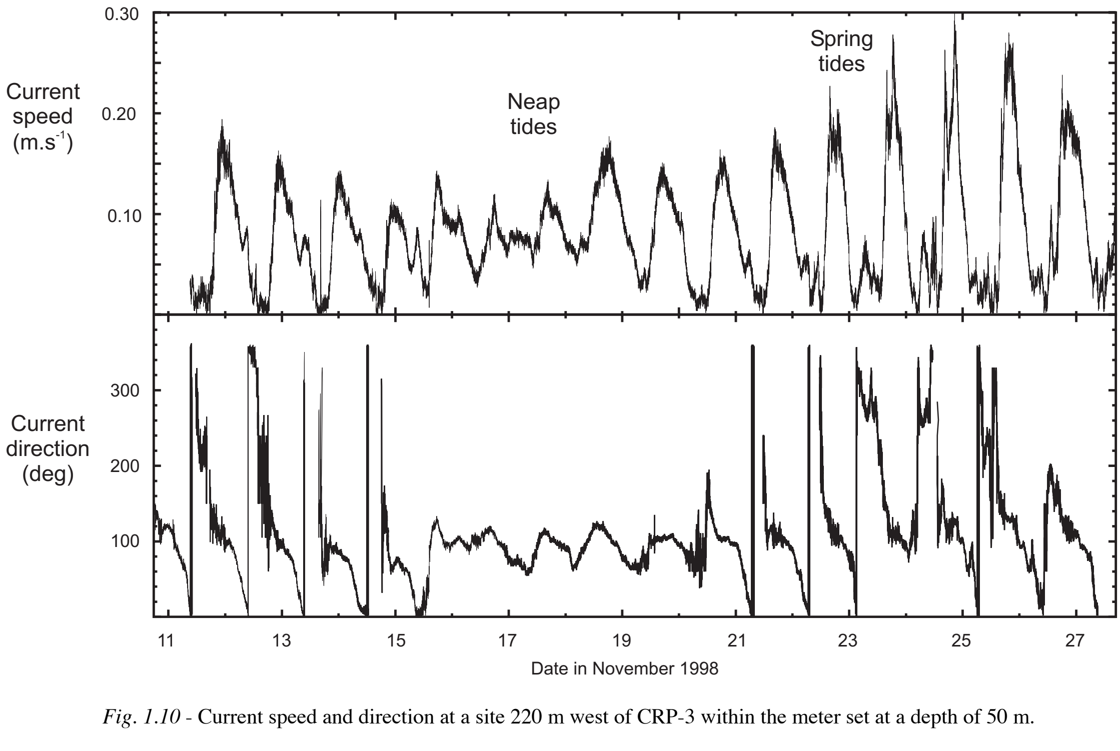


Fig. 1.10 - Current speed and direction at a site 220 m west of CRP-3 within the meter set at a depth of 50 m.

Fig. 1.11 - Aerial of view the CRP-3 drill site to show the layout of the rig, with sloping covered ramp down to the mudroom, and with core processing and physical properties laboratories in a cluster 30 m to the right.Photo: P.J. Barrett.

spring tide period, was there slight horizontal rotation of the sea riser (<1°) due to increased tidal speeds.

DRILLING OPERATIONS

INTRODUCTION

The drilling system was set up and operated as for CRP-2 and described in Cape Roberts Science Team (1999, p. 11). The layout of the rig and surrounding buildings is shown in figure 1.11, and the drilling system with sea riser installed and ready to continue drilling in figure 1.12. Core recovery began on 9 October and finished on 19 November at a depth of 939.42 mbsf. Downhole progress is shown in figure 1.13, with daily core summaries in table 1.4. Drilling activity is summarised in table 1.5.

SEA RISER DEPLOYMENT PHASE

The sea riser is a casing string of 5” OD flush-jointed high-strength drill pipe, comprised mostly of 5.5-m lengths with 3- and 1-m “shorts”. It extends from just above the fast ice through the water column to a depth of several metres into the sea floor. Its functions are to support the rotating drill string in the water column, and to provide an annulus for returning drilling fluid to the rig. A casing shoe of hardened weld material (OD 5.5”) was fitted to improve the cutting and flushing down

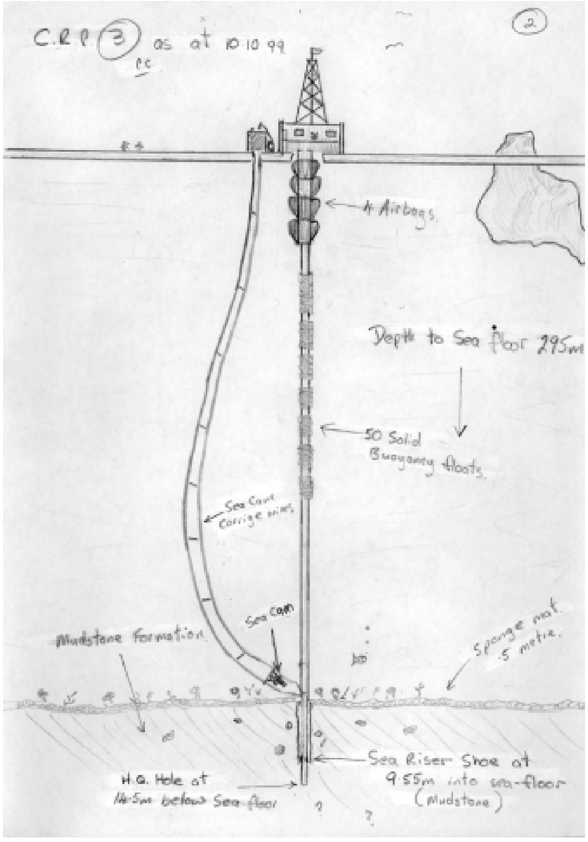


Fig. 1.12 - Drilling system set up at CRP-3 showing the sea riser set in mudstone. Sketch: Pat Cooper.

Tab. 1.4 - Summary data on downhole progress and core recovery. The 24-hour day extends from 08.00 to the same time the following day. Note that the bottom of the lowest core is at 939.42 mbsf on account of 0.13 m "stickdown" below the measured depth of the bottom of the coring run.

DATE	DEPTH	DRILLED	RECOVERED		
	(m)	(m)	(m)	(%)	(CUM%)
9 Oct	9.98	8.58	5.28	62%	62%
10 Oct	14.50	5.40	4.58	85%	75%
10 Oct	Sea riser cemented at 9.50 mbsf				
13 Oct	24.74	10.34	9.27	90%	82%
14 Oct	51.30	26.56	25.83	97%	90%
15 Oct	81.06	29.76	29.55	99%	94%
16 Oct	114.20	33.14	33.09	100%	95%
17 Oct	147.20	33.00	33.05	100%	96%
18 Oct	177.20	30.00	30.00	100%	97%
19 Oct	207.20	30.00	30.02	100%	98%
20 Oct	246.20	39.00	38.95	100%	98%
21 Oct	285.70	39.50	36.26	92%	97%
22 Oct	Change of HQ bit at 293 mbsf				
22 Oct	294.70	9.00	8.72	97%	97%
23 Oct	327.50	32.80	32.85	100%	97%
24 Oct	345.85	18.35	18.27	100%	97%
24 Oct	Beginning of down-hole logging to 345 mbsf				
29 Oct	Beginning of NQ coring – replaced surface set bit				
29 Oct	348.82	2.97	0.66	22%	97%
30 Oct	395.50	46.68	42.33	91%	96%
31 Oct	437.18	41.68	39.99	96%	96%
1 Nov	485.72	48.54	47.76	98%	96%
2 Nov	Change of NQ bit at 492 mbsf				
2 Nov	510.10	24.38	20.95	86%	96%
3 Nov	552.23	42.13	40.42	96%	96%
4 Nov	588.85	36.62	35.01	96%	96%
4 Nov	Change of NQ bit at 605 mbsf				
5 Nov	606.00	17.15	17.27	101%	96%
6 Nov6	640.30	34.30	32.70	95%	96%
7 Nov	668.90	28.60	28.44	99%	96%
8 Nov	704.91	36.01	35.89	100%	96%
9 Nov	738.00	33.09	33.12	100%	96%
10 Nov	774.00	36.00	35.94	100%	97%
11 Nov	Beginning of down-hole logging to 774 mbsf				
13 Nov	Continuing with NQ coring				
13 Nov	798.20	24.20	24.24	100%	97%
14 Nov	833.30	35.10	35.22	100%	97%
15 Nov	869.32	36.02	34.45	96%	97%
16 Nov	900.30	30.98	30.43	98%	97%
17 Nov	918.10	17.80	17.44	98%	97%
18 Nov	939.29	21.19	21.51	102%	97%

through the formation and to create an annulus between the formation and the riser.

The configuration of the floatation on the sea riser at the CRP-3 site was based on a water depth of 295 m, which was first measured on 4 October with a weight attached to the wire line. Twelve 4x1 m and one 2x1 m rigid flotation units were clamped on 5.5-m sea-riser lengths. This reduced the weight of the riser in sea water from 6580 kg to a residual weight of approximately 2000 kg once fully deployed to the sea floor. The residual weight is used to install the riser into the sea floor with washing and bumping (also termed jetting and jarring) techniques.

The sea floor consisted of a soft surficial muddy sponge mat about 0.5-m thick, underlain by soft sediments to a depth of 1.4 m. All downhole measurements for CRP-3 are made in metres below the sea floor (mbsf), which is taken to be the base of the sponge mat.

The sea riser was initially jetted into the sea floor to a depth of 1.4 m, and then hung from a hydraulic deployment frame beneath the drill floor in the "cellar". The HQ coring barrel was then run inside the riser to the bottom of the hole, and coring was progressively carried out in short runs of 1.5 to 2 m beyond the sea riser casing. After each run the riser was bumped into the newly cored hole. This method reveals the type of formation present, which allows us to assess its suitability as an anchor for the riser. It also recovers core virtually right from the sea floor for scientific study. This process was repeated to a depth of 9.55 mbsf, with HQ coring ahead to 14.50 mbsf confirming competent ground to that depth. The decision to cement the sea riser at 9.55 mbsf was made because a suitable interval of competent ground had been encountered, and continuing to bump the sea riser would have stressed it, perhaps leading to tool joint failure as resistance from the formation increased. The annulus was then cemented, with a visible return of cement to the sea floor on the submarine video system, indicating a gauge hole, with space for a good seal.

HQ DRILLING PHASE

We continued coring with the HQ drill string to a depth of 345.85 mbsf with a 3-m barrel and HQ3 impregnated-diamond series-2 bits, cutting core of 61 mm in diameter. Core was recovered by wire line with an inner tube containing stainless steel splits. Coring through this drilling phase averaged 28 m/24 hrs and ranged from 8 to 39 m/24 hrs (Fig. 1.13). The HQ drill rod was then cemented in from 345.55 up to 50 mbsf, using two HQ rubber cementing displacement bungs, in preparation for NQ coring.

NQ DRILLING PHASE

The cementing bungs were top drilled with an NQ surface-set stepped-faced diamond bit. An NQ3 series-2 impregnated-diamond bit was then substituted in place of the surface-set bit, and coring continued using a 6-m barrel cutting core 45 mm in diameter. Core was recovered with an inner tube containing steel splits, as 6-m stainless steel splits are unavailable. The NQ coring phase, which ran from 345.85 to 939.42 mbsf, averaged 31 m/24 hrs and ranged from 11-48 m/24 hrs (Fig. 1.13).

Core recovery for the entire hole averaged 97% with most of the loss coming from the initial HQ coring during deployment of the sea riser and in intervals of unconsolidated sands between 380 and 530 mbsf.

RECOVERY PHASE

On completion of the final logging run, we cemented the HQ-cased section of the hole to within 50 m of the sea floor, using HQ cementing plugs and the NQ drill string

Tab. 1.5 - Main drilling events during CRP-3.

Date	Drilling Activity
2/10/99	Drilled access hole for drill rig.
3/10/99	Diver installed air bags under sea ice beneath drill rig.
4/10/99	Prepared sea riser casing. Wire line measurement to sea floor =290 m.
5/10/99	Lowered 132 m of sea riser.
6/10/99	Lowered sea riser to about 280 m, including 12x4 m and 1x2 m rigid buoyancy modules.
7/10/99	Stripped over air bag tensioning system and prepared HQ drill string. 24 hour operation begins.
8/10/99	Lowered and bumped/washed in sea riser about 2.3 mbsf. Tagged sea floor at 295 mbsf (13.00 hrs). Ran HQ drill string and began slow coring from 2.8 to 5.4 mbsf
9/10/99	Cored to 6.9 mbsf, advanced riser to 4.3 mbsf, cored to 9.1 mbsf, advanced riser to 5.30 mbsf and cored to 13.17 mbsf.
10/9/99	Cored to 14.40 mbsf, ran in HQ drill string, advanced sea riser to 9.4 mbsf. Ran in HQ string with casing shoe, cemented sea riser and recovered HQ string.
11/10/99 – 12/10/99	Ran in HQ coring string.
13/10/99	Cored out cement and then cored formation from 14.40 to 24.74 mbsf.
14/10/99 – 24/10/99	Cored HQ from 24.74 to 345.85 mbsf.
24/10/99	Tripped out HQ string, changed core barrel to casing shoe for advancer. Set casing shoe at 18.3 mbsf and conditioned hole for downhole logging.
25/10/99-26/10/99	Downhole logging interval 18.30-255.00 mbsf.
26/10/99	Lowered HQ string with casing advancer to 345.80 mbsf, washed and drilled past shear zone. Cleared and conditioned hole and pulled back to 271.55 mbsf.
26/10/99-27/10/99	Downhole logging interval 271.50 to 345.50 mbsf.
27/10/99	Washed HQ casing to bottom of hole and cement with casing advancer.
27/10/99-28/10/99	Care and maintenance while cement set. Prepared NQ drill string and drilled out rubber bungs (used in cementing) with a stepped surface set diamond bit to 348.82 mbsf.
29/10/99-02/11/99	Changed to an impregnated-diamond series-2 bit and cored NQ from 348.82 to 492.10 mbsf.
02/11/99-05/11/99	Bit was replaced at 492.10 mbsf with another impregnated-diamond bit and NQ coring continued to 604.88 mbsf.
05/11/99-11/11/99	Bit was replaced at 604.88 mbsf with another impregnated-diamond bit and NQ coring continued to 774.00 mbsf.
11/11/99-13/11/99	Downhole logging interval 345.50 to 774.00 mbsf.
13/11/99-19/11/99	Continue coring in NQ with new impregnated-diamond bit from 774.00 to 939.42 mbsf.
19/11/99	Coring was terminated because of squeezing formation at 901.00-902.00 and 919.00-920.00 mbsf.
19/11/99-21/11/99	Downhole logging interval 774.00 to 918.00 mbsf.

for displacing cement. A hydraulically operated HQ casing cutter was run on the NQ drill string and the HQ casing was cut at 10 m below the sea floor. The sea riser was severed *c*. 3 m above the sea floor with a SwETech AB colliding drill collar charge type 2 (oil field-type explosive), which was wire-lined into position and exploded electrically. The sea riser and air-bag pipes were recovered in the following 24 hours.

The technical objectives planned for CRP-3 were to core continuously to a minimum depth of 700 mbsf, and to run a full set of geophysical logs for the hole. CRP-3 cored to 939 mbsf, and logging was carried out to a depth of 918 mbsf, over 30% beyond the target depth and a significant new benchmark for Antarctic bedrock drilling.

HYDROCARBON CONSIDERATIONS

We recognised that a deep hole in the sedimentary strata off Cape Roberts could potentially contain hydrocarbons, because small amounts of tar residue (dead oil) had been reported from around 632 mbsf in CIROS-1 (Barrett, 1989) and from below 500 mbsf in CRP-2A (Cape Roberts Science Team, 1999). Although the prospect of encountering hydrocarbons was considered very low, inflammable gas and hydrogen-sulphide Sieger series-2000 gas sensors were operated during the drilling for safety reasons. The air space above the mud-scavenge tank in the drill-rig cellar was continuously sampled through a heat-traced tube connected to a glycol trap (located on the rig floor). Gas

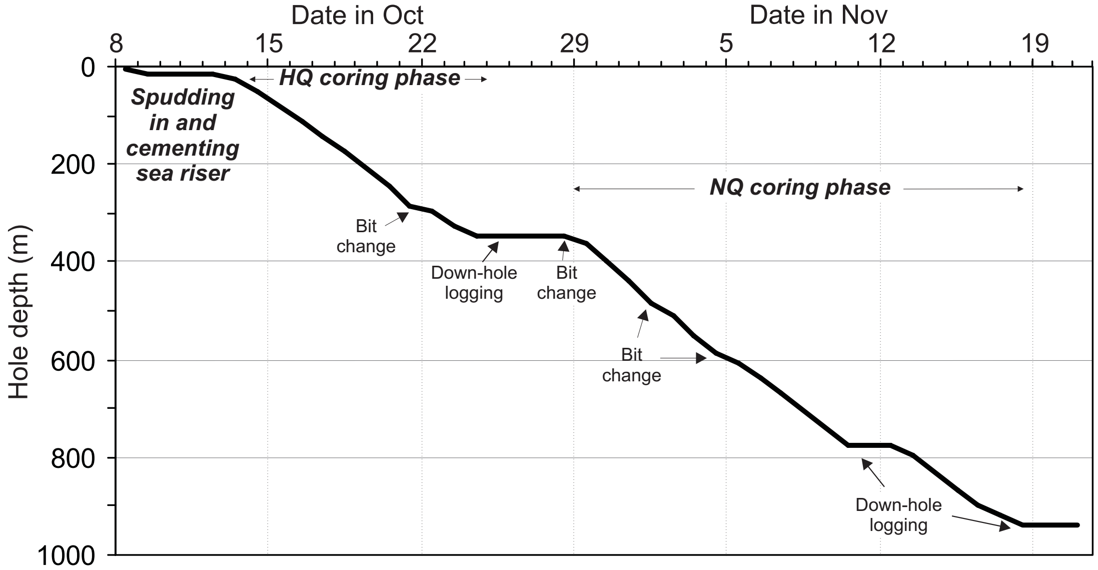


Fig. 1.13 - Downhole progress during the drilling of CRP-3.

extracted in this way was then pumped through tubing to the gas sensors in the generator hut workshop (passing through a warmed walkway and mud huts). The response time of the system was approximately 15 seconds. The inflammable gas sensor appeared to be affected by diurnal temperature changes and required periodic re-zeroing.

CORE MANAGEMENT AND SAMPLING

DRILL SITE AND CAPE ROBERTS CAMP

Initial core curation began at the drill site. Upon core recovery, downhole depths were measured on the core to the nearest centimetre and expressed as metres below the sea floor (mbsf).

The core was first cut into one-metre lengths and then longitudinally into an Archive Half and a Working Half using a rotary diamond saw. The Archive and Working halves were placed in separate core boxes (3 m *per* box for HQ size core and 4 m *per* box for NQ size core). Yellow plastic separators, with the mbsf depth written on them, were placed at one-metre intervals within the core box. Any voids in the core box were filled with foam blocking to minimize movement of the core during transport.

Sampling of the core also began at the drill site. A 10-cm section of the Working Half was taken at approximately 20 m intervals. This "fast-track" sample was sent the same day by helicopter to the palaeontologists at McMurdo Station for age determination. In addition to the "fast-track" sample, fourteen 10- to 20-cm long whole-core sections were removed from the core for clast-fabric and shape studies.

TRANSPORTATION

Core Boxes from Cape Roberts Drill Site to McMurdo Helicopter Pad. Insulated, vinyl-covered carrying cases, with a capacity of three or four core boxes each, were used to transport the core *via* helicopter between the Cape Roberts Drill Site and the Cape Roberts Camp, and then on to McMurdo Station. The carrying cases were placed inside the helicopter to protect the core from freezing. Two to four carrying cases (6-16 core boxes) were transported each day along with a "fast-track" sample. The Working and Archive halves of the core were sent on alternate days as a safety measure.

Core Boxes to Core Storage Facility (CSEC-CSF). The cases containing the core arrived at the McMurdo helicopter pad between 20.00 and 24.00 hrs each day and were transported, by truck, from the helicopter pad to the Crary Science and Engineering Center-Core Storage Facility (CSEC-CSF). The insulated cases were carried into the CSEC-CSF where the individual core boxes were removed from the carrying cases, logged in, and placed on shelving. The Archive and Working halves were placed in separate areas of the Facility. The CSEC-CSF was maintained at a temperature of 4°C and at a relative humidity of 60%.

SEQUENCE OF EVENTS IN THE CSEC CORE LABORATORY

Core Laboratory, McMurdo. A core laboratory was set up in room 201 of the CSEC. The walls, the floor, the benches, and all equipment in the room were thoroughly cleaned prior to the core arrival at the laboratory and at the end of each sampling session to minimize the potential for contamination of the core. The temperature of the room was maintained at 18°C. The relative humidity of room 201 was low (40%), despite the addition of two humidifiers operating 24 hrs/day. The laboratory contained 10 m of bench space covered with an easily cleaned surface. Fluorescent lighting was augmented by high-intensity halogen lighting to enhance the viewing of the core.

The morning following the arrival of the core at McMurdo Station, the core boxes were repackaged into the insulated cases and then carried by hand to the Core Laboratory in the CSEC. The core boxes were removed from the carrying cases and placed on the laboratory benches in depth sequence.

Initial Core Appearance. In general, the core arrived from the Cape Roberts Camp in excellent condition. The core was moist, with a sheen of water on the cut surface of the sediment. Occasionally, minor longitudinal shifting had occurred within the individual metre-long sections. The cores were misted with filtered water on a regular basis to counteract the dehydration effects of the low humidity in the room.

Core Logs Rechecked, Photography, and Viewing of the Core. Each day 18 to 40 m of the Working Half of the core were logged and photographed by the sedimentologists, and the core logs received from the Cape Roberts Camp were checked for discrepancies against the core. Upon completion of core logging, the sedimentologists provided a short briefing and a tour of the displayed core to the Cape Roberts science group.

Selecting Sample Intervals. On average, 18 to 40 m of core were available for sampling each day. The investigators selected their sample intervals by placing disposable sample "flags" (a toothpick with an adhesive label wrapped around it) alongside the core. The palaeomagnetic investigators marked their samples by placing 4□x 7 mm slips of paper over their requested intervals.

Disputed Sample Intervals. Overlaps between investigators requesting the same interval were resolved through discussions with the on-ice parties involved, the curators, and the Cape Roberts Sample Committee (Harwood, Janecek, Powell, Talarico).

Data Entry. The curators entered the sample interval data into a relational database (4th Dimension). These data included: the investigator, hole number (CRP-3), box number (1-256), top interval of sample (mbsf), bottom interval of sample (mbsf), volume of the sample (cubic centimetres), date, and comments. The comments section recorded the type of sample taken (*e.g.*□sediment, fossil, or clast) and the discipline and type of analysis to be performed on each sample (*e.g.* petrology-thin section or palaeontology-diatoms). This sample information and other coring information can be accessed through the WWW sites of the curatorial facilities at the Antarctic Marine Geology Research Facility, at the Florida State University in Tallahassee, Florida (www.arf.fsu.edu) and the Alfred-Wegener-Institute for Polar and Marine Research in Bremerhaven, Germany (www.pangaea.de).

SAMPLING

General Sampling. The core curators carried out the routine daily sampling, with over 5 900 samples taken for on-ice investigation. Common laboratory spatulas, small scoops, and forceps were used to remove samples from unlithified core. A diamond saw was used cut the more lithified material, as well as the large clasts. All of these tools were cleaned prior to the beginning of the sampling session and between the sampling of different intervals. At no time was any tool used more than once before it was cleaned. The sampling tools were washed with hot water and a laboratory detergent, rinsed with clean water, and then given a final rinse with filtered water. The tools were allowed to air dry to minimize the potential for contamination by paper or cloth fibre. The voids left in the core following extraction of the samples were filled with cut foam blocks to stabilize the core. Upon completion of sampling, the core was misted with filtered water and then returned to the CSEC-Core Storage Facility. The benches, the floor, and all sampling equipment were washed in preparation for the next shipment of core.

Palaeomagnetic Sampling. The palaeomagnetists conducted their own sampling. To avoid contamination of the core, orientated, coherent sections were removed from the core box, placed on a carrying tray, and taken to the palaeomagnetic sampling lab (a separate building located on the loading dock of CSEC room 201). A diamond drill was used to remove the sample and the remaining core section was replaced in the core box in the proper orientation.

CORE SHIPMENT

The core was re-examined in the CSEC-CSF prior to packaging for shipment to the core repositories in Florida and Germany. Additional foam blocking was added where needed, and the core was misted with filtered water again before the core-box lids were taped into place.

The core boxes were placed into specially constructed wooden boxes that contained nine separate compartments holding four boxes each. The containers were marked with arrows pointing to the upright position and with signs designating the correct temperature for transport (4°C/40°F). The wooden boxes were shipped in a refrigerated container via the cargo ship *Greenwave* to Lyttleton, New Zealand. The Working Halves of the core were off-loaded for ocean transport to Germany. The Archive Halves continued aboard the *Greenwave* to California, where they were off-loaded and transported overland *via* refrigerated truck to Florida.