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Seismic Stratigraphy of the Pre-Quaternary Strata Off Cape Roberts and their Correlation with Strata Cored in the CIROS-1 Drillhole, McMurdo Sound

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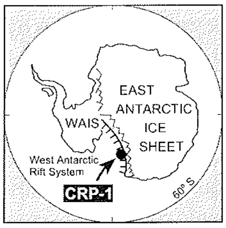
Abstract - The seismic stratigraphy of the western McMurdo Sound region has been re-evaluated in response to the apparent 8 m.y. discrepancy in the age of seismic units traced between the CRP-1 drillhole located off Cape Roberts and the CIROS-1 drillhole, located 70 km further south. All the available seismic reflection in the region, including new single and multi-channel seismic data recorded in the region in 1996 by R/V N B PALMER, have been compiled and reanalysed to develop a consistent interpretation of the seismic units in the region, using the seismic stratigraphy of Bartek et al. (1996). The interpretation has been based on the original interpretation of seismic units in the data recorded by the R/V S. P. LEE (Cooper & Davey, 1987) and has been traced across the region to the CRP-1 drillsite. A crucial correlation at the CRP-1 site is for the boundary between the Units V3 and V4. This unconformity lies at depth east of the drillsite and the associated reflection event has been traced to the CRP-1 site in two ways; one directly across the Roberts Ridge, where it has to be traced through the seafloor multiple, and the second through deep water north of Roberts Ridge. The two correlation pathways result in a discrepancy of about 100 m where the unconformity intersects CRP-1. If the correlation across Roberts Ridge is correct then the strata equivalent to 318 m in CIROS-1 will, at the CRP-1 site, be 21 thick and the V3/V4 boundary lies 163 mbsf. If the alternative is correct then the equivalent strata at the CRP-1 site will have also reduced in thickness, but only to about 120 m, and the V3/V4 boundary lies around 250 mbsf.



INTRODUCTION

The CRP-1 drillhole located off Cape Roberts on the western margin of the Victoria Land Basin, sampled Quaternary cover sediments underlain by early Miocene glacigenic strata. The Miocene sediments ranged in age from approximately 17 Ma at 43 metres below the sea floor (mbsf) to approximately 22 Ma at 148 mbsf, where drilling was terminated (Cape Roberts Science Team, 1998). These initial results estimated that the bottom of the hole lay approximately 15 m above the seismic reflector inferred to be the base of seismic sequence V3 of Cooper & Davey (1985) (base of RSS-2 in the terminology of Brancolini et al., 1995). Earlier studies (Barrett et al., 1995; Bartek et al., 1996) have traced the boundary between seismic sequences V3 and V4 (V3/V4) from the Cape Roberts region to the CIROS-1 drillhole 70 km further south (Fig. 1), where it was considered to correspond to a major unconformity covering the period 30-34 m.y. at 366 mbsf (Harwood et al.,1989). The apparent 8 m.y. difference in age has prompted a reassessment of the correlation between the two drillsites.

Correlation of seismic sequences on the margin of the Victoria Land Basin is difficult. The flanks of the topographic highs are sites of periodic erosion, indicated by sequences that appear condensed and include filled channels. Tracing reflections through the bathymetric highs is also difficult, as the reflectors need to betraced through and beneath the sea-floor multiple - a significant problem in the area of the CIROS-1 hole. Dating the seismic sequences in the Victoria Land Basin is also difficult because there are still only a small number (4 to date) of drillholes in the southern corner of the basin, and only one of these cored a significant thickness of strata (CIROS-1, cored to 702 mbsf, Barrett, 1989).

The purpose of this paper is to evaluate the previously published seismic stratigraphy using all available single and multichannel seismic data and seek consistency in the age of seismic reflectors and sequences between CIROS-1 and CRP-1. To do this it was necessary to review the nature of the V3/V4 boundary, as first recognised in the R/V S.P. LEE data by Cooper & Davey (1987). After establishing abroad but robust correlation of their data with recently acquired high-resolution data we present an

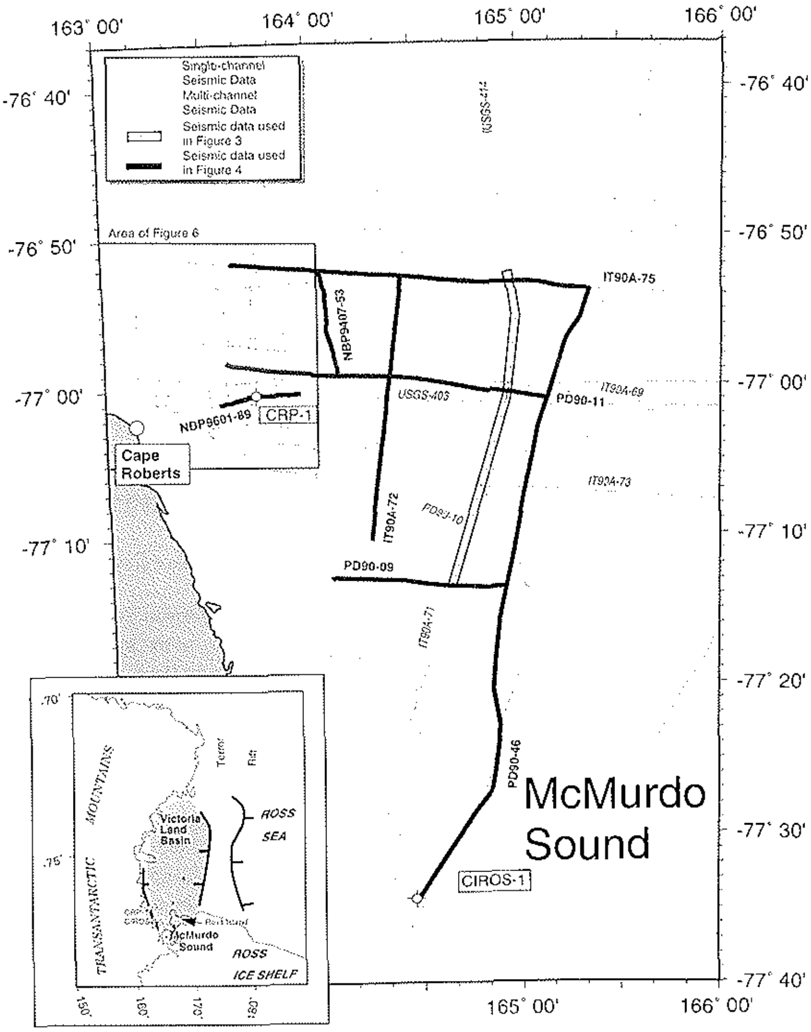


Fig. 1 - Map of the southwestern corner of the Ross Sea, showing tracks along which the seismic data used in this review were collected. Inset shows the structural setting and the location of the CRP-1 and CIROS-1 drillholes on the western margin of the isopach map of seismic sequence V4 and a structure contour map of the V3/V4 surface over the area around Roberts Ridge (Fig. 1).

DATA

A regional stratigraphic framework was established for the whole Victoria Land Basin by theR/V S.P. LEE from 1 850 km of multichannel seismic profiles (Cooper &Davey, 1985). A deep basin, 10 to 14 km thick was delineated containing sediments and volcanic rocks, and six seismic sequences (V1-V6) were identified within the strata that could be widely mapped above acoustic basement (V7). The OGS EXPLORA (Brancolini et al., 1995) carried out a further multi-channel survey in the southern part of the Victoria Land Basin in 1990. These data were used to extend the regional stratigraphy developed by Cooper & Davey (1985, 1987), recognising eight units (from RSS1 up to RSS8) equivalent to V1 to V5 (see Tab. 1 for correlation between stratigraphic nomenclature). The use of multi-channel seismic data can significantly reduce sea-floor multiple energy and improves the correlation of events below and through the multiple. However, the process usually results

Tab. 1 - Main features of seismic sequences off Cape Roberts, with a comparison of the stratigraphy of Cooper & Davey (1985, 1987), Barrett et al. (1995) and Bartek et al.(1996), and Brancolini et al.(1995).

Barrett et al., 1995	Age	Thickness (m)	Bartek et al., 1996	Cooper & Davey, 1985, 1987	Brancolini et al., 1995	Facies/Comments
V3	< 22 m.y. Early Miocene to Late Oligocene	0.250	N.O	V2	RSS-3	Diamictite sandstone and mudstone
					RSU5	
			P.Q		RSS-2	
				V3	RSU6	
V4	~30-55 m.y. Early Oligocene to Mid Eocene	0 – 800	R		RSS-1	Deepwater mudstone some sandstone & diamictite
			S,T	V4		Turbidites and deepwater mudstones
V5	> 55 m.y. Paleocene to Late Cretaceous	> 2500 ?	—	V5		Unsampled/Unknown
V6	Late Cenozoic	??	—	V6		Volcanics
V7	Pre-Jurassic	??	—	V7		Metasedimentary, volcanic & igneous basement rocks

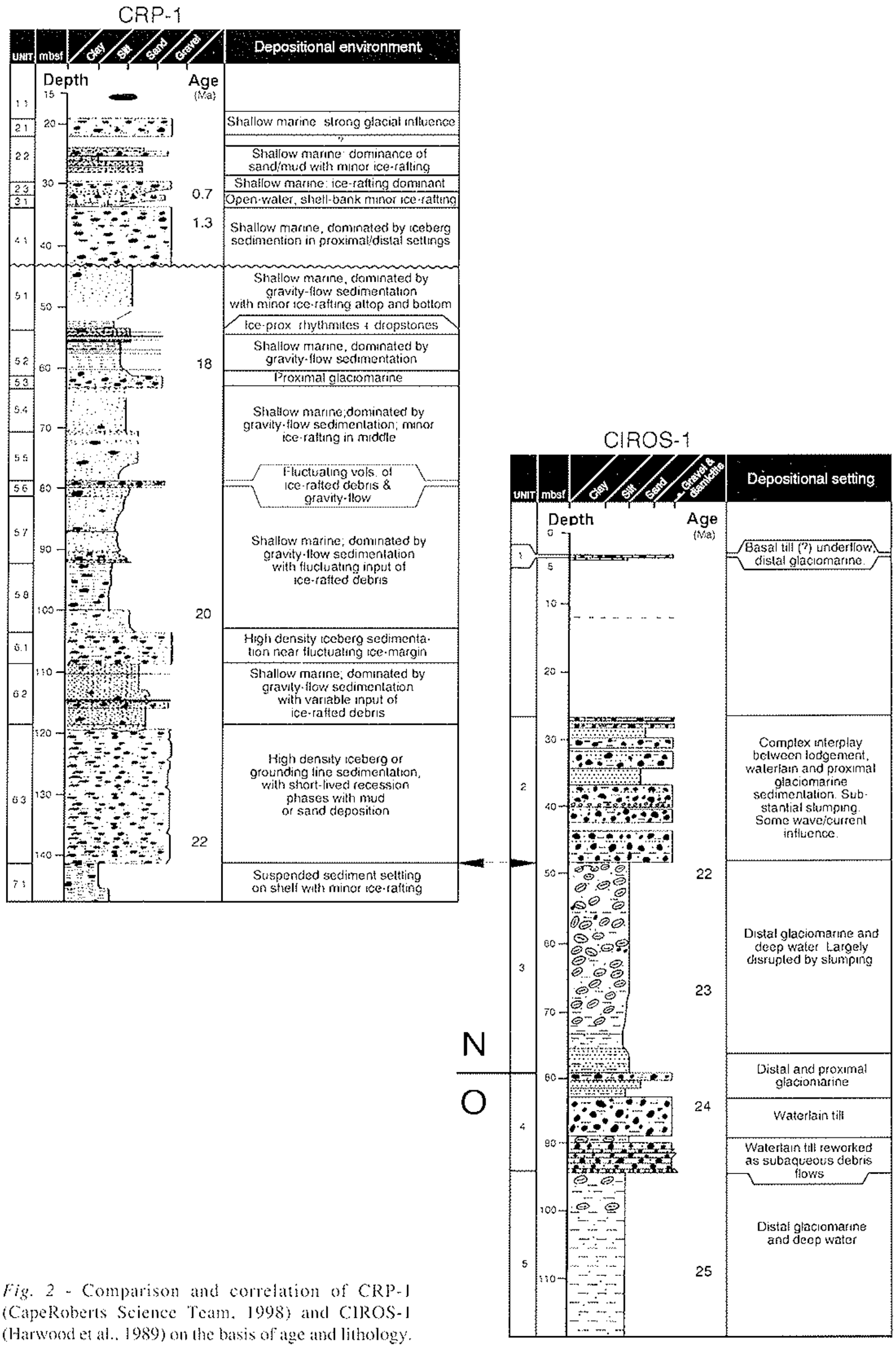


Fig. 2 - Comparison and correlation of CRP-1 (CapeRoberts Science Team, 1998) and CIROS-1 (Harwood et al., 1989) on the basis of age and lithology.

in the reduction of vertical resolution (lower frequency) and effectively limits detailed stratigraphic correlations to the use of major sequence boundaries.

The R/V S.P. LEE database in the area off Cape Roberts has been expanded by over 600 km of near-channel data from the OGS EXPLORA, single-channel high-resolution data (about 650 km) collected from the R/V POLAR DUKE in 1990 (Anderson & Bartek, 1992; Barrett et al., 1995; Bartek et al., 1996), and near-channel data (150 km) from a survey by R/V N. B. PALMER in 1996 (NBP9601) (Bartek & Luyendyk Co-Chief Scientists on NBP9601 and Hamilton et al., this volume). These data provide the basis for a review of the correlation in seismic stratigraphy between the two drillholes CRP-1 and CIROS-1, and the deep-water section.

The geological data from the two drillholes are summarised in figure 2. Comparison of ages shows that the sediments at the base of CRP-1 are approximately the

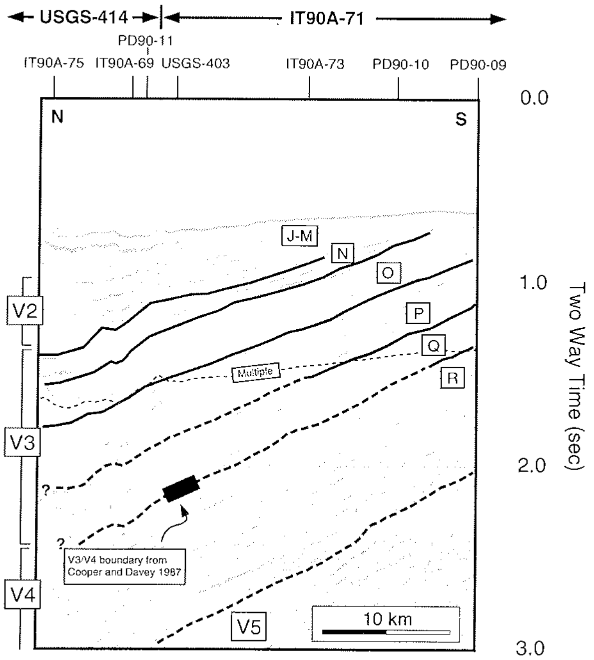


Fig. 3 - Combined portion of seismic profile USGS 414 and IT90A-71, showing intersections with profiles PD90-9, 10, 11, profiles IT90A-69, 73, 75, and profiles USGS 403. Seismic sequence boundary V3/V4 is defined on profile USGS 414 and its depth is marked by the heavy line. See figure 1 for location.

same age (*c.* 22 Ma) as the youngest pre-Quaternary strata in CIROS-1 (also *c.* 22 Ma), and the lithofacies of these time-correlative strata are also similar, comprising indistinctly stratified diamictite and interbedded sandstone underlain by mudstone. This suggests that the base of Unit 6 at 142 mbsf in CRP-1 would be equivalent to the base of Unit 2 in CIROS-1. However, in CRP-1, the base of V3 is placed at only 21 m below the base of Unit 6, whereas it is 318 m below the equivalent horizon, the base of Unit 2, in CIROS-1, around 300 m deeper stratigraphically and 8 million years older in time (Barrett et al.,1995).

ANALYSIS

The stratigraphy of the Victoria Land Basin is best developed towards in the centre of the basin, and has been most closely examined in high resolution single channel data from the central 900 m deep of McMurdo Sound. Here Bartek et al.(1996) have recognised 20 distinct and unconformity-bound seismic sequences, each typically a few tens of metres thick, and labelled from T through A (oldest to youngest) (N throughto T are shown in Tab. 1). This stratigraphy was carried southwest from central McMurdo Sound by IT90A-71 (Plate 6 of Cooper et al., 1995; part of which is shown in Fig. 3) and PD90-46 (Fig. 4), and onto the shallow (200 m) western shelf of theSound and the CIROS-1 drillhole. Although, the tracing of these units across the shelf edge is not unequivocal, a number of sequences can be traced into CIROS-1 including N, O, P and Q (Barrett et al., 1995; Bartek et al., 1996). At CIROS-1 the base of Q was picked by Barrett et al. (1995) to be 366 mbsf, a lithological change from muddy sandstone beneath to sandstone and conglomerate above. The change represes an unconformity spanning the period 30-34 m.y. (Harwood et al., 1989). This was also interpreted to be the base of V3 by Barrett et al. (1995) in the stratigraphy of Cooper & Davey (1987) and the baseof RSS2 in the stratigraphy of Brancolini et al. (1995); see table 1.

The bases for this were comparisons of USGS line 403, which crosses IT90A-72, IT90A-71 and PD90-46 (Fig. 4) and, importantly, USGS 414, all with IT90A-75 and PD90-11 which they cross (Figs. 3 & 4). In reviewing this correlation with drillsites and with other seismic lines, we return to the reflector first recognised by Cooper & Davey (1987) as the V3/V4 boundary. This is shown by them on USGS 403/414 at 2.2 sec (Cooper & Davey, 1987, Fig. 5, and shown in Fig. 3) and lies below the sea-floor multiple in seismic data across the Roberts Ridge. To help confirm our identification of this boundary on the single channel data, we have relied on multichannel processed data along lines IT90A-69 and IT90A-71 and tying into these data where this boundary occurs either just above or

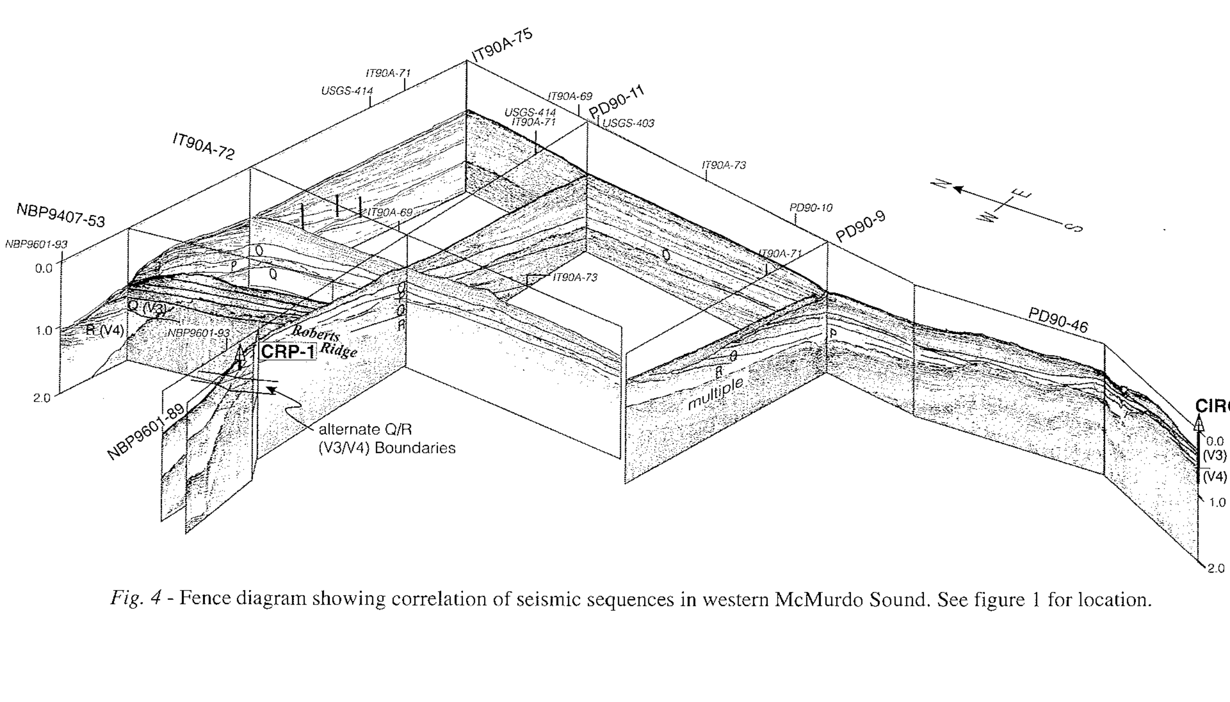
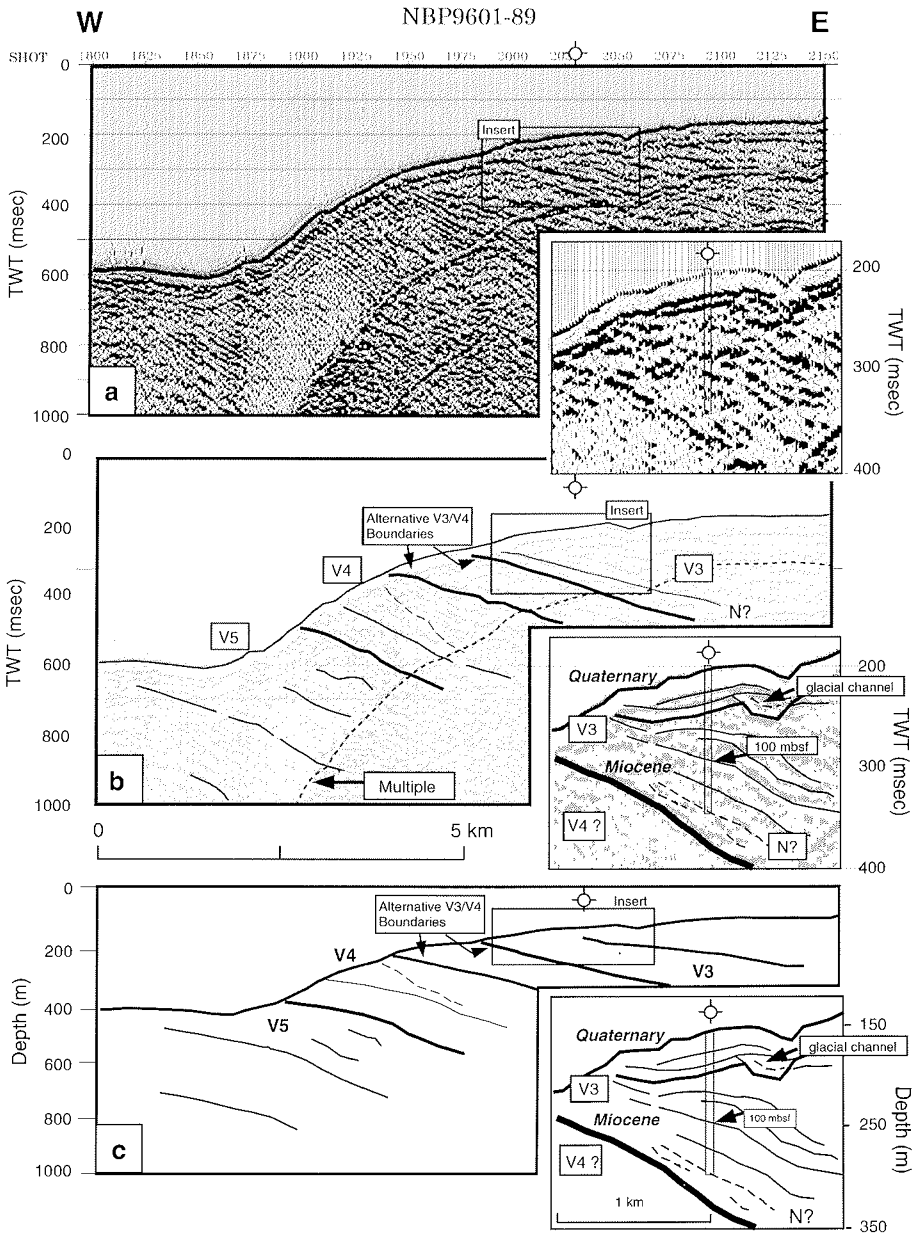


Fig. 4 - Fence diagram showing correlation of seismic sequences in western McMurdo Sound. See figure 1 for location.

Fig. 5 - Seismic record for line NBP9601-89 (*a*) with interpretation of stratigraphic Units V3, V4 and V5 in terms of travel time (*b*) and depth (*c*). Insets provide detail of the record at the CRP-1 site.



below the multiple (*e.g.* IT90A-71 and PD90-9, Figs. 3 & 4). We then attempted to trace the seismic event corresponding to the V3/V4 boundary across Roberts Ridge using PD90-11 and IT90A-69. Our interpretation correlates it with a seismic unconformity intersecting the sea floor at 270 msec (TWT) on line NBP9601-89 (Fig. 5, upper V3/V4 boundary). This seismic unconformity is the boundary shown in the initial report on CRP-1 (Cape Roberts Science Team, 1998) and reproduced here as figure 5.

We do not have full confidence in the existing correlation (Cape RobertsScience Team, 1998) because of the difficulty in tracing the seismic reflector through the multiple beneath Roberts Ridge, whose high point is less than 100 m below sea level along PD90-11 and IT90A-69. Processing of IT90A-69 was only partially successful in removing strong sea-floor multiple reflections, and only sequence N and to a lesser extent O could be confidently traced across the ridge. We also note that some units appear to thin towards the ridge crest, onlapping as a series of unconformities against tilted fault blocks that comprise the structure of Roberts Ridge (Hamilton et al., this volume). Here we propose an alternate correlation path which allows a correlation to be achieved using data recorded in deeper water regions so that older Units O and P, and in places Q, can be followed above the sea-floor multiple. From PD90-46 we follow seismic units northwards in deep water, where it intersects line IT90A-75 near the middle of the basin. Line IT90A-75 runs west across the nose of Roberts Ridge (across water depths never shallower than 400 mbsl) and along the Mackay Sea Valley. Using NBP9601-92, 93, and 94 (Fig. 6a), where they intersect IT90A-75, allows us to carry the seismic stratigraphy southward to CRP-1. We are confident of our identification of Units O and P onto IT90A-75, since we were able to use the east-west and north-south tie-lines marked in figure 4 to keep our correlation path above the seafloor multiple.

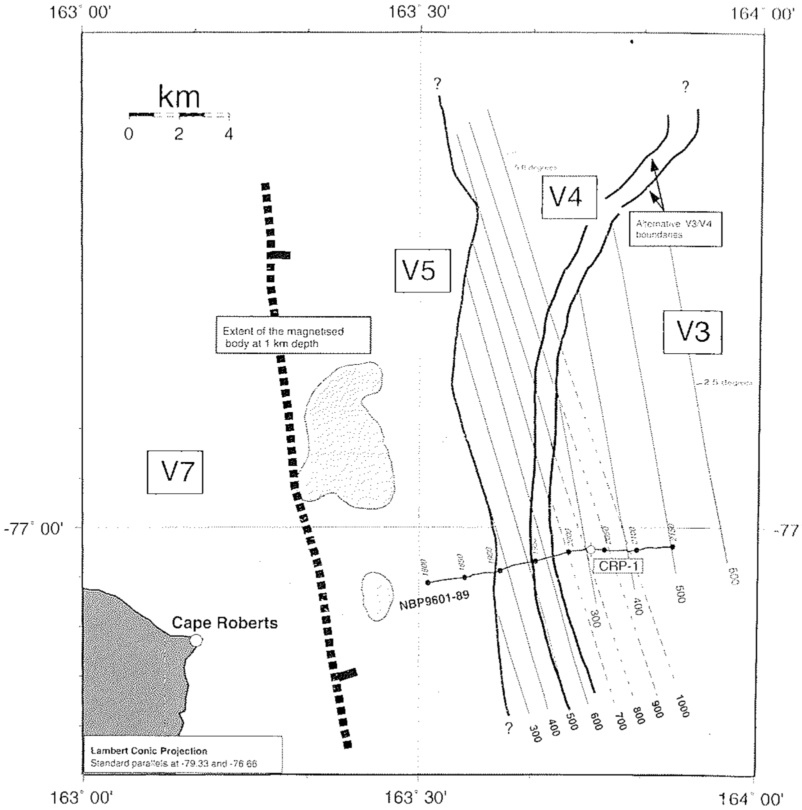
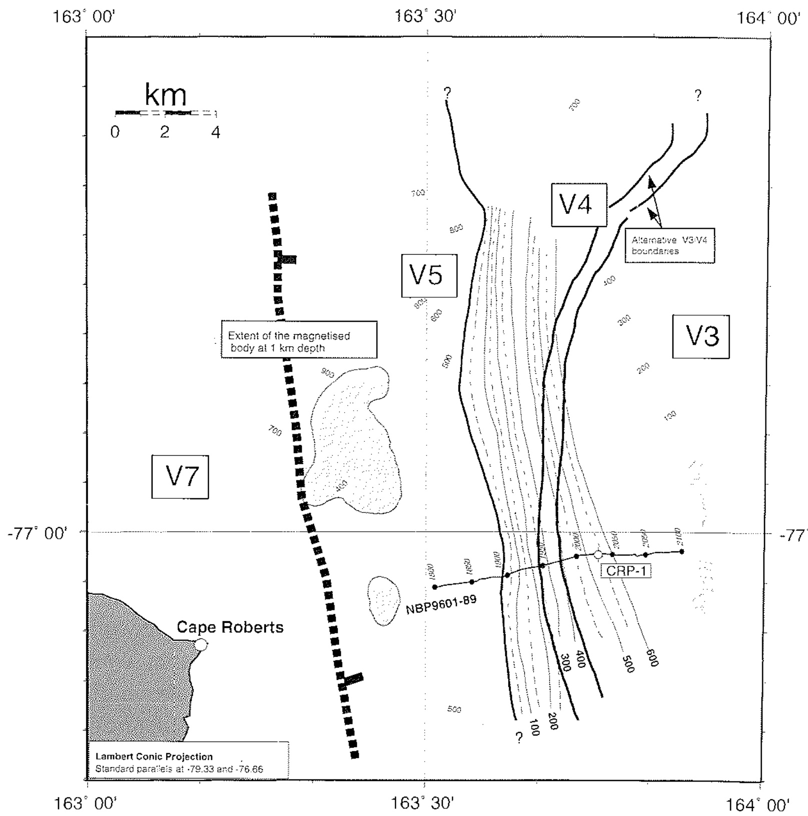


Fig. 6 - Map of the area off Cape Roberts showing the distribution of the sedimentary sequences (V3, V4, and V5) beneath the Quaternary cover beds. The heavy dashed line is the main boundary fault that separates the sedimentary sequence from the basement granitic rocks (V7), which crop out at the coast. The extent of a shallow stratiform basic igneous body, inferred from magnetic data is also shown.
a) Shiptracks (dotted) and structure contours on the base of V3 and V4.



b) Bathymetry (grey) and isopachs for V4 (both in metres) off Cape Roberts.

The correlation of units deeper than P is less reliable. Using the path described above we traced the base of Unit Q to a seismic unconformity at 330 msec (TWT) below the sea floor on NBP9601-89 (shot point 1940 on Fig. 5), about 100 msec (about 100 m) stratigraphically below the V3/V4 boundary, identified previously in the strata off Cape Roberts. We now consider each of these to be equally valid estimates for the V3/V4 boundary, and thus show them both in figure 5. Hamilton et al. (this volume) uses the lower of these alternate boundaries.

The two alternative V3/V4 boundaries, cropping out on the western flank ofRoberts Ridge, are shown in figure 6. Structural contours and isopachs derived using the shallower V3/V4 boundary indicate that the base of V4 is a planar, easterly dipping surface with steadily increasing thickness eastwards at around 100 m/km. Westward, V4 will thin out near where we have identified the main boundary fault that separates the sedimentary sequence from basement rocks (Fig. 6). A consequence of the V3/V4 boundary being 100 m deeper (*i.e.* using the lower of the alternate boundaries shown in Fig. 5) would be the addition of another 100 m to the structure contours and the reduction of 100 m from the V4 isopachs. Once the strata beneath those sampled by CRP-1 have been cored, the exact depth and significance of the V3/V4 boundary will be known.

CONCLUSIONS

The seismic stratigraphy of the western McMurdo Sound region has been re-evaluated in response to the apparent 8 m.y. discrepancy in the age inferred for the sediments corresponding to seismic sequences traced between CIROS-1 and CRP-1 located off Cape Roberts. The crucial correlation at both CIROS-1 and CRP-1 sites is the identification of the seismic boundary between the Units V3 and V4. This unconformity has been mapped in the Victoria Land Basin, east and north of the drillsites, and the associated reflection event has been traced to the CIROS-1 site where it was considered to correspond to a major unconformity at 366 mbsf (Barrett et al., 1995; Bartek et al., 1996). At the CRP-1 site the identification of the V3/V4 boundary has been made in two ways; one directly across the Roberts Ridge, where it has to be traced through the sea-floor multiple, and is about 100 ms shallower at CRP-1 than the correlation through deep water north of Roberts Ridge. Because seismic sequences appear to thin and onlap as series of unconformities, as they approach the crest of Roberts Ridge (Fig. 5), there is the possibility of Units O, P, and Q (correlated with late Oligocene rocks at CIROS-1) being eroded or condensed at CRP-1. Furthermore, the interpretation of seismic units over the basin flanks and above the sea-floor multiple at the CIROS-1 site also remains uncertain and the difference in dating the seismic sequence boundary may also arise here; correlation of the seismic reflection dataset with CIROS-1 has not been re-evaluated. The drilling of CRP-2 should resolve between these different hypotheses.

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