Terra Antartica
2000, 7(4), 611-619

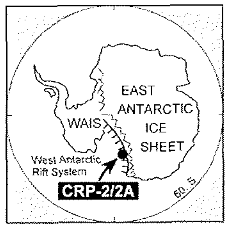
Strontium Isotope Stratigraphy and Age Model for CRP-2/2A, Victoria Land Basin, Antarctica

M. LAVELLE

British Antarctic Survey, High Cross, Madingley Road, Cambridge CB3 0ET and
Department of Earth Sciences, University of Cambridge, Downing Street, Cambridge CB2 3EQ – UK
(mlavelle@esc.cam.ac.uk)

Received 21 January 2000; *accepted in revised form* 18 July 2000

Abstract – Strontium isotope stratigraphy was used to date 16 discrete horizons within the CRP-2/2A drillhole. Reworked Quaternary (<1.7 Ma) and possible Pliocene (<2.4 Ma) sediments overlie a major sequence boundary at 25.92 metres below sea floor (mbsf). This hiatus is estimated to account for *c.* 16 Myr of missing section. Early Miocene to ?earliest Oligocene (*c.* 18.6 to >31 Ma) deposits below this boundary were cut by multiple erosion surfaces of uncertain duration. Strontium isotope ages are combined with $^{40}Ar/^{39}Ar$ dates, diatom and calcareous nannofossil datums and a palaeomagnetic polarity zonation, to produce an age model for the core.



INTRODUCTION

Strontium isotope dating allows accurate age estimates to be obtained from *in situ*, unaltered marine carbonates. In the Antarctic, the technique has proven particularly useful in dating shallow-water sequences where biostratigraphic control is restricted (*e.g.* Barrera, 1989; Prentice et al., 1993; Dingle et al., 1997; Dingle & Lavelle 1998; Lavelle, 1998).

The 624-m-long CRP-2/2A core encountered a succession of Quaternary, Pliocene, Early Miocene, Oligocene and possibly latest Eocene age marine sediments (Cape Roberts Science Team, 1999). The strontium isotope stratigraphy presented here is combined with all available chronological data to produce an age model for CRP-2/2A. A depth-ordered look-up table for derivation of numerical age is provided for the entire sequence.

ANALYTICAL METHODS

Biogenic carbonate that is potentially suitable for Sr isotope dating was obtained from twenty-two horizons within the working half of the CRP-2/2A core. A review of the strontium isotope dating technique, including diagenetic considerations, is presented by Lavelle & Armstrong (1993) and McArthur (1994). In summary, surficial contaminants were removed from the shell surface by a repeated 10-second ultrasound treatment in 1M acetic acid and quartz-distilled water. All samples were visually inspected using a binocular microscope, and homogenous and well-preserved macrofossil specimens were divided into working and archive splits. The archive fractions were examined using a scanning electron microscope (SEM) to identify original shell ultrastructure at the sub-micron scale (Fig. 1). A further study of shell taphonomy (position in core, shell type, and preservation) was also carried out to assist in the identification of *in situ* and reworked specimens (see below). For archive samples that were identified as homogenous and well preserved, the matching working halves were rinsed in distilled water in an ultrasonic tank and dissolved in quartz-distilled 1.75 M HCl.

Strontium was extracted using standard ion-exchange techniques and was loaded onto a tantalum filament as a nitrate. Isotope measurements were carried out using a VG Sector 54 mass spectrometer in the Department of Earth Sciences, University of Cambridge. $^{87}Sr/^{86}Sr$ ratios were normalised to NIST-987 = 0.7210249 (n=55, 2SD=0.000015) measured during this study period, and $^{86}Sr/^{88}Sr = 0.1194$. Analytical blanks were typically <100 pg Sr. Corrected mean isotope measurements were converted to best-fit age and error using the LOWESS fit to the marine Sr curve of Howarth & McArthur (1997) [Look-Up Table version 2:1/98]. As we have no long-term laboratory average $^{87}Sr/^{86}Sr$ value for modern biogenic carbonate, the long-term precision value for NIST-987 was used to calculate the 95% confidence limits on the best-fit age. Where internal within-run errors exceed this external value, the larger 2SE value is applied. No statistical attempt has been made to reduce sampling and analytical uncertainty below that of the long-term standard deviation value quoted above. The relatively large errors quoted for several of the samples are due to small sample size; in many cases, the cleaned $CaCO_3$ samples weighed < 1 mg (typically < 200 ng Sr for pectinid calcite) which makes it difficult to measure the *c.* 150 multicollector ratios often necessary for high precision dating.

Throughout this study, a cautious approach was taken to linking measured age and depositional age. All dated samples are identified as *in situ*, reworked, or of uncertain provenance (Tab. 1). Evidence for *in situ* faunas includes: disposition in the core (*e.g.* fauna are recovered in life

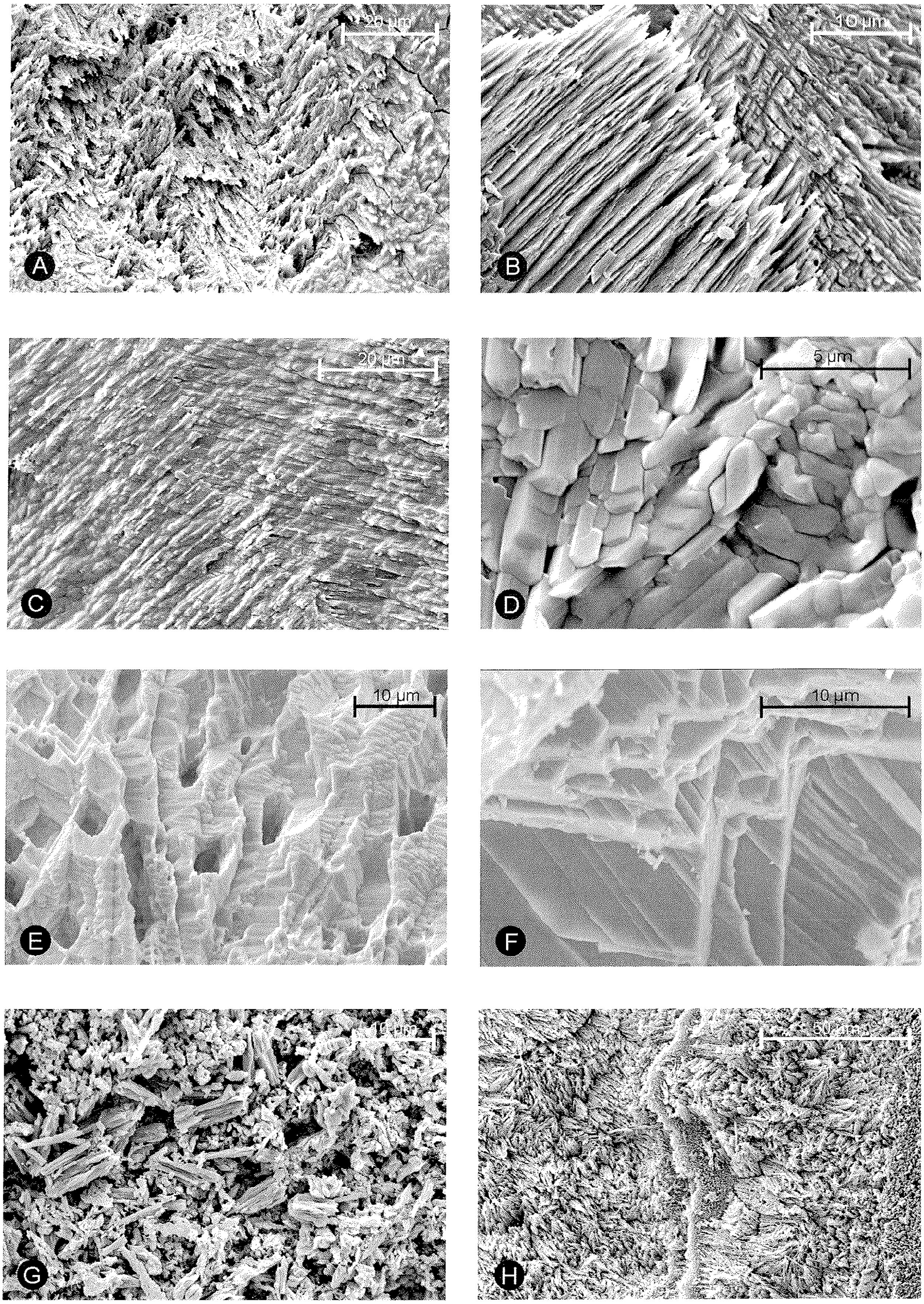


Fig. 1 - Scanning electon micrographs of preserved ultrastructures from selected CRP-2/2A carbonate samples: A) 10.28 mbsf, abraded bivalve fragment showing poor preservation of the original crossed foliated calcite. B) 24.49 mbsf, relatively well preserved ?pectinid bivalve fragment diplaying two first-order lamellae of crossed foliated calcite. C) 126.55 mbsf, weakly abraded pectinid bivalve displaying two first-order lamellae of crossed foliated calcite. D) 246.99 mbsf, well preserved aragonite from unidentified articulated bivalve. E) 463.36 mbsf, vertical section through well preserved aragonitic modiolid. F) 483.15 mbsf, horizontal section through well preserved aragonitic modiolid. G) 34.62 mbsf, partially recrystallised calcite from unidentified bivalve. H) 263.16 mbsf, partially recrystallised calcite from unidetified bivalve.

Tab. 1 – Strontium isotope data for marine carbonates from the CRP-2/2A drillhole. UCL/LCL (upper/lower confidence limit). Unit numbers refer to sedimentary units in Cape Roberts Science Team (1999). N/a = not applicable. For the definition of statistical terms used here, see "Analytical Methods" in the text. Datum codes refer to figure 3.

Datum	Depth range (mbsf) min	max	Unit	Sample	Shell type	Preservation	Interpretatior	$^{87}Sr/^{86}Sr$	Uncertainty 2SE (x10-6)	Age (Ma) (Best Fit)	Age (Ma) (UCL)	Age (Ma) (LCL)
n/a	10.28	10.29	2.1	Unidentified bivalve	Fragment	Strongly bored and abraded	Reworked	0.708981	11	6.1	6.6	5.8
n/a	15.15	15.16	2.1	Unidentified bivalve	Fragment	Moderately bored and abraded	Reworked	0.709099	12	1.7	2.2	1.4
n/a	22.05	22.06	2.2	Unidentified bivalve	Fragment	Moderately abraded	Reworked	0.709076	11	2.4	3.9	1.9
n/a	23.9	23.91	2.2	Pectinid bivalve	Fragment	Strongly abraded	Reworked	0.709005	12	5.7	6.0	5.4
n/a	24.49	24.51	2.2	Pectinid bivalve	Fragment	Moderately abraded	Reworked	0.709005	12	5.7	6.0	5.4
S1	36.24	36.27	3.1	Solitary coral in life position	Fragment	Partially dissolved	*In situ*	0.708556	12	18.6	18.8	18.4
S2	54.94	54.98	5.1	Unidentified bivalve	Fragment	Well preserved	Uncertain	0.708430	18	20.4	20.7	19.9
S2	54.94	54.98	5.1	Unidentified bivalve	Fragment	Well preserved	Uncertain	0.708434	33	20.3	20.9	19.7
S3	126.55	126.56	8.1	Pectinid bivalve	Fragment	Weakly abraded	Uncertain	0.708331	13	22.2	22.6	21.9
S4	194.87	194.91	9.3	Unidentified bivalve	Articulated	Well preserved	*In situ*	0.708217	31	24.5	25.2	23.9
S5	198.74	198.75	9.3	Unidentified bivalve	Fragment	Well preserved	Uncertain	0.708239	13	24.1	24.5	23.7
S6	246.97	247	9.6	Unidentified bivalve	Articulated	Well preserved	*In situ*	0.708243	14	24.0	24.4	23.7
S7	247.67	247.71	9.6	Unidentified bivalve	Fragment	Well preserved	Uncertain	0.708201	12	24.8	25.2	24.5
S8	445.03	445.06	13.1	Unidentified bivalve	Articulated	Well preserved	*In situ*	0.708000	11	29.4	29.9	28.9
S9	460.64	460.67	13.1	Modiolid bivalve	Complete valve	Well preserved	*In situ*	0.707995	15	29.6	30.1	29.0
S10	463.36	463.38	13.1	Modiolid bivalve	Articulated	Well preserved	*In situ*	0.707983	12	29.9	30.4	29.4
S11	483.15	483.18	13.2	Modiolid bivalve	Complete valve	Well preserved	*In situ*	0.707954	14	30.7	31.1	30.2
S11	483.15	483.18	13.2	Modiolid bivalve	Complete valve	Well preserved	*In situ*	0.707967	19	30.3	30.8	29.8
S11	483.15	483.18	13.2	Modiolid bivalve	Complete valve	Well preserved	*In situ*	0.707965	11	30.4	30.9	29.9
Diagenetic study												
n/a	34.62	34.63	3.1	Unidentified bivalve	Fragment	Partially recrystallised	Uncertain	0.708597	11			
n/a	182.17	182.22	8.4	Unidentified bivalve	Articulated	Partially recrystallised	*In situ*	0.708432	14			
n/a	225.96	226	9.4	Unidentified bivalve	Fragment	Partially recrystallised	Uncertain	0.708364	15			
n/a	263.16	263.17	9.7	Unidentified bivalve	Fragment	Partially recrystallised	Uncertain	0.708605	13			
n/a	565.48	565.5	15.2	Unidentified bivalve	Articulated	Partially recrystallised	*In situ*	0.710200	26			
n/a	599.19	599.21	15.4	Unidentified bivalve	Fragment	Partially recrystallised	Uncertain	0.708104	12			

position); for bivalves, the preservation of articulated valves; absence of abrasion features on internal, and to a lesser extent, external surfaces; absence of internal shell borings, etc. It should be noted that this is a cautious approach, and does not preclude the possibility that samples identified as reworked in this study may actually be *in situ* (*e.g.* many calcareous shallow marine faunas may exhibit both external surface abrasion and boring while alive). Well preserved fragmented shell material is labelled as of uncertain provenance in table 1, and is treated as reworked in all further discussions. In summary, only *in situ* dates are interpreted as representing the actual time of deposition; all other ages are treated as maxima.

To maintain consistency between sedimentological, palaeontological and chronological techniques discussed in this study, all references to depth in CRP-2/2A are given in metres below sea floor (mbsf). The timescales of Shackleton et al., (1994) [0-7 Ma] and Cande & Kent (1995) [7-72 Ma] are used throughout this study.

RESULTS

Interpreted SEM images of a representative subset of the twenty-five analysed samples are presented in figure 1. Multiple interpreted images of all analysed samples are available in digital format from the author. Additional example images of criteria used to define original and altered biogenic ultrastructure can be found in Lavelle (1998). Strontium isotope results are summarised in table 1 and are plotted in figure 2. Lithostratigraphic and sequence stratigraphic unit numbers refer to the summary of results in Cape Roberts Science Team (1999).

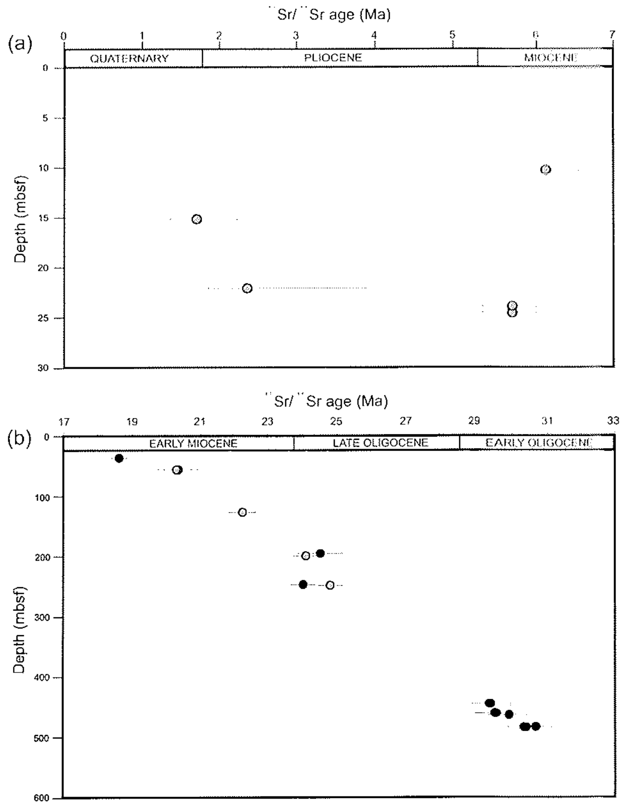


Fig. 2 – Strontium isotope ages for (a) the Pliocene and Quaternary intervals, and (b) the Oligocene - Miocene interval of the CRP-2/2A drillhole. Black circles represent *in situ* ages, grey symbols represent potentially reworked ages (*i.e.* maxima). Error bars are 2SD (95% confidence limits).

QUATERNARY AND PLIOCENE (Fig. 2a)

Initial biostratigraphic interpretation (Cape Roberts Science Team, 1999) and subsequent work (Strong & Webb, this volume) identified Quaternary strata between the sea floor and 21.20 mbsf, and a thin Pliocene interval from 21.20–26.80 mbsf. Five biogenic carbonate samples from depths between 10.28 and 24.51 mbsf have been dated by Sr isotope stratigraphy (Tab. 1). The samples showed the preservation of original carbonate microstructure at the sub-micron level. A further taphonomic study of the bivalve fragments showed them to have been moderately to strongly abraded and in one case, strongly bored. This suggests the macrofossil material is unlikely to be *in situ* (Cape Roberts Science Team, 1999 and Tab. 1, this study).

Two shell samples were dated from the Quaternary sequence. The first, from 10.28 mbsf indicates a latest Miocene [6.1 (+0.5/-0.3) Ma] age for the bivalve fragment. The second sample, from 15.15 mbsf indicates an earliest Pleistocene or latest Pliocene [1.7 +0.5/-0.3) Ma] age. Note that both must be considered maximum (*i.e.* reworked) ages. The three samples analysed from the "Pliocene" section show a c. 4 Myr scatter of latest Miocene to latest Pliocene ages. Dating of samples from 22.05 mbsf, 23.90 mbsf and 24.49 mbsf yielded ages of 2.4 (+1.5/-0.5) Ma, 5.7 (+0.3/-0.3) Ma and 5.7 (+0.3/-0.3) Ma, respectively. Again, all three samples are strongly abraded and should be considered as potentially reworked.

EARLY MIOCENE (Fig. 2b)

Initial biostratigraphic study and a single $^{40}Ar/^{39}Ar$ pumice date at 111 to 114 mbsf, suggested that the cored section between 26.80 and 130.27 mbsf was deposited between *c.* 19 and 22 Ma, respectively (Cape Roberts Science Team, 1999). Four Sr-isotope analyses on an unidentified solitary coral (36.24 mbsf), two unidentified bivalve fragments (54.94 mbsf), and a single fragment of the pectinid bivalve ?*Adamusium* n. sp. (126.55 mbsf) yielded ages of 18.6 (+0.2/-0.2) Ma, 20.4 (+0.4/-0.4) Ma, 20.3 (+0.6/-0.6) Ma and 22.2 (+0.4/-0.4) Ma respectively. Only the coral, preserved in life position, was determined to be *in situ*; the aragonitic skeleton showed evidence of the early stages of dissolution and reprecipitation, requiring extensive surface cleaning of the picked fragments. Both bivalve fragments from 54.94 mbsf, while being unabraded and well preserved cannot, due to their fragmented nature, be considered as *in situ*. The dated pectinid fragment was weakly abraded and is also considered to be of uncertain provenance.

OLIGOCENE (FIG. 2B)

The section between 130.27 and c. 484 mbsf was dated by biostratigraphy as spanning much of the Oligocene (*c.* 24 to *c.* 31 Ma). The lowermost 140 m of the core (*c.* 484 to 624.15 mbsf) was devoid of age diagnostic biostratigraphic datums. Ten samples from eight horizons were dated using strontium isotope stratigraphy. The uppermost four samples from 194.87 to 247.67 mbsf, yielded mean ages of 24.0 to 24.8 Ma (Tab. 1 and Fig. 2b). While all four bivalve samples are well preserved, only the articulated specimens recovered from 194.87 and 246.97 mbsf are identified as *in situ*.

The remaining six samples were extracted from four depths between 445.03 and 483.15 mbsf. All samples are considered to be *in situ*, based on the prevalence of articulated valves (often in growth position), and the specialised ecological requirements of the modiolid bivalve fauna, which restricts their distribution to a narrow interval within the core (Taviani et al., this volume). Calculated mean ages range from 29.4 Ma at 445.03 mbsf, to 30.7 Ma at 483.15 mbsf (Tab. 1 and Fig. 2b).

DIAGENESIS

Two *in situ* and four reworked bivalve specimens were identified as recrystallised, based on visual criteria (Tab. 1). No definitive authigenic carbonate (*e.g.* sparry calcite) was observed, rather the replacement of characteristic molluscan ultrastructure with amorphous carbonate was used as a guide in rejecting samples. The upper four samples between 34.62 and 263.16 mbsf yielded Sr-isotope signatures only slightly more ^{87}Sr enriched (*c.* 50 to 350 ppm) than the true depositional seawater Sr-isotope signature derived from associated well-preserved specimens. All four values are lower than modern day seawater. A single sample from 565.48 mbsf yielded an ^{87}Sr/^{86}Sr value of 0.710200, which is c. 1‰ more radiogenic than modern seawater strontium (0.709176). This standard trend towards more radiogenic diagenetic fluids with depth is upset by a further ^{87}Sr/^{86}Sr value of 0.708104 measured at 599.19 mbsf.

It is clear that the fluid involved in the diagenetic reaction at 565.48 mbsf was of continental (*i.e.* derived from rock - water interaction) rather than marine origin. There are multiple possibilities for the origin of the fluid affecting the remaining five samples, such as re-exposure at/near the sea floor and total/partial alteration in the presence of younger relatively ^{87}Sr-enriched seawater, or partial recrystallisation in the presence of an ^{87}Sr-enriched continental fluid. As interstitial waters were not sampled during the drilling of CRP-2/2A, and the degree of sample alteration proved impossible to estimate using visual techniques, no further diagenetic conclusions can be made.

DISCUSSION

Strontium isotope stratigraphy has allowed the accurate dating of *in situ* biogenic carbonate from seven depths, plus the calculation of maximum ages from reworked biogenic carbonate at a further nine depths within CRP-2/2A. While the rigorous treatment of specimens prior to analysis is expected to minimise the risk of error, there are two main mechanisms by which the calculated ages may be inaccurate.

1 - *Diagenesis*: the simple diagenetic study above indicates that unrecognised recrystallisation of biogenic carbonate (*e.g.* epitaxial replacement) in CRP2/2A is likely to produce calculated ages that are younger than the true depositional age. There is no visual evidence of diagenetic resetting in any of the samples for which ages are quoted. The visual identification of six altered specimens, which subsequently showed reset or partially reset Sr-isotope values, confirms that detailed diagenetic evaluation of crystal structure at the sub-micron level is a powerful tool in proofing samples for dating.

2 - *Reworking*: unrecognised reworking of carbonate macrofossils will result in Sr-isotope ages that are older than the depositional age of their sedimentary host. For this reason, only results from specimens showing convincing evidence of *in situ* preservation are considered as depositional ages (see Analytical Methods, this study). All shell fragments of uncertain provenance are considered reworked and are treated as maximum ages.

To further minimise these potential influences, I have combined the Sr-isotope data with all available chronologic data from CRP-2/2A to form a comprehensive age model.

CALCULATION OF THE CRP-2/2A CHRONOSTRATIGRAPHIC ZONES

The derivation of the chronostratigraphic zones permits the simple combining of multiple datums, while accounting for occasional discrepancies between different dating techniques. In summary, in a geological succession, the lower confidence limit (LCL) of a dated horizon cannot exceed the LCL of an overlying dated horizon. For example, datum A occurs at 10 mbsf and spans an age range of 5 to 7 Ma. Datum B occurs at 15 mbsf, and spans an age range of 4 to 6 Ma. Chronostratigraphic Zone 1 is then confined by the LCL of datum A, and the upper confidence limit (UCL) of datum B, *i.e.* 5 to 6 Ma. Twenty-three chronostratigraphic zones have been calculated for CRP-2/2A. The ^{87}Sr/^{86}Sr, ^{40}Ar/^{39}Ar and biostratigraphic datums used are listed in table 1 and table 2. The CRP-2/2A chronostratigraphic zones are defined in table 3 and are displayed in figures 3 and 4.

CALIBRATION OF THE CRP-2/2A MAGNETIC POLARITY ZONATION

Minor subdivision of the chronostratigraphic zones shown in figure 3 may be made by comparing the detailed magnetic polarity stratigraphy of CRP-2/2A (Cape Roberts Science Team, 1999; Wilson et al. (this volume)) with the Magnetic Polarity Time Scale (MPTS) of Cande & Kent (1995). Throughout much of the core, two uncertainties

Tab. 2 - Additional datums used in the calculation of the chronostratigraphic zones from the CRP-2/2A drillhole. Datum codes refer to figure 3 (A = $^{40}Ar/^{39}Ar$; D = diatom and Nf = calcareous nannofossil datums).

Datum $^{40}Ar/^{39}Ar$	Depth (mbsf)	Type	Age (Ma)
A1	36.02	Basaltic clast	<19.44
A2	c.111 - c.114	Pumice	21.39 - 21.49
A3	125.92 - 125.93	Trachyte clast	<22.85
A4	c.193	Pumice	23.85 - 24.11
A5	280.03	Pumice	24.16 - 24.28
A6	294.22	Trachyte clast	<25.15
Diatom			
D1	36.25	FCAD *Thalassiosira praefraga*	20.3 (C6r)
D2	259.21	LO *Lisitzinia ornata*	24.1 (C6Cr)
D3	n/a	n/a	n/a
D4	444.96	LO *Asterolampra punctifera*	27.0 (C9n)
D5	444.96	LO *Rhizosolenia oligocaenica*	29.6 (C11n.1r)
D6	309.88	LO *Pyxilla reticulata*	30.1 (C11r)
D7	543.81	FO *Cavitatus jouseanus*	30.9 (C12n)
D8	>564.76 (abs)	LO Assemblage B (CIROS-1)	c.33.0 (C13n)
Nannofossil			
Nf1	144.44	LO *Dictyococcites bisectus*	23.80 (C6Cn.2r)
Nf2	412.25	LO *Chiasmolithus altus*	25.82 (C8n)

combine to make correlation of the CRP-2/2A magnetic polarity stratigraphy to the MPTS ambiguous.

1 - It is often impossible to confidently extrapolate single polarity zones across sequence bounding unconformities. Only where there is strong independent evidence that no significant time break occurs at the sequence boundary, may a polarity zone be linked between two or more sequences. Twenty-four sequence boundaries have been identified in CRP-2/2A (Cape Roberts Science Team, 1999). All are at the base of metre - to deci-metre - thick diamictite units, and all display large facies dislocations. This suggests that there has been significant removal of sediment and, therefore, potentially time, throughout much of the section (Fielding et al., this volume).

2 – Below *c.* 280 mbsf in CRP-2/2A, multiple zones of uncertain and unmeasurable polarity occur within the core. This adds to the complexity of the correlation,

Tab. 3 – Chronostratigraphic zones (see text) and look-up table for the derivation of numerical age from the Tertiary section of the CRP-2/2A drillhole.

Chronostratigraphic Zone	Depth range (mbsf) min	max	Age range (Ma) LCL	UCL	Datums LCL	UCL
1	36.24	36.28	18.4	18.8	S1	S1
2	36.28	55.98	18.4	20.8	S1	S2
3	55.98	c.111	18.4	21.49	S1	A2
4	c.111	c.114	21.39	21.49	A2	A2
5	c.114	126.56	21.39	22.6	A2	S3
6	126.56	144.44	21.39	24.11	A2	A4
7	144.44	c.193	23.80	24.11	Nf1	A4
8	c.193	c.193	23.85	24.11	A4	A4
9	c.193	259.21	23.85	24.28	A4	A5
10	259.21	280.03	24.12	24.28	D2	A5
11	280.03	280.03	24.16	24.28	A5	A5
12	280.03	294.22	24.16	25.15	A5	A6
13	294.22	412.25	24.16	29.9	A5	S8
14	412.25	445.03	25.82	29.9	Nf2	S8
15	445.03	445.06	28.9	29.9	S8	S8
16	445.06	460.64	28.9	30.1	S8	S9
17	460.64	460.67	29.0	30.1	S9	S9
18	460.67	463.36	29.0	30.4	S9	S10
19	463.36	463.38	29.4	30.4	S10	S10
20	463.38	483.15	29.4	30.9	S10	S11
21	483.15	483.18	30.0	30.9	S11	S11
22	483.18	543.81	30.0	30.93	S11	D7
23	543.81	>564.67	30.0	c.33.00	S11	D8

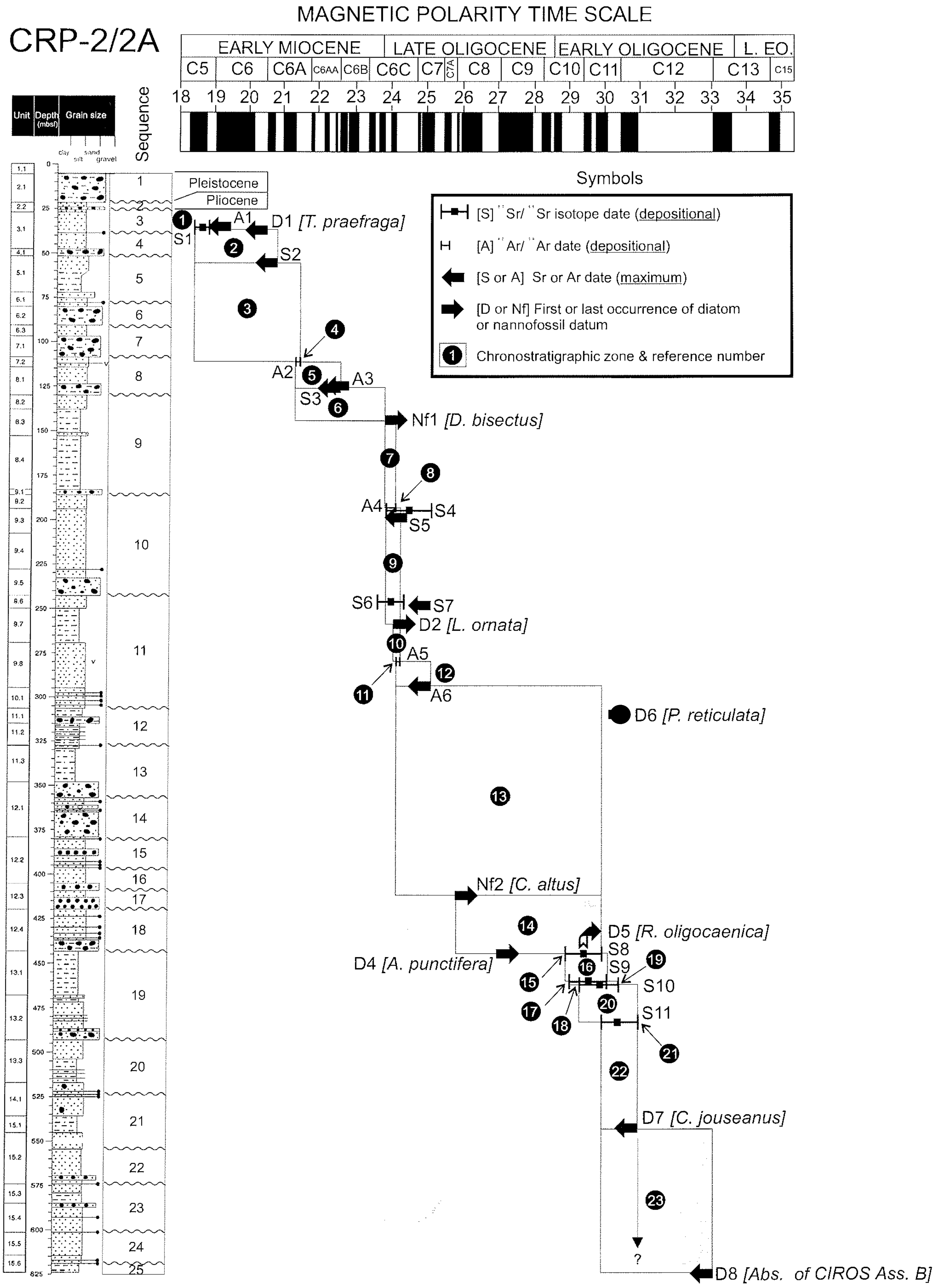


Fig. 3 – Datums (Tabs. 1 & 2) and chronostratigraphic zones (Tab. 3) for the CRP-2/2A drillhole. The lithology and sequence stratigraphy are from Cape Roberts Science Team (1999). The magnetic polarity timescale is that of Cande & Kent (1995).

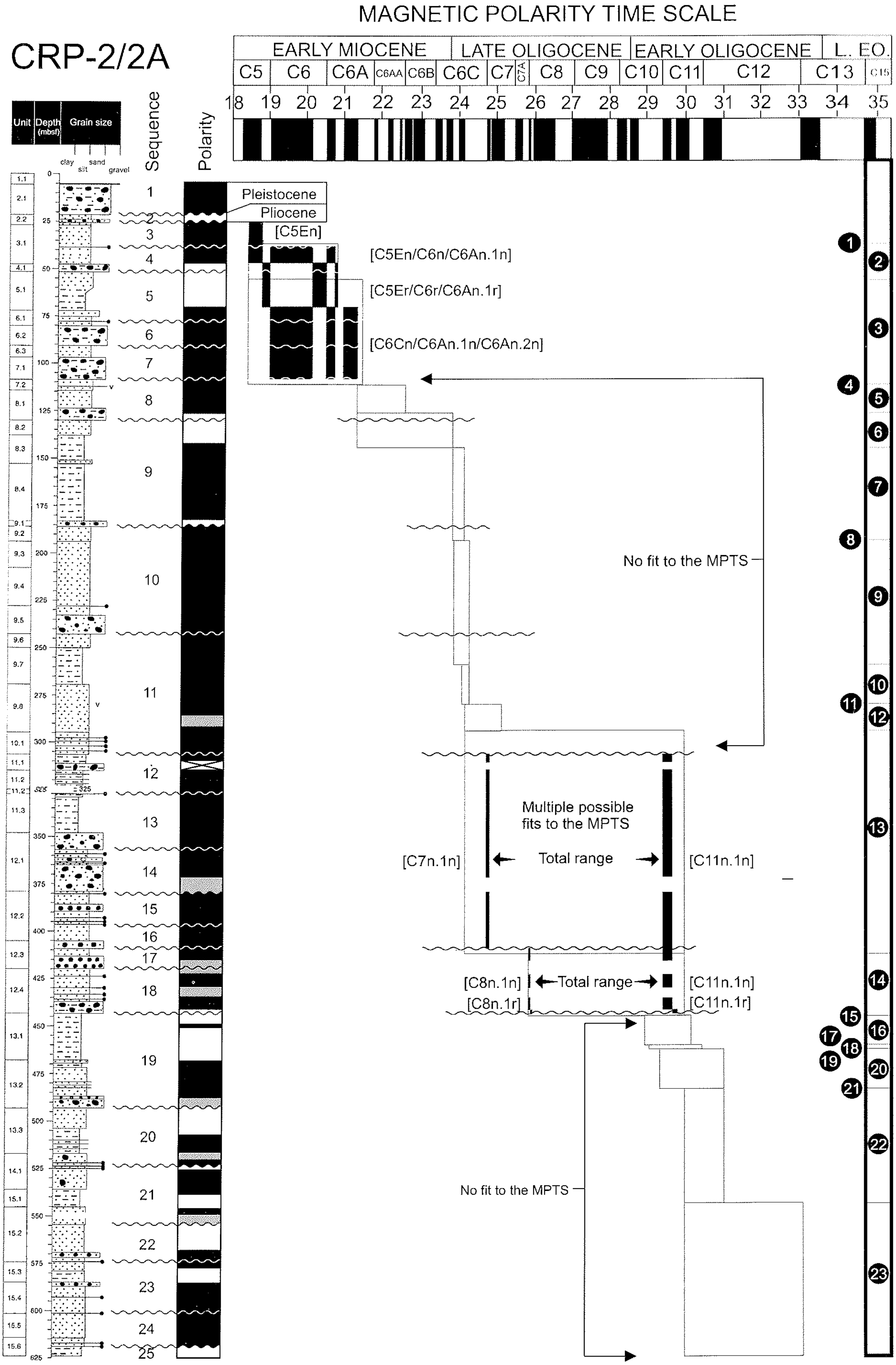


Fig. 4 – Age model for CRP-2/2A, combining chronostratigraphic zones (grey shading in the main body of the diagram) and magnetic polarity data (left-hand polarity column; black - normal; white - reversed) from Wilson, Florindo et al., (this volume). Potential correlations to the MPTS are indicated by black bars within the chronostratigraphic zones. The chronostratigraphic zones are labelled in the right-hand column.

since polarity zones cannot be confidently linked either side of these uninterpreted areas.

Where three or fewer correlations to the MPTS are possible, a black box spanning each entire MPTS chron is used in figure 4. The boxes have vertical sides because high sedimentation rates tend towards a vertical line at this scale. Four or more potential correlations are displayed as end-members only.

Within CRP-2/2A, only Chronostratigraphic Zone 1 can be uniquely tied to the MPTS (C5En). Chronostratigraphic zones 2 to 3 and the lower part of Chronostratigraphic Zone 13 to Zone 14 allow multiple possible fits to the MPTS. Chronostratigraphic zones 4 to upper 13 and 15 to 23 cannot be matched to the MPTS. This large mismatch to the MPTS (*c.* 60% of the recovered core) is due to two main factors.

1 - The correlation of Chronostratigraphic Zones 4 to 13, which span sequences 8 to 11 (Fig. 4), to the MPTS requires either the re-interpretation of the $^{40}Ar/^{39}Ar$ chronology or the MPTS calibration (see McIntosh (this volume) and Wilson, Bohaty et al. (this volume) for further discussion).

2 - Chronostratigraphic Zones 15 to 23 span a maximum of four reverse and three normal polarity chrons of the MPTS (28.9 to *c.* 33 Ma; C10r to C12r). The CRP-2/2A magnetic polarity stratigraphy over this interval contains eight reversed polarity intervals, eight normal polarity intervals and three zones of uncertain polarity.

It should be noted that the MPTS contains numerous cryptochrons in this time interval (Cande & Kent, 1995). Uncertainty concerning correlation of cryptochrons makes interpretation of the CRP-2/2A polarity record ambiguous.

CONCLUSIONS

The Plio-Pleistocene sedimentary section recovered in CRP-2/2A contains multiple generations of reworked Pliocene and Miocene macrofossil fragments. The youngest dated specimen from the Quaternary section suggests a maximum mean age of 1.7 Ma. Similar material from the postulated Pliocene section suggests a maximum mean age of *c.* 2.4 Ma.

The remaining Tertiary sedimentary section represents multiple ice advance and retreat cycles that occurred between the early Miocene (18.4 Ma) and the earliest Oligocene (*c.* 33 Ma). Twenty-four erosional sequence boundaries divide the core into 25 sedimentary sequences. The resolution of the current age model is insufficient to accurately determine the time missing at individual unconformities.

Strontium isotope stratigraphy may be used to accurately date high-latitude, near-shore Cenozoic successions. However, care must be taken during sample selection and preparation, to ensure that samples are well preserved and identified as either *in situ* or potentially reworked. Combining multiple chronological methods is necessary to generate a robust age model for complex Antarctic near-shore marine sections.

NOTE

Since the manuscript was completed, twelve additional "amorphous" carbonate samples from sequence stratigraphic units 10 and 11 have been analysed for Sr-isotope ratios. The new data suggests that samples S4, S5 and S6 may contain a small amount of post-depositional calcite. As a precaution, the calculated ages for samples S4, S5 and S6 should be considered as minima. The interpretation of sample S7 is unaffected. The new data and further discussion will be presented in the forthcoming scientific report for CRP-3.

ACKNOWLEDGEMENTS

The author thanks M. Greaves and M. J. Cooper for laboratory assistance, and M. Taviani, T. Janecek and M. Curren for sampling and curatorial assistance. Detailed and constructive reviews by A. Roberts and J. M. McArthur improved the clarity of the manuscript.

REFERENCES

Barrera E., 1989. Strontium isotope ages. In: Barrett P.J. (ed). Antarctic Cenozoic history from the CIROS-1 drillhole, McMurdo Sound. *DSIR Bulletin*, **245**, 151-152.

Cande S.C. & Kent D.V., 1995. Revised calibration of the geomagnetic polarity timescale for the Late Cretaceous and Cenozoic. *J. Geophys. Res.*, **100**, 6093-6095.

Cape Roberts Science Team, 1999. Initial Report on CRP-2/2A, Cape Roberts Project, Antarctica. *Terra Antartica*, **6** (1/2), 173/228 p.

Dingle R.V. & Lavelle M., 1998. Antarctic Peninsula cryosphere: early Oligocene (c.30 Ma) initiation and a revised glacial chronology. *J. Geol. Soc. Lond.*, **155**, 433-437.

Dingle R.V., McArthur J.M. & Vroon P., 1997. Oligocene and Pliocene interglacial events in the Antarctic Peninsula dated using strontium isotope stratigraphy. *J. Geol. Soc. Lond.*, **154**, 257-264.

Howarth R.J. & McArthur J.M., 1997. Statistics for strontium isotope stratigraphy: a robust LOWESS fit to the marine Sr-isotope curve for 0 to 206 Ma, with look-up table for derivation of numeric age. *J. Geology*, **105**, 441-456. Look-up table version 2: 1/98.

Lavelle M., 1998. Strontium isotope stratigraphy of the CRP-1 drillhole, Ross Sea, Antarctica. *Terra Antartica*, **5**(3), 691-696.

Lavelle M. & Armstrong R.A., 1993. Strontium isotope ratios in modern marine biogenic and chemical marine precipitates from southern Africa. *S. Afr. J. Sci.*, **89**, 553-536.

McArthur J.M., 1994. Recent trends in strontium isotope stratigraphy. *Terra Nova*, **6**, 331-358.

Prentice M.L., Bockheim J.G., Wilson S.C., Burckle L.H., Hodell D.A., Schluchter C. & Kellogg D.E., 1993. Late Neogene Antarctic glacial history: evidence from central Wright Valley. In: Kennett J.P. & Warnke D.A. (eds.), The Antarctic paleoenvironment: a perspective on global change, 2, AGU, Antarctic Res. Ser., 60, 207-250.

Shackleton N.J., Crowhurst, S., Hagelburg, T., Pisias, N. & Schneider, D., 1994. A new late Neogene time scale: Application to Leg 138 sites. In: Proc. *Ocean Drilling Program 138, Scientific Results*, College Station, Texas, 73-101.