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33. STRONTIUM ISOTOPE DATING OF PALEOCEANOGRAPHIC, LITHOLOGIC, AND DOLOMITIZATION EVENTS ON THE NORTHEASTERN AUSTRALIAN MARGIN, LEG 133[1]

Judith A. McKenzie,[2] Alexandra Isern,[2] Henry Elderfield,[3] Ann Williams,[3] and Peter K. Swart[4]

ABSTRACT

The strontium-isotope dating method, based on the strontium-isotope seawater curve, was used to date stratigraphic events recognized in carbonate sediments drilled during Leg 133 on the Queensland and Marion plateaus. The strontium isotope ages of these events are used to correlate paleoceanographic changes, delineated from oxygen isotope signals, and paleoenvironmental or facies changes recorded in the lithostratigraphy. Results indicate that a strong connection exists between prevailing paleoenvironmental conditions and the developmental style of a carbonate platform. Also, the strontium-isotope ages of discrete dolomite intervals within the sequences were determined, indicating that multiple dolomitization events took place and that a hydrodynamically driven process may be currently active within the modern carbonate platform.

INTRODUCTION

Marine carbonates record the strontium isotopic ($^{87}Sr/^{86}Sr$) composition of the seawater in which they are formed. Recognizing that the $^{87}Sr/^{86}Sr$ ratio of seawater has fluctuated throughout geologic time, much effort in recent years has been directed toward determining the strontium-isotope seawater curves for specific time periods (Burke et al., 1982; DePaolo, 1986; DePaolo and Ingram, 1985; Elderfield, 1986; Hess et al., 1986; Hess et al.,1989; Hodell et al., 1990; Hodell et al., 1991; Koepnick, et al., 1985; McKenzie et al., 1988; Miller et al., 1988; Miller et al., 1991; Oslick et al., 1992). These curves provide a valuable method for the dating of marine carbonates. In particular, the strontium isotope dating technique is useful for samples that cannot be dated using other methods, such as biostratigraphy and magnetostratigraphy.

One of the major objectives of Leg 133 was to study the temporal and spatial evolution of the carbonate platforms on the northeastern Australian margin. However, drilling recovered material that had been deposited in a variety of environments where biostratigraphic and magnetostratigraphic methods have limited applicability. For example, the shallow-water temperate and tropical carbonates deposited on the platforms contain few diagnostic fossils, which can provide only a limited time resolution. In addition, the paleomagnetic signals are often very weak or not preserved in these sediments. Early diagenesis of metastable carbonates produced in these shallow-water environments is intense and further complicates the age determination of the samples by obliterating or altering the original magnetic and fossil components, as well as the changing the original isotopic signatures. Age signals may, also, be affected by the reworking of shallow-water sediments into those of the deeper slopes during fluctuations in sea level. We proposed to apply the strontium isotope technique as an alternative or additional dating method for sediments cored during Leg 133, as all of these age dating problems potentially exist for the carbonate sediments deposited on the northeastern Australian margin.

For this preliminary investigation, we identified as our dating targets specific paleoceanographic, lithologic, and dolomitization events on the northeastern Australian carbonate platforms. Our selection was based on a combination of shipboard stratigraphic interpretations and shore-based isotopic studies. $^{87}Sr/^{86}Sr$ ratios were used to date these events and, where appropriate, to correlate their timing among the Leg 133 sites studied. These correlations then were used to evaluate the causes and consequences of changes that affected the onset, development, and demise of these carbonate platforms.

METHODOLOGY

A limited number of representative sediment samples (61) were selected for strontium isotopic analysis. These samples, with a brief description of their composition, are listed in Table 1, together with the corresponding strontium isotope data. For the study of Neogene paleoceanographic events, individual shell fragments were analyzed when available. In addition, hand-picked planktonic foraminifer samples were used. These samples, which had been previously analyzed for their oxygen and carbon isotopic compositions (Isern et al., this volume), proved to be valuable for dating and correlating paleoceanographic events among sites, as discussed below. Where it was not possible to analyze discrete fossils, bulk carbonates were used.

The carbonate mineralogy of samples for the dolomitization study was determined using X-ray diffraction prior to the strontium isotopic analyses run on bulk powders (Table 2). Only monomineralic samples were analyzed. Some important samples from Site 812 were found to be partially dolomitized. To obtain a purified dolomite fraction for strontium isotopic analysis, these samples were ground and seived through a 63-µm sieve. They then were treated with an acetic acid sodium acetate buffered solution for 2 hr to remove any calcium carbonate. They were examined by X-ray diffraction to ensure that all $CaCO_3$ had been removed. These purified samples are designated as dolomite fraction in Table 1. For $\delta^{18}O$ and $\delta^{13}C$ analyses, samples were reacted at 82°C in phosphoric acid and analyzed using an automated carbonate system attached to a VG-PRISM triple-collector mass spectrometer. No correction factor was applied to the isotopic data for the dolomite. The isotopic results are included in Table 2.

Strontium was separated from 100-µL aliquots by conventional cation exchange chromatography (Elderfield et al., 1991), and $^{87}Sr/^{86}Sr$ ratios were determined using a VG Sector 54 instrument having seven collectors using a multidynamic peak-switching program. Results obtained for NBS 987 $SrCO_3$ standard gave $^{87}Sr/^{86}Sr = 0.71023$, and aliquots of an in-house seawater standard gave $^{87}Sr/^{86}Sr = 0.70916$. The data were normalized to $^{86}Sr/^{88}Sr = 0.1194$ and to $^{87}Sr/^{86}Sr = 0.70916$. The $^{87}Sr/^{86}Sr$ results for the measured samples are listed in Table 1, along with the 2-sigma errors and calculated ages of the samples.

[1] McKenzie, J.A., Davies, P.J., Palmer-Julson, A., et al., 1993. *Proc. ODP, Sci. Results,* 133: College Station, TX (Ocean Drilling Program).
[2] Geologisches Institut, Eidgenossische Technische Hochschule, Sonneggstrasse 5, CH-8092 Zürich, Switzerland.
[3] Department of Earth Sciences, University of Cambridge, Downing Street, Cambridge CB2 3EQ, United Kingdom.
[4] Stable Isotope Laboratory, MGG/RSMAS, University of Miami, Miami, FL 33149, U.S.A.

Table 1. Strontium isotope data for Leg 133 sediments.

Core, section, interval (cm)	Depth (mbsf)	Lith. unit	Description	$^{87}Sr/^{86}Sr$ ($\pm 10^6 \bullet 2\sigma$)	Age (Ma)
133-811A-					
3H-3,145-147	19.45	IC	Foraminifers	0.709058 (17)	1.9
9H-1, 71-73	72.71	IIB	Foraminifers	0.709032 (17)	2.5-5.0
10H-1, 42-44	81.92	IIB	Shell fragment	0.709025 (20)	2.5-5.0
11H-3, 80-82	94.80	IIB	Foraminifers	0.708980 (21)	5.1
12H-1, 110-112	101.60	IIB	Foraminifers	0.708964 (20)	5.2
12H-4, 55-56	105.55	IIB	Shell fragment	0.708814 (26)	11.5-15.0
14H-6, 138-140	128.38	IIB	Foraminifers	0.708856 (18)	10.8
19H-1, 109-111	168.09	III	Packstone	0.708764 (17)	15.8
20H-3, 100-102	180.50	III	Foraminifers	0.708884 (21)	9.8
133-811B-					
16X-2, 94-96	310.45	IV	Rudstone	0.708365 (20)	21.0
20X-1, 46-48	347.06	IV	Packstone	0.708136 (28)	27.6
21X-1, 80-82	357.10	V	Packstone	0.708141 (18)	27.4
133-825B-					
8R-1, 19-21	437.59	VI	Rudstone	0.707858 (21)	36.4
133-812A-					
5X-1, 4-5	27.95	IIA	Hardground	0.708951 (23)	5.2
5X-1, 55-56	28.45	IIA	Hardground	0.708960 (18)	5.2
5X-1, 88-90	28.78	IIA	Hardground	0.708971 (17)	5.2
12X-1, 64-66	84.25	IIB	Dolomite fraction	0.709047 (18)	2.1
12X-3, 66-70	87.26	IIC	Dolomite fraction	0.709065 (20)	1.8
12X-5, 66-70	90.26	IIC	Dolomite fraction	0.709057 (20)	1.9
12X-6, 66-70	91.76	IIC	Dolomite fraction	0.709059 (18)	1.9
15X-1, 45-46	113.15	IID	Shell fragment	0.708930 (18)	5.5-8.5
18X-cc, 12-13	142.22	IIIA	Dolomite	0.709015 (20)	5.0
20X-1, 112-113	162.02	IIIA	Dolomite	0.709033 (17)	2.4
22X-1, 50-51	180.70	IIIA	Dolomite	0.709047 (20)	2.1
133-812B-					
17R-1, 1-2	284.78	IIIC	Dolomite	0.708956 (20)	5.2
133-812C-					
3H-4, 95-97	22.37	I	Shell fragment	0.709073 (21)	1.6
5H-2, 130-132	32.30	IIA	Shell fragment	0.708944 (18)	5.2
7H-6, 50-52	56.50	IIA	Dolomite fraction	0.709047 (17)	2.1
8H-5, 130-132	59.36	IIA	Shell fragment	0.708955 (20)	5.2
9H-1, 9-11	67.59	IIB	Shell fragment	0.708952 (21)	5.2
10H-1, 70-72	77.70	IIB	Bryozoan	0.708954 (18)	5.2
10H-6, 50-52	85.0	IIB	Dolomite fraction	0.709051 (18)	2.0
11H-cc, 7-8	96.27	IIC	Shell fragment	0.708978 (21)	5.1
12H-1, 66-68	96.66	IIC	Oyster shell	0.708962 (17)	5.2
13H-1, 102-104	108.20	IID	Dolomite	0.709015 (18)	5.0
133-816B-					
3R-1, 74-76	106.04	II	Dolomite	0.708969 (20)	5.2
133-816C-					
4R-1, 46-52	154.46	II	Dolomite	0.708960 (17)	5.2
8R-1, 106-109	193.46	III	Dolomite	0.708927 (18)	5.5-8.5
13R-1,27-30	240.57	III	Dolomite	0.708915 (24)	8.8
133-817A-					
13H-4, 106-108	115.76	I	Foraminifers	0.709068 (18)	1.7
20H-1, 70-72	177.40	I	Foraminifers	0.709009 (20)	5.0
20H-6, 70-72	184.90	I	Foraminifers	0.709006 (18)	5.0
21H-1, 70-72	186.90	I	Foraminifers	0.709003 (17)	5.1
21H-6, 20-22	193.90	I	Foraminifers	0.708984 (21)	5.1
21H-6, 70-72	194.40	I	Foraminifers	0.708976 (18)	5.1
22H-2, 20-22	197.40	I	Foraminifers	0.708956 (21)	5.2
22H-5, 20-22	201.90	II	Foraminifers	0.708874 (18)	10.2
133-817D-					
26R-2, 7-9	495.77	IIIB	Packstone	0.708706 (20)	16.4
30R-1, 28-32	532.28	IIIB	Packstone	0.708716 (20)	16.3
39R-1, 4-8	618.44	IIIC	Dolomite	0.708729 (20)	16.2
43R-cc, 4-7	657.14	IIIC	Dolomite	0.708966 (20)	5.2
133-823B-					
16X-2, 125-127	144.15	II	Foraminifers	0.709090 (17)	1.3
18X-2, 125-127	163.85	II	Foraminifers	0.709069 (17)	1.7
36X-5, 140-150	341.60	II	Foraminifers	0.709022 (20)	2.5-5.0
56X-6, 30-34	534.20	IIIC	Foraminifers	0.709011 (20)	5.0
75X-5, 89-91	715.79	V	Foraminifers	0.708957 (16)	5.2
80X-6, 92-96	765.72	V	Foraminifers	0.708970 (20)	5.2
133-823C-					
2R-3, 73-76	797.33	VI	Nannofossil chalk	0.708901 (18)	9.3
4R-1, 74-77	813.34	VI	Nannofossil chalk	0.708919 (19)	8.7
11R-4, 59-64	885.49	VI	Nannofossil chalk	0.708907 (23)	9.1
24R-4, 45-48	1010.55	VII	Packstone	0.708818 (20)	11.5-15.0

$^{87}Sr/^{86}Sr$ AGE CALCULATIONS

The strontium-isotope seawater curve shows that the $^{87}Sr/^{86}Sr$ ratio of seawater has increased throughout the last approximately 40 m.y. (Burke et al., 1982; DePaolo, 1986; DePaolo et al., 1985; Elderfield, 1986; Hess et al., 1986; Koepnick et al., 1985). During this period, the slope of the curve has not remained constant, as the increase in the $^{87}Sr/^{86}Sr$ ratio has proceeded in a stepwise manner, with intervals of greater slope on the curve separated by intervals with low or zero slope. Maximum age resolution is possible for intervals with a high slope, whereas periods of lower slope are of less value for age determinations.

The ages of the Leg 133 sediments were calculated using a series of published linear regression equations (Table 3), which were constructed for discrete portions of the strontium-isotope seawater curves. For this study, the equations found in Ohde and Elderfield (1992) and Elderfield (1986) were applied. These equations are derived from deep-sea sections having good recovery and, whenever possible, good biostratigraphic and magnetostratigraphic age control. In the time range considered for this study, three periods show nearly constant $^{87}Sr/^{86}Sr$ values, the Pliocene (5.0–Ma), late Miocene (8.5–5.5 Ma), and middle Miocene (15.0–11.5 Ma) with $^{87}Sr/^{86}Sr$ values of ~0.709025, ~0.708925, and ~0.708825, respectively (Hodell et al., 1989; Hodell et al., 1990; Hodell et al., 1991; Ohde and Elderfield, 1992). Samples having these ratios were considered to have been deposited within the broad time span of these intervals. Otherwise, the ages of samples with $^{87}Sr/^{86}Sr$ ratios that corresponded to sections of the curve that had increasing values were calculated using the regression equations for the specified time intervals and $^{87}Sr/^{86}Sr$ ranges listed in Table 3. The $^{87}Sr/^{86}Sr$ ranges were calculated from the regression equations using the boundary ages of the designated time intervals that had been adjusted to avoid overlap with the $^{87}Sr/^{86}Sr$ values for the portions of the curve having near zero slopes.

The calculated $^{87}Sr/^{86}Sr$ ages are given in Table 1. The age resolution of the strontium isotope method for ages calculated from the regression equations from steeper sections of the curve, such as between 5.5 and 5.0 Ma, has been estimated to be about ±0.5 Ma (95% confidence interval) (McKenzie et al., 1988). Because of the above mentioned problems associated with defining the regression equations and the relatively high uncertainty in the age resolution, the calculated ages presented in Table 1 cannot be considered absolute values. However, these are representative ages within a stratigraphic context that can be used to evaluate the timing of specific events and to correlate among the various sites. The strontium isotopic ages of the analyzed samples are discussed below. The biostratigraphic ages associated in the text and figures with the evaluated samples were taken from the preliminary shipboard data (Davies, McKenzie, Palmer-Julson, et al., 1991) and the results of shore-based analyses (Gartner et al., this volume; Wei and Gartner, this volume).

STRONTIUM ISOTOPIC AGES OF STRATIGRAPHIC EVENTS

Results from Sites 811/825

Sites 811/825 were located on the western margin of the Queensland Plateau, 3.5 nmi east of Holmes Reef (Fig. 1) (Davies, McKenzie, Palmer-Julson, et al., 1991). The sediments from the upper 200 m of the section are deep-water deposits that are composed of alternating periplatform and pelagic oozes. They contain a stable isotopic record of paleoceanographic changes that occurred on the northeastern Australian margin during the last 10 m.y. (Isern et al., this volume). Based on benthic foraminifer assemblages, the depositional site was at middle bathyal paleobathymetric depths (600–1000 m) during this period. Below 200 mbsf, reworking and redeposition of shallower-water deposits were indicated by the occurrence of large benthic foraminifers and reefal debris. Below 270 mbsf, redeposited skeletal grains document the transition to a neritic environment, possibly forereef or backreef. At about 350 mbsf, the sediments changed abruptly from the overlying tropical neritic fauna to the directly underlying temperate-to-subtropical shelf bioassemblage. Samples (Table 1) were selected for strontium isotope analyses to date paleoceanographic events recognized in both the isotope-stratigraphies and lithostratigraphies, as well as to provide additional age control for the section that lacked magnetostratigraphy because of rust contamination from the drill

Table 2. Stable isotope data for Leg 133 diagenetic carbonates.

Core, section, interval (cm)	Depth (mbsf)	Lithologic Description	$\delta^{13}C_{PDB}$ (‰)	$\delta^{18}O_{PDB}$ (‰)	Dolomite (%)	Age (Ma)
133-812A-						
18X-cc, 12-13	142.22	Dolomitic packstone	2.93	4.07	100	5.0
20X-1, 112-113	162.02	Dolomitic packstone	2.74	3.83	100	2.4
22X-1, 50-51	180.70	Dolomitic packstone	3.31	4.40	100	2.1
133-812B-						
17R-1, 8-9	284.78	Dolomitic packstone	2.72	3.65	100	5.2
133-812C-						
13H-2, 102-104	108.20	Sucrosic dolomite	2.45	4.27	100	5.0
133-816B-						
3R-1, 74-76	106.04	Dolomitic rudstone	3.50	2.81	100	5.2
133-816C-						
4R-1, 46-52	154.46	Dolomitic boundstone	3.32	2.95	100	5.2
8R-1, 106-109	193.46	Dolomitic boundstone	2.94	2.49	100	5.5-8.5
13R-1,27-30	240.57	Dolomitic boundstone	2.26	2.32	100	8.8
133-817D-						
26R-2, 7-9	495.77	Calcitic packstone	2.96	-0.55	0	16.4
30R-1, 28-32	532.28	Calcitic packstone	2.83	-0.64	0	16.3
39R-1, 4-8	618.44	Sucrosic dolomite	2.61	0.42	100	16.2
43R-cc, 4-7	657.14	Coarse crystalline dolomite	1.68	0.45	100	5.2

Table 3. Regression equations and $^{87}Sr/^{86}Sr$ ranges for specific time intervals.

Time interval	Age (Ma)	$^{87}Sr/^{86}Sr$ range	Regression equation
latest Pliocene/Pleistocene	2.5 to 0	0.709030 to 0.70916[1]	Age (Ma) = 13011.5 - 18347.7 x $(^{87}Sr/^{86}Sr)^2$
Pliocene	5.0 to 2.5	~0.709025 (±5 x 10^{-6})[3]	Approximately zero change in slope
latest Miocene	5.5 to 5.0	0.708930 to 0.709030	Age (Ma) = 2182.46 - 3071.08 x $(^{87}Sr/^{86}Sr)^2$
late Miocene	8.5 to 5.5	~0.708925 (±5 x 10^{-6})[3]	Approximately zero change in slope
middle Miocene/late Miocene	11.5 to 8.5	0.708835 to 0.708920	Age (Ma) = 23065.3 - 32523.6 x $(^{87}Sr/^{86}Sr)^2$
middle Miocene	15.0 to 11.5	~0.708825 (±10 x 10^{-6})[2]	Approximately zero change in slope
early Miocene/middle Miocene	18.8 to 15.0	0.708475 to 0.708815	Age (Ma) = 7349.39 - 10347.0 x $(^{87}Sr/^{86}Sr)^2$
early Miocene	25.0 to 18.8	0.708167 to 0.708475	Age (Ma) = 14363.9 - 20247.9 x $(^{87}Sr/^{86}Sr)^2$
middle Eocene/Oligocene	43.6 to 25.0	0.707632 to 0.708167	Age (Ma) = 22493.85 - 31725.89 x $(^{87}Sr/^{86}Sr)^4$

[1]Cambridge coral standard $^{87}Sr/^{86}Sr$, [2] Ohde and Elderfield, 1992, [3]Hodell et al. 1989, [4]Elderfield, 1986

string. The $^{87}Sr/^{86}Sr$ ages of the samples from the unconsolidated upper 200 m of the section have been plotted vs. depth in Figure 2, along with the age range of the nannofossil zones in which they are contained.

At Sites 811/825, a sudden decrease in oxygen isotopic values was recorded in the upper Pliocene (N21, CN13) periplatform ooze and was interpreted as a rapid transition from cooler-to-warmer surface-water temperatures (Isern et al., this volume). The strontium isotopic age of the onset of this event is 1.9 Ma (Sample 133-811A-3H-3, 145–147 cm), essentially occurring at the Pliocene/Pleistocene boundary (1.88 Ma).

An oxygen isotopic shift to more positive values occurred in the lower Pliocene (N1–N19, CN11) sediments (Isern et al., this volume). This change was dated between 2.5 and 5.0 Ma (Sample 133-811A-9H-1, 71–73 cm), an age range that encompasses the biostratigraphic age of the sediments (Fig. 2). The strontium isotopic age would be consistent with a time-equivalent globally recognized shift in oxygen isotope values, which is related to the onset of Northern Hemisphere glaciation between 2.5 and 2.7 Ma (Shackleton et al., 1984; Shackleton and Opdyke, 1977).

Rapid fluctuations in the $\delta^{18}O$ values of the foraminiferal samples separated from older pelagic ooze occur prior to the overlying shift to a more positive value (Isern et al., this volume). A shell fragment secured from a lower Pliocene (N18–N19, CN10) sample (Sample 133-811A-10H-1, 42–44 cm) constrains these fluctuations to a broad period between 2.5 and 5.0 Ma, when the strontium-isotope seawater curve flattened.

A shift in the carbon isotopic composition of the world's oceans to more negative values occurred between 6.7 and 6.2 Ma (Keigwin and Shackleton, 1980; Vincent et al., 1980). This late Miocene carbon shift was recorded at Site 811 (Isern et al., this volume). An upper Miocene (N16–N17, CN9) foraminiferal sample (Sample 133-811A-11H-3, 80–82 cm) was selected to date the uppermost boundary of the shift. The strontium isotopic age of the sample, 5.1 Ma, indicates that shift is, indeed, a late Miocene event on the northeastern Australian margin. In addition, the sample was selected to date the late Miocene cooler surface-water temperatures (16°–19°C) recorded in the oxygen isotope stratigraphy (Isern et al., this volume). A second upper Miocene (N16–N17, CN9) foraminiferal sample (Sample 133-811A-12H-1, 110–112 cm) further constrains the late Miocene carbon shift at 5.2 Ma.

A shell fragment (Sample 133-811A-12H-4, 55–56 cm) recovered in upper Miocene (N16-N17, CN9) sediments gave a late middle Miocene strontium age of between 11.5 and 15.0 Ma, implying the reworking of older material downslope into younger sediments. This is illustrated diagrammatically in Figure 2, where the age of the shell fragment plots well to the right of the regression curve fitted to the isotopic and biostratigraphic data. This indicates that shell fragments may not necessarily provide reliable strontium isotope ages due to the potential for reworking.

A third upper Miocene (N16–N17, CN9) foraminiferal sample (Sample 133-811A-14H-6, 138–140 cm) was selected to constrain the lower boundary of the late Miocene carbon shift at Site 811. The strontium isotope age of 10.8 Ma appears to be too old considering

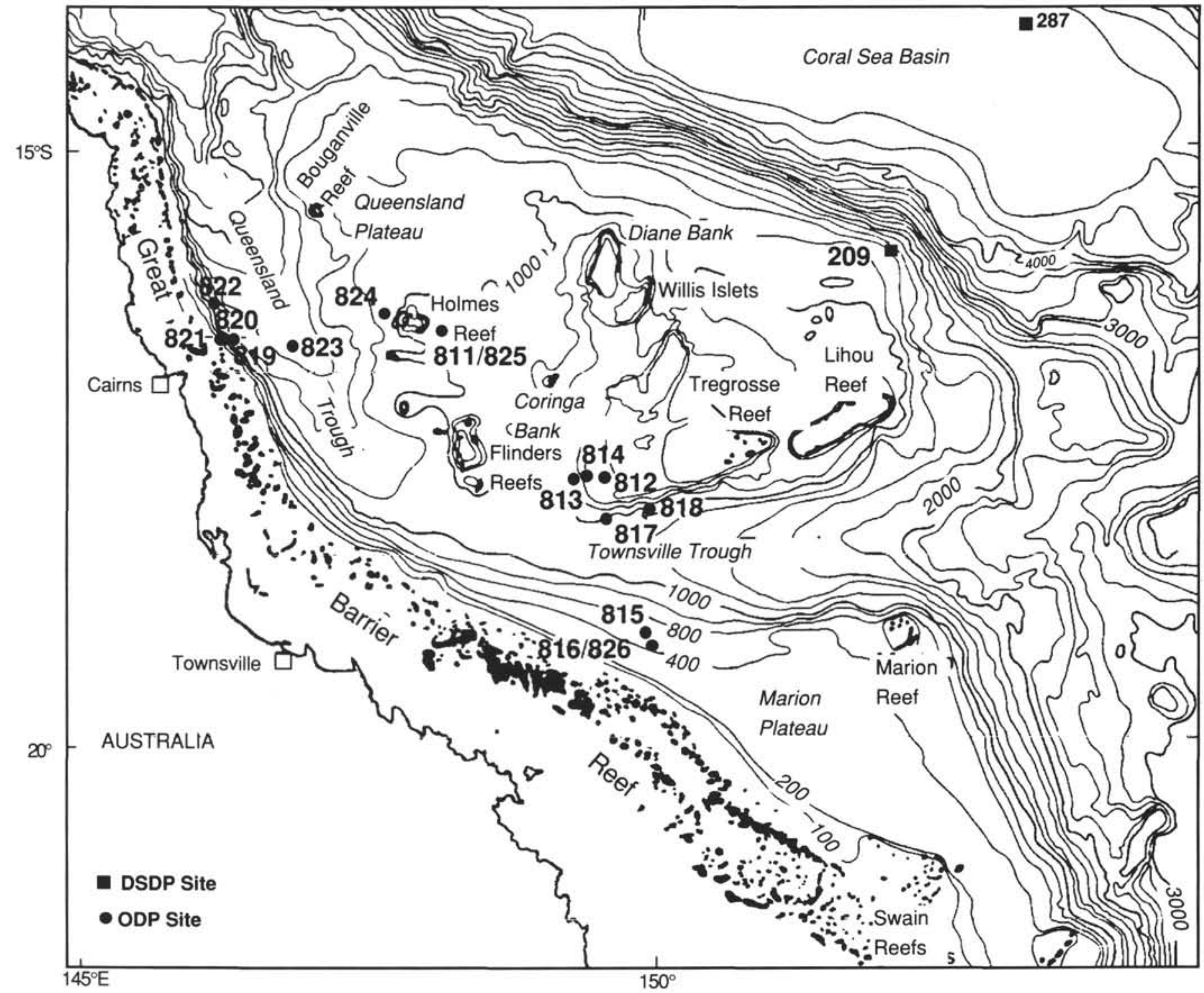

Figure 1. Bathymetric map of northeastern Australian margin indicating locations of Leg 133 drill sites on the Queensland Plateau, Marion Plateau, and Great Barrier Reef slope. Bathymetry in meters.

the younger nannofossil age (Fig. 2) and may represent a mixture of reworked planktonic material.

The biostratigraphically dated middle to upper Miocene sediments of lithologic Unit III are periplatform ooze and chalk with gravity- and debris-flow deposits. A foraminiferal sample (Sample 133-811A-20H-3, 100–102 cm) separated from this ooze (N15?/CN7) provides a strontium isotope age of 9.8 Ma, indicating deposition in the earliest late Miocene. A sample of reefal material (Sample 133-811A-19H-1, 109–111 cm) found redeposited within the overlying periplatform ooze (N16–N17, CN8) shows a strontium isotope age of 15.8 Ma. This middle Miocene lithic component within upper Miocene sediments indicates that reworked middle Miocene, possibly exposed, platform top material was transported downslope during the earliest late Miocene. A major lowering in eustatic sea level occurred at 10.4 Ma (Haq et al., 1987) and may have led to significant exposure and erosion of the Queensland platform with subsequent downslope transport.

The dramatic bioassemblage change from upper Oligocene (P22–N3), temperate-to-subtropical, open-marine shelf fauna to lower Miocene, tropical neritic fauna within a 10 m section at about 350 mbsf probably represents a major modification of the ocean circulation pattern on the northeastern Australian margin (Davies, McKenzie, Palmer-Julson, et al., 1991). This change occurred too rapidly to have been the result of northward drift of the Australian Plate to bring the Queensland Plateau into warmer tropical waters. One sample (Sample 133-811B-16X-2, 94–96 cm) of reefal limestone confirmed the timing of early Miocene tropical sedimentation with a strontium isotope age of 21.0 Ma. Two samples (Samples 133-811B-20X-1, 46–48 cm, and 133-811B-21X-1, 80–82 cm) of the underlying upper Oligocene packstone yielded an average strontium isotope age of 27.5 Ma, further refining the biostratigraphic age interpretation. These dates indicate that the Queensland Plateau was bathed in cooler waters until the latest Paleogene. The onset of tropical reef growth in the western Coral Sea region was apparently an early Neogene event, related to the reorganization of surface-water circulation patterns in the southwest Pacific Ocean.

Drilling at Site 825, at the same location as Site 811, penetrated the entire carbonate section on the Queensland Plateau and recovered metasediments of the underlying continental basement. A rudstone sample (Sample 133-825B-8R-1, 19–21 cm) from the sediment core taken directly above basement was selected to date the initiation of

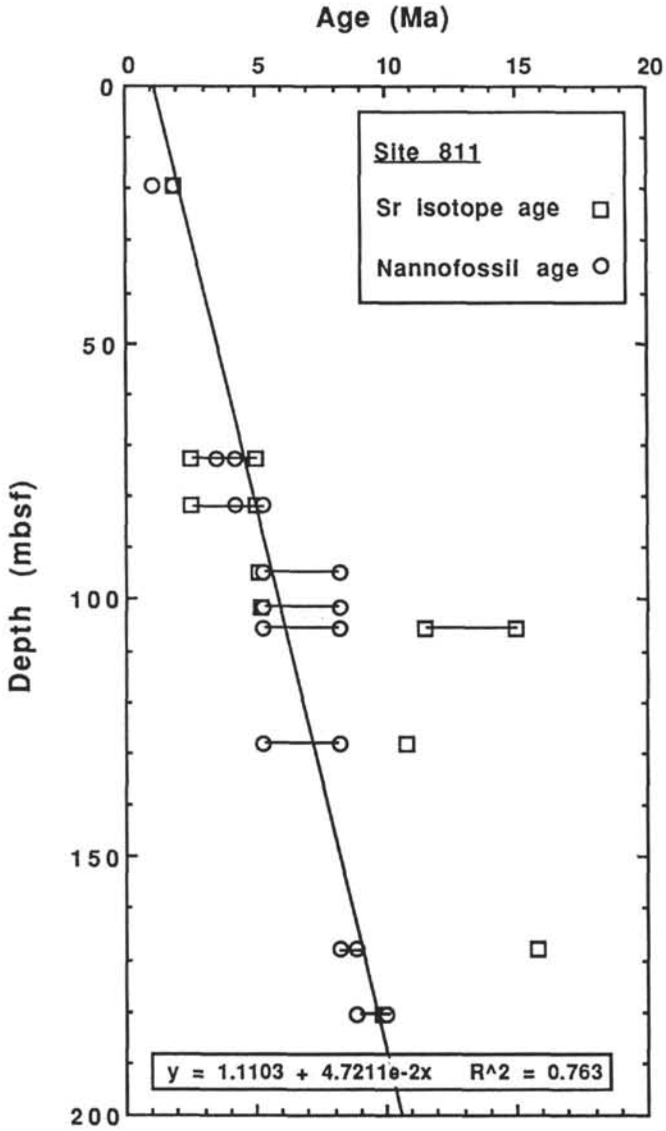

Figure 2. The $^{87}Sr/^{86}Sr$ ages of selected samples from the upper 200 m of unconsolidated, alternating periplatform and pelagic oozes drilled at Site 811 are plotted vs. depth in the section. The nannofossil ages of the discrete samples (Wei and Gartner, this volume), as determined from the age range of the nannofossil zones in which they are contained, also are plotted. The linear regression curve is fitted to both the strontium and nannofossil ages.

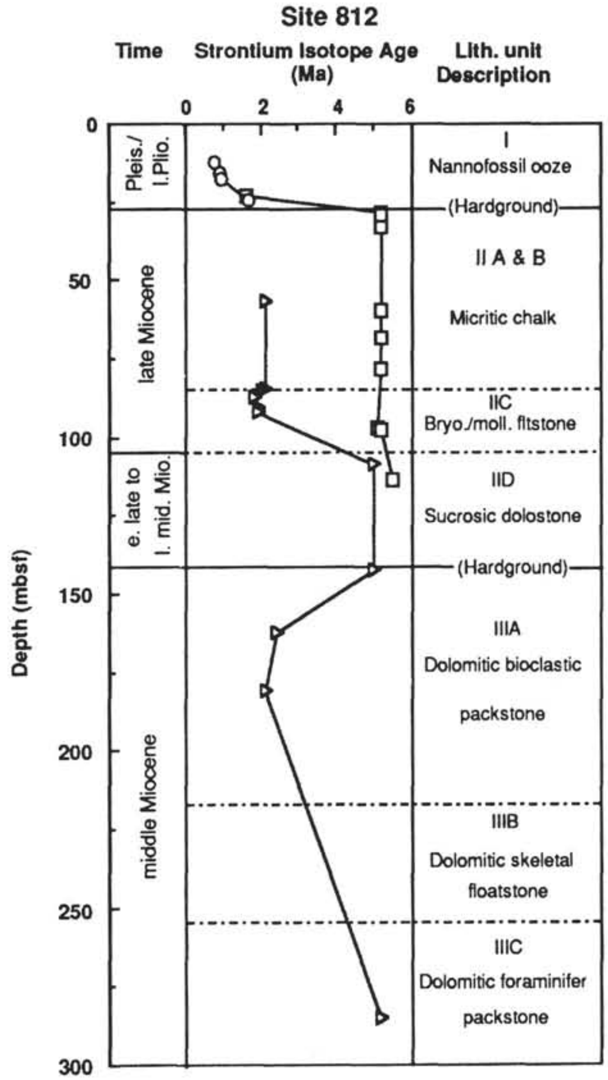

Figure 3. The $^{87}Sr/^{86}Sr$ ages of selected samples from the 300-m-thick sequence of middle Miocene to Pleistocene platform-top sediments drilled at Site 812 are plotted vs. depth in the section. The $^{87}Sr/^{86}Sr$ ages are for calcium carbonate (squares) or dolomite (triangles) samples, selected to date lithologic changes and dolomitization event(s). Magnetostratigraphic ages (circles) for the upper Pliocene/Pleistocene sediments are also plotted. The lithologic descriptions and time scale are from Davies, McKenzie, Palmer-Julson, et al. (1991).

carbonate sedimentation on the platform. The strontium isotope age of the sample is 36.4 Ma, a date that is coincident with that of the Eocene/Oligocene boundary.

Results from Site 812

Site 812 is located on the southern margin of the Queensland Plateau, between Flinders Reef and Tregrosse Reef (Fig. 1). This site was a lagoonal-bank site selected to study facies changes in response to sea-level fluctuations in a carbonate platform environment (Davies, McKenzie, Palmer-Julson, et al., 1991). Drilling penetrated a 300-m-thick sequence of middle Miocene to Pleistocene platform-top sediments (Fig. 3). Sedimentation during the middle Miocene occurred in a shallow-water, lagoonal, or backreef environment. Subsequently, the site underwent a progressive deepening from a neritic setting (0–200 m) during the late Miocene to early Pliocene, to an upper bathyal environment (200–600 m) during the late Pliocene and Pleistocene. Increasing water depth, in conjunction with apparent paleoceanographic events, are reflected by facies changes in the sedimentary record. The neritic and lagoonal sediments have undergone extensive dolomitization. Samples (Table 1) were selected for strontium isotope analyses to date the lithologic changes and the dolomitization event(s).

At Site 812, upper Pliocene/Pleistocene pelagic ooze unconformably overlies a 1.5-m-thick lower Pliocene (N18–N19?, CN11 or older) hardground. A shell fragment retrieved from an upper Pliocene (CN113b–CN13A) pelagic ooze (Sample 133-812C-3H-4, 95–97 cm) at 22.4 mbsf, approximately 5 m above the hardground, has a strontium isotope age of 1.6 Ma. Good magnetostratigraphy is available for the upper part of the sequence to just above the hardground. At 23.7 mbsf, the Matuyama/Olduvai polarity reversal boundary (1.66 Ma) was observed, which is in good age agreement with the strontium dated shell (Fig. 3). This agreement implies that the shell has not been reworked from significantly older sediments, as observed in the data from Site 811.

Three samples (Samples 133-812A-5X-1, 4–5 cm, -5X-1, 55–56 cm, and -5X-1, 88–90 cm) of the hardground drilled from the top, middle, and base of the recovered core were used for strontium dating. The strontium isotope age of all three samples is 5.2 Ma, within the age resolution in the dating method. Based on the ages of the overlying pelagic ooze and the hardground, a period of nondeposition or erosion of at least 3 m.y. must have occurred on the Queensland Plateau margin and is represented at Site 812 by hardground formation.

Beneath the hardground, a 60-m-thick sequence of upper Miocene (CN9–CN12c-a) micritic chalk, deposited in a neritic (outer shelf) environment, was recovered. Shell and bryozoan fragments found within this chalk (lithologic Subunits IIA and IIB) were analyzed to determine their strontium isotopic ages. The age of these fossils (Samples 133-812C-5H-2, 130–132 cm, -8H-5, 130–132 cm, -9H-1, 9–11 cm, and -10H-1, 70–72 cm) is exclusively 5.2 Ma. One cannot exclude the fact that the shell fragments have been reworked into younger sediments, but the strontium isotope age of 5.2 Ma for the overlying hardground would imply otherwise. The singular age for all of the fossils might indicate that the strontium isotope signal of the late Miocene age sediments was reset or overprinted during the time of the upper hardground formation.

The sediments (CN9) of lithologic Subunit IIC stratigraphically below the micritic chalk contain a high concentration of molluscan shells and were probably deposited as an oyster-encrusting bryozoan bank in an inner shelf environment (Fig. 3). As observed in the oxygen isotope stratigraphy of Site 811 (Isern et al., this volume), cooler surface-waters flowing across the Queensland Plateau were apparently characteristic for the latest Miocene. A shell fragment (Sample 133-812C-11H-CC, 7–8 cm) and an oyster shell (Sample 133-812C-12H-1, 66–68 cm) gave strontium isotope ages of 5.1 and 5.2 Ma, respectively, indicating that this nontropical, oyster-bryozoan build-up developed during the latest Miocene. Again, the similarity of the strontium ages for these two samples with those of samples from the overlying units might indicate reequilibration of the $^{87}Sr/^{86}Sr$ in the latest Miocene coincident with the hardground formation.

Six samples of the treated dolomite fraction from sediments of lithologic Subunits IIA, IIB, and IIC were analyzed (Samples 133-812A-12X-1, 64–66 cm, -12X-3, 66–70 cm, -12X-5, 66-70, -12X-6, 66–70 cm, 133-812C-10H-6, 50–52 cm, and -7H-6, 50–52 cm). Their strontium isotope ages range between 1.8 and 2.1 Ma (Table 1). The approximately 3 m.y. younger age of the dolomite with respect to the surrounding sediments indicates that dolomitization occurred significantly later than deposition.

Below the oyster-bryozoan bank, the sediments of lithologic Subunit IID become increasingly more dolomitized and contain no age-diagnostic fossils, probably as a result of increasingly pervasive diagenesis. A shell fragment (Sample 133-812A-15X-1, 45–46 cm) from within the dolomitized sediments gave a strontium isotope age of 5.5 to 8.5 Ma, which is older than the surrounding dolomite (Samples 133-812C-13H-1, 102–104 cm) at 5.0 Ma. Again, this strongly implies that the dolomitization of these uppermost Miocene sediments occurred at least 0.5 m.y. if not longer after deposition. Three samples (Samples 133-812A-18X-CC, 12–13 cm, -20X-1, 112–113 cm, and -22X-1, 50–51 cm) of dolomite from the underlying lithologic Subunit IIIA were dated as having been formed at 5.0, 2.4, and 2.1 Ma, respectively. The older dolomite is from the hardground capping the unit (Fig. 3). The apparent inverse age gradient is notable. The age of the younger dolomite samples is similar to that of dolomite measured from Subunits IIA, IIB, and IIC (Fig. 3). Strontium isotopic data for deeper pore waters in the Site 812 sequence indicate that fluids having near-modern seawater values are flowing beneath the upper hardground (Elderfield et al., this volume). Perhaps, this fluid flow is promoting dolomitization, and the inverse age gradient recorded in the deeper dolomitized sediments may reflect a Pleistocene, or even a modern, continuing process. Dolomite (Sample 133-812B-17R-1, 1–2 cm) from near the base of the section (lithologic Subunit IIIC) again shows a latest Miocene age of 5.2 Ma (Fig. 3).

Results from Site 816

Site 816 is located on the northwestern corner of the Marion Plateau (Fig. 1). Drilling penetrated a middle Miocene tropical reef complex that was directly overlain by Pliocene/Pleistocene clayey nannofossil ooze (Davies, McKenzie, Palmer-Julson, et al., 1991). The shallow-water carbonates, which are pervasively dolomitized, were divided into two lithologic units on the basis of an upsection facies change from reef flat (Unit III) to proximal backreef (Unit II). Strontium isotopes were measured on four dolomite samples to determine the maximum possible age of the dolomitization event (Table 1). The data show that the dolomites of Unit II may be younger than those of Unit III. Unit II dolomites (Samples 133-816B-3R-1, 74–76 cm, and -816C-4R-1, 46–52 cm) may have been dolomitized as early as 5.2 Ma, whereas the underlying Unit III dolomites (Samples 133-816C-8R-1, 106–109 cm, and -13R-1, 27–30 cm) give progressively older strontium isotope ages with depth (i.e., 5.5–8.5 and 8.8 Ma, respectively). This increase in age with depth implies that dolomitization of the middle Miocene carbonates at Site 816 may have proceeded in an upward direction, with the more deeply buried sediments being dolomitized earlier. A single drill site does not allow for the delineation of a flow pattern for the dolomitizing fluids. In any case, the dolomitization has led to a resetting of the strontium isotope age of the shallow-water carbonate from its original middle Miocene age to the present late Miocene one.

Results from Site 817

Site 817 is located on the northern side of the Townsville Trough, on the lower slope of the Queensland Plateau southwest of the Tregrosse/Lihou/Coringa Bank complex (Fig. 1). Drilling penetrated a 700-m-thick, late early Miocene to Pleistocene sequence of carbonate platform slope sediments (Davies, McKenzie, Palmer-Julson, et al., 1991). A stable isotopic record of paleoceanographic changes that occurred at this location during the last approximately 7 m.y. was generated for the sequence from the surface sediments to a major unconformity at 200.8 mbsf (Isern et al., this volume). The entire sequence records the varying flux to the slope of platform vs. pelagic-derived carbonate sediments. Sedimentation during the latest early to middle Miocene and the early late Pliocene to Pleistocene was dominated by redeposited sediments from the platform, whereas during the intervening period, from the late middle Miocene to early late Pliocene, the Queensland Plateau was apparently drowned and did not produce significant amounts of sediment, allowing the pelagic flux to the seafloor to accumulate undiluted by platform material (200–120 mbsf). The lowermost carbonates in the sequence, deeper than 570 mbsf, have been dolomitized. Samples from Site 817 (Table 1) were selected for strontium isotope analyses to date the paleoceanographic changes observed in the oxygen isotope record, sediment-flux changes, a major unconformity, and dolomitization event(s).

As at Site 811/825, a rapid decrease in oxygen isotopic values was recorded at Site 817 in the upper Pliocene (N21, CN12a) periplatform ooze and this was interpreted as a transition from cooler (16°–19°C) to warmer (~25°C) surface-water temperatures (Isern et al., this volume). The strontium isotopic age of the onset of this event is 1.7 Ma (Sample 133-817A-13H-4, 106–108 cm); at or near the Pliocene/Pleistocene boundary (1.88 Ma), similar to that at Sites 811/825. The biostratigraphic interpreted age of the oxygen isotope event is older at Site 817 than at Sites 811/825 (i.e., the oxygen isotope change is recorded in nannofossil Zone CN12a [3.45–2.6 Ma] at Site 817 vs. Zone CN13 [1.88–0.93 Ma] at Sites 811/825). This age discrepancy may result from a reworking of older, fine-grained sediment from the upper slope to the lower slope sediments at Site 817, making them appear older than their depositional age. The hand-picked foraminiferal sample used for both the oxygen and strontium isotope studies may be more representative of the true environmental conditions at the time of deposition. In addition, correlating the lithostratigraphic change from underlying pelagic to overlying periplatform ooze sedimentation at 120 mbsf in the sequence with the strontium isotope age of 1.7 Ma for the periplatform sediments at 116 mbsf indicates that the renewal of carbonate bank production on the platform, with off-bank transport of platform material to the slope site, is nearly synchronous with the isotopic evidence for surface-water warming.

Six other samples of pelagic ooze were selected for strontium isotope analysis to provide additional age control for the late Miocene/early Pliocene interval of the sequence. All six samples (Samples 133-817A-20H-1, 70–72 cm; -20H-6, 70–72 cm; -21H-1, 70–72 cm; -21H-6, 20–22 cm; -21H-6, 70–72 cm; and -22H-2, 20–22 cm) contain age-diagnostic nannofossils that indicate deposition during the late Miocene to early Pliocene (CN9b–CN10a-b) between 6.74 and 4.60 Ma (Gartner et al., this volume). The strontium isotope ages show a systematic increase with depth from 5.0 Ma at 177 mbsf to 5.2 Ma at 197 mbsf (Table 1). This series of samples indicates that the strontium isotope dating method using separated foraminifers can provide extremely high-resolution age control for sediments deposited during periods when the slope of the strontium-isotope seawater curve is steep. However, while the trend is intriguing, it is not statistically significant without duplicate analyses.

Foraminifers from the upper Miocene (N16–N17, CN9a) Sample 133-817A-22H-5, 20–22 cm, 1 m below the major unconformity at 200.8 mbsf, give a strontium isotopic age of 10.2 Ma. Although strontium age calculations are less accurate in this interval of the seawater curve, the difference between the age of this sample and that of the overlying dated sample at 197.40 mbsf (10.2 vs. 5.2 Ma, respectively) indicates that the duration of the period of nondeposi-tion or erosion was about 5 m.y., or most of the late Miocene. The sharp change in slope in a graph of strontium isotope and nannofossil ages vs. depth illustrates the magnitude of this unconformity (Fig. 4). This major nondepositional or erosional event was extensive on the upper slopes and is traceable in seismic profiles along the southern edge of the Queensland Plateau (Davies, McKenzie, Palmer-Julson, et al., 1991).

The upper lower Miocene to middle Miocene (CN3–CN4), coarse-grained bioclastic packstones of lithologic Unit III represent platform-derived sediments that were apparently deposited into a deeper-water setting and form part of a large base-of-slope debris apron (Davies, McKenzie, Palmer-Julson, et al., 1991). The unit becomes progressively more dolomitized downsection, with pervasive dolomitization and moldic porosity occurring in Subunit IIIC. Two samples from Subunit IIIB (Samples 133-817D-26R-2, 7–9 cm, and -30R-1, 28–32 cm), which are 100% calcite, have an average strontium isotope age of 16.4 Ma, indicating that deposition and/or lithification occurred near the early Miocene/middle Miocene boundary. Likewise, a 100% dolomitized sucrosic dolomite (Sample 133-817D-39R-1, 4–8 cm) of Subunit IIIC has a similar isotopic age (16.2 Ma), indicating that the dolomitization event may have occurred at the early Miocene/middle Miocene boundary. Surprisingly, a more deeply buried, coarse crystalline dolomite (Sample 133-817D-43R-CC, 4–7 cm) shows an age of 5.2 Ma. This younger age implies that a second dolomitization event occurred at Site 817, which might be synchronous with the late Miocene (5.20 Ma) dolomitization event recorded in the presumed middle Miocene lagoonal carbonates of Subunit IIIC, on the margins of the platform at Site 812.

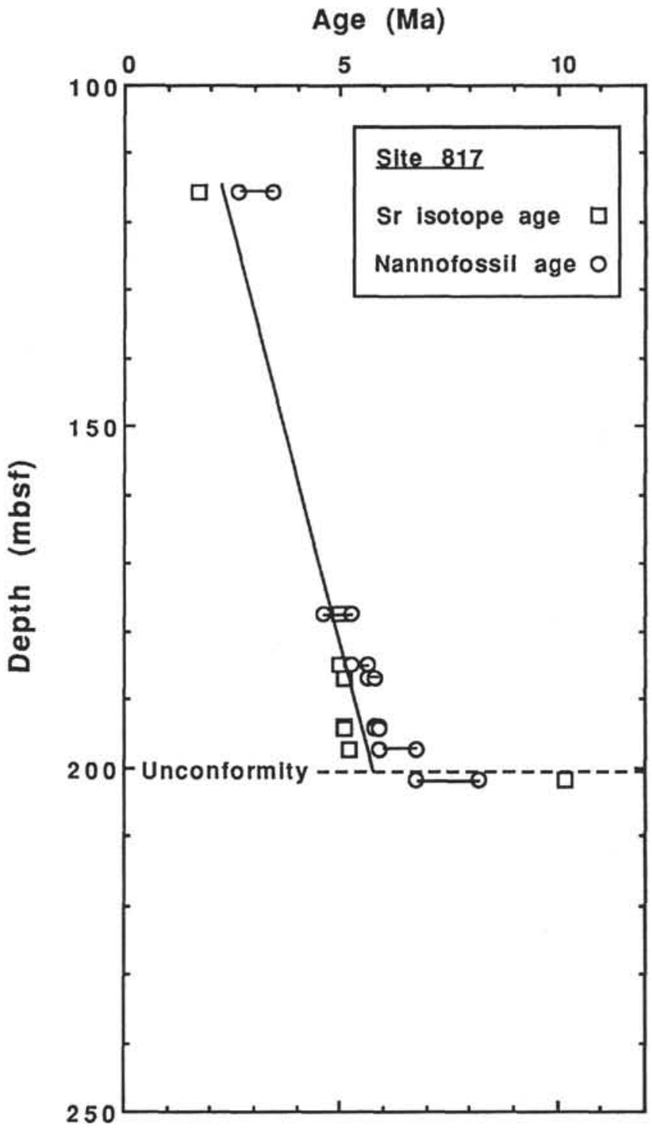

Figure 4. The $^{87}Sr/^{86}Sr$ ages of selected samples from the upper 200 m of unconsolidated, alternating periplatform and pelagic oozes drilled at Site 817 are plotted vs. depth in the section. The nannofossil ages of the discrete samples (Gartner et al., this volume), as determined from the age range of the nannofossil zones in which they are contained, are also plotted. A straight-line fit of the data points is projected to the major unconformity recognized at 200.8 mbsf (Davies, McKenzie, Palmer-Julson, et al. 1991).

Results from Site 823

Site 823, located in the central-western Queensland Trough toward the deepest part of the basin (Fig. 1), was drilled to recover a basinal section that would provide a record of the basin-fill sediments to correlate with the other drill sites on the transect from the continental margin onto the Queensland Plateau (Davies, McKenzie, Palmer-Julson, et al., 1991). The middle Miocene to Pleistocene hemipelagic to pelagic sediments are interbedded with numerous gravity-flow deposits that were interpreted as turbidites, debris flows, and slumps. The type and composition of gravity-flow deposits varied systematically throughout the sequence (Watts et al., this volume). Samples (Table 1) were selected for strontium isotope analyses to date depositional events or changes in redepositional patterns. Figure 5 shows the relatively good correlation between strontium isotope and nannofossil ages with depth in the section.

Two samples from within Unit II (Samples 133B-823B-16X-2, 125–127 cm and -18X-2, 125–127; CN13b and CN12d, respectively) were selected to place boundary ages on the observed sudden decrease in oxygen isotopic values recorded in the hemipelagic to pelagic nannofossil ooze (unpubl. data, 1993). The strontium isotope ages of the samples are 1.3 and 1.7 Ma, respectively. This early Pleistocene oxygen isotope excursion, which was also observed at Sites 811/825 and 817, was interpreted as a rapid transition from cooler-to-warmer

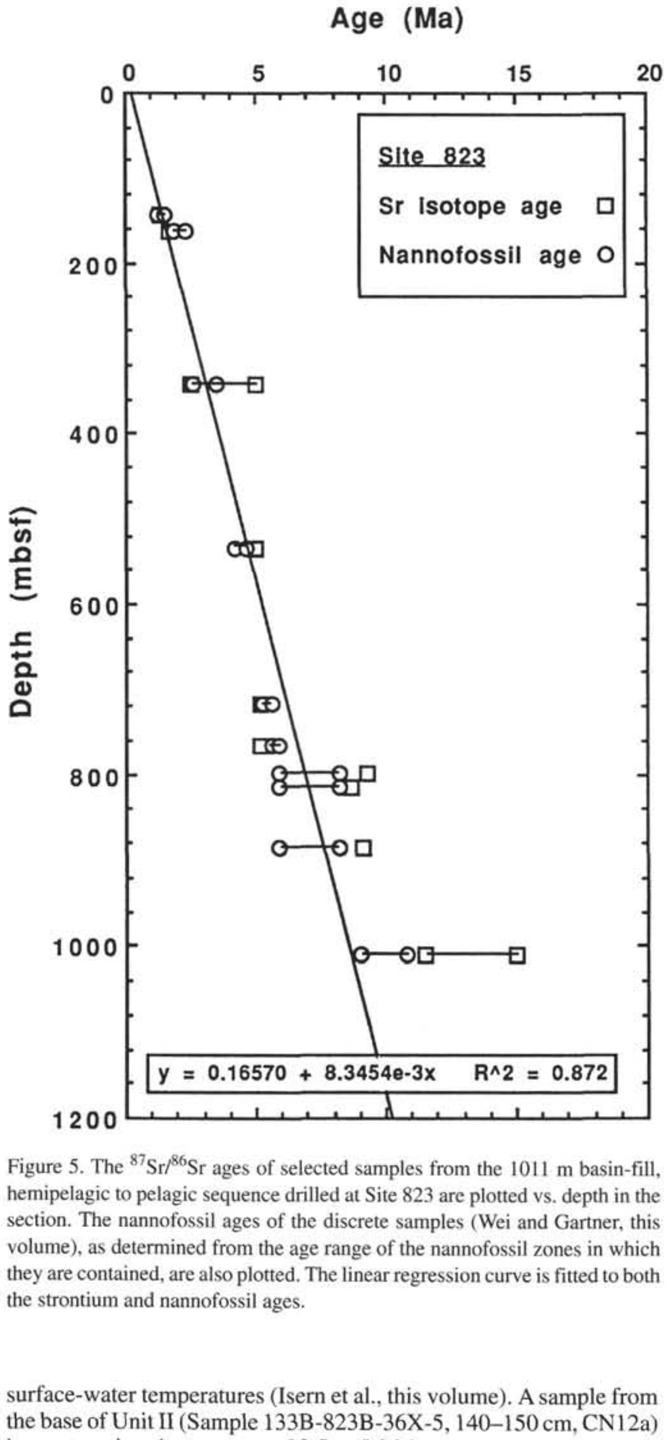

Figure 5. The $^{87}Sr/^{86}Sr$ ages of selected samples from the 1011 m basin-fill, hemipelagic to pelagic sequence drilled at Site 823 are plotted vs. depth in the section. The nannofossil ages of the discrete samples (Wei and Gartner, this volume), as determined from the age range of the nannofossil zones in which they are contained, are also plotted. The linear regression curve is fitted to both the strontium and nannofossil ages.

surface-water temperatures (Isern et al., this volume). A sample from the base of Unit II (Sample 133B-823B-36X-5, 140–150 cm, CN12a) has a strontium isotope age of 2.5 to 5.0 Ma.

Foraminifers separated from an early Pliocene age (N18–N19, CN10C) nannofossil chalk (Sample 133-823B-56X-6, 30–34 cm) deposited within the lower of two large debris flows in Unit III give a strontium isotope age of 5.0 Ma. This sample is from near the base of lithologic Unit III and is underlain by the hemipelagic sediments of Unit IV, which contains the greatest number of slumps in the entire sequence. The strontium isotope age of foraminifers from upper Miocene (N16–N17, CN9) sediments at the boundary between Units IV and V (Sample 133-823B-75X-5, 89–91 cm) is 5.2 Ma. Thus, Unit IV sedimentation represented by major amounts of slumping apparently occurred during an approximately 200,000-yr period at the Miocene/Pliocene boundary.

In addition, foraminifers separated from an upper Miocene (N16–N17, CN9) sample deposited within Unit V (Sample 133-823B-80X-6, 92–96 cm) have a strontium isotope age of 5.2 Ma, while the boundary between Units V and VI has been dated at 9.3 Ma by an upper Miocene (N16–N17, CN9) nannofossil chalk (Sample 133-823C-2R-3, 73–76 cm). The hemipelagic sediments of Unit V contain relatively few, but thin, turbiditic intercalations, implying that between ~9.3 and 5.2 Ma, the reworking of sediments from the upper slopes and the subsequent delivery of gravity-flow deposits to the deep basin site were at a minimum.

In the underlying Unit VI (N16–N17, CN9), with an age of 8.7 Ma for a sample from the middle of the unit (Sample 133-823C-4R-1, 74–77 cm) and a basal age of 9.1 Ma (Sample 133-823C-11R-4, 59–64 cm), one can see an increase in the number and thickness of turbidites and debris flows. Thus, the deposition of the 100-m-thick Unit VI probably occurred during a relatively short period centered around 9 Ma.

The basal Unit VII is characterized by the intercalation of shallow-water carbonate platform debris that includes angular fragments of corals, coralline algae, columnar corallinaceans, large benthic foraminifers, and thick mollusk shells. The strontium age at the bottom of the 1011.0-m-thick sequence, based on the analysis of a middle Miocene (N14, CN6–CN7) packstone (Sample 133-823C-24R-4, 45–48 cm), indicates a late middle Miocene age for the sediments, within the range of 11.5 to 15.0 Ma.

CORRELATION OF PALEOCEANOGRAPHIC AND LITHOLOGIC EVENTS

The strontium-isotope dating of late Neogene paleoceanographic changes recorded in oxygen isotope stratigraphies at Sites 811 and 817 on the lower slopes of the Queensland Plateau (Isern et al., this volume) provide us with age criteria for correlating these events with similarly dated lithologic changes observed on the plateau's upper margins at Site 812 and in the basin sequence at Site 823 in the Queensland Trough. The oxygen-isotope temperature data from Sites 811 and 817 indicate that surface-water temperatures were from 5° to 10°C cooler than modern values (~24°C) during the late Miocene/early Pliocene. This is in agreement with biological indicators of nontropical waters at Site 812 during the latest Miocene/earliest Pliocene (Davies, McKenzie, Palmer-Julson, et al., 1991). The hardground found at Site 812 is evidence for condensed sedimentation from the latest Miocene until the latest Pliocene (~5.2–1.7 Ma). At Site 823, the hemipelagic sediments deposited between ~9.3 and 5.2 Ma contain relatively few, but thin, turbiditic intercalations, implying that the reworking of sediments from the upper slopes and the subsequent delivery of gravity-flow deposits to the deep basin site was at a minimum. This would be the case had there been a reduction in carbonate-bank productivity on the platform top, as indicated by the sedimentary facies at Site 812, which led to a significant decrease in the off-bank transport of material to the slopes and, hence, into the basins.

The oxygen-isotope temperature data from Sites 811, 817, and 823 show a warming of the surface-water temperatures toward modern values, beginning at about 1.9 to 1.7 Ma. This trend toward warmer tropical conditions would be nearly synchronous with the Pleistocene initiation of the Great Barrier Reef (Davies, McKenzie, Palmer-Julson, et al., 1991) and the resumption of sedimentation over the hardground found at Site 812 on the Queensland Plateau. Together, the data indicate that there must have been a major reorganization of the circulation pattern on the northeastern Australian margin, beginning in the latest Pliocene, that apparently brought warm tropical waters into the region. Based on these correlations, we propose that paleoceanography is a significant factor for determining the history of a carbonate platform's development.

TIMING OF DOLOMITIZATION EVENTS

Pervasive dolomitization was recognized in both shallow-water carbonates at Sites 812 and 816 and deeper-water deposits at Site 817. Because these dolomites contain relatively few or no age-diagnostic fossils, probably the result of obliteration by diagenesis, strontium isotope dating was used to determine possible ages of the dolomitization event(s). Assuming that the dolomitizing fluid was seawater, it should be possible to date the dolomitization event using the strontium-isotope seawater curve. Given the fact that sea water has relatively low strontium concentrations and that the original calcium carbonate sediments have relatively higher concentrations, significant amounts of seawater must reequilibrate with the sediment to reset the original strontium isotope value to that of contemporaneous seawater. This is probably the case because significant amounts of seawater must be circulated through a calcium carbonate sediment to dolomitize it completely. Land (1985) estimated that about 1000 pore volumes of seawater are required to supply enough magnesium to dolomitize a given volume of calcium carbonate. In any case, the strontium isotope ages for the dolomite in this study can be considered to be maximum ages for the dolomitization events, with a possibility that they represent the actual ages of dolomitization.

The oxygen isotope data for the dolomites show that the shallow-water samples are isotopically more enriched in ^{18}O than the deeper-water samples, regardless of age (Table 2). The isotope formation temperatures of the dolomites were calculated by assuming a modern $\delta^{18}O$ value for seawater and by using the dolomite-water fractionation equation of Matthews and Katz (1977) after converting the $\delta^{18}O$ PDB values to SMOW (Clayton et al., 1968). The diagenetic temperature for the shallow-water dolomites ranged between 12.5° and 15.5°C, indicating isotopic equilibration at the present in-situ borehole temperatures at Sites 812 and 816 (Davies, McKenzie, Palmer-Julson, et al., 1991). This was also the case for the deeper-water dolomites from Site 817, which have a calculated isotopic equilibration temperature of 29°C. Using the measured geothermal gradient at Site 817 (Davies, McKenzie, Palmer-Julson, et al., 1991), a temperature of about 35° to 40°C would exist at the depth of dolomite occurrence. Thus, the dolomites apparently formed in isotopic equilibrium or have reequilibrated with near-modern in-situ temperatures.

The inverse stratigraphic position of younger dolomites beneath older dolomites at Site 812 is probably indicative of a renewed phase of dolomitization during the latest Pliocene/Pleistocene, if not even more recently. Pore fluids secured from this section have near-modern strontium isotope values, indicating seawater flow within the carbonate platform (Elderfield et al., this volume). This information, combined with the young age of the dolomite and other geochemical pore-water data (Davies, McKenzie, Palmer-Julson, et al., 1991; Swart et al., this volume), implies that circulation of dolomitizing fluids through the platform may be leading to modern dolomite formation. A reversal in the strontium isotope ages of the dolomite from Site 817 also was measured, with the deeper, more crystallized sample giving a younger strontium age (~5.2 vs. ~16.2 Ma). At this site, the geochemical patterns in the pore fluids are consistent with the occurrence of evaporites at depth, an alternative source of dolomitizing fluid (Davies, McKenzie, Palmer-Julson, et al., 1991; Elderfield et al., this volume).

The strontium isotope ages of the studied dolomites (Table 1) indicate that there were at least two dolomitization periods on the Queensland Plateau, one during the latest Pliocene/Pleistocene (~2.4–1.8 Ma) and the other in the latest Miocene (~5.2–5.0 Ma). There may have been a third period at the early Miocene/middle Miocene boundary (~16.2 Ma), as indicated by one sample from Site 817. On the Marion Plateau, the dolomitization event may have been continuous, as indicated by the upward-increasing ages from ~8.8 to 5.2 Ma at Site 816. Subsidence pulses on the Southern Queensland Plateau (Sites 812 through 814) occur at ~2.8 and 6 Ma and on the Marion Plateau (Site 815) at ~6.8 Ma (Katz and Miller, this volume). These rapid deepening events or relative rises in sea level may have induced changes in the hydrodynamic circulation patterns within the carbonate platforms, leading to an increased flux of seawater through the platform. It is, also, very interesting to note that two distinct dolomitization events occurring at ~2 and 5 Ma have been recorded in carbonate platforms at two other locations, Kita-daito-jima Atoll, North Philippine Sea (Ohde and Elderfield, 1992) and Little Bahama Bank, Bahamas (Vahrenkamp et al., 1988). This synchronism in the timing of dolomitization at these three locations may reflect a global process driven by a common cause, such as control of eustatic sea level, or it may simply be a coincidence. These initial findings warrant further detailed geochemical studies of the fluids and solids from the Queensland Plateau to determine the hydrodynamic processes promoting this significant carbonate platform dolomitization.

CONCLUSIONS

This study demonstrates that the strontium-isotope dating method, based on the strontium-isotope seawater curve, can be used successfully to date stratigraphic events in a carbonate platform environment and that its application is not strictly limited to dating deep-sea pelagic sequences. The results presented for the Leg 133 samples have allowed us to correlate paleoceanographic changes, delineated from oxygen isotope signals, with paleoenvironmental or facies changes recorded in the lithostratigraphy. These correlations show that there is a strong connection between the prevailing paleoenvironmental conditions and the developmental style of a carbonate platform. In this particular case, the healthy growth or demise of the Queensland Plateau was probably ultimately dictated by changes in paleotemperature and paleocirculation patterns. In addition, the strontium-isotope dating of discrete dolomite intervals allowed us to substantiate other geochemical evidence indicating that dolomization is a hydrodynamically active process within this modern carbonate platform.

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* Abbreviations for names of organizations and publication titles in ODP reference lists follow the style given in *Chemical Abstracts Service Source Index* (published by American Chemical Society).

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