Carbonate preservation variation in the Caroline Basin during the last 330 kyr

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The carbonate content of two cores from the West Caroline Basin in the western equatorial Pacific was examined during the last 330 kyr. The results show that carbonate content varied greatly in core C4402, which was taken from a water depth of 4,402 m between the present-day lysocline and the Carbonate Compensation Depth (CCD), whereas the content in core NGC34 which was recovered from a water depth of 2,188 m, displays no distinct glacial-interglacial difference. The fluctuations observed in core C4402 are ascribed to dissolution induced by change in seawater chemistry rather than by changes in local rain rate of organic carbon. The degree and pattern of carbonate preservation in the West Caroline Basin differ from that observed in cores from the Ontong Java Plateau although both areas are within the western equatorial Pacific.

The chronostratigraphy for cores C4402 and NGC34 is based on $\delta^{18}\text{O}$ records to the SPECMAP stack record and on coccolithophorid stratigraphy. We chose $\delta^{18}\text{O}$ records as the second variable in a cross-spectral analysis of $\delta^{18}\text{O}$ versus the preservation degree. No significant differences were found even when we used a stacked $\delta^{18}\text{O}$ record. Spectral comparison of carbonate preservation and $\delta^{18}\text{O}$ records shows high coherencies at the 100-kyr and 41-kyr periodicities, but low coherency at the precessional period (23-kyr). We interpret the high coherencies as evidence that deep-water circulation changes, driven by high-latitude climatic forcing in the North Atlantic, are the principal source of variability in the carbonate preservation record of the West Caroline Basin. Carbonate preservation is in phase with $\delta^{18}\text{O}$ at the 100-kyr period, indicating a rapid response of the dissolution intensity in Pacific deep and/or bottom water to changing climate.

INTRODUCTION

The carbonate variations recorded in deep-sea sediments provide important geological information about paleoclimatic change and the global carbon cycle. The distribution, preservation, and accumulation of carbonate on the seafloor is largely controlled by the balance between the precipitation of calcium carbonate in supersaturated surface waters and its dissolution in the undersaturated deep waters. Fluctuations in carbonate dissolution are largely affected by changes in the global mass balance of carbonate and ocean cir-

culation, which are mediated by global climate condition. These processes, which actively promote the transfer of carbon among several carbon reservoirs, serve as important controls of atmospheric carbon dioxide content as well as the carbon chemistry of the ocean over the late Pleistocene (Farrell and Prell, 1989).

Previous studies demonstrated that dissolution changes in cores below the present lysocline are greater than those above the lysocline (Luz and Shackleton, 1975). A high-resolution study of dissolution variations in the Indian Ocean over the past 800 kyr found a significant correlation be-

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tween carbonate dissolution and the orbital variations at the periodicities of 100 kyr and 41 kyr but not at the precessional 23 kyr (Peterson and Prell, 1985a, b). Moore *et al.* (1977) found that dissolution at the Ontong-Java Plateau in the western equatorial Pacific has strong power and coherency with ice volume near the 23-kyr cycle but not at the 41-kyr cycle. Le and Shackleton (1992) reported that dissolution in the same area has significant variance distributions and coherencies with $\delta^{18}\text{O}$ over the 100-kyr, 41-kyr, and 23-kyr periods of orbital variations and that intermediate and deep waters experienced the same patterns of dissolution.

Previous dissolution studies in the western Pacific were concerned with intermediate and deep water depths of the abyssal sea (Groetsch *et al.*, 1991; Hebbeln *et al.*, 1990; Wu *et al.*, 1991; Le and Shackleton, 1992; Thunell *et al.*, 1992). In this paper, we present a reconstruction of carbonate

preservation patterns in the deep water (about 4400 m) of the semi-isolated deep basin, the West Caroline Basin which is located west of Ontong-Java Plateau.

SEDIMENTS AND METHODS

Study area and sediment sample

The West Caroline Basin is approximately 4,000 to 5,000 m deep and is semi-enclosed with a rise near Sonsorol and Caroline islands as well as Eauripik Rise (Fig. 1). These rises which separate the West Caroline Basin from the western North Pacific are approximately 2,000–3,000 m deep and allow Pacific deep (approximately more than 2,000 m water depth) and intermediate water (approximately 1,000–2,000 m water depth) to enter the basin (Uehara and Taira, 1990). On the other hand, the deep sill below approximately 4,000 m water depth is located along the Yap-

Fig. 1. Bathymetric map of the West Caroline Basin showing the location of the cores used in this study (Solid circle represents C4402 at 4,402 m of 135°01.3' E and 2°59.2' N and solid square NGC34 at 2,188 m of 141°29.4' E and 3°48.1' N). The heavy arrow identifies the predicted primary flow path of the Pacific bottom and deep waters into the West Caroline Basin (Piper *et al.*, 1987; Uehara and Taira, 1990; Nishimura *et al.*, 1993).

Mariana trench (about 4,000 to 8,000 m deep), which connects the West Caroline Basin with the open western Pacific Ocean. This strait serves as the only conduit for Pacific bottom water (approximately several hundreds meters above seafloor) to ventilate the West Caroline Basin (Nishimura *et al.*, 1993).

Sediment cores C4402 and NGC34 were collected during the NH92-1 cruise of the *R/V HAKUREI* from a water depth of 4,402 m and 2,188 m of the West Caroline Basin, respectively (Fig. 1). No turbidites were observed in the cores and sediment trap studies were against significant bottom transport of terrigenous sediments (Kawahata, 1994).

Stratigraphy

Given their sensitive locations between the depth of the present-day lysocline and the CCD (Carbonate Compensation Depth), cores C4402 and NGC34 were sampled at 4 to 8-cm intervals. Sediments aliquots for isotopic analyses were disaggregated and wet-sieved at 63 μm . *Globorotalia tumida*, a deep-dwelling planktonic foraminifera, was picked for $\delta^{18}\text{O}$ analysis. It was the only species consistently abundant enough for analysis throughout Core C4402. *Globigerinoides sacculifer* was chosen for the $\delta^{18}\text{O}$ analysis of NGC34. Ten to twenty specimens of *Globorotalia tumida*, >250 μm , and forty to fifty specimens of *Globigerinoides sacculifer*, >250 μm , were served for $\delta^{18}\text{O}$ on a Finnigan MAT Delta E at the University of Ryukyus. The standard deviation for the $\delta^{18}\text{O}$ was 0.036‰.

The oxygen isotope data from cores C4402 and NGC34 are plotted against depth and estimated age in Figs. 2 and 3, respectively. The chronostratigraphy is based on the correlation of our $\delta^{18}\text{O}$ record to the SPECMAP stack record (Imbrie *et al.*, 1984) and on coccolithophorid stratigraphy (Table 1). The first occurrence of *Emiliani huxley* (at 275 ka) occurs at 831 cm depth in C4402 and is consistent with the isotope chronostratigraphy. Core C4402 showed higher average sedimentation rate of 3.7 cm kyr⁻¹. For the carbonate analyses 251 samples were taken at

about 4 cm intervals, giving an average temporal sample interval of about 1.2 kyr. Core NGC34 has a lower average sedimentation rate of 1.1 cm kyr⁻¹ due to lower primary productivity (Berger *et al.*, 1989). Sixty-two sediment samples taken at about 4 cm (4.3 kyr) intervals were used for carbonate analysis.

Carbonate contents

Separate samples were taken for other chemical analyses. Sediment samples for chemistry including organic carbon, carbonate, biogenic opal and inorganic components were frozen on board and kept at -20°C before these analyses in the land-based laboratory. They were crushed to fine powders after drying at 40–50°C and split into several aliquots.

The carbonate content for C4402 core was calculated by measuring Ca concentration. Sediment samples were reacted with diluted HCl for one hour for the decalcification. Small amount of Ca was dissolved out. The amount was on average 0.40 wt.%. Therefore we carried out the correction of the contribution of Ca from clay minerals and sea-salt in the sediments. A resulting precision was $\pm 2\%$.

Carbonate content for NGC34 core was calculated from the difference between total carbon and organic carbon contents. Organic carbon was determined with a Yanako MT-5 CHN analyzer after removing carbonate by acidification within ceramic sample boats using HCl vapor. Samples were weighed out into precombusted ceramic boats and 100 μl ultra-pure water was pipetted into each sample boat (Yamamuro and Kayanne, 1995). The samples were reacted with HCl vapor to remove carbonate completely. Then the samples were dried up to drive off HCl and water at 50°C for at least 3 hours until the determination of carbon with Yanako MT-5 analyzer. Total carbon measurements were made on dried and ground bulk sediment samples with the CHN analyzer. The relative standard deviation of carbonate was $\pm 1\%$ in the case of duplicate analysis for carbonate of 90 wt.%.

Fig. 2. The values of $\delta^{18}\text{O}$ versus depth for C4402 (cross) and NGC34 (open square).

Fig. 3. The values of $\delta^{18}\text{O}$ versus age for C4402 (solid square) (A) and NGC34 (open square) (B). The SPECMAP stack $\delta^{18}\text{O}$ record is presented for comparison (solid line).

Table 1. Age control points and linear sedimentation rates. Data for core C4402 and NGC34

Depth in core (cm)	C4402			Depth in core (cm)	NGC34		
	Estimated age (Ka)	Isotopic events	Sedimentation rate (cm kyr ⁻¹)		Estimated age (Ka)	Isotopic events	Sedimentation rate (cm kyr ⁻¹)
0	0			0	0		
35	12	2.0	2.92	21.2	19	2.2	1.12
47	19	2.2	1.71	61.2	71	5.0	0.77
91	28	3.1	4.89	81.2	99	5.3	0.71
223	59	4.0	4.26	117.2	128	6.0	1.24
243	65	4.2	3.33	157.2	186	7.0	0.69
255	71	5.0	2.00	193.2	228	7.4	0.86
271	80	5.1	1.78	217.2	245	8.0	1.41
319	107	5.4	1.78				1.41
339	122	5.5	1.33				
400	135	6.2	4.71				
472	146	6.3	6.55				
504	151	6.4	6.40				
536	171	6.5	1.60				
688	216	7.3	3.38				
720	228	7.4	2.66				
736	238	7.5	1.60				
768	249	8.2	2.91				
888	287	8.5	3.16				
920	299	8.6	2.67				
			2.67				

RESULTS

Carbonate sedimentation

Carbonate contents of core C4402 ranged between 0.08 and 38.6 wt.%, averaging 10.0 wt.% (Fig. 4(a); Table 2). The low concentrations were found at present and around 28 ka, 70–130 ka

(excluding short periods near 90 ka and 110 ka), 190–210 ka, and 270–290 ka. High concentrations were observed around 10 ka, 50–60 ka, 140 ka, 170–180 ka, 220 ka, and 250–260 ka.

In order to determine whether carbonate content reflects surface water supply or seafloor degradation (or burial), another core (NGC34) was

Table 2. Weight percents and mass accumulation rates (MARs) of carbonate, sedimentation rate and dry bulk density (DBD) for core C4402

Sample number	Total depth (cm)	Isotopic stage for control point (Ka)	Age (Ka)	$\delta^{18}\text{O}$ (‰)	Sedimentation rate (cm kyr ⁻¹)	DBD (g cm ⁻³)	Carbonate (wt.%)	Carbonate MAR (mg cm ⁻² kyr ⁻¹)
B 92	0		0.00		2.92	0.33	1.33	13
B 93	1		0.34		2.92	0.36	1.50	16
B 94	4		1.37		2.92	0.36	2.33	25
B 1	7		2.40	0.13	2.92	0.40	7.74	90
B 95	8		2.74		2.92	0.48	3.91	55
B 2	11		3.77	-0.12	2.92	0.50	12.41	181
B 96	12		4.11		2.92	0.52	12.49	190
B 3	15		5.14	-0.07	2.92	0.53	15.15	234
B 4	19		6.51	0.15	2.92	0.53	15.07	233
B 5	23		7.89	0.41	2.92	0.49	14.65	210
B 6	27		9.26		2.92	0.44	9.82	126
B 7	31		10.63	0.42	2.92	0.44	9.66	124
B 8	35	2.0 (12)	12.00	0.06	1.71	0.42	13.57	98
B 9	39		14.33	0.23	1.71	0.39	7.58	51
B 10	43		16.67	0.57	1.71	0.39	7.99	53
B 11	47	2.2 (19)	19.00	1.08	4.89	0.39	7.83	149
B 12	51		19.82	1.03	4.89	0.37	6.24	113
B 13	55		20.64	0.72	4.89	0.35	9.08	155
B 14	59		21.45	0.83	4.89	0.33	5.25	85
B 15	63		22.27	0.86	4.89	0.32	5.33	83
B 16	65		22.68		4.89	0.31	5.16	78
B 17	67		23.09	0.74	4.89	0.30	4.33	64
B 18	71		23.91	0.78	4.89	0.30	4.25	62
B 19	75		24.73	0.70	4.89	0.30	3.83	56
B 20	79		25.55	0.57	4.89	0.30	4.83	71
B 21	83		26.36	0.63	4.89	0.30	5.33	78
B 22	87		27.18		4.89	0.30	3.58	53
B 23	91	3.1 (28)	28.00		4.26	0.31	1.00	13
B 24	95		28.94	0.66	4.26	0.31	4.16	55
B 25	99		29.88	0.59	4.26	0.31	7.91	104
B 26	103		30.82	0.61	4.26	0.32	4.91	67
B 27	107		31.76	0.53	4.26	0.32	4.91	67
B 28	111		32.70	0.40	4.26	0.33	4.33	61
B 29	115		33.64	0.45	4.26	0.33	8.16	115
B 30	119		34.58	0.73	4.26	0.34	9.08	132
B 31	123		35.52	0.59	4.26	0.34	14.57	211
B 32	127		36.45	0.53	4.26	0.34	14.15	205
B 33	131		37.39	0.71	4.26	0.34	7.91	115
B 34	135		38.33	0.56	4.26	0.34	12.24	177
B 35	139		39.27	0.76	4.26	0.34	14.49	210
B 36	143		40.21	0.58	4.26	0.34	13.82	200
B 37	147		41.15	0.53	4.26	0.34	14.82	215
B 38	151		42.09	0.51	4.26	0.34	14.40	209
B 39	155		43.03	0.90	4.26	0.33	11.24	158
B 40	159		43.97	0.74	4.26	0.33	10.74	151
B 41	163		44.91	0.67	4.26	0.32	11.16	152
B 42	167		45.85	0.63	4.26	0.32	11.07	151
B 43	171		46.79	0.54	4.26	0.32	16.90	230
B 44	175		47.73	0.45	4.26	0.32	12.90	176
B 45	179		48.67	0.33	4.26	0.33	17.65	248
B 46	183		49.61	0.67	4.26	0.33	19.82	279
B 47	187		50.55	0.38	4.26	0.34	12.90	187
B 48	191		51.49		4.26			
B 49	195		52.42	0.19	4.26	0.38	21.48	348

Table 2. (continued)

Sample number	Total depth (cm)	Isotopic stage for control point (Ka)	Age (Ka)	$\delta^{18}\text{O}$ (‰)	Sedimentation rate (cm kyr ⁻¹)	DBD (g cm ⁻³)	Carbonate (wt.%)	Carbonate MAR (mg cm ⁻² kyr ⁻¹)
B 50	199		53.36	0.36	4.26	0.40	26.81	457
B 51	203		54.30	0.23	4.26	0.43	32.05	587
B 52	207		55.24	0.26	4.26	0.46	26.64	522
B 53	211		56.18	0.31	4.26	0.46	20.73	406
B 54	215		57.12	0.44	4.26	0.44	25.81	484
B 55	219		58.06	0.43	4.26	0.42	26.14	468
B 56	223	4.0 (59)	59.00	0.18	3.33	0.40	17.48	233
B 57	227		60.20	0.57	3.33	0.38	23.40	297
B 58	231		61.40	0.33	3.33	0.35	11.66	136
B 59	235		62.60	0.58	3.33	0.34	6.24	71
B 60	239		63.80	1.22	3.33	0.32	6.91	74
B 61	243	4.2 (65)	65.00	0.73	2.00	0.31	7.49	47
B 62	247		67.00	0.63	2.00	0.30	3.91	24
B 63	251		69.00	0.78	2.00	0.30	1.00	6
B 64	255	5.0 (71)	71.00	0.58	1.78	0.31	3.25	18
B 65	259		73.25	0.51	1.78	0.32	0.08	0
B 66	263		75.50		1.78	0.33	0.08	0
B 67	267		77.75	0.11	1.78	0.35	1.25	8
B 68	271	5.1 (80)	80.00	0.12	1.78	0.38	0.08	1
B 69	275		82.25	0.71	1.78	0.41	0.08	1
B 70	279		84.50	0.40	1.78	0.44	0.08	1
B 71	283		86.75	0.15	1.78	0.48	2.91	25
B 72	287		89.00	-0.24	1.78	0.51	11.41	104
B 73	291		91.25	-0.43	1.78	0.49	6.41	56
B 74	295		93.50	-0.15	1.78	0.47	1.42	12
B 75	299		95.75		1.78			
B 76	303		98.00	-0.30	1.78	0.43	1.00	8
B 77	307		100.25	-0.46	1.78	0.41	0.25	2
B 78	311		102.50	-0.41	1.78	0.43	0.08	1
B 79	315		104.75	-0.17	1.78	0.45	0.08	1
B 80	319	5.4 (107)	107.00	-0.33	1.33	0.47	1.91	12
B 81	323		110.00	-0.23	1.33	0.49	7.49	49
B 82	327		113.00	-0.20	1.33	0.51	3.00	20
B 83	331		116.00	-0.45	1.33	0.50	1.08	7
B 84	335		119.00	-0.51	1.33	0.49	3.58	23
B 85	339	5.5 (122)	122.00	-0.61	4.71	0.49	3.00	69
B 86	343		122.85	-0.32	4.69	0.48	0.08	2
B 87	347		123.71	-0.50	4.69	0.47	0.08	2
B 88	351		124.56		4.69	0.48	0.08	2
B 89	355		125.41	0.03	4.69	0.49	0.25	6
B 90	359		126.26	0.29	4.69	0.50	0.67	16
B 91	363		127.12	-0.13	3.94	0.51	0.33	7
B 128	363		127.12		4.69	0.51	4.16	100
B 129	367		127.97		4.69	0.51	2.91	70
B 129i	368		128.18	-0.09	4.69			
B 130	371		128.82		4.69	0.51	5.41	130
B 131	375		129.67		4.69	0.50	8.16	192
B 131i	376		129.89	0.25	4.69			
B 132	379		130.53		4.69	0.44	11.74	243
B 133	383		131.38		4.69	0.40	10.32	194
B 133i	384		131.59	0.37	4.69			
B 134	387		132.23		4.69	0.37	11.66	203
B 135	391		133.08		4.69	0.34	13.82	221
B 135i	392		133.30	0.81	4.69			

Table 2. (continued)

Sample number	Total depth (cm)	Isotopic stage for control point (Ka)	Age (Ka)	$\delta^{18}\text{O}$ (‰)	Sedimentation rate (cm kyr ⁻¹)	DBD (g cm ⁻³)	Carbonate (wt.%)	Carbonate MAR (mg cm ⁻² kyr ⁻¹)
B 136	395	6.2 (135)	133.94	0.64	4.69	0.33	9.08	141
B 137	399		134.79		4.69	0.32	12.41	186
B 137i	400		135.00		6.56			
B 138	403		135.46	0.60	6.55	0.31	11.24	228
B 139	407		136.07		6.54	0.32	10.16	213
B 139i	408		136.22		6.55			
B 140	411		136.68	0.89	6.55	0.33	11.24	243
B 141	415		137.29		6.54	0.34	10.32	230
B 141i	416		137.44		6.55			
B 142	419		137.90	0.74	6.55	0.35	13.40	307
B 143	423		138.51		6.54	0.37	14.24	345
B 143i	424		138.67		6.55			
B 144	427		139.13	0.70	6.55	0.38	16.15	402
B 145	431		139.74		6.54	0.40	15.15	397
B 145i	432		139.89		6.55			
B 146	435	6.3 (146)	140.35	0.74	6.55	0.41	16.98	456
B 147	439		140.96		6.54	0.43	16.40	462
B 147i	440		141.11		6.55			
B 148	443		141.57	0.46	6.55	0.43	14.40	406
B 149	447		142.18		6.54	0.42	9.74	268
B 149i	448		142.33		6.55			
B 150	451		142.79	0.35	6.55	0.41	9.66	259
B 151	455		143.40		6.54	0.40	12.49	327
B 151i	456		143.56		6.55			
B 152	459		144.01	0.62	6.55	0.39	10.66	272
B 153	463		144.63		6.54	0.38	8.41	209
B 153i	464		144.78		6.55			
B 154	467		145.24	0.58	6.55	0.38	9.57	238
B 155	471		145.85		6.54	0.37	8.91	216
B 155i	472		146.00		6.41			
B 156	475	6.4 (151)	146.47	0.36	6.40	0.37	7.99	189
B 157	479		147.09		6.40			
B 157i	480		147.25		6.40			
B 158	483		147.72	0.52	6.40	0.36	8.99	207
B 159	487		148.34		6.40	0.36	8.08	186
B 159i	488		148.50		6.40			
B 160	491		148.97	0.74	6.40	0.35	5.66	127
B 161	495		149.59		6.40	0.35	8.58	192
B 161i	496		149.75		6.40			
B 162	499		150.22	0.85	6.40	0.36	10.32	238
B 163	503		150.84		6.40	0.36	11.24	259
B 163i	504		151.00		1.60			
B 164	507		152.88	1.26	1.60	0.36	10.24	59
B 165	511		155.38		1.60	0.36	7.08	41
B 165i	512		156.00		1.60			
B 166	515	6.5 (171)	157.88	0.48	1.60	0.37	6.41	38
B 167	519		160.38		1.60	0.38	12.07	73
B 167i	520		161.00		1.60			
B 168	523		162.88	0.48	1.60	0.39	11.41	71
B 169	527		165.38		1.60	0.40	9.32	60
B 169i	528		166.00		1.60			
B 170	531		167.88	0.25	1.60	0.41	10.74	71
B 171	535		170.38		1.60	0.42	20.56	138
B 171i	536		171.00		3.38			

Table 2. (continued)

Sample number	Total depth (cm)	Isotopic stage for control point (Ka)	Age (Ka)	$\delta^{18}\text{O}$ (‰)	Sedimentation rate (cm kyr ⁻¹)	DBD (g cm ⁻³)	Carbonate (wt.%)	Carbonate MAR (mg cm ⁻² kyr ⁻¹)
B 172	539		171.89		3.38	0.43	26.31	383
B 173	543		173.07		3.38	0.45	23.15	352
B 173i	544		173.37		3.38			
B 174	547		174.26		3.38	0.46	21.23	330
B 175	551		175.44		3.38	0.48	28.89	469
B 175i	552		175.74	0.23	3.38			
B 176	555		176.62		3.38	0.47	21.23	337
B 177	559		177.81		3.38	0.47	16.24	258
B 177i	560		178.10	0.22	3.38			
B 178	563		178.99		3.38	0.46	17.57	273
B 179	567		180.18		3.38	0.45	19.32	294
B 179i	568		180.47	0.40	3.38			
B 180	571		181.36		3.38	0.44	22.65	337
B 181	575		182.55		3.38	0.43	2.91	42
B 181i	576		182.84	0.28	3.38			
B 182	579		183.73		3.38	0.43	3.16	46
B 183	583		184.91		3.38	0.42	5.08	72
B 183i	584		185.21	0.29	3.38			
B 184	587		186.10		3.38	0.41	4.41	61
B 185	591		187.28		3.38	0.41	9.24	128
B 185i	592		187.58	0.51	3.38			
B 186	595		188.47		3.38	0.40	2.50	34
B 187	599		189.65		3.38	0.40	7.66	104
B 187i	600		189.95	0.37	3.38			
B 188	603		190.83		3.38	0.40	4.16	56
B 189	607		192.02		3.38	0.40	3.91	53
B 189i	608		192.31	0.24	3.38			
B 190	611		193.20		3.38	0.40	3.75	51
B 191	615		194.39		3.38	0.41	3.50	48
B 191i	616		194.68	0.37	3.38			
B 192	619		195.57		3.38	0.41	4.91	68
B 193	623		196.75		3.38	0.42	1.67	24
B 193i	624		197.05	0.21	3.38			
B 194	627		197.94		3.38	0.43	1.17	17
B 195	631		199.12		3.38	0.43	0.25	4
B 196	635		200.31		3.38	0.44	2.50	37
B 197	639		201.49		3.38	0.45	5.41	82
B 198	643		202.68		3.38	0.47	1.42	22
B 199	647		203.86		3.38	0.48	0.08	1
B 200	651		205.04		3.38	0.49	0.50	8
B 201	655		206.23		3.38	0.50	0.08	1
B 201i	656		206.52	0.33	3.38			
B 202	659		207.41		3.38	0.51	0.08	1
B 203	663		208.60		3.38	0.53	4.41	79
B 203i	664		208.89	0.06	3.38			
B 204	667		209.78		3.38	0.54	16.24	296
B 205	671		210.96		3.38	0.55	20.81	387
B 205i	672		211.26	0.08	3.38			
B 206	675		212.15		3.38	0.51		
B 207	679		213.33		3.38	0.48	0.83	14
B 208	683		214.52		3.38	0.45	4.16	63
B 209	687		215.70		3.38	0.43		
B 209i	688	7.3 (216)	216.00	-0.39	2.66			

Table 2. (continued)

Sample number	Total depth (cm)	Isotopic stage for control point (Ka)	Age (Ka)	$\delta^{18}\text{O}$ (‰)	Sedimentation rate (cm kyr ⁻¹)	DBD (g cm ⁻³)	Carbonate (wt.%)	Carbonate MAR (mg cm ⁻² kyr ⁻¹)
B 210	691		217.12		2.67	0.41	12.99	142
B 211	695		218.62		2.67	0.40	12.32	132
B 211i	696		219.00	0.06	2.67			
B 212	699		220.12		2.67	0.39		
B 213	703		221.62		2.67	0.38	19.07	193
B 213i	704		222.00	0.11	2.67			
B 214	707		223.12		2.67	0.38	10.41	106
B 215	711		224.62		2.67	0.38	5.66	57
B 215i	712		225.00	0.05	2.67			
B 216	715		226.12		2.67	0.39	6.83	71
B 217	719		227.62		2.67	0.39	3.08	32
B 217i	720	7.4 (228)	228.00	0.25	1.60			
B 218	723		229.88		1.60	0.41	5.08	33
B 219	727		232.38		1.60	0.42		
B 219i	728		233.00	0.17	1.60			
B 220	731		234.88		1.60	0.43	16.48	114
B 221	735		237.38		1.60	0.45	15.57	112
B 221i	736	7.5 (238)	238.00	-0.15	2.91			
B 222	739		239.03		2.91	0.47	14.74	202
B 223	743		240.41		2.91	0.49	17.65	252
B 223i	744		240.75	0.03	2.91			
B 224	747		241.78		2.91	0.51	15.90	236
B 225	751		243.16		2.91	0.54	10.82	170
B 226	755		244.53		2.91	0.54	10.82	170
B 227	759		245.91		2.91	0.54	12.57	198
B 227i	760		246.25	-0.03	2.91			
B 228	763		247.28		2.91	0.53	17.73	274
B 229	767		248.66		2.91	0.51	18.65	277
B 229i	768	8.2 (249)	249.00	0.62	3.16			
B 230	771		249.95		3.16	0.50	18.90	299
B 231	775		251.22		3.16	0.49	20.81	322
B 231i	776		251.53	0.44	3.16			
B 232	779		252.48		3.16	0.48	25.39	385
B 233	783		253.75		3.16	0.47	22.65	336
B 233i	784		254.07	0.53	3.16			
B 234	787		255.02		3.16	0.47	30.39	451
B 235	791		256.28		3.16	0.46	35.47	516
B 235i	792		256.60	0.60	3.16			
B 236	795		257.55		3.16	0.46	34.55	502
B 237	799		258.82		3.16	0.47	38.63	574
B 237i	800		259.13	0.43	3.16			
B 238	803		260.08		3.16	0.48	35.47	538
B 239	807		261.35		3.16	0.49	35.05	543
B 239i	808		261.67	0.53	3.16			
B 240	811		262.62		3.16	0.51	26.23	423
B 241	815		263.88		3.16	0.48	28.06	426
B 241i	816		264.20	0.32	3.16			
B 242	819		265.15		3.16	0.46	25.89	376
B 243	823		266.42		3.16	0.44	15.74	219
B 243i	824		266.73	0.57	3.16			
B 244	827		267.68		3.16	0.42	7.58	101
B 245	831		268.95		3.16	0.41	11.24	146
B 245i	832		269.27	0.46	3.16			

Table 2. (continued)

Sample number	Total depth (cm)	Isotopic stage for control point (Ka)	Age (Ka)	$\delta^{18}\text{O}$ (‰)	Sedimentation rate (cm kyr ⁻¹)	DBD (g cm ⁻³)	Carbonate (wt.%)	Carbonate MAR (mg cm ⁻² kyr ⁻¹)
B 246	835		270.22		3.16	0.39	15.49	191
B 247	839		271.48		3.16	0.39	2.41	30
B 247i	840		271.80	0.43	3.16			
B 248	843		272.75		3.16	0.38	3.66	44
B 249	847		274.02		3.16	0.38	3.16	38
B 250	851		275.28		3.16	0.38	6.49	78
B 251	855		276.55		3.16	0.38	5.58	67
B 252	859		277.82		3.16	0.38	1.75	21
B 253	863		279.08		3.16	0.38	1.33	16
B 254	867		280.35		3.16	0.39	0.08	1
B 255	871		281.62		3.16	0.40	0.08	1
B 256	875		282.88		3.16	0.41	0.50	6
B 257	879		284.15		3.16	0.43	0.08	1
B 258	883		285.42		3.16	0.44	3.58	50
B 259	887		286.68		3.16	0.46	11.74	171
B 259i	888	8.5 (287)	287.00	-0.92	2.66			
B 260	891		288.12		2.67	0.49	7.66	100
B 261	895		289.62		2.67	0.48	12.49	160
B 261i	896		290.00	-0.31	2.67			
B 262	899		291.12		2.67	0.47	18.07	227
B 263	903		292.62		2.67	0.46	21.31	262
B 263i	904		293.00	-0.16	2.67			
B 264	907		294.12		2.67	0.45	14.15	170
B 265	911		295.62		2.67	0.44	6.41	75
B 265i	912		296.00	-0.05	2.67			
B 266	915		297.12		2.67	0.45	8.66	104
B 267	919		298.62		2.67	0.47	11.49	144
B 267i	920	8.6 (299)	299.00	0.11	2.67			
B 268	923		300.12		2.67	0.48	8.74	112
B 269	927		301.62		2.67	0.49	16.82	220
B 269i	928		302.00	-0.07	2.67			
B 270	931		303.12		2.67	0.50	17.48	233
B 271	935		304.62		2.67	0.49	7.58	99
B 272	939		306.12		2.67	0.48	3.33	43
B 273	943		307.62		2.67	0.47	7.41	93
B 274	947		309.12		2.67	0.46	12.32	151
B 275	951		310.62		2.67			
B 275i	952		311.00	-0.18	2.67	0.45	12.16	146
B 276	955		312.12		2.67	0.46	9.32	115
B 277	959		313.62		2.67	0.47	5.74	72
B 277i	960		314.00	-0.34	2.67			
B 278	963		315.12		2.67	0.47	2.91	37
B 284	987		324.12		2.67	0.47	3.08	39
B 285	991		325.62		2.67	0.47	0.67	8
B 286	995		327.12		2.67	0.47	1.17	15
B 287	999		328.62		2.67	0.47	0.92	11
B 288	1003		330.12		2.67	0.47	7.66	96
B 289	1007		331.62		2.67	0.47	11.91	149
B 290	1011		333.12		2.67	0.47	11.57	145
B 291	1015		334.62		2.67	0.47	15.49	194
B 292	1019		336.12		2.67	0.47	8.91	112
B 293	1023		337.62		2.67	0.47	3.83	48
B 294	1027		339.12		2.98	0.47	1.58	22

Table 3. Weight percents and mass accumulation rates (MARs) of carbonate, sedimentation rate and dry bulk density (DBD) for core NGC34. DBD values were estimated from the data reported by Ikehara *et al.* (1993).

Sample number	Total depth (cm)	Isotopic stage for control point (Ka)	Age (Ka)	$\delta^{18}\text{O}$ (‰)	Sedimentation rate (cm kyr^{-1})	DBD (g cm^{-3})	Carbonate (wt.%)	Carbonate MAR ($\text{mg cm}^{-2}\text{kyr}^{-1}$)
C 132	0.0	0	0.00	-2.54	1.12	0.79	80.05	706
C 133	1.6		1.43	-2.10	1.12	0.79	80.24	707
C 134	3.6		3.23	-2.40	1.12	0.79	82.69	729
C 135	6.4		5.74	-2.13	1.12	0.79	83.88	739
C 136	9.6		8.60	-2.06	1.12	0.79	83.83	739
C 137	13.2		11.83	-1.86	1.12	0.79	81.68	720
C 138	17.2		15.42	-1.10	1.12	0.79	80.77	712
C 139	21.2		19.00	-0.99	0.78	0.79	81.60	501
C 140	25.2		24.15	-1.00	0.78	0.79	82.34	505
C 141	29.2		29.30	-1.09	0.78	0.79	82.29	505
C 142	33.2	2.2 (19)	34.45	-1.22	0.78	0.79	82.75	508
C 143	37.2		39.60	-1.13	0.78	0.79	82.29	505
C 144	41.2		44.75	-1.21	0.78	0.79	82.27	505
C 145	45.2		49.90	-1.09	0.78	0.79	82.84	508
C 146	49.2		55.05	-1.47	0.78	0.79	83.45	512
C 147	53.2		60.20	-1.20	0.78	0.79	82.70	507
C 148	57.2		65.35	-1.22	0.78	0.79	81.71	501
C 149	61.2		70.50	-1.22	0.78	0.79	79.54	488
C 150	65.2		75.65	-1.62	0.78	0.79	82.48	506
C 151	69.2		80.80	-1.55	0.78	0.79	81.69	501
C 152	73.2	5.5 (122)	85.95	-1.60	0.78	0.79	84.14	516
C 153	77.2		91.10	-1.48	0.78	0.79	82.00	503
C 154	81.2		96.25	-2.16	0.78	0.79	82.27	505
C 155	85.2		101.40	-1.75	0.78	0.79	82.58	507
C 156	89.2		106.55	-1.72	0.78	0.79	82.37	505
C 157	93.2		111.70	-1.81	0.78	0.79	82.86	508
C 158	97.2		116.85	-1.99	0.78	0.79	81.46	500
C 159	101.2		122.00	-2.00	0.83	0.79	82.40	539
C 160	105.2		126.83	-1.82	0.83	0.79	83.30	545
C 161	109.2		131.66	-1.79	0.83	0.79	83.45	546
C 162	113.2	6.4 (151)	136.49	-1.36	0.83	0.79	82.55	540
C 163	117.2		141.32	-1.05	0.83	0.79	82.57	540
C 164	121.2		146.15	-0.91	0.83	0.79	81.58	534
C 165	125.2		150.99	-0.76	0.84	0.79	78.50	519
C 166	129.2		155.76	-1.06	0.84	0.79	82.02	542
C 167	133.2		160.54	-0.82	0.84	0.79	82.36	545
C 168	137.2		165.32	-1.54	0.84	0.79	81.89	541
C 169	141.2		170.10	-1.06	0.84	0.79	83.71	554
C 170	145.2		174.88	-1.29	0.84	0.79	84.27	557
C 171	149.2		179.66	-0.98	0.84	0.79	82.59	546
C 172	153.2	7.1 (194)	184.44	-1.06	0.84	0.79	83.92	555
C 173	157.2		189.22	-1.14	0.84	0.79	80.84	535
C 174	161.2		194.00	-1.75	1.09	0.79	82.48	711
C 175	165.2		197.66	-1.36	1.09	0.79		
C 176	169.2		201.33	-1.65	1.09	0.79	83.94	723
C 177	173.2		205.00	-1.34	1.09	0.79	82.79	714
C 178	177.2		208.66	-1.49	1.09	0.79	85.92	741
C 179	181.2		212.33	-1.65	1.09	0.79	82.52	711
C 180	185.2		215.99	-1.58	1.09	0.79	85.47	737
C 181	189.2		219.66	-1.07	1.09	0.79	84.76	731
C 182	193.2	7.5 (238)	223.33	-1.22	1.09	0.79	82.13	708
C 183	197.2		226.99	-1.09	1.09	0.79	81.70	704
C 184	201.2		230.66	-1.54	1.09	0.79	80.92	697
C 185	205.2		234.33	-1.48	1.09	0.79	84.91	732
C 186	209.2		237.99	-1.86	1.09	0.79	83.59	720
C 187	213.2		241.66	-1.54	1.09	0.79	81.57	703
C 188	217.2		245.33	-1.30	1.09	0.79	81.12	699
C 189	221.2		248.99	-0.82	1.09	0.79	81.80	705
C 190	225.2		252.66	-1.12	1.09	0.79	83.88	723
C 191	229.2		256.32	-0.90	1.09	0.79	84.75	730
C 192	233.2		259.99	-1.11	1.09	0.79	83.44	719
C 193	237.2		263.66	-0.99	1.09	0.79	84.68	730
C 194	241.2		267.32	-1.00	1.09	0.79	84.14	831

Fig. 4. (a) Time series of the carbonate content for cores C4402 (solid square) and NGC34 (open square) from the West Caroline Basin. Chronostratigraphies are based on the respective oxygen isotope stratigraphies. (b) Time series of the carbonate content for ERDC130p (open circle, from a water depth of 4,112 m; Wu *et al.*, 1991) and ERDC132p (solid circle, from a water depth of 4,445 m; Wu *et al.*, 1991) from the Ontong-Java Plateau as well as RC11-209 (solid triangle, from a water depth of 4,400 m; Farrell and Prell, 1989) were presented for the comparison.

recovered from a water depth of 2,188 m. The core displays no distinct glacial-interglacial difference in carbonate content during the last 262 kyr (Fig. 4(a)); the carbonate content has remained nearly constant between 80 and 90% (ignoring minor excursions of carbonate values of up to 5% in magnitude) (Table 3). Based upon the analysis of calcareous nannofossils, carbonate is well preserved throughout the NGC34 core while calcareous nannofossils are more or less dissolved through the C4402 core (Tanaka, 1994). These observations are confirmed from planktonic foraminiferal analysis. Therefore, the relatively well-preserved sediments in core C4402 are indicated by higher values of carbonate contents, whereas

the poorly-preserved sediments are indicated by the lower values. The regular variations in preservation can be clearly traced with a first-order periodicity of approximately 100 kyr.

Spectrum of the dissolution record

A cross-spectral analysis of $\delta^{18}\text{O}$ versus the carbonate content (the preservation degree) for core C4402 was conducted. We chose $\delta^{18}\text{O}$ records as the second variable because it is a well-established climate indicator. We chose the individual core $\delta^{18}\text{O}$ record rather than a stacked record such as the SPECMAP stack (Imbrie *et al.*, 1984) based on the thought that phase results from two variables from the same core may be equally influ-

enced by local factors such as bioturbation. However, even when we used a stacked $\delta^{18}\text{O}$ record (Imbrie *et al.*, 1984), no significant differences were found in the results from the cross-spectral analysis.

The variance spectrum of the $\delta^{18}\text{O}$ record shows the well-documented concentrations of power at the orbital periodicities of 100 kyr and near 23 kyr since power near 41 kyr is found in a broad frequency band of 100 kyr (Fig. 5(a)). The spectrum of the preservation degree reveals that much of the variance in the preservation signal is also concentrated in the low-frequency bands near 100 kyr and 41 kyr. However resolution of the precessional bands in the preservation record is much less clear. The absence of discrete spectral peaks at both 23 kyr and 19 kyr in the spectrum of the preservation suggests that preservational variations do not record a strong precessional response.

Of great interest with regard to understanding the possible origin of the observed dissolution cycles is the significant coherency between the two records over the lower orbital frequency. The coherency spectrum shows that the $\delta^{18}\text{O}$ and the preservation record are coherent over the eccentricity (100 kyr) and obliquity (41 kyr) frequency bands. Coherency is a measure of the correlation between two signals over given frequency band after the effects of any phase differences have been removed. High coherencies imply not only the mutual presence of significant periodicities, but also a high degree of similarity between their time-varying amplitudes, and provide strong evidence of a causal link between the two signals. The measured coherencies at the 100-kyr period is not only surprisingly high in absolute value (0.87), but lie well above the 95% significance level (Fig. 5(b)). The lack of significant coherency at 19 kyr and the absence of a discrete peak in the preservation spectrum at 23 kyr suggest that the preservation degree and $\delta^{18}\text{O}$ are, at most, weakly linked over the precessional frequency bands.

An additional product of the analysis is the phase spectrum between $\delta^{18}\text{O}$ and the preservation degree shown in Fig. 5(c). The results quan-

Fig. 5. (a) Variance spectra of the $\delta^{18}\text{O}$ (solid line) and the carbonate content (dotted line) records from C4402 and the SPECMAP stack and coherency spectrum between the two records from C4402 (solid line with pluses) for the interval from 0 to 330 kyr. The sample interval is 1.2 kyr. Significance levels for the coherency spectrum are shown (0.80 and 0.95 levels). (b) Phase spectrum of $\delta^{18}\text{O}$ versus the carbonate content (wt.%) for C4402. Positive values indicate that isotopic maxima and minima lead preservation maxima and minima, respectively.

tify general impressions gained from the previous visual examination of the two records. Given the confidence level for the calculations, there is no significant phase lag between the time series of carbonate content and $\delta^{18}\text{O}$ at the 100-kyr period. At the 41-kyr band, this lag is on the order of 90° , around 10 kyr.

DISCUSSION

Carbonate preservation fluctuations

The solubility of carbonate minerals in seawater increases as temperature decreases and pressure increases. As a result, the rate at which carbonate dissolves typically increases with increasing water depth. The lysocline represents that level where there is an abrupt increase in the dissolution rate (Berger, 1975), while the CCD is the water depth below which the rate of carbonate supply approximately equals the rate of dissolution. The lysocline for today's ocean is at approximately 3.4 km in the western equatorial Pacific (Groetsch *et al.*, 1991) while the CCD is at approximately 4.5–4.7 km in the West Caroline Basin.

During the glacial and interglacial modes there were significant changes in the carbonate preservation, which is controlled by the CO_3^{2-} concentration of the oceans and this, in turn, is a function of the CO_2 content of deep and/or bottom waters. As the CO_2 content of deep waters increases, the CO_3^{2-} concentration decreases and dissolution and alkalinity increase. The CO_2 content of deep water at any given location is the combined product of both the local rain rate of organic carbon and the age of the deep water (the higher the organic carbon flux and the older the water, the higher the CO_2 content). Our results regarding changes in the carbonate content indicate that bottom waters in the West Caroline Basin had a higher CO_3^{2-} concentration (and lower CO_2 content) at early Stage 1, early Stage 3, Stage 6, middle Stage 7–late Stage 8, early Stage 8–late Stage 9 than present-day deep waters. Kawahata *et al.* (1994a, b) reported a relationship between organic carbon burial rate and the orbital variations at the periodicities of 100 kyr and 26 kyr but not at the

41 kyr while carbonate preservation has power and coherence with $\delta^{18}\text{O}$ at 100 and 41 kyr but not at the 23 kyr. It indicates that the primary records of carbonate preservation was affected by seawater chemistry rather than by local rain of organic matter.

We compare carbonate contents at a water depth of approximately 4,400 m of the West Caroline Basin with those of Ontong-Java Plateau and the central equatorial Pacific (Wu *et al.*, 1991; Farrell and Prell, 1989). Carbonate contents data from these areas are displayed in Fig. 4(b). Surface sediments from the West Caroline Basin contain little carbonate while the carbonate contents of the surface sediments from similar depth of Ontong-Java Plateau and the central equatorial Pacific are in the range of 69 to 87 wt.%. Measurements of total alkalinity and total carbon dioxide of seawater through the water column were carried out in the West Caroline Basin and Ontong Java Plateau during the NH95-1 cruise (Fig. 6). The results indicate that the deep and/or bottom water below 3,000 m water depth in the West Caroline Basin are more enriched in total alkalinity and total carbon dioxide than the water above the Ontong-Java Plateau. In addition, downcore records of carbonate contents reveal much lower carbonate contents in the West Caroline Basin through the last 330 kyr, which implies that the deep water of the West Caroline Basin has remained total alkalinity- and total carbon dioxide-rich relative to the Ontong-Java Plateau and the central equatorial Pacific at all times over the last 330 kyr. The abyssal water in the North Pacific has been considered to be supplied by bottom flow from the south (Stommel and Arons, 1960; Warren, 1981). However, at present, the Pacific abyssal water shows only slight chemical gradients because of effective lateral advection and mixing (Craig *et al.*, 1982). Foraminiferal carbon isotope data, one crude proxy index for the age of the deep and/or bottom water indicates that Pacific abyssal waters were rather chemically homogeneous during the most recent glacial period as well (Vincent *et al.*, 1981, 1982; Shackleton *et al.*, 1983; Boyle and Keigwin, 1985/86). These results

Fig. 6. (a) Vertical distribution of potential temperature (a), total alkalinity (A_T : circle) and total carbon dioxide (C_T : square) (b) in Station W95 ($10^{\circ}12.3' \text{ N}$, $142^{\circ}58.7' \text{ E}$ of the West Caroline Basin) and Station W104 ($1^{\circ}23.6' \text{ N}$, $163^{\circ}50.5' \text{ E}$ of Ontong-Java Plateau).

suggest that the bottom water flowing into the West Caroline Basin is expected to be more corrosive than the bottom and/or deep water in the abyssal equatorial Pacific and that more stagnant bottom water might intensify carbonate dissolution because the West Caroline Basin is semi-isolated from the open North Pacific Ocean below depth of 4,000 m.

Comparison of cross-spectral analysis between the West Caroline Basin and other area

The general downcore pattern of maxima and minima of core C4402 is such that carbonate abundance maxima correspond to glacial times and minima correspond to interglacials. It is different from the pattern obtained from Ontong-Java Plateau, that minima appear during glacial mode such

as during Stages 4, 6 and 8. These results show significant time lag between both areas despite a relatively short distance between locations.

Cross-spectral analysis between carbonate preservation and $\delta^{18}\text{O}$ have been reported from the Indian and Pacific Oceans. In the eastern equatorial Indian Ocean, the dominant cycles visible in carbonate preservation from V34-53 (3,812 m deep) are of about 100 kyr and 41 kyr (Peterson and Prell, 1985a, b). However, a well-defined precessional (23 kyr and 19 kyr) response in the preservation is lacking. At 100-kyr frequency band changes in preservation lag behind changes in $\delta^{18}\text{O}$ by approximately 70° , or about 19 kyr. At the 41-kyr band, this lag is on the order of 110° , about 12 kyr (Peterson and Prell, 1985a, b). This means that preservation maxima lag behind isotopic

maxima (glacials) and preservation minima lag behind isotopic minima (interglacials). Results from the Ontong-Java Plateau (1,619 m to 3,120 m deep) (Le and Shackleton, 1992) showed that intermediate and deep waters experienced the same pattern of the dissolution through climatic cycles. The dissolution records from intermediate and deep waters show significant concentrations of variance and high coherencies with $\delta^{18}\text{O}$ records over the 100-kyr, 41-kyr, and 23-kyr orbital periods, maximum dissolution lags minimum ice volume by 6 to 20 kyr (Le and Shackleton, 1992). Similar results were obtained in the eastern equatorial Pacific. Luz and Shackleton (1975) suggested that the preservation lag reflected a delayed response of the ocean CO_3^{2-} carbonate ion system to changes in CaCO_3 deposition elsewhere, such as at higher latitudes or in the North Atlantic. Our West Caroline Basin results show the predominance of 100-kyr and 41-kyr bands in carbonate concentration. The maximum dissolution lags minimum ice value by approximately 10 kyr at the 41-kyr band. However, if the confidence level is taken into consideration, the record of carbonate preservation and the $\delta^{18}\text{O}$ are essentially in phase over the 100-kyr frequency bands. This feature differs from previous works.

Abyssal waters in the Indian and Pacific Oceans are largely a mixture of waters of both Atlantic and Antarctic origin. Basin to basin fractionation of carbonate was proposed to explain the out-of-phase dissolution patterns between the Atlantic and Pacific (Crowley, 1985). Today North Atlantic Deep Water (NADW) accumulates CO_2 oxidized from falling organic debris and becomes more corrosive to carbonate (Broecker and Peng, 1982). During glacial periods the diminished production of NADW should be associated with the increased contribution of AABW (Antarctic Bottom Water), which improved carbonate preservation in the Pacific (Boyle and Keigwin, 1982, 1985/86; Curry and Lohmann, 1982). Because of their high-latitude source areas, production of these deep and bottom waters is apt to be particularly sensitive to climatic forcing. In North Atlantic, Ruddiman and McIntyre (1981, 1984) have shown

that downcore foraminiferal estimates of past sea surface temperatures contain mostly 23-kyr power south of about 50°N . North of this latitude, in the principal source regions of NADW, equivalent foraminifer faunal-based sea surface temperature estimates contain mostly 41-kyr and 100-kyr power. Boyle (1984) and Boyle and Keigwin (1985/86) found 41-kyr cycles in the North and South Atlantic records of Cd/Ca ratios in benthic foraminifera. Given our data and simple interpretation of frequency-domain relationships, we view little linkage of the carbonate preservation and $\delta^{18}\text{O}$ over the precessional frequencies and the high coherencies at 100 kyr and 41 kyr as evidence that deep-water circulation changes, driven by high-latitude climatic forcing in the North Atlantic, are the principal source of variability in the carbonate preservation record of the West Caroline Basin. In addition, the close phase relationship between extremes in preservation state and the $\delta^{18}\text{O}$ record suggest a rapid response of the carbon system to climatic forcing.

Alternatively, on-phase between the carbonate preservation and $\delta^{18}\text{O}$ may be ascribed to the linkage between sea level change and the ventilation of the bottom water. The interaction of surface water between the Pacific and Indian Oceans is active through the Indonesian straights during interglacial times while the interaction is interrupted during glacial times. The West Caroline Basin is located at the end of the flow path of the bottom waters in the western equatorial Pacific. Bottom water would diffuse up slowly. So the changes of surface flow path might affect the ventilation of the bottom water.

CONCLUSIONS

Carbonate contents in C4402 (taken from 4402 m) from the West Caroline Basin were examined for the last 330 kyr at sample intervals of approximately 1.2 kyr to study the fluctuation of carbonate preservation in a semi-isolated deep basin in the western equatorial Pacific.

1. Core NGC34 taken above present lysocline reveals no distinct glacial-interglacial difference

in carbonate content, while core C4402 from a water depth of 4,402 m displays high carbonate during glacial stages and low carbonate during interglacial stages. This pattern is different from that obtained from Ontong Java Plateau, although both were located in relatively short distance of the western equatorial Pacific.

2. The carbonate content variation in core C4402 is interpreted as a dissolution signal affected by seawater chemistry rather than by the local rain rate of organic carbon.

3. The CaCO_3 content record from the deep core shows significant concentrations of variance and high coherencies with $\delta^{18}\text{O}$ record over the 100 kyr and 41 kyr, but does not show a precessional response. Carbonate preservation is in phase with the $\delta^{18}\text{O}$ record, which is different from the results reported previously. These results suggested that variability in the carbonate preservation record is closely related to deep-water circulation changes and responds rapidly to climatic forcing.

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