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Circulation through the Central American Seaway during the Miocene Carbonate Crash

Derrick R. Newkirk and Ellen E. Martin

Table DR1-Nd isotopic values for modern and Miocene water masses

Water Mass	Modern ε_{Nd}	Miocene ε_{Nd}
AAIW	-7 to -9 [(4)]	-8 [(10, 11)]
AABW	-8 to -9 [(4)]	-8 [(10)]
UNADW/NAIW	-13 [(2)]	-11 [(5, 8)]
NADW	-13.5 [(2)]	-11.5 [(7)]
PDW	-4 [(3)]	-4 [(6, 9)]
EEPDW*	-3.8 [(3)]	-3.6 to -1.6 [(10, 13)]
NPUDW[#]/NPIW	-3 [(3)]	-2.5 to -1.5 [(12)]
Equatorial PIW	0 [(1)]	+2 to -0.6 [(13)]

[1]Piepgras and Wasserburg, 1982; [2]Piepgras and Wasserburg, 1987; [3]Piepgras and Jacobsen, 1988; [4]Jeandel, 1993; [5]Burton et al., 1997; [6]Ling et al., 1997; [7]O'Nions et al., 1998; [8]Burton et al., 1999; [9]Martin and Haley, 1999; [10]Frank et al., 1999; [11]Scher and Martin, 2004; [12]van de Flierdt et al., 2004; [13]this study.
* EEPDW = Eastern Equatorial Pacific Deep Water
[#] NPUDW = North Pacific Upper-Deep Water.

Table DR2-Nd isotopic results for Sites 846B, 998A, 999A and 1241A

Site 846B	Depth (mbsf)	Age (Ma) [a]	$^{143}Nd/^{144}Nd$ [b]	$\varepsilon_{Nd(o)}$ [c]	$\varepsilon_{Nd(t)}$ [d]
29X-6W 61-67	272.34	8.09	0.512488	-2.9	-2.9
30X-3W 110-116	278.03	8.43	0.512549	-1.7	-1.7
31X-1W 77-83	284.30	8.81	0.512547	-1.8	-1.7
31X-2W 101-107	286.04	8.92	0.512523	-2.2	-2.2
31X-4W 98-104	289.02	9.10	0.512535	-2.0	-1.9
31X-6W 101-107	292.04	9.29	0.512522	-2.3	-2.2
	292.04	9.29	0.512536	-2.0	-1.9
32X-4W 103-109	298.66	9.69	0.512523	-2.2	-2.1
	298.66	9.69	0.512545	-1.81	-1.8
32X-6W 27-33	300.90	9.82	0.512526	-2.2	-2.1
	300.90	9.82	0.512534	-2.0	-1.9
32X-6W 94-100	301.57	9.86	0.512532	-2.1	-2.0
33X-1W 100-107	303.84	10.00	0.512554	-1.6	-1.5
33X-2W 31-37	304.64	10.05	0.512526	-2.2	-2.1
33X-4W 144-150	308.78	10.30	0.512527	-2.2	-2.1
33X-6W 30-36	310.63	10.42	0.512510	-2.5	-2.4
34X-1W 140-146	313.83	10.61	0.512488	-2.9	-2.8
34X-3W 121-127	316.64	10.78	0.512519	-2.3	-2.2
	316.64	10.78	0.512534	-2.0\	-1.9
34X-4W 111-117	318.04	10.87	0.512531	-2.1	-2.0
	318.04	10.87	0.512512	-2.5	-2.4
34X-7W 21-27	321.64	11.09	0.512541	-1.9	-1.8
36X-2W 128-134	334.51	11.87	0.512500	-2.7	-2.6
	334.51	11.87	0.512482	-3.0	-2.9
36X-3W 128-134	336.01	11.96	0.512481	-3.1	-3.0
37X-2W 93-99	343.76	12.43	0.512519	-2.3	-2.2
	343.76	12.43	0.512520	-2.3	-2.2
38X-4W 144-150	356.98	13.23	0.512490	-2.9	-2.8
40X-1W 121-127	371.54	14.14	0.512446	-3.7	-3.6

Site 998A	Depth (mbsf)	Age (Ma) [a]	$^{143}Nd/^{144}Nd$ [b]	$\varepsilon_{Nd(o)}$ [c]	$\varepsilon_{Nd(t)}$ [d]
10H-2W 45-50	86.78	4.50	0.512260	-7.4	-7.3
11H-6W 129-134	103.12	5.50	0.512286	-6.9	-6.8
12H-6W 58-63	111.91	6.50	0.512312	-6.4	-6.3
13H-4W 66-71	118.49	7.25	0.512306	-6.5	-6.4
14H-1W 6-11	122.88	7.75	0.512451	-3.7	-3.6
14H-3W 145-150	127.28	8.25	0.512323	-6.2	-6.1
14H-3W 64-69	129.47	8.50	0.512349	-5.6	-5.6
15H-1W 21-26	132.51	8.95	0.512300	-6.6	-6.5
15H-3W 107-113	136.37	9.33	0.512323	-6.2	-6.1
15H-5W 27-32	138.58	9.52	0.512333	-6.0	-5.9

	138.58	9.52	0.512314	-6.3	-6.2
16H-1W 54-59	141.85	9.79	0.512379	-5.1	-5.0
16H-3W 126-129	146.05	10.14	0.512351	-5.6	-5.5
16H-4W 32-37	146.62	10.18	0.512396	-4.7	-4.6
	146.62	10.18	0.512416	-4.5	-4.45
16H-4W 45-50	146.77	10.19	0.512457	-3.5	-3.5
16H-5W 25.5-30	148.11	10.30	0.512378	-5.1	-5.0
16H-6W 32-36	149.65	10.46	0.512400	-4.7	-4.6
16H-6W 125-130	150.58	10.59	0.512491	-2.9	-2.8
17H-1W 21-26	151.53	10.73	0.512496	-2.8	-2.7
17H-1W 32-37	151.62	10.75	0.512545	-1.8	-1.7
17H-1W 77-82	152.08	10.82	0.512498	-2.7	-2.7
17H-1W 105-110	152.35	10.86	0.512466	-3.4	-3.3
17H-2W 25-30	153.05	10.97	0.512440	-3.9	-3.8
17H-2W 54-60	153.36	11.02	0.512476	-3.2	-3.1
17H-2W 126-131	154.06	11.13	0.512438	-3.9	-3.8
	154.06	11.13	0.512431	-4.1	-4.0
17H-4W 55-60	156.38	11.50	0.512574	-1.3	-1.2
17H-5W 2-7	157.38	11.66	0.512440	-3.9	-3.8
17H-5W 134-139	158.68	11.82	0.512491	-2.9	-2.8
17H-6W 26-31	159.09	11.87	0.512637	-0.0	0.06
17H-6W 81-87	159.65	11.93	0.512594	-0.9	-0.8
17H-CCW 2-7	160.62	12.03	0.512626	-0.2	-0.2
18X-1W 105-111	161.85	12.17	0.512420	-4.3	-4.2
18X-3W 32-36	164.12	12.41	0.512457	-3.5	-3.4
19X-1W 53-58	166.75	12.70	0.512418	-4.3	-4.2
19X-5W 24-28	172.44	13.50	0.512445	-3.8	-3.7
20X-2W 32-36	177.72	14.05	0.512434	-4.0	-3.9
22X-3W 21-26	198.34	16.00	0.512435	-4.0	-3.8
24X-2W 145-150	217.38	17.00	0.512420	-4.3	-4.1
25X-3W 76-81	227.79	17.50	0.512399	-4.7	-4.5
26X-4W 7-12	238.20	18.00	0.512514	-2.4	-2.3

Site 999A	Depth (mbsf)	Age (Ma) [a]	$^{143}Nd/^{144}Nd$ [b]	$\varepsilon_{Nd(o)}$ [c]	$\varepsilon_{Nd(t)}$ [d]
17X-5W 42-47	156.55	5.0	0.512301	-6.57	-6.54
18X-6W 90-95	168.03	5.5	0.512316	-6.09	-6.04
19X-4W 14-19	173.77	5.75	0.512338	-5.85	-5.81
20X-1W 88-93	179.51	6.00	0.512309	-6.42	-6.37
23X-2W 34-39	202.47	7.00	0.512291	-6.77	-6.72
23X-6W 8-13	208.21	7.25	0.512361	-5.41	-5.35
24X-3W 62-67	213.95	7.50	0.512334	-5.93	-5.88
24X-7W 36-41	219.67	7.75	0.512381	-5.02	-4.96
25X-4W 100-105	225.43	8.00	0.512322	-6.17	-6.11
26X-2W 14-19	231.17	8.25	0.512363	-5.37	-5.30

26X-5W 128-133	236/91	8.50	0.512344	-5.74	-5.67
27X-3W 52-57	242.65	8.75	0.512377	-5.09	-5.02
28X-1W 18-23	248.91	8.98	0.512395	-4.75	-4.68
28X-3W 32-36	252.04	9.10	0.512337	-5.88	-5.81
28X-4W 84-88	254.06	9.18	0.512360	-5.42	-5.35
28X-5W 55-59	255.27	9.22	0.512474	-3.21	-3.14
29X-1W 72-76	259.14	9.38	0.512546	-1.79	-1.72
29X-2W 51-57	260.44	9.52	0.512498	-2.73	-2.66
29X-4W 25-29	263.17	9.83	0.512555	-1.63	-1.55
29X-6W 5-10	265.98	10.15	0.512414	-4.37	-4.29
	265.98	10.15	0.512420	-4.25	-4.17
29X-6W 66-70	266.58	10.22	0.512489	-2.92	-2.84
29X-6W 104-109	266.97	10.26	0.512428	-4.09	-4.01
30X-2W 3-8	269.56	10.46	0.512473	-3.22	-3.13
30X-3W 59-63.5	271.61	10.56	0.512421	-4.24	-4.16
30X-4W 8-14	272.61	10.61	0.512506	-2.58	-2.50
30X-5W 2-7	274.05	10.69	0.512495	-2.79	-2.70
30X-6W 105-110	276.58	10.78	0.512634	-0.07	0.01
30X-7W 28-33	277.31	10.80	0.512508	-2.53	-2.45
31X-2W 34-38	279.46	10.87	0.512628	-0.19	-0.11
31X-3W 7-12	280.70	10.91	0.512506	-2.58	-2.50
31X-4W 53-59	282.66	10.98	0.512494	-2.80	-2.72
32X-1W 28-33	287.51	11.14	0.512550	-1.72	-1.63
	287.51	11.14	0.512545	-1.81	-1.73
32X-2W 90-94	289.62	11.21	0.512598	-0.78	-0.69
32X-6W 18-23	294.91	11.39	0.512580	-1.14	-1.05
32X-6W 79-84	295.52	11.41	0.512472	-3.25	-3.16
33X-2W 4-10	298.27	11.50	0.512539	-1.94	-1.85
33X-3W 4-8	299.76	11.55	0.512568	-1.37	-1.27
33X-4W 106-111	302.29	11.63	0.512470	-3.29	-3.20
33X-6W 65-69	304.87	11.72	0.512455	-3.56	-3.47
33X-CCW 13-18	305.96	11.77	0.512514	-2.43	-2.33
	305.96	11.77	0.512509	-2.53	-2.52
34X-2W 145-150	309.28	12.01	0.512302	-6.55	-6.46
	309.28	12.01	0.512319	-6.22	-6.13
	309.28	12.01	0.512302	-6.55	-6.45
34X-3W 63-67	309.95	12.06	0.512486	-2.96	-2.87
34X-6W 100-105	314.83	12.41	0.512448	-3.70	-3.61
34X-6W 118-122	315.00	12.43	0.512447	-3.72	-3.63
35X-3W 109-113	320.11	12.80	0.512486	-2.96	-2.86
35X-5W 54-59	322.57	12.98	0.512514	-2.42	-2.32
	322.57	12.98	0.512492	-2.85	-2.74
35X-7W 17-21	325.19	13.17	0.512484	-3.00	-2.90
37X-1W 15-19	335.37	13.39	0.512513	-2.44	-2.33
37X-2W 6-11	336.79	13.42	0.512497	-2.76	-2.66
38X-1W 55-60	345.38	13.69	0.512470	-3.29	-3.18

38X-1W 69-73	345.51	13.70	0.512478	-3.12	-3.01
38X-5W 55-60	351.38	14.01	0.512359	-5.45	-5.34
39X-4W 94-99	359.87	14.50	0.512338	-5.86	-5.74
42X-3W 133-138	387.75	16.00	0.512387	-4.90	-4.78

Site 1241A	Depth (mbsf)	Age (Ma) [a]	$^{143}Nd/^{144}Nd$ [b]	$\varepsilon_{Nd(o)}$ [c]	$\varepsilon_{Nd(t)}$ [d]
14H-3W 123-128	122.17	5.00	0.512480	-3.09	-3.04
16H-3W 47-52	140.40	5.50	0.512679	0.80	0.85
19H-4W 77-82	170.73	6.00	0.512630	-0.16	-0.11
23H-3W 29-34	206.71	6.50	0.512685	0.91	0.97
25H-2W 0-5	223.95	7.00	0.512727	1.74	1.80
26H-1W 58-63	232.48	7.25	0.512685	0.91	0.98
27H-6W 79-84	249.76	7.75	0.512675	0.72	0.79
28H-3W 139-144	255.30	8.00	0.512628	-0.20	-0.13
29H-5W 49-54	266.91	8.25	0.512649	0.21	0.28
30H-4W 109-114	275.51	8.50	0.512651	0.25	0.33
31H-4W 19-24	284.12	8.75	0.512671	0.64	0.72
33H-2W 139-144	301.33	9.25	0.512671	0.64	0.72
35X-3W 130-135	318.50	9.75	0.512701	1.23	1.31
40X-7W 40-45	371.10	11.25	0.512608	-0.59	-0.49

[a] Age models for all four sites are based on biostratigraphic boundaries and age datums defined Raffi and Flores (1995) at Site 846 and applied to Sites 998 and 999 by Kameo and Bralower (2000) and to Site 1241 by Mix et al. (2003).

[b] $^{143}Nd/^{144}Nd$ values analyzed on a given day were corrected by the difference between the average JNdi-1 value for that day and JNdi-1 = 0.512103 (TIMS average at University of Florida).

[b] $\varepsilon_{Nd(o)} = [^{143}Nd/^{144}Nd_{(sample)}/^{143}Nd/^{144}Nd_{(CHUR)} - 1] \times 10^4$, where $^{143}Nd/^{144}Nd_{(CHUR)} = 0.512638$.

[c] $\varepsilon_{Nd(t)} = [^{143}Nd/^{144}Nd_{(sample\ (t))}/^{143}Nd/^{144}Nd_{(CHUR(t))} - 1] \times 10^4$.

[d] The 2σ external uncertainty based on normalized repeat analyses of JNdi-1 is ±0.000015, which is equivalent to 0.3 ε_{Nd} units. Within run uncertainties were consistently less than this value.

Methods

Sediment samples were oven dried, disaggregated and wet sieved prior to picking fossil fish teeth from the >125 μm fraction. The fossil fish teeth were then cleaned using an oxidative/reductive cleaning technique from Boyle (1981) and Boyle and Keigwin (1985) that removes organic matter and Fe-Mn oxide coatings. Concentrations of Nd in teeth typically range from 100 to 400 ppm (Martin and Haley, 2000), thus ~100 μg of cleaned teeth were processed in order to produce at least 10 ng Nd for analysis. Cleaned teeth were dissolved in aqua regia and then dried prior to a two step chemical separation to isolate Nd. Bulk rare earth elements (REEs) were separated from the sample on a primary quartz column that uses Mitsubishi cation exchange resin with HCl as the eluent (Scher and Martin, 2004). Nd was further isolated using quartz columns packed with Teflon beads coated with bis-ethylhexyl phosphoric acid and HCl as the eluent. The total blank for this technique is 14 pg Nd.

Nd isotopic ratios were measured on a Nu Multi-Collector-Inductively Coupled Plasma-Mass Spectrometer (MC-ICP-MS) at the University of Florida. Dried samples were re-dissolved with 0.3 ml of 2% optima HNO_3, and then a portion of the sample was pipetted into a Teflon sampling beaker and diluted 100 times using 2% optima HNO_3. Additional acid or sample was then added as needed to achieve the ideal voltage of 2-6 volts for ^{143}Nd. Belshaw et al. (1998) describe the instrument and the optimal operating conditions for the Nu-MC-ICP-MS. JNdi-1 standard was run between every 4 to 6 samples, depending on the number of analyses acquired. All of the JNdi-1 values analyzed during one day were averaged and that value was normalized to the long-term TIMS value of 0.512103±0.000014 (2σ). Individual sample runs were then normalized by the same amount to correct for the daily variations in running conditions. A drift correction was not applied because variations throughout a run did not indicate a consistent drift.

The 2σ error for the Nu MC-ICP-MS based on the variability of normalized JNdi-1 analyses is $\pm$0.000015, which is equivalent to 0.3 ε_{Nd} units and agrees well with data from replicate analyses (Table DR 2), which vary by 0.05 to 0.53 ε_{Nd} units with an average difference of 0.25 ε_{Nd} units.

Concentrations of Sm and Nd were analyzed on an Element II for three samples from each site in order to determine $^{147}Sm/^{144}Nd$ ratios. The average $^{147}Sm/^{144}Nd$ ratios are 0.120 for Site 846, 0.134 for Site 998, 0.135 for Site 999, and 0,127 for Site 1241. These ratios were then used to correct for age-dependent ingrowth of radiogenic ^{143}Nd. This correction was minor (0.03 to 0.14 ε_{Nd} units) for these young samples.

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