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1. DATA REPORT: BIOGENIC OPAL IN PALMER DEEP SEDIMENTS, SITE 1098, LEG 178[1]

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INTRODUCTION

High-resolution records of sedimentary proxies provide insights into fine-scale geochemical responses to climatic forcing. Gamma-ray attenuation (GRA) bulk-density data and magnetic stratigraphy records from Palmer Deep, Site 1098, show variability close to the same scale as ice cores, making this site ideal for high-resolution geochemical investigations. In conjunction with shipboard geophysical measurements, silica records allow high-resolution evaluation of the frequencies and amplitudes of biogenic variability. This provides investigators additional data sets to evaluate the global extent of climatic events that are presently defined by regional oceanic data sets (e.g., Younger Dryas in the North Atlantic) and to evaluate the potential mechanisms that link biological productivity and climate in the Southern Ocean.

In addition, because of the observed links between diatom blooms and export productivity (Michaels and Silver, 1988), biogenic silica may be an indicator of the efficiency of the biological pump (removal of organic carbon from the euphotic zone and burial within the sediments). Because the net removal of CO_2 (on short time scales up to millennial, the balance between upwelled CO_2, carbon fixation, and the removal of organic carbon from the surface ocean) can determine the atmospheric concentration; proxies that allow us to quantify export production yield insights into carbon cycle responses.

In today's ocean, diatoms are integrally linked with new production (production based on the use of nitrate and molecular nitrogen rather than ammonium, which is generated by the microbial degradation of organic carbon) (Dugdale and Goering, 1967). Thus, as with nutrient

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utilization proxies, biogenic silica may be a good indicator of export production. The difficulties lie in translating the biogenic opal burial records to export production. Numerous factors control the preservation of sedimentary biogenic silica, including depth of the water column, water temperature, trace element chemistry, grazing pressure, bloom structure, and species composition of the diatom assemblage (Nelson et al., 1995). In addition, several recent investigations have noted additional complications. Iron limitation increases the uptake of Si relative to carbon (Hutchins et al., 1998; Takeda, 1998). In the Southern Ocean, iron limitation could produce more robust, and thus better preserved, diatoms; thus, the burial record may be a record of iron limitation rather than of the export of organic carbon (Boyle, 1998). In addition, laboratory experiments show that bacteria accelerate the dissolution of biogenic silica (Bidle and Azam, 1999). Both the species composition and temperature seem to influence the amount of dissolution. Evidence of recycling of silicic acid within the photic zone (Brzezinski et al., 1997) suggests that the silica pump (removal from the euphotic zone of silica relative to nitrogen and phosphorus) may work with variable efficiency. This becomes an issue when trying to reconstruct the removal of organic carbon from sedimentary biogenic silica records. In fact, there is a wide range in the $Si:C_{organic}$ molar ratio in the Southern Ocean (0.18–0.81) (Nelson et al., 1995; Ragueneau et al., 2000).

Thus, the presence (or absence) of biogenic silica alone may tell us little about the export productivity, complicating the interpretation of age-related trends. One recent assessment has added some hope to links between productivity and opal burial in the Southern Ocean (Pondaven et al., 2000). Quantitative comparison of different productivity proxies will greatly aid in this evaluation.

METHODS

We measured silica concentration in sediment samples using a base dissolution technique described by Mortlock and Froelich (1989). We modified the technique to use smaller centrifuge tubes so that we could have a larger sample throughput. All reagents were decreased by a factor of three. Sample weights were decreased accordingly to assure that the saturation of silica hydroxide was not exceeded (the equivalent of 8 mg of Si or a solution concentration of 60 mM) (Mortlock and Froelich, 1989). We found that the replication of the analyses was improved if we followed the peroxide addition with 60 min of sonication (removal of organic carbon).

Splits of 10-cm^3 samples were freeze-dried, lightly ground, and sieved to assure a uniform size distribution. Weighed samples (ranging from 0.03 to 0.05 g) were processed in replicate. A bulk consistency standard (composed of a mixture of sediments from Site 1098) was run as a sample at the beginning and the end of each group of 40 samples. Si concentration in known volumes of extractants (and thus in the solid samples) were determined using an automated spectrophotometric flow injection analysis system (Lachat QuickChem 8000). Results are reported as the mean ±1 s (sample standard deviation, $N = 4$).

The detection limit, assessed as three time the standard deviation of replicate measurements of a blank, was equivalent to 0.9 wt% for a typical sample size. Detection limits may be decreased by increasing the mass of sediment extracted. As these sediments were generally silica rich, this was not an issue. The bulk consistency standard had an average relative standard deviation of 4% within each run and a long-term mean (24 separate runs) of 23 ± 2 wt% biogenic opal.

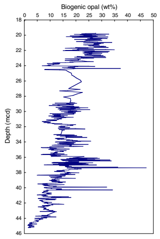
RESULTS

Biogenic Si concentrations range between 3.5 and 32 wt%, with episodic spikes of 32–47 wt%. There is a general trend toward decreasing weight percentage downcore (Tables **T1, T2;** Fig. **F1**). Fine-scale variability occurs over most of the core interval, although the amplitude of the variability generally decreases below 29 meters composite depth (mcd), with the exception of several large episodic spikes (Fig. **F1**). A turbidite sequence is coincident with the loss of variability at ~25–29 mcd (Fig. **F1**).

T1. General trend in biogenic silica with depth, p. 6.

T2. Biogenic opal, Site 1098, p. 7.

F1. Weight percentage of biogenic silica, p. 5.



Our future work on this site will include applying an age model, calculating the mass accumulation rates (MARs), evaluating the spectral evolution of the opal MAR, and comparing our results to other records from this site.

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Figure F1. Weight percentage of biogenic silica over the depth interval of 19–14 mcd, Site 1098.

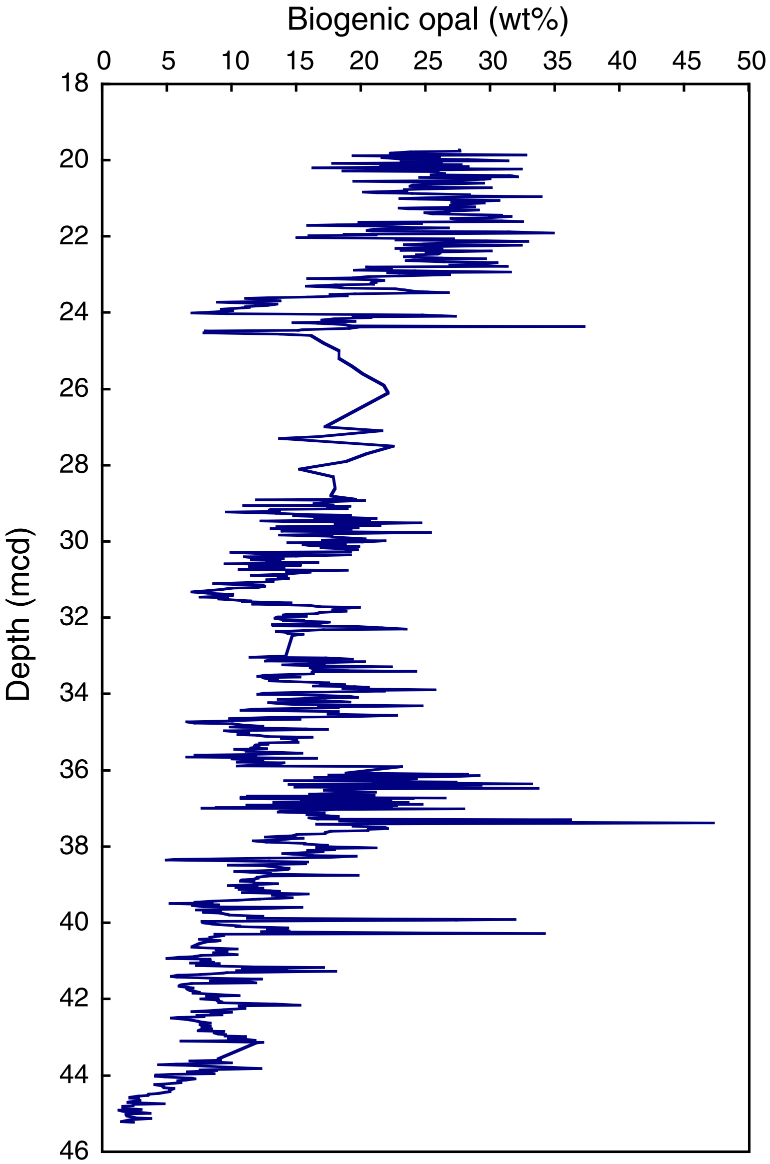

Table T1. General trend in biogenic silica with depth.

Depth (mcd)	Biogenic opal (wt%)	
	Range	Mean
20-24.5	15-36	24.0 ± 5.1
29-39	7-25	15.6 ± 4.5
38-44	5-35	10.6 ± 4
44-45	2-5	5.4 ± 1.5

Note: Biogenic opal mean is given ±1 standard deviation.

Table T2. Biogenic opal for Site 1098.

Core, section, interval (cm)	Depth (mbsf)	Depth (mcd)	Biogenic opal (wt%)	
			Mean	Standard deviation
178-1098A-5H-3 (working half)				
45.0-46.0	33.85	36.07	9.44	0.54
47.5-48.5	33.88	36.10	10.10	0.58
50.0-51.0	33.90	36.12	11.34	0.18
52.5-53.5	33.92	36.14	11.31	0.99
55.0-56.0	33.95	36.17	10.51	2.45
57.5-58.5	33.97	36.19	11.96	1.57
60.0-61.0	34.00	36.22	12.82	0.63
62.5-63.5	34.03	36.25	16.21	1.42
65.0-66.0	34.05	36.27	13.84	0.72
67.5-68.5	34.08	36.30	14.70	0.35
70.0-71.0	34.10	36.32	15.03	0.45
72.5-73.5	34.13	36.35	14.84	0.32
75.0-76.0	34.15	36.37	15.12	0.06
77.5-78.5	34.17	36.39	12.16	0.27
80.0-81.0	34.20	36.42	12.82	0.34
82.5-83.5	34.22	36.44	11.92	0.25
85.0-86.0	34.25	36.47	11.78	0.57
87.5-88.5	34.28	36.50	12.12	0.86
90.0-91.0	34.30	36.52	11.45	0.38
92.5-93.5	34.33	36.55	12.73	0.77
95.0-96.0	34.35	36.57	10.21	0.26
97.5-98.5	34.38	36.60	11.68	0.17
100.0-101.0	34.40	36.62	11.13	0.85
102.5-103.5	34.42	36.64	13.97	0.13
105.0-106.0	34.45	36.67	11.47	0.50
107.5-108.5	34.47	36.69	11.85	0.09
110.0-111.0	34.50	36.72	16.56	0.12
112.5-113.5	34.53	36.75	11.91	0.23
115.0-116.0	34.55	36.77	10.41	0.16
117.5-118.5	34.58	36.80	12.60	0.23
120.0-121.0	34.60	36.82	10.43	0.23
122.5-123.5	34.63	36.85	11.21	0.31
125.0-126.0	34.65	36.87	10.72	0.14
127.5-128.5	34.67	36.89	10.72	0.38
130.0-131.0	34.70	36.92	20.03	0.23
132.5-133.5	34.72	36.94	13.25	0.14
135.0-136.0	34.75	36.97	11.17	0.10
137.5-138.5	34.78	37.00	8.80	0.38
140.0-141.0	34.80	37.02	7.72	0.09
178-1098B-3H-3 (archive half)				
3.5-4.5	18.53	19.73	18.85	0.35
6.0-7.0	18.56	19.76	28.26	1.29
8.5-9.5	18.58	19.78	17.49	0.47
11.0-12.0	18.61	19.81	29.16	0.94
13.5-14.5	18.64	19.84	26.72	0.84
16.0-17.0	18.66	19.86	16.44	0.88
18.5-19.5	18.68	19.88	24.29	0.37
21.0-22.0	18.71	19.91	22.78	1.09
23.5-24.5	18.74	19.94	14.09	0.48
26.0-27.0	18.76	19.96	27.35	0.58
28.5-29.5	18.78	19.98	20.93	0.42
31.0-32.0	18.81	20.01	33.18	0.75
33.5-34.5	18.83	20.03	14.46	0.43
36.0-37.0	18.86	20.06	29.30	1.56
38.5-39.5	18.89	20.09	18.24	1.06
41.042.0	18.91	20.11	14.90	1.13
43.5-44.5	18.93	20.13	33.69	0.05
46.0-47.0	18.96	20.16	18.00	0.89
48.5-49.5	18.99	20.19	17.19	0.74
51.0-52.0	19.01	20.21	18.21	0.55
53.5-54.5	19.03	20.23	21.14	1.06
56.0-57.0	19.06	20.26	19.83	1.25

Note: Only a portion of this table appears here. The entire table is available in **ASCII format.**