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Reconstruction of secular variation in seawater sulfate concentrations

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Table 1. MSR fractionation data for modern aqueous systems

Rec.	**Site**	**Env Type**[a]	**δ^{34}S-sulfate**	**δ^{34}S-sulfide**[b]	**$\Delta^{34}S_{\text{sulf-py}}$**	**±1 s.d.**	**[SO_4^{2-}]**	**Reference**
			(‰)	**(‰)**	**(‰)**	**(‰)**	**(μM)**	
1	Linsley Pond, Conn.	FW-O	7.7	-1.0†	8.7		45	Nakai & Jensen, 1964
2	Queechy Pond, Conn.	FW-O	5.8	4.6†	1.2		48	Nakai & Jensen, 1964
3	Mt. Tom Pond, Conn.	FW-O	6.1	-3.0†	9.1		53	Nakai & Jensen, 1964
4	Lake Fukami-ike, Japan	FW-O	-15.0	-22.0‡	7.0		4(17	Nakagawa et al., 2012
5	Lake Ontario	FW-O	6.9	-1.2†	8.1		302	Nriagu & Coker, 1976
6	McFarlane Lake, Ontario	FW-O	6.0	-3.0	9.0		250	Nriagu & Soon, 1985; Nriagu & Harvey, 1978
7	Kelley Lake, Ontario	FW-O	5.0	-10.0	15.0		5000	Nriagu & Soon 1985
8	Turkey Lake, Ontario	FW-O	6.0	2.0	4.0		55	Nriagu & Soon 1985
9	Batchawana Lake, Ontario	FW-O	5.0	2.0	3.0		55	Nriagu & Soon 1985
10	Okefenokee Swamp, Georgia	FW-O	9.0	6.2	2.8	4.0	521	Price & Casagrande, 1991
11	New Jersey Pinelands-swamp	FW-O	5.0	-8.8*	13.8	5.0	400	Mandernack et al., 2000
12	Lake Biwa, Japan	FW-O	2.3	-4.0‡	6.3	1.5	110	Karube et al., 2012; Nakano et al., 2008
13	Everglades, Florida (2 cores)	FW-O	17.0	10.2	6.8		530	Bates et al., 1998
14	Mud Lake, Florida (2cores)	FW-O	12.0	4.3	7.7		1000	Bates et al., 1995
15	Hufeisensee, Germany	FW-E	1.8	-4.1*	5.9		1200	Asmussen & Strauch, 1998
16	Lago di Cadagno, Switzerland	FW-E	27.0	-8.0	35.0		2000	Canfield et al., 2010
17	Steisslingensee, Germany	FW-E	-6.0	-15.0	9.0		490	Mayer & Schwark, 1999
18	McCarrons Lake, MN	FW-E	5.0	-0.1	5.1		302	Gomes & Hurtgen, 2013
19	Aarhus Bay, Denmark	BW-O	21.6	-35.5	56.5	4.5	20747	Johnston et al., 2008
20	Apalachicola Bay, Florida (EB)	BW-O	12.0	-24.0‡	36.0	7.0	4149	Chanton & Lewis, 1999
21	Apalachicola Bay, Florida (CP-DB)	BW-O	18.0	-13.5‡	31.5	7.0	16598	Chanton & Lewis, 1999
22	Monie Bay, Maryland (HWY)	BW-O	22.5	2.4‡	20.1		300	Stribling et al., 1998
23	Monie Bay, Maryland (DB2)	BW-O	21.7	-11.1‡	32.8		6000	Stribling et al., 1998
24	Monie Bay (BAY)	BW-O	20.8	-22.4‡	43.2		12448	Stribling et al., 1998
25	Monie Bay (DB1)	BW-O	21.7	-2.5‡	24.2		6000	Stribling et al., 1998
26	Jade Bay, Waddensee, Germany	BW-O	20.5	-22.5	43.0		22500	Llobet-Brossa et al., 2002
27	Baltic Sea	BW-O			23.5	9.5	8299	Lein, 1983
28	Black Sea	BW-O	21.5	-46.8	68.0	3.0	16000	Johnston et al., 2008
29	Black Sea	BW-O	18.5	-33.0	51.5	12.0	16000	Wijsman et al., 2001

30	Logten Lagoon, Denmark	BW-O	26.0	-7.0	33.0		13000	Habicht & Canfield, 1997
31	Everglades, Florida-Little Shark River	BW-O	17.0	-28.0	45.0	5.0	21875	Price & Casagrande, 1991
32	Everglades, Florida-Mud Bay	BW-O	12.0	3.0	9.0	2.0	3125	Price & Casagrande, 1991
33	Sapelo Island, GA	BW-O	21.0	-19.0*	40.0		19500	Peterson & Howarth, 1987
34	Lake Chany, Russia	BW-O	29.8	16.6‡	18.6		2240	Doi et al., 2004
35	Long Island Sound, Conn.	BW-O	20.5	-12.5†	33.0	0.5	7542	Nakai & Jensen, 1964
36	Branford Bay, Conn.	BW-O	20.4	-21.3†	41.7	0.5	6802	Nakai & Jensen, 1964
37	Green Lake, NY	BW-E	24.6	-17.7*	55.8		13542	Nakai & Jensen, 1964; Suits & Wilkin, 1998
38	Fayetteville Green Lake, NY	BW-E	25.9	-30.9*	56.8		15000	Fry, 1986a, 1986b; Fry et al., 1995
39	Fayetteville Green Lake, NY	BW-E	32.0	-24.0*	57.0		15000	Zerkle et al., 2010
40	Lake Mogil'noe, Russia	BW-E	30.0	-27.0*	57.0		21875	Ivanov et al., 2001
41	Lake Mogil'noe, Russia	BW-E		*	39.5	7.5	21875	Gorlenko et al., 1978
42	Baltic Sea	BW-E			35.0	11.0	9959	Lein, 1983
43	Black Sea	BW-E	19.5	-38.2	57.7	2.5	17500	Wijsman et al., 2001
44	Black Sea	BW-E			50.5	7.5	17500	Lyons, 1997; Wijsman et al., 2001
45	Black Sea	BW-E		*	59.0	2.0	17500	Sweeney & Kaplan, 1980; Wijsman et al., 2001
46	Black Sea	BW-E	23.9	-38.0	61.9	4.0	17500	Johnston et al., 2008; Wijsman et al., 2001
47	Black Sea	BW-E		*	62.0		17500	Fry et al., 1991; Wijsman et al., 2001
48	Framvaren Fjord	BW-E	21.0	-22.8*	43.8	2.3	18550	Mandernack et al., 2003
49	Gotland Deep, Baltic Sea	BW-E	20.0	-26.0	46.0	6.0	9959	Sternbeck & Sohlenius, 1997
50	Kiel Bay, Baltic Sea	BW-E	20.0	-29.4‡	49.4	2.0	19565	Hartmann & Nielsen, 1968
51	Maringer Fjord, Norway	BW-E	20.5	-16.0*	36.5	6.0	13000	Sørensen & Canfield, 2004
52	Lake Sakovo, Russia	BW-E	14.0	-11.0	27.0		8125	Matrosov et al., 1975; Gorlenko & Chebotarev, 1981
53	Chernyi Kichiyer (Black Kichier)	BW-E			23.0		896	Matrosov et al., 1975
54	Bol'shoy Kichiyer (Big Kichier)	BW-E			4.1		448	Matrosov et al., 1975
55	FOAM, Long Island Sound, NY	SW-O		-29.0	49.0		23237	Canfield et al., 1992; Canfield & Thamdrup, 1994; Lee & Lwiza, 2005
56	Black Hole, Long Island Sound	SW-O			41.0		20747	Canfield & Thamdrup, 1994; Lee & Lwiza, 2005
57	NW Control, Long Island Sound, NY	SW-O			58.0		23237	Canfield & Thamdrup, 1994; Lee & Lwiza, 2005
58	Sachem, Long Island Sound, NY	SW-O			34.0		23237	Canfield & Thamdrup, 1994; Lee & Lwiza, 2005
59	Pearl River Delta, China	SW-O	20.5	-20.0‡	40.5		27386	Böttcher et al., 2010
60	San Diego Trough, California Shelf	SW-O	20.4	-28.8	49.2		27500	Kaplan et al., 1963
61	Newport Marsh, California	SW-O	20.4	-20.0	40.4		23571	Kaplan et al., 1963
62	St Andrew Bay, Florida	SW-O	21.5	-25.8	47.3	4.0	24897	Brüchert and Pratt, 1996
63	St Andrew Bay, Florida (WB)	SW-O	21.5	-15.5	37.0		28000	Brüchert and Pratt, 1999

64	St Andrew Bay, Florida (CB)	SW-O	21.5	-19.2	40.7		22800	Brüchert and Pratt, 1999
76	Makirina Bay, Croatia	HY-O	21.0	-29.0	50.0	2.0	34025	Lojen et al., 2004
77	Solar Lake, Egypt	HY-O	23.4	-20.8	44.2	2.0	126000	Johnston et al., 2008; Jorgensen & Cohen, 1977
78	Solar Lake, Egypt	HY-O	22.0	-17.0	39.0		65000	Habicht & Canfield, 1997; Jorgensen & Cohen, 1977
79	Lake Vanda, Antarctica (deep)	HY-E	46.0	13.9*	32.1		55187	Purdy et al., 2001
80	Lake Vanda, Antarctica (deep)	HY-E	46.0	10.5*	35.5		55187	Nakai et al., 1975
81	Mahooney Lake, B.C., Canada	HY-E	27.5	-24.1*	51.6	0.5	420000	Overmann et al., 1996

Notes:

[a] Environment types are hypersaline (HY)(>40 psu); seawater (SW)(30-40 psu); brackish water (BW)(10-30 psu); and freshwater (FW)(<10 psu). Depositional environments are further classified as containing oxic (O) or euxinic (E) porewaters.

[b] Sulfide $\delta^{34}S$ is based on pyrite unless indicated: † = sediment AVS, ‡ = sediment total reduced sulfur, and * = aqueous H_2S.

Table 2. Phanerozoic $\delta^{34}S_{CAS}$ data (used to generate Table 3)

Paytan et al. (1998)			**Kampschulte & Strauss (2004)**	
Age (Ma)	**$\delta^{34}S_{CAS}$ (‰)**		**Age (Ma)**	**$\delta^{34}S_{CAS}$ (‰)**
0.0	20.9		130.0	15.3
0.0	21.0		132.0	15.9
0.0	21.1		133.0	17.0
0.0	21.1		134.0	18.0
0.0	21.3		134.0	17.4
0.0	21.4		134.0	16.2
0.2	20.9		136.0	18.5
0.2	21.1		136.0	15.2
2.2	22.0		136.0	16.7
2.6	22.0		138.0	16.5
3.8	21.9		139.0	16.1
4.8	22.3		140.0	25.0
5.2	21.8		140.0	21.8
5.7	22.1		140.0	14.8
6.0	22.0		142.0	13.3
6.4	22.3		144.0	12.7
6.8	22.3		154.0	16.1
7.8	21.8		157.0	15.3
7.8	22.0		161.0	16.6
8.1	22.3		161.0	15.8
9.3	21.8		164.0	17.5
9.7	22.1		167.0	20.7
10.2	21.9		170.0	18.5
11.4	22.2		173.0	18.1
12.1	22.1		178.0	18.0
12.6	21.9		184.0	23.6
12.6	22.0		187.0	17.4
12.7	22.0		197.0	14.3
12.7	22.7		208.0	24.4
12.8	22.2		210.0	18.5
12.9	22.7		211.0	18.0
13.4	22.1		214.0	19.0
13.7	22.0		216.0	17.4
14.2	21.7		221.0	19.2
15.1	22.0		225.0	18.5
15.1	22.1		237.0	17.5
15.7	22.4		240.0	20.1
16.3	21.8		242.0	26.4
16.3	22.0		245.0	16.7

17.2	22.1		245.0	15.7
18.1	21.9		246.0	24.5
19.0	21.8		253.0	10.9
20.0	21.6		264.0	12.5
21.0	22.0		289.0	12.5
22.2	22.0		295.0	11.8
23.5	21.9		297.0	12.3
24.1	21.9		298.0	11.0
25.6	21.7		304.0	12.9
26.4	21.4		305.0	13.3
26.4	21.8		306.0	13.8
26.4	21.9		306.0	12.6
27.4	21.4		309.0	12.6
28.5	21.2		310.0	13.0
29.0	21.3		311.0	15.4
29.0	21.5		313.0	15.1
29.5	21.7		316.0	15.4
30.0	21.6		316.0	14.5
30.8	21.4		317.0	15.0
31.0	21.7		318.0	16.8
32.6	21.6		318.0	15.0
33.7	22.0		319.0	15.7
33.8	21.8		321.0	17.5
34.2	21.6		321.0	16.7
34.6	21.8		324.0	15.7
35.1	22.4		324.0	14.7
35.1	22.5		324.0	13.5
35.6	22.2		326.0	16.2
36.5	22.5		326.0	15.2
37.5	22.1		327.0	12.1
37.5	22.3		329.0	14.1
39.4	22.2		330.0	15.3
40.5	22.3		331.0	14.0
41.7	22.1		331.0	13.8
43.8	22.4		331.0	12.8
44.5	21.9		332.0	15.0
44.5	22.0		334.0	14.5
46.0	21.6		334.0	13.7
46.0	21.5		335.0	12.9
48.2	20.3		336.0	15.6
49.7	19.1		337.0	14.5
49.9	19.3		338.0	12.8
50.2	19.1		339.0	13.4
51.2	18.7		343.0	14.6
51.6	18.0		343.0	13.7
51.9	18.1		345.0	15.9

53.6	17.8		346.0	21.2
55.5	17.4		349.0	17.7
56.4	17.7		351.0	18.5
57.0	17.5		353.0	17.6
57.6	18.2		355.0	23.3
57.6	18.3		355.0	21.3
57.9	17.9		360.0	20.6
57.9	18.0		360.0	19.7
59.2	18.1		380.0	22.7
60.7	18.6		380.0	22.0
60.9	19.0		383.0	16.4
61.8	19.1		386.0	17.3
63.9	18.8		391.0	23.3
65.2	19.0		403.0	24.5
65.2	18.9		406.0	28.5
65.5	19.1		408.0	24.4
66.0	18.8		413.0	26.6
66.8	18.8		422.0	25.8
68.7	18.9		426.0	25.8
68.7	18.9		426.0	24.8
70.0	18.8		426.0	24.5
71.3	19.1		427.0	27.5
73.0	19.2		427.0	23.4
74.2	19.1		432.0	24.3
74.4	19.3		434.0	30.2
75.3	19.4		435.0	28.9
75.6	19.3		436.0	35.6
76.4	19.1		436.0	29.2
78.4	19.0		436.0	28.2
78.8	19.1		436.0	27.6
80.3	19.0		437.0	31.5
82.0	18.9		438.0	26.2
83.0	18.2		439.0	14.5
83.6	18.4		441.0	24.3
83.7	18.4		441.0	24.0
83.9	18.1		443.0	27.0
85.6	18.3		443.0	22.6
88.4	18.3		445.0	31.6
88.4	18.1		445.0	21.8
91.0	18.6		445.0	21.1
93.0	18.9		446.0	23.0
93.4	19.1		447.0	32.9
93.5	19.0		454.0	29.3
93.6	18.8		454.0	24.5
93.8	19.0		456.0	27.4
95.0	19.2		461.0	22.9

95.8	19.0		468.0	19.1
97.0	19.1		471.0	26.8
97.0	18.5		472.0	28.7
98.9	17.9		475.0	27.8
98.9	17.8		475.0	25.8
100.0	16.3		477.0	17.6
104.0	15.6		478.0	26.8
104.0	15.6		484.0	29.0
107.0	15.7		484.0	27.6
108.0	15.9		486.0	32.3
109.0	16.1		491.0	30.5
110.0	15.9		510.0	30.8
111.1	16.1		511.0	20.9
111.5	16.3		512.0	36.2
111.9	16.1		512.0	34.5
112.0	16.6		512.0	30.6
112.0	16.0		513.0	29.2
112.0	16.3		514.0	45.4
112.7	16.3		514.0	32.5
113.1	15.4		515.0	27.8
116.0	15.5		516.0	50.7
116.0	15.8		516.0	36.4
116.0	15.9		517.0	46.4
116.3	15.3		517.0	40.2
116.5	15.5		518.0	39.1
116.5	15.5		518.0	34.7
119.6	15.5		519.0	30.6
119.8	16.4		521.0	38.5
120.0	17.2		524.0	36.2
120.5	18.7		526.0	39.0
120.7	17.8		527.0	29.7
122.8	19.5		550.0	34.5
122.8	19.2		553.0	31.6
125.0	19.7		556.0	29.4
126.7	20.0		557.0	37.0
129.2	20.1		558.0	30.8
			560.0	38.2
			560.0	34.8
			562.0	37.3
			563.0	34.2

Table 3. Phanerozoic seawater sulfate δ^{34}S curve

Age (Ma)	**$\delta^{34}S_{SW}$**[a] **(‰)** mean	**$\delta^{34}S_{SW}$**[a] **(‰)** -1 st.dev.	**$\delta^{34}S_{SW}$**[a] **(‰)** +1 st.dev.	**$[SO_4^{2-}]$**[b] **mM** max	**$\Delta^{34}S_{sulf-py}$**[c] **(‰)**	**$[SO_4^{2-}]$**[d] **mM** mean	**$[SO_4^{2-}]$**[d] **mM** -1 st.dev.	**$[SO_4^{2-}]$**[d] **mM** +1 st.dev.
0	21.2	20.9	21.5	364	45.8	20.5	11.8	35.7
5	22.0	21.6	22.3	901	45.9	20.6	11.9	35.8
10	22.0	21.7	22.3	2550	46.0	20.7	12.0	36.0
15	22.0	21.7	22.3	1383	46.0	20.7	12.0	36.0
20	21.8	21.4	22.2	1481	45.8	20.5	11.8	35.7
25	21.7	21.3	22.1	942	45.5	20.2	11.6	35.2
30	21.6	21.2	21.9	696	45.6	20.3	11.7	35.3
35	22.0	21.6	22.5	817	45.8	20.5	11.8	35.7
40	22.0	21.3	22.7	244	45.9	20.6	11.9	35.8
45	21.6	20.7	22.4	121	44.4	19.0	10.8	33.4
50	19.2	18.4	20.0	144	42.5	17.1	9.6	30.6
55	18.1	17.2	18.9	297	41.8	16.5	9.1	29.6
60	18.5	17.9	19.2	589	41.8	16.5	9.1	29.6
65	18.9	18.5	19.3	1059	42.1	16.8	9.3	30.0
70	18.9	18.5	19.3	802	42.3	17.0	9.5	30.3
75	19.2	18.9	19.6	504	42.2	16.9	9.4	30.1
80	18.9	18.4	19.4	478	41.4	16.1	8.9	29.0
85	18.4	17.9	18.8	619	41.3	16.0	8.8	28.8
90	18.5	17.9	19.1	274	39.5	14.4	7.8	26.3
95	18.9	18.3	19.4	142	39.4	14.3	7.7	26.2
100	17.3	16.3	18.2	173	40.1	14.9	8.1	27.1
105	16.1	15.2	17.0	449	39.0	14.0	7.5	25.7
110	16.2	15.6	16.7	400	38.6	13.6	7.3	25.1
115	15.9	15.2	16.6	150	38.8	13.8	7.4	25.4
120	17.1	16.0	18.1	101	39.6	14.5	7.8	26.5
125	19.0	17.7	20.2	124	40.3	15.1	8.2	27.4
130	17.2	15.4	19.0	172	40.5	15.3	8.4	27.7
135	17.1	15.6	18.6	86	42.3	17.0	9.5	30.3
140	18.1	14.9	21.3	60	43.4	18.0	10.2	31.9
145	15.7	12.8	18.7	86	43.0	17.6	9.9	31.3
150	16.7	14.3	19.1	236	42.6	17.2	9.7	30.7
155	16.3	14.9	17.7	283	43.1	17.7	10.0	31.5
160	16.5	15.3	17.8	185	43.8	18.4	10.4	32.5
165	18.0	16.4	19.6	254	43.7	18.3	10.4	32.4
170	18.5	17.2	19.8	442	43.9	18.5	10.5	32.7
175	18.3	16.8	19.7	185	43.7	18.3	10.4	32.4
180	18.9	16.5	21.2	87	45.0	19.7	11.3	34.4
185	19.3	16.6	21.9	68	45.0	19.7	11.3	34.4
190	18.4	15.7	21.1	83	45.2	19.9	11.4	34.7
195	17.5	14.6	20.3	92	45.5	20.2	11.6	35.2

200	17.9	15.0	20.9	75	45.6	20.3	11.7	35.3
205	19.4	16.5	22.3	102	45.9	20.6	11.9	35.8
210	19.3	16.9	21.7	221	46.2	20.9	12.1	36.3
215	18.7	16.7	20.7	335	46.6	21.4	12.4	37.0
220	18.7	16.7	20.7	477	47.3	22.1	12.9	38.1
225	18.7	16.5	20.9	735	48.2	23.1	13.6	39.6
230	18.8	16.0	21.5	284	48.1	23.0	13.6	39.5
235	19.0	16.0	22.1	116	46.9	21.7	12.6	37.4
240	19.8	16.3	23.3	96	46.4	21.1	12.3	36.6
245	19.3	15.5	23.2	88	45.4	20.1	11.5	35.0
250	17.7	13.3	22.0	75	44.8	19.4	11.1	34.1
255	15.8	11.6	20.1	91	43.7	18.3	10.4	32.4
260	15.4	11.5	19.3	105	41.0	15.7	8.7	28.4
265	14.8	11.3	18.3	109	38.9	13.9	7.5	25.5
270	15.4	11.7	19.0	197	38.4	13.5	7.2	24.9
275	15.4	11.8	19.1	254	37.5	12.7	6.7	23.7
280	15.0	11.6	18.4	165	35.8	11.4	5.9	21.6
285	14.2	11.2	17.2	161	35.0	10.8	5.5	20.6
290	13.6	11.0	16.1	210	34.5	10.4	5.3	20.0
295	13.2	10.9	15.5	234	32.6	9.1	4.5	17.9
300	13.5	11.3	15.6	239	33.0	9.4	4.6	18.3
305	13.8	12.0	15.7	175	30.0	7.5	3.5	15.2
310	14.4	12.6	16.1	126	30.2	7.6	3.6	15.4
315	15.0	13.4	16.7	117	30.3	7.7	3.6	15.5
320	15.3	13.7	16.9	135	30.2	7.6	3.6	15.4
325	15.0	13.3	16.7	196	29.5	7.2	3.3	14.7
330	14.6	13.0	16.3	403	29.0	6.9	3.2	14.2
335	14.7	12.8	16.5	158	29.1	7.0	3.2	14.3
340	15.1	12.8	17.4	74	29.1	7.0	3.2	14.3
345	16.4	13.7	19.1	59	29.4	7.1	3.3	14.6
350	17.8	15.0	20.6	50	27.5	6.1	2.7	12.8
355	19.1	16.2	21.9	74	28.7	6.7	3.1	13.9
360	19.4	16.6	22.2	196	29.7	7.3	3.4	14.9
365	19.4	16.1	22.6	287	30.2	7.6	3.6	15.4
370	19.7	16.1	23.4	158	30.3	7.7	3.6	15.5
375	20.3	16.8	23.9	69	30.3	7.7	3.6	15.5
380	20.5	17.3	23.7	38	30.4	7.7	3.6	15.6
385	20.0	16.6	23.4	38	29.2	7.0	3.2	14.4
390	21.3	17.7	24.9	74	29.0	6.9	3.2	14.2
395	22.7	18.8	26.5	84	28.7	6.7	3.1	13.9
400	24.1	20.4	27.7	67	29.4	7.1	3.3	14.6
405	25.1	22.0	28.3	92	29.5	7.2	3.3	14.7
410	25.3	22.2	28.4	177	29.6	7.2	3.4	14.8
415	25.5	22.4	28.7	310	31.5	8.4	4.0	16.7
420	25.6	22.6	28.6	276	32.0	8.7	4.2	17.3
425	25.7	22.9	28.5	108	32.3	8.9	4.3	17.6

430	26.4	23.1	29.7	45	32.8	9.3	4.5	18.1
435	27.1	23.3	31.0	36	33.3	9.6	4.8	18.7
440	25.9	21.8	30.0	54	31.9	8.7	4.2	17.1
445	25.7	21.8	29.6	106	31.1	8.2	3.9	16.3
450	26.2	22.3	30.1	104	30.0	7.5	3.5	15.2
455	26.3	22.8	29.7	79	28.4	6.6	3.0	13.6
460	25.6	21.9	29.3	93	27.9	6.3	2.8	13.2
465	25.1	21.1	29.2	105	26.8	5.7	2.5	12.2
470	25.6	21.7	29.5	161	29.0	6.9	3.2	14.2
475	25.9	22.1	29.8	113	28.8	6.8	3.1	14.0
480	26.7	22.5	30.9	63	29.4	7.1	3.3	14.6
485	28.5	24.6	32.5	98	30.5	7.8	3.7	15.7
490	29.6	25.2	33.9	207	31.1	8.2	3.9	16.3
495	30.5	25.2	35.7	154	31.4	8.3	4.0	16.6
500	31.8	25.8	37.8	113	31.2	8.2	3.9	16.4
505	32.8	26.7	38.8	49	31.4	8.3	4.0	16.6
510	33.5	27.4	39.5	37	31.0	8.1	3.9	16.2
515	35.7	29.6	41.8	75	28.6	6.7	3.0	13.8
520	36.3	30.8	41.8	199	28.9	6.8	3.1	14.1
525	35.5	30.5	40.5	115	29.6	7.2	3.4	14.8
530	34.7	29.6	39.8	186	29.9	7.4	3.5	15.1
535	34.2	28.9	39.5	449	30.4	7.7	3.6	15.6
540	33.7	28.7	38.8	281	22.1	3.6	1.4	8.5
545	33.5	29.2	37.8	109	21.3	3.3	1.2	7.9
550	33.4	30.0	36.7	38	18.9	2.5	0.8	6.3
555	33.4	30.2	36.6	28	17.4	2.0	0.6	5.5
560	34.4	31.4	37.4	39	16.7	1.9	0.5	5.1
565	34.6	31.5	37.7	153	15.8	1.6	0.4	4.6

Notes:

[a] $\delta^{34}S_{SW}$ values for LOWESS curve calculated from data in Table 2; shown in Figure 3A.
[b] $[SO_4^{2-}]$(max) calculated from $\delta^{34}S_{SW}$ in col B using eqs 1-3; shown in Figure 4.
[c] $\Delta^{34}S_{\text{sulf-py values}}$ from figure 3 of Wu et al. (2010), GCA 74:2053-2071; shown in Figure 3C.
[d] $[SO_4^{2-}]$ values calculated from MSR fractionation relationship (Eqs 5-7); shown in Figure 4.

Table 4. Analysis of high-frequency seawater sulfate variation

Rec.	Unit	Location	System	Age	n	$\Delta^{34}S_{sulf\text{-}py}$	$\delta^{34}S_{CAS}$ shift	$\partial\delta^{34}S_{CAS}/\partial t$(max)
				(Ma)		(‰)		(‰ Myr^{-1})
	Neoproterozoic units (Fig 6)							
a	lwr Doushantuo Fm	China	up Proterozoic	636-570	40	11.6 (±6.3)	38 to 24‰ at 636-633 Ma	5 (±2X)
b	Brachina Fm/Wilpena Grp	Namibia	up Proterozoic	636-620	2	31 (±5)	18 to 42‰ at 636-620 Ma	1.5 (±2X)
c	Maieberg Fm/Otavi Grp	Namibia	up Proterozoic	636-620	5	11.2 (±15.2)	31 to 14‰ at ~636-635 Ma	17 (±3X)
d	Sonora succession	Sonora	lwr Ediacaran	600-580	11	7.4 (±4.2)	17 to 29‰ over ~2 Myr	6 (±3)
e	Wonoka Fm/Wilpena Grp	Namibia	up Proterozoic	585-581	4	39 (±6)	22 to 18‰ at 585-581 Ma	1.0 (±3X)
f	Sonora succession	Sonora	up Ediacaran	580-542	8	14.6 (±7.0)	33 to 18‰ over ~4 Myr	4 (±2)
g	up Doushantuo Fm	China	up Proterozoic	570-551	17	23.9 (±9.3)	35 to 11‰ at 568-551	1.3 (±2X)
h	Zarls Fm/Nama Grp	Namibia	up Proterozoic	555-542	18	5.8 (±3.4)	30 to 70‰ at 549-548 Ma	40 (±2X)
j	upper Huqf Supergroup	Oman	up Proterozoic-Cambrian	>580-540	70	30.0 (±5.7)	23 to 43‰ at 548-547 Ma	20 (±2X)
k	Death Valley succession	Death Valley	Proterozoic-Cambrian	544-542	30	11.3 (±7.1)	24 to 37‰ over ~1.2 Myr	11 (±6)
	Paleozoic units (Fig 7)							
m	Sonora succession	Sonora	Cambrian/Terreneuvian	542-520	6	15.7 (±6.5)	34 to 8‰ in ~4 Myr	7 (±4)
n	Sonora succession	Sonora	Cambrian/Series 2-3	520-505	3	11.3 (±8.5)	8 to 38‰ in ~1.4 Myr	22 (±11)
n'	Death Valley succession	Death Valley	Cambrian/Series 2-3	520-505	1	11	31 to 14‰ in ~0.8 Myr	23 (±11)
p	Lancara Fm-Genestosa	Spain	Lower-Middle Cambrian	520-505	19	16.1 (±3.6)	18 to 27‰ in ~1 Myr	9 (±3X)
p'	Lancara Fm-Cremenes	France	Lower-Middle Cambrian	520-505	36	10.8 (±4.4)	22 to 29‰ in ~0.3 Myr	20 (±3X)
q	Spice excursion	Australia	Upper Cambrian	499-494	11	26.0 (±9.8)	63 to 35‰ at 495.4-494.0 Ma	20 (±1.5X)[b]
q'	Spice excursion	Missouri, USA	Upper Cambrian	499-494	8	28.8 (±10.1)	38 to 27‰ at 496.2-495.2 Ma	11 (±1.5X)[b]
q"	Spice excursion	Nevada, USA	Upper Cambrian	499-494	2	2.1 (±4.9)	46 to 33‰ at 494.9-493.3 Ma	8 (±1.5X)[b]
	Meso-Cenozoic units (Fig 8)							
r	Nanpanjiang Basin carbs	China	Lower Triassic	252-250	143	36 (±4)	25 to 33‰ over ~0.3 Myr	25 (±2X)
s	Bravaisberget Fm	Spitsbergen	Middle Triassic	245-238	40	15.1 (±5.6)	14 to 22‰ over 1.2 Myr[d]	4 (±2X)
t	Toarcian succession	England	Lower Jurassic	183-178[c]	~60	51 (±6)[e]	16.5 to 22.5‰ in 300 kyr	20 (±4)
t	Toarcian succession	England	Lower Jurassic	183-178[c]	55	51 (±6)[e]	16 to 22‰ in 300 kyr	20 (±4)
t'	Toarcian succession	Tibet	Lower Jurassic	183-178[c]	25	51 (±6)[e]	19 to 37‰ in 300 kyr(?)	60 (±30) (?)
v	Early Cretaceous	South Atlantic	Lower Cretaceous	120-118	~100	46 (±4)[f]	15.5 to 20.0‰ in 1.2 Myr	12-16
w	Cenomanian-Turonian	Colorado, USA	Middle Cretaceous	94-93	22	46 (±4)[f]	12 to 19‰ in 400 kyr	15-20
w'	Cenomanian-Turonian	England	Middle Cretaceous	94-93	~50	45 (±7)[f]	18 to 22‰ in 600 kyr	6-7
w"	Cenomanian-Turonian	Italy	Middle Cretaceous	94-93	~80	47 (±7)[f]	20 to 24‰ in 600 kyr	6-7
z	Sapropel	Mediterranean	Pleistocene	1.8-1.4	11	+60.4 (±4.8)	N/A	<0.5[g]

Table 4. Analysis of high-frequency seawater sulfate variation (cont.)

Rec.	Ocean model [a]	$[SO_4^{2-}]_{SW}$ (Rate method)	$[SO_4^{2-}]_{SW}$ (MSR-trend method)	Source
		(mM)	(mM)	
Neoproterozoic units (Fig 6)				
a	O	0.5-6	0.1-3	McFadden et al. (2008)
b	O	8-52	5-16	Hurtgen et al. (2005)
c	O	<0.1-3	<0.1-7	Hurtgen et al. (2006)
d	A	0.2-1.2	<0.1-1.0	Loyd et al. (2012)
e	A	25->100	24-70	Hurtgen et al. (2005)
f	A	3-22	0.5-11	Loyd et al. (2012)
g	A	13-100	3-35	McFadden et al. (2008)
h	A	0.1-1.0	<0.1-1.6	Ries et al. (2009)
j	A	1.5-8	12-45	Fike & Grotzinger (2008)
k	A	0.3-4	0.1-8	Loyd et al. (2012)
Paleozoic units (Fig 7)				
m	A	2-18	0.8-14	Loyd et al. (2012)
n	A	0.2-4	<0.1-9	Loyd et al. (2012)
n'	A	0.7-3.5	1.2-2.8	Loyd et al. (2012)
p	A	1.2-14	2-8	Wotte et al. (2012)
p'	A	0.3-5	0.3-6	Wotte et al. (2012)
q	A	1.2-6	4-40	Gill et al. (2011a)
q'	A	2-12	5-13	Gill et al. (2011a)
q"	A	0.1-2.5	2-6	Gill et al. (2011a)
Meso-Cenozoic units (Fig 8)				
r	O	0.5-2.5	8-20	Song et al. (2014)
s	A	3-22	1-10	Karcz (2010)
t	O	1.5-3	18-50	Gill et al. (2011b)
t	O	1.5-3	18-50	Newton et al. (2011)
t'	O	0.5-2	18-50	Newton et al. (2011)
v	O	2.5-4	15-30	Wortmann & Chernyavsky (2007)
w	O	1.5-3	15-30	Adams et al. (2010)
w'	O	5-8	12-40	Owens et al. (2013)
w"	O	5-8	12-40	Owens et al. (2013)
z	O	60-120	n/a	Scheiderich et al. (2010)

Notes:

[a] Compared to the oxic (O) ocean model, the anoxic (A) model yields seawater sulfate concentrations that are larger by a factor of 2.4X.
[b] Rates also given in Table 5 of Gill et al. (2007).
[c] Age control from McArthur et al. (2000).
[d] $\partial\delta^{34}S_{CAS}/\partial t(max)$ estimated from Song et al. (2014).
[e] CAS $\delta^{34}S$ values are 16.4‰ and 37‰ for the *tenuicostatum* and *falciferum* zones, respectively. Pyrite $\delta^{34}S$ values are -37±5‰ and -12±3‰ for the same zones, respectively (from Berner et al., 2013).
[f] Based on Cretaceous pyrite $\delta^{34}S$ data of Strauss (1997, 1999).
[g] Based on Cenozoic sulfate $\delta^{34}S$ data of Paytan et al. (1998).