Supplementary Material

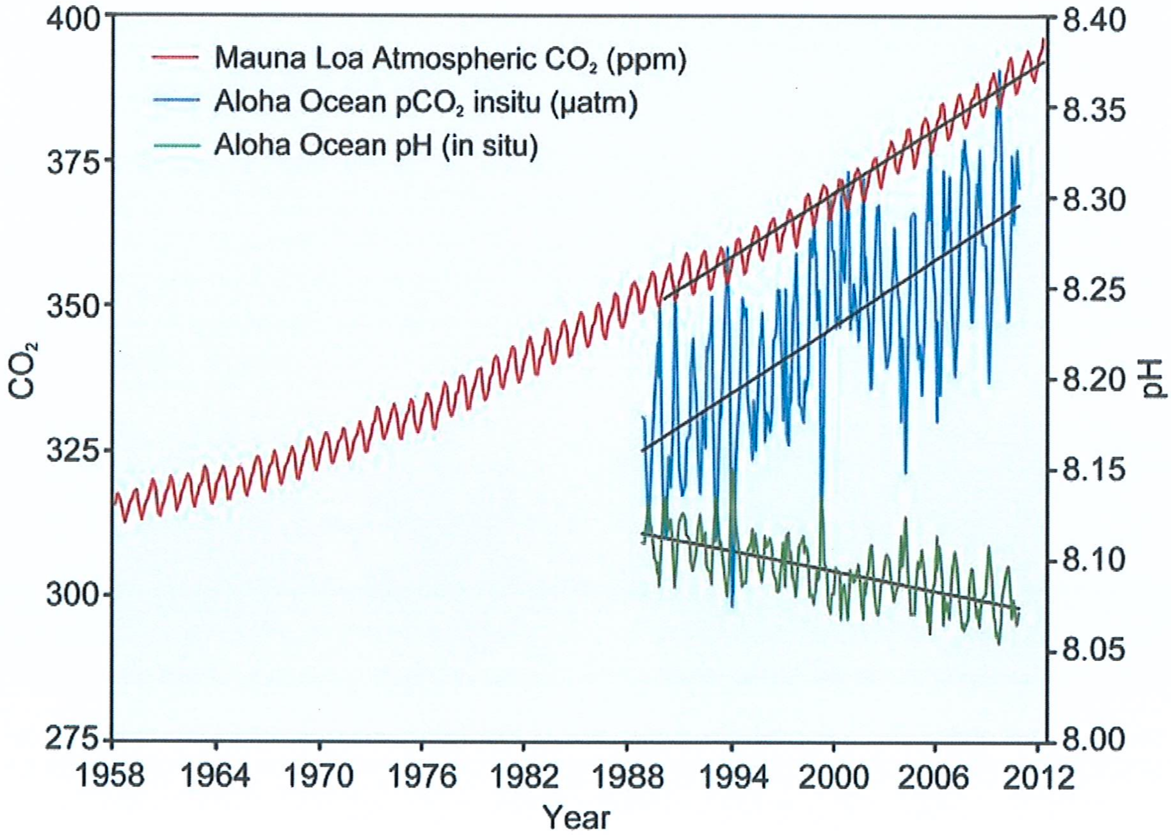
Table A: Astrocal Thermal showing how seasonal variations in pCO_2 correlate inversely with variations in carbonate and calcite solubility. Data are shown graphically in Figure 4

UP	I=12,M=0.0000005,U=0.0025615,T=0.000000075,P=8.05,S=35,Z=0.00042								CO2MOD2						
	Mauna Loa		Manua Loa pCO_2 in response to seawater temperature at Hilo, Hawaii												
	UP	δT K	1	2	3	4	5	6	7	8	9	10	11	12	13
a			9.843	9.901	9.959	10.018	10.077	10.137	10.198	10.258	10.32	10.382	10.444	10.507	10.57
b			1658.081	1663.553	1669.042	1674.547	1680.069	1685.607	1691.163	1696.735	1702.325	1707.931	1713.554	1719.195	1724.852
c			218.753	218.235	217.716	217.195	216.674	216.151	215.627	215.102	214.576	214.049	213.521	212.992	212.461
C			1886.677	1891.689	1896.717	1901.76	1906.82	1911.895	1916.988	1922.095	1927.221	1932.362	1937.519	1942.694	1947.883
Ac			2095.597	2107.086	2104.474	2108.937	2113.417	2117.909	2122.417	2126.939	2131.477	2136.029	2140.596	2145.179	2149.774
Ab			2190.651	2194.795	2198.954	2203.127	2207.315	2211.518	2215.736	2219.968	2224.216	2228.478	2232.756	2237.049	2241.357
Ksp			4.26E-07	4.26E-07	4.26E-07	4.26E-07	4.27E-07	4.27E-07	4.27E-07	4.27E-07	4.27E-07	4.27E-07	4.27E-07	4.27E-07	4.28E-07
$K [Ca^{2+}][CO_3^{2-}]$			4.33E-07	4.32E-07	4.31E-07	4.30E-07	4.29E-07	4.28E-07	4.27E-07	4.26E-07	4.25E-07	4.24E-07	4.23E-07	4.22E-07	4.21E-07
Ω			1.016673	1.013928	1.011184	1.008441	1.005698	1.002956	1.000216	9.97E-01	0.994737	0.991999	9.89E-08	0.986526	0.9837902
pH			8.05	8.05039	8.05077	8.05115	8.051537	8.05192	8.0523	8.05E+00	8.05306	8.05344	8.05E+00	8.05419	8.05457
Temperature K			299.8	299.617	299.433	299.25	299.067	298.833	298.7	2.99E+02	298.333	298.15	2.98E+02	297.7833	297.6
pCO2 ppmv			420	420.575	421.15	421.75	422.3	422.875	423.45	424.025	424.6	425.175	425.75	426.325	426.9
		δCO2													
a			9.857	9.914	9.973	10.032	10.091	10.151	10.211	10.272	10.334	10.396	10.458	10.521	10.584
b			1661.826	1667.304	1672.799	1678.31	1683.837	1689.382	1694.943	1700.521	1706.117	1711.729	1717.358	1723.004	1728.668
c			219.442	218.921	218.399	217.875	217.351	216.825	216.298	215.77	215.241	214.711	214.18	213.648	213.115
C			1891.125	1896.139	1901.171	1906.217	1911.279	1916.358	1921.452	1926.563	1931.692	1936.836	1941.996	1947.173	1952.367
Ac			2100.711	2105.146	2109.596	2114.06	2118.539	2123.032	2127.54	2132.061	2136.6	2141.151	2145.718	2150.3	2154.898
Ab			2195.776	2199.92	2204.078	2208.252	2212.44	2216.642	2220.86	2225.092	2229.34	2233.603	2237.88	2242.173	2246.482
Ksp			4.26E-07	4.26E-07	4.26E-07	4.26E-07	4.27E-07	4.27E-07	4.27E-07	4.27E-07	4.27E-07	4.27E-07	4.27E-07	4.27E-07	4.28E-07
$K [Ca^{2+}][CO_3^{2-}]$			4.34E-07	4.33E-07	4.32E-07	4.31E-07	4.30E-07	4.29E-07	4.28E-07	4.27E-07	4.26E-07	4.25E-07	4.24E-07	4.23E-07	4.22E-07
Ω			1.019875	1.017115	1.014356	1.011598	1.008841	1.006085	1.00333	1.000576	0.997822	0.99507	0.992318	0.989567	0.986818
pH			8.05039	8.05077	8.05115	8.05154	8.05192	8.0523	8.05268	8.05306	8.05344	8.05382	8.05419	8.05457	8.05494
Temperature K			299.8	299.617	299.433	299.25	299.067	298.833	298.7	298.517	298.333	298.15	297.9777	297.783	297.6
pCO2 ppmv			420.575	421.15	421.75	422.3	422.875	423.45	424.025	424.6	425.175	425.75	426.325	426.9	427.475
DOWN	I=12,M=0.0000005,U=0.0025615,T=0.000000075,P=8.0482,S=35,Z=0.00042195								CO2MOD3						
	Mauna Loa		Manua Loa pCO_2 in response to seawater temperature at Hilo, Hawaii												
	DOWN	δT K	26	25	24	23	22	21	20	19	18	17	16	15	14
a			9.889	9.943	9.998	10.054	10.11	10.166	10.222	10.28	10.338	10.396	10.455	10.514	10.574
b			1658.89	1664.263	1669.652	1675.058	1680.481	1685.92	1691.376	1696.849	1702.338	1707.845	1713.368	1718.908	1724.466
c			217.955	217.49	217.025	216.558	216.089	215.619	215.148	214.675	214	213.726	213.349	212.771	212.291
C			1886.734	1891.696	1896.675	1901.67	1906.68	1911.705	1916.746	1921.804	1926.877	1931.967	1937.172	1942.193	1947.331
Ac			2094.8	2099.243	2103.702	2108.174	2112.659	2117.158	2121.672	2126.199	2130.74	2135.297	2140.066	2144.45	2149.048
Ab			2189.559	2193.735	2197.924	2202.127	2206.344	2210.575	2214.82	2219.08	2223.353	2227.641	2231.943	2236.259	2240.59
Ksp			4.26E-07	4.26E-07	4.26E-07	4.26E-07	4.27E-07	4.27E-07	4.27E-07	4.27E-07	4.27E-07	4.27E-07	4.27E-07	4.27E-07	4.28E-07
$K [Ca^{2+}][CO_3^{2-}]$			4.32E-07	4.31E-07	4.30E-07	4.29E-07	4.28E-07	4.27E-07	4.26E-07	4.25E-07	4.24E-07	4.23E-07	4.22E-07	4.21E-07	4.20E-07
Ω			1.012961	1.010468	1.007975	1.00548	1.002985	1.00049	0.997993	0.995497	0.99299	0.990501	0.988003	0.985504	0.983004
pH			8.0482	8.04872	8.04923	8.04975	8.05026	8.05077	8.05128	8.05179	8.05229	8.05281	8.05331	8.05382	8.05431
Temperature K			299.8	299.617	299.433	299.25	299.067	298.833	298.7	298.517	298.333	298.15	297.783	297.967	297.6
pCO2 ppmv			421.95	422.375	422.8	423.225	423.65	424.075	424.5	424.925	425.35	425.775	426.2	426.625	427.05
		δCO2													
a			9.899	9.953	10.008	10.064	10.12	10.176	10.233	10.29	10.348	10.406	10.465	10.525	10.584
b			1662.535	1667.914	1673.309	1678.721	1684.15	1689.595	1695.057	1700.535	1706.03	1711.543	1717.072	1722.618	1728.182
c			218.693	218.226	217.758	217.288	216.816	216.343	215.869	215.393	214.916	214.438	213.958	213.478	212.995
C			1891.127	1896.093	1901.075	1906.073	1911.086	1916.114	1921.159	1926.218	1931.294	1936.387	1941.495	1946.621	1951.761
Ac			2099.922	2104.366	2108.825	2113.297	2117.782	2122.281	2126.795	2131.321	2140.419	2140.419	2144.988	2149.574	2154.172
Ab			2194.683	2198.859	2203.048	2207.252	2211.469	2215.7	2219.945	2224.204	2232.765	2232.765	2237.067	2241.384	2245.714
Ksp			4.26E-07	4.26E-07	4.26E-07	4.26E-07	4.27E-07	4.27E-07	4.27E-07	4.27E-07	4.27E-07	4.27E-07	4.27E-07	4.27E-07	4.28E-07
$K [Ca^{2+}][CO_3^{2-}]$			4.33E-07	4.32E-07	4.31E-07	4.30E-07	4.29E-07	4.28E-07	4.27E-07	4.26E-07	4.26E-07	4.25E-07	4.24E-07	4.23E-07	4.22E-07
Ω			1.016395	1.013887	1.011379	1.00887	1.00636	1.00385	1.001339	0.998828	0.996316	0.993803	0.99129	0.988777	0.9862628
pH			8.04872	8.04923	8.04975	8.05026	8.05077	8.05128	8.05179	8.0523	8.05281	8.05331	8.05381	8.05432	8.05482
Temperature K			299.8	299.617	299.433	299.25	299.067	298.833	298.7	298.517	298.333	298.15	297.783	297.967	297.6
pCO2 ppmv			422.375	422.8	423.225	423.65	424.075	424.5	424.925	425.35	425.775	426.2	426.625	427.05	427.475

Run with CO2MOD2 (ascending temperature) and CO2MOD3 (descending temperature). Models are run assuming temperature as K, initial pCO_2 values and rates of pCO_2 variations. Alkalinity (Ac, Ab) and dissolved inorganic carbon (C or DIC) is generated in the model thermodynamically.

Table B. Year 2000 DIC values at Point Barrow, Alaska for atmospheric pCO_2, modelled with Thermal, from temperature data; alkalinity and dissolved inorganic carbon and pH values were generated by model; bold values for Ω represent increased aggregation for calcite

Point Barrow		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
a	δT K	22.139	22.139	22.139	22.139	22.139	22.139	20.286	18.189	17.856	19.584	20.704	21.903
b		2944.164	2944.164	2944.164	2944.164	2944.164	2944.164	2890.089	2778.621	2734.484	2802.185	2856.641	2912.173
c		201.358	201.358	201.358	201.358	201.358	201.358	217.458	230.467	227.37	211.768	205.388	199.128
C		3167.661	3167.661	3167.661	3167.661	3167.661	3167.661	3127.833	3027.277	2979.71	3033.537	3082.733	3133.204
Ac		3346.88	3346.88	3346.88	3346.88	3346.88	3346.88	3325.005	3239.555	3189.224	3225.721	3267.417	3310.429
Ab		3418.16	3418.16	3418.16	3418.16	3418.16	3418.16	3400.664	3319.911	3269.732	3258.644	3341	3381.698
Ksp		4.28E-07	4.28E-07	4.28E-07	4.28E-07	4.28E-07	4.28E-07	4.29E-07	4.30E-07	4.30E-07	4.29E-07	4.29E-07	4.28E-07
K $[Ca^{2+}][CO_3^{2-}]$		3.99E-07	3.99E-07	3.99E-07	3.99E-07	3.99E-07	3.99E-07	4.31E-07	4.56E-07	4.50E-07	4.19E-07	4.07E-07	3.94E-07
Ω		0.931524	0.931524	0.931524	0.931524	0.931524	0.931524	**1.003477**	**1.061241**	**1.04696**	**0.977122**	**0.948928**	**0.921211**
pH		8.26	8.26	8.26	8.26	8.26	8.26	8.26	8.26152	8.26259	8.2619	8.2609	8.25991
Temperature K		270.95	270.95	270.95	270.95	270.95	270.95	273.15	275.35	275.35	273.15	272.05	270.95
pCO2 ppmv		375.2	375.2	375.2	375.2	375.2	375.2	375.2	**366.15**	**359.45**	**362.35**	**366.85**	**371.35**
a	δCO2	22.139	22.139	22.139	22.139	22.139	22.139	19.797	17.863	18.007	19.835	20.967	22.089
b		2944.164	2944.164	2944.164	2944.164	2944.164	2944.164	2830.285	2735.618	2753.301	2831.639	2886.253	2932.06
c		201.358	201.358	201.358	201.358	201.358	201.358	213.706	227.46	228.566	213.503	207.043	200.159
C		3167.661	3167.661	3167.661	3167.661	3167.661	3167.661	3063.788	2980.941	2999.874	3064.977	3114.263	3154.308
Ac		3346.88	3346.88	3346.88	3346.88	3346.88	3346.88	3257.698	3190.538	3210.433	3258.644	3300.338	3332.378
Ab		3418.16	3418.16	3418.16	3418.16	3418.16	3418.16	3333.358	3270.894	3290.948	3334.575	3373.923	3403.647
Ksp		4.28E-07	4.28E-07	4.28E-07	4.28E-07	4.28E-07	4.28E-07	4.29E-07	4.30E-07	4.30E-07	4.29E-07	4.29E-07	4.28E-07
K $[Ca^{2+}][CO_3^{2-}]$		3.99E-07	3.99E-07	3.99E-07	3.99E-07	3.99E-07	3.99E-07	4.23E-07	4.50E-07	4.53E-07	4.23E-07	4.10E-07	3.96E-07
Ω		0.931524	0.931524	0.931524	0.931524	0.931524	0.931524	**0.986164**	**1.047392**	**1.052484**	**0.985224**	**0.956574**	**0.925978**
pH		8.26	8.26	8.26	8.26	8.26	8.26	8.26152	8.26259	8.2619	8.2609	8.25991	8.2592
Temperature K		270.95	270.95	270.95	270.95	270.95	270.95	273.15	275.35	275.35	273.15	272.05	270.95
pCO2 ppmv		375.2	375.2	375.2	375.2	375.2	375.2	**366.15**	**359.45**	**362.35**	**366.85**	**371.35**	**374.35**



NCCARF Plot of Aloha Station Data

National Climate Change Research Facility

Australian Government

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Appendix 4.2 equations were employed in CO2MOD2 THERMAL

$$K_{P,3} = \frac{[PO_4^{3-}] \times [H^+]}{[HPO_4^{2-}]} \tag{4A1.6}$$

$$K_W = [OH^-][H^+] \tag{4A1.7}$$

4A1.2

The following Matlab function program finds the root of the cubic equation for $[H^+]$ in terms of $A_{C\&B}$ and DIC resulting from the combination of the equations in 4A1.1 (a) and (b) above (Zeebe and Wolf-Gladrow, 2000). Input values are temperature, salinity, depth, $A_{C\&B}$ and DIC and the outputs are f_{CO_2}, pH, $[CO_2]$, $[HCO_3^-]$ and $[CO_3^{2-}]$. Units and equilibrium constants used are indicated in the comment statements, which are preceded by a % sign.

```
    function [fco2, pH, co2, hco3, co3] = co3eq (temp, s, z, alk, dic)
% Function to calculate fCO2, HCO3, and CO3 from ALK and DIC as a
% f(temp,sal,Z)
% temp = temp(deg C),
% sal = salinity(ppt),depth = z(m),alk = ALK(microeq/kg),
% dic = DIC(micromol kg^-1)
% HCO3, CO3, and CO2 are returned in mol kg^-1, fCO2 in atm
% This program uses the equations in Zeebe and Wolf-Gladrow (2000) and
% Matlab's root finding routine
% checked for fCO2 against Luecker et al. (2000), May 2002;
% Depth dependence has not been checked
    t = temp + 273.15;
    Pr = z/10;
    alk = alk * .000001;
    dic = dic * .000001;
    R = 83.131;
% Calculate total borate (tbor) from chlorinity
    tbor = .000416 * s / 35.0;
% Calculate Henry's Law coeff, KH (Weiss, 1974)
    U1 = -60.2409 + 93.4517 * (100/t) + 23.3585 * log(t/100);
    U2 = s * (.023517 - .023656 * (t/100) + .0047036 * (t/100) ^ 2);
    KH = exp(U1 + U2);
% Calculate KB from temp & sal (Dickson, 1990)
    KB = exp((-8966.9 -2890.53 * s ^0.5 -77.942 * s + 1.728 * s^1.5
      - 0.0996*s^2)/t ... + 148.0248 + 137.1942 * s^0.5 + 1.62142 * s
      - (24.4344 + 25.085 * s^0.5 + ...0.2474 * s) * log(t) + 0.053105 * s^0.5 * t);
% Calculate K1 and K2 (Luecker et al., 2000)
    K1 = 10^(-(3633.86/t - 61.2172 + 9.67770 *
    log(t) - 0.011555*s + 0.0001152 * s^2));
    K2 = 10^(-(471.78/t + 25.9290 -3.16967 *
    log(t) - 0.01781*s + 0.0001122 * s^2));
% Pressure variation of K1, K2, and KB (Millero, 1995)
    dvB = -29.48 + 0.1622 * temp - .002608 * (temp)^2;
    dv1 = -25.50 + 0.1271 * temp;
    dv2 = -15.82 - 0.0219 * temp;
    dkB = -.00284;
    dk1 = -.00308 + 0.0000877 * temp;
```

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```
    dk2 = +.00113 -.0001475 * temp;
    KB = (exp( - (dvB/(R*t))*Pr + (0.5 * dkB/(R*t))*Pr^2)) * KB;
    K1 = (exp( - (dv1/(R*t))*Pr + (0.5 * dk1/(R*t))*Pr^2)) * K1;
    K2 = (exp( - (dv2/(R*t))*Pr + (0.5 * dk2/(R*t))*Pr^2)) * K2;
% temperature dependence of Kw (DoE, 1994)
    KW1 = 148.96502-13847.26/t-23.65218*log(t);
    KW2 = (118.67/t-5.977 + 1.0495*log(t))*s ^ .5-0.01615*s;
    KW = exp(KW1 + KW2);
% solve for H ion (Zeebe and Wolf-Gladrow, 2000)
    a1 = 1;
    a2 = (alk + KB + K1);
    a3 = (alk*KB-KB*tbor-KW + alk*K1 + K1*KB + K1*K2-dic*K1);
    a4 = (-KW*KB + alk*KB*K1-KB*tbor*K1-KW*K1 + alk*K1*K2
        + KB*K1*K2-dic*KB*K1-2*dic*K1*K2);
    a5 = (-KW*KB*K1 + alk*KB*K1*K2-KW*K1*K2-KB*tbor*K1*K2 -2*dic*KB*
        K1*K2);
    a6 = -KB*KW*K1*K2;
    p = [a1 a2 a3 a4 a5 a6];
    r = roots(p);
    h = max(real(r));
% calculate the HCO3, CO3 and CO2aq using DIC, AlK and H+
    format short g;
    hco3 = dic/(1 + h/K1 + K2/h);
    co3 = dic/(1 + h/K2 + h*h/(K1*K2));
    co2 = dic/(1 + K1/h + K1*K2/(h*h));
    fco2 = co2 / KH;
    pH = -log10(h);
% calculate B(OH)4- and OH
    BOH4 = KB*tbor/(h + KB);OH = KW/h;
% recalculate DIC and Alk to check calculations
    Ct = (hco3 + co3 + co2)*1e6;
    At = (hco3 + 2*co3 + BOH4 + OH-h)*1e6;
```

Appendix 4.2 Equations for calculating the equilibrium constants of the carbonate and borate buffer system

Constants are based on the "total" pH scale, pH_T (Dickson, 1984, 1993). Values are first presented at 1 atm pressure and then equations are given for calculating the pressure effect on *K*. *T* is temperature in either degrees Kelvin (*T*), or degrees centigrade (T_C). Salinities are on the practical salinity scale. Equilibrium constants for the equilibria other than K_H, K_1', K_2', K_B', and K_W' given in Appendix 4A1.1(c) can be found in DoE (1994) and in Zeebe and Wolf-Gladrow (2000).

4A2.1. Values at 1 atmosphere

(a) The Henry's Law constant for CO_2 in seawater ($mol\ kg^{-1} atm^{-1}$), Eq. (4.14)

Source: From Weiss (1974) as reported in DoE (1994).

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$$
\begin{aligned}
\ln K_{\mathrm{H}} &= \frac{9345.17}{T} - 60.2409 + 23.3585 \ln\left(\frac{T}{100}\right) \\
&\quad + S\left[0.023\,517 - 0.000\,236\,56T + 0.004\,7036\left(\frac{T}{100}\right)^2\right] \\
&= -3.5617\ (T_{\mathrm{C}} = 25\ (\mathrm{T} = 298.15), \mathrm{S} = 35). \qquad (4A2.1)
\end{aligned}
$$

(b) The first (Eq. (4.11)) and second (Eq. (4.9)) dissociation constants for carbonic acid in seawater (mol kg^{-1})

Mehrbach's constants are given on the total pH scale (Luecker *et al.*, 2000).

$$
\begin{aligned}
\mathrm{p}K_1' &= \frac{3633.86}{T} - 61.2172 + 9.6777 \ln(T) - 0.011\,555S + 0.000\,1152S^2 \\
&= 5.847\ (T_{\mathrm{C}} = 25,\ S = 35) \qquad (4A2.2)
\end{aligned}
$$

$$
\begin{aligned}
\mathrm{p}K_2' &= \frac{471.78}{T} + 25.9290 - 3.169\,67 \ln(T) - 0.017\,81S + 0.000\,1122S^2 \\
&= 8.966\ (T_{\mathrm{C}} = 25, S = 35). \qquad (4A2.3)
\end{aligned}
$$

(c) Boric acid in seawater, mol kg^{-1} (Eqs. (4.19 and 4.20))

Based on Dickson (1990) as reported in DoE (1994).

$$
B_{\mathrm{T}} = [\mathrm{B(OH)_3}] + [\mathrm{B(OH)_4^-}] = 4.16 \times 10^{-4}\ \ (S = 35) \qquad (4A2.4)
$$

$$
\begin{aligned}
\ln K_{\mathrm{B}} &= \frac{-8966.90 - 2890.53S^{1/2} - 77.942S + 1.728S^{3/2} - 0.0996S^2}{T} \\
&\quad + 148.0248 + 137.1942S^{1/2} + 1.621\,42S \\
&\quad - \left(24.4344 + 25.085S^{1/2} + 0.2474S\right)\ln(T) + 0.053\,105S^{1/2}T \\
&= -19.7964\ (T_{\mathrm{C}} = 25\,,\ S = 35). \qquad (4A2.5)
\end{aligned}
$$

(d) The dissociation constant of water, mol^2 kg^{-1}

From Dickson and Riley (1979) as reported in DoE (1994).

$$
\begin{aligned}
\ln K_{\mathrm{W}} &= 148.965\,02 - \frac{13\,847.26}{T} - 23.652\,1 \ln(T) \\
&\quad + \left(\frac{118.67}{T} - 5.977 + 1.0495 \ln(T)\right)S^{1/2} - 0.016\,15\,S \\
&= -30.434\ (T_{\mathrm{C}} = 25\,,\ S = 35). \qquad (4A2.6)
\end{aligned}
$$

4A2.2 The pressure dependence (from Millero, 1995)

The effect of pressure can be calculated from the molal volume, ΔV, and compressibility, $\Delta\kappa$, changes for any given reaction

$$
\ln\frac{K_{\mathrm{P}}}{K_0} = -\left(\frac{\Delta V}{RT}\right)\mathrm{P} + \left(\frac{0.5\Delta\kappa}{RT}\right)\mathrm{P}^2, \qquad (4A2.7)
$$

Table 4A2.1. *Parameters for calculating the effect of pressure change on carbonate buffer system reactions and values of equilibrium constants at P = 0 and 300 bar*

Constant	a_0	a_1	$a_2 \times 10^3$	$b_0 \times 10^3$	$b_1 \times 10^3$	P = 0	P = 300	K^{300}/K^0
pK_1'	25.50	−0.1271	0.0	3.08	−0.0877	5.847	5.726	1.32
pK_2'	15.82	0.0219	0.0	−1.13	0.1475	8.966	8.883	1.21
pK_B'	29.48	−0.1622	2.608	2.84	0.0	8.598	8.455	1.39
pK_W'	25.60	0.2324	−3.6246	5.13	0.0794	13.217	13.106	1.43

where K_P and K_0 are equilibrium constants for the reaction of interest at pressure P and at 0 bars (1 atm), respectively. P is pressure in bars, $R = 83.131$ (cm^3 bar mol^{-1} K^{-1}) and T is in degrees Kelvin. The molar volume (cm^3 mol) and compressibility can be fit to equations of the form ($S = 35$)

$$-\Delta V = a_0 + a_1 T_C + a_2 T_C^2; \tag{4A2.8}$$

$$-\Delta\kappa = b_0 + b_1 T_C, \tag{4A2.9}$$

where T_C is now temperature in degrees C. Values for the coefficients a and b are presented in Table 4A2.1 along with calculated differences in pK′ and K′ at two different pressures ($T_C = 25$ °C, $S = 35$).

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```
May 29, 2022   PLUS TREND 0.15 umoles
CO2MOD2  includes borate
Models Mauna Loa oscillation
Inputs pH, pCO2 T to compute C and A
Varies H,K1,K2,Kw,Kc with T & salt S
C=[CO2+HCO3-+CO32-] total C mmoles/kg
A=[HCO3-+2CO32-+OH--H++B(OH4)-]
DIC alkalinity = Ac
140 moles CO2/m^2 dCO2=1=0.3333 m/m^2
Iterations of increment,say 12/demi yr
Adjust Ko solubility at 1532
Ionic product calcite  0.198x0.7=0.17
Ionic product CO32- x0.85
0520     096     LABEL
0521     073     I
0522     107     STO MEM
0523     048       0
0524     048       0
0525     119     print
0526     002     HALT
Margin, 0.000001 atm for d(pCO2)/month
0567     096     LABEL
0568     077     M
0569     107     STO MEM
0570     057       9
0571     057       9
0572     119     print
0573     002     HALT
Input pCO2 trend 0.00000015 (0.15 ppm)
0614     096     LABEL
0615     084     T
0616     107     STO MEM
0617     055       7
0618     056       8
0619     119     print
0620     002     HALT
{CO2-calcite} U mmoles/kg 65 depth
0661     096     LABEL
0662     085     U
0663     107     STO MEM
0664     056       8
0665     057       9
0666     119     print
0667     002     HALT
Alkalinity=[HCO3-]+2[CO32-]+B(OH)4-+OH
0708     096     LABEL
0709     065     A
0710     107     STO MEM
0711     048       0
0712     049       1
0713     119     print
0714     002     HALT
Label C[CO2+HCO3-+CO32-] mmol/kg
0755     096     LABEL
0756     067     C
0757     107     STO MEM
0758     048       0
0759     056       8
0760     119     print
0761     002     HALT
Input pH value
0802     096     LABEL
0803     080     P
0804     107     STO MEM
0805     048       0
0806     051       3
0807     119     print
0808     002     HALT
Label pK1o
0849     096     LABEL
0850     078     N
0851     107     STO MEM
0852     048       0
0853     052       4
0854     119     print
0855     002     HALT
Label pK2o
0896     096     LABEL
0897     079     O
0898     107     STO MEM
0899     048       0
0900     053       5
0901     119     print
0902     002     HALT
Label Henry's constant Kaw
0943     096     LABEL
0944     072     H
0945     107     STO MEM
0946     048       0
0947     054       6
0948     119     print
0949     002     HALT
Input lowest temperature K
0990     096     LABEL
0991     075     K
0992     107     STO MEM
0993     053       5
0994     055       7
0995     119     print
0996     002     HALT
Input salinity S %o g/kg
1037     096     LABEL
1038     083     S
1039     107     STO MEM
1040     048       0
1041     057       9
1042     119     print
1043     002     HALT
Input pCO2 atmospheres
1084     096     LABEL
1085     090     Z
1086     107     STO MEM
1087     049       1
1088     056       8
1089     119     print
1090     002     HALT
Execute
1131     096     LABEL
1132     088     X
1133     096     LABEL
```

1134	104	Hyperbol

Recall iterations to set To

Establish temperature gradient

1215	040	(
1216	109	RCL MEM
1217	053	5
1218	055	7
1219	043	+
1220	040	(
1221	109	RCL MEM
1222	048	0
1223	048	0

Divide by I/dT

1264	042	x
1265	053	5
1266	046	.
1267	048	0
1268	047	/
1269	049	1
1270	050	2
1271	041	)
1272	041	)

Print and stow current T

1313	119	print
1314	107	STO MEM
1315	048	0
1316	055	7

Get Bt =total borates

1357	096	LABEL
1358	115	Sine
1359	040	(
1360	048	0
1361	046	.
1362	052	4
1363	049	1
1364	054	6
1365	042	x
1366	040	(
1367	109	RCL MEM
1368	048	0
1369	057	9
1370	047	/
1371	051	3
1372	053	5
1373	041	)
1374	041	)
1375	119	print
1376	107	STO MEM
1377	056	8
1378	056	8

Get pKo Henry's coefficient repCO2

1419	040	(
1420	048	0
1421	045	−
1422	054	6
1423	048	0
1424	046	.
1425	050	2
1426	052	4
1427	048	0
1428	057	9
1429	043	+
1430	040	(
1431	057	9
1432	051	3
1433	052	4
1434	053	5
1435	046	.
1436	049	1
1437	055	7
1438	047	/
1439	109	RCL MEM
1440	048	0
1441	055	7
1442	041	)
1443	043	+
1444	040	(
1445	109	RCL MEM
1446	048	0
1447	055	7
1448	042	x
1449	049	1
1450	101	EE
1451	050	2
1452	111	+/−
1453	041	)
1454	110	LOG e
1455	042	x
1456	050	2
1457	051	3
1458	046	.
1459	051	3
1460	053	5
1461	056	8
1462	053	5
1463	041	)
1464	043	+
1465	040	(
1466	109	RCL MEM
1467	048	0
1468	057	9
1469	042	x
1470	040	(
1471	048	0
1472	046	.
1473	048	0
1474	050	2
1475	051	3
1476	053	5
1477	049	1
1478	055	7
1479	045	−
1480	040	(
1481	049	1
1482	101	EE
1483	050	2
1484	111	+/−
1485	042	x
1486	109	RCL MEM
1487	048	0

1488	055	7
1489	041	)
1490	042	x
1491	048	0
1492	046	.
1493	048	0
1494	050	2
1495	051	3
1496	054	6
1497	053	5
1498	054	6
1499	043	+
1500	040	(
1501	049	1
1502	101	EE
1503	050	2
1504	111	+/-
1505	042	x
1506	109	RCL MEM
1507	048	0
1508	055	7
1509	041	)
1510	113	Square
1511	042	x
1512	048	0
1513	046	.
1514	048	0
1515	048	0
1516	052	4
1517	055	7
1518	048	0
1519	051	3
1520	054	6
1521	041	)
1522	041	)
1523	041	)

Adjust solubility factor

Print lnK'o function

1604	119	print
1605	064	Inverse
1606	110	LOG e
1607	042	x
1608	049	1
1609	101	EE
1610	051	3
1611	042	x
1612	048	0
1613	046	.
1614	056	8
1615	048	0

Print Ho' mM

1656	061	=
1657	119	print
1658	107	STO MEM
1659	048	0
1660	054	6

Get pK1'

1701	040	(
1702	040	(
1703	051	3
1704	054	6
1705	055	7
1706	048	0
1707	046	.
1708	055	7
1709	047	/
1710	109	RCL MEM
1711	048	0
1712	055	7
1713	045	-
1714	054	6
1715	050	2
1716	046	.
1717	048	0
1718	048	0
1719	056	8
1720	043	+
1721	040	(
1722	109	RCL MEM
1723	048	0
1724	055	7
1725	110	LOG e
1726	042	x
1727	057	9
1728	046	.
1729	055	7
1730	057	9
1731	052	4
1732	052	4
1733	041	)
1734	045	-
1735	040	(
1736	048	0
1737	046	.
1738	048	0
1739	049	1
1740	049	1
1741	056	8
1742	042	x
1743	109	RCL MEM
1744	048	0
1745	057	9
1746	041	)
1747	043	+
1748	040	(
1749	109	RCL MEM
1750	048	0
1751	057	9
1752	113	Square
1753	042	x
1754	048	0
1755	046	.
1756	048	0
1757	048	0
1758	048	0
1759	049	1
1760	049	1
1761	054	6
1762	041	)
1763	041	)

```
Print pk1'
1804    119    print
1805    107    STO MEM
1806    048     0
1807    052     4
Get pK2'
1848    040     (
1849    040     (
1850    049     1
1851    051     3
1852    057     9
1853    052     4
1854    046     .
1855    055     7
1856    047     /
1857    109    RCL MEM
1858    048     0
1859    055     7
1860    041     )
1861    043     +
1862    052     4
1863    046     .
1864    055     7
1865    055     7
1866    055     7
1867    045     -
1868    048     0
1869    046     .
1870    048     0
1871    049     1
1872    056     8
1873    052     4
1874    042     x
1875    109    RCL MEM
1876    048     0
1877    057     9
1878    043     +
1879    040     (
1880    109    RCL MEM
1881    048     0
1882    057     9
1883    113    Square
1884    042     x
1885    048     0
1886    046     .
1887    048     0
1888    048     0
1889    048     0
1890    049     1
1891    049     1
1892    056     8
1893    041     )
1894    041     )
Print pk2'
1935    119    print
1936    107    STO MEM
1937    048     0
1938    053     5
Get water dissociation lnKw
1979    040     (
1980    049     1
1981    052     4
1982    056     8
1983    046     .
1984    057     9
1985    054     6
1986    053     5
1987    048     0
1988    050     2
1989    045     -
1990    040     (
1991    049     1
1992    051     3
1993    056     8
1994    052     4
1995    055     7
1996    046     .
1997    050     2
1998    054     6
1999    047     /
2000    109    RCL MEM
2001    048     0
2002    055     7
2003    041     )
2004    045     -
2005    040     (
2006    109    RCL MEM
2007    048     0
2008    055     7
2009    110    LOG e
2010    042     x
2011    050     2
2012    051     3
2013    046     .
2014    054     6
2015    053     5
2016    050     2
2017    049     1
2018    041     )
2019    043     +
2020    040     (
2021    040     (
2022    040     (
2023    049     1
2024    049     1
2025    056     8
2026    046     .
2027    054     6
2028    055     7
2029    047     /
2030    109    RCL MEM
2031    048     0
2032    055     7
2033    041     )
2034    045     -
2035    053     5
2036    046     .
2037    057     9
2038    055     7
2039    055     7
```

```
2040   043   +
2041   040   (
2042   109   RCL MEM
2043   048   0
2044   055   7
2045   110   LOG e
2046   042   x
2047   049   1
2048   046   .
2049   048   0
2050   052   4
2051   057   9
2052   053   5
2053   041   )
2054   041   )
2055   042   x
2056   109   RCL MEM
2057   048   0
2058   057   9
2059   064   Inverse
2060   113   Square
2061   041   )
2062   041   )
2063   045   -
2064   048   0
2065   046   .
2066   048   0
2067   049   1
2068   054   6
2069   049   1
2070   053   5
2071   042   x
2072   109   RCL MEM
2073   048   0
2074   057   9
2075   041   )
2076   119   print
2077   107   STO MEM
2078   048   0
2079   050   2
2080   064   Inverse
2081   110   LOG e
2082   119   print
2083   107   STO MEM
2084   054   6
2085   049   1
Get calcite pKs for solubility product
2126   040   (
2127   049   1
2128   055   7
2129   049   1
2130   046   .
2131   057   9
2132   048   0
2133   054   6
2134   053   5
2135   043   +
2136   040   (
2137   048   0
2138   046   .
2139   048   0
2140   055   7
2141   055   7
2142   057   9
2143   057   9
2144   051   3
2145   042   x
2146   109   RCL MEM
2147   048   0
2148   055   7
2149   041   )
2150   045   -
2151   040   (
2152   050   2
2153   056   8
2154   051   3
2155   057   9
2156   046   .
2157   051   3
2158   049   1
2159   057   9
2160   047   /
2161   109   RCL MEM
2162   048   0
2163   055   7
2164   041   )
2165   045   -
2166   040   (
2167   109   RCL MEM
2168   048   0
2169   055   7
2170   108   LOG 10
2171   042   x
2172   055   7
2173   049   1
2174   046   .
2175   053   5
2176   057   9
2177   053   5
2178   041   )
2179   043   +
2180   040   (
2181   048   0
2182   046   .
2183   055   7
2184   055   7
2185   055   7
2186   049   1
2187   050   2
2188   045   -
2189   040   (
2190   048   0
2191   046   .
2192   048   0
2193   048   0
2194   050   2
2195   056   8
2196   052   4
2197   050   2
2198   054   6
```

2199	042	x
2200	109	RCL MEM
2201	048	0
2202	055	7
2203	041	)
2204	045	-
2205	040	(
2206	049	1
2207	055	7
2208	056	8
2209	046	.
2210	051	3
2211	052	4
2212	047	/
2213	109	RCL MEM
2214	048	0
2215	055	7
2216	041	)
2217	041	)
2218	042	x
2219	040	(
2220	109	RCL MEM
2221	048	0
2222	057	9
2223	064	Inverse
2224	113	Square
2225	041	)
2226	041	)
2227	043	+
2228	040	(
2229	048	0
2230	046	.
2231	048	0
2232	055	7
2233	055	7
2234	049	1
2235	049	1
2236	042	x
2237	109	RCL MEM
2238	048	0
2239	057	9
2240	041	)
2241	045	-
2242	040	(
2243	048	0
2244	046	.
2245	048	0
2246	048	0
2247	052	4
2248	049	1
2249	050	2
2250	052	4
2251	057	9
2252	042	x
2253	040	(
2254	109	RCL MEM
2255	048	0
2256	057	9
2257	091	Exponent
2258	049	1
2259	046	.
2260	053	5
2261	041	)
2262	041	)
2263	041	)

Print pKs calcite

2304	119	print
2305	107	STO MEM
2306	049	1
2307	054	6
2308	111	+/-
2309	064	Inverse
2310	108	LOG 10

Print Ks calcite solubility product

2351	119	print
2352	107	STO MEM
2353	049	1
2354	055	7

Get lnKb boric acid

2395	040	(
2396	040	(
2397	048	0
2398	045	-
2399	056	8
2400	057	9
2401	054	6
2402	054	6
2403	046	.
2404	057	9
2405	048	0
2406	045	-
2407	109	RCL MEM
2408	048	0
2409	057	9
2410	064	Inverse
2411	113	Square
2412	042	x
2413	050	2
2414	056	8
2415	057	9
2416	048	0
2417	046	.
2418	053	5
2419	051	3
2420	045	-
2421	109	RCL MEM
2422	048	0
2423	057	9
2424	042	x
2425	055	7
2426	055	7
2427	046	.
2428	057	9
2429	052	4
2430	050	2
2431	043	+
2432	109	RCL MEM
2433	048	0
2434	057	9
2435	091	Exponent

2436	049	1
2437	046	.
2438	053	5
2439	042	x
2440	049	1
2441	046	.
2442	055	7
2443	050	2
2444	056	8
2445	045	-
2446	109	RCL MEM
2447	048	0
2448	057	9
2449	113	Square
2450	042	x
2451	048	0
2452	046	.
2453	048	0
2454	057	9
2455	057	9
2456	054	6
2457	041	)
2458	047	/
2459	109	RCL MEM
2460	048	0
2461	055	7
2462	043	+
2463	049	1
2464	052	4
2465	056	8
2466	046	.
2467	048	0
2468	050	2
2469	052	4
2470	056	8
2471	043	+
2472	109	RCL MEM
2473	048	0
2474	057	9
2475	064	Inverse
2476	113	Square
2477	042	x
2478	049	1
2479	051	3
2480	055	7
2481	046	.
2482	049	1
2483	057	9
2484	052	4
2485	050	2
2486	043	+
2487	109	RCL MEM
2488	048	0
2489	057	9
2490	042	x
2491	049	1
2492	046	.
2493	054	6
2494	050	2
2495	049	1
2496	052	4
2497	050	2
2498	045	-
2499	040	(
2500	050	2
2501	052	4
2502	046	.
2503	052	4
2504	051	3
2505	052	4
2506	052	4
2507	043	+
2508	109	RCL MEM
2509	048	0
2510	057	9
2511	064	Inverse
2512	113	Square
2513	042	x
2514	050	2
2515	053	5
2516	046	.
2517	048	0
2518	056	8
2519	053	5
2520	043	+
2521	109	RCL MEM
2522	048	0
2523	057	9
2524	042	x
2525	048	0
2526	046	.
2527	050	2
2528	052	4
2529	055	7
2530	052	4
2531	041	)
2532	042	x
2533	040	(
2534	109	RCL MEM
2535	048	0
2536	055	7
2537	110	LOG e
2538	041	)
2539	043	+
2540	109	RCL MEM
2541	048	0
2542	055	7
2543	042	x
2544	109	RCL MEM
2545	048	0
2546	057	9
2547	064	Inverse
2548	113	Square
2549	042	x
2550	048	0
2551	046	.
2552	048	0
2553	053	5
2554	051	3
2555	049	1

```
2556    048     0
2557    053     5
2558    041     )
Print lnkb
2599    119     print
2600    047     /
2601    049     1
2602    048     0
2603    110     LOG e
2604    041     )
2605    111     +/-
Print pKb
2646    119     print
2647    107     STO MEM
2648    049     1
2649    057     9
Get R= [HCO3-]/[CO2] Inlg(pH-pK1)
2690    040     (
2691    109     RCL MEM
2692    048     0
2693    051     3
2694    045     -
2695    109     RCL MEM
2696    048     0
2697    052     4
2698    041     )
2699    119     print
2700    064     Inverse
2701    108     LOG 10
2702    119     print
2703    107     STO MEM
2704    049     1
2705    049     1
Get [CO32-]/HCO3-]=S
2746    040     (
2747    109     RCL MEM
2748    048     0
2749    051     3
2750    045     -
2751    109     RCL MEM
2752    048     0
2753    053     5
2754    041     )
2755    119     print
2756    064     Inverse
2757    108     LOG 10
Print S
2798    119     print
2799    107     STO MEM
2800    049     1
2801    050     2
Get B(OH)4-
2842    040     (
2843    109     RCL MEM
2844    056     8
2845    055     7
Print previous B(OH)4-
2886    119     print
2887    107     STO MEM
2888    056     8
2889    054     6
2890    041     )
2891    040     (
2892    040     (
2893    049     1
2894    043     +
2895    040     (
2896    040     (
2897    109     RCL MEM
2898    049     1
2899    057     9
2900    045     -
2901    109     RCL MEM
2902    048     0
2903    051     3
2904    041     )
2905    064     Inverse
2906    108     LOG 10
2907    041     )
2908    041     )
2909    114     1/x
2910    042     x
2911    109     RCL MEM
2912    056     8
2913    056     8
2914    041     )
Print new B(OH)4-
2955    119     print
2956    107     STO MEM
2957    056     8
2958    055     7
2959    109     RCL MEM
2960    056     8
2961    054     6
2962    038     If zero
2963    099     Cosine
2964    040     (
2965    109     RCL MEM
2966    056     8
2967    055     7
2968    045     -
2969    109     RCL MEM
2970    056     8
2971    054     6
2972    041     )
Print d[BOH]4-
3013    119     print
3014    107     STO MEM
3015    056     8
3016    053     5
3017    096     LABEL
3018    099     Cosine
Compute [CO2] from pCO2 and H
[CO2] = Ho'xZ
3099    040     (
3100    109     RCL MEM
3101    048     0
3102    054     6
3103    042     x
3104    109     RCL MEM
```

```
3105    049     1
3106    056     8
3107    041     )
Print [CO2] mmoles/kg
3148    119     print
3149    107     STO MEM
3150    049     1
3151    051     3
Compute [HCO3-] = [CO2]xR
3192    040     (
3193    109     RCL MEM
3194    049     1
3195    049     1
3196    042     x
3197    109     RCL MEM
3198    049     1
3199    051     3
3200    041     )
Print HCO3-
3241    119     print
3242    107     STO MEM
3243    049     1
3244    052     4
Compute CO32- = [HCO3-]xS
3285    040     (
3286    109     RCL MEM
3287    049     1
3288    050     2
3289    042     x
3290    109     RCL MEM
3291    049     1
3292    052     4
3293    041     )
Print [CO32-]
3334    119     print
3335    107     STO MEM
3336    049     1
3337    053     5
Get pH
3378    040     (
3379    040     (
3380    109     RCL MEM
3381    048     0
3382    052     4
3383    043     +
3384    040     (
3385    109     RCL MEM
3386    049     1
3387    052     4
3388    047     /
3389    109     RCL MEM
3390    049     1
3391    051     3
3392    041     )
3393    108     LOG 10
3394    041     )
3395    041     )
Print and stow pH
3436    119     print
3437    107     STO MEM
3438    048     0
3439    051     3
Get CaxCO32-
3480    040     (
3481    049     1
3482    046     .
3483    054     6
3484    053     5
3485    101     EE
3486    051     3
3487    111     +/-
3488    042     x
3489    109     RCL MEM
3490    049     1
3491    053     5
3492    042     x
3493    049     1
3494    101     EE
3495    051     3
3496    111     +/-
3497    041     )
Print ionic product CaxCO3
3538    119     print
3539    047     /
3540    109     RCL MEM
3541    049     1
3542    055     7
3543    041     )
Print insolubility ratio
3584    119     print
Compute C=[CO2]+[HCO3-]+[CO32-]
3625    040     (
3626    109     RCL MEM
3627    049     1
3628    051     3
3629    043     +
3630    109     RCL MEM
3631    049     1
3632    052     4
3633    043     +
3634    109     RCL MEM
3635    049     1
3636    053     5
3637    041     )
Print total carbon C
3678    119     print
3679    107     STO MEM
3680    048     0
3681    056     8
Compute alkalinity including borate
3722    040     (
3723    109     RCL MEM
3724    049     1
3725    052     4
3726    043     +
3727    040     (
3728    050     2
3729    042     x
3730    109     RCL MEM
3731    049     1
```

```
3732     053       5
3733     041       )
3734     043       +
3735     109     RCL MEM
3736     056       8
3737     055       7
3738     043       +
3739     040       (
3740     109     RCL MEM
3741     048       0
3742     050       2
3743     111      +/-
3744     064     Inverse
3745     110     LOG e
Print Kw
3786     119     print
3787     114      1/x
3788     042       x
3789     040       (
3790     109     RCL MEM
3791     048       0
3792     052       4
3793     111      +/-
3794     064     Inverse
3795     108     LOG 10
3796     041       )
3797     041       )
3798     045       -
3799     040       (
3800     109     RCL MEM
3801     048       0
3802     052       4
3803     111      +/-
3804     064     Inverse
3805     108     LOG 10
3806     041       )
3807     041       )
Print alkalinity = Ac+Ab
3848     119     print
3849     107     STO MEM
3850     048       0
3851     049       1
3852     040       (
3853     109     RCL MEM
3854     057       9
3855     057       9
3856     043       +
3857     109     RCL MEM
3858     055       7
3859     056       8
3860     043       +
3861     109     RCL MEM
3862     049       1
3863     056       8
3864     041       )
Print and stow next pCO2
3905     119     print
3906     107     STO MEM
3907     049       1
3908     056       8
```

```
Get new C=[CO2+HCO3-+Co32-]=a+b+c
Add U mmolescalcite/kg=d(pCO2)
3989     040       (
3990     109     RCL MEM
3991     048       0
3992     056       8
3993     043       +
3994     109     RCL MEM
3995     056       8
3996     057       9
3997     045       -
3998     048       0
3999     046       .
4000     048       0
4001     048       0
4002     048       0
4003     041       )
4004     119     print
4005     107     STO MEM
4006     048       0
4007     056       8
Get next [CO2] = a using KH
4048     040       (
4049     109     RCL MEM
4050     048       0
4051     054       6
4052     042       x
4053     109     RCL MEM
4054     049       1
4055     056       8
4056     041       )
Print next [CO2] = a
4097     119     print
4098     107     STO MEM
4099     049       1
4100     051       3
Compute z=K2/(K1a)=c/b^2;b=HCO3-,c=CO3
Solve quadratic Ax^2+Bx+C=0
Set Ab^2+Bb+C=0
c=b^2K2/aK1=(A-b)/2
A=2Z, B=1, C=-Ac
Solve Ab^2+Bb+C=0 equating c's
2Zb^2+b-A=0
x=-B+-(B^2-8ZA)^0.5/4Z
4421     040       (
4422     040       (
4423     109     RCL MEM
4424     048       0
4425     053       5
4426     111      +/-
4427     064     Inverse
4428     108     LOG 10
4429     041       )
4430     047       /
4431     040       (
4432     109     RCL MEM
4433     048       0
4434     052       4
4435     111      +/-
4436     064     Inverse
```

```
4437    108     LOG 10
4438    041       )
4439    041       )
4440    047       /
4441    109     RCL MEM
4442    049       1
4443    051       3
4444    041       )
Print Z
4485    119     print
4486    107     STO MEM
4487    057       9
4488    056       8
Get new DIC alkalinity
4529    040       (
4530    109     RCL MEM
4531    049       1
4532    052       4
4533    043       +
4534    050       2
4535    042       x
4536    109     RCL MEM
4537    049       1
4538    053       5
4539    043       +
4540    050       2
4541    042       x
4542    109     RCL MEM
4543    056       8
4544    057       9
4545    045       -
4546    048       0
4547    046       .
4548    048       0
4549    041       )
4550    119     print
4551    107     STO MEM
4552    055       7
4553    057       9
Solve c=Zb^2=(Ac-b)/2
So 2Zb^2+b-A=0 to solve
4634    040       (
4635    040       (
4636    049       1
4637    043       +
4638    040       (
4639    056       8
4640    042       x
4641    109     RCL MEM
4642    057       9
4643    056       8
4644    042       x
4645    109     RCL MEM
4646    055       7
4647    057       9
4648    041       )
4649    041       )
4650    064     Inverse
4651    113     Square
4652    045       -
```

```
4653    049       1
4654    041       )
4655    047       /
4656    040       (
4657    052       4
4658    042       x
4659    109     RCL MEM
4660    057       9
4661    056       8
4662    041       )
4663    041       )
Print and stow b
4704    119     print
4705    107     STO MEM
4706    049       1
4707    052       4
Compute y=C-a=b+c
4748    040       (
4749    109     RCL MEM
4750    048       0
4751    056       8
4752    045       -
4753    109     RCL MEM
4754    049       1
4755    051       3
4756    041       )
Print y=b+c=C-a
4797    119     print
4798    107     STO MEM
4799    057       9
4800    055       7
Compute pH
4841    040       (
4842    040       (
4843    109     RCL MEM
4844    048       0
4845    052       4
4846    043       +
4847    040       (
4848    109     RCL MEM
4849    049       1
4850    052       4
4851    047       /
4852    109     RCL MEM
4853    049       1
4854    051       3
4855    041       )
4856    108     LOG 10
4857    041       )
4858    041       )
Print and stow pH
4899    119     print
4900    107     STO MEM
4901    048       0
4902    051       3
Compute c=[CO32-]
4943    040       (
4944    109     RCL MEM
4945    049       1
4946    052       4
```

```
4947     113     Square
4948     042       x
4949     109     RCL MEM
4950     057       9
4951     056       8
4952     041       )
Print c
4993     119     print
4994     107     STO MEM
4995     049       1
4996     053       5
Compute C=a+b+c
5037     040       (
5038     109     RCL MEM
5039     049       1
5040     051       3
5041     043       +
5042     109     RCL MEM
5043     049       1
5044     052       4
5045     043       +
5046     109     RCL MEM
5047     049       1
5048     053       5
5049     041       )
Print and stow C
5090     119     print
5091     107     STO MEM
5092     048       0
5093     056       8
Compute A=b+2c
5134     040       (
5135     109     RCL MEM
5136     049       1
5137     052       4
5138     043       +
5139     040       (
5140     050       2
5141     042       x
5142     109     RCL MEM
5143     049       1
5144     053       5
5145     041       )
5146     041       )
Print alkalinity Ac
5187     119     print
5188     107     STO MEM
5189     048       0
5190     049       1
Compute and print Ac+Ab
5231     040       (
5232     109     RCL MEM
5233     048       0
5234     049       1
5235     043       +
5236     109     RCL MEM
5237     056       8
5238     055       7
5239     041       )
5240     119     print
```

```
Get [Ca2+][CO32-] product
5281     040       (
5282     049       1
5283     046       .
5284     054       6
5285     053       5
5286     101       EE
5287     051       3
5288     111       +/-
5289     042       x
5290     109     RCL MEM
5291     049       1
5292     053       5
5293     042       x
5294     049       1
5295     101       EE
5296     051       3
5297     111       +/-
5298     041       )
5299     119     print
5300     107     STO MEM
5301     057       9
5302     054       6
5303     040       (
5304     109     RCL MEM
5305     057       9
5306     054       6
5307     047       /
5308     109     RCL MEM
5309     049       1
5310     055       7
5311     041       )
Print Omega solubility
5352     119     print
5353     109     RCL MEM
5354     048       0
5355     048       0
5356     039     Dec JPNZ
5357     104     Hyperbol
5358     049       1
5359     107     STO MEM
5360     048       0
5361     048       0
5362     039     Dec JPNZ
5363     104     Hyperbol
5364     040       (
5365     053       5
5366     046       .
5367     048       0
5368     047       /
5369     049       1
5370     050       2
5371     041       )
5372     064     Inverse
5373     117     SUM MEM
5374     048       0
5375     055       7
5376     040       (
5377     109     RCL MEM
5378     048       0
```

5379	055	7	5384	055	7
~~5380~~	~~119~~	~~print~~	~~5385~~	~~041~~	~~)~~
5381	045	-	5386	038	If zero
5382	109	RCL MEM	5387	115	Sine
5383	053	5	5388	002	HALT