GSA Data Repository 2016092

Can CO_2 trigger a thermal geyser eruption?

Bethany S. Ladd[1]*
bladd@ucalgary.ca

M. Cathryn Ryan[1]
cryan@ucalgary.ca

SUPPLEMENTARY INFORMATION

Dissolved gas concentrations

Table DR1. CO_2 concentrations in Spouter Geyser surface waters a) as analyzed and b) reconstructed in the source zone (~60 m deep and ~165°C), assuming 100% adiabatic cooling. N_2 and O_2 concentrations in near-atmospheric ratios in three samples (marked with an asterix) were believed to be due to atmospheric contamination during analysis.

Sample ID	Date	Time	A. CO_2 (mmol/L) As analyzed from near surface sampling	B. CO_2 (mmol/L) Reconstructed for source water conditions
YNP6-1	11/8/2013	10:20	0.059	7.1
YNP6-2	11/8/2013	10:37	0.027	3.2
YNP6-3	11/8/2013	10:51	0.034	4.0
YNP6-4	11/8/2013	11:06	0.035	4.1
YNP6-5	11/8/2013	11:20	0.035	4.2
YNP6-5D	11/8/2013	11:22	0.038	4.5
YNP6-6	11/8/2013	11:36	0.036	4.2
YNP6-7	11/8/2013	11:51	0.040	4.8
YNP6-8	11/8/2013	12:06	0.046	5.5
YNP6-9	11/8/2013	12:20	0.049	5.8
YNP6-10	11/8/2013	12:31	0.050	5.9
YNP6-10D	11/8/2013	12:34	0.062	7.3
YNP6-11	11/8/2013	12:50	0.036	4.2
YNP6-12	11/8/2013	13:05	0.031	3.6
YNP7-1	11/8/2013	13:21	0.030	3.6
YNP7-2	11/8/2013	13:36	0.029	3.5
YNP7-3	11/8/2013	13:49	0.027	3.2
YNP7-4	11/8/2013	14:07	0.035	4.2
YNP7-5	11/8/2013	14:24	0.041	4.8
YNP7-5D	11/8/2013	14:27	0.037	4.4
YNP7-6	11/8/2013	14:40	0.039	4.7
1	10/27/14	15:20	0.040	4.8
2	10/27/14	15:55	0.034	4.0
3	10/27/14	16:18	0.053	6.3
4*	10/27/14	16:37	0.036	4.3

5	10/27/14	16:46	0.043	5.1
6	10/27/14	16:52	0.041	4.8
7	10/27/14	17:03	0.033	4.0
8	10/27/14	17:16	0.024	2.9
9	10/27/14	17:31	0.026	3.1
10*	10/27/14	17:52	0.022	2.6
10-D	10/27/14	18:02	0.020	2.4
11*	10/27/14	18:14	0.027	3.2
12	10/27/14	18:25	0.031	3.7
13	10/28/2014	9:36	0.034	4.0
14	10/28/14	10:30	0.017	2.0
15	10/28/14	10:43	0.014	1.7
16	10/28/14	10:49	0.017	2.0
17	10/28/14	11:00	0.022	2.7
18	10/28/14	11:11	0.028	3.4
19	10/28/14	11:21	0.027	3.2
20	10/28/14	11:31	0.030	3.5
20-D	10/28/14	11:31	0.029	3.4
21	10/28/14	11:42	0.030	3.5
22	10/28/14	11:52	0.031	3.7
23	10/28/14	12:02	0.030	3.5
24	10/28/14	12:14	0.034	4.1
25	10/28/14	12:26	0.031	3.7
26	10/28/14	12:31	0.038	4.5
27	10/28/14	12:43	0.022	2.7
28	10/28/14	12:58	0.021	2.5
29	10/28/14	13:14	0.018	2.1
30	10/28/14	13:33	0.018	2.2
30-D	10/28/14	13:33	0.021	2.5
31	10/28/14	14:04	0.016	1.9
32	10/28/14	14:13	0.018	2.1
33	10/28/14	14:33	0.035	4.1
34	10/28/14	14:49	0.025	2.9
35	10/28/14	15:05	0.025	2.9
36	10/28/14	15:18	0.027	3.2
37	10/28/14	15:29	0.027	3.2
38	10/28/14	15:44	0.032	3.8
39	10/28/14	16:01	0.031	3.7
40	10/28/14	16:14	0.043	5.1
40-D	10/28/14	16:14	0.034	4.1
41	10/28/14	16:23	0.036	4.3
42	10/28/14	16:26	0.039	4.7
43	10/28/14	16:37	0.048	5.8
44	10/28/14	16:48	0.025	2.9
45	10/28/14	16:58	0.020	2.3
46	10/29/14	9:09	0.023	2.7

47	10/29/14	9:25	0.023	2.7
48	10/29/14	9:41	0.018	2.2
49	10/29/14	9:49	0.020	2.4
50	10/29/14	10:00	0.023	2.7
50-D	10/29/14	10:00	0.023	2.8
51	10/29/14	10:17	0.031	3.7
52	10/29/14	10:34	0.029	3.5
53	10/29/14	10:50	0.034	4.1
54	10/29/14	11:07	0.032	3.8
55	10/29/14	11:21	0.038	4.5
56	10/29/14	11:27	0.033	4.0
57	10/29/14	11:34	0.038	4.5
58	10/29/14	11:38	0.031	3.6
59	10/29/14	11:48	0.033	3.9
60	10/29/14	12:09	0.024	2.9
60-D	10/29/14	12:09	0.021	2.5
61	10/29/14	12:30	0.022	2.6
62	10/29/14	12:50	0.020	2.4
63	10/29/14	13:00	0.022	2.7
64	10/29/14	13:15	0.028	3.4
65	10/29/14	13:31	0.031	3.7
66	10/29/14	13:47	0.025	3.0
67	10/29/14	14:05	0.031	3.7
68	10/29/14	14:26	0.034	4.0
69	10/29/14	14:39	0.041	4.9
70	10/29/14	14:44	0.036	4.3
71	10/29/14	14:56	0.030	3.5
71-D	10/29/14	14:56	0.029	3.5
72	10/29/14	15:16	0.020	2.4
73	10/29/14	15:36	0.020	2.4
74	10/29/14	15:56	0.017	2.0
75	10/29/14	16:15	0.019	2.2
76	10/29/14	16:36	0.018	2.1
77	10/29/14	16:56	0.020	2.3

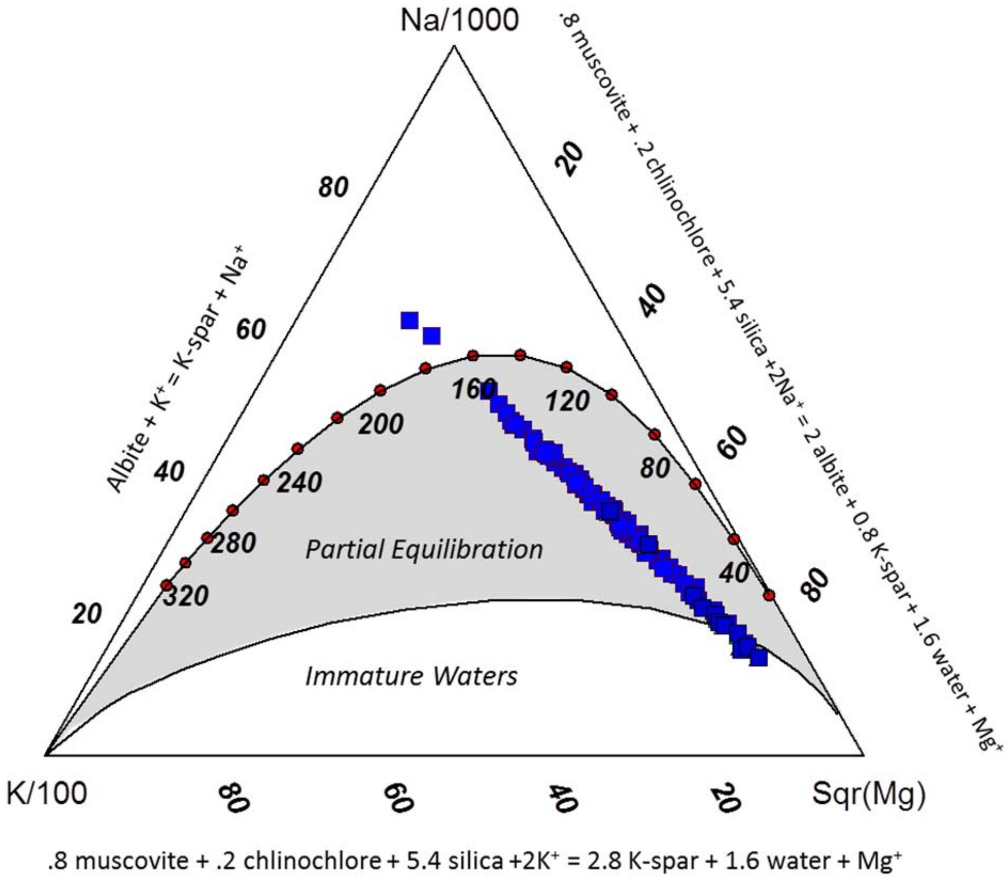

Fig. DR1. Na-K-Mg ternary diagram showing the extent of water-rock equilibration of waters feeding Spouter Geyser (after Giggenbach, 1988). The diagram is based on temperature-dependent mineral reactions that represent felsic minerals expected to form through recrystallization of average crustal rock as the fluid reaches equilibrium with a stable alteration assemblage (shown by equations on the sides of the ternary diagram). Waters that are fully equilibrated plot on the line with red dots, where the numbers indicate the temperatures of equilibration. The zone of partial equilibration is shaded gray, while immature waters plot at the base of the triangle. Almost all water samples from Spouter Geyser plot in the zone of partial equilibration, satisfying the condition necessary to apply the Na/K geothermometer used in this study.

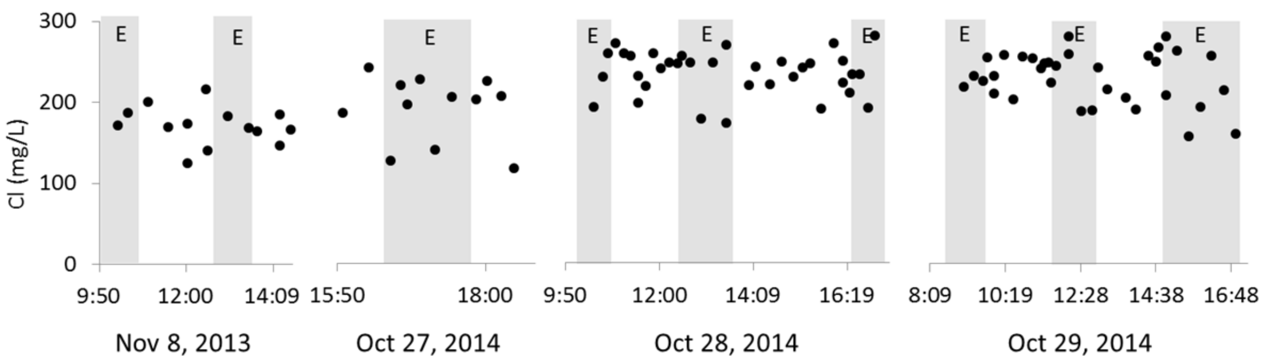

Fig DR2. Time series of [Cl] in Spouter Geyser discharge. As a conservative ion, Cl best illustrates the absence of a cyclic pattern; other ion data are available in Ladd (2014).

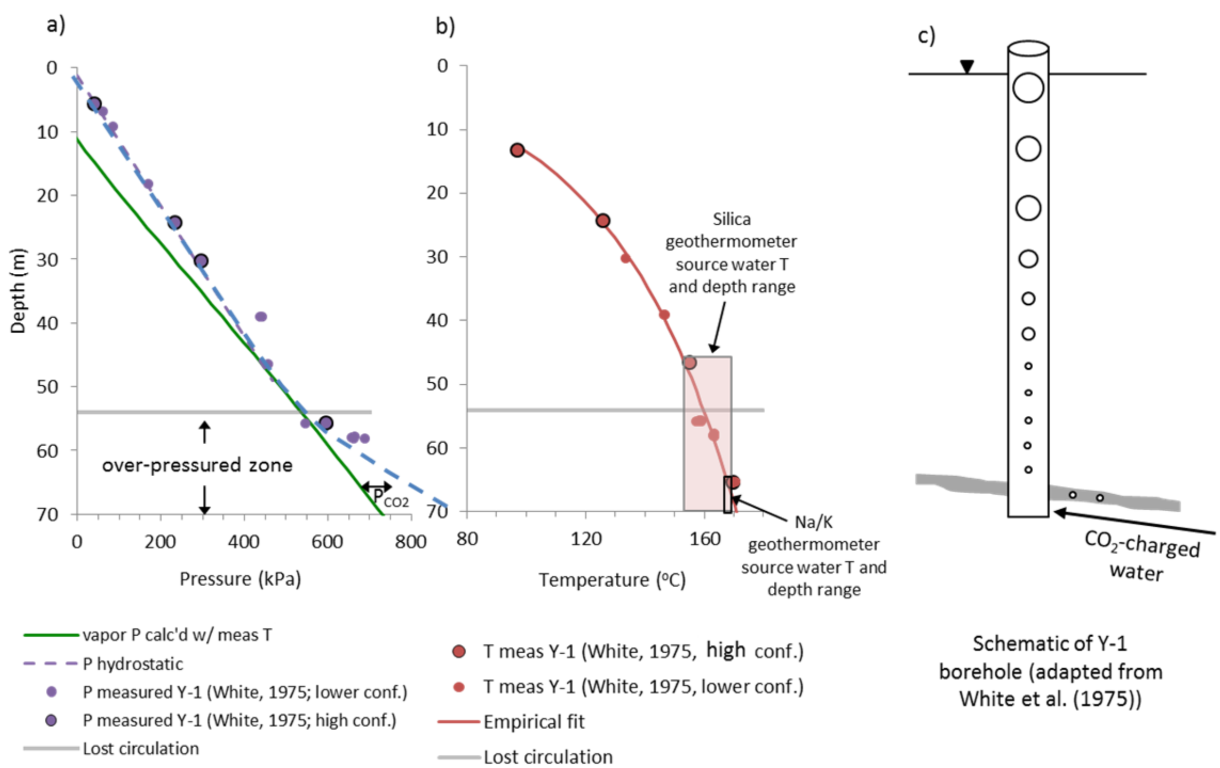

Fig. DR3. a) Depth vs measured hydrostatic pressure (White et al., 1975), calculated vapor pressure (see Table S2) and b) temperature (White et al., 1975). Small and large symbols reflect the authors' confidence in their measurements. c) Schematic of the Y-1 borehole.

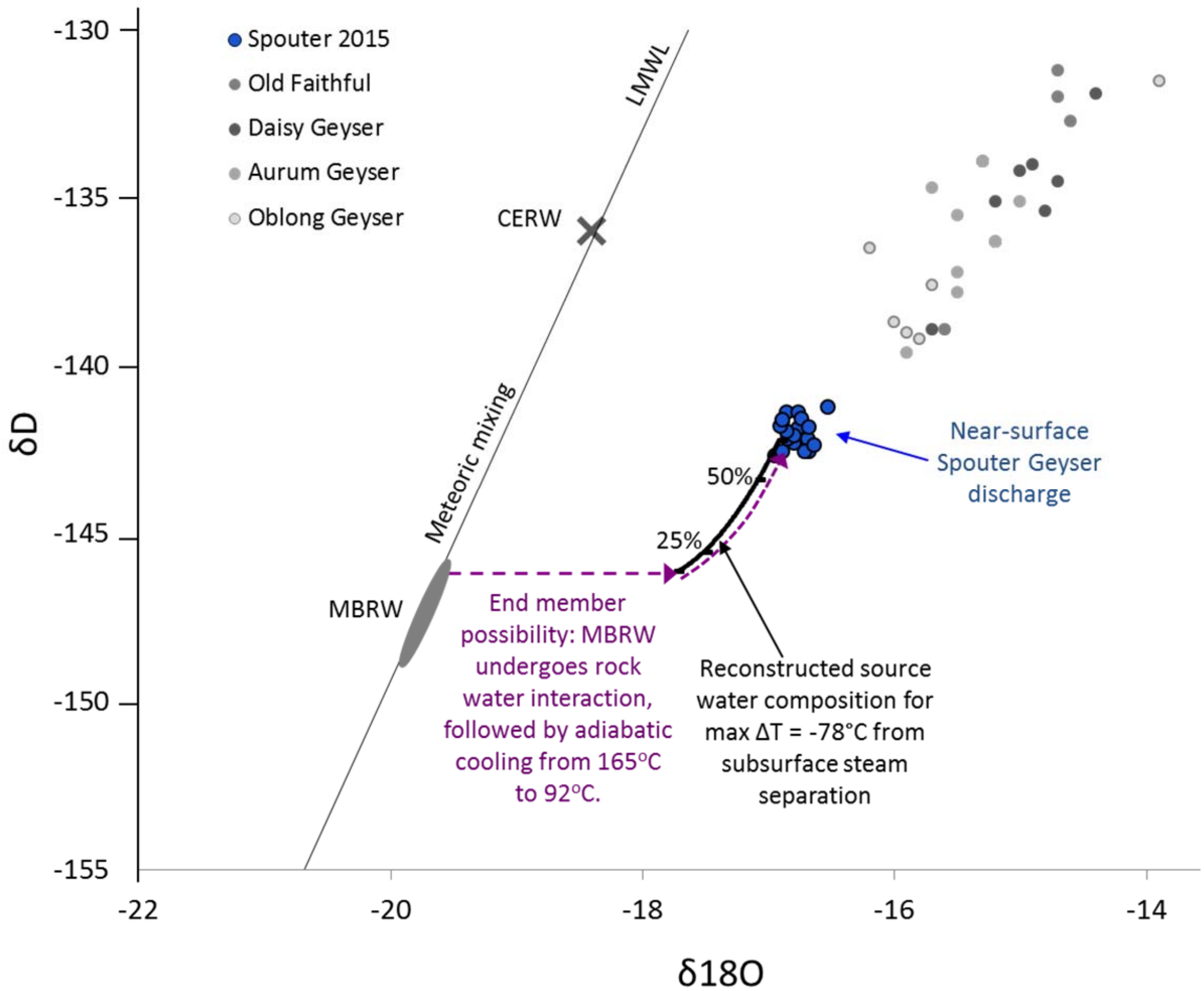

Fig. DR4. Water isotope compositions of Spouter Geyser (blue symbols), plotted with other geyser waters from Hurwitz et al. (2012) (gray symbols). These are plotted with the local meteoric water line (LMWL, y = 8.2x + 14.7; Kharaka et al. 2002), mountain block recharge water composition believed to recharge the Yellowstone hydrothermal system (MBRW; Truesdell et al., 1977; Rye and Truesdell, 2007), and the weighted average of caldera elevation meteoric water (CERW; Rye and Truesdell, 2007). Major processes that may alter water isotopic values are i) mixing between the two meteoric end-members, ii) water-rock interaction, and iii) single stage steam separation. The latter process was calculated specifically for Spouter Geyser, which has an geochemically estimated subsurface temperature of ~165°C and a measured surface temperature of 92^{o}C.

Table DR2. Calculations for reconstructing source zone CO2 concentrations as outlined in Eqs. 1-5 in the text. Concentrations are then converted to partial pressures using Henry's Law. The data that pertain to [CO2]aq measured immediately before eruptions (shaded in Figure 2) are highlighted in yellow.

Sample ID	Date	Time	CO_2 (mg/L) measured	CO_2 (mmol) measured	CO_2 (mmol) reconstructed	mol fraction	P_CO_2 (kPa)	P_H_2O (kPa)	Total Pressure (kPa)
1	10/27/14	15:20	1.72	0.039	4.8	0.000096	58.8	675	733.832
2	10/27/14	15:55	1.43	0.032	4.0	0.000080	48.9	675	723.884
3	10/27/14	16:18	2.26	0.051	6.3	0.000127	77.3	675	752.347
4	10/27/14	16:37	1.55	0.035	4.3	0.000087	53.0	675	727.979
5	10/27/14	16:46	1.82	0.041	5.1	0.000102	62.6	675	737.558
6	10/27/14	16:52	1.73	0.039	4.8	0.000097	59.2	675	734.222
7	10/27/14	17:03	1.41	0.032	4.0	0.000079	48.5	675	723.491
8	10/27/14	17:16	1.02	0.023	2.9	0.000057	34.9	675	709.902
9	10/27/14	17:31	1.12	0.026	3.1	0.000063	38.5	675	713.476
10	10/27/14	17:52	0.93	0.021	2.6	0.000052	32.0	675	707.026
10-D	10/27/14	18:02	0.86	0.020	2.4	0.000048	29.4	675	704.423
11	10/27/14	18:14	1.13	0.026	3.2	0.000063	38.7	675	713.740
12	10/27/14	18:25	1.30	0.030	3.7	0.000073	44.7	675	719.728
13	10/28/14	9:36	1.44	0.033	4.0	0.000081	49.3	675	724.280
14	10/28/14	10:30	0.72	0.016	2.0	0.000040	24.6	675	699.580
15	10/28/14	10:43	0.59	0.013	1.7	0.000033	20.2	675	695.203
16	10/28/14	10:49	0.73	0.017	2.0	0.000041	25.1	675	700.051
17	10/28/14	11:00	0.95	0.022	2.7	0.000053	32.5	675	707.541
18	10/28/14	11:11	1.20	0.027	3.4	0.000067	41.0	675	716.000
19	10/28/14	11:21	1.13	0.026	3.2	0.000063	38.6	675	713.628
20	10/28/14	11:31	1.26	0.029	3.5	0.000071	43.4	675	718.364
20-D	10/28/14	11:31	1.22	0.028	3.4	0.000068	41.7	675	716.740
21	10/28/14	11:42	1.26	0.029	3.5	0.000071	43.2	675	718.204
22	10/28/14	11:52	1.31	0.030	3.7	0.000073	44.8	675	719.818

23	10/28/14	12:02	1.26	0.029	3.5	0.000071	43.2	675	718.184
24	10/28/14	12:14	1.45	0.033	4.1	0.000082	49.8	675	724.797
25	10/28/14	12:26	1.33	0.030	3.7	0.000075	45.5	675	720.541
26	10/28/14	12:31	1.60	0.036	4.5	0.000090	54.7	675	729.720
27	10/28/14	12:43	0.95	0.022	2.7	0.000053	32.6	675	707.614
28	10/28/14	12:58	0.90	0.020	2.5	0.000051	30.9	675	705.907
29	10/28/14	13:14	0.77	0.017	2.1	0.000043	26.2	675	701.242
30	10/28/14	13:33	0.78	0.018	2.2	0.000044	26.6	675	701.606
30-D	10/28/14	13:33	0.90	0.020	2.5	0.000050	30.7	675	705.710
31	10/28/14	14:04	0.69	0.016	1.9	0.000039	23.8	675	698.789
32	10/28/14	14:13	0.74	0.017	2.1	0.000042	25.4	675	700.444
33	10/28/14	14:33	1.47	0.033	4.1	0.000082	50.2	675	725.245
34	10/28/14	14:49	1.05	0.024	2.9	0.000059	35.8	675	710.828
35	10/28/14	15:05	1.05	0.024	2.9	0.000059	35.9	675	710.865
36	10/28/14	15:18	1.12	0.026	3.2	0.000063	38.6	675	713.556
37	10/28/14	15:29	1.14	0.026	3.2	0.000064	39.2	675	714.174
38	10/28/14	15:44	1.34	0.030	3.8	0.000075	45.9	675	720.950
39	10/28/14	16:01	1.33	0.030	3.7	0.000075	45.6	675	720.561
40	10/28/14	16:14	1.80	0.041	5.1	0.000101	61.8	675	736.791
40-D	10/28/14	16:14	1.45	0.033	4.1	0.000081	49.6	675	724.576
41	10/28/14	16:23	1.54	0.035	4.3	0.000087	52.9	675	727.917
42	10/28/14	16:26	1.67	0.038	4.7	0.000094	57.2	675	732.164
43	10/28/14	16:37	2.05	0.047	5.8	0.000115	70.4	675	745.411
44	10/28/14	16:48	1.05	0.024	2.9	0.000059	35.9	675	710.949
45	10/28/14	16:58	0.83	0.019	2.3	0.000047	28.6	675	703.621
46	10/29/14	9:09	0.96	0.022	2.7	0.000054	32.9	675	707.927
47	10/29/14	9:25	0.98	0.022	2.7	0.000055	33.5	675	708.507
48	10/29/14	9:41	0.77	0.018	2.2	0.000043	26.5	675	701.505
49	10/29/14	9:49	0.87	0.020	2.4	0.000049	29.8	675	704.779
50	10/29/14	10:00	0.96	0.022	2.7	0.000054	32.8	675	707.848
50-D	10/29/14	10:00	0.98	0.022	2.8	0.000055	33.8	675	708.759

51	10/29/14	10:17	1.33	0.030	3.7	0.000075	45.7	675	720.651
52	10/29/14	10:34	1.24	0.028	3.5	0.000070	42.6	675	717.571
53	10/29/14	10:50	1.45	0.033	4.1	0.000081	49.8	675	724.787
54	10/29/14	11:07	1.37	0.031	3.8	0.000077	46.9	675	721.902
55	10/29/14	11:21	1.59	0.036	4.5	0.000089	54.7	675	729.654
56	10/29/14	11:27	1.42	0.032	4.0	0.000079	48.5	675	723.521
57	10/29/14	11:34	1.61	0.037	4.5	0.000090	55.2	675	730.175
58	10/29/14	11:38	1.30	0.030	3.6	0.000073	44.6	675	719.564
59	10/29/14	11:48	1.38	0.031	3.9	0.000078	47.4	675	722.372
60	10/29/14	12:09	1.02	0.023	2.9	0.000057	35.0	675	709.973
60-D	10/29/14	12:09	0.87	0.020	2.5	0.000049	30.0	675	704.976
61	10/29/14	12:30	0.93	0.021	2.6	0.000052	31.9	675	706.913
62	10/29/14	12:50	0.86	0.020	2.4	0.000048	29.6	675	704.595
63	10/29/14	13:00	0.95	0.022	2.7	0.000053	32.5	675	707.505
64	10/29/14	13:15	1.20	0.027	3.4	0.000067	41.1	675	716.116
65	10/29/14	13:31	1.33	0.030	3.7	0.000075	45.7	675	720.670
66	10/29/14	13:47	1.07	0.024	3.0	0.000060	36.6	675	711.578
67	10/29/14	14:05	1.32	0.030	3.7	0.000074	45.1	675	720.088
68	10/29/14	14:26	1.44	0.033	4.0	0.000081	49.3	675	724.269
69	10/29/14	14:39	1.76	0.040	4.9	0.000099	60.3	675	735.282
70	10/29/14	14:44	1.53	0.035	4.3	0.000086	52.5	675	727.512
71	10/29/14	14:56	1.25	0.028	3.5	0.000070	43.0	675	717.962
71-D	10/29/14	14:56	1.24	0.028	3.5	0.000070	42.6	675	717.625
72	10/29/14	15:16	0.86	0.020	2.4	0.000048	29.5	675	704.484
73	10/29/14	15:36	0.84	0.019	2.4	0.000047	28.8	675	703.833
74	10/29/14	15:56	0.73	0.017	2.0	0.000041	24.9	675	699.944
75	10/29/14	16:15	0.79	0.018	2.2	0.000044	27.2	675	702.171
76	10/29/14	16:36	0.74	0.017	2.1	0.000042	25.5	675	700.475
77	10/29/14	16:56	0.83	0.019	2.3	0.000047	28.5	675	703.525
YNP6-1	11/8/13	10:20	2.52	0.057	7.1	0.000141	86.2	675	761.228
YNP6-2	11/8/13	10:37	1.16	0.026	3.2	0.000065	39.6	675	714.605

YNP6-3	11/8/13	10:51	1.44	0.033	4.0	0.000081	49.4	675	724.360
YNP6-4	11/8/13	11:06	1.47	0.033	4.1	0.000082	50.3	675	725.316
YNP6-5	11/8/13	11:20	1.50	0.034	4.2	0.000084	51.3	675	726.302
YNP6-5D	11/8/13	11:22	1.60	0.036	4.5	0.000090	54.8	675	729.763
YNP6-6	11/8/13	11:36	1.51	0.034	4.2	0.000085	51.6	675	726.648
YNP6-7	11/8/13	11:51	1.70	0.039	4.8	0.000095	58.3	675	733.346
YNP6-8	11/8/13	12:06	1.95	0.044	5.5	0.000109	66.8	675	741.751
YNP6-9	11/8/13	12:20	2.06	0.047	5.8	0.000116	70.7	675	745.708
YNP6-10	11/8/13	12:31	2.11	0.048	5.9	0.000118	72.3	675	747.348
YNP6-10D	11/8/13	12:34	2.62	0.059	7.3	0.000147	89.7	675	764.667
YNP6-11	11/8/13	12:50	1.51	0.034	4.2	0.000084	51.6	675	726.602
YNP6-12	11/8/13	13:05	1.30	0.029	3.6	0.000073	44.4	675	719.404
YNP7-1	11/8/13	13:21	1.28	0.029	3.6	0.000072	44.0	675	718.985
YNP7-2	11/8/13	13:36	1.23	0.028	3.5	0.000069	42.2	675	717.174
YNP7-3	11/8/13	13:49	1.15	0.026	3.2	0.000064	39.4	675	714.381
YNP7-4	11/8/13	14:07	1.50	0.034	4.2	0.000084	51.3	675	726.288
YNP7-5	11/8/13	14:24	1.72	0.039	4.8	0.000097	59.0	675	734.046
YNP7-5D	11/8/13	14:27	1.56	0.036	4.4	0.000088	53.6	675	728.585
YNP7-6	11/8/13	14:40	1.66	0.038	4.7	0.000093	57.1	675	732.052

Eq. 1: Vapor fraction, y

T_o	T_f	H_o	H_l	H_v	y
165	92	696.58	389	2664	0.1352

Eqs 2-5: Application of partition coefficient, B

T_o	y	log B	B	C_o/C_l
165	0.135	2.96	906.78	123.46

Water vapor pressure at 165 ^{o}C (Plummer an d Busenberg, 2000)			
Temp (^{o}C)	**Temp (K)**	**PH_2O (atm)**	**PH_2O (kPa)**
165	438.15	6.66	674.65

Henry's coefficient (Kh; Harvey, 1996)		
Temp (^{o}C)	**Temp (K)**	**Kh (MPa/mol fr)**
165	438	610.84

Additional references

Harvey, A.H., 1996, Semiempirical correlation for Henry's constants over large temperature ranges: AIChE Journal v. 42, p. 1491-1494.

Plummer, L.N. and Busenberg, E., 2000. Chlorofluorocarbons. In: Cook, P., Herczeg, A.L. (Eds.), Environmental Tracers in Subsurface Hydrology, 441-478. Boston: Kluwer Academic Publishers.