UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

Tabulation of N_2, O_2, CO_2, and He Concentrations in Soil Gases Collected Regularly for 13 Months at a Site on the Summit of Kilauea Volcano

By M.E. Hinkle

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ABSTRACT

Concentrations of N_2, O_2, CO_2, and He were measured in soil gases collected regularly for 13 months from a probe emplaced in the ground at the summit of Kilauea Volcano, Hawaii. Soil and air temperatures, percent relative humidity, barometric pressure, and rainfall were also monitored. Sampling and analysis of the soil gases are described and measurements of gas concentrations and meteorological parameters are listed. Rain had a larger impact than any other parameter on concentrations of the soil gases. Gas concentrations increased slowly during the short intervals between rains, but decreased rapidly with the onset of heavy rain.

INTRODUCTION

Measurement of concentrations of N_2, O_2, CO_2, and He in soil gases and meteorological parameters has been monitored on a long-term basis at several sites within the United States (Klusman and Jaacks, 1987; Hinkle, 1988; Hinkle and Ryder, 1988; Hinkle and Dennen, 1989). The purpose of these studies has been to better understand the effects of environmental conditions on concentrations of soil gas components that are often used for geochemical exploration for mineral and geothermal resources.

Results of these long-term monitoring studies indicate that soil moisture and soil and air temperatures have the greatest impact on soil-gas concentrations. High moisture content tends to either flush gases from the soil pores or to dissolve the gases; the effect in both cases is decreased concentration of gases in the soil. Increased concentrations of soil-gas CO_2 generally occur with increased soil temperatures in summer, whereas higher soil temperatures generally coincide with decreased concentrations of He (Hinkle and Ryder, 1987, 1988; Reimer, 1979, 1980).

The summit area of Kilauea Volcano was chosen as the site for a long-term monitoring study in a humid environment. Kilauea summit normally receives about 120 - 160 cm annual rainfall, with trace amounts of rain (about 0.01 cm) received almost daily during much of the year and up to several cm received daily during seasonal storms. In addition, the summit area is cool throughout the year with a mean air temperature of about 14 °C. Therefore, Kilauea summit provides a different environment for soil gas monitoring than the areas previously studied.

The site selected for monitoring was located close to the Uwekahuna vault, about 0.5 km northwest of the Hawaii Volcano Observatory. Personnel from the Observatory measure rainfall at the vault daily and were available to supervise data collection at the site.

SAMPLE COLLECTION AND ANALYSIS

Soil-gas samples were collected from a hollow probe driven 0.75 m into the ground. The hollow probe used in this study was described by Reimer and Bowles (1979) and has been widely used for collecting soil-gas samples. The probe was driven into the ground by means of a sliding hammer attached to the shaft of the probe. After it was driven into the ground, the probe was fitted with an airtight cap and septum for withdrawal of the soil-gas

sample. A PVC pipe was placed over the probe and cap, and the pipe was covered with an inverted plastic beaker to protect the probe from the weather. The probe was left in place for the duration of the study.

Before removal of the first sample, 10 ml of air were withdrawn from the probe to remove air introduced when the probe was emplaced in the ground; 10 ml of air were also removed from the probe whenever the rubber septum was changed. All soil-gas samples, except those of the first day, had equilibrated for a minimum of 24 hours before collection. Samples were collected from the hollow probe by inserting the needle of a syringe through the septum in the cap and withdrawing 10 ml of the soil gas. The soil-gas samples were transferred to 5-ml evacuated blood sampling vials for storage by inserting the needle of the syringe containing the gas sample through the rubber cap of the evacuated vial and allowing the sample in the syringe to be drawn inside. The needle hole was covered with silicone glue. Soil-gas samples can be stored in these evacuated vials for as long as 2 months without leakage (Hinkle and Kilburn, 1979).

Samples were collected and meteorology measurements were made daily, except weekends and holidays. Most of the samples were collected between 6:00-8:00 a.m. A total of 283 samples were collected during the period from February 2, 1989 through March 30, 1990.

Barometric pressure was measured by a barometer located inside the Hawaii Volcano Observatory. Air temperature, relative humidity, and rainfall were measured at the Uwekahuna vault. Surficial soil temperature was measured by a metal dial-type thermometer located next to the probe; the tip of the thermometer stem was buried at a depth of 20 cm.

Gas in the vials was removed by injecting 5 ml of air (equal to the volume of the vial) into the vial and removing the mixture of air and soil gas. The samples were analyzed for He using mass spectrometry (Reimer and Denton, 1978). Standard samples of air containing known concentrations of He were analyzed several times per day to ensure stability of the instrument. Concentrations of He were measured as differences compared to the concentration of He in air; these differences were positive or negative, depending on whether the sample concentration was above or below the concentration of He in air (5,240 parts per billion) (Glueckhauf, 1946; Oliver and others, 1984). The reproducibility of measurement was 10 ppb above or below the concentration of He in air. The tubes used for sample storage were approximately 80 percent evacuated and contained a residual concentration of He that was introduced during the manufacturing process. The residual He was the same for all the tubes in each lot produced by the manufacturer and was measured and subtracted from the raw measurement of He in the soil gas.

Samples were analyzed for N_2, O_2, and CO_2 using gas chromatography; operating conditions for the gas chromatograph are shown in table 1. Concentrations of N_2, O_2, and CO_2 were measured compared to standard curves, and are reported as volume percents of the total gas sample. Standard samples containing known concentrations of the gases were analyzed several times per day to insure stability of the instrument.

DESCRIPTION OF THE DATA TABLES

Data from the analyses were entered into an IBM personal computer and stored on disks, using STATPAC programs developed for personal computers by Grundy and Miesch (1987). Data for all measurements obtained during the study include (table 2): date of sample collection, number of days since start of sample collection (day 1 = January 1, 1989), soil temperature (°C), air temperature (°C), relative humidity (%), rainfall (cm), barometric pressure (cm), and volume/volume concentrations of N_2 (%), O_2 (%), CO_2 (%), and He (ppb). The letter "B" indicates that no analysis was performed for that particular parameter.

Minimum, maximum, and mean values for all the variables are listed in table 3. These values were calculated using only the unqualified data; that is, no "B" values were used in the computations. Plots of the data (figs. 1-7) show the daily measurements of the variables during the course of the study.

DISCUSSION OF THE RESULTS

Both soil and air temperatures varied seasonally (figs. 1 and 2). However, seasonal temperature variations apparently did not affect concentrations of CO_2 or He, in contrast to previous studies of seasonal changes. Barometric pressure and relative humidity did not affect any gas concentrations.

Rain appeared to have a large impact on soil gas concentrations (figs. 3-7). Concentrations of all gases were observed to increase slowly during the short time intervals of less than about 0.5 cm rain. However, gas concentrations dropped abruptly if 2 cm or more rain fell suddenly; concentrations decreased slowly when 0.5 - 1 cm of rain fell steadily for several days.

Concentrations of CO_2 were much higher during the first few days of the study than during the rest of the study. The reason for this difference is not known. It is possible that emplacement of the probe disturbed the soil sufficiently to create channelways that permitted rain to easily trickle down to the tip of the probe. It was impossible to remove soil gas samples from the probe when rains were heavy, however, this fact may be related more to the quantity of rain than to channelways through the soil. The soil at the monitoring site was sandy with less than 0.5% organic content--conditions that generally are not conducive to channel formation.

Concentrations of He increased gradually throughout the study. The reason for this increase is not known, but might be related to outgassing of light gases by the volcano. This hypothesis would require the addition of another light gas such as H_2 to the gases monitored and require a much longer monitoring time than 1 year.

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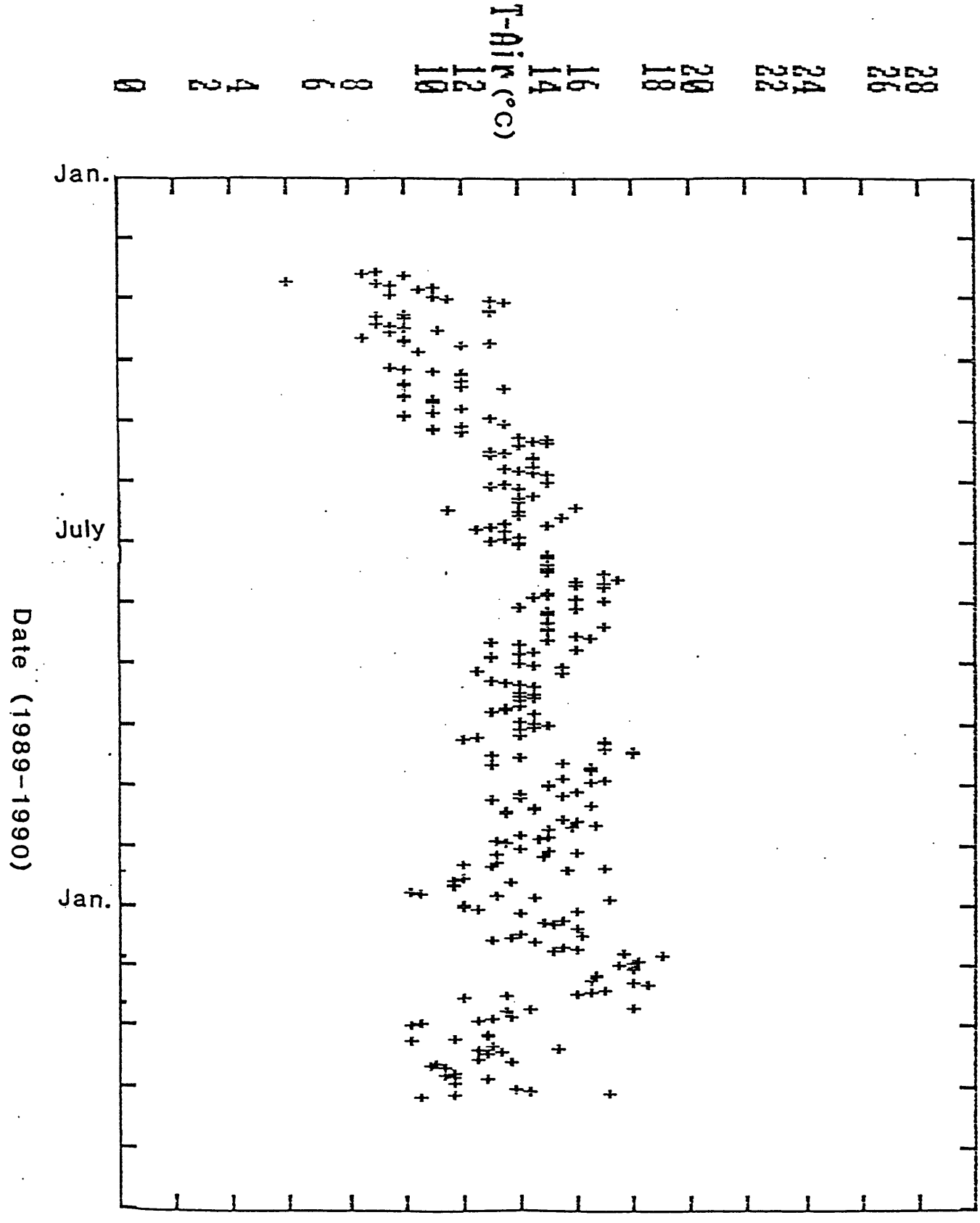

Figure 1--Air temperatures

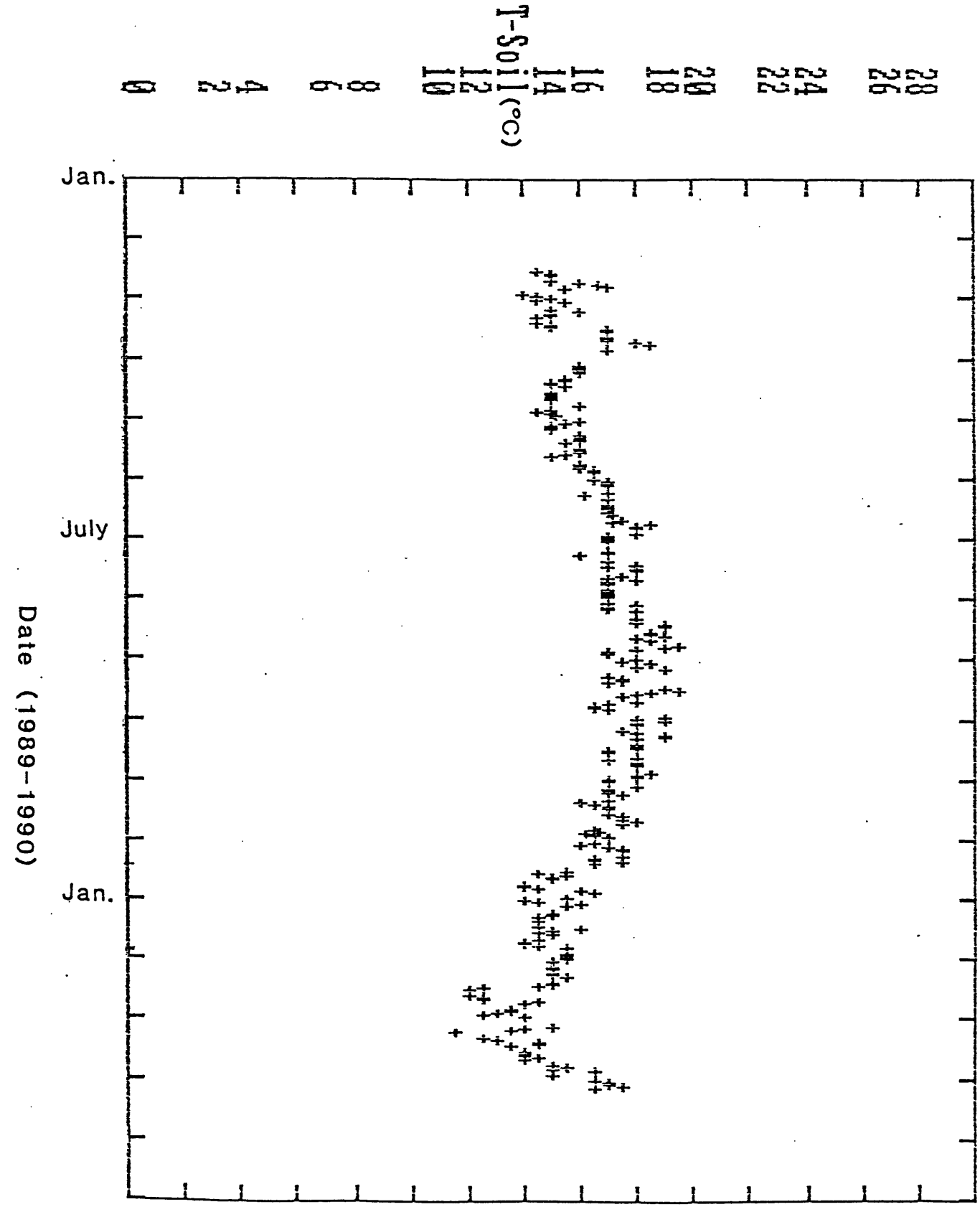

Figure 2.--Soil temperatures

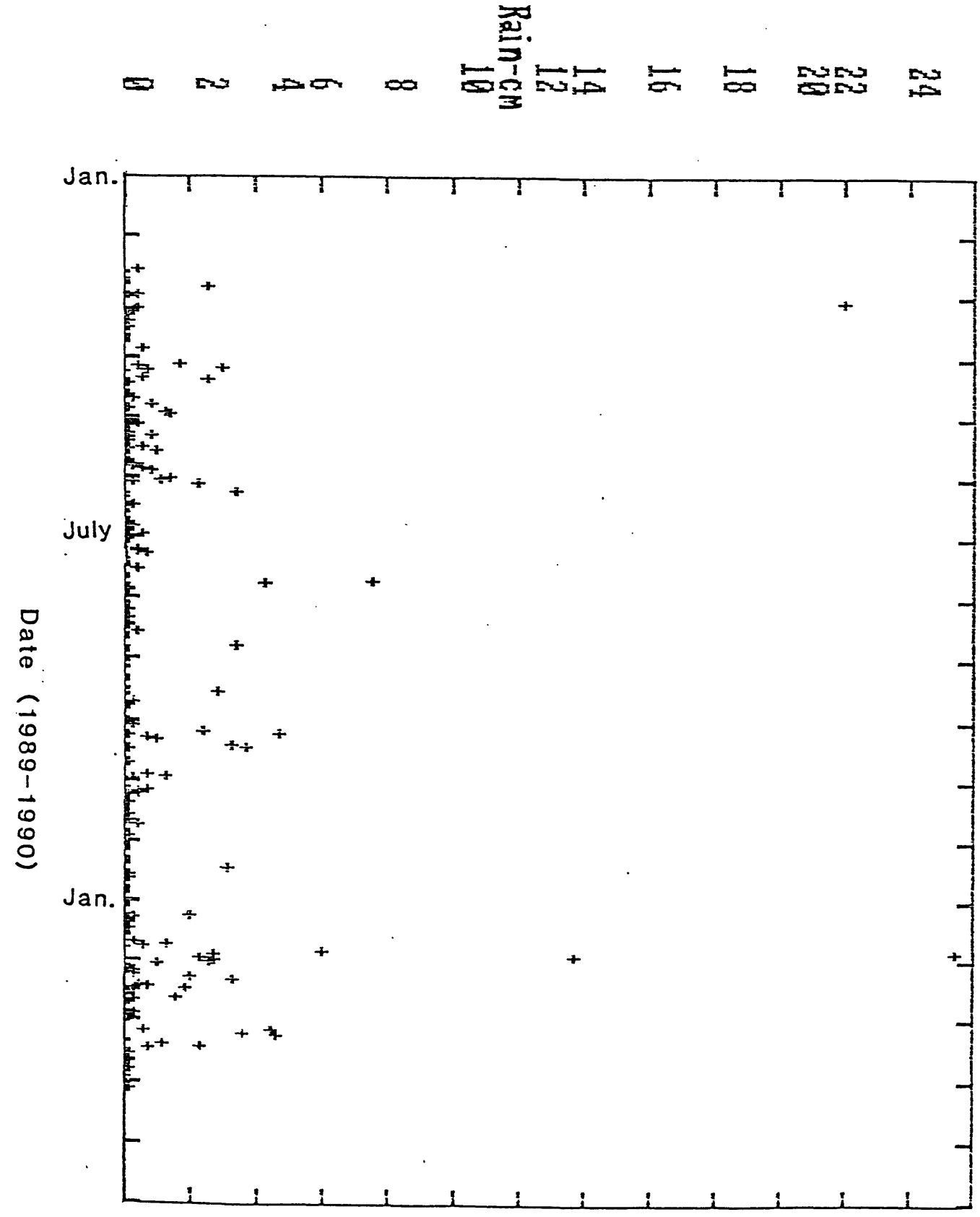

Figure 3.--Rainfall

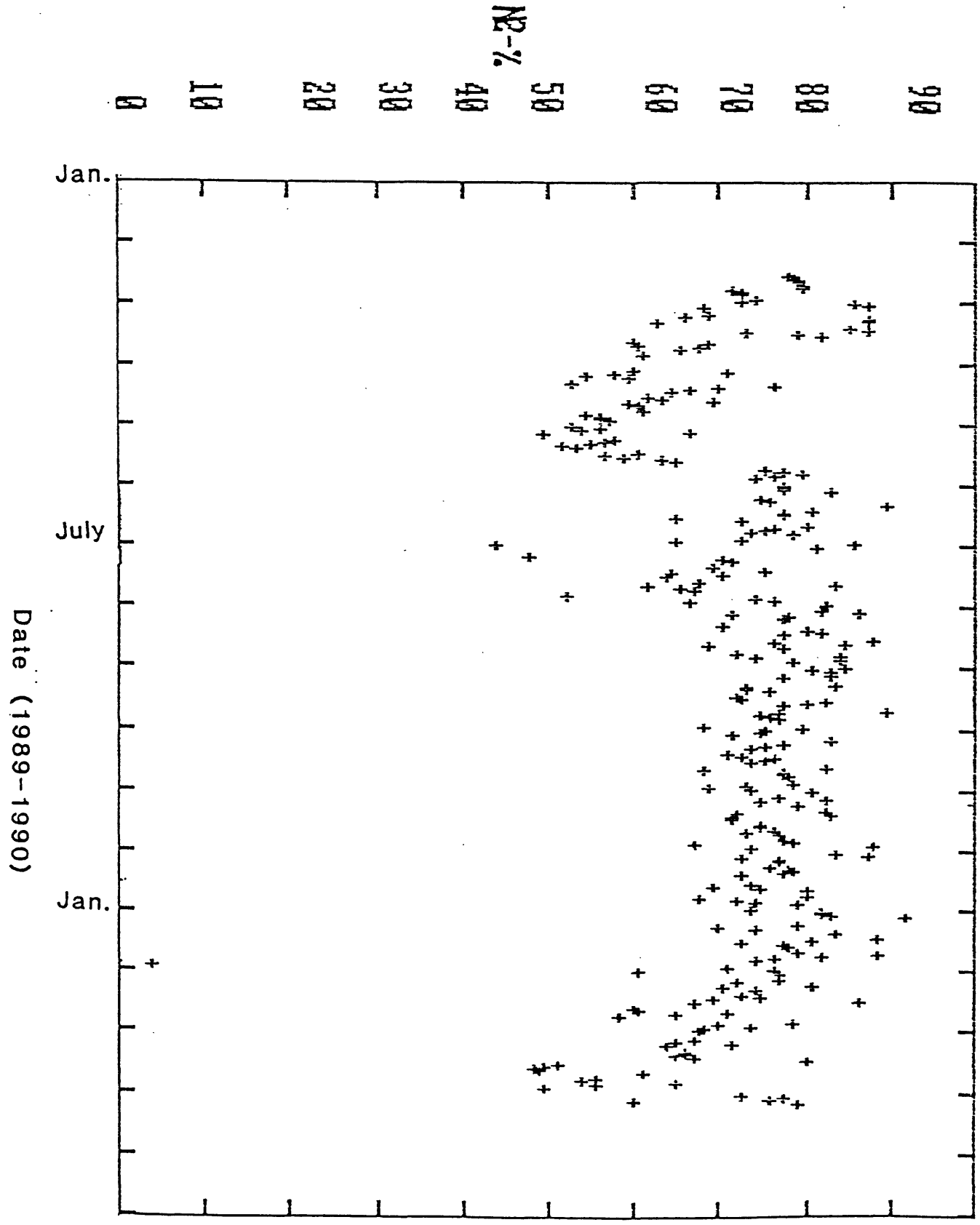

Figure 4.--Nitrogen concentrations

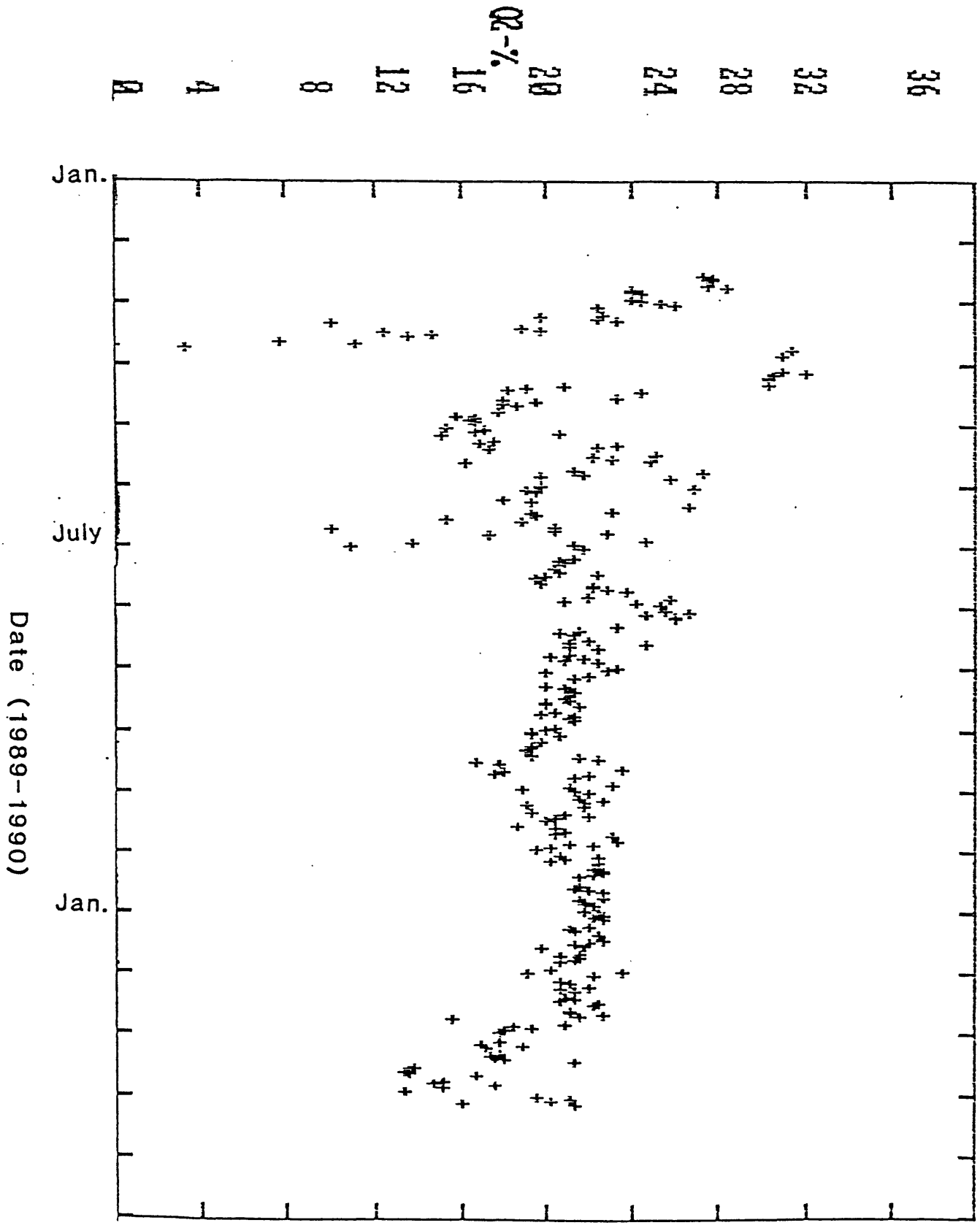

Figure 5.--Oxygen concentrations

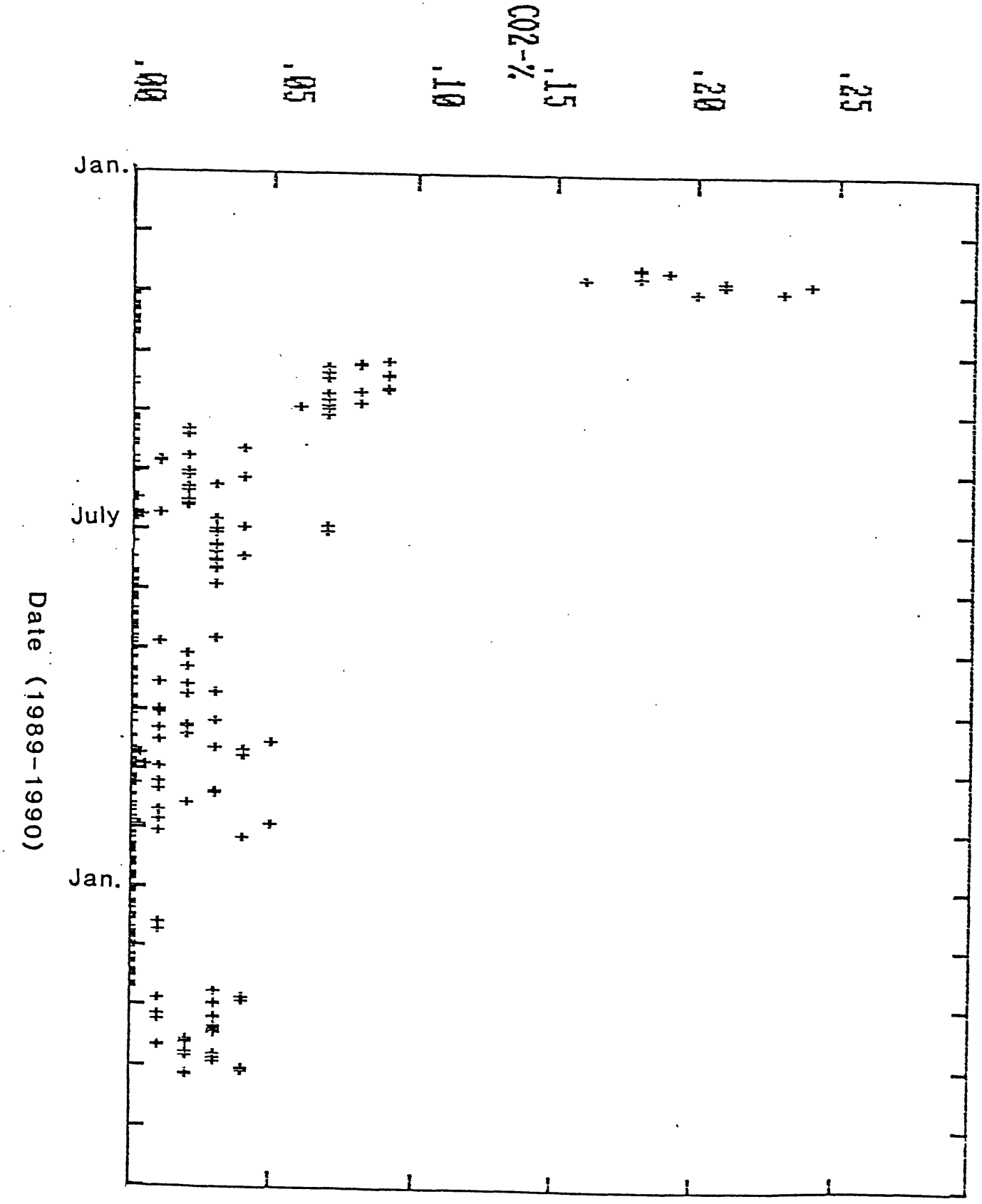

Figure 6.--Carbon dioxide concentrations

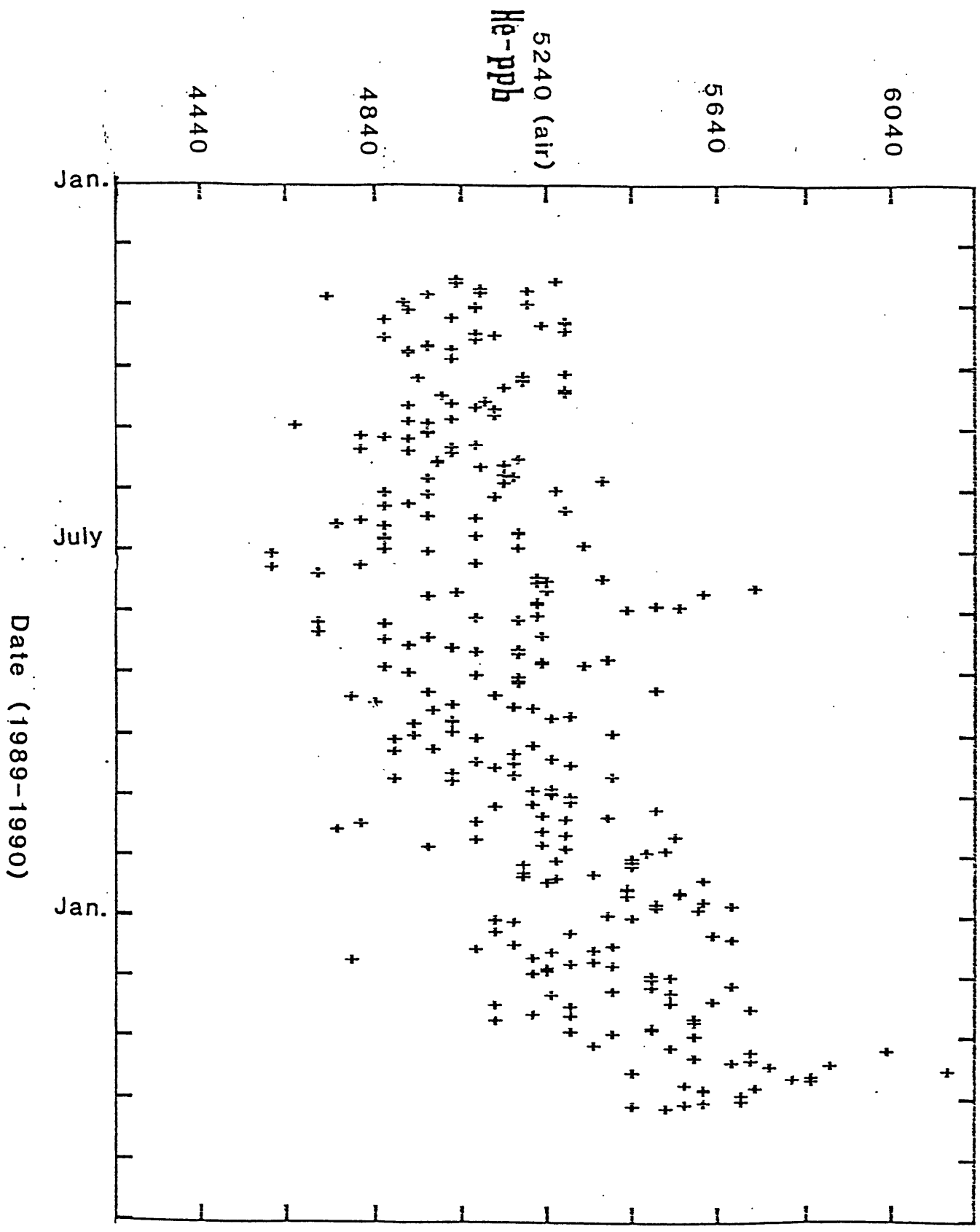

Figure 7.--Helium concentrations

Table 1. Operating conditions for the gas chromatograph.

Type of gas chromatograph	Carle AGC-100
Detector	thermistor detector
Lower limit of detection	1% N2 or O2, .03% CO2
Reproducibility	+/- 5%
Column	concentric stainless steel, outer column 72 in x 1/4 in molecular sieve inner column 72 in x 1/8 in porapak mixture (Alltech Associates, Deerfield, IL)
Carrier gas	helium at 90 mL/minute
Temperature	column: 70 C detector: "low" mode

Table 2. Soil Gas Concentrations and Meteorology

Date	Day	T-Soil	T-Air	%RelHum	Rain-cm	B.P.-cm	N2-%	O2-%	CO2-%	He-ppb
21589	46	14.5	9.0	95.0	0.46	75.57	77.9	27.2	0.18	5026
21689	47	15.0	8.5	88.0	0.00	75.69	78.8	27.8	0.18	5258
21789	48	15.0	10.0	95.0	0.00	75.69	79.0	27.6	0.19	5026
22089	51	15.0	6.0	41.0	0.00	75.54	79.4	27.5	0.18	5084
22189	52	16.0	9.0	72.0	0.00	75.69	79.5	28.3	0.16	5200
22289	53	16.6	9.6	88.0	0.03	75.57	71.2	23.9	0.21	5084
22389	54	17.0	11.0	100.0	0.01	75.69	72.3	23.9	0.24	4968
22489	55	15.5	10.5	100.0	2.57	75.67	72.7	24.3	0.21	4736
22789	58	14.0	9.5	87.5	0.05	75.23	74.3	23.9	0.23	4910
22889	59	14.5	11.0	100.0	0.36	75.18	72.8	24.5	0.20	5200
30189	60	15.0	11.6	100.0	0.05	75.18	85.7	25.2	B	5072
30289	61	14.5	13.0	100.0	0.00	75.23	87.2	26.0	B	5072
30389	62	15.5	13.5	100.0	21.97	75.23	68.1	22.5	B	4916
30689	65	15.0	13.0	100.0	0.43	75.69	68.9	22.6	B	5020
30789	66	16.0	13.0	100.0	0.23	75.64	65.7	19.8	B	4864
30889	67	15.0	10.0	100.0	0.08	75.49	87.2	22.4	B	5280
30989	68	15.0	9.0	80.0	0.00	75.44	87.2	23.4	B	5280
31089	69	14.5	10.0	100.0	0.08	75.44	62.7	10.1	B	5228
31389	72	14.5	9.0	97.0	0.10	75.74	85.1	18.9	B	5280
31489	73	15.0	9.5	68.0	0.00	75.67	87.2	19.8	B	5072
31589	74	15.0	10.0	70.0	0.00	75.59	73.2	12.6	B	5124
31689	75	17.0	11.2	100.0	0.13	75.49	79.2	14.7	B	4864
31789	76	17.0	9.5	90.0	0.00	75.49	81.7	13.6	B	5072
32089	79	17.0	8.5	70.0	0.00	75.64	59.8	7.6	B	4968
32189	80	17.0	10.0	75.0	0.00	75.74	68.7	11.2	B	4968
32289	81	17.0	10.0	58.0	0.00	75.69	60.3	0.1	B	5020
32389	82	18.0	13.0	32.0	0.00	75.64	67.4	3.3	B	4916
32489	83	18.5	12.0	79.0	0.00	75.69	65.3	31.4	0.63	4916
32789	86	17.0	10.5	100.0	0.64	75.64	60.8	30.9	0.64	5020
40389	93	16.0	9.5	95.0	1.70	75.44	59.9	30.9	0.61	5280
40489	94	16.0	10.0	88.0	0.41	75.39	71.1	32.1	0.09	5188
40589	95	16.0	11.0	100.0	2.97	75.34	57.5	30.6	0.08	4948
40689	96	16.0	12.0	88.0	0.66	75.41	54.3	30.4	0.08	5188
40789	97	16.0	12.0	97.0	0.05	75.41	59.4	30.4	0.07	5188
41089	100	15.5	12.0	100.0	0.51	75.44	52.6	30.3	0.07	5140
41189	101	15.5	10.0	100.0	2.54	75.59	76.1	20.9	0.09	5284
41289	102	15.0	10.0	73.0	0.03	75.54	69.9	19.2	0.09	5284
41389	103	15.0	12.0	100.0	0.13	75.54	66.6	18.2	0.07	5284
41489	104	15.5	13.5	95.0	0.01	75.49	64.5	24.4	0.00	4996
41789	107	15.0	10.0	98.0	0.00	75.49	61.7	23.4	0.00	5092
41889	108	15.0	10.0	97.0	0.00	75.59	63.4	18.0	0.09	5020
41989	109	15.0	11.0	85.0	0.00	75.44	69.2	19.5	0.09	4916
42089	110	15.0	11.0	100.0	0.01	75.62	59.2	18.1	0.08	5072
42189	111	15.0	11.0	95.0	0.23	75.64	60.6	18.7	0.07	5124
42489	114	16.0	12.0	92.0	0.84	75.67	61.0	17.8	0.07	5124
42589	115	15.0	11.0	93.0	0.08	75.49	54.2	15.9	0.08	5020
42689	116	14.5	10.0	64.0	0.00	75.46	56.2	16.6	0.07	4916
42789	117	15.0	10.0	97.0	1.35	75.46	55.8	16.4	0.06	4968
42889	118	15.2	13.0	100.0	1.37	75.46	57.0	16.8	0.07	4656
50189	121	16.0	13.5	100.0	0.13	75.49	52.6	15.4	0.07	4968
50289	122	15.5	12.0	100.0	0.23	75.49	56.0	17.1	0.00	4968

Table 2. Soil Gas Concentrations and Meteorology

Date	Day	T-Soil	T-Air	%RelHum	Rain-cm	B.P.-cm	N2-%	O2-%	CO2-%	He-ppb
50389	123	15.0	11.0	92.0	0.36	75.51	53.7	16.7	0.00	4812
50489	124	15.0	11.0	95.0	0.08	75.64	66.7	20.6	0.00	4864
50589	125	15.0	12.0	95.0	0.00	75.62	49.2	15.1	0.00	4916
50889	128	16.0	14.0	100.0	0.18	75.77	57.9	17.5	0.00	5072
50989	129	16.0	15.0	100.0	0.84	75.74	56.8	16.9	0.02	5020
51089	130	16.0	14.5	100.0	0.08	75.74	54.7	23.2	0.00	4812
51189	131	16.0	15.0	100.0	0.03	75.74	51.6	22.5	0.00	4916
51289	132	15.5	14.0	77.0	0.13	75.74	53.3	17.4	0.02	5020
51589	135	16.0	13.0	82.0	0.56	75.74	60.2	25.1	0.00	5176
51689	136	16.0	13.5	75.5	0.13	75.77	56.7	22.3	0.00	4982
51789	137	16.0	13.0	86.0	0.94	75.69	58.8	23.1	0.00	4982
51889	138	15.5	14.5	64.0	0.00	75.64	63.2	24.8	0.00	5142
51989	139	15.0	14.5	46.0	0.00	75.64	64.9	16.3	0.04	5084
52289	142	16.0	14.5	100.0	0.20	75.74	75.2	21.4	0.02	5142
52389	143	16.0	13.5	95.0	0.25	75.79	77.7	27.2	0.00	5164
52489	144	16.0	14.0	95.0	0.23	75.79	79.7	21.8	0.01	4968
52589	145	16.5	14.5	89.0	0.61	75.84	76.6	19.7	0.01	5374
52689	146	16.5	15.0	70.0	0.81	75.79	74.4	25.8	0.00	5142
53089	150	16.5	15.0	100.0	1.42	75.79	77.7	19.7	0.02	5258
53189	151	17.0	13.5	100.0	1.14	75.74	77.7	26.6	0.00	4864
60189	152	17.0	13.0	91.0	0.25	75.72	77.5	19.2	0.02	4968
60289	153	17.0	14.0	100.0	2.26	75.74	82.9	19.6	0.04	5124
60689	157	17.0	14.5	100.0	3.48	75.79	75.0	18.0	0.03	4916
60789	158	16.2	14.0	83.0	0.01	75.74	76.0	19.4	0.02	4864
60989	160	17.0	14.0	95.0	0.00	75.84	89.6	26.5	0.02	5280
61289	163	17.0	16.0	88.0	0.00	75.74	80.9	23.0	.00	4968
61389	164	17.0	11.5	94.0	0.30	75.84	77.3	19.4	.00	5072
61489	165	17.0	14.0	92.0	0.00	75.79	77.7	19.5	0.02	4812
61589	166	17.0	14.0	100.0	0.03	75.79	64.7	15.4	0.02	4760
61989	167	17.2	15.5	82.5	0.00	75.84	72.7	18.9	0.02	4864
61989	170	17.5	13.5	92.0	0.00	75.82	80.4	20.5	.00	5176
62089	171	17.2	15.0	40.0	0.00	75.74	76.3	10.1	0.01	5176
62189	172	18.5	13.0	100.0	0.18	75.69	75.1	20.5	.00	5072
62289	173	18.0	12.5	99.0	0.05	75.69	73.9	22.9	.00	4864
62389	174	18.0	13.5	100.0	0.23	75.69	78.6	17.4	0.03	4864
62689	177	18.0	14.0	95.0	0.20	75.69	72.5	24.7	0.07	5332
62789	178	17.0	13.5	93.0	0.61	75.79	64.7	13.9	0.04	5176
62889	179	17.0	13.0	91.0	0.03	75.74	85.8	21.4	0.03	4864
62989	180	17.0	14.0	91.5	0.00	75.74	43.9	11.0	0.07	4968
63089	181	17.0	14.0	86.0	0.15	75.74	81.3	21.7	0.03	4604
70589	186	17.0	15.0	100.0	0.48	75.79	47.7	21.3	0.00	5072
70689	187	17.0	15.0	96.0	0.41	75.82	70.1	20.6	0.03	4812
70789	188	16.0	15.0	58.0	0.69	75.77	71.7	20.8	0.03	4604
71089	191	17.0	15.0	100.0	0.03	75.74	69.3	20.4	0.03	4708
71189	192	18.0	15.0	100.0	0.00	75.74	75.5	20.6	0.04	5214
71289	193	17.0	15.0	91.5	0.03	75.74	64.5	22.4	0.00	5374
71389	194	18.0	15.0	94.0	0.05	75.72	70.5	20.1	0.03	B
71489	195	18.0	17.0	100.0	0.46	75.72	63.6	19.6	0.03	5214
71789	198	17.5	17.5	71.0	0.03	75.84	67.8	19.8	0.03	5722
71889	199	17.0	16.0	52.0	0.00	75.69	83.4	22.1	0.03	B
71989	200	18.0	17.0	100.0	0.00	75.69	61.5	22.2	0.00	5026

Table 2. Soil Gas Concentrations and Meteorology

Date	Day	T-Soil	T-Air	%RelHum	Rain-cm	B.P.-cm	N2-%	O2-%	CO2-%	He-ppb
72089	201	17.0	16.0	100.0	7.62	75.82	65.6	22.9	0.00	5606
72189	202	17.0	17.0	88.0	4.32	75.84	67.2	23.7	0.00	4968
72489	205	17.0	15.0	80.0	0.08	75.90	52.3	21.9	0.00	5214
72589	206	17.0	15.0	100.0	0.18	76.10	74.3	25.8	0.00	5214
72689	207	17.0	14.5	100.0	0.05	74.68	76.4	20.9	0.03	5490
72789	208	17.0	16.0	79.0	0.03	75.92	66.4	24.2	0.00	5548
72889	209	17.0	17.0	71.0	0.00	75.92	82.6	25.2	0.00	5432
73189	212	17.0	14.0	81.0	0.03	75.84	82.0	25.4	0.00	5214
80189	213	18.0	16.0	49.0	0.03	75.84	86.3	26.5	0.00	5072
80289	214	17.0	15.0	100.0	0.05	75.84	71.6	24.7	0.00	5176
80389	215	17.0	15.0	70.0	0.01	75.74	77.8	26.0	0.00	4708
80489	216	18.0	15.0	90.0	0.13	75.79	77.2	26.0	0.00	4864
80789	219	18.0	15.0	98.5	0.13	75.90	70.1	23.4	0.00	4708
80989	221	18.0	17.0	45.0	0.00	75.72	80.1	21.6	0.00	5228
81089	222	19.0	15.0	100.0	0.20	75.74	82.1	20.6	0.00	4968
81189	223	19.0	15.0	84.0	0.18	75.84	77.2	21.4	0.00	4864
81489	226	18.5	16.0	100.0	0.46	75.84	87.9	22.0	0.00	4916
81589	227	18.5	16.5	95.0	0.01	75.84	76.5	21.2	0.00	5020
81689	228	19.0	15.0	87.0	0.05	75.74	84.8	24.7	0.00	5176
81789	229	18.0	13.0	97.0	0.00	75.72	68.7	21.2	0.00	5072
81889	230	18.5	14.0	86.0	0.00	75.74	77.2	22.5	0.00	5176
82189	233	19.5	16.0	100.0	3.48	75.90	72.0	21.2	0.00	5384
82289	234	19.0	14.5	87.0	0.03	75.77	84.1	20.3	0.03	5228
82389	235	18.0	14.0	76.0	0.00	75.74	74.4	21.7	0.00	5228
82489	236	17.0	13.0	76.0	0.01	75.79	84.0	20.9	0.01	5332
82589	237	17.0	13.0	72.0	0.00	75.82	78.3	22.5	0.00	4864
82889	240	18.0	14.0	96.0	0.05	75.74	84.6	23.4	0.00	4916
82989	241	17.5	14.5	66.0	0.01	75.74	80.9	22.8	0.00	5072
83089	242	18.5	15.5	99.0	0.00	75.74	83.0	19.9	0.02	5176
83189	243	18.0	12.5	86.0	0.00	75.72	82.9	21.9	0.00	5176
90189	244	19.0	15.5	78.0	0.00	75.69	77.6	21.4	0.00	5176
90589	248	17.0	13.0	99.0	0.05	75.69	83.6	20.0	0.02	5488
90689	249	17.5	13.5	77.0	0.00	75.69	72.9	20.9	0.00	4968
90789	250	17.5	14.0	68.0	0.00	75.72	72.9	21.1	0.00	5116
90889	251	17.0	14.5	81.0	0.01	75.74	75.8	21.3	0.00	4794
91189	254	19.0	14.0	78.0	0.00	75.69	72.2	20.8	0.00	4840
91289	255	19.5	14.5	48.0	0.00	75.67	72.7	21.0	0.00	5024
91389	256	18.5	14.0	91.0	2.82	75.79	82.3	20.1	0.01	5162
91489	257	18.0	14.5	60.0	0.01	75.72	80.0	19.9	0.02	5208
91589	258	17.5	14.0	98.0	0.01	75.74	77.5	21.6	0.00	4978
91889	261	18.0	14.0	98.0	0.25	75.90	89.7	20.5	0.03	5300
91989	262	17.0	13.5	88.0	0.05	75.84	77.0	19.8	0.02	5254
92089	263	16.5	13.5	96.0	0.08	75.82	74.9	21.3	0.00	5024
92189	264	16.5	13.0	83.0	0.01	75.79	75.9	21.1	0.00	5024
92289	265	17.0	14.5	79.0	0.00	75.77	77.1	21.3	0.00	4932
92589	268	19.0	14.0	94.0	0.00	75.74	68.4	20.4	0.00	5024
92689	269	18.0	14.5	89.0	0.00	75.84	79.7	20.0	0.01	5392
92789	270	19.0	15.0	100.0	0.05	75.79	75.1	19.4	0.01	4932
92889	271	18.0	14.5	92.0	0.00	75.72	74.5	19.3	0.01	5070
92989	272	18.0	14.0	100.0	0.25	75.74	71.7	20.7	0.00	4886
100289	275	17.5	14.0	87.0	2.39	76.69	83.2	19.8	0.03	5208

Table 2. Soil Gas Concentrations and Meteorology

Date	Day	T-Soil	T-Air	%RelHum	Rain-cm	B.P.-cm	N2-%	O2-%	CO2-%	He-ppb
100389	276	18.0	12.5	100.0	4.75	75.84	0.0	0.0	0.00	240
100489	277	19.0	12.0	100.0	0.15	75.84	77.7	19.4	0.02	4978
100589	278	19.0	17.0	100.0	0.76	75.74	75.5	19.3	0.02	4886
100689	279	18.0	17.0	100.0	1.02	75.69	73.8	19.1	0.01	5162
100989	282	18.0	17.0	100.0	3.23	75.69	71.1	19.3	0.02	5254
101089	283	18.0	18.0	100.0	3.78	75.90	72.3	21.6	0.00	5070
101189	284	18.0	18.0	100.0	0.10	75.95	76.1	22.4	0.00	5162
101289	285	17.0	13.0	87.0	0.05	75.84	75.3	16.8	0.01	5300
101389	286	17.0	14.0	80.0	0.00	75.77	73.9	17.8	0.05	5116
101689	289	18.0	15.5	99.0	0.03	75.74	82.5	23.5	0.03	5024
101789	290	17.0	13.0	84.0	0.00	75.74	68.2	18.0	0.04	5162
101889	291	18.0	16.5	100.0	0.18	75.69	77.4	17.6	.00	5392
101989	292	18.0	16.5	91.0	0.03	75.84	77.3	21.9	.00	4886
102089	293	18.0	16.5	79.0	0.03	75.82	77.8	21.3	0.04	5024
102389	296	18.5	15.5	100.0	0.71	76.00	78.7	23.1	.00	5254
102489	297	18.0	17.0	88.0	1.35	76.00	72.9	21.1	0.01	5208
102589	298	18.0	16.5	99.0	0.25	75.90	68.7	18.9	0.01	5254
102689	299	17.0	15.0	99.9	0.05	75.79	73.5	21.4	0.00	5254
102789	300	17.0	15.0	87.0	0.05	75.82	80.8	22.0	0.00	5300
103089	303	18.0	16.0	96.0	0.03	75.84	76.8	21.6	0.00	5300
103189	304	17.0	14.0	89.0	0.66	75.82	82.2	22.6	0.00	5208
110189	305	17.0	15.5	100.0	0.38	75.74	75.0	21.7	0.00	5116
110289	306	17.0	14.0	100.0	0.36	75.69	100.0	19.2	0.01	6528
110389	307	17.5	13.0	54.0	0.10	75.74	79.1	21.7	.00	5488
110689	310	17.0	16.5	88.0	0.03	75.97	82.2	19.3	0.01	5228
110789	311	16.0	14.5	55.0	0.20	75.87	71.9	20.9	0.03	5384
110889	312	16.5	14.5	94.0	0.01	75.84	82.7	22.0	0.03	5280
110989	313	17.0	13.5	91.5	0.03	75.82	71.6	20.5	0.00	5072
111089	314	17.0	13.5	96.0	0.01	75.82	71.2	19.9	0.00	4812
111389	317	17.0	15.5	55.0	0.08	75.82	74.6	18.6	0.02	4760
111489	318	17.5	16.0	84.9	0.01	75.82	74.9	20.5	0.00	5228
111589	319	17.5	16.7	97.5	0.08	75.77	76.2	20.8	0.00	5280
111689	320	18.0	15.9	94.0	0.05	75.82	73.1	20.5	0.01	5540
111789	321	17.5	15.0	100.0	0.43	75.82	76.9	23.1	0.00	5072
112089	324	16.5	14.0	94.2	0.01	75.82	77.3	23.2	0.00	5228
112189	325	16.6	15.0	96.2	0.03	75.87	78.4	21.2	0.01	4968
112289	326	16.2	14.7	93.7	0.01	76.07	67.1	22.3	0.00	5280
112389	327	16.5	13.2	94.8	0.08	76.12	87.7	20.2	0.05	5518
112489	328	17.0	13.5	88.0	0.05	76.05	73.4	19.6	.00	5476
112789	331	16.5	14.0	76.0	0.01	75.97	83.6	20.7	0.01	5434
112889	332	16.0	15.0	81.5	0.01	76.02	87.3	22.5	0.00	5266
112989	333	17.0	16.0	97.0	0.01	75.97	72.6	20.9	0.00	5434
113089	334	17.5	13.2	72.0	0.01	75.92	76.8	20.2	0.04	5182
120189	335	17.5	14.9	83.0	0.03	76.02	76.7	22.5	0.00	5434
120489	338	17.5	13.2	94.2	0.03	75.97	76.0	22.2	0.00	5182
120589	339	16.5	12.0	77.0	0.03	75.92	77.9	22.6	0.00	5350
120689	340	16.5	13.0	89.0	0.01	75.90	78.4	22.6	0.00	5182
120789	341	17.5	17.0	100.0	0.03	75.92	77.4	22.1	0.00	5258
120889	342	16.5	15.7	97.0	0.05	75.97	72.3	21.6	0.00	5606
120989	343	B	B	100.0	3.10	B	B	B	B	B
121189	345	15.5	12.0	94.2	0.05	75.62	B	B	B	5432

Table 2. Soil Gas Concentrations and Meteorology

Date	Day	T-Soil	T-Air	%RelHum	Rain-cm	B.P.-cm	N2-%	O2-%	CO2-%	He-ppb
121289	346	14.5	11.7	85.0	0.08	75.62	73.9	21.5	0.00	5432
121389	347	15.5	13.7	85.0	0.03	75.67	69.1	21.3	0.00	5548
121489	348	15.0	11.7	93.8	0.18	75.67	74.9	21.9	0.00	5548
121589	349	15.0	11.7	91.0	0.03	75.72	80.3	22.7	0.00	5432
121889	352	14.0	10.2	95.0	0.03	75.87	80.1	22.6	0.00	5604
121989	353	14.0	10.5	22.2	0.03	75.90	67.5	21.6	0.00	5490
122089	354	14.5	13.2	32.5	0.00	75.92	71.9	21.7	0.00	5664
122189	355	16.0	14.5	100.0	0.03	75.97	74.0	21.8	0.00	5488
122289	356	16.5	17.2	99.0	0.03	75.97	79.3	22.3	0.00	5592
122589	359	15.5	12.0	60.0	0.01	76.05	73.9	21.8	0.00	5384
122689	360	14.0	12.0	74.5	0.01	76.02	82.1	22.5	0.00	5436
122789	361	14.5	12.5	71.0	0.03	76.00	81.6	22.7	0.00	5124
122889	362	16.0	16.0	75.2	0.01	75.97	82.8	22.3	0.00	5162
122989	363	15.5	14.0	67.0	0.00	75.95	91.9	22.6	0.00	6404
10290	367	15.0	15.5	84.0	1.98	76.02	79.1	21.9	0.00	5116
10390	368	15.0	14.9	100.0	0.33	76.07	69.7	21.0	0.00	5300
10490	369	14.5	15.2	96.5	0.10	76.05	74.2	21.4	0.00	5622
10590	370	14.5	16.0	72.0	0.10	76.12	83.4	22.4	0.00	5668
10890	373	14.5	14.0	82.5	0.08	76.02	88.4	22.6	0.00	5162
10990	374	16.0	16.2	96.8	0.01	76.07	81.0	22.0	0.00	5392
11090	375	15.0	13.7	100.0	0.03	76.07	72.3	21.3	0.00	5070
11190	376	14.5	13.0	90.0	0.01	76.02	77.7	21.7	0.00	5346
11290	377	15.0	14.5	100.0	0.05	76.12	77.8	19.7	0.01	5254
11590	380	14.5	15.5	57.0	0.28	75.74	79.2	21.5	0.00	5208
11690	381	14.0	16.0	93.0	1.32	75.82	88.7	20.7	0.01	4794
11790	382	14.0	15.2	64.0	0.64	75.74	81.8	21.6	0.00	5346
11890	383	14.5	17.7	87.0	0.05	75.72	76.2	21.3	0.00	5300
11990	384	15.5	19.0	100.0	6.05	75.84	74.4	20.7	0.00	5392
12090	385	B	B	100.0	25.40	B	B	B	B	B
12190	386	B	B	100.0	2.69	B	B	B	B	B
12290	387	15.5	18.2	100.0	13.72	75.84	71.3	20.2	0.00	5208
12390	388	15.5	18.0	100.0	2.34	75.82	71.1	20.3	0.00	5208
12490	389	15.5	17.5	100.0	2.72	75.77	76.1	23.5	0.00	5484
12590	390	15.5	18.0	100.0	2.51	75.82	60.6	19.2	0.00	5530
12690	391	15.0	18.0	100.0	1.07	75.92	76.8	22.1	0.00	5484
12990	394	15.0	16.7	100.0	0.15	76.10	76.9	20.7	0.00	5668
13090	395	15.0	16.7	96.5	0.23	76.02	72.2	21.1	0.00	5484
13190	396	15.0	16.5	80.0	0.28	76.10	80.8	21.9	0.00	5392
20190	397	15.0	18.0	100.0	2.01	76.17	70.5	20.6	0.00	5530
20290	398	15.5	18.5	100.0	3.23	76.20	74.4	21.3	0.00	5254
20590	401	15.0	17.0	100.0	0.38	76.28	72.7	20.9	0.00	5622
20690	402	15.0	16.5	100.0	0.69	76.33	74.6	21.4	0.00	5530
20790	403	14.5	16.0	100.0	1.88	76.33	69.1	20.6	0.00	5116
20890	404	12.5	13.5	89.0	0.33	76.38	86.3	22.4	0.00	5300
20990	405	12.0	12.0	46.0	0.10	72.14	67.2	22.1	0.00	5714
21290	408	12.0	B	100.0	1.60	B	60.0	21.1	0.00	5208
21390	409	12.5	B	B	0.30	B	60.6	21.2	0.00	5300
21490	410	12.5	18.0	B	0.05	B	70.8	22.6	0.00	5576
21590	411	14.5	14.4	98.0	0.05	B	64.9	21.6	0.00	5116
21690	412	14.0	13.5	83.0	0.01	B	58.5	15.6	0.03	5576
21990	415	13.5	13.7	98.0	0.01	B	78.6	20.8	0.04	5484

Table 2. Soil Gas Concentrations and Meteorology

Date	Day	T-Soil	T-Air	%RelHum	Rain-cm	B.P.-cm	N2-%	O2-%	CO2-%	He-ppb
22090	416	13.5	13.0	100.0	0.33	B	69.9	18.4	0.01	5484
22190	417	13.0	12.5	99.0	0.05	B	73.8	19.4	0.04	5300
22290	418	12.5	10.5	96.0	0.13	B	68.1	18.1	0.03	5392
22390	419	14.0	10.3	B	0.13	B	67.6	17.9	0.03	5576
22790	423	15.0	12.8	100.0	4.50	B	66.8	17.8	0.01	5346
22890	424	14.0	12.8	B	0.64	B	64.6	16.9	0.03	5530
30190	425	13.5	11.7	100.0	3.61	B	71.2	19.0	0.03	6036
30290	426	11.5	10.3	100.0	4.52	B	63.9	17.1	0.01	5714
30590	429	12.5	13.1	B	0.01	B	66.1	17.7	0.03	5576
30690	430	13.0	15.3	B	0.01	B	65.7	17.4	0.03	5714
30790	431	14.5	12.5	100.0	1.17	B	64.7	17.5	0.03	5668
30890	432	14.5	13.3	100.0	2.29	B	67.2	18.1	0.03	5898
30990	433	13.5	12.8	B	0.69	B	80.3	21.3	0.03	5760
31290	436	14.0	12.5	B	0.20	B	51.0	13.9	0.02	6174
31390	437	14.0	13.6	B	0.05	B	49.5	13.7	0.02	5438
31490	438	14.0	11.1	B	0.02	B	48.4	13.3	0.02	5852
31590	439	14.5	10.8	B	0.10	B	49.0	13.6	0.01	5806
31690	440	14.0	11.4	B	0.08	B	60.9	16.8	0.01	5852
31990	443	15.0	11.7	B	0.00	B	55.7	15.1	0.02	5560
32090	444	15.5	11.4	B	0.15	B	53.8	14.7	0.03	5728
32190	445	15.0	11.7	B	0.01	B	65.1	17.6	0.02	5602
32290	446	16.5	12.8	B	0.01	B	55.3	15.1	0.03	5602
32390	447	15.0	11.7	B	0.00	B	49.5	13.5	0.03	5686
32690	450	16.5	13.9	B	0.01	B	72.3	19.5	0.04	5686
32790	451	17.0	14.4	B	0.01	B	77.5	21.0	0.04	5602
32890	452	17.0	17.2	B	0.00	B	75.9	20.2	0.04	5560
32990	453	17.5	11.7	B	0.10	B	60.1	16.1	0.02	5434
33090	454	16.5	10.6	B	0.03	B	79.1	21.3	0.02	5518

Table 3. Basic statistics.

Variable	Minimum	Maximum	Mean
Soil Temperature (°C)	11.5	19.5	16.3 +/- 1.5
Air Temperature (°C)	6.0	19.0	13.9 +/- 2.2
Relative Humidity (%)	22.2	100.0	88.2 +/-14.7
Rainfall (cm)	0.0	25.4	0.5 +/- 1.3
Barometric Pressure (cm)	72.14	76.69	75.77 +/-0.32
N_2 (%)	0.0*	100.0	73.0 +/-10.2
O_2 (%)	0.0*	32.1	21.4 +/- 3.5
CO_2 (%)	0.0*	0.64	0.03 +/- 0.08
He (ppb)	0*	6530	5130 +/- 420

* Saturated ground prevented removal of soil gas samples.
Gas concentrations were assumed to be zero.