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ENVIRONMENTAL BASELINE MONITORING IN THE AREA OF GENERAL CRUDE OIL - DEPARTMENT OF ENERGY PLEASANT BAYOU NUMBER 2-- A GEOPRESSURED GEOTHERMAL TEST WELL--1979

by

Thomas C. Gustavson
Rory C. Howard
Douglas McGookey

INTRODUCTION AND TECHNICAL REPORT

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INTRODUCTION

A program to monitor baseline air and water quality, subsidence, microseismic activity, and noise in the vicinity of Brazoria County geopressured geothermal test wells, Pleasant Bayou #1 and #2, has been underway since March 1978 (fig. 1). The findings of certain parts of the work, including the results of an initial first-order leveling survey completed by Teledyne Geotronics, a preliminary noise survey completed by Radian Corporation, a preliminary microseismicity survey completed by Teledyne Geotech, and an archeological survey of the site completed by Texas A & M University have been reported earlier and will not be repeated here. The initial report on environmental baseline monitoring at the test well contained descriptions of baseline air and water quality, a noise survey, an inventory of microseismic activity, and a discussion of the installation of a liquid tilt meter (Gustavson, 1979). The following report continues the description of baseline air and water quality of the test well site, includes an inventory of microseismic activity during 1979 with interpretations of the origin of the events, and discusses the installation and monitoring of a liquid tilt meter at the test well site. In addition, a brief description of flooding at the test site is presented.

On the basis of analyses of geopressured geothermal resources by Bebout and others (1975a and b, 1976, 1978), a series of geothermal fairways were recognized within the Frio Formation along the Texas Gulf Coast. From the group of Frio Formation fairways, the Brazoria County fairway was determined to be the most suitable for testing because the permeabilities of the reservoir rocks containing the resource were higher here than the reservoir-rock permeabilities in all other known geothermal fairways in the Texas Gulf Coast. On this basis, the Department of Energy-General Crude Oil Corporation Pleasant Bayou #1 well was spudded in July 1978.

Drilling of Pleasant Bayou #1 continued through the latter half of 1978 and into 1979. As this well was nearing total depth of approximately 17,000 ft (5,150 m), the drill string became stuck in the hole. This and additional mechanical problems required that the hole be plugged back to approximately 8,400 ft (2,500 m). Pleasant Bayou #1 was then converted into a disposal well.

After the completion of Pleasant Bayou #1 as a disposal well, the drilling rig was moved approximately 500 ft (150 m) to the north, and Pleasant Bayou #2 was drilled to a depth of nearly 16,500 ft (5,030 m). This well was completed in early November 1979, and flow tested. Initial formation fluid had a salinity of 131,000 ppm. The first injectivity tests using produced water indicated that disposal rates of 13,000 BWPD (2,000 $m^3 d^{-1}$) at 0 psi (0 kg cm^2) and 35,000 BWPD (5,600 $m^3 d^{-1}$) at 700 psi (50 kg cm^{-2}) could be expected. Flow testing of the well continued through November and into December.

Concurrent with early geopressured geothermal resource analysis was a series of environmental studies to determine both the major environmental concerns and the areas along the coast of Texas that were most likely to be seriously affected by geopressured geothermal energy development (Gustavson and Kreitler, 1976; Gustavson and others, 1978). Following the designation of the Brazoria County fairway as a test well site late in 1977, a detailed environmental analysis of the prospect area was initiated (White and others, 1978). The results of all environmental analyses to date are similar; induced surface subsidence and fault activation are the most serious potential environmental impacts, followed closely by potential impacts to air and water quality resulting from accidental releases of geopressured geothermal fluids at the surface. Because of the proximity of the test well site to several homes along the Chocolate Bayou and to two large petrochemical plants that produce continuous background rumbles, noise was also considered to be an important environmental parameter at the Brazoria County test well site.

Based on the preceding environmental studies, a program to obtain environmental baseline data in the vicinity of the test well site was initiated early in 1978. Baseline studies evaluated microseismicity, subsidence, air and water quality, and noise. All these parameters except noise will continue to be monitored throughout 1980.

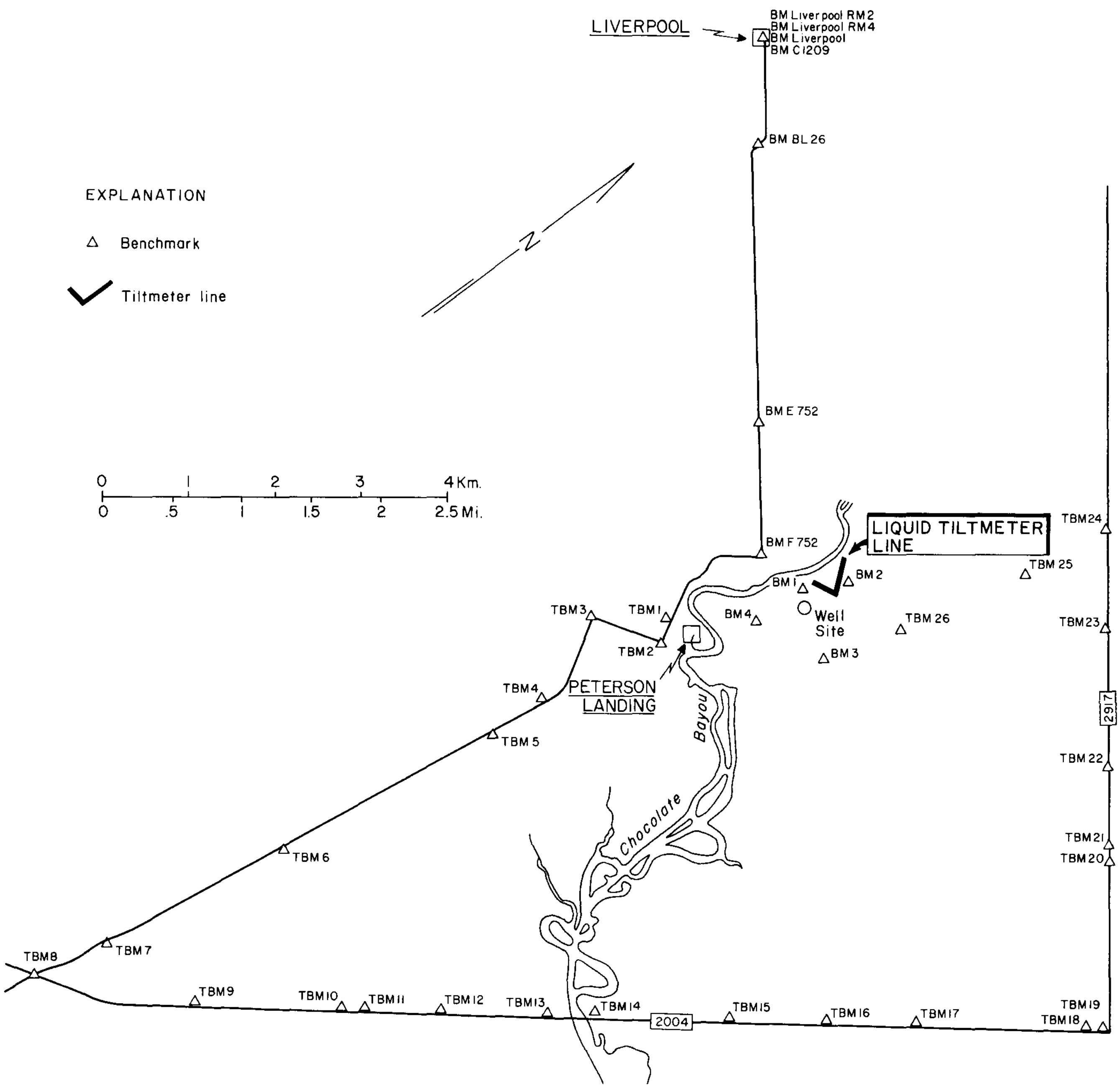

Figure 1. Location of Department of Energy-General Crude Oil Corporation Pleasant Bayou #1 and #2 geothermal test wells and environmental monitoring facilities.

BASIC OBJECTIVE OF BASELINE SUBSIDENCE STUDIES IS TO DETERMINE, FIRST, IF NATURAL SUBSIDENCE IS OCCURRING IN THE VICINITY OF PLEASANT BAYOU #1 AND #2 AND, SECOND, IF PRODUCTION AND/OR DISPOSAL OF GEOTHERMAL FLUIDS HAVE INDUCED SUBSIDENCE OR FAULTING.

Microseismic monitoring in the vicinity of Pleasant Bayou #1 and #2 indicates that there is evidence of (1) naturally occurring seismic activity of local magnitudes in excess of 0.25 within 4 km of the test well site, (2) seismic activity of local magnitudes, which were induced by disposal of geothermal fluids or by other commercial waste fluid disposal operations in the vicinity, in excess of 0.25 within 4 km of the test well site.

Testing of the energy resources stored in geopressured formations beneath the Texas Gulf Coast will require withdrawal of massive volumes of fluid at relatively high rates. Currently, production rates from a single test well may be as high as 30,000 bbl (4,800 m^3) per day. Since recharge into the geopressured formations is expected to be negligible compared with the withdrawal, substantial pressure drops and subsequent reservoir compaction are anticipated. In particular, it is estimated that the reservoir compaction caused by one year's production from a single well could result in internal volumetric losses of approximately 10^7 bbl (10^6 m^3). Volume changes of this magnitude, when concentrated in an area with maximum dimensions of only a few kilometers, will impose a significant additional load upon the rocks surrounding the reservoir. On the basis of a disc approximation to the reservoir, the cumulative deviatoric component of this additional load will be about 100 bars within a few hundred meters of the reservoir and about 10 bars as far as 1.25 mi (2 km) away after one year's production from a single well. Deviatoric stress perturbations of this magnitude are sufficient to trigger substantial nonelastic deformation of the rocks surrounding the reservoir. This deformation may well be manifested through multiple discrete slips on both pre-existing and newly created fracture planes, thus releasing part of the stored strain energy as seismic waves. Since the release of seismic energy can be a risk to the local environment, the possible correlation between the production of geopressured brines and the occurrence of microearthquakes deserves serious consideration. To relate clearly geopressured brine production to the occurrence of seismic activity, it is desirable to obtain a local seismic history before the onset of the withdrawal of fluids.

Teledyne Geotech was authorized to monitor seismic activity in the vicinity of the test well. The results of a previous reconnaissance survey in the same region have been documented in an earlier publication (Teledyne Geotech Staff, 1978). The objective of this part of this report is to summarize the principal results obtained from January through December 1979 from the operation of a semipermanent microseismic monitoring network installed near the test well site.

The initial operating system included five surface instruments. Beginning in September 1979, four of these instruments were replaced by downhole instruments in 100-ft (30-m) deep boreholes. The background noise spectra for the surface and downhole seismometers are compared in figure 2. The downhole sensors provide a noise reduction factor of 10 in power and about 3 in amplitude, thus lowering the detection threshold by one-half magnitude. Events with magnitude of -0.5 have been detected with the current array.

SUMMARY OF SEISMICITY BEFORE JANUARY 1, 1980

Since monitoring began at the Brazoria County site, a total of 1,374 events have been observed and logged, of which 202 have been located (Appendix II). The activity by month is listed in table 1. Most fall into a class with the following general characteristics:

a. Times of origin during daylight hours only;

b. Impulsive first motions;

c. Frequencies from 8 to 12 Hz;

d. Time delays across the array up to 6 seconds;

Table 1. Seismicity by month

		Total events	Total located events	Natural events	Natural located events
1978	Sept	40	0	-	-
	Oct	53	0	6	0
	Nov	259	78	10	8
	Dec	74	0	1	0
1979	Jan	14	2	-	-
	Feb	0	0	-	-
	Mar	90	25	-	-
	Apr	180	39	-	-
	May	200	0	-	-
	Jun	40	0	-	-
	Jul	System down			
	Aug	System down			
	Sept	101	0	-	-
	Oct	100	2	2	2
	Nov	177	46	78	38
	Dec	46	10	4	4
		1374	202	101	52

e. Local magnitudes of 0.9 ± 0.2;

f. Durations of 3 to 4 seconds.

Epicenters for 150 events of this type were located and plotted in figure 3. They are evidently explosive shots for seismic surveys running perpendicular and parallel to the regional geologic structure. A record of this type of event is shown in figure 4.

During November and December 1979, 82 well-defined events were recorded that differed sharply from the usual seismic shots in each of the above characteristics (table 2). This second class of events have:

a. Times of origin during all hours;

b. Emergent first motions;

c. Frequencies from 4 to 8 Hz;

d. Time delays across the array of up to 14 seconds;

e. Local magnitudes of 0.5 ± 0.5;

f. Durations of 4 to 30 seconds.

An example of this type is in figure 5 and can be contrasted with the shot record in figure 4.

These arrivals were noteworthy in that they appeared to consist primarily of surface waves with weak to undiscernible P and S waves. Recorded on vertical seismometers, these waves have arrival times that vary by up to 14 seconds across the 4.3-km array. Many traces have two or more readily apparent phases. Thus, these arrivals are assumed to be fundamental and higher mode Rayleigh waves with velocities in the range of 1,000 to 1,150 ft s^{-1} (300 to 350 m s^{-1}).

The absence of observable P waves and the presence of multiple modes in the surface wave train makes arrival time selection difficult. For each event, the arrival time of the phase that was most consistently observable across the four channels was selected for location purposes. Often this was the first arriving Rayleigh mode, but sometimes the last (fundamental) mode had greater amplitude so it was used instead.

Table 2. Microseismic events (surface waves)

Date			Event	Time			Coordinates		Depth	
yr	mo	day	No.	h	min	s	Y (km)	X (km)	(km)	Magnitude
78	10	12	1	15	11	54.96	-1.996	0.376	0.001	0.89
78	11	07	2	16	39	55.32	-1.844	-0.835	0.001	0.99
78	11	29	3	15	40	27.25	-0.029	-3.376	0.001	1.06
78	11	30	4	14	21	42.81	-0.033	-3.078	0.001	1.00
78	11	30	5	16	28	17.99	-0.205	-3.793	0.001	1.04
78	11	30	6	17	11	3.77	-0.354	-2.413	0.001	0.93
78	11	30	7	17	11	32.48	-0.228	-2.004	0.001	1.01
78	11	30	8	17	19	3.32	-0.151	-3.096	0.001	0.96
78	11	30	9	17	40	51.43	0.065	-3.892	0.001	1.03
78	12	01	10	13	46	40.71	-1.071	-5.957	0.001	1.47
78	10	15	11	2	55	45.00	-7.000	-3.000	0.000	0.60
79	10	15	12	2	55	54.00	-7.100	-3.100	0.000	0.60
79	11	04	13	16	11	42.11	-0.240	-2.412	0.001	0.68
79	11	04	14	16	12	14.15	-0.741	-3.378	0.001	0.96
79	11	04	15	16	19	0.00	-0.700	-3.000	0.000	0.47
79	11	04	16	16	21	2.83	-0.711	-3.076	0.001	0.87
79	11	22	17	0	10	58.09	-1.348	1.377	0.001	0.99
79	11	22	18	0	14	15.21	-1.549	0.987	0.001	0.98
79	11	22	19	0	18	38.35	-1.603	4.671	0.001	1.41
79	11	22	20	0	19	16.98	-3.179	4.719	0.001	1.70
79	11	22	21	0	21	29.09	-9.043	6.491	0.001	1.93
79	11	22	22	0	35	15.25	-1.922	3.606	0.001	1.00
79	11	22	23	0	43	42.00	-4.000	4.500	0.000	0.42
79	11	22	24	1	3	0.00	-4.000	4.500	0.000	1.12
79	11	22	25	1	42	56.34	-5.214	7.128	0.001	1.47
79	11	22	26	1	46	44.75	-2.719	5.088	0.001	1.02
79	11	22	27	1	48	25.63	-2.168	4.389	0.001	0.84
79	11	22	28	1	55	31.00	-3.000	5.000	0.000	0.39
79	11	22	29	1	58	21.00	-3.000	5.000	0.000	0.91

Table 2. Microseismic events (surface waves) (cont.)

Date			Event	Time			Coordinates		Depth	
Yr	mo	day	No.	h	min	s	Y (km)	X (km)	(km)	Magnitude
79	11	22	30	2	0	5.00	-3.000	5.000	0.000	0.96
79	11	22	31	2	41	52.00	-6.100	-2.600	0.000	1.17
79	11	22	32	2	44	12.00	-6.000	-2.800	0.000	1.10
79	11	22	33	2	45	2.48	-6.204	-2.681	0.001	1.05
79	11	22	34	3	9	4.00	-6.000	-2.500	0.000	-0.15
79	11	22	35	3	11	55.63	-2.371	-0.439	0.001	0.44
79	11	22	36	3	20	35.27	-1.818	-0.725	0.001	0.62
79	11	22	37	3	22	8.39	-2.010	-0.626	0.001	0.88
79	11	22	38	3	23	45.42	-2.988	-0.913	0.001	0.62
79	11	22	39	3	26	52.00	-2.500	-0.600	0.000	-0.50
79	11	22	40	3	28	7.00	-2.500	-0.600	0.000	0.75
79	11	22	41	3	29	45.40	-2.496	-0.564	0.001	0.49
79	11	22	42	3	33	7.73	-1.628	-0.679	0.001	0.49
79	11	22	43	3	37	14.07	-2.450	-0.627	0.001	0.54
79	11	22	44	3	39	21.67	-2.105	-0.752	0.001	0.39
79	11	22	45	3	48	34.74	-3.705	-0.968	0.001	0.64
79	11	22	46	3	51	23.53	-1.903	-0.968	0.001	0.56
79	11	22	47	4	12	51.94	-2.654	-0.263	0.001	0.73
79	11	22	48	4	15	46.00	-1.500	0.500	0.000	0.92
79	11	22	49	4	18	15.87	-1.861	0.108	0.001	0.66
79	11	22	50	4	19	44.00	-1.500	0.500	0.000	0.61
79	11	22	51	4	21	13.00	-1.500	0.500	0.000	0.89
79	11	22	52	4	24	0.00	-1.500	0.500	0.000	0.26
79	11	22	53	4	27	43.00	-1.500	0.500	0.000	0.81
79	11	22	54	4	28	52.00	-1.500	0.500	0.000	0.81
79	11	22	55	4	32	36.00	-1.500	0.500	0.000	0.74
79	11	22	56	4	36	40.00	-1.500	0.500	0.000	1.00
79	11	22	57	4	40	39.40	-1.631	0.522	0.001	0.68
79	11	22	58	4	42	20.84	-2.791	-0.377	0.001	0.69
79	11	22	59	4	40	41.00	-1.500	0.500	0.000	0.33

Table 2. Microseismic events (surface waves) (cont.)

Date			Event	Time			Coordinates		Depth	
Yr	mo	day	No.	h	min	s	Y (km)	X (km)	(km)	Magnitude
79	11	22	60	4	45	17.00	-1.500	0.500	0.000	0.56
79	11	22	61	4	57	16.17	-1.653	0.619	0.001	0.78
79	11	22	62	5	3	3.00	-1.500	0.500	0.000	0.24
79	11	22	63	5	7	10.00	-1.500	0.500	0.000	0.24
79	11	22	64	5	8	0.00	-1.500	0.500	0.000	0.00
79	11	22	65	5	10	50.00	-1.500	0.500	0.000	0.75
79	11	22	66	5	15	33.00	-3.000	4.500	0.000	1.37
79	11	22	67	5	40	13.40	-3.246	4.177	0.001	0.99
79	11	22	68	6	4	30.00	-3.000	4.500	0.000	0.76
79	11	22	69	6	51	0.00	-3.000	4.500	0.000	0.56
79	11	22	70	7	28	54.00	-3.000	4.500	0.000	1.07
79	11	22	71	7	44	0.00	-3.000	4.500	0.000	0.97
79	11	22	72	7	45	19.02	-15.468	15.101	0.001	1.89
79	11	22	73	8	4	12.92	-1.576	6.182	0.001	1.38
79	11	22	74	8	12	29.90	-0.278	2.431	0.001	0.44
79	11	22	75	8	20	49.12	-1.323	7.963	0.001	1.23
79	11	22	76	8	31	59.00	-1.500	6.000	0.000	1.11
79	11	22	77	8	44	20.00	-1.500	6.000	0.000	1.25
79	11	22	78	9	40	30.00	-1.000	-1.000	0.000	0.57
79	11	22	79	11	56	30.00	-1.000	-1.000	0.000	0.73
79	11	22	80	12	33	49.00	-1.000	-1.000	0.000	0.03
79	11	22	81	12	51	0.00	-1.000	-1.000	0.000	0.21
79	11	22	82	12	55	8.00	-1.000	-1.000	0.000	0.21
79	11	22	83	12	56	27.00	-1.000	-1.000	0.000	0.51
79	11	22	84	12	59	58.23	-1.316	-1.100	0.001	0.84
79	11	22	85	13	12	44.00	-1.500	0.000	0.000	0.77
79	11	22	86	13	14	38.22	-1.525	0.187	0.001	0.45
79	11	22	87	13	21	24.88	-4.706	2.675	0.001	0.99
79	11	22	88	13	23	1.51	-6.438	6.105	0.001	1.46

Table 2. Microseismic events (surface waves) (cont.)

Date			Event	Time			Coordinates		Depth	
Yr	mo	day	No.	h	min	s	Y (km)	X (km)	(km)	Magnitude
79	11	22	89	13	24	0.00	-5.500	4.500	0.000	1.68
79	11	22	90	13	27	19.00	-5.500	4.500	0.000	1.28
79	11	22	91	13	37	10.00	-5.500	4.500	0.000	1.27
79	11	22	92	13	51	14.22	-1.421	8.512	0.001	1.49
79	12	07	93	15	15	2.96	3.065	-1.865	0.001	0.99
79	12	07	94	15	18	24.13	2.998	-1.663	0.001	0.67
79	12	07	95	17	56	0.35	0.171	-2.765	0.001	1.05
79	12	26	96	17	6	38.59	-0.095	-3.002	0.001	0.98

A model velocity of 1,036 ft s^{-1} (315 m s^{-1}) was used for all events, and the depth was arbitrarily constrained to 1 m. Magnitudes were calculated using a body wave formula and are thus relative values only. Forty-one of these events were located by MEHYPO, whereas the rest were assigned approximate locations based on similar signals with MEHYPO locations. Results are in table 4 and figure 6.

The epicenters are scattered over four linear regions that were active during the months of October, November, and December 1979. The scattering in the eastern region is greater because it is farther from the array. Each of these regions lie parallel and close to a known growth fault mapped by Bebout and others (1978). The southwestern region lies 3 mi (4.8 km) southwest of station 5; the western region passes 1 mi (1.6 km) south of Liverpool, Texas; the central region runs just east of station 5; and the eastern region passes either through or just north of the Monsanto petrochemical plant.

These events were noted only because of their number and frequency of occurrence. Since the accepted procedure has been to log and locate only events with well-defined P waves, it was believed that similar events have occurred during the monitoring period that were not noted because they had no clear P arrivals, were few in number, and were widely scattered in time. A review of film data and logs for October and November 1978 did in fact reveal several surface wave signals of the type discussed above. These events were also located and plotted in figure 6. The months between November 1978 and November 1979 have not been fully scanned for this type of event.

Two events on October 14, 1979, were located adjacent to a growth fault southwest of the array. The four events of November 4 were closely grouped in the western region. The 74 events during the night of November 21 alternated between the central and eastern faults with one or two events on the southwestern fault. Table 3 demonstrates this pattern of activity. The three events of November 7 and the one on December 26 were in the western region where the sequence began.

In the 1978 sequence, the activity progressed from east to west, commencing with single events in the central region on October 12 and November 7, 1978, peaking with seven events in the west on November 29-30, and ending with one in the far west on December 1.

Table 3. Seismic activity on November 21-22, 1979.

Local time period	No. of events	Region
6:00- 8:00 p.m.	14	Eastern
8:45-11:15 p.m.	34	Central
11:15- 2:45 a.m.	12	Eastern
3:40- 7:15 a.m.	9	Central
7:15- 7:37 a.m.	5	Eastern

Microseismic events of the type recorded in figure 6 appear to be associated with major growth fault systems. The structure map was developed on a stratigraphic surface with depth varying from 12,000 to 15,000 ft (3,640 to 4,545 m) below sea level. All the faults are normal faults that probably dip from 45° to 60° along a curving zone that steepens towards the surface. The epicenters of the microseismic events appear to have occurred preferentially toward the upthrown sides of several faults. If the events actually occurred within the fault zone, then they occurred at depths intermediate between the surface and 12,000 ft (3,640 m). The estimated depth of the microseismic events, on the basis of the known position of subsurface faults, calculated epicenters, and the estimated dip of growth faults, probably ranges from 5,000 to 6,000 ft (1,530 to 1,830 m) below sea level.

The concentration of microseismic events in the vicinity of the test well and the similarity in predicted depth of microseismic events and the known depth of disposal, 6,460 to 6,518 ft (1,969 to 1,986.7 m) below sea level, suggest that the events may be related to fluid injection. The chronological relationship further supports this interpretation in that over 40,000 bbl (6,350 m^3) of water were injected at approximately 6,500 ft (1,960 m) during the week preceding the swarm of events that occurred on November 21 and 22, 1979.

Production testing at Pleasant Bayou #2 was initiated November 15, 1979. Between November 15 and November 18, approximately 40,000 bbl (225,000 ft^3 or 6,400 m^3) of water were produced and injected through perforations between 6,460 ft and 6,518 ft (1,969 m and 1,986.7 m) in the disposal well, Pleasant Bayou #1 (table 4). Injection pump pressure data is not available for this interval but probably was on the order of 500 to 600 psi (35 to 42 kg cm^{-2}). No fluids were produced between November 19 and November 22. Between November 23 and November 25, 46,839 bbls (7,435 m^3) of water were produced and disposed of. Production testing ceased again on November 26. Testing was resumed on December 4 and continued at a rate of approximately 13,000 bbl (2,060 m^3) of water per day until December 13 (table 4). Production during this interval was 155,483 bbls (24,680 m^3) of water. Injection pressures steadily increased from 540 psi (38 kg cm^2) on December 4 to 700 psi (50 kg cm^2) when the well was shut in on December 13.

During the same time period, however, Monsanto Corporation disposed of approximately 30,000 to 40,000 bbls (4,762 to 6,350 m^3) per day of fluid at average pump pressure of 500 to 1,200 psi (35 to 85 kg cm^{-2}) in the interval of 3,000 to 6,400 ft (910 to 1,940 m). Monsanto disposal wells are located approximately 1.2 mi (2 km) east of Pleasant Bayou #2. These wells have operated almost continuously since 1965 and have disposed of 150,000,000 bbls (23,800,000 m^3) of fluid. Injection of waste fluids into these wells may also be related to observed microseismic events. Perhaps the only difference between injection in these wells and injection into Pleasant Bayou #1 is the timing of the swarm of microseismic events with respect to the onset of disposal in Pleasant Bayou #1.

Table 4. Disposal Well, Pleasant Bayou.[1]

Date	Volume[3]	Injection pressure	BHP[2]
11/16/79	12,721	∿ 550 psi	3,222 psig
11/17/79	∿ 16,000	∿ 550	3,244
11/19/79	Well Shut In	∿ 550	3,028
11/23/79	10,625	∿ 550	3,208
11/24/79	15,853	∿ 550	3,232
11/25/79	15,986	∿ 550	3,258
12/4/79	5,505	540	3,177.17
12/5/79	3,266	605	3,219.18
12/6/79	13,580	630	3,233.02
12/7/79	13,712	640	3,249.15
12/8/79	13,694	650	3,253.12
12/9/79	13,831	660	3,264.02
12/10/79	13,670	680	3,275.65
12/11/79	13,647	680	3,285.29
12/12/79	13,602	700	3,294.29
12/13/79	13,569.6	700	3,296.92
12/14/79	Well shut in	700	3,292.25

[1]Perforated interval, 6,460-6,518 ft below MSL
[2]Bottom hole pressure
[3]Volume in barrels

Although the relationship between high-volume fluid disposal and microseismicity/seismicity has been documented elsewhere by Raleigh and others (1976, 1972) and Healy and others (1968), the relationship between microseismicity, fluid injection, and structure in the vicinity of Pleasant Bayou #1 and #2 is still not clearly understood. Continued microseismic monitoring through 1980 may provide additional data when flow testing of the well is resumed. It should be clearly understood that disposal of large volumes of fluids has been underway in the vicinity of the geopressured geothermal test well since 1962 without recognizable impacts to the surface environment. It is, therefore, reasonable to assume that disposal of geothermal fluids at the test well site will probably not result in any recognizable surface impacts.

A multiliquid tilt meter is operational at the test well site. The tilt meter was installed to discern short-term increases in the regional subsidence rate that might accompany fluid withdrawal or disposal at the test well site.

The multiliquid tilt-meter experiment was installed by staff members of the Geophysical Laboratory of The University of Texas at Galveston late in 1979 (fig. 7). Initial plans called for the tilt meter to be operational by late 1978. A series of technical problems, vandalism, and very wet weather precluded installation until late 1979. During November and December, the liquid tilt meter was undergoing calibration and adjustment.

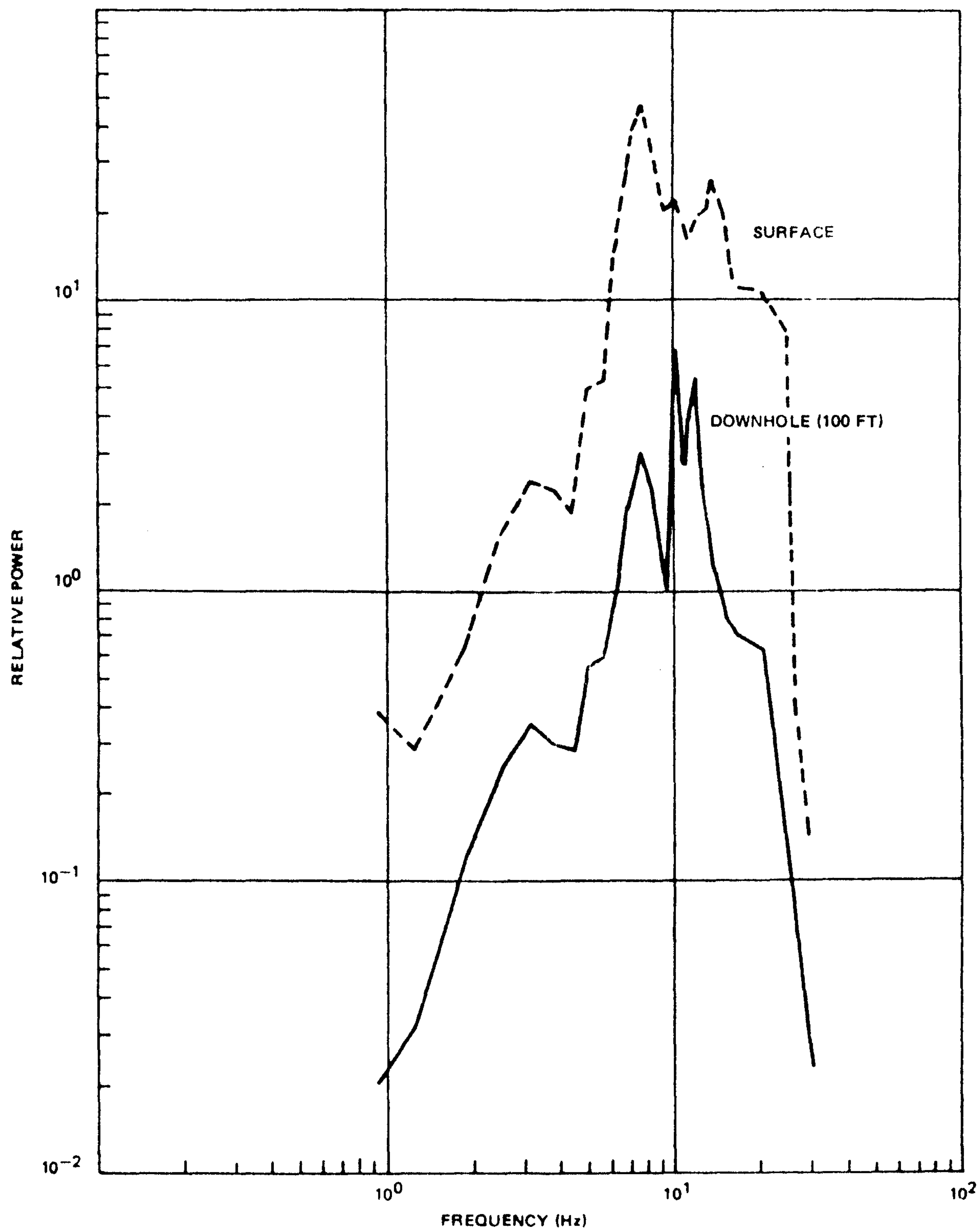

Figure 2. Spectral comparison of a background noise sample recorded by the downhole and surface monitoring systems during a quiet period.

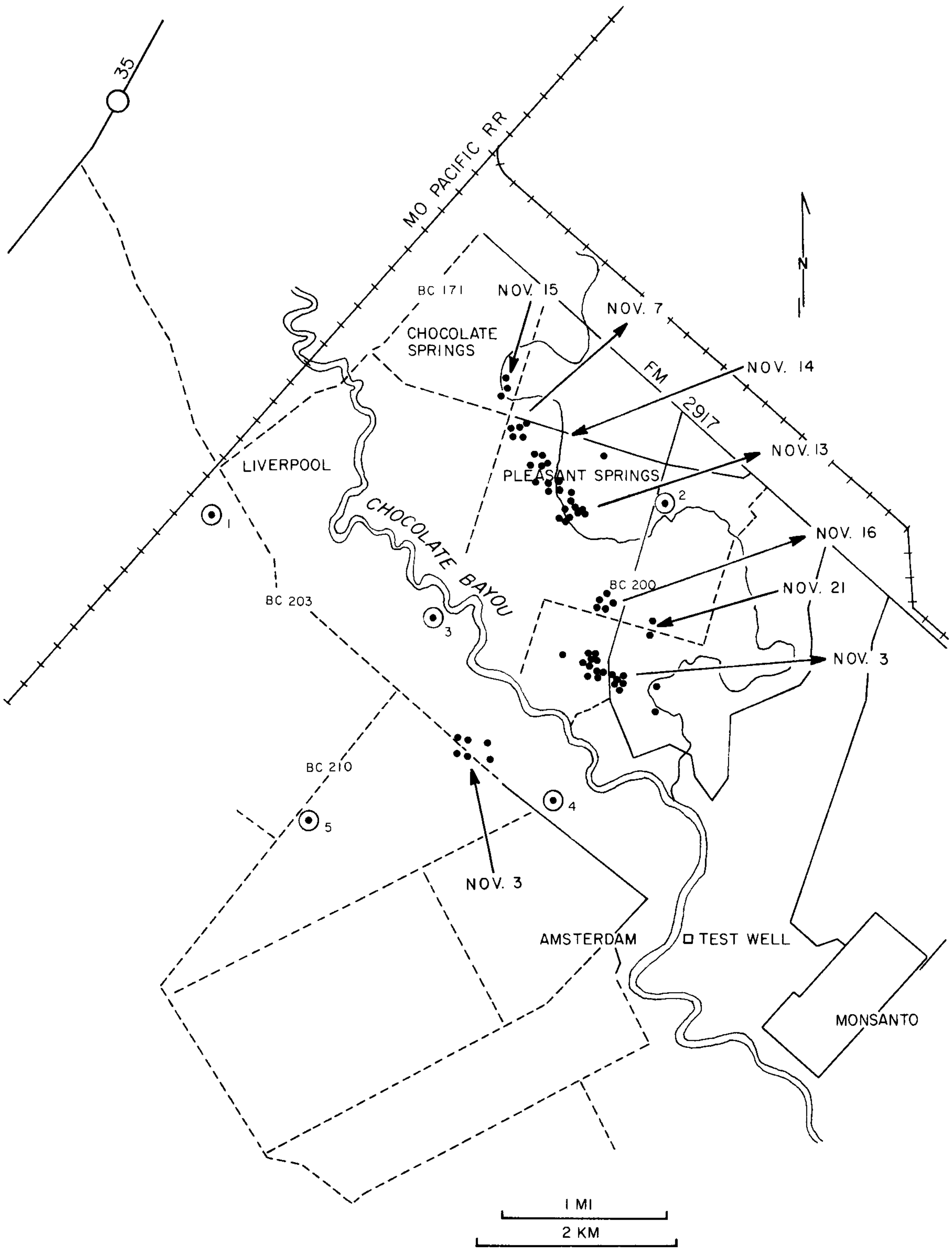

Figure 3. Epicenter locations of seismic shot activity.

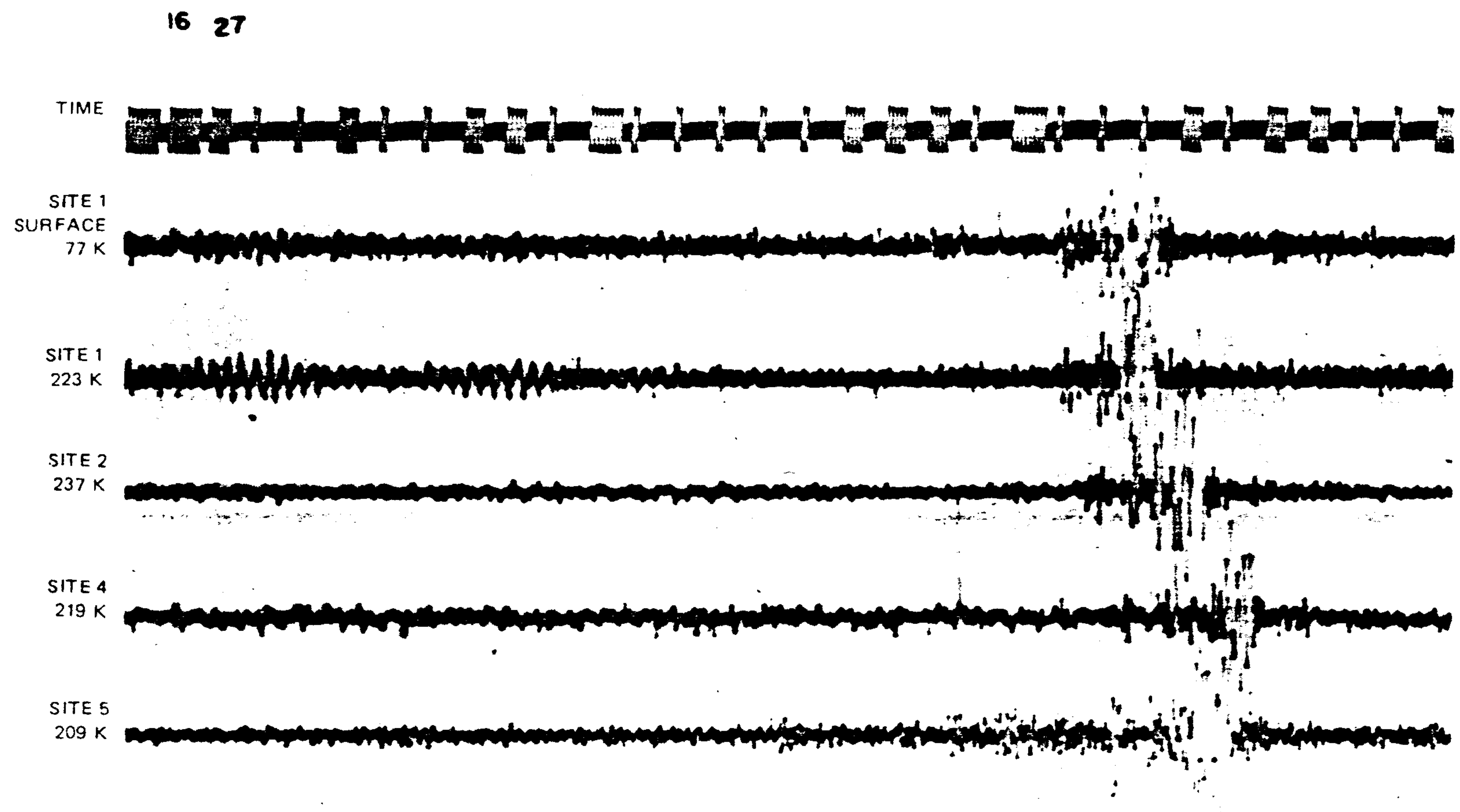

Figure 4. Typical seismic shot event, November 3, 1979.

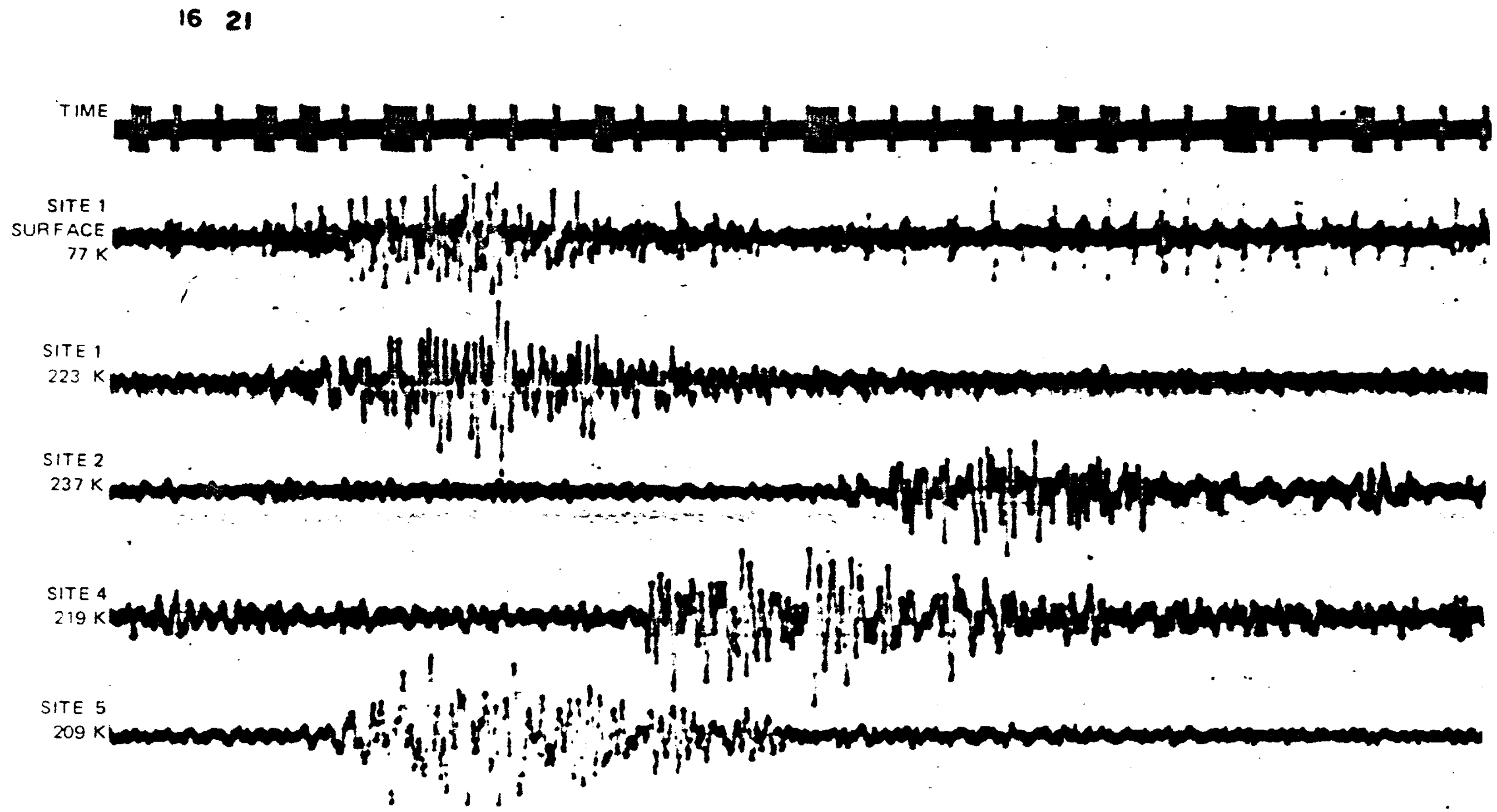

Figure 5. Typical surface wave event, November 4, 1979.

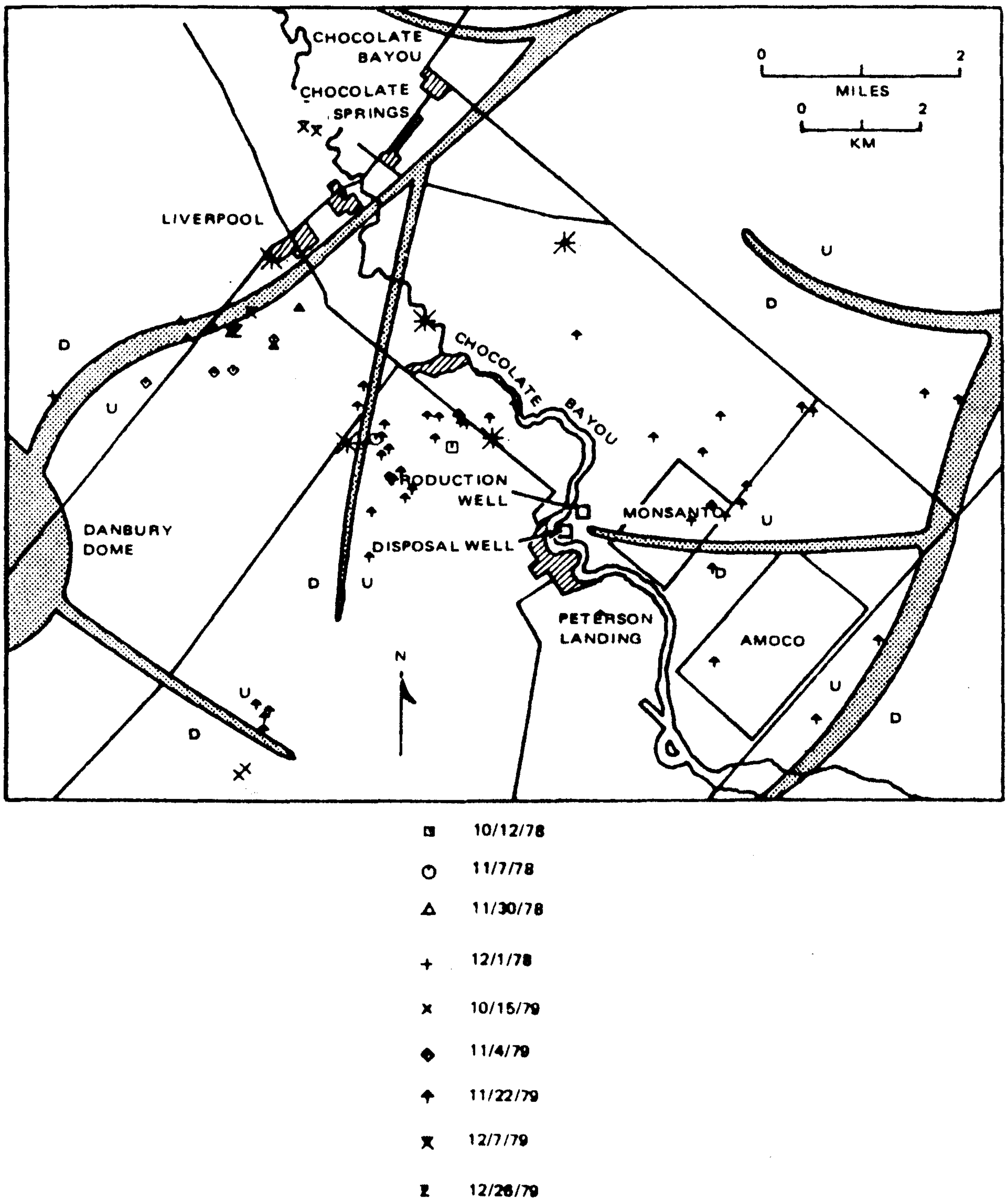

Figure 6. Growth faults at 15,000 ft (4,545 m) depth and associated epicenters.

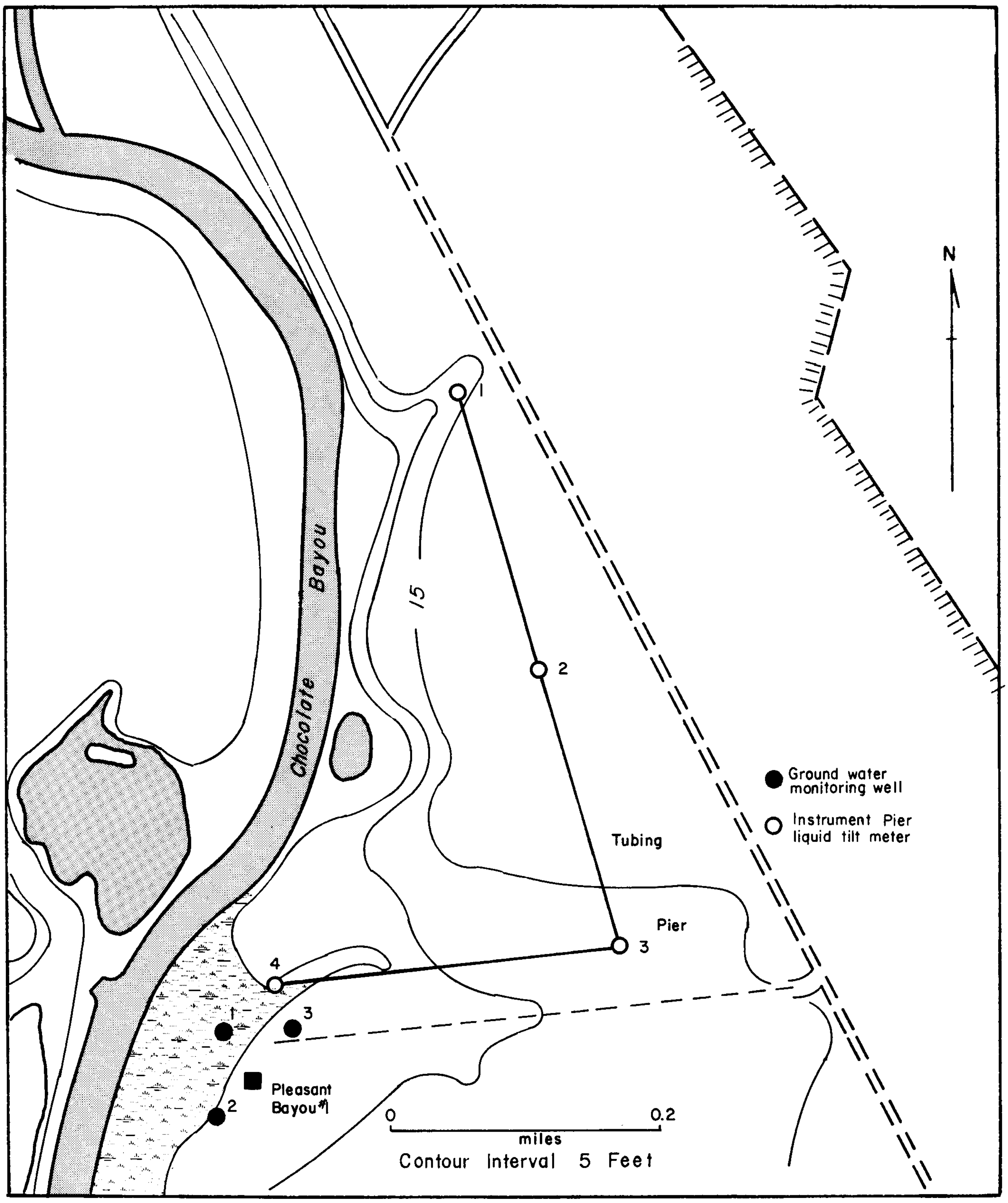

Figure 7. Location of ground-water monitoring wells and multiliquid tilt meter line.

THE OBJECTIVE OF AIR QUALITY MONITORING IS TO PROVIDE AN UNDERSTANDING OF BASELINE AIR QUALITY AT THE SITE OF THE GEOPRESSURED GEOTHERMAL TEST WELL.

Air quality at Pleasant Bayou #1 and #2 test well site does not exceed national ambient air quality standards for particulates or sulfur oxide.

Four air quality parameters--particulates, sulfur dioxide, methane, and hydrogen sulfide--are being monitored at Pleasant Bayou #1 and #2 to determine local baseline air quality. National ambient air quality standards for particulates and sulfur oxides were not exceeded during 1978 (figs. 8a, b, c and 9a, b, c, and d). National standards are not available at this time for methane and hydrogen sulfide (figs. 10a-g and 11a, b, c, and d).

Data summarized in figures 3 through 6 were collected by Radian Corporation at a point approximately 0.5 mi northwest of the test well site during 1979 (see Appendix I for data acquired and for descriptions of instrument systems and sampling program). In January 1979, an automated climate recording station was installed at the test well site to provide on-site wind direction and velocity data.

The data presented in figures 8 through 11 provide an adequate baseline assessment for air quality in the vicinity of the test well. Casual analysis of figures 8 through 11 suggests that major sources of air pollution lie to the northwest, north, east, and southeast. These source directions coincide with the general positions of major petrochemical and industrial complexes in Houston, Galveston, and Texas City. Nearby petrochemical plants probably somewhat affect air quality when winds are from the southeast. Composition of emissions from petrochemical processing and waste disposal at local petrochemical plants is not known; therefore, a direct relationship cannot be firmly established between observed air quality at the test well site and emissions from local petrochemical plants.

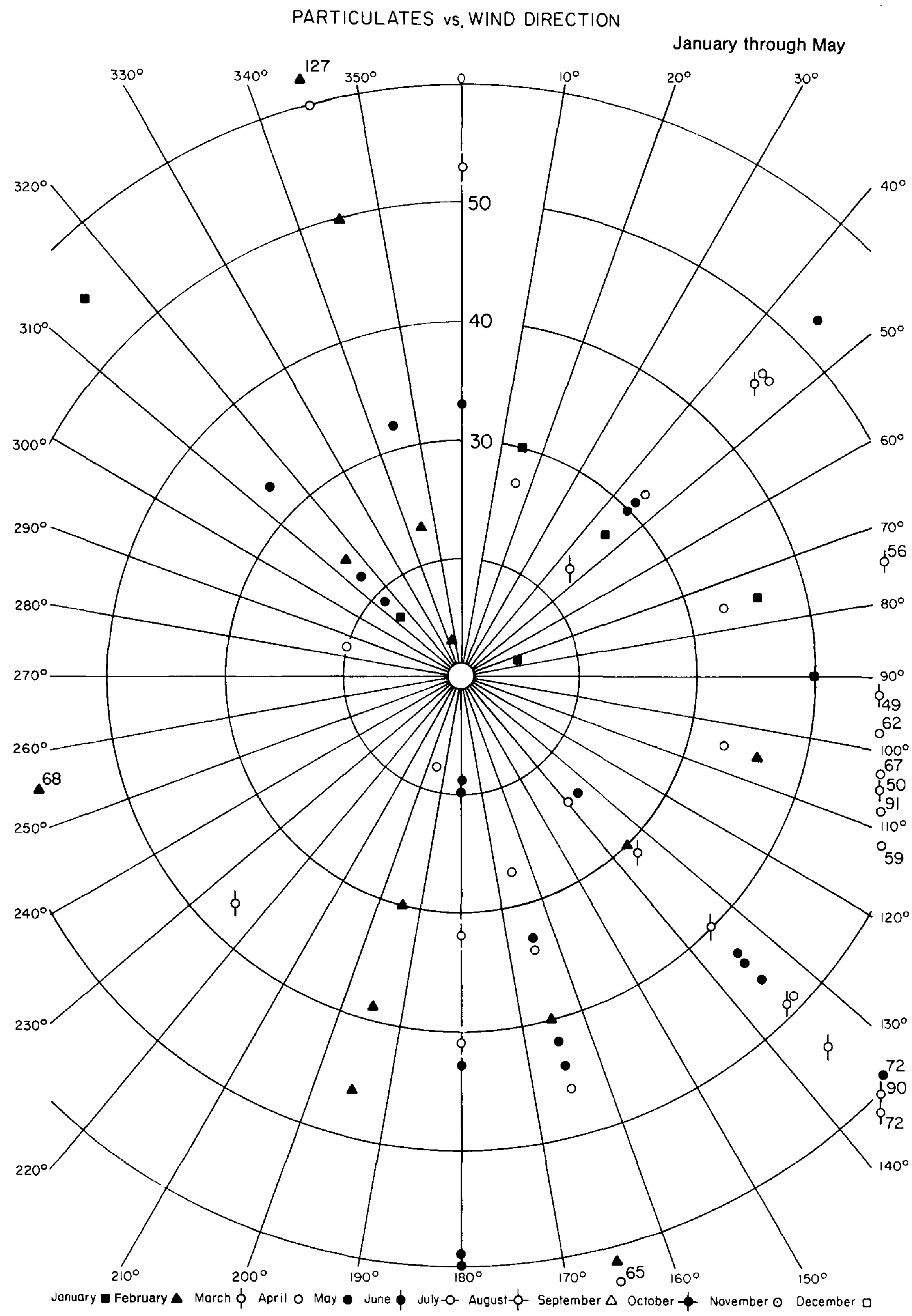

Figure 8a. Daily particulate concentration averages in micrograms per cubic meter for January through May.

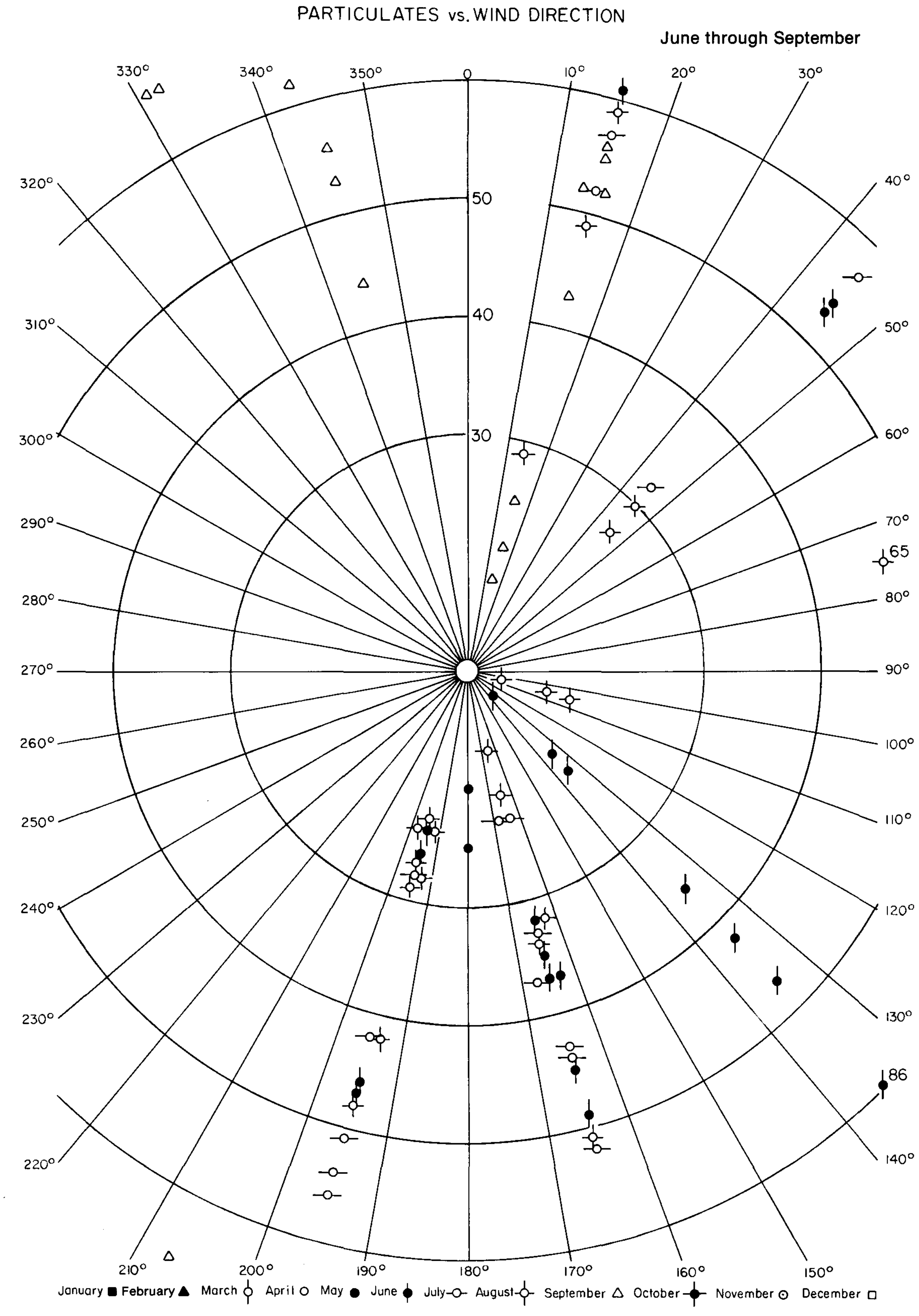

Figure 8b. Daily particulate concentration averages in micrograms per cubic meter for June through September.

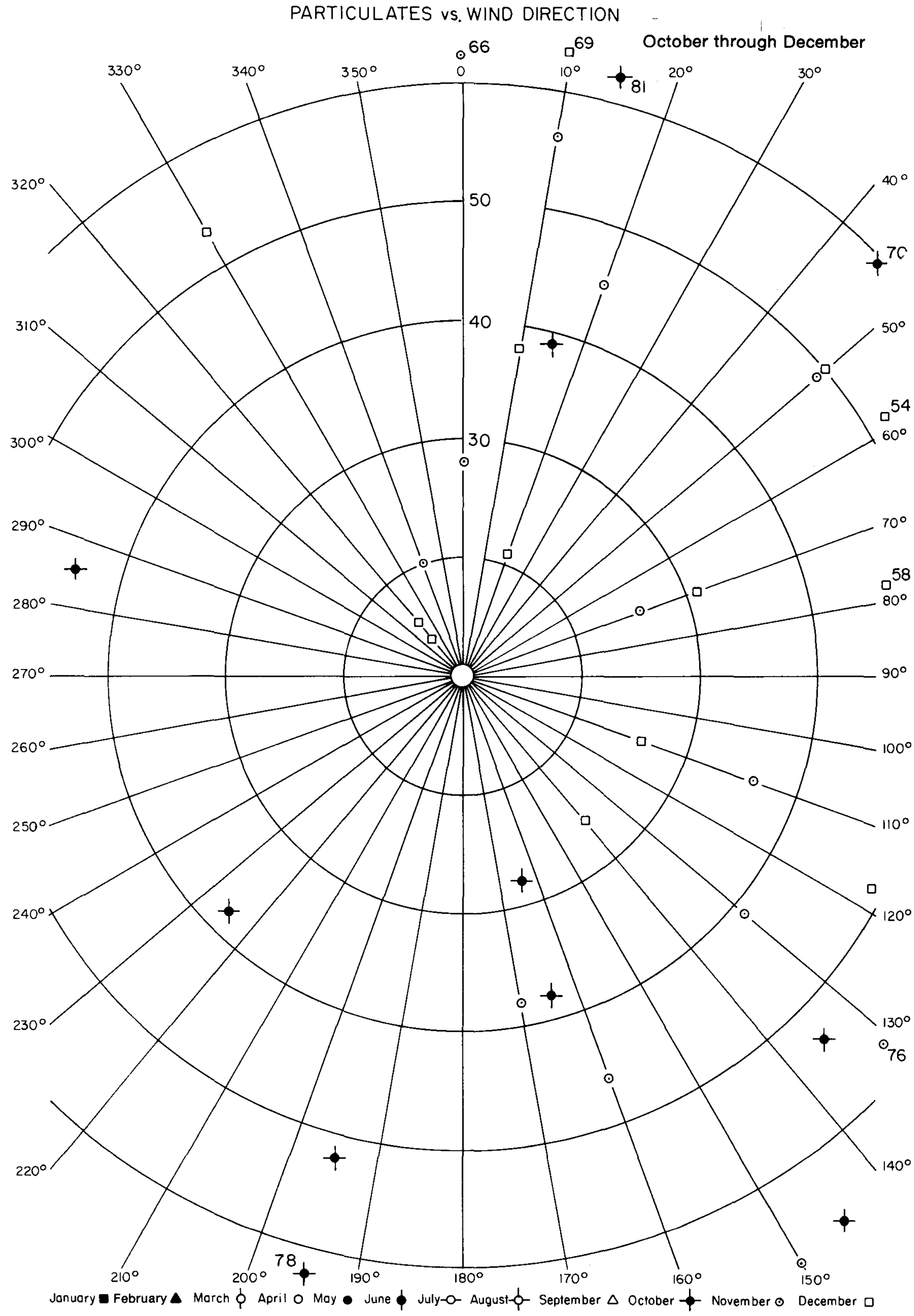

Figure 8c. Daily particulate concentration averages in micrograms per cubic meter for October through December.

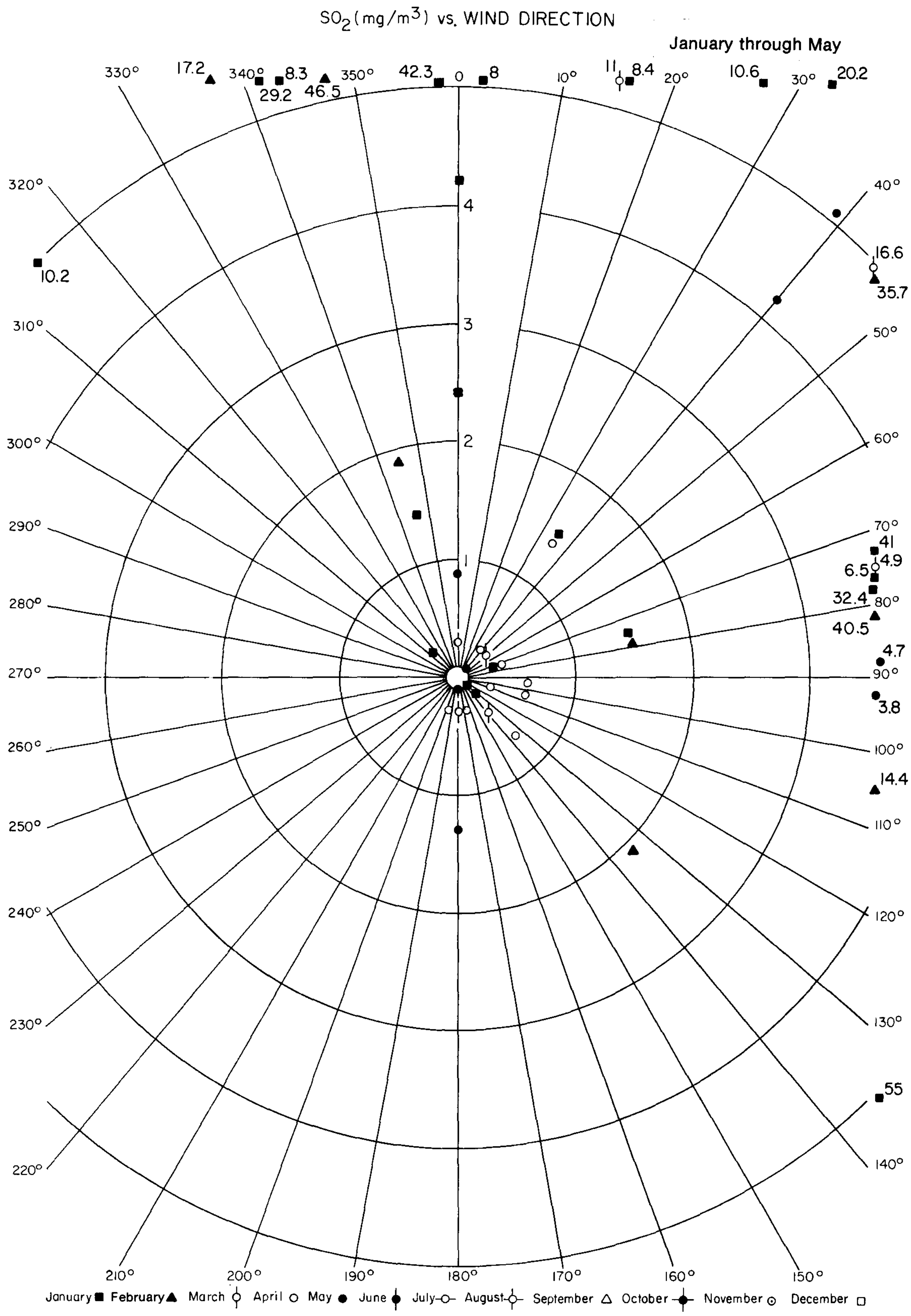

Figure 9a. Daily sulfur dioxide concentration averages in micrograms per cubic meter for January through May.

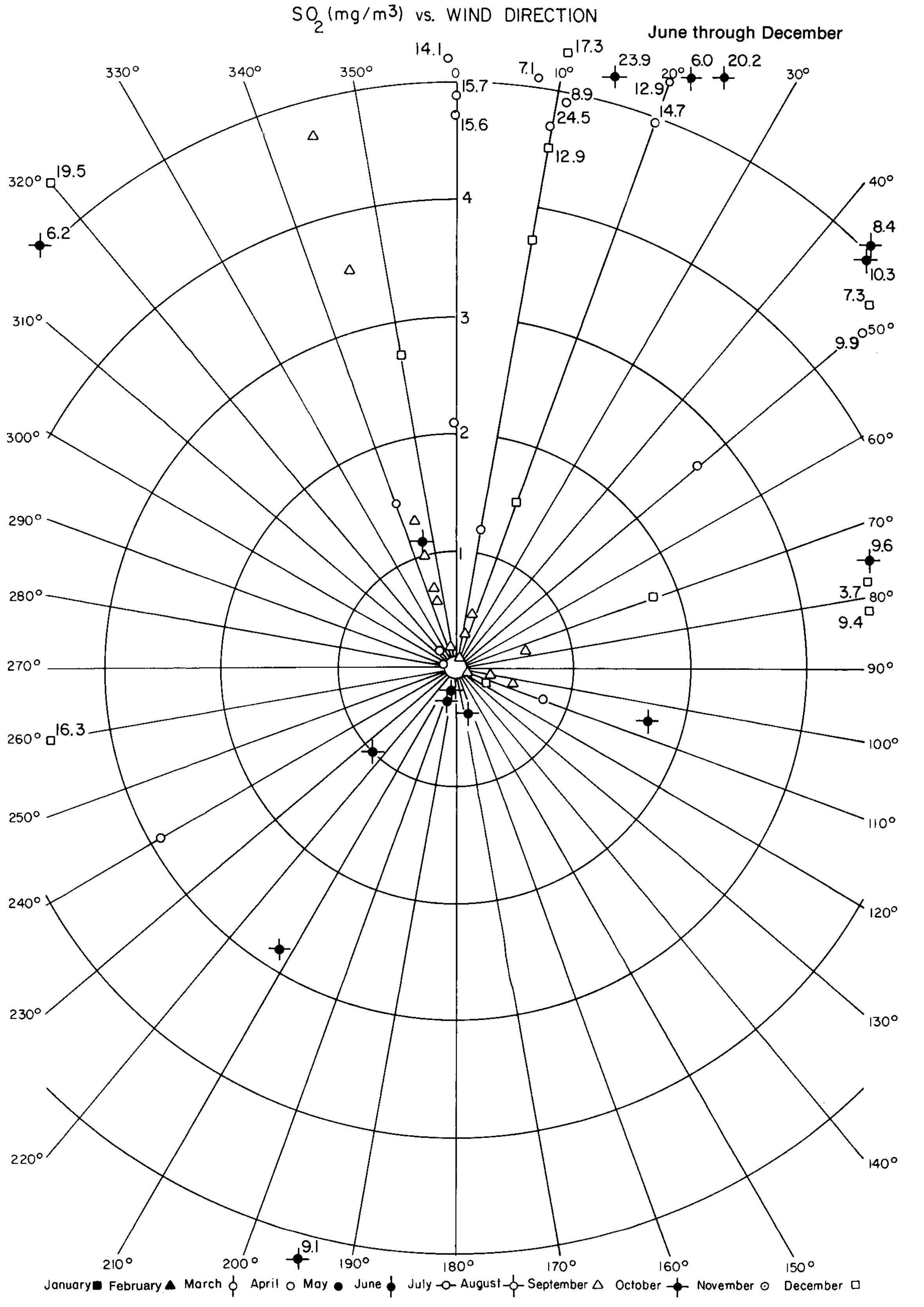

Figure 9b. Daily sulfur dioxide concentration averages in micrograms per cubic meter for June through December.

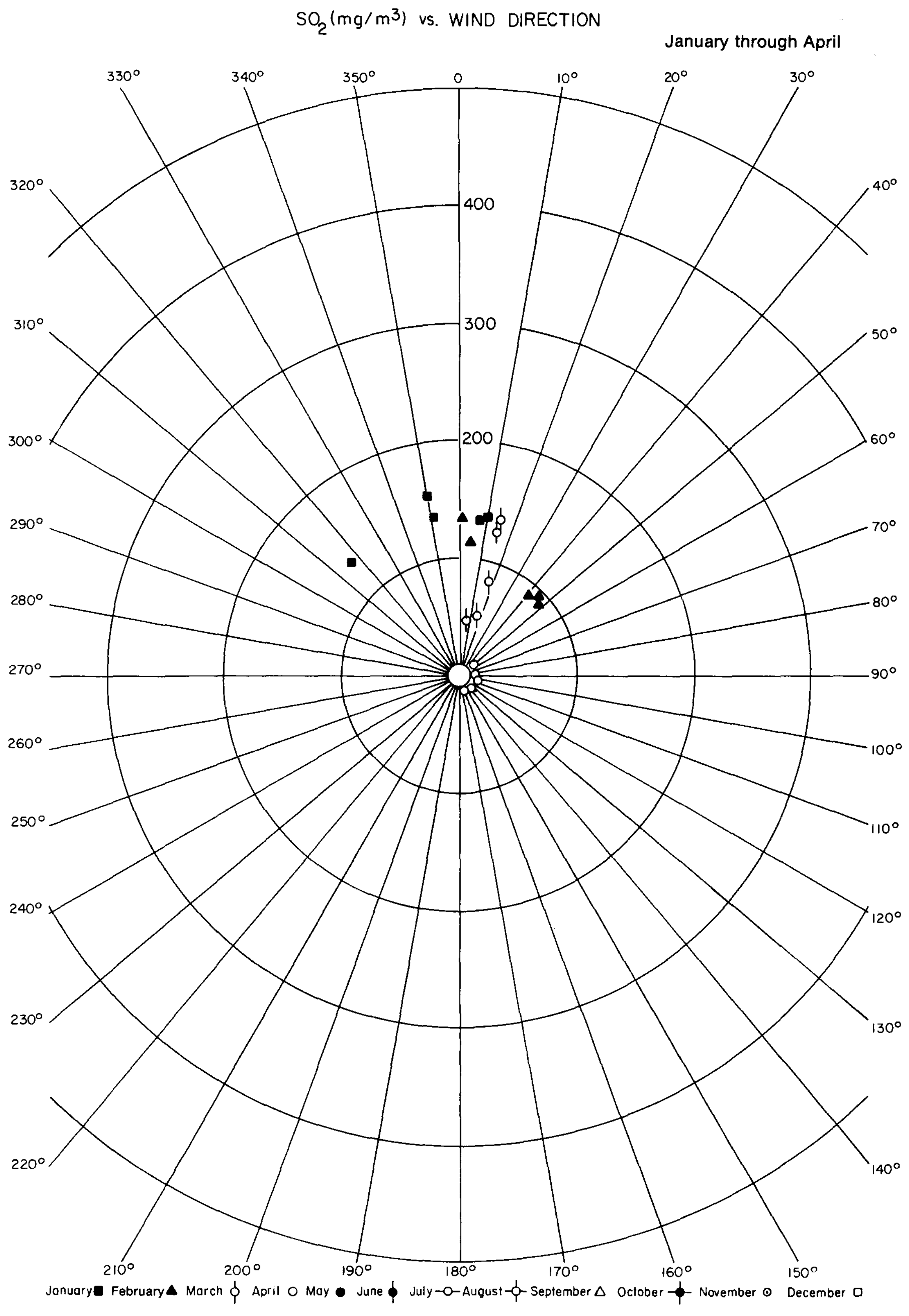

Figure 9c. Sulfur dioxide. Five maximum 30-minute sliding averages per month in micrograms per cubic meter for January through April.

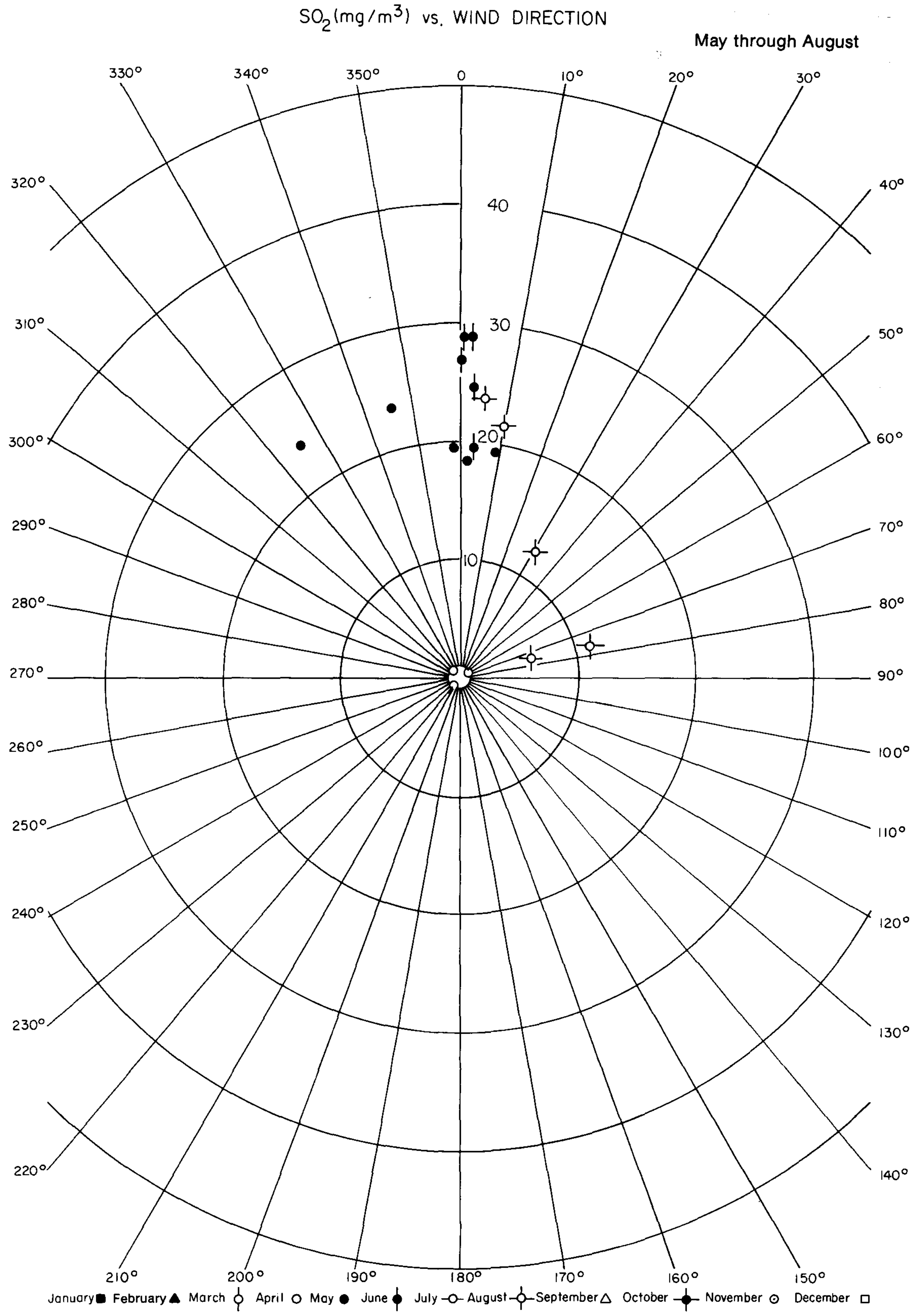

Figure 9d. Sulfur dioxide. Five maximum 30-minute sliding averages per month in micrograms per cubic meter for May through August.

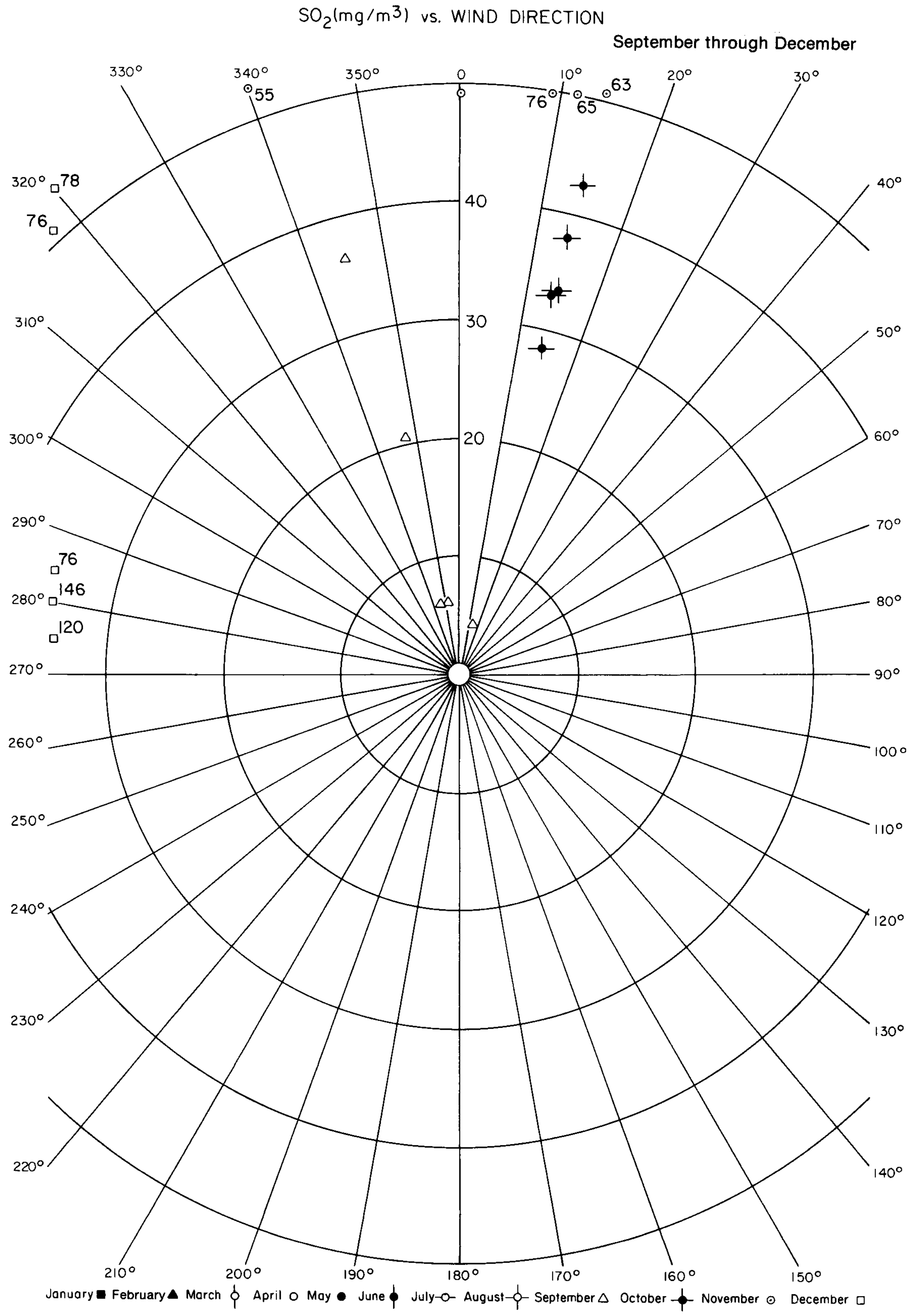

Figure 9e. Sulfur dioxide. Five maximum 30-minute sliding averages per month in micrograms per cubic meter for September through December.

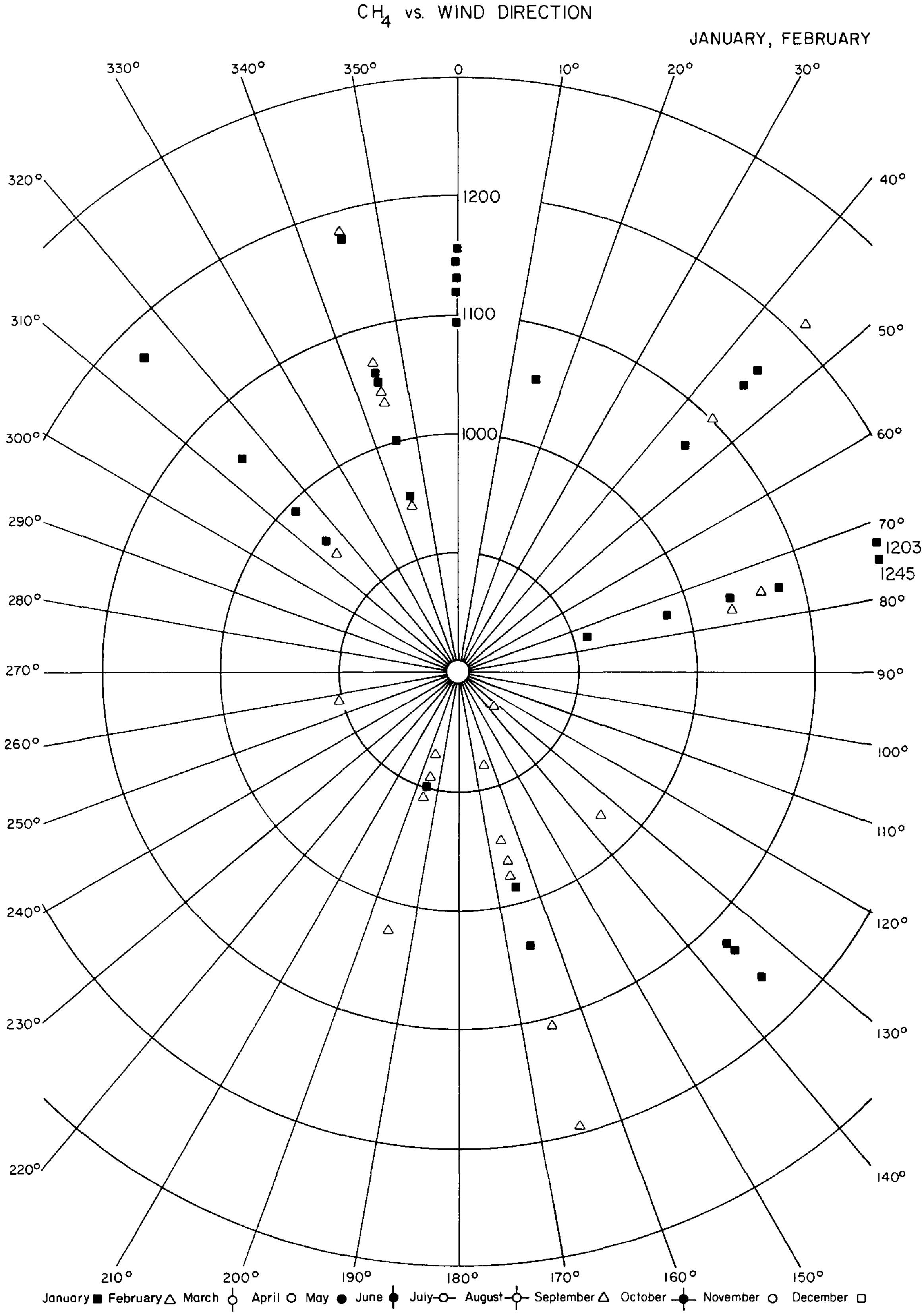

Figure 10a. Daily methane concentration averages in micrograms per cubic meter for January and February.

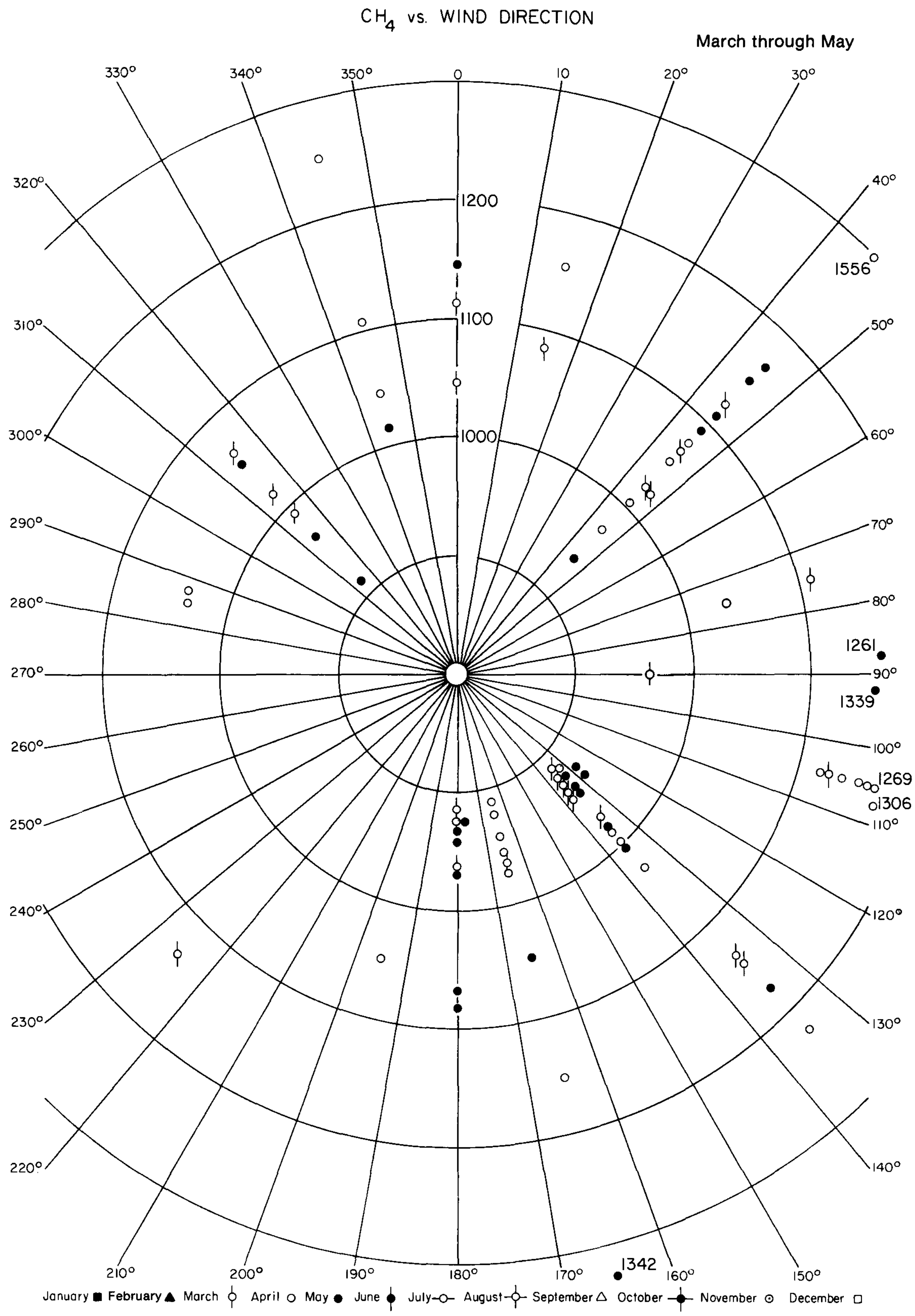

Figure 10b. Daily methane concentration averages in micrograms per cubic meter for March, April, and May.

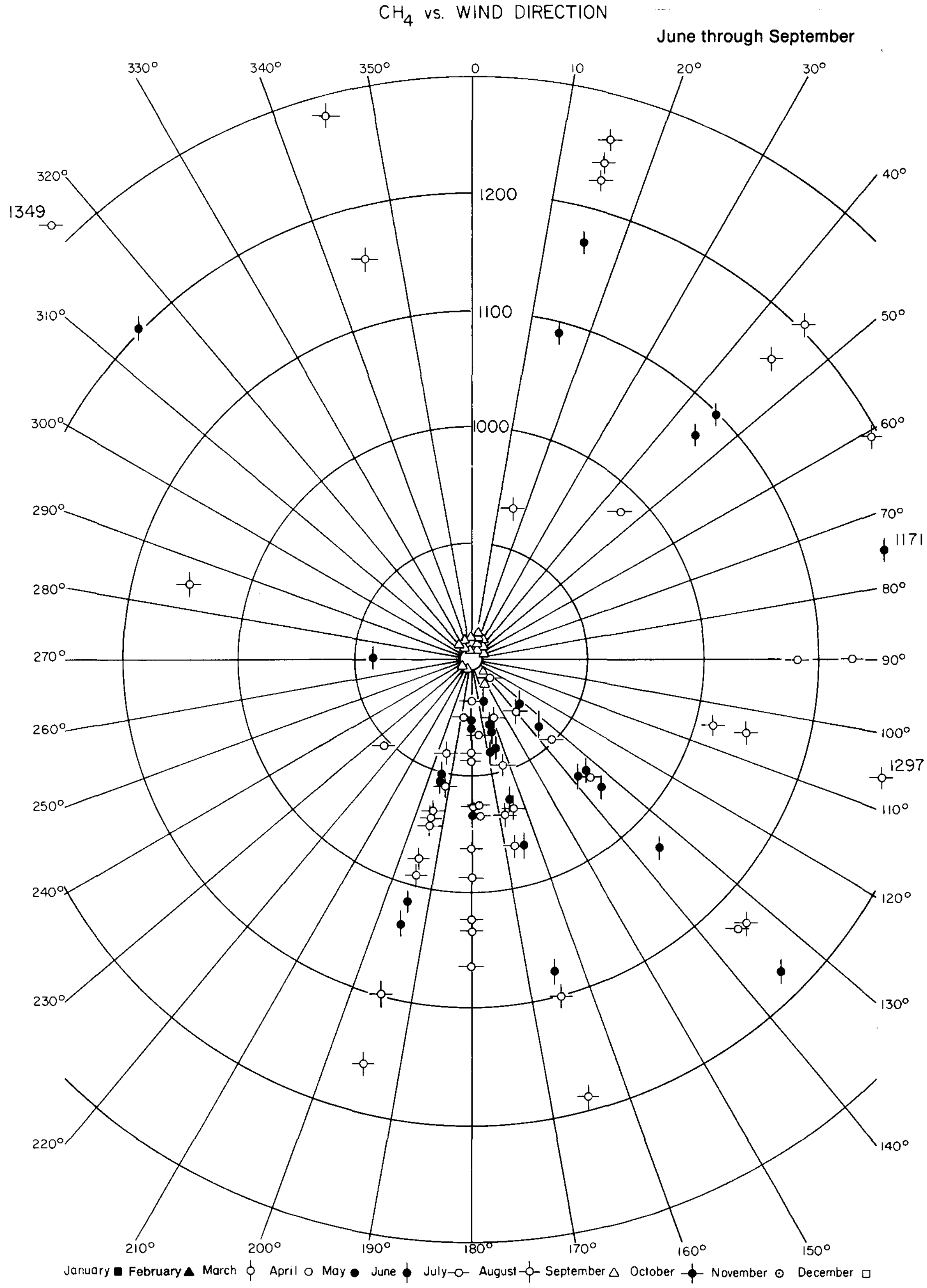

Figure 10c. Daily methane concentration averages in micrograms per cubic meter for June through September.

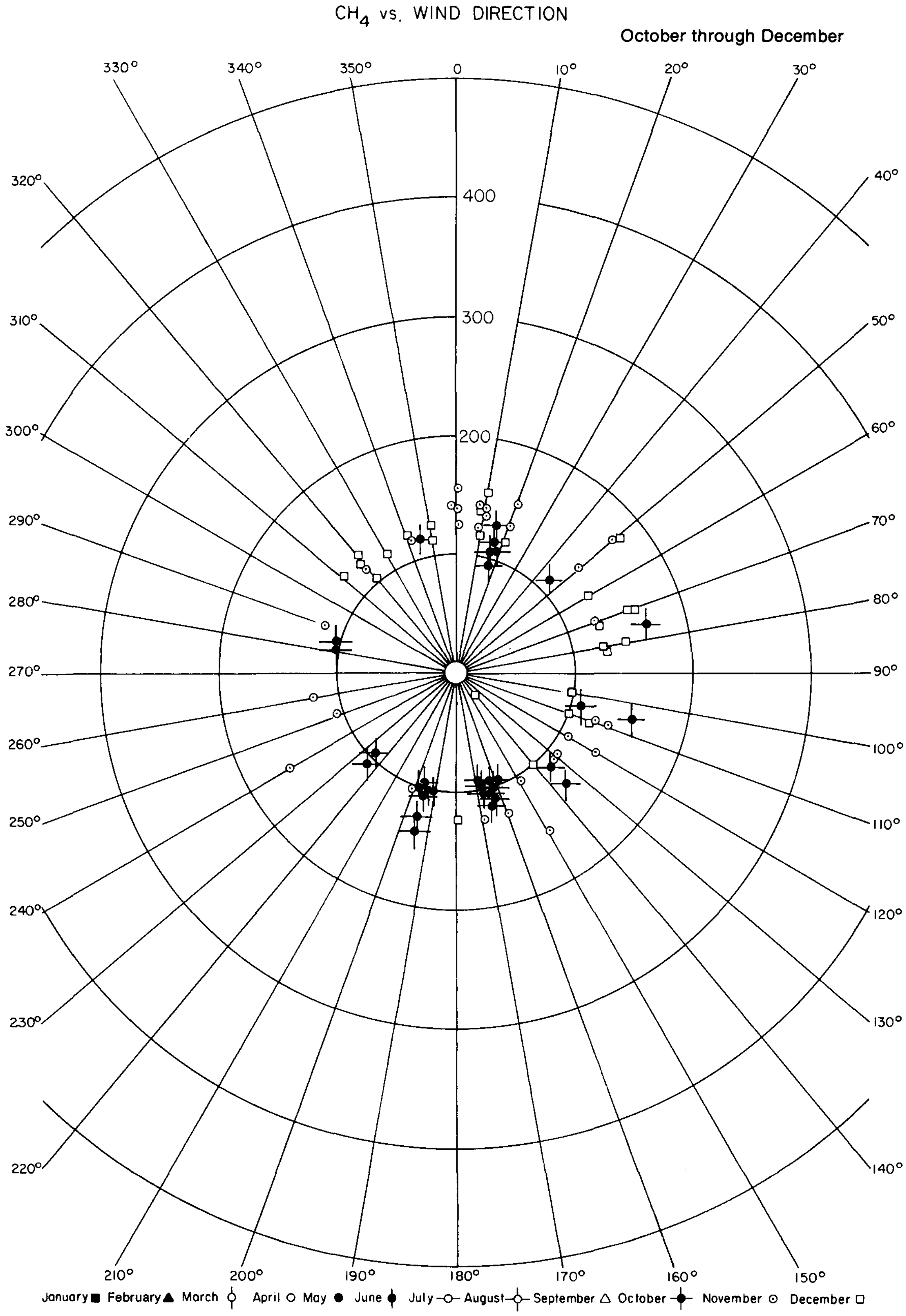

Figure 10d. Daily methane concentration averages in micrograms per cubic meter for October, November, and December.

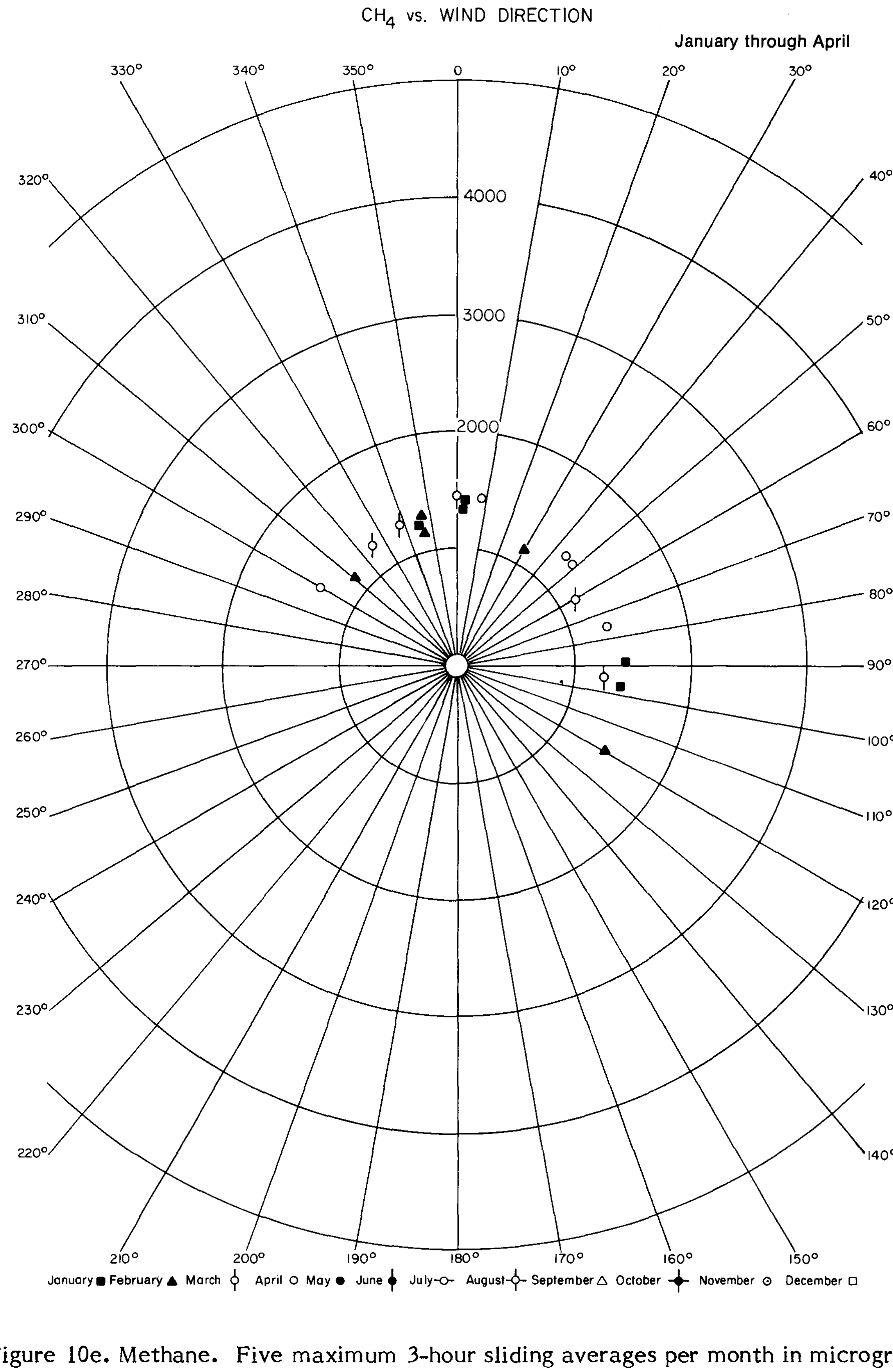

Figure 10e. Methane. Five maximum 3-hour sliding averages per month in micrograms per cubic meter for January through April.

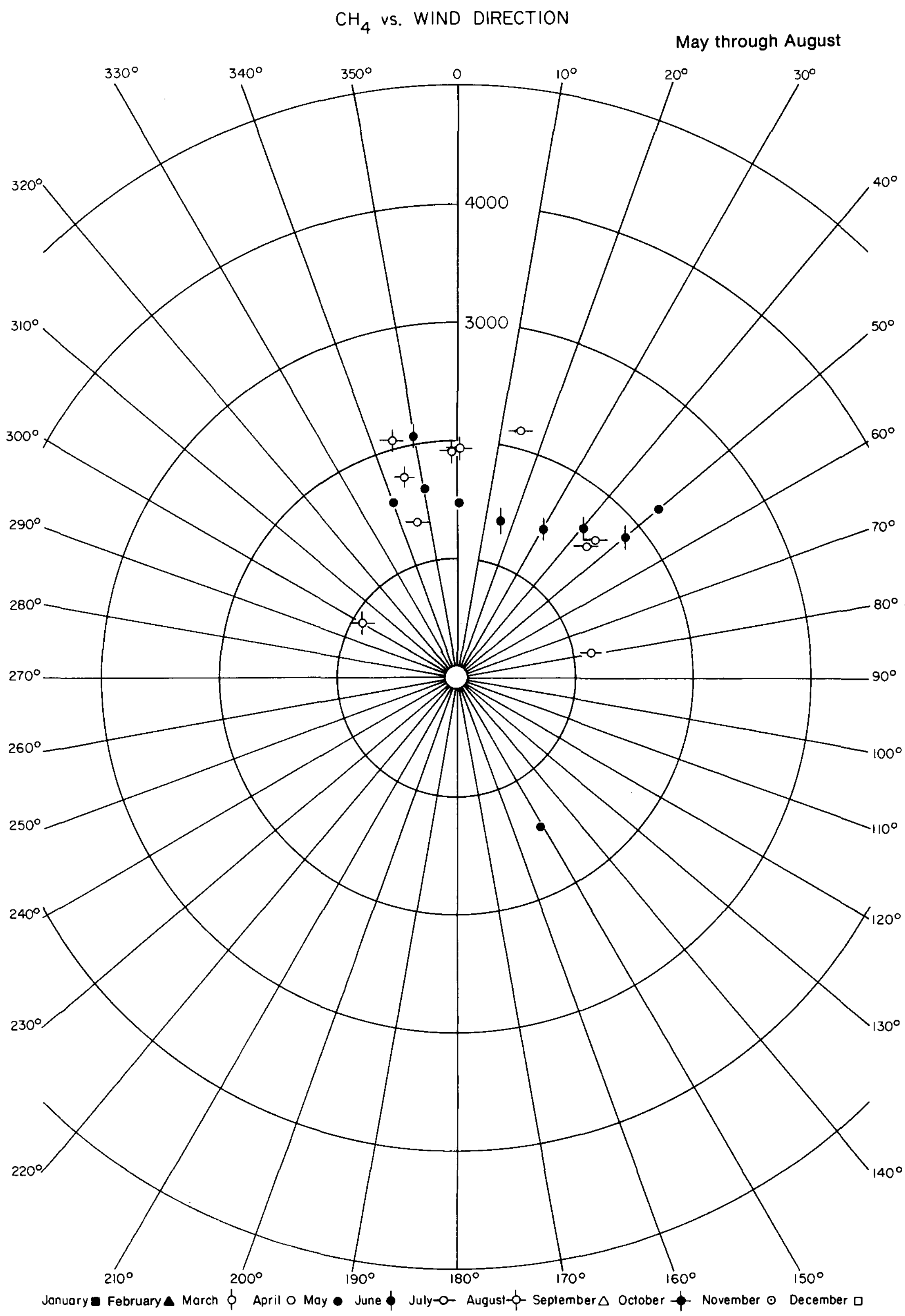

Figure 10f. Methane. Five maximum 3-hour sliding averages per month in micrograms per cubic meter for May through August.

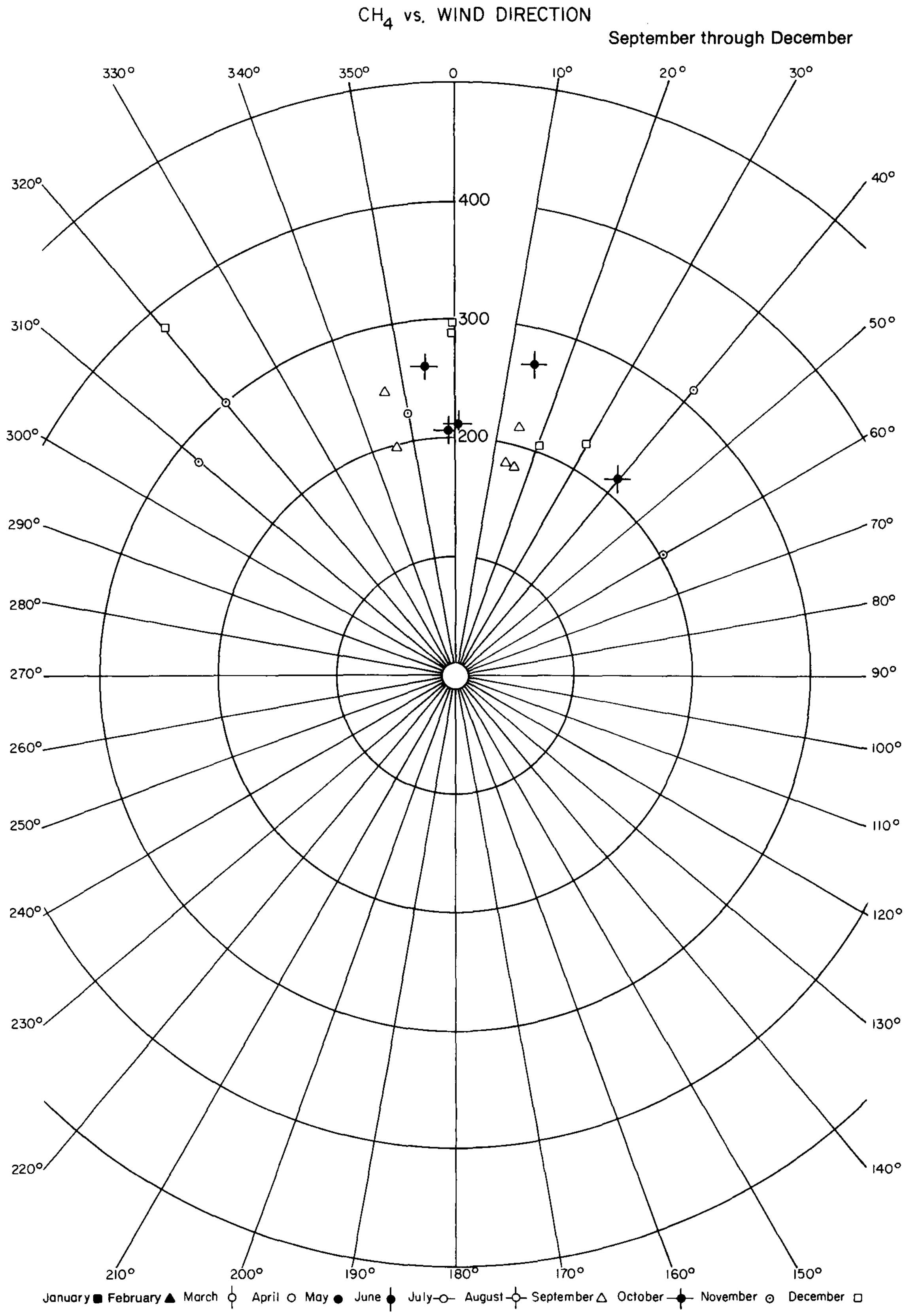

Figure 10g. Methane. Five maximum 3-hour sliding averages per month in micrograms per cubic meter for September through December.

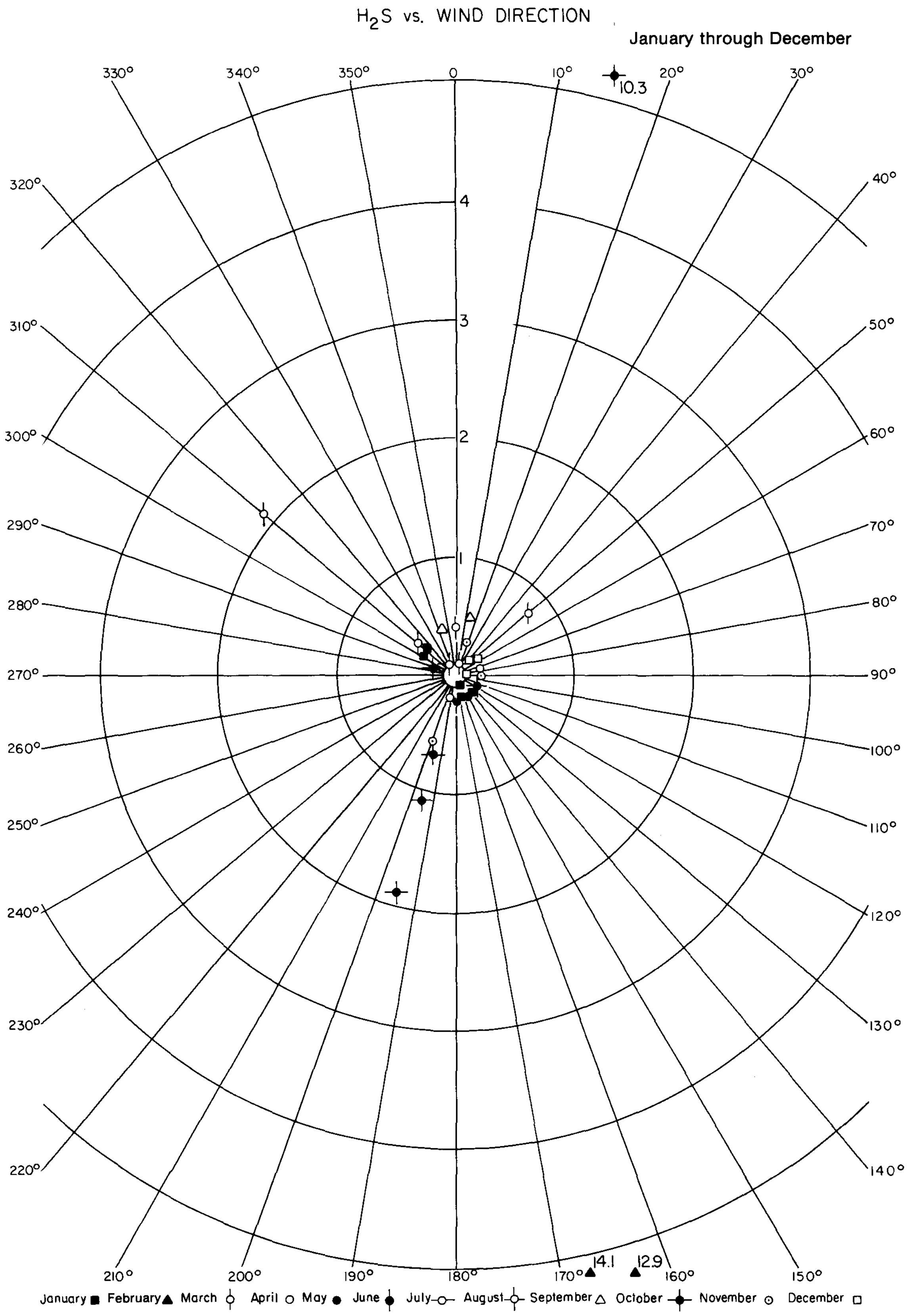

Figure 11a. Daily hydrogen sulfide concentration averages in micrograms per cubic meter for January through December.

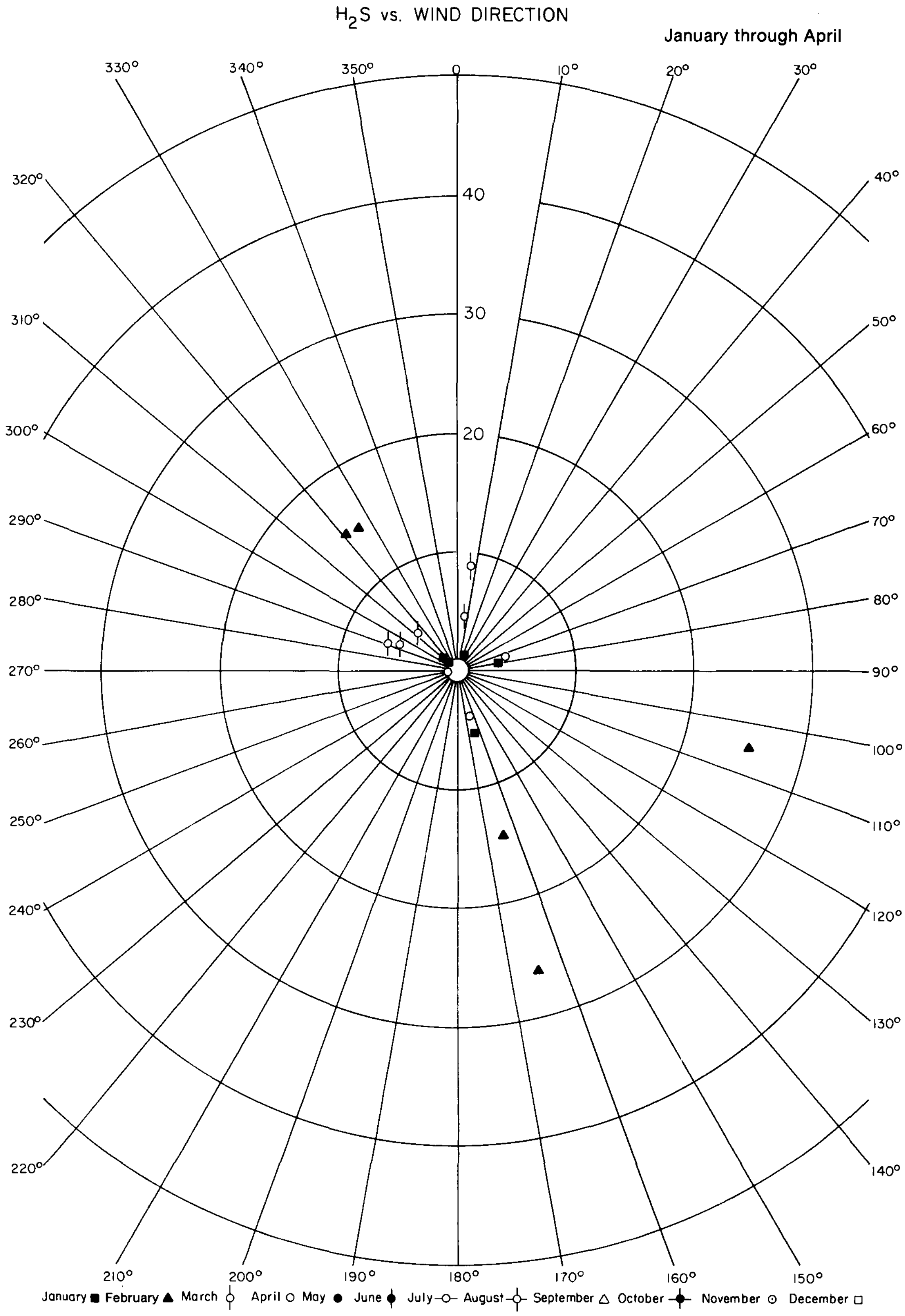

Figure 11b. Hydrogen sulfide. Five maximum 1-hour sliding averages per month in micrograms per cubic meter for January through April.

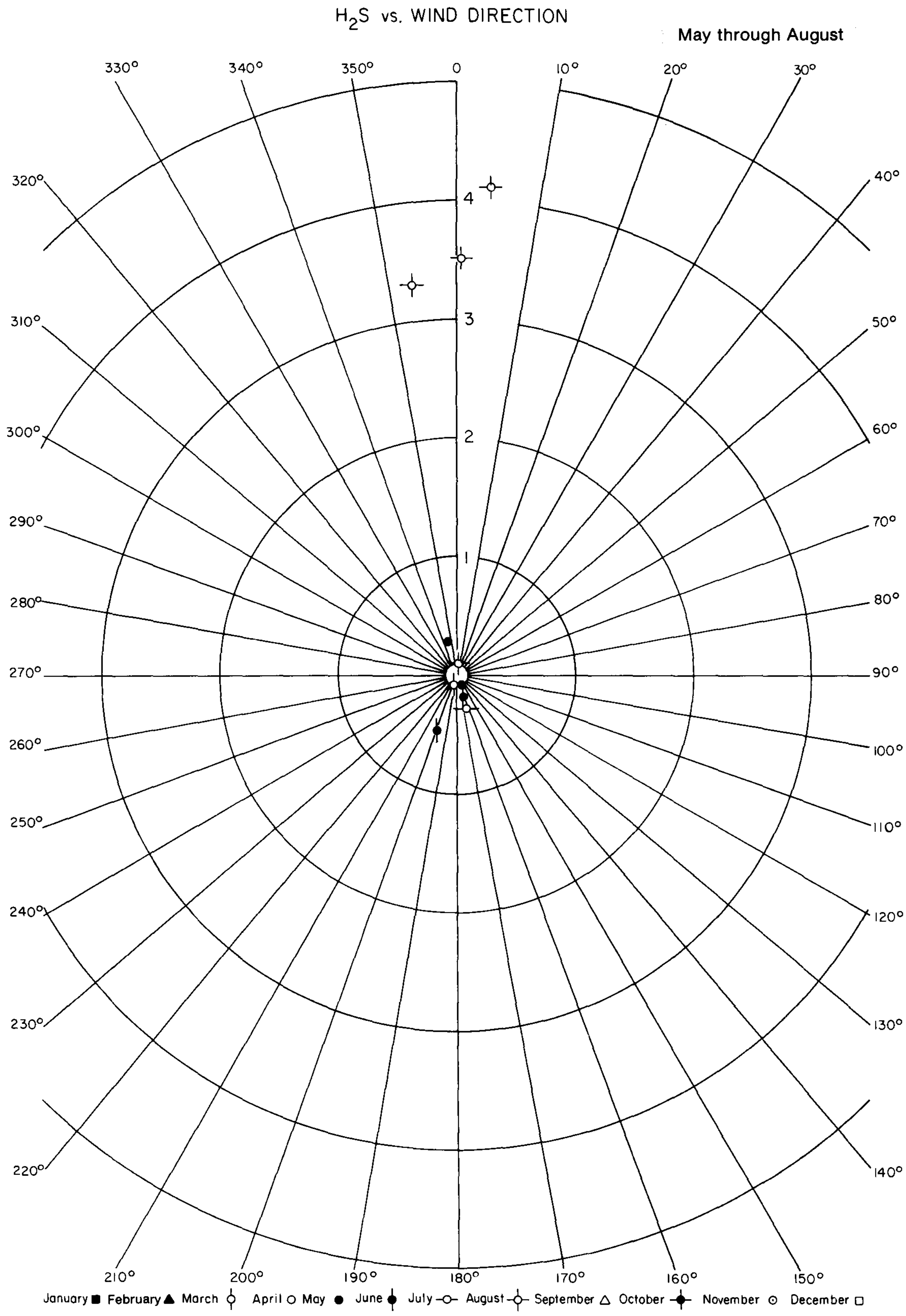

Figure 11c. Hydrogen sulfide. Five maximum 1-hour sliding averages per month in micrograms per cubic meter for May through August.

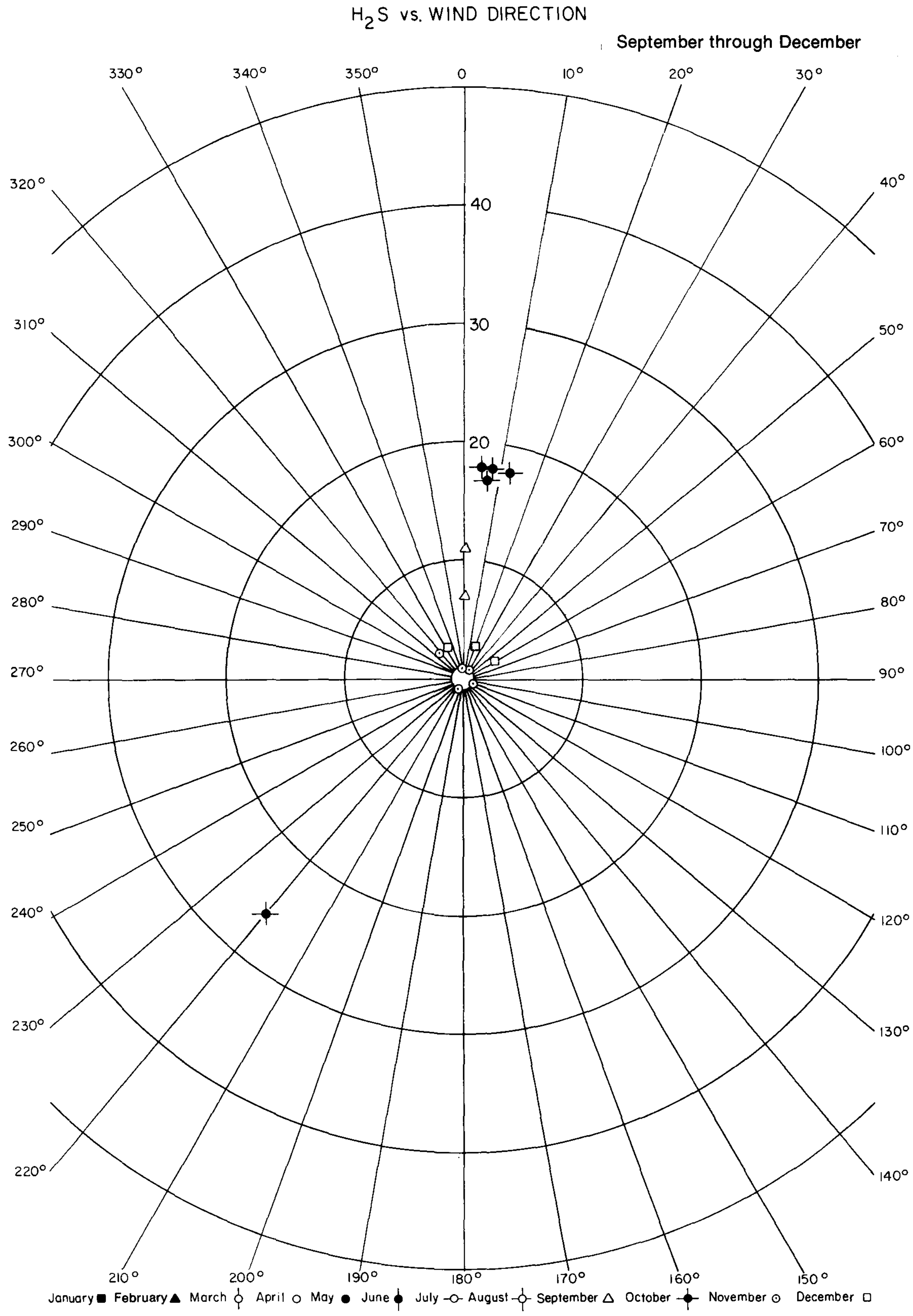

Figure 11d. Hydrogen sulfide. Five maximum 1-hour sliding averages per month in micrograms per cubic meter for September through December.

THE OBJECTIVE OF WATER QUALITY MONITORING IS TO PROVIDE AN UNDERSTANDING OF BASELINE WATER QUALITY AT THE GEOPRESSURED GEOTHERMAL TEST WELL SITE OF BOTH SURFACE WATER AND SHALLOW GROUND WATER.

Water chemistry of Chocolate Bayou is highly variable because mixing with marine waters of West Bay occurs in this part of the bayou.

Analyses of Chocolate Bayou waters are given in table 5. Water samples were collected monthly from the bayou surface and from just above the floor of the channel. Since November 1978, four sets of samples have been collected each month, two upstream and two downstream from the test well site.

Ionic concentrations were determined using an IL 651 atomic absorption spectrophotometer with a graphite furnace for flameless atomization. Owing to the complex matrix (salt water) of these samples, all values were obtained using the method of "standard additions," which eliminates interferences from the matrix.

Water samples from Chocolate Bayou are strongly influenced by marine waters from West Bay and consequently are brackish. The presence of a salt-water wedge along the floor of the bayou is indicated by consistently high salinities of bayou bottom samples and relatively low surface salinities. The salinity of surface samples varies from 26 to 6,529 mg/l for chloride and indicates that the degree of mixing with marine waters varies and that a wide range in salinities can be expected for bayou waters.

Analyses of shallow ground water in the vicinity of this test well site indicate only a minor influence from mixing with salt water.

Analyses of ground water from the Pleasant Bayou #1 and #2 test well site began in November 1978 and was continued throughout 1979 (table 6). Wells were drilled until appreciable flow of ground water was reached. Wells were then screened and lined with 4-inch (10 cm) PVC pipe. Monthly samples are being taken by installing a portable pump and pumping the well to remove all water standing in the pipe. Only then are samples collected. Sampling depths are approximately 40 ft (12.2 m) in each well (fig. 7).

Concentrations of sodium and chlorine in analyses of shallow ground water suggest that ground water is essentially fresh, being little influenced by salt intrusion from the Bayou. Salinity values from well #2 are higher possibly because well #2 lies closer to both West Bay and Chocolate Bayou than do monitoring wells #1 and #3 (fig. 7).

Table 5. Chocolate Bayou, water quality analyses.*

Lab. No.	79-45 79-52	79-44 79-51	79-47 79-54	79-46 79-53	79-164 79-168	79-165 79-169	79-166 79-170	79-167 79-171
Location	Bottom Upstream	Surface Upstream	Bottom Downstream	Surface Downstream	Bottom Upstream	Surface Upstream	Bottom Downstream	Surface Downstream
Date	1/79	1/79	1/79	1/79	2/79	2/79	2/79	2/79
Cl	20.7	49.9	18.8	51.2	41.0	44.0	42.0	43.0
SO_4	88.8	37.8	78.0	39.9	20.4	20.4	21.0	20.4
NO_3	2.3	0.3	3.5	2.9	0.27	<0.1	<0.1	<0.1
F	0.20	0.27	0.21	0.20	0.36	0.35	0.34	0.34
Na	210.0	57.0	230.0	74.0	30.5	31.2	30.7	29.6
K	11.5	4.85	12.0	6.0	2.83	2.83	2.97	2.94
Ca	37.4	30.3	34.7	30.5	21.7	22.1	21.4	21.0
Mg	26.4	9.3	23.2	9.6	6.35	6.31	6.32	6.31
SiO_2	5.88	6.92	5.79	6.48	11.0	11.0	11.3	11.3
B	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Mn	0.13	0.08	0.11	0.08	0.01	0.01	<0.01	<0.01
Pb	<0.02	0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
Cd	0.0024	0.008	0.0018	0.0026	0.0006	0.0007	0.0007	0.0010
Ba	0.37	0.32	0.32	0.32	0.12	0.14	0.12	0.12
As	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
NH_3	0.02	0.31	0.29	0.05	<0.01	0.22	0.19	0.24
Hg	0.027	0.001	<0.001	0.001	<0.001	0.001	<0.001	<0.001

*Data measured in milligrams per liter.

Table 5. Chocolate Bayou, water quality analyses. (continued)*

Lab. No.	79-288 79-295	79-287 79-294	79-290 79-297	79-289 79-296	79-343 79-350	79-342 79-349	79-345 79-352	79-344 79-351
Location	Bottom Upstream	Surface Upstream	Bottom Downstream	Surface Downstream	Bottom Upstream	Surface Upstream	Bottom Downstream	Surface Downstream
Date	3/79	3/79	3/79	3/79	4/79	4/79	4/79	4/79
Cl	1980.0	1730.0	2078.0	1720.0	52.6	59.2	53.4	53.4
SO_4	331.0	284.0	340.0	279.0	36.5	37.8	37.4	37.0
NO_3	< 0.05	< 0.05	<0.05	<0.05	1.3	1.6	1.3	1.5
F	0.46	0.44	0.48	0.44	0.20	0.22	0.20	0.20
Na	1360.0	1264.0	1414.0	1226.0	46.8	47.2	46.4	46.4
K	45.8	42.8	48.2	41.6	3.56	3.5	3.56	3.66
Ca	109.0	108.0	110.0	108.0	38.6	39.0	37.0	36.8
Mg	185.0	175.0	194.0	169.0	10.2	10.2	9.8	10.0
SiO_2	9.9	9.5	9.4	10.8	27.5	14.6	14.6	15.5
B	0.4	0.4	0.5	0.5	<0.1	<0.1	<0.1	<0.1
Mn	0.06	0.06	0.08	0.06	0.01	0.01	0.01	0.01
Pb	< 0.01	< 0.01	<0.01	<0.01	<0.01	<0.01	0.04	0.02
As	0.053	< 0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Ba	0.27	0.24	0.24	0.22	0.13	0.13	0.13	0.16
Cd	0.044	0.044	0.047	0.041	0.003	0.003	0.002	0.003
NH_3	0.21	0.17	0.05	0.06	0.30	0.19	0.26	0.37
Hg	0.0001	0.0005	0.0003	0.0002	0.0001	0.0004	<0.0001	0.0001

*Data measured in milligrams per liter.

Table 5. Chocolate Bayou, water quality analyses. (continued)*

Lab. No.	79-448 79-455	79-447 79-454	79-450 79-457	79-449 79-456	79-525 79-532 79-539	79-524 79-531 79-538	79-527 79-534 79-541	79-526 79-533 79-540
Location	Bottom Upstream	Surface Upstream	Bottom Downstream	Surface Downstream	Bottom Upstream	Surface Upstream	Bottom Downstream	Surface Downstream
Date	5/79	5/79	5/79	5/79	6/79	6/79	6/79	6/79
Cl	44.9	45.5	47.5	42.4	2590.0	222.0	2320.0	1130.0
SO_4	31.6	30.0	33.8	32.1	405.0	112.0	348.0	176.0
NO_3	1.15	1.10	0.69	0.25	0.22	1.55	0.13	0.69
F	0.20	0.21	0.19	0.19	0.33	0.24	0.30	0.26
Na	30.1	28.6	30.0	28.7	1780.0	401.0	1590.0	551.0
K	2.1	2.1	2.1	1.8	84.6	17.0	79.9	24.7
Ca	30.9	31.3	30.1	29.4	94.5	41.4	91.3	64.7
Mg	6.83	6.84	6.74	6.34	171.0	47.8	158.0	78.4
SiO_2	12.9	14.1	14.3	13.9	11.9	15.5	11.4	15.0
B	<0.1	<0.1	<0.1	<0.1	0.6	0.2	0.6	0.30
Mn	<0.1	<0.1	<0.1	<0.1	0.06	0.01	0.04	0.02
Pb	0.003	0.002	0.001	0.003	0.10	0.033	0.083	0.06
As	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050
Ba	0.10	0.09	0.10	0.09	0.19	0.15	0.17	0.12
Cd	0.003	0.003	0.002	0.003	0.066	0.018	0.06	0.03
NH_3	0.39	0.34	0.39	0.45	0.12	0.12	0.96	0.32
Hg	0.0003	<0.0001	0.0001	<0.0001	0.0004	0.0003	0.0001	0.0002

*Data measured in milligrams per liter.

Table 5. Chocolate Bayou, water quality analyses. (continued)*

Lab. No.	79-696	79-697	79-698	79-699	79-840	79-839	79-842	79-841
Location	Bottom Upstream	Surface Upstream	Bottom Downstream	Surface Downstream	Bottom Upstream	Surface Upstream	Bottom Downstream	Surface Downstream
Date	7/79	7/79	7/79	7/79	8/79	8/79	8/79	8/79
Cl	2066.0	110.0	1567.0	94.3	88.6	86.2	86.5	88.2
SO_4	217.0	33.5	297.0	36.1	30.3	31.2	30.3	30.0
NO_3	0.97	0.46	0.85	0.53	0.42	0.16	0.23	0.30
F	1.95	0.37	0.40	0.56	0.33	0.32	0.35	0.35
Na	610.8	72.7	773.0	87.1	67.1	67.4	66.1	67.5
K	28.0	6.0	38.6	6.5	5.2	5.4	5.2	5.4
Ca	84.3	41.1	90.3	40.6	40.9	41.9	40.5	41.6
Mg	97.3	12.48	123.2	13.07	11.45	11.45	11.81	11.5
SiO_2	16.3	18.6	13.8	17.5	12.4	12.3	14.3	11.9
B	0.856	0.089	0.359	0.123	0.12	0.19	<0.10	<0.10
Mn	0.07	<0.01	0.15	<0.01	<0.01	<0.01	<0.01	<0.01
Pb	0.085	0.022	0.106	0.020	0.004	0.005	0.005	0.006
As	11.3	2.7	2.7	2.2	7.0	9.4	7.3	11.9
Ba	0.14	0.18	0.15	0.13	0.277	0.248	0.303	0.22
Cd	0.026	0.003	0.033	0.003	0.004	0.004	0.004	0.004
NH_3	0.21	0.03	0.33	0.13	0.07	0.19	<0.01	0.04
Hg	8.0	0.7	1.8	3.0	0.5	0.3	0.2	0.3

*Data measured in milligrams per liter.

Table 5. Chocolate Bayou, water quality analyses. (continued)*

Lab. No.	79-845	79-853	79-856	79-855	79-1036	79-1035	79-1038	79-1037
Location	Bottom Upstream	Surface Upstream	Bottom Downstream	Surface Downstream	Bottom Upstream	Surface Upstream	Bottom Downstream	Surface Downstream
Date	9/79	9/79	9/79	9/79	10/79	10/79	10/79	10/79
Cl	20.8	26.0	13.8	13.8	4113.5	951.9	4087.4	1170.6
SO_4	6.0	6.6	6.6	5.7	303.9	133.9	315.1	149.4
NO_3	0.16	1.34	0.56	<0.01	<0.01	0.42	0.42	0.12
F	0.14	0.19	0.19	0.14	0.39	0.32	0.39	0.29
Na	11.8	11.6	12.1	11.3	1656.5	425.7	1677.0	866.0
K	4.0	4.1	4.0	4.1	95.8	20.0	96.5	22.7
Ca	9.7	9.4	9.1	9.6	121.4	54.6	99.2	62.0
Mg	1.64	1.8	1.83	1.71	187.55	70.68	188.15	83.35
SiO_2	2.8	2.4	5.0	2.8	22.3	25.4	24.0	28.1
B	<0.10	0.11	<0.10	<0.10	0.35	0.27	0.51	0.32
Mn	0.02	0.02	0.02	0.02	0.22	<0.01	0.25	<0.01
Pb	0.004	0.006	0.006	0.003	0.003	0.003	0.008	0.004
As	11.4	16.5	6.1	3.9	20.5	14.9	11.6	12.6
Ba	0.064	0.06	0.089	0.074	0.295	0.264	0.384	0.306
Cd	<0.001	<0.001	<0.001	<0.001	0.06	0.012	0.072	0.015
NH_3	<0.01	<0.01	<0.01	0.43	<0.01	<0.01	<0.01	<0.01
Hg	0.4	0.6	0.3	0.4	<0.1	0.1	0.1	0.2

*Data measured in milligrams per liter.

Table 5. Chocolate Bayou, water quality analyses. (continued)*

Lab. No.	79-1088	79-1087	79-1090	79-1089	79-1157	79-1156	79-1159	79-1158
Location	Bottom Upstream	Surface Upstream	Bottom Downstream	Surface Downstream	Bottom Upstream	Surface Upstream	Bottom Downstream	Surface Downstream
Date	11/79	11/79	11/79	11/79	12/79	12/79	12/79	12/79
Cl	6123.1	3027.9	6529.3	3090.3	4930.9	4690.9	4967.3	4720
SO_4	366.2	278.6	378.1	283.7	333.8	321.4	333.1	329.2
NO_3	0.27	0.52	0.07	0.09	<0.01	0.50	0.11	<0.01
F	0.50	0.42	0.50	0.38	0.68	0.66	0.66	0.66
Na	3633	1815	3898	1854	2883	2763	3012	2814
K	121	59.6	131	61.6	109.2	107.6	110.0	108.2
Ca	170	122	177	124	142.0	140.4	142.0	140.7
Mg	430	214	461	222	336.6	295.8	343.7	317.5
SiO_2	4.2	8.8	3.3	8.8	7.8	8.7	7.6	7.8
B	0.55	0.30	1.0	0.10	0.87	1.03	0.93	0.87
Mn	0.08	0.24	0.07	0.22	0.02	0.01	0.02	0.02
Pb	0.009	0.003	0.002	0.003	0.002	<0.001	0.002	0.002
As	8.1	3.7	1.5	4.5	6.5	8.2	9.5	4.7
Ba	0.305	0.318	0.301	0.290	0.978	1.087	0.100	0.891
Cd	0.105	0.049	0.110	0.052	0.108	0.104	0.096	0.104
NH_3	0.24	0.43	0.23	0.32	<0.01	<0.01	< 0.01	<0.01
Hg	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	< 0.1	<0.1

*Data measured in milligrams per liter.

Table 6. Pleasant Bayou geothermal test well area, shallow ground-water analyses*

Lab. No.	79-48 79-55	79-49 79-56	79-50 79-57	79-187 79-190	79-188 79-191	79-189 79-192
Location	Well #1	Well #2	Well #3	Well #1	Well #2	Well #3
Date	1/79	1/79	1/79	2/79	2/79	2/79
Cl	56.1	125.7	89.1	143.0	207.0	154.0
SO_4	23.4	26.4	24.3	29.4	25.5	21.3
NO_3	<0.1	<0.1	<0.1	0.20	0.38	0.15
F	0.44	0.32	0.55	0.56	0.38	0.56
Na	103.0	190.0	92.0	174.0	214.0	90.0
K	1.05	1.60	2.65	2.0	2.1	3.2
Ca	92.8	118.0	113.0	99.0	139.0	125.0
Mg	14.6	19.5	27.8	19.8	23.0	28.3
SiO_2	10.8	13.0	11.3	20.8	23.3	20.3
B	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Mn	0.08	0.26	0.63	0.09	0.22	0.57
Pb	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
Ba	0.55	0.71	0.62	0.21	0.38	0.28
NH_3	0.07	0.22	0.13	<0.01	0.02	0.09
Hg	<0.001	0.001	<0.001	<0.001	<0.001	<0.001
As	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Cd	0.0015	0.0012	0.0016	0.0005	0.0002	Nil

*Data measured in milligrams per liter.

Table 6. Pleasant Bayou geothermal test well area, shallow ground-water analyses (cont.)*

Lab. No.	79-291 79-298	79-292 79-299	79-293 79-300	79-346 79-353	79-347 79-354	79-348 79-355
Location	Well #1	Well #2	Well #3	Well #1	Well #2	Well #3
Date	3/79	3/79	3/79	4/79	4/79	4/79
Cl	174.0	284.0	141.0	122.0	375.0	129.0
SO_4	29.9	28.6	23.8	26.0	26.4	20.2
NO_3	<0.05	0.45	<0.05	<0.01	<0.01	<0.01
F	0.42	0.26	0.36	0.37	0.22	0.34
Na	167.0	195.0	104.0	121.0	198.0	75.2
K	<0.6	1.0	2.4	1.04	1.42	2.52
Ca	84.6	117.0	101.0	93.0	119.0	113.0
Mg	16.6	21.6	28.2	16.4	22.2	28.8
SiO_2	18.5	23.3	23.6	18.2	22.2	19.9
B	<0.5	<0.5	<0.5	<0.1	<0.1	<0.1
Mn	0.09	0.24	0.52	0.13	0.39	0.63
Pb	<0.01	0.04	0.11	0.06	0.07	0.05
Ba	0.14	0.26	0.23	0.22	0.39	0.25
NH_3	0.10	0.05	0.08	0.01	0.02	0.01
Hg	0.0003	0.0013	0.0003	<0.0001	<0.0001	<0.0001
As	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Cd	0.008	0.011	0.008	0.007	0.009	0.006

*Data measured in milligrams per liter.

Table 6. Pleasant Bayou geothermal test well area, shallow ground-water analyses (cont.)*

Lab. No.	79-451 79-458	79-452 79-459	79-453 79-460	79-528 79-535 79-542	79-529 79-536 79-543	79-530 79-537 79-544
Location	Well #1	Well #2	Well #3	Well #1	Well #2	Well #3
Date	5/79	5/79	5/79	6/79	6/79	6/79
Cl	104.0	273.0	154.0	103.0	287.0	139.0
SO_4	26.6	33.4	22.9	18.6	26.6	18.6
NO_3	<0.01	<0.01	<0.01	<0.01	0.06	<0.01
F	0.35	0.19	0.30	0.33	0.21	0.29
Na	97.5	180.0	57.9	97.0	206.0	69.7
K	<0.5	1.0	1.5	2.1	3.50	4.4
Ca	91.8	122.0	113.0	97.7	106.0	105.0
Mg	13.0	19.5	22.9	12.7	20.2	23.9
SiO_2	18.2	22.6	21.2	20.1	23.7	22.0
B	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Mn	0.11	0.28	1.03	0.04	0.15	0.38
Pb	0.003	0.015	0.010	0.038	0.043	0.033
Ba	0.23	0.40	0.29	0.43	0.40	0.19
NH_3	0.14	0.15	0.15	<0.01	0.07	0.11
Hg	0.0002	0.0001	0.0002	0.0002	0.0002	0.0001
As	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Cd	0.007	0.011	0.009	0.008	0.013	0.007

*Data measured in milligrams per liter.

Table 6. Pleasant Bayou geothermal test well area, shallow ground-water analyses (cont.)*

Lab. No.	79-700	79-701	79-702	79-836	79-837	79-838
Location	Well #1	Well #2	Well #3	Well #1	Well #2	Well #3
Date	7/79	7/79	7/79	8/79	8/79	8/79
Cl	114.0	311.0	158.0	103.8	292.4	145.7
SO_4	19.4	29.9	17.7	16.5	31.2	16.8
NO_3	<0.01	<0.01	0.14	0.39	0.27	<0.01
F	0.38	0.27	0.31	0.42	0.21	0.33
Na	157.9	196.6	99.6	101.0	206.3	83.2
K	3.5	4.8	5.8	2.7	3.7	4.0
Ca	96.3	159.1	104.1	28.9	36.9	101.2
Mg	13.39	19.99	22.95	12.25	19.20	21.9
SiO_2	20.0	25.0	22.5	16.5	21.9	19.9
B	0.127	0.13	0.047	0.17	0.21	0.17
Mn	0.05	0.30	0.63	0.08	0.30	2.8
Pb	0.037	0.055	0.044	0.005	0.005	0.004
Ba	0.18	0.30	0.20	0.295	0.439	0.330
NH_3	0.08	0.12	0.07	<0.01	0.11	0.65
Hg	0.5	0.7	0.9	0.2	0.3	0.3
As	<1.0	1.5	6.6	7.7	0.7	27.4
Cd	0.006	0.009	0.006	0.006	0.011	0.006

*Data measured in milligrams per liter.

Table 6. Pleasant Bayou geothermal test well area, shallow ground-water analyses (cont.)*

Lab. No.	79-867	79-868	79-869	79-1039	79-1040	79-1041
Location	Well #1	Well #2	Well #3	Well #1	Well #2	Well #3
Date	9/79	9/79	9/79	10/79	10/79	10/79
Cl	294.1	148.8	110.7	112.6	293.6	142.4
SO_4	31.5	16.8	17.0	20.9	36.4	19.7
NO_3	<0.01	0.26	0.16	0.03	0.27	0.15
F	0.20	0.23	0.33	0.35	0.27	0.28
Na	197.1	78.4	103.5	96.9	161.3	73.1
K	3.7	3.8	2.1	2.6	4.0	4.2
Ca	95.2	99.8	64.8	64.4	103.0	102.2
Mg	19.96	22.17	13.36	13.54	19.02	20.7
SiO_2	24.0	24.2	19.0	45.2	46.6	44.9
B	0.39	<0.10	0.12	0.17	0.16	0.06
Mn	0.30	2.53	0.06	0.08	0.28	0.45
Pb	0.003	0.002	0.003	.002	0.002	0.001
Ba	0.514	0.341	0.343	0.347	0.551	0.447
NH_3	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Hg	0.2	0.3	0.5	<0.1	<0.1	<0.1
As	18.9	34.4	1.6	3.9	21.3	36.3
Cd	0.009	0.006	0.009	0.005	0.007	.005

*Data measured in milligrams per liter.

Table 6. Pleasant Bayou geothermal test well area, shallow ground-water analyses (cont.)*

Lab. No.	79-1091	79-1092	79-1093	79-1160	79-1161	79-1162
Location	Well #1	Well #2	Well #3	Well #1	Well #2	Well #3
Date	11/79	11/79	11/79	12/79	12/79	12/79
Cl	121.3	301.4	176.5	110.9	288.7	145.5
SO_4	19.0	32.1	18.6	18.7	27.2	19.5
NO_3	<0.01	0.06	0.03	<0.01	0.80	0.55
F	0.40	0.28	0.32	0.74	0.41	0.42
Na	103.8	175.1	80.5	176.2	258.4	130.3
K	2.5	4.3	4.1	2.8	3.8	4.0
Ca	74.5	134.1	130.6	101.4	126.1	122.5
Mg	15.7	23.1	24.9	14.11	21.13	23.24
SiO_2	18.8	24.4	22.1	21.2	22.7	22.3
B	0.05	0.05	0.10	0.07	0.08	0.06
Mn	0.09	0.29	0.42	0.07	0.28	0.32
Pb	0.002	<0.001	0.001	<0.001	<0.001	0.002
Ba	0.265	0.403	0.335	0.674	0.978	0.698
NH_3	0.01	0.09	0.06	<0.01	<0.01	<0.01
Hg	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
As	3.8	3.5	8.6	8.2	9.3	6.6
Cd	0.005	0.008	0.005	0.007	0.011	0.008

*Data measured in milligrams per liter.

FLOODING AT THE PLEASANT BAYOU #1 AND #2

During flooding following Hurricane Claudette, Pleasant Bayou #2 was covered by approximately 2 ft (60 cm) of water. Hurricane Claudette made landfall on the Texas Gulf Coast after being downgraded to a tropical storm. The storm poured up to 26 inches (66 cm) of rain onto areas adjacent to the coast and caused extensive flooding of low-lying areas in Brazoria County.

Chocolate Bayou recorded the highest level of flooding in the county. The level of flooding on the bayou 5 mi (8 km) northwest of the test well was approximately 22 ft (6.7 m) above a normal high-water level, resulting in about 2 ft (60 cm) of overbank. Near Liverpool, flood level was 15 ft (4.6 m) above normal, or between 1 and 5 ft (0.3 and 1.5 m) overbank. Across from the test well, water level was about 11 ft (3.35 m) above normal, or 11 ft (3.35 m) above mean sea level. This is approximately 2.5 ft (0.76 m) above the test well site, which lies 8.5 ft (2.59 m) above sea level. The geothermal test well site lies well within the 100-year floodplain of Chocolate Bayou (White and others, 1978), and probably lies partly within the 10-year floodplain.

Eyewitness Accounts

The rain began Wednesday afternoon (July 25) at about 3 p.m. Chocolate Bayou went over its banks between 11 p.m. and midnight Wednesday, and the water rose rapidly Wednesday night and all day Thursday, reaching its highest level at 6 to 7 a.m. Friday. At the test well site, the bayou was 11 ft, 4 inches (3.45 m) above a normal water level. By Friday morning the water was about 2 ft (61 cm) over the drilling platform. Only two bulldozers and a pickup truck were slightly damaged by water in their engines and transmissions.

Rainfall records from the National Weather Service, Alvin Station, for Houston and surrounding stations are as follows:

Wednesday, July 25
Alvin received 4.5 inches (11.4 cm) before 4 p.m.

Thursday, July 26

Alvin	21.25 inches	(54 cm)	Period from 4 p.m. Wed. to Thurs. evening
Cleveland	1.52	(3.86)	
Conroe	1.12	(2.84)	
Lake Conroe	0.46	(1.17)	
Liberty	12.00	(30.84)	
Livingston	2.35	(5.97)	
Intercont. Airport	2.73	(6.93)	
Alief	1.25	(3.18)	
Heights	2.05	(5.21)	
San Jacinto Dam	7.78	(19.76)	
Spring Branch	1.56	(3.96)	
Westbury	3.65	(9.27)	

Friday, July 27

Alvin	0.70	(1.78)

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