Annual Report

Volume I

ENVIRONMENTAL BASELINE MONITORING IN THE AREA OF GENERAL CRUDE OIL--DEPARTMENT OF ENERGY PLEASANT BAYOU NUMBER 1--A GEOPRESSURED-GEOTHERMAL TEST WELL--1978

by

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INTRODUCTION AND TECHNICAL REPORT

Prepared for

The U. S. Department of Energy, Division of Geothermal Energy
Provided by Contract Number DE-AS05-77ET27031
(formerly EG-77-S-05-5401)

Bureau of Economic Geology
The University of Texas at Austin
W. L. Fisher, Director

1979

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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 well, Pleasant Bayou #1 and #2 has been underway since March 1978 (fig. 1). The findings of certain portions 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 and M University have been reported earlier and will not be repeated here. The following report contains a description of baseline air and water quality of the test well site, a noise survey, an inventory of microseismic activity including interpretations of the origin of the events, and a discussion of progress in the installation of a liquid tilt meter at the test well site. In addition, the first-order leveling survey recently completed by the National Geodetic Survey is briefly discussed. This survey has allowed the calculation of local baseline subsidence rates.

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-rocks 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.

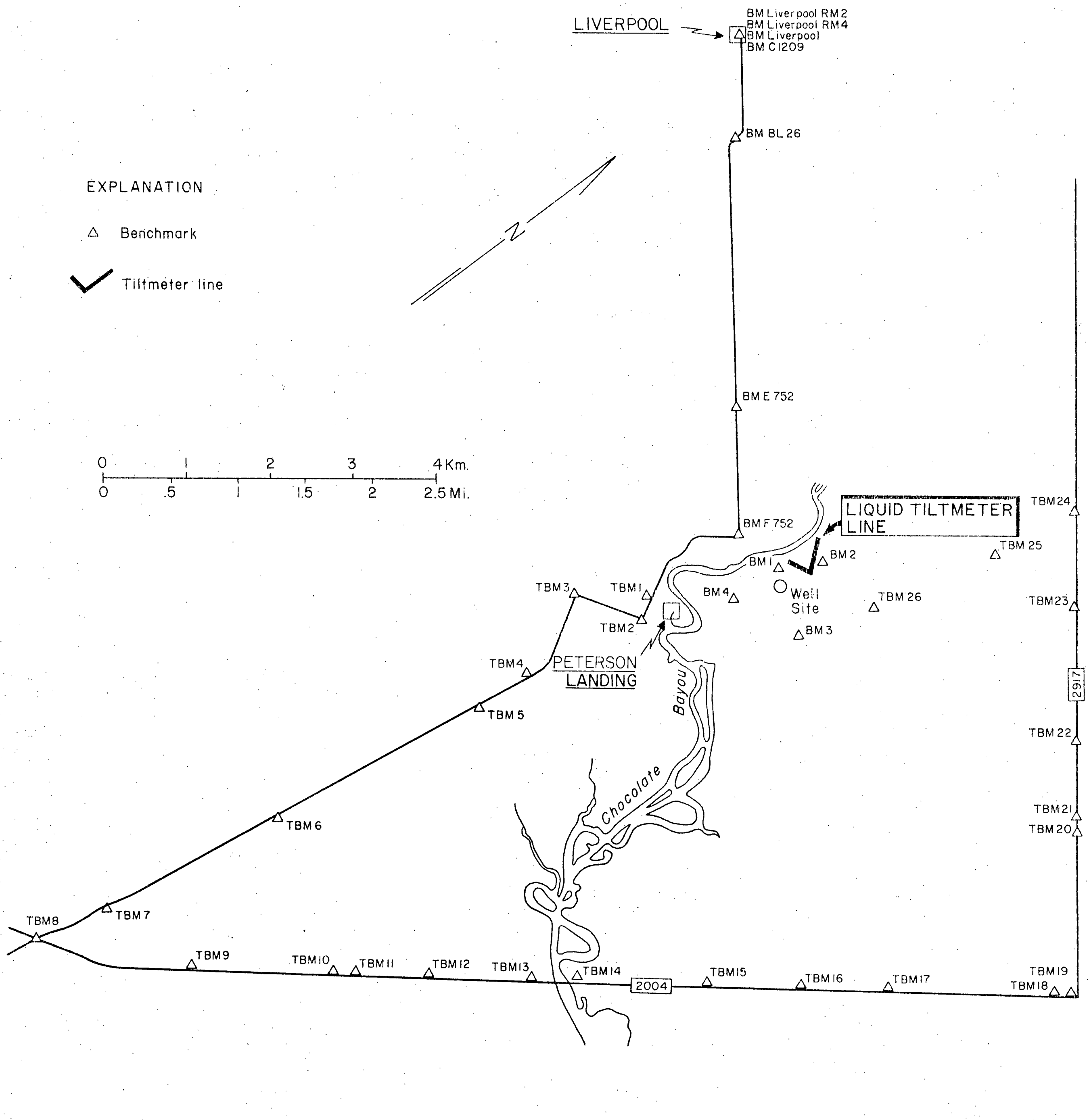

Figure 1. Location of Department of Energy-General Crude Oil Corporation-Pleasant Bayou #1 geothermal test well and environmental monitoring facilities.

Concurrent with 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 of these parameters will continue to be monitored throughout 1979.

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 OF GEOTHERMAL FLUIDS HAVE INDUCED SUBSIDENCE OR FAULTING.

Microseismic monitoring in the vicinity of Pleasant Bayou #1 and #2 indicates that there is no evidence of naturally occurring seismic activity of local magnitudes 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. At the present time, production rates from a single test well may be as high as 10^4 barrels 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 10^6 cubic meters. 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. Based upon 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 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 preexisting and newly created fracture plans, thus releasing part of the stored strain energy as seismic waves. Since the release of seismic energy can potentially pose 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 portion of this report is to summarize the principal results obtained from September through December 1978 from the operation of a semipermanent microseismic monitoring network installed near the test well site.

Results

From September through December several hundred microseismic events were recorded in the vicinity of the test well site (see Appendix I). The arrival times of these events at each station in the array and their maximum amplitudes and the coordinates of their sources, when they could be determined, were routinely tabulated. However, the emergent character of these signals made it difficult to estimate the onset times of the compressional and shear waves with a precision sufficient to justify computation of the coordinates of the source. Unfortunately this was a characteristic common to most of the events observed. Therefore, precise estimation of source coordinates was not possible.

The microseismic data observed to date also share other common characteristics that permit classification of the occurrence as being the result of either natural processes or human activites. For example, all observed activity occurred exclusively during normal working hours. Since the seismicity resulting from natural processes is not likely to suffer from such a constraint, this behavior indirectly indicates that the observed activity is the result of human activities. Similarly, the frequency of occurrence of events within a given suite, as well as the distribution of local magnitudes as a function of the cumulative number of occurrences, provide additional indirect evidence for a culturally derived source mechanism such as a seismic survey.

First-order leveling surveys in the vicinity of Liverpool and Chocolate Bayou, Texas, indicate a range in subsidence of 0.771 to 1.224 ft since 1942 and a mean subsidence rate of 0.029 ft per year.

A first-order leveling survey in the vicinity of Chocolate Bayou and Pleasant Bayou #1 was completed during 1978. The results and details of this effort were submitted in early 1978. The National Geodetic Survey (NGS) recently completed a first-order leveling survey through Liverpool and Pleasant Baytou #1. Figure 1 shows the location of benchmarks in the vicinity of the test well. The completion of the National Geodetic Survey first-order lines, which includes one of the benchmarks in the Teledyne Geotronics Survey (BM F 752), allows the determination of the absolute elevation of all benchmarks including the test well along the Teledyne line of survey. Of greater importance is that the 1978 NGS data allow the determination of baseline amounts and rates of subsidence in the vicinity of Pleasant Bayou #1 and #2 (table 1). Data from seven benchmarks provide 15 references points for determining annual rates of subsidence with a range from 0.005 to 0.066 ft/yr. In only two instances are slight increases in elevation indicated between 1973 and 1978 for benchmarks Liverpool Rm 2 and C 1209. For these data the mean rate of subsidence is 0.029 (Std. Dev. 0.016 ft/yr) ft/yr.

Comparison of the Teledyne Geotronics survey to the National Geodetic Survey results indicates that the ground level elevation of the test well, Pleasant Bayou #1, is only 7.81 ft above sea level. By visual comparison, Pleasant Bayou #2 differs little in elevation from Pleasant Bayou #1. Mud pits for both wells lie lower than the elevation of Pleasant Bayou #1 or #2, approximately 5 to 6 ft above sea level.

Table 1. Benchmark Elevations

Liverpool, Texas

Benchmark	1942-3	1950-1	1958-9	1963-4	1957	1973	1978	Elevation Change
Liverpool Rm 2	20.751[1]	20.538	20.394	20.374	-	19.780	19.9802	- .7708
C 1209	-	-	-	-	-	19.308	19.4899	+ .182
Liverpool Rm 4	-	-	-	-	-	18.592	18.7657	- .391
Liverpool	19.692	19.439	19.134	19.081	-	18.592	18.4688	-1.224
E 752	-	-	-	-	17.926	-	17.5342	- .3918
F 752	-	-	-	-	18.337	-	17.8915	- .4455
BL 26	-	-	-	-	16.109	-	15.5878	- .521

Annual Rates Of Subsidence

Liverpool Rm 2	-	.0304	.0206	.005	-	.066	-
C 1209	-	-	-	-	-	-	-
Liverpool Rm 4	-	-	-	-	-	-	.033
Liverpool	-	.032	.044	.013	-	.049	.025
E 752	-	-	-	-	-	-	.017
F 752	-	-	-	-	-	-	.021
BL 26	-	-	-	-	-	-	.025

[1] elevation in feet

A multiliquid tilt meter is under construction in order to discern short-term increases in the regional subsidence rate induced by fluid withdrawal at the test well site.

Several months delay in the construction of a multiliquid tilt meter resulted from inavailability of tubing. Additional delay occurred when tubing purchased to construct the tilt meter was found to be permeable with respect to one of the heavy liquids used in the meter. A different liquid was substituted and appears to work satisfactorily. Piers to mount micrometer housings along the line of the tilt meter are in place in the field (fig. 2). Following additional testing and a period of dry weather, the liquid tilt meter will be installed and should be operational by late April 1979.

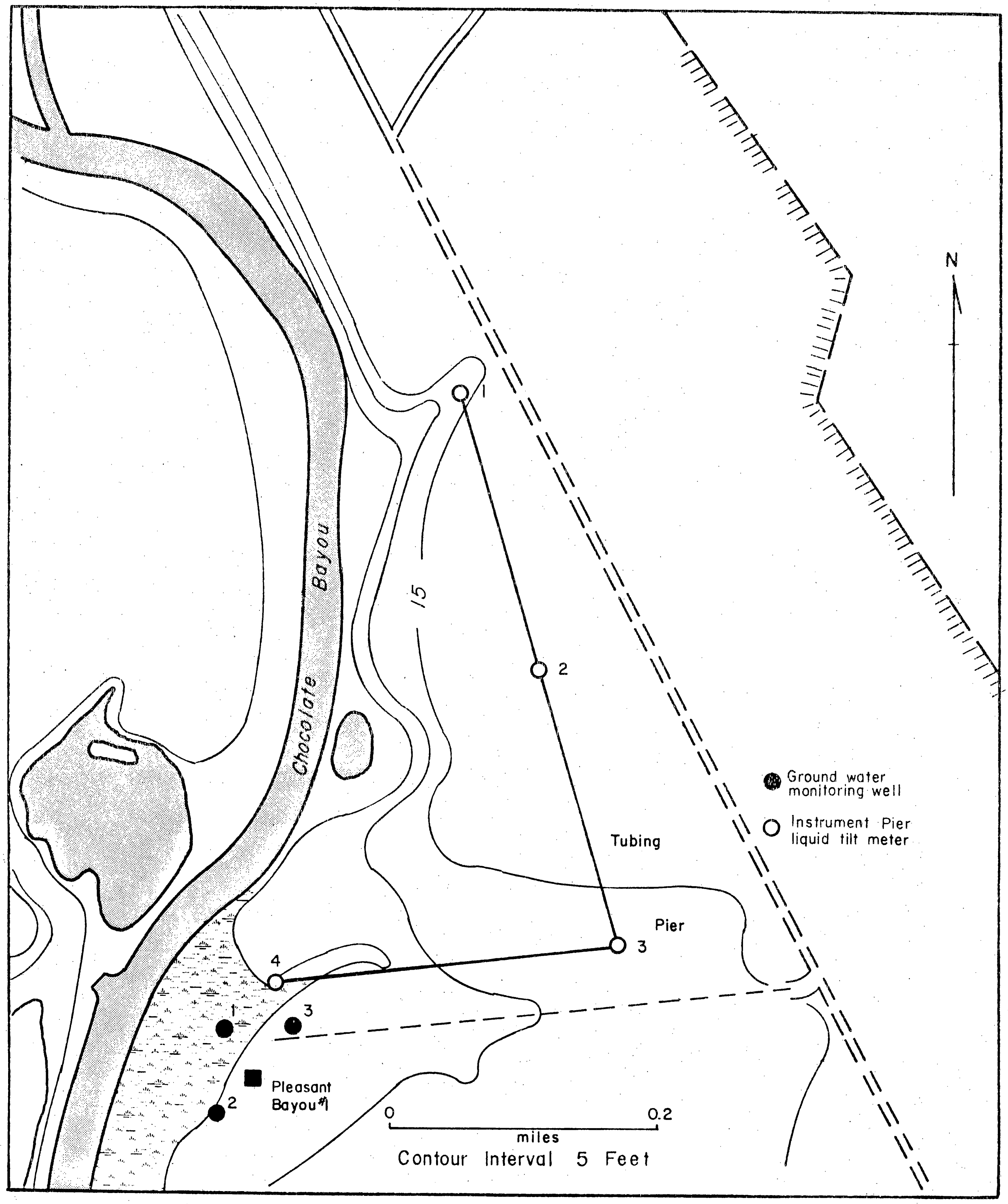

Figure 2. Location of ground-water monitoring wells and multiliquid tilt meter line.

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.

Four air quality parameters--particulates, sulfur dioxide, methane, and hydrogen sulfide--are 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. 3, and 4a, b, c and d). National standards are not available at this time for methane and hydrogen sulfide (figs. 5a, b, c, and 6a, b, c and d).

Data summarized in figures 3 through 6 were collected by Radian Corporation at a point approximately one half mile northwest of the test well site (see Appendix II for data acquired and for descriptions of instrument systems and sampling program).

The data presented in figures 3 through 6 provide an adequate baseline assessment for air quality in the vicinity of the test well. During 1978, however, budgetary limitations prevented the acquisition of on-site wind velocity and direction data. Consequently, wind direction data were obtained from the climatic data for Houston, and the wind directional data in figures 3 through 6 are used assuming that mean daily wind directions at Houston and at the test well site are not likely to differ substantially. In January 1979, an automated climate recording station was installed at the test well site to provide on-site wind direction and velocity data.

Casual analysis of figures 3 through 6 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 have some effect on air quality when winds are from the southeast. Composition of emissions from

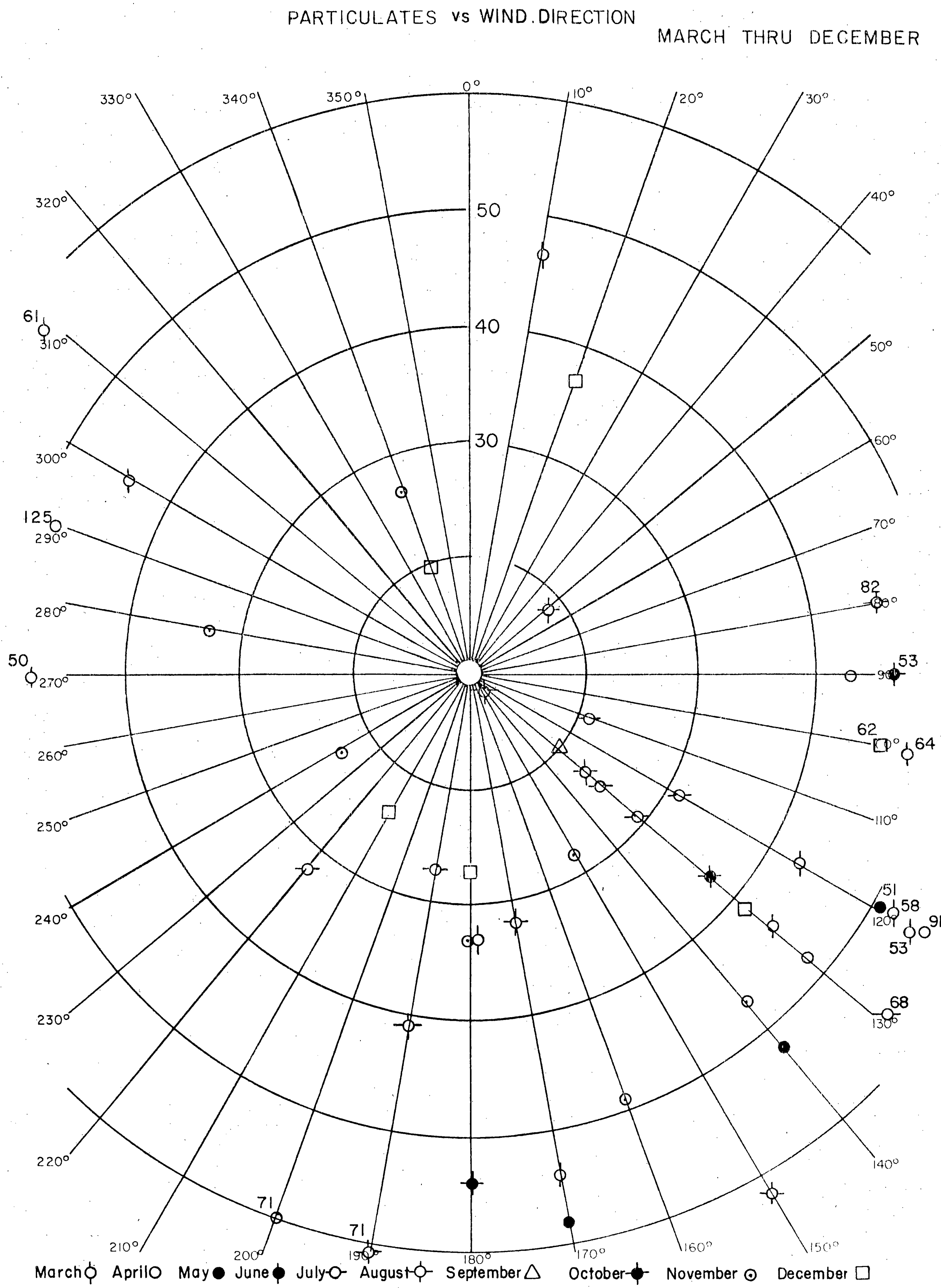

Figure 3. Particulate concentrations are in micrograms per cubic meter.

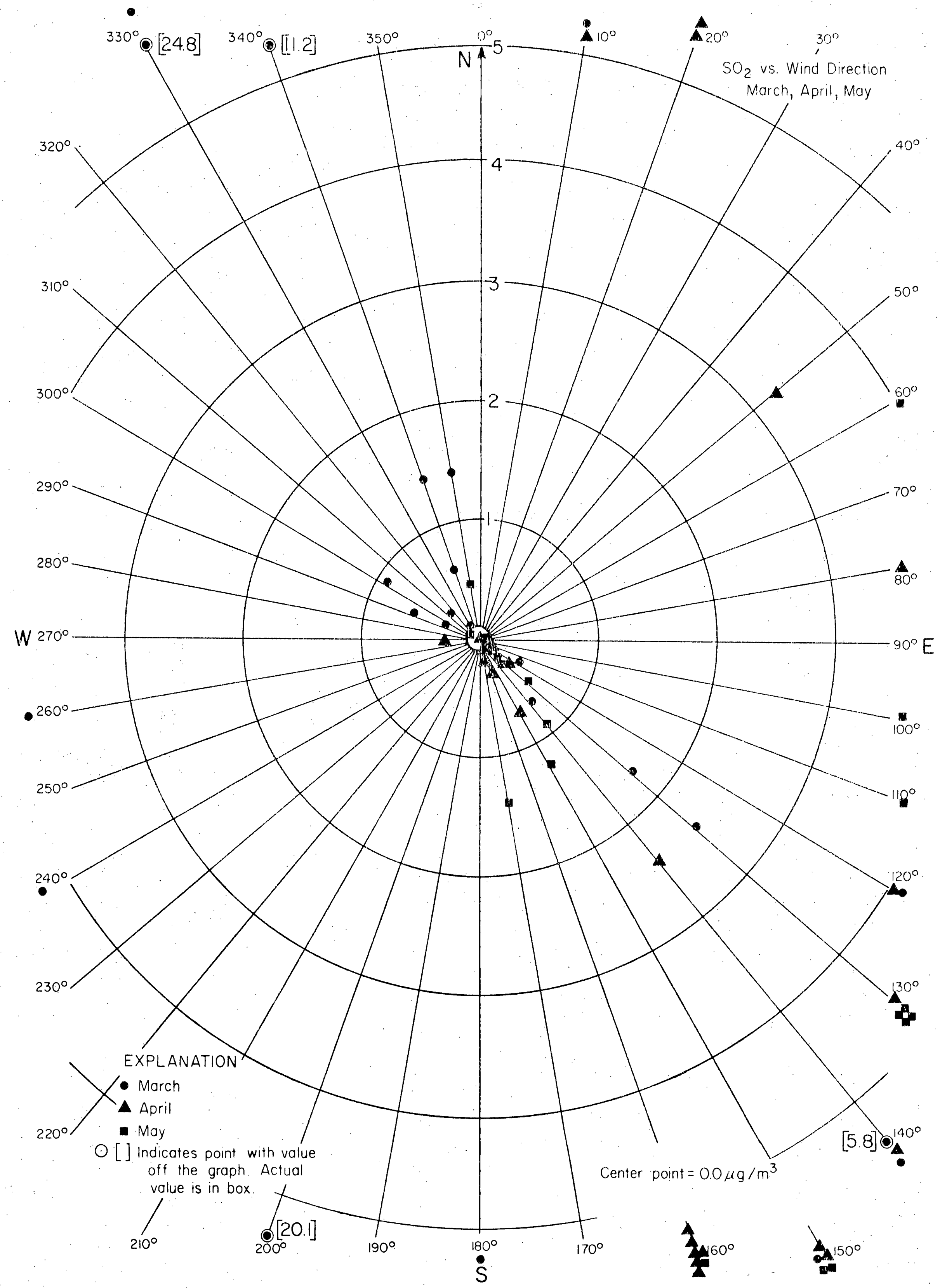

Figure 4a. Sulfur dioxide concentrations are in micrograms per cubic meter.

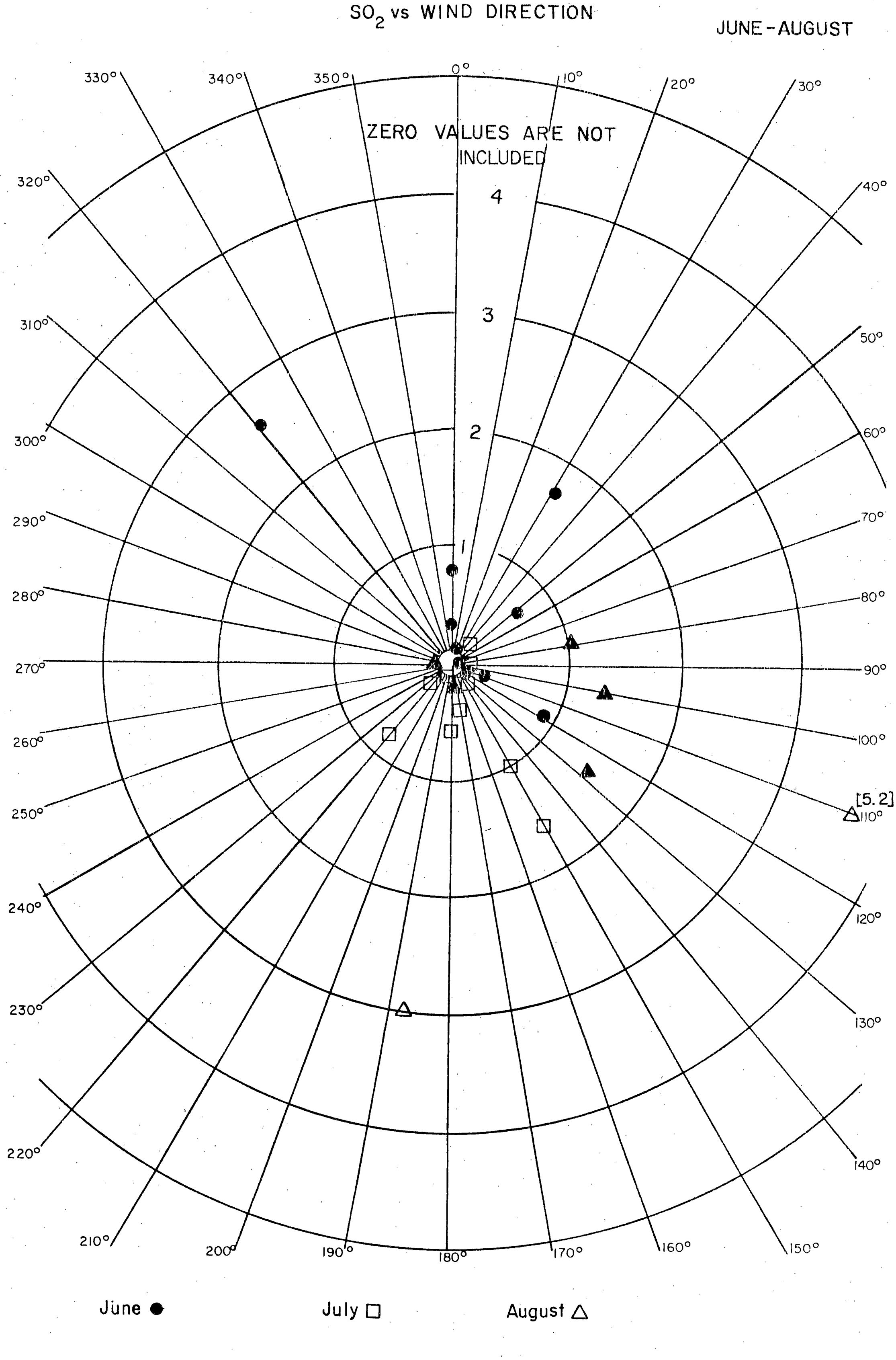

Figure 4b. Sulfur dioxide concentrations are in micrograms per cubic meter.

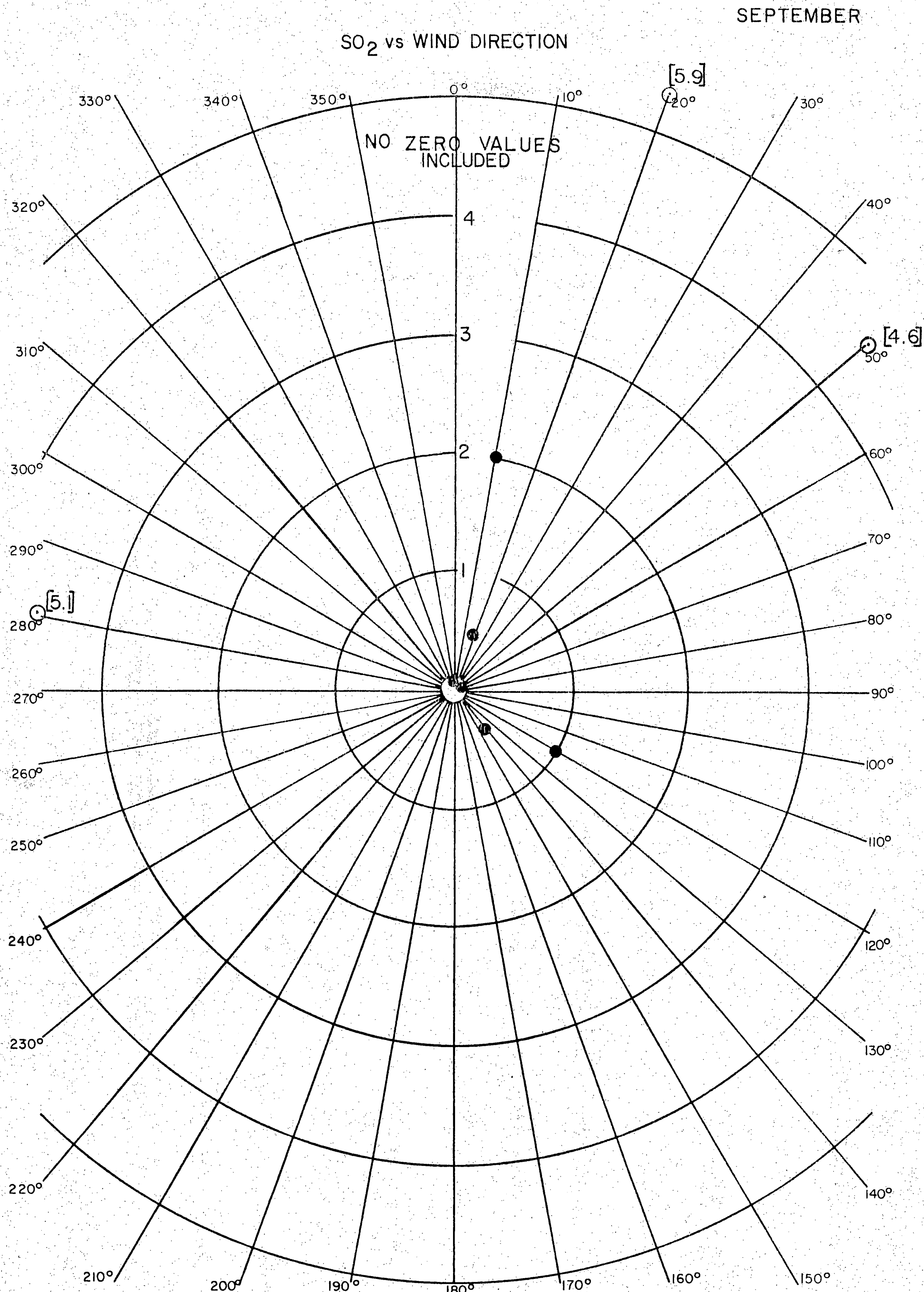

Figure 4c. Sulfur dioxide concentrations are in micrograms per cubic meter.

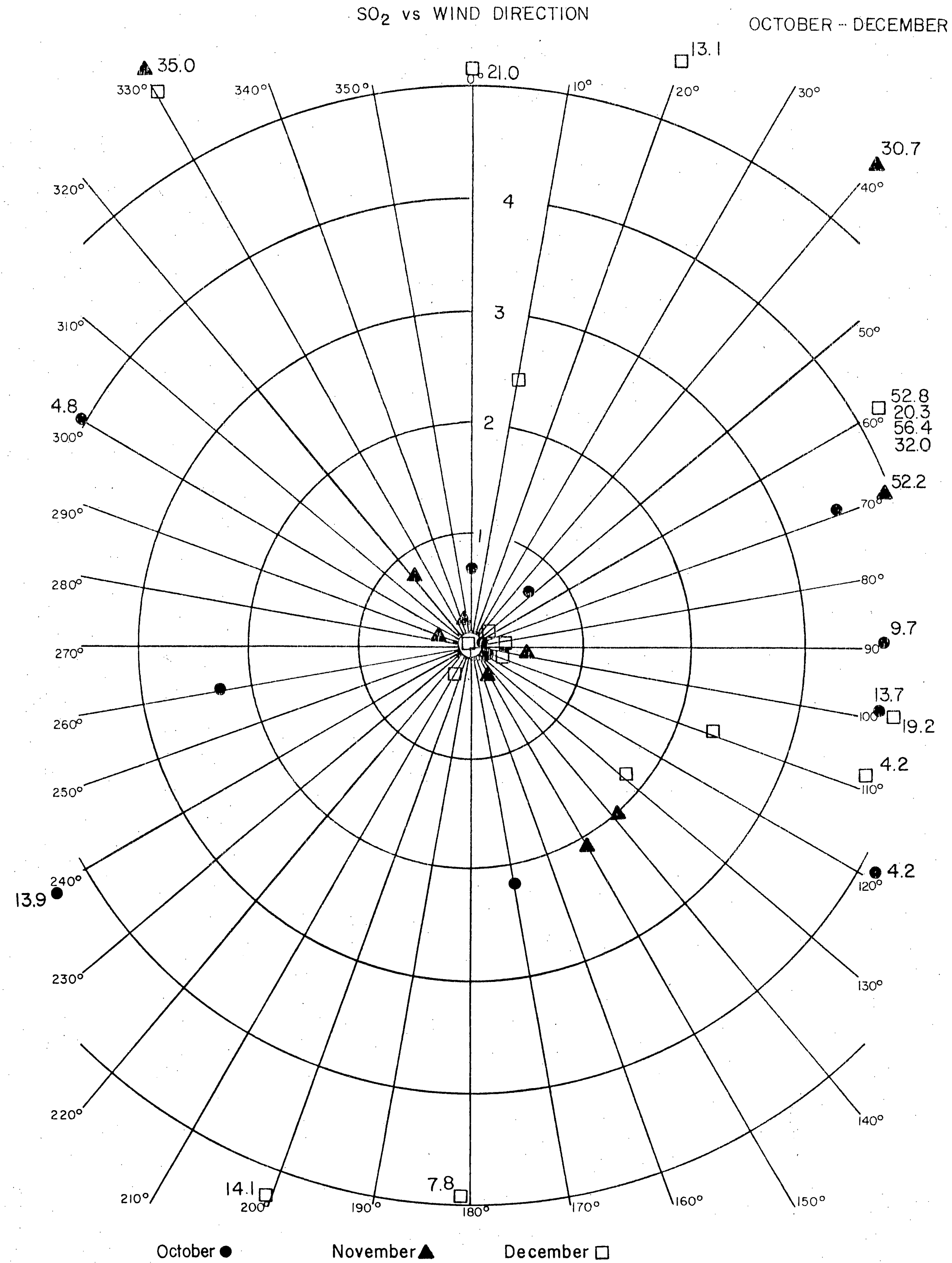

Figure 4d. Sulfur dioxide concentrations are in micrograms per cubic meter.

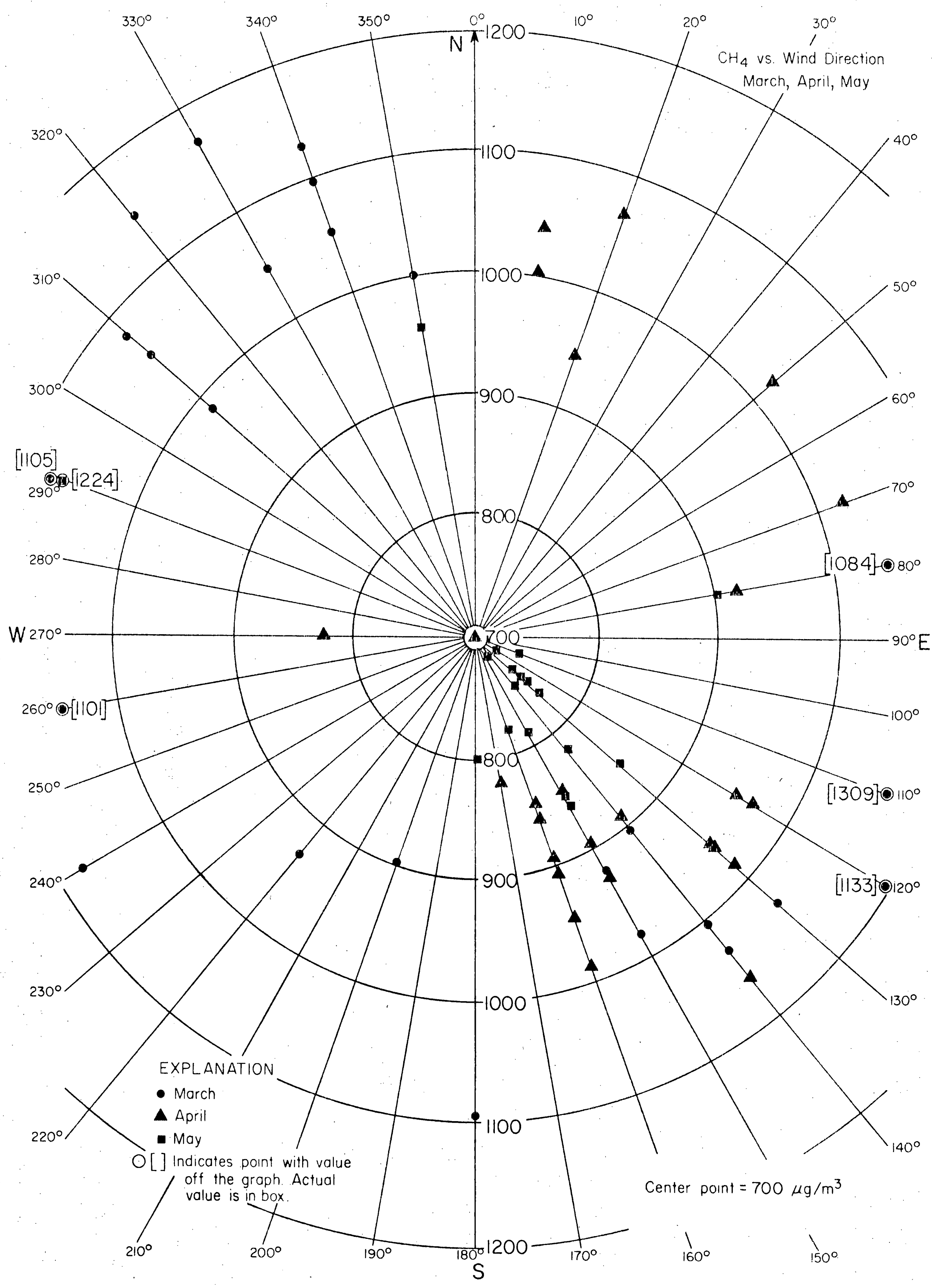

Figure 5a. Methane concentrations in micrograms per cubic meter.

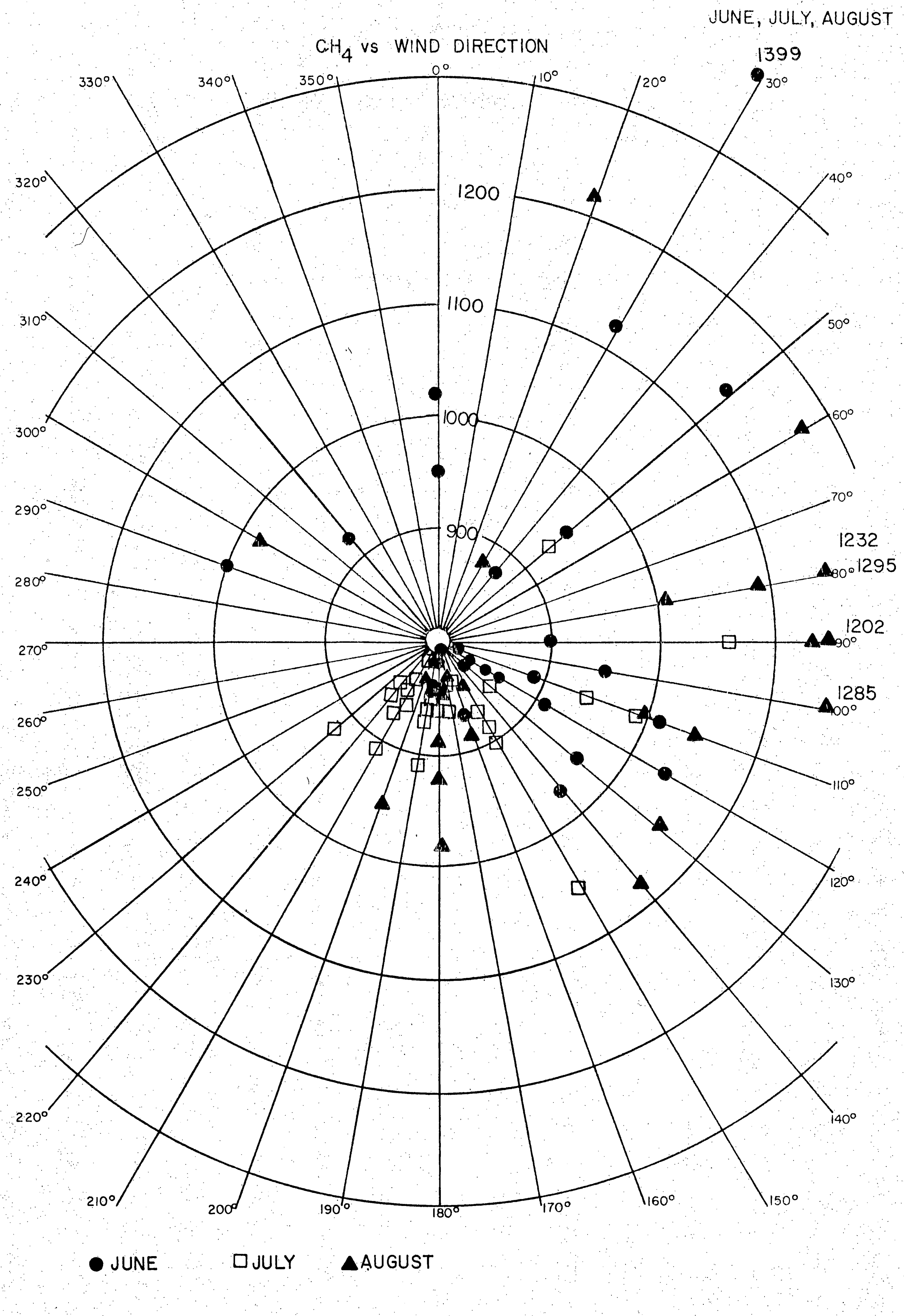

Figure 5b. Methane concentrations in micrograms per cubic meter.

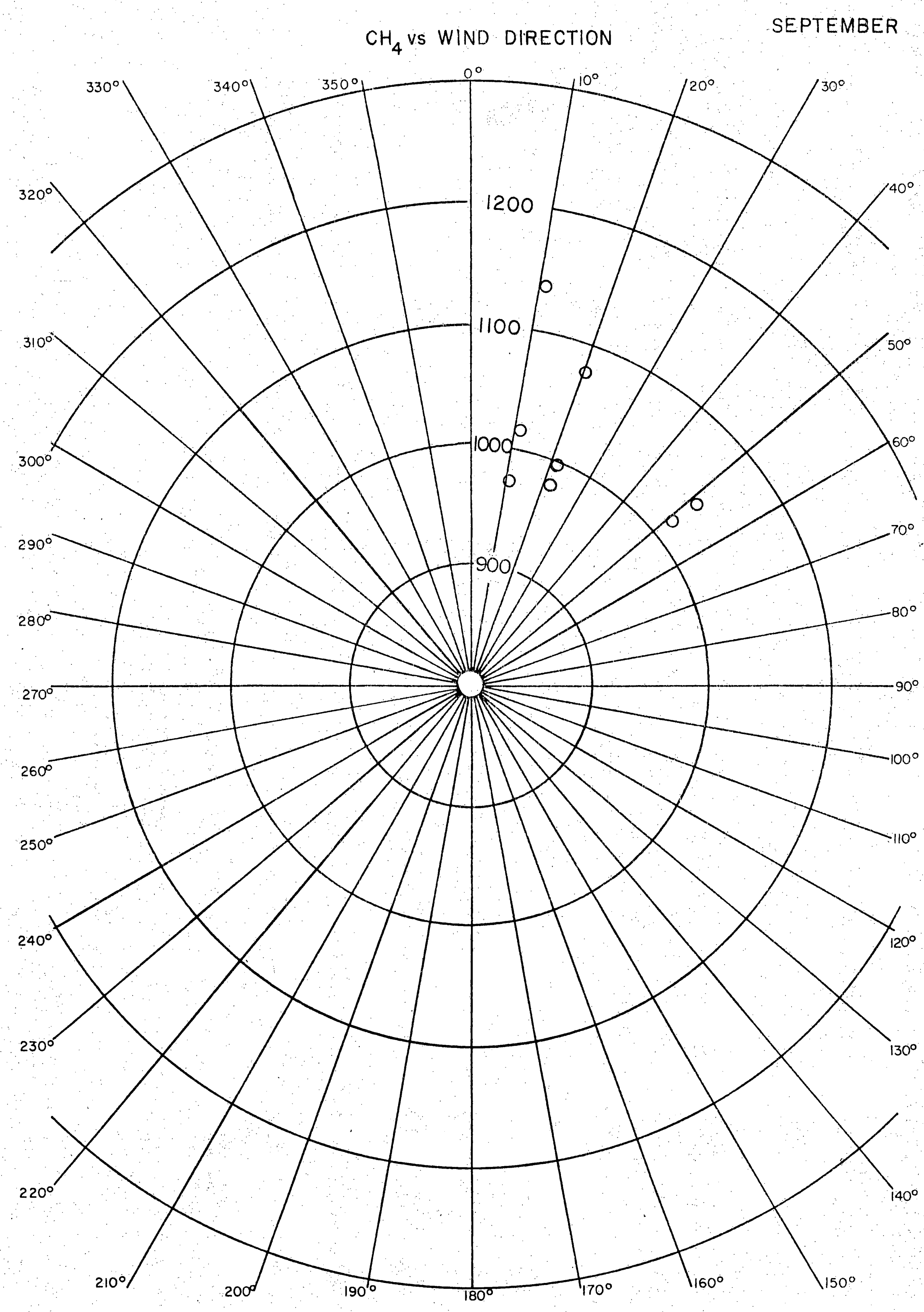

Figure 5c. Methane concentrations in micrograms per cubic meter.

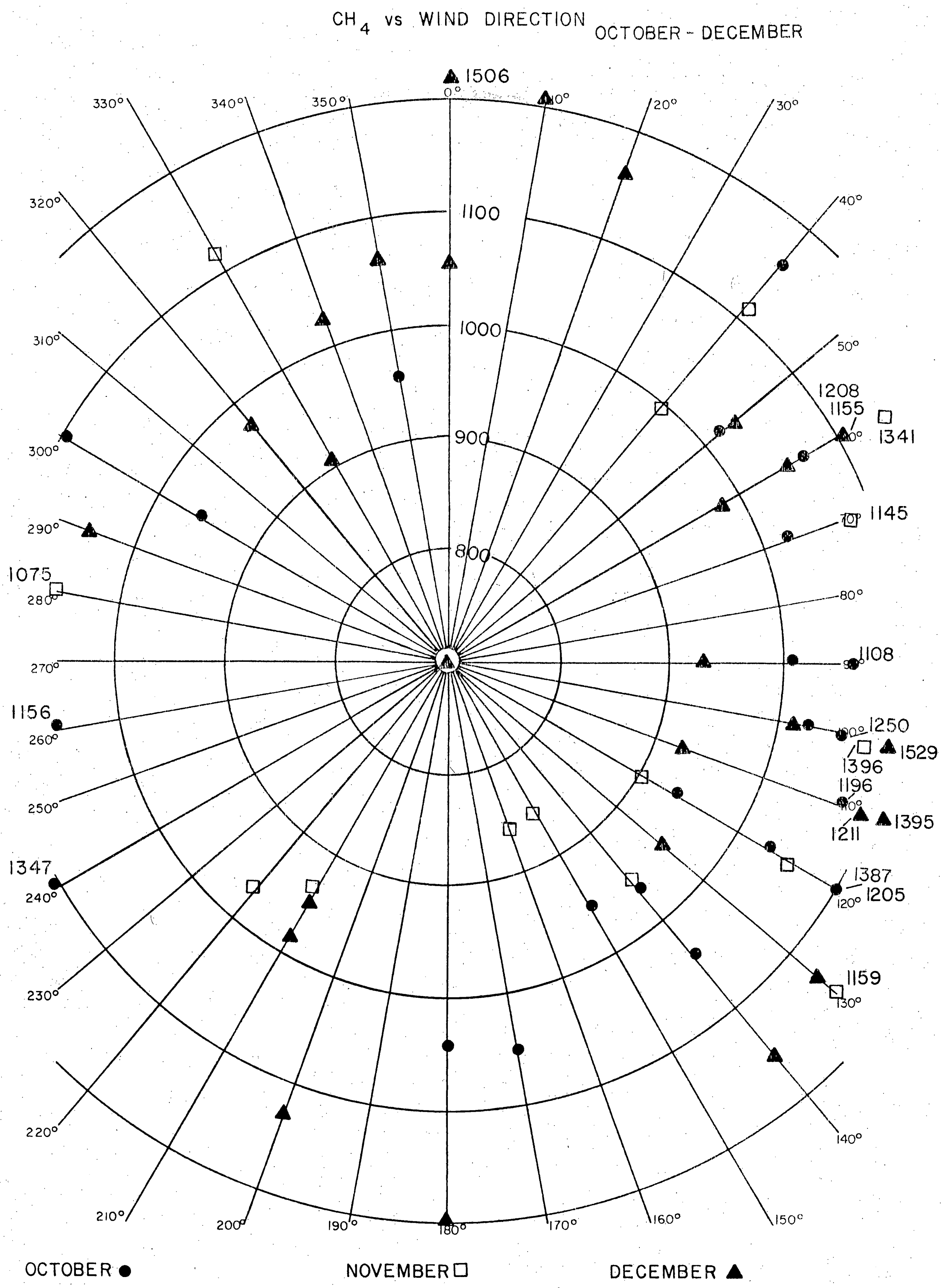

Figure 5d. Methane concentrations in micrograms per cubic meter.

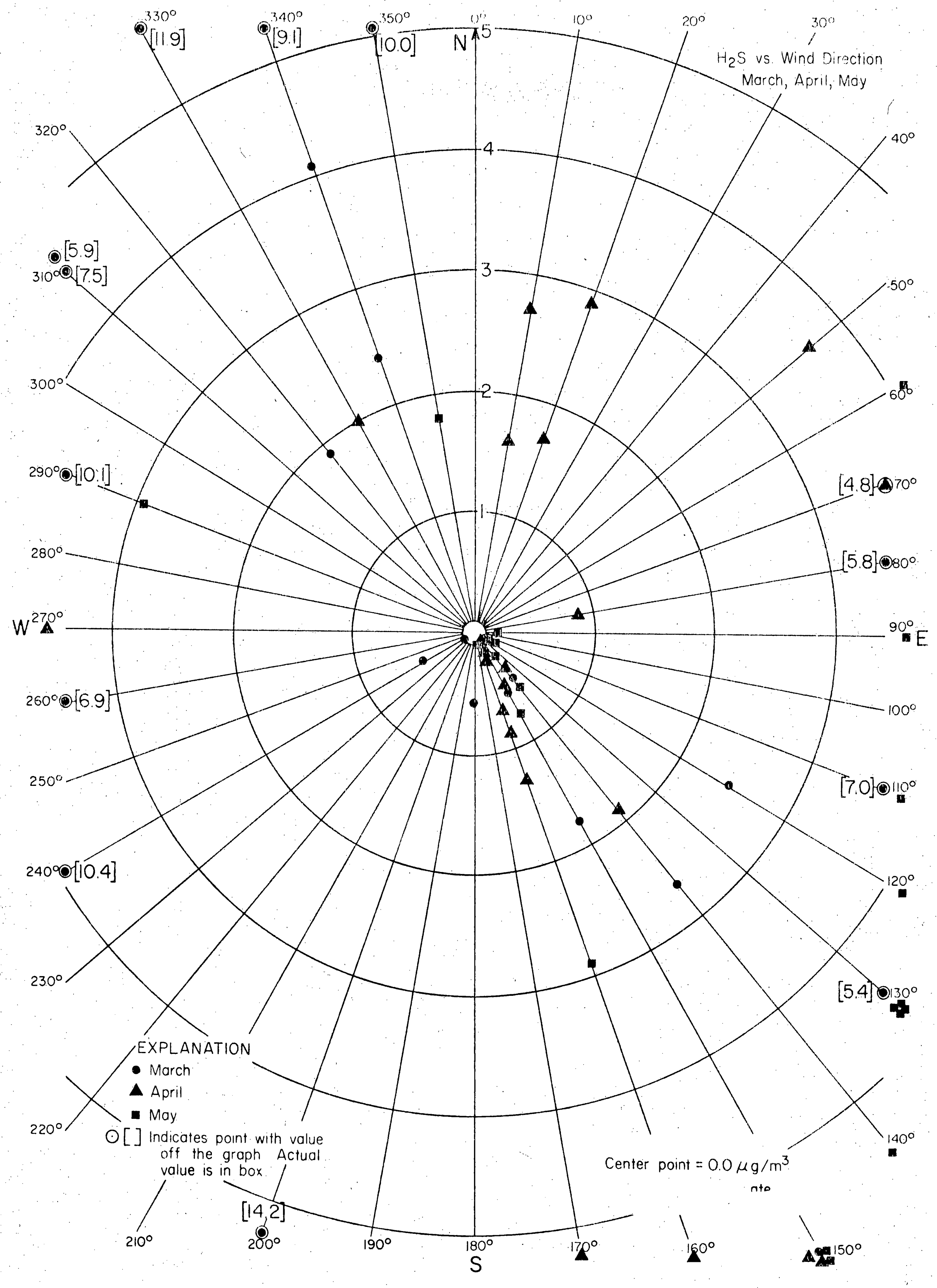

Figure 6a. Hydrogen sulfide concentrations are in micrograms per cubic meter.

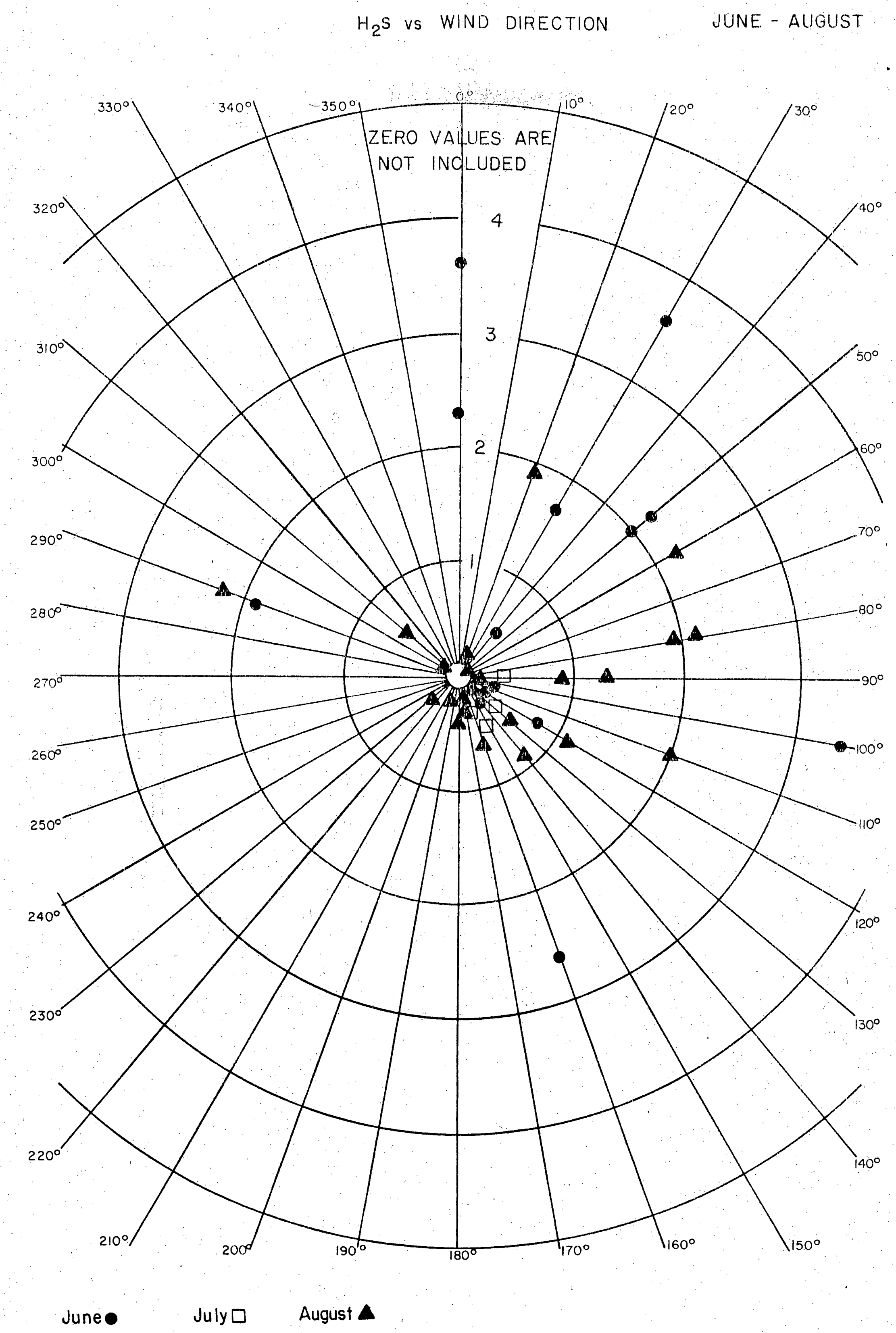

Figure 6b. Hydrogen sulfide concentrations are in micrograms per cubic meter.

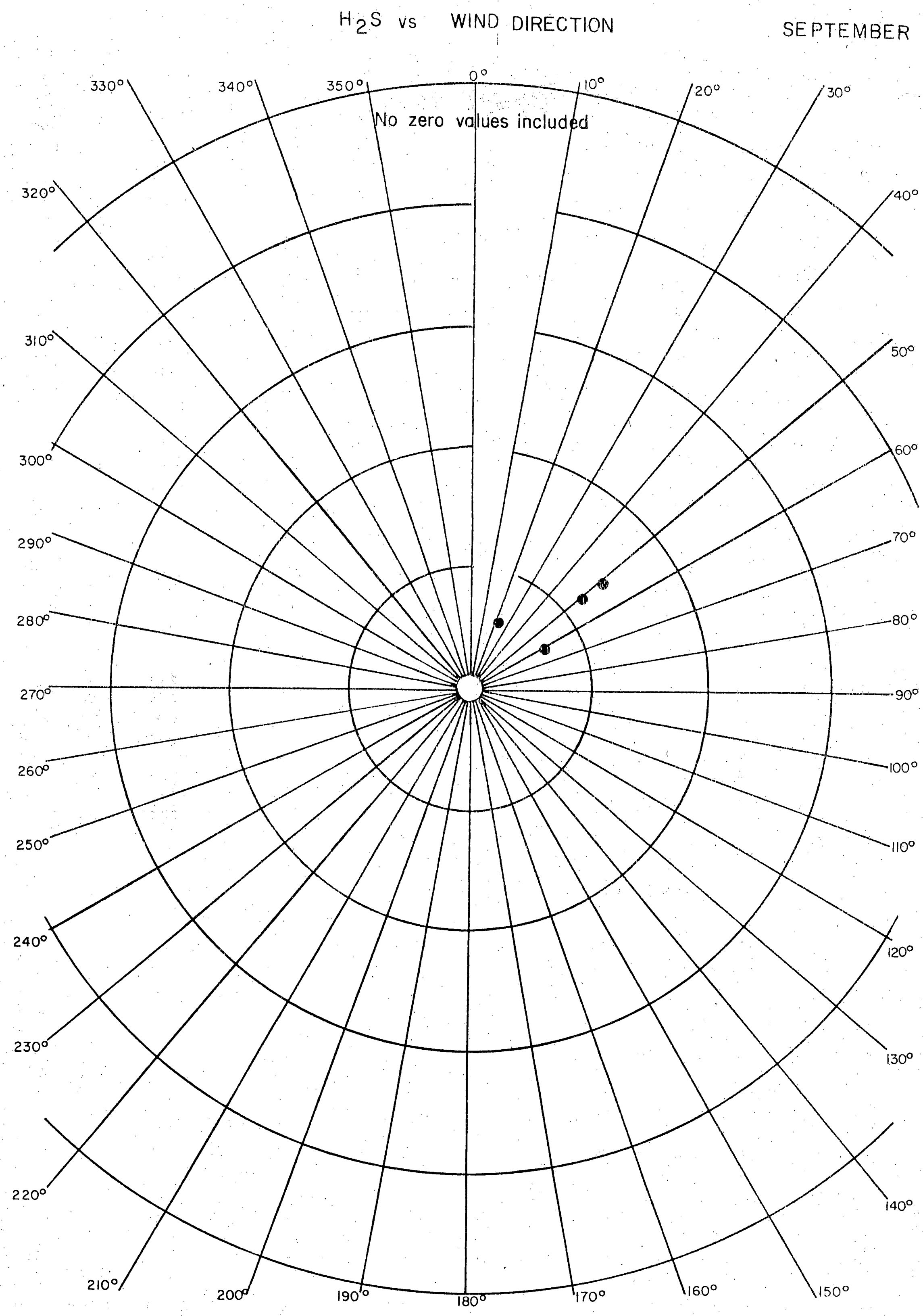

Figure 6c. Hydrogen sulfide concentrations are in micrograms per cubic meter.

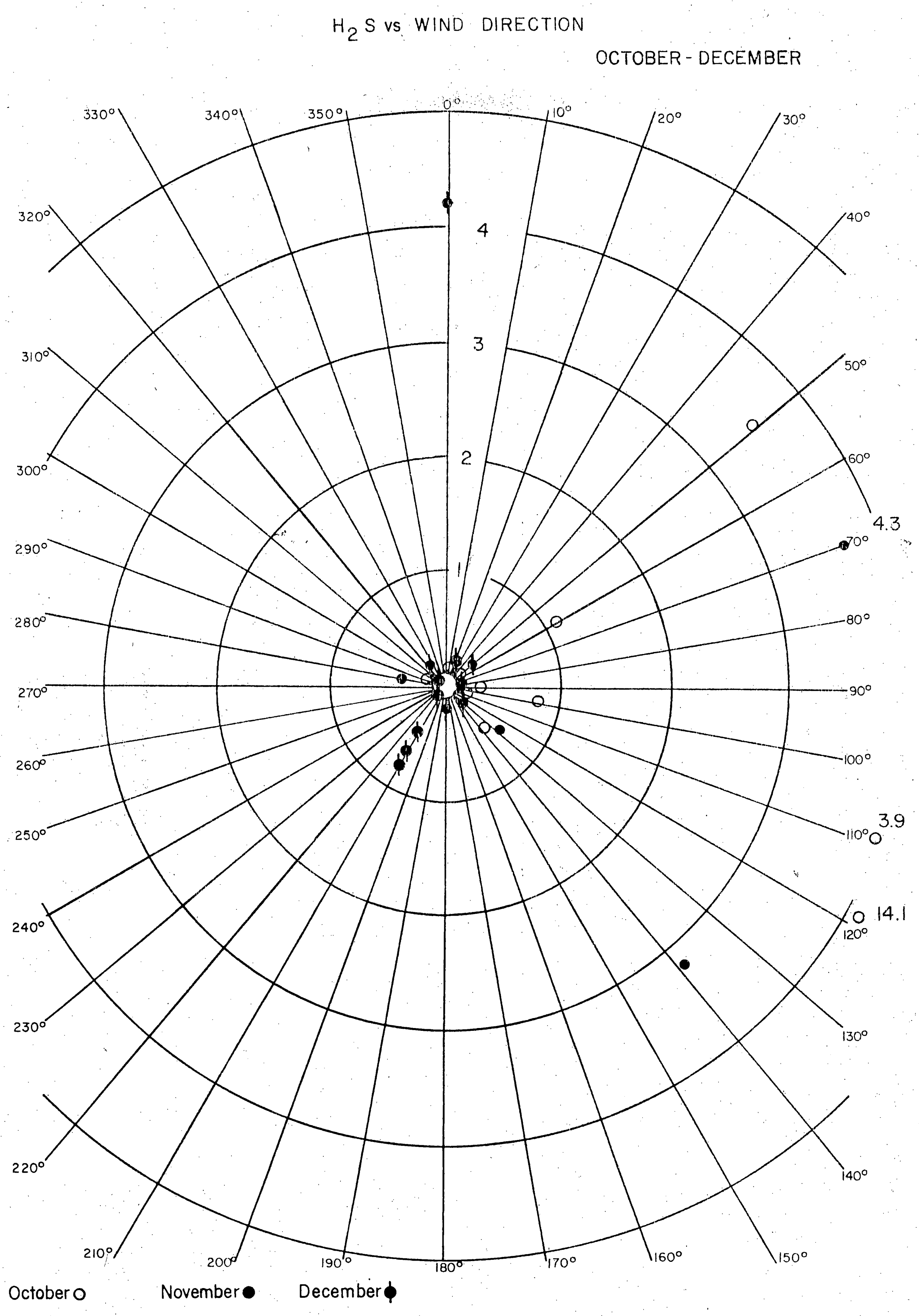

Figure 6d. Hydrogen sulfide concentrations are in micrograms per cubic meter.

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.

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 2. Water samples were collected monthly from the bayou surface and from just above the floor of the channel. Before October 1978, only one set of samples was collected each month at the test well site. Since November 1978, two sets of samples have been collected each month, one upstream and one 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 450 to 3,750 mg/l for chlorine and suggests that the degree of mixing with marine waters varies and that a wide range in salinities may be expected for bayou waters.

Table 2. Chocolate Bayou, water quality analyses.*

Lab. No.	78-836	-837	-847	-846	1137	-1138	-1203	-1201
Location	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom W/HNO_3	Surface W/HNO_2
Date	3/78	3/78	4/78	4/78	7/78	7/78	8/78	8/78
Cl^-	2870	1400	7380	3680	742	671	-	-
SO_4	441	234	1095	570	154	147	-	-
NO_3	1.11	0.24	1.38	1.11	0.93	3.59	-	-
F^-	0.39	0.39	0.58	0.50	0.40	0.38	-	-
Na^+	1638	820	4120	2082	440	381	-	-
K^+	83.4	44.0	186	106	18.2	16.6	-	-
Ca^{++}	115	105	185	132	102	104	-	-
Mg^{++}	85	30	250	500	51	48	-	-
SiO_2	7.8	8.8	5.5	7.9	10.8	12	-	-
B	<0.5	<0.5	<0.5	< 0.5	0.6	0.5	-	-
Mn^{++}	0.01	0.01	0.04	0.01	0.01	0.04	0.34	0.01
Pb	<0.02	<0.02	<0.02	< 0.02	<0.02	<0.02	<0.02	< 0.02
Cd	0.033	0.024	0.100	0.058	0.018	0.006	0.085	0.007
Ba	0.4	0.4	0.4	0.4	0.2	0.1	0.29	0.24
As	0.26	0.15	<0.058	< 0.05	<0.05	<0.05	0.070	0.05
NH^3	0.35	0.05	0.014	0.001	0.001	0.001	-	-
Hg	0.001	0.001	0.002	0.002	<0.001	<0.001	-	-

*Data measured in milligrams per liter.

Table 2. Chocolate Bayou, water quality analyses. (continued)*

Lab. No.	78-1205	78-1204	78-1953 78-1948	78-1947 78-1952	78-1979 78-1986	78-1980 78-1987	78-1981 78-1988	78-1982 78-1989
Location	Bottom W/$CHCl_3$	Surface W/$CHCl_3$	Bottom	Surface	Bottom	Surface	Bottom	Surface
Date	8-78	8-78	9-78	9-78	11-78	11-78	12-78	12-78
Cl^-	6000	1100	5700	3750	2500	450	2200	660
SO_4	840	121	990	612	420	97.5	465	112
NO_3	0.57	nil	0.47	0.09	1.46	0.82	0.47	1.28
F^-	-	-	0.42	0.10	0.42	0.33	0.42	0.26
Na^+	3200	380	3360	1900	1610	400	1785	480
K^+	150	14	126	83	90	11.5	98	12.4
Ca^{++}	149	68.3	177	136	94.5	40.0	96.5	41.5
Mg^{++}	403	93	354	194	152	28	182	34
SiO_2	1.9	2.3	9.7	14.3	13	20	12.5	20
B	1.2	0.5	1.4	1	0.75	0.5	0.75	0.5
Mn^{++}	-	-	0.04	0.02	0.06	0.02	0.05	0.08
Pb	-	-	<0.02	<0.02	<0.02	<0.02	<0.02	0.02
As	-	-	0.071	< 0.05	< 0.050	<0.050	0.055	<0.050
Ba	-	-	0.19	0.21	0.24	0.13	0.16	0.13
Cd	-	-	0.002	< 0.001	0.0037	< 0.001	0.0018	0.001
NH^3	-	-	0.12	0.10	0.18	0.04	0.26	0.06
Hg	0.001	<0.001	0.001	0.001	0.280	0.002	0.038	0.001

*Data measured in milligrams per liter.

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 (table 3). Wells were drilled until appreciable flow of ground water was reached. Wells were then screened and lined with 4-inch 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 feet in each well (fig. 2).

Concentrations of sodium and chlorine in analyses of shallow ground water suggest that ground water is essentially fresh with only minor influence from 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. 2).

Table 3. Pleasant Bayou geothermal test well area shallow ground-water analyses.*

Lab. No.	78-1949 78-1954	78-1950 78-1955	78-1951 78-1956	78-1976 78-1983	78-1977 78-1984	78-1978 78-1985
Location	Well #1	Well #2	Well #3	Well #1	Well #2	Well #3
Date	11/78	11/78	11/78	12/78	12/78	12/78
Cl	106.0	351.0	280.0	94.0	255.0	165.0
SO_4	31.5	28.5	39.6	18.0	21.0	15.0
NO_3	0.11	0.09	0.31	0.66	0.62	0.13
F	0.25	0.17	0.26	0.45	0.31	0.47
Na	68.8	127.3	87.4	107.0	360.0	93.6
K	1.04	1.11	1.77	1.5	2.1	3.4
Ca	90.1	112.0	120.0	92.5	106.0	104.0
Mg	13.8	21.6	33.5	13.7	17.5	21.5
SiO_2	19.1	22.8	20.3	22.5	26.5	22.6
B	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Mn	0.13	0.24	0.64	0.12	0.26	0.69
Pb	<0.02	<0.02	<0.02	0.03	0.02	0.02
Ba	0.14	0.26	0.15	0.17	0.34	0.24
NH_3	0.13	0.10	0.77	0.06	0.01	0.21
Hg	<0.001	<0.001	<0.001	<0.001	<0.001	0.042
As	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050
Cd	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

*Data measured in milligrams per liter.

THE BASIC OBJECTIVE OF THE NOISE SURVEY IS TO DETERMINE BASELINE NOISE LEVELS IN THE VICINITY OF THE GEOPRESSURED-GEOTHERMAL TEST WELL.

Noise surveys in the vicinity of Pleasant Bayou #1 and #2 indicate baseline noise levels of approximately 45 to 50 dB. Introducing noise of 45 to 50 dB from the geopressured-geothermal test well would increase noise levels in Peterson's Landing by only about 3 dB, hardly a discernible change.

Radian Corporation conducted noise surveys in the vicinity of Pleasant Bayou #1 and #2 (Appendix III). To forecast accurately potential noise impacts, it was necessary to obtain a description of the radiated noise at preselected distances from the drilling operation in units of octave-band sound pressure level and directivity. These data were unavailable from the drilling rig manufacturer; therefore, it was necessary to perform source measurements on a drilling rig of similar characteristics.

It had initially been anticipated that a 2,100 HP drilling system was to be used at the Chocolate Bayou well site. Such a system was located operating near Hallettsville, Texas, in an environment that partly duplicated the Chocolate Bayou location. Sound pressure levels and directivity data were measured and used as input data in Radian's Environmental Noise Prediction Model (ENPM). Thus, the retrieved data from the Hallettsville operation served as a reference noise source to predict noise impacts of the Chocolate Bayou drilling operation.

Analysis of the existing sound field throughout the Peterson Landing area revealed a dominant influence from noise radiated by the Monsanto Chemical facilities located across the Chocolate Bayou. Superimposition of ENPM (L_{dn}) results onto the residential baseline data from the study area graphically displayed that no additional noise (L_{dn}) to the Peterson Landing area would be created if the drilling rig were properly oriented. The Hallettsville data did indicate obvious directivity characteristics, making system orientation a critical consideration for the Chocolate Bayou installation.

Once drilling had begun, a complete noise survey was again performed throughout the study area. A map of the study area was prepared showing sound level isopleths in units of L_{dn} with the drilling system in full operation. The final survey data demonstrated that no significant noise was added to the Peterson Landing residential area from the drilling operation.

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