UNITED STATES DEPARTMENT OF THE INTERIOR

U.S. GEOLOGICAL SURVEY

CONCENTRATIONS OF N_2, O_2, CO_2, and He IN SOIL GASES COLLECTED OVER AND NEAR THE DIXIE VALLEY KNOWN GEOTHERMAL RESOURCE AREA NORTHERN DIXIE VALLEY, NEVADA

By

Margaret E. Hinkle*

Open-File Report 95-80

1995

* U.S. Geological Survey, P.O. Box 25046, Mail Stop 973, Denver, CO, 80225

CONTENTS

ABSTRACT

Concentrations of N_2, O_2, CO_2, and He were measured in 189 soil-gas samples collected October 16-19, 1994, from over and near the Dixie Valley Known Geothermal Resource Area (KGRA) and along the front of the Stillwater Mountains south of the KGRA in the northern Dixie Valley, Nevada. The study was funded by the U.S. Department of Energy, and was part of a geochemical and biogeochemical survey seeking surficial evidence for subsurface features, many of which were already known from drilling, of the geothermal reservoir at Dixie Valley. Sampling and analysis of the soil gases are described and measurements of gas concentrations are listed. Plots of soil-gas concentrations show that sample sites with highest concentrations of He and CO_2 are located over and near the KGRA and also over faults in Dixie Valley.

INTRODUCTION

The Dixie Valley Known Geothermal Resource Area (KGRA) is located in west-central Nevada, about 200 km by road northeast of the town of Fallon. Road access is by U.S. highway 50 and Nevada state road 121. The KGRA is located on the east side of the Stillwater Mountains, close to the boundary between Churchill and Pershing Counties in the northern part of Dixie Valley.

The northern part of Dixie Valley is a playa. The Humboldt Salt Marsh lies south of the playa (fig. 1). The marsh is the major groundwater discharge area of the northern Dixie Valley (Waibel, 1987; Karst and others, 1988).

The northern Dixie Valley basin consists of north-to-northeast-trending grabens bordered by elongate mountain ranges--the Stillwater Range on the west and the Clan Alpine Range on the east. The basin is asymmetrical, with the deepest portions being on the west side along the Stillwater Range where basin-filling sediments are more than 2100 meters thick as measured in some of the geothermal wells. The sediments are 600-900 meters thick toward the center and eastern part of the valley.

The geology and the structural history of the KGRA and of the whole Dixie Valley is quite varied and complex. Lithologic units encountered in the geothermal field range from Triassic marine sediments to recent basin-filling sediments. Structural features affecting the location of the geothermal activity include Mesozoic thrusting, late Tertiary normal faulting, and Quaternary to recent normal faulting (Speed, 1976; Waibel, 1987). Fumaroles along the Stillwater (rangefront) fault (one fumarole is actively depositing sulfur crystals), along with numerous hot-springs along the east side of the mountains and isolated hot springs in the center of the valley are evidence of the complex structure of the area.

Geothermal production at the Dixie Valley KGRA is related to an extended, complex network of fault and fracture permeability that varies with the physical characteristics of each rock type (Waibel, 1987). The temperature of the geothermal reservoir is about 250^0 C. The power plant at the KGRA began operation in 1988, and currently produces about 60 megawatts of electricity from geothermal steam (Benoit, 1993).

Although many studies have been done in the area of the Dixie Valley KGRA, there has been only one geochemical survey prior to the one described in this report. Broad-scale (730 x 305-m grid) soil-sampling by Juncal and Bell (1981) showed that anomalous concentrations of As and Hg exist along the east side of the Stillwater Mountains. Anomalous As concentrations were found along faults near the playa, whereas anomalous Hg concentrations were found along faults close to the mountain front.

Studies by the USGS of soil-gases and soils have proved to be useful for distinguishing subsurface features of geothermal areas. For example, soil gases collected over faults associated with the geothermal area at the Roosevelt Hot Springs KGRA in southwestern Utah contained anomalous concentrations of He and CO_2. Plots of elemental suites in soil-gas and soil samples collected over and near the Roosevelt Hot Springs KGRA identified faults associated with the geothermal field, sinter deposits, elements from geothermal sources adsorbed on clays along faults, and non-geothermal detrital elements weathering from the adjacent Mineral Mountains (Hinkle and Copp, in press).

In the San Luis Valley, Colorado, anomalous He and CO_2 concentrations were present in soil gases collected over the major faults of the valley (Hinkle, 1993). A multimedia survey including soil-gases, soils, and plants identified an area where an unsuspected geothermal heat source may exist, and other anomalies unrelated to geothermal activity (Erdman and others, 1993).

This report summarizes results of a soil-gas survey in the northern Dixie Valley, Nevada, concentrating on the area of the Dixie Valley KGRA. The soil-gas survey was part of an integrated soil-gas, soil, and plant survey of the area. The purpose of the study was to use elemental suites determined by the integrated survey to try to distinguish subsurface features of the Dixie Valley geothermal system. Many of the subsurface features already had been identified by drilling.

ACKNOWLEDGEMENTS

This work was funded by the U.S. Department of Energy, Geothermal Technology Division. We thank Oxbow Power Services, Inc. for permission to sample at the Dixie Valley KGRA and to publish the results of our studies. We also thank Dick Benoit and Don Wells of the Oxbow Company for arranging lodging for us in company-owned facilities at the power plant.

SAMPLE COLLECTION

A total of 189 soil-gas samples was collected from October 16-19, 1994 (fig. 1). Samples were collected by driving a hollow probe into the ground to a depth of 0.6-0.7-m; the hollow probe was described by Reimer and Bowles (1979). The probe was driven into the ground by means of a sliding hammer attached to the shaft of the probe. After the probe was driven into the ground, it was fitted with an airtight cap and septum for withdrawal of the soil-gas sample.

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. 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. The soil-gas samples were transferred to four 5-mL evacuated blood-sampling vials for storage (two each for gas chromtographic and mass spectrometer analyses), 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 holes were covered with silicone glue. Soil-gas samples can be stored in these evacuated vials for as long as two months without leakage (Hinkle and Kilburn, 1979).

Soil and air temperatures were measured at each sample site because soil and air temperatures (and the air-soil temperature difference) can strongly affect concentrations of He and CO_2 (Hinkle, 1993). In addition, samples were collected daily from a "permanent" probe emplaced in the ground at site-189 on October 15th, and left there for the duration of the sample collection. The purpose of the daily sampling was to determine the effect of soil and air temperature variations on soil-gas concentrations at a single site. The ground at site-189 was damp to a depth of 10 cm, due to rain on the night of October 14th.

SAMPLE ANALYSIS

For He analysis, 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 reported as parts per billion volume/volume; reproducibility of the measurement was +/- 20 ppb. The concentration of He in air is 5,220 ppb (Holland and Emerson, 1987). The tubes used for sample storage were approximately 80 percent evacuated. They contained a residual concentration of He that was the same for all the tubes in each lot produced by the manufacturer. This residual He concentration 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. For gas chromatography analysis, gas in the vials was removed by injecting 5 mL of pure He (equal to the volume of the vial) into the vial and removing the mixture of He and soil gas for the chromatographic analysis. Concentrations of N_2, O_2, and CO_2 were measured compared to standard curves and are reported as volume percents. The standard curves were prepared from gas standards containing known concentrations of N_2, O_2, and CO_2, which were diluted with He and placed in the same vials used for sample storage; these prepared standards were analyzed several times per day to ensure stability of the instrument.

DESCRIPTION OF THE DATA TABLES

Data from the analyses were entered into an IBM-compatible personal computer and stored on disks, using the Quattro Pro program (Borland International, Inc.). The data were converted into the U.S. Geological Survey STATPAC format for statistical analyses (Grundy and Miesch, 1987), and into the U.S. Geological Survey

GSMAP format for plotting (Selner and Taylor, 1992). Table 2 shows the minimum, maximum, mean, and standard deviation of the measurements for the data. Table 3 lists the percentile data for the data. Table 4 lists soil and air temperature measurements and soil-gas concentrations for samples collected periodically from the "permanent" probe. Table 5 lists the results of the 189 soil-gas analyses along with soil and air temperatures measured in the field. The concentrations of He listed in the tables are significant only to between two and three figures, and not to the four figures implied by the raw data. Digital STATPAC- and Quattro Pro-based formats of the data in table 5 can be found on floppy disk in the pocket of this report.

DISCUSSION

Soil-gas concentrations at the "permanent" probe (site 189).

The first soil-gas sample taken at the "permanent" probe had the highest concentrations of N_2 and O_2 measured at this site (table 4). These measurements probably indicate that the first sample at the site contained a higher proportion of atmospheric air than succeeding samples which had been in equilibrium with subsurface gases for at least 24 hours. For the sake of consistency, the first-sample concentrations at site 189 were considered to be the "true" concentrations and were listed in table 5 along with the gas concentrations measured at the other sites, because all of the soil-gas samples were essentially "first" samples.

Plots showed that air temperatures and air-soil temperature differences had an inverse effect on concentrations of N_2 and O_2 measured at the "permanent" probe (figs. 2a-2b). Concentrations of CO_2 appeared to be unrelated to air and soil temperatures---CO_2 concentrations are both directly and inversely correlated with temperatures (fig. 2c), probably because the soil temperatures were less than 10^0 C, the temperature at which bacterial production of CO_2 in the soil appears to increase (Hinkle, 1994).

Increasing air temperatures and air-soil temperature differences were related to increased concentrations of He (fig. 2d), a response opposite to that usually seen, where increasing air and air-soil temperature differences are related to decreasing He concentrations (Hinkle, 1994). The relationship of increased air-soil temperature differences to decreased He concentrations generally is attributed to the effect of warm air drying and heating the upper portion of the soil, creating a local pumping effect with increased dispersal of He into the air (Reimer and Roberts (1985). However, this pumping effect is related to the permeability of the soil. The damp soil at the "permanent" probe site may have created an impermeable layer that concentrated any He rising from depth beneath a layer of moist soil.

A linear regression equation for He concentrations versus air-soil temperature differences was calculated for the six samples at the "permanent" probe:

$$\text{He(calculated)} = 5223 + 12\ (\text{air temperature} - \text{soil temperature})$$

The equation was then applied to the other soil-gas samples and the calculated-He concentrations were listed in table 5. However, the He values resulting from this equation may not be valid for the entire set of soil-gas samples because the amounts of soil-moisture (which could impede soil-gas movement) at the other sites is unknown. Helium concentrations calculated from the regression equation and the raw-He concentrations measured in soil-gas samples were different at many sites in Dixie Valley (fig. 3). Although many of the sites around the producing geothermal field and near the Stillwater fault were anomalous in both types of He, sites along the fault south of Dixie Hot Springs were anomalous only in raw-measurement He, indicating that the raw-measurement values were more useful for fault detection.

Soil-gas concentrations

The soil and air temperatures varied during the day, from 1°C to 18°C (soils) and from -4°C to 19.0°C (air). These variation did not appear to have an appreciable effect on soil-gas concentrations, probably because the soil and air temperatures generally were similar at the individual sites. Correlation coefficients for the 189 N_2, O_2, CO_2, and He concentrations with soil and air temperatures were low (table 2).

Plots of the measurements of N_2, O_2, CO_2, and He in the soil-gas samples are shown in figures. 4-7. The plots show concentration values of less than 25th percentile, 25th through approximately 90th percentile, and greater than about the 90th percentile. Highest concentrations of He in soil gases were located over and near the producing geothermal field and over faults near the range front. Highest concentrations of CO_2 (>1.2 percent) were in soil gases collected near the geothermal wells and near the fumaroles located on the Stillwater fault, indicating a component of geothermal steam in the soil gases and a probable channelway for geothermal steam along the fault. Anomalously high concentrations of O_2 and N_2 can indicate a large component of atmospheric air in the samples. Anomalously high N_2 concentrations also may indicate thermal breakdown of organic components or ammonium-containing minerals in sediments (Krohn and others, 1993).

High concentrations (>90th percentile) of both He and CO_2 were found primarily in the vicinity of the producing geothermal wells and over faults associated with the KGRA (fig. 8). Concentrations of O_2 were anomalously low (<10th percentile) at many of the sites over the geothermal field where CO_2 was anomalously high (fig. 9). The combination of high He and CO_2 with low O_2 in soil gases observed here also was observed at the Roosevelt Hot Springs KGRA, Utah, (Hinkle and Copp, in press) and probably results from similar processes. The combination of anomalously high He and CO_2 in soil gases probably indicates transport and degassing of geothermal brine within the faults. High CO_2 and low O_2 may indicate oxidation at depth of geothermal gases such as CH_4 to CO_2 (D'Amore and Panichi, 1980). Also, geothermal H_2S oxidized to H_2SO_4 could react with calcite deposited within the faults to form CO_2 and produce the same combination of anomalies.

REFERENCES

Benoit, Dick, 1993, Review of geothermal power generation projects in the Basin and Range Province, 1993, Geothermal Resources Council Bulletin, v. 23, no. 5, p. 173-178.

D'Amore, Franco, and Panichi, Costanzo, 1980, Evaluation of deep temperatures of hydrothermal systems by a new gas geothermometer: Geochimica et Cosmochimica Acta, v. 44, no. 3, p. 549-556.

Erdman, J.A., Hinkle, M.E., Watson, Ken, Gallagher, A.J., Ager, C.M., and Smith, K.S., 1993, A new approach to geothermal exploration--integrating geochemistry with remote sensing [Abs.]: The 16th International Geochemical Exploration Symposium, Beijing, China, p. 40-41.

Grundy, W.D., and Miesch, A.T., 1987, Brief descriptions of STATPAC and related statistical programs for the IBM Personal Computer: U.S. Geological Survey Open-File Report 87-411-A, 34 p.

Hinkle, M.E., 1993, Concentrations of N_2, O_2, CO_2, and He in soil gases collected in the northern San Luis Valley, Colorado: U.S. Geological Survey Open-File Report 93-584, 16 p.

Hinkle, M.E., 1994, Environmental conditions affecting concentrations of He, CO_2, O_2, and N_2 in soil gases: Applied Geochemistry, v. 9, no. 1, p. 53-63.

Hinkle, M.E., and Copp, J.F., in press, Soil and soil-gas geochemistry over and near the Roosevelt Hot Springs KGRA, Utah: Journal of Applied Geochemistry.

Hinkle, M.E., and Kilburn, J.E., 1979, The use of vacutainer tubes for collection of soil samples for helium analysis: U.S. Geological Survey Open-File Report 79-1441, 23 p.

Holland, P.W., and Emerson, D.E., 1987, A determination of the helium 4 content of near-surface atmospheric air within the continental United States: Journal of Geophysical Research, vol. 92B, p. 12,557-12,566.

Juncal, R.W., and Bell, E.J., 1981, Solid-sample geochemistry study of western Dixie Valley, Churchill County, Nevada--Part II, soil geochemistry: Geothermal Resources Council, v. 5, p. 51-54.

Karst, G.B., Campana, M.E., and Jacobson, R.L., 1988, A mixing-cell model of the hydrothermal flow system, northern Dixie Valley, Nevada: Geothermal Resources Council Transactions, v. 12, p. 167-174.

Krohn, M.D., Kendall, Carol, Evans, J.R., and Fries, T.L., 1993, Relations of ammonium minerals at several hydrothermal systems in the western U.S.: Journal of Volcanology and Geothermal Research, v. 56, no. 4, p. 401-413.

Reimer, G.M., and Bowles, C.G., 1979, Soil-gas helium concentrations in the vicinity of a uranium deposit, Red Desert, Wyoming: U.S. Geological Survey Open-File Report 79-975, 9 p.

Reimer, G.M., and Denton,E.H., 1978, Improved inlet system for the U.S. Geological Survey helium sniffer: U.S. Geological Survey Open-File Report 78-588, 4 p.

Reimer, G.M., and Roberts, A.A., 1985, Correcting soil-gas helium concentrations for diurnal variations: Bulleting of the Association of Petroleum Geology Exploration, v. 1, p. 1-17.

Selner, G.I., and Taylor, R.B., 1992, System 8. Programs to assist workers in the earth sciences in using geodetic or cartesian xyz data from row column (GSPV85) files: GSPDC, contours and grids interpolated from triangulated network; GSPCS, graphic sections; GSPUV, univariant statistics and histograms; GSPPROB, probability diagrams; GSPXY, regression statistics and XY plots; GSPTD, ternary diagrams, and GSPV85, postplots, for IBM PC and compatible computers: U.S. Geological Survey Open-File Report 92-372, 83 p.

Speed, R.C., 1976, Geologic map of the Humboldt lopolith and surrounding terrane, Nevada: Geological Society of America MC-14.

Waibel, A.F., 1987, An overview of the geology and secondary mineralogy of the high temperature geothermal system in Dixie Valley, Nevada: Geothermal Resources Council, Transactions, V. 11, p. 479-486.

Table 1. Operating conditions for the gas chromatograph

Type of gas chromatograph	Carle AGC-100
Detector	thermistor detector
Lower limit of detection	1% N_2 or O_2, 0.03% CO_2
Reproducibility	+/- 10 %
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 60 mL/minute
Temperature	column: 60°C detector: "low" mode

Table 2. Summary data for soil and air temperatures and soil gases (189 samples)

VARIABLE	MINIMUM	MAXIMUM	MEAN	STANDARD DEVIATION
Soil Temperature (C)	1.0	18.0	10.7	3.2
Air Temperature (C)	-4.0	19.0	11.5	4.5
N_2 (%)	60.5	87.3	75.6	4.4
O_2 (%)	16.1	23.4	20.0	1.2
CO_2 (%)	0.05	9.2	0.18	0.73
He (measured) (ppb)	5070	5440	5220	60
He (calculated) (ppb) (from air-soil) (temperature) (differences)	5140	5390	5230	30

Correlation Coefficients

AirT	SoilT	AirT -SoilT	N_2	O_2	CO_2	$N_2+O_2+CO_2$	He (meas)	
1.00	0.80	0.70	-0.20	-0.18	0.09	-0.19	-0.01	Air Temperature
	1.00	0.13	-0.08	-0.09	0.11	-0.07	0.05	Soil Temperature
		1.00	-0.24	-0.20	0.02	-0.24	-0.08	AirT minus SoilT
			1.00	0.86	-0.16	0.99	0.03	N_2
				1.00	-0.22	0.89	0.03	O_2
					1.00	-0.05	0.14	CO_2
						1.00	0.05	$N_2+O_2+CO_2$
							1.00	He (measured)

Table 3. Percentile data for soil and air temperatures and soil gases (189 samples)

Variable	25th	50th	75th	90th	95th	97.5th	99th
Soil Temp.(C)	10	11	12	14	16	17.5	18
Air Temp.(C)	10	12	14	17	17	19	19
N_2 (%)	72.9	75.5	78.6	81.3	83.0	83.6	84.2
O_2 (%)	19.3	20.0	20.8	21.6	22.0	22.2	22.4
CO_2 (%)	0.02	0.04	0.10	0.27	0.62	1.21	2.40
He (ppb)	5200	5200	5240	5280	5320	5355	5385

Table 4. Data from the "permanent" probe

No.	Date	Time of Day	Air Temp.(C)	Soil Temp.(C)	N_2 (%)	O_2 (%)	CO_2 (%)	$N_2+O_2+CO_2$ (%)	He (ppb)
1	15 Oct.	1630	5	8	77.9	21.9	0.26	100.1	5230
2	16 Oct.	1640	5	10	73.3	20.8	0.22	94.3	5200
3	17 Oct.	1710	14	5	70.2	19.7	0.25	90.1	5400
4	18 Oct.	1500	20	5	74.2	19.1	0.21	93.5	5240
5	19 Oct.	630	3	5	74.4	20.0	0.28	94.7	5150
6	19 Oct.	1200	19	5	71.1	19.6	0.21	90.9	5480

Table 5. Concentrations of soil-gas components

No.	Latitude	Longitude	Air-T(C)	Soil-T(C)	AirT-SoilT	N2(%)	O2(%)	CO2(%)	N2+O2+CO2(%)	He(ppb)	He(calculated)
1	39.963	117.853	5	10	-5	80.6	21.4	0.16	102.2	5200	5239
2	39.963	117.855	5	11	-6	74.9	20.1	0.06	95.1	5240	5230
3	39.963	117.857	5	10	-5	82.9	22.3	0.04	105.2	5150	5239
4	39.964	117.858	5	10	-5	80.4	21.6	0.02	102.0	5240	5239
5	39.964	117.861	5	10	-5	78.9	21.2	0.02	100.1	5200	5239
6	39.965	117.862	5	8	-3	78.1	20.9	0.08	99.1	5280	5256
7	39.966	117.863	5	8	-3	80.3	20.9	0.01	101.2	5150	5256
8	39.966	117.865	5	9	-4	87.3	23.4	0.02	110.7	5240	5247
9	39.965	117.867	5	9	-4	83.6	22.3	0.08	106.0	5150	5247
10	39.966	117.868	5	9	-4	83.8	19.9	0.05	103.8	5240	5247
11	39.967	117.870	5	10	-5	82.3	22.1	0.02	104.4	5200	5239
12	39.968	117.872	5	10	-5	77.2	20.7	0.02	97.9	5240	5239
13	39.969	117.874	5	9	-4	77.2	20.7	0.02	97.9	5200	5247
14	39.970	117.875	8	8	0	77.0	20.6	0.01	97.6	5200	5283
15	39.971	117.876	8	9	-1	75.7	20.3	0.01	96.0	5110	5274
16	39.972	117.878	8	9	-1	80.4	21.5	0.03	101.9	5150	5274
17	39.973	117.879	9	10	-1	82.1	22.0	0.03	104.1	5240	5274
18	39.968	117.874	12	10	2	80.8	21.6	0.05	102.5	5200	5301
19	39.966	117.873	12	10	2	76.3	20.5	0.02	96.8	5280	5301
20	39.965	117.873	12	10	2	75.1	20.1	0.01	95.2	5240	5301
21	39.964	117.873	12	10	2	71.3	19.0	0.04	90.3	5200	5301
22	39.963	117.872	12	10	2	72.5	19.4	0.02	91.9	5200	5301
23	39.962	117.870	15	10	5	73.5	19.6	0.08	93.2	5200	5328
24	39.961	117.868	12	10	2	77.1	20.6	0.01	97.7	5200	5301
25	39.961	117.867	9	9	0	70.4	18.7	0.02	89.1	5280	5283
26	39.960	117.866	12	10	2	71.7	20.8	0.02	92.5	5240	5301
27	39.959	117.864	11	11	0	68.7	18.3	0.04	87.0	5200	5283
28	39.959	117.862	12	10	2	75.2	20.0	0.02	95.2	5150	5301
29	39.958	117.861	12	10	2	71.0	18.8	0.08	89.9	5240	5301
30	39.958	117.859	12	10	2	73.7	19.6	0.10	93.4	5240	5301
31	39.957	117.858	16	11	5	72.1	19.2	0.08	91.4	5200	5328
32	39.956	117.857	16	11	5	69.4	18.3	0.06	87.8	5200	5328
33	39.956	117.854	16	11	5	73.6	19.6	0.12	93.3	5200	5328
34	39.955	117.852	16	11	5	72.8	19.4	0.17	92.4	5240	5328
35	39.955	117.851	16	12	4	79.1	21.0	0.27	100.4	5240	5319
36	39.955	117.849	16	12	4	76.7	20.4	0.09	97.2	5200	5319
37	39.955	117.847	16	12	4	72.9	19.4	0.09	92.4	5240	5319
38	39.955	117.846	12	12	0	73.4	19.5	0.17	93.1	5200	5283
39	39.955	117.844	12	12	0	75.2	19.7	0.45	95.4	5280	5283
40	39.955	117.842	12	12	0	78.5	19.3	2.40	100.2	5280	5283
41	39.955	117.840	12	12	0	78.1	19.7	0.60	98.4	5240	5283
42	39.955	117.838	12	12	0	68.0	17.4	0.72	86.1	5280	5283
43	39.955	117.836	12	12	0	75.5	19.6	0.64	95.7	5240	5283
44	39.954	117.834	14	12	2	79.4	21.1	0.01	100.5	5200	5301
45	39.955	117.832	14	12	2	75.9	20.3	0.09	96.3	5240	5301
46	39.955	117.830	14	12	2	72.6	19.3	0.08	92.0	5200	5301
47	39.954	117.829	14	12	2	78.3	20.9	0.08	99.3	5280	5301
48	39.954	117.827	14	12	2	75.3	20.0	0.12	95.4	5200	5301
49	39.954	117.825	13	12	1	72.7	19.3	0.11	92.1	5070	5292
50	39.954	117.823	13	12	1	70.5	18.8	0.07	89.4	5070	5292
51	39.954	117.822	13	12	1	76.9	20.5	0.05	97.5	5150	5292

Table 5. Concentrations of soil-gas components

No.	Latitude	Longitude	Air-T(C)	Soil-T(C)	AirT-SoilT	N2(%)	O2(%)	CO2(%)	N2+O2+CO2(%)	He(ppb)	He(calculated)
52	39.954	117.820	13	12	1	73.4	19.6	0.05	93.1	5200	5292
53	39.954	117.817	13	12	1	72.6	19.4	0.03	92.0	5240	5292
54	39.954	117.816	13	12	1	81.6	21.8	0.03	103.4	5110	5292
55	39.955	117.814	13	12	1	75.8	20.2	0.07	96.1	5150	5292
56	39.955	117.812	13	12	1	79.0	19.8	0.02	98.8	5150	5292
57	39.955	117.810	13	12	1	73.8	19.8	0.02	93.6	5150	5292
58	39.955	117.808	13	12	1	83.6	18.5	0.02	102.1	5150	5292
59	39.955	117.806	12	12	0	70.9	18.9	0.01	89.8	5150	5283
60	39.955	117.804	12	12	0	83.7	19.9	0.05	103.7	5200	5283
61	39.955	117.803	-4	1	-5	70.9	19.0	0.02	89.9	5280	5239
62	39.955	117.801	-4	1	-5	74.7	20.0	0.01	94.7	5200	5239
63	39.955	117.799	-4	3	-7	73.8	19.7	0.01	93.5	5200	5221
64	39.955	117.796	-4	3	-7	80.9	21.7	0.01	102.6	5200	5221
65	39.955	117.794	-2	3	-5	75.9	20.1	<0.01	96.0	5200	5239
66	39.955	117.792	-1	3	-4	73.1	19.5	<0.01	92.6	5150	5247
67	39.955	117.791	2	3	-1	80.0	21.3	0.02	101.3	5240	5274
68	39.955	117.789	2	3	-1	77.8	20.8	0.01	98.6	5240	5274
69	39.955	117.787	4	3	1	75.9	20.3	0.01	96.2	5200	5292
70	39.955	117.784	4	3	1	73.4	19.6	0.03	93.0	5200	5292
71	39.953	117.820	6	8	-2	77.2	20.6	0.04	97.8	5200	5265
72	39.952	117.820	6	8	-2	83.9	20.0	0.02	103.9	5240	5265
73	39.951	117.820	8	8	0	73.6	19.6	0.01	93.2	5150	5283
74	39.950	117.821	8	8	0	75.0	20.0	0.04	95.0	5200	5283
75	39.948	117.822	8	8	0	79.7	21.3	0.10	101.1	5240	5283
76	39.947	117.822	10	10	0	80.3	21.4	0.05	101.8	5240	5283
77	39.946	117.823	10	10	0	72.9	19.4	0.03	92.3	5240	5283
78	39.945	117.823	10	10	0	67.1	17.9	0.03	85.0	5200	5283
79	39.943	117.823	10	10	0	73.8	19.6	<0.01	93.4	5200	5283
80	39.942	117.823	10	10	0	80.2	21.3	0.07	101.6	5150	5283
81	39.941	117.823	9	9	0	65.8	17.5	0.03	83.3	5200	5283
82	39.995	117.851	14	13	1	68.3	18.1	9.20	95.6	5320	5292
83	39.994	117.850	14	13	1	72.8	19.3	0.53	92.6	5150	5292
84	39.993	117.848	14	13	1	73.0	19.0	0.16	92.2	5150	5292
85	39.991	117.847	14	13	1	74.0	19.7	0.13	93.8	5110	5292
86	39.990	117.846	13	13	0	78.3	20.9	0.18	99.4	5110	5283
87	39.989	117.845	12	12	0	70.5	18.9	0.61	90.0	5200	5283
88	39.988	117.844	12	12	0	69.1	18.4	1.60	89.1	5200	5283
89	39.987	117.843	12	12	0	69.6	18.6	0.20	88.4	5200	5283
90	39.986	117.842	12	12	0	72.5	19.3	0.20	92.0	5280	5283
91	39.985	117.841	12	12	0	75.4	20.0	0.18	95.6	5320	5283
92	39.985	117.838	12	12	0	82.7	20.7	0.75	104.2	5280	5283
93	39.984	117.837	14	12	2	72.6	18.2	0.46	91.3	5110	5301
94	39.984	117.835	14	12	2	76.1	18.7	0.31	95.1	5200	5301
95	39.984	117.832	14	12	2	73.0	17.9	0.65	91.6	5200	5301
96	39.984	117.829	14	12	2	78.1	20.1	0.24	98.4	5200	5301
97	39.990	117.823	14	13	1	82.6	19.4	0.11	102.1	5240	5292
98	39.987	117.827	14	13	1	71.2	17.8	1.50	90.5	5240	5292
99	39.944	117.890	14	13	1	79.9	21.5	0.04	101.4	5200	5292
100	39.953	117.889	14	13	1	62.6	16.6	0.05	79.3	5280	5292
101	39.947	117.902	14	13	1	76.8	20.5	0.03	97.3	5150	5292
102	39.946	117.941	14	13	1	67.5	18.1	0.02	85.6	5150	5292

Table 5. Concentrations of soil-gas components

No.	Latitude	Longitude	Air-T(C)	Soil-T(C)	AirT-SoilT	N2(%)	O2(%)	CO2(%)	N2+O2+CO2(%)	He(ppb)	He(calculated)
103	39.944	117.940	14	13	1	73.8	19.6	0.02	93.4	5280	5292
104	39.943	117.939	14	13	1	69.5	21.0	0.02	90.5	5200	5292
105	39.941	117.937	17	13	4	69.7	18.7	<0.01	88.4	5200	5319
106	39.940	117.936	17	13	4	60.5	16.1	<0.01	76.6	5200	5319
107	39.940	117.934	17	14	3	70.9	18.9	<0.01	89.8	5150	5310
108	39.939	117.934	17	14	3	68.3	18.3	<0.01	86.6	5200	5310
109	39.938	117.933	17	14	3	83.1	22.2	0.02	105.3	5200	5310
110	39.937	117.932	17	14	3	73.6	19.7	0.02	93.3	5200	5310
111	39.936	117.931	17	14	3	79.2	21.2	0.03	100.4	5200	5310
112	39.935	117.931	16	13	3	76.8	20.5	0.06	97.4	5200	5310
113	39.933	117.933	16	13	3	78.2	20.8	0.07	99.1	5150	5310
114	39.932	117.933	16	13	3	70.2	18.7	0.05	89.0	5200	5310
115	39.931	117.932	16	14	2	71.9	19.0	0.14	91.0	5280	5301
116	39.930	117.930	16	14	2	76.1	20.4	0.03	96.5	5200	5301
117	39.953	117.916	17	14	3	69.7	18.5	2.40	90.6	5200	5310
118	39.796	118.069	12	17	-5	80.6	21.5	0.07	102.2	5360	5239
119	39.794	118.070	11	10	1	75.9	20.1	0.24	96.2	5200	5292
120	39.793	118.070	11	10	1	70.7	18.1	0.92	89.7	5240	5292
121	39.791	118.070	11	10	1	81.1	21.6	0.04	102.7	5240	5292
122	39.790	118.070	11	11	0	76.5	20.4	0.04	96.9	5320	5283
123	39.789	118.070	11	11	0	80.8	21.6	0.06	102.5	5360	5283
124	39.787	118.071	11	11	0	75.3	20.1	<0.01	95.4	5410	5283
125	39.786	118.071	11	11	0	74.1	19.7	0.06	93.9	5240	5283
126	39.785	118.071	11	11	0	82.2	22.0	0.04	104.2	5280	5283
127	39.783	118.071	10	11	-1	70.3	18.7	0.05	89.1	5280	5274
128	39.782	118.071	10	11	-1	84.5	22.6	0.11	107.2	5360	5274
129	39.780	118.072	10	11	-1	76.1	20.2	0.05	96.4	5320	5274
130	39.779	118.073	10	11	-1	77.9	20.7	0.13	98.7	5320	5274
131	39.778	118.073	10	11	-1	73.6	19.7	0.13	93.4	5320	5274
132	39.777	118.074	11	11	0	83.6	21.9	0.11	105.6	5280	5283
133	39.775	118.075	11	11	0	80.8	21.4	0.17	102.4	5200	5283
134	39.774	118.076	11	11	0	75.9	20.1	0.12	96.1	5240	5283
135	39.773	118.077	11	11	0	69.8	18.5	0.07	88.4	5240	5283
136	39.772	118.078	11	11	0	74.7	19.9	0.02	94.6	5150	5283
137	39.771	118.080	11	11	0	79.3	21.1	0.11	100.5	5280	5283
138	39.770	118.082	11	11	0	73.8	19.7	0.07	93.6	5280	5283
139	39.769	118.084	11	11	0	69.2	18.4	0.13	87.7	5280	5283
140	39.768	118.084	11	11	0	76.3	20.3	0.04	96.6	5240	5283
141	39.767	118.086	14	11	3	68.4	18.2	0.06	86.7	5200	5310
142	39.766	118.087	14	11	3	73.1	22.0	0.06	95.2	5150	5310
143	39.765	118.089	14	11	3	72.6	19.2	0.05	91.9	5200	5310
144	39.766	118.090	13	11	2	77.0	20.5	0.05	97.6	5150	5301
145	39.767	118.091	14	11	3	77.5	20.7	0.01	98.2	5110	5310
146	39.768	118.092	14	11	3	75.2	22.0	0.01	97.2	5200	5310
147	39.868	118.017	17	12	5	79.1	21.1	<0.01	100.2	5150	5328
148	39.866	118.013	17	12	5	77.5	20.7	0.03	98.2	5240	5328
149	39.865	118.011	17	12	5	78.5	20.9	0.01	99.4	5240	5328
150	39.863	118.012	17	17	0	79.5	21.2	0.08	100.8	5440	5283
151	39.862	118.011	17	17	0	77.2	20.5	0.06	97.8	5240	5283
152	39.862	118.010	17	17	0	73.4	19.6	0.01	93.0	5240	5283
153	39.952	117.917	19	17	2	75.8	20.5	0.01	96.3	5200	5301

Table 5. Concentrations of soil-gas components

No.	Latitude	Longitude	Air-T(C)	Soil-T(C)	AirT-SoilT	N2(%)	O2(%)	CO2(%)	N2+O2+CO2(%)	He(ppb)	He(calculated)
154	39.950	117.917	19	18	1	83.4	22.3	0.03	105.7	5200	5292
155	39.949	117.917	19	18	1	76.9	20.4	0.04	97.3	5240	5292
156	39.947	117.916	19	18	1	72.0	19.2	0.01	91.2	5350	5292
157	39.946	117.916	19	18	1	81.1	21.7	0.05	102.9	5240	5292
158	39.945	117.916	19	18	1	77.8	20.7	0.05	98.6	5280	5292
159	39.974	117.878	10	5	5	80.7	21.5	0.01	102.2	5240	5328
160	39.975	117.875	10	5	5	76.2	20.3	0.01	96.5	5240	5328
161	39.975	117.873	10	5	5	74.4	19.8	0.03	94.2	5240	5328
162	39.976	117.871	10	5	5	81.3	21.7	0.04	103.0	5200	5328
163	39.976	117.870	10	5	5	75.2	20.0	0.01	95.2	5320	5328
164	39.976	117.868	9	5	4	78.6	21.0	0.05	99.7	5240	5319
165	39.977	117.867	9	5	4	82.2	21.9	<0.01	104.1	5280	5319
166	39.977	117.866	9	5	4	74.9	20.0	0.03	94.9	5280	5319
167	39.977	117.863	9	5	4	73.9	19.7	<0.01	93.6	5320	5319
168	39.978	117.861	9	5	4	76.1	19.0	0.01	95.1	5150	5319
169	39.978	117.860	9	5	4	75.7	19.9	0.02	95.6	5200	5319
170	39.978	117.858	9	7	2	71.7	19.2	0.01	90.9	5280	5301
171	39.978	117.857	9	7	2	72.9	19.5	0.02	92.4	5200	5301
172	39.978	117.855	10	9	1	75.0	20.0	0.01	95.0	5200	5292
173	39.977	117.853	10	9	1	77.2	20.5	0.03	97.7	5200	5292
174	39.977	117.851	10	9	1	80.4	21.5	0.04	101.9	5200	5292
175	39.977	117.849	10	9	1	81.4	21.7	0.01	103.1	5240	5292
176	39.977	117.847	10	9	1	73.7	19.6	0.05	93.4	5280	5292
177	39.977	117.846	10	9	1	68.1	18.1	0.04	86.2	5310	5292
178	39.978	117.844	10	9	1	79.2	20.8	0.16	100.2	5200	5292
179	39.979	117.842	10	10	0	76.2	20.0	0.27	96.5	5200	5283
180	39.980	117.841	5	10	-5	73.7	18.8	0.32	92.8	5280	5239
181	39.981	117.840	16	12	4	76.4	20.0	0.20	96.6	5200	5319
182	39.983	117.838	16	12	4	74.4	19.4	0.47	94.3	5320	5319
183	39.975	117.846	16	12	4	71.8	19.2	0.03	91.0	5240	5319
184	39.975	117.848	16	12	4	68.6	18.3	0.02	86.9	5240	5319
185	39.973	117.849	15	15	0	77.7	20.7	0.01	98.4	5230	5283
186	39.972	117.850	15	15	0	74.8	20.0	0.02	94.8	5240	5283
187	39.971	117.851	15	15	0	74.7	20.0	0.02	94.7	5200	5283
188	39.970	117.853	15	15	0	74.8	20.0	0.04	94.8	5280	5283
189	39.966	117.857	5	8	-3	77.9	21.9	0.26	100.1	5230	5408

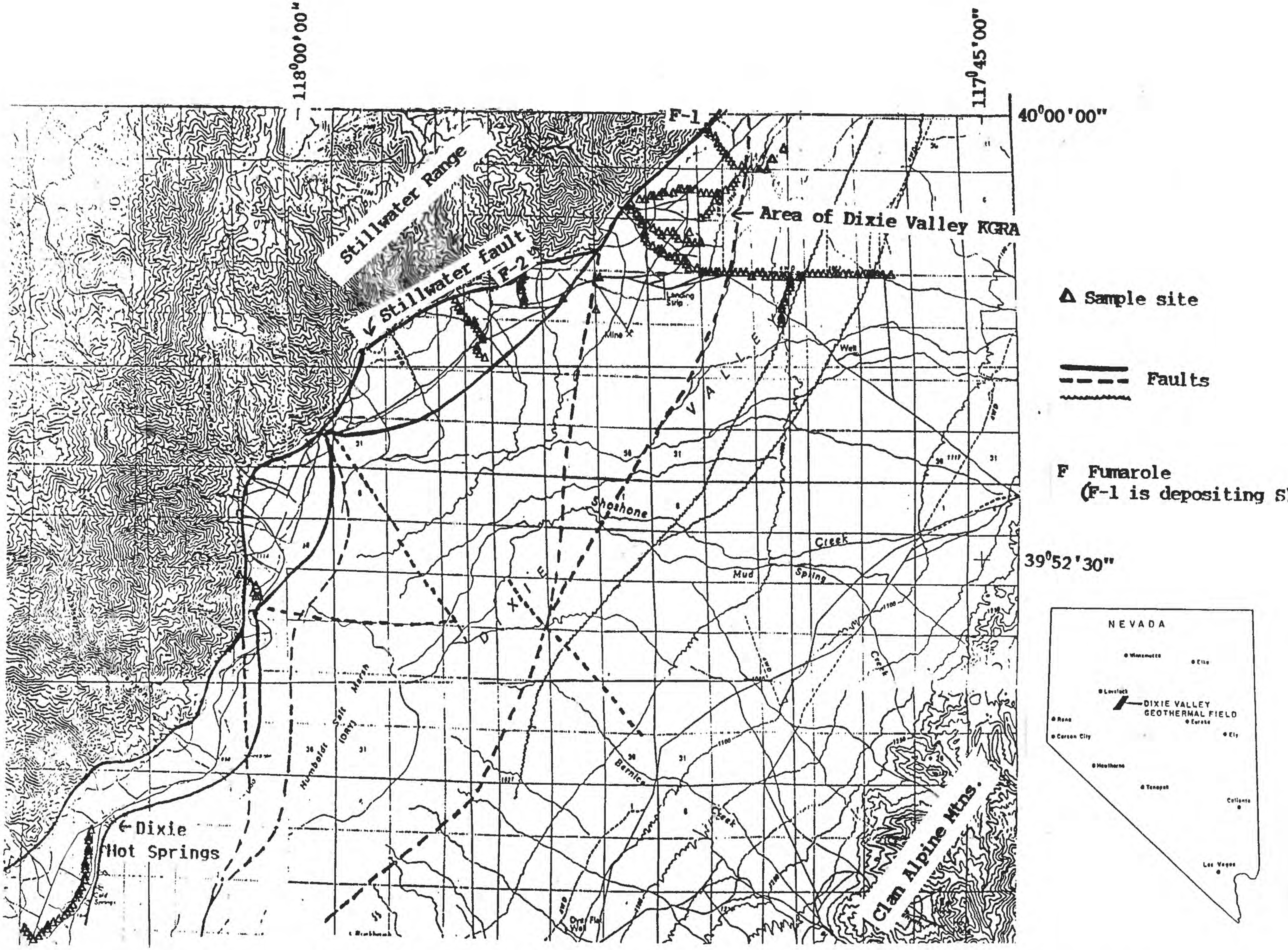

Fig.1: Locations of sample sites and major faults, Dixie Valley

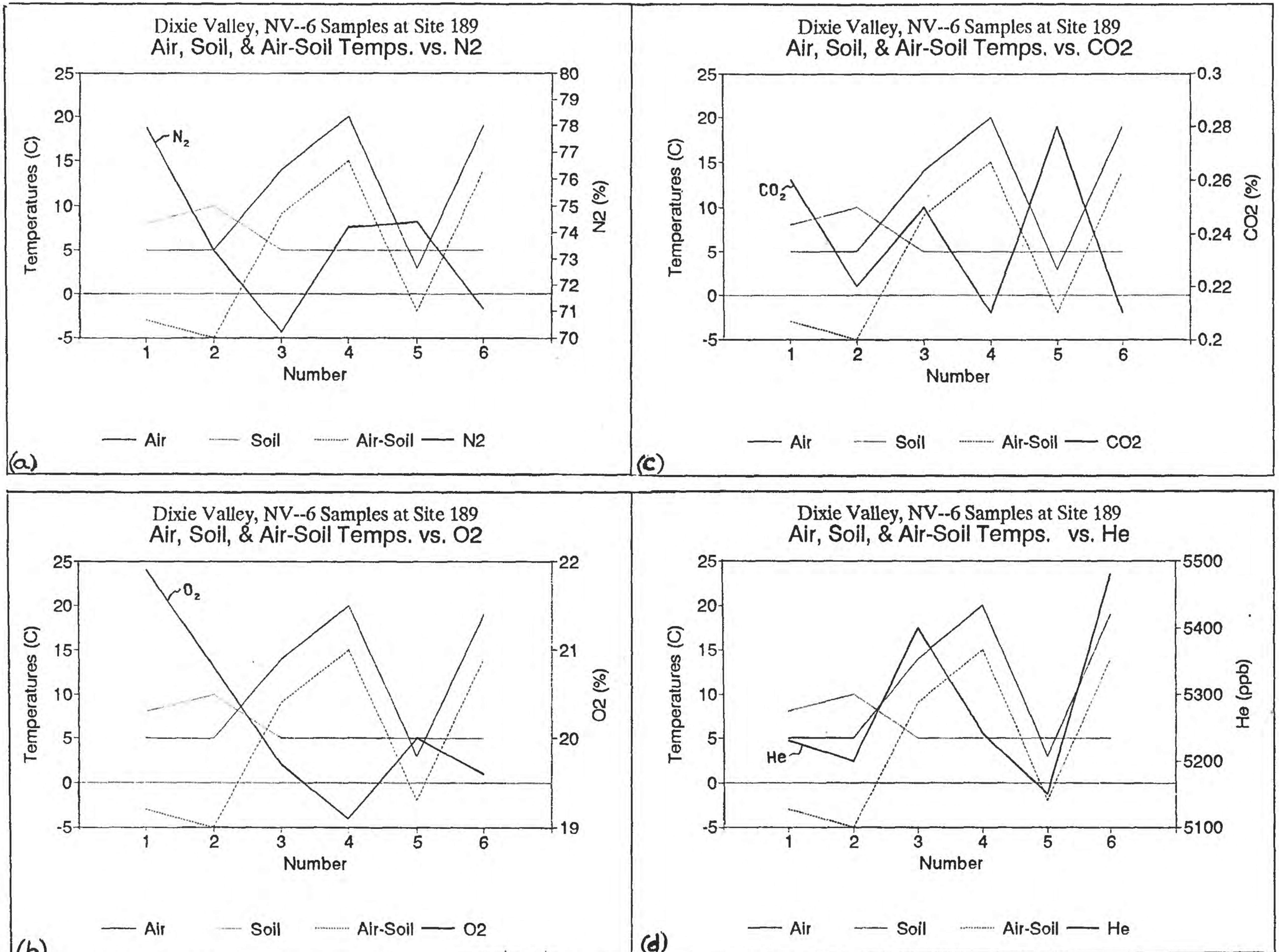

Figure 2. Comparison of soil-gas concentrations at the "permanent probe".

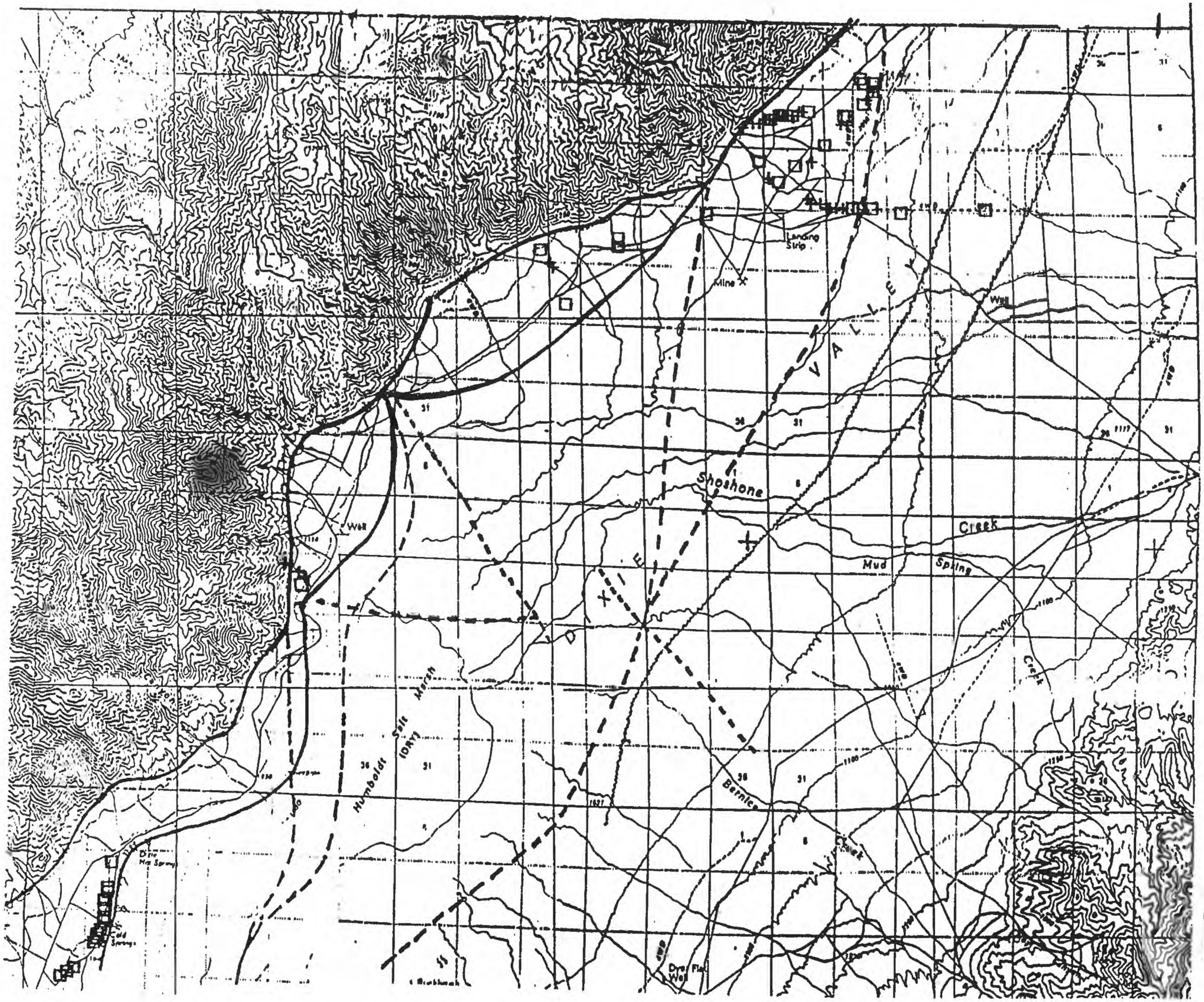

Fig. 3. >90th percentiles of He: □ =raw He, +=calculated He

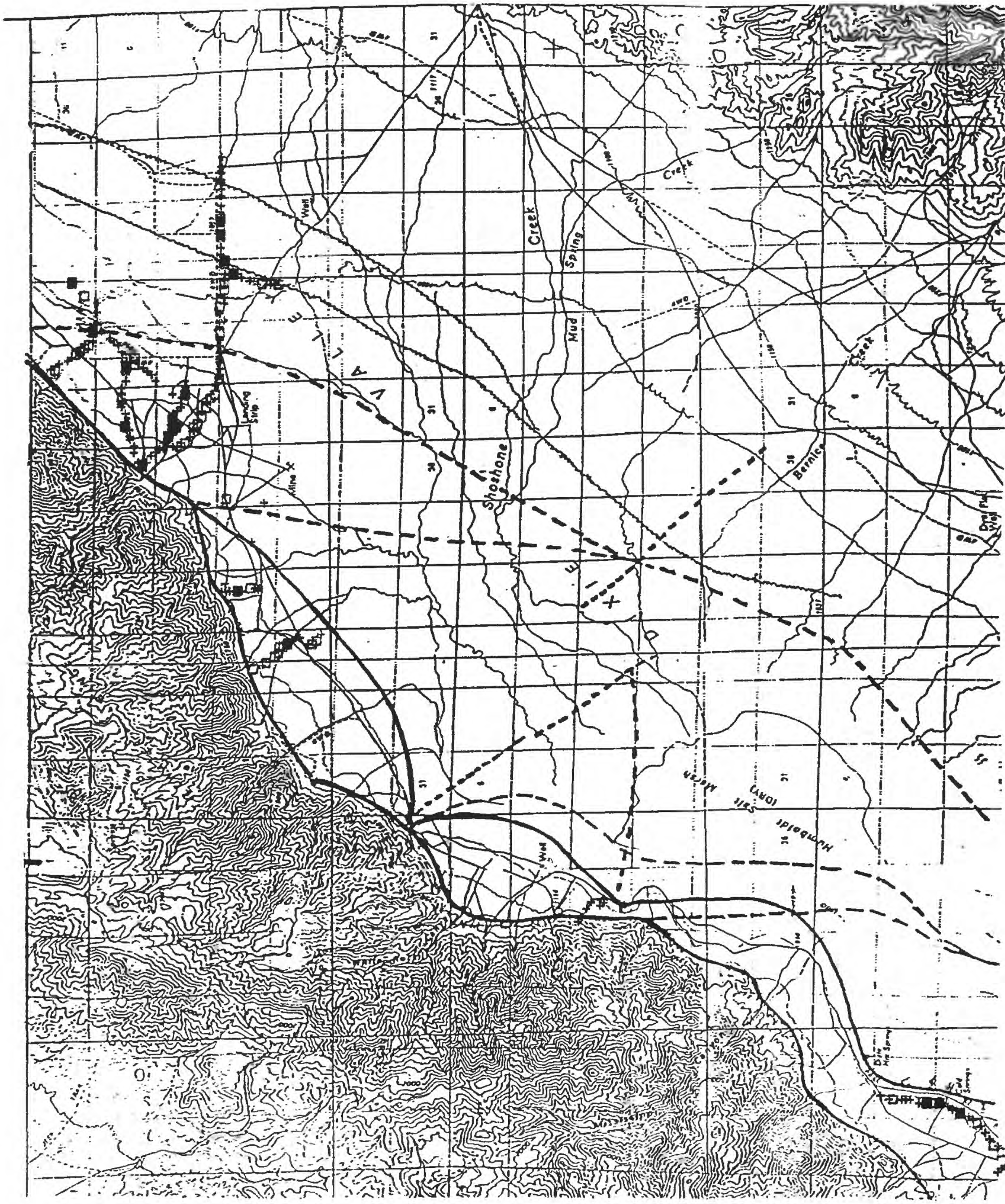

Fig. 4. N2: □ <25th, + 25th-90th, ■ >90th percentiles

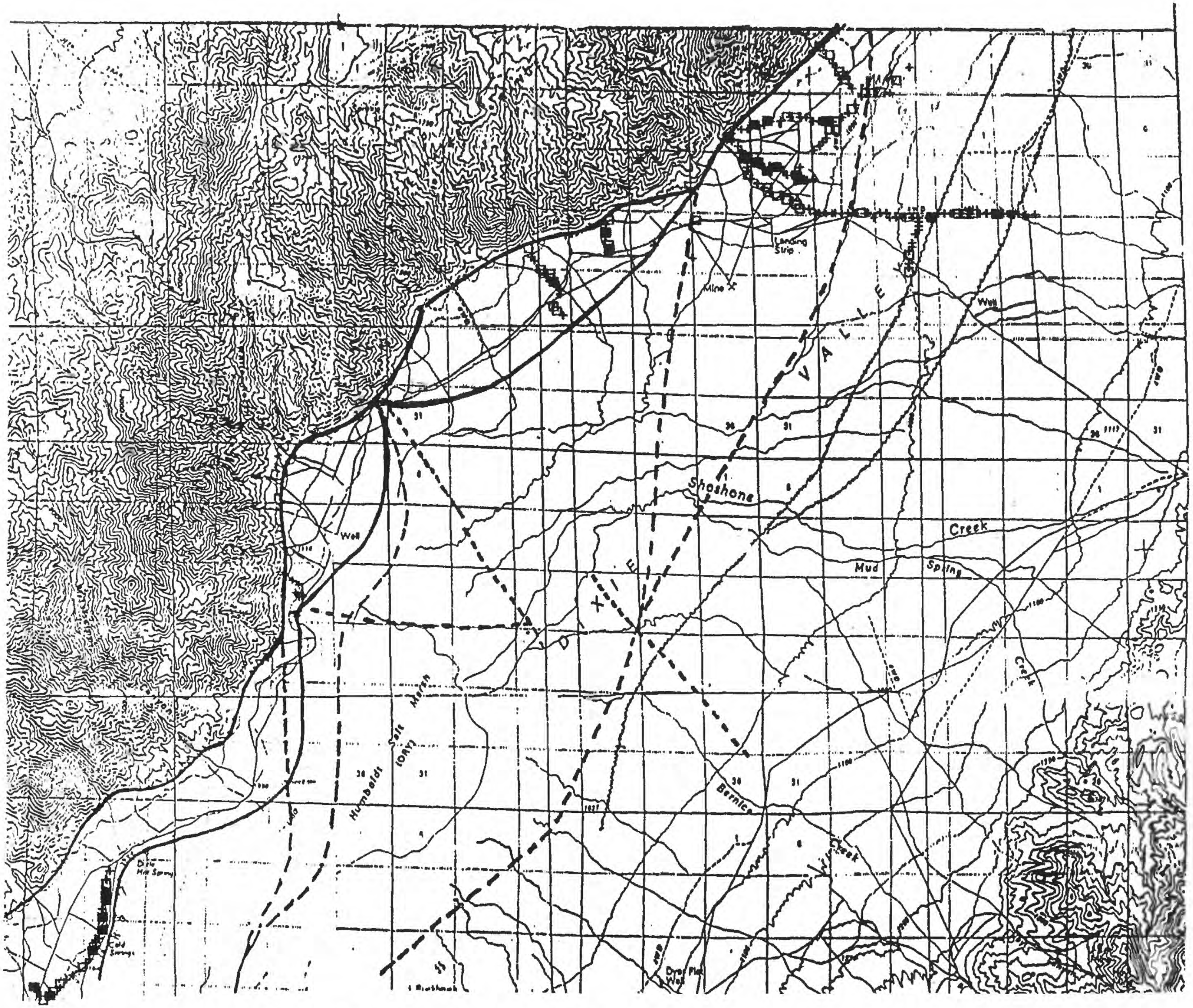

Fig.5. O2: □ <25th, + 25th–90th, ■ >90th percentiles

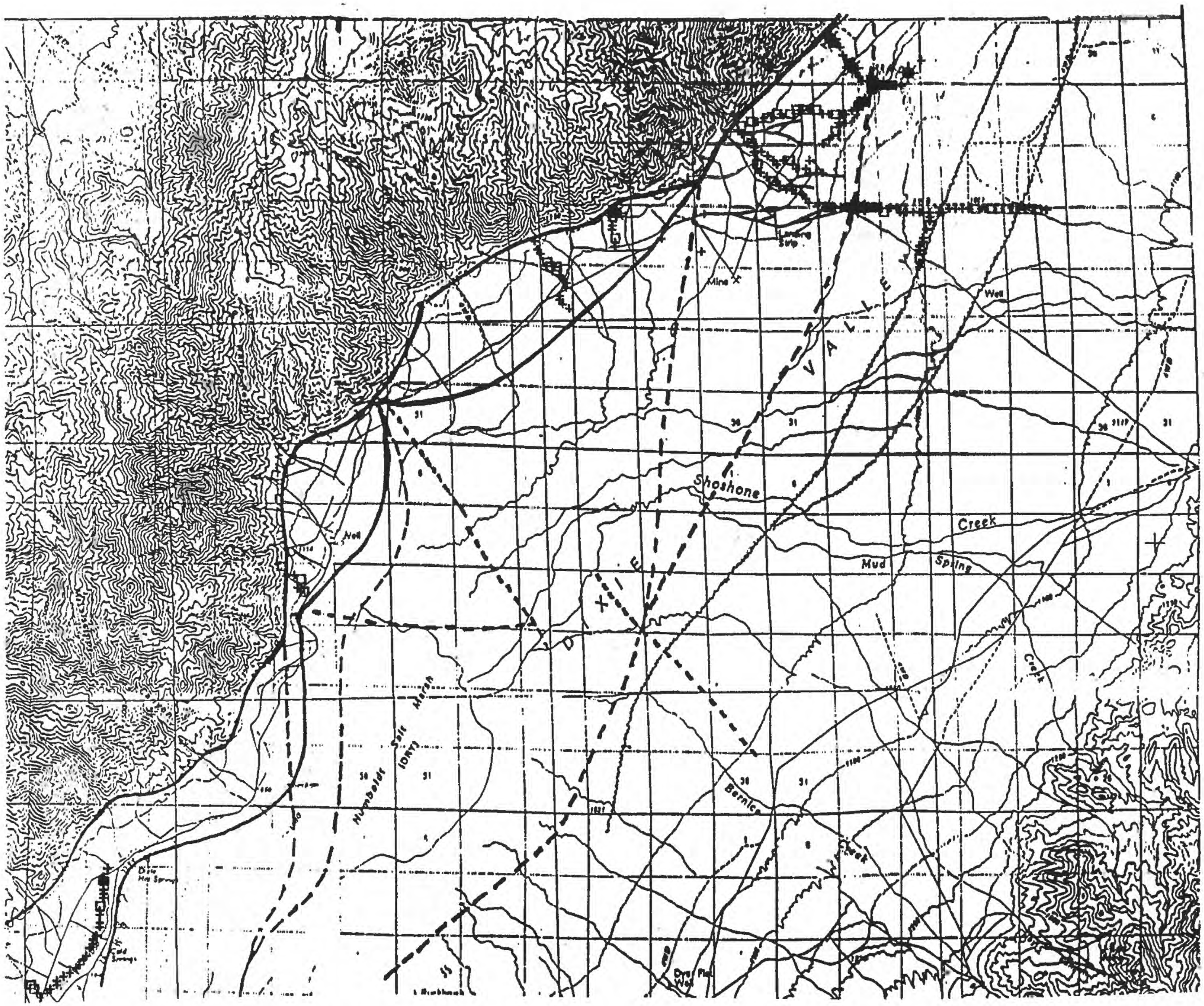

Fig.6. CO2: □ <25th, + 25th–90th, ■ 90th–97.5th, ✱ >97.5th percentile

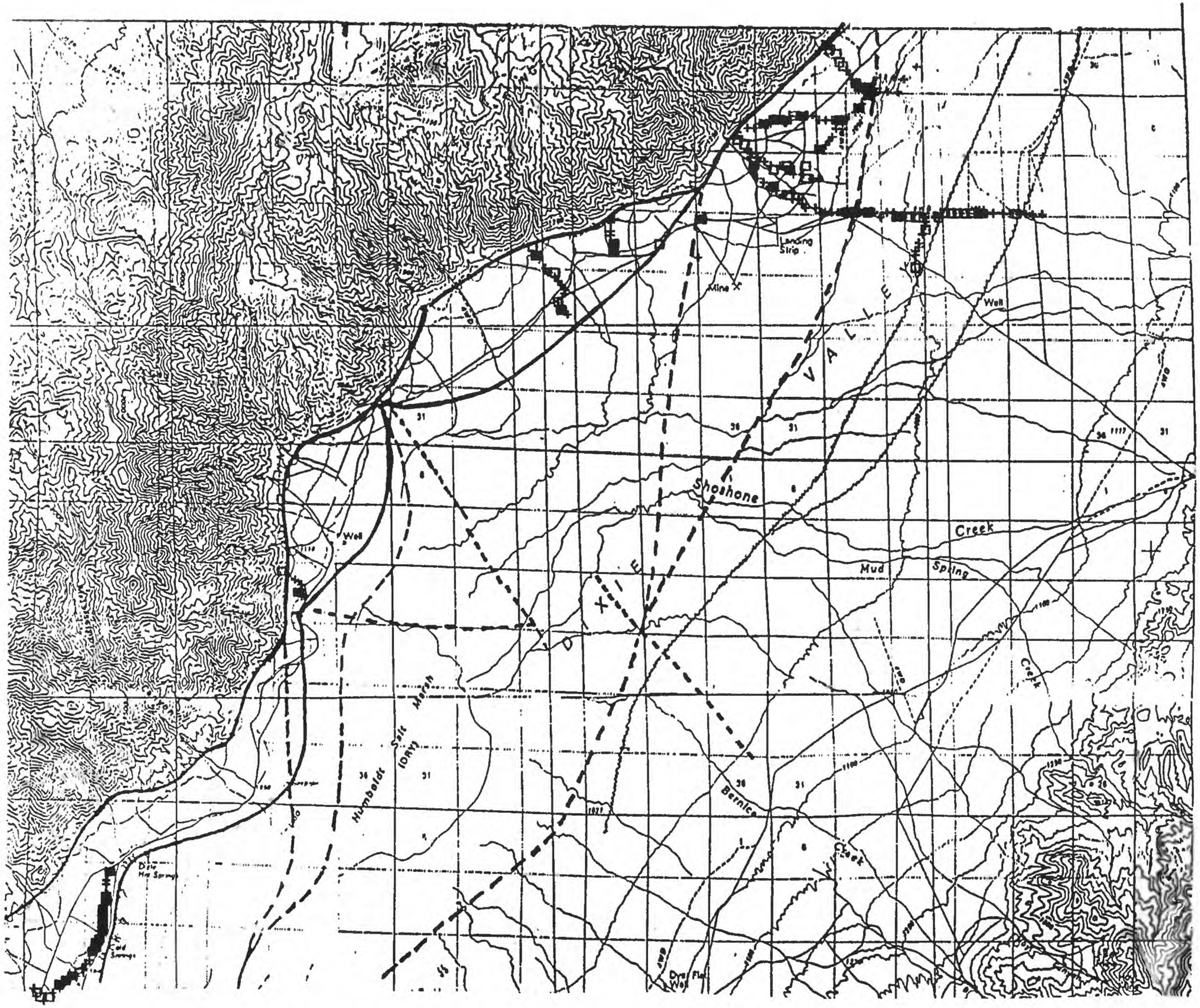

Fig.7. He-measured: □ <25th, + 25th-90th, ■ >90th percentiles

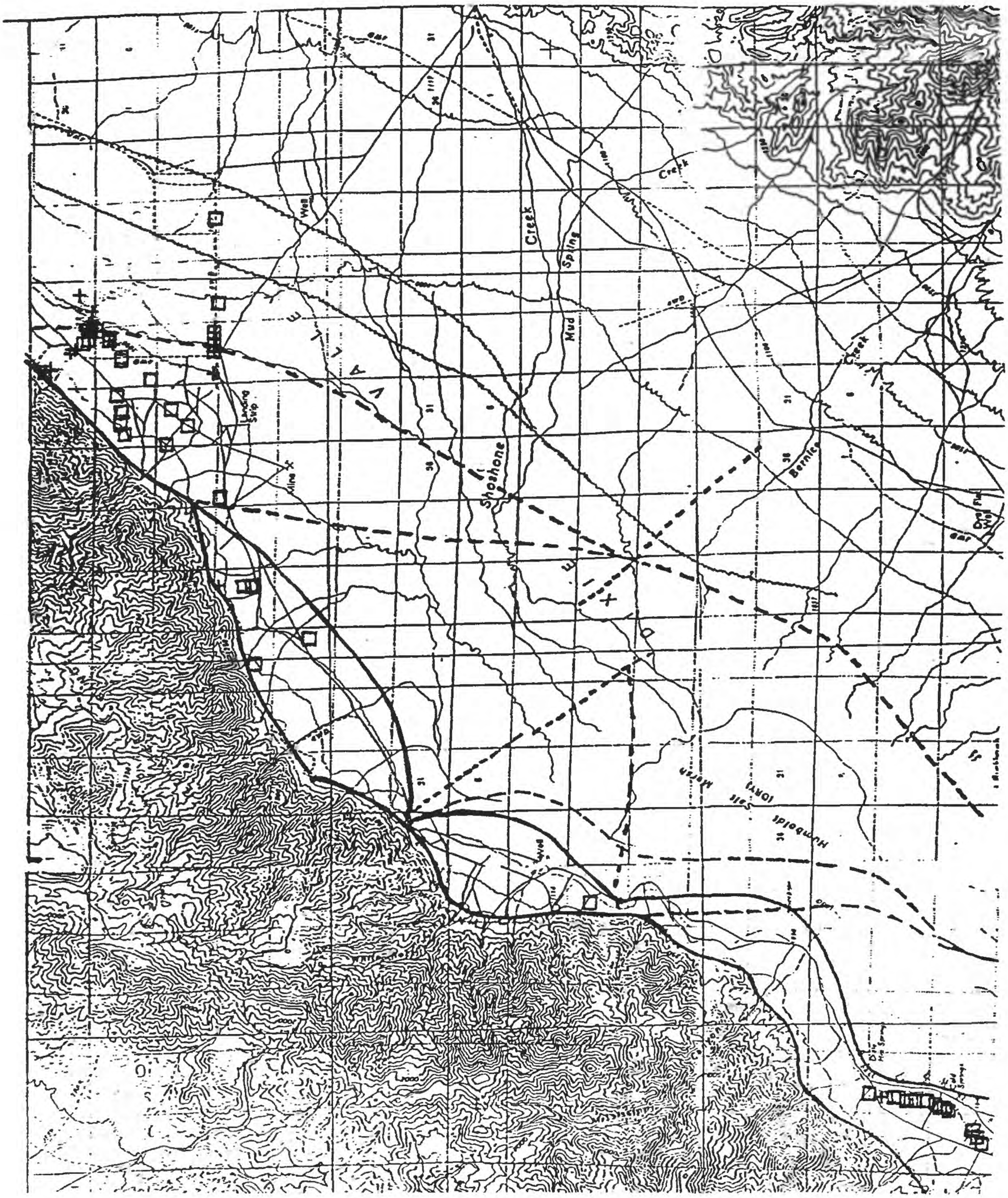

Fig. 8. +=>90th percentile CO_2; □ =>90th percentile He

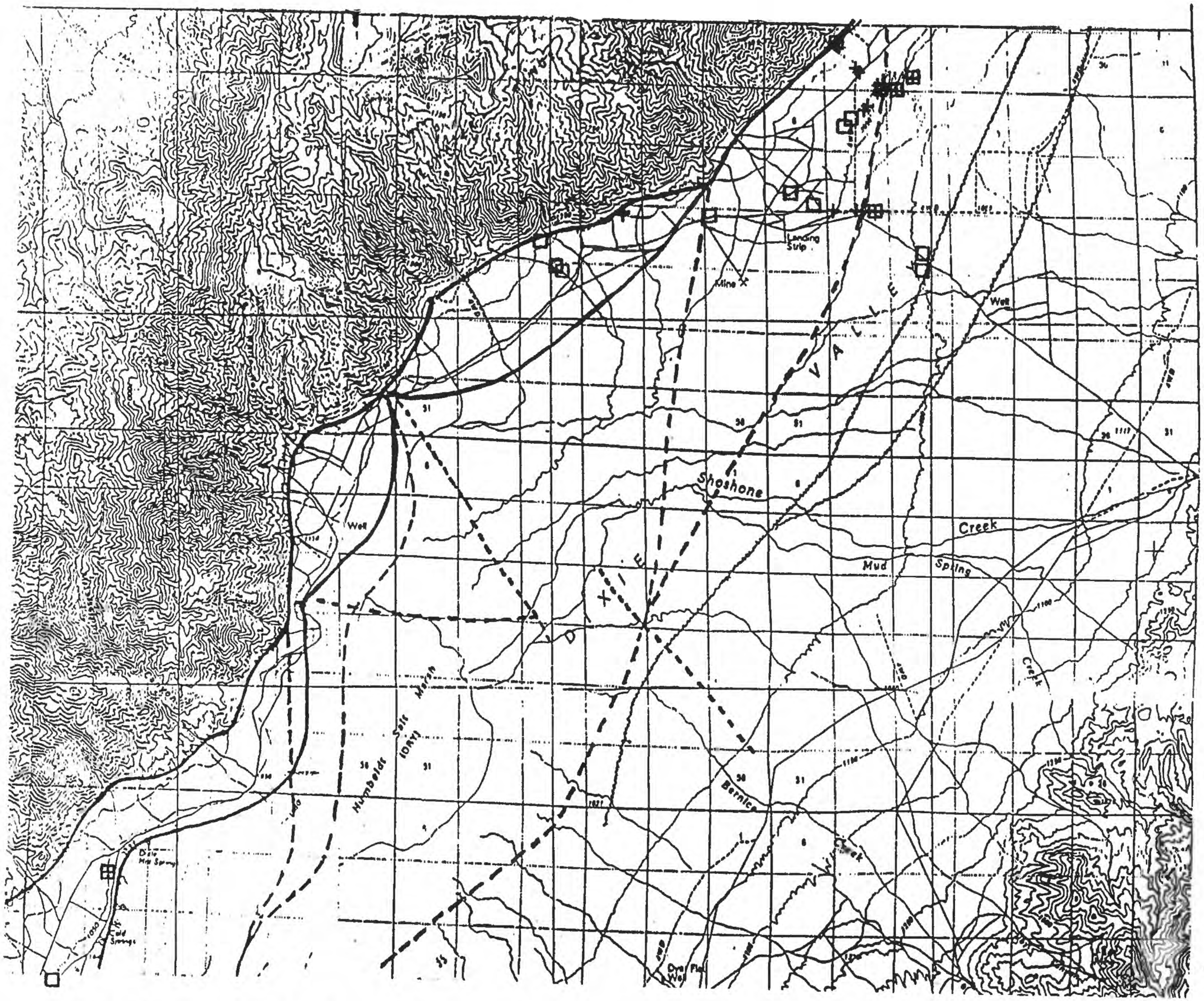

Fig.9. +=>90th percentile CO_2; □ =<10th percentile O_2