UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

Survey of Helium in Soils and Soil Gases and Mercury in Soils at Roosevelt Hot Springs Known Geothermal Resource Area, Utah

By

Margaret E. Hinkle
U.S. Geological Survey

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ABSTRACT

The concentrations of helium and mercury in soils and of helium in soil gases were surveyed in part of the Roosevelt Hot Springs Known Geothermal Resource Area to see what relationship helium and mercury concentrations might have to geothermal features of the area. High concentrations of helium occurred over the producing geothermal field, in an area of high temperature gradients. Low concentrations of helium in soils occurred over an area of visible hydrothermal activity. High concentrations of mercury coincided with areas of high thermal gradients and low resistivity.

INTRODUCTION

Roosevelt Hot Springs Known Geothermal Resource Area (KGRA) is situated about 20 km northeast of the town of Milford, in Beaver County, Utah (fig. 1). The KGRA is associated with Quaternary silicic volcanic rocks, which occur as domes, flows, and tuffs.

The hot-water-dominated system was named for a group of hot springs that discharged silica-rich waters until about 1966, when the flow stopped (Mundorff, 1970). The Roosevelt area has been intensively studied by several groups, including the U.S. Geological Survey, the Utah Geological and Mineralogical Survey, the University of Utah, Phillips Petroleum Company, and Thermal Power Company (Geothermex, 1977).

Roosevelt Hot Springs itself is located at the northern end of a wide north-south-trending fault zone, called both the Opal Mound fault and the Dome fault, on the western side of the Mineral Mountains (fig. 1). Exposures of opal, siliceous sinter, and silica-cemented alluvium occur along the fault zone south of Roosevelt Hot Springs (Petersen, 1975).

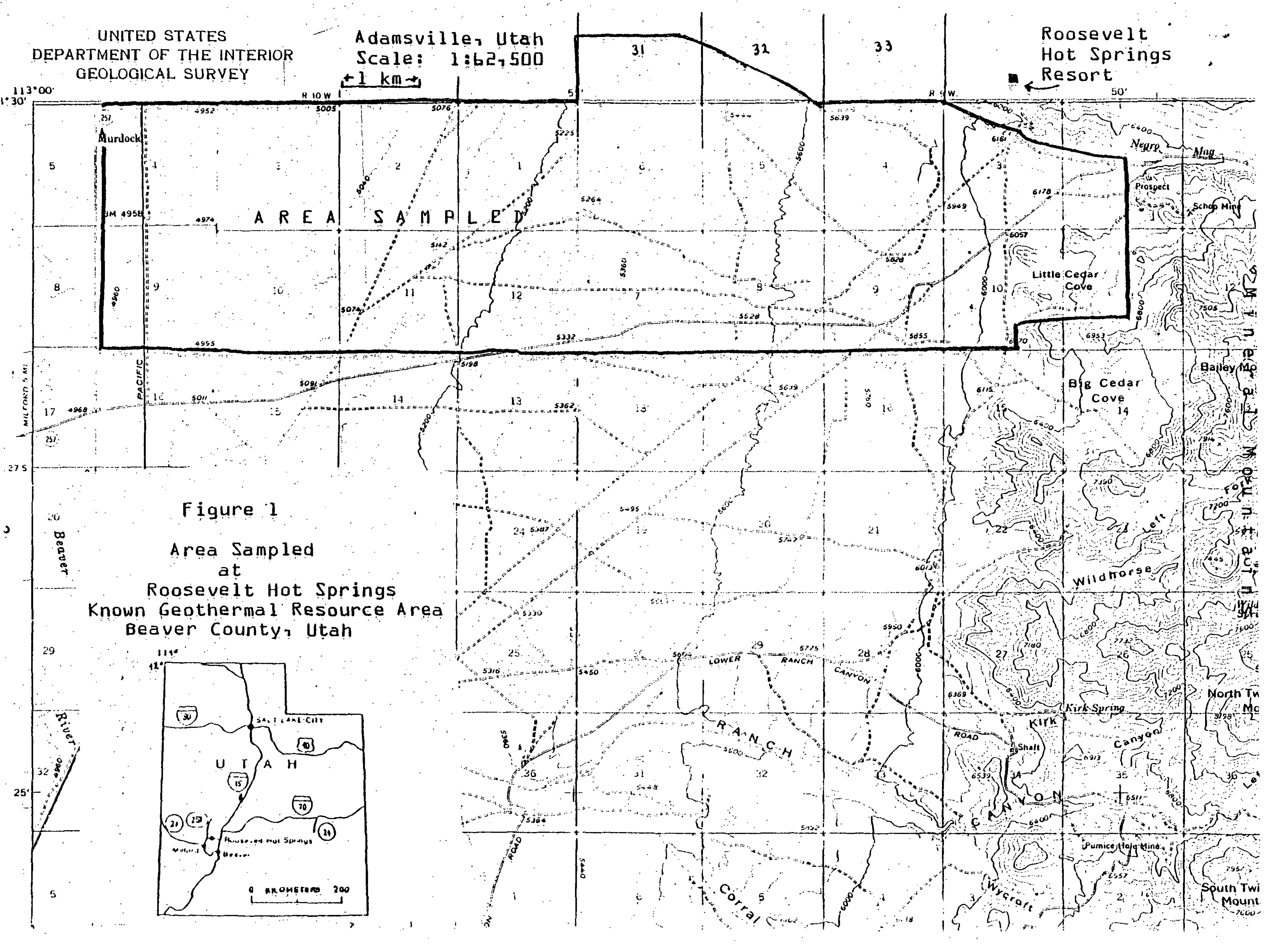


Figure 1

Area Sampled
at
Roosevelt Hot Springs
Known Geothermal Resource Area
Beaver County, Utah

The geothermal field is bounded by the range front on the east and the Opal Mound fault on the west (Nielson and others, 1978). Nearly all known hot spring deposits, surface alteration, and associated mineralization at Roosevelt Hot Springs are confined to a belt 5.6 km long by 0.4 km wide, centered on and parallel to the Opal Mound fault (Hulen, 1978; Parry and others, 1977). Both high thermal gradients and low resistivity measurements due to hot brine and associated hydrothermal alteration are aligned along the Opal Mound fault. The area between the Opal Mound fault and Fault 1 to the east of it is very highly fractured. Other north-trending faults and east-west faults are also important in bringing meteoric water from the Mineral Mountains into the geothermal system and in localizing the reservoir (Petersen, 1975; Ward and Sill, 1976; Sill and Bodell, 1977; Geothermex, 1977).

Previous studies with helium at Roosevelt Hot Springs either concentrated on developing the helium-sniffing technique (Denton, 1977) or attempted to distinguish faulted from nonfaulted area (Hinkle and others, 1978). Concentrations of mercury in soils along three traverses across the KGRA were measured by Capuano and Bamford (1978). A part of the KGRA containing six geothermal wells was sampled in this study. The study area extends from the Negro Mag Wash on the north, to the vicinity of the Opal Mound, an abandoned opal quarry west of Davies Steamwell, on the south. The samples were collected in April-May, 1977.

The present study had several goals: (1) expand and better explain results of the 1976 helium study; (2) compare usefulness of helium analyses from soil and probe samples; (3) see what relationship concentrations of helium and mercury have to geologic features such as faults and alteration; (4) see if helium concentration can be related to depth of geothermal wells; and (5) compare helium and mercury concentrations to results of geophysical studies of resistivity and temperature gradients.

SAMPLE COLLECTION

Both soil and soil gas samples were collected at each of 479 sample sites (fig. 2). Nearly all the samples were collected in secs. 2 through 11 of T. 27 S., R. 9 W. Seven sites were sampled south of Negro Mag Wash in secs. 31 and 32, T. 26 S., R. 9 W. Six additional sites were sampled in the Escalante Valley between Utah Highway 257 (fig. 2) and the main sampling area. Bedrock is not exposed in most of the area sampled. All except two samples were collected in alluvium, which ranges in thickness from zero along the mountain front to 1,400 m thick in the middle of the Escalante Valley west of the main sampling area; the two other samples were collected atop a hill.

Soil gas samples were collected by pounding a hollow steel probe about 0.5 m into the ground. Ten milliliters of air was withdrawn from the probe by a syringe and discarded. Then a 10-ml sample was withdrawn and injected through the rubber stopper into a 5-ml size Vacutainer[1/] brand evacuated blood sample collection tube, and the hole in the stopper was plugged with silicone glue.

Soil samples were collected by scraping off the top 5 to 8 cm of soil and using the underlying soil to fill a 20-ml Vacutainer sample tube to within 2-3 cm of the top, taking care to avoid small stones and organic debris. Dirt was brushed away from the neck of the tube and the tube was sealed with its airtight rubber stopper. Soil samples for mercury analysis were collected in cloth bags.

In the northern part of the area (secs. 2 through 6), samples were collected at 160-m spacings in east-west traverses. In the southern part (secs. 7 through 11), the samples were collected at 320-m spacings in east-west traverses. Samples around geothermal wells 13-10 (1,636 m deep) and 54-3 (880 m deep) (Geothermex, 1977) were collected at 50-meter spacings, north, south, east, and west of the edge of the drill pad.

1/ The use of a brand name in this report is for descriptive purposes only and does not constitute endorsement by the U.S. Geological Survey.

Figure 2

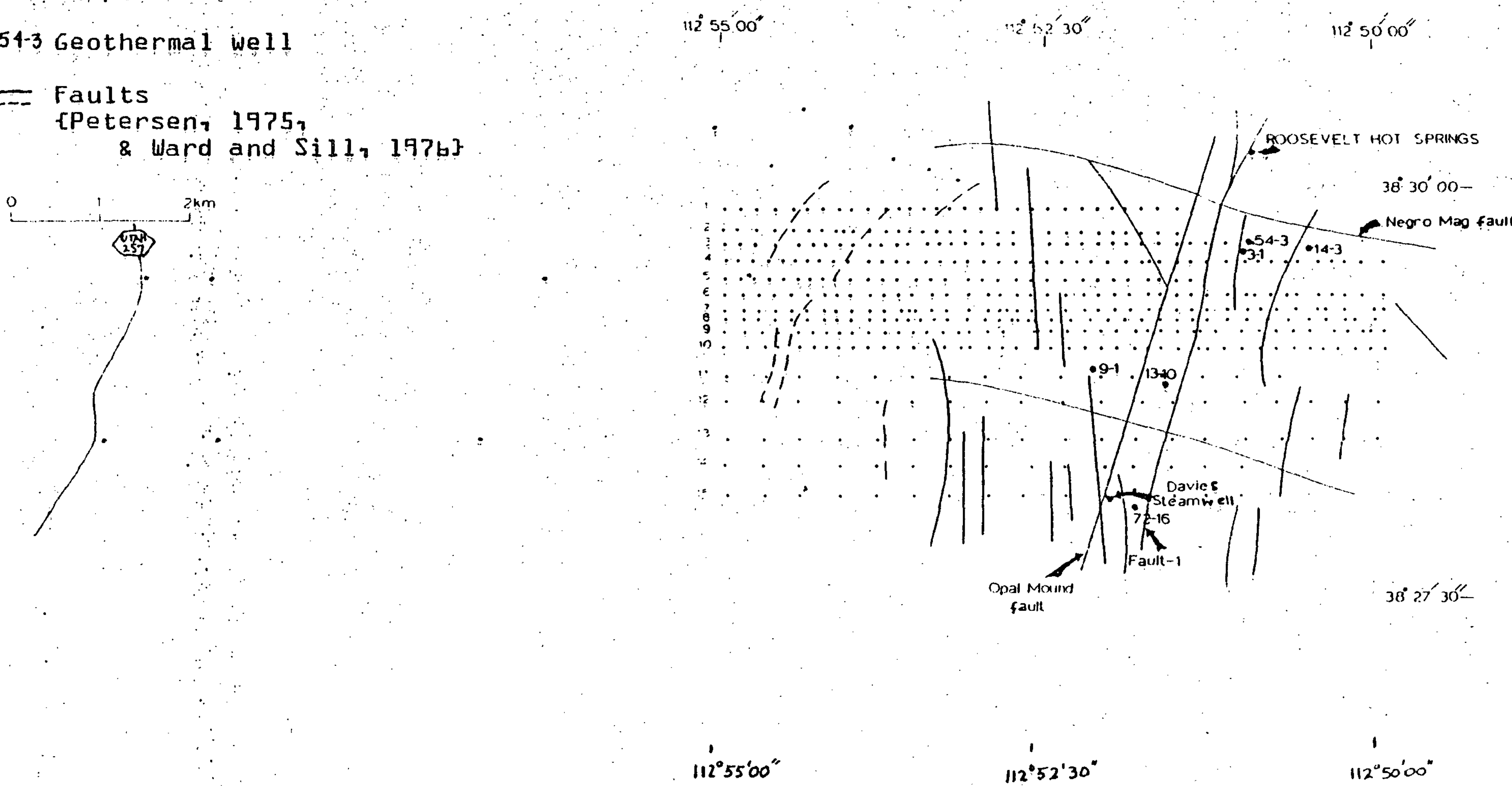
ROOSEVELT HOT SPRINGS

SAMPLE SITES

• Sample site

•54-3 Geothermal well

Faults
{Petersen, 1975, & Ward and Sill, 1976}



SAMPLE PREPARATION AND ANALYSIS

A helium sniffer developed by Friedman and Denton (1975) was used for the analyses. Soil gas samples were analyzed at U.S. Geological Survey laboratories in Denver from 14 to 22 days after collection. Gas samples were removed from the 5-ml Vacutainers by inserting a hypodermic needle with empty syringe attached through the rubber stopper; 4-5 cm^3 of the overpressured gas was expelled from the Vacutainer into the syringe. Fifty-one of the 479 soil gas samples in Vacutainers had leaked, and no gas samples were obtained from them. Samples were analyzed by direct injection into the helium detector and comparison with ambient air (5,240 parts per billion (ppb) helium). Reproducibility of the measurements was $\pm$ 15 ppb helium. Experimental data on the use of 5-ml Vacutainers for gas storage are included in the appendix of this report.

Soil samples were analyzed from 30 to 40 days after collection. The samples were placed in an ultrasonic bath and agitated for one hour to break up clay particles, then the samples were allowed to stand for 3 days to equilibrate the gases in the Vacutainer tube. Soil samples were analyzed by injecting 5 cm^3 of ambient air into the Vacutainer tube, stirring the contents of the tube for 30 seconds on a Vortex stirrer, removing the mixture of added air and air equilibrated with soil in the tube into an empty hypodermic syringe, and injecting this mixed air sample into the helium detector. The dead space volume of the Vacutainer tube containing the soil sample and the weight of the soil sample were measured. Helium in the pore space of dry soil was calculated by the following expression:

$$\text{He pore space (ppb)} = \frac{(5 + \text{dead volume})(\text{excess He}) - 37 \times \text{weight moisture}}{\left[1 - \frac{(22 - \text{dead volume} - \text{weight moisture})}{(22 - \text{dead volume})}\right](22 - \text{dead volume} - \text{weight moisture})}$$

where

22 is the volume (ml) of a nominal 20-ml Vacutainer tube;

dead volume is volume of Vacutainer tube not occupied by the soil sample (determined by evacuating the Vacutainer tube containing the sample, and measuring the volume of ambient air necessary to return the tube to atmospheric pressure);

5 is the 5 ml of ambient air added to the tube to pressurize the contents for removal of a gas sample for analysis;

excess He is the amount of helium measured, in excess of He in ambient air;

weight moisture is the difference between undried and dried weight of the soil sample; and

37 is the assumed concentration of He in moisture (ml x 10^{-9}/ml H_2O).

Details of the analytical procedure were described by Hinkle and Kilburn (1979). The detector was calibrated 3 times a day against a standard gas mixture containing 9,800 ppb helium. Reproducibility of the measurement was ± 30 percent of the calculated concentration for the soil samples.

Soil samples for mercury analysis were sieved to 180 µm (-80 mesh) and pulverized, then analyzed for mercury by the flameless atomic absorption procedure of Vaughn and McCarthy (1964).

RESULTS

1. Helium in soil gas: Concentrations of helium in soil gas samples collected by probes over the entire region ranged from 4,650 to 5,250 ppb; the mean and standard deviation were 4,785 ± 70 ppb (Table 1). Soil gas samples contained less helium than ambient air. The reason for this defecit is not known, but it appears to be constant and may be due to the method of sample storage used. Multiples of the standard deviation above and below the mean were used as the values for contours in preparing a map of helium concentrations in soil gas in the area (fig. 3).

The highest concentrations of helium in soil gas were east of the Opal Mound fault in the producing geothermal field. The alignment of high concentrations of helium between the Opal Mound fault and Fault 1 in the northern part of the study area coincides with an area of high thermal gradient and low resistivity (figs. 4, 5, 6).

The cause of high helium concentrations in soil gas east of the Opal Mound fault is not known. One possibility, though, is that meteoric water from the Mineral Mountains could flush helium up through faults and fractures east of the fault but might cross the silica-cemented fault zone too slowly to affect the helium concentrations west of the fault.

FIG. 3
HELIUM IN SOIL GAS
ROOSEVELT HOT SPRINGS
KGRA

MEAN AND STANDARD DEVIATION

4785 ± 70 ppb

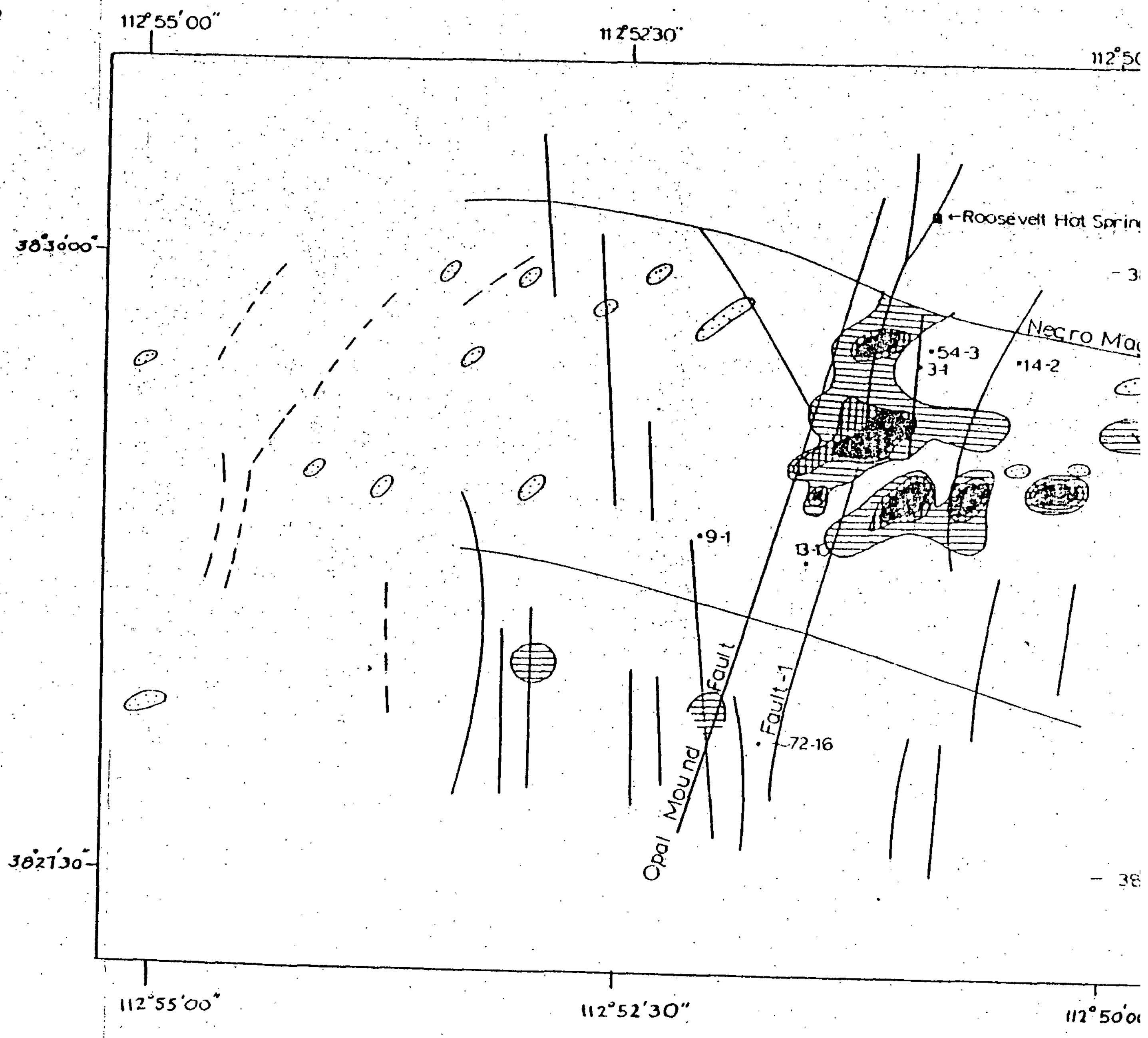
- ≤4714
- 4715 - 4854
- 4855 - 4924
- 4925 - 4994
- ≥4995

• 54-3 Geothermal Well

FAULTS — — —

(Petersen, 1975, & Ward and Sill, 1976)

0 1 2 Km



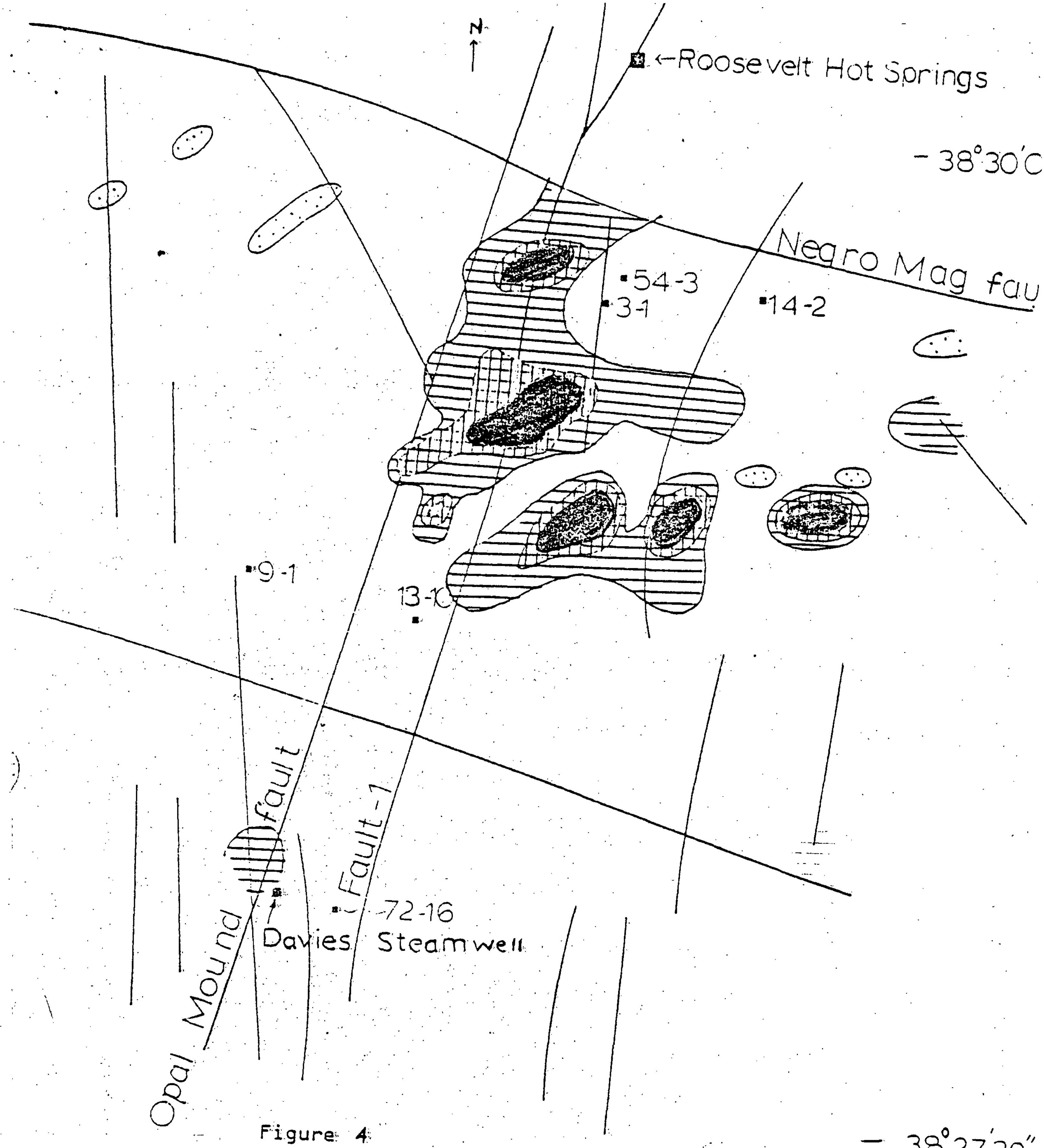


Figure 4

Helium in Soil Gas near Opal Mound Fault

≤ 4714 ppb

4715-4854

4855-4924

4925-4994 ppb

≥ 4995

0 1 Km

54-3 Geothermal Well

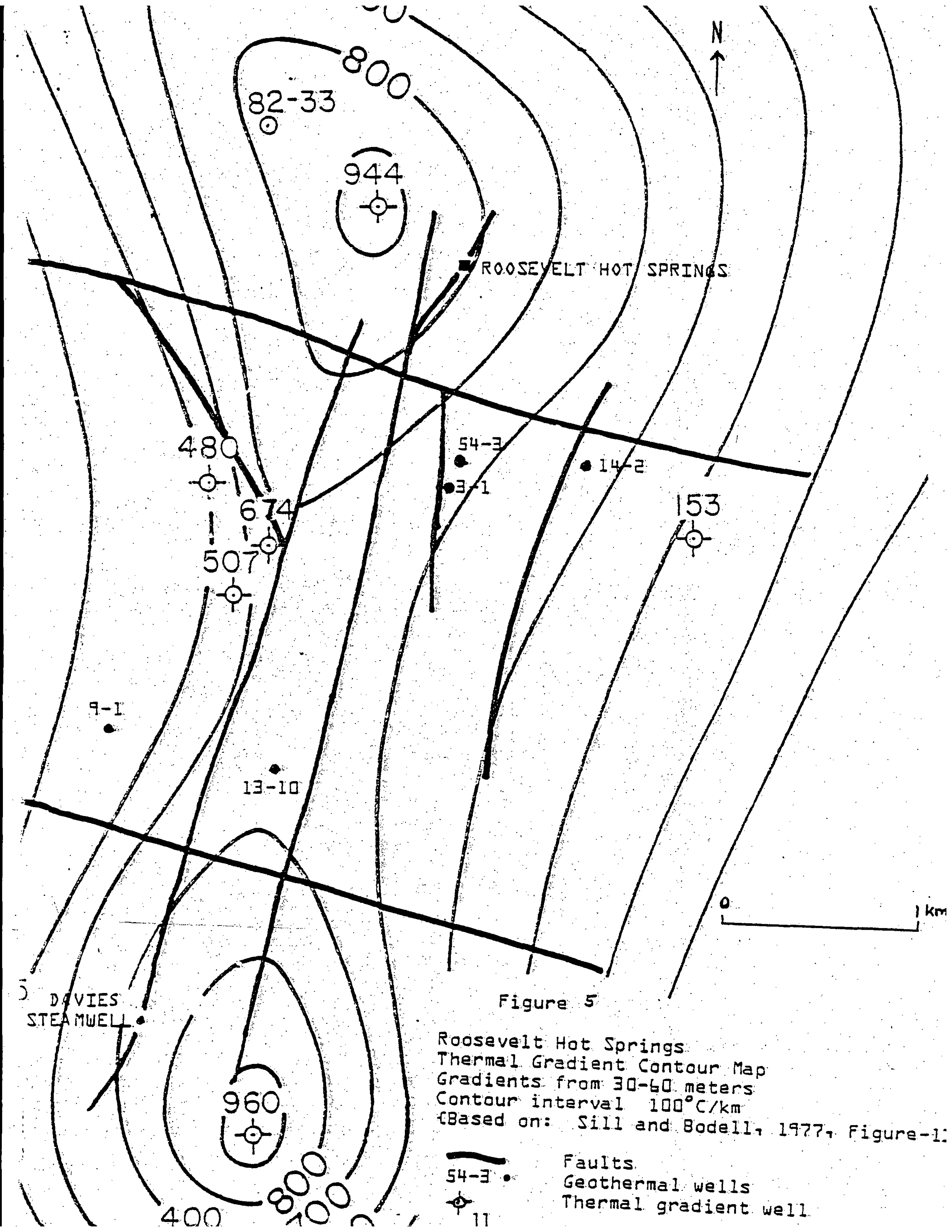


Figure 5

Roosevelt Hot Springs
Thermal Gradient Contour Map
Gradients from 30-60 meters
Contour interval 100°C/km
(Based on: Sill and Bodell, 1977, Figure-1

Faults
54-3 • Geothermal wells
Thermal gradient well

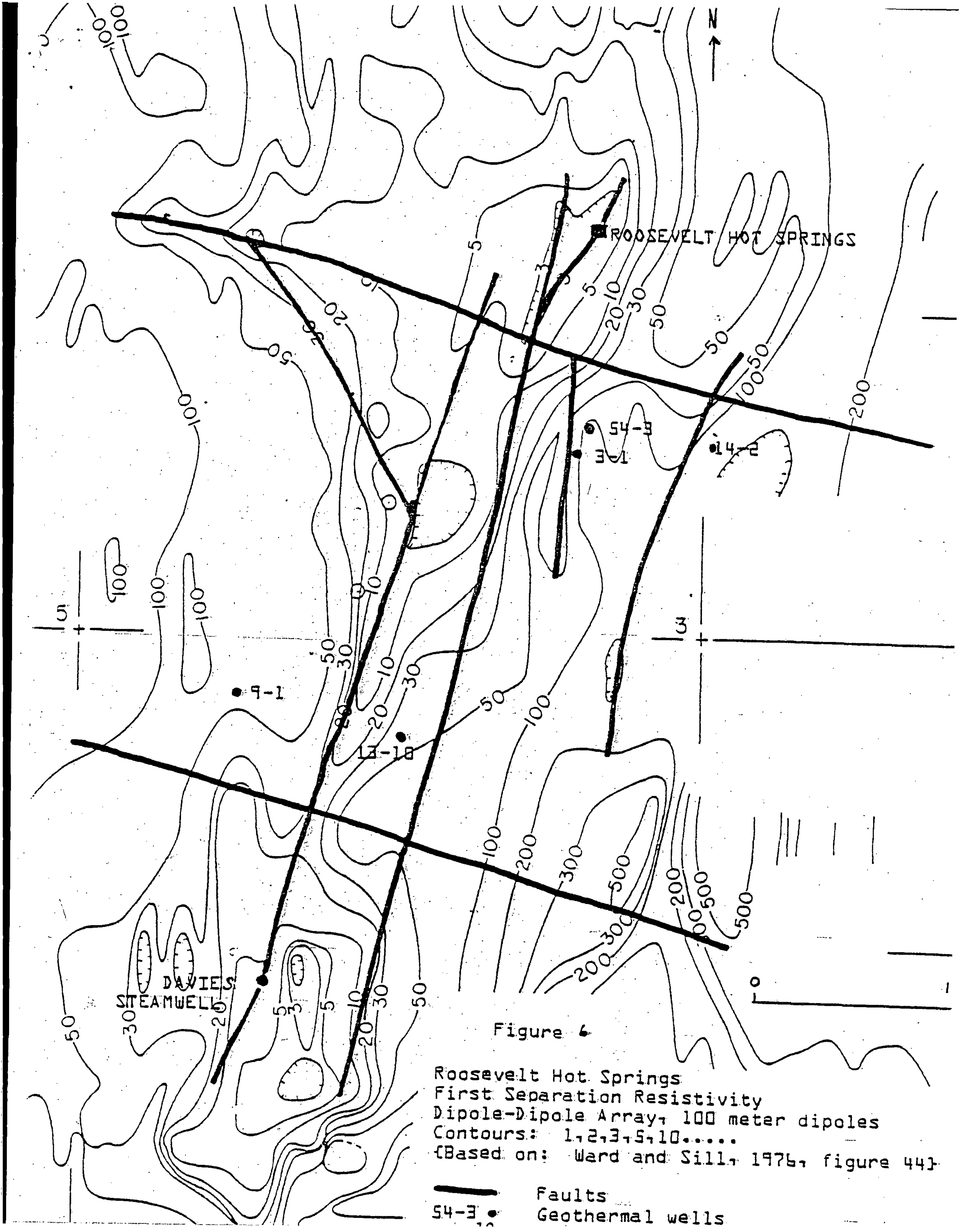


Figure 6

Roosevelt Hot Springs
First Separation Resistivity
Dipole-Dipole Array, 100 meter dipoles
Contours: 1,2,3,5,10.....
(Based on: Ward and Sill, 1976, figure 44)

Faults
54-3 • Geothermal wells

2. Helium in the pore space of dry soils: Concentrations of helium in the pore space of soils collected in Vacutainer tubes ranged from 559 to 21,000 ppb in excess of helium in ambient air (Table 1). The mean and standard deviation were 6,454 ± 2,983 ppb. Multiples of the standard deviation above and below the mean were used as the values for contours in preparing a map of helium concentrations in soils (fig. 7). Anomalously high concentrations of helium in soils occurred in the same regions that had high helium concentrations in the traverses run previously (Hinkle and others, 1978). High concentrations of helium occurred both east and west of the Opal Mound fault; most of the high concentrations were located over the producing field. No apparent correlation existed between concentrations of helium in soils and the patterns of thermal gradient or resistivity measurements (figs. 5, 6, 8). Anomalously low concentrations of helium occurred over the Opal Mound, an area of visible hydrothermal activity.

3. Concentrations of helium around two geothermal wells of different depths: Average concentrations of helium in soil samples were slightly higher around geothermal well 54-3 than around well 13-10. However, the difference in helium concentrations was not significant enough to use it as a measure of well depth. Average concentrations of helium in soil gases collected by probes were essentially the same around both wells (Table 2).

4. Mercury in soils: Concentrations of mercury in soil ranged from 20 to 3,000 ppb, and averaged about 60 ppb (Table 1). The pattern of concentrations of mercury in soils seen in this study agrees with and helps coordinate the concentrations of mercury in soils of the traverses run by Capuano and Bamford (1978). Highest concentrations occurred along the Opal Mound fault in the northern part of the area sampled (fig. 9). High concentrations of mercury coincided with high thermal gradients and low resistivity measurements along the Opal Mound fault (figs. 5, 6, 10).

Table 1.--*Concentrations of helium and mercury in samples*

[Collected in traverses west to east across study area]

No.	He in soil gas (ppb)	He in soil (ppb)	Hg in soil* (ppm)	No.	He in soil gas (ppb)	He in soil (ppb)	Hg in soil* (ppm)
LINE 1							
1	4,725	4,877	0.04	16	4,750	2,849	0.08
2	4,750	3,306	.02	17	4,725	4,315	.06
3	--	4,308	.02	18	4,700	4,411	.06
4	--	3,393	.02	19	4,725	3,930	.06
5	4,725	3,722	.02	20	4,725	5,350	.10
6	4,750	4,789	0.02	21	4,725	6,114	0.10
7	4,800	991	.04	22	4,725	5,591	.16
8	4,750	3,711	.08	23	4,650	6,822	.08
9	4,750	7,141	.02	24	--	10,750	.08
10	--	7,265	.02	25	4,725	7,078	.08
11	4,750	4,026	0.02	26	4,750	5,339	0.06
12	4,750	6,397	.06	27	--	8,491	.08
13	4,750	4,750	.06	28	4,750	10,324	.04
14	4,700	6,714	.04	29	4,750	6,482	.08
15	4,725	8,231	.04	30	4,750	6,516	.08
LINE 2							
1	--	3,392	0.02	16	4,750	4,891	0.08
2	--	5,837	.04	17	--	8,666	.02
3	--	5,987	.04	18	4,750	4,603	.04
4	4,750	1,180	.02	19	4,750	7,621	.04
5	4,800	5,334	.02	20	4,750	3,006	.06
6	--	6,793	0.04	21	4,800	4,081	0.08
7	4,750	3,443	.04	22	4,700	10,616	.10
8	4,750	6,606	.04	23	4,750	5,288	.08
9	4,800	5,071	.02	24	4,750	8,143	.06
10	4,750	4,533	.04	25	4,750	7,785	.08
11	4,750	4,486	0.04	26	4,750	9,980	0.10
12	--	5,257	.04	27	--	7,876	.24
13	4,750	3,565	.02	28	4,650	7,182	.12
14	4,750	2,595	.04	29	4,750	4,781	.08
15	4,750	3,439	.04	30	4,725	6,766	.08
				31	4,750	6,967	.18
LINE 3							
1	4,800	5,889	0.04	21	4,775	7,862	0.06
2	4,750	5,922	.04	22	4,800	5,371	.02
3	4,750	4,861	.02	23	4,775	5,252	.14
4	4,750	1,608	.06	24	4,750	7,822	.08
5	4,750	5,434	.06	25	4,700	8,803	.08
6	4,750	7,448	0.04	26	4,750	7,221	0.04
7	4,750	7,000	.02	27	4,750	9,660	.30
8	4,750	4,429	.04	28	4,775	6,367	.08
9	4,750	5,240	.06	29	4,725	7,232	.18
10	--	3,443	.04	30	--	6,518	3.0
11	4,725	6,387	0.04	31	--	4,527	2.0
12	4,725	3,969	.08	32	--	6,051	.35
13	4,800	4,373	.04	33	4,825	7,721	.28
14	4,725	3,359	.02	34	--	3,289	--
15	--	19,353	.04				
16	4,750	5,898	0.04				
17	4,725	5,046	.04				
18	4,750	5,045	.06				
19	4,725	6,001	.04				
20	4,750	6,718	.06				

* Analyst: E. C. Tapia

Table 1.--*Concentrations of helium and mercury in samples*--Continued

[Collected in traverses west to east across study area]

No.	He in soil gas (ppb)	He in soil (ppb)	Hg in soil* (ppm)	No.	He in soil gas (ppb)	He in soil (ppb)	Hg in soil* (ppm)
			LINE 4				
1	4,800	9,261	0.06	26	4,800	9,820	0.16
2	4,800	3,518	.02	27	4,750	8,997	.12
3	4,800	4,903	.02	28	4,800	13,218	.12
4	4,750	579	.02	29	--	9,157	.45
5	4,750	1,401	.02	30	4,850	10,655	.50
6	--	4,109	0.04	31	4,800	8,980	.30
7	4,800	3,699	.02	32	4,800	8,876	3.0
8	4,725	3,858	.04	33	4,900	2,926	1.2
9	4,750	4,537	.06	34	5,150	6,051	.35
10	4,750	4,304	.06	35	5,000	14,345	.06
11	4,750	4,563	0.04	36	4,725	8,883	0.06
12	4,725	3,449	.04	37	4,800	9,549	.04
13	4,725	4,386	.06	38	--	10,147	.06
14	4,700	5,100	.04	39	4,800	7,445	.06
15	4,725	3,977	.04	40	4,725	7,946	.06
16	4,650	8,253	0.06	41	4,800	6,963	0.04
17	4,750	4,516	.04	42	4,800	6,286	.04
18	4,725	3,953	.04	43	4,800	11,185	.02
19	--	3,970	.06	44	4,800	8,816	.16
20	4,750	9,648	.04	45	4,800	15,431	.08
21	4,750	4,200	0.08				
22	4,800	7,295	.08				
23	4,725	8,920	.10				
24	4,775	10,313	.08				
25	4,800	10,939	.08				
			LINE 5				
1	4,800	3,457	0.02	21	4,725	4,039	0.04
2	--	2,793	.02	22	4,750	8,232	.04
3	4,800	4,621	.04	23	4,750	4,881	.06
4	4,725	1,671	.02	24	4,775	10,910	.04
5	4,750	5,544	.02	25	4,750	9,346	.08
6	--	12,061	0.06	26	4,800	10,298	0.08
7	4,750	7,752	.04	27	--	7,686	.06
8	4,750	5,750	.06	28	4,800	8,878	.08
9	4,750	9,225	.02	29	4,800	10,707	.04
10	4,750	3,916	.06	30	4,800	8,830	.12
11	4,750	5,836	0.04	31	4,875	9,776	0.35
12	4,750	6,291	.06	32	4,775	6,038	.20
13	--	7,542	.04	33	--	6,737	3.0
14	--	4,559	.02	34	--	12,288	.06
15	4,800	7,750	.04				
16	4,725	3,925	0.04				
17	4,725	4,985	.04				
18	4,800	5,672	.06				
19	--	1,877	.06				
20	4,750	4,647	.02				

Table 1.--*Concentrations of helium and mercury in samples*--Continued

[Collected in traverses west to east across study area]

No.	He in soil gas (ppb)	He in soil (ppb)	Hg in soil* (ppm)
LINE 6			
1	--	4,607	0.02
2	4,800	4,914	.04
3	4,825	5,949	.08
4	4,800	4,907	.02
5	--	11,148	.02
6	4,800	8,288	0.04
7	4,750	6,129	.02
8	4,800	6,726	.02
9	4,800	6,245	.04
10	--	1,907	.02
11	4,800	4,234	0.02
12	4,750	4,877	.04
13	4,700	3,021	.04
14	4,750	7,621	.06
15	4,700	3,253	.04
16	4,750	6,132	0.06
17	4,750	5,362	.04
18	4,750	2,992	.02
19	4,750	1,558	.06
20	4,800	9,428	.06
21	4,800	10,149	0.06
22	4,775	10,614	.04
23	4,775	5,105	.04
24	4,800	4,928	.04
25	4,800	9,859	.10
26	4,800	4,318	0.16
27	4,800	12,223	.12
28	4,800	6,493	.06
29	4,850	2,660	.60
30	4,925	2,604	.04
31	4,850	7,904	0.02
32	--	5,602	.02
33	4,800	5,974	.08
34	4,800	9,875	.06
35	4,800	6,596	.08
36	--	6,207	0.06
37	4,800	8,810	.04
38	4,800	14,154	.06
39	4,800	8,328	.04
40	4,800	11,913	.06
41	4,825	12,549	0.04
42	4,700	9,090	.60
LINE 7			
1	4,800	4,829	0.04
2	4,750	3,558	.08
3	4,800	5,416	.02
4	4,750	5,275	.04
5	4,750	5,472	.02
6	4,800	5,451	0.02
7	4,750	6,079	.02
8	4,750	5,189	.02
9	4,750	3,858	.02
10	4,750	8,353	.02
11	4,750	3,363	0.02
12	4,750	8,315	.06
13	4,775	5,637	.04
14	--	5,426	.02
15	4,800	5,700	.02
16	--	5,418	0.02
17	4,750	4,069	.02
18	4,800	6,424	.06
19	--	3,649	.06
20	4,800	5,439	.04
21	4,750	9,173	0.06
22	4,725	3,511	.04
23	4,800	8,523	.08
24	4,800	9,584	.06
25	4,750	6,292	.08
26	4,750	11,446	0.08
27	4,750	6,833	.08
28	4,800	8,969	.12
29	4,800	3,176	.08
30	4,750	6,139	3.0
31	4,900	4,776	0.08
32	4,925	5,597	.80
33	5,150	6,698	.08
34	5,050	8,188	.04
35	4,850	13,291	.02
36	4,850	8,938	0.08
37	4,850	10,667	.04
38	4,800	8,886	.06
39	4,825	14,403	.06
40	4,775	5,716	.06
41	4,800	8,847	0.08
42	--	11,558	.02
43	4,850	13,918	.04

Table 1.--*Concentrations of helium and mercury in samples*--Continued

[Collected in traverses west to east across study area]

No.	He in soil gas (ppb)	He in soil (ppb)	Hg in soil* (ppm)	No.	He in soil gas (ppb)	He in soil (ppb)	Hg in soil* (ppm)
LINE 8							
1	4,750	4,705	0.02	26	4,800	4,803	0.04
2	4,775	3,931	.02	27	4,800	5,180	.04
3	4,775	4,482	.02	28	4,750	6,394	.08
4	4,775	4,950	.02	29	4,800	4,628	.16
5	4,750	3,010	.02	30	4,800	7,487	.16
6	4,750	5,096	0.02	31	4,825	4,063	0.35
7	4,750	6,596	.02	32	5,000	9,173	.06
8	4,775	4,296	.02	33	5,750	5,884	.04
9	4,750	8,789	.02	34	4,900	8,418	.04
10	4,775	3,343	.02	35	4,825	13,295	.02
11	--	1,064	0.04	36	--	12,428	0.08
12	4,750	4,194	.02	37	4,800	11,696	.02
13	4,750	5,134	.06	38	4,825	13,470	.06
14	4,800	4,090	.06	39	4,825	10,648	.04
15	4,800	5,003	.02	40	--	12,500	.02
16	4,825	6,384	0.06	41	4,825	14,947	0.02
17	4,750	5,222	.04	42	4,850	21,000	.02
18	4,750	5,013	.02				
19	4,800	6,375	.04				
20	4,750	4,205	.06				
21	4,650	4,521	0.04				
22	4,800	17,441	.04				
23	4,800	5,932	.04				
24	4,750	9,323	.06				
25	4,750	8,668	.04				
LINE 9							
1	4,750	9,048	0.02	26	4,800	8,989	0.02
2	4,750	6,973	.02	27	4,825	6,618	.04
3	4,750	4,621	.04	28	4,800	5,492	.08
4	4,725	5,574	.02	29	4,950	7,197	.06
5	4,750	6,639	.02	30	4,875	12,618	.06
6	4,725	9,834	0.04	31	--	4,568	0.04
7	4,750	4,884	.02	32	4,850	1,615	.04
8	4,650	4,994	.02	33	4,800	7,498	.04
9	4,750	4,723	.06	34	4,800	8,392	.04
10	4,750	3,295	.06	35	4,800	7,822	.04
11	4,800	3,119	0.02	36	4,800	6,792	0.06
12	4,650	4,190	.06	37	--	8,357	.04
13	4,750	4,078	.02	38	4,675	10,487	.04
14	4,725	6,997	.04	39	--	9,582	.06
15	4,800	10,890	.02	40	4,800	8,317	.02
16	4,750	5,970	0.04	41	4,675	8,276	0.04
17	4,725	3,052	.06	42	4,800	8,513	.08
18	--	6,576	.04	43	--	4,454	.06
19	4,750	4,652	.04				
20	4,750	3,103	.02				
21	4,800	5,818	0.02				
22	4,825	5,600	.02				
23	4,800	7,340	.04				
24	--	4,474	.02				
25	4,825	6,247	.04				

Table 1.--*Concentrations of helium and mercury in samples*--Continued

[Collected in traverses west to east across study area]

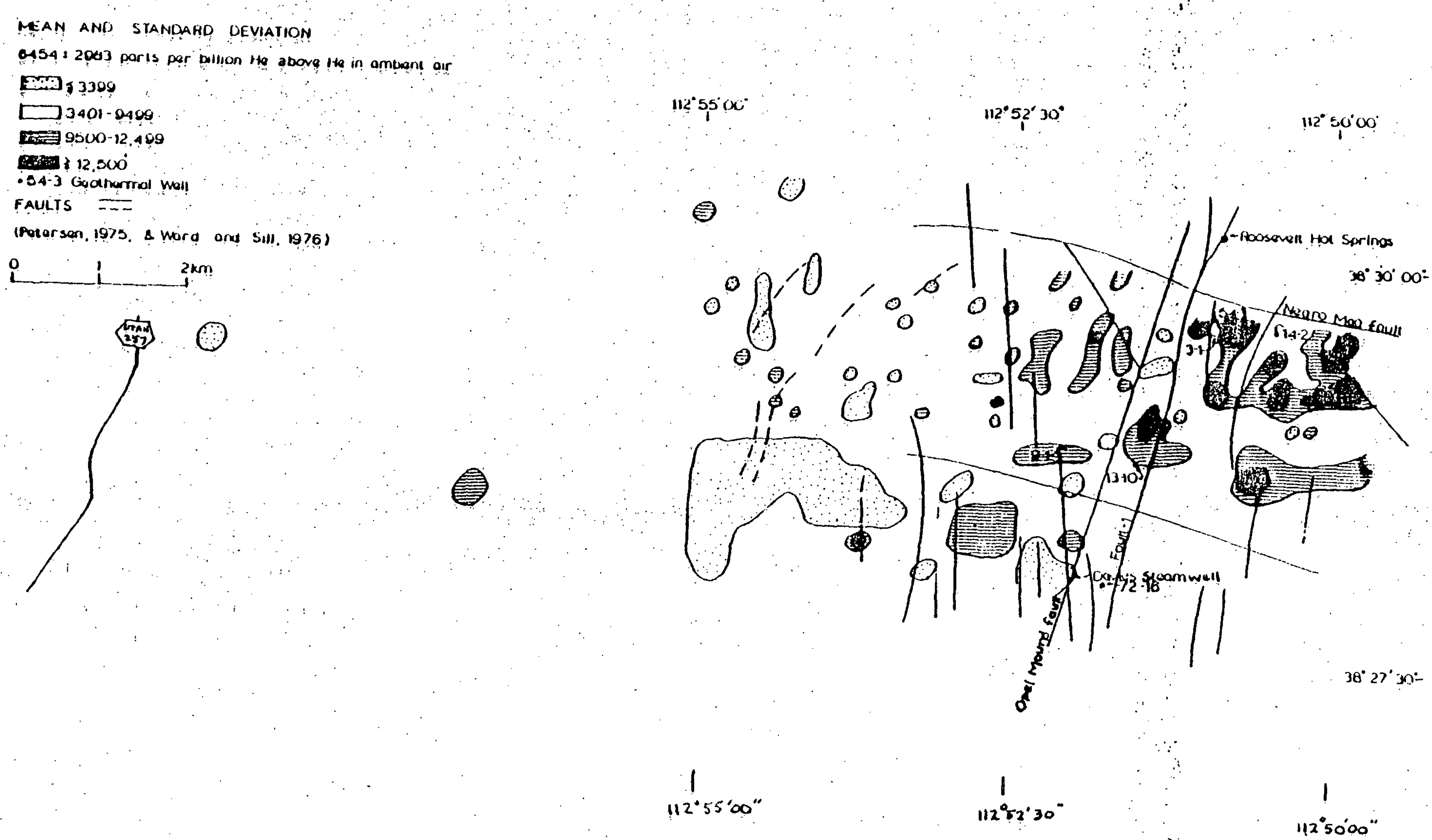
No.	He in soil gas (ppb)	He in soil (ppb)	Hg in soil* (ppm)	No.	He in soil gas (ppb)	He in soil (ppb)	Hg in soil* (ppm)
LINE 10							
1	4,800	4,605	0.04	26	4,800	5,717	0.06
2	4,800	11,770	.06	27	4,800	3,928	.06
3	4,725	6,062	.02	28	4,800	7,171	.04
4	4,725	5,019	.04	29	4,825	11,368	.02
5	4,750	5,776	.04	30	5,000	13,594	.04
6	4,825	3,650	.02	31	4,825	10,174	0.02
7	4,725	4,681	.02	32	4,725	6,564	.06
8	4,725	6,151	.02	33	--	3,856	.04
9	--	3,780	.02	34	5,250	6,083	.06
10	--	6,946	.02	35	4,875	8,053	.04
11	4,700	7,235	0.02	36	5,250	8,151	0.04
12	4,725	6,285	.02	37	4,825	4,343	.06
13	4,725	4,325	.04	38	4,825	5,430	.06
14	4,725	3,328	.06	39	5,100	2,445	.02
15	4,725	5,326	.04	40	5,150	11,396	.06
16	4,750	3,956	0.06	41	4,800	9,122	0.08
17	4,725	5,596	.02	42	4,800	7,932	.06
18	4,650	5,763	.02	43	--	5,316	.06
19	--	4,831	.02				
20	4,750	6,900	.02				
21	4,800	3,842	0.02				
22	4,800	5,842	.04				
23	4,800	4,157	.06				
24	4,800	7,089	.02				
25	4,750	4,885	.04				
LINE 11							
1	4,800	2,190	0.04	11	4,800	11,035	0.04
2	4,800	2,973	.08	12	4,825	2,415	.04
3	4,775	3,905	.06	13	4,825	10,234	.02
4	4,750	3,361	.08	14	4,900	11,277	.02
5	4,800	3,696	.04	15	4,850	5,105	.02
6	4,800	3,878	0.04	16	4,900	10,940	0.02
7	4,800	6,369	.02				
8	4,800	5,622	.04				
9	4,825	6,074	.04				
10	4,750	11,681	.08				
LINE 12							
1	4,800	2,927	0.04	11	--	3,184	0.06
2	4,800	3,316	.06	12	4,825	6,998	.02
3	4,775	3,371	--	13	4,800	6,210	.06
4	4,775	3,332	.06	14	4,800	7,246	.06
5	4,800	2,768	.04	15	4,825	7,429	.04
6	4,800	3,474	.02	16	4,825	16,036	.04
7	4,800	7,010	.02	17	--	11,643	.10
8	4,800	3,155	.02	18	--	9,537	.08
9	4,825	5,516	.04	19	4,825	10,558	.06
10	4,800	5,455	.04				

Table 1.--*Concentrations of helium and mercury in samples*--Continued

[Collected in traverses west to east across study area]

No.	He in soil gas (ppb)	He in soil (ppb)	Hg in soil* (ppm)	No.	He in soil gas (ppb)	He in soil (ppb)	Hg in soil* (ppm)
LINE 13							
1	4,825	4,740	0.04	16	4,800	6,297	0.06
2	4,850	4,147	.02	17	4,800	5,525	.12
3	4,800	11,499	.08	18	4,825	6,336	.07
4	4,825	999	.04	19	4,825	5,657	.04
5	4,800	2,912	.04	20	4,800	7,342	.04
6	4,800	4,366	0.02	21	4,800	9,092	0.06
7	4,775	2,164	.06	22	4,800	6,342	.06
8	4,800	2,473	.06				
9	4,800	2,681	.02				
10	4,800	4,446	.02				
11	4,825	9,614	0.02				
12	4,800	11,553	.02				
13	4,800	7,371	.04				
14	4,825	6,363	.04				
15	4,800	5,700	.04				
LINE 14							
1	4,825	2,766	0.06	11	4,825	11,644	0.06
2	--	6,403	.04	12	4,800	4,828	.24
3	4,750	4,598	.08	13	4,725	5,136	.04
4	4,750	4,188	.06	14	4,800	5,532	.02
5	4,750	21,000	.06	15	4,825	5,655	.04
6	--	5,758	0.04				
7	4,775	6,482	.02				
8	4,850	9,997	.08				
9	4,800	11,428	.04				
10	4,800	3,195	.06				
LINE 15							
1	4,700	3,141	0.04	11	4,850	1,008	0.08
2	4,800	7,912	.04	12	--	4,751	.10
3	4,750	8,283	.08	13	4,800	3,732	.08
4	4,750	4,201	.04	14	--	4,992	.06
5	4,775	5,670	.06	15	--	5,492	.04
6	4,825	5,927	0.08				
7	4,775	3,273	.04				
8	4,800	6,910	.04				
9	4,800	3,607	--				
10	4,800	3,054	--				
NEGRO MAG WASH							
1	4,750	9,832	0.08	6	4,750	6,013	0.04
2	4,725	4,609	.06	7	--	7,258	.06
3	4,800	2,550	.04				
4	4,750	5,532	.08				
5	4,750	6,565	.04				
DAVIES STEAMWELL							
--	5,200	--	0.18				

Figure 7
HELIUM IN SOILS
ROOSEVELT HOT SPRINGS
KGRA



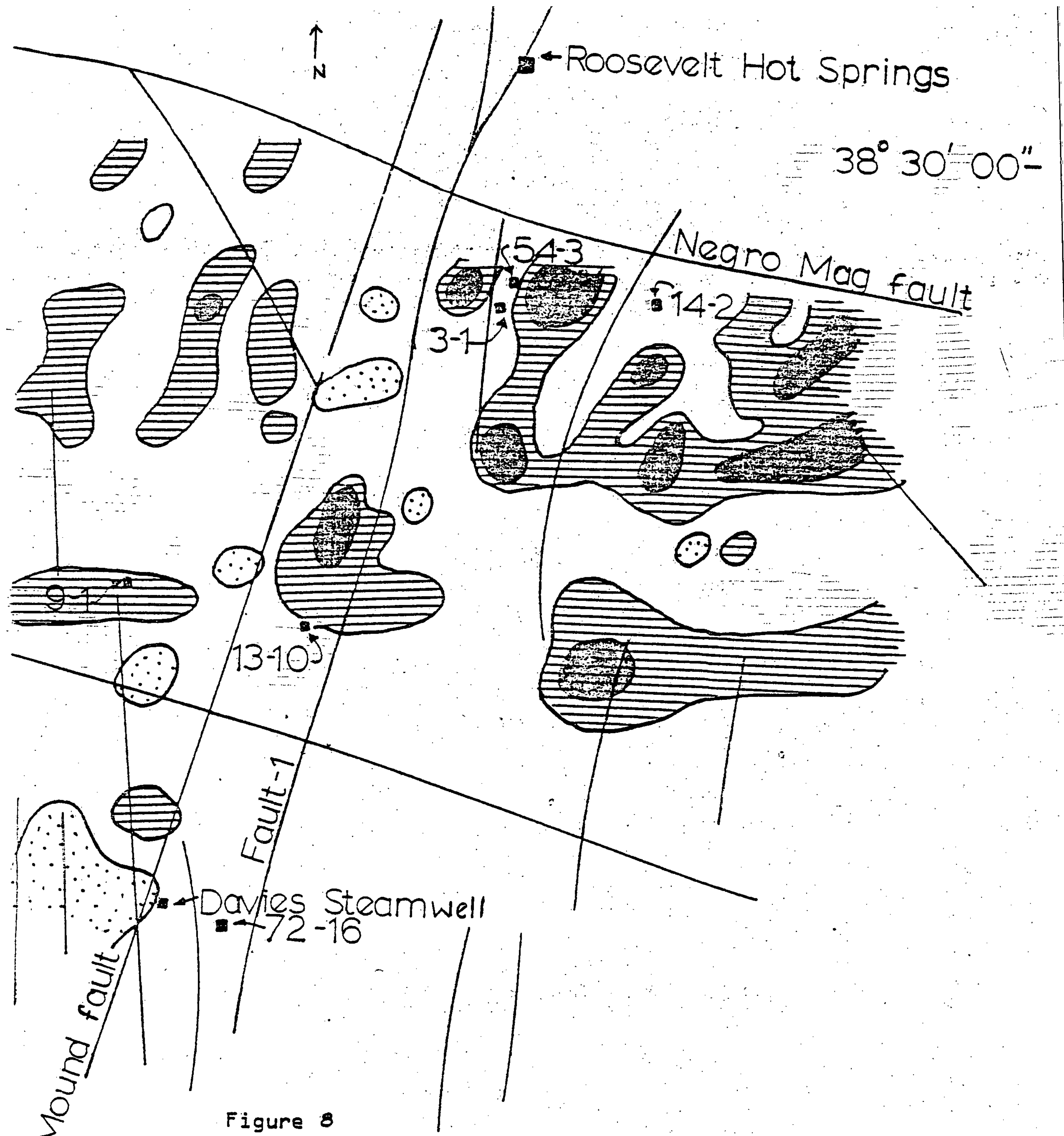


Figure 8

Helium in Pore Space of Soils Near Opal Mound Fault

≤ 3399 ppb

3401-9499

9500-12,499 ppb

≥ 12,500

54-3■ Geothermal Well

0 1 Km

Table 2.--*Comparison of helium concentrations around two geothermal wells*

Geothermal well 13-10 (1,636 meters deep)			Geothermal well 54-3 (880 meters deep)		
Location	Helium in pore space of dry soils, in excess of helium in air (ppb)	Helium in soil gas collected by probe (ppb)	Location	Helium in pore space of dry soils, in excess of helium in air (ppb)	Helium in soil gas collected by probe (ppb)
0 meters east	1,090	4,750	0 meters east	6,381	4,850
50 -----do----	3,478	4,850	50 -----do----	7,213	--
100 -----do----	3,414	4,850	100 -----do----	7,525	4,850
150 -----do----	4,378	4,850	150 -----do----	3,225	4,850
200 -----do----	9,704	4,850	200 -----do----	8,687	4,850
0 meters west	6,064	4,750	0 meters west	5,637	4,900
50 -----do----	3,582	4,850	50 -----do----	17,883	4,900
100 -----do----	4,758	4,850	100 -----do----	8,046	4,850
150 -----do----	7,812	4,850	150 -----do----	11,915	4,900
200 -----do----	5,872	4,750	200 -----do----	7,446	4,750
0 meters south	9,108	4,800	0 meters south	4,837	4,800
50 -----do-----	4,368	4,850	50 -----do-----	4,970	4,850
100 -----do-----	5,561	4,800	100 -----do-----	3,768	4,850
150 -----do-----	4,830	--	150 -----do-----	--	--
200 -----do-----	3,086	4,750	200 -----do-----	5,643	4,850
0 meters north	5,658	4,750	0 meters north	7,253	--
50 -----do-----	5,334	4,750	50 -----do-----	4,402	4,800
100 -----do-----	5,214	4,750	100 -----do-----	--	4,750
150 -----do-----	5,675	4,750	150 -----do-----	--	4,850
200 -----do-----	5,056	4,750	200 -----do-----	3,289	4,750
Mean	5,202	4,797	Mean	6,950	4,835
Standard deviation	2,000	48	Standard deviation	3,584	49

Figure 9

MERCURY IN SOILS
ROOSEVELT HOT SPRINGS
KGRA

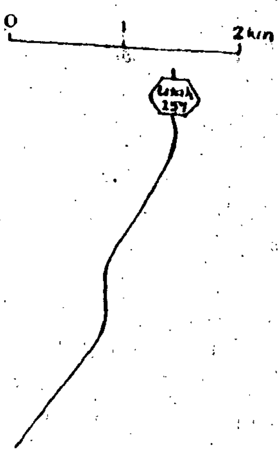
MEAN: 0.06 parts per million

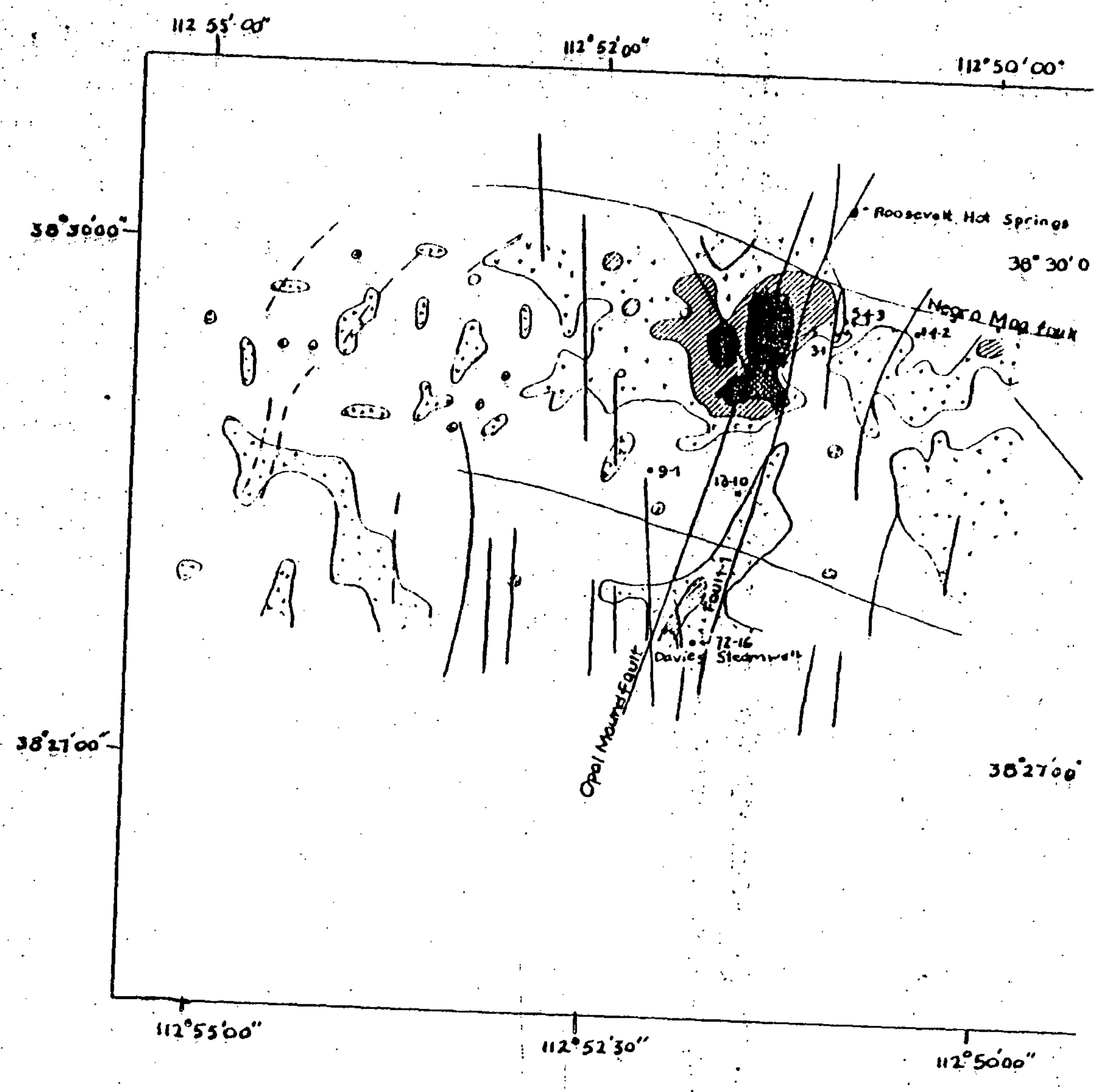
- ≤0.05 ppm
- 0.06 - 0.10
- 0.11 - 0.49
- 0.50 - 1.0
- ≥1.1 - 35

• 54-3 Geothermal Well

FAULTS

(Petersen, 1975, & Ward and Sill, 1976)





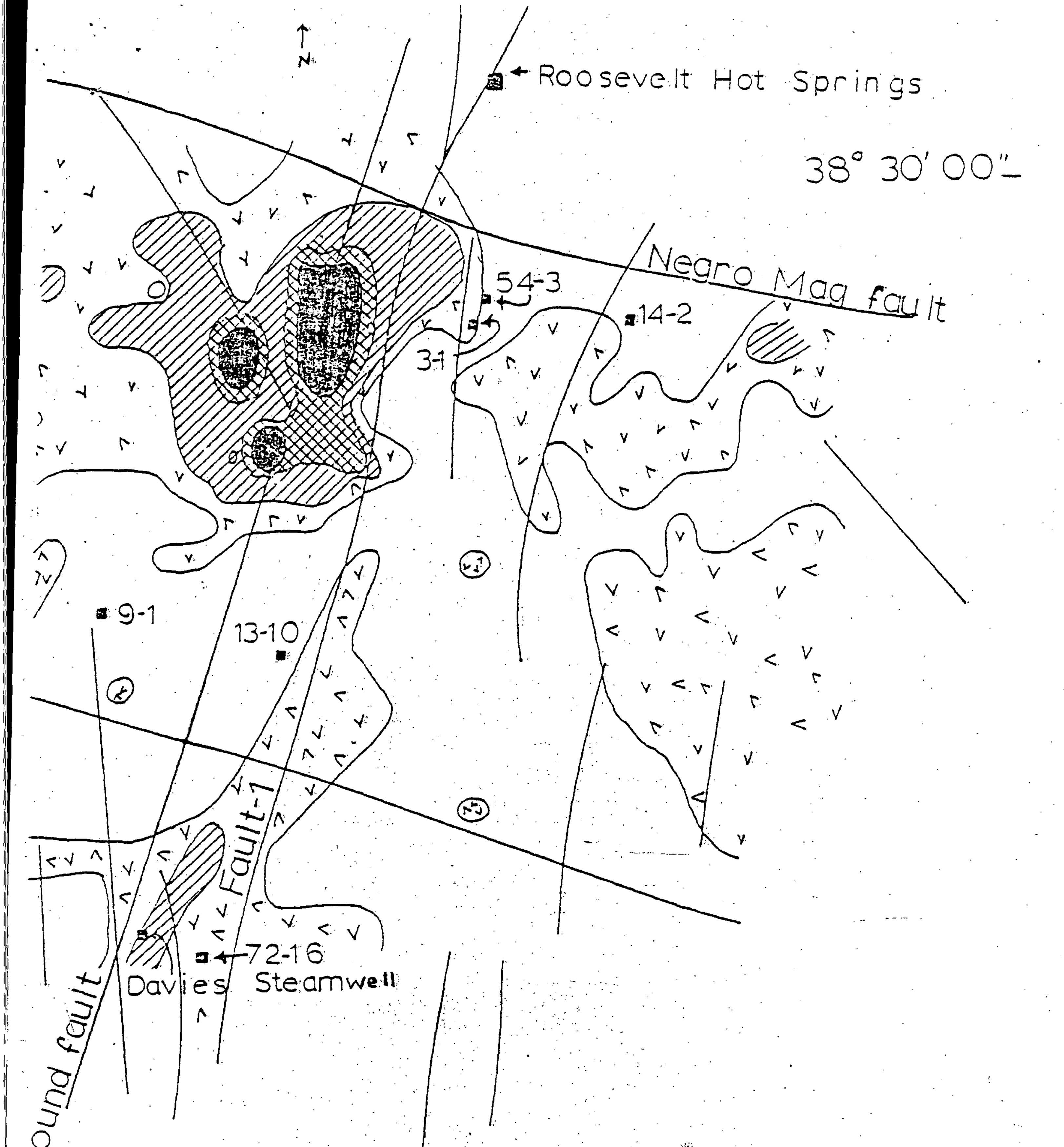


Figure 10

Mercury in Soils Near Opal Mound Fault

≤0.05 ppm

0.06–0.10

0.11–0.49

0.50–1.0 ppm

≥1.1–3.5

54-3 ■ Geotherma Well

0 — 1 km

CONCLUSION

1. Concentrations of helium in soil gas were highest over the producing geothermal field.

2. The pattern of high helium concentrations in soils was more dispersed than the pattern of helium in soil gas; however, most of the highest concentrations were over the producing field. Low concentrations of helium in soils occurred over an opal deposit.

3. High concentrations of mercury in soil coincided with high thermal gradients and low resistivity along the Opal Mound fault.

4. Concentrations of helium in soils and soil gas could not be related to the depths of geothermal wells.

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Appendix: The use of 5-ml Vacutainer tubes for collection and storage of soil gas samples

To determine the amount of leakage from 5-ml Vacutainer tubes when they are filled with 10-ml of gas, three sets of 35 tubes were injected with 10 ml of air having various contents of helium; the needle holes in the stoppers were filled with silicone glue.

Set-1: 5-ml tubes were filled with 10 ml of ambient air (5,240 ppb He). An empty syringe was used to remove 5 ml of overpressured gas for analysis.

Set-2: 5-ml tubes were filled with 10 ml of a standard air mixture that contained 5 ml of 8,300 ppb helium and 5 ml of ambient air. An empty syringe was used to remove 5 ml of overpressured gas for analysis. Theoretical concentration of helium in the mixture was 6,770 ppb.

Set-3: 5-ml tubes were filled with 10 ml of a standard air mixture containing 8,300 ppb helium. An empty syringe was used to remove 5 ml of overpressured gas for analysis.

The contents of the tubes were analyzed after various time intervals (Table 3). Only a little more than 5 percent of the helium had been lost, as much as 73 days after filling the tubes (fig. 11).

All of the Vacutainer tubes contained residual helium. The amount of helium recovered from a tube depended on the amount of helium added; the more helium added, the less residual helium measured (fig. 12). The cause of these results is unknown, consequently, the helium recovered from each 10 ml of soil-gas sample in a 5-ml Vacutainer from Roosevelt Hot Springs was compared to figure 12 to determine the actual amount of helium in the soil gas collected in the Vacutainer.

Table 3.--*Helium recovered from Vacutainers after various time intervals*

Set 1: 5,240 ppb helium added

	Days after filling: 0	2	4	7	11	18	73
	5,900 ppb	5,860 ppb	5,920 ppb	5,848 ppb	5,592 ppb	5,864 ppb	5,735 ppb
	5,860	5,860	5,880	5,848	5,592	5,864	5,735
	5,900	5,880	5,860	5,886	5,576	5,825	5,766
	5,860	5,880	5,860	5,886	5,576	leaked out	5,735
	5,860	leaked out	5,860	5,848	5,560	----do----	5,766
Av.	5,876	5,870	5,876	5,863	5,579	5,851	5,747
	± 22	± 11	± 26	± 21	± 13	± 22	± 17

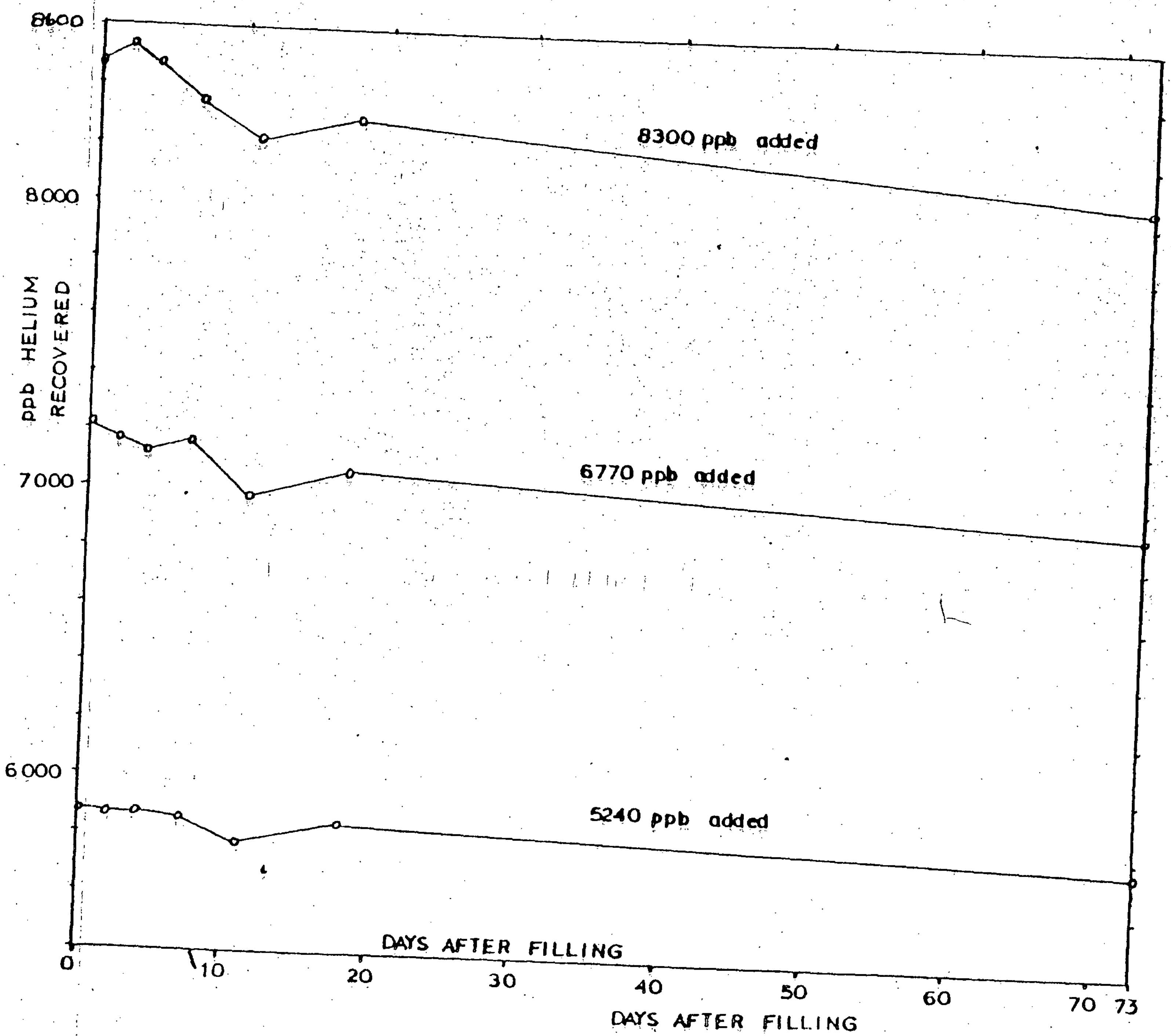
Set 2: 6,770 ppb helium added

	Days after filling: 0	2	4	7	11	18	73
	7,167 ppb	7,160 ppb	7,084 ppb	7,164 ppb	6,649 ppb	7,073 ppb	6,821 ppb
	7,249	7,160	7,190	7,201	6,960	7,112	6,852
	7,167	7,160	7,112	7,164	7,120	7,112	6,945
	7,249	7,200	7,034	7,127	7,120	7,034	7,038
	7,249	-----	7,190	7,164	7,040	7,034	6,945
Av.	7,216	7,170	7,122	7,164	6,976	7,073	6,920
	± 45	± 20	± 68	± 26	± 199	± 39	± 86

Set 3: 8,300 ppb helium added

	Days after filling: 0	2	4	7	11	18	73
	8,479 ppb	8,560 ppb	8,516 ppb	8,311 ppb	8,040 ppb	8,321 ppb	7,999 ppb
	8,479	8,560	8,477	8,274	8,320	8,360	8,092
	8,479	8,520	8,477	8,385	8,280	8,321	8,061
	8,479	8,560	8,477	8,385	8,200	8,321	8,150
	8,479	8,520	8,438	8,385	8,240	8,165	7,937
Av.	8,479	8,544	8,477	8,348	8,216	8,298	8,049
	± 0	± 22	± 28	± 52	± 108	± 76	± 84

FIG. II
LOSS OF HELIUM FROM 5-ml VACUTAINERS



RESIDUAL HELIUM IN 5-ml VACUTAINERS

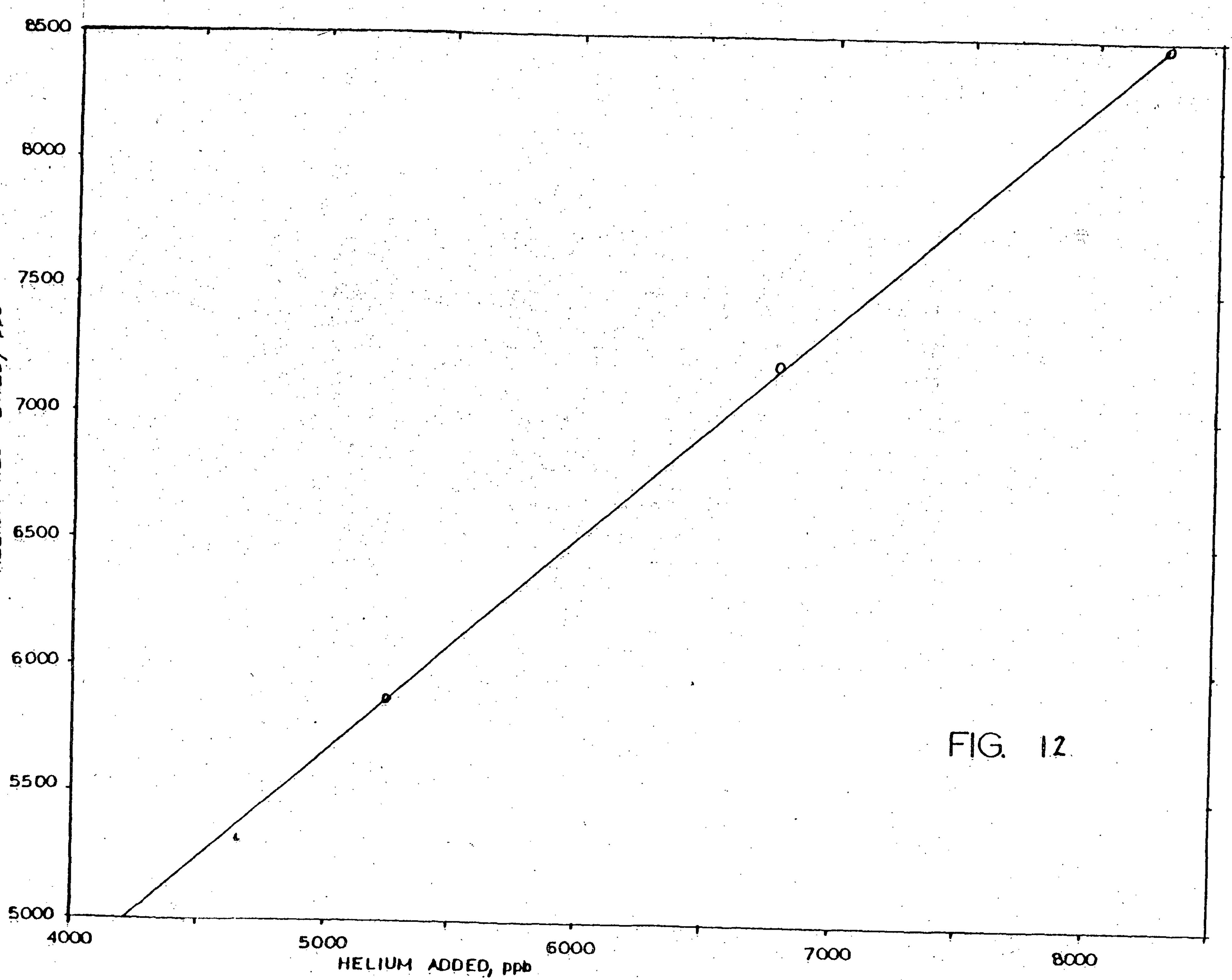


FIG. 12