Principal facts and preliminary interpretation for gravity profiles and continuous magnetometer profiles in Surprise Valley, California

By Andrew Griscom and Arthur Conradi, Jr.

U.S. Geological Survey

Open-file Report No. 76-260

1976

Introduction

These geophysical data were collected in order to investigate faults and thickness of alluvium near hot spring areas in the Surprise Valley area of northeastern California. Surprise Valley lies on the western edge of the Basin and Range province and appears to be a typical basin in a north-trending block-faulted structure. It is flanked on the west by the Warner Range, a westerly dipping block of Tertiary sediments and volcanic rocks and on the east (along the California-Nevada border) by the Hays Canyon Range, composed of similar rocks. Surprise Valley has no outlet and within the valley are three shallow alkali lakes, Lower, Middle, and Upper Alkali Lakes.

Simple Bouguer gravity anomaly values are reported here for 191 gravity stations in the Surprise Valley area. The stations are located between 41°35' and 41°42' north latitude and between 120°00' and 120°15' west longitude. The data provide six gravity profiles (Figs. 1 to 6) the location of which is shown in Fig. 7. In addition there is a gravity map of Surprise Valley, scale 1:62,500, by J. Gimlett (Fig. 8, sheets 1 and 2). This gravity map is part of an unpublished report and is available from the California Department of Water Resources at a scale of 1:31,250.

The magnetic data consist of 12 magnetic profiles (Figs. 9-13) collected with a continuously recording truck-mounted magnetometer. An index map (Fig. 14) shows the location of the profiles, which were collected in the general vicinity of the gravity profiles.

Gravity data

The gravity data were collected with LaCoste-Romberg Meter 130 along roads at a station spacing of 100-200 m. Elevations were surveyed with an alidade and are accurate to ±0.7 m absolute and to ±0.03 m relative to adjacent stations. The datum for each profile is a bench mark or spot elevation on the profile. Local terrain corrections relative to adjacent stations are negligible so that relative accuracy of adjacent stations is about ±0.03 mgal. The stations are referenced to the Alturas Base Station 14 of Chapman (1966, p. 18).

Gravity data format

The principal facts for all 191 gravity stations are listed in table 1. Each data column is described below.

1. STATION column - An alphanumeric combination of up to 5 characters used for station identification.
2. LATITUDE and LONGITUDE columns - Values are listed in degrees and minutes to the nearest hundredth of a minute. These values were determined from U.S. Geological Survey topographic quadrangle maps at a scale of 1:24,000. Values were checked for errors by obtaining a computer plot of the stations and comparing this to the hand-plotted stations.
3. ELEV. column - The station elevation is in feet to the nearest tenth.
4. OBSV. GRAV. column - Each station's observed gravity value is reported to the nearest hundredth of a milligal.
5. THEO-GRAV column - The theoretical gravity value for each station is determined by the formulae given under number 6.

6. FAA column - The free air gravity anomaly values for each station are listed to the nearest hundredth of a milligal. The formula used in calculating these values is:

$FAA = OG-TG + (.09411549 - .000137789 \sin^2\theta)E - .0000000067E^2$

where FAA is the free air anomaly in milligals

O.G. is the observed gravity in milligals

T.G. is the theoretical gravity in milligals obtained by the International Gravity Formula of 1950

$TG = 978049[1+.0052884 \sin^2\theta - .0000059 \sin^2(2\theta)]$

θ is latitude

E is elevation in feet.

7. BA1 column - The listed simple Bouguer anomaly values were determined to the nearest hundredth of a milligal for a crustal density of 2.67 g/cm^3 according to the formula:

$$BA1 = FAA - .012774 \times 2.67E$$

8. The remaining columns (CC, TC, CBA1, CBA2) relate to the calculation of terrain corrections and therefore are irrelevant to this report, being artifacts of the computer program.

Preliminary gravity interpretation

After reduction to simple Bouguer anomalies, the gravity profiles provide us with information on the distribution of rock masses with various densities beneath the surface. The steep gravity gradient down to the east in the profiles on the west side of the valley is the result of the large thick mass of low-density valley fill in the center of Surprise Valley. Superimposed on this gradient are various smaller features of geologic

significance. Inflection points are likely to be the location of concealed faults and such features are identified on the profiles.

Of considerable interest are the small gravity highs (0.5 mgal) associated with faults on profiles 1, 2, and 3 (Fig. 1, 2, and 3, respectively). The phrase, "FAULT(?)", indicates a fault deduced from the gravity profile. The features are only 500 to 1000 feet (150 to 300 m) wide and, because of their small width and narrow marginal gradients, must be caused by density differences within 300 to 500 feet (100 to 150 m) of the surface. The association of these anomalies exclusively with faults containing hot waters suggests that the high are caused by partial cementation of the alluvium at the faults which increases the alluvium density by filling some of the pore space with silica or calcium carbonate. The results indicate that in some areas detailed gravity profiles can be used to follow faults through areas of thick alluvium if there are hot saline waters depositing material in the pore space of the alluvium.

Also noted on the gravity profiles are faults taken from plate 21 of Bulletin 98 of the California Department of Water Resources (1963). Some of these faults have no expression on the gravity profiles and must be either very minor or nonexistent. On profile 2 (Fig. 2) at Lake City the Surprise Valley Fault is crossed without even an inflection of 0.1 mgal. Vertical offset of only 100 feet (30 m) in a shallow concealed fault at this location would cause an effect of at least 0.6 mgal (for density contrast of 0.5 g/cm^3) so that the fault cannot exist here.

Conclusions

1. Small gravity highs are associated with faults containing hot saline water and are probably caused by local density increase due to cementation of alluvium.
2. Such gravity highs may be useful guides to hot saline water circulating in areas of thick alluvium.
3. Small gravity highs over the Lake City fault in the center of the valley suggest that the fault contains hot saline water and that the fault acts as a connection between the hot spring areas on the east and west sides of the valley.
4. Inflection points on gravity profiles confirm the existence of previously deduced faults.
5. Lack of inflection points on certain gravity profiles deny the existence of previously deduced faults, especially the Surprise Valley Fault near Lake City.

Gravity map

The gravity map, Fig. 8, sheets 1 and 2, was surveyed by J. I. Gimlett for the California Department of Water Resources in 1960 and is unpublished. Details of the survey are described in Bulletin 98, California Department of Water Resources (1963). The data are simple Bouguer anomalies but the lack of terrain corrections is not particularly important because much of Surprise Valley is extremely level. Gimlett calculated various two-dimensional gravity profiles across the valley in order to locate concealed faults and to determine the depth of the valley fill. Geologic cross-sections based upon these calculated profiles were published in

Bulletin 98 as figures 20 and 21. A manuscript basement contour map was prepared by Gimlett but is not available at present from the California Division of Water Resources, although the inferred faults are shown in plate 21 of Bulletin 98, California Department of Water Resources (1963).

Magnetic profiles

The magnetic profiles were collected along roads by a continuously recording truck-mounted flux-gate magnetometer mounted approximately 13 ft (4 m) above the ground. The data tapes are photographically reduced to a scale of approximately 1:70,500 so that they may be compared easily with the traverse map Fig. 14 (scale 1:62,500). Full scale on the tapes (i.e., from 1 to 11) is 2000 gammas. Location points are the hand-numbered tic marks on the pen tracing along the top of the tapes and are also plotted on the traverse map.

Occasional datum shifts on the magnetic profiles are necessary in order that the recorder stay on scale and are indicated on the records by a four-digit push-button setting (pbs) number. The first digit refers to the number of 2000-gamma increments which have been added to the basic instrument datum level (48,4000 gammas); the second digit refers to the number of 400-gamma increments; the third digit refers to the number of 100-gamma increments; and the fourth digit refers to the number of 20-gamma increments. The sum of the four products (increment value times number of increments) added to the basic instrument datum (48,400 gammas) gives the approximate absolute value of the earth's field when added in turn to the reading on the tape trace.

The magnetic records, in addition to the magnetic effects of nearby rocks, document a variety of man-made magnetic anomalies. Anomalies of the latter type include culverts, bridges, vehicles, certain fences, water pipes, etc. In general such anomalies are distinguished as a very sharp, short-wavelength spike which may be positive or negative depending on the relative locations of source and magnetometer. The instrument operator crossed out or flagged most of these man-made features on the record, at the time of the magnetic survey, but man-made effects can totally obscure the natural magnetic record, especially near or in towns and cities (see Fig. 9 showing effects at Cedarville and Lake City).

The highly magnetic Tertiary volcanic rocks which form the surrounding mountains of Surprise Valley also underlie the non-magnetic alluvium and lake deposits of the valley itself. Where this alluvial material is more than a few hundred feet thick, the effect of the underlying magnetic volcanic rocks is subdued so that only the longer wavelength magnetic anomalies are perceived on the record. Thus an abrupt change from a jagged short-wavelength record to a smooth record implies a sudden change of the position of the volcanic rocks from a near-surface location to one of considerable depth. Such an abrupt change is therefore considered to be good evidence for a steeply dipping fault contact. A more gradual change from rough to smooth record is for similar reasons interpreted as a gently dipping contact, more likely a depositional contact of alluvium on volcanic rocks.

The magnetic profiles have been annotated to indicate the interpreted faults and contacts. A careful study of the geophysically located contacts

shows in general a reasonably good agreement with the known geology but also shows some places where the contacts on the geologic map (Bulletin 98, plate 21, California Department of Water Resources) can be better located or, in a few cases, where they are incorrect.

Another type of magnetic feature is observed on the magnetic records taken over areas of thick alluvium in the center of the valley. The alluvium that came from the west side of the valley has a higher amplitude magnetic "noise" associated with it than that of the eastern alluvium. The explanation is not clear but perhaps there are magnetic boulders of volcanic rock near the surface of the western alluvium.

A different and very significant area of magnetic "noise" can be observed on the magnetic record of traverse S-4 (Fig. 10, documentation point 5) in the area where the traverse crosses the Lake City fault. These small magnetic anomalies are associated with an area of small gravity anomalies and are caused by minor amounts of magnetic minerals at depths of less than 200 feet in the alluvium. The associations indicate that perhaps chemical reactions of the hot saline waters have generated these small amounts of magnetic minerals near the fault in the otherwise non-magnetic alluvium. Such anomalies could be used to trace the fault zone across the valley. The data suggest that the Lake City fault in the alluvium is actually a zone about 2000 feet wide.

Conclusions

1. Traverses across Lake City Fault (Traverse S-4, Fig. 10) in the center of valley indicate several minor shallow magnetic features and noise which are associated with minor gravity anomalies. It

is suspected that chemical reactions of the hot saline waters have generated minor local amounts of magnetic minerals in the otherwise non-magnetic alluvium near the faults. The data suggest that the Lake City fault is actually a zone about 2000 feet wide with at least two major strands. Another similar area of noise is observed on traverse S-3, Fig. 10, and is not located on a known fault.

2. Alluvium on the west side of the valley is "noisier" magnetically. See traverses S-4, S-11, and S-12, Figs. 10 and 13. Perhaps this alluvium contains magnetic boulders.

3. Various faults, especially on the east side of the valley, are visible in the magnetic records and in general confirm the geologic map.

   a. The faults on each side of the narrow buried horst of volcanic rocks extending south for 15 miles along the east side of Middle Alkali Lake are clearly defined in traverse S-9, Fig. 12.

   b. Several crossings of the southeast extension of the Lake City fault (east of Surprise Valley) indicate the presence of this fault on the magnetic record of traverse S-9, Fig. 12.

   c. The fault shown on the geologic map as defining the west edge of the small horst of exposed volcanic rocks at the radio facility probably does not exist and in any event does not offset the contact between alluvium and volcanic rocks. The magnetic data (and also the gravity data) show that the more

significant contact lies some 1600 feet farther west and dips west at a sufficiently low angle to imply a sedimentary rather than a fault contact between the alluvium and volcanic rocks.

References Cited

California Department of Water Resources, 1963, Northeastern counties groundwater investigation: Bulletin 98, various pages.

Chapman, R. H., 1966, Gravity base station network: California Div. Mines and Geology, Spec. Rept. 90, 49 p.

List of Figures

Table 1. Principal facts for 191 gravity stations in the Surprise Valley area, northeast California.

SURPRISE VALLEY CAL 1975 JAN2310003

CHAPMAN 148 GRV 979887.95 METER 130 READING 3583.89 T+D -0.05 D1 2.67 D2 2.27

STA	LATITUDE	LONGITUDE	ELEV	READING	T+D	OBSV-GRAV	THEO-GRAV	FAA	BAI	CC	TC	CBA1	CBA2
19CSM	41 37.87	120 7.13	4547.2	3570.07	-0.07	979873.42	980326.05	-25.10	-180.19	1.36	0.00	-181.54	-158.10
LAKEC	41 38.72	120 13.02	4618.0	3587.13	-0.07	979891.34	980327.32	-1.79	-159.29	1.37	0.00	-160.65	-136.85
MILL1	41 38.68	120 13.02	4699.0	3582.10	-0.08	979886.04	980327.26	0.60	-159.68	1.38	0.00	-161.05	-136.83
MILL2	41 38.69	120 12.95	4821.0	3575.92	-0.08	979879.55	980327.28	5.56	-158.88	1.39	0.00	-160.27	-135.42
MILL3	41 38.70	120 12.89	4901.0	3571.10	-0.08	979874.49	980327.29	8.00	-159.17	1.40	0.00	-160.56	-135.31
MILL4	41 38.71	120 12.78	4980.0	3566.29	-0.08	979869.43	980327.31	10.36	-159.50	1.41	0.00	-160.91	-135.26
MILL5	41 38.72	120 12.71	5120.0	3558.46	-0.08	979861.21	980327.32	15.27	-159.36	1.43	0.00	-160.79	-134.41
18OGG	41 39.43	120 2.88	5494.0	3523.10	-0.03	979824.11	980328.38	12.26	-175.13	1.47	0.00	-176.59	-148.30

SURPRISE VALLEY CAL 1975 JAN2410003

CHAPMAN 14H GRV 979887.05 METER 130 READING 3583.99 T+D -0.05 D1 2.67 D2 2.27

STA	LATITUDE	LONGITUDE	ELEV	READING	T+D	OBSV-GRAV	THEO-GRAV	FAA	BA1	CC	TC	CBA1	CBA2
19CGM	41 37.87	120 7.13	4547.2	3570.08	-0.06	979874.44	980326.05	-25.08	-180.17	1.36	0.00	-181.52	-158.08
15E01	41 37.88	120 7.04	4559.5	3569.77	-0.09	979873.08	980326.07	-24.29	-179.80	1.36	0.00	-181.15	-157.65
15E02	41 37.88	120 6.95	4570.9	3569.54	-0.09	979872.84	980326.07	-23.46	-179.36	1.36	0.00	-180.71	-157.15
15E03	41 37.91	120 6.83	4577.6	3569.69	-0.09	979873.00	980326.11	-22.72	-178.84	1.36	0.00	-180.20	-156.61
15E04	41 37.93	120 6.73	4585.0	3569.69	-0.09	979873.00	980326.14	-22.05	-178.43	1.36	0.00	-179.79	-156.16
15E05	41 37.94	120 6.66	4589.1	3570.05	-0.09	979873.37	980326.16	-21.30	-177.82	1.36	0.00	-179.18	-155.53
15E06	41 37.96	120 6.57	4592.4	3570.42	-0.09	979873.76	980326.19	-20.63	-177.27	1.36	0.00	-178.62	-154.95
15E07	41 37.98	120 6.49	4602.4	3570.47	-0.09	979873.82	980326.22	-19.67	-176.64	1.36	0.00	-178.00	-154.28
15E08	41 38.00	120 6.40	4614.6	3570.41	-0.09	979873.75	980326.25	-18.62	-176.01	1.37	0.00	-177.37	-153.58
15E09	41 38.02	120 6.32	4624.4	3570.44	-0.09	979873.78	980326.28	-17.70	-175.42	1.37	0.00	-176.78	-152.95
15E10	41 38.03	120 6.24	4634.4	3570.58	-0.09	979873.93	980326.29	-16.62	-174.69	1.37	0.00	-176.05	-152.17
15E11	41 38.05	120 6.16	4649.2	3570.46	-0.09	979873.81	980326.32	-15.39	-173.96	1.37	0.00	-175.32	-151.36
15E12	41 38.07	120 6.08	4674.1	3569.45	-0.09	979872.74	980326.35	-14.14	-173.56	1.37	0.00	-174.92	-150.84
15E13	41 38.09	120 6.00	4691.8	3568.57	-0.09	979871.82	980326.38	-13.43	-173.45	1.38	0.00	-174.82	-150.64
15E14	41 38.12	120 5.92	4713.8	3567.59	-0.09	979870.79	980326.43	-12.44	-173.21	1.38	0.00	-174.58	-150.29
15E15	41 38.13	120 5.84	4731.9	3566.24	-0.09	979869.37	980326.44	-12.17	-173.56	1.38	0.00	-174.93	-150.55
15E16	41 38.16	120 5.76	4770.1	3564.89	-0.09	979867.95	980326.49	-10.04	-172.73	1.39	0.00	-174.11	-149.53
15E17	41 38.21	120 5.71	4775.0	3565.61	-0.09	979868.71	980326.56	-8.90	-171.76	1.39	0.00	-173.14	-148.53

SURPRISE VALLEY CAL 1975 JAN2510003

CHAPMAN 148 GRV 979887.95 METER 130 READING 1581.92 T+D -0.08 D1 2.67 D2 2.27

STA	LATITUDE	LONGITUDE	ELEV	READING	T+D	OBSV-GRAV	THEO-GRAV	FAA	BA1	CC	TC	CBA1	CBA2
15E18	41 38.29	120 5.63	4776.1	3566.46	-0.04	979869.65	980326.68	-7.97	-170.87	1.39	0.00	-172.25	-147.64
15E19	41 38.35	120 5.55	4789.4	3566.63	-0.04	979869.83	980326.77	-6.63	-169.98	1.39	0.00	-171.37	-146.69
15E20	41 38.38	120 5.42	4807.5	3565.52	-0.04	979868.66	980326.82	-6.14	-170.11	1.39	0.00	-171.50	-146.73
15E21	41 38.39	120 5.36	4820.9	3564.38	-0.04	979867.47	980326.83	-6.10	-170.52	1.39	0.00	-171.91	-147.07
15E22	41 38.42	120 5.23	4831.0	3563.56	-0.04	979866.60	980326.88	-6.05	-170.82	1.39	0.00	-172.21	-147.32
15E23	41 38.44	120 5.15	4859.7	3561.42	-0.04	979864.36	980326.90	-5.63	-171.38	1.40	0.00	-172.78	-147.74
15E24	41 38.48	120 5.02	4882.3	3559.86	-0.04	979862.72	980326.96	-5.21	-171.73	1.40	0.00	-173.12	-147.97
15E25	41 38.52	120 4.92	4888.6	3559.34	-0.04	979862.17	980327.02	-5.22	-171.96	1.40	0.00	-173.35	-148.17
15E26	41 38.55	120 4.85	4901.3	3558.43	-0.04	979861.21	980327.07	-5.03	-172.20	1.40	0.00	-173.60	-148.34
15E27	41 38.58	120 4.76	4915.5	3557.64	-0.05	979860.37	980327.11	-4.58	-172.23	1.41	0.00	-173.63	-148.31
15E28	41 38.60	120 4.69	4939.9	3556.19	-0.05	979858.85	980327.14	-3.84	-172.32	1.41	0.00	-173.73	-148.28
15E29	41 38.63	120 4.59	4946.9	3556.08	-0.07	979858.72	980327.19	-3.36	-172.08	1.41	0.00	-173.49	-148.00
15E30	41 38.67	120 4.48	4971.2	3554.68	-0.07	979857.25	980327.25	-2.61	-172.16	1.41	0.00	-173.57	-147.96
15E31	41 38.71	120 4.40	4979.3	3554.32	-0.07	979856.87	980327.31	-2.29	-172.11	1.41	0.00	-173.52	-147.87
15E32	41 38.73	120 4.32	4993.8	3553.50	-0.08	979856.00	980327.34	-1.82	-172.15	1.41	0.00	-173.56	-147.83
15E33	41 38.77	120 4.23	5009.6	3552.37	-0.08	979854.81	980327.40	-1.59	-172.45	1.42	0.00	-173.86	-148.05
15E34	41 38.79	120 4.16	5022.8	3551.00	-0.08	979853.37	980327.43	-1.82	-173.13	1.42	0.00	-174.54	-148.66
15E35	41 38.85	120 4.08	5068.2	3548.23	-0.09	979850.45	980327.52	-0.56	-173.42	1.42	0.00	-174.84	-148.73
15E36	41 38.92	120 4.05	5105.6	3546.33	-0.09	979848.45	980327.62	0.87	-173.28	1.43	0.00	-174.70	-148.40
15E37	41 38.98	120 4.01	5150.2	3543.85	-0.09	979845.85	980327.71	2.36	-173.30	1.43	0.00	-174.73	-148.20
15E38	41 39.03	120 3.95	5191.2	3541.55	-0.09	979843.43	980327.79	3.73	-173.34	1.44	0.00	-174.77	-148.03
15E39	41 39.10	120 3.90	5212.6	3540.62	-0.10	979842.44	980327.89	4.64	-173.15	1.44	0.00	-174.58	-147.73
SV001	41 39.16	120 3.85	5211.8	3540.73	-0.10	979842.56	980327.98	4.60	-173.17	1.44	0.00	-174.61	-147.76
SV003	41 38.50	120 4.33	4986.0	3554.01	-0.10	979856.51	980326.99	-1.70	-171.75	1.41	0.00	-173.16	-147.48
15W01	41 37.88	120 7.16	4545.0	3570.25	-0.09	979873.58	980326.07	-25.15	-180.16	1.36	0.00	-181.52	-158.09
15W02	41 37.88	120 7.25	4540.9	3570.15	-0.09	979873.48	980326.07	-25.64	-180.52	1.35	0.00	-181.86	-158.46
15W03	41 37.88	120 7.33	4536.8	3570.14	-0.09	979873.47	980326.07	-26.04	-180.77	1.35	0.00	-182.12	-158.74
15W04	41 37.88	120 7.43	4527.8	3570.50	-0.08	979873.86	980326.07	-26.49	-180.92	1.35	0.00	-182.27	-158.93
15W05	41 37.89	120 7.52	4523.2	3570.57	-0.08	979873.93	980326.08	-26.87	-181.14	1.35	0.00	-182.49	-159.17
15W06	41 37.89	120 7.62	4521.3	3570.66	-0.08	979874.02	980326.08	-26.95	-181.16	1.35	0.00	-182.50	-159.20
15W07	41 37.89	120 7.73	4518.9	3570.85	-0.08	979874.22	980326.08	-26.98	-181.10	1.35	0.00	-182.45	-159.16
15W08	41 37.89	120 7.83	4516.5	3571.10	-0.08	979874.49	980326.08	-26.94	-180.98	1.35	0.00	-182.33	-159.05
15W09	41 37.89	120 7.93	4513.7	3571.42	-0.07	979874.83	980326.08	-26.86	-180.81	1.35	0.00	-182.15	-158.89
15W10	41 37.89	120 8.01	4510.0	3571.77	-0.07	979875.20	980326.08	-26.84	-180.66	1.35	0.00	-182.00	-158.76
15W11	41 37.89	120 8.08	4512.3	3571.58	-0.07	979875.00	980326.08	-26.82	-180.72	1.35	0.00	-182.07	-158.81
15W12	41 37.89	120 8.15	4515.1	3571.14	-0.07	979874.54	980326.08	-27.02	-181.02	1.35	0.00	-182.36	-159.09
15W13	41 37.89	120 8.24	4515.6	3571.04	-0.07	979874.43	980326.08	-27.08	-181.09	1.35	0.00	-182.44	-159.16
15W14	41 37.89	120 8.34	4518.3	3570.89	-0.06	979874.29	980326.08	-26.97	-181.08	1.35	0.00	-182.42	-159.13
15W15	41 37.89	120 8.42	4518.7	3570.88	-0.06	979874.27	980326.08	-26.95	-181.06	1.35	0.00	-182.41	-159.12
15W16	41 37.89	120 8.50	4519.9	3570.88	-0.06	979874.27	980326.08	-26.83	-180.99	1.35	0.00	-182.34	-159.04

3/7

SURPRISE VALLEY CAL 1975 JAN2610007

CHAPMAN 14H GRV 979887.95 METER 130 READING 3583.35 T+D -0.10 D1 2.67 D2 2.27

STA	LATITUDE	LONGITUDE	ELEV	READING	T+D	OBSV-GRAV	THEO-GRAV	FAA	BA1	CC	TC	CBA1	CBA2
15W53	41 37.92	120 11.64	4549.0	3580.16	-0.06	979884.12	980326.13	-14.30	-169.45	1.36	0.00	-170.80	-147.35
15W52	41 37.91	120 11.57	4548.0	3579.67	-0.06	979883.60	980326.11	-14.89	-170.01	1.36	0.00	-171.36	-147.92
15W51	41 37.90	120 11.50	4548.4	3579.10	-0.06	979883.00	980326.10	-15.44	-170.57	1.36	0.00	-171.92	-148.48
15W50	41 37.90	120 11.42	4550.2	3578.56	-0.06	979882.44	980326.10	-15.84	-171.03	1.36	0.00	-172.38	-148.93
15W49	41 37.90	120 11.35	4550.9	3578.03	-0.06	979881.88	980326.10	-16.33	-171.54	1.36	0.00	-172.90	-149.44
15W48	41 37.90	120 11.22	4550.2	3577.16	-0.07	979880.96	980326.10	-17.32	-172.51	1.36	0.00	-173.86	-150.41
15W47	41 37.90	120 11.12	4549.3	3576.62	-0.07	979880.39	980326.10	-17.97	-173.13	1.36	0.00	-174.48	-151.03
15W46	41 37.90	120 11.02	4547.9	3576.03	-0.07	979879.77	980326.10	-18.72	-173.83	1.36	0.00	-175.19	-151.75
15W45	41 37.90	120 10.95	4547.0	3575.67	-0.07	979879.39	980326.10	-19.18	-174.27	1.36	0.00	-175.62	-152.18
MIL10	41 38.45	120 13.05	4658.0	3585.33	-0.11	979889.50	980326.92	0.55	-158.33	1.37	0.00	-159.70	-135.69
MILL9	41 38.48	120 13.00	4640.0	3586.14	-0.11	979890.35	980326.96	-0.35	-158.60	1.37	0.00	-159.97	-136.06
MILL8	41 38.50	120 12.93	4628.0	3587.14	-0.11	979891.40	980326.99	-0.46	-158.30	1.37	0.00	-159.66	-135.81
MILL7	41 38.51	120 12.86	4607.0	3587.88	-0.11	979892.18	980327.01	-1.67	-158.80	1.36	0.00	-160.16	-136.41
MILL6	41 38.51	120 12.78	4590.0	3588.23	-0.11	979892.55	980327.01	-2.90	-159.45	1.36	0.00	-160.80	-137.15
SV004	41 38.34	120 12.90	4623.0	3586.64	-0.11	979890.88	980326.76	-1.21	-158.89	1.37	0.00	-160.25	-136.42

SURPRISE VALLEY CAL 1975 JAN2710003

CHAPMAN 14H GRV 979897.95 METER 130 READING 3583.88 T+D -0.11 D1 2.67 D2 2.27

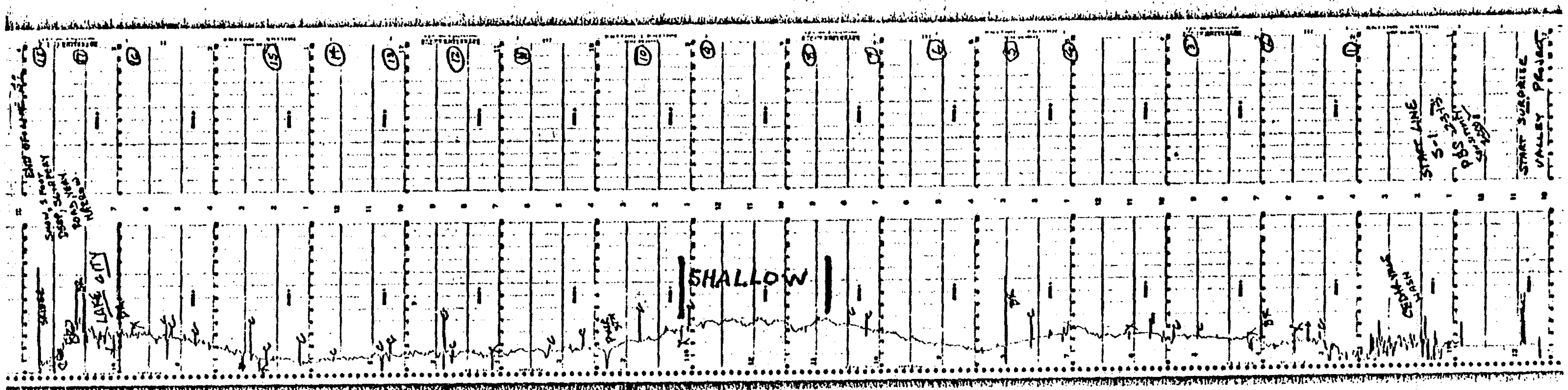
STA	LATITUDE	LONGITUDE	ELEV	READING	T+D	OBSV-GRAV	INFO-GRAV	FAA	BA1	CC	TC	CBA1	CBA2
LKC06	41 38.77	120 10.83	4493.1	3575.00	-0.08	979878.66	980327.40	-27.23	-180.13	1.35	0.00	-181.47	-158.36
LKC07	41 38.77	120 10.94	4487.5	3575.40	-0.08	979879.08	980327.40	-26.39	-179.45	1.35	0.00	-180.79	-157.66
LKC08	41 38.77	120 11.03	4486.8	3576.21	-0.07	979879.94	980327.40	-25.60	-178.63	1.35	0.00	-179.97	-156.84
LKC09	41 38.77	120 11.15	4486.7	3577.12	-0.07	979880.89	980327.40	-24.65	-177.68	1.35	0.00	-179.02	-155.89
LKC10	41 38.77	120 11.25	4487.5	3577.82	-0.07	979881.63	980327.40	-23.84	-176.89	1.35	0.00	-178.23	-155.10
LKC11	41 38.77	120 11.42	4493.8	3578.96	-0.07	979882.83	980327.40	-22.05	-175.32	1.35	0.00	-176.66	-153.50
LKC12	41 38.77	120 11.53	4495.8	3579.80	-0.06	979883.72	980327.40	-20.97	-174.31	1.35	0.00	-175.65	-152.48
LKC13	41 38.77	120 11.70	4499.3	3581.27	-0.06	979885.26	980327.40	-19.10	-172.55	1.35	0.00	-173.89	-150.70
LKC14	41 38.76	120 11.82	4501.3	3582.41	-0.06	979886.46	980327.38	-17.69	-171.22	1.35	0.00	-172.56	-149.36
LKC15	41 38.75	120 11.97	4505.0	3583.94	-0.06	979888.07	980327.37	-15.72	-169.37	1.35	0.00	-170.72	-147.50
LKC16	41 38.75	120 12.07	4506.5	3584.86	-0.05	979889.04	980327.37	-14.61	-168.31	1.35	0.00	-169.65	-146.43
LKC17	41 38.74	120 12.29	4515.6	3586.31	-0.05	979890.57	980327.35	-12.21	-166.23	1.35	0.00	-167.57	-144.30
LKC18	41 38.74	120 12.40	4525.2	3586.72	-0.05	979891.00	980327.35	-10.88	-165.22	1.35	0.00	-166.57	-143.24
LKC19	41 38.73	120 12.50	4533.6	3587.12	-0.04	979891.43	980327.34	-9.65	-164.27	1.35	0.00	-165.62	-142.25
LKC20	41 38.73	120 12.61	4544.2	3587.62	-0.04	979891.95	980327.34	-8.12	-163.11	1.36	0.00	-164.46	-141.04
LKC05	41 38.72	120 12.71	4558.0	3588.36	-0.03	979892.74	980327.32	-6.02	-161.48	1.36	0.00	-162.83	-139.34
LKC04	41 38.71	120 12.78	4566.6	3588.47	-0.03	979892.86	980327.31	-5.09	-160.84	1.36	0.00	-162.19	-138.65
LKC03	41 38.70	120 12.89	4584.3	3588.26	-0.03	979892.64	980327.29	-3.63	-159.98	1.36	0.00	-161.34	-137.71
LKC02	41 38.69	120 12.94	4595.9	3588.16	-0.03	979892.53	980327.28	-2.63	-159.38	1.36	0.00	-160.74	-137.05
LKC01	41 38.68	120 13.02	4614.8	3587.41	-0.03	979891.74	980327.26	-1.62	-159.02	1.37	0.00	-160.38	-136.60
F4459	41 40.52	120 12.00	4459.0	3586.31	-0.01	979890.61	980330.01	-20.15	-172.23	1.34	0.00	-173.57	-150.59
13E01	41 40.52	120 11.93	4455.5	3585.43	-0.01	979889.68	980330.01	-21.41	-173.37	1.34	0.00	-174.70	-151.74
13E02	41 40.52	120 11.91	4453.0	3584.55	-0.01	979888.76	980330.01	-22.57	-174.44	1.34	0.00	-175.78	-152.83
13W01	41 40.52	120 12.11	4461.6	3587.73	-0.01	979892.10	980330.01	-18.42	-170.59	1.34	0.00	-171.92	-148.93
13W02	41 40.52	120 12.22	4465.9	3589.15	-0.01	979893.59	980330.01	-16.52	-168.84	1.34	0.00	-170.17	-147.16
13W03	41 40.52	120 12.33	4474.4	3590.15	-0.01	979894.64	980330.01	-14.67	-167.28	1.34	0.00	-168.62	-145.55
13W04	41 40.52	120 12.42	4480.9	3591.21	-0.01	979895.76	980330.01	-12.95	-165.77	1.35	0.00	-167.11	-144.02
13W05	41 40.52	120 12.58	4496.6	3592.26	-0.02	979896.85	980330.01	-10.38	-163.74	1.35	0.00	-165.08	-141.91
13W06	41 40.52	120 12.75	4517.7	3592.67	-0.02	979897.28	980330.01	-7.96	-162.05	1.35	0.00	-163.39	-140.11
13W07	41 40.52	120 12.88	4539.9	3593.07	-0.02	979897.70	980330.01	-5.46	-160.30	1.35	0.00	-161.65	-138.25
13W08	41 40.52	120 12.97	4555.3	3593.45	-0.02	979898.10	980330.01	-3.61	-158.98	1.36	0.00	-160.33	-136.85
13W09	41 40.52	120 13.03	4569.7	3593.33	-0.03	979897.96	980330.01	-2.39	-158.25	1.36	0.00	-159.60	-136.05
15W16	41 37.89	120 8.50	4519.9	3570.95	-0.08	979874.40	980326.08	-26.71	-180.87	1.35	0.00	-182.21	-158.92
15W17	41 37.89	120 8.62	4523.2	3570.94	-0.08	979874.39	980326.08	-26.41	-180.68	1.35	0.00	-182.03	-158.71
15W18	41 37.89	120 8.70	4524.2	3571.04	-0.08	979874.50	980326.08	-26.21	-180.51	1.35	0.00	-181.86	-158.54
15W19	41 37.89	120 8.79	4527.5	3570.88	-0.08	979874.33	980326.08	-26.07	-180.48	1.35	0.00	-181.83	-158.50
15W20	41 37.89	120 8.88	4532.9	3570.46	-0.08	979873.89	980326.08	-26.00	-180.60	1.35	0.00	-181.95	-158.59
15W21	41 37.89	120 8.98	4533.4	3570.45	-0.09	979873.87	980326.08	-25.97	-180.59	1.35	0.00	-181.94	-158.57
15W22	41 37.89	120 9.07	4533.5	3570.50	-0.09	979873.92	980326.08	-25.91	-180.53	1.35	0.00	-181.88	-158.52
15W23	41 37.89	120 9.15	4538.1	3570.18	-0.09	979873.58	980326.08	-25.82	-180.59	1.35	0.00	-181.94	-158.55
15W24	41 37.89	120 9.23	4540.1	3570.02	-0.09	979873.41	980326.08	-25.80	-180.64	1.35	0.00	-181.99	-158.59
15W25	41 37.89	120 9.32	4544.4	3569.77	-0.09	979873.15	980326.08	-25.65	-180.65	1.36	0.00	-182.00	-158.58
15W26	41 37.89	120 9.40	4546.3	3569.72	-0.09	979873.10	980326.08	-25.53	-180.59	1.36	0.00	-181.94	-158.51
15W27	41 37.89	120 9.50	4548.7	3569.58	-0.10	979872.94	980326.08	-25.46	-180.60	1.36	0.00	-181.95	-158.51
15W28	41 37.89	120 9.58	4550.5	3569.59	-0.10	979872.95	980326.08	-25.28	-180.48	1.36	0.00	-181.83	-158.38
15W29	41 37.89	120 9.66	4551.7	3569.78	-0.10	979873.15	980326.08	-24.97	-180.21	1.36	0.00	-181.56	-158.10
15W30	41 37.89	120 9.75	4547.9	3570.21	-0.10	979873.60	980326.08	-24.87	-179.99	1.36	0.00	-181.34	-157.90
15W31	41 37.89	120 9.83	4544.1	3570.61	-0.10	979874.02	980326.08	-24.81	-179.79	1.36	0.00	-181.14	-157.72
15W32	41 37.89	120 9.92	4537.7	3571.34	-0.10	979874.79	980326.08	-24.64	-179.41	1.35	0.00	-180.76	-157.37
15W33	41 37.90	120 9.98	4531.5	3572.09	-0.10	979875.58	980326.10	-24.45	-179.01	1.35	0.00	-180.36	-157.00
15W34	41 37.90	120 10.08	4530.6	3572.54	-0.10	979876.05	980326.10	-24.07	-178.59	1.35	0.00	-179.94	-156.59
15W35	41 37.90	120 10.18	4531.7	3572.85	-0.10	979876.38	980326.10	-23.64	-178.20	1.35	0.00	-179.55	-156.19
15W36	41 37.90	120 10.27	4534.3	3573.05	-0.11	979876.58	980326.10	-23.19	-177.84	1.35	0.00	-179.19	-155.82
15W37	41 37.90	120 10.35	4535.4	3573.33	-0.11	979876.87	980326.10	-22.79	-177.48	1.35	0.00	-178.83	-155.45
15W38	41 37.90	120 10.41	4536.7	3573.53	-0.11	979877.08	980326.10	-22.46	-177.19	1.35	0.00	-178.54	-155.16

15W39	41	37.90	120	10.50	4537.9	3573.00	-0.11	979877.36	980326.10	-22.07	-176.84	1.35	0.00	-178.19	-154.80
15W40	41	37.90	120	10.58	4540.0	3574.13	-0.11	979877.71	980326.10	-21.52	-176.37	1.35	0.00	-177.72	-154.32
15W41	41	37.90	120	10.68	4543.5	3574.39	-0.11	979877.98	980326.10	-20.92	-175.88	1.35	0.00	-177.23	-153.82
15W42	41	37.90	120	10.75	4546.4	3574.66	-0.11	979878.27	980326.10	-20.36	-175.43	1.36	0.00	-176.78	-153.34
15W43	41	37.90	120	10.83	4547.8	3574.99	-0.11	979878.62	980326.10	-19.89	-175.00	1.36	0.00	-176.35	-152.91

SURPRISE VALLEY CAL 1975 JAN2A10003

CHAPMAN 148 GHV 979887.95 METER 130 READING 3583.92 T+D -0.11 D1 2.67 D2 2.27

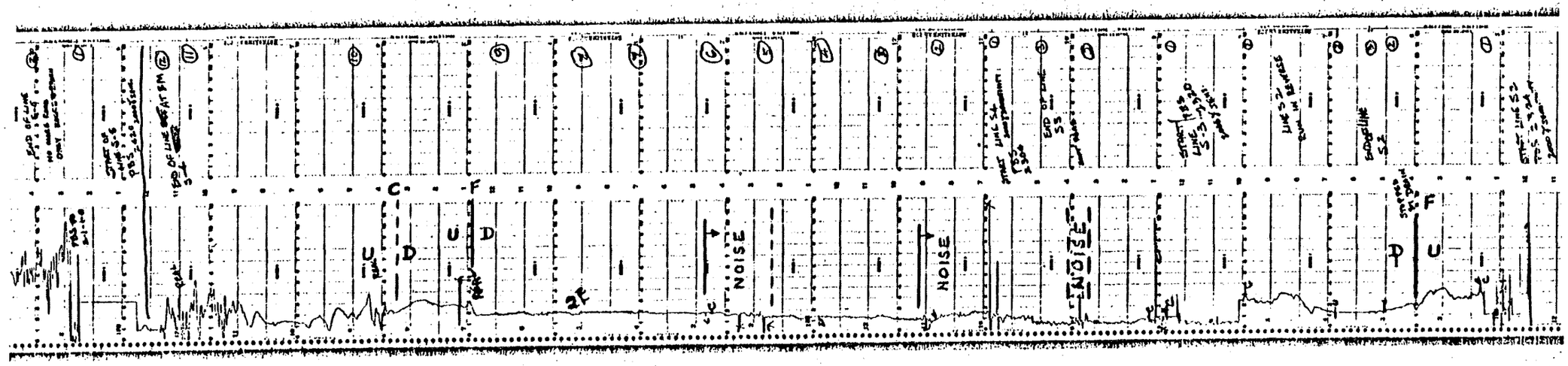
STA	LATITUDE	LONGITUDE	ELEV	READING	T+D	OBSV-GRAV	THEO-GRAV	FAA	BAI	CC	TC	CBA1	CBA2
SV005	41 33.73	121 16.20	6305.0	3483.74	-0.11	979782.71	980319.87	55.59	-159.46	1.51	0.00	-160.97	-128.53
SV006	41 36.97	120 12.45	4755.0	3579.37	-0.06	979883.22	980324.71	5.60	-156.59	1.38	0.00	-157.97	-133.47
SV007	41 36.60	120 12.31	4807.0	3576.67	-0.05	979880.40	980324.16	8.21	-155.75	1.39	0.00	-157.13	-132.37
SV008	41 36.36	120 12.22	4829.0	3575.13	-0.04	979878.79	980323.80	9.03	-155.68	1.39	0.00	-157.07	-132.19
SV009	41 36.10	120 12.03	4827.0	3575.08	-0.03	979879.59	980323.41	10.03	-154.61	1.39	0.00	-156.00	-131.13
SV010	41 36.15	120 11.40	4744.0	3576.12	-0.02	979879.85	980323.49	2.41	-159.40	1.38	0.00	-160.78	-136.33
SV011	41 36.15	120 10.83	4696.0	3574.58	-0.02	979878.23	980323.49	-3.72	-163.89	1.38	0.00	-165.26	-141.06
SV012	41 36.15	120 10.27	4573.0	3577.89	-0.01	979881.72	980323.49	-11.80	-167.77	1.36	0.00	-169.12	-145.55
SV013	41 36.16	120 9.69	4518.0	3575.68	-0.01	979879.40	980323.50	-19.30	-173.40	1.35	0.00	-174.74	-151.46
SV014	41 36.16	120 9.40	4508.0	3572.91	-0.01	979876.49	980323.50	-23.15	-176.91	1.35	0.00	-178.25	-155.02
SV015	41 36.17	120 8.82	4483.0	3569.72	0.00	979873.15	980323.52	-28.86	-181.76	1.35	0.00	-183.10	-159.99
SV016	41 36.15	120 8.54	4486.0	3567.63	0.00	979870.95	980323.49	-30.75	-183.75	1.35	0.00	-185.09	-161.97
SV017	41 36.14	120 7.99	4493.0	3564.64	0.00	979867.81	980323.47	-33.21	-186.45	1.35	0.00	-187.80	-164.64
SV018	41 36.13	120 7.36	4506.0	3563.55	0.00	979866.66	980323.46	-33.12	-186.81	1.35	0.00	-188.15	-164.93
SV019	41 36.12	120 5.92	4519.0	3573.65	0.01	979877.29	980323.44	-21.26	-175.39	1.35	0.00	-176.74	-153.45
SV020	41 35.15	120 1.57	4781.0	3554.60	-0.02	979857.33	980321.99	-15.15	-178.21	1.39	0.00	-179.60	-154.96
SV021	41 38.17	119 59.15	6457.0	3522.47	-0.05	979823.45	980326.50	10.01	-176.11	1.46	0.00	-177.57	-149.47
SV022	41 40.58	119 59.77	6497.0	3527.87	-0.07	979829.11	980330.10	15.83	-171.67	1.47	0.00	-173.13	-144.82
SV023	41 39.20	120 1.64	5308.0	3533.53	-0.09	979835.03	980328.04	6.05	-175.00	1.45	0.00	-176.44	-149.10
15S34	41 35.68	120 4.61	4566.9	3574.61	-0.10	979878.18	980322.78	-15.21	-170.97	1.36	0.00	-172.32	-148.78
15S32	41 35.80	120 4.79	4558.0	3575.84	-0.10	979879.48	980322.96	-14.93	-170.39	1.36	0.00	-171.74	-148.25
11CGM	41 35.88	120 5.00	4547.4	3574.70	-0.10	979878.28	980323.08	-17.24	-172.34	1.36	0.00	-173.69	-150.25
15S29	41 36.01	120 5.08	4547.8	3574.29	-0.10	979877.85	980323.28	-17.83	-172.94	1.36	0.00	-174.29	-150.85
15S28	41 36.05	120 5.19	4543.7	3574.55	-0.10	979878.12	980323.34	-18.00	-172.97	1.35	0.00	-174.32	-150.90
15S27	41 36.07	120 5.29	4544.1	3575.16	-0.10	979878.76	980323.37	-17.35	-172.34	1.36	0.00	-173.69	-150.27
15S26	41 36.18	120 5.39	4546.4	3575.48	-0.10	979879.10	980323.53	-16.97	-172.03	1.36	0.00	-173.38	-149.95
15S25	41 36.18	120 5.43	4548.3	3575.87	-0.10	979879.51	980323.53	-16.38	-171.50	1.36	0.00	-172.85	-149.41
15S24	41 36.23	120 5.52	4547.6	3576.59	-0.10	979880.26	980323.60	-15.76	-170.86	1.36	0.00	-172.21	-148.78
15S23	41 36.27	120 5.60	4549.5	3576.29	-0.10	979879.95	980323.66	-15.96	-171.13	1.36	0.00	-172.48	-149.03
15S22	41 36.32	120 5.70	4548.9	3576.42	-0.10	979880.09	980323.74	-15.95	-171.10	1.36	0.00	-172.45	-149.00
15S21	41 36.37	120 5.79	4549.4	3576.76	-0.10	979880.44	980323.81	-15.62	-170.79	1.36	0.00	-172.14	-148.69
15S20	41 36.42	120 5.86	4554.4	3576.51	-0.10	979880.18	980323.89	-15.49	-170.82	1.36	0.00	-172.18	-148.70
15S19	41 36.47	120 5.95	4571.0	3575.26	-0.10	979878.87	980323.96	-15.32	-171.22	1.36	0.00	-172.57	-149.01
15S18	41 36.54	120 6.02	4572.9	3574.96	-0.10	979878.55	980324.07	-15.56	-171.52	1.36	0.00	-172.88	-149.31
15S17	41 36.62	120 6.10	4566.5	3575.12	-0.10	979878.72	980324.19	-16.11	-171.86	1.36	0.00	-173.21	-149.68
15S16	41 36.69	120 6.16	4567.1	3574.97	-0.10	979878.56	980324.29	-16.32	-172.09	1.36	0.00	-173.44	-149.90
15S15	41 36.76	120 6.23	4558.5	3574.20	-0.10	979877.75	980324.40	-16.04	-171.51	1.36	0.00	-174.87	-151.37
15S14	41 36.82	120 6.30	4559.0	3572.78	-0.10	979876.26	980324.49	-19.57	-175.07	1.36	0.00	-176.42	-152.92
15S13	41 36.87	120 6.37	4560.5	3571.22	-0.09	979874.63	980324.56	-20.38	-176.20	1.36	0.00	-177.55	-154.01
15S12	41 36.98	120 6.42	4586.8	3569.61	-0.09	979872.94	980324.72	-20.52	-176.96	1.36	0.00	-178.32	-154.68
15S11	41 37.07	120 6.48	4587.5	3569.10	-0.09	979872.40	980324.86	-21.12	-177.59	1.36	0.00	-178.94	-155.30
15S10	41 37.15	120 6.50	4590.7	3568.79	-0.09	979872.08	980324.98	-21.27	-177.84	1.36	0.00	-179.20	-155.54
15S09	41 37.23	120 6.52	4588.7	3568.85	-0.09	979872.14	980325.10	-21.51	-178.02	1.36	0.00	-179.37	-155.72
15S08	41 37.31	120 6.53	4602.0	3568.06	-0.09	979871.31	980325.22	-21.21	-178.17	1.36	0.00	-179.53	-155.81
15S07	41 37.40	120 6.57	4594.8	3568.48	-0.09	979871.75	980325.35	-21.58	-178.30	1.36	0.00	-179.65	-155.97
15S06	41 37.46	120 6.64	4576.6	3569.49	-0.09	979872.81	980325.44	-22.32	-178.41	1.36	0.00	-179.77	-156.18
15S04	41 37.62	120 6.73	4569.6	3570.13	-0.08	979873.50	980325.68	-22.54	-178.39	1.36	0.00	-179.74	-156.19
15S03	41 37.72	120 6.83	4559.1	3570.55	-0.08	979873.94	980325.83	-23.23	-178.73	1.36	0.00	-180.08	-156.58
15S02	41 37.78	120 6.93	4556.0	3570.51	-0.08	979873.90	980325.92	-23.65	-179.04	1.36	0.00	-180.40	-156.91
15S01	41 37.84	120 7.03	4555.8	3569.84	-0.08	979873.19	980326.01	-24.47	-179.85	1.36	0.00	-181.20	-157.72
15S05	41 37.53	120 6.70	4569.7	3569.83	-0.06	979873.20	980325.55	-22.69	-178.54	1.36	0.00	-179.90	-156.35


SHALLOW
LAKE CITY
START LINE S-1
START SURPRISE VALLEY PROJECT

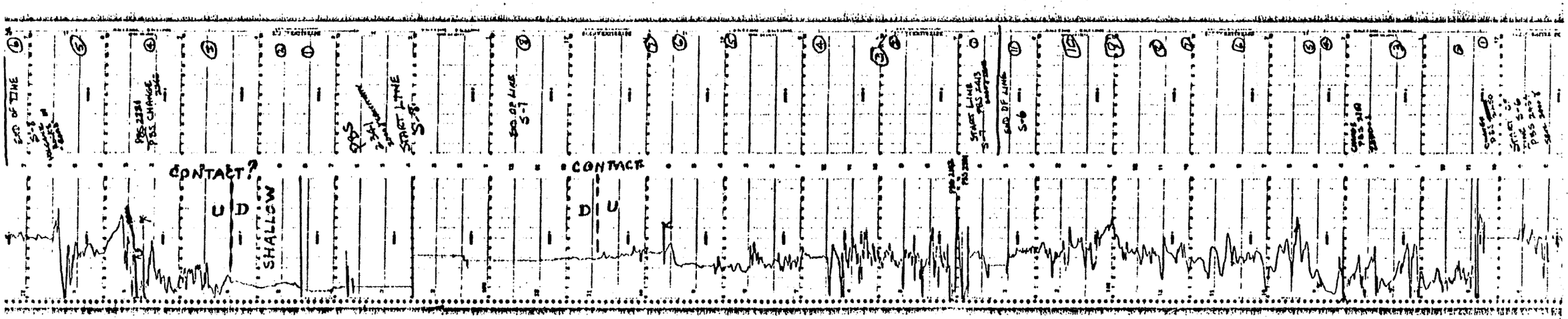
S-1 FIG 9

S-2, S-3, S-4, S-5

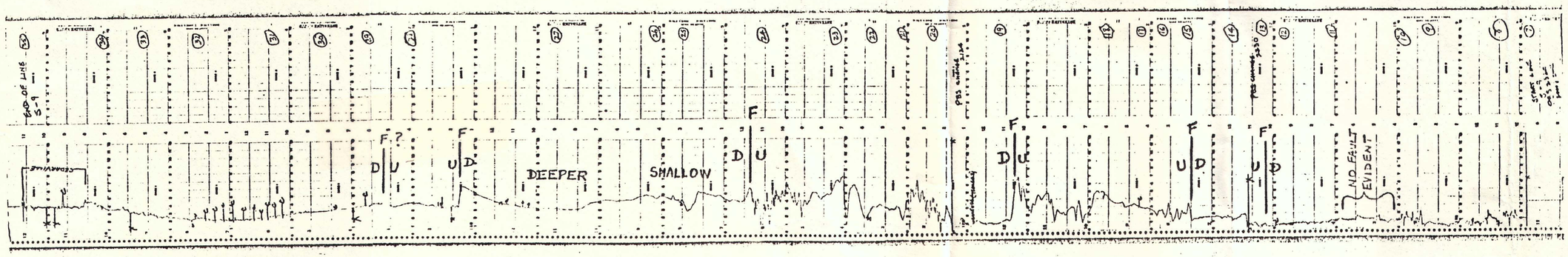
FIG. 10



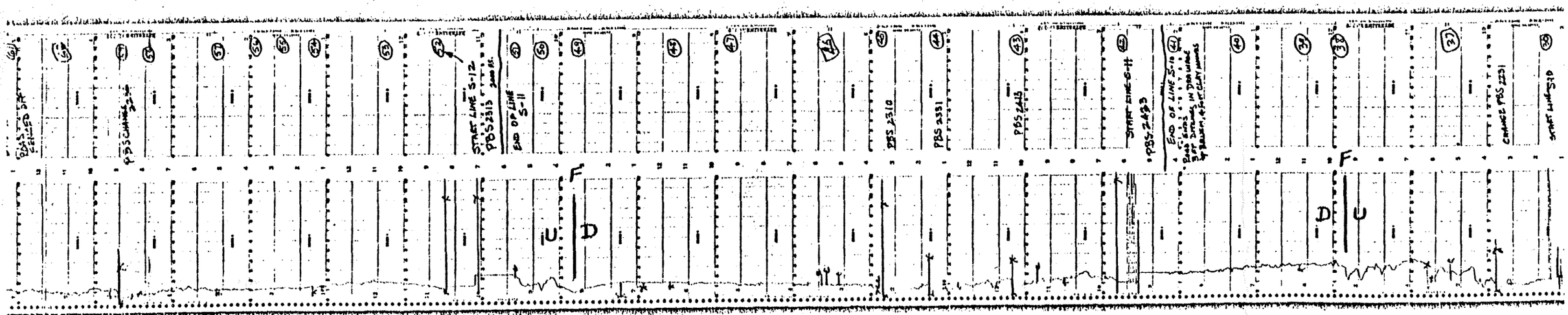
S-6, S-7, S-8 FIG. 11



S-9 FIG. 12


END OF LINE S-9
F ?
D U
U D
F
DEEPER
SHALLOW
D U
F
D U
F
U D
F
U D
NO FAULT EVIDENT

S-10, S-11, S-12 FIG. 13



LAKE CITY K.G.R.A., 37,160 ACRES

REGIONAL GEOLOGY: Surprise Valley is an elongated, north-south trending, faulted depression (graben), bound by tilted mountain ranges. A thick section of Tertiary and Quaternary sedimentary rocks overlie a basement complex of unknown nature and age. Interspersed within the sedimentary section are andesitic and basaltic rocks. The Warner Range, to the west, consists of Miocene and possibly Pliocene volcanic and volcaniclastic rocks.

The most prominent and important structural feature is the Surprise Valley fault which parallels the west side of the valley as it strikes southward from Fort Bidwell to beyond the area covered by the map. The rugged scarp along the eastern face of the Warner Mountains is the result of over 5,000 feet of displacement on this fault.

Geophysical surveys indicate that the subsurface has been broken into many tilted fault blocks and that the depth of basin fill ranges from a few hundred feet to over 5,000 feet (see generalized cross section). Some of the faults have created fractured, permeable zones which apparently act as conduits for the upward migration of hot water and steam. Several hot springs and a mud volcano complex are associated with these subsurface structural features.

INFERRED HEAT SOURCE: Unknown

SURFACE THERMAL PHENOMENA (Hot springs are listed below):

NAME	LOCATION	TEMP.(°F)	FLOW (GPM)	ASSOCIATED ROCKS
Unnamed	2 mi N Lake City	120-207	100	Alluvium
(Several springs at site of spectacular mud eruption in 1951, see Ref. No. 95)				
Leonard Springs	7 mi NE Cedarville	104	50	Alluvium, faulted volcanics
Unnamed	5 mi NE Cedarville	122; 130	500	" " "
Cedar Plunge	5 mi E Cedarville	165; 183; 202	115	" " "
Benmac Hot Springs	5 mi E Cedarville	204; 206	200	" " "

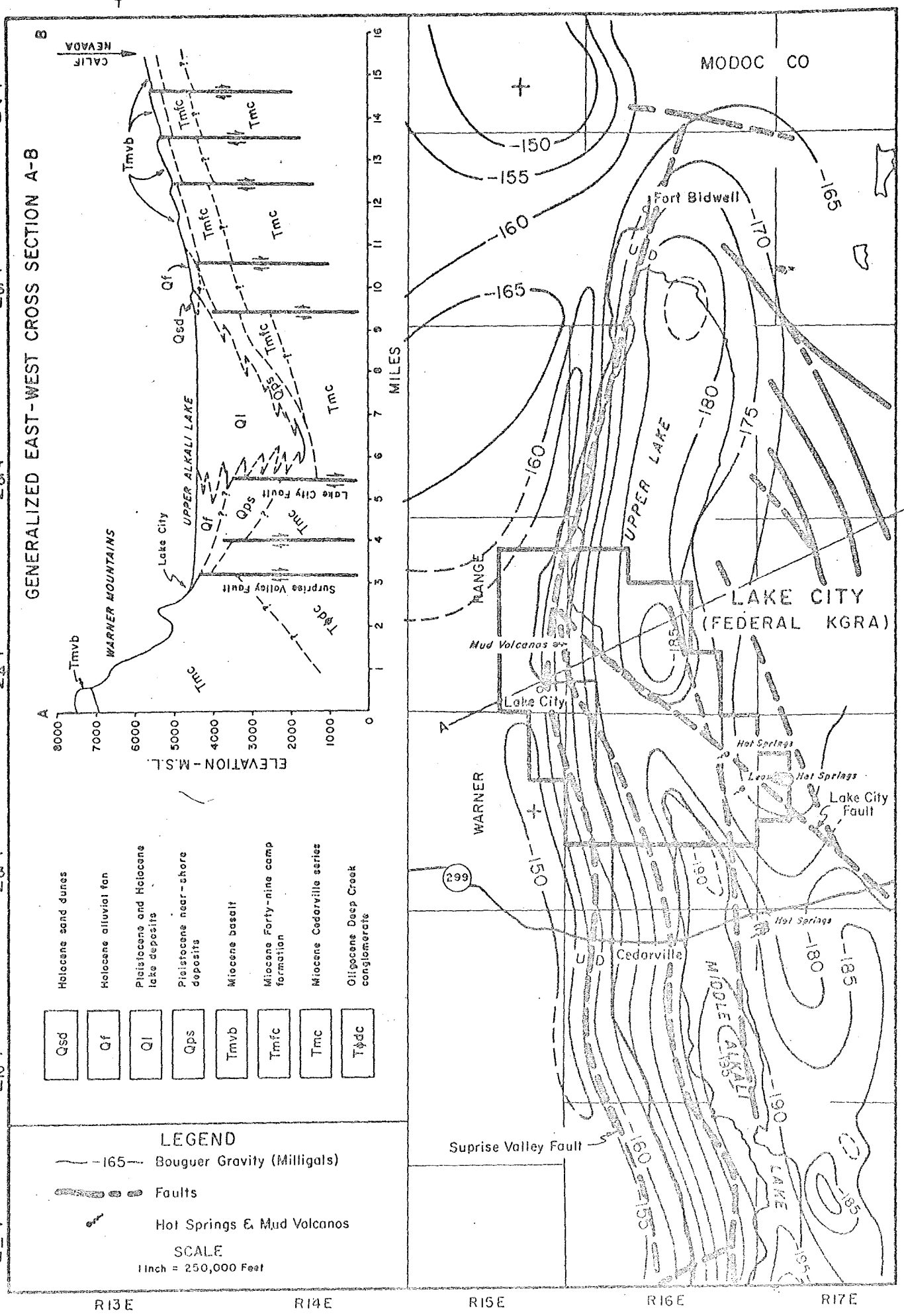
WATER QUALITY: Thermal artesian wells and hot springs yield waters high in electrical conductivity, sulfate, boron, fluoride and sodium; some also contain excessive arsenic.

WELL DATA

LAKE CITY AREA: Magma Power Company (and associates) drilled four wells between 1959-1962 in Sections 23 and 24, T. 44 N., R. 15 E., M.D.B.& M. The greatest depth reached was 2,150 feet and the highest temperature recorded was 320° F.

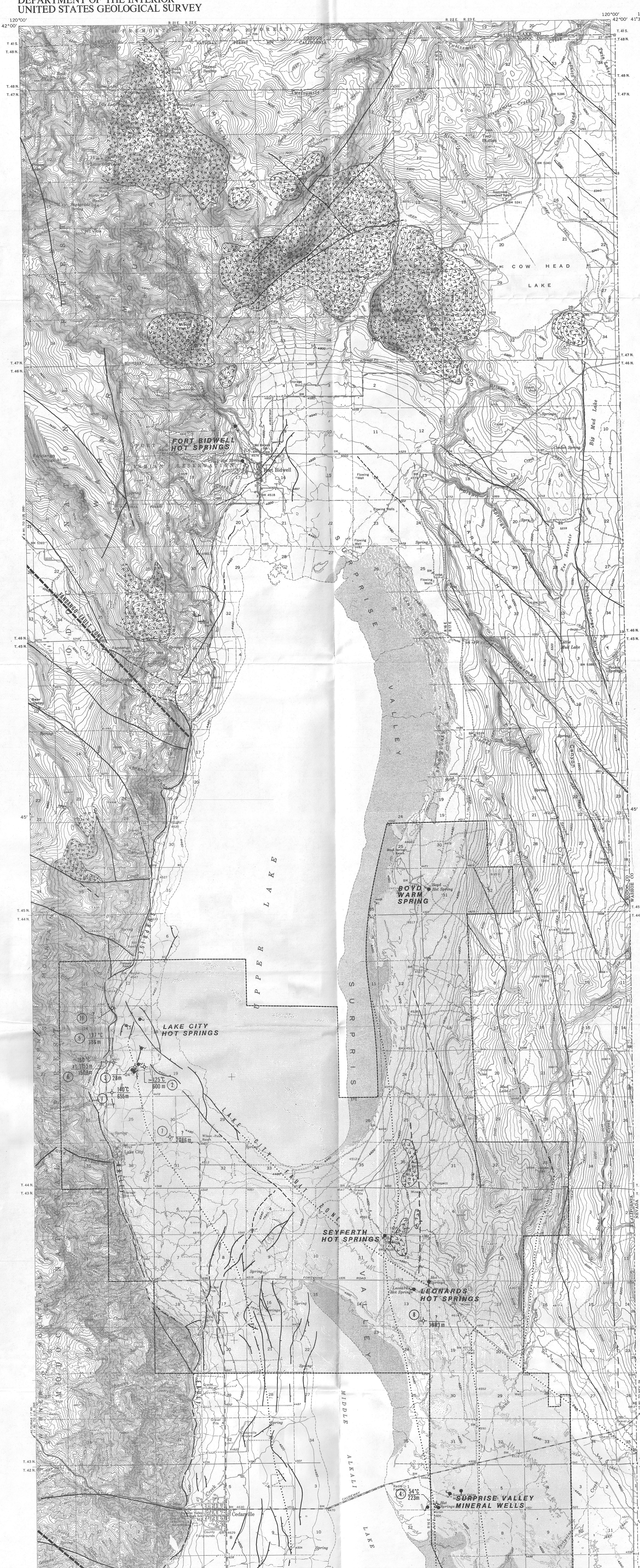
CEDARVILLE AREA: Magma Power Company (and associates) drilled one well in 1962 in Section 6, T. 42 N., R. 17 E., M.D.B.& M. to a total depth of 734 feet. The maximum temperature measured was 129° F.

BIBLIOGRAPHY: 8, 65, 85, 89, and 95


GENERALIZED EAST-WEST CROSS SECTION A-8
CALIF
NEVADA
WARNER MOUNTAINS
UPPER ALKALI LAKE
Lake City
Lake City Fault
Surprise Valley Fault
Tmvb
Tmfc
Tmc
Qf
Qsd
Ql
Qps
Tmc
Tφdc
Tmc
A
B
MILES
ELEVATION - M.S.L.
8000
7000
6000
5000
4000
3000
2000
1000
0
Holocene sand dunes
Holocene alluvial fan
Pleistocene and Holocene lake deposits
Pleistocene near-shore deposits
Miocene basalt
Miocene Forty-nine camp formation
Miocene Cedarville series
Oligocene Deep Creek conglomerate
Qsd
Qf
Ql
Qps
Tmvb
Tmfc
Tmc
Tφdc
LEGEND
-165- Bouguer Gravity (Milligals)
Faults
Hot Springs & Mud Volcanos
SCALE
1 Inch = 250,000 Feet
MODOC CO
Fort Bidwell
UPPER LAKE
WARNER RANGE
LAKE CITY
(FEDERAL KGRA)
Mud Volcanos
Lake City
Hot Springs
Lake City Fault
WARNER
299
Cedarville
Hot Springs
MODOC PLATEAU
Suprise Valley Fault
-150
-155
-160
-165
-170
-175
-180
-185
-190
-195
T 47 N
T 46 N
T 45 N
T 44 N
T 43 N
T 42 N
T 41 N
R13E
R14E
R15E
R16E
R17E

DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY

MISCELLANEOUS FIELD STUDIES
MAP MF-1299



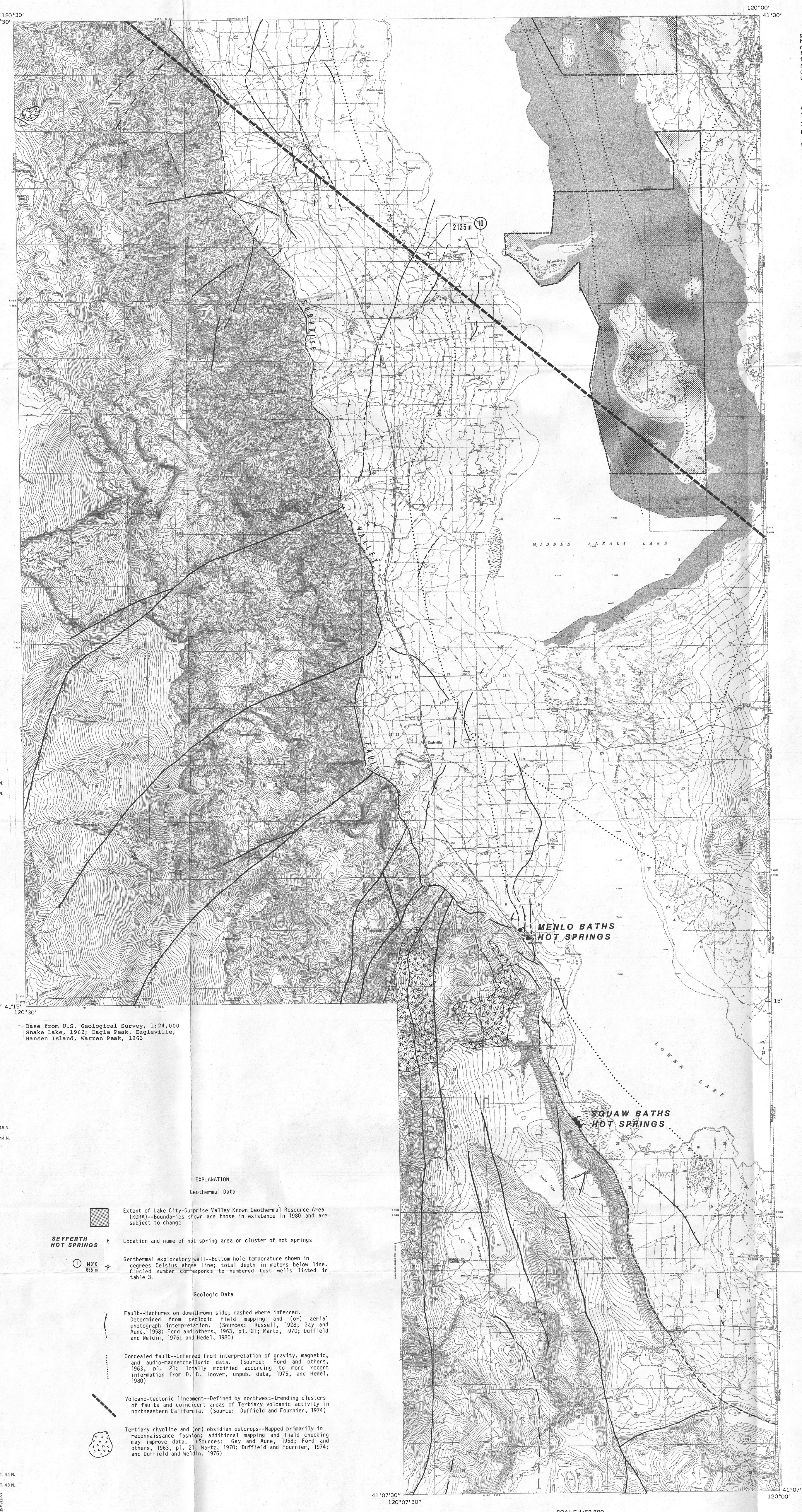
Base from U.S. Geological Survey Cedarville, Fort Bidwell, 1962

SCALE 1:62 500

CONTOUR INTERVAL 40 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

Compiled in 1980; aerial-photograph interpretation and field mapping in 1978-79.

NORTHERN PORTION



Base from U.S. Geological Survey, 1:24,000 Snake Lake, 1963; Eagle Peak, Eagleville, Hansen Island, Warren Peak, 1963

SCALE 1:62 500

CONTOUR INTERVAL 40 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

SOUTHERN PORTION

EXPLANATION

Geothermal Data

Extent of Lake City-Surprise Valley Known Geothermal Resource Area (KGRA)--Boundaries shown are those in existence in 1980 and are subject to change

SEYFERTH HOT SPRINGS — Location and name of hot spring area or cluster of hot springs

(1) 140°C / 655 m — Geothermal exploratory well--Bottom hole temperature shown in degrees Celsius above line; total depth in meters below line. Circled number corresponds to numbered test wells listed in table 3

Geologic Data

Fault--Hachures on downthrown side; dashed where inferred. Determined from geologic field mapping and (or) aerial photograph interpretation. (Sources: Russell, 1928; Gay and Aune, 1958; Ford and others, 1963, pl. 21; Martz, 1970; Duffield and Weldin, 1976; and Hedel, 1980)

Concealed fault--Inferred from interpretation of gravity, magnetic, and audio-magnetotelluric data. (Source: Ford and others, 1963, pl. 21; locally modified according to more recent information from D. B. Hoover, unpub. data, 1975, and Hedel, 1980)

Volcano-tectonic lineament--Defined by northwest-trending clusters of faults and coincident areas of Tertiary volcanic activity in northeastern California. (Source: Duffield and Fournier, 1974)

Tertiary rhyolite and (or) obsidian outcrops--Mapped primarily in reconnaissance fashion; additional mapping and field checking may improve data. (Sources: Gay and Aune, 1958; Ford and others, 1963, pl. 21; Martz, 1970; Duffield and Fournier, 1974; and Duffield and Weldin, 1976)

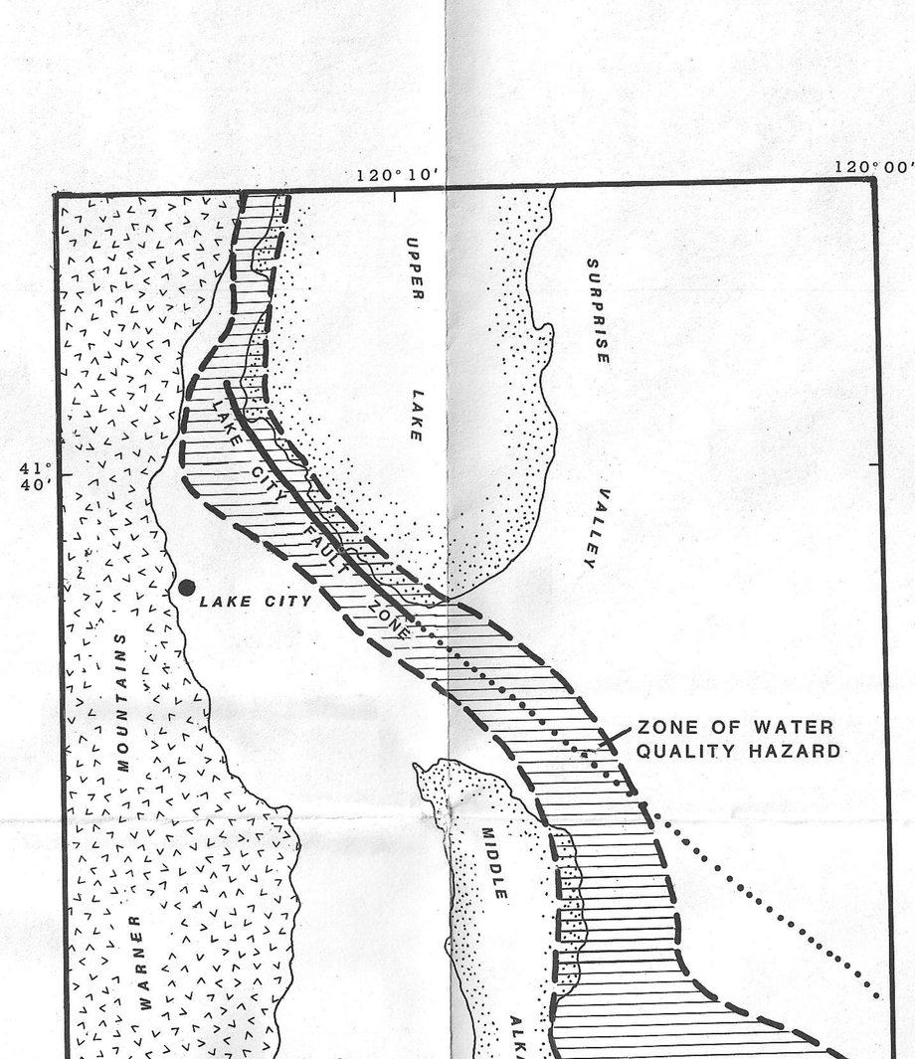


Figure 1--Area of hazardous groundwater (lined area) that is defined by high concentrations of boron, fluoride, sodium, and sulfate. Note close association with Lake City fault zone (from Ford and others, 1963, pl. 23).

INTRODUCTION

This report summarizes geothermal data from published and unpublished geophysical, geochemical, and geologic reports on Surprise Valley that have been prepared during the past 26 years. Particular emphasis is placed on a comprehensive structural interpretation of the west half of the valley that is based on map compilation of concealed faults that have been inferred from geophysical methods and exposed faults that can be seen in the field and (or) on aerial photographs. The faults apparently control the location of modern geothermal activity and are thus important to geothermal exploration.

HISTORY

Geothermal activity in Surprise Valley has long been known. Archeologists have found that the first known human inhabitants of the valley constructed dwellings selectively in hot spring areas 5000 to 6000 years ago (O'Connell and Ericson, 1974). In the early 1900's, spas flourished at Leonards Hot Springs, Menlo Baths, and Surprise Valley Mineral Wells (sometimes called Cedar Plunge), and the operators claimed therapeutic benefits to those who bathed in pools filled with mineralized water from thermal springs. However, Surprise Valley was not considered to be an attractive target for geothermal prospecting until 1951 when a spectacular phreatic eruption of mud volcanoes (White, 1955) occurred at an isolated group of hot springs near Lake City. This eruption propelled rocks, clots of mud, steam, and gases upward as much as 1600 m from six vents ranging from 18 m to 61 m in diameter. Immediately after the explosive eruption, springs at the site discharged water at or near boiling temperatures. Subsequent investigations have shown this group of hot springs to be among the most important geothermal resources in Surprise Valley.

In accordance with the provisions of the Federal Geothermal Steam Act of 1970, 150 km² (37,160 acres) in the vicinity of Lake City were designated as potentially valuable for the production of geothermal energy and were classified as a "Known Geothermal Resource Area" (KGRA) by the U.S. Geological Survey (Godwin and others, 1971). In 1974, an additional 145 km² (35,780 acres) were so classified, bringing the total area of the KGRA to 295 km² (72,940 acres).

NATURE OF GEOTHERMAL RESOURCES

The geothermal resources of Surprise Valley consist of hydrothermal convective systems that are dominated by hot water (Brook and others, 1979, p. 46, 62). Such convective systems typically form when permeable rocks are underlain by a heat source at shallow (≤10 km) depth and meteoric water and (or) surface runoff percolate downward toward the heat source. Heating and thermal expansion cause thermal fluid to circulate upward where it may be trapped beneath an impermeable cap rock or escape to the ground surface if open channelways permit. Most known convecting systems are characterized by hot springs and (or) fumaroles that discharge at the ground surface.

Thermal springs occur in eight principal areas in Surprise Valley (table 1). Analyses of waters issuing from Seyferth Hot Springs, Leonards Hot Springs, Surprise Valley Mineral Wells, and Lake City Hot Springs show that the water chemistry of these four groups of springs is similar and that they are apparently part of the same system (Mariner and others, 1978, p. 85). Chemical geothermometers, useful in predicting subsurface temperatures from ions whose concentrations are dependent upon temperature, suggest that the reservoir underlying the four groups of springs has an estimated mean temperature that might locally exceed 150°C (table 2). Such areas would have a potential to generate electricity. Reservoirs at Fort Bidwell and elsewhere in the valley are apparently somewhat cooler and are attractive for uses other than generation of electricity.

Surprise Valley is considered favorable for the discovery and development of low-temperature (approximately 30° to 90°C) geothermal resources other than those which are directly observable at the ground surface as hot springs (Sammel, 1979, p. 104). Low-temperature geothermal waters are believed to occur locally in extensive reservoirs within 1 km of the ground surface. Such aquifers are not associated with zones of high permeability (such as faults) that allow percolation to the surface and are usually discovered accidentally in Surprise Valley by residents who drill unsuccessfully for cold water.

Minor sinter has been deposited at both the Lake City Hot Springs and the Surprise Valley Mineral Wells, whereas cinnabar and metacinnabar have been reported at only the Surprise Valley Mineral Wells (Raab and Dickinson, 1969). Mild hydrothermal alteration also occurs throughout the Warner Mountains, adjacent to Surprise Valley to the west. In the field, this alteration is expressed as a pervasive green color that is caused by the presence of disseminated celadonite. Other secondary minerals, found mainly in joints and in cavities, include zeolites, carbonates, hyaline opal, and crystalline or cryptocrystalline varieties of SiO_2 (Duffield and Weldin, 1976, p. 11). This mineralization is probably Tertiary in age and is interpreted to predate uplift of the Warner Mountains.

The source of heat within the geothermal system is not fully understood, but it may be related to residual heat associated with late Tertiary silicic magma within the crust beneath the Surprise Valley-Warner Mountains area (Smith and others, 1978, table 1). Silicic magma chambers at shallow (≤10 km) depths (Smith and Shaw, 1975, p. 59) appear to have a direct relationship with many large geothermal fields elsewhere. Duffield and Fournier (1974, p. 11, 12) have noted that, with one possible exception, all hot springs in Surprise Valley are no farther than 4.8 km from extrusive rhyolite and (or) rhyolitic plugs and that the most significant known geothermal resources of the area, found in the northern half of Surprise Valley, are associated with the most extensive and youngest rhyolite-obsidian outcrops in the Warner Mountains. The youngest of these rhyolites, with a K-Ar age of 7.1 m.y. (Smith and Shaw, 1975, p. 68), are interpreted to be coeval with the most recent emplacement of silicic magma beneath the area. Moreover, an equivalent K-Ar age on extrusive rhyolite? from 80 km north-northwest of Lake City, at the Cougar Peak, Oregon, geothermal area (fig. 2) suggests that the two systems might be heated by the same or related plutons (Smith and Shaw, 1975, p. 68 and 71). Until more information is gathered on the age, size, and location of the magma reservoir that is hypothesized to be the heat source for the system, estimates of the initial and remaining thermal energy in the magma reservoir cannot be made.

Alternatively, Surprise Valley thermal water may be heated by deep circulation along major faults in a region of higher-than-average heat flow, with or without a direct magmatic component of thermal energy. The heat source is unresolved at this time.

STRUCTURE

Surprise Valley is a graben located between the west-tilted Warner Mountains horst to the west and the Hays Canyon Range horst to the east, in Nevada [not shown on map]. An estimated 3800 m of vertical displacement between the Warner Mountains and Surprise Valley fault blocks has occurred along the Surprise Valley fault. Episodic normal slip along the fault began no more than 15 m.y. ago (Duffield and McKee, 1974) and has continued into the Holocene (Hedel, 1980, p. 42-86). The age and amount of the fault displacement between Surprise Valley and the Hays Canyon Range are not well known, but are probably similar to those of the Surprise Valley fault.

Brittle fracture of the Warner Mountains accompanied the late Tertiary and Quaternary uplift of the range as shown by faults of variable strike that offset the lithologic section. Similarly, subsidiary faults exist within the buried Surprise Valley block. Many of these structures are covered by great thicknesses of lacustrine and alluvial deposits and are detectable only by geophysical methods. Relatively youthful movements on others have propagated to the surface and are manifested as degraded fault scarps on the valley floor.

Structural control of hot springs, where thermal fluids are concentrated in permeable fault zones, is evident in Surprise Valley. Seyferth Hot Springs, Leonards Hot Springs, Surprise Valley Mineral Wells, and Squaw Baths Hot Springs are clearly localized along known or inferred faults. Lake City Hot Springs and Menlo Baths Hot Springs occur in highly fractured areas where faults of diverse trends converge. Fort Bidwell Hot Springs and Boyd Warm Springs may be associated with faults, but evidence for such faults is lacking.

Lake City Fault Zone

The Lake City fault zone has been recognized by geophysical techniques between Upper Lake and Middle Alkalai Lake as a northwest-trending cluster of fractures that is about 610 m wide with at least two principal strands (D.B. Hoover, unpub. data, 1975). In the western part of the valley, the fault zone is also expressed as a group of obscure, low scarps and photolineaments (Hedel, 1980, pl. 1). The northwest-trending, linear form of the southwestern shoreline of Upper Lake appears to be controlled by the position of the Lake City fault zone. To the southeast, the surface expression becomes progressively less distinct and eventually disappears beneath poorly consolidated lacustrine and eolian deposits, but geophysical data suggest the subsurface continuation of the fault zone to the east side of the valley (Ford and others, 1963, pl. 21). Anomalies of apparent resistivity, determined from audio-magnetotelluric (AMT) soundings, suggest that the Lake City fault zone splays to the south toward the Surprise Valley Mineral Wells (D.B. Hoover, unpub. data, 1975). If it does, the northwest-trending northeastern shoreline of Middle Alkalai Lake might also be controlled by faulting. The sense of motion along the fault zone is down to the northeast, with a possible lateral component of slip (Hedel, 1980, p. 40-41).

Several lines of evidence (D.B. Hoover, unpub. data, 1975) indicate that the Lake City fault zone is an area of high permeability that allows communication of thermal fluids between the east and west sides of the valley:

1) Water Quality: Figure 1 depicts an area of hazardous groundwater that is defined by high concentrations of boron, fluoride, sodium, and sulfate. The area of poor-quality water is coextensive with the Lake City fault zone and thus provides substantial evidence that the group of linear fractures function as a permeable zone across the valley.

2) Gravity Anomalies: Small gravity highs associated with the Lake City fault zone occur immediately below the southern extent of Upper Lake, away from hot spring areas. These anomalies are probably caused by local density increases caused by silica cement replacing calcium carbonate in basin-fill deposits within 90 m to 150 m of the ground surface. This suggests that hot mineralized fluids are or were present within the fault zone.

3) Magnetic Anomalies: Magnetic "noise" that accompanies gravity highs along the Lake City fault zone signifies the presence of magnetic minerals localized in the fault zone in otherwise nonmagnetic basin-fill deposits. Presumably, chemical reactions of hot saline fluids in the fault zone have generated small amounts of magnetic minerals within about 60 m of the surface.

4) Geothermal Ground Noise: Preliminary interpretation of anomalous levels of microseismic activity reveals a clear association of geothermal ground noise with the Lake City fault zone. Isoseismic lines encompass the Lake City Hot Springs and are distinctly elongated to the southeast along the Lake City fault zone, apparently outlining an area where thermal fluids migrate. (Similar anomalies also occur in Fort Bidwell; see Eng and Decker, 1974, and Eng, 1975.)

The Lake City fault zone clearly has an important affect on the location of geothermal resources in Surprise Valley. Significant hot spring activity in northern Surprise Valley appears to be localized where north-trending faults intersect the Lake City fault zone.

Volcano-Tectonic Lineaments

Two northwest-trending lineaments (fig. 2) have been inferred in the Surprise Valley-Warner Mountains area (Duffield and Fournier, 1974, p. 7-10). In the north, the Fandango fault zone is defined by a cluster of northwest-trending normal-slip faults (with a possible strike-slip component) in the vicinity of Fandango Valley in the Warner Mountains. Evidently, this area has acted as a hinge, because south of Fandango Valley the Warner Mountains block is tilted westward, whereas dips are eastward north of the valley. Rhyolite and obsidian are particularly abundant near the lineament. West of the Warner Mountains the lineament projects across Goose Lake and into southern Oregon.

To the south, a second lineament trends to the northwest from Hays Canyon Peak in Nevada, a Tertiary volcanic vent, across Surprise Valley, and through the Warner Mountains near Cedar Pass, the locus of two major Tertiary volcanoes. West of the Warner Mountains, it projects across the Devils Garden to include a zone of northwest-trending faults east of Carr Butte in northwestern Modoc County (Gay and Aune, 1958) and into southern Oregon where it has been mapped as the Mount McLoughlin fault zone. In Oregon, the lineament is thought to have offset the crest of the Cascade Range 15-20 km in a right-lateral sense during Quaternary time (Lawrence, 1976, p. 848). The only known outcrops of rhyolite and obsidian (Tertiary in age) in the Devils Garden are found along the lineament just west of Blue Mountain.

Both lineaments parallel the Lake City fault zone and the Likely fault (Gay and Aune, 1958), located west-southwest of the Warner Mountains. Collectively, these features define a northwest-trending structural grain through northeastern California. Some of these structures have been the locus of reported late Cenozoic volcanism. In Surprise Valley and elsewhere in northeastern California, attractive areas for geothermal exploration might occur along these faults and lineaments.

GEOTHERMAL PROSPECTING AND DEVELOPMENT

Commercial exploration of the Surprise Valley geothermal area began in the late 1950's. To date, actual development by private industry includes ten test wells which range in depth from 28 m to over 2100 m. Bottom-hole temperatures in test wells (table 3), where known, are in reasonably close agreement with subsurface temperatures predicted from water chemistry of hot springs (table 1). With present technology, maximum reservoir temperatures are marginal for generating electricity. However, hot spring resources are adequate and could be enhanced by flow from wells to support nonelectric commercial developments. Uses such as heating greenhouses, drying lumber in wood kilns, warming feed lots and agricultural fields for winter crops, and space heating of commercial, residential, and public buildings are economically practical and readily achievable applications of geothermal energy in Surprise Valley (California Division of Oil and Gas, unpub. report, 1977). At present, some buildings at Surprise Valley Mineral Wells and at Menlo Baths are heated by hot water, but nearly all geothermal resources are unused.

GEOTHERMAL DEVELOPMENT AND EARTHQUAKE HAZARDS

As with many of the deep, fault-bounded structural valleys in the Great Basin, Surprise Valley is tectonically active. The Surprise Valley fault has apparently generated magnitude 7+ earthquakes during the Holocene Epoch, and events of this size are likely to recur (Hedel, 1980, p. 91-103). Late Quaternary surface rupture has occurred along the range-front fault as well as along many strands on the valley floor, including the western part (and possibly the entire length) of the Lake City fault zone, although there is no record of significant historic seismicity in Surprise Valley. The best producing geothermal wells and any related industrial buildings are likely to be located along or near these faults. If so, seismic risks, both natural and induced, must be considered in the development of the geothermal resources. Moreover, faulting during an earthquake can greatly affect the longevity of geothermal reservoirs, as discharge from hot springs and wells may be greatly enhanced or diminished by seismically induced changes in permeability.

REFERENCES CITED

Brook, C. A., Mariner, R. H., Mabey, D. R., Swanson, J. R., Guffanti, M., and Muffler, L. J. P., 1979, Hydrothermal convection systems with reservoir temperatures ≥ 90°C, in Muffler, L. J. P., ed., Assessment of geothermal resources of the United States--1978: U.S. Geological Survey Circular 790, p. 18-85.

Duffield, W. A., and Fournier, R. O., 1974, Reconnaissance study of the geothermal resources of Modoc County, California: U.S. Geological Survey, Open-File Report (74-1024), 19 p., map scale 1:250,000.

Duffield, W. A., and McKee, E. H., 1974, Tertiary stratigraphy and timing of Basin and Range faulting of the Warner Mountains, northeastern California [abs.]: Geological Society of America Abstracts with Programs, v. 6, no. 3, p. 168.

Duffield, W. A., and Weldin, R. D., 1976, Mineral resources of the South Warner Wilderness, Modoc County, California: U.S. Geological Survey Bulletin 1385-D, 31 p., map scale 1:48,000.

Eng, K. J., 1975, Seismic ground noise survey in Surprise Valley, California: EOS (American Geophysical Union Transactions), v. 56, no. 6, p. 398.

Eng, K. J., and Decker, R. W., 1974, Anomalous microseisms in Surprise Valley, California [abs.], in Colp, J. L., and Furumoto, A. S., eds., The utilization of volcano energy: Albuquerque, New Mexico, Sandia Laboratories, p. 225.

Ford, R. S., Soderstrand, J. N., Franson, R. E., Beach, F. H., Feingold, S. A., Hail, W. R., Iwamura, T. I., and Swanson, A. A., 1963, Northeastern counties ground-water investigation: California Department of Water Resources Bulletin 98, v. 1 and 2, 224 p., map scale 1:125,000.

Gay, T. E., and Aune, Q. A., compilers, 1958, Geologic map of California, Alturas sheet: California Division of Mines and Geology, scale 1:250,000.

Godwin, L. H., Haigler, L. B., Rioux, R. L., White, D. E., Muffler, L. J. P., and Wayland, R. G., 1971, Classification of public lands valuable for geothermal steam and associated geothermal resources: U.S. Geological Survey Circular 647, 18 p.

Hedel, C. W., 1980, Late Quaternary faulting in western Surprise Valley, Modoc County, California: San Jose, California State University, M.S. thesis, 113 p., map scale 1:62,500.

Lawrence, R. D., 1976, Strike-slip faulting terminates the Basin and Range province in Oregon: Geological Society of America Bulletin, v. 87, p. 846-850.

Mariner, R. H., Brook, C. A., Swanson, J. R., and Mabey, D. R., 1978, Selected data for hydrothermal convection systems in the United States with estimated temperatures ≥ 90°C--back-up data for U.S. Geological Survey Circular 790: U.S. Geological Survey Open-File Report 78-858, 493 p.

Martz, P. W., 1970, Geology of a portion of the northern Warner Mountains: Davis, University of California, M.S. thesis, 70 p., map scale 1:24,000.

O'Connell, J. F., and Ericson, J., 1974, Earth lodges to wickiups: A long sequence of domestic structures from the northern Great Basin: Nevada Archeological Survey Research Paper No. 5, p. 43-61.

Petroleum Information Corporation, 1979, The geothermal resource: Denver, Petroleum Information Corporation, 199 p.

Raab, W. J., and Dickinson, F. W., 1969, Deposition of cinnabar and metacinnabar at Cedarville hot springs, California [abs.]: Geological Society of America Special Paper 121, p. 548.

Reed, M. J., 1975, Chemistry of thermal water in selected geothermal areas of California: California Division of Oil and Gas Publication No. TR15, 31 p.

Russell, R. J., 1928, Basin range structure and stratigraphy of the Warner Range, northeastern California: California University Publications in Geological Sciences, v. 17, no. 11, p. 387-496, map scale approximately 1:130,000.

Sammel, E. A., 1979, Occurrence of low-temperature geothermal waters in the United States, in Muffler, L. J. P., ed., Assessment of geothermal resources of the United States--1978: U.S. Geological Survey Circular 790, p. 86-131.

Smith, R. L., and Shaw, H. R., 1975, Igneous-related geothermal systems, in White, D. E., and Williams, D. L., eds., Assessment of geothermal resources of the United States--1975: U.S. Geological Survey Circular 726, p. 58-83.

Smith, R. L., Shaw, H. R., Luedke, R. G., and Russell, S. L., 1978, Comprehensive tables giving physical data and thermal energy estimates for young igneous systems of the United States: U.S. Geological Survey Open-File Report 78-925, 15 p.

White, D. E., 1955, Violent mud-volcanoe eruption of Lake City hot springs, northeastern California: Geological Society of America Bulletin, v. 66, no. 9, p. 1109-1130.

Table 1.--Location and temperatures of hot springs in Surprise Valley

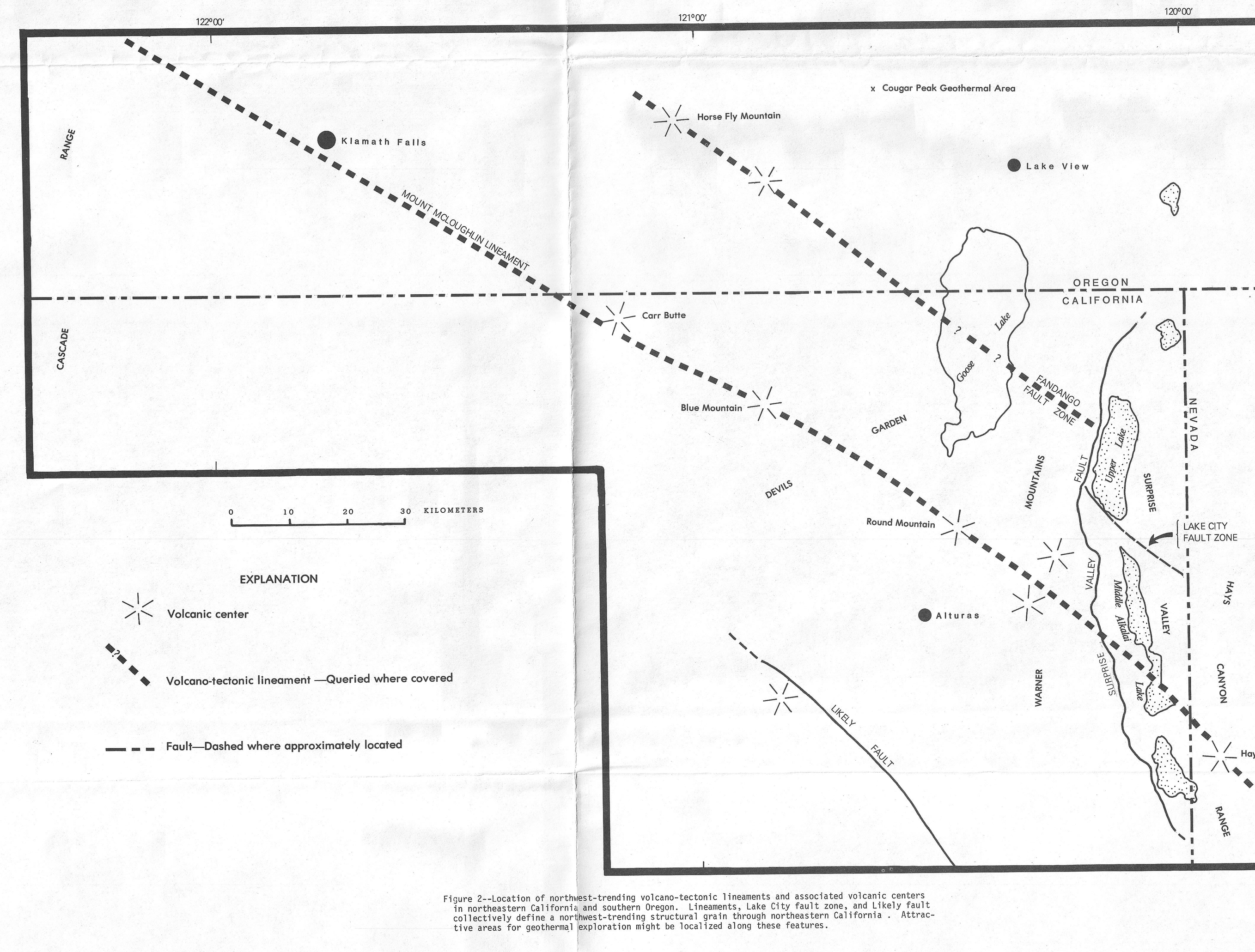
[illegible]

Table 2.--Estimates of temperatures, volumes and thermal energies for geothermal reservoirs of the Fort Bidwell and Lake City areas

[illegible]

Table 3.--Geothermal test wells drilled in Surprise Valley

[illegible]



EXPLANATION

Volcanic center

Volcano-tectonic lineament —Queried where covered

Fault—Dashed where approximately located

Figure 2--Location of northwest-trending volcano-tectonic lineaments and associated volcanic centers in northeastern California and southern Oregon. Lineaments, Lake City fault zone, and Likely fault collectively define a northwest-trending structural grain through northeastern California . Attractive areas for geothermal exploration might be localized along these features.

MAP SHOWING GEOTHERMAL RESOURCES OF THE LAKE CITY—SURPRISE VALLEY KNOWN GEOTHERMAL RESOURCE AREA, MODOC COUNTY, CALIFORNIA

Compiled by
Charles W. Hedel
1981

Interior—Geological Survey, Reston, Va.—1981

For sale by Branch of Distribution, U.S. Geological Survey, Box 25286, Federal Center, Denver, CO 80225