TEC-9

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INTERPRETATION OF THE SEISMICITY OF THE CALISTOGA PROSPECT NAPA AND SONOMA COUNTIES CALIFORNIA

March 12, 1975

MICRO GEOPHYSICS CORPORATION

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ABSTRACT

MICROEARTHQUAKE EPICENTER LOCATIONS RUN ON DATA SUPPLIED BY AMAX, INC., FROM THE CALISTOGA REGION OF CALIFORNIA, INDICATE TWO DISTINCT AREAS OF SEISMIC ACTIVITY. ONE AREA WHICH EXHIBITS A CLUSTER WITH SWARM CHARACTERISTICS IS OUTSIDE THE AREA OF INTEREST. THE OTHER SUGGESTS TWO LINEAR TRENDS OF ACTIVITY (STRIKING NNW) INTERSECTING IMMEDIATELY NORTHEAST OF CALISTOGA.

ALTHOUGH THE DATA IS INSUFFICIENT TO DETERMINE MECHANISM MODELS OR 3-D PLANES, THE SPATIAL DISTRIBUTION OF THE EPICENTERS IN PLAN APPEARS TO AGREE WITH THE MC EVILLY, U.C., EPICENTER LOCATIONS. THE COMBINED DATA SET, THOUGH SPARSE AND ROUGHLY DEFINED, IS CONSISTENT WITH A COMMERCIAL GEOTHERMAL OCCURRANCE ON THE CALISTOGA PROSPECT.

INTRODUCTION

In late October and early September 1974, Amax, Inc. had Senterion Services of Tulsa, Oklahoma run a 70 sq mi (180km^2) seismic noise survey near and north of the town of Calistoga, Napa and Sonoma Counties California (see location and index map, Figure 1 and 2). During this survey, 40 microearthquakes were recorded. These events have been interpreted and located by Microgeophysics Corporation.

The purpose of this interpretation is to locate discrete seismic events (microearthquakes) and thereby map tectonially active structures. Recurrent active tectonic processes are believed to be a necessary ingredient to a commercial geothermal occurrence (Lange and Westphal, 1969; Ward and Bjornson, 1971; Ward and Jacob, 1971; Hamilton and Muffler, 1972; Ward, 1972).

The next section contains the observations and results followed by an interpretation of the results; conclusions and recommendations are listed in the last section of the body of the report. The appendix contains a listing of the coordinates of the recorded events.

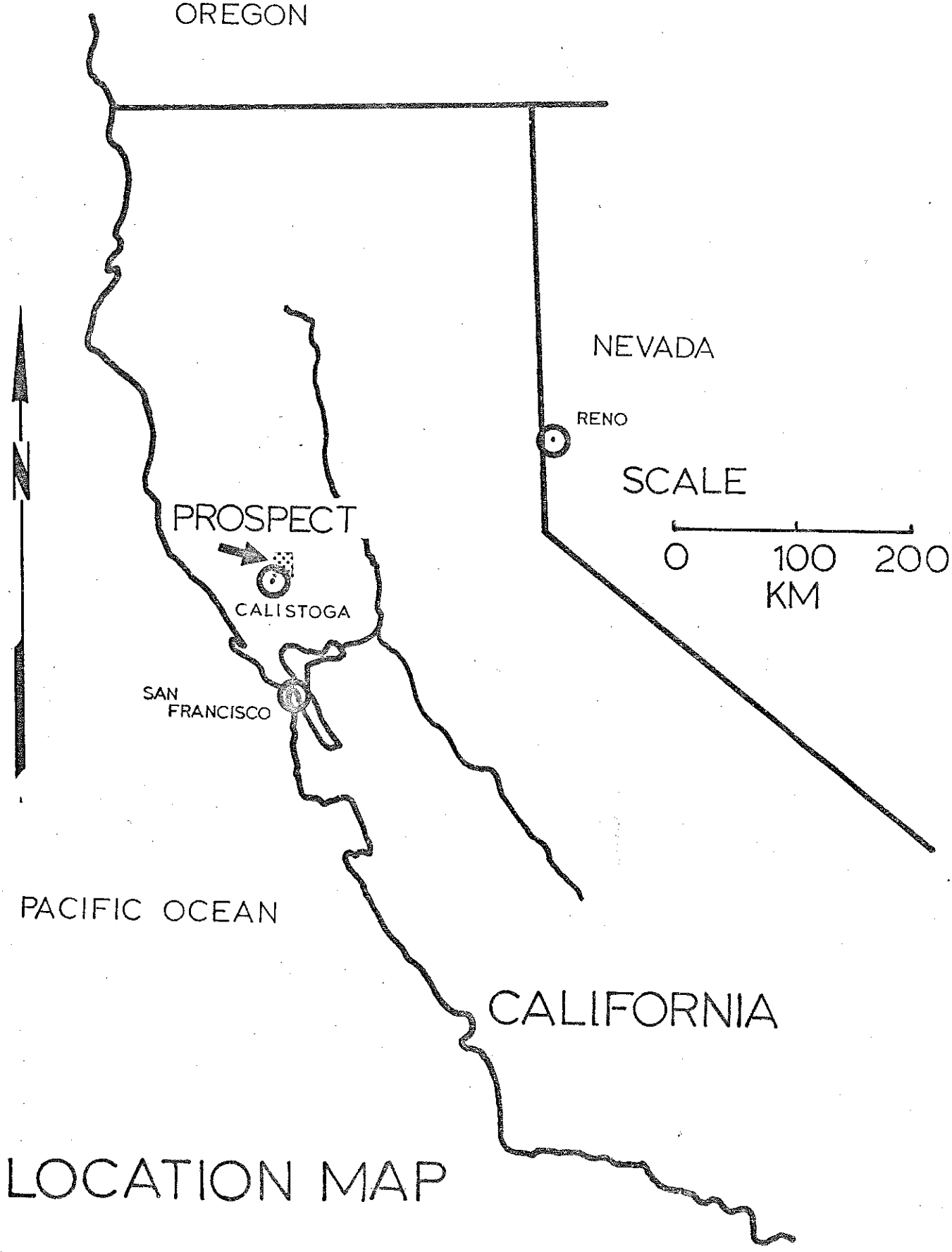

OREGON
NEVADA
RENO
N
SCALE
0 100 200
KM
PROSPECT
CALISTOGA
SAN
FRANCISCO
PACIFIC OCEAN
CALIFORNIA
LOCATION MAP

Figure 1

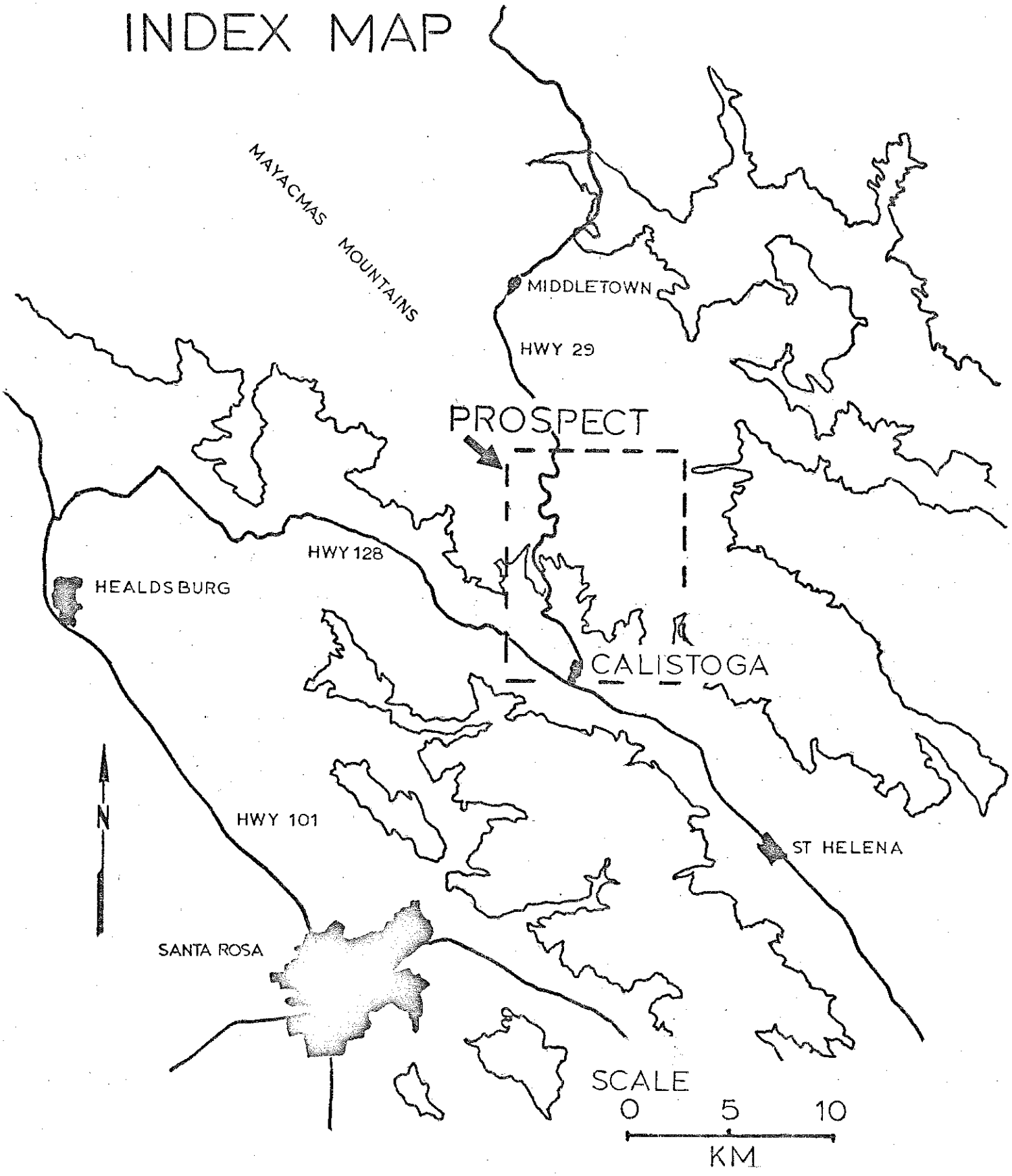

INDEX MAP
MAYACMAS MOUNTAINS
MIDDLETOWN
HWY 29
PROSPECT
HWY 128
HEALDSBURG
CALISTOGA
N
HWY 101
ST HELENA
SANTA ROSA
SCALE
0 5 10
KM

Figure 2

OBSERVATIONS AND RESULTS

During the microseismic noise survey, 40 microearthquakes were recorded. Figure 3 shows the time of occurrence of these events. As Figure 3 shows, none of the events occurred during local working hours. This is due to the fact that a noise array is moved to another location and not operational during most of the working hours. Because the events occurred during time periods presumed to include minimal cultural noise influences, these events are probably natural microearthquakes, i.e., they are not mine or construction explosions.

A total of 7 distinct arrays detected microearthquakes. These 7 arrays are shown in Figure 4 through 10. Each array is shown with respect to the town of Calistoga, California. Figure 11 is a detailed operation schedule and Table 1 is a listing of the station coordinates. As Figure 4 through 10 show, these arrays were designed for a noise survey and not for optimum microearthquake locations. The apertures (distance across the array) are of the order of a few kilometers, indicating that the azimuth of arrival of a microearthquake will be well determined while the distance control will be poor. Given these array geometries, an estimate of the location precision can be made. At distances up to 2 apertures, the location precision is $\pm$2km in plan and $\pm$3km in depth, with the location precision decreasing to $\pm$5km in plan at 5 apertures. Of course, the accuracy is a function of the velocity model used to locate the microearthquakes.

The velocity model used for this interpretation is a linear velocity increase with depth model which is an approximation of

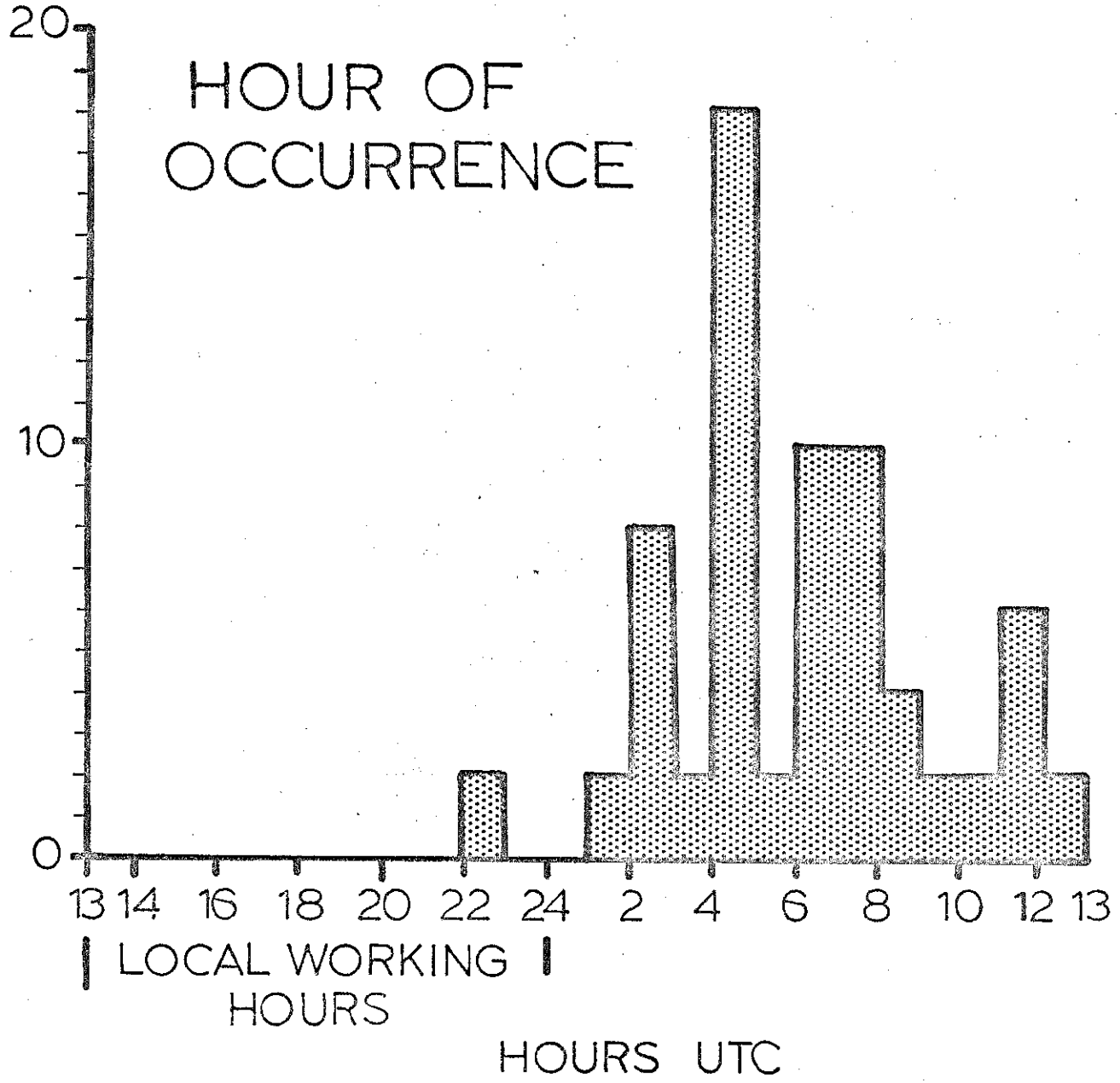

20
10
0
HOUR OF
OCCURRENCE
13 14 16 18 20 22 24 2 4 6 8 10 12 13
LOCAL WORKING
HOURS
HOURS UTC

Figure 3

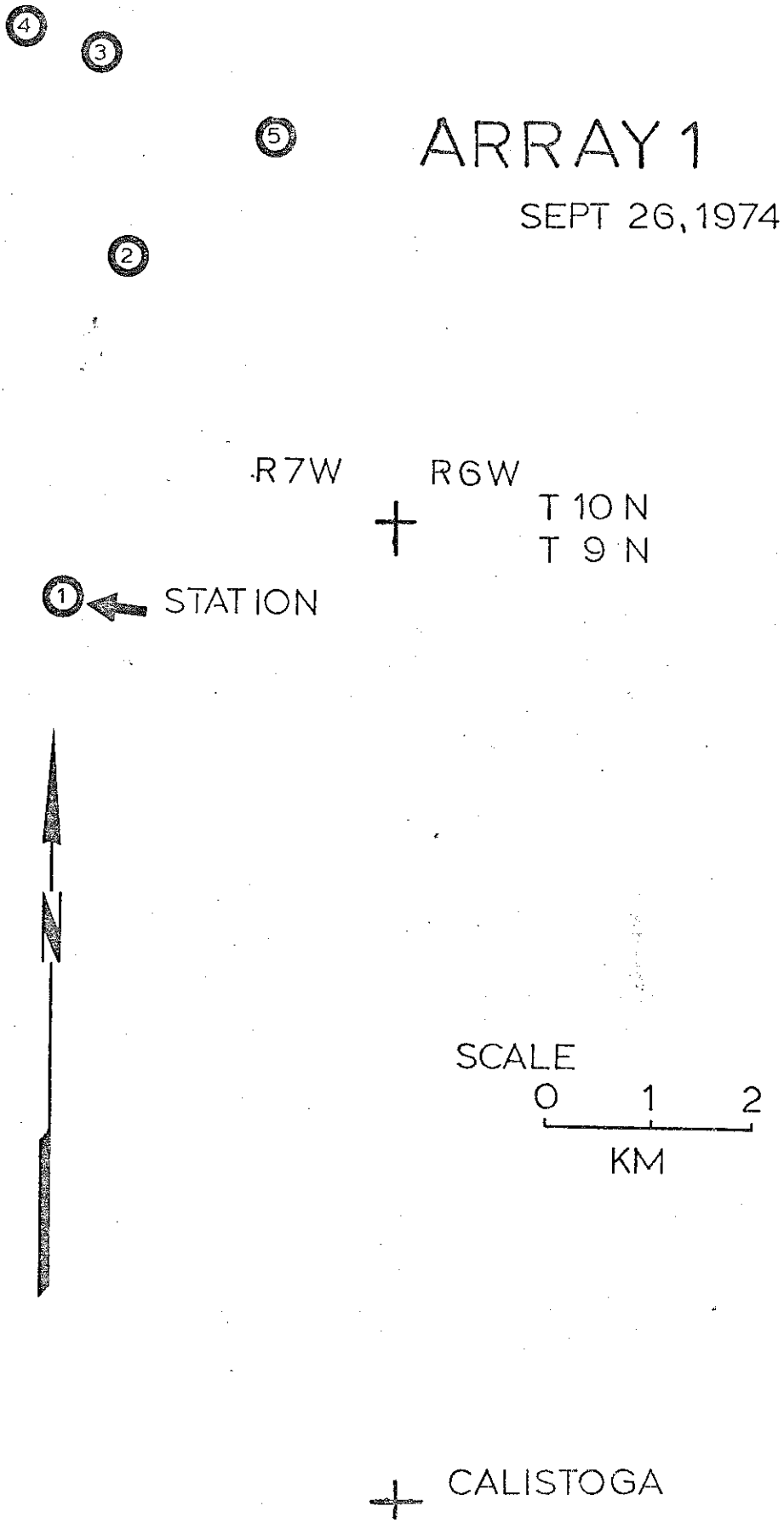

4
3
5
2
ARRAY 1
SEPT 26, 1974
R7W
R6W
T 10 N
T 9 N
1
STATION
N
SCALE
0 1 2
KM
CALISTOGA

Figure 4

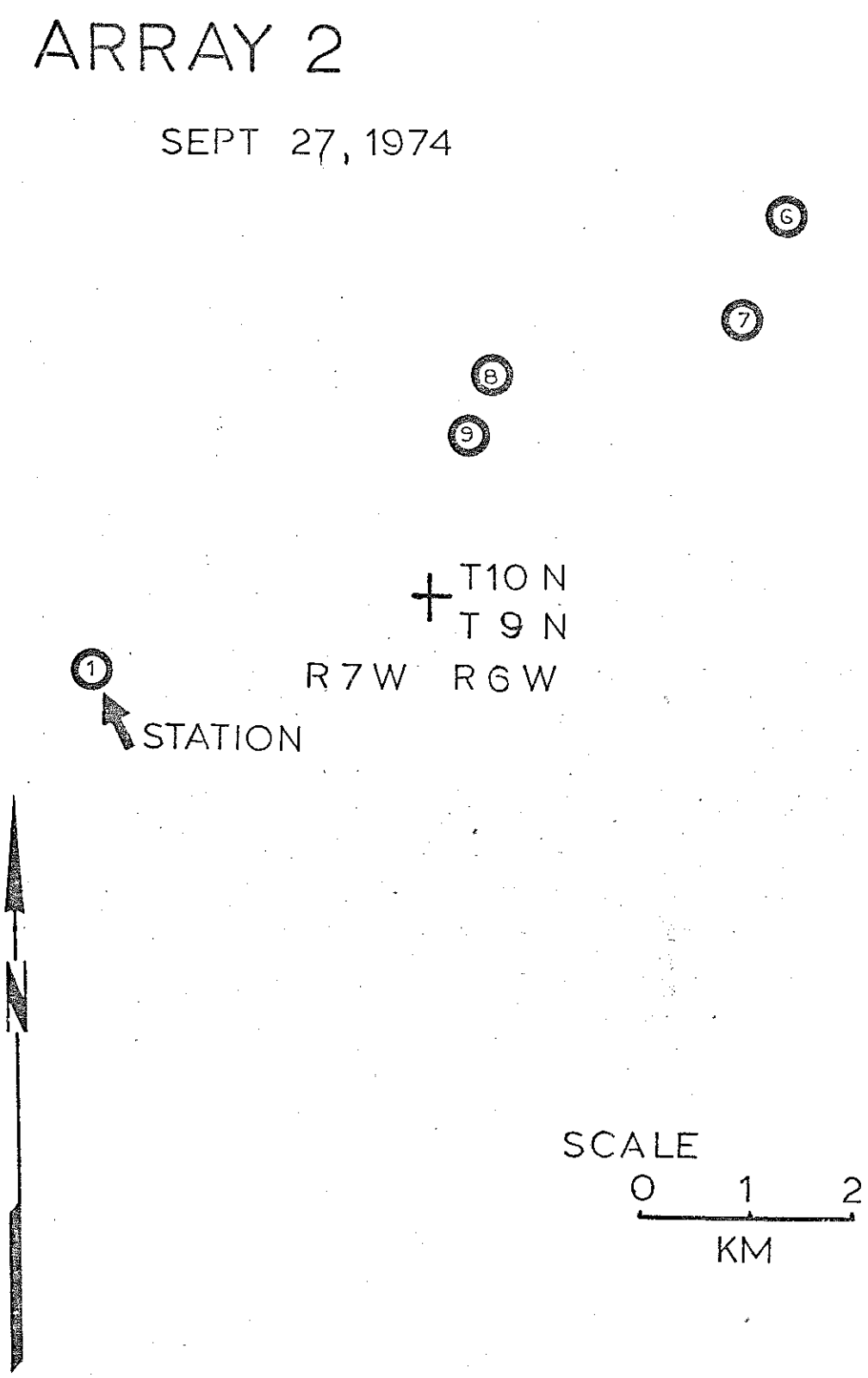

ARRAY 2
SEPT 27, 1974
6
7
8
9
T10 N
T 9 N
R 7W R 6W
1
STATION
N
SCALE
0 1 2
KM
CALISTOGA

Figure 5

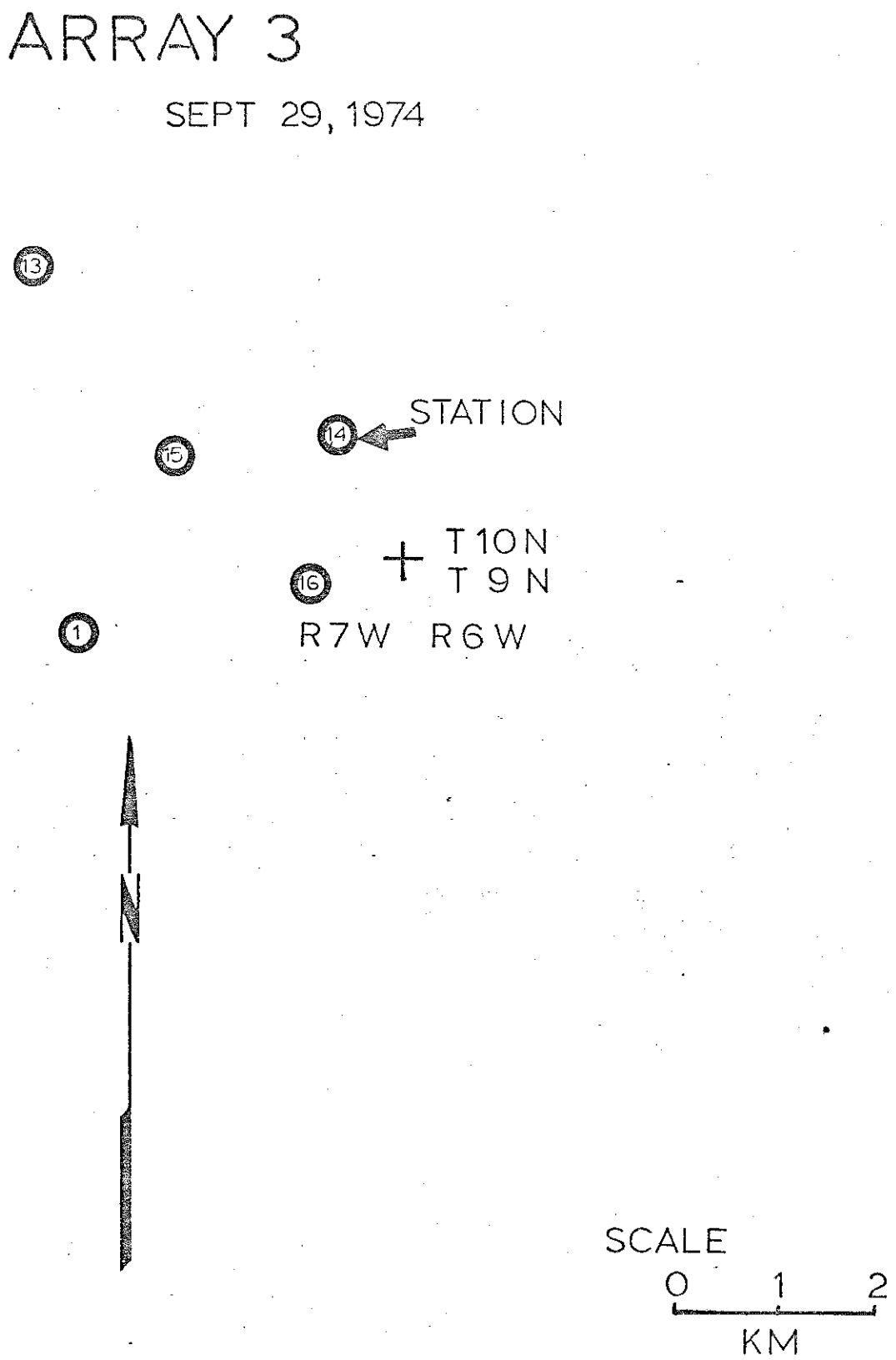

ARRAY 3
SEPT 29, 1974
13
STATION
14
15
T10N
T 9 N
16
1
R7W R6W
N
SCALE
0 1 2
KM
CALISTOGA

Figure 6

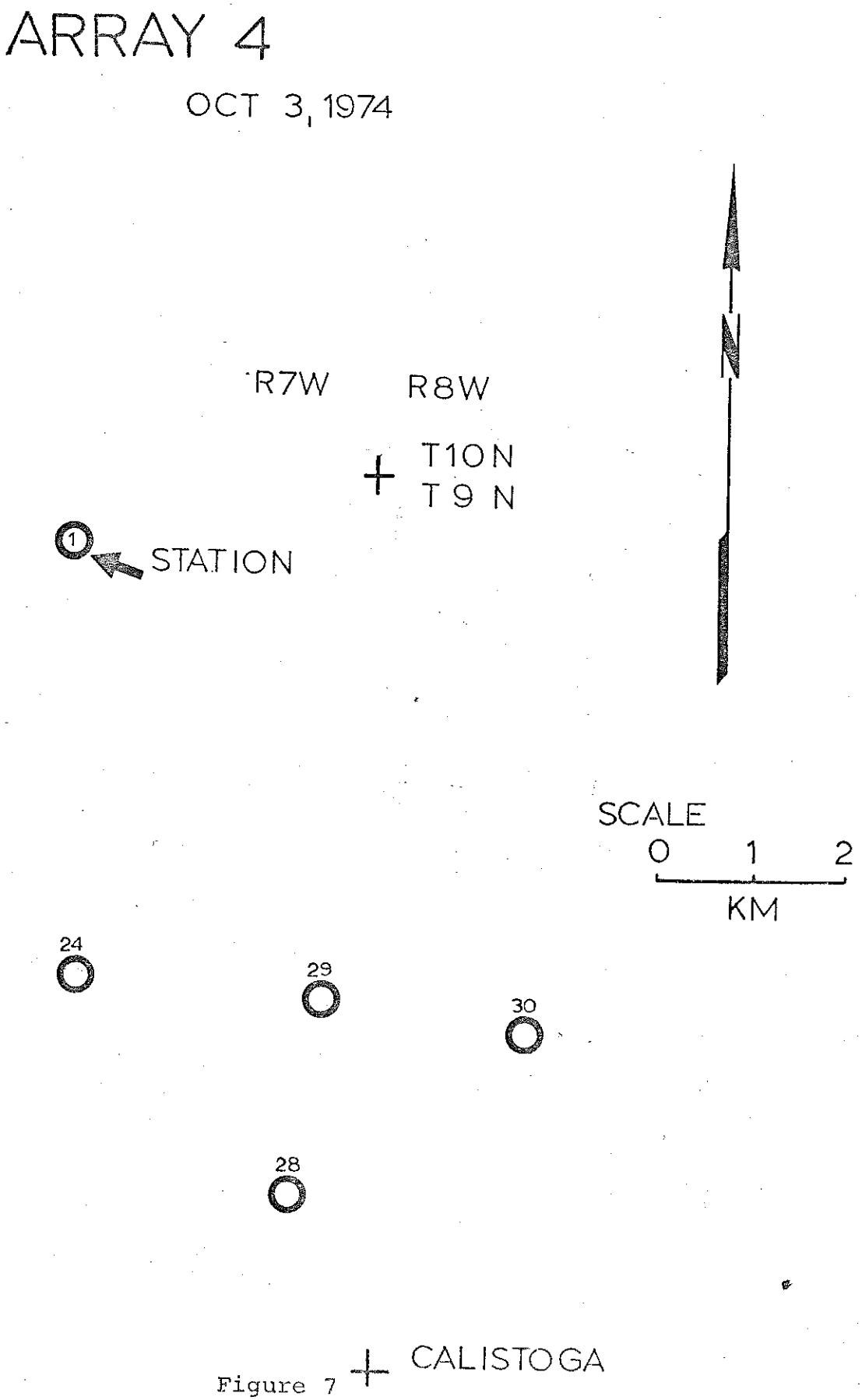

ARRAY 4
OCT 3, 1974
R7W
R8W
T10N
T9N
1
STATION
N
SCALE
0 1 2
KM
24
29
30
28
CALISTOGA

Figure 7

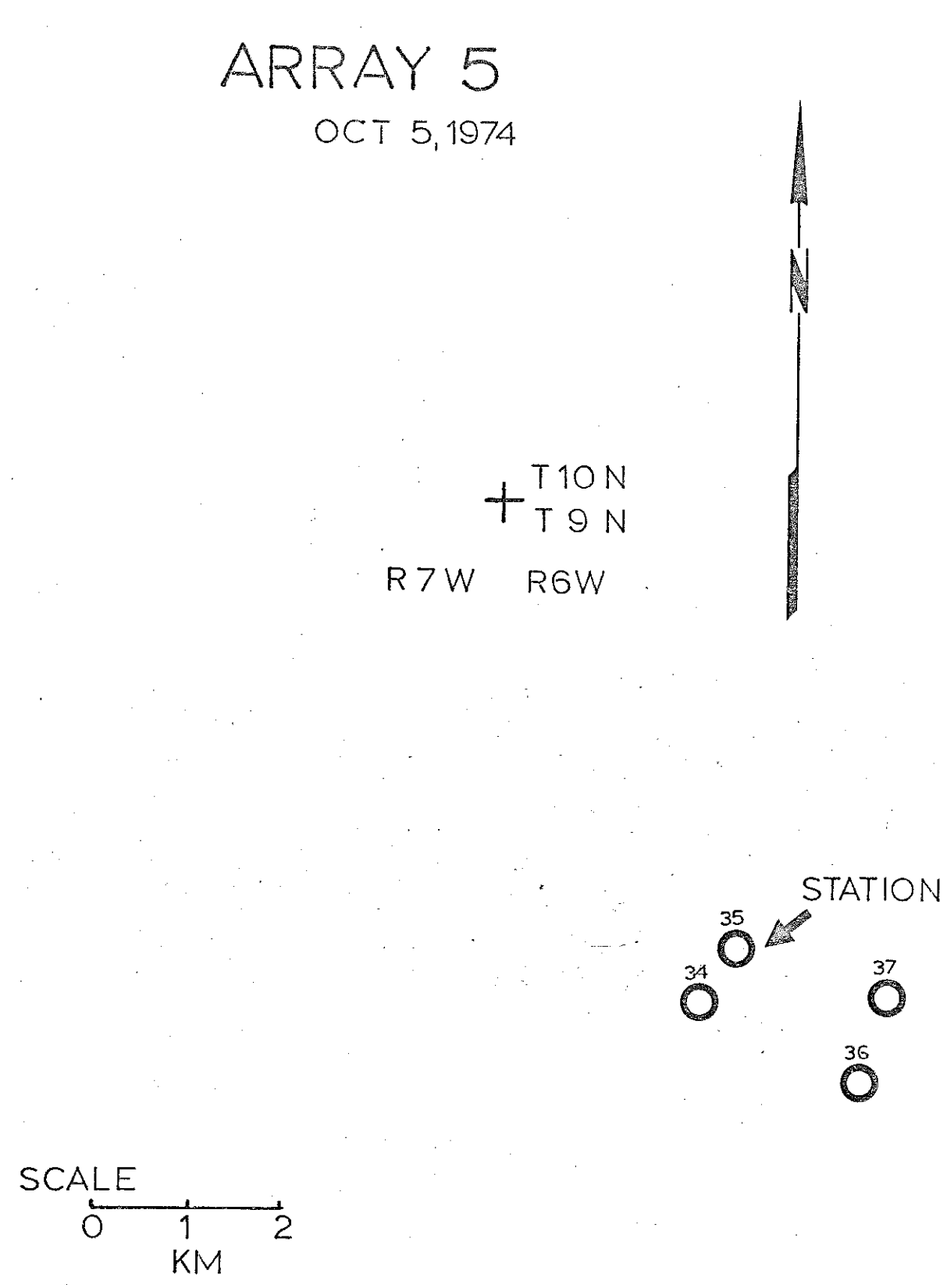

ARRAY 5
OCT 5, 1974
N
T 10 N
T 9 N
R 7 W
R 6 W
STATION
35
34
37
36
SCALE
0
1
2
KM
CALISTOGA

Figure 8

ARRAY 6

OCT 8, 1974

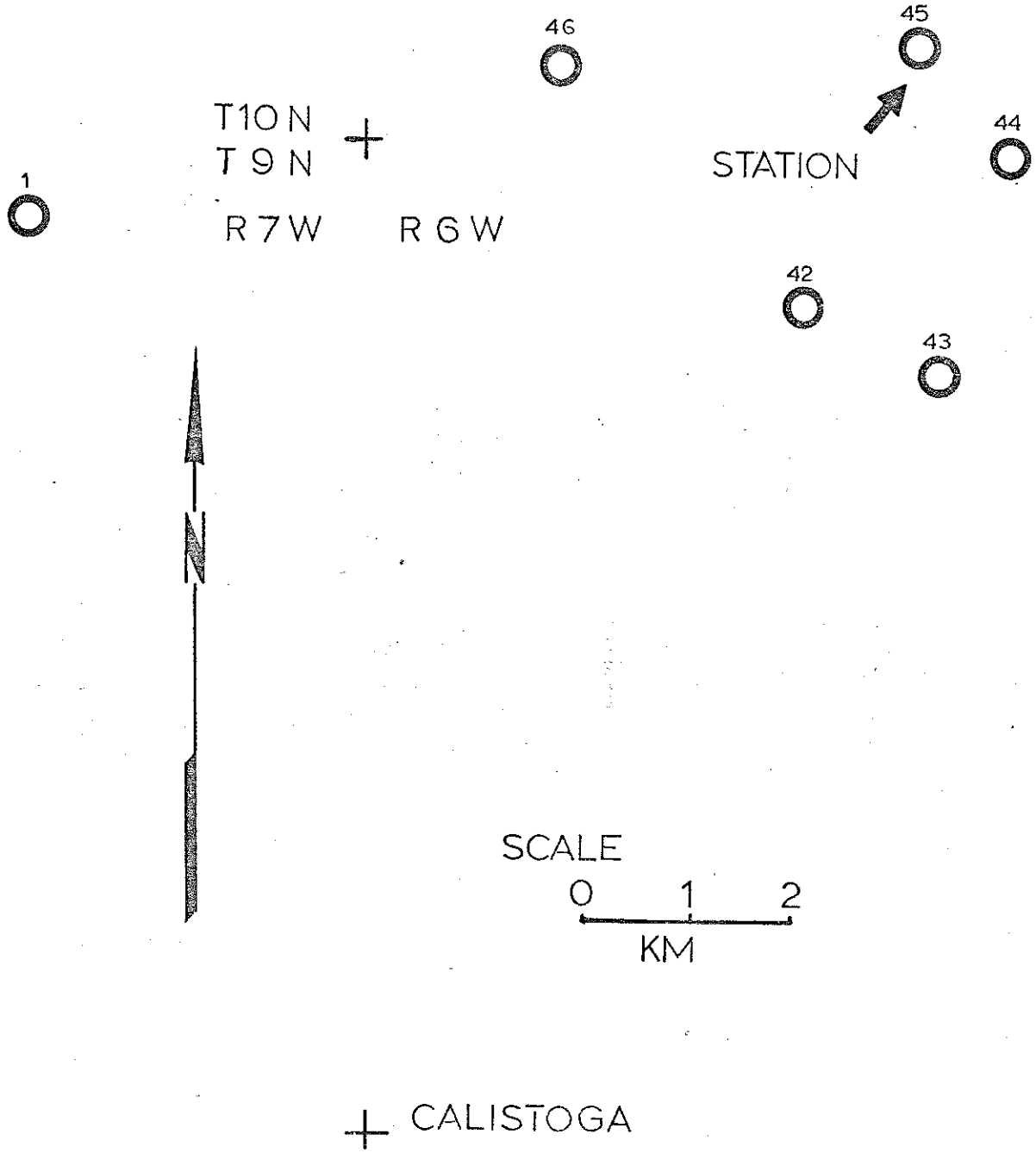
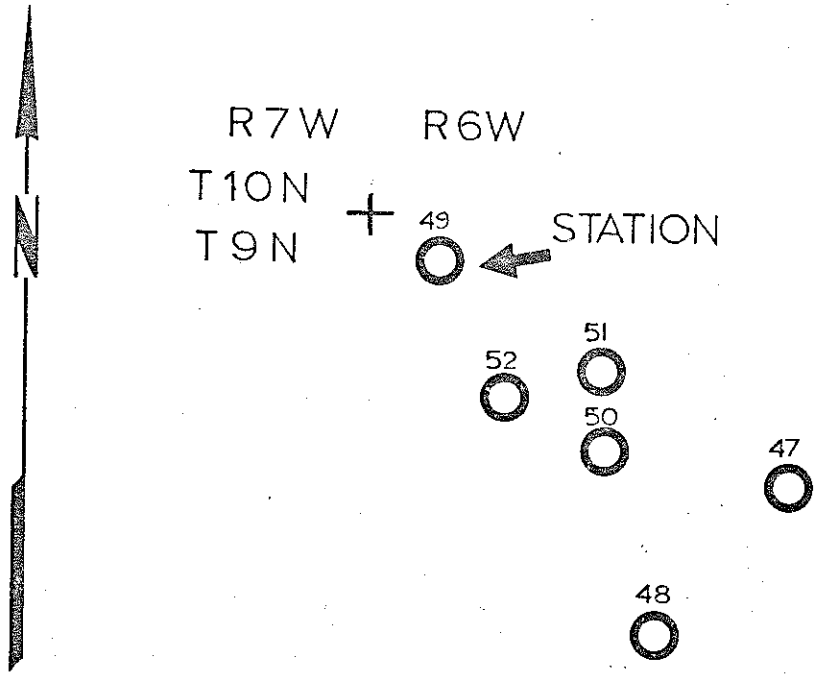


Figure 9

ARRAY 7

OCT 9 1974



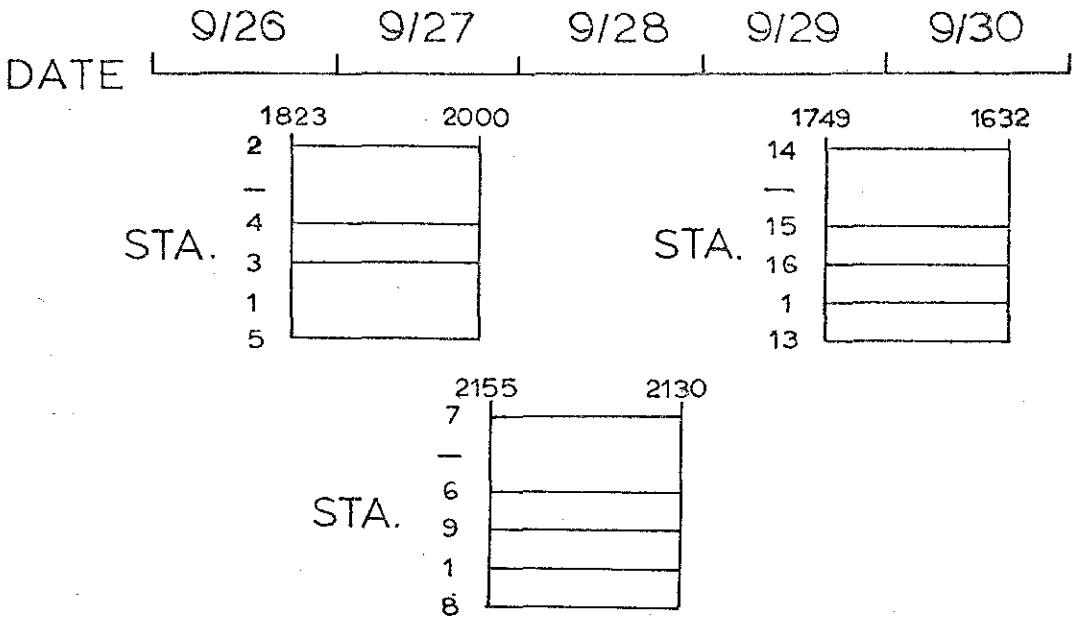
SCALE 0 1 2

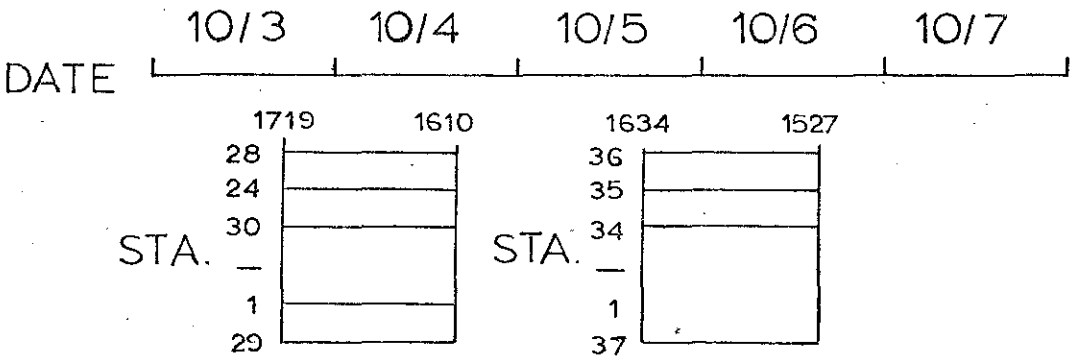
KM

CALISTOGA

Figure 10

OPERATION SCHEDULE





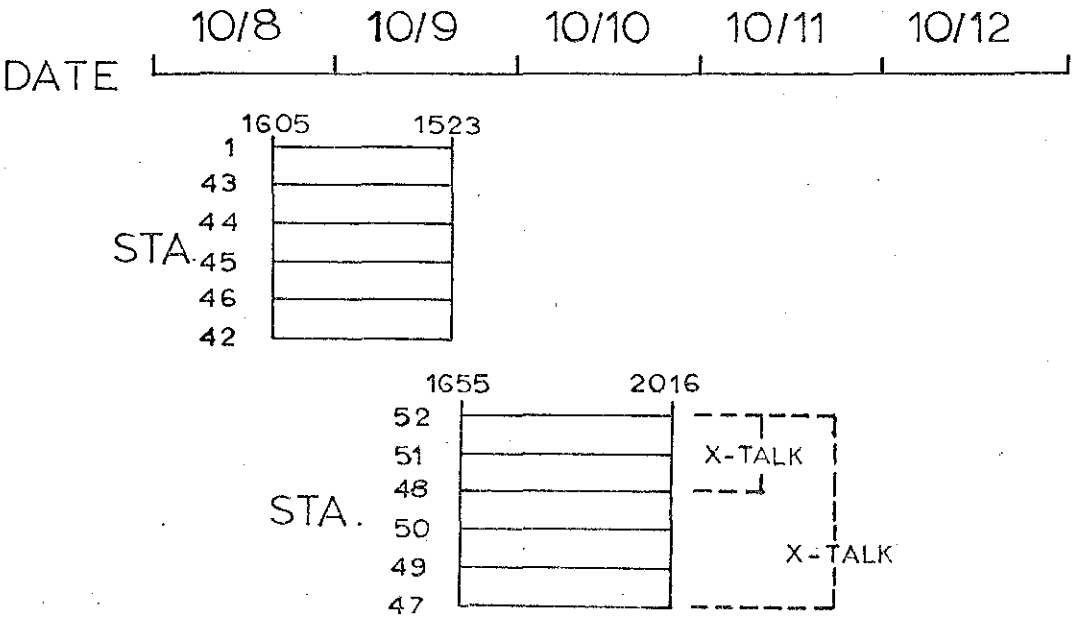


Figure 11

TABLE 1

STATION COORDINATES

Station	X(km)	Y(km)	Z*(km)
1	6.40	8.88	1.12
2	7.00	12.16	.51
3	6.72	14.08	.296
4	6.00	14.40	.39
5	8.40	13.31	.39
6	12.96	13.28	.51
7	12.60	12.24	.51
8	10.16	11.71	.63
9	9.92	11.12	.54
13	5.92	12.48	.45
14	8.96	10.80	.39
15	7.32	10.56	.51
16	8.64	9.31	.51
24	6.48	4.32	.083
28	8.72	2.00	.022
29	9.04	4.08	.112
30	11.20	3.68	.39
34	11.68	4.32	.51
35	12.08	4.88	.63
36	13.36	3.52	.51
37	13.60	4.40	.54
42	13.76	8.08	.63
43	15.04	7.36	.51
44	15.76	9.44	.39

Station	X (km)	Y (km)	Z* (km)
45	14.88	10.48	.27
46	11.50	10.27	.66
47	12.99	7.36	.75
48	11.96	6.16	.66
49	10.16	9.20	.51
50	11.52	7.68	.66
51	11.52	8.35	.66
52	10.72	8.14	.66

* Elevation is from a datum at 100 meters above sea level.

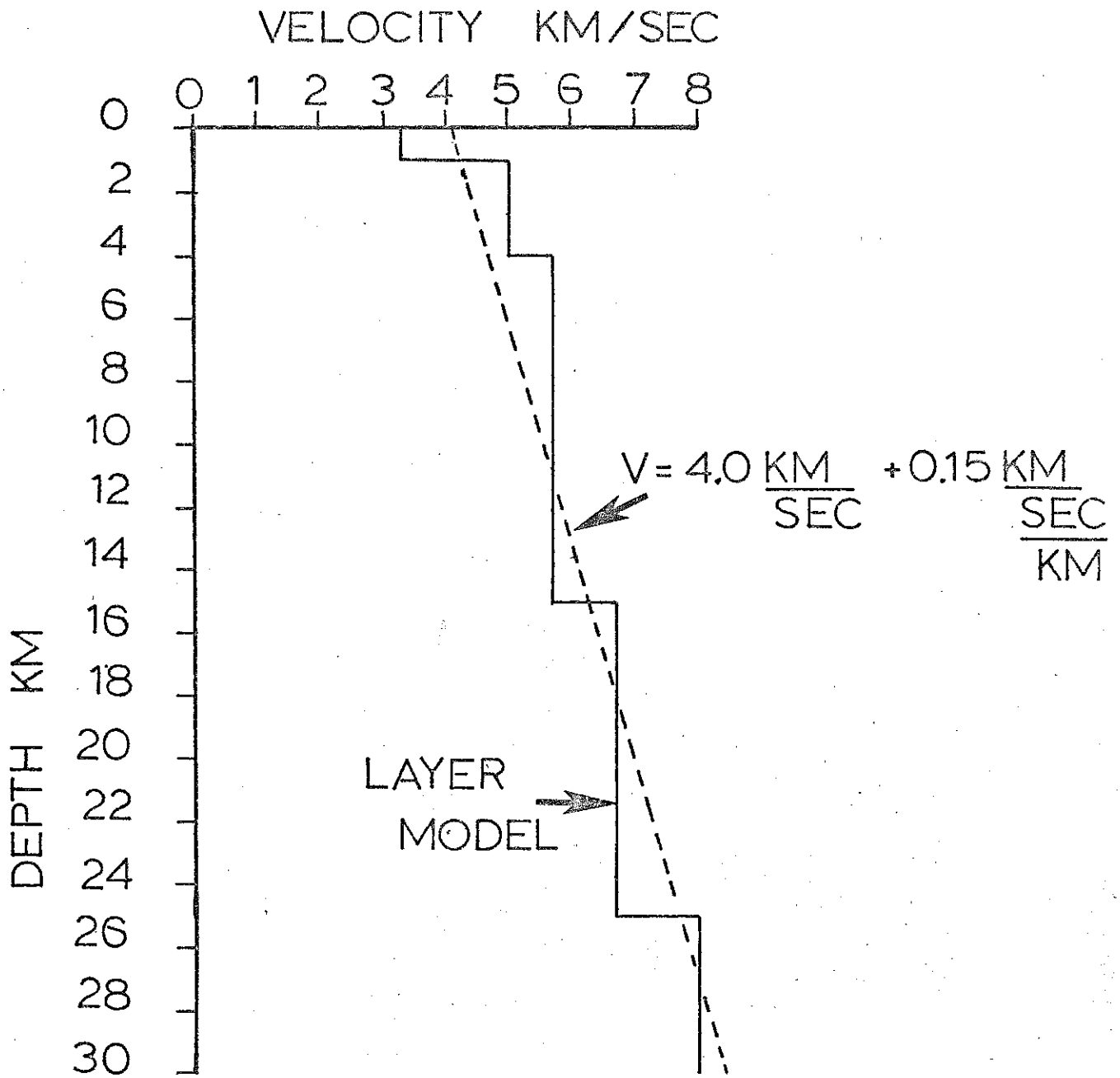
The origin of this Coordinate system is the SE corner of Sec 36 T9N, R8W, near Calistoga, California.

Positive X and Y are east and north respectively.

the layered model used by the U.S.G.S. for the 1969 SANTA ROSA EARTHQUAKES and by Hamilton and Muffler, 1972, for microseismic events near the Geysers, California. Both models are illustrated in Figure 12.

Of the 40 events detected, 29 events were locatable. The epicentral plot of these events are shown in Figure 13. Depths of the microseismic events are shown near the epicenters. Two main groups of epicenters are apparent, one large swarm group 25km to the northeast of Calistoga, and the second group around and north of Calistoga. The swarm group occurred on October 10. Since the majority of events detected are from this group, an example of their signature is shown in Figure 14. The signature and P-S time shown in Figure 14 is consistant with distant microearthquakes. Since these are outside the immediate area of interest, they will not be considered further.

The group of epicenters of interest are the epicenters that occurred near and north of Calistoga, California. An overlay map of these epicenters is contained in the cover leaf of this report. These local events showed a complicated signature with no recognizable or pickable S phase. Due to the size and distribution of the arrays that detected these local events, the first motion study is inconclusive. Therefore no fault plane solution can be made.



MODEL

Figure 12

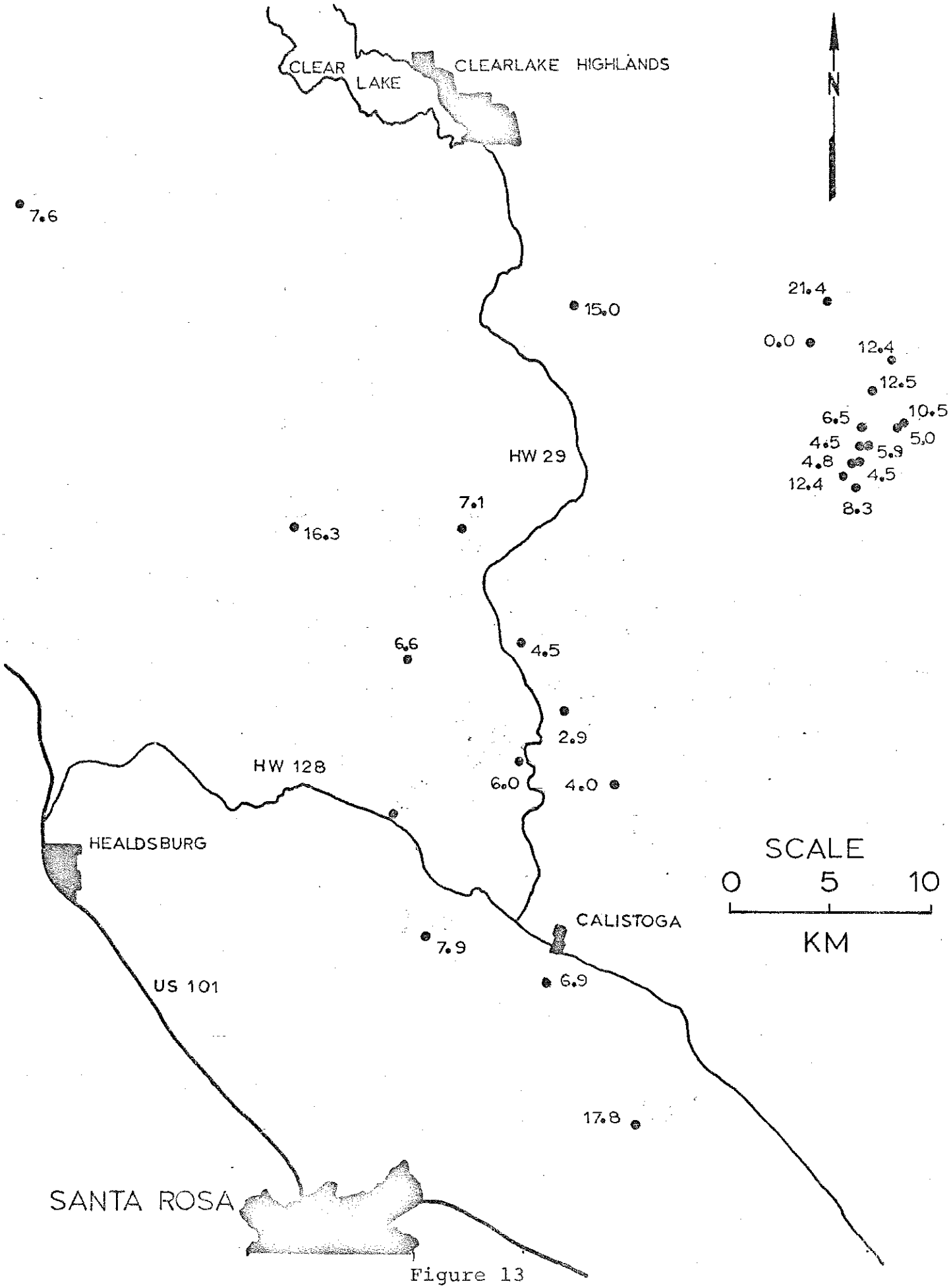

CLEAR LAKE
CLEARLAKE HIGHLANDS
N
7.6
15.0
21.4
0.0
12.4
12.5
6.5
10.5
4.5
5.0
4.8
5.9
12.4
4.5
8.3
HW 29
7.1
16.3
6.6
4.5
2.9
HW 128
6.0
4.0
HEALDSBURG
SCALE
0 5 10
KM
CALISTOGA
7.9
6.9
US 101
17.8
SANTA ROSA

Figure 13

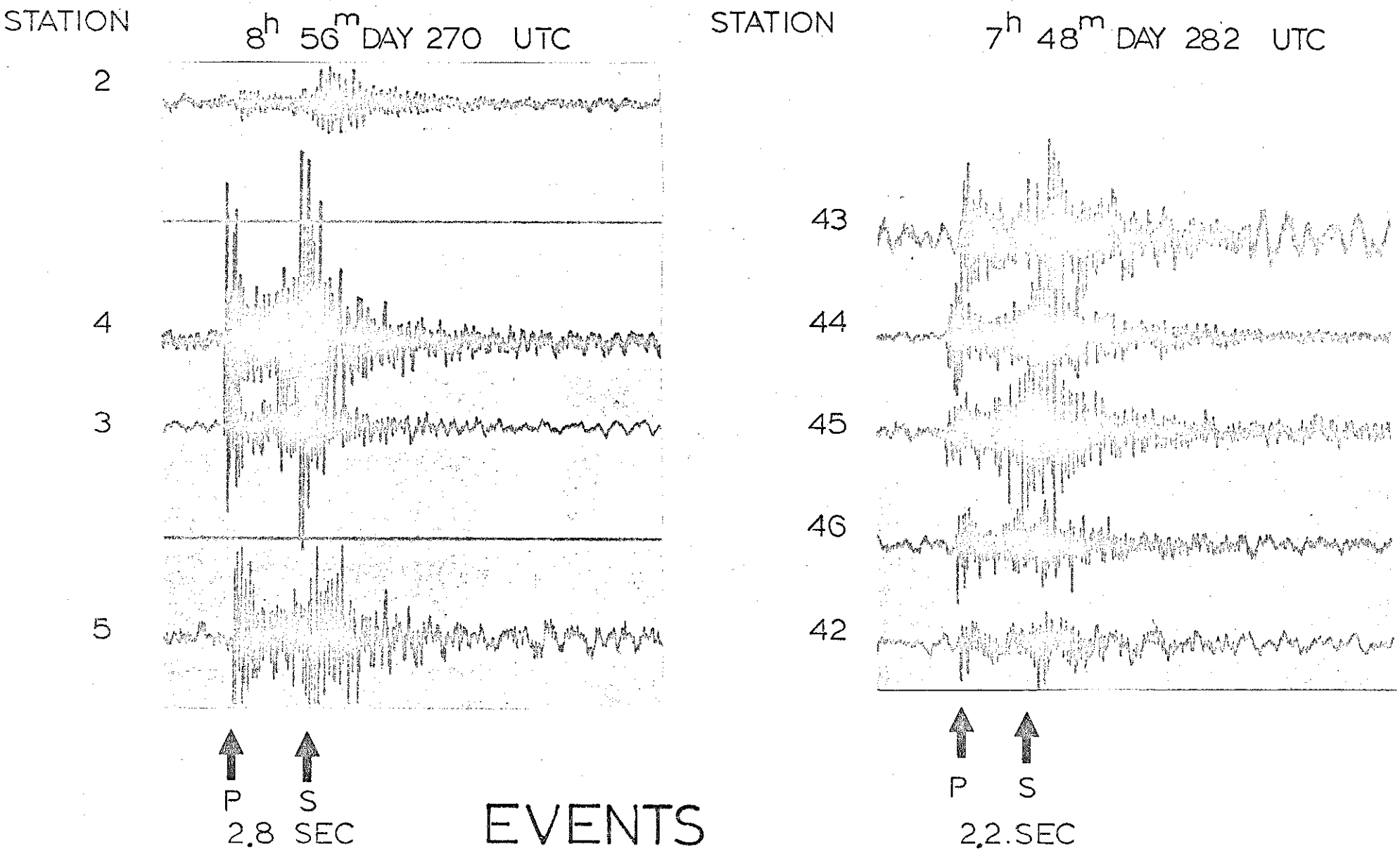

STATION
8h 56m DAY 270 UTC
2
4
3
5
P
S
2.8 SEC
EVENTS
STATION
7h 48m DAY 282 UTC
43
44
45
46
42
P
S
2.2 SEC

Figure 14

INTERPRETATION

Since only 11 seismic events were located near the prospect, no clear seismic structures can be delineated. However, the epicenters suggest tectonically active trends NNW through the prospect. Because no conclusive first motion or fault plane solution can be made for the events recorded, either strike slip or thrusting (both of which are consistant with the regional geology) could exhibit the observed trends.

Figure 15 is an interpretation assuming a set of steep dipping faults (such as a strike-slip) which strike NNW with a intersection of fault zones directly NE of Calistoga. This figure also contains additional information supplied by Amax, Inc. on microearthquake locations.

The arrays used during this survey were designed primarily to record ground noise, their geometry and small size precludes any attempt to study the velocity ratio's of the microearthquakes, the first motion for fault plane solution, or the magnitude for seismicity comparison. Without this information the interpretation is severely limited, however, the location and suggested trends of the epicenters is not inconsistant with a commercial geothermal occurrance.

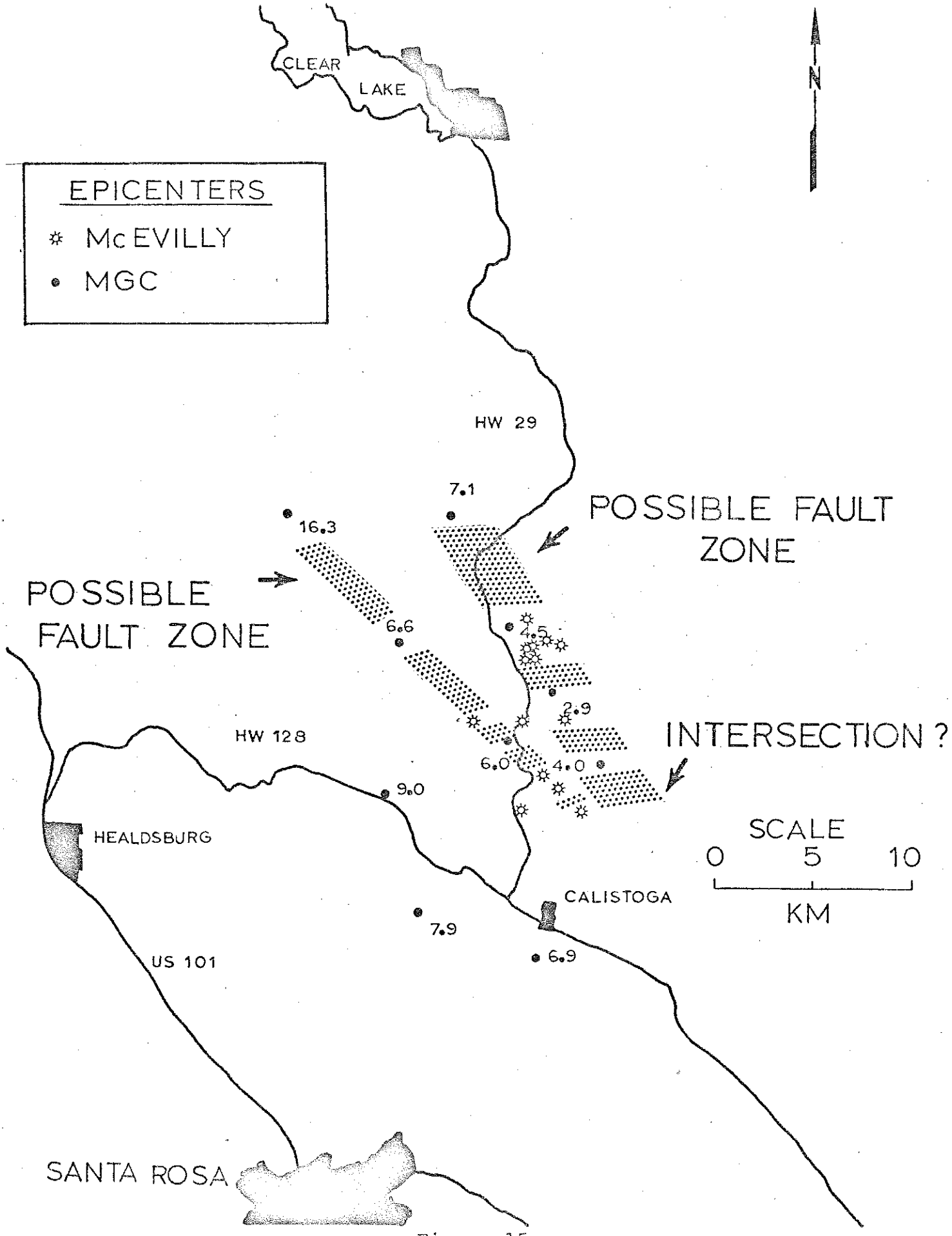

CLEAR
LAKE
N
EPICENTERS
McEVILLY
MGC
HW 29
7.1
16.3
POSSIBLE FAULT ZONE
POSSIBLE FAULT ZONE
6.6
4.5
2.9
HW 128
INTERSECTION ?
6.0
4.0
9.0
HEALDSBURG
SCALE
0 5 10
KM
CALISTOGA
7.9
6.9
US 101
SANTA ROSA

Figure 15

CONCLUSIONS

1. 11 Microseismic events recorded in September and October, 1974 are located on or near the Calistoga prospect, Napa and Sonoma Counties, California. This seismicity is consistant with a commercial geothermal occurrance on the prospect.

2. Due to active faults in the area, a seismic threat is present for any significant structure constructed in the area, though a careful engineering analysis would be necessary to establish the significance of the threat.

RECOMMENDATIONS

1. A careful geologic investigation of this area to establish the connection between the mapped fault zones and other geologic data is a high priority item. If the geologic data is favorable with respect to the existance of probable heat sources and reservoir rocks, additional detailed geophysical investigations should be undertaken. Secondly, the areas of fault zone intersection if established should be scrutinized, with the second priority the fault zones themselves or other areas indicated on the basis of geologic interpretation.

2. Construction of a commercial geothermal plant should comply with adequate building codes and be accompanied by careful monitoring of the seismic effects of fluid injection and withdrawal.

APPENDIX - EVENT LOCATION

EVENT	JULIAN DATE	G.M.T. TIME	X	Y	Z*	NUMBER STATIONS UP	NUMBER PICKS
1	270	0520	21.6	30.1	0.0	4	4
2	270	0535	1.0	6.8	9.0	4	4
3	270	0712	24.8	28.0	12.5	4	4
4	270	0820	NO LOCATION --------			4	3
5	270	0856	-13.9	58.7	4.8	4	4
7	271	0931	10	32.2	15.0	5	5
8	271	1238	- 4.2	20.8	16.3	5	5
9	273	0200	1.8	14.5	6.6	5	5
10	273	1041	- 1.6	-40.5	40.2	5	5
11	273	1137	4.2	20.9	7.1	5	4
12	273	1142	NO LOCATION --------			5	3
13	277	0208	2.6	0.4	7.9	5	5
14	277	?	8.6	- 1.6	6.9	4	4
15	279	0402	NO LOCATION --------			3	3
16	279	0441	13.1	- 8.6	17.8	4	4
17	282	0442	7.5	15.2	4.5	5	5
18	281	2218	45.3	28.9	0.0	4	4
19	282	0342	NO LOCATION --------			5	5
20	282	0234	22.6	32.5	21.4	5	5
23	282	0737	26.2	26.2	10.5	5	5
24	282	0442	NO LOCATION --------			5	3
25	282	0443	9.5	11.8	2.9	6	6
27	282	0451	-18.0	36.7	7.6	6	6
28	282	0451	7.5	9.3	6.0	6	5
29	282	0456	NO LOCATION --------			6	5
30	282	0428	25.6	29.4	12.4	6	6

EVENT	JULIAN DATE	G.M.T. TIME	X	Y	Z*	NUMBER STATIONS UP	NUMBER PICKS
31	282	0628	23.3	23.6	12.4	6	6
33	282	0630	24.2	25.0	5.9	6	5
34	282	0637	24.1	25.5	4.5	6	5
35	282	0637	24.1	26.2	6.5	6	5
36	282	0637	23.9	24.4	4.5	6	5
37	282	0731	26.0	26.4	5.0	6	5
39	282	0737	23.9	23.2	8.3	6	5
40	282	0748	23.7	24.2	4.8	6	5
42	282	0957	NO LOCATION --------			6	3
43	---	----	NO LOCATION --------			6	0
44	---	----	NO LOCATION --------			6	3
45	283	0156	12.0	8.3	4.0	6	4
46	283	0238	NO LOCATION --------			6	6
47	283	1118	NO LOCATION --------			6	4

* Elevation is from a datum at 100 meters above sea level.

The origin of this Coordinate system is the SE corner of Sec 36 T9N, R8W, near Calistoga, California.

Positive X and Y are east and north respectively.

REFERENCES

Brune, J.N., and Allen, C.R., 1967, A Microearthquake Survey of the San Andreas Fault System in Southern California; BSSA, vol.57,no.2,p.277-296.

Bolt, B.R., and Miller, R.D., 1971, Seismicity of Northern and Central California, 1965-1969; BSSA, vol.61,no.6,p.1831-1848.

Cloud, W.K., Hill, D.M., et.al., 1970, The Santa Rosa Earthquakes of October, 1969; California Division of Mines and Geology Mineral Information Service, vol.23,p.43-63.

Hamilton, R.M., and Muffler, L.J.P., 1972, Microearthquakes at the Geysers Geothermal Area, California: JGR, vol.77,p.2081-2086.

Lange, A.L., and Westphal, W.H., 1969, Microearthquakes near the Geysers, Sonoma County, California: JGR, vol.77,p.2081-2086.

Sanford, A.R., Singh, S., 1968, Microearthquake Activity. Minimum Recording Time for Determining Short-term Seismicity Forms, BSSA, vol.58,no.2,pp.639-644.

Ward, P.L., 1972, Microearthquakes: Prospecting Tool and Possible Hazard in the Development of Geothermal Resources: Geothermics, vol.1,no.1,p.3-12.

Ward, P.L., and Jacob, R.H., 1971, Microearthquakes in the Ahuachopan Geothermal Field, El Salvador, Central America: Science, vol.173,p.328-330.

16.3

7.1

6.6

4.5

2.9

6.0

4.0

9.0

N

7.9

CALISTOGA

6.9

LEGEND

EPICENTER DEPTH KM 2.5

STATIONS IN FIT

4

5

6

17.8

SCALE

0 5

KM