# SOME EFFECTS OF GEOLOGICAL STRUCTURE
# ON RADIO RECEPTION

By

B. F. Howell, Jr.

Presented
in partial fulfillment of the requirements
for the Master of Science degree
at the California Institute of
Technology.

Division of Geological Sciences

1942

Frontispiece: Typical fault trace topography on the San Andreas fault southeast of Garnet.

TABLE OF CONTENTS

List of illustrations and tables. - - - - - - - iv

Abstract. - - - - - - - - - - - - - - - - - - v

1. The problem. - - - - - - - - - - - - - - - 1

2. Previous work. - - - - - - - - - - - - - - 2

3. The apparatus. - - - - - - - - - - - - - - 3

4. Procedure. - - - - - - - - - - - - - - - - 6

5. Recording of observations. - - - - - - - - 9

6. Some precautions in making observations. - 11

7. Location and geologic setting of the surveys. - - - - - - - - - - - - - - - - - 13

8. Theory. - - - - - - - - - - - - - - - - - 16

9. Results of the surveys. - - - - - - - - - 18

10. Conclusions. - - - - - - - - - - - - - - 36

11. Future work. - - - - - - - - - - - - - - 38

Acknowledgements. - - - - - - - - - - - - - 39

Bibliography. - - - - - - - - - - - - - - - 40

List of illustrations:

Frontispiece. Typical fault trace topography on the San Andreas Fault southeast of Garnet. - - - - - - - - - - - - - - - ii

Figure 1. Wiring diagram of the portable directional range finder. - - - - - - 4

2. Photograph of the directional range finder. - - - - - - - - - - - - - - - - - 5

3. Wiring diagram of the field strength meter. - - - - - - - - - - - - - - - - - - 6

4. Map showing the areas studied. - - - 12

5. Map of the San Jacinto Valley showing location of the traverses. - - - - - - 14

6. San Jacinto Valley curves J4, J5, J6, J7, J8, J14, J15, J16. - - - - - - - - 21

7. San Jacinto Valley curves J1, J9, J10. - - - - - - - - - - - - - - - - - - - 22

8. Indio-Garnet area curves T13F, T14F, T18F, T22F, T23F. - - - - - - - - - - 24

9. Imperial Valley curves I1, I2, I10.- 26

10. Map of the San Bernardino area showing the roads surveyed and weak spots. - - - - - - - - - - - - - - 28

11. Map of the New Jersey area showing weak spots, geology, and the roads surveyed. - - - - - - - - - - - - - - - 32

12. New Jersey survey curves T5N, T6N, T7N, T8N. - - - - - - - - - - - - - - - 34

List of tables:

Table 1. Radio stations whose broadcast signals were used in this survey. - - 7

2. Samples of data sheets to show methods used to record data. - - - - 10

3. Frequencies of variation of the horizontal angle of the radio fields in the San Jacinto Valley. - - - - - - 20

ABSTRACT.

Radio fields at standard broadcast frequencies were examined over faults to determine how the geologic conditions affected the fields. The fields in rugged and densely inhabited areas were found to be too irregular to yield understandable patterns. Very small variations in the direction of the field were suggested but not proven over the San Jacinto Fault in the San Jacinto Valley. No variations in intensity were found over the San Andreas Fault east of Palm Springs, but variations were observed at some places over the Piedmont Fault in New Jersey. Such variations might be due to the higher conductivity of the fault plane, or to the addition of waves reflected and refracted by the fault surface. Weak areas near San Bernardino were noted, but could not be correlated with faults. Further studies, especially directional, with more delicate apparatus than used in this survey are needed.

# SOME EFFECTS OF GEOLOGIC STRUCTURE ON RADIO RECEPTION.

## 1. The problem:

The existance of areas where radio signals are received relatively weakly or not at all has been well known for a long time. Anyone who has listened to a car radio while traveling will have noticed that the radio went "dead" when passing under a railway overpass or through a tunnel, And he will recall the static caused by nearby power lines. Any form of metallic shielding, and in many cases buildings, or rises in ground such as road cuts, hills, or mountains strikingly cut down the signals received in their "shadow". Besides these obvious cases of shielding, there appear to be other less well understood causes of "weak spots" of radio reception. (The term "dead spots" has been commonly used to describe areas of especially poor reception, but the author feels that "weak spots" is a more accurate description.) It has been suggested that certain geologic structures, notably contacts between rocks of different compositions, especially fault contacts, might have some influence on the strength of radio waves[1]. Relatively little work has been done on this problem; and what has been done has not, in most cases, been published. The result is that no clear explanation of the relationship between geologic structures and radio weak spots has been made known.

The problem undertaken was to examine certain geologic structures to ascertain if there were any irregularities in the radio field near these structures and not the result of non-geologic influences; and to examine any known, available weak spots, apparently due to geologic structures, in order to determine, if possible, exactly what the effect of the geologic structure was.

The value of a survey of this sort arises from the possibility of developing a simple, inexpensive, new method of locating faults and contacts, both for scientific interest, and because the location of valuable mineral and oil deposits is frequently controlled in part by these structures.

2. <u>Previous work</u>:

The most important work on this subject is that of Ernst Cloos[1]. His findings are quite specific; he discovered "dead" spots over certain faults and sedimentary contacts between the Baltimore gneiss and the Setters formation, which is composed of mica schists and gneiss and quartzites[2], and between the Setters formation and the Cokeysville marble in the region just north of Baltimore, Maryland. He did not attempt to explain the cause of the "dead" spots.

Considerable work has been done by German scientists on the transmission of radio waves in the ground; and it has been pointed out that these waves are both reflected and refracted at the contacts between bodies of different material[3].

Studies have also been made showing that the depth of penetration of radio waves into the ground is relatively small, half of their intensity being absorbed in a few tens of feet[4,5,6,7].

Besides this, the author has a number of personal communications relating to studies similar to that of Dr. Cloos. Some of these corroborated him, while others were inconclusive.

A similar method has been used by Mr. W. M. Barrett in the mid-continent and gulf-coast regions[8]. He claims, among other things, to be able to locate faults by their effects on the field of a portable broadcaster set up nearby. The chief differences between his methods and those used here are that he uses his own broadcaster, whereas this survey used commercial broadcasting stations; and Mr. Barrett measures a different component of the radio field than is measured here.

3. <u>The apparatus</u>:

The two sets of apparatus used were provided by the geological department of the California Institute of Technology, being built with application to this particular problem in mind and for use is courses in applied geophysics. The first set was a portable directional range finder (figs. 1

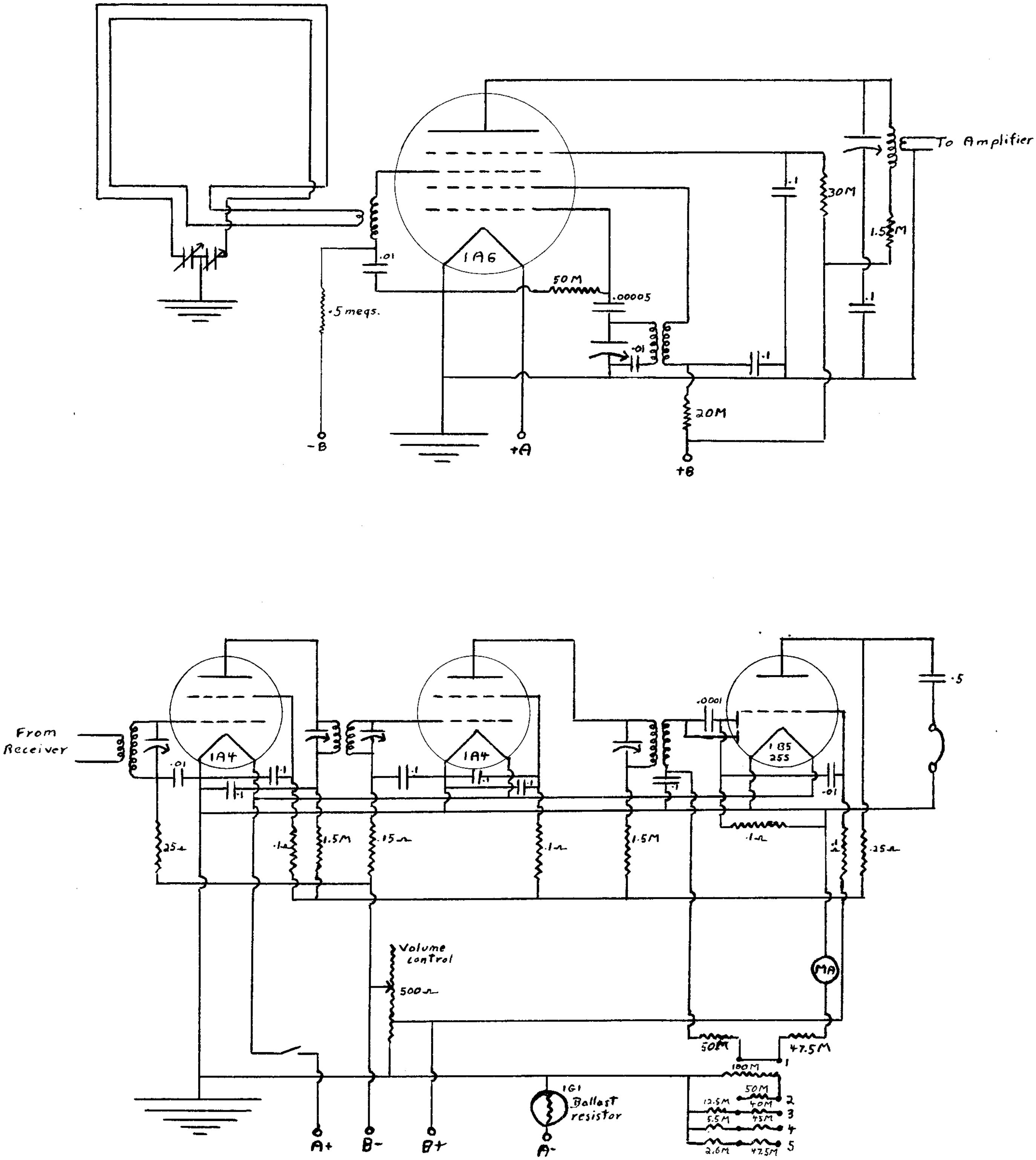



Figure 1. Wiring diagram of the portable directional range finder.

Figure 2. Photograph of the directional range finder.

and 2), consisting of a pair of loop antennae leading to a superheterodyne receiver grounded to its case and mounted on a sturdy tripod. The tripod head was rotatable about two perpendicular axes, and was equipped with an orienting compass and leveling screws to make one axis vertical. It was connected to an amplifier which, for convenience, could be hung on one leg of the tripod, and was equipped with earphones. A milliammeter in the output circuit measured the field strength.

The second set of apparatus was a portable field strength meter (fig. 3) consisting of a radio-frequency tuned receiver with three stages of amplification including the detector tube.

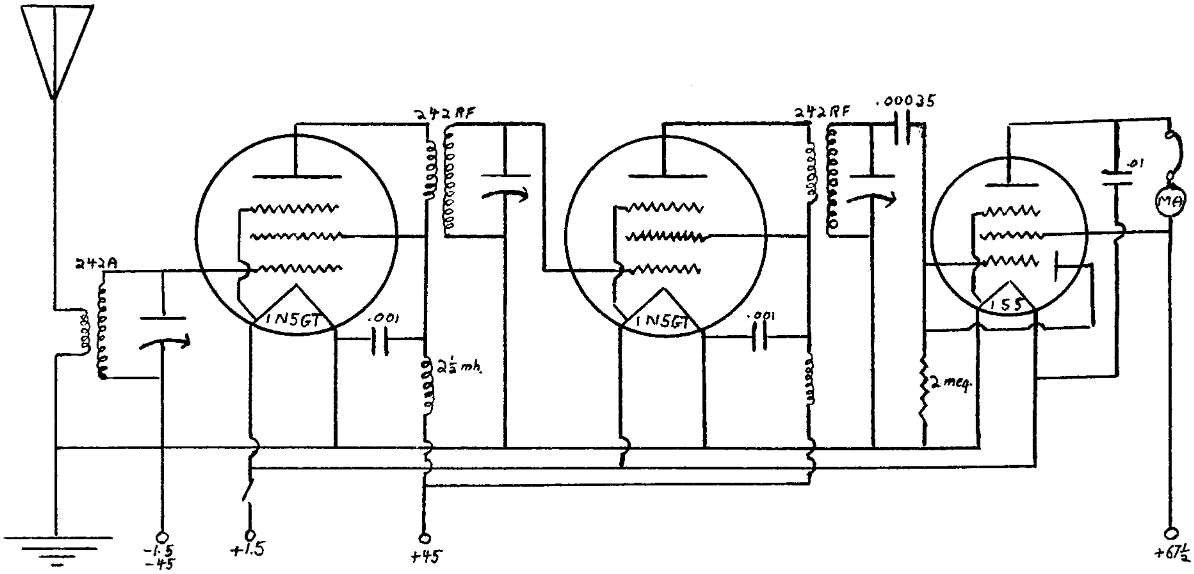



Figure 3. Wiring diagram of the field strength meter.

The antenna was a small whip-type car antenna. A milliammeter and phones composed the load circuit. This instrument was used in place of the other where only the field strength was to be measured. It was easier to handle, reduced directional effects to a minimum in the field strength recorded, and readings could be made with it much more rapidly than with the awkward directional instrument.

Both instruments were tuned to the standard broadcast range. Table 1 shows the stations used.

4. <u>Procedure</u>:

Type I: Directional measurements.

Series of traverses were run across known faults using the portable directional range finder. In most cases several parallel lines were run separated by a small distance. In several cases lines were also run parallel to the fault

| STATION | FREQ. (kc.) | POWER | LOCATION | AREAS WHERE STUDIED |
|---|---|---|---|---|
| KFI | 640 | 50kw. | Fullerton, Cal. | San Jacinto Valley, Indio-Garnet area, Imperial Valley. |
| KNX | 1050 | 50kw. | Redondo Beach, California. | San Jacinto Valley. |
| | 1070 | 50kw. | Redondo Beach, California. | Indio-Garnet area, Imperial Valley. |
| KFXM | 1240 | ¼kw. | San Bernardino, California. | San Bernardino area, Imperial Valley. |
| XECL | 990 | 5kw. | Mexicali, Baja California. | Imperial Valley. |
| KYUM | 1240 | ¼kw. | Yuma, Arizona. | Imperial Valley. |
| WCAO | 600 | ¼kw. | Baltimore, Maryland. | Baltimore area. |
| WABC | 880 | 50kw. | New York City. | New Jersey area. |
| WEAF | 660 | 50kw. | New York City. | New Jersey area. |
| WOR | 710 | 50kw. | New York City. | New Jersey area. |
| WJZ | 770 | 50kw. | New York City. | New Jersey area. |
| WMCA | 570 | 1kw. | New York City. | New Jersey area. |
| WIP | 610 | 5kw. | Philadepphia, Pennsylvania. | New Jersey area. |

Table 1. Radio stations whose broadcast signals were used in this survey.

for comparison. At regular intervals (different intervals being used in different cases) observations were made of the horizontal angle position of the loop antennae (referred to north magnetic line) at which minimum signal was received from either KFI or KNX, the loops lying in a vertical plane. The loops were then rotated through 90° about the vertical axis, clamped in azimuth, and rotated about a horizontal axis until another minimum was found. Then with the loops at right angles to this, and in the same azimuthal setting, the field strength was noted. Since the instrument had a capacitance with the operator, it was found that it was best for the operator to stand as far as possible from the instrument while finding the minimum signal positions. A long handle was provided with which to move the loops, and the operator, in so far as was possible, stood in the same position with respect to the instrument each time he made the adjustments, in this way minimizing the effect.

Type II: Absolute field strength measurements.

Traverses were arranged using the field strength meter as in the case of the directional instrument. Stations were also located in the same fashion. The meter stood directly on the ground, and was oriented roughly in a vertical position. The observer sat or knelt before the instrument, always in the same azimuthal direction from it. The meter readings were noted, field strength being a function of the deflection of the ammeter needle from the position of no signal.

Type III: Type used by Cloos[1].

The field strength meter was carried in the baggage shelf behind the seat of a convertible coupe with the top down. In some cases variations in the audible output were noted by listening with the earphones; in other cases readings were taken at intervals without removing the instrument from its place.

5. Recording of observations:

Samples of data sheets are included here (table 2). The data were plotted against horizontal distance on transparent graph paper so that one sheet could be superimposed on another for purposes of comparison. In a few cases data were also plotted against time to see if certain regular variations were a harmonic function of time rather than distance; and for that reason, and so that a diurnal variation correction could be made if necessary, times were recorded in every case, though they were never used for the latter purpose. In the case of some of the field strength data gradient curves were plotted. It should be noted that the intensity figures probably are not points on a linear scale,

A. San Jacinto Valley traverses:

Date: 9-28-40 Station: KFI
Weather: Clear-very slight haze.
Location: NW end of river flats on edge of cultivated land. N. side of telephone line. T. runs towards San Gorgonio.
Observer: Howell

| T# | S# | Time | Azimuth | V. Angle | Intens. | Remarks |
|---|---|---|---|---|---|---|
| J9 | 1 | 9:31 | N66:00°E | 91:00 | 7.3 | 0 paces |
| | 2 | 9:40 | 67:00 | 94:00 | 7.5 | 10 p. |
| | 3 | 9:48 | 71:00 | 94:00 | 6.2 | 20 p. |

B. Indio-Garnet area traverses:

Date: 4-12-41 Observer: Howell
Traverse #T13F
Location: T=N13°E 100p. W T12F
Weather: Cloudy, threatening rain.

| Time | Dist | Fld. Str. | Remarks |
|---|---|---|---|
| 3:15 | 0p | .788 | |
| 3:16 | 20p | .798 | |
| 3:17 | 40p | .800 | |

C. Imperial Valley Survey:

Observer: Howell Traverse #I1
Location: Redlands to Morongo Valley. KFI field strength unless otherwise noted.
Weather: Clear, sunny. Date: 6-2-41

| Station | Time | Dist | Fld. Str. | Remarks |
|---|---|---|---|---|
| 1. | 9:18 | -0.7 | .86/.90 | KFI, KMTR?, KNX |
| | | | .85/.90 | Vista Drive, Redlands |
| 2. | | 1.9 | .84 | KFI Hill facing west |
| | | | .88 | KFXM Shadow? |
| 3. | | 2.8 | .88 | KFI Shadow? Shallow valley. |
| | | | .87 | KFXM |

Table 2. Samples of data sheets to show methods used to record data.

but on one of undetermined shape.

6. Some precautions in making observations:

The effect of the capacity between the observer and the directional instrument has already been noted. Because of the smallness of the variations, and the difficulty in picking the minimum signal accurately, at least three readings of each directional position at each station were customarily taken with the directional instrument, and these readings averaged.

Care was taken in choosing the locations of the surveys to avoid in so far as possible overhead wires, fences, pipelines, secondary fields due to metallic substances of any sort, and shadowing effects due to hills, buildings, trees, bushes, or cars. Directional effects are likely on sloping ground, especially where the slope changes, strong shadow zones occur in narrow gullies and road cuts. Observations were more difficult to take on windy days than on quiet days, because the wind blows the antenna and causes fluctuations in the meter readings.

Normally, observations were taken between the hours of eight and four, sun time, since near sunrise and sunset atmospheric conditions disturb radio reception most greatly.

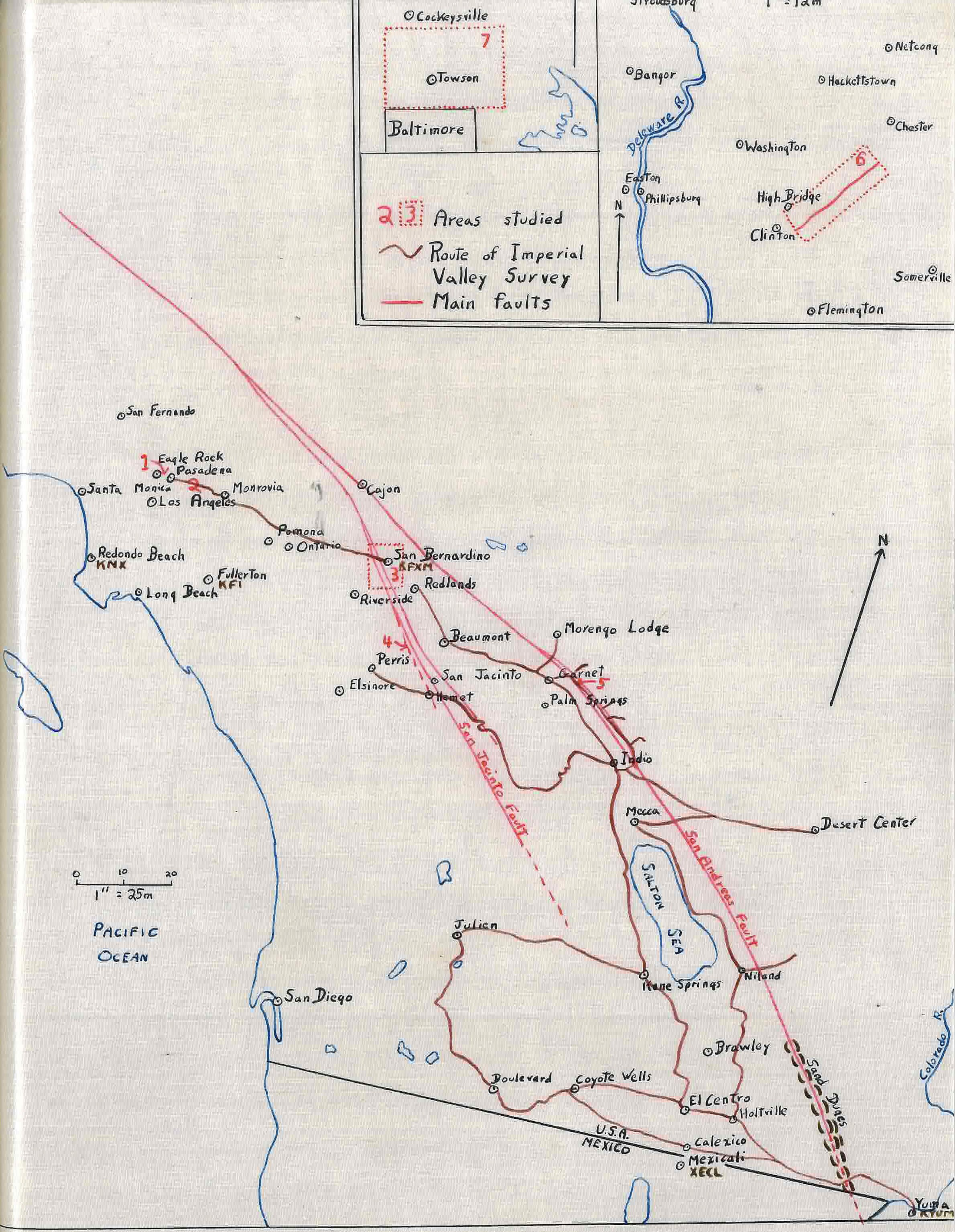



Figure 4. Map showing the areas studied.

7. Location and geologic setting of the surveys:

Preliminary tests were made with the directional instrument on the Eagle Rock Fault in the vicinity of the Eagle Rock between Pasadena and the town of Eagle Rock (fig. 4, area #1). The Eagle Rock Fault brings granite against Tertiary sediments at the surface, a south facing scarp and shear zone marking the trace of the fault.

Traverses were also run on the Raymond Fault between Pasadena and Monrovia (fig. 4, area #2). The Raymond Fault is marked by a low, gentle scarp facing south, the height varying from almost nothing to about fifteen feet where studied. The bedrock is not exposed, a granite-Tertiary sediment contact being buried by alluvium at shallow depths as indicated by wells.

The main directional survey was conducted on the San Jacinto Fault in the region northwest of the town of San Jacinto (fig. 4, area #4). The San Jacinto Fault is believed to follow the San Jacinto Valley. One branch follows the northeast side of the valley. Another is thought to lie against the feet of Mt. Russell and Mt. Rudolf to the southwest (fig. 5). A third, middle branch runs down the center of the alluvium filled valley, being marked by a mound, Casa Loma, about one hundred feet high. The surveys covered the southwest and central of these faults. A recent survey for

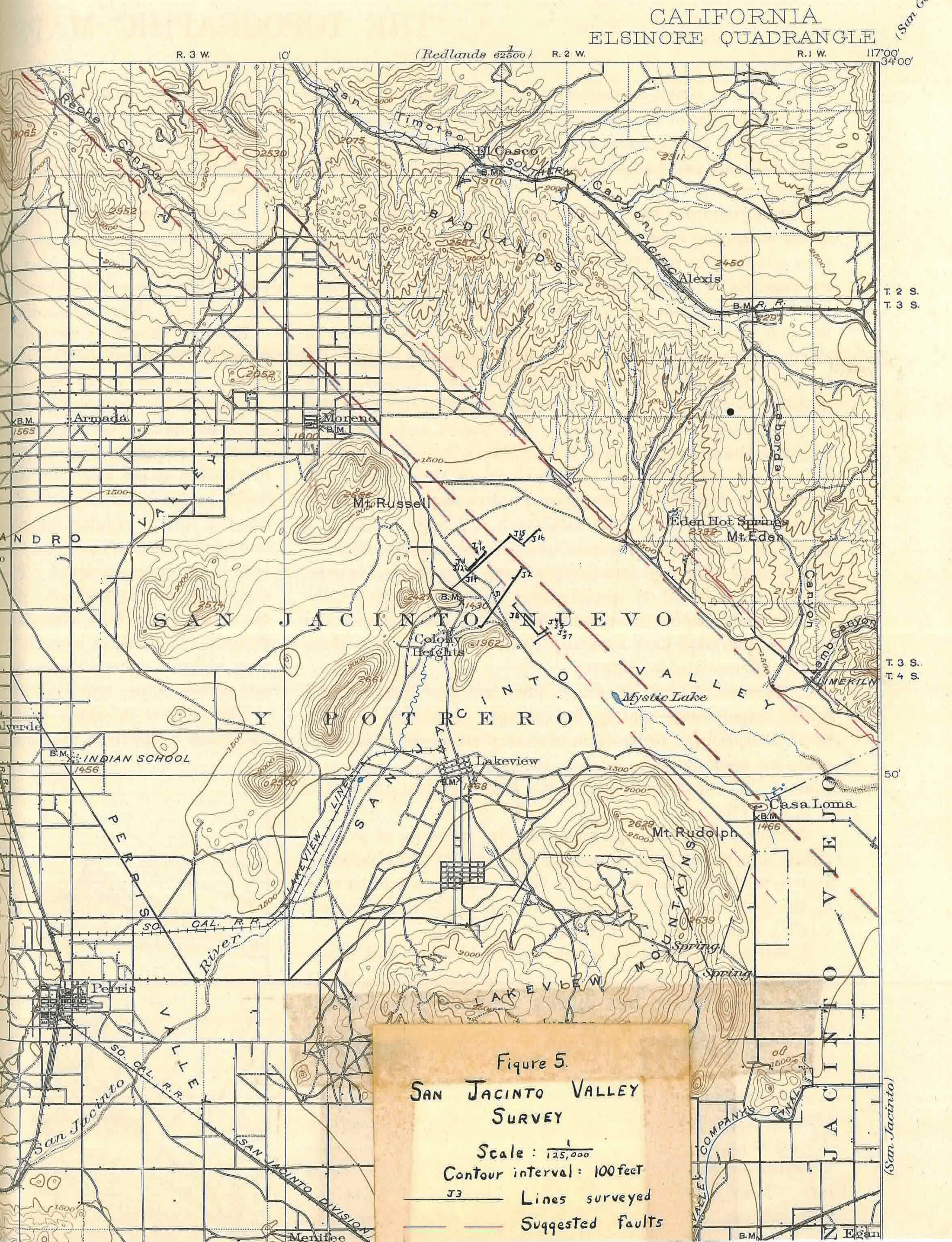



Figure 5.
San Jacinto Valley Survey
Scale: 1/125,000
Contour interval: 100 feet
J3 —— Lines surveyed
— — Suggested faults

the Colorado River Aqueduct has given accurate information on the location of these faults at a number of places (oral communication to the author by Dr. J. P. Buwalda, Division of Geological Sciences, California Institute of Technology.)

The main absolute field strength survey (type II) was conducted on the San Andreas fault east of Palm Springs in the region just southeast of Garnet and northwest of the Indio Hills (fig. 4, area #5). (This region is henceforth called the Indio-Garnet area.) Two branches of the San Andreas Fault cross from the San Bernardino Mountains to the Indio Hills in this region. Their courses are marked by gentle scarps and hills in the alluvium, and at places by a clear "vegetation line". The area is completely buried in alluvium from the Little San Bernardino Mountains.

A broader survey was run over the whole of the Imperial Valley and adjacent territory (see fig. 4), which has a reputation of being an area of weak reception. The stations on this survey were a mile or more apart. The Imperial Valley is the southern part of the Salton Basin, a graben lying between the peninsular ranges on the southwest and the Sonoran Desert on the northeast[9]. It is filled with alluvium from the mountains on either side, and by an old fan of the Colorado River, which in the Pleistocene flowed from the southwest into Lake Cahuila, the then much expanded

Salton Sea. The basin lies in the southern part of the Pacific Depression. Its location appears to be determined by the San Andreas Fault system, and it is a structural continuation of the Gulf of California.

Cloos-type surveys (type III) were conducted in the vicinity of San Bernardino, California, and along the Piedmont Fault between the Triassic and Pre-Cambrian and Paleozoic rocks in northwestern New Jersey (fig. 4, areas #3 and #6). The field strength meter was also taken to Maryland and checked against Cloos's "type locality" to be sure that its response was comparable to that of Cloos's instrument (fig. 4, area #7).

8. Theory:

Since weak spots due to geologic influences are so poorly known, no complete, adequate picture of their cause can be given here. The incident radio field is eliptically polarized[10a], being the sum of all the different field strength vectors present: that is, it is the sum of the primary field, any secondary fields present, and any other fields reaching the point under consideration by other than the direct path from the sending station. Fritsch has pointed out the way radio waves are reflected and refracted at the surfaces between different rock bodies[3]. The problem is simplified by the fact that when radio waves pass through the ground, they are rapidly absorbed[4,5,6,7], so that the receiver is largely shielded from the complex reflections and refractions from geologic structures other than those quite near the receiving station. However, surface features such as mountains may produce multiple incident rays; and gouge zones in faults, offset rock formations, sedimentary or igneous contacts, or differences in water table elevation across a fault may also be expected to have some effect of this sort. Secondary fields may come from a multitude of sources, both geologic and man-made.

According to Heiland, weak spots probably are due to distortion of the equipotential lines near the contacts of good and poor conductors[10:p.817]. Heiland does not discuss the nature of this distortion. Barrett states that the variations are an interference phenomenon whereby the fault structure results in waves arriving by different paths[8:p.5]. Barrett's theory, when analysed, turns out to be a case of induced currents resulting in a secondary field, not a case of true reflection and refraction. Mingins, studying the effect of the ground on sky wave reception, has also shown how the direction of the field would be affected by a conducting body[11:p.1435-42]. This survey found directional patterns of the same sort poorly suggested over the San Jacinto Fault. It is quite possible that fault planes may have higher conductivity than the surrounding rocks because of the presence of certain minerals, or because they contain more water than the adjacent rocks. When this occurs, a secondary field will be present. The secondary field will oppose the primary field, causing a decrease in total field intensity. It will also cause variations in the direction of the resultant field by addition to the primary of an out of phase secondary having a direction varying with position. This would explain why disturbed areas occur in only a few places along faults. These would be the only places which were more mineralized or contained larger amounts of water than the adjacent rocks. Other parts of the fault would be little more conductive than the adjacent rock, and would not deform the electromagnetic field appreciably.

Both types of phenomena, interference by reflected and refracted rays, and secondary fields, are probably involved; and only further study will show the relative importance of each.

9. <u>Results of the surveys</u>:

The Eagle Rock and Raymond Fault investigations were inconclusive. This was due largely to local conditions of a non-geologic nature. The Eagle Rock Fault where studied is in very rugged topography; and the Raymond Fault lies in a largely built-up area having houses, accompanying telephone and electric wires, and similar disturbances.

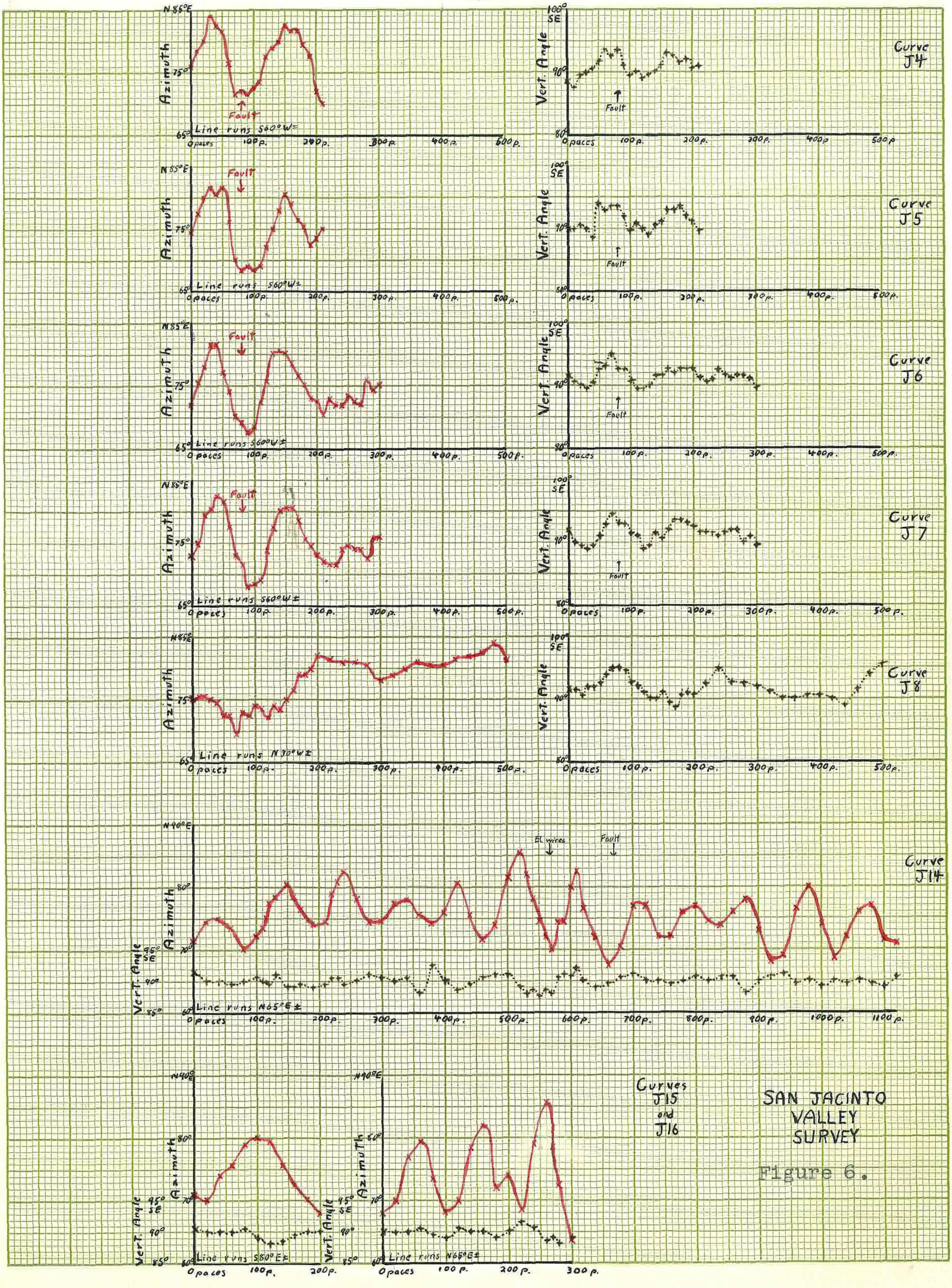
The San Jacinto Valle traverses were almost free of such disturbances. Their most marked characteristic is a periodic variation in the direction of the field. This is most strongly shown in the azimuth curves, the vertical angle variations being smaller and somewhat less regular, though these curves vary fairly synchronously with the azimuth curves (fig. 6 and fig. 7). The wave length of this variation depends on the direction of the traverse, being smallest on traverses across the fault. This effect was observed both in the near vicinity of the fault, and at considerable distances from it, and consequently is believed not to be due to the influence of the fault. The pattern suggests standing waves, perhaps due to reflection from the northeast side of the San Jacinto valley. However, the wave length of this variation was not always greater than one half that of the electromagnetic field being received (see table 3), so this explanation is not satisfactory. The author hopes to make further experiments on this phenomenon in the future.

A second type of variation is shown at 80 paces on curve J9 (fig. 7), and can be faintly made out on curves J10, J6, and J7 (figs. 6 and 7). Curves J4 and J5 (fig. 6) probably show the same

| Transmitter being used. | Traverse # | Approximate direction of traverse | Average separation of maxima. | Number of maxima shown. |
|---|---|---|---|---|
| KNX | J1 | N34°E | 160 meters | 4 |
| KNX | J2 | N34°E | 170 meters | 3 |
| KNX | J4 | S52°W | 210 meters | 2 |
| KNX | J5 | S52°W | 195 meters | 2 |
| KNX | J6 | S52°W | 185 meters | 2 |
| KNX | J7 | S52°W | 195 meters | 2 |
| KNX | J8 | N38°W | 480 meters | 2 |
| KFI | J9 | N50°E | 160 meters | 2 |
| KFI | J10 | N50°E | 175 meters | 2 |
| KFI | J11 | N50°E | 175 meters | 2 |
| KNX | J14 | N50°E | 185 meters | 12 |
| KNX | J15 | S53°E | 280 meters | 1 |
| KNX | J16 | N50°E | 175 meters | 3 |

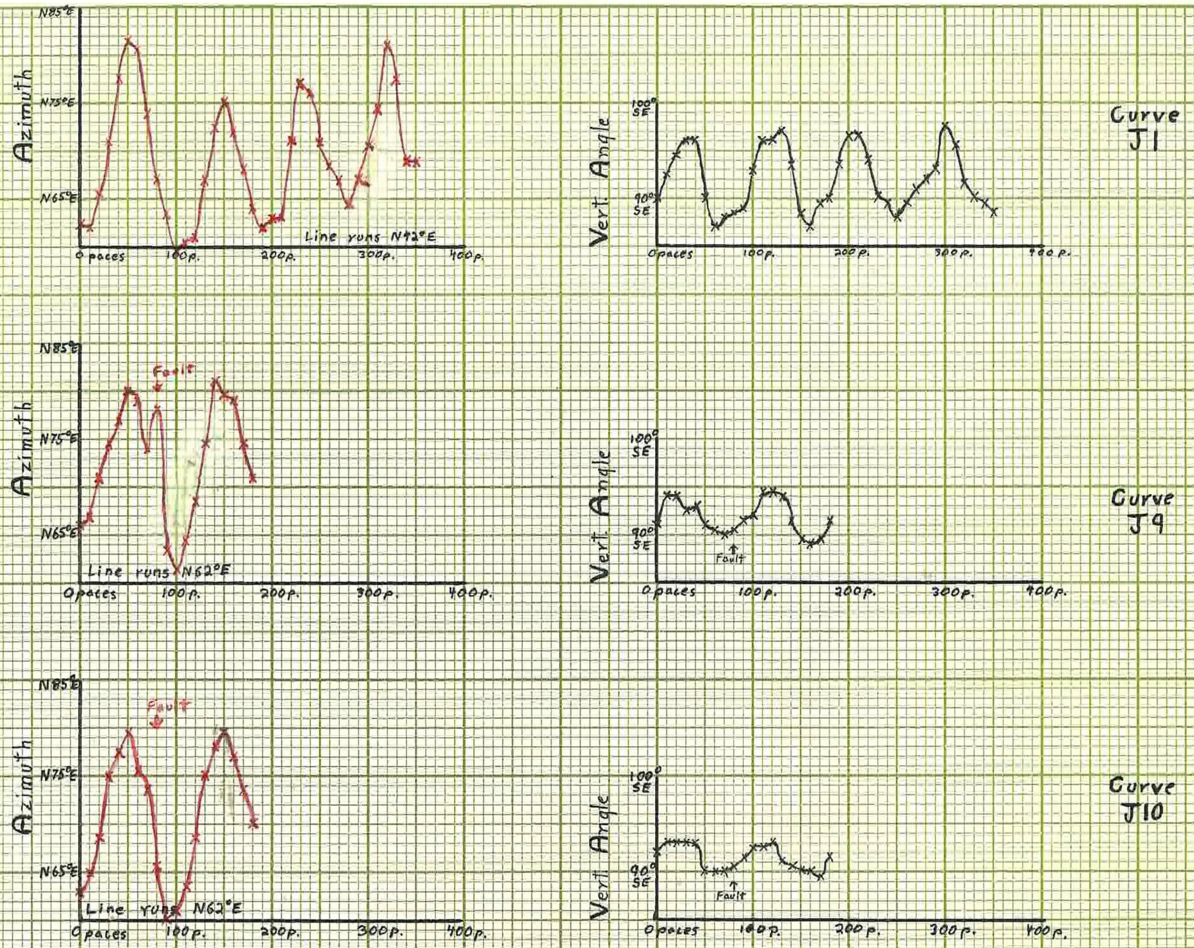
Table 3. Frequencies of variation of the horizonatl angle of the fields in the San Jacinto Valley.

thing also, though less clearly. This variation occurs at points where the fault is expected to occur from geologic evidence. Curve J1 (fig. 7) shows like variations at 270 paces where no fault is known or expected to occur; and a similar phenomenon occurs at 180 paces on curve J8 (fig. 6). Other less clear cases can be found. For this reason, and because the anomalies in each case depend on but one point, their significance should not be overestimated. The results are suggestive but not conclusive evidence of a genetic connection between faults of this type and variations in the radio field. A similar variation occurs in the vertical angle curves J4, J5, J6, and J7. In curve J14 a similar anomaly occurs at 580 paces, but at 670 paces,




SAN JACINTO VALLEY SURVEY

Figure 6.




SAN JACINTO VALLEY SURVEY

Figure 7.

where the fault is believed to occur, no anomaly is observed. Two strands of electric wire on poles cross the traverse at 568 paces, and the anomaly at 580 paces, may be genetically connected with these.

One difficulty in interpreting these curves arises from the uncertainty of the location of the San Jacinto fault. Since there is no surface trace where the survey was made, its location was estimated by projection of its strike from adjoining areas, the resulting inaccuracy in location being unavoidable.

In the remaining surveys field intensity, not direction, was studied. In the case of the Indio-Garnet traverses, three groups of traverses were run, two groups on the north branch of the fault, and one on the south branch. The first two groups proved nothing. In the third a slight drift of all of the readings showing decreasing field strength from northeast to southwest may be discovered, in most cases, by careful investigation of the curves (fig. 8: T13F, T14F, T18F, T22F). Plotting the curves in the form of gradients did not clarify the situation, only showing that the variation is irregularly distributed, and less than the point to point variation within the curves. Curve T23F (fig. 8) shows that there is no drift of the readings in the perpendicular direction. The parallel lines were run alternately northeast-southwest and southwest-


Figure 8.

**INDIO-GARNET SURVEY**

northeast, on different days, and at different times of day in order to eliminate any possibility of superimposing a regular variation of the field strength from one of these causes on all of the curves in the same manner. No distinct break marks the fault, the gradient observed is more gentle than sudden. It is concluded that this faint irregularity of the field is due to shielding by the mountains, probably of the San Jacinto Range. The shielding effect of the ground in even a small gully is shown by curves T13F, T14F, and T18F (fig. 8). The effect of an overhead wire, in this case the trans-continental telephone, is well shown by curve T22F, and appears in T13F, T14F, and T18F.

Anomalies of the type observed by Mr. Barrett may be present, but if so they are of such small amplitude that they are not distinguishable from the other irregularities in the curves[8].

The Imperial Valley survey shows that while reception of most stations was poor by day, it was excellent at night, KRLD, Dallas, and KOA, Denver, being strong on some occasions, and KSL, Salt Lake City, being strongly received always. During the day as well as at night XECL, Mexicali, was received strongly all over the southern part of the valley. This reception is shown by curve I10 (fig. 9), which is a normal curve of field strength decrease with distance (compare reference

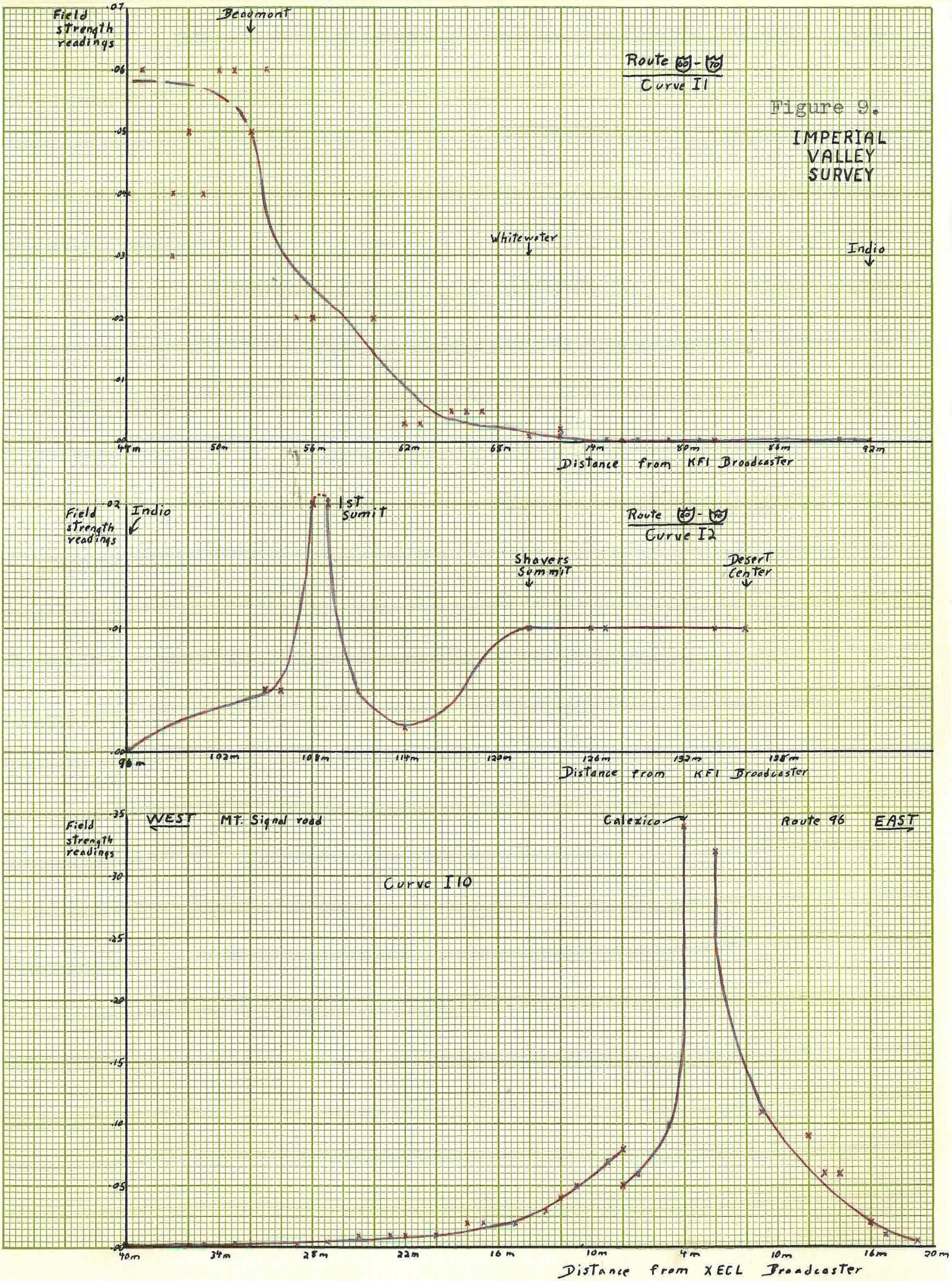


Figure 9.
IMPERIAL VALLEY SURVEY
Route 60 - 70
Curve I1
Field strength readings
Beaumont
Whitewater
Indio
Distance from KFI Broadcaster
Route 60 - 70
Curve I2
Field strength readings
Indio
1st sumit
Shavers Summit
Desert Center
Distance from KFI Broadcaster
Field strength readings
WEST
Mt. Signal road
Calexico
Route 96
EAST
Curve I10
Distance from XECL Broadcaster

12). KYUM, Yuma, could also be heard near Yuma. The conclusion to be drawn from this is that while there is considerable shielding of the valley from the ground waves of stations beyond the enclosing mountains, none of this effect is due to subsurface geology. It should be noted in this respect that none of the Los Angeles stations are received strongly by day anywhere outside of the mountain enclosed Los Angeles basin system. Curve Il (fig. 9) shows how the field intensity drops off as one goes out of the basin thru San Gorgonio Pass. The effect of altitude is also illustrated by curve I2 (fig. 9), where reception is seen to improve with higher altitude.

Fig 10 is a map of the San Bernardino area showing the weak spots observed which could not be explained by overhead wires or some other non-geologic cause. The brown lines represent most of the roads surveyed, but many of the roads covered only on the recheck surveys have been omitted. The faults are drawn in from field observation, supplemented by advice from Dr. J. P. Buwalda of the Division of Geological Sciences of the California Institute of Technology, whose familiarity with the geology of the region exceeds that of the author. Two symbols are used to show the location of the weak spots, as indicated in the legend. One stands for weak spots observed consistently on all three visits to the

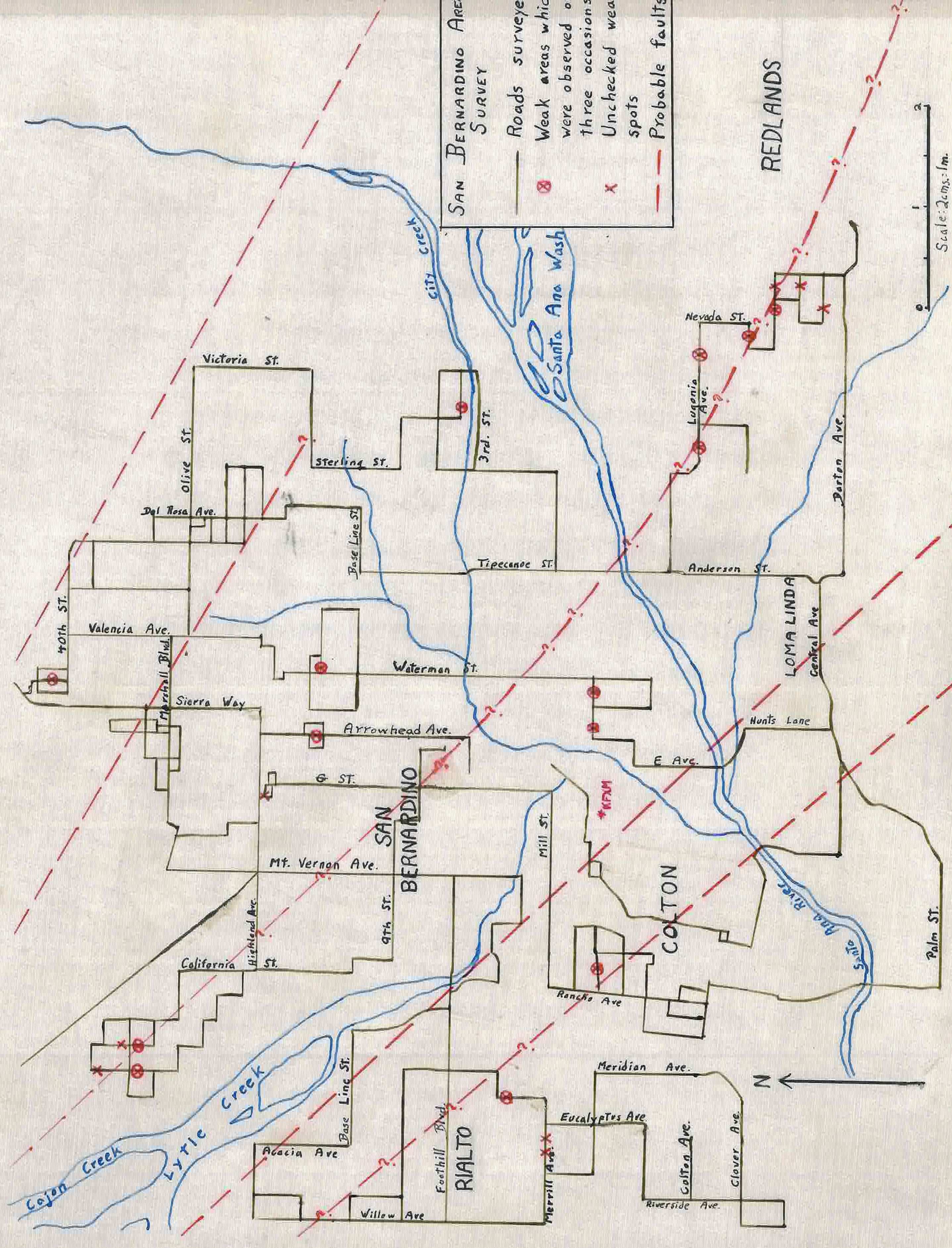



Figure 10. Map of the San Bernardino area showing the roads surveyed and the weak spots.

area; the other for weak spots examined on one or two of the surveys only, and not checked. Many other weak spots, not aparently due to wires, which were not heard on reexamination have been omitted.

The location of the central of the five faults is purely speculative; its very existance is unproven, though it is known to enter the area from the northwest, and a fault leaving the area on the southeast where shown is suggested. It is probable that there are many more faults in the area than those shown on the map. Of those shown the most important are the northeastern, which is the main branch of the San Andreas, and the two southwestern, which are the two main branches of the San Jacinto Fault. These faults are probably not as straight as shown, and probably are zones rather than lines.

Unfortunately, since the region is buried by alluvium, correlation between the weak spots and the faults is not possible, though eight out of fourteen of the checked weak spots are near the shown faults. Hence the distribution can not be said to disprove a relation between faults and the weak areas.

It was in this area that the effect of overhead wires on the radio-frequency field was best observed. Innumerable weak spots were noted associated with these wires. The exact relationship was not determined, as not all wires appear to have an effect; but it is possible that the effect is partly a function of the direction of the wire with respect to the direction to the radio station. It is also possible that the lengths of the wires between turns have some connection with this phenomenon, since the wires might act as parasitic antennae on which certain frequencies are more easily absorbed than others.

Station KFXM in San Bernardino (shown on the map) was used exclusively in this survey.

A test of the field strength meter was made at Cloos's "type locality" north of Baltimore[1]. This was a Cloos-type survey. Almost all of Cloos's "dead" spots were visited, and with one or two exceptions were observed with the field strength meter used in the surveys described here. However, in most cases the spots were found not to be "dead", but only "weak"; and in a number of cases the author feels that other factors than geology may be responsible for the variations in the field strength. This leads to the suggestion that all of the "dead" spots observed may in reality be only "weak" spots, and the reason that they appear dead is, as Cloos suggested, only because of the lack of amplification possessed by the instruments used. In this connection, the observation made by Cloos[1] and confirmed in the New Jersey surveys described below that the "dead" spots were dead only for weak stations and not for strong stations is of importance, as it may explain why "dead" spots are so rarely found, since relative decrease of sound is harder to notice than a complete cessation.

The New Jersey survey covered a stretch of the Piedmont fault between Pottersville and Lebanon, Hunterdon County, and thence westward across the folded and faulted section to West Portal on Musconetcong Mountain. The western part of this area was visited only once, and no weak areas were found. It was necessary to use WJZ and WOR, New York's two strongest stations, in order to hear the signals at all; and it amy be as suggested by Cloos that strong radio-frequency fields are but little affected by geologic structures[1]. Figure 11 shows ten well-marked weak areas consistently noted in the area. Other weak areas, not shown, were noted on but one or two of the three surveys, but were definitely not observed on the others, or were attributable to other than geologic causes. The grouping of the weak areas along the fault is at once apparent. The weak spot at Pottersville is complicated by telephone and electric wires, but the weakness is probably due in part to the presence of the fault, as it is wider than the usual weak area beneath an overhead wire. The

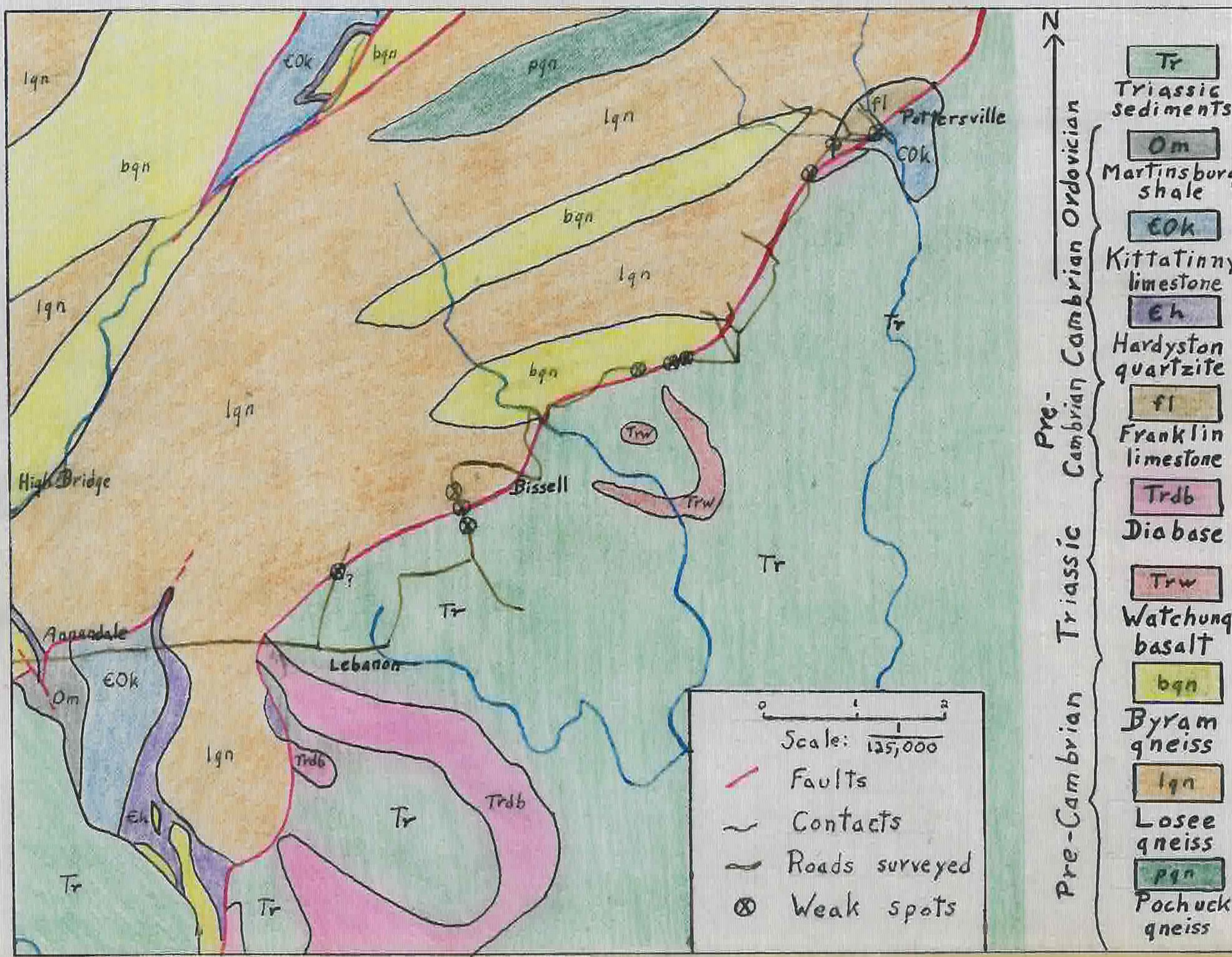


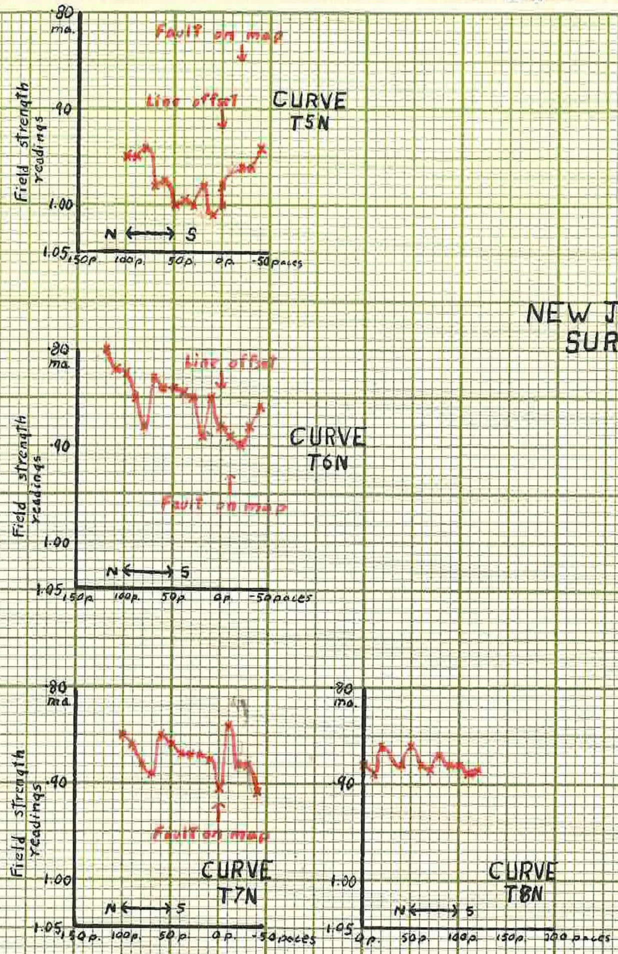

Figure 11. Map of the New Jersey area showing weak spots, geology, and the roads surveyed. Geology is from the Raritan Folio[13].

first weak area west of Pottersville is not on the fault, but is on the contact of the Lossee gneiss and the Franklin limestone. The first weak area northeast of Bissell is just off the Byram gneiss-Triassics fault contact as shown on the geologic map of the area[13], but as outcrops are rare here, the location of the fault on the geologic map can be considered only an approximation, and it is as likely under the weak area as where it is shown; or the weak area may be on a branch of the fault shown. West of Bissell are three weak areas spread across the fault. The Piedmont Fault where it outcrops at the surface in a quarry near Bernardsville, Somerset County, New Jersey, has several parallel branches spaced a few hundred feet apart (oral communication: Dr. B. F. Howell, Princeton University). In the area studied the fault is nowhere clearly exposed, and the same situation may occur here as at Bernardsville, especially in view of the deflection of the fault at Lebanon, near which the changing stress pattern might be expected to cause a more complicated fault pattern than elsewhere. The three weak areas may thus be over three branches of the fault.

Four absolute field strength traverses were run in this area as shown by figure 12. The curves are so irregular that the results must be considered indefinite. The northeasternmost of the three areas corresponds to about 60 paces on curve T5N. Distinct minimums are shown by T6N and T7N at 80 and 70 paces respectively, and T5N may have a modified weakness at 70 paces. The pattern along the central weak area is not as clear as along the northern branch, but weaknesses are shown on T6N and T7N near where the fault is shown on the map. The associated high on T7N is not explained, nor is it clear why T5N is generally low. The general upward trend of curves T6N and T7N from south to north may be due to the increase

Figure 12.

NEW JERSEY SURVEY



in elevation in that direction, resulting in better reception, though no such increase is exhibited by T5N. Curve T8N is roughly an extension of T7N, and is the only traverse which crosses the line of the southern weak area, the position of which is not apparent from the curve. Scattered trees throughout this whole area may be the cause of some of the complications, though they were avoided where possible.

It is interesting to note, first: that the weak areas noted when driving across the fault in the car are not as clearly seen in a series of plotted observations; and second: that they are sometimes accompanied by maxima not noted in driving past, the pattern as a whole being much more irregular than might be expected. A stronger station (WOR) was used in the absolute field strength readings than was listened to in the car, and this may have some effect on the difference between the ease of observation in the car and in the walking traverses. A weaker station could not be used as the field strength meter was not delicate enough to show the variations of a weaker field adequately; that is, the milliammeter was less sensitive to the field strength variations than the observer's ear. This pattern suggests that field strength maxima associated with other weak areas may easily have been overlooked. A similar pattern was suggested at a place about $1\frac{1}{2}$ miles south of Lebanon where the radio field over the fault was examined; but telephone and electric wires and topography made the picture here uncertain. A suggestion of a maximum was also noted in connection with the third weak area northeast of Bissell.

The weak area northeast of Lebanon is marked with a question mark because the change in field strength was only barely perceptible, and it is not certain that it is exactly over the fault, whose location here is only roughly known.

It is interesting to note that the weak areas all occur on the more east-westerly parts of the fault, and not on the north-southerly sections. This may mean that the angle between the fault and the direction to the sending station is involved. Since the weak areas were examined using stations roughly straight east (New York), and roughly south (WIP, Philadelphia), that is at right angles, directional sensitivity of this sort appears doubtful.

10. Conclusions:

Firstly, the difficulty in applying this method in rugged or densely inhabited areas has been brought out. Further study may simplify the problem here, but at the present stage of understanding, interference from such sources is a limiting factor.

Secondly, a small variation in the direction of the radio-frequency field over faults such as the San Jacinto Fault is suggested, but not proven. However, the Indio-Garnet traverses show that field strength variations under such circumstances are small, perhaps inappreciable. It is possible that the direction of the field varies over other types of faults; it is certain that the intensity may.

Faults and contacts coming to, or nearly to, the surface sometimes have areas of noticeably weak reception over their surface traces. Weak fields seem to be more affected than strong ones. How deeply such a fault trace can be buried and still be detectable has not been demonstrated; nor has why these anomalies occur at some places and not at others been shown, though theory suggests that a secondary field due to conducting material in the fault plane is a factor. Faults between rocks of different composition like the Piedmont Fault in New Jersey appear to be more often associated with such phenomena than do faults whose surface trace is in thick alluvium.

In making an intensity survey it is probably wisest to have the receiver on some sort of tripod to escape the effects of minor ground irregularities and vegetation on the radio field. This is indicated by the irregularity of the Indio-

Garnet curves, where the receiver was set directly on the ground. Since absorption of the waves is relatively slow in air, the field at a few feet above the surface of the ground probably will show any large irregularity which exists at the ground surface itself. The size of the anomalies obtained suggests that twenty feet is a good interval between stations for a survey where absolute readings are taken, although a larger interval was most commonly used in this survey (60 feet).

It should be remembered that these conclusions depend on the limitations of the apparatus used.

11. Future work:

The greatest need today is for the accumulation of more data on weak spots apparently connected with geologic structure. When such places are found, they should be studied with respect to what frequencies are affected, whether the angle between the fault or contact trace and the direction to the transmitter in involved, what range of field intensities are affected, and what variations there are in the direction of the field near the weak area. Also, whenever a good, clear-cut weak area is found, it should be carefully mapped to determine its size; and quantative figures of the field strength should be recorded if possible. It is especially important to determine what characteristics of the fault are usually present when weak spots occur.

Further work of the type described here using more sensitive apparatus and a closer spacing of stations would be very worth while.

The study of directional effects is at least as promising as that of intensity variations.

More detailed work is needed on the theory of the reflection and refraction of radio waves at surfaces in and on the ground, including the calculation of expectable anomalies.

In closing I wish to thank the many persons who have aided me in this investigation. There is not space here to make individual acknowledgement of all the advice and assistance I have received. I especially want to thank the Division of Geological Sciences of the California Institute of Technology for providing the equipment used in the survey. Especial appreciation is also due to Prof. G. W. Potapenko, Mr. Charles Miller, and Mr. William Hornbostle for their generous advice and assistance in all phases of the work.

BIBLIOGRAPHY:

1. Cloos, Ernst; Auto radio, an aid in geologic mapping. Am. Jour. Sci., Series V, Vol.28, 1934, pp.255-268.

2. Geologic map of Maryland. Maryland geological survey, 1933.

3. Fritsch, Volker; Grundzuge der Funkgeologie. Especially abb. 37, p. 40, and accompanying text. Friedr. Vieweg und Sohn, Braunschweig, 1939.

4. Joyce, J. W.; Electromagnetic absorption by rocks. U. S. Bureau of Mines technical paper #497.

5. Eve, A. S.; Absorption of electromagnetic induction and radiation by rocks. A. I. M. E. Geophysical Prospecting Volume for 1932, p.160.

6. Eve, A. S., Steel, W. A., Olive, G. W., McEwan, A. R., Thompson, J. H.; Reception experiments in Mount Royal tunnel. Proceedings of the Inst. of Radio Eng., V.17, p.347, 1929.

7. Eve, A. S., and Keys, D. A.; Studies in geophysical methods, 1930, part I. Canadian Geological Survey Memoir #170.

8. Barrett, W. M.; Electrical apparatus and method for geological studies. U. S. Patent #2,172,688.

9. Brown, J. S.; The Salton Sea region, California. U. S. G. S. water supply paper #497.

10. Heiland, C. A.; Geophysical Exploration. Prentice-Hall, 1940.
   a) p.815-818
   b) p.651-656

11. Mingins, C. R.; Electromagnetic wave fields near the earth's surface. Proceedings of the Inst. of Radio Eng., V.25, p.1419, 1937.

12. Dellinger, J. H. (chairman), etc.; Report of the committee on radio propagation data. Proceedings of the Inst. of Radio Eng., V.21, p.1419, 1933.

13. Bayley, W. S., Salisbury, R. D., and Kummel, H. B.; Geologic atlas of the United States, Raritan folio; U. S. G. S., 1914.