GL03306 8of8

ZONGE ENGINEERING & RESEARCH ORGANIZATION

3322 EAST FORT LOWELL ROAD, TUCSON, ARIZONA 85716 U.S.A.
TELEPHONE (602) 327-5501 TELEX 165532 CEERHO TUC

May 15, 1986

Joe Iovenitti
Diamond Shamrock Geothermal
3333 Mendocino Ave. #120
Santa Rosa, Ca. 95401

RECEIVED
MAY 27 1986
TPC - Santa Rosa

Dear Joe:

This letter is a preliminary draft of our technical assumptions for the proposed Hawaii geothermal survey, as we discussed by phone this afternoon.

As mentioned in our turn-key price quote of May 5, the survey will consist of two phases. Phase I will be run with full-tensor data, as depicted in the enclosed figure. Phase II logistics will depend upon the preliminary in-field analysis to be performed at the conclusion of Phase I. The work will be done with a coincident dual-dipole source, as shown in the figure.

Our logistical assumptions are as follows:

1) We can get sufficient power (10 amps or better) from the sources. May need to auger drill electrode holes for better electrode contact.

2) Sources to be oriented roughly parallel to the two principal strike directions of faults and structure in the area to assure maximum signal coupling. Will require some geologic control.

3) Survey weather, culture, etc. will allow data repeatability to better than 10%, which will be needed for proper interpretation. Survey should not be run during thunderstorm season; avoid running parallel or coupling into major cultural features.

4) Positioning of the sources will be critical. See enclosed excerpt from a recent CSAMT paper.

5) No data must be obtained in the near-field; it should all be obtained in the far-field or transition zones. In 10 ohm-meter ground at 0.125 Hz, this dictates a minimum source-sounding separation of about 5 miles (8 miles for all-far-field data, but this would be impractical from the standpoint of signal levels).

6) Penetration will be about 3 km at 0.125 Hz in 10 ohm-meter ground.

7) Lateral resolution will be about equal to the electric field dipole size.

8) Vertical resolution for conductors will be very roughly 20% of the depth of burial. Resolution for resistors may be twice this. Independent geologic control will help refine this.

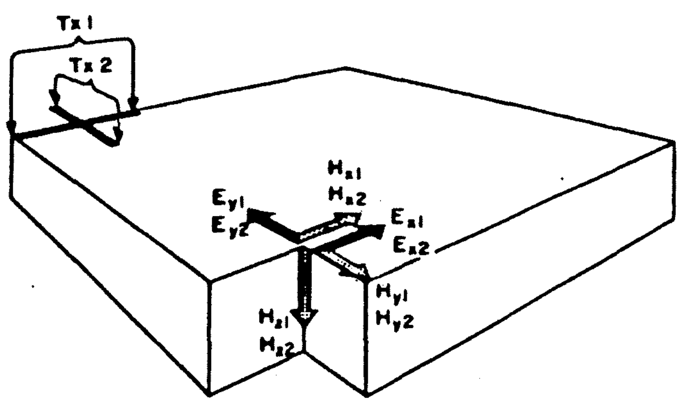
At the end of the survey, we seek to produce maps and pseudosections of apparent resistivity parallel and perpendicular to strike. The goal will be to define the geometry of subsurface conductors, and to determine which conductors are of interest in geothermal exploration.

Please give me a call once you've had a chance to look this over, and we can modify it to your needs. I will be out of the country beginning May 30, but I will make every effort to get this document finalized before then.

Sincerely,

Larry Hughes
Geophysicist

Tensor CSAMT, Coincident Sources



Horizontal or lateral density considerations can be summed up in several rules-of-thumb utilized by the authors: 1) try to obtain at least twice as much "background" data as "anomalous" data; 2) always make more than one sounding over the target in order to define its plan-view extent; 3) obtain a sufficiently large data base to establish the statistical significance of features under investigation; 4) obtain enough coverage to causally distinguish an anomaly from unrelated effects such as culture, topography, and geology; 5) never settle for an "end-of-the-line anomaly" - always close it off at the end of line by adding extra coverage; 6) try to avoid irregular spacings for the soundings, which can induce a biasing effect in the interpretation.

Plan-View Coverage Considerations

The zone which is explored most effectively in plan-view is limited by three factors: the near field/far field transition, signal threshold, and angle-to-bisector signal deterioration.

The minimum separation between the transmitter and receiver is normally fixed by skin depth criteria. It is usually desirable to make most or all measurements in the far field. It was observed earlier that the far-field zone begins at a distance of roughly three skin depths from the source. Thus, one generally desires to keep the transmitter-receiver separation at three skin depths or more for the majority of the frequency range under consideration. This then fixes the minimum separation, although one also can make measurements at a closer separation and try to deal with the transition zone effects later.

The maximum separation is determined by the minimum signal thresholds available in the field. While modern digital instrumentation can measure signal levels as low as tenths of microvolts, much larger signals are usually needed to facilitate economic data acquisition. In general, using a digital acquisition system with stacking-and-averaging capability, at least two bits of resolution are needed to adequately define the signal. The minimum signal level needed to achieve a given resolution is given by:

$$\frac{10 \text{ volts}}{2^{(N+M-R-1)}} \qquad (3.7)$$

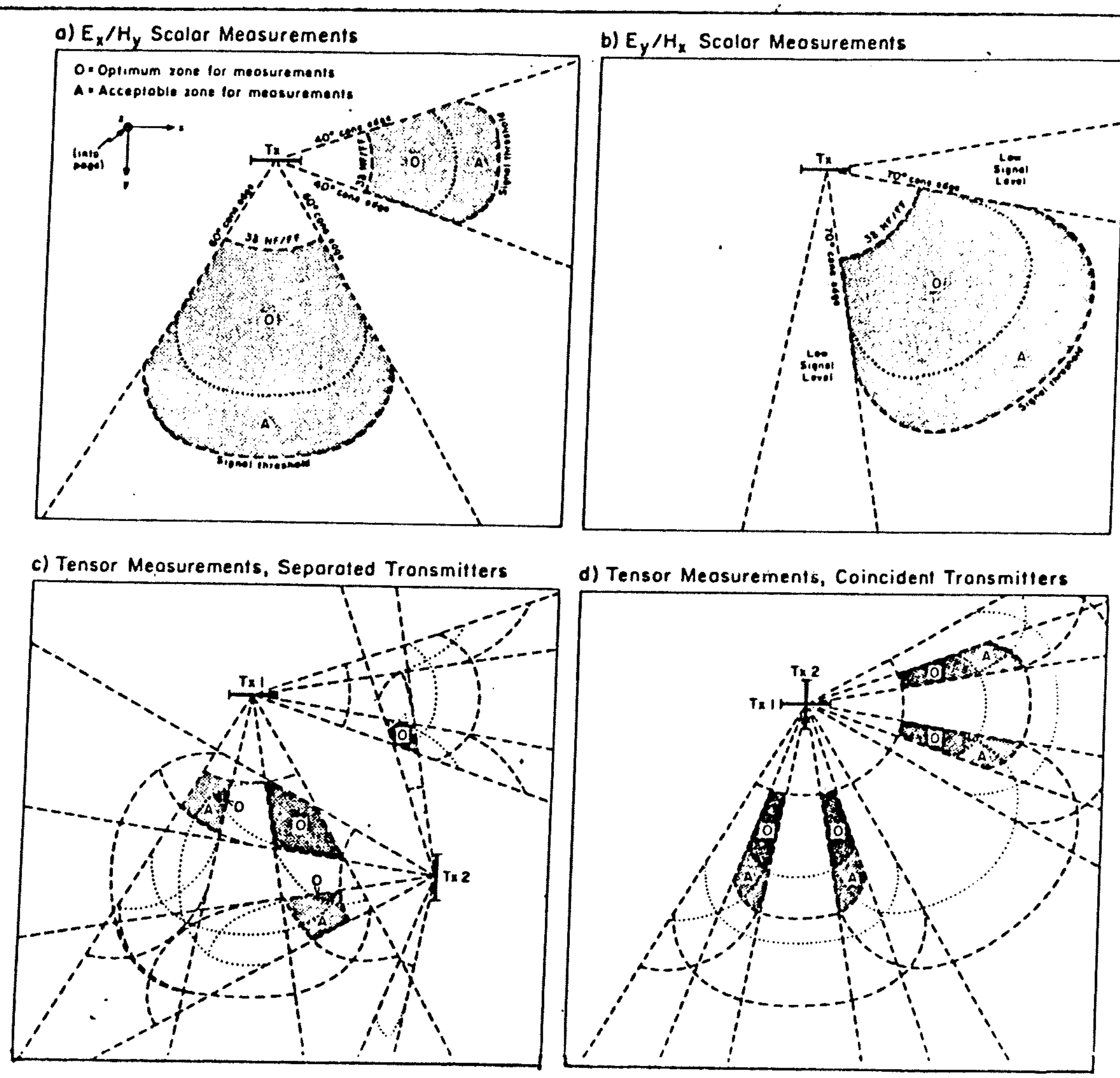
in which 10 volts is the maximum signal input for the analog-to-digital (A/D) converter, N is the A/D resolution in bits, M is the number of bits in the receiver gain function, and R is the required signal resolution in bits. For example, for a 12-bit A/D (N=12), a minimum resolution of three bits (R=3), and a maximum usable gain of 32768 (M=15), the minimum detectable signal is 1.2 microvolts. One can then use equation (2.49), plugging in maximum practical transmitter dipole size, expected current, and expected ground resistivity, to determine the largest transmitter-receiver separation r needed to obtain the 1.2 microvolt signal level. In very noisy environments, the separation calculated in this manner can be too large to permit adequate signal levels, so the best way of determining this separation is by experimentation in the field. A very general rule-of-thumb for modern 12-bit and 16-bit digital receivers is that one should keep the separation to less than about 10 skin-depths if possible.

Distinct limitations are placed on plan-view coverage by the location of the measurement with respect to the orientation of the transmitter. For "broadside" measurements in the Ex/Hy mode illustrated in Figures 2.3 and 2.4, the maximum distance in the x-direction from the perpendicular bisector of the transmitter is fixed by the sin ϕ loss of signal described earlier in the theoretical discussion. It is normally desirable to make all measurements within a 30 degree angle of the perpendicular bisector, or within a 60 degree "cone" centered on the perpendicular bisector. There are two reasons for this. The first involves a significant drop in signal levels outside the cone. This occurs in a frequency-dependent manner and results in erratic behavior of the E and H fields well off the bisector (see Figure 2.4 for an illustration of this effect). The second reason is that one also encounters an increasing ambiguity farther from the bisector regarding the exact polarization of the measurements. In a three-dimensional environment, this can lead to interpretational difficulties, especially in scalar measurements. In a similar manner, "end-on" measurements of Ex/Hy are limited to a 40 degree cone centered along the axis of the transmitter dipole. Ey/Hx mode measurements, on the other hand, cannot be made along the axis or along the perpendicular bisector of the transmitter due to the signal nulls along these axes.

Figure 3.4 sums up the primary plan-view limitations to CSAMT coverage for various modes of data acquisition. This figure is very diagrammatic in nature, and the patterns shown will change radically with different ground and logistical parameters. Figure 3.4a shows the zones of data acquisition for Ex/Hy measurements, and Figure 3.4b shows the corresponding zones for Ey/Hx measurements. These zones are broad and they allow considerable flexibility in where the measurements are taken. However, in the case where both Ex/Hy are Ey/Hx are obtained or where more than one transmitter is used, the zones in which measurements may be taken become rather narrow. For example, Figure 3.4c and 3.4d illustrate the much restricted zones for separated-transmitter and coincident-transmitter tensor measurements, respectively. Hence, tensor CSAMT requires a good deal of advance planning in order to locate the transmitters at the optimum positions relative to the area under investigation. This often requires a scouting trip to the field site to ascertain ground resistivity, cultural and access limitations, electrode grounding conditions, etc.

Topographic Considerations

Any electric field measurement will be affected by current density changes resulting from topography, and CSAMT is no exception. As described more fully in a subsequent section on interpretation, higher current densities are found in valleys, resulting in artificially high resistivities at depth, while lower current densities are found in hills, resulting in



Note: This is the severest case — things are a bit more flexible than shown.

Figure 3.4