Report On

**PRELIMINARY DESIGN FOR MUTI-ARRAY
BOREHOLE ELECTRICAL GEOPHYSICAL METHOD**

by

*Dale J. Green
and
Stanley H. Ward*

Earth Science Laboratory

University of Utah Research Institute
391 Chipeta Way, Suite C
Salt Lake City, Utah 84108
(801) 524-3422

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PRELIMINARY DESIGN FOR MULTI-ARRAY
BOREHOLE ELECTRICAL GEOPHYSICAL METHOD

1.0 Introduction

The technical direction given UURI, under Task 86-3 of Contract DE-AC03-84SF12196, for fiscal year 1986, reads as follows:

UURI Task 86-3 Development of Electrical Geophysical
Techniques for Mapping Fractures in Geothermal Systems

UURI has conducted theoretical studies to develop unique computer algorithms to model the response of several electrical geophysical techniques to fractures in geothermal wells. UURI is now at the stage of developing techniques to interpret field data from borehole-to-surface, surface-to-borehole, and borehole-to-borehole surveys. Current research will: (1) complete electrical model development and report the results, (2) begin development of an inverse method for interpretation of borehole resistivity data, and (3) study the specifications for a field data acquisition system.

This report addresses item (3) of the Technical Direction.

2.0 RATIONALE FOR TASK 86-3

The principal reason for the proposed research is to support cost-effective development of fracture controlled (or other complex) geothermal reservoirs. Depths of these reservoirs may be 300-3000 m. It is important to improve the utility of the first few drill holes by detailed characterization of the surrounding rock volume, to a radius of 30-100 m, and of the volume between holes. Electrical geophysics can assist in this characterization.

The proposed method will provide information on the locations of fluid-filled fracture zones, areas of wallrock altera-

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tion, and higher temperature/higher salinity fluids. The result of application of the methods should be fewer drill holes; and a higher percentage of successful wells. Because of the high cost of drilling geothermal wells, a higher success ratio and need to drill fewer wells would translate into substantial cost savings in the development of resources.

3.0 MULTI-ARRAY BOREHOLE RESISTIVITY AND INDUCED POLARIZATION METHOD

The multi-array borehole resistivity and induced polarization method (Figure 1) relates to a means of converting a conventional long lateral array used in well logging (current electrodes A_B and B) to a multi-array method capable of providing hole-to-surface ($A_B B M_S N_S$), and surface-to-borehole ($A_S B M_B N_B$) measurements. Rapid sequencing of electrode combinations is necessary so that all measurements are made before the logging sonde has moved significantly up the borehole.

The following sequence of measurements is envisioned:

1. $B \approx A_B M_B N_B$ long lateral
2. $B \approx A_B M_S(-4) N_S(-3)$ borehole-to-surface
3. $B \approx A_B M_S(-3) (N_S)(-2)$ borehole-to-surface
4. $B \approx A_B M_S(-2) N_S(-1)$ borehole-to-surface
5. $B \approx A_B M_S(-1) N_S(0)$ borehole-to-surface
6. $B \approx A_B M_S(0) N_S(1)$ borehole-to-surface
7. $B \approx A_B M_S(1) N_S(2)$ borehole-to-surface
8. $B \approx A_B M_S(2) N_S(3)$ borehole-to-surface
9. $B \approx A_B M_S(3) N_S(4)$ borehole-to-surface

10.	$B_{\infty}A_S(-4)M_BN_B$	surface-to-borehole
11.	$B_{\infty}A_S(-3)M_BN_B$	surface-to-borehole
12.	$B_{\infty}A_S(-2)M_BN_B$	surface-to-borehole
13.	$B_{\infty}A_S(-1)M_BN_B$	surface-to-borehole
14.	$B_{\infty}A_S(0)M_BN_B$	surface-to-borehole
15.	$B_{\infty}A_S(1)M_BN_B$	surface-to-borehole
16.	$B_{\infty}A_S(2)M_BN_B$	surface-to-borehole
17.	$B_{\infty}A_S(3)M_BN_B$	surface-to-borehole
18.	$B_{\infty}A_S(4)M_BN_B$	surface-to-borehole

MULTI-ARRAY BOREHOLE RESISTIVITY SURVEY

LONG LATERAL ARRAY — $A_B B_\infty M_B N_B$ *CONVENTIONAL LOGGING TRUCK

SURFACE-TO-BOREHOLE — $A_S B_\infty M_B N_B$ *POTENTIAL AND CURRENT
ELECTRODES ON SURFACE AND
BOREHOLE-TO-SURFACE — $A_B B_\infty M_S N_S$ DOWNHOLE

MISE-A-LA-MASSE ————— A_B in fracture zone *RAPID SEQUENCING THROUGH
 $M_B N_B$ or $M_S N_S$ ELECTRODES

FIGURE 1

As described in Section 4.1, 10 transmitter electrode combinations must be energized for each sequence of measurements. Using a transmitted waveform period of 0.5 to 1 second, 5 to 10 seconds will be required for the sequence. If these measurements are made in a 1 m interval, a logging speed of 6 meters to 12 meters per minute results. Electromagnetic induction effects, which are not accounted for in d.c. resistivity formulation, increase with frequency. The magnitude of these effects is not predictable. By testing the final system configuration, the shortest transmitter period which will result in the fastest logging speed without distorting the resistivity measurement will be chosen.

Referring to Figure 2, the electrodes A_S , M_S , and N_S can be in single section through the borehole for section surveys (electrode locations -4 through +4) or deployed at selected radial distances from the borehole for azimuth surveys (electrode locations a through h). The section survey in the surface-to-hole measuring mode is especially useful for determining depth to the center of the body while the azimuth survey is useful for determining the direction to the body from the borehole and the strike of the body. The hole-to-surface measurement may be best for locating the lateral position of the body.

The mise-a'-la-masse method is also accommodated by the multi-array. When the electrode A_B lies in the body, the body is directly energized. Then measurements of potential via $M_S N_S$ yield the conventional mise-a'-la-masse result.

MULTI-ARRAY BOREHOLE RESISTIVITY SURVEY

LOCATIONS OF A_s :	-4,-3,-2,-1,0,1,2,3,4	SECTION SURVEY
	a,b,c,d,e,f,g,h	AZIMUTH SURVEY

FIGURE 2

With all of the electrode positions used, electrical geotomography possibly can be used in interpretation. We visualize three-dimensional data inversion to effect interpretation analogous to seismic geotomography, an idea first suggested to us by Jeffrey J. Daniels of Ohio State University. There is a question, of course, as to the use of the word "geotomography" since it implies resolution approaching that of photography. Such resolution is not possible with the d.c. resistivity method.

4.0 INSTRUMENTATION FOR MULTI-ARRAY BOREHOLE ELECTRICAL GEOPHYSICAL METHOD

4.1 RECEIVER REQUIREMENTS

Within a small vertical movement of a logging sonde, the transmitter must be switched into 10 different current electrode pairs and 18 voltage measurements made; see Sec. 3.0 above for a description of the method. To reduce measurement time, a multi-channel receiver is proposed that will take the long lateral and all 8 borehole-to-surface measurements simultaneously. The 9 surface-to-borehole measurements must be made one-at-a-time.

A block diagram of this receiver is shown in Figure 3. Input protection is provided by series resistors, clamped diodes and a shorting-reed relay to positively prevent accidental transmitter connections from damaging the input stage. A high-impedance input instrumentation amplifier is next used to provide isolation and common-mode signal voltage rejection. The elec-

FIGURE 3

trode self-potential and very low frequency telluric voltages are cancelled with a 12-bit digital-to-analog converter which shifts the instrumentation amplifier's output. A notch-filter tuned to the power-line frequency removes interference from this source. For the type of signal sampling proposed for resistivity measurements, an anti-alias filter will not be required. Several signal-conditioning channels can be mounted on one printed circuit card.

Most amplification is obtained with multiplexing, programmable-gain amplifiers. The analog portion of the receivers will be in a separate chassis outside of the computer. To reduce noise, no active digital computer bus lines will be physically routed to the analog chassis. Instead, the analog gain and SP buckout controls will come from static registers loaded from the bus.

The analog output will be processed by an IBM AT (or compatible) computer with a data translation 12-bit analog-to-digital converter capable of 150 000 samples per second. Additional gain, from 1 to 8, is available on this module.

4.2 SIGNAL PROCESSING

For resistivity measurements, only a single point on each half-cycle of the transmitted waveform needs to be sampled. (A "single point" is defined as the average of at least 16 samples taken as rapidly as possible, approximately 107 microseconds elapsed time). This allows sampling of all nine analog channels

in less than 1 millisecond. It is expected that EM coupling effects may influence the measurement. Several points along the waveform will be sampled to evaluate this effect. An additional sampling time must be allowed for each transmitter electrode pair to measure the transmitted current, for computation of resistivity, and to enter other parameters such as depth of probe. The computer must also continuously set the gain and SP buckout voltage of each analog amplifier as the logging sonde moves up the hole.

The IBM-AT will be capable of processing much of the data in real time and possibly do all the final data reduction before leaving the site.

4.3 TRANSMITTER REQUIREMENTS

Each of the 10 transmitting electrode pairs has a unique impedance, each of which may require a unique setting of the transmitter's voltage and current controls. There are presently no high-power transmitters on the market which will allow these settings to be done automatically by a computer; they all require operator intervention. This is, of course, impractical for a continuously moving logging sonde. The differing voltage requirement for each electrode may be equalized by inserting power resistors into each line, the value to be determined in a pre-logging test. Even though the voltages are equalized in this manner, an adjustment will be required of the current to stay within the transmitter's operating bounds. According to Zonge

Engineering the output of a digital-to-analog converter (DAC) may be substituted for the transmitter's current control potentiometer on their series of transmitters. The DAC's input would come from the computer.

The above scheme is suitable only for transmitting into the surface electrodes where impedances remain constant. A much more complex situation is presented by the borehole electrode because it is continuously moving through areas of varying resistance. It is proposed to use a system of several resistors in series with the electrode which can be individually shorted by relays controlled by the computer. A predictive algorithm would compute the required resistance based on previous trends.

4.4 ELECTRODE ARRAY SWITCHING

One transmitter current electrode is always at the "infinity" point. The other 10 current electrodes (one borehole and surface) must each have a series relay to control which transmitter pair is selected. Additional relays must be placed in the receiver inputs to prevent damage. All relays can easily be controlled with the computer using one of a wide variety of available plug-in cards.

4.5 TRANSMITTER CURRENT REQUIREMENTS

Because the borehole receiver electrode spacing ($M_B N_B$) is small, consequently giving a small signal, it is expected that a high transmitter current will be required for surface-to-borehole

measurements. The recommended Zonge transmitter is capable of 25 amperes with certain impedances but this current may not be obtainable with the long separation required by the B electrode. Some compensation for low transmitter current is possible by increasing receiver amplification but this has limits because of natural, man-made, and instrumentation noise interference with the signal. We believe that the full power capabilities of the Zonge GGT-25 transmitter will be required.

5.0 PRELIMINARY COSTS TO BUILD A TEST FIELD SYSTEM

A. Salaries and Wages

1. Design and build multi-channel receiver	40 man-days
2. Design and build interface for above	10 man-days
3. Modify transmitter and interface to computer	5 man-days
4. Construct series resistor units	5 man-days
5. Construct relay switching	10 man-days
6. Procure parts	10 man-days
7. Drawworks, cable, sonde	<u>10 man-days</u>

80 X 8 = 640 hrs \$38,725

B. Purchase Services 8,650

C. Supplies 21,275

1. Wires and reels

2. Cable

3. Switching relays,
enclosures, etc.

4. Relay control card

D. Equipment

84,525

1. Zonge GGT-25 Transmitter

2. Vehicle, 4-wheel drive
1-ton, tandem wheels
on rear

3. Zonge ZMG-25 Motor-
generator

4. Multi-channel receiver
and interface

5. IBM-AT or compatible
computer with printer

6. Analog-to-Digital
converter

Total through burden &
fee

\$153,175

6.0 ANTICIPATED PROBLEMS

Programming the transmitter for the various transmitting electrode impedances to be encountered is the major problem anticipated. Accordingly, we plan to measure the impedance of all surface electrode pairs prior to logging. Then the sonde will be lowered in a borehole and a continuous record made of transmitting electrode impedance. With these two pieces of information we expect to be able to program the transmitter for logging uphole. However, it may be necessary from time to time to stop the sonde movement while manual adjustments are made for impedance matching.