APPLICATION OF ROVING BIPOLE-DIPOLE MAPPING METHOD TO THE CHINGSHUI GEOTHERMAL AREA, TAIWAN

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ABSTRACT

The roving bipole-dipole mapping method was used to explore the Chingshui geothermal area in Taiwan in 1978. This method was basically modified from single bipole-dipole mapping. Four pairs of current bipoles intersecting one another at 45 degrees were set up at the same station, and two pairs of receiving dipoles perpendicular to each other were used to observe potential differences at the field station. Two marked anomalies including surface geothermal manifestation and a blind region were delineated from the average resistivity and resistivity anisotropy pattern obtained by this method. Although more complicated procedure has to be taken in data reduction, it clearly reveals that this method is superior to single bipole-dipole mapping method in defining the resistivity boundaries and in predicting fracture zones at depth.

INTRODUCTION

The geothermal exploration program in the Chingshui area was commenced in 1973 and supervised by the Mining Research & Service Organization. The area is underlain by the Lower Miocene Lushan Formation consisting of slate and some thin quartzite interbeds. Geological, geochemical, and geophysical investigations have been carried out in this area. The highest temperature recorded is 228°C in one drill hole. Exploratory wells are still being drilled there by the Chinese Petroleum Corporation. The hot water is of the sodium bicarbonate type with pH values ranging from 8.5 to 8.9. In October, 1977, a non-condensing 1,500 KW pilot geothermal power plant was installed in the Chingshui area and has been operated successfully since then. The pilot plant was established for the purpose of experimentation and demonstration.

Geophysical investigations conducted in the area include shallow hole temperature survey, electric resistivity, and self potential surveys. The production zones with high ground temperature show resistivity lows and surface temperature anomaly. Telluric method was also tested in this area. It proves that this survey is a less expensive reconnaissance tool for regional mapping.

In order to obtain reliable resistivity anomaly in the metamorphic rocks of strong electric anisotropy, roving bipole-dipole resistivity survey was applied in the Chingshui and adjacent areas (Figure 1) in 1978. The results of resistivity and resistivity anisotropy partten are presented to show the fracture patterns and resistivity anomalies.

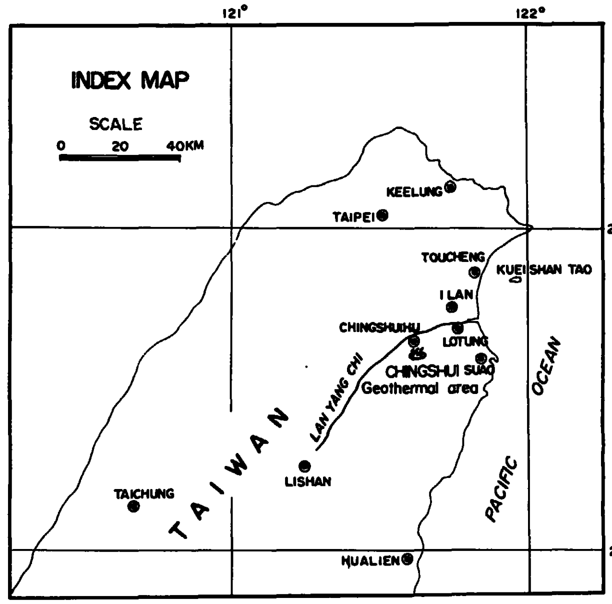

Fig. I. Index map of the Ching Shui geothermal area Taiwan.

ROVING BIPOLE-DIPOLE MAPPING METHOD

The use of electrical resistivity exploration techniques in geothermal exploration is based on the fact that rock saturated with hot water has a lower resistivity about 5 times than that of similar rocks with water at normal temperatures. The bipole-dipole mapping method which has been proved to be quite useful in determining the apparent resistivity of the geothermal area was first applied to Chingshui, one of the prospective geothermal areas in Taiwan in 1976. Two source bipoles with different orientations were set up at a distance of a few kilometers apart from each other. The results showed that large ambiguities were discovered at the same receiver site from the two source bipoles. It is well known that the location and orientation of source bipole with respect to resistivity structure will often form false anomalies. In order to improve the dipole mapping method, several papers have been written to study the use of two or three source bipoles to measure the earth resistivity by Keller and Furgerson (1975), Doicin (1976), Hall and Davis (1977), and Harhill(1978). The roving bipole-dipole mapping method which is characterized by the use of four pairs of source bipoles is basically modified from the dipole mapping method to acquire more reliable resistivity values.

The configuration of this method is shown in figure 2. Four pairs of current bipoles are set up at the same station intersecting one another at 45 degrees. Four different electrical fields are established by injecting electrical currents with continuous square waves through each current bipole. At each receiver site, four resultant fields are obtained from eight electrical field components, and thus giving four apparent resistivity values by use of their individual geometric factors. A single value, average resistivity, which is thought to be more reliable, is procured by averaging the four resistivity values. The resistivity anisotropy pattern is constructed by plotting resistivity vectors, resistivities vs. directions of the electric fields, in the receiver sites. By means of average resistivity and resistivity anisotropy pattern, it is hoped that this method may be capable of delineating the low resistivity boundaries and predicting the fracture zones at depth.

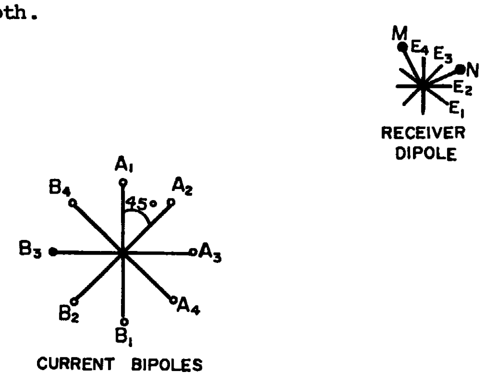

Fig.2. Electrode layout used for roving bipole—dipole mapping method.

INSTRUMENTATION AND FIELD PROCEDURE

Source bipoles, composed of four pairs of bipoles, are located approximately 4 km north of the surface geothermal manifestation. Each current bipole is 600m long. The azimuths of current bipoles are 0, 45, 90, 135 degrees. Power was provided to each bipole on schedule from a 30 KVA disel engine generator set. The 220v, 60hz, single-phase output of the generator was transformed to 400-1000v, rectified to form direct current which was driven to the earth through the current electrodes by transmitter. The time and duration of transmitting current for each current bipole was scheduled in advance. Continuous square wave, about 20 seconds per cycle, was applied by changing the direction of current flow. In order to assign a polarity to the voltage measured at the receiver site, the wave form of the current square wave was asymmetrical, with different durations in the opposite directions of current flow. The current intensities ranged from 4 to 8 A, depending mainly on the contact resistance of current electrodes in ground and the voltages applied.

Potential electrodes were set up in L-shaped array at each receiver site. The seperation of potential electrodes varied from 20m to 200m, depending on the distance between the current bipole and the receiver site and the signal strength they received. While lengthening the electrode seperation will enlarge signal amplitude, telluric noise will be magnified at the same time and seriously distort the record, particularly when the signal is weak. The farthest receiver site from the current bipole was about 10 km. The density of receiving station was greater than 4 points per square kilometer in average. Receiver sites totaling 384 were set up, covering an area greater than 90 km^2.

DATA REDUCTION

The procedures used to calculate the apparent resistivity for each current bipole are exactly the same as for dipole mapping. At each receiver site, four resistivity vectors (four resistivity values and their individual electric fields) are calculated, showing resistivity as a function of electric field which is established by current bipole. It is evident that changing the direction of current flow in bipole will theoretically reverse the direction of electric field without changing its intensity in every receiver site. Therefore, each direction of electric fields is reversed by adding or subtracting 180 degrees in azimuth, and the resistivity is kept the same value as its primary electric field has. This procedure generates eight resistivity vectors in total, with two of them identical in value, opposite in direction. The eight electric field directions, rearranged in order of azimuth, are assigned as θ_1-θ_8, and the corresponding resistivity values as ρ_1-ρ_8 respectively.

Drawing the resistivity vectors (ρ,θ) at fixed proportion of ρ, the anisotropy pattern which shows the relations between apparent resistivity and electric field is formed by connecting the tips of resistivity vectors (Figure 3). The average resistivity is obtained as follows:

$$\rho_{ave}=\left(\sum_{i=1}^{8}\Phi_i/\pi\right)^{\frac{1}{2}}=(\Phi/\pi)^{\frac{1}{2}}$$

The area, Φ , can be acquired either by planimeter or by means of computation.

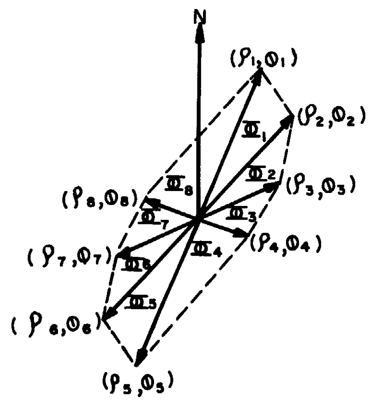

Fig.3. Schematic diagram of resistivity anisotropy pattern

RESULT

A computer program was designed to calculate the average resistivity derived from primary field data. 384 average resistivity values were made from 1536 apparent resistivity values and resultant electric fields. Figure 4 is a histogram showing the distribution of average resistivity values which range from about 20 ohm-meters in hot spring zones to several hundreds ohm-meters in background regions. The majority of average resistivity lies between 50 ohm-meters and 100 ohm-meters. The average resistivity map and resistivity anisotropy patterns map are shown in Figures 5 and 6 respectively.

21 rock samples, saturated with water, from the exploration area were tested for their resistivity values at different directions in relation to strike. It is shown that the resistivity values lie roughly between 100 ohm-meters and 1000 ohm-meters, the resistivity anisotropy coefficient is about 1.7-2.3, with max. resistivity value in the direction perpendicular to the bedding plane, and min. value in the direction parallel to the bedding plane.

In considering the fact that the resistivity of rock, saturated with hot water, will decrease obviously, the regions with average resistivity lower than 50 ohm-meters are regarded as the most significant low resistivity zones. From Figure 5, it is important to note that the region of surface geothermal manifestation coincides with zone of low resistivity. Some lows scatter to the south of the surface geothermal manifestation. Because of the rugged terrain, no further information can be provided to delineate resistivity boundaries away from the local lows toward the south. The other low resistivity zones are located along the stream Lan Yang Chi to the northwest of the exploration area. From the temperature gradients of the exploratory wells drilled by MRSO, the regions defined by 100 ohm-meters and 50 ohm-meters, which are about 3-4 times lower than the adjacent areas, may be related to geothermal activities.

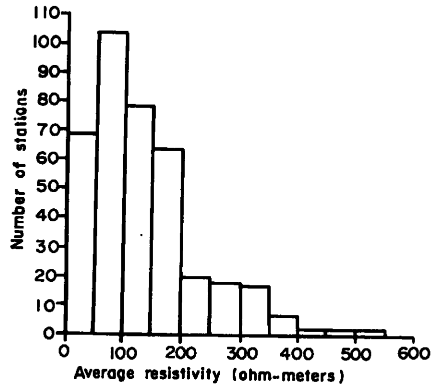

Fig.4. Histogram of averge resistivity values measured from roving bipole-dipole mapping meathod in the Ching-shui area.

The patterns in Figure 6 show the geoelectrical anisotropy. Because the patterns at all receiver sites are drawn in the same ratio of resistivity value, the variations of resistivity can be judged from the relative size of the patterns. The polarization of patterns, mainly resulting from the strong geoelectrical anisotropy of rock formations in this area, can provide valuable information about subsurface resistivity structure. Generally speaking, the strike is along the northeast direction with steep dip toward the southeast. As a consequence, the normal direction of polarization axis will trend northwest, perpendicular to the strike. Fracture zones at depth, associated with geothermal activity, may disturb the primary geoelectrical anisotropy in the rock formations and result in variations of polarization patterns.

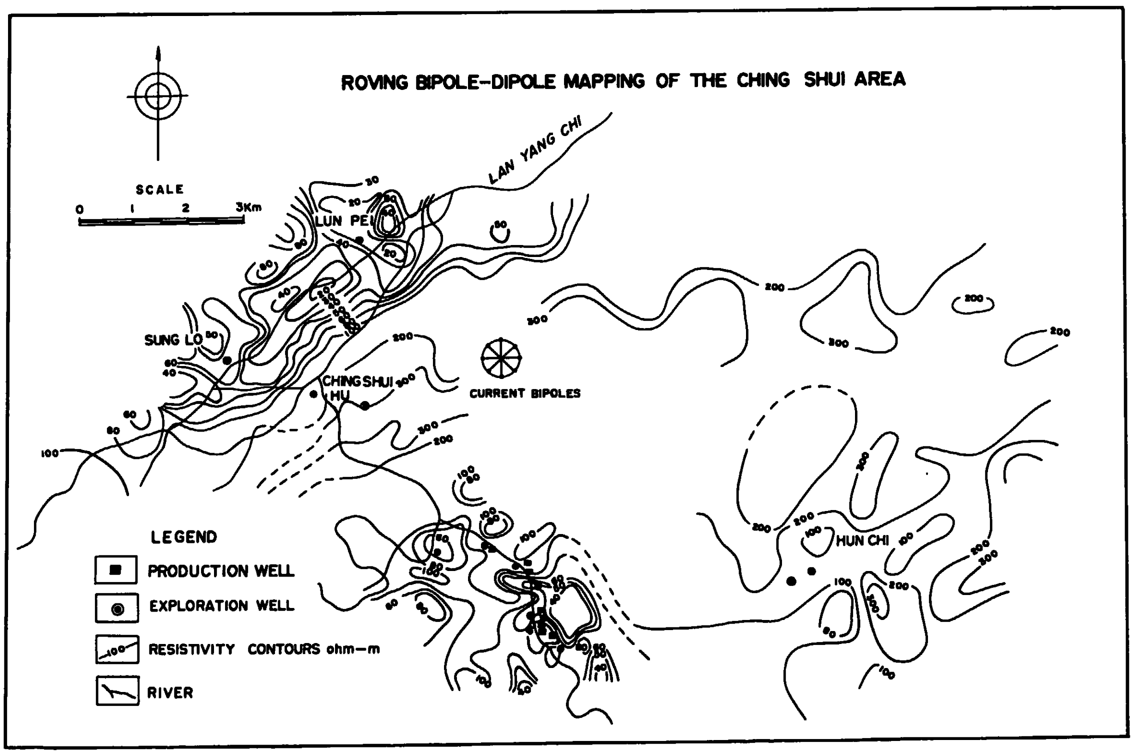

Fig.5. Average resistivity contours of the Ching Shui area.

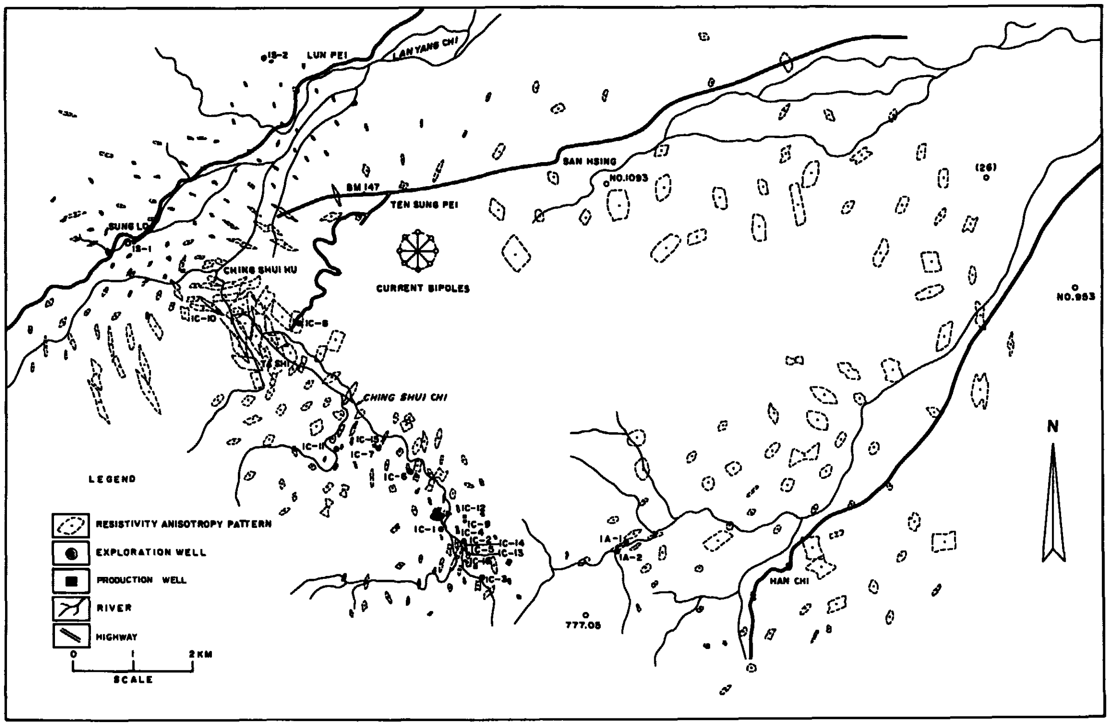

Fig.6. Resistivity anisotropy patterns of the Ching Shui area.

In the vicinity of surface geothermal manifestation, the patterns show a random arrangement in the directions of polarization axes, possibly caused by subsuface geothermal activities and fracture zones along which hot water is introduced. The patterns in the region along the Lan Yang Chi show two major types of polarization. The upper half part of this region, north of Sung Lo and Ching Shui Hu, is a normal type polarization, with directions of polarization axes approximately perpendicular to the strike. The exploratory well IS-2, located in the north corner of this region, shows a normal temperature gradient. Patterns of the lower half part where the temperature gradient of IS-1 is about $60^{o}C/km$ show the directions of polarization axes roughly parellel to the strike. The region between Ching Shui Hu and Ta Shi is an extremely high resistivity zone with strong polarization pattern in normal direction. It is believed that this is caused by an anticline composed mainly of quartzite with poor permeability underlying the surface deposits of the Ching Shui Chi at shallow depth. Resistivity highs with patterns of circular polarization, i.e. less anisotropy in formation, were found in the eastern part of the exploration area and thought to be of little relation to geothermal activities.

CONCLUSIONS

The results clearly reveal that there are two obivious anomalies in resistivity and anisotropy pattern. One is located near the surface geothermal manifestation, the other is distributed to the northwest along the stream Lan Yang Chi. Therefore, in addition to the surface geothermal manifestation, the northwest part of the exploration area is also considered to be closely related to geothermal activities. This inferrence is substantially surpported by the termperature gradients of exploratory wells, drilled by MRSO.

The roving bipole-dipole mapping method can provide two kinds of essential information(average resistivity and resistivity ansotropy pattern). As compared to the single bipole-dipole mapping applied in the same area in 1976, roving bipole-dipole mapping method is proved to be superior to the former method in delineating the resistivity boundaries and in predicting the fracture zones at depth.

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