COMBINED ELECTROMAGNETIC AND GALVANIC (d.c.) ELECTRICAL RESISTIVITY SOUNDINGS

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The problem often encountered in the exploration for geothermal resources by any geophysical method is the complexity of the geologic setting. Because the known geothermal fields of the world are associated with crustal block movement, volcanic activity, faulting and fracturing systems, (Combs, 1975) two and three dimensional geologic structures are normally encountered and have to be considered when planning an exploration program. Electrical resistivity methods have been very successful in locating areas of low resistivity associated with geothermal resources, but resolving the complexity of the geoelectric structure is difficult because of the high cost of detailed surveys or because of weaknesses inherent in some of the less expensive methods, such as galvanic or telluric current methods. Dissatisfaction with the magnetotelluric method as a detailing tool has been expressed (Goldstein, 1978) because two dimensional structures, such as near surface inhomogeneities, strongly affect the tensor impedances.

A new combination of three of the basic electrical methods, galvanic, controlled source electromagnetic and telluric profiling methods, is suggested as an alternative detailing tool which can provide less ambiguous results at a reasonable cost. This combined method will be referred to as Electro-Sonde Profiling (ESP).

A plan view of the ESP scheme is shown in Figure 1. A grounded source bipole is located in conjunction with at least one parallel ESP profile, such that the center of the profile is located along the perpendicular bisector of the bipole and is separated from the bipole by a distance "r". A receiver unit traverses the profile and records on magnetic tape the electric field measurements obtained at the twelve adjacent sites utilizing a receiver dipole $\overline{MN}$ and source bipole $\overline{AB}$. At every second or at least every fourth receiver site, the vertical and radial (horizontal) components of the magnetic field generated by the subordinate source bipoles $\overline{AC}$ or $\overline{CB}$ are recorded. Bipole $\overline{AC}$ is energized only when the magnetic field is required along the left-hand half of the profile and dipole $\overline{CB}$ is energized only when the magnetic field is required along the right-hand half of the profile. Utilization of the shorter bipoles provides a better approximation of a dipole source as required by the theory of electromagnetic soundings (Vanyan, 1967). A schedule of alternating periods of power on (source bipole energized) and power off (source bipole not energized) allows recording of both the actively and passively generated electric fields at the surface of the earth. The ratio of the passive electric fields (end-on-end tellurics) can then be determined (Beyer, 1977). A summary of the six parameters measured along the profile are given on Figure 1.

The distribution of the frequency and the relative depth of penetration of each of these six measurements in an H-type geoelectric section is shown in Figure 2. Given that the profile separation "r" is large, a nearly complete probing of a conductive basin is accomplished by this combined technique as opposed to tensor magnetotelluric soundings which may show incomplete sounding curves in the 0.1-5hz frequency band due to low coherency between orthogonal electric and magnetic fields. Lateral and vertical resistivity variations are readily determined along the profile because of the continuous set of electromagnetic soundings and telluric electric field ratios. Multiple profile coverage in an area of complex geologic structures will aid in the determination of the three dimensionality of the exploration problem.

Interpretation of the electromagnetic soundings can be accomplished by curve-matching techniques, (Banyan, 1967) comparison of field curves with computer generated sounding curves, and inversion techniques (Anderson, 1974; Anderson, 1977).

In addition to the profiles, a set of modified Schlumberger depth soundings are obtained along the source bipole $\overline{AB}$ (see Figure 1). This is done by expanding a short receiver dipole collinearly from both source electrodes towards the center of the bipole. The depth of penetration of the array is equivalent the distance from the closest electrode to the center of the dipole. This array is much more sensitive to lateral resistivity variations than a Schlumberger sounding so vertical and horizontal resistivity variations can be observed in the determined sounding curves. Equatorial soundings constructed from the static parallel electric field along the profiles extends the depth of penetration of the galvanic sounding.

The advantages of this detailing scheme can be briefly stated as:

(1) The collective use of galvanic and electromagnetic depth soundings provides definition of the longitudinal and transverse resistivity of layers within a multi-layered earth. These can be an important set of parameters in many geophysical problems.

(2) The controlled source electromagnetic soundings provide definition of the electrical resistivity variation beneath and in the vicinity of the receivers, but are less affected by lateral resistivity variations than passive electromagnetic soundings or galvanic soundings.

(3) ESP field logistics are simpler than for galvanic profiling or sounding techniques that attempt to achieve similar depths of penetrations, especially in moderately difficult terrain.

(4) The end-on-end telluric profiles and electromagnetic soundings are inductive techniques that provide better definition of conductive layers and are not screened by near surface resistive layers as galvanic methods are.

(5) The sub-audio EOE tellurics will be more definitive in mapping basement structure because the upper section conductance will be determined by the electromagnetic soundings.

(6) This combined method is not as dependent upon the existance of suitable natural electromagnetic field amplitudes since only the peak energy in the spectrum is required.

(7) ESP is less expensive and more definitive than telluric-magnetotelluric surveys in complex areas.

Several detailed field surveys have been conducted in the Western United States utilizing ESP profiles and more definitive results were obtained than from conventional electrical resistivity surveys that could have been completed at a similar cost (Pritchard and Zebal, 1978). This was especially true in those areas which contained a considerable thickness of moderately resistive material above the conductive layer.

The versatility of this technique lends itself to solving both geothermal and petroleum problems where complex geologic settings occur. However, it must be remembered that while less ambiguous results can be obtained from this type of survey, a certain degree of ambiguity will exist in the interpretation of any geophysical data obtained in complex areas.

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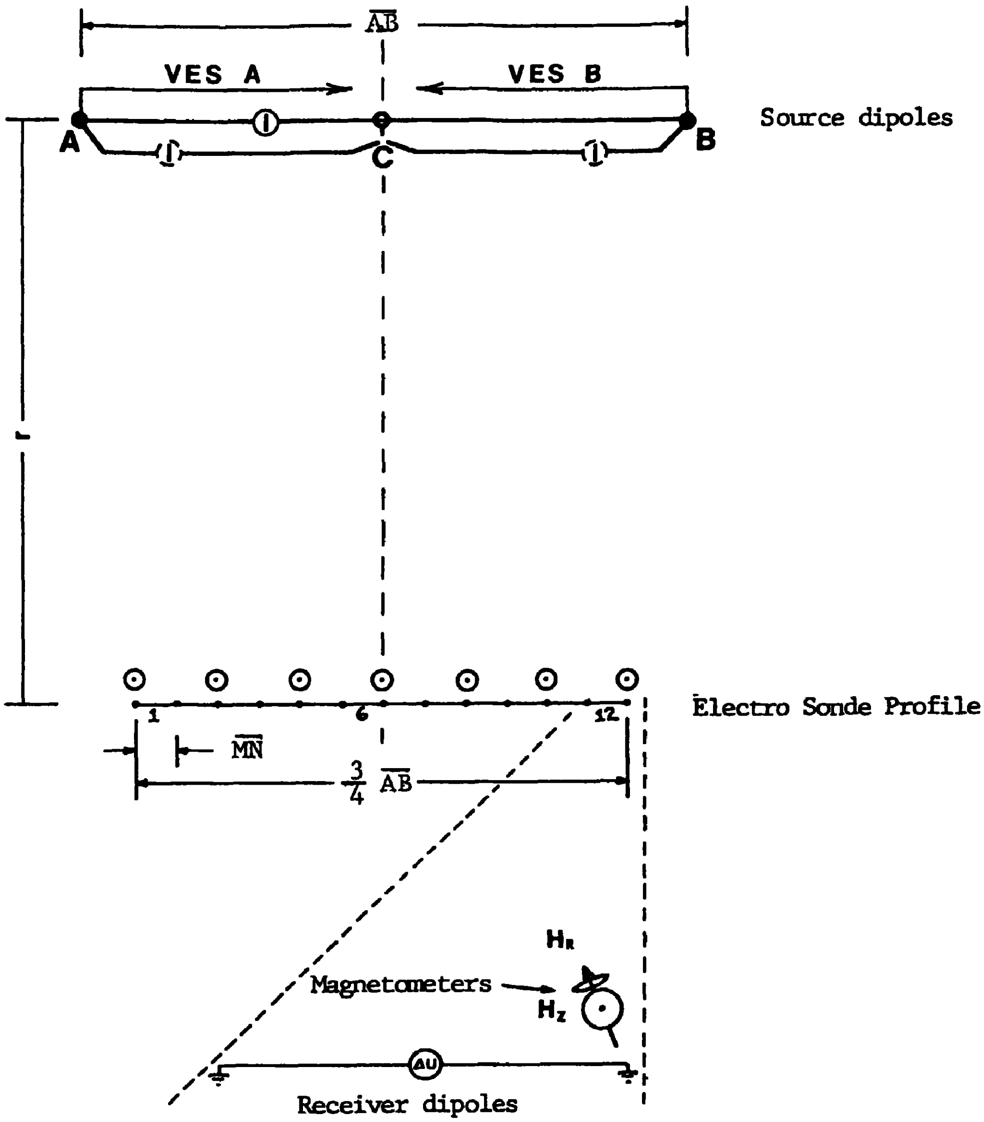

LEGEND

H_Z Time domain vertical magnetic field response (0.08-10hz equiv.)
H_R Time domain horizontal radial magnetic field response (0.08-10hz equiv.)
ΔU_{AT} End-on-end audio-telluric response (8-32hz)
ΔU_{EMP} Parallel electric field time domain response (0.8-10hz equiv.)
ΔU_T End-on-end telluric response (0.02-0.06hz)
ΔU_{DCP} Parallel static electric field response (0.0hz equiv.)
VES A Modified Schlumberger sounding

Figure 1. Electro Sonde Profile scheme.

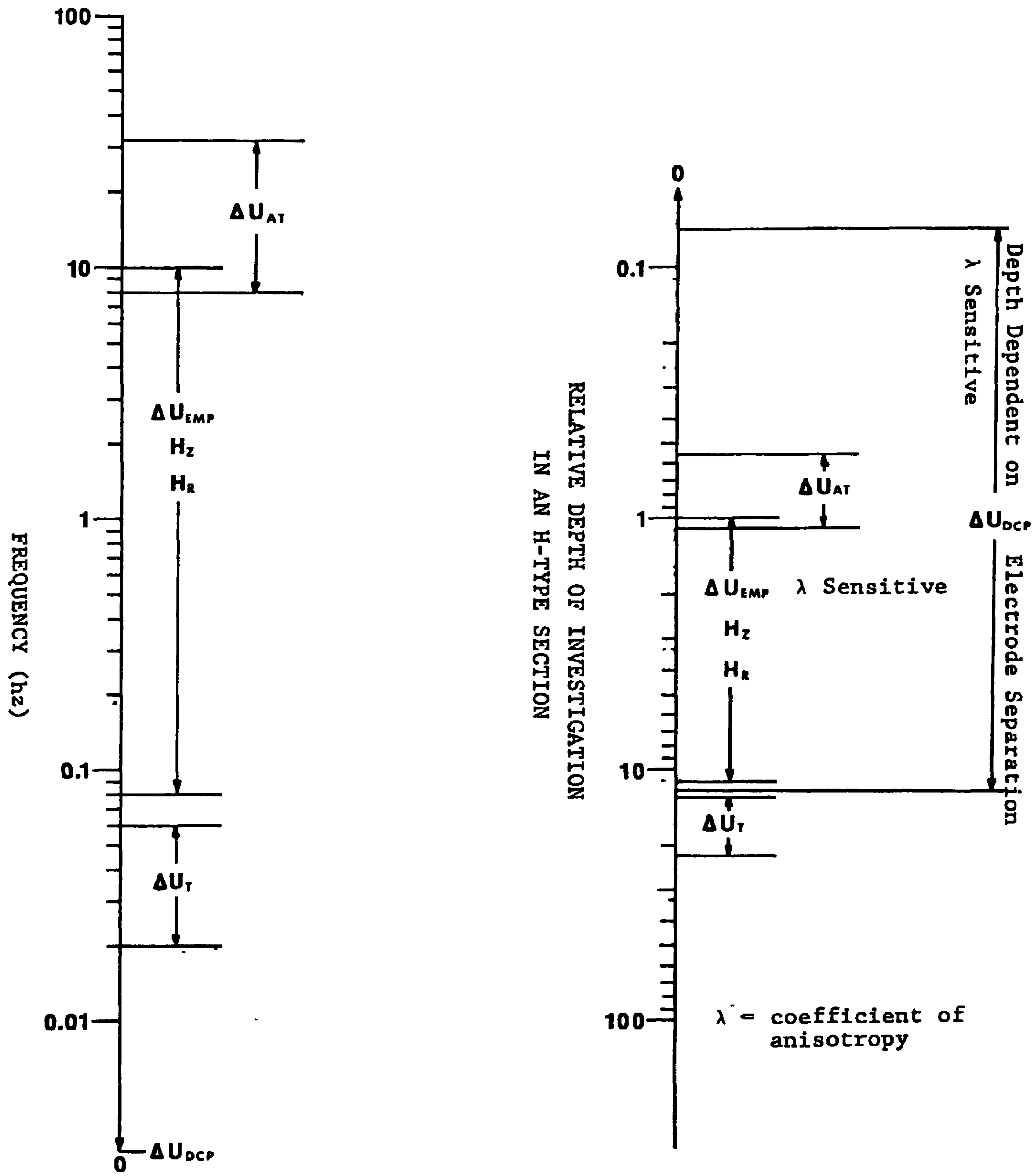

Figure 2. Frequency distribution and relative depth of investigation of the various Electro Sonde Profiling measurements. See Figure 3 for definition of the abbreviations.