Evaluation of Airborne Electromagnetic Surveys for Geothermal Exploration

by

Karen Christopherson*, Carl Long*, and Don Hoover*

In 1979, the U.S. Geological Survey in cooperation with the U.S. Department of Energy Office of Advanced Technology Projects conducted INPUT+ airborne electromagnetic (AEM) surveys in five Known Geothermal Resource Areas (KGRA's). In the past AEM surveys have not had significant utilization for geothermal exploration because it was thought that a shallow exploration tool could not be useful, particularly in conductive environments. Extensive AMT (audio-magnetotelluric) work by the U.S. Geological Survey in KGRA's, however, suggested that many geothermal systems had sufficient near-surface electrical expression to be detected by a deep-looking AEM survey. The results of this AEM test in Steamboat Hot Springs, Nevada, is evaluated along with previous geophysical work.

The geology and thermal history of the Steamboat Springs area is well documented in 1960's studies by D. E. White and others. During 1974 and 1975 AMT, telluric, E-field ratio telluric, and self-potential surveys were made in the Steamboat Springs KGRA to supplement geologic data. These supplemental data identified a significant north-trending conductive zone within the KGRA that was offset west of the area of surface thermal manifestations and abruptly cut off on the south.

+Trademark Barringer Research Ltd. Use of trade or brand names in this report does not constitute endorsement by the U.S. Geological Survey.
*U.S. Geological Survey, Denver Federal Center, Mail Stop 964, Box 25046, Denver, Colorado 80225.
Inversion of the AMT data and modeling of the INPUT response showed that this conductive zone should be identifiable as a conductor within a relatively conductive host background. Results of the AEM work, nested INPUT profiles and channel ratio maps, clearly revealed the presence of the north-trending conductor. It is the most significant conductive zone in the KGRA as suggested by the earlier data. Similar results in the other KGRA's flown (Raft River, Long Valley, Surprise Valley, and Wabuska) show that deep looking AEM methods can be effective in the search for and definition of geothermal systems.

Because of the success of this survey, helicopter AEM work is planned for flying in the Cascades during the fall of 1980.
During 1979, the U.S. Geological Survey contracted for using PE method airborne electromagnetic surveys, specifically, INPUT surveys, to be flown over five known geothermal resource areas in the Western U.S. The work was done in cooperation with the Dept. of Energy, who provided major funding at the project.

In the past, airborne electromagnetics had not been utilized for geothermal purposes because it was thought that a shallow exploration method would not be effective. However, extensive audio magnetoTelluric work done by the USGS in the KGRA's showed that many geothermal systems do have near-surface electrical signatures which should be detectable by airborne electromagnetic work.

The main purpose of this study was to determine the reliability of an airborne electromagnetic technique as a reconnaissance tool in geothermal exploration.
This was done by comparing results of the airborne surveys with previous ground geophysical studies in the five KGRA's.

The five areas studied were Surprise Valley, Mono Valley, California; Wabuska + Steamboat Hills, Nevada + Raft River, Idaho. Steamboat Hills will be discussed further in this talk.
The INPUT airborne electromagnetic system was developed by Barringer Research and this project was flown by Questor Surveys.

The INPUT survey is conducted by an aircraft flying 400' above the ground towing a bird on a 400' cable.

A horizontal coil around the aircraft generates a primary electromagnetic field at a fund freq. of 144 hertz. The primary field creates eddy current in buried conductors which in turn generate a secondary electromagnetic field. Both the primary and secondary field are recorded through the receiver in the bird.

The primary field is transmitted as 1/2 sine wave pulses of 1 millisecond duration separated by 2.47 millisecond off time.

The primary field is detected by the receiver in the bird as the 2nd set of curves. The secondary field occurs as a decay curve of the rate of decay proportional to the conductiveness of the body. A slower rate of decay would signify a good conductor and vice versa. This is illustrated in the third set of curves.
The decay curve is sampled a six times or gates after the primary pulse ends. The first gate is at 310 microsec and the sixth at 2.11 millisec with the other gates at times shown at the bottom of the far slide.

The gates are recorded both on digital tape and analog record. A sample of an analog record from Steamboat Hills is on your left. It shows traces of the six INPUT channels over a good conductor, where Channel 6 is the deepest penetration channel.

The INPUT system also monitors 60 Hz power, the top trace on the record, along with the total magnetic field in gammas and altitude of the aircraft in feet.
Steamboat Hills is located about 10 miles south of Reno in western Nevada within the Basin and Range Province. The KGRA lies in a valley between the Carson and Virginia Ranges.

For the study of the Steamboat Hills KGRA, INPUT airborne electromagnetic and magnetic measurements were compared with ground telluric, audiomagnetotelluric, and self-potential studies by the USGS and geologic work done by White and others in the 1960's.

The northern part of the Steamboat area is covered mostly by Quat. alluvium lying on relatively flat terrain. To the south, exposures of metamorphic and igneous rocks comprise Sbt. hills which have a topographic relief of about 1000' above the valley. Comprising Sbt. hills are a Quat. Rhy dome is exposed to the SW. Another dome is proposed by White (point out) and others lie to the NE. Thus there is a trend of N N45E along which these domes lie.

There has been extensive recent faulting mostly of northerly + northwesterly trends.

Sixteen deep's surround the areas of present geothermal manifestations near the highway where there is a line of numerous h. spgs. This has been area of greatest exploration effort in the past. Other h. spgs + hot wells lie to the west and north also.
I'd also like to point out a subtle N-S trend through the saddle at the high and the rhyolite dome. This trend is not apparent on surface geology, and is also apparent in the geophysical data. The strike of this high could be misinterpreted as a body of intrusive material, and the depth to the top was measured by aerial photography. This high could be a rhyolite dome and the intrusive body of rhyolite could have been extruded to the north.

The most striking feature appears to be a high of 2000 gamma over a hill on the beach. The most likely feature is the hill to the north. This interval is 50 gamma higher, and values appear to drop off of the hill. The contour is shown in 100 gamma and this is considered significant.
The INPIT survey was flown with W-E flight lines spaced 1/4 mile apart. INPIT data can be presented in many forms; here we have used nested profiles + a channel ratio map.

Nested profiles of the channel, the deepest looking channel with a probe max penetration of 150 meters. Ch. 6 response is plotted along the flight lines with large amplitude waves denoting higher conductivity or lower resistivity zones. These may be of interest in geothermal exploration since low resistivities can result from alteration or presence of geothermal or saline waters. Here the most conductive zones lie to the NE, change increases abruptly to the west and south.

The data is also presented on a channel ratio map on the right. This contours the ratio of ch. 6 to ch. 3 where the higher numbers (red to yellow) designate more conductive regions or deeper conductors. The channel ratio map again shows the most conductive region lying to the NE, being cut off abruptly to the W + S.

For comparison with the ground geographical data, the nested profiles will remain on the left screen.
A standard or T-value telluric survey was done using 1 base sta and 11 rover stas located approx. 1 mile apart. Signals were measured at a 10 to 70 sec. period or .1 to .014 Hz freq. which samples a skin depth of 5 to 13 km in 10 rm earth.

The base sta was located on Sot. hills and given a value of 1.0. The ratios of rover to base are plotted & contoured on your right.

The lowest resistivities trend N-S. Thus the middle of the KGRA cutoff across geologic boundaries and coinciding with the conductive bend shown by the heated profiles. Resistivity decreases most to the N to <1/10 of the base sta. value.
Two telluric profiles were made running EW using 300 m dipoles. Signals were filtered to a freq. of 0.03 Hz on a 30 sec period resulting in a depth of investigation of several kilometers.

The profiles of relative voltage, which is equiv. to sq. root of resistivity, show significant drop in resistivity in middle of KGRA. The resistivity change is greater on the longer, or more northerly, profile. The blue lines mark the flanks of low.

When shown in plan view again, the low within the blue lines trends north with resistivity decreasing to NE N. This low coincided with the low mapped by the standard telluric survey and the nested profiles.
Several self-potential lines were run, mostly in E-W direction. The changes in self-potential voltage relative to the base station are contoured with 20 mv contours. Value range from \(-80\) to \(+100\) mv.

Most obvious features are 2 elongate lows, shown in purple, and 1 high, shown by red, trending N-S, near the middle of the KGRA.

The elong. hi and lws to the NE are defn. assoc. with the geothermal anomaly. Uplifted fluids can produce a horiz dipole, i.e. a hi flanked by a low, although it is unexplainable why there are 2 lows assoc. with the hi. Regardless, these features are clearly connected with the N-trending structure defined by 2 telluric methods. The high lies on the flank of the low resistivity trend shown by tellurics.

The low mv readings in the south are most likely caused by topography or an increase in elevation on Sbt. Hills.
25 AMT sites were done most 20x with a 1 m station spacing.

The USGS AMT system measures 12 props from 7.5 kV to 18.0 kV.

The P values at each site were log averaged for test the two orthogonal Erden directions plotted and contoured.

The 27 hertz map shown on right plots P values with logar. contours where warm colors indicate lower resistivity.

Skin depth at 27 hertz is ~300 m in 10 am material.

Lowest values to NE increase abruptly to W + S

with high over 566 hills. Lows asoc. w/ li. sexes

& increase depth of sed. in valley.

The 7.5 hertz map of skin depth of ~600 m in

10 am rock show same pattern - low to NE

gradient to W + S. Gradient to W in same trend
defined by tellurics, aeromag, & s.d., INPIT.
Summarize results in Steamboat Hills area

SL. 12

Ground geophysical techniques detected a deeper low p trend N-S + not connected w/ mapped geologic units or surface faulting.

Most of the NE of the KGRA is marked by a narrow surface low p zone which increases abruptly to W + S

SL. 14

The airborne INPUT technique mapped a narrow surface conductive zone which coincides with that mapped by the ground techniques. The western gradient in trends through the lower north-trending conductor shown by ground methods.
AMT apparent resistivity maps, the most conductive zone apparent on the nested profiles lies to the northeast of Wabuska. This coincides with lower resistivities of the AMT survey.

The southern part of the KGRA shows no major conductors. Conductors trending north-northwest in the northern part of the KGRA could be associated with faulting in the volcanic hills.

In conclusion, the INPUT airborne electromagnetics proved very effective in detecting major conductors within the five KGRA's surveyed. These major conductors coincided well in most cases with conductive zones mapped by previous magnetotelluric work. At the same time the INPUT work provided a much larger data base since it collects continuous data along the flight lines.
Since these flight lines are usually spaced 1/4 to 1/2 mile apart,
compared to the 1-2 mile spacing between AMT stations.
The INUIT method not only gives a more reliable
and larger
data net but also is capable of detecting
smaller conductors.

For these reasons, airborne techniques like INUIT
can be a useful tool in locating areas of low
resistivity for further study in geothermal regions.
At this time the USGS has more airborne surveys
planned for flying in some of the Cascade geothermal
areas.