Evaluation of Airborne Electromagnetic Surveys for Geothermal Exploration

by

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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.

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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.

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SEG '80

Steamboat Hills

During 1979, the U.S. Geological Survey contracted for airborne electromagnetic surveys, ~~specifically~~ using the INPUT ~~surveys~~ method, to be flown over five know geothermal resource areas in The Western U.S. The work was done in cooperation with the Dept. of Energy, Office of Adv. Tech. Prjts who provided major funding of 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 and ... 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 + Long 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 currents in buried conductors which in turn generate a secondary electromag 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 millisec duration separated by 2.47 msec of 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 w/ the rate of decay proportional to the conductiveness of the body. A slower rate of decay would signify a good conductor + 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

Slide 2 The gates are recorded both on digital tape and analog records. 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 penetrating channel.

The INPUT system also monitors 60 hz power, the top trace on the record, along with the total magnetic field in gammas + altitude of the aircraft in feet.

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Slide 3 Steamboat Hills is located about 10 miles south of Reno in Western Nevada within the Basin + Range Province. The KGRA lies in a valley between the Carson + 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 + others in the 1960's.

The northern part of the Steamboat area is covered mostly by Quat. alluvium lying on ~~of~~ relatively flat ~~topographic~~ terrain. To the south, exposures of metamorphic and igneous rx comprise Sbt. Hills which have a topo 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 ~ N45E along which these domes lie.

There has been extensive recent faulting mostly w/ northerly + northwesterly trends.
Sinter dep's surround the areas of present geothermal manifestations near the highway where there is a line of numerous h. sprgs. This has been area of ~~[illegible]~~ greatest exploration effort in the past. Other h. sprgs + hot wells lie to the west and north ~~of the~~ also

[illegible]e 4

Slide 4

The magnetic data collected by the INPUT survey are contoured and shown on the left. The contour interval is 50 gammas and the warm colors signify higher values.

The most striking feature is the hi to the N; this lies beneath fairly flat terrain of Quat. alluv. Here there is a change of ~1000 gammas over ~1 mi. distance. I assumed that this high is caused by an intrusive and estimated its depth by the slope distance and ½ width rules. These gave a depth to the top of the body of between 500 and 700 meters. The intrusive could possibly be a rhyolite dome and a heat source. The exposed dome to south is under a magnetic high + the high to north lies roughly along the NE trend of exposed rhyolite domes.

I'd also like to point out a subtle N-S trend through the saddle of the high and the flexures in the contours. This trend ties in well with other geophysical data and is not apparent on surface geology.

[Sli]de 5

Slides

The INPUT survey was flown w/ EW flight lines approx 1/4 mile apart. INPUT data can be presented in many forms; here we have used nested profiles + a channel ratio map

Nested profiles were made of ~~the~~ channel 6, the deepest looking channel w/ a prob max penetration of 150 meters. Ch. 6 response is plotted along the flight lines w/ the larger 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 + the resistivity ~~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 (reds + yellows) 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 geophysical data, the nested profiles will remain on the left screen.

Slide 6 — Slide 4

A standard or J-value telluric survey was done using 1 base sta and 11 rover sta's. 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 Ωm earth.

The base sta was located on Sbt. Hills and given a value of 1.0. The ratio's of rover to base are plotted + contoured on your right.

The lowest resistivities trend N-S. thru the middle of the KGRA cutting across geologic boundaries and coinciding w/ the conductive trend shown by the nested profiles. Resistivity decreases most to the N to <1/10 of the base sta. value.

~~Slide 7~~ Slide 7 Two telluric profiles were made running EW using 300 m dipoles. Signals were filtered to a freq. of .03 hz or a 30 sec period resulting in a depth of investigation of several kilometers.

Slide 8 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.

Slide 7 When shown in plan view again, the low within the blue lines trends north w/ resistivity decreasing to the N. This low coincided with the low mapped by the standard telluric survey and the nested profiles

Slide 9

Several self-potential lines were run, mostly in E-W direction. The changes in self-potential voltage relative to the base station are contoured w/ 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 elon. hi and lo's to the NE are defin assoc. w/ the geothermal anomaly. Upwelling fluids can produce a horiz dipole, ie a hi flanked by a low, altho here it is unexplaindable why there are 2 lows assoc. w/ the hi. Regardless these features are clearly connected w/ the N-trending structure defined by the two 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

AMT

25 AMT sta's were done most ~~up~~ with a 1 mi station spacing. The USGS AMT system measures 12 freqs from 7.5 hertz to 18.6 K hz
The ρa values at each stat were log averaged for ~~tot~~ the two orthogonal
S1.10 E-line directions, plotted + contoured.

The 27 hertz map shown on right plots ~~conto~~ ρa values with logar. contours where warm colors indicate lower resistivity. Skin depth at 27 hertz is ~300 m in 10 Ωm material.

Lowest values to NE increasing abruptly to W + S w/ highs over Stb. Hills. Lows assoc. w/ h. springs + increasing depth of sed. in valley

S1.11 The 7.5 hertz map of skin depth of ~600 m in
S1.12 10 Ωm rock shows same pattern - low to NE gradient to W + S Gradient to W on same trend defined by tellurics, aeromag, + S.P., INPUT.

Summarize results in Steamboat Hills area

Sl. 12 Ground geophysical techniques detected a deeper low ρ trend N-S + not connected w/ mapped geologic units or surface faulting.

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

Sl. 14 The airborne INPUT technique mapped a near surface conductive zone which coincides with that mapped by the ground techniques. The western gradient also trends ~~through~~ along the ~~low north trending~~ deeper 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 resistivites 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 audiomagnetotelluric and other geophysical 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.~~

~~Thus~~ The INPUT 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 INPUT

can be a useful tool in ~~the~~ 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.