Integration of Full Tensor Gravity and Z-Axis Tipper Electromagnetic Passive Low Frequency EM Instruments for Simultaneous Data Acquisition

Final Technical Report

Period Covered: September 2011 – December 2014

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PROJECT INFORMATION

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EXECUTIVE SUMMARY

Ground gravity is a common and useful tool for geothermal exploration. Gravity surveys map density changes in the subsurface that may be caused by tectonic deformation such as faulting, fracturing, plutonism, volcanism, hydrothermal alteration, etc. Full Tensor Gravity Gradient (FTG) data has been used for over a decade in both petroleum and mining exploration to map changes in density associated with geologic structure. Measuring the gravity gradient, rather than the gravity field, provides significantly higher resolution data. Modeling studies have shown FTG data to be a viable tool for geothermal exploration, but no FTG data had been acquired for geothermal applications to date.

Electromagnetic methods have been used for geothermal exploration for some time. The Z-Axis Tipper Electromagnetic (ZTEM) was a newer technology that had found success in mapping deep conductivity changes for mining applications. ZTEM had also been used in limited tests for geothermal exploration. This newer technology provided the ability to cost effectively map large areas whilst detailing the electrical properties of the geological structures at depths. The ZTEM is passive and it uses naturally occurring audio frequency magnetic (AFMAG) signals as the electromagnetic triggering source.

The ability to map and isolate different geologic features of varying densities from an airborne platform allows exploration of large land areas in difficult terrain, remote locations, and sensitive ground environments quickly and efficiently. This allows for survey data to be acquired with no or significantly reduced costs and delays caused by obtaining permits and landowner permissions for ground surveys. Additionally, high potential targets can be quickly generated for more detailed ground follow up. Traditionally, due to limited budgets, companies have had to choose whether to acquire FTG or ZTEM over an exploration property. Combining these technologies onto a single aircraft for simultaneous acquisition was expected to increase acquisition efficiency with minimal impact to the individual systems performance compared to acquiring both of these technologies on separate platforms. Finally, these data combined with other available geological, geophysical, and remote sensing data could have been used for an integrated interpretation that provided a higher confidence model, and increased accuracy over the interpretation of any one of these technologies individually.

These geophysical methods were to be tested over a known geothermal site to determine whether or not the data provided the information required for accurately interpreting the subsurface geologic structure associated with a geothermal deposit. After successful acquisition and analysis of the known source area, an additional survey of a “greenfield” area was to be completed. The final step was to develop a combined interpretation model and determine if the combination produced a higher confident geophysical model compared to models developed using each of the technologies individually.

PROJECT GOALS AND ACCOMPLISHMENTS

GOALS

Bell Geospace and its partners were to (1) combine airborne full tensor gravity (FTG) and the Z-axis Tipper Electromagnetic (ZTEM) deep penetrating, low frequency, passive electromagnetic exploration system onto one airborne platform for simultaneous acquisition; (2) test the applicability of each of these technologies for geothermal exploration over a known geothermal deposit; (3) if the initial tests successfully showed the usefulness of these combined technologies, test surveys were to be acquired over a more “greenfield” area; and (4) use the ZTEM, FTG, and Passive Magnetic data, all acquired simultaneously, to perform an integrated interpretation that could be used to determine whether or not a combined interpretation produced a higher confident geophysical model than any one of the technologies by itself.

ACCOMPLISHMENTS VS. GOALS

The manufacturing and integration of the winching system for the ZTEM antenna, antenna capture system, and ZTEM electronics, on the Bell Geospace Basler BT-67 (turbine DC-3), were completed by Lake Central Air Services. The system installation was based on a previous towed sensor installation which minimized the design and certification aspects.

Once the system was installed all aircraft dynamic flight performance testing was completed to support final Transport Canada Supplemental Type Certification. Both of these subtasks of goal #1 were competed, ahead of schedule, by the end of Q2 2012.

Due to aircraft and survey equipment availability to complete testing of the tow cable, and the dependency of the remaining project goals, no additional goals were accomplished.

PROJECT SUMMARY AND CONCLUSION

SUMMARY

The integration and initial dynamic flight testing were completed with no issues and ahead of schedule as stated previously. At the start of Q3 2012, the aircraft was relocated to the initial test survey area to continue calibration testing of the ZTEM survey equipment installed. During the ground checkout of the ZTEM installation the system functioned as intended, but during the ZTEM calibration flights the system stopped functioning. After significant troubleshooting, it was determined the wiring inside the tow cable connected to the ZTEM deployed antenna had failed. The field testing and analysis showed the conductors inside the tow cable were broken in multiple locations. Due to the aircraft availability, additional analysis time, and build schedule for a replacement tow cable the system was removed from the aircraft and the project schedule was extended by 6 months with any additional project cost absorbed by Bell Geospace, Inc.

Further analysis of the tow cable, conducted at the Lake Central facility, concluded the loads applied by the pulley system used to guide the rope from the winch drum, located in the aircraft cabin, to the external ZTEM antenna connection were higher than predicted. The higher loads were developed during the deployment and retrieval process where the bend radius at each of the guide pulleys caused the tow cable section, between each guide pulley, to be stretched too far. This resulted in the multiple conductor breaks throughout the deployed section of the tow cable.

Based on the initial tow cable failure analysis, the tow cable design was improved to handle higher loads and adjustments were made in the diameters of the guide pulleys to reduce stress on the tow cable. Prior to fabrication additional pull-tests were devised and conducted using a test article and the increased load measurements. This test article passed both physical and electrical tests. In an effort to reduce the project delays, two new tow cables were fabricated and an additional external ZTEM tow antenna. Two separate aircraft were equipped with similar winching systems to expedite testing. The alternate aircraft was Geotech's ZTEM production aircraft (Cessna Grand Caravan) which had the same winch system, but due to its size did not require all the guide pulleys along the tow cable path to exit the aircraft. The initial dynamic flight tests proved the redesigned tow cable routed through the larger guide pulleys functioned as intended throughout multiple deployment and retrieval cycles. However, during longer fully deployed flights on each of the separate aircraft both tow cables failed.

Failure analysis of the second iteration tow cable showed both tow cable conductors broke at ~300 ft into the tow cable. This measurement coincided with the point where the tow cable rested on the exit pulley (identical on both aircraft) during flight. It was determined that the aerodynamic drag load, on the towed antenna, was higher than estimated. This higher drag resulted in a significant increase in the angle of incident at the exit pulley which overstretched the tow cable and broke the internal conductors. Again, due to the failure analysis, redesign and manufacturing time frame for replacing the tow cable, and aircraft availability the system had to be removed which delayed the project. An additional 6 month no-cost extension was granted.

The analysis and redesign were completed by the end of fiscal year 2012, and a test article of the latest tow cable design was manufactured. Additionally, a full replica pulley system was fabricated to test the new tow cable, and ground testing was completed using this configuration. After 400 deployment and retrieval cycles, again the test article passed all strength and electrical tests. This was completed well ahead of the projected extension obtained for completion of the project.

The installation of this latest tow cable was delayed until the end January of 2013 as the schedule for the test aircraft had to be re-arranged. With the system re-installed and ground testing on the aircraft completed, the flight test proceeded with the third iteration of the tow cable. On initial deployment, it was immediately observed that there was an aerodynamic issue with the changes made to this third tow cable design. In the redesign, the internal wiring was replaced with co-axial cable, a load bearing strength member added, and the outer weave was loosened to allow for better movement over the pulley system.

The ground testing did not include any aerodynamic stability testing, as none of the previous iterations showed any aerodynamic stability issues during flight tests. As the tow cable was deployed it flattened in the wind and vibrated side-to-side, and these vibrations caused the towed antenna to swing as well. The crew determined that antenna could not be retrieved in flight, so the emergency procedures were followed to perform a controlled jettison of the towed antenna and deployed tow cable. As it was mid-winter in eastern Canada, the best option was to release the antenna over a shallow frozen lake. The antenna was deployed to the pre-determined tow cable length and flown down to a reasonable altitude to allow the antenna to land in the snow on the frozen lake. After the maneuver was completed the crew performed a low altitude fly-over the drop location and confirmed the position of the antenna for recovery. Upon arrival with the ground recovery vehicles, it was observed that the antenna had landed with a slight nose-down attitude. On impact with the snow and ice the center section (area with all the electronics installed) had broken off from the antenna, penetrated the ice, and had sunk to the bottom of the lake. All of the antenna parts were recovered, but none of it was salvageable.

With only one remaining ZTEM antenna available the project was delayed, but still expected to be completed within the project schedule extensions. The ZTEM system was removed and the project test aircraft was released back to production, and planned to be available once the redesign and ground tests were completed.

A complete review and failure analysis were performed by Bell Geospace, Geotech, and Lake Central. Lake Central redesigned the tow cable using the knowledge obtained with the latest failed tow cable and all the two previous iterations. The final tow cable design was ground testing and installed on the Geotech production aircraft for flight testing. The final version of the tow cable worked as designed and went in to production service for Geotech’s ZTEM survey operations. An addition tow cable was manufactured for installation on the project test aircraft, but due to test aircraft availability the project was delayed.

CONCLUSION

The project was schedule to end by December 31, 2014. Just prior to the end of the contract Bell Geospace proposed an alternate means of completing the project goals utilizing two aircraft, one with FTG installed and one with ZTEM installed. This proposal allowed all of the goals of the project to be completed with the exception of determining the increased efficiency of simultaneous acquisition. The DOE review determined the alternate proposal could not be approved under the project contract, so the project was closed out.

DEVELOPED PRODUCTS

The only product developed and released under this project was the following paper which was submitted as a deliverable for the project.

Helen Gibson, Ben Delwiche, Des Fitzgerald, Scott Wieberg, John Mims, and Paolo Berardelli: *Demonstration of New Geophysical Methods for Geothermal Exploration – the Technology Explained*. *Proceedings World Geothermal Congress 2015.* Melborne, Australia