

Towed Transient Electromagnetic (tTEM) Resistivity Imaging - a Novel Method for Rapid Geologic Characterization and a Response to Western Canada's Drought

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Summary

Towed transient electromagnetic (tTEM) resistivity imaging is a novel geophysical method that allows for rapid 2-D or 3-D geoelectrical surveying to depths of between 50 and 150 meters below ground surface (mbgs). The method applies the same principles as transient electromagnetic (TEM) soundings (Auken et al, 2021; McNeill, 1980). Stationary TEM soundings are performed by laying out a large transmitter and smaller receiver loop on the ground surface. Current is sent through the transmitter loop, and then abruptly terminated, inducing secondary voltages and a secondary magnetic field into subsurface conductors. The time rate-of-change of the decaying secondary magnetic field is measured by the receiver coil at surface. Inverse modeling of each decay curve results in a 1-D geoelectric model of the thickness and resistivity of each petrophysical layer.

Since the 1980's, stationary TEM soundings have been and continue to be widely carried out. In Western Canada, TEM soundings have been used for paleochannel mapping, oil sands mapping, groundwater salinity mapping, till thickness determination, mineral exploration, and a wide variety of other geological applications. Typically, a TEM crew of 3 to 5 persons can do from 5 to 15 soundings in a day, largely depending on the size of the transmitter loop. In sharp contrast, tTEM soundings are collected in a continual mode with the 3 m X 3 m transmitter coil and the approximately 1 m X 0.5 m receiver coil towed behind an all-terrain vehicle (ATV) or snowmobile. As such, a typical day of tTEM data collection may survey approximately 50,000 soundings and traverse a linear distance of approximately 50 km. If surface conditions allow, the coils can be towed at a speed of up to 20 km per hour. However, data collection at even a fast walking pace of say 5 km per hour is rapid compared to petrophysically comparable geophysical methods of 2-D resistivity or stationary TEM soundings.

2-D sections of inverted tTEM data are very similar in appearance, resolution, and utility to geoelectric sections inverted from 2-D resistivity data (also known as electrical resistivity tomography or ERT). Over moderately resistive (say 30 to 60 Ohm-m) Quaternary sediments, tTEM will typically provide a depth of investigation of 70 to 100 mbgs. The vertical and lateral resolution of tTEM data will be very similar to a 2-D resistivity array configured to image to similar depths. However, while a three person 2-D resistivity crew would likely collect approximately 1.5 km of resistivity data in a single day, a two person tTEM crew could easily collect 20 km of data over plowed farm fields or abandoned logging roads.

Surveys of tTEM clearly have significant productivity advantages over resistivity surveys as ERT surveys require planting and removing electrodes as well as laying and spooling cables. Nevertheless, tTEM and transient EM methods also suffer from a number of disadvantages. All transient EM methods are very susceptible to noise from above and below-ground infrastructure including power lines, fences, pipelines, vehicles, railroad tracks, and other linear and massive metal features; resistivity methods are largely immune to anthropogenic noise sources. Indeed, 2-D resistivity surveys can be routinely performed in dense urban or industrial areas, an impossibility with tTEM surveys. The tTEM method has a maximum depth of investigation controlled by the resistivity of subsurface materials and the hardware configurations. There is no theoretical limit to the depth of investigation of 2-D resistivity methods, though in Western Canada resistivity investigation depths are typically limited to the top 600 m of the subsurface. Given that tTEM is towed behind a vehicle and that the transmitter coil is 3 m across, reasonable access and cutlines or pathways at least 4 m across are mandatory; 2-D resistivity surveys can be performed essentially over any terrain that is accessible by foot.

Due to the high rates of data collection and the wide range of resistivities that characterize the subsurface, the range of applications of tTEM are broad. These include buried valley aquifer mapping, mineral exploration, gravel exploration, fracture mapping, aquifer protection mapping, subsurface characterization for managed aquifer recharge, crystalline basement aquifer mapping, saltwater intrusion mapping, groundwater contaminant mapping, and 3-D geological characterization to meet a range of general goals. Given the speed of acquisition, surveys can be carried out on a local or a regional scale.

Currently (Government of Canada, 31 January 2024), approximately 50% of Western Canada (British Columbia and Alberta) is in a state of Drought Intensity of D3 (Extreme Drought) and D4 (Exceptional Drought). Over the last decade, both Geoscience BC (Best et al., 2019) and the Alberta Geological Survey (Slattery et al., 2018) have flown extensive Airborne EM surveys for aquifer exploration and delineation. However, without follow up ground geophysical surveys, airborne surveys rarely provide sufficient vertical or spatial resolution to generate drilling targets. The method of tTEM is currently the most cost-effective ground-based geophysical tool that has the potential to identify and delineate significant additional groundwater resources. In Alberta, for instance, intra-till aquifers, buried valley aquifers, the Paskapoo Formation, thick coal seams, the Milk River Sandstone, and many other aquifers serve as excellent targets for tTEM exploration. Planned tTEM surveys over the next six months in Western Canada are intended to realize this exploration potential.



Figure 1: (Brendan O'Brien) tTEM survey in Northern Alberta. The small coil in the foreground is the receiver coil. The larger, 3 m X 3 m coil supported by the four orange struts is the transmitter coil. All electronics are located in the ATV.

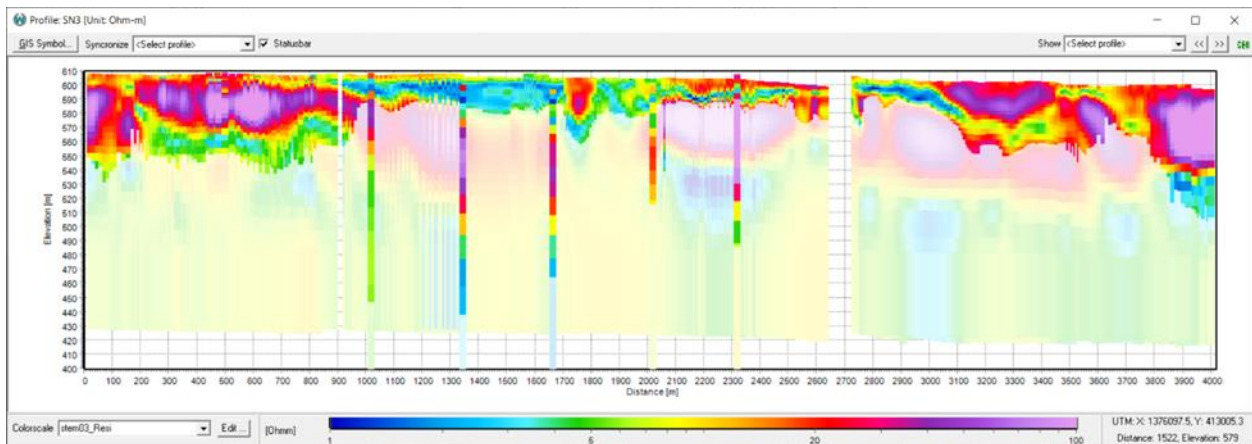


Figure 2: This four-kilometer section of modeled tTEM data was collected in the Turkana Desert of northwestern Kenya in approximately 30 minutes. The low resistivity zones (yellow to blue) are likely clays or saline water. The high resistivity zones (red to pink) are likely sand and gravel or volcanics. The depth of investigation varies from about 30 m over subsurface zones of very low resistivity to about 100 m over subsurface zones of high resistivity. Overlying the tTEM section are five stationary TEM soundings. The 1-D TEM soundings required about 4 hours to sample a very limited area. However, the TEM soundings do explore to significantly greater depths than does the tTEM survey.



Figure 3: (Denys Grombacher) tTEM data collection at speeds of 5 to 20 km per hour in Turkana West sub-County in Northwestern Kenya. Historically, 1-D resistivity soundings have been the main geophysical water exploration method in this area as well as across much of sub-Saharan Africa. As much of the Turkana desert lies in the East African Rift Valley, the geology is very complex and poorly suited to any type of 1-D mapping approach. Given its high resolution and high productivity, tTEM is particularly well suited to 2-D and 3-D subsurface imaging. While not all resistive targets in the Turkana desert are potable water aquifers, imaged potential aquifers can be further triaged with other methods such as seismic refraction which, for instance, can easily differentiate between high velocity massive volcanics and low velocity sand and gravel.

References

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