An Interpretation of the 2008 SkyTEM Airborne TEM Survey

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The intention of this report is to

1. Provide input as to the functionality of EMIGMA for time-domain EM interpretation
2. Provide some insight into SiroTEM III ground survey

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Airborne TDEM Interpretation 1– SkyTEM example Basics

Data Description

In this SkyTEM survey, there are actually 2 TDEM surveys. Both use the same transmitter geometry but the 2 surveys have different base frequencies ; 25Hz – High Moment (HM) and 222.2Hz Low Moment (LM). Both have relatively low dipole moments – 131000Am^2 (HM) and only 14000Am^2 (LM). Both use the same transmitter but with different number of wire turns and different currents. However, the data is dipole moment normalized and so the dipole moment is not an issue for the interpreter. Each survey has different time windows and different current waveforms. These are issues for setting the system correctly for the interpreter but will be discussed in detail later.

In this case, the data file is contained in two(2) .csv files one for the HM and one for the LM. This is not normal as a geosoft .gdb file is normally used but this may be due to the early date of this survey for the SkyTEM system. However, in both cases (.csv or .gdb), for EMIGMA the data is first imported to QCTools for processing and then import. The contents of the data files are specified in the SkyTEM report but the user should understand that the data contains data for the vertical component (Hz) and the inline horizontal component (Hx).

System Criteria

Two important aspects need to be dealt with by the user. The first is the time channels which must be correctly used during import. SkyTEM, in this case, does not provide a file for the time channels and thus this must be constructed by the user. Secondly, the current waveform must be determined as accurately as possible and set during the import. We will now deal with this issue. In this case, we do not have a waveform file so that parameters need to be determined in a different manner.

Airborne TDEM Interpretation 2– Fundamentals

Airborne TDEM Fundamentals

Certain fundamentals should be understood and their relation to using EMIGMA. Unlike, other TDEM software EMIGMA attempts to include in the simulation of data as much of the *instrument*'s system response as possible in order to use effectively the accurate algorithms that we provide. The SkyTEM report addresses a number of these issues for this system as the developers well understood the importance of clarifying these issues and addressing these issues in simulation. Ground systems can be less informative concerning their system response depending on the particular manufacturer.

Airborne time-domain instruments just like ground TEM instruments, utilize a periodic current and this current almost always has two polarities during any period. This is to help reduce the issue of the DC response in the instrument. Data is normally sampled at a regular interval during both polarities. Data is then appropriately stacked to reduce system noise and then the data binned into logarithmically space windows.

The lowest frequency content in the derived data is the fundamental or basefrequency of the current waveform. The use of waveform, here, is a common geophysics slang to mean the exact shape of the current during a half-cycle. The upper frequency contained in the data is constrained by many factors such as the sampling interval, the low pass aspects of any amplifiers, feedback during turn-on and turn-off of the current in the transmitter loop and many other factors.

There are two fundamentally different TEM waveforms, one termed an impulse response and the other a step-response. This term, *response*, refers to the shape of the measured coil response in freespace which is the time derivative of the current. Historically, the impulse response has been utilized for conducting environments with weaker conductors and the step response for strong conductors. There have been systems which tried to marry the two forms by measuring during the on-time (current ON) and the off-time (current OFF). The SkyTEM system is an impulse response system which in this survey does not attempt to measure during the on-time. Step response systems are utilized primarily for exploring for very strong conductors such as nickel.

Impulse systems have varying current waveforms but most are similar to the SkyTEM, turning ON with an exponential and then off with an approximate linear form or an exponential form. In most cases, a current waveform file is provided and sometimes a calibration coil response at high altitude but in this case, we have neither. The current waveform being provided by a non-comprehensive description and plots in the report as described below. If contracting an airborne survey, it is important to include in the report, the need for high altitude calibration data.

Additionally, time windows are provided in the report but no ascii file for use in the import. This is also discussed below.

Import to EMIGMA is done via a .qct file using the airborne TEM import with the SkyTEM system selected.

Airborne TDEM Interpretation 3– Waveform

SkyTEM Waveform

The time channel and waveform information are given in Appendix 1 and 2 of the survey report. Figure 18 of the report presents the designed current waveform versus the actual waveforms for the 2 surveys (LM and HM). In the table on pg 39, there is given the parameters of the designed waveform. The turn-ON is an inverse exponential of the form A(1 – exp(-t/tau)) where A is the maximum current. The turn-OFF is specified by 4 different modes. These are not explained but we assume that these are fits to particular functions.

What is important in this situation, where the very shallow response is not required, is the overall time to current off which prescribes that amplitude of the impulse which defines the strength of the induced response. Thus, we chose to digitize the curves in Figure 18 to prescribe the waveform parameters. As mentioned earlier this is not normally required for airborne TEM surveys as digital waveform files are provided with the survey.

First, as an example, we deal with the turn-on for the HM survey. Decay constants are normally provided in msec. In the chart, the decay constant is given as 364 in units of inverse seconds. This is equal to a decay constant of 2.747msec. The digitized waveform is inputted to QCTools and the exponential decay constant calculated. It is calculated at 2.77msec which is quite close to the designed response. The linear turn-off was calculated as 0.03msec.

The time channels are transcribed from Appendix 1. In this case, the times of each channel are defined with respect to the beginning of turn-off. The beginning of turn-off is taken from the digitized waveform as 10msec in agreement with the information that is provided. This provide 9.97msec of off-time.

These parameters are provided during import to EMIGMA along with an ascii file which defines the middle of the time channels.

For the LM survey, the exponential turnON constant is 0.09345msec and the linear turn-off as .0045msec with the turnoff beginning a 1msec. However, little is not given in this report for the LM data as this data seems of little use for this project.

We will thus focus on the stronger source HM survey at lower basefrequency of 25Hz providing a more suitable survey for detection of deeper conductors.

Airborne TDEM Interpretation 4– HM Initial Analyses and Processing

SkyTEM HM Survey Data Units

The provided EM data is in units of V/m^4*Amps which is equal to Tesla/sec/Amps being the units of a time varying magnetic field, i.e.. dB/dt. This means that the data has been current normalized. This is similar to VTEM surveys which allows for the crew not to have to maintain a constant current during the surveys. The stated current is therefore nominal. Secondly, the data is normalized by the area of the transmitter times the number of wire turns in the transmitter. The remaining square meters is due to the equivalent area of the receiver coil via Faraday's law and thus this provides data in units of Volts normalized by transmitter loop area, receiver coil area and current. EMIGMA expects data units in nT/sec or pT/sec and thus when the data is imported to QCTools either in this form of .csv or in the normal .gdb format the data needs to be multiplied by 10**9 for import to EMIGMA.

Note, when importing to EMIGMA the data is multiplied during the import by loop area and the resulting system configuration has a loop of equivalent area. The loop may be edited to give the precise dimensions if desired. This multiplication by source area is because when computing the response of a 3D target, the actual dimensions of the loop is very necessary unlike in other approximate algorithms .

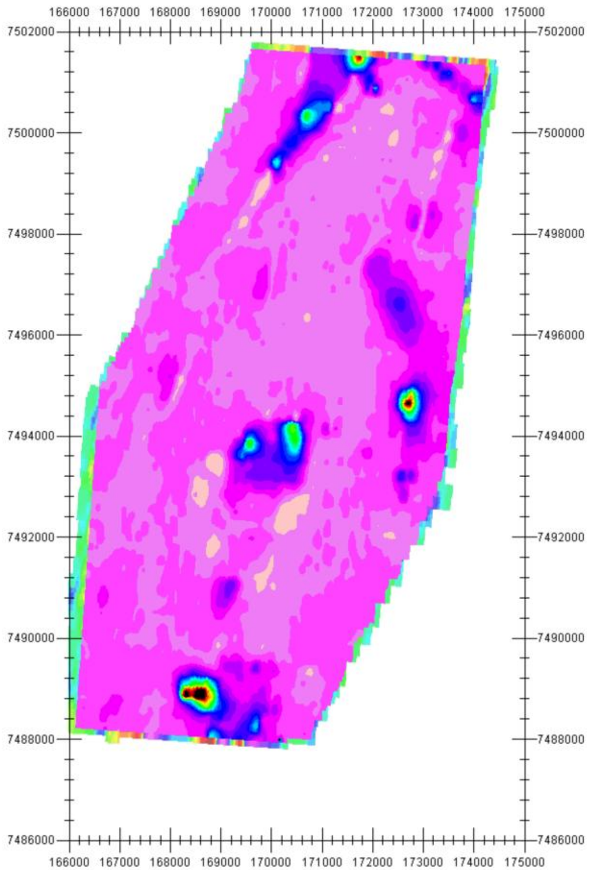
Further Processing prior to Modeling

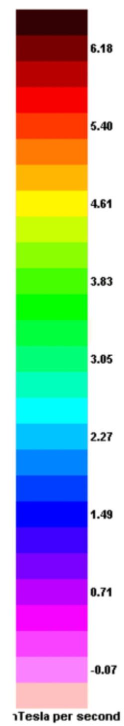
The data is provided with an inline spacing varying from approximately 2.5m to 4.5m. This resolution is unlikely as it would not provide sufficient data for adequate stacking during data collection . In addition, with a transmitter of this size ($314m^2$) and at an altitude of approximately 40m such a spatial resolution is not realized in the resolution of the data. Thus, we normally decimate the data using a statistical spatial decimation filter which has the advantage of reducing the noise through spatial stacking. In this case, the data is decimated to an average inline spatial sampling of approximate 10m which is likely still of higher resolution than required. Further, the tie lines are removed as the responses cannot be leveled because the response is significantly due to the actual height above the ground. Additionally, any split lines are joined to enable easier comparison to 3D models vs. data in the plotting routines. Later, after initial analyses the data is cut to encompass the ground surveys which are now in focus.

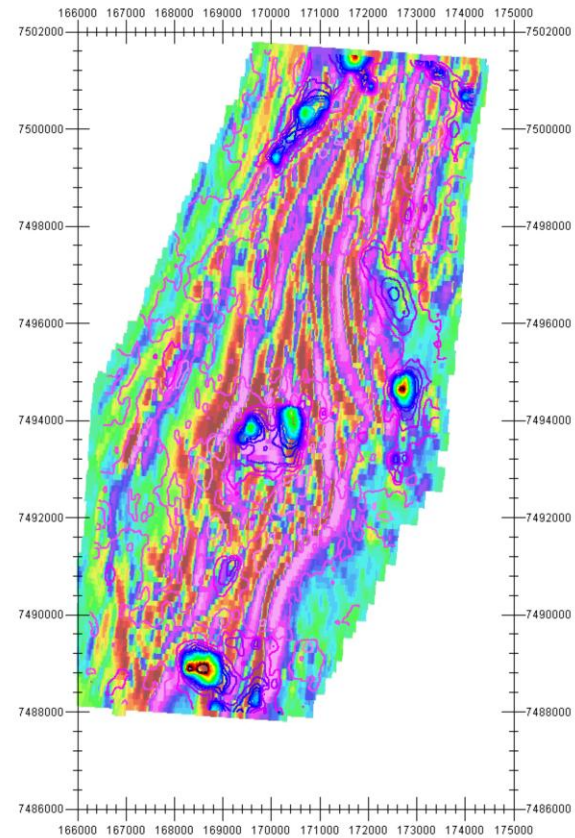
Airborne TDEM Interpretation 5– HM Initial Analyses and Processing

Initial Analyses

On the left is a contour of the 4th time channel of Hz and on the right this is underlain with the horizontal derivatives of the magnetic field. There are a few anomalies in the survey and in particular 2 anomalies within the ground survey area, i.e. ground TEM, MT and gravity. Note, the data is still normalized by current but not by loop area.



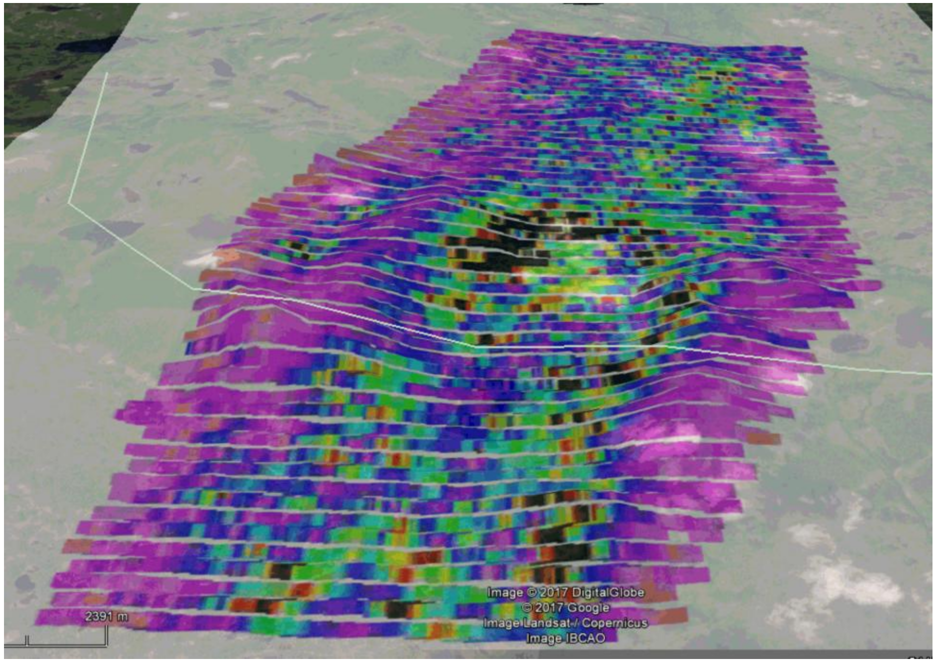




Relationship between Geophysical Response and Topography

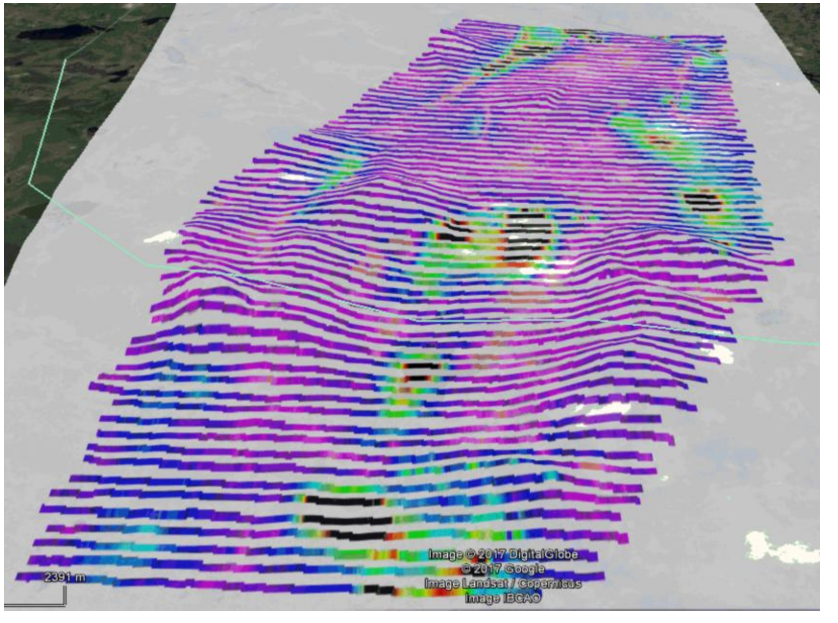
Initial Analyses

On the left is the magnetic analytic signal draped on the topography while on the right, the Ch1 EM anomalies similarly draped.
These images are in WGS84 as Google Earth is used to drape the maps. The magnetic responses ring the inside of the valley while there are areas of higher early time response in the center of the valley. A determination of the effects of cover material will be required to determine the extent of the overburden response.



Analytic Signal draped on Topography

HM Hz Ch1 Draped on Topography



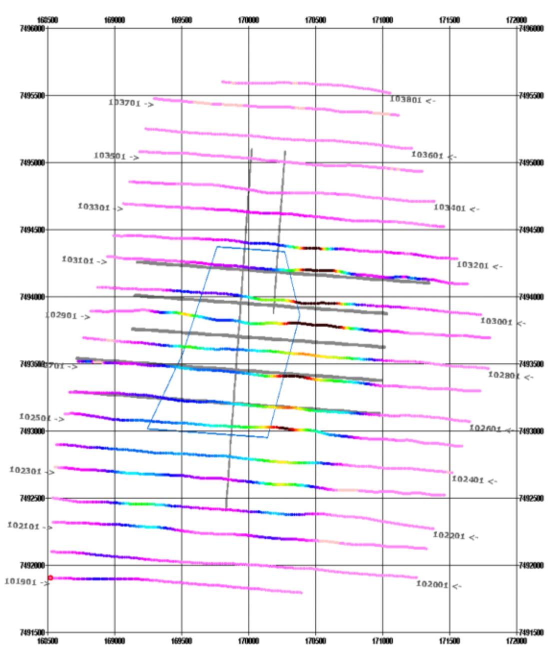
Airborne TDEM Interpretation 6– HM Initial Analyses and Processing

Initial Analyses

We show nothing of the higher basefrequency, lower dipole moment survey as we cannot see any useful information in this survey within the area of the ground TEM and MT surveys.

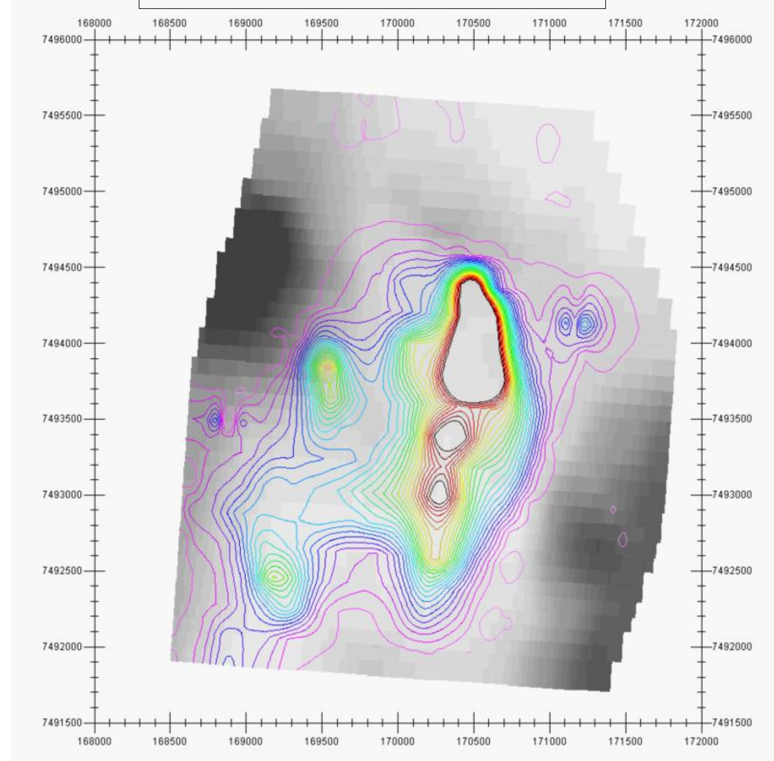
Using ProfileModifier tool, we cut out an area of the HM SkyTEM survey around the ground TEM survey (figure left). On the right, contouring Ch1 with the DEM model derived from the airborne data, we see that there is a region of higher response in an area of low topography. This indicates possibly an area of thicker overburden in the areas of lower elevation. Thus, the possibility that the higher airborne TEM responses are due to thicker overburden. This is an issue which is relevant not only to the airborne EM data but also the ground TEM.

While all early channel EM anomalies are in areas of low topography not all low topography areas have higher EM responses. It should be noted that the strongest EM anomaly is to the south of the ground survey.



Survey Cutout

Hz Ch1 with DEM underlay

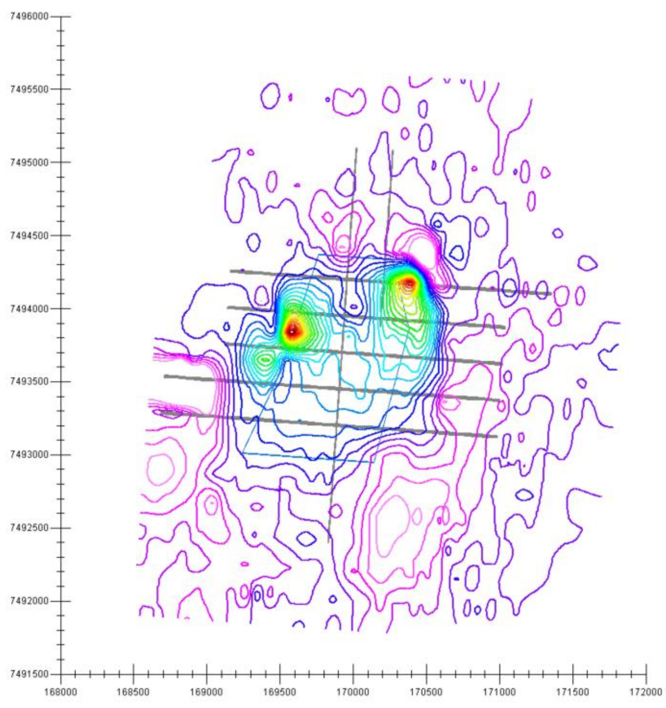


Airborne TDEM Interpretation 8– HM Initial Analyses and Processing

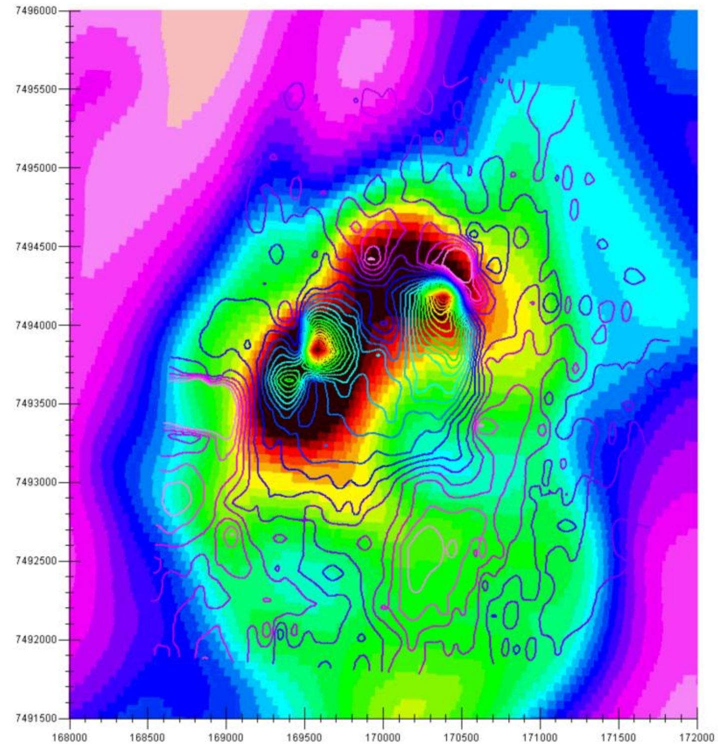
Initial Analyses

As we move to slightly later times, two anomalies are isolated which we term the East and West anomalies. Here, we show on the left Ch5 contoured with the ground TEM survey underlain. On the right, is the same data but with the inline magnetic anomaly underlain. The west anomaly is tucked inside a magnetic structure while the east structure is sitting on top of the boundary between magnetic structures. This would indicate that the east structure is merely due to overburden while the west may be due to a more interesting structure.

On the right, this channel is contoured with the magnetic data upward continued to 200m indicating a possible relation with the magnetic data and these EM anomalies.



Hz Ch5



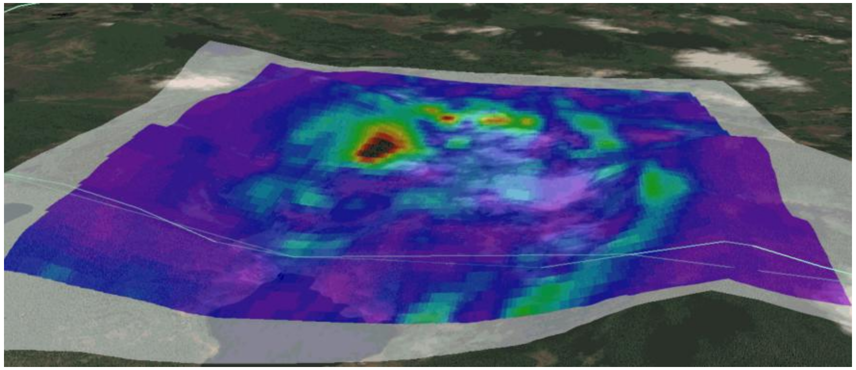
Hz Ch5 contour – magnetic anomaly grid underlain

Relationship to Topography Project Area

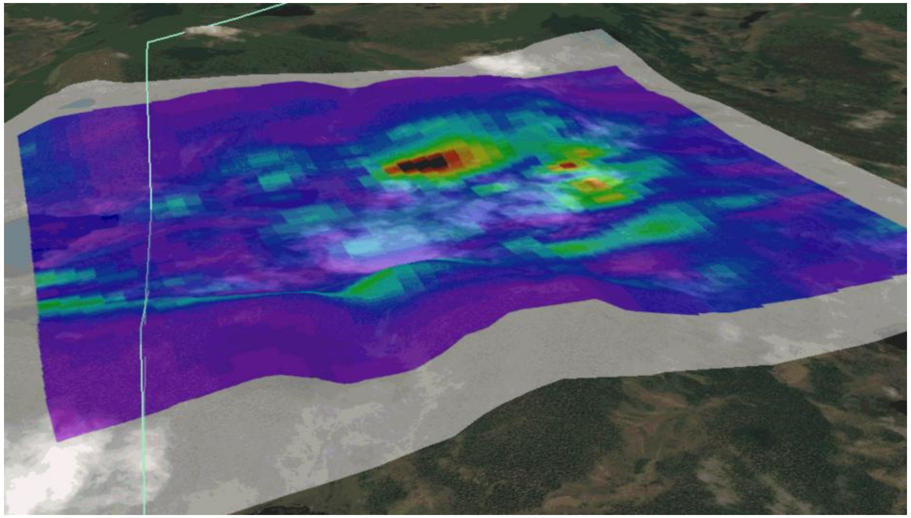
Magnetic Targets
Here, we focus more on the northern part of the valley containing the ground surveys.

We show the analytic signal draped on the topography from 2 angles.
Again, the magnetic structure appears to form a ring on the valley edges with our shallow magnetic target appearing more clearly.

Analytic Signal draped on Topography



from South

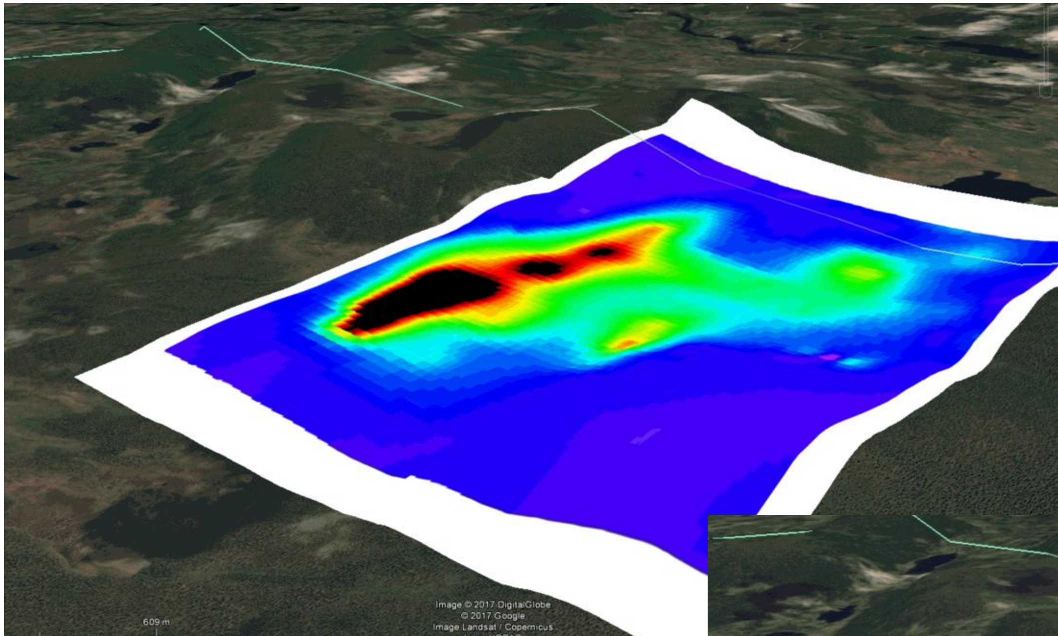


from East

Relationship to Topography Project Area

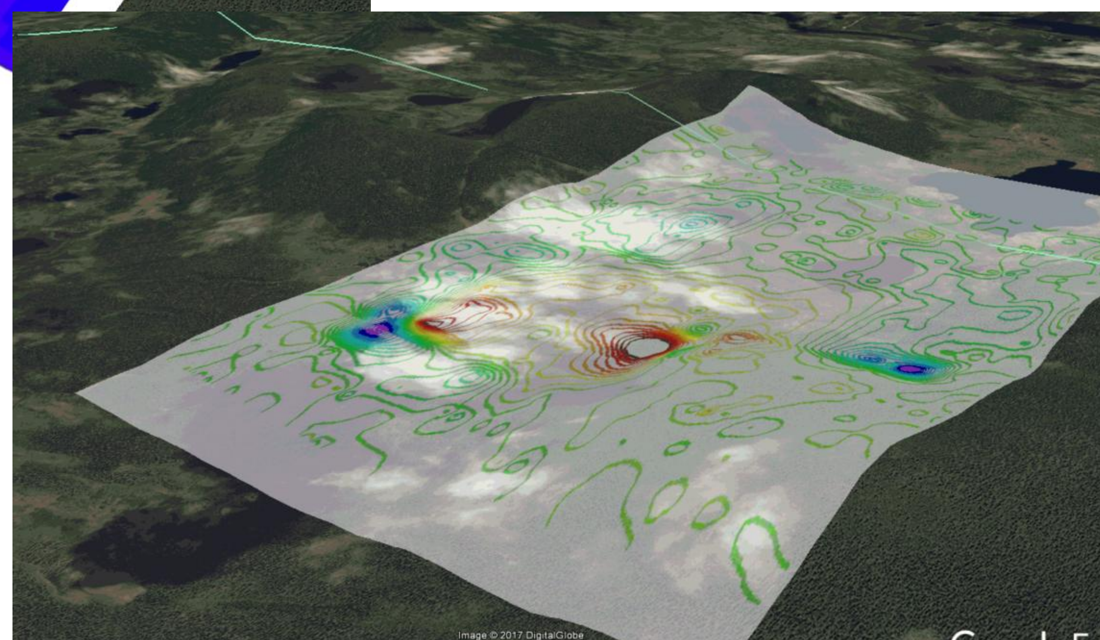
SkyTEM EM

We show, Ch1 and Ch6 Hz, for the HM survey draped on the topography. .



HM Hz Ch1 – view from NE

Ch1 shows a significant response following the contours of the valley floor.



HM Hz Ch6 – view from NE

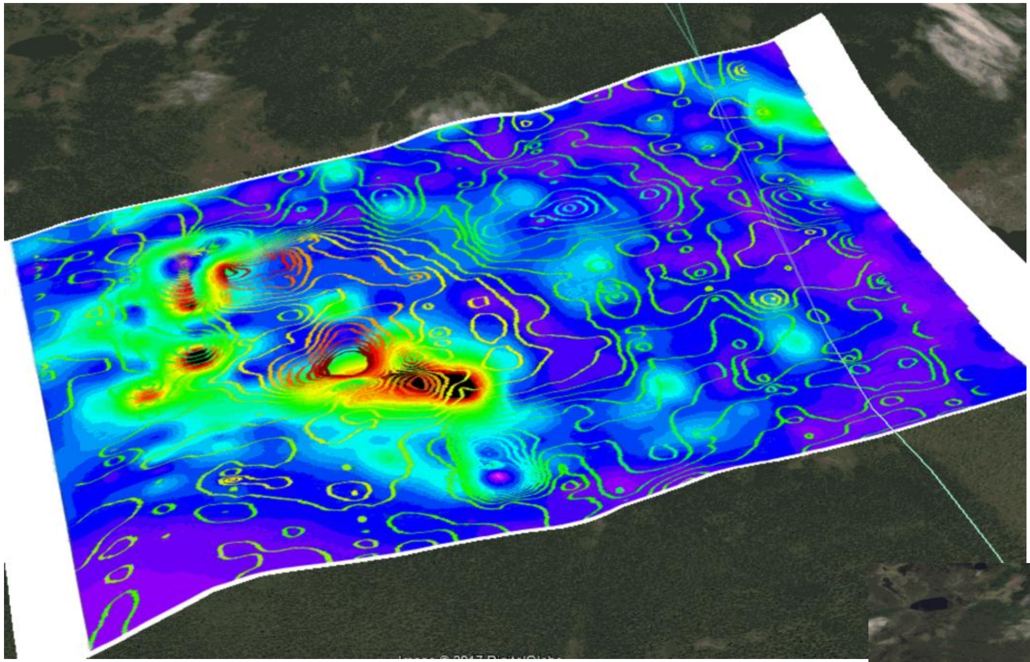
Ch6 now indicates 2 isolated anomalies, the East and West anomalies

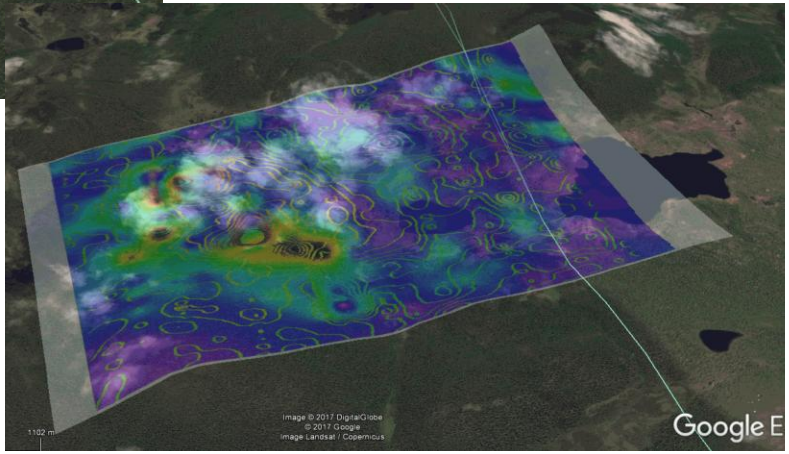
Relationship to Topography Project Area

SkyTEM EM

Again, the magnetic structure appears to form a ring on the valley edges with our shallow magnetic target appearing more clearly.

HM Hz Ch6 – view from West
Analytic signal underlain



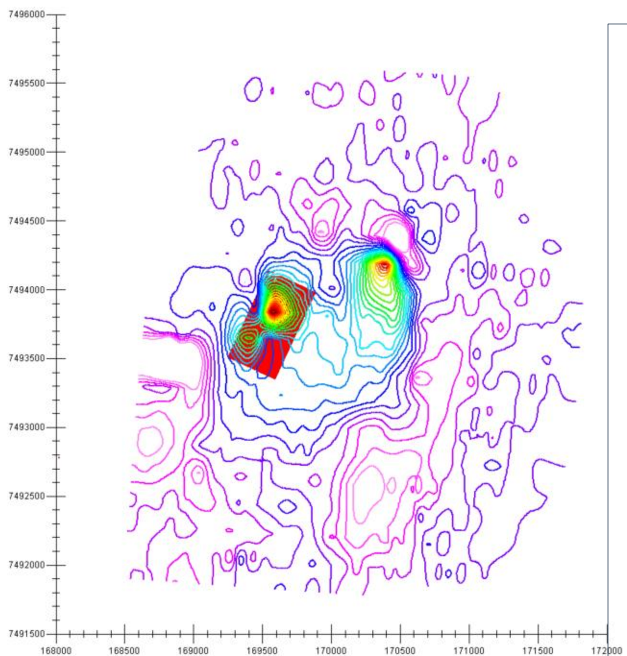


Airborne TDEM Interpretation 9– Relationship to Magnetic Targets

Magnetic Targets

On the left is Chn5 contoured with a projection of the magnetic target discussed in the aeromagnetic report/tutorial. Recall that the top of the magnetic structure is at a depth of approximately 145m. We will return later to the West anomaly which lies over the shallow magnetic target.

On the right, we contour the decay constant (tau) for the first 5 channels with the shallow magnetic anomaly underlain. The area around the West anomaly has the slowest decay in the ground survey area. This is another indication of a possible EM target as opposed to simply overburden responses.



Hz Ch5, magnetic target underlay

Magnetic Target

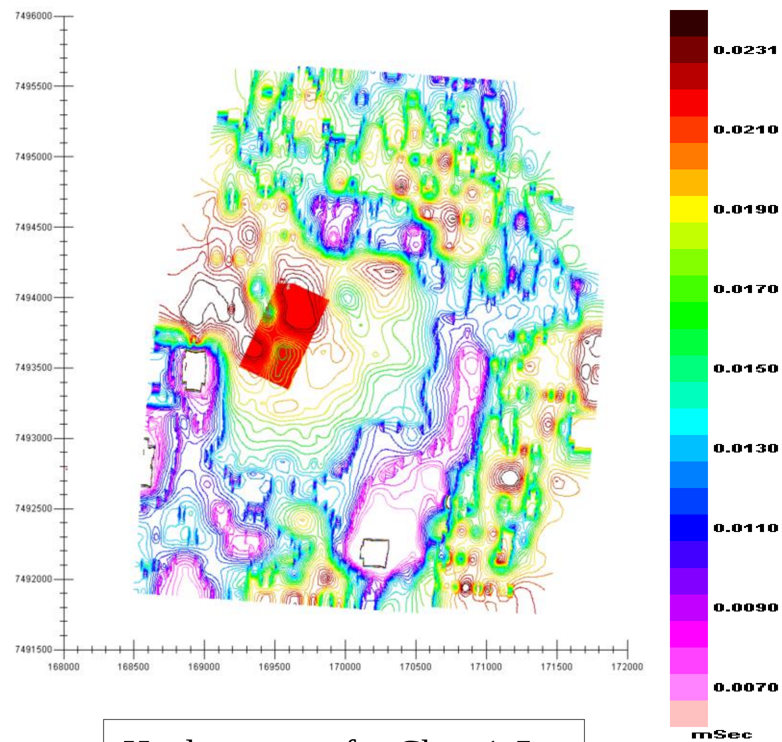
top center:
169440E, 7493804N

dimensions:
strike – 700m
dip extent – 400m
thickness -100m

orientation:
strike – 20deg EofN
dip – 35 degrees

depth:
GPSZ (– 390m)
to surface: 145m

suceptibility: 10SI



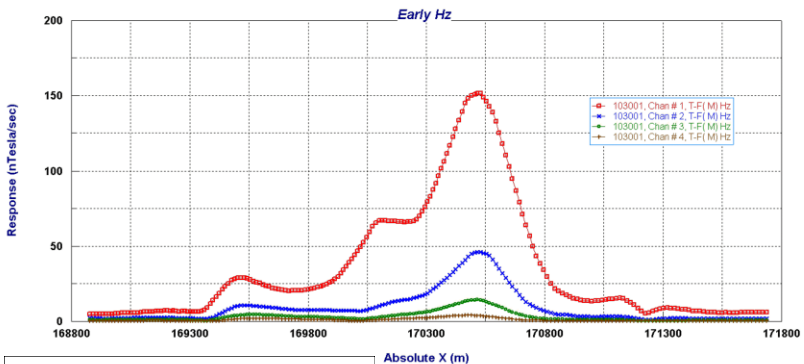
Hz decay, tau, for Chns 1-5.
[A exp(- t/ tau)]

Airborne TDEM Interpretation 10– HM Initial Analyses and Processing

Data Examination

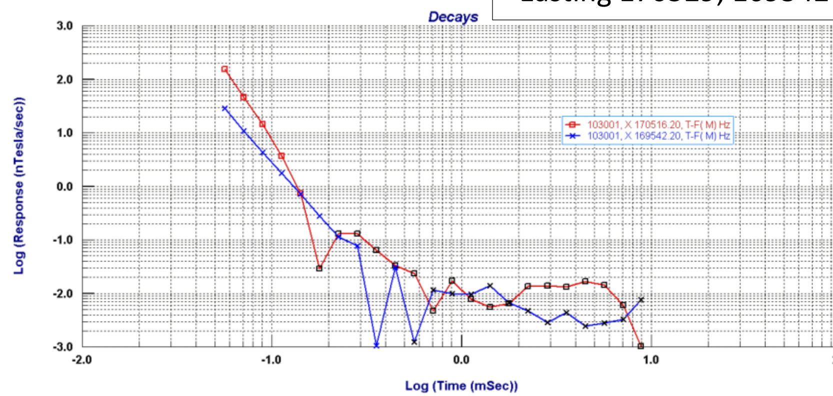
Here, we show a portion of our examination of the east anomaly. The upper left figures, are line plots of channels 1-4 of Hz along line 103001. The bottom right shows a contour of Ch2. The east anomaly is obviously stronger than the west in the early times. The lower left figure shows a decay at station 171629E and this is a typical station away from anomalies. Although, Ch1 may be partially due to system response due to its proximity to the end of turn-on, the next 3 channels are obviously data. This tells use that there is cover with a weak inductance which is important for examination of the airborne EM anomalies but also the ground TEM.

The figure on the top right is very important. It shows in red the decay over the East anomaly and the decay over the West anomaly. The east anomaly may be stronger but the decay is as in areas without anomaly (lower left) while the west has a slower decay indicating a possible EM target.

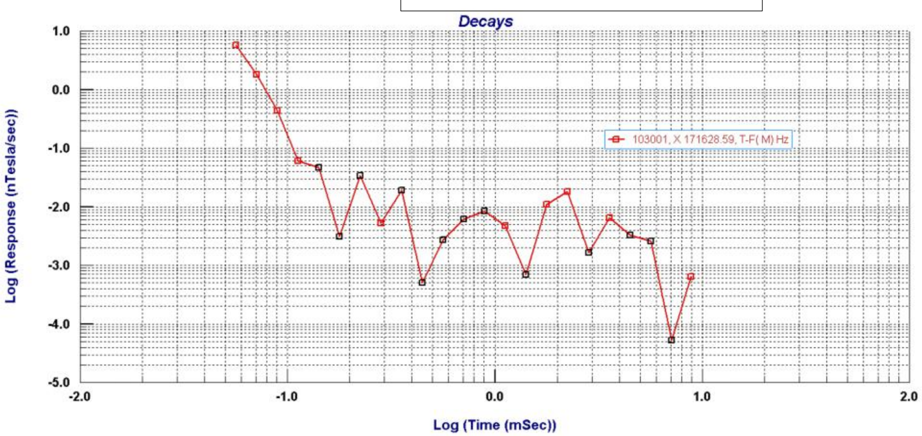


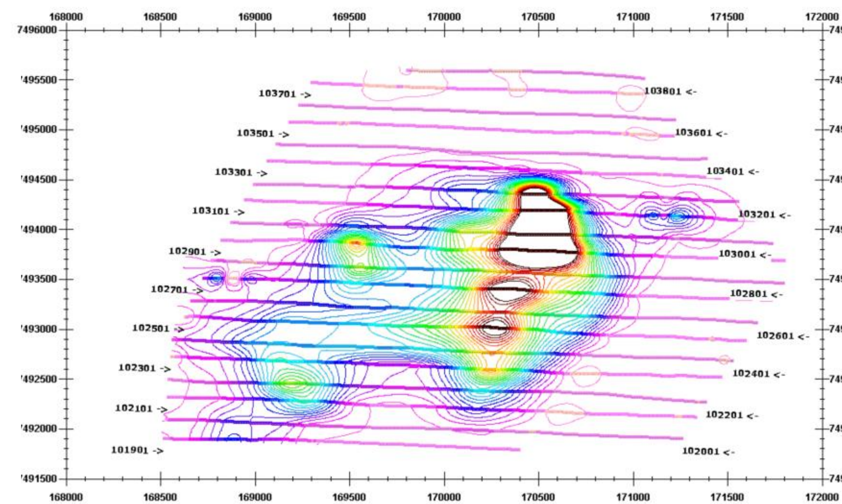
Line 103001 – Hz – Ch1-4

Line 103001 – Hz Decays
Easting 170529, 169542



Line 103001 – Hz Decays
Easting 171629





Airborne TDEM Interpretation 11– Inversion

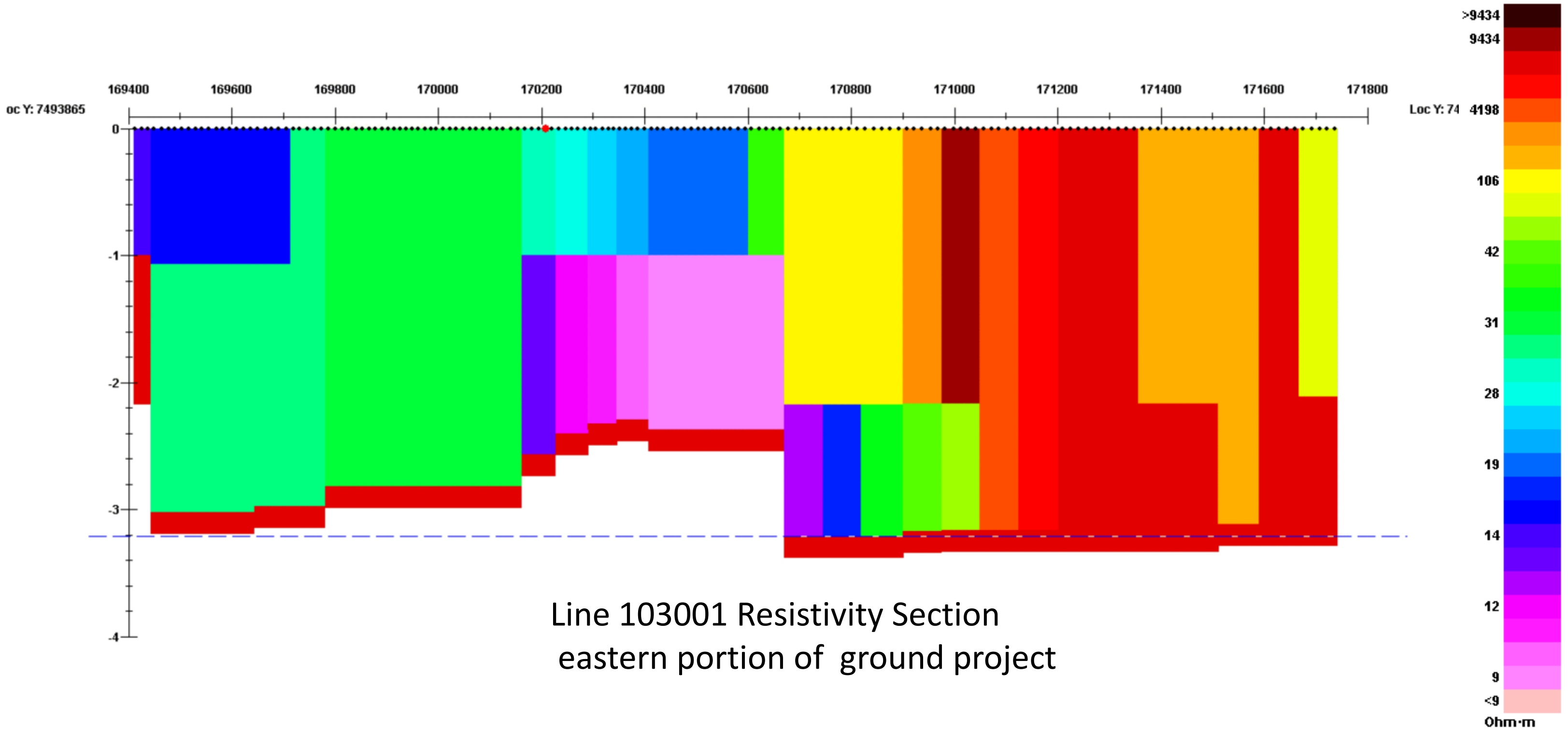
1D Stacked Resistivity Sections

EMIGMA does offer the ability to use conventional stacked 1D inversions. This capability is quite extensive but we will not go into these aspects in any detail here.

However, examination of the data throughout the survey indicates while the principle structure is very resistive, there is some cover and thus we proceeded to try to determine the resistivity of the cover and the basement. This information will be required when attempting to model any conductors whether in the ground or airborne TEM.

In this instance, we utilized only the first 4 channels of the data, restricted the model to 2 layers over a half-space and used a moving multi-station window to invert. The multi-station inversion both helps to constrain lateral variations but also helps with the issue of noise in the data.

In examining the east anomaly in the area, it seemed that the data although stronger in the early channels must be due simply to cover material. Thus, we attempted an inversion to image the cover on the major portion Line 103001 as shown on the previous page. The inversion was generally successful except over the western anomaly. We show here the results on the eastern two-thirds of this line.

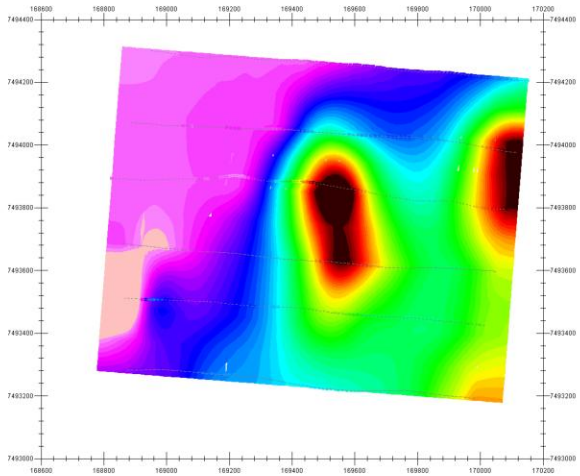


Line 103001 Resistivity Section
eastern portion of ground project

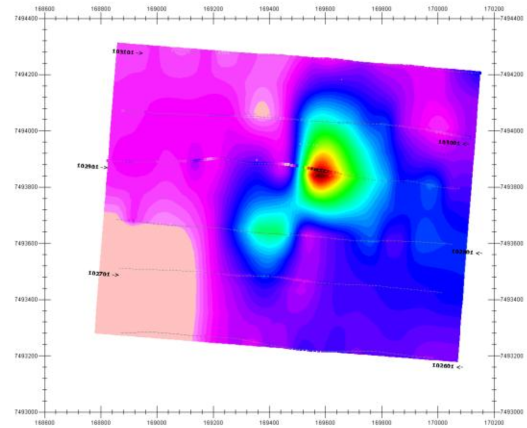
Airborne TDEM Interpretation 12 – Modeling

Modeling of the West Anomaly

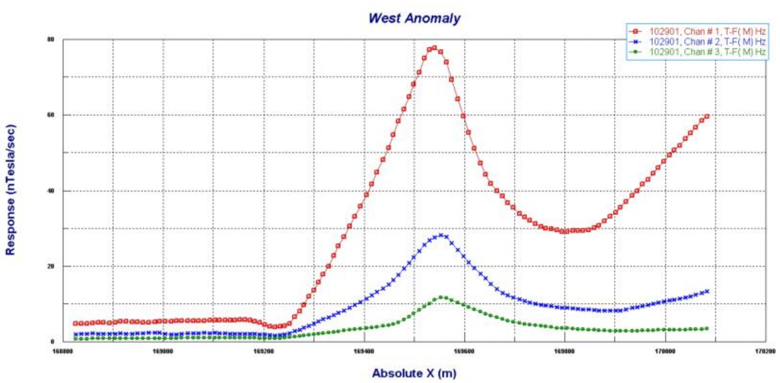
Cutting out a portion about the West anomaly, we show contours of Ch1 and Ch5. The east anomaly is still seen in Ch1 but not Ch5. The anomaly center is on L102901. We choose to show here only the model results for this line.



Ch1 centered over the West anomaly



Ch5 centered over the West anomaly



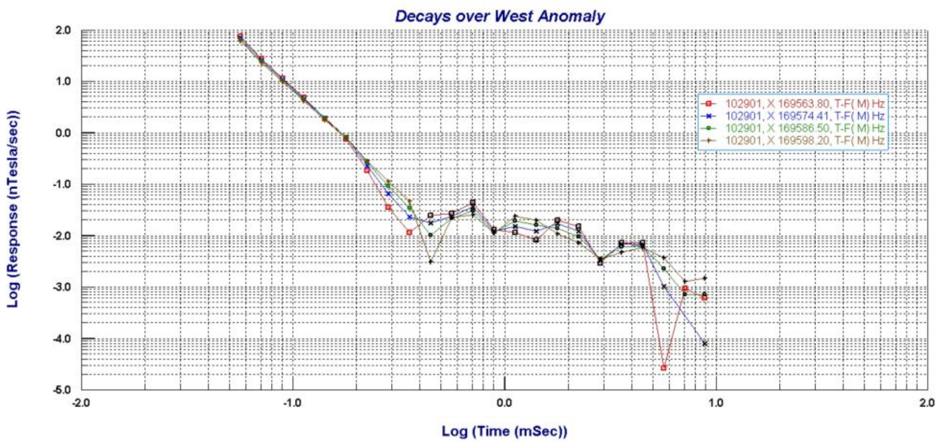
Ch 1-3 over West Anomaly

Airborne TDEM Interpretation 13 – Modeling

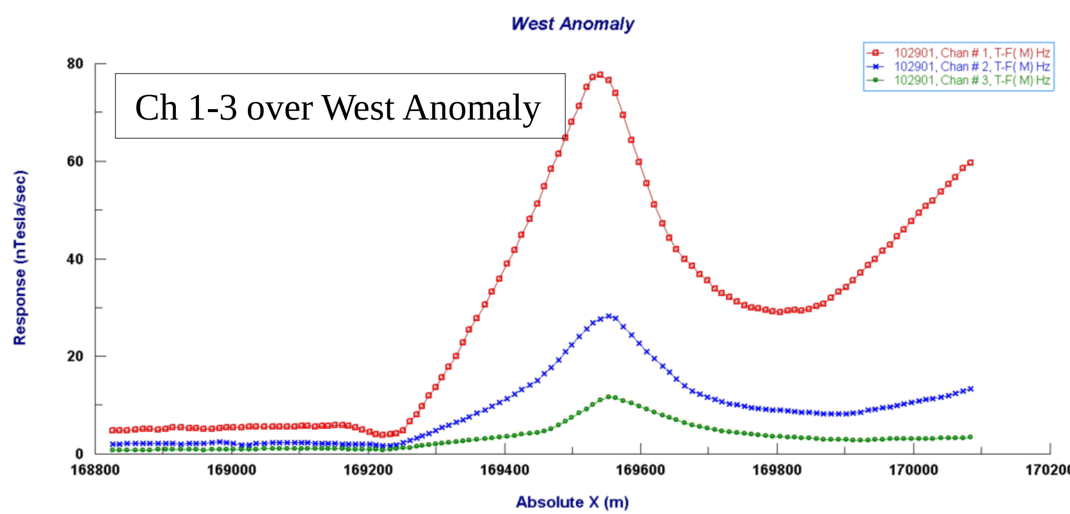
Modeling of the West Anomaly

Below is a decay curve for 4 stations, one just to the west of center of the anomaly and then 3 consecutive stations over the center of the anomaly. While, the early time decay is the same for all stations, there is indications of a deeper anomaly beginning at Ch5. Unfortunately, the response of this anomaly is lost as the data deteriorates into noise at Ch10.

Importantly, however, it does indicate 2 structures. One shallow structure and one deeper structure. Recall, that our magnetic anomaly is immediately below the west anomaly.



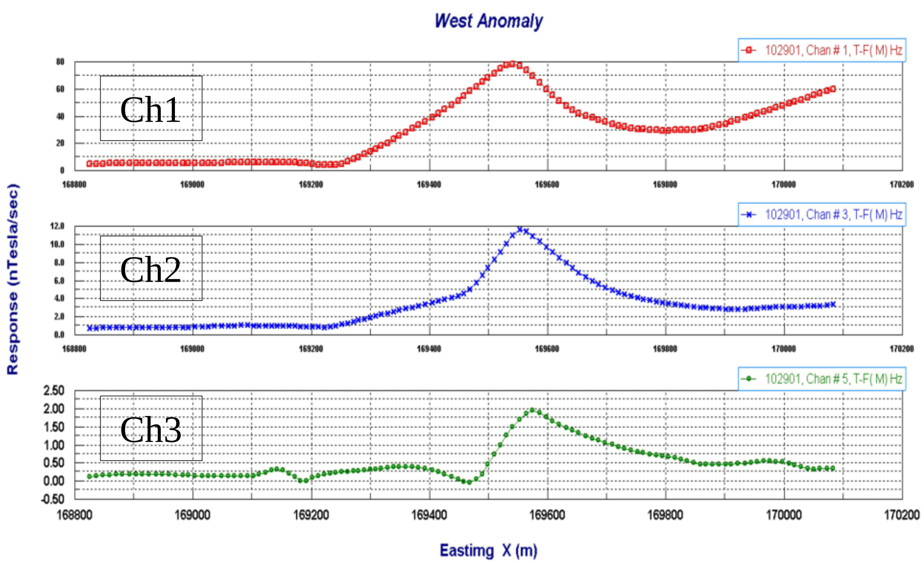
Ch 1-3 over West Anomaly



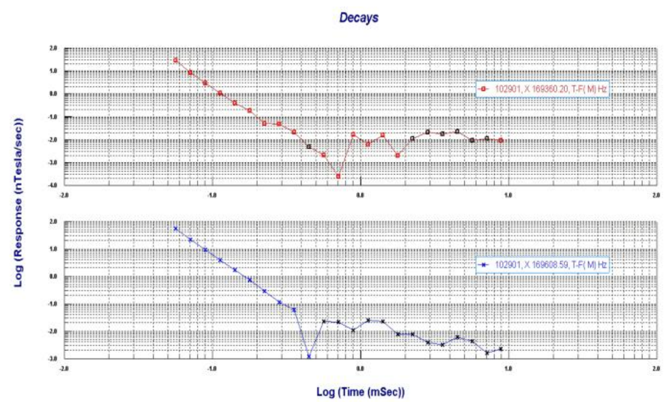
Airborne TDEM Interpretation 14 – Modeling

Modeling of the West Anomaly

The response over the West anomaly contains at least 2 structures. A western portion which is weak and a eastern portion centered over the late time anomaly which is stronger and deeper. The western structure appears to dip west and is shallow indicating cover and the eastern structure dipping east but deeper and more conductive.



Ch 1-3 over West Anomaly

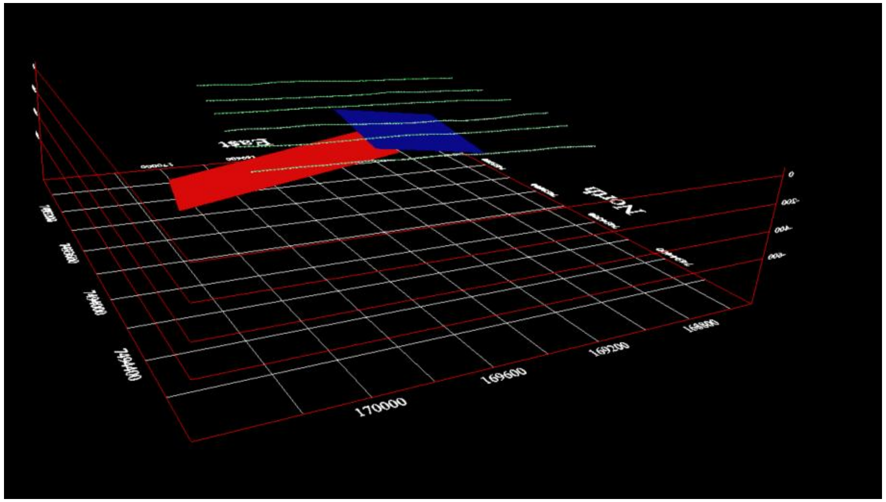


Decays – 169360E top
169608E bottom

Airborne TDEM Interpretation 15 – Modeling

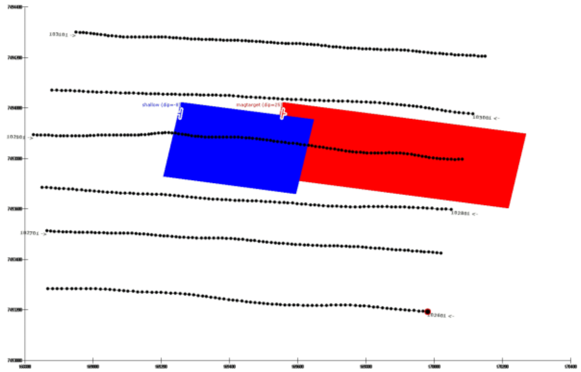
Modeling of the West Anomaly

The 2 structures shown in 3D view and plan view.



View from North
Shallow –blue, Deep - red

Shallow –blue, Deep - red



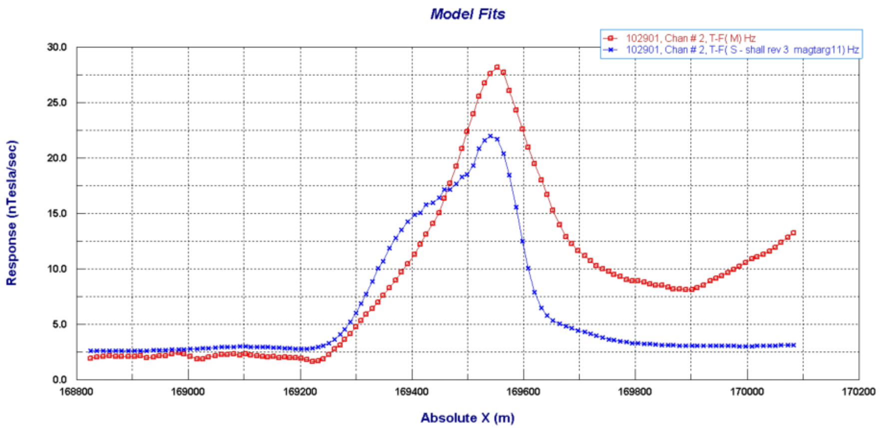
Shallow Target
top center:
169622E, 7493808N
dimensions:
strike – 300m
dip extent – 400m
orientation:
strike – 10deg EofN
dip – 8 degrees west
depth:
to surface: 8m
conductance: 0.3S

Deep Target
top center:
169530E, 7493878N
dimensions:
strike – 300m
dip extent – 800m
orientation:
strike – 10deg EofN
dip – 25 degrees east
depth:
to surface: 70m
conductance: 15S

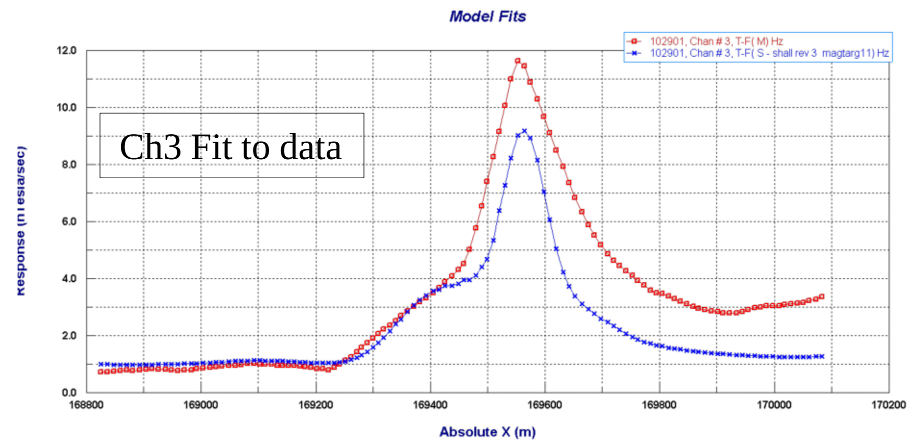
Airborne TDEM Interpretation 16 – Modeling

Modeling of the West Anomaly

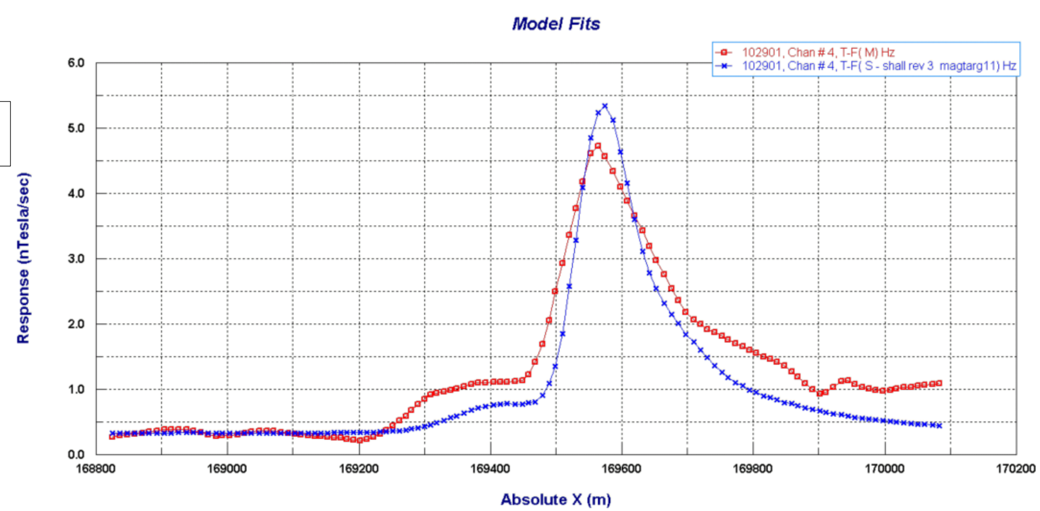
We show the model fits to Ch2, Ch3 and Ch4. Ch1 may not be practical to model. This is not the best model but we limited our work for time constraints.



Ch2 Fit to data



Ch4 Fit to data



Airborne TDEM Interpretation 17 – Conclusions

Conclusions

- The LM survey did not appear useful but the vertical component of the HM survey contained some valuable information
- The early time responses are concluded to be due to cover material
- The magnetic anomaly drew our attention to an EM anomaly in the ground survey region which appeared promising
- The resulting information is likely useful to the interpretation of both the MT and ground TEM data