

A VTEM and HeliGEOTEM II Data Comparison

Summary

At the beginning of 2008 both the Geotech VTEM and the contractor Fugro's HeliGEOTEM II were flown over the same block in the McFauld's Lake area of the Superior Province in Canada. The overlapping area flown comprises 220 line-km flown at 100 m line spacing in a north – south line direction.

The goal of the current paper is to give a more comprehensive and objective analysis of the VTEM and HeliGEOTEM II data.

The analysis of the actual survey data shows that VTEM outperforms HeliGEOTEM II in a number of key parameters, such as:

- VTEM generates much stronger secondary fields in the EM receiver
- VTEM has much lower noise for all comparable channels, resulting in much better signal/noise ratios
- VTEM has a wider range of time gates in both early and late times

The advantages of the VTEM system design result in superior data quality that leads to detection and characterization of deeper, smaller footprint features than other systems including the HeliGEOTEM II are unable to detect.

Introduction

The quality of the airborne time-domain data depends on a number of factors; the most important of which are transmitter pulse shape, transmitter integrated dipole moment, transmitter base frequency, sensitivity of the EM receiver, transmitter and receiver terrain clearance, etc. The advantage in only one feature (the peak dipole moment, for example) together with disadvantages in other features will result in the system producing inferior data. The differences between the systems make it difficult to come to correct conclusions about the data quality by analyzing the system theoretically. Further comparison with actual field data is required to determine which system produces better quality data.

At the time of the survey the VTEM system employed only a Z-coil in the EM receiver, while HeliGEOTEM II used a three component receiver coil. Starting from 2009 an X-coil was added to the VTEM receiver so that VTEM surveys now employ Z and X receiver coils (Y coil is optional and could be used as well).

System configuration

Table 1 shows the system configurations used for the McFauld's Lake survey.

	VTEM	HeliGEOTEM II
Transmitter loop diameter	26 m	14 m
Peak dipole moment	425,000 NIA	550,000 NIA
Transmitter base frequency	30 Hz	90 Hz
Transmitter Pulse	Rectangular, 7.5 ms	Half-sine, 2 ms
Geometry	Symmetrical in-loop	Asymmetrical out-of-loop
EM transmitter loop terrain clearance	30 m	35 m
EM receiver terrain clearance	30 m	65 m



Receiver coils*	Z-Axis (X,Y now available)	X,Y and Z-Axis
Windowed EM data sampling rate	10 Hz	4 Hz
Magnetometer terrain clearance	60 m	68 m

Table 1 – System configurations (* X and Z and optional Y coils available from 2009 for VTEM)

The main advantages of VTEM are:

- **Transmitter Current Pulse Shape and Length.** VTEM uses a long rectangular waveform pulse. The VTEM waveform is the most efficient waveform. This fact was concluded by Liu (1998) that half sine (HeliGEOTEM II) current waveform systems produce at most 64% of the secondary signal in the off-time. Liu calculated the GEOTEM waveform (same as HeliGEOTEM II) to produce only 30% of the primary signal in the off time. A triangular current (e.g. AeroTEM) waveform would produce at most 50% of the square pulse signal. The VTEM waveform was calculated by Liu to produce 80% of the ideal waveform. These Liu waveform factors (LWF) are easily applied to the peak dipole moments:

	Peak Dipole Moment	LWF	Effective Moment
VTEM	425,000 NIA	0.8	340,000 NIA
HeliGEOTEM II	550,000 NIA	0.3	165,000 NIA

- **Low Transmitter Base Frequency.** VTEM uses a 30 Hz base frequency while HeliGEOTEM II uses a 90 Hz base frequency. The lower base frequency provides more late time gates, and, as a result, greater depth of investigation and better conductor discrimination.
- **Symmetrical In-Loop Geometry.** The VTEM receiver is situated directly in the middle of and coplanar with the transmitter loop, while the HeliGEOTEM II receiver is located about 15 m in front and 30 m above the centre of the transmitter. The VTEM response over the same point does not depend on the flight direction, while the HeliGEOTEM II response varies with the line direction. Having a symmetric response allows for rapid and accurate conductor location and direct drilling from VTEM data without the use of ground geophysics to confirm the targets.
- **Lower Terrain Clearance.** The VTEM receiver and transmitter terrain clearance of 30 m has a definite advantage over the higher HeliGEOTEM II transmitter (35 m) and receiver (65 m) clearances. As a result, the secondary field from conductors is stronger for VTEM than for HeliGEOTEM II, even with the slightly higher HeliGEOTEM II peak dipole moment.
- **EM Sampling Rate.** VTEM samples the EM data at 10 Hz or approximately every 2.5 m, while HeliGEOTEM II samples at 4 Hz or approximately every 6.3 m. The higher VTEM data sampling rate (EM data) together with the lower terrain clearance provides better spatial resolution of conductors.
- **Wider Range of Time Gates.** The standard range of the decay time windows (off-time gates) for 30 Hz VTEM is 0.11 ms – 7.20 ms (channels 10 – 33), while the HeliGEOTEM II 90 Hz off-time gates theoretically covers only the range 0.09 ms – 3.36 ms (channels 7 – 20). As it is shown later, however, the first off-time gate for HeliGEOTEM, the channel 7, produces EM responses similar to channel 17 (0.37 – 0.45 ms) of VTEM, so in fact only VTEM provides early time gates (0.11 ms – 0.37 ms), which are not available in the HeliGEOTEM II data. Furthermore, VTEM also offers non-standard measuring early time gates to 70 microseconds and lower.

Transmitter pulse and secondary EM response in receiver

Figure 1 shows the transmitter pulses and the off-time gates used for the survey for both VTEM and HeliGEOTEM.

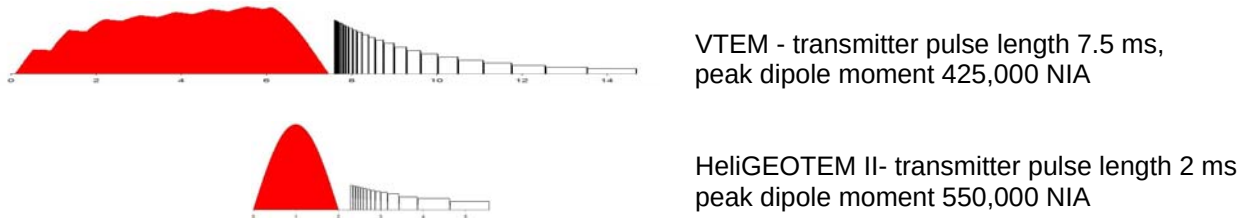


Figure 1 – Transmitter pulses and off-time gates

Although the peak dipole moment for VTEM is slightly lower than for HeliGEOTEM II, the integrated dipole moment calculated as the pulse area reflecting the energy sent in one pulse is approximately three times higher for VTEM. A higher integrated dipole moment provides better responses for the late time gate conductors and greater penetration. The secondary field in the EM receiver depends on a number of factors, so the analysis of actual EM responses over the same lines is required to compare the systems. Figures 2, 3 and 4 show VTEM and HeliGEOTEM II responses over the same line 40840.

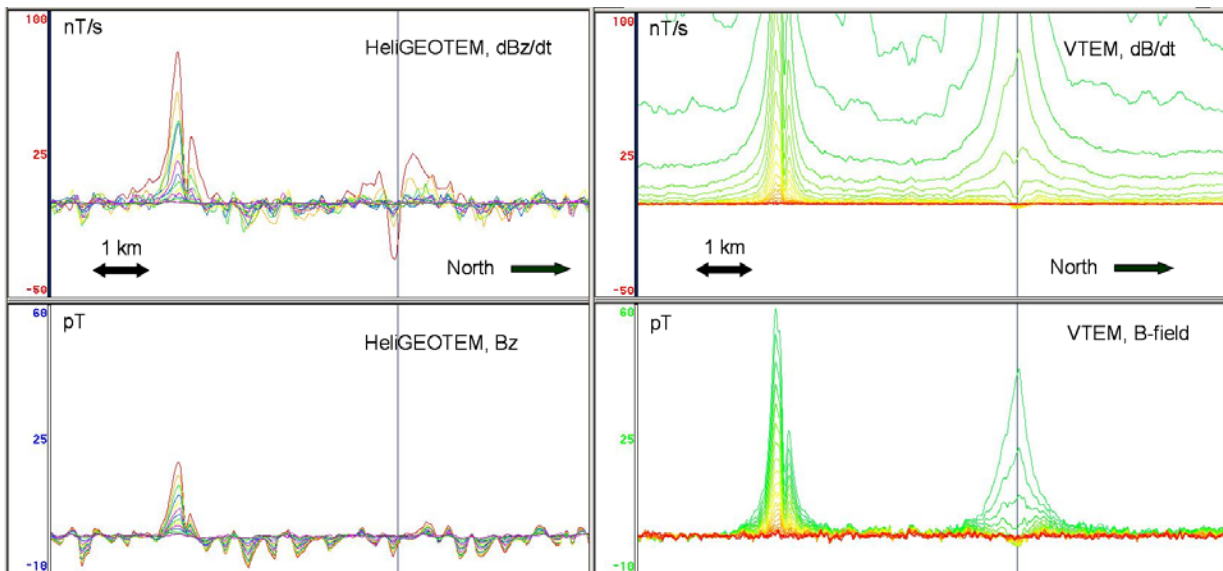


Figure 2 – Line 40840, VTEM time gates 0.11 ms – 7.20 ms (channels 10 – 33),
HeliGEOTEM II off-time gates 0.09 ms – 3.36 ms (channels 7 – 20)

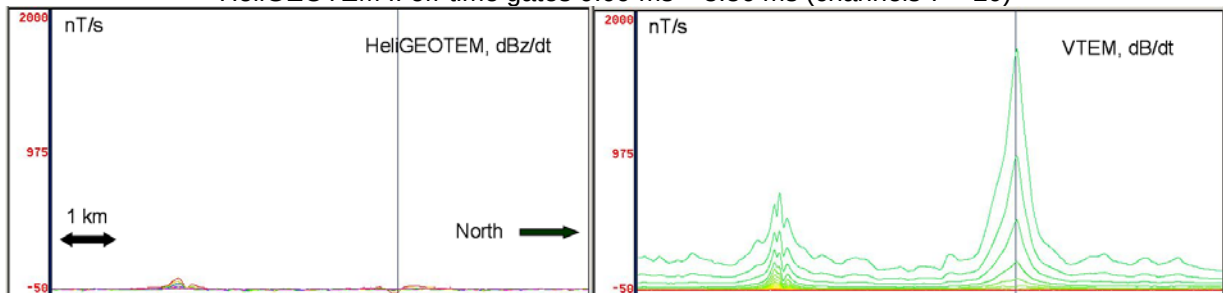


Figure 3 – Line 40840, dB/dt response at 2000 nT/s scale, VTEM time gates 0.11 ms – 7.20 ms
(channels 10 – 33), HeliGEOTEM II off-time gates 0.09 ms – 3.36 ms (channels 7 – 20)

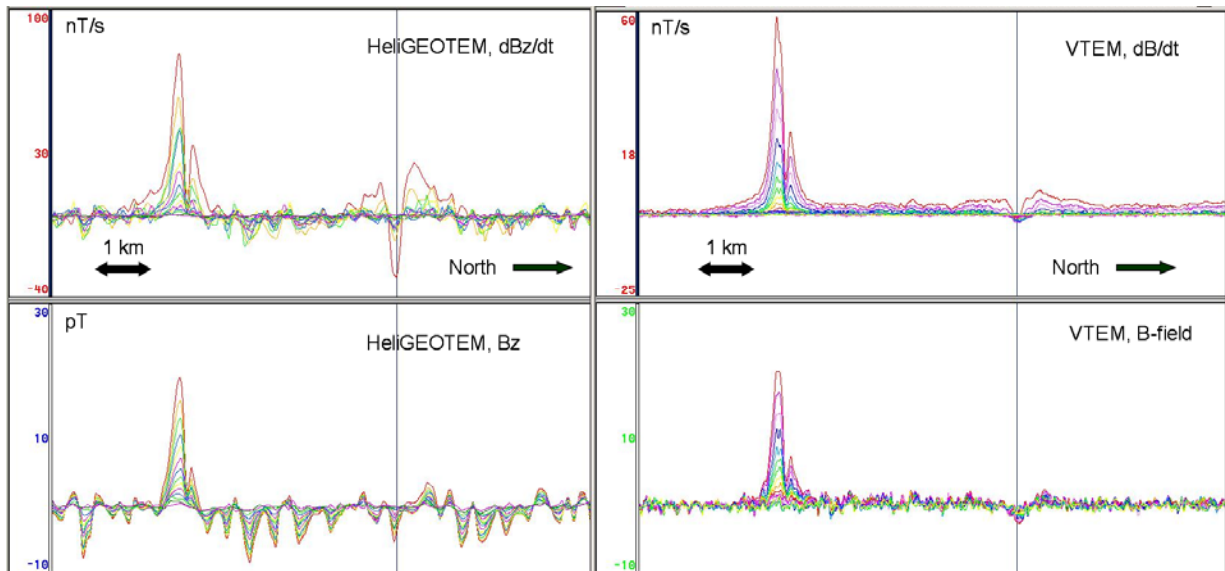


Figure 4 – Line 40840, VTEM time gates 0.37 ms – 7.20 ms (channels 17 – 33), HeliGEOTEM II off-time gates 0.09 ms – 3.36 ms (channels 7 – 20)

The Z off-time profiles for both VTEM and HeliGEOTEM II are shown in Figure 2. The scale in Figure 2 is chosen to maximize the HeliGEOTEM II response range. Figure 3 shows the same dB/dt profiles, but at a scale to maximize the range of the VTEM responses. There are two anomalies detected. The southern anomaly (on the left) is the classic double peak anomaly over a steeply dipping conductor. The low values in the middle indicate the approximate location of the top of the conductor.

Figure 4 compares the HeliGEOTEM II responses to VTEM responses by plotting channel 17 to 33 of VTEM and channels 7 to 20 of HeliGEOTEM II and maximizing the scales of each system. The second anomaly, marked by the vertical black line on Figures 2, 3 and 4, is the typical anomaly over a chargeable zone with the IP effect. The VTEM responses over a conductor with the IP effect are strong positive anomalies on the early time gates and negative anomalies for the later time gates and a weak positive or no response for the late time gates. The HeliGEOTEM II responses over the same chargeable zone do not have the strong positive response on the early time gates – just the positive-negative-positive response starting from the first off-time channel 7. The HeliGEOTEM II channel 7 response is similar to the VTEM response for VTEM channel 17 (0.37 ms – 0.45 ms window) - shown in Figure 4. The early VTEM time gates from 0.11 ms to 0.37 ms do not have the corresponding HeliGEOTEM II time gates (see Figure 2 and 3, dB/dt profiles). Considering the actual responses over the same line, it is reasonable to conclude that the first HeliGEOTEM II off-time channel 7 matches the off-time 0.37 ms of the VTEM time gate windows.

The corresponding ranges of the time gates for both systems are shown in Figure 5. The VTEM data provides more time gates for both the late and early times.

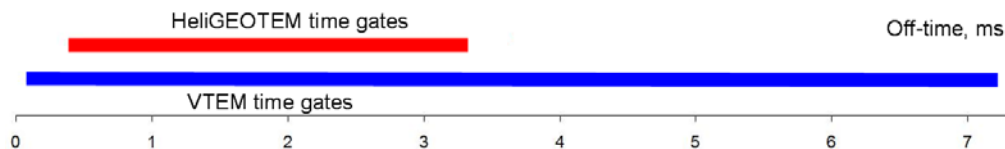


Figure 5 – VTEM time gate range and the corresponding HeliGEOTEM II time gate range

Signal / noise analysis

The signal/noise ratio is the most critical parameter that determines the system's ability to detect anomalies. A number of factors contribute to the system noise such as the electronic noise, the turbulence noise, the noise due to data processing/correction techniques, etc. The combination of different factors defines the level of noise in the

data. Figures 6 and 7 display the VTEM and HeliGEOTEM II responses over line 40740, which is a line with no significant EM response. The VTEM early time gates represent the real geological response, but the variations in the HeliGEOTEM II data and in the late time VTEM data are within the noise envelope.

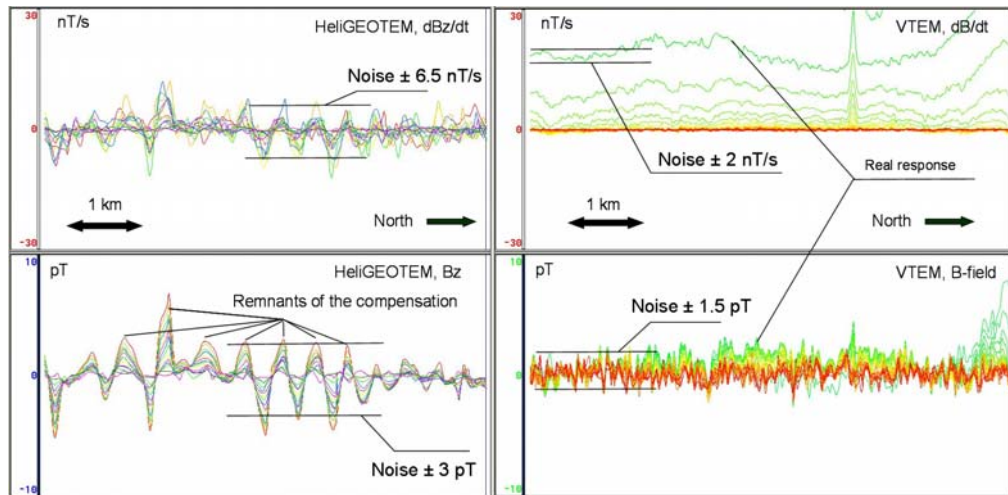


Figure 6 – Line 40740 with no significant EM response, all off-time gates shown. VTEM time gates 0.11 ms – 7.20 ms (channels 10 – 33), HeliGEOTEM II off-time gates 0.09 ms – 3.36 ms (channels 7 – 20)

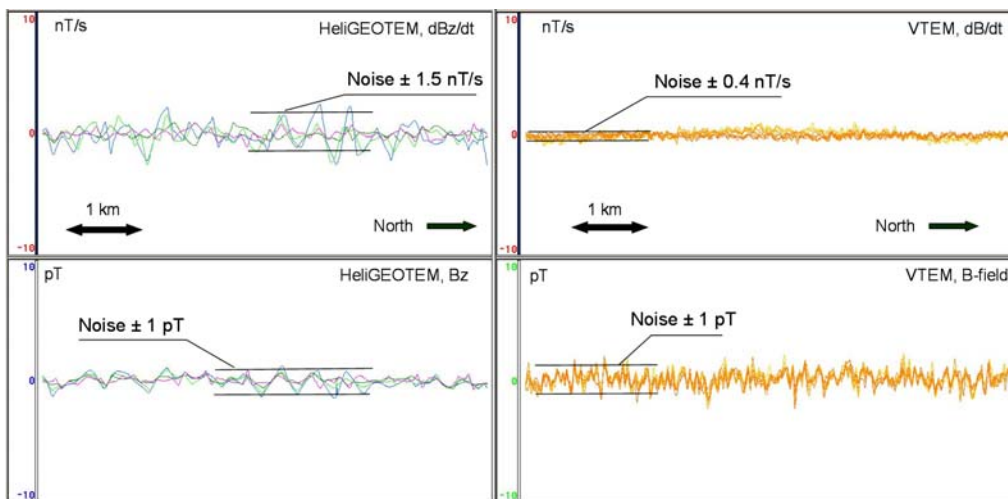


Figure 7 – Line 40740, late time gates shown. VTEM time gates 0.97 ms – 3.6 ms (channels 22 – 29), HeliGEOTEM II time gates 0.96 ms – 3.36 ms (channels 17 – 20)

The long wavelength variations on both dB/dt and B-field HeliGEOTEM II profiles are obvious. These variations have been reported by the Contractor as “a remnant of the compensation during primary field removal to measure on-time and calculate full waveform B-field”. In other words, these variations are a system artifact since they do not correlate with the geological signal and are generated by the HeliGEOTEM II system. For the analysis of the signal/noise ratio the line 40870 was used – see Figure 8.

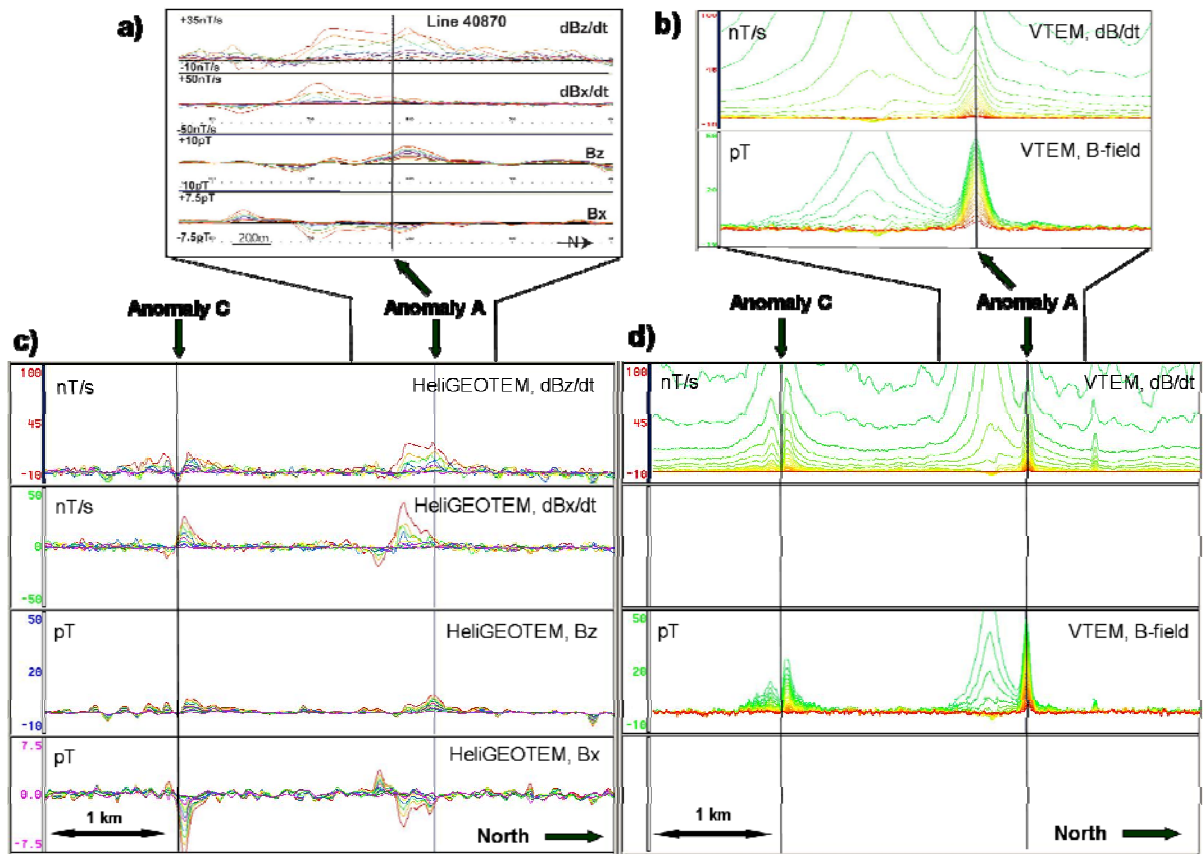


Figure 8 – Line 40870. a) HeliGEOTEM II x and z components over Anomaly A, conductor axis presented by Contractor, part of line only b) VTEM profiles over Anomaly A, part of line only, c) HeliGEOTEM II x and z components for the complete line (presented by Geotech), d) VTEM components for the complete line

There are three different types of conductors that are present on the line. All three are clearly shown in the VTEM data: Anomalies A and C, and the early time anomaly, located immediately south of anomaly A. Anomaly C is a classic double peak anomaly over a steeply dipping conductor. Anomaly A is over a relatively small flat lying conductor. The early time gate VTEM anomaly is due to a chargeable zone with the IP effect. Although the Contractor claims, that HeliGEOTEM II shows the Anomaly A “very clearly on dB/dt and B-field data on all channels, and x and z components”, it does appear on the profiles provided by the Contractor (Figure 8, a). The wavelength of the Anomaly A on the HeliGEOTEM II data is the same as the wavelength of the noise due to the remnants of the compensation. With the signal amplitude levels being just above the noise such an anomaly could easily be confused with the noise. The HeliGEOTEM II late time response over Anomaly A is barely above the noise level, while the VTEM late time response is strong – Figure 9.

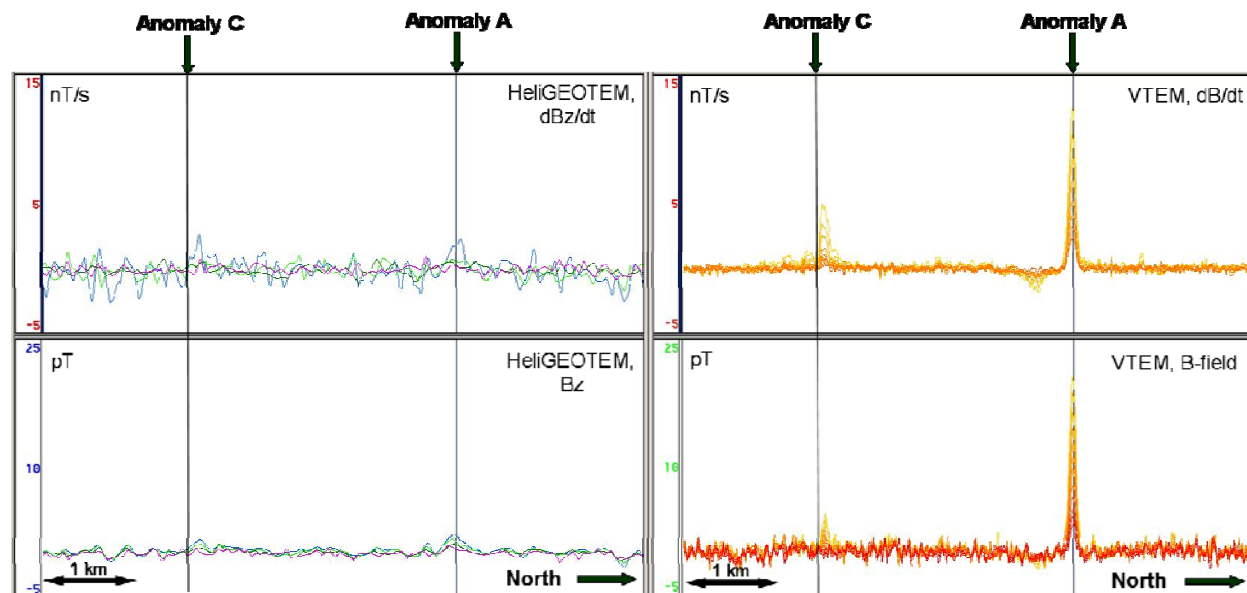


Figure 9 – Line 40870, late time gates shown. VTEM time gates 0.97 ms – 3.6 ms (channels 22 – 29), HeliGEOTEM II time gates 0.96 ms – 3.36 ms (channels 17 – 20)

The signal/noise ratios for three anomalies on the line 40780 are presented in Table 2.

	dB/dt Z-coil				B-field Z-coil			
	Early times, signal/noise		Late times, signal/noise		Early times, signal/noise		Late times, signal/noise	
	VTEM	HeliGEOTEM	VTEM	HeliGEOTEM	VTEM	HeliGEOTEM	VTEM	HeliGEOTEM
Anomaly A	25	4	31	1.5	30	3.0	21	2.5
Anomaly C	130	3	12	1.2	17	2.5	4.5	1.5
Conductor with IP effect	1200	4	no response	no response	1200	1.5	no response	no response

Table 2 – Signal/noise ratios for VTEM and HeliGEOTEM II for the anomalies on line 40870

VTEM provides by far the better signal/noise ratio for all types of anomalies. The VTEM early time response over the chargeable zone with the IP effect is about 300 times stronger than the early time HeliGEOTEM II response. The reason is, as it was shown earlier in this comparison, that HeliGEOTEM II does not provide early time gates in the VTEM range from 0.11 ms to 0.37 ms. The first off-time channel 7 corresponds to the VTEM channel 17 (0.406 ms middle time gate). The late time VTEM signal/noise ratios are 3 – 20 times greater than the corresponding HeliGEOTEM II signal/noise ratios.

The early time gate VTEM signal/noise ratios for good conductors (Anomalies A and C) are 8 – 50 times better, than the corresponding HeliGEOTEM II signal/noise ratios.

Data Comparison – Grids

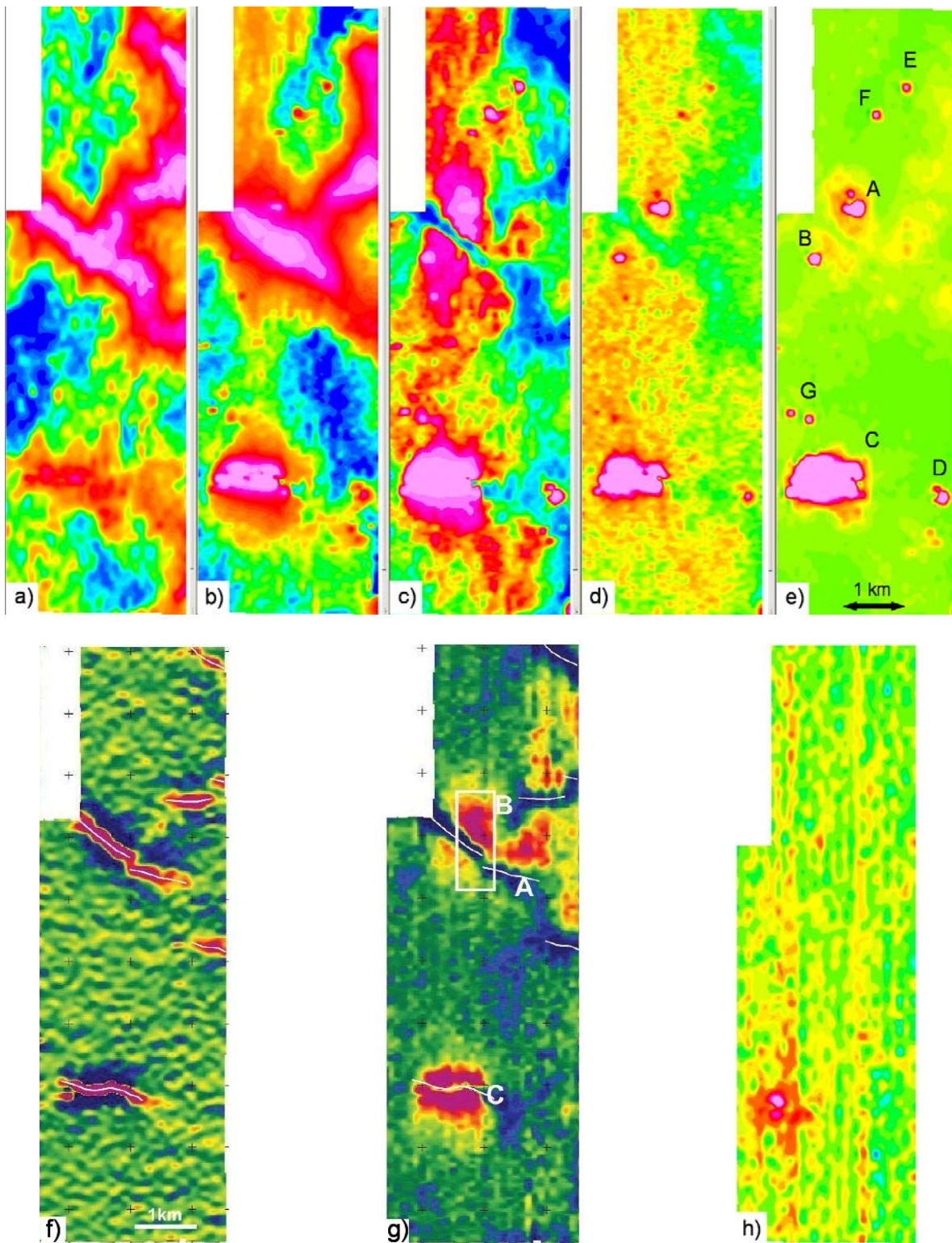


Figure 10 – EM time gate grids, a – VTEM dB/dt 0.12 ms, b – VTEM dB/dt 0.234 ms, c – VTEM dB/dt 0.4 ms, d – VTEM B-field channel 0.4, e – VTEM TAU, f - HeliGEOTEM II channel 7 dBx/dt (Fraser filtered), presented by Contractor, g - HeliGEOTEM II channel 7 dBz/dt, presented by Contractor, h - HeliGEOTEM II B-field channel 13 (0.51 milliseconds)

Figure 10 shows the VTEM and HeliGEOTEM II gridded data for several time gates, as well as the TAU grid which is the measured decay constants of the VTEM data. The grid (a) of the VTEM early time gate 0.12 ms (channel 10) shows a number of conductive zones. The grid (g) of the first off-time HeliGEOTEM II gate shows fewer conductive zones and a significant part of the area has either no response (green color) or a negative response (blue color). The grid (g) resembles the VTEM grid (c) of the off-time channel 17 (0.4 ms), but with less details and a number of conductive zones missing. The HeliGEOTEM II channel 7 dBx/dt grid (f) shows several conductive zones, all of them correspond with the positive responses on the VTEM grids (a) and (b). Some features shown on the VTEM grids are not present on the HeliGEOTEM II grids. In fact VTEM has identified seven anomalies in the area (letters A – G on Figure 10e), while HeliGEOTEM II detected only two Anomalies A and C.

Additional VTEM anomalies

Several anomalies detected by VTEM are not identified in the HeliGEOTEM II data at all. The anomalies B, D, E, F and G were detected by VTEM on two – four lines each, while HeliGEOTEM II data exhibits no anomalous responses over the same areas. Figures 11 and 12 depict the profiles over anomalies B and D.

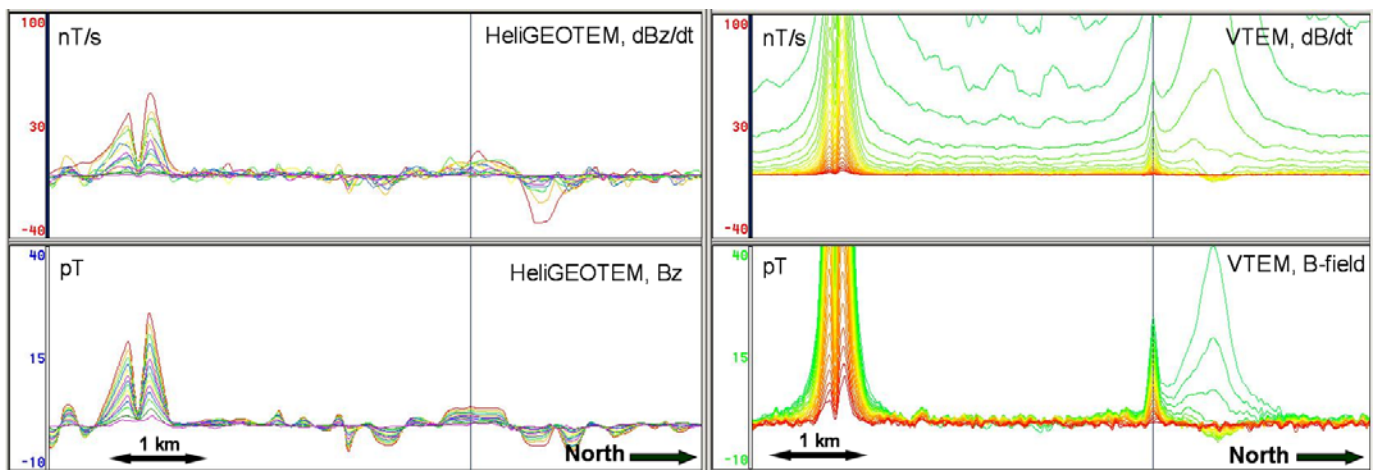


Figure 11 – Anomaly B on Line 40840 (location of the anomaly is shown by the vertical line), VTEM time gates 0.11 ms – 7.20 ms (channels 10 – 33), HeliGEOTEM II off-time gates 0.09 ms – 3.36 ms (channels 7 – 20)

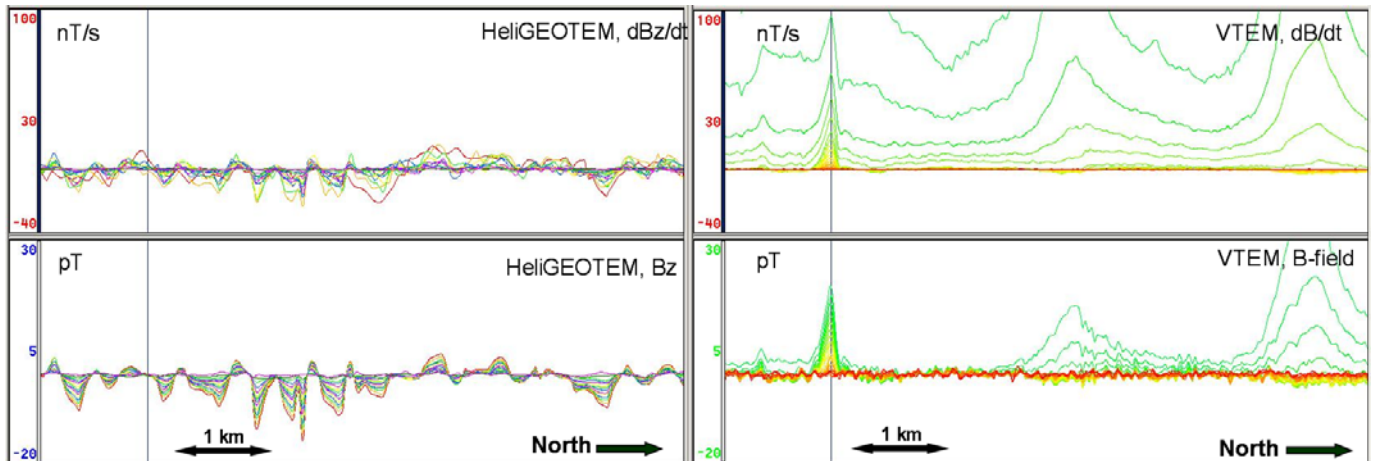


Figure 12 – Anomaly D on Line 41000 (location of the anomaly is shown by the vertical line), VTEM time gates 0.11 ms – 7.20 ms (channels 10 – 33), HeliGEOTEM II off-time gates 0.09 ms – 3.36 ms (channels 7 – 20)

Anomaly B was detected by VTEM on three lines. In comparison HeliGEOTEM II did not detect any anomalous responses over this area. It is clear from the VTEM data, Anomaly B is not part of the chargeable zone, but a separate anomaly. The modeling of the Anomaly B data showed that the conductor is dipping north 50 degrees; the

estimated depth to the top is 117 m. The Anomaly D was detected by VTEM on four lines. The modeling showed, that this conductor is dipping approximately 55 degrees south-east with an estimated depth to the top of 95 m.

On both Figures 11 and 12 the long wave length noise in the HeliGEOTEM II data (the remnants of the compensation) is obvious. The wavelength of the noise (400 – 600 m) and the amplitude are similar to the amplitude and the wavelength of the real anomalies. The other obvious characteristic of the HeliGEOTEM II data is that the early time responses are weak or non-existent compared to the VTEM early time responses. The VTEM early times anomalies are not present on the HeliGEOTEM II early time gates.

Time Constant Comparisons

Figure 13 shows the amplitude versus time plots of the VTEM dB/dt, VTEM B-Field, HeliGEOTEM II dBz and Bz data over the peak of Anomaly A. The VTEM decay curve changes smoothly showing good signal-to-noise. The HeliGEOTEM II dBz decay is erratic from point to point due to noise. The time constant estimate is 4.8 ms with the VTEM B-Field and 2.3 ms with the dB/dt at late times. Using the HeliGEOTEM II data, the time constant estimate is approximately 0.5 ms obtained from the Bz late times (a highly conductive target is absent). The reason for this difference is due to the fact that VTEM has a longer measurement time which allows for the resolution of higher conductance targets.

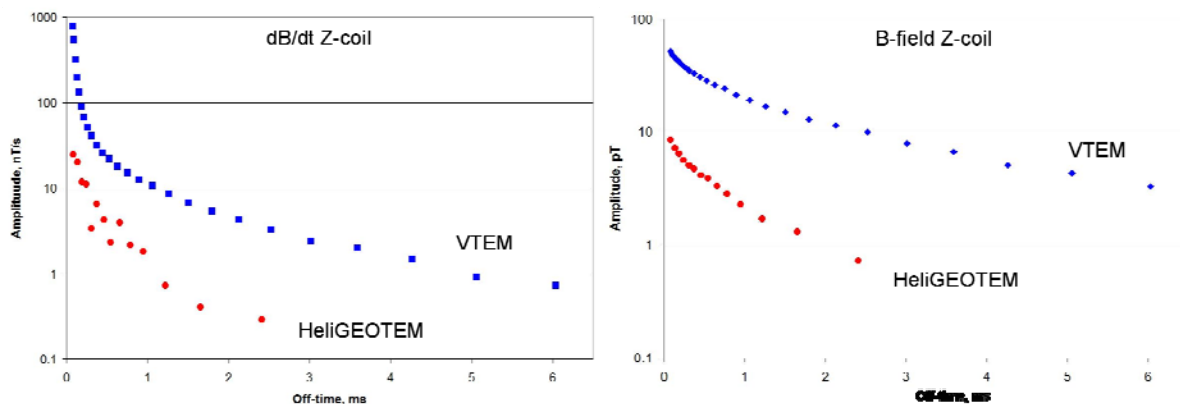


Figure 13 - Amplitude versus time plots of the VTEM and HeliGEOTEM II dB/dt, B-Field responses of Anomaly A

Interpretation and Modeling

The VTEM data provide a wider range of time gates in both the early and late times. The VTEM signal/noise ratio is higher than for HeliGEOTEM II for all comparable time gates. As a result, an interpreter is able to use more interpretation techniques, like CDIs, modeling, gridding, etc. with VTEM data, than with HeliGEOTEM II data. Due to the superior VTEM data quality and the wider range of the time gates, the interpretation with VTEM data is more accurate. For example, in “Case History of an IP anomaly in HeliGEOTEM II Data” the Contractor came to the conclusion, that “the northwest trend of negative EM readings (Anomaly A) is clearly much more than a resistive zone” (Figure 10g, area A). According to their interpretation the zone is “interesting as an exploration target”. According to the VTEM data, the zone is not a resistive zone, but a conductive zone with the IP effect causing the negative responses in the middle time gates, but strong positive responses in the early time gates. Because the early time gates are not present in the HeliGEOTEM II data, the Contractor did not realize that what was called the “resistive zone” is, in fact, a conductive zone (VTEM early time gates grids, Figure 10, a and b). Considering that the zone coincides with the lake, the “interesting exploration target” is, most probably, the lake bottom clay sediments. There are some other instances of lakes with sediments that are on the block, where visible IP effects are apparent in the VTEM data. The real exploration targets in that area are Anomalies A and B (Figure 10e).

A very powerful tool for the data analysis and data interpretation is the decay time constant, or TAU. The VTEM TAU grid is presented in Figure 10e. The TAU grid shows the location of the good conductors – exploration targets in this area (marked with the letter A – E). The grid also shows, that most of the conductive zones on the VTEM early time gate grid (Figure 10 a) are in fact weak conductors with low TAU (clays, for example).

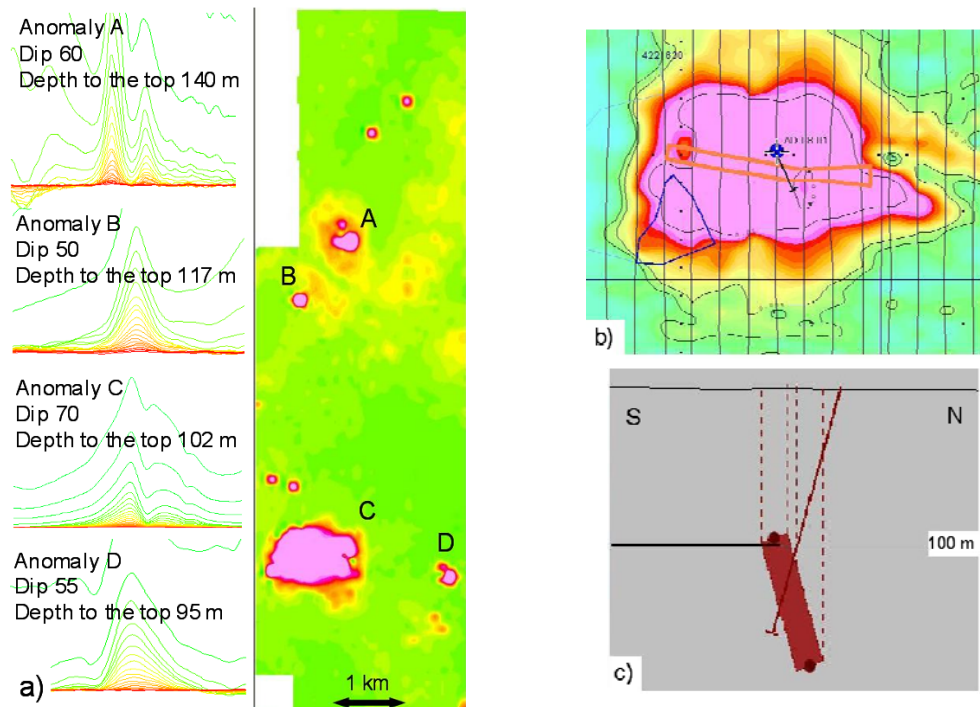


Figure 14 – VTEM modeling results; a – Selected anomalies with estimated depth to the top and dip, b – Projection of the drill hole on the surface with VTEM B-field channel 23 grid, c – Model of the conductor with the location of the planned drill hole

Several VTEM conductors were picked for modeling with the Maxwell plate model program. For each conductor a number of parameters were calculated such as depth to the top, dip, conductance, etc. Figure 14a shows the estimated parameters for the anomalies A, B, C and D. The drill hole location together with the modeled conductor are shown in Figure 10(b & c). The actual drill hole intersected the conductor within 10 m from the estimated depth.

VTEM X-coil

Starting in 2009 Geotech has been flying VTEM with the improved EM receiver combining both Z-coil and X-coil. A number of successful VTEM surveys have been already flown with the Z-X coil receiver. The VTEM data profiles for both Z and X coils are shown in Figure 15 flown over the industry's acknowledged EM Test at Reid-Mahaffy.

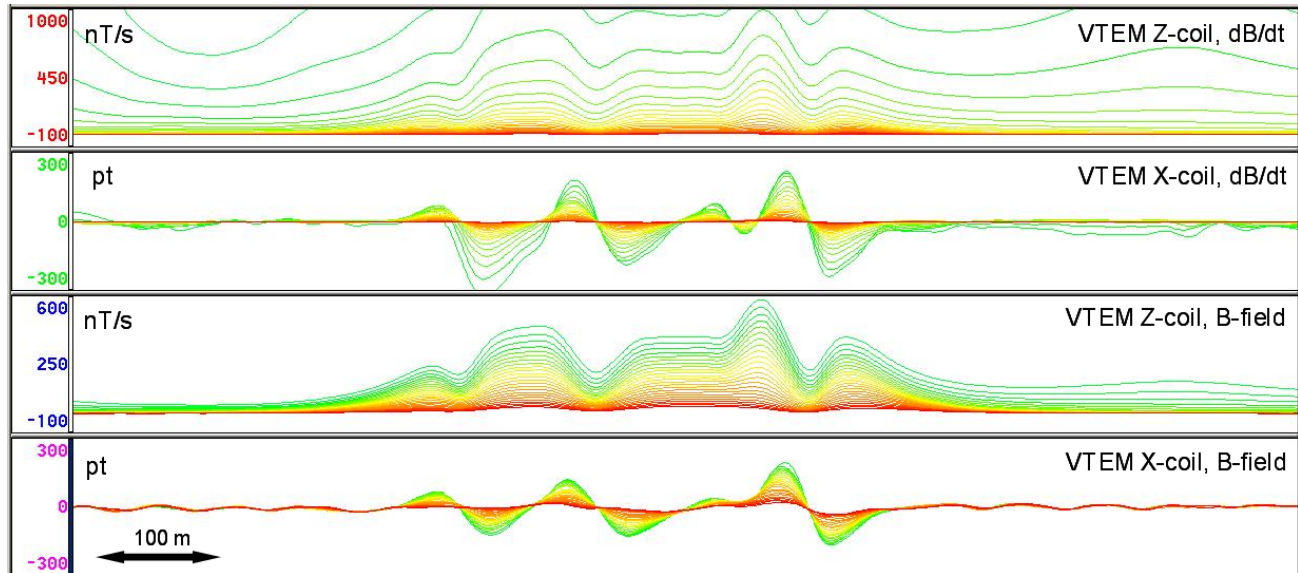


Figure 15 – VTEM profiles over a part of the line 40, Reid-Mahaffy, Ontario, Canada

Conclusions

The present study that compares the two systems using actual survey data collected over the same area shows that VTEM outperforms HeliGEOTEM II in terms of signal-to-noise, spatial resolution, conductor location, conductor definition and data interpretation. The key advantages of VTEM are:

- VTEM provides a wider range of off-time gates in both the early and late time gates.
- VTEM provides 2-10 times better signal/noise ratios on late times and 6 – 300 times better signal/nose ratios on early times for both dB/dt and B-field Z component. This implies that even if the HeliGEOTEM II dipole moment were doubled, the VTEM system would still exhibit 1 - 5 times better signal to noise on the late time channels and 3 – 150 times better signal to noise on the early time channels
- VTEM detects anomalies not apparent in the HeliGEOTEM II data.
- Interpretation of VTEM data is more accurate due to the wider range of time gates, the higher signal/noise ratio, and superior overall data quality.