The AeroTEM airborne electromagnetic system

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Airborne electromagnetic (EM) systems have evolved into 2 basic platforms since their introduction in the 1950's. The helicopter-borne frequency-domain systems (HEM) use narrow band, low moment transmitters and closely-spaced receivers with a rigid geometry between the transmitter and receiver coils. A wide range of conductance discrimination, excellent spatial resolution, and moderate depth penetration characterizes these systems. The fixed-wing time-domain systems (AEM) use wide band, high moment transmitters, and separated receiver coils in a non-rigid geometry. These systems have a moderate range of conductance discrimination, moderate spatial resolution, and much greater depth penetration compared to HEM systems. Since 1995 there have been a number of attempts at adapting the advantages of the fixed-wing time-domain systems to the helicopter platform. The AeroTEM system is the result of one such effort.

The AeroTEM system (Figure 1) is based on a rigid, concentric-loop geometry with the receiver coils placed in the centre of the transmitter loop. This configuration has a number of advantages; maximum coupling is achieved to all target geometries regardless of their depth below surface; sharper anomalies are produced with simpler shapes compared to fixed-wing systems; the anomaly shapes are independent of the flight line direction; coincident transmitter-receiver coils have a lower sensitivity to conductive overburden when compared to separated transmitter-receiver systems.

The AeroTEM transmitter waveform (Figure 2) is a triangular current pulse of 1150 microseconds duration operating at a base frequency of 150 Hz. The transmitter loop consists of 8 turns of copper wire, 5 m in diameter, with a maximum current of 250 A that produces a peak moment of 40,000 Am^2. The receiver coils are oriented one in a vertical plane (Z-axis) and one in an in-line horizontal plane (X-axis). The secondary field is sampled at a rate of 126 samples per half cycle, or 38,400 Hz. This raw streaming data includes the transmitter current and is stored on a removable hard disk for post-flight processing. Time channels are programmable and include samples while the transmitter current is turned on (i.e. on-time data).

The transmitter and receiver coils are rigidly mounted to a circular frame containing the transmitter driver circuitry. This is towed at a nominal 30 m clearance above the terrain and 40 m below the helicopter. A cesium-vapour magnetometer is towed in a separate bird 10 m above the EM system. The acquisition system and ancillary equipment such as GPS and radar altimeter is stored within the helicopter for monitoring by the system operator.

The high-moment transmitter in combination with the lower terrain clearance produces stronger secondary field responses in most conductors when compared to a typical fixed-wing system. For discrete targets of high conductance, AeroTEM has a detection advantage over both the conventional HEM and AEM designs in that AeroTEM energizes these targets with a much larger moment than do the HEM systems, and is able to measure the on-time secondary fields in the presence of a strong primary field, unlike the AEM systems. In the past, the main disadvantage of concentric-coil systems has been the strong primary field that is present during the on-time and extends into the off-time as a high system transient. The high primary field in the presence of a weaker secondary field has prevented previous systems from achieving the required signal to noise ratio necessary to make them competitive with existing AEM and HEM technologies.

The AeroTEM system has overcome the primary field problem in two ways. First, a bucking coil is used to reduce the amplitude of the primary field at the Z-axis receiver coil from 10^9 nT/s during the on-time to less than 10^3 nT/s. Second, variations in the residual primary field are removed from the Z-axis coil using a proprietary post-processing algorithm that includes deconvolution of the system's current waveform. The resulting noise level is +/- 1 nT/s in the on-time and less than +/- 0.25 nT/s in the off-time. Through the use of the deconvolution algorithm, the residual primary field in the off-time is made a constant such that it can be removed as a DC offset after stacking of the data. The X-axis coil is null coupled to the transmitter and does not suffer the same high primary field problem as the Z-axis receiver.

The ability to measure the secondary field in the on-time greatly improves the detection of high conductance targets. But because the off-time noise level is lower, there is an advantage to measuring in the off-time over a certain conductance range. Figure 3 shows the AeroTEM response nomogram in the off-time. The approximate conductance range of the system is 0.05 S to 500 S with a peak response in early time at 5 S and at late time of 50 S. The on-time nomogram is shown in Figure 4. Conductance discrimination is similar in the on-time compared to the off-time, but detection of high conductance targets is greatly increased. Conductance discrimination is not possible over 500 S for the base frequency of 150 Hz because the response shows no measurable decay. The conductor can still be detected, however, owing to the strong amplitude that exists on all of the on-time channels.

AeroTEM has flown in excess of 30,000 line-km since its debut in 1999 and has been credited with at least two discoveries. The system has also detected conductors that were missed by previous AEM and HEM surveys. The advantage of the high-moment, concentric-coil design is proving itself in its ability to energize and detect discrete, high-conductance targets, the very ones that are normally associated with mineral deposits.

Powerline Discovery

An AeroTEM survey was flown for FNX Mining Company Inc in the search for Ni-Cu-PGE deposits in Sudbury, Ontario during the summer of 2002. In addition to detecting the known deposits (Figure 5), the survey identified new targets. One such target (Figure 6), named the Powerline Deposit, was located between two major powerlines, but within an area of favourable geology known to host such deposits. A series of drillholes was collared to intersect the conductor directly from an interpretation of the airborne responses without a ground follow-up geophysical program. All of the boreholes on the initial section intersected mineralization, the third borehole encountering 6.7% Cu, 1.3% Ni, and 13.3 g/t TPM over 12.9 m in what is now regarded as the discovery hole. The deposit continued to be drilled without any ground geophysics.

Montcalm Deposit

The AeroTEM system was flown over the Montcalm Deposit, a Ni-Cu orebody owned by Falconbridge Limited, and discovered by HEM (Fraser, 1978). The off-time profiles, shown in Figure 7, show a peak response in the latest off-time channel of 19.2 nT/s. The on-time response, shown in Figure 8, has a peak response in the latest on-time channel of 190 nT/s. The strong on-time response is characteristic of high conductance targets such as Ni-deposits. An estimate for conductance of 350 S was obtained for both the on-time and off-time responses. In reality the conductance of the Montcalm Deposit could be much higher, but the maximum conductance discrimination of AeroTEM is less than 500 S for the base frequency of 150 Hz. While discrimination is limited to 500 S, detection of higher conductance targets such as Montcalm is not limited because that portion of the target response that is in-phase with the primary field is not subtracted during primary field removal as is the case with the fixed-wing systems where the variable geometry between the transmitter and receiver makes accurate primary field removal impossible.

Conductor Thickness

The concentric-coil configuration produces EM responses that are diagnostic of conductor thickness for steeply dipping targets. A double peak Z-axis coil response and positive to negative X-axis coil crossover are diagnostic of a thin conductor. A single peak in the Z-axis coil and a lower-amplitude negative to positive X-axis coil crossover are diagnostic of a thick tabular conductor, such as a typical steeply dipping mineral deposit. For conductors with a thickness less than 8 m, the responses appear as thin conductors. There is a transition from a thin conductor response to that of a thick conductor from 8 m to 15 m. Conductors thicker than 15 m have a thick conductor response. Figure 9 shows the responses for both thin and thick conductors recorded on the same flight line.

Conclusions

The AeroTEM system is capable of achieving the depth penetration of AEM systems, and with the spatial resolution and conductance discrimination of the HEM systems. This is made possible by using a rigid platform and measuring during the transmitter on-time with accurate primary field removal. The concentric-coil geometry produces simple and diagnostic conductor responses that are independent of the flight line direction. This makes it possible to proceed directly to a drilling program without the requirement for ground geophysics. Maximum conductance discrimination is 500 S with the current base frequency of 150 Hz, which is greater than off-time systems operating at 30 Hz. A new AeroTEM system is under development having a transmitter moment of 120,000 Am^2. This system will have an exploration depth in excess of 300 m.

Acknowledgments

Aeroquest Limited thanks the FNX Mining Company Inc and Falconbridge Limited for permission to show the AeroTEM results from their respective properties.

References

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Boyko, W., Paterson, N.R., and Kwan, K., 2001, AeroTEM characteristics and field results: The Leading Edge, Vol. 20, No 10, pp 1130-1138.

Fraser, D.C., 1978, Geophysics of the Montcalm township copper-nickel discovery: Canadian Institute for Mining Bulletin, January 1978, 99-104.

Figure 1. The AeroTEM system transmitter-receiver coils are shown here during a break in a diamond exploration program in Venezuela.

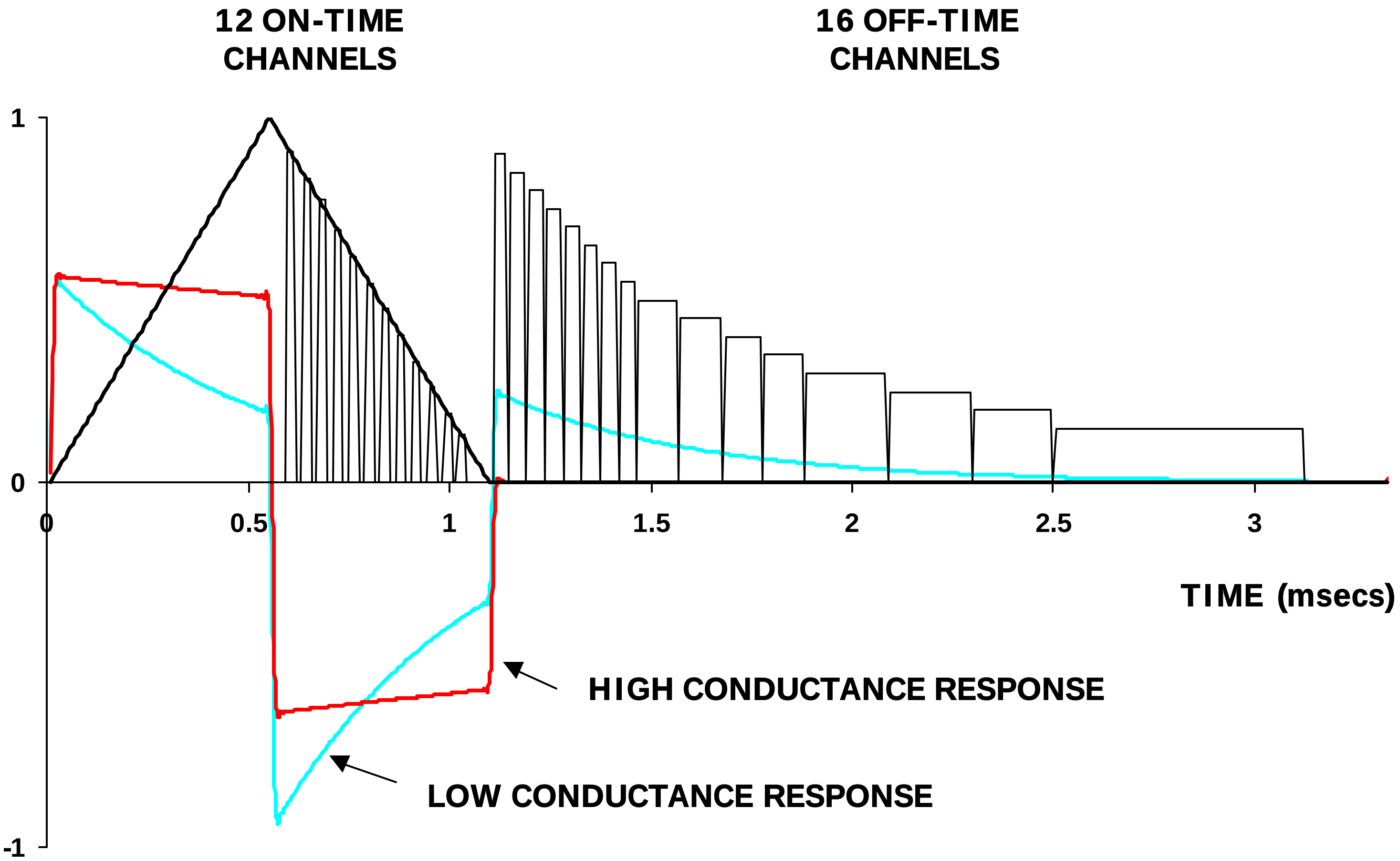

Figure 2. The AeroTEM waveform is shown for the 150 Hz base frequency for the positive current pulse. The on-time channels are equally spaced at one sample interval or 26.5 microseconds. The first 8 off-time channels are also equally spaced to one sample interval. The remaining 8 off-time channels are logarithmically spaced.

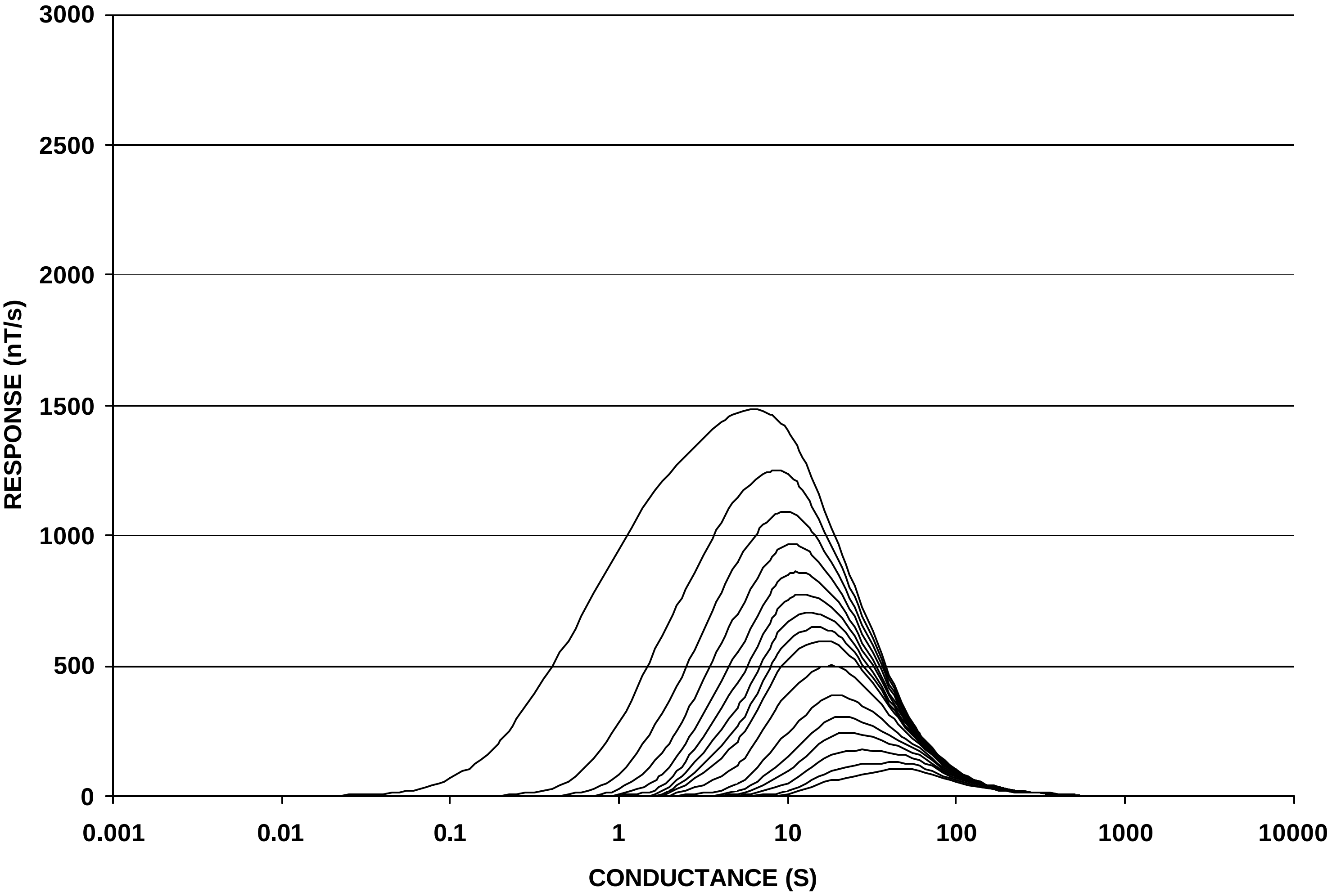

Figure 3. Off-time nomogram for the AeroTEM 16-channel configuration using a 200 m by 200 m flat-lying conductor located 50 m below surface within a resistive half-space. The early time peak occurs near 5 S while the late time peak occurs near 50 S. The approximate range of detection and conductance discrimination is 0.05 S to 500 S.

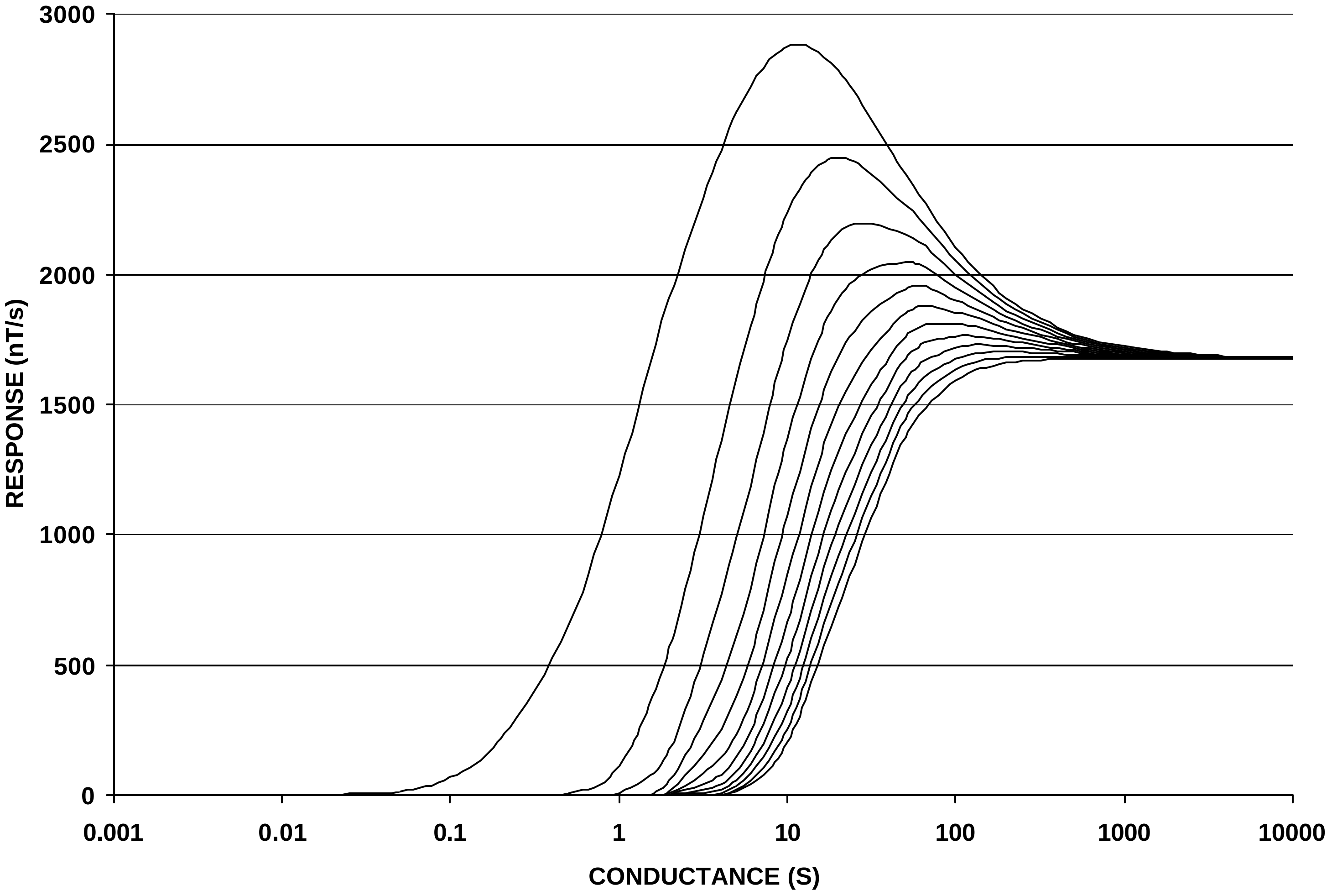

Figure 4. On-time nomogram for the AeroTEM 12-channel configuration using a 200 m by 200 m flat-lying conductor located 50 m below surface within a resistive half-space. The early on-time peak occurs near 5 S while the late time peak approaches the inductive limit response beyond 500 S. The approximate range of conductance discrimination is 0.05 S to 500 S, but the detection range is not limited by high conductance.

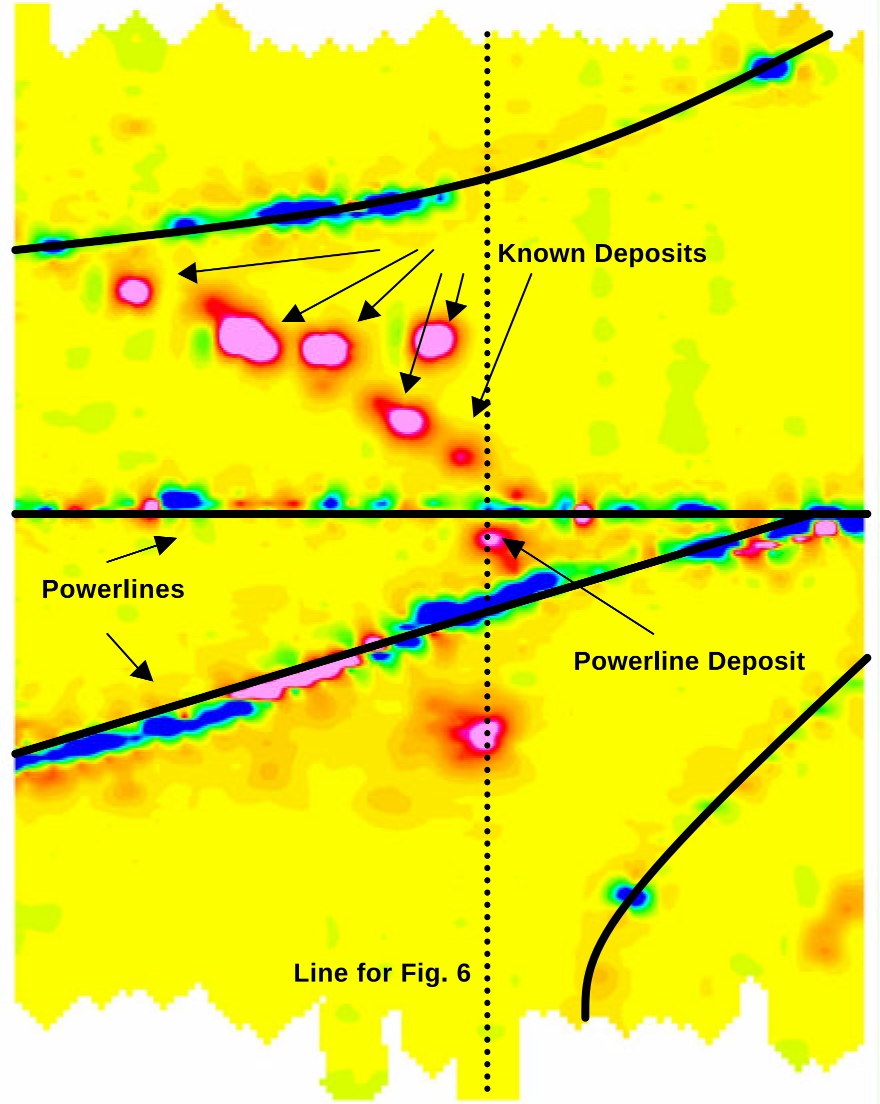

Figure 5. Plan view of the AeroTEM early-time Z-axis response for the Victoria Property owned by FNX Mining Company Inc, Sudbury Ontario.

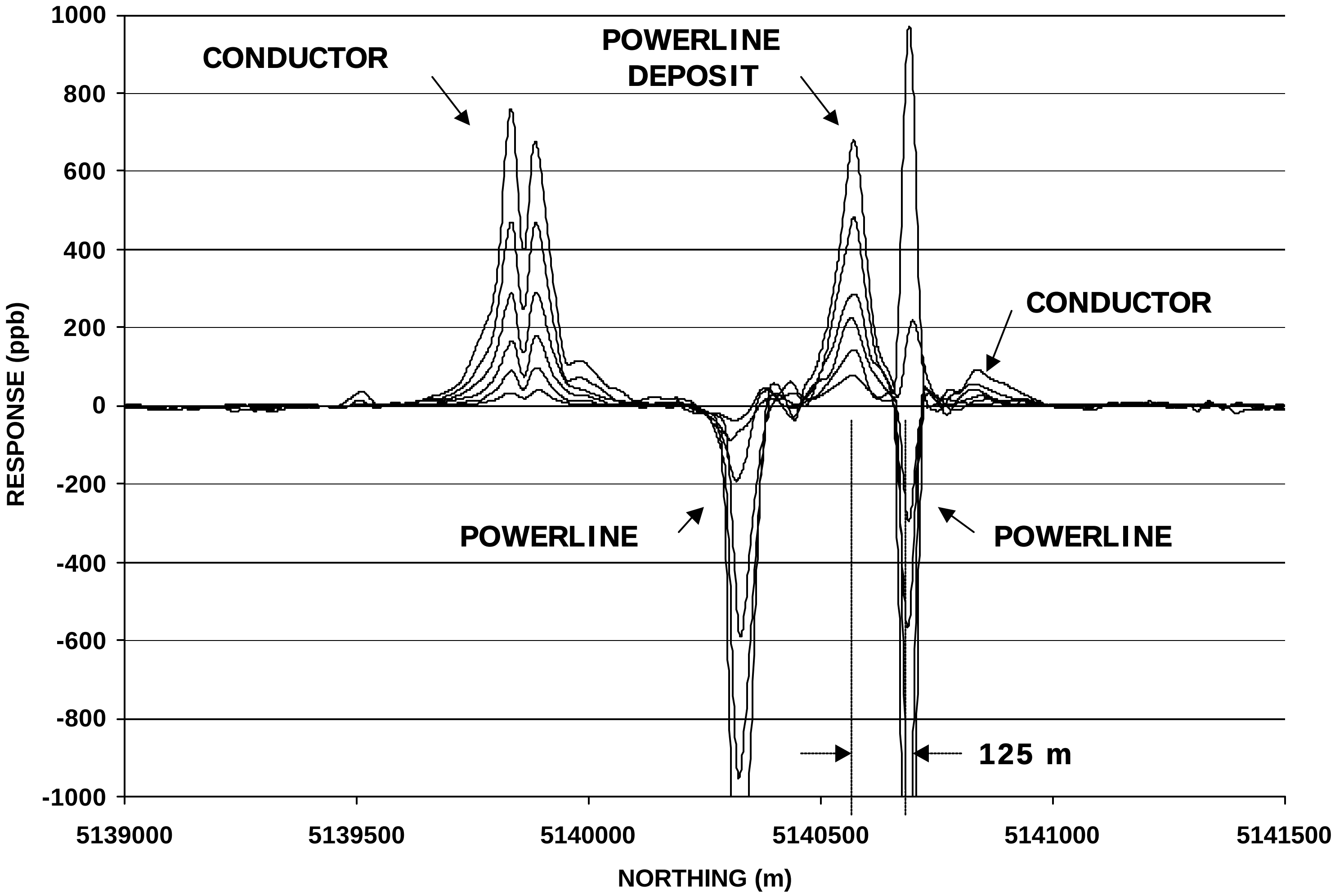

Figure 6. AeroTEM Z-axis profiles for the Powerline Deposit. The response is located within 125 m of a major powerline.

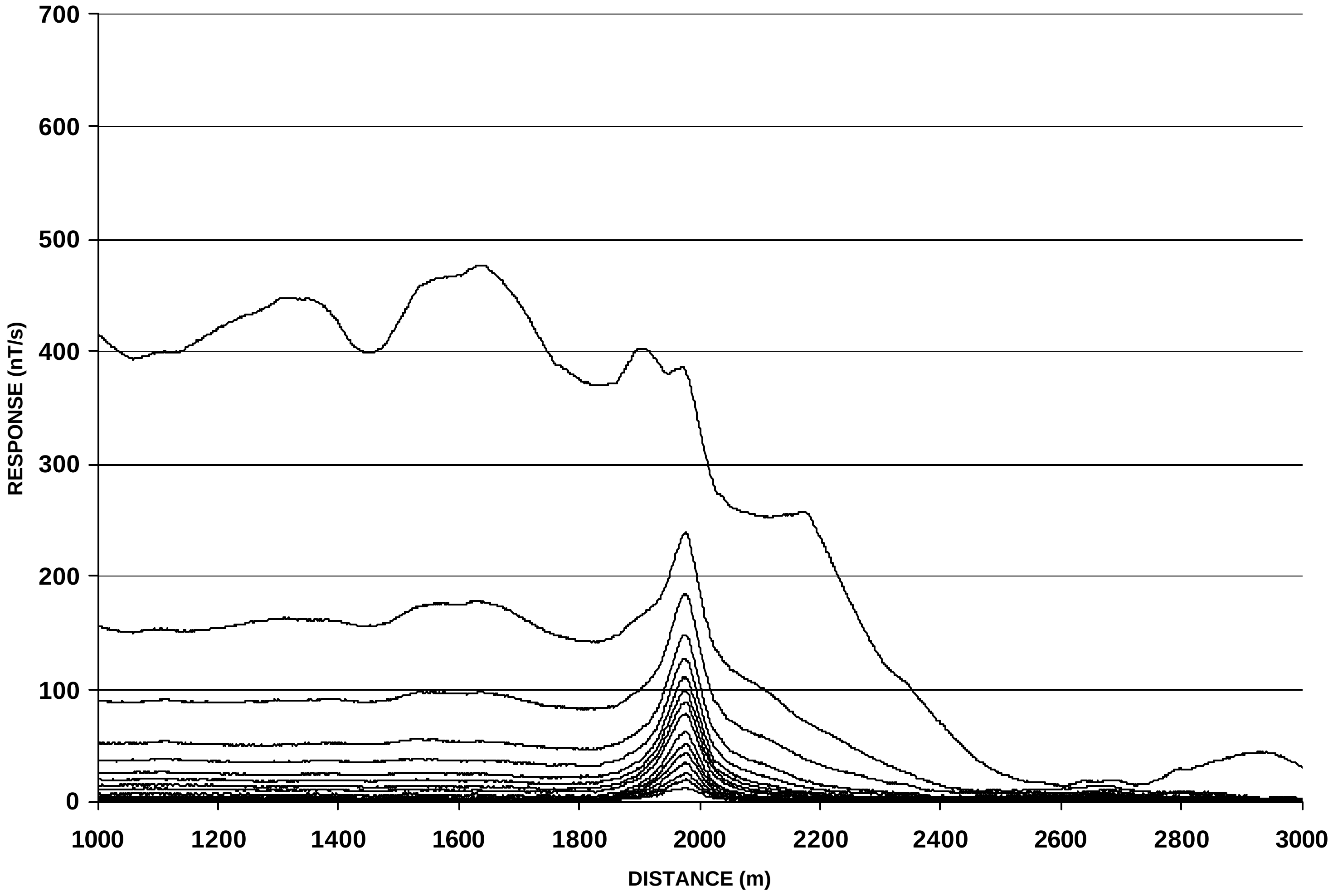

Figure 7. AeroTEM off-time response for the Montcalm Nickel Deposit. The latest time channel shows a peak response of 20 nT/s. The deposit is overlain by moderately conductive overburden.

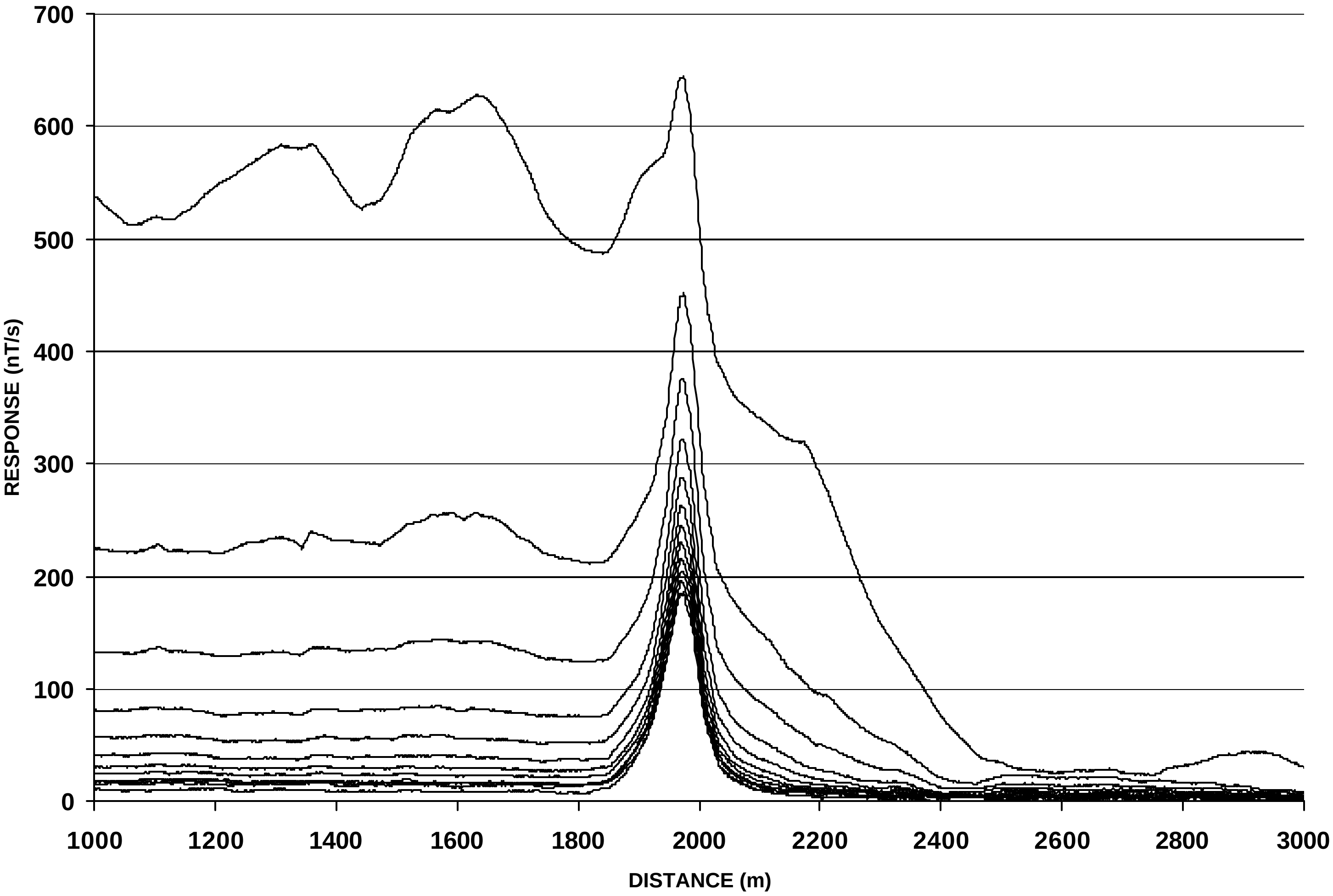

Figure 8. AeroTEM on-time response for the Montcalm Nickel Deposit. The latest on-time channel has a peak response of 190 nT/s.

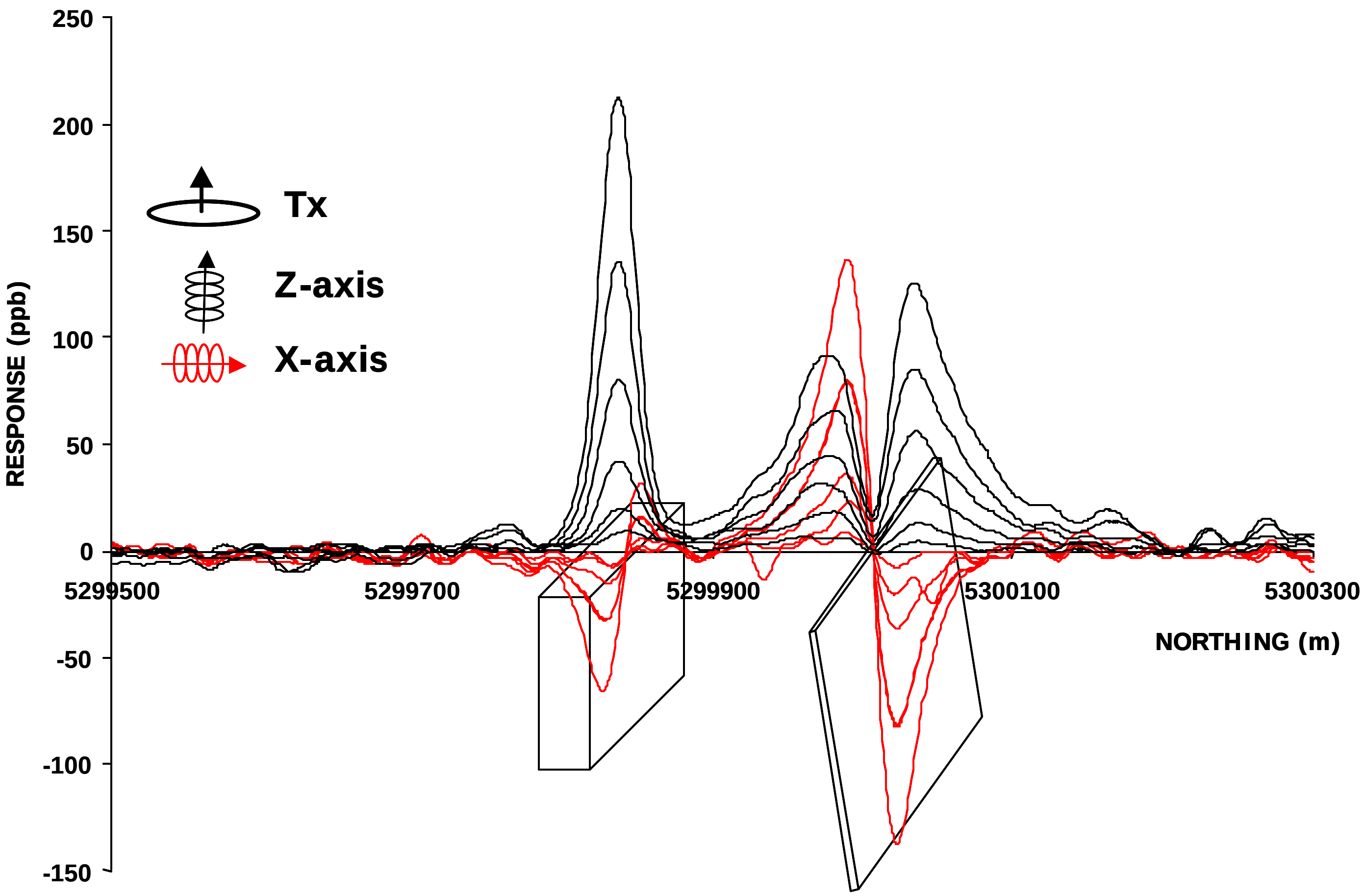

Figure 9. Thick conductors have a characteristic single peak in the Z-axis coil and a low amplitude negative to positive cross-over in the X-axis coil, while thin steeply dipping conductors have a double peak in the Z-axis and positive to negative peak cross-over in the X-axis of similar amplitude.