The Spectrem Airborne Electromagnetic System—Latest Developments and Field Examples

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ABSTRACT

In 1989, as a major re-engineering of the A-Cubed (Toronto, Canada) PROSPECT 1 system, the SPECTREM system was commissioned by Anglo American Corporation, utilising in-house expertise and staff. From 1990 to 1993 all the electronic hardware and software in the system was replaced which resulted in a five-fold reduction in noise levels. Subsequently, further evolutionary developments have contributed incremental improvements.

The system was designed with two main purposes in mind, namely the detection of massive sulphides at considerable depths in conductive or resistive environments, and accurate electromagnetic sounding to depths in excess of 300 m below surface. In order to achieve the design aims, the system has the following features:

- *Time domain STEP response operation.*
- *Wideband 60kW transmitter with base frequencies of 25, 30, 75, and 90HZ.*
- *Large transmitted dipole moment of 3 000 000Am^2 RMS (630 000Am^2 peak)*
- *3 component air-cored receiver coil*
- *High drag towed bird for invariant TX-RX separation*
- *Onboard 64 bit multiprocessor receiver computer operating of 500 megaflops*
- *Full waveform recording of TX and X, Y, Z received signals*
- *Accurate in-flight calibration system*
- *Transmitter-receiver separation of 128m*
- *Simultaneous operation with Cesium towed-bird magnetometer system.*
- *Differential GPS navigational system*
- *Basler DC-3 turboprop airborne platform*

Interactive interpretation software allowing determination of coordinates, conductivity-thickness, product, dip, depth, magnetic association and grade of any conductor within 40 seconds.

Accurate conductivity depth imaging using either Maximum Entropy or Lamontagne algorithms

The SPECTREM system has collected data over a variety of areas in Canada over the last three years. These areas have included prospective terrains for volcanogenic massive sulphides and nickel-bearing intrusives. To date two new economic ore deposits have been discovered with the SPECTREM system in northern Manitoba, namely the recently commissioned Photo Lake mine, and the Konuto Lake deposit (in the commissioning stage).

The system performance is evaluated over the Tyrrell Lake massive sulphide body in Northern Manitoba. It was noted that the conductor was evident on the airborne records even at flying heights of 350 metres above ground level. A case study using a proprietary conductivity - depth imaging algorithm is also presented over an area in Southern Africa. This example shows that bedrock conductors can be detected under deep and conductive cover with a system such as SPECTREM.

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INTRODUCTION

In 1982 Anglo American Corporation (AAC) entered into a contract with A-Cubed of Toronto, Canada for the construction of a new wide-band, digital, towed bird AEM system called PROSPECT 1 (Annan, 1986). In 1988 development of the system was taken over by AAC. After extensive modifications, the prototype system because operational in 1989 at which time it was renamed SPECTREM. In 1990 a new research and development program was started on replacing all the electronic hardware and software in the system. At the completion of this program in 1993, noise levels were lower by a factor of 5 compared to the original prototype system. Since 1993, further upgrades have been made which have increased the reliability of the system and further lowered its noise levels.

DESIGN AIMS

The design aims of the system were as follows:

- To detect bedrock conductors at considerable depths in conductive environments.
- Deep and accurate AEM sounding for mineral/water search and geological mapping.
- Cost effectiveness.
- Automated data processing.

IMPLEMENTATION

To achieve these design aims, the system has the following features:

Time domain STEP response—was chosen because of its wide bandwidth and better geological noise rejection in the search for highly conductive massive sulphide bodies.

Figure 1 shows a comparison of bandwidth and penetration through conductive cover of the SPECTREM system versus a PULSE system.

At 90Hz base frequency, SPECTREMs bandwidth covers delay times with window centres from 22 to 4156 microseconds versus the 220 to 3300 microseconds off time window centres of the PULSE system. The earlier SPECTREM delay times result in a better shallow sounding capability.

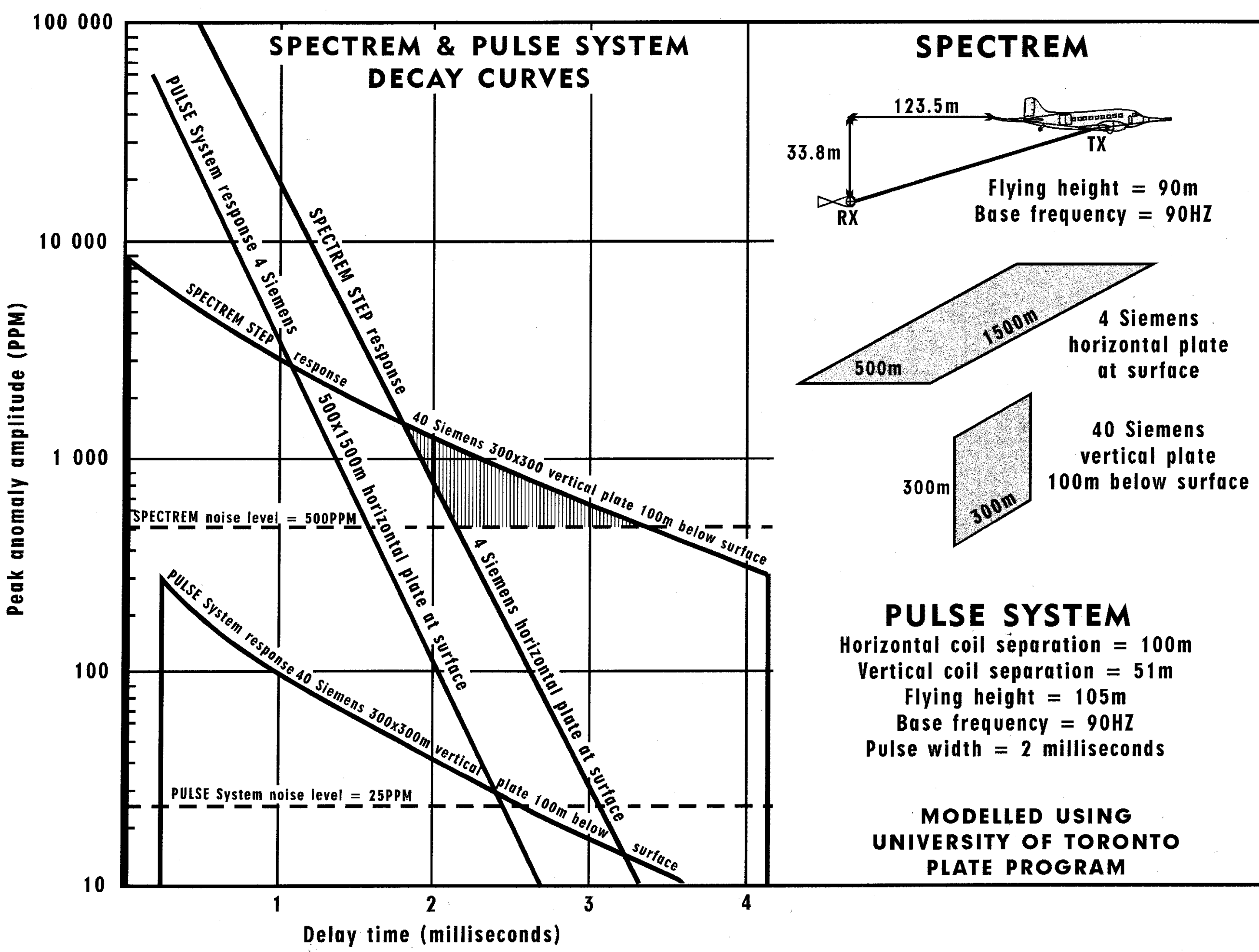


Figure 1: *Comparison of bandwidth and penetration through conductive cover. SPECTREM versus a PULSE system.*

For a 40 Siemen vertical plate at 100 m depth (simulating a massive sulphide orebody), situated under a 4 Siemen horizontal plate at surface (simulating conductive overburden), the SPECTREM Step response amplitude of the vertical plate, is greater than that of the horizontal plate and greater than the noise level, for delay times ranging from 1.8 milliseconds to 3.3 milliseconds (see hatched area). For the PULSE system this is not the case which indicates that SPECTREM probably has better penetration in conductive environments.

The SPECTREM STEP response amplitudes at long delay times (e.g., 3.3. milliseconds) for the 40 Siemen plate at 100 m depth, are 40 times larger than those of the PULSE system. However the SPECTREM noise levels are only 20 times larger and have in the past been only 10 times higher under optimum flying conditions. This indicates that SPECTREM has better sensitivity at long delay times. At early delay times of around 1 millisecond, the response of the 4 Siemen horizontal plate (simulating overburden) for SPECTREM, is only 5 times that of the PULSE system. This implies that SPECTREM probably rejects geological noise better than a PULSE system, for an equivalent base frequency.

A Wideband 60kW transmitter—with base frequencies of 25, 30, 75 and 90 HZ. The root mean square dipole moment of SPECTREM is 3000 000 Am2 which is considerably larger than that of other towed bird systems. The transmitter waveform of SPECTREM is a close approximation to a square wave. Essentially, a current is switched through a STEP of 1 500 AMPS into a loop of area 420 square metres. This waveform has abundant low frequency spectral content for deep penetration in conductive environments. It also has sufficient high frequency spectral content for shallow sounding applications. At present a new transmitter is being built which will increase the moment by a further factor of two in a year's time.

A three-component air-cored receiver coil —which has good linear response from low to high frequencies together with very low drift. It allows the geometry of conductors to be resolved considerably better and assists in the detection of deep conductors whose amplitudes are near the noise level. This occurs because the response is usually visible on both the X and Z components.

A high drag towed bird—which flies at an angle of only 16 from the horizontal. This results in the tow cable being almost straight and hence the TX-RX separation stays essentially invariant under normal surveying conditions. Since there is little amplitude modulation of the overburden response in this fixed geometry configuration, high quality sounding and easier conductor detection is the end result.

An onboard 64-bit multiprocessor receiver computer—operating at a speed well in excess of 500 megaflops. This allows sophisticated real time signal processing and a 30 fold reduction of data volume to tape for subsequent ground reprocessing.

Full waveform recording—of TX and X, Y, Z received signals for later reprocessing on the ground in order to reduce noise levels if required.

Accurate in flight calibration system—which allows known signals to be injected at various points along the signal path for calibration or other purposes.

Large transmitter-receiver separation—of 128 m in order to give a good ground footprint and high sensitivity.

Cesium vapour magnetometer—operating simultaneously with the EM system. The transmitted waveform has no off time for making the magnetic measurements. Therefore technology was developed in 1985 to measure the magnetic field whilst the transmitter signal was on.

Differential GPS navigation system—Various improvements were made to this system over the years which allow lines to be flown very accurately.

The Basler DC-3 TP67 turboprop platform—allows a long survey flight duration of up to 7 hours and excellent single engine survey performance for safety. The aircraft has proved to be very cost effective under AEM survey conditions. A spectrometer system can be added if required.

Interactive interpretation software—has been developed over several years which allows comprehensive parameterization of any bedrock or surficial conductor in a period of less than 40 seconds. These parameters include the conductor location within its geological setting, the conductivity-thickness product, dip, depth, associated magnetic anomaly and grade. Interpretation can therefore proceed at a faster rate than the data can be collected. In less complex environments, data can be autopicked and automatically parameterized using inversion algorithms.

Conductivity depth imaging algorithms— Research and development has been carried out over several years on optimising these algorithms. Currently the best results have been obtained using a maximum entropy algorithm developed by research scientists Neil Pendock and Peter Leggatt which built on the original theoretical work of Yves Lamontagne and his co-workers.

MODELLED SPECTREM STEP FUNCTION RESPONSES

Figure 2 shows the modelled SPECTREM STEP function responses for dipping plates of dimensions 300 X 300m. The responses were modelled using the University of Toronto's Plate program.

The STEP response amplitudes at long delay times are approximately 40 times larger that those of an equivalent PULSE system operating at the same base frequency. However SPECTREM noise levels are 20 times larger, so the increase in sensitivity is at best currently only a factor of two.

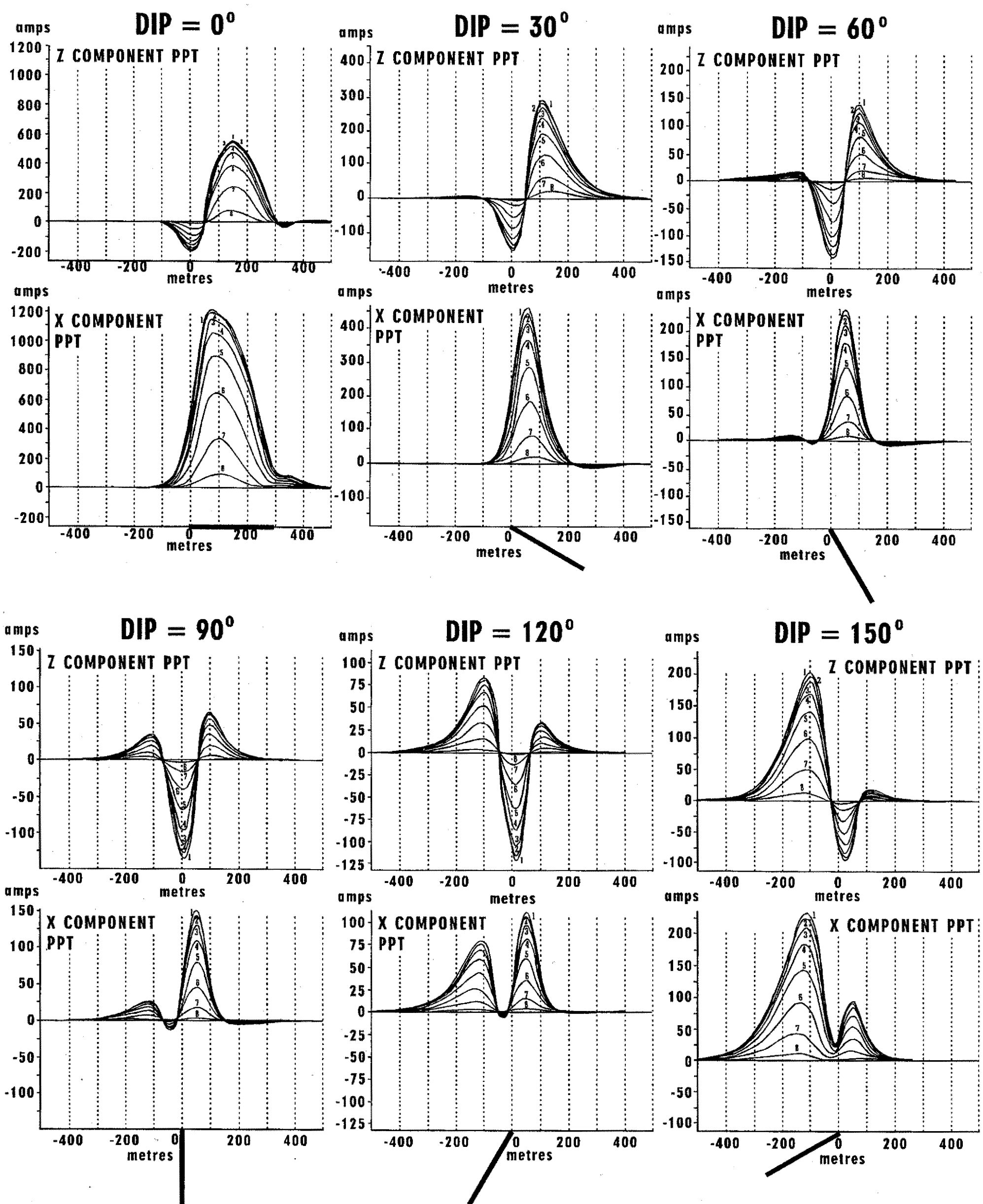
The dip of the conductor is easily determined visually by comparing the ratio of the two positive Z peaks on the Z component anomaly profiles together with the shape information from the X component anomaly profiles. Inversion algorithms can also be used for finding the dip but these are a lot slower and do not work well if there are numerous adjacent conductors or conductive overburden with varying thickness or conductivity present in the vicinity of the conductor.

Note that the STEP response anomaly amplitudes at the earlier delay times for horizontal plates, are eight times larger than those due to vertical plates. The same is essentially true for the PULSE system.

CASE HISTORIES

Tyrrell Lake massive sulphide body

Figure 3 shows the response of the SPECTREM system over the Tyrrell Lake massive sulphide body which occurs in the Flin Flon area, Manitoba.



Aircraft flying height	= 90 metres
Conductivity thickness product of plate	= 40 siemens
Horizontal RX - TX coil separation	= 123.5 metres
Vertical RX - TX coil separation	= 33.8 metres
Base frequency	= 90 HZ
Amplitudes in parts per thousand of the primary field at the receiver	
Modelled using University of Toronto PLATE program	

WINDOW No.	WINDOW CENTRE (microsecs)
1	22
2	54
3	119
4	250
5	510
6	1031
7	2072
8	4156

Figure 2: *Modelled SPECTREM STEP function responses for 300 × 300m dipping plates.*

This body, was flown during 1993 immediately after major upgrades had been made to the SPECTREM system. Noise levels were not yet as low as they are currently because of interference from a nearby AM radio station.

The body consists mainly of pyrhotite massive sulphides about 50 m thick and dipping at 40 northwards. Depth extent is unknown but the airborne response indicates that it is substantial. At least two other bodies occur in close proximity to the main body. These are clearly evident on the airborne records.

As can be seen from the Figure 3, a detectable response was still obtained in both flight directions at a flying height of 350 m above the body. Since the normal flying height is 90 m, this indicates that the body would probably have been detected in a very resistive environment if it had been at a depth of 260 m below ground level. This gives some indication of the depth of penetration of the system. Continual improvements are being made to the system to reduce the noise levels even further. These include a new, very high power transmitter for operation in conductive environments at base frequencies of 25 and 30HZ.

There was a problem with the magnetometer system for this test so the noise levels were far higher than is currently the case.

Photo Lake Orebody

Figure 4 shows the SPECTREM responses over the Photo Lake massive sulphide orebody. This body was discovered with the SPECTREM system during 1993 in the Snow Lake area, Manitoba. Earlier airborne electromagnetic surveys flown with other systems using the same line spacings had failed to detect it.

The body is lens shaped with a thickness of 40 metres, maximum strike length of 150 metres and a depth extent of 1300 metres. The top of the body occurs at 30 metres below surface but the full thickness is only

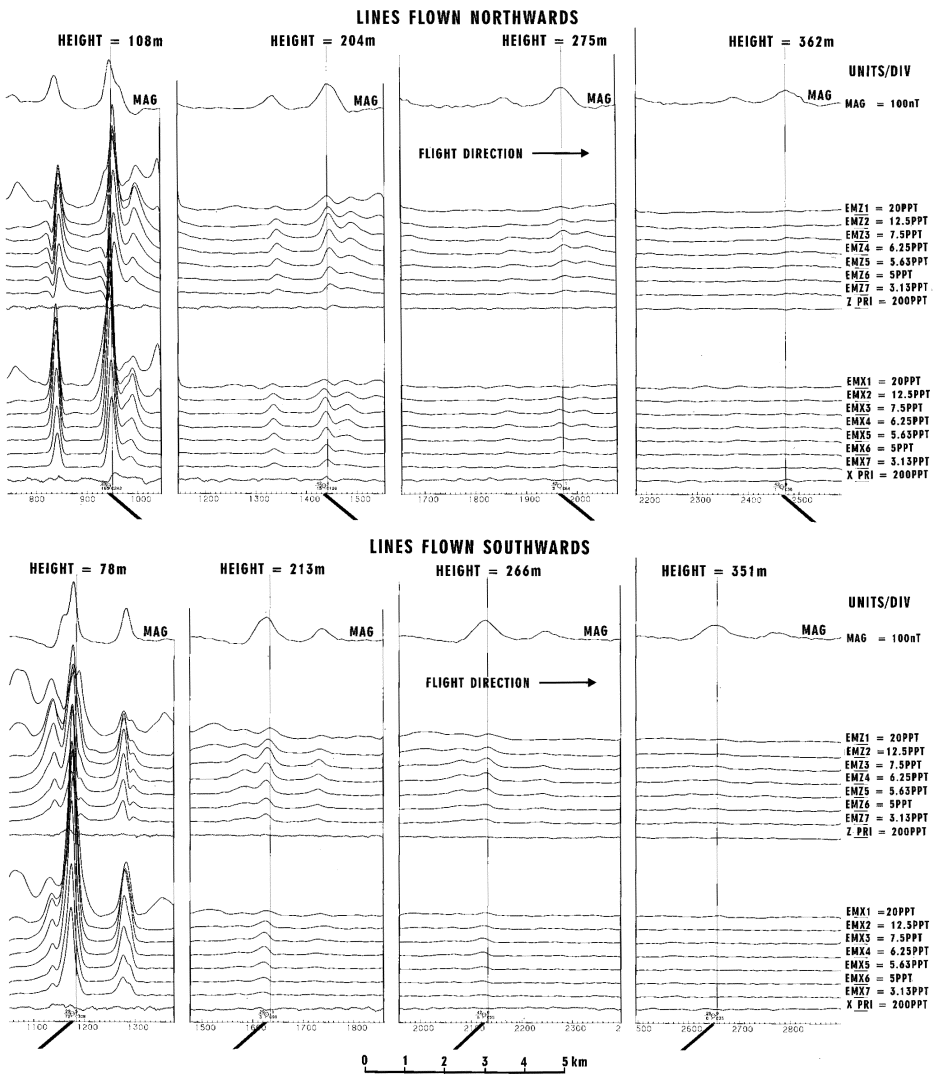


Figure 3: *SPECTREM responses versus flying height-Tyrrell Lake massive sulphide body.*

reached below 90 metres. The strike is east-west and the plunge is approximately 45° north eastwards.

After the initial discovery, the body was flown in line directions at 45° and 90° to the original north-south flight direction. The response of the body was several times the noise level on at least two flight lines in each flight direction, all of which were flown at line spacings of 200 metres. Only the best response in each line direction is shown in Figure 4.

The body was very easily detected since the amplitudes of the responses are all around 5 to 10 times the peak to peak noise levels. The calculated conductivity-thickness products for the body on all the lines was 28 Siemens assuming the standard 300 × 300m plate model which is used for routinely parameterizing all the conductors.

CONDUCTIVITY DEPTH IMAGES

Figure 5 shows an example of conductivity depth images generated form data collected in 1989 with the SPECTREM system:

The geology here consists of Kalahari sands overlying resistive basement rocks which host lithological bedrock conductors. On the images, these bedrock conductors were successfully traced under the sand cover even in areas where the sand is up to 80 m thick and has a conductivity thickness product of 6 Siemens.

The line to line correlation on the images is good showing that the system geometry is tightly controlled and that the conductivity depth algorithm developed by Lamontagne is working well. More recently, images are generated using a maximum entropy algorithm which generally results in less diffuse conductivity boundaries and gives good images down to depths of 500 metres below ground level.

These images are very valuable for mapping sub-surface geology and in the interpretation of complex structure. In addition they have application in the discovery of kimberlites under conductive cover and in the location of potable ground water.

CONCLUSIONS

SPECTREM is a new wideband, digital, towed bird AEM system which has been developed with two main purposes in mind, namely the detection bedrock conductors at considerable depths in conductiv