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Integrated interpretation of SPECTREM geophysical data

C.T. Archer
Anglo American Corporation of South Africa Limited,
PO Box 61587,
Marshalltown, Gauteng 2001,
South Africa.

ABSTRACT

Electromagnetic attribute maps of SPECTREM AEM data are useful for geological interpretation, particularly where prior ground knowledge is limited. Single time-window maps require a baseline drift correction, which is accomplished by line-by-line modal filtering. Time-constant maps remove much of the effect of flight height variation on acquired data, without making any assumption about the geometry of conductive bodies. In addition, they map the changing behaviour of the electromagnetic decay curve, not just its amplitude at a particular sample time, across a survey area.

Combining three electromagnetic maps in a ternary plot can be used to incorporate a large degree of information from the electromagnetic decay curve into a single image. An RGB (red-green-blue) representation is found to be an effective display. However, low signal amplitudes at late time preclude very deep information from being incorporated into such an image.

INTRODUCTION

The SPECTREM airborne electromagnetic system was designed with two main purposes in mind: the detection of massive sulphides at considerable depths in conductive and resistive environments, and accurate electromagnetic sounding to depths in excess of 300 m below the surface. To achieve these design aims, the system has the following characteristics:

- a wide-band transmitter (25 Hz to 23040 Hz)
- high transmitted power over the full bandwidth (RMS dipole moment of 300 000 Am^2)
- a high-drag, stable bird for minimising variation in transmitter-receiver coil separation
- a highly linear three-component receiver coil
- a large transmitter-receiver coil separation of 135 m
- a custom receiver system with 19-bit A/D converters sampling at a rate of 46080 samples per second
- an onboard 64-bit receiver computer system operating at 500 megaflops for real-time signal processing
- a custom data acquisition system

The current geometry of the SPECTREM system is shown in Figure 1.

From 1993 to 1996, the SPECTREM system was used for prospecting for volcanogenic massive sulphides and nickel-bearing intrusives in central Manitoba, Canada, and led to the discovery of two orebodies. In this region, the ground surveyed had generally been previously well-explored, and bedrock exposure was good.

In 1997, SPECTREM was commissioned to fly a number of surveys in central Africa, and the interpretative problem changed dramatically. Here, there was little geological outcrop (although fortunately overburden proved generally to be electrically resistive), and areas were poorly understood, having been little explored with modern techniques. It became evident that any geological information which the SPECTREM AEM data could supply would be extremely useful in delineating geological units and defining potential areas of interest for ground follow-up. It was in this context that the research to be presented in this paper was carried out.

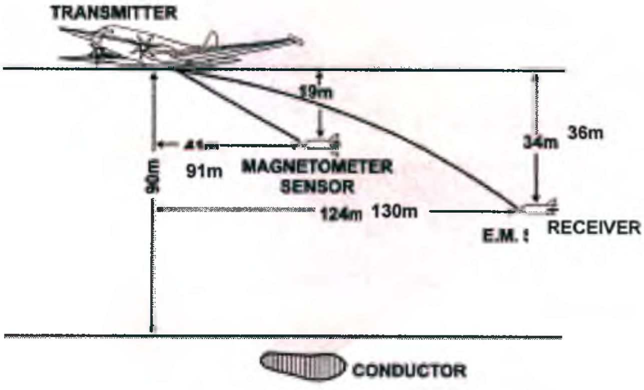

Figure 1. Geometry of the SPECTREM system.

In Canada, SPECTREM AEM data interpretation had been limited to the picking of point anomalies, which were parameterised in terms of their CTP (conductivity-thickness product), dip, residual X channel window 4 amplitude, equivalent depth, and magnetic association, and assigned a grade. In central Africa, a more detailed interpretation, involving line-to-line correlation of electromagnetic and magnetic anomalies, radiometric interpretation (a 256-channel radiometric sensor was installed in May 1997) and the delineation and description of electromagnetic anomaly zones, was undertaken.

Electromagnetic maps were not required by the client in Canada, and thus none were delivered. The purpose of the present paper is to demonstrate the usefulness of electromagnetic maps in geological interpretation, particularly in areas where little is known about the geology from previous work. Electromagnetic maps have been generated for the central African surveys, but their usefulness has yet to be fully determined.

METHODOLOGY

Single-window maps

The SPECTREM AEM system collects eight windows of data in each of three channels - X, Y and Z. In this paper, only X channel data will be considered, specifically windows EMX1 (26.0 µs delay), EMX2 (65.1 µs delay), EMX3 (143.2 µs delay), EMX4 (299.5 µs delay) and EMX5

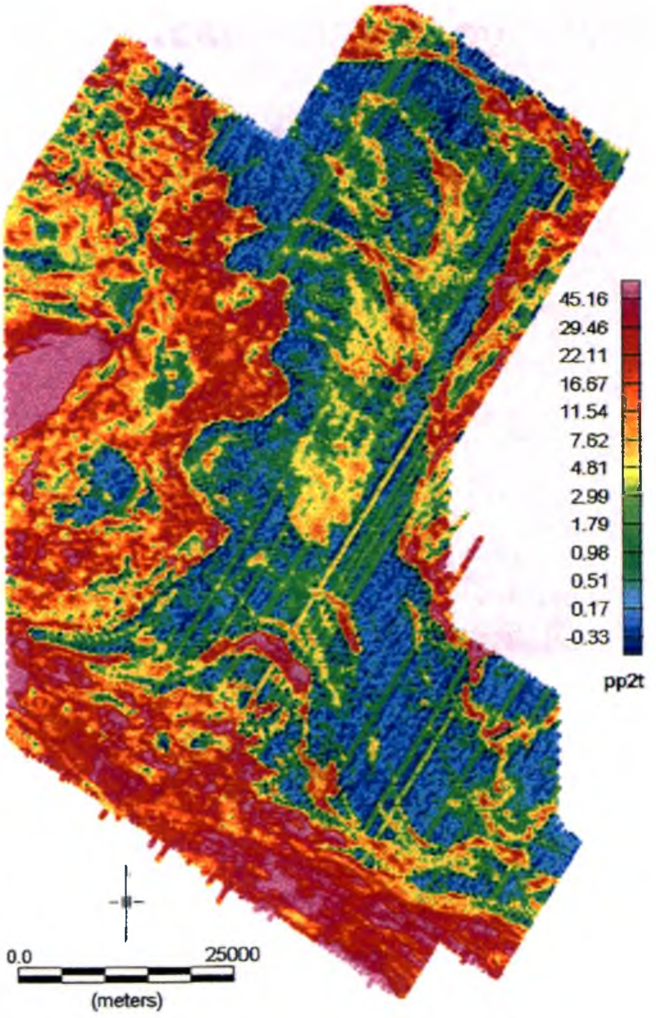

Figure 2. Raw EMX4.

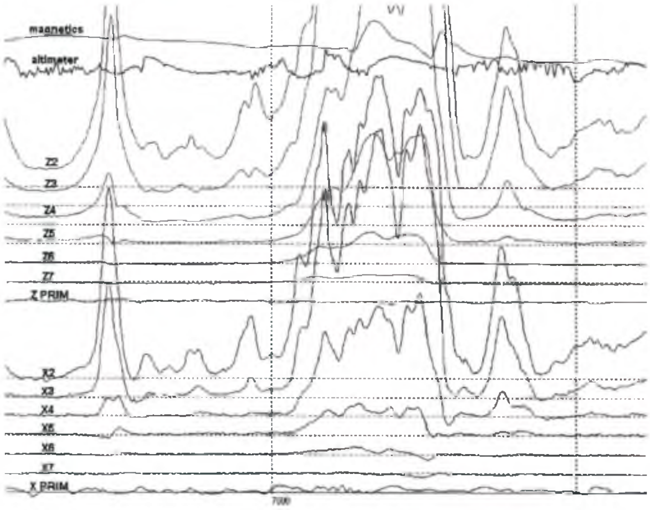

Figure 3. Baseline drifts for SPECTREM AEM data (note: vertical scale differs from window to window).

(612.0 μs delay). Figure 2 shows a map of EMX4 data collected over a survey area in central Africa from May to July 1997.

One of the most obvious features of this map is the data striping, caused largely by electronic drift of the window's baseline, or zero-level value. This drift occurs on all data windows, and varies from flight to flight, from line to line, and from data window to data window. Figure 3 shows a section of airborne record, in which the different baseline drifts for the X and Z data windows can be seen.

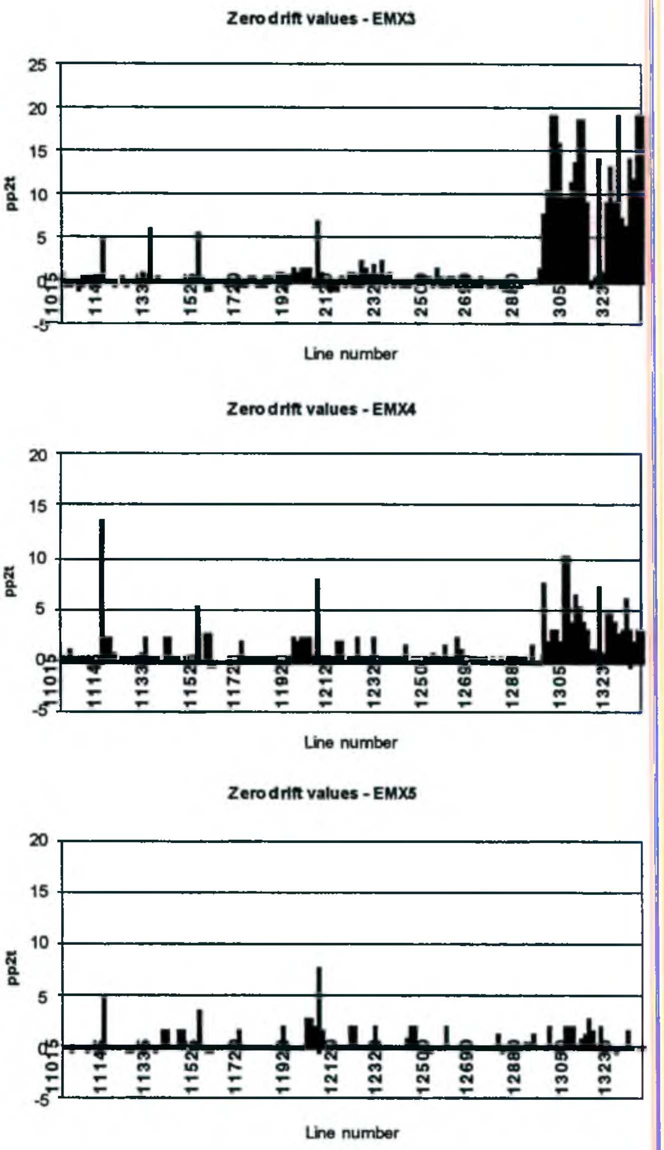

Figure 4. EMX3, EMX4 and EMX5 baseline drift values (note that two of the baseline drift values reported for EMX3 proved spurious in subsequent mapping, and were changed).

In order to correct for the X channel baseline drifts, a modal filter was applied to the data in each of windows EMX3 to EMX7 (EMX1 and EMX2 amplitudes have sufficient dynamic range to be little affected by changes in their baseline levels). The baseline drift for each window along each flight-line was assumed to be constant, and was defined as the most common (mode) data value recorded on the interval [-10000 ppm, 10000 ppm] for that window along that line.

In the modal filtering process, the appropriate baseline drift (as defined above) was subtracted from each data value along the flight-line. This modal filtering procedure should be compared with the levelling procedure illustrated in Figure 4 of Vaughan (1985).

The baseline drift values applied to EMX3, EMX4 and EMX5 for the presented dataset are shown in Figure 4. Note that for the SPECTREM system, signal amplitudes are reported in parts per two thousand (pp2t), where the peak-to-peak amplitude of the primary square waveform is defined as 2000 pp2t.

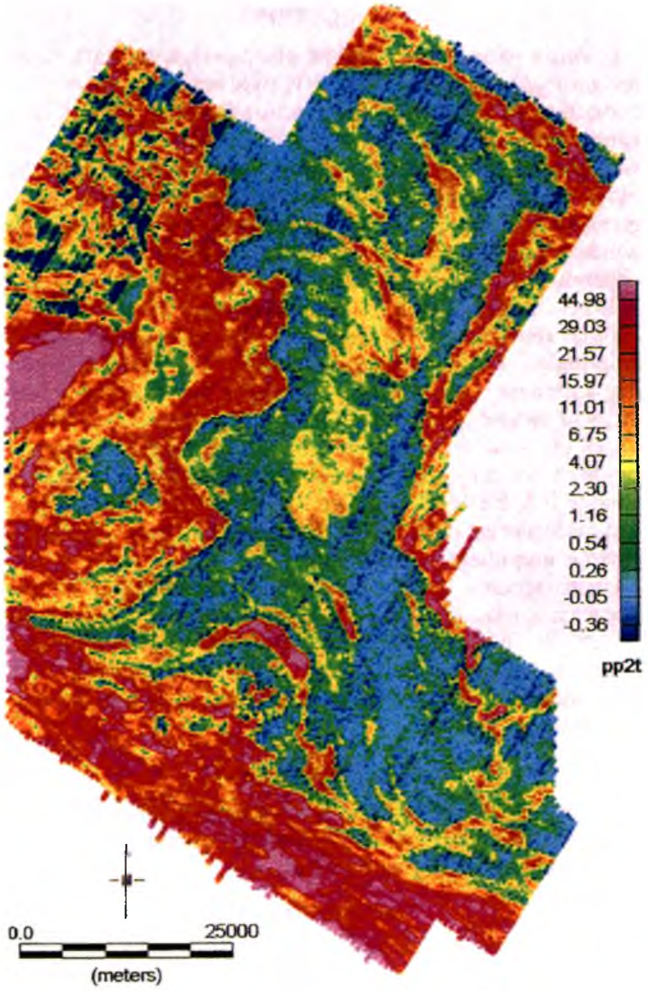

Figure 5. Zero drift-corrected EMX4.

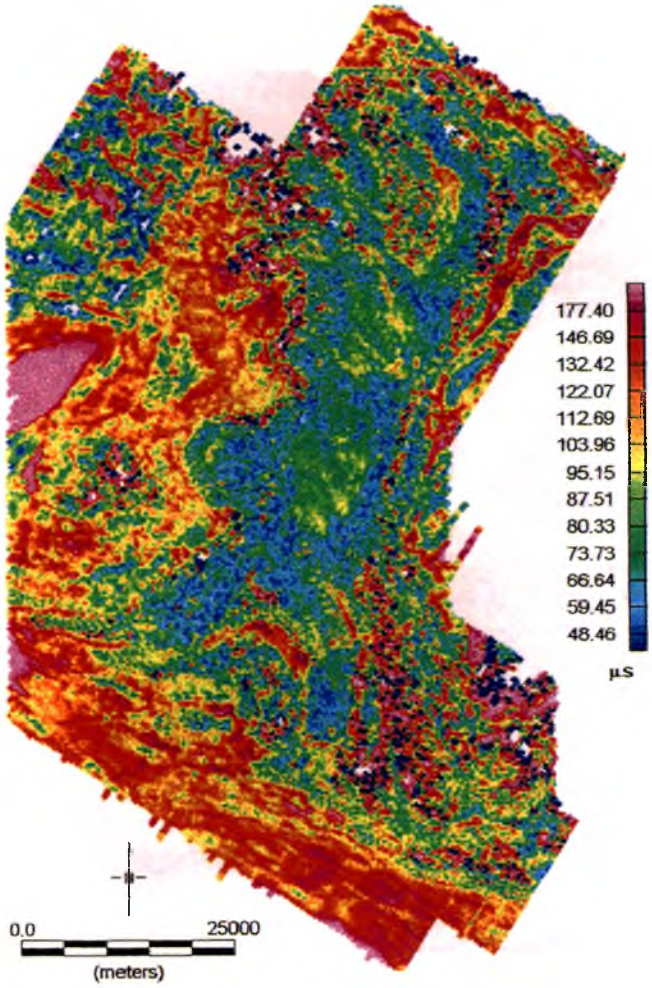

Figure 6. Time constant map derived from EMX2 and EMX4.

Figure 5 is the baseline drift-corrected map for EMX4, and demonstrates the substantial improvement in map coherence achieved by modal filtering.

Time-constant maps

A better indication of an area's electromagnetic character can be obtained from a time-constant map than from a single-window map. This is because effects of flight height variation are largely removed from the map (without making any assumption about the geometry of conductive bodies), and the behaviour of the electromagnetic decay curve with time, and not just its instantaneous amplitude, is being mapped.

Using the basic equation for the changing amplitude of an exponentially decaying electromagnetic signal with time:

$$A = A_0 e^{-t/\tau},$$

where A is the amplitude of the EM signal at time t, A_0 is the amplitude of the EM signal at time $t = 0$ (i.e., the inductive limit amplitude), and τ is the time-constant of the EM decay, we solve for τ by considering the above equation at two arbitrary times t_1 and t_2:

$$\tau = (t_2 - t_1)/\ln(A_1/A_2).$$

Thus, the time-constant of the decay can be determined from the EM signal amplitudes in two windows of known delay times on that decay (Leggatt, pers. comm.).

Figure 6 shows a time-constant map derived from the baseline drift-corrected electromagnetic signal amplitudes measured in windows EMX2 and EMX4. The null values and noise in this map are due largely to very low window amplitudes and the presence of environmental (turbulence, altitude and/or spheric) noise.

Ternary maps

Plotting three maps against one another in RGB (red-green-blue) space is a technique commonly exploited in viewing radiometric and Landsat TM datasets. The technique can be applied to AEM data to give a more comprehensive picture of the conductivity structure of a survey area than is possible from either a single-window map or a two-window (e.g. time-constant) map. In Figure 7, red, green and blue indicate high amplitudes for baseline drift-corrected EMX1, EMX3 and EMX5 respectively. White areas in the image correspond to high amplitudes recorded in all three windows simultaneously; black areas conversely.

In the dataset presented in this paper, younger sediments on the western and eastern margins of the survey area overlie repeatedly thrusted basement. The arcuate conductive feature to the south is probably a sliver of young sedimentary material; the resistive kidney-shaped feature in the north of the survey area has yet to be explained.

To optimise the electromagnetic information shown in a ternary image, data maps used should be as widely time-separated from each other as possible. For the present dataset, the EMX6 and EMX7 signal amplitudes were too

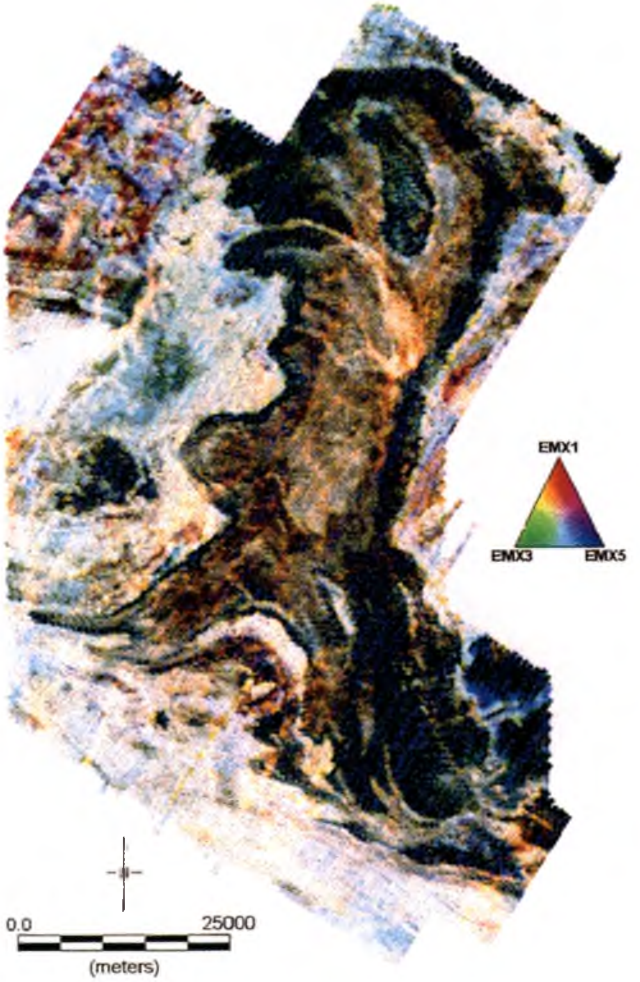

Figure 7. EMX1 vs EMX3 vs EMX5 ternary map.

low (i.e. the data were too noisy) to yield sufficiently coherent maps for ternary plotting, and thus EMX1 vs EMX3 vs EMX5 was used, with a resultant partial loss of late-time information in the ternary image.

CONCLUSIONS

In order to use SPECTREM electromagnetic data maps for geological interpretation, it is first necessary to apply a correction to each data window for baseline drift, which varies from window to window and from survey line to survey line. This correction can be made by subtracting the mode signal amplitude recorded in a given window on a given line from all the signal amplitudes recorded in that window on that line. A substantial improvement in map coherence is achieved by applying this correction.

Time-constant maps can be generated by applying a simple formula to the ratio of electromagnetic signal amplitudes obtained in two data windows. Time-constant maps are a more accurate representation than single-window maps of an area's electromagnetic character, because effects of flight height variation have been largely removed (without making any assumption about the geometry of conductive bodies), and the behaviour of the electromagnetic decay curve with time, and not just its instantaneous amplitude, is being mapped.

Using ternary images, the changing behaviour of the electromagnetic decay curve across a survey area can be effectively mapped, and used in geological interpretation, although low signal amplitudes at late time preclude very deep information from being effectively incorporated into such images.

ACKNOWLEDGMENTS

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