Unlike previous surveys, the Zonge GGT-10 transmitter was configured to produce a 50% duty cycle (time domain) waveform at a frequency of 8 Hz. This was done in order to permit the examination of time domain IP parameters. The transmitted current was 7.5 A. Data were recorded along lines oriented grid east-west and spaced 20 m apart. The magnetic declination of the survey grid was 5.0°. The magnetic inclination was -49.5°.

8.3.5 Results

8.3.5.1 Total Magnetic Intensity (TMI)

The magnetic field data were corrected for diurnal variation and imaged to produce the "Raw" magnetic data in Figure 8-24. The image is generally very flat. Dipolar anomalies are due to scrap iron, steel pickets and drill collars. The large anomaly in the southeast corner was due to a drill rig which was operating in the area at the time. There is a great deal of fine detail in the image consisting of a series of linears trending generally north-east. The most dominant of these coincides with the McArthur River which bisects the grid. The river has gouged a 10 m gully through the survey area leaving a series of levee banks which contrast magnetically with the less disturbed soil. Other linears evident in the image are also likely to be due to either present or palaeo-drainage patterns. As expected, there is no evidence of a magnetic signature corresponding with the subcropping mineralisation.

8.3.5.2 Total Field Magnetometric Resistivity (TFMMR)

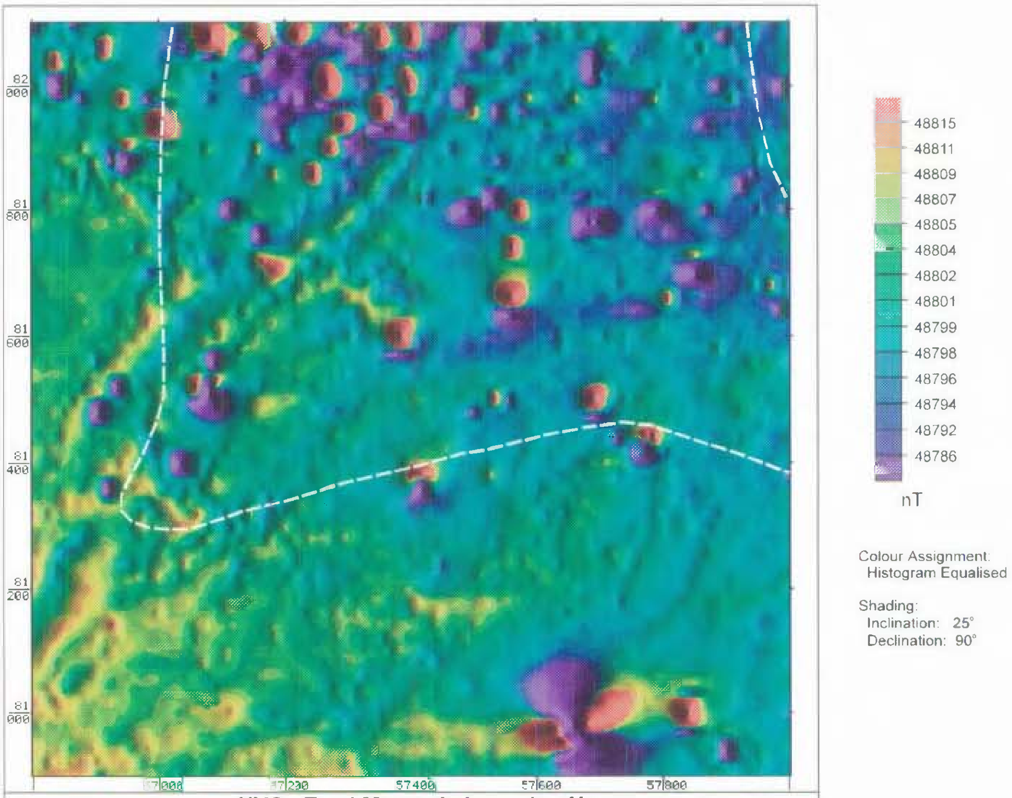
A 50% duty cycle time domain transmitter signal was used at HYC, primarily to permit a preliminary investigation into the use of time domain parameters to characterise both TFMMR and TFMMIP. It was envisaged that the calculation of a chargeability parameter by integrating under the decay curve during the transmitter "Off" time, would enable a measure of induced polarisation in the absence of any influence from the Primary field.

For calculation of time domain parameters, the recorded waveforms require correction for the SAMCard filter response as described in Section 7.7.1. Accordingly, the recorded waveforms were corrected using the compensation filter coefficients which had been previously determined in the laboratory. However, examination of the reconstructed waveforms revealed that the correction did not adequately restore their shape. The degree of distortion was not great but was found to be variable across the survey area. That variation rendered the time domain extraction procedures ineffective. The reason for the problem was believed to be that the specifications of the components used in the SAMCard filters varied from those determined in the laboratory as a result of the considerable variation in temperature which was experienced during the survey.

A second factor which complicated the procedure was that the waveforms exhibited electromagnetic coupling effects which, in some areas, caused quite severe distortion of the square waves. Some effect from electromagnetic coupling had been anticipated given the 8 Hz transmitter frequency used in the SAM surveys to date. However, the survey performed at HYC provided the first data in which those effects were clearly recognisable.

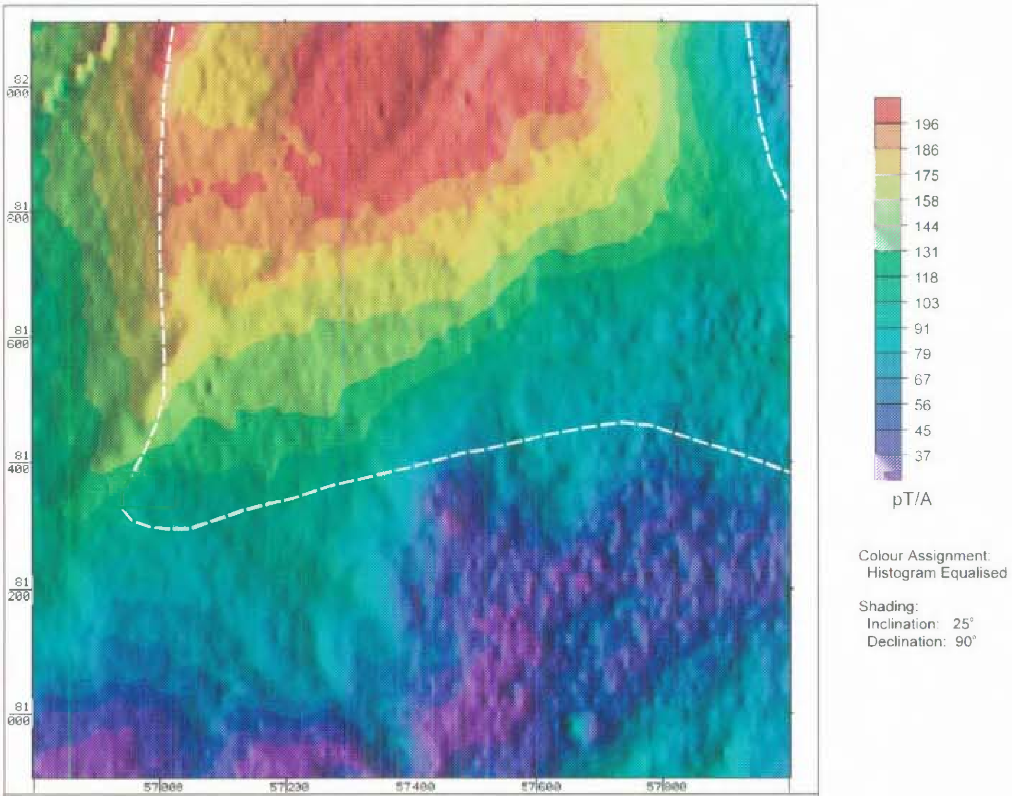
In consideration of the difficulties encountered in applying the time domain data extraction procedures, the frequency domain parameters described for all prior SAM surveys were again adopted. The normalised TFMMR data, H_N, is shown in Figure 8-25 together with an outline of the orebody. The image portrays a broad TFMMR "high" which coincides remarkably well with the known areal extent of the orebody. In addition, a "ridge" in the TFMMR coincides with the location of the subcrop. A second "ridge" follows the course of the McArthur River, presumably due to the current channelling effect of the watercourse. Several linears are also in evidence in the south of the image. Their cause is not known.

A comparison of the TFMMR data with the H_N parameter from Figure 8-21 yields some interesting observations. The H_N parameter does appear to have detected the subcrop. However, the general increase in amplitude to the east of the image is not evident in the TFMMR data. A possible reason for this is that in order to merge the H_N data from the four sub-grids, the authors added a correction factor of 40% to the data from the two grids on the eastern half of the block (Hishida *et al.*, 1993). It would appear that with the benefit of hindsight, the correction was inappropriate, giving a quite misleading bias to the data.



HYC - Total Magnetic Intensity, H_S

Figure 8-24. HYC - Total Magnetic Intensity, H_S.



HYC - Normalised TFMMR, H_N

Figure 8-25. HYC - Normalised TFMMR, H_N.

The other major contrast is the spatial resolution obtainable from the two techniques. The rapid sampling capability of SAM enabled data acquisition specifications of 1.5 m sample intervals along lines spaced 20 m apart compared to the 50 m sample intervals, 100 m line separation selected for the MMR/MIP survey. The result is much greater detail for significantly less expense.

8.3.5.3 Total Field Magnetometric Induced Polarisation (TFMMIP)

The phase of the fundamental frequency. corrected for the influence of the Primary field, is shown in Figure 8-26. A section of the image on the eastern half of the grid between 81600 mN and 81700 mN was found to be invalid. The cause of this was lack of synchronisation between the transmitter and the TM-4 due to a faulty GPS unit. Apart from this, the image generally reflects the electromagnetic coupling of the Primary field and the geological conductor.

Hishida *et al.* (1993) were aware of the potential problems with EM coupling but regarded the site as very resistive and expected few problems. It appears that at the frequencies they were using (1 Hz) the effect was insignificant. However, at the higher transmit frequency used for the SAM trials (8 Hz), the electromagnetic coupling was found to dominate any effect which may have been present due to induced polarisation. The calculated phase data generally reflected this phenomenon.

8.3.6 Discussion

As expected, the magnetics component of the SAM data was fairly uninteresting apart from mapping palaeo-drainage patterns. However, the TFMMR response appeared to map the areal extent of the orebody quite closely and has, consequently, generated considerable interest in the technique as an exploration tool in the area. The TFMMIP parameter was dominated by EM coupling and, as a result, was not diagnostic in mapping the body. Valuable information was gathered with regard to the severity of electromagnetic coupling at the frequencies used in conductive areas. For future surveys, effort will be put into reducing the transmit frequencies in an effort to obtain a valid IP parameter.

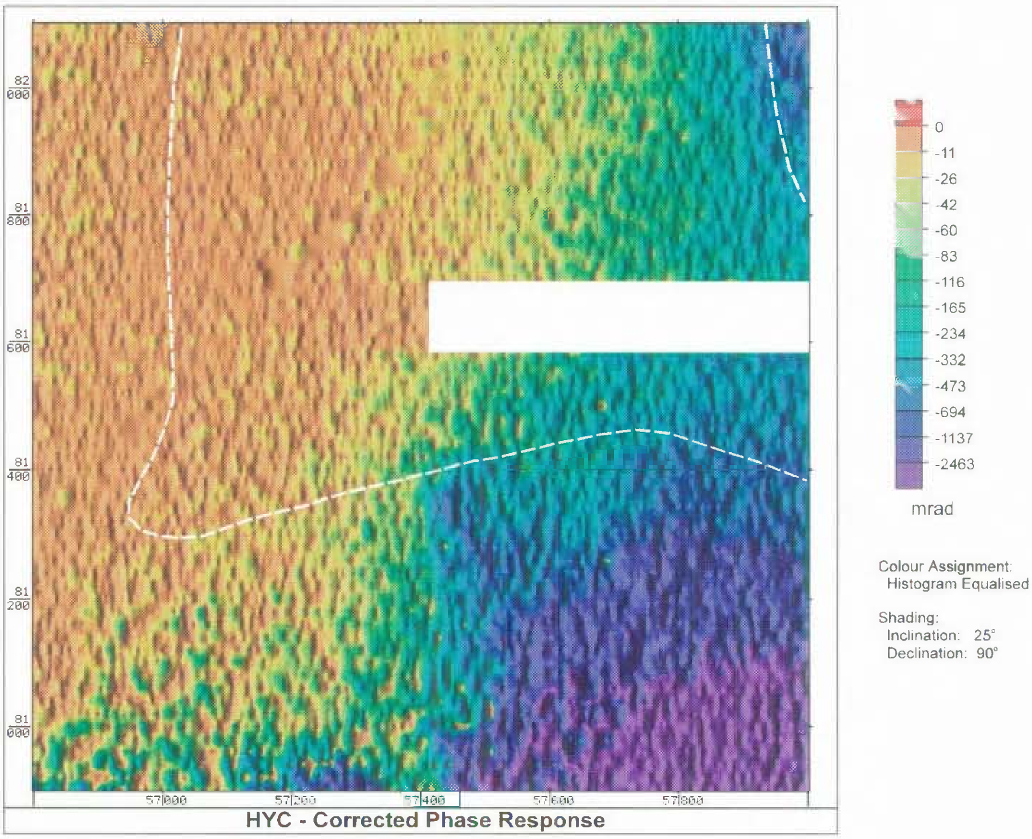


Figure 8-26. HYC - Corrected Phase Response.

8.4 Case Study #3 - Homogeneous Half-Space, McArthur River, Northern Territory

8.4.1 Location

The SAM technique requires corrections to be made to Total Field Magnetometric Resistivity (TFMMR) measurements in order to compensate for

(i). The Primary field, $H_{Primary}$, due to current flowing through the wires feeding the electrodes, and

(ii). The Normal field, H_{Normal}, the electromagnetic field expected due to current flow in a homogeneous half-space

During the feasibility stage of the program, several attempts were made to survey geologically "barren" areas in order to verify the theoretical calculations and corrections being applied to the data. However, the experiments were thwarted due to the detection of apparent fractures / faults, some of which caused quite significant TFMMR anomalies. Consequently, the objective of the surveys was never attained.

In May 1995, a Sub-Audio Magnetics survey was conducted at a site near the McArthur River, NT. The geology of the area comprised a thick sequence of sediments which in terms of its electrical properties was found to approximate a homogeneous half-space. The survey proved invaluable from a research perspective as it was the first SAM survey undertaken which enabled verification of some fundamental theory. This section presents the results of the survey and compares them with the theoretical response for a homogeneous half-space.

8.4.2 SAM Field Procedure

A single 1 km x 1 km SAM grid was surveyed at the site. The boundaries of the survey area were defined in AMG coordinates as shown in Figure 8-27.

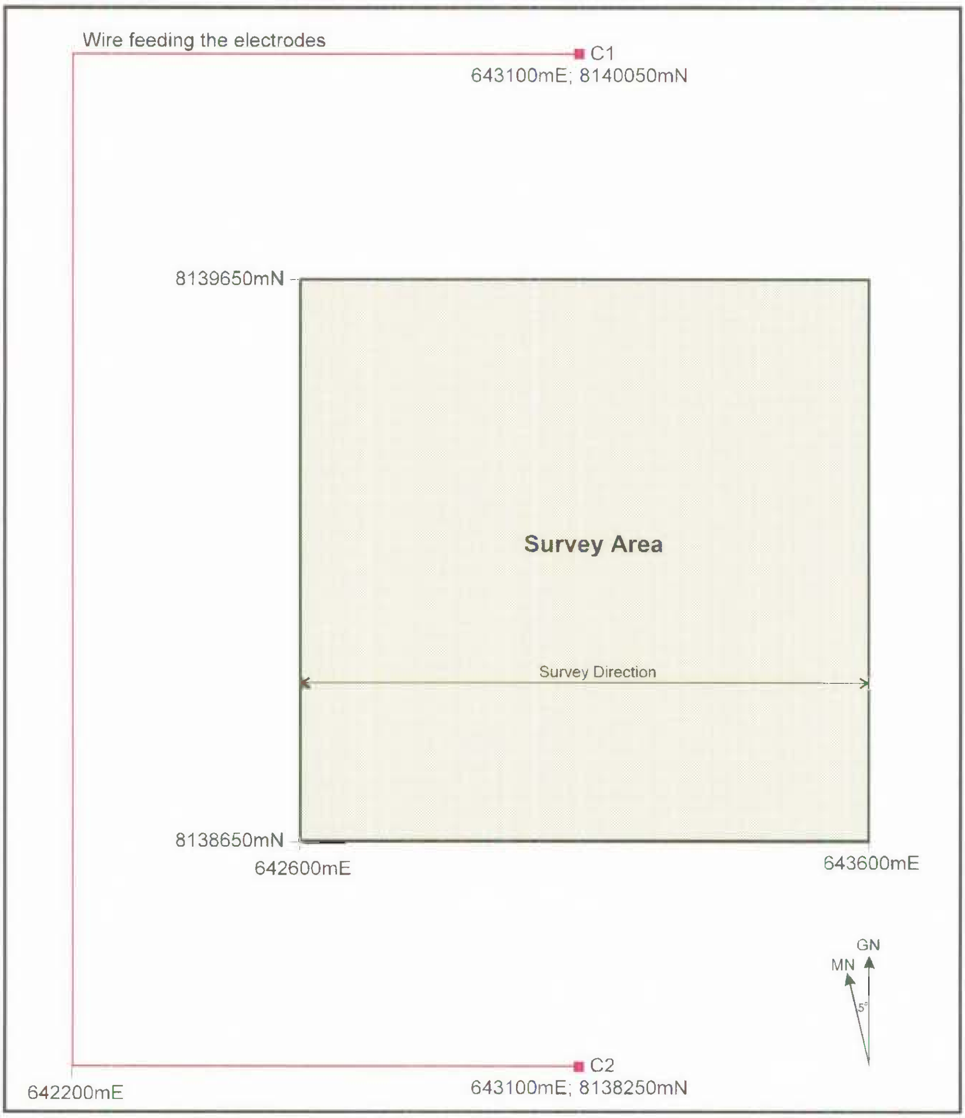


Figure 8-27. Schematic showing the layout of the electrodes with respect to the survey area.

Electrodes were emplaced at 643100 mE; 8140050 mN (C1) and 643100 mE; 8138250 mN (C2). Initially, 3 electrodes approximately 1 m^2 in area were established at each end of the grid. However, the soil consisted of a sandy-loam which was found to be very resistive to current flow. Consequently, two more electrodes were dug at each end of the grid. These were much larger, of the order of 3 m x 2 m in area and 0.5 m deep. In spite of the effort put into electrode preparation, the maximum current which could be maintained was 3.8 A.

The wire feeding the electrodes was laid out to the west of the survey area as shown in Figure 8-27. The GGT-10 was configured to produce a 50% duty cycle square wave (time domain) at a frequency of 8 Hz. Data were recorded along lines which were orientated grid east-west and spaced 20 m apart.

8.4.3 Results

8.4.3.1 Total Magnetic Intensity (TMI)

The Total Magnetic Intensity data were corrected for diurnal variation and imaged to produce Figure 8-28. As can be seen from the figure, the data were quite noisy although there is a distinct boundary originating at 42900 mE on the southern edge of the grid which extends to about 43400 mE on the northern edge of the grid. To the north and west of the boundary, the data are of significantly higher frequency and amplitude than the data to the east of the boundary

The different signatures may simply represent different soil types although a contact between different lithologies may be indicated. In order to recognise any deeper anomalies, the data were upward continued to an elevation of 20 m. The result of the procedure is shown in Figure 8-29. As expected, the image is considerably cleaner than the raw data image although the boundary mentioned previously is still quite apparent.

8.4.3.2 Total Field Magnetometric Resistivity (TFMMR)

The processing steps required to reduce the TFMMR data are described and illustrated below:

- The amplitude of the SAM modulation (H_{Mod}) during the transmitter "ON" time, H_{Pk}, was determined by calculating the amplitude of the fundamental frequency in the received waveform and correcting for its theoretical relationship to the square wave. The unfiltered data were imaged and are shown in Figure 8-30.
- The theoretical Primary field, $H_{Primary}$, due to current flowing through the wire feeding the electrodes was calculated for the wire layout used and is shown in Figure 8-31. H_{Pk} is dominated by $H_{Primary}$ and, as expected, this image was found to closely resemble that in Figure 8-30.

- Subtraction of $H_{Primary}$ from H_{Pk} to extract the Ground field, H_G, yielded the data represented in the image in Figure 8-32.
- The Normal field, H_{Normal} was calculated for the electrode locations used and is shown in Figure 8-33.
- Subtraction of H_{Normal} from H_G yielded the "normalised" TFMMR data, H_N, shown in Figure 8-34.
- The data appear noisy, although it should be noted that 98% of the data falls within a range of only 20 pT/A.

8.4.4 Discussion

It is clear from the magnetics component of the SAM data that the site is not homogeneous magnetically. A distinct boundary exists between two different magnetic signatures. However, as can be seen from the figures, there is great similarity between H_G and H_{Normal} suggesting that the area is indeed homogeneous in terms of it electrical characteristics. The agreement between the recorded data and the calculated response could only be achieved if the correction models were valid.

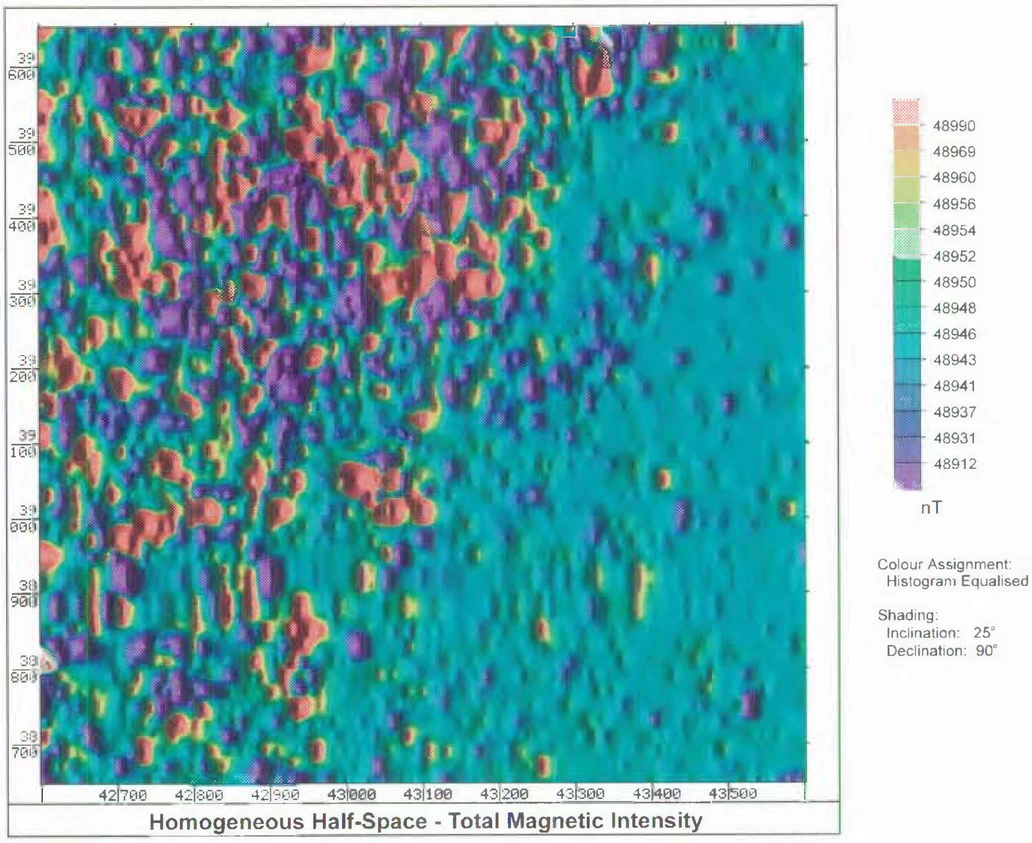


Figure 8-28. Total Magnetic Intensity, H_S.

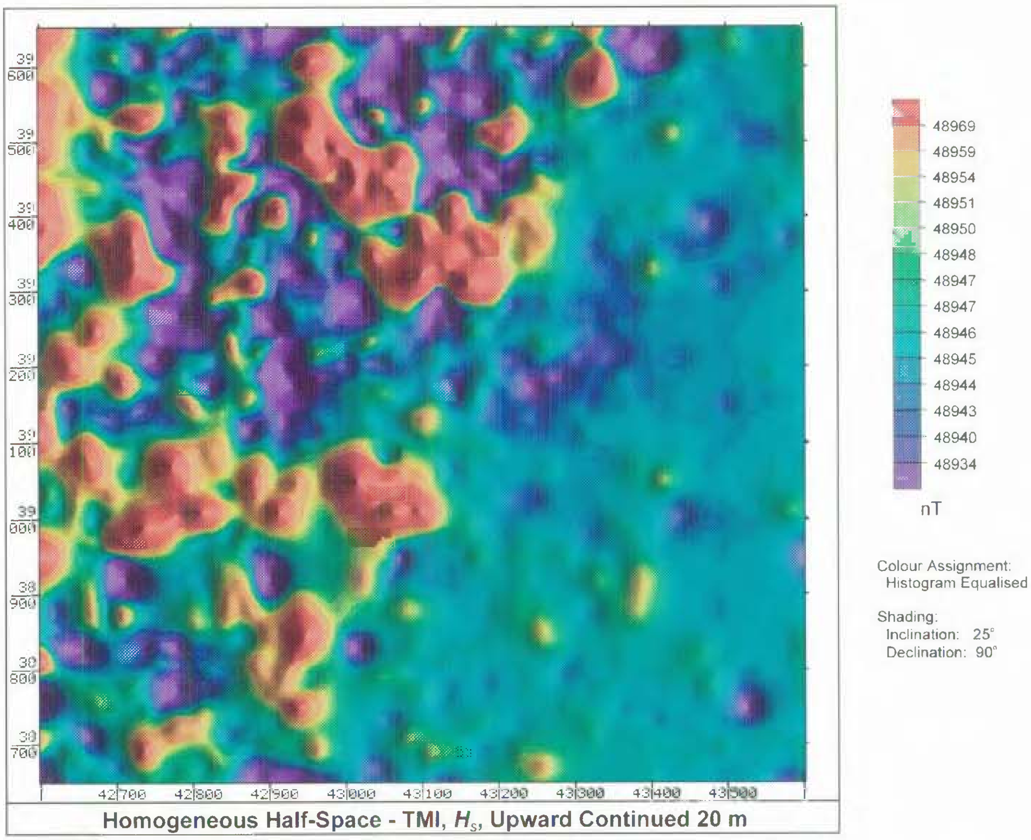


Figure 8-29. Homogeneous Half-Space -TMI, H_S - Upward Continued 20 m.

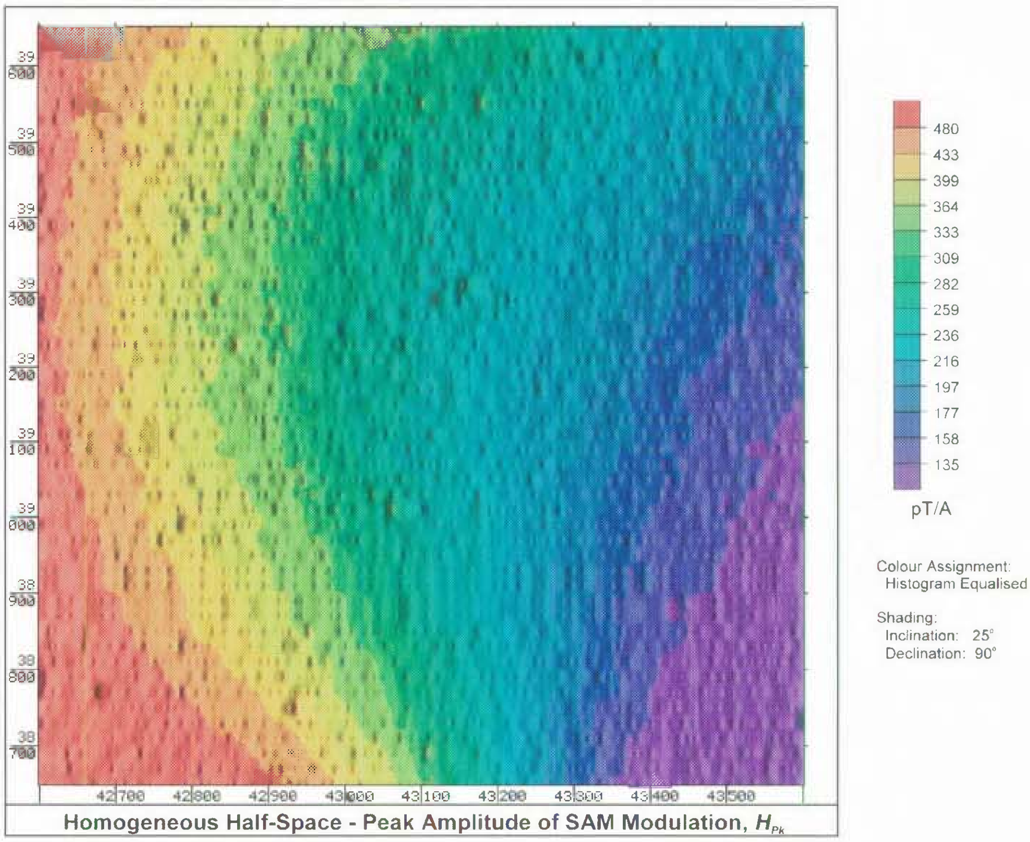


Figure 8-30. Homogeneous Half-Space - Peak amplitude of H_{Mod}, H_{Pk}.

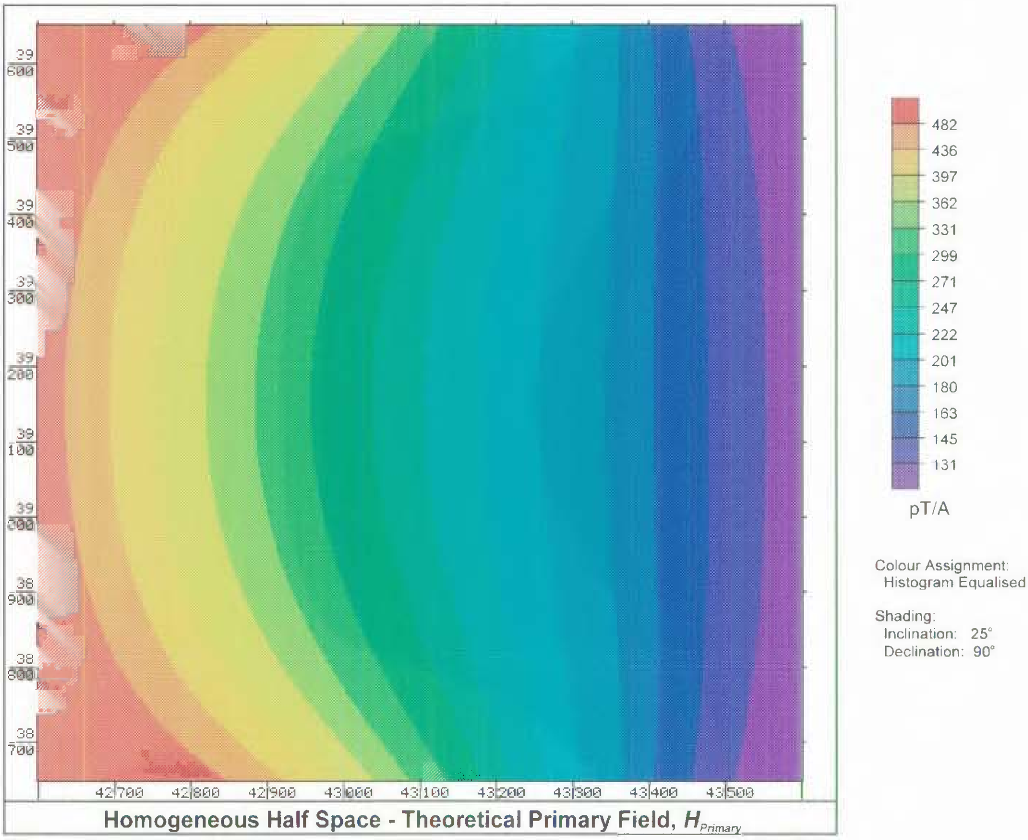


Figure 8-31. Homogeneous Half-Space -Theoretical Primary field, $H_{Primary}$.

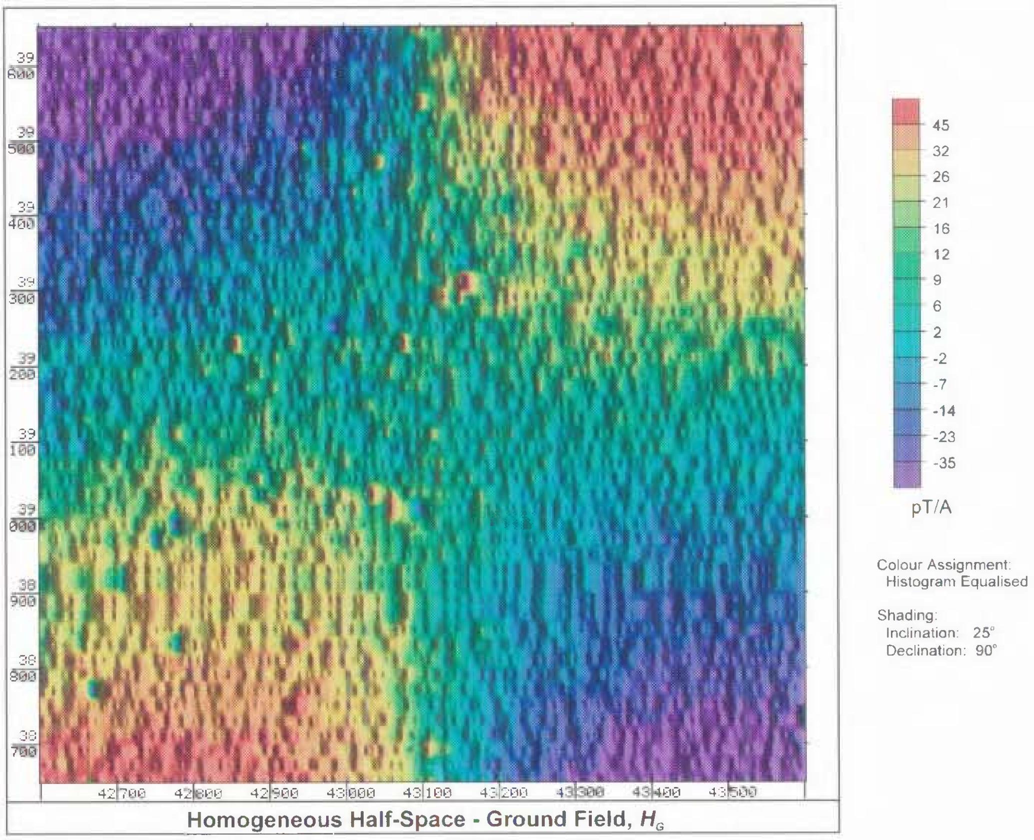


Figure 8-32. Homogeneous Half-Space - Ground field, H_G.

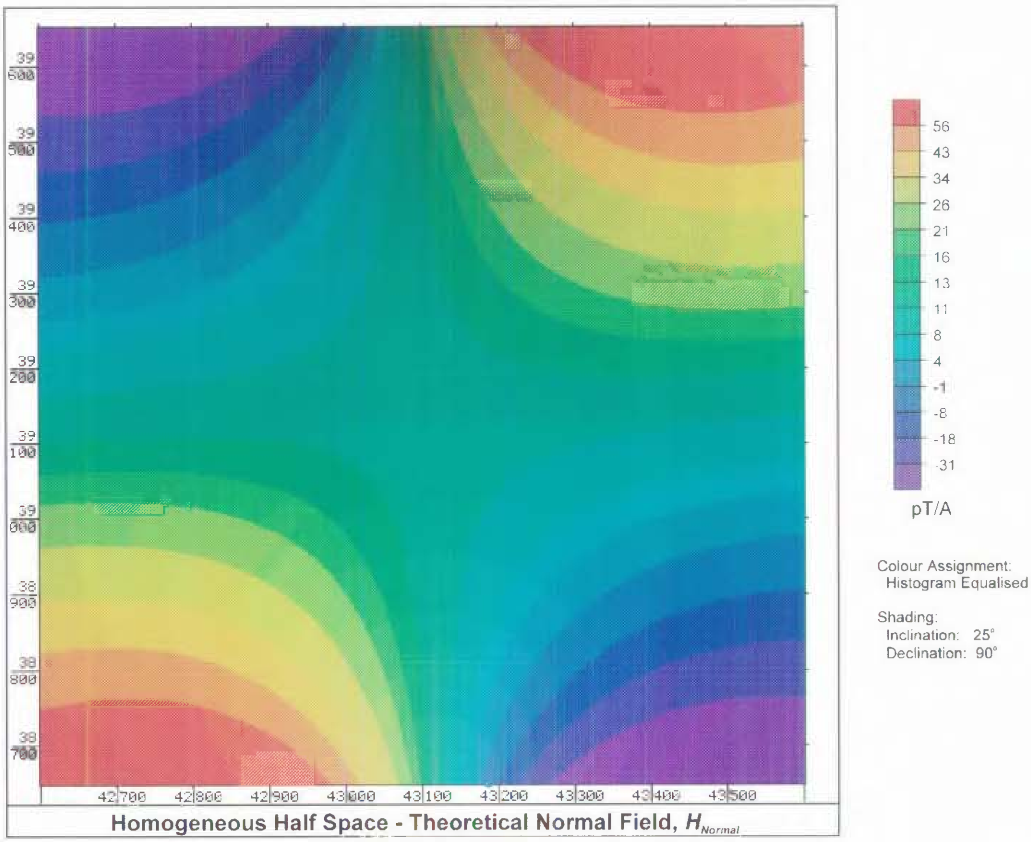


Figure 8-33. Homogeneous Half-Space - Theoretical Normal field, H_{Normal}.

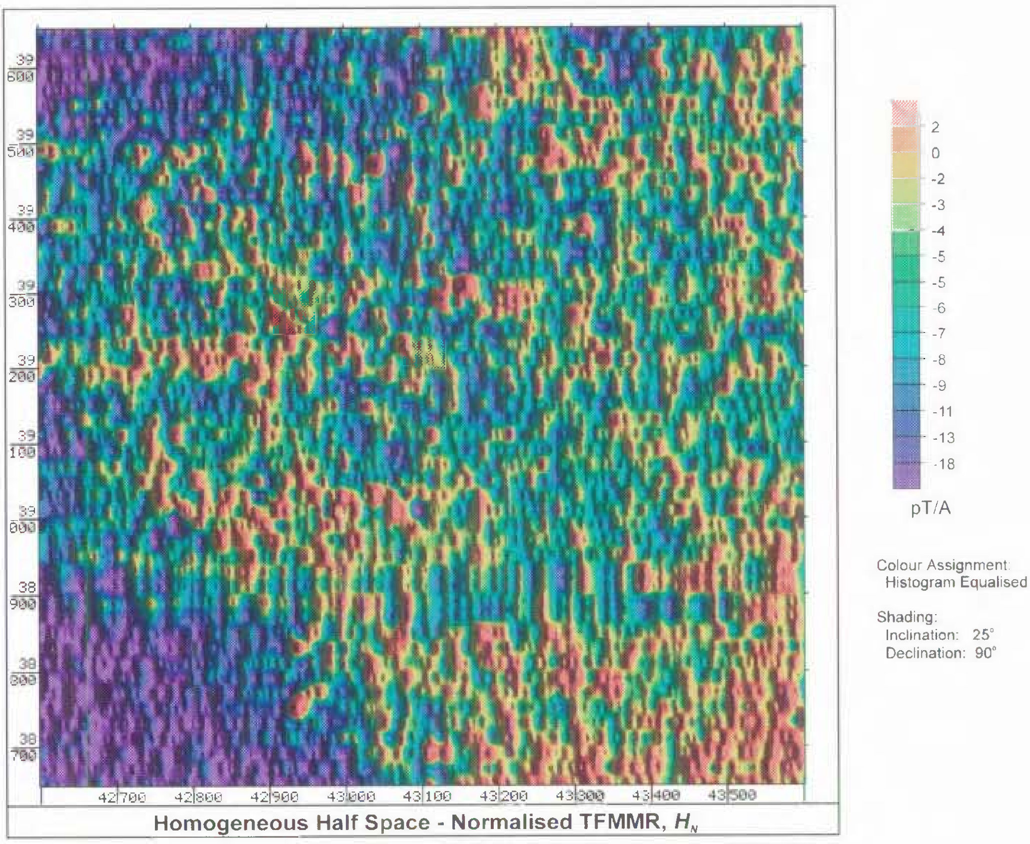


Figure 8-34. Homogeneous Half-Space - Normalised TFMMR, H_N. Note the very low amplitude of the residual noise (20 pT/A).

8.5 Conclusions

In Section 7.2, the requirements of a purpose-built SAM receiver were defined. The SAMCard approach used to accommodate those requirements was presented in detail in Section 7.3. A major objective of the field trials described in this Chapter was to appraise the performance of this receiver. That assessment is summarised below.

8.5.1 Assessment of the Prototype SAM Receiver for the Determination of Total Magnetic Intensity, TMI

The approach used to obtain Total Magnetic Intensity information was to use the standard TM-4's period counter. Real-time lowpass digital filtering was employed to remove the synthetic modulation on the magnetic field resulting from the transmitted current. The strategy was found to perform as expected. Sample rates of 10 samples per second for H_S were easily achieved with no noticeable degradation of the signal.

The greatest potential source of error resulting from the strategy was the time delay incurred by the 41-point digital filter. Total field, H_T sampling rates of about 200 samples per second, resulted in a 0.2 s time delay in the determination of H_S parameters. At an average walking speed of 1.5 m/s, this would translate to a positional error of 0.3 m. The speed of traverse is readily determined with either cotton thread odometer or GPS positioning and with that knowledge, this error could be readily corrected if required. The error would be more significant for close line spacing surveys, particularly where speed of traverse is high.

8.5.2 Assessment of the Prototype SAM Receiver for the Determination of TFMMR and TFMMIP

The development of the SAMCard as a solution for acquiring parameters related to the electrical characteristics of the ground, was considered to be highly successful in meeting most of the objectives of the development. The demodulation circuitry proved capable of permitting high precision, high bandwidth characterisation of the SAM signal. GPS synchronisation and the constant sample interval enabled stacking of the waveforms which, in turn, facilitated statistical noise suppression as well as a reduction in the volume of the recorded data. In addition, automatic detection of polarity reversals and quantification of phase lags between the received signal and the transmitted current were achieved.

The TFMMR signal-to-noise ratios were high and the frequency domain parameter extracted from the data was believed to adequately characterise the amplitude of the TFMMR signal. However, the determination of a phase lag parameter to quantify the TFMMIP response was less successful. The TFMMIP signal is significantly smaller in amplitude than the TFMMR signal. Consequently, signal-to-noise ratios are much lower resulting in an even greater need for precise measurement. The phase calculation was further complicated by interference from the Primary field for which a correction needed to be applied.

It was anticipated that the employment of time domain IP signal processing techniques would have provided a means of measuring parameters related to the IP phenomenon in the absence of the Primary field. However, the successful application of those procedures was found to be critically dependent on the integrity of the filter used to compensate for the frequency response of the demodulation circuitry in the SAMCard. Accurate determination of the compensation filter coefficients proved to be difficult due to the variable nature of the filter response which was believed to be due to ambient temperature variation. As a consequence of these difficulties, the successful determination of a chargeability parameter was not achieved.

Although highly successful for the determination of TMI and TFMMR parameters, the following deficiencies were identified pertaining to its application for the measurement of TFMMIP.

(i). The demodulation circuitry introduced an unacceptable amount of "noise" into the H_{Mod} signal which reduced the accuracy of the phase calculation.

(ii). The frequency response of the high pass filter used to extract H_{Mod} from H_T was found to be variable, presumably due to ambient temperature variation. Compensation for the frequency response consequently proved difficult. As a result, the square waves could not be accurately reconstructed from the recorded waveforms and this prevented the application of time domain data extraction procedures.

(iii). The analogue filters were designed for a given transmitter frequency of 8 Hz. The case study performed at HYC highlighted the need to reduce the transmitter frequency in order to reduce the influence of electromagnetic coupling. For future surveys these filters will need to be modified to facilitate lower transmitter frequencies.

If time domain TFMMR and TFMMIP parameters are to be extracted from the waveforms, the hardware problems outlined above would need to be addressed. It would be desirable if an alternative means of separating the H_{Mod} and H_S signals could be developed which would not require the demodulation circuitry or the analogue high pass filter. An ideal remedy to the problem, if it were technically feasible, would be to develop a frequency counter which would be capable of accommodating all of the SAM receiver specifications defined in Section 7.2. Separation of the signals could be much more effectively achieved with a zero-phase response, digital filter. In addition, a digital filter would permit much greater flexibility as it could be readily tailored to suit different transmitter frequencies.

The field trials successfully demonstrated the SAMCard development as a means of efficiently and simultaneously acquiring High Definition, Total Magnetic Intensity and Total Field Magnetometric Resistivity. In addition, the trials provided a first look at the difficulties in determining Total Field Magnetometric Induced Polarisation parameters. Several aspects of the hardware have been found to be deficient for that purpose. Future development will need to address those deficiencies.