AIRBORNE GEOTEM® ELECTROMAGNETIC and MAGNETIC SURVEY

in the
BLAKE RIVER SYNCLINE of ONTARIO

for the
GEOLOGICAL SURVEY OF CANADA

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geoterrex

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I

INTRODUCTION

During the period from April 4th to May 13th, 1992, a combined airborne GEOTEM® electromagnetic and magnetic survey was flown for the GEOLOGICAL SURVEY OF CANADA by GEOTERREX. In all, 7093 line-kilometres of survey were flown over an area near Kirkland Lake, Ontario.

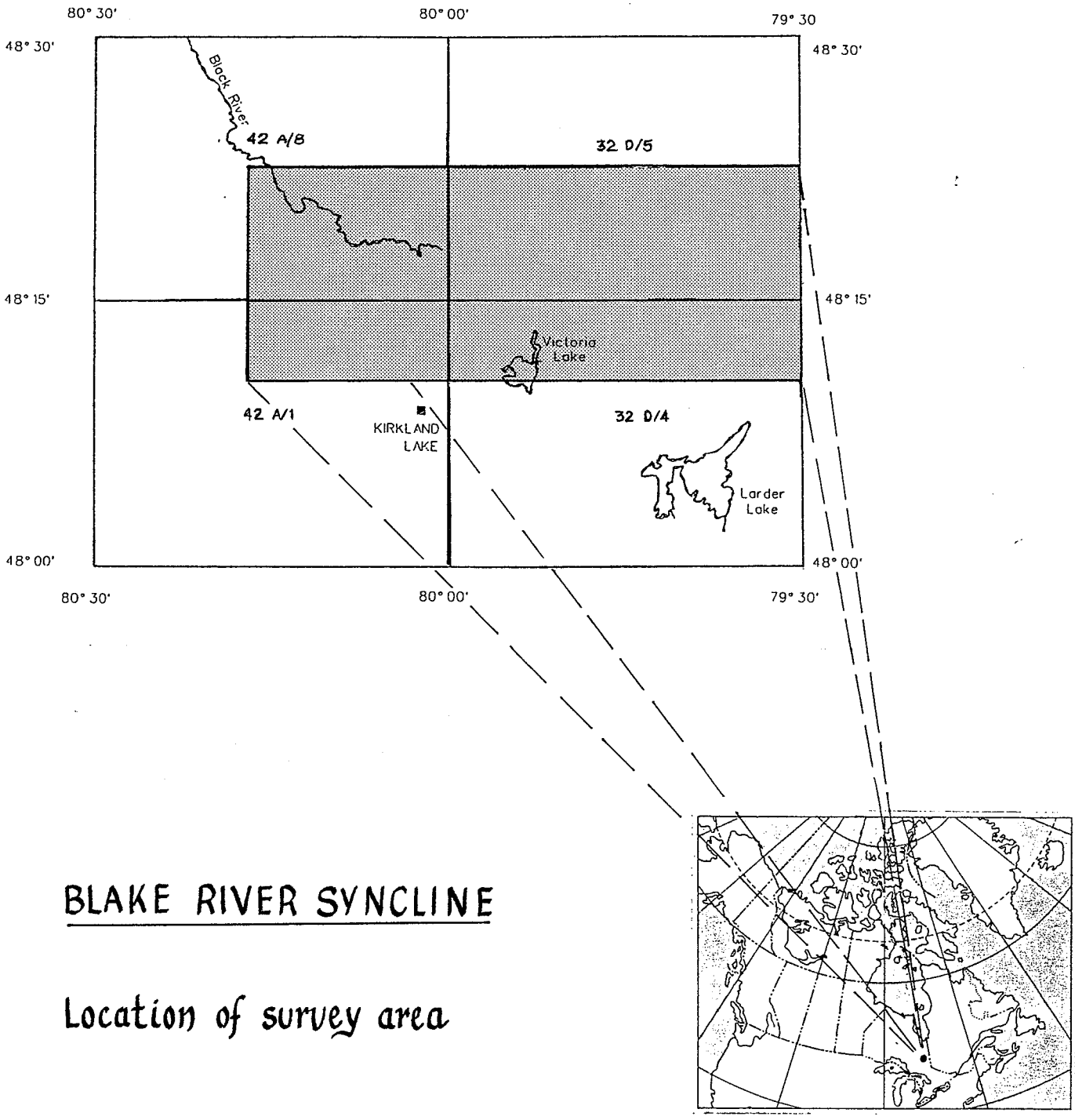
In addition to the direct detection of conductors which may reflect massive metallic sulphides, the electromagnetic and magnetic responses mapped can yield important structural, textural and compositional information which will be useful in most exploration applications.

The final data were compiled and processed in Ottawa by Geoterrex and are presented as:

- maps of conductors and apparent conductivity of overburden;
- aeromagnetic total-field contour map;
- stacked profile maps of GEOTEM® channel 3, colour infilled with the decay constant values and combined with a map of bedrock conductors;
- colour magnetic anomaly maps (residual total field);
- colour maps of apparent conductivity of overburden;
- colour maps of apparent conductance of bedrock conductors;

- multiparameter stacked profiles;
- and digital archive tapes.

This project, funded by the Geological Survey of Canada, is a contribution to the Canada-Ontario Subsidiary Agreement on Northern Ontario Development (1991-1995), a subsidiary agreement under the Economic and Regional Development Agreement.



BLAKE RIVER SYNCLINE

Location of survey area

figure 1

II

SURVEY OPERATIONS

1. Location of the Survey Area

The survey area, referred to as the Blake River Syncline, is located just north Kirkland Lake, Ontario, covering part of the NTS topographic sheets 32D/4, 32D/5, 42A/1, 42A/8. (see figure 1)

2. Flight Grid

The survey area was covered with north-south flight lines at intervals of 200 m, with east-west control lines spaced at 1.5 kilometre intervals. A total of 7093 line kilometres of data were collected.

3. Flight Altitude

The nominal survey flying elevation was 122 m above ground, whenever possible, with regard to topographic relief and commensurate with the safety of the aircraft and birds. This flying altitude maintains the EM sensor (located in a towed bird at the end of a 135-m cable) at approximately 64 m above the ground. The magnetic sensor was located in a second towed bird (on a 110 m cable) which maintains a height above ground of approximately 70 m. Statistics on the radar altimeter values for the entire survey indicate the mean flying elevation to have been 123 m with a standard deviation $\pm$ 8.2 m.

4. Navigation

The navigation was done using the Global Positioning System (GPS) with an on-board Doppler system as a backup in the event of satellite outages.

5. Aircraft and Geophysical On-board Equipment

The survey aircraft used was a CASA C212-200, twin turbo-prop STOL aircraft, maintaining a nominal survey speed of 120 knots (220 km/h, 61 m/s). Statistics on the true aircraft speed maintained during the survey indicate the average flying speed to have been 222 km/h with a standard deviation of ± 16 km/h.

The following equipment was on board the aircraft:

- GEOTEM® Electromagnetic System: Comprising a transmitter and loop, a digital receiver, and a sensor mounted in a towed bird. Operating frequency for this survey was 150 Hz. A description of the gate settings used for this survey may be seen in Table 1. A description of the system is included as Appendix A.

TABLE 1 **GEOTEM® Gate Description**

Gate	Centre	Width
1	393 µsec	156 µsec
2	550	156
3	706	156
4	862	156
5	1019	156
6	1175	156
7	1331	156
8	1487	156
9	1644	156
10	1800	156

11	1956	156
12	2112	156
13-18	Used for diagnostic purposes.	
19	191	78
20	-929	182

Note: All times shown are in microseconds referenced to nominal termination of the transmitter current.

- *MADACS Digital Acquisition System:* Combining an Interdata 6/16 16-bit microprocessor and a Digi-Data 1640, 9-track, 800-bpi tape drive. The following information was recorded digitally:

  - 20 GEOTEM® EM channels (ppm)
  - Magnetic total field (nT x 100)
  - Barometric altitude (millivolts)
  - Radar altitude (feet)
  - Time (fiducials) (seconds)
  - Doppler velocity along track (128520 units/nautical mile/sec)
  - Doppler velocity across track (64260 units/nautical mile/sec)
  - Doppler heading (45.51 units/degree)
  - Primary EM field (microvolts)
  - 60 hertz powerline monitor (microvolts)
  - Noise monitor (ppm)
  - 3 reference monitors (microvolts)
  - 7 GPS fields: lat., long., elevation, acquired time, universal time, satellite time, standard deviation.

- *Magnetometer:* Scintrex cesium vapour, single-cell, split-beam magnetometer, 0.1 nT sensitivity, 0.1 s sample rate, mounted in a bird towed behind the aircraft.

- *Altimeters:*
  - Radar altimeter: King KRA405
  - Barometric altimeter: Rosemount AVH8
- *Electronic Positioning Systems:*
  - Trimble 4000 AX Global Positioning System
  - Decca 71 Doppler navigation system
- *Tracking Camera:* Panasonic VHS video with 4.2-mm lens mounted vertically, recording in NTSC mode, with fiducial marks every second.
- *Analog Recorder:* RMS-GR-33A-1 heat-sensitive graphic recorder, displaying the following information on a 32-cm wide chart, running at a speed of 9 cm/min:
  - 12 GEOTEM® EM channels (low-pass filtered with a 1.5-second time constant in real time) at a vertical scale of 200 ppm/cm for the first 10 cm, 400 ppm for the next 10 cm, and 800 ppm to the top of the chart.
  - Channels 3 and 12 are plotted, without the filter, at a vertical scale of 200 ppm/cm.
  - Channel 20 (sampled during the primary field pulse) at a vertical scale of 2000 ppm/cm.
  - The primary EM field monitor at a vertical scale of 240 000 ppm/cm.
  - The earth's field monitor at a vertical scale of 400 000 microvolts/cm.
  - The total magnetic field at vertical scales of 20 and 200 nT/cm.

- Fourth difference of the total magnetic field at a vertical scale of 10 nT/cm.
- The radar altitude at a vertical scale of 50 feet/cm.
- The barometric pressure at a vertical scale of 20 millibars/cm, downward (lower pressure) indicates higher altitude.
- 60 Hz powerline monitor at a vertical scale of 150 000 microvolts/cm.
- Time (fiducial) markers, ticked every 2 seconds and labelled every 20 seconds.
- Absolute values of the magnetic total field and both altimeters are printed every 40 seconds.

6. Base Station Equipment

- A Scintrex single-cell, split-beam, cesium vapour magnetometer measuring the total magnetic field at 0.1 nT sensitivity with a 1.0-second sample rate.
- A microcomputer based digital acquisition and recording system, recording time and outputs from the magnetometer and the GPS receiver.
- A TRIMBLE 4000 AX GPS receiver.
- A standard dot matrix line printer.

7. Survey Specifications

Lines were reflown if any of the following limits were exceeded.

a) Altitude

Altitude was not to exceed ±15 m from the nominal flying elevation of 120 m above ground, unless required for safety.

b) EM Noise Level

Noise level was not to exceed ± 20 ppm, as monitored on the late channels of the analog, with a 1.5-second time constant, applied.

c) Magnetic Noise Level

The noise envelope was not to exceed 0.35 nT during straight and level flying. This was monitored on the analog fourth difference trace where 0.5 nT noise will be expanded to 5.0 nT.

d) Magnetic Diurnal Conditions

The diurnal variation was not to exceed deviations of 2 nT over a period of time equal to the flying distance between control lines (approximately 30 sec).

e) Line Spacing

Gaps in the flight line spacing were not to exceed 275 m over a 2 km distance, and never greater than 300 m or less than 75 m in any one point.

8. Field Operations

Field operations were based out of Kirkland Lake, Ontario. The following Geoterrex personnel were present in the field:

S. Hay	Chief Pilot
A. Capyk, H. Girouard	Pilots
A. Proulx	Electronics Technician
R. Hattle	Aircraft Maintenance Engineer
D. Skubiski, K. Ireland	Geophysical Technicians

D. Beattie Geophysicist

Visits were made during the field operations by the scientific authority, G. Palacky and the technical inspector, F. Kiss.

General Survey Statistics:

Total production	7093 km
Number of flights	33 (includes 5 test flights)
Total flying hours	78.2 hours
Average production per day	228.8 km
Average production per flight	215.0 km
Average production per hour of flight	90.7 km

9. System Calibrations

a) Tests done in Ottawa

Lag Test

The system lag for both the GEOTEM® system and the magnetometer (towed-bird installation) was verified on April 6th, 1992, (flight #1) by flying over the Ottawa River Railroad Bridge near Fitzroy Harbour.

The lag value for the magnetometer was established at 2.8 sec; the large value for the GEOTEM® was established at 4.4 sec.

Pitch Test

Since a towed-bird installation was used on this survey rather than a stinger installation for the magnetometer, a "pitch" test was flown on April 6th, 1992 over Bourget, to replace the standard Figure of Merit test, as described in the RFP, article A3.2.4. Results of the test showed a slight susceptibility to pitching, reflected by oscillations to 4 to 6 seconds and 0.2 to 0.4 nT in amplitude.

A difference in noise level was also detected, relative to aircraft heading, with the southbound direction giving a noise level of 0.3 nT and the northbound direction giving a noise level of 0.7 nT.

Bourget Test

The Bourget test was flown on April 6th, 1992, (flight #2), giving an instrument offset of 12.2 nT. The average heading difference in the magnetometer readings between north and south was 1.15 nT; the average heading difference between east and west was 1.25 nT.

GPS Check

The Bourget test was also used as a GPS Cloverleaf check to verify the positioning accuracy of the system. The RMS error in the position of the crossroads from the 8 passes was 10.2 m.

b) Tests done on-site

The crew and aircraft mobilized to Kirkland Lake, selected as the base of operations for the survey, on April 13th, 1992.

Noise problems with the magnetometer, detected during the pitch test flown on April 6th, 1992, had increased by the time the aircraft arrived in Kirkland Lake, and it was decided to change the magnetometer. Upon consultation with the GSC, a new suite of tests, in the form of a repeatability line and ground reading comparison, was established to verify the reading differences between the two magnetometers and to avoid having to refly the Bourget test.

Flight #3, April 14th, 1992

A repeatability line was flown and a ground comparison measurement was made between the base station and aircraft magnetometers, using the original magnetometer, calibrated at Bourget.

Flight #4, April 15th, 1992

The same exercise from flight #3 was repeated with the new magnetometer, to establish the reading differences between the two magnetometers.

A new cloverleaf and pitch test was attempted, but the results were inconclusive due to the nature of the local magnetic gradient which is too steep over the test area selected. These tests will be reflown before the demobilization of the aircraft from the survey area.

Finally, a full altimeter calibration (radar and barometric) was flown over the runway in Kirkland Lake during this test flight.

Flight #10, April 18th, 1992

A new GPS cloverleaf test was flown as a check. The average positioning error between the 8 passes was 10 to 12 m.

c) Summary of results

Bourget Test

- Flown on 06.04.92 with the original magnetic sensor
- Offset value: +12.2 nT
- Average N-S heading difference: 1.15 nT
- Average E-W heading difference: 1.25 nT

- Flown on 12.05.92 with the replaced magnetic sensor
- Offset value: +19.6 nT
- Average N-S heading difference: 4.8 nT
- Average E-W heading difference: 1.1 nT

System Lag Check

- Flown on 06.04.92 over a railroad bridge
- Magnetometer lag: 2.8 s
- GEOTEM® lag: 4.4 s

GPS Accuracy Check

- Flown over the Bourget Crossroads on 06.04.92
- The mean RMS error in the position of the crossroads from 8 passes was 10.2 m.

Noise/Pitch Test

- Flown with the original sensor on 06.04.92, over Bourget
- Southbound noise envelope: 0.3 nT
- Northbound noise envelope: 0.7 nT

- Sensor replaced in Kirkland Lake and test reflown on 15.04.92
- Southbound noise envelope: 0.3 nT
- Northbound noise envelope: 0.3 nT

Offset Difference between the Original and the New Sensor

The instrument offset between the two aircraft magnetic sensors was established by comparing them to the base station magnetometer, which was used as a reference. Simultaneous recordings were made with all sensors side by side.

- Original sensor: 8.6 nT higher than the base station
- New Sensor: 20.5 nT higher than the base station

Therefore, the new sensor was reading 11.9 nT higher than the original sensor (which explains the higher Bourget value obtained with this sensor). However, all production data was obtained from the new sensor, so there is no difference within the data set. As this offset represents an arbitrary constant, common to the entire data set, it has no effect on the residual amplitude of the magnetic anomalies and therefore will not reflect in the quality of the final magnetic maps. It was therefore not necessary to account for this offset in the reduction of the data.

Repeatability Line

To verify the response differences between the two aircraft sensors, a selected line (line 85) was flown in both north and south heading with each sensor separately. Allowing for minor flight path and ground speed differences, a very good agreement was shown between the two sensors.

Altimeter Calibration

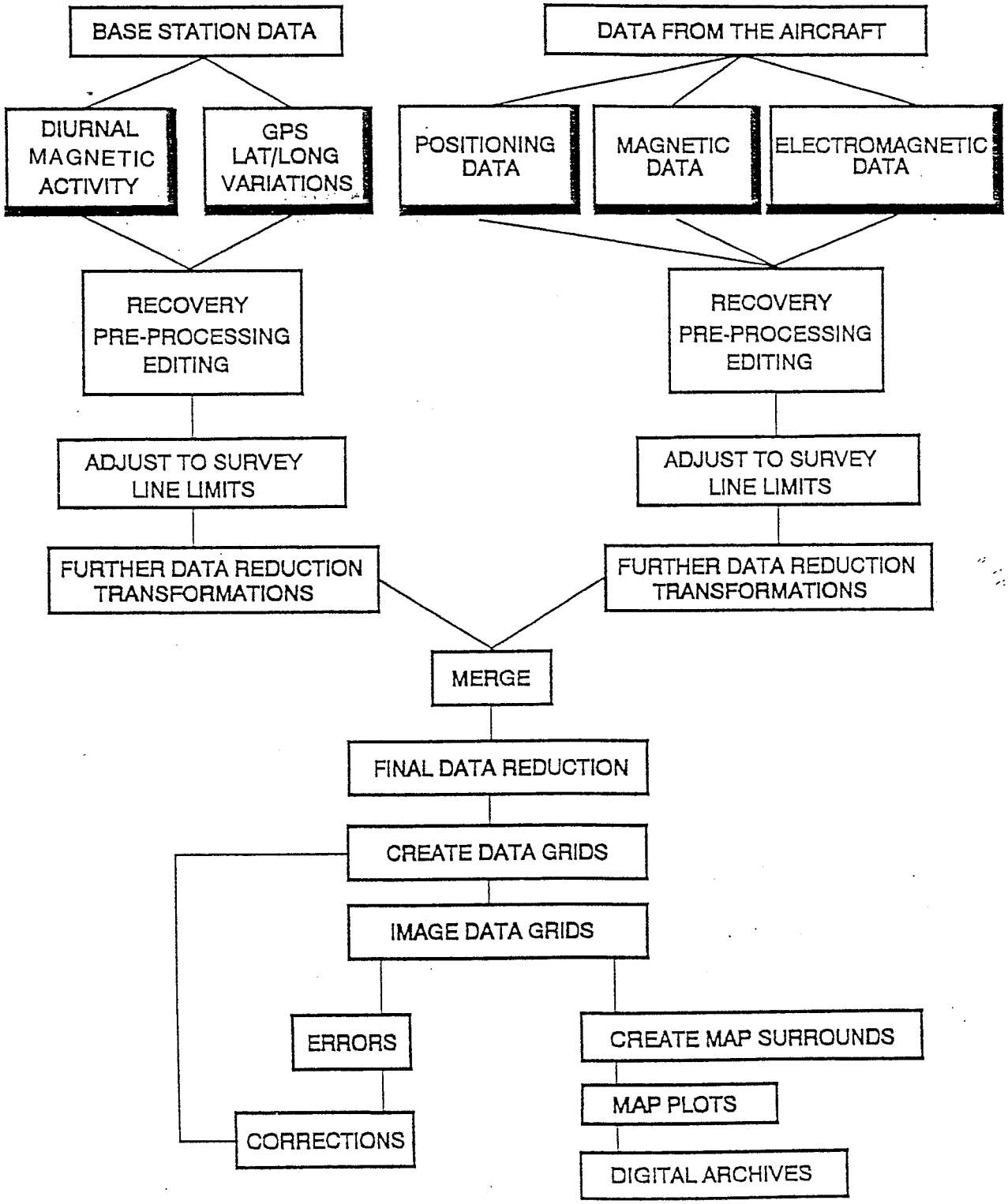
An altimeter calibration was flown over the runway at the Kirkland Airport on 15.04.92 and again over the Ottawa River on 12.05.92. Both radar and barometric altimeters displayed a good linear relationship from 300 to 1000 feet above ground.

Cloverleaf

A cloverleaf check was attempted with the new sensor in an area near Kirkland Lake on 15.04.92. However, the local gradient over the selected site was too steep and the results were inconclusive.

GENERAL FIELD OR OFFICE PROCESSING FLOWCHART

See separate list of processing steps for details on each data type



PROCESSING OF POSITIONING DATA (GPS, DOPPLER)

- Reformat raw data.
- Data verification by statistical analysis.
- Re-synchronize GPS data, if necessary.
- Incorporate base station positioning data.
- Match GPS bases station data to the air data.
- Apply differential corrections to GPS.
- Convert GPS latitude and longitude from WGS84 to local map projection and datum, then to UTM metres.
- Edit raw Doppler data for spikes, bad values.
- Generate Doppler x,y coordinates from heading and long-track/cross-track velocities.
- Generate speed field from both the GPS and Doppler x,y coordinates and compare.
- Bridge in Doppler x,y coordinates to replace sections of poor GPS records, if necessary.
- Separate the flight data to proper line limits.
- Generate a preliminary flight path map to control the navigation.
- Export x,y coordinates to other processing files.

PROCESSING OF BASE STATION DATA

- Reformat raw data.
- Data verification by statistical analysis.
- Select portion of data to correspond to exact start and end time of the flight.
- Fourth difference editing of diurnal magnetics.
- Interactive graphic screen editing of diurnal to remove events caused by man-made disturbances.
- Noise-filtering of diurnal magnetics, if necessary.
- Base station GPS data and diurnal field exported to appropriate processing files.

PROCESSING STEPS FOR MAGNETIC DATA

- Reformat raw data.
- Data verification by statistical analysis.
- Adjust for system lag.
- Fourth difference editing of bad values.
- Interactive graphic screen editing, if necessary.
- Noise filtering, if necessary.
- Separate the flight data into line limits.
- Incorporate positioning and base station data.
- Apply necessary data corrections, such as diurnal subtraction.
- Calculate the positions of the control points (intersections of lines and tie-lines).
- Calculate the magnetic differences at the control points.
- Apply levelling corrections (combination of movements and compensations).
- Generate a grid of the corrected data.
- Image the grid and verify.
- Apply corrections to the line data, if necessary, and re-grid.
- Generate contour file and other map components (map surrounds, titles, etc.).
- Preliminary map plot.

PROCESSING OF ELECTROMAGNETIC DATA (GEOTEM®)

- Reformat raw data.
- Data verification by statistical analysis.
- Adjust for system lag.
- Baseline adjustments to EM channels.
- Separate the flight data into line segments.
- Isolate and remove sferic events.
- EM transformations/calculation of derived parameters, such as the decay constant, the apparent conductivity, etc.
- Noise filtering of EM channels and derived parameters.
- Automatic selection of anomalies and calculation of depth to source and conductance.
- Interactive editing of anomaly selection via a graphic screen.
- Incorporate positioning data.
- Generate grid of selected EM channel or derived parameter.
- Image grid and verify.
- Apply corrections to line data, if necessary, and re-grid.
- Generate contour file and other map components (map surrounds, titles, etc.).
- Preliminary map plot.

III

DATA PROCESSING

1. Flight Path Recovery

During all on-line surveying, including turn-arounds, the aircraft's GPS and Doppler positioning information was recorded digitally. In addition, the video camera continuously recorded the flight path.

The first step in establishing line locations was to recover GPS digital data. Data recorded by the ground station was used to make post-flight differential corrections. Wherever the GPS positions were questionable, segments of lines were bridged by Doppler digital data and/or verified by visually-picked points.

A reference GPS base station established on a point of known coordinates acts as a static reference, measuring the satellite errors resulting in temporal variations in the calculated GPS position. Using the GPS clock to synchronize the two data sets (GPS positions from the mobile receiver on-board the aircraft and the GPS information from the base receiver), the temporal variation in the GPS positions, as measured by base receiver, can effectively be removed from the GPS positions measured on-board the aircraft, thus greatly improving the final positions.

The resulting merged flight path was then checked for errors by calculating the aircraft's speed between selected points. Unrealistic speed changes were investigated and the flight path re-adjusted where necessary.

Final line locations were automatically plotted at a scale of 1:20 000. The flight path co-ordinates were recovered in UTM metres, using the CLARKE 1866 Spheroid projection with a central meridian of 81°W.

2. Magnetic and Altimeter Data

a) Editing of Airborne Data

After reformatting the field tapes, the flights were broken into individual lines and the total magnetic field readings, radar altimeter and time fiducials were verified for continuity and validity by generating a statistical listing of maximum, minimum, mean, standard deviation, and variance. This will locate any major busts or gaps in the data.

Following this, other errors in the digital records of the raw total intensity values were searched by examining the fourth difference and by viewing the data on a line by line basis on a screen editor. Any errors found were corrected interactively.

b) Editing of Diurnal Records

The ground station analogs were initially examined to identify cultural disturbances such as anomalies created by passing vehicles. Once identified, these disturbances were removed from the digital data by fitting a curve to the data based on the best polynomial fit (via the use of a graphics terminal) or manually smoothed and digitized.

The data were then examined to determine if the diurnal variation exceeded specification during any periods when the aircraft was on line. Any lines flown during such periods were reflown.

The digital data were then verified and edited in the same manner as the airborne data. That is, the data were first examined for busts or gaps using the statistical analysis. They were then edited using the same graphics routine as used on the airborne data.

c) Subtraction of Diurnal Variation

The effect of diurnal variation on the airborne records was carefully examined. The diurnal events of short period observed at the base station did not correlate well with

the airborne records. Thus, only the long wavelength component of the diurnal records could be removed from the airborne magnetic data. A triangular filter was used to remove all diurnal events of less than 50 seconds duration, prior to ground subtraction.

After subtraction of the long wavelength ground data, the mean value of the ground station data was added to the airborne data.

d) Drift Correction to Barometric Altimeter

The barometric altimeter was corrected for linear drift based on the pre- and post-flight readings taken on the runway at the Kirkland Lake airport; no instrument adjustments were done during the flight. A small smoothing operator was then applied to the corrected barometric values.

e) Smoothing the Data

Digital smoothing was applied as follows:

Data Recorded	Type of Filter	Amplitude Threshold	Designed to smooth events of less than x seconds
Airborne Magnetometer	Running Average Convolution	0.75 nT	0.5
Radar Altimeter	Running Average Convolution	15 feet	3.0
Barometric Altimeter	Running Average Convolution	25 feet	4.0

f) Interpolation of the Data

The magnetic data, which were originally recorded at the rate of 10 samples per second, were reduced to 6 samples per second when transferring the data from the digital field tapes to the processing data base. This was done to allow easy matching of the magnetic

values with the electromagnetic values which are directly recorded at a rate of 6 samples per second. The interpolation was done by initially expanding the data to 30 samples per second using a 4^{th} order polynomial, then reselecting this expanded data field to retain only every 5^{th} value, thus obtaining a new field of data containing only 6 samples per second.

g) Correction for Lag

The magnetic digital values were shifted back in time by 2.8 s (corresponding to 18 EM samples) to make them coincide with their true positions over the ground.

h) Contouring

The magnetic data used as input to the contours were the total field after editing of bad values, noise filtering and long wavelength ground subtraction.

In order to contour the magnetometer data, the values from the lines and tie-lines were levelled together. This was done automatically by comparing the values of the total field at the intersection of each line and tie-line. The differences were analyzed and a compensation was calculated at each intersection in order to provide a pattern of smoothly varying adjustments along each line and tie-line. Erratic differences, implying an error in the intersection location, were carefully checked and corrected. See Appendix A for further notes on the levelling procedure.

The values were then sorted and gridded along a 50 m grid, at the map scale of 1:20 000 and contoured automatically using an interval of 5 nT. See Appendix B for notes on the gridding procedure.

For the 1:50,000 colour map presentation, the International Geomagnetic Reference Field (IGRF) was removed. It was calculated from the 1990 coefficients for the period 1992.47 at an elevation of 410 m above sea level.

3. GEOTEM® Electromagnetic Data

a) Profile Processing

After reformatting the field tapes, the data were verified and edited to produce files representing continuous EM coverage of the area flown. Statistics were generated (minima, maxima, mean, standard deviation and variance) on a line-by-line basis for each channel of the raw data recorded in order to verify the data content and check for any irregularities.

A lag of 4.5 s (27 digital samples) was then applied to the data to align EM anomaly peaks caused by "typical" near-vertical, narrow to moderately-wide conductive horizons. See Appendix F for further discussion on response patterns.

The data were then inspected for the presence of EM sferics (electrical discharges in the atmosphere). In a routine involving up to four separate passes, sferics are located on the basis of anomaly width, decay rate, and reversal. Any data corrupted by sferics are removed and replaced by interpolated values.

The frequency distribution and noise amplitudes of the data were studied by examining selected lines on a VGA graphics screen. The derived information was used to design filters which separate the high-frequency instrumental noise from the true signal.

GEOTEM® data are subjected to minimal base level drift and are automatically normalized to ppm. The very slight drift that does occur, most often restricted to the earlier channels, was easily identified and corrected by reviewing the channel base levels as recorded during the pre- and post-flight compensation/calibration intervals.

b) Anomaly Selection and Map of Conductors

Geoterrex uses the University of Toronto Plate program (originally written by A.P. Annan) with some modifications, to compute the theoretical secondary field response produced by various common geological models. Using these results, nomograms were developed for each of the models relating amplitude and decay rate of the secondary field to the conductivity, thickness or conductance and depth of the causative body.

For this project, a vertical plate model (600 m strike length x 300 m depth) was selected as the model for anomaly fitting.

The anomaly selection routine scans the amplitude, width and decay of each anomaly simultaneously. If the anomaly fits the criteria of narrow width, predetermined amplitude range and normal rate of decay, it is selected as a significant anomaly. This routine computes the conductance of the theoretical vertical plate and the depth to the top of the plate below surface. A more complete description of the plate fitting algorithm is found in Appendix D.

With reference to a provisional EM plan map, the data are then studied on a VGA graphics screen by an experienced geophysicist to confirm that all valid anomalies have been selected. Any errors in the automated anomaly selection are corrected directly via a graphic screen editing routine.

c) Decay Constant

The decay constant values are obtained by fitting the data from a selected portion of the decay transient (using either the complete decay curve from channels 1 to 12 or only a selected window of the decay using the appropriate early, mid or late-time channels) to a single exponential function of the form:

$$y = Ae^{-t/\tau}$$

where A = amplitude at time zero, t = time in ms and τ is the decay constant. A semi-log plot of this exponential function will be displayed as a straight line, the slope of which will reflect the rate of decay resulting in a conductivity estimate. A slow rate of decay (high conductivity) will be represented by a gentle slope yielding a high decay constant value and vice-versa.

For the present dataset, the decay constant values were calculated from the GEOTEM® data by fitting the decay information from all 12 channels to the exponential function. The decay constant values obtained from EM responses which were clearly of man-made origin (powerlines, pipelines, etc.) were removed from the data by linear interpolation using a graphic screen editor.

As a single parameter, the decay constant provides more useful information than the amplitude information of any given channel as it indicates not only the peak position of the response but also the conductivity of the conductor. It also often allows better discrimination of conductive axes within a broad formational group of conductors. This parameter is represented as the colour infill to the stacked profile map of channel 3.

d) Apparent Conductivity of Overburden

The apparent conductivity of overburden was calculated from the amplitude line data of the on-time channel (20) using the response from the homogenous half-space model. These values were then gridded along a 50 m grid interval and contoured using an interval of 2 mS/m. See Appendix E for further notes on the conversion of channel 20 data to units of apparent conductivity (mS/m).

e) Apparent Conductance of the Bedrock Conductors

Conductance derived by fitting the anomaly peak amplitudes to the vertical plate model, as part of the EM anomaly selection routine described in b), was selected as a parameter for colour map presentation at 1:50,000.

As singular values along the lines of data, a small tapering function was applied to allow gridding for the map presentation. The amount of the amplitude threshold required by the tapering function in order to produce a smooth transition of the values, was first added to the calculated conductance values, prior to tapering, such that the full amplitude of the values were retained after the tapering function.

4. Products

The final data were presented as the following products:

Map products at 1:20,000 (8 sheets)

- Aeromagnetic total field contour maps (5 nT contour interval), presented with the flight path and the topographic base. (20371G, 20372G, 20373G, 20374G, 20375G, 20376G, 20377G, 20378G)

- Contour maps of apparent conductivity of overburden map (2 mS/m contour interval), presented with symbols depicting bedrock conductors, flight path and the topographic base. (25053G, 25054G, 25055G, 25056G, 25057G, 25058G, 25059G, 25060G)

- Stacked profile maps of GEOTEM® channel 3, displayed at a vertical scale of 100 ppm/cm (truncated at 500 ppm), with colour infill based on the decay constant values and presented with a map of bedrock conductors and flight path. This map is not part of the open-file data set released to the public.

Map products at 1:50,000 (2 sheets)

- Colour magnetic anomaly maps (residual total field) presented on a topographic base. (C20369G, C20370G)

- Colour maps of apparent conductivity of overburden, presented on a topographic base. (C25051G, C25052G)

- Colour maps of apparent conductance of bedrock conductors, presented on a topographic base. (C25049G, C25050G)

Multiparameter profiles at 1:20,000

Delivered as paper prints and microfiches displaying the following information for every survey line:

- EM primary field (25%/cm),
- total field magnetics (500 nT/cm and 50nT/cm),
- radar altimeter (25 m/cm),
- overburden conductivity (10 mS/m/cm),
- bedrock conductance (2 S/m),
- GEOTEM® channels 1 to 12 (250 ppm/cm),
- EM noise monitor (250 ppm/cm),
- powerline monitor (mV/cm),
- EM anomaly selections.

The microfiches (10 x 15 cm) were published as an Open File # 2460, consisting of 35 plates.

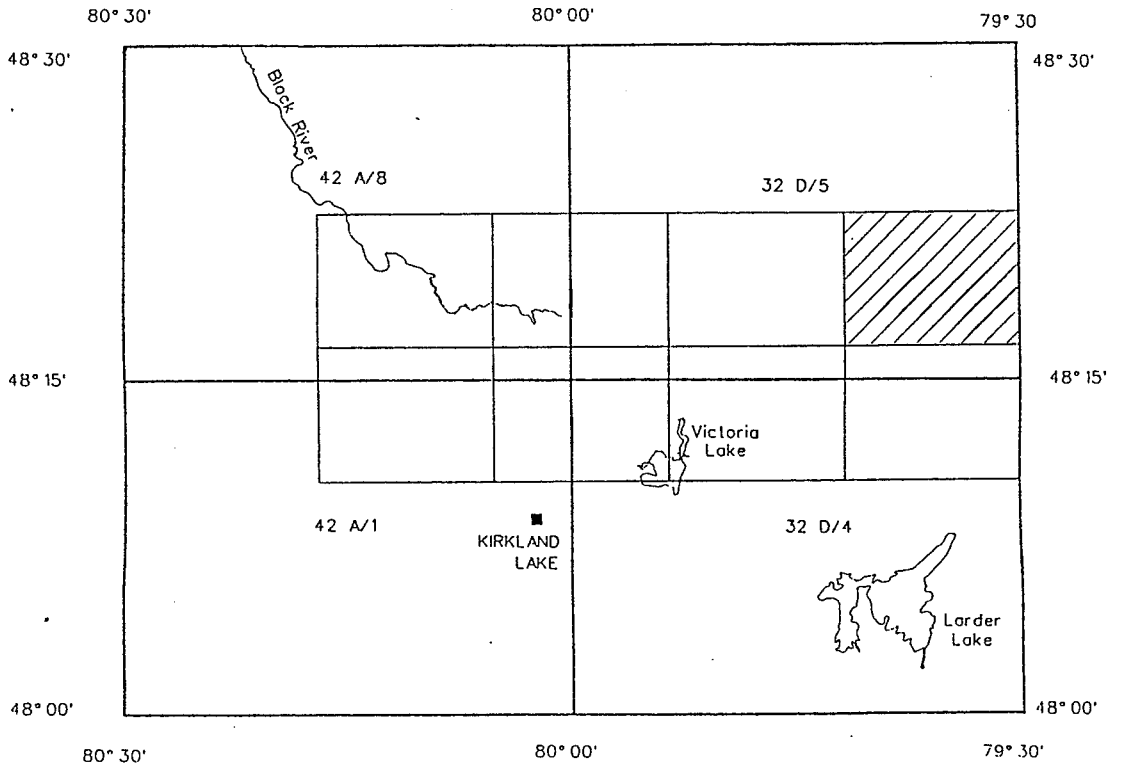
Digital Archives

Digital archives of all data channels in line form as well as the final processed grid sets presented on the maps were delivered, coded in ASCII. A full format description is given in Appendix G. The raw EM line data with calibrations from each flight were also delivered. A full format description is given in Appendix G.

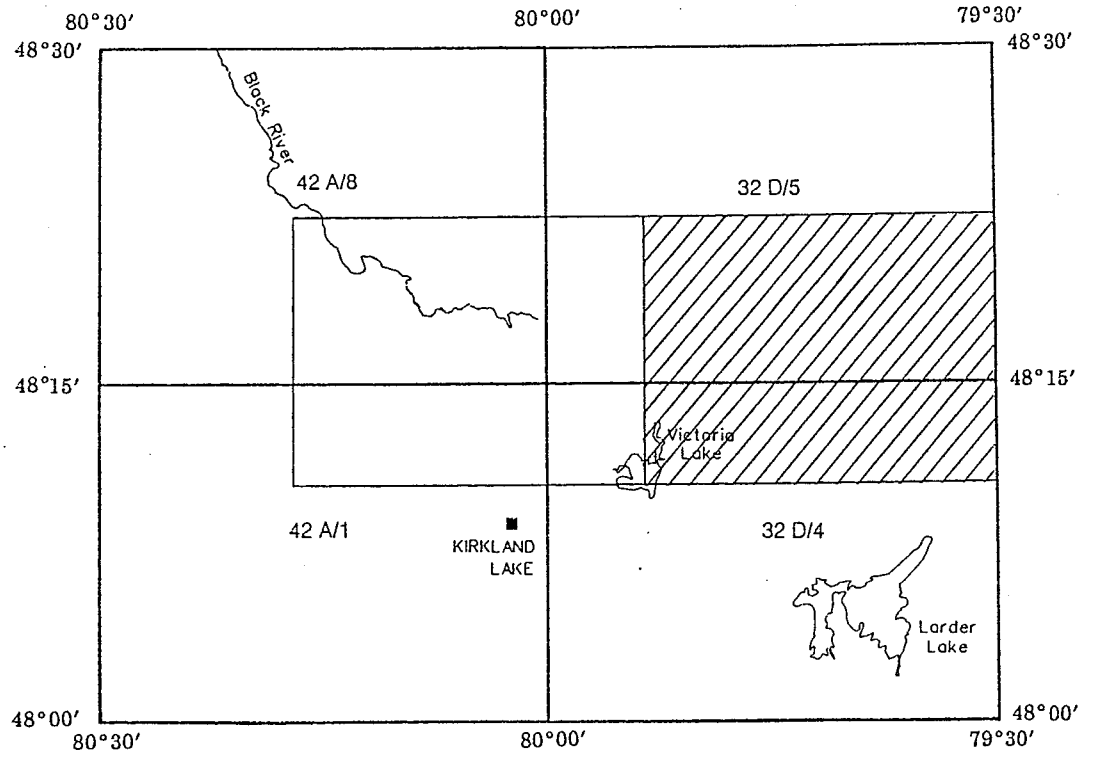
Field Data

All field data material, including the analogue records, the flight logs and the VHS video cassettes of the flight track.

Sheet Index Maps



scale of 1:20,000



scale of 1:50,000

figure 2

Appendix A
Note on Levelling Procedure

MAGNETIC DATA LEVELLING PROCEDURES

1. INTRODUCTION

The lines and tie-lines of an aeromagnetic survey form a network, and the points where they cross one another are called intersections. At each intersection, it is easy to interpolate the magnetic value on the line and on the tie-line from adjacent values. In theory, the two magnetic values at the intersection should be identical. In practice, they will usually be different as a result of:

1. Time variation of the magnetic field. The major part of these diurnal differences may be removed by subtracting ground from airborne magnetic measurements.
2. Heading effects. If a cloverleaf has been flown, corrections for heading effects can be applied.
3. Altitude differences. Since the earth's magnetic field varies with altitude above the ground, any difference in flight altitude will cause a difference in magnetic value. For surveys flown at constant height above sea level, a partial correction can be made, using a constant vertical magnetic gradient.
4. Position errors. These have little effect in areas of low magnetic gradients, but can introduce large differences in steep gradients.

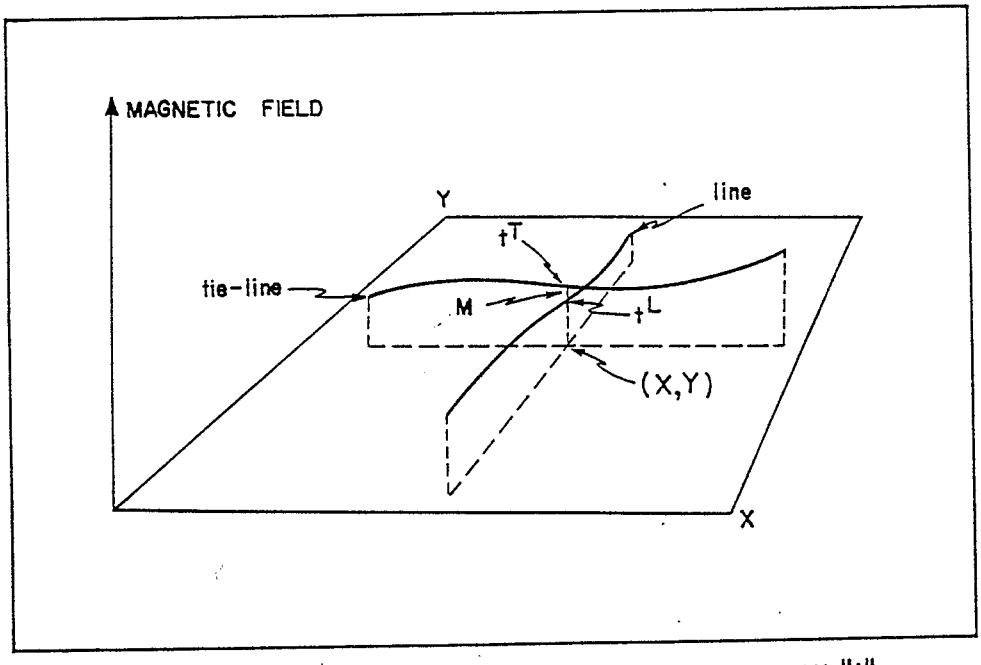
In the levelling process, it is assumed that most of the required level adjustments will vary smoothly along each line or tie-line, in the same manner as the time variations of the magnetic field. Even if ground magnetic measurements have been subracted from the airborne, we cannot be sure that the time variations at the aircraft and the ground station were identical. There may be some intersections which cannot be fitted with

smooth level adjustments on both line and tie-line. These are usually attributed to errors in the aircraft position, and the flight path is adjusted to change the L-T (line minus tie-line) value to one which can be fitted by smooth adjustments.

Even after correction of the magnetic measurements for the above effects, L-T differences in the magnetic values at the intersections will still be present. Before the data can be contoured these L-T misclosures must be resolved, as the ultimate purpose of the levelling process is to reduce all misclosures to zero.

II. MATHEMATICAL ANALYSIS

The network of lines and tie-lines are assumed to lie in the X-Y plane. The position of an intersection "i" is then characterized by the coordinates (x,y) and times t^L and t^T. The measured magnetic field is characterized by a value on the vertical axis (Z axis) perpendicular to the X-Y plane. The difference between the magnetic field values on the line and the tie-line (the L-T difference) at intersection "i" is the misclosure M.



PARAMETRIC REPRESENTATION AT INTERSECTION "i"

FIGURE 1

II.1 OUTLINE OF PROCESS

The first stage of the levelling process is the calculation of the line and tie-line level adjustment at each intersection. These vary smoothly along a line or tie-line and define the levelled baseline of the magnetic profile. The line and tie-line level adjustments (A^L and A^T respectively) account for the diurnal. The level adjustments are calculated with two averaging operations, MOYA and MOYB (MOY is from the French word MOYENNE, meaning average). MOYA removes the slowly varying component of the misclosures, and MOYB removes the rapidly varying component. After MOYA and MOYB, at the "i" intersection, the misclosure remaining after adjustment, R, is given by

$$R = M + A^L - A^T. \qquad ...(1)$$

The next stage consists in tilting the line baseline by a maximum allowed tilt of T to reduce the misclosure R to zero.

If $$|R| \leq T, \qquad ...(2)$$

then $$M + AA^L - A^T = 0 \qquad ...(3)$$

where $$AA^L = A^L - R \qquad ...(4)$$

is the new line level adjustment.

If the remaining misclosure R cannot be reduced to zero within the maximum allowed tilt T, the position of the intersection instead is shifted in the X-Y plane to the point closest to the intersection (within a maximum allowed displacement) where the relation

$$R + D^L - D^T = O \qquad ...(5)$$

is satisfied. D^L and D^T are the differences, (or magnetic value at the new intersection position minus the magnetic value at the original intersection position). The initial misclosure $\vec{M}$ is then corrected to give

$$M_{corr} = M + D^L - D^T \qquad ...(6)$$

such that

$$M_{corr} + A^L - A^T = O \qquad ...(7)$$

If the remaining misclosure R cannot be reduced to zero within the maximum allowed displacement, the maximum allowed tilt is increased and the tilting calculation (equations 2 to 4) is reapplied. If R is still not reduced to zero, the maximum allowed displacement is also increased and a tilt and shift are applied simultaneously to the intersection. The position of the intersection is now shifted in the X-Y plane to a point where the relation

$$\left| R + D^L - D^T \right| \leq T \qquad ...(8)$$

is satisifed. The intersection can be moved to the closest point or to the point with the smallest tilt which satisfies equation (8). The first option is usally preferred. After tilting and shifting of the intersection, the misclosure and line compensations are corrected to give

$$M_{corr} + AA^L - A^T = O \qquad ...(9)$$

where $$AA^L = A^L - (R + D^L - D^T) \quad ...(10)$$

is the new line level adjustment, and

$$M_{corr} = M + D^L - D^T \quad ...(11)$$

is the corrected misclosure.

The intersection is flagged if it is closed using condition (8) (relaxed specfications). If the misclosure R at the intersection still cannot be reduced to zero under relaxed specfications, it is specially flagged as a "bad" intersection. This requires checking of the flight path recovery. The data set can then be relevelled automatically or the bad intersection can be closed manually.

The levelling process can thus be summarized as follows:

Compensation:	MOYA on the tie-lines (run 1)
	MOYA on the lines (run 1)
	MOYA on the tie-lines (run 2)
	MOYA on the lines (run 2)
	MOYB on the lines
	MOYB on the tie-lines (twice)
If necessary,	Tight specifications:
	Tilt the line baseline, or
	Shift the position of the intersection
	Relaxed specifications:
	Tilt the line baseline, or
	Shift the intersection and tilt the line baseline
If $M \neq O$:	Bad intersection.

smooth level adjustments on both line and tie-line. These are usually attributed to errors in the aircraft position, and the flight path is adjusted to change the L-T (line minus tie-line) value to one which can be fitted by smooth adjustments.

Even after correction of the magnetic measurements for the above effects, L-T differences in the magnetic values at the intersections will still be present. Before the data can be contoured these L-T misclosures must be resolved, as the ultimate purpose of the levelling process is to reduce all misclosures to zero.

II. MATHEMATICAL ANALYSIS

The network of lines and tie-lines are assumed to lie in the X-Y plane. The position of an intersection "i" is then characterized by the coordinates (x,y) and times t^L and t^T. The measured magnetic field is characterized by a value on the vertical axis (Z axis) perpendicular to the X-Y plane. The difference between the magnetic field values on the line and the tie-line (the L-T difference) at intersection "i" is the misclosure M.

Appendix B
Note on Gridding Procedure

SORTING AND GRIDDING ROUTINE

I. INTRODUCTION

In general, the geophysical data processing (i.e., magnetic or radiometric survey data) will be presented as contour maps. Preliminary contours may be used for error analysis such as synchronization of digital data, levelling, filtering and subtracting of regional effect, etc. The final contour map along with the profiles may be used by the geophysicists for interpretation of geological features.

The contouring package at Geoterrex is designed for airborne surveys. The data of a field operation are represented by digital data on magnetic tapes, and positions are recorded on film in the tracking camera. For processing purposes, the data is broken up into lines and tie-lines (control lines). The tie-lines are usually perpendicular to the lines. The two types of lines form a network. This sparsely formed network can not be used to produce high quality contours directly. The first step is to establish small scaled grids over the whole area. For simplicity, we have chosen square grids.

By interpolating information provided by the lines, the geophysical values are calculated at all grid vertices. Searching through these fine grids, we can then trace contour curves at different levels.

I.1 Terminology

For clarity, terminologies used frequently are defined as follows. (We assume that the x-axis is parallel to the lines, this can be done by a simple rotation of the axes.)

1) Bands: In the sorting stage, the whole area is divided into vertical strips. They are called bands.

2) Cells: In the gridding stage, each band is again cut into blocks for further processing. These subregions are called cells. They do not have to be square, but we have used only square cells so far.

3) Grids: Inside each cell, the area is divided into grids. For example, the small square PQRS in Figure 1 is a grid.

4) Side of Grid: PQ, QR, PS, SP are the four sides of the above grid.

5) X-Direction Grid Divisions: the horizontal lines which divide the grids, e.g., $\overline{UU}$ or $\overline{WW}$ in Figure 1.

6) Y-Direction Grid Division: The vertical lines which divide the grids, e.g. $\overline{VV}$ in Figure 1.

7) Grid Corner or Grid Point: The intersections between any Y-Direction grid divisions and any X-Direction grid divisions, e.g., P, Q, R, S, in Figure 1.

8) Data Points: These points are on the lines or tie-lines with the field data recorded. They are denoted by "."'s in Figure 1.

9) Band Boundaries: The grid divisions used to divide the cells i.e., the first row, last row, first column and last column of each cell.

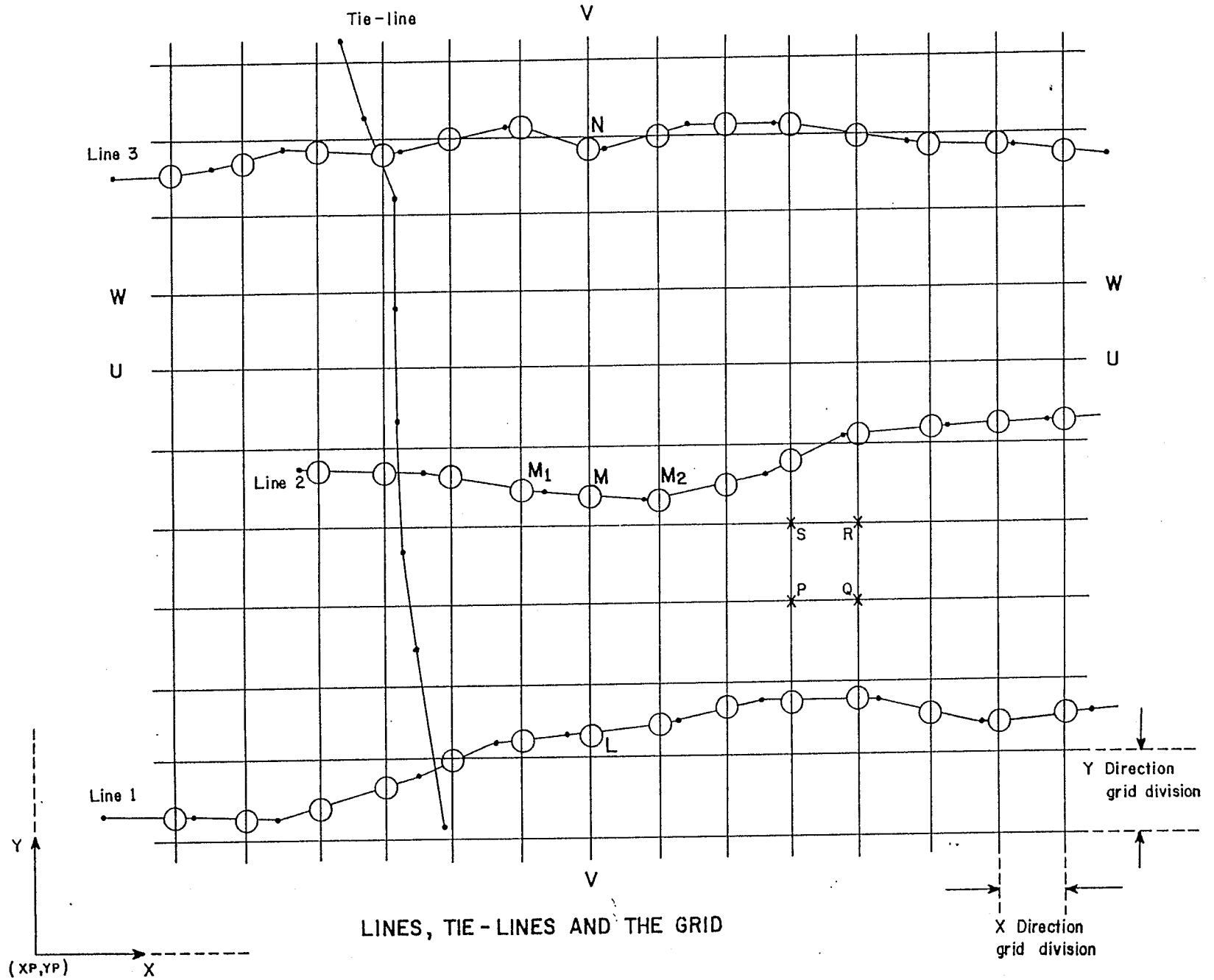
2. SORTING

Sorting is the first step in the contour package. Before carrying out the sorting, grids and bands must be set up.

2.1 Grids and Bands:

The grids are set up with the lower left corner point of the first grid (xp, yp) as the origin. The required grid interval is defined as INC. Starting from the origin, equally spaced (incremented by INC each time) horizontal lines (x-direction grid divisions) and vertical lines (y-direction grid divisions) are drawn until the upper right corner point of this area is reached.

The procedure of dividing the area into bands and subdividing the bands into cells (during the gridding) is necessary because the



LINES, TIE-LINES AND THE GRID

FIGURE 1

contour density varies from area to area. Usually a job will have some flat areas and other areas having steep gradient. Dividing the whole area into cells, we can then avoid unnecessary searching for the nonexisting contours in the flat gradient region.

2.2 Sorting

The idea of sorting is to interpolate values at all the intersections (denoted by "O"s in Figure 1) of the lines with the y-direction grid divisions and then store the interpolated values on various disc files for different bands. This procedure is described step by step by the following example.

Proceeding along line 2, we see that this line intersects a y-direction grid division ($\overline{VV}$) at point M in Figure 1. The nearest data point on each side of M is M_1 and M_2. Let the corresponding data values and their coordinates be (T_1, X_1, Y_1) and (T_2, X_2, Y_2). Hence the geophysical value at M could be linearly interpolated by

$$T = T_1 + (T_2 - T_1) * \frac{X-X_1}{X_2-X_1}$$

and the Y-coordinate is

$$Y = Y_1 + (Y_2 - Y_1) * \frac{X-X_1}{X_2-X_1}$$

where X is the x-coordinate of the grid division $\overline{VV}$, (i.e. $\overline{VV} = X$).

After all lines are sorted, there will be a data value T and

a y-coordinate Y at every point denoted by "O" in Figure 1. These interpolated values are then stored in various disc files according to the bands to which they belong. The index of each disc file identifies the band.

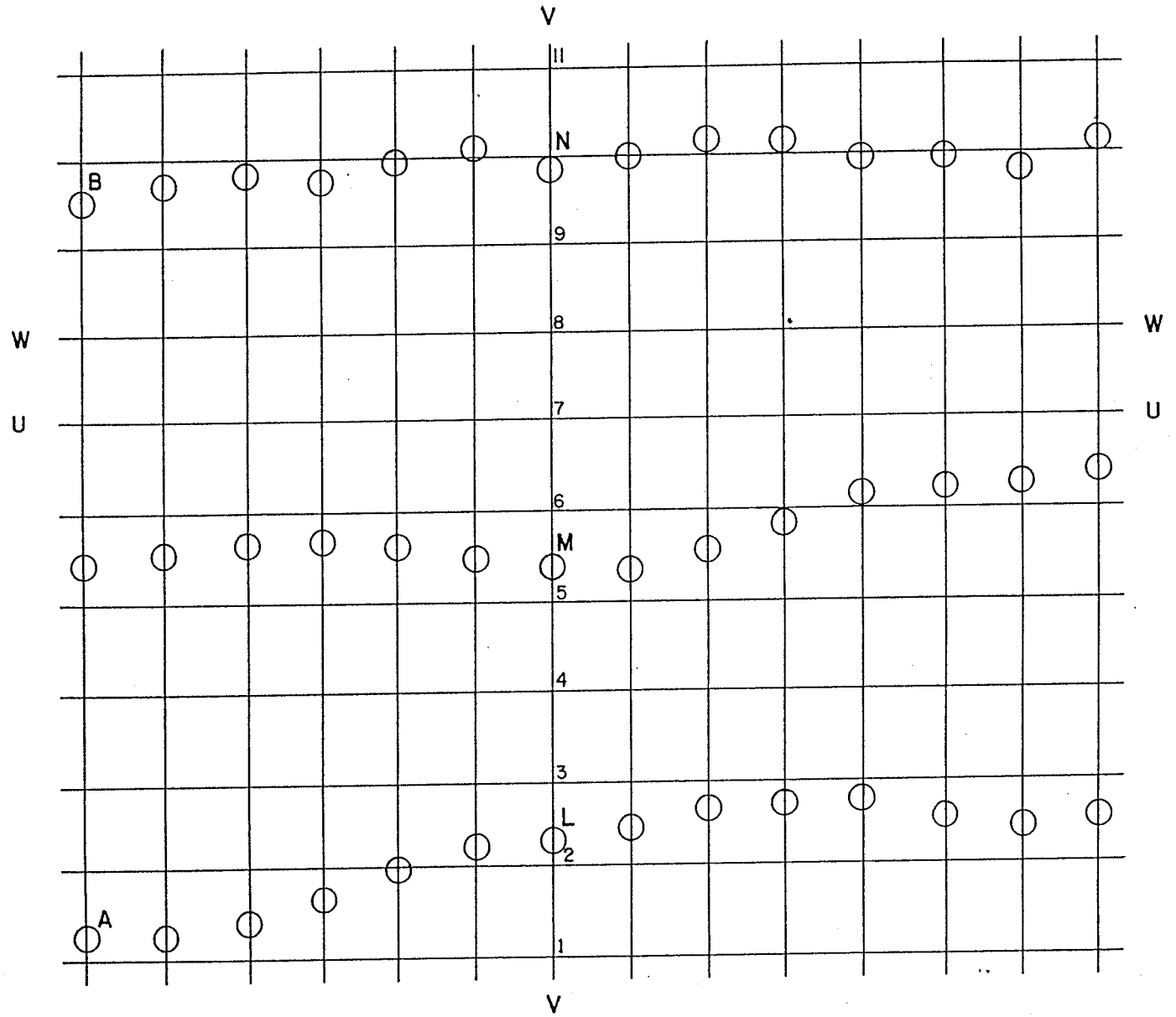
Along the band boundary, the same set of data will be stored for both bands. For example, see Figure 1 or Figure 2, if the grid division $\overline{VV}$ is used to divide the area into 2 bands. Then the values for points on $\overline{VV}$, e.g., L, M, N, will be used by band 1 as well as band 2 to ensure continuity.

3. GRIDDING

The purpose of gridding is to calculate data values on all grid corners and write them onto tape, cell by cell. The gridding is proceeded band by band.

3.1 Gridding

First, the program reads all sorted values on one band into memory from disc files. The data are then processed from the left most y-grid division to the right most y-grid division for every band. When all the data along one y-grid division are selected, such as point L, M, N on $\overline{VV}$ in Figure 2, from them, values are interpolated for all grid corners on this grid division (see section 3.3). If there is only one intersection value output, or none, on a y-grid division by the previous sorting processing, the values at all grid corners on this grid division are set to zero.



SORTED DATA

FIGURE 2

When all the grid point values are defined for this band, the gridded data are written onto a magnetic tape, cell by cell. This process is repeated for each subsequent band.

3.2 Interpolation

In the sorting stage, linear interpolation is sufficiently accurate, since the data points on lines are very close. The distance between them is usually the same order as the grid interval. However, the distance between the lines is much larger than the interval of the grids. Interpolation perpendicular to the lines has to be performed more carefully to obtain the maximum accuracy. Hence a modified Akima's method is used. Four points are used to interpolate the curve between the centre two points. Assuming that there are four points, denoted as (T_1, Y_1), (T_2, Y_2), (T_3, Y_3) and (T_4, Y_4) in Figure 3, with the magnitude of the data plotted against the y-coordinates. Now two assumptions are made to recover the data between point 2 and point 3:

i) The equation of the curve between those two centre points, is part of a third order equation.

ii) The tangent of the curve at a point is the average of the two slopes in either side of the point.

Hence we have

$$T = C_0 + C_1 Y + C_2 Y^2 + C_3 Y^3 \qquad Y_1 \leq Y \leq Y_4$$
$$= f(Y)$$

and

. . . . . (3-1)

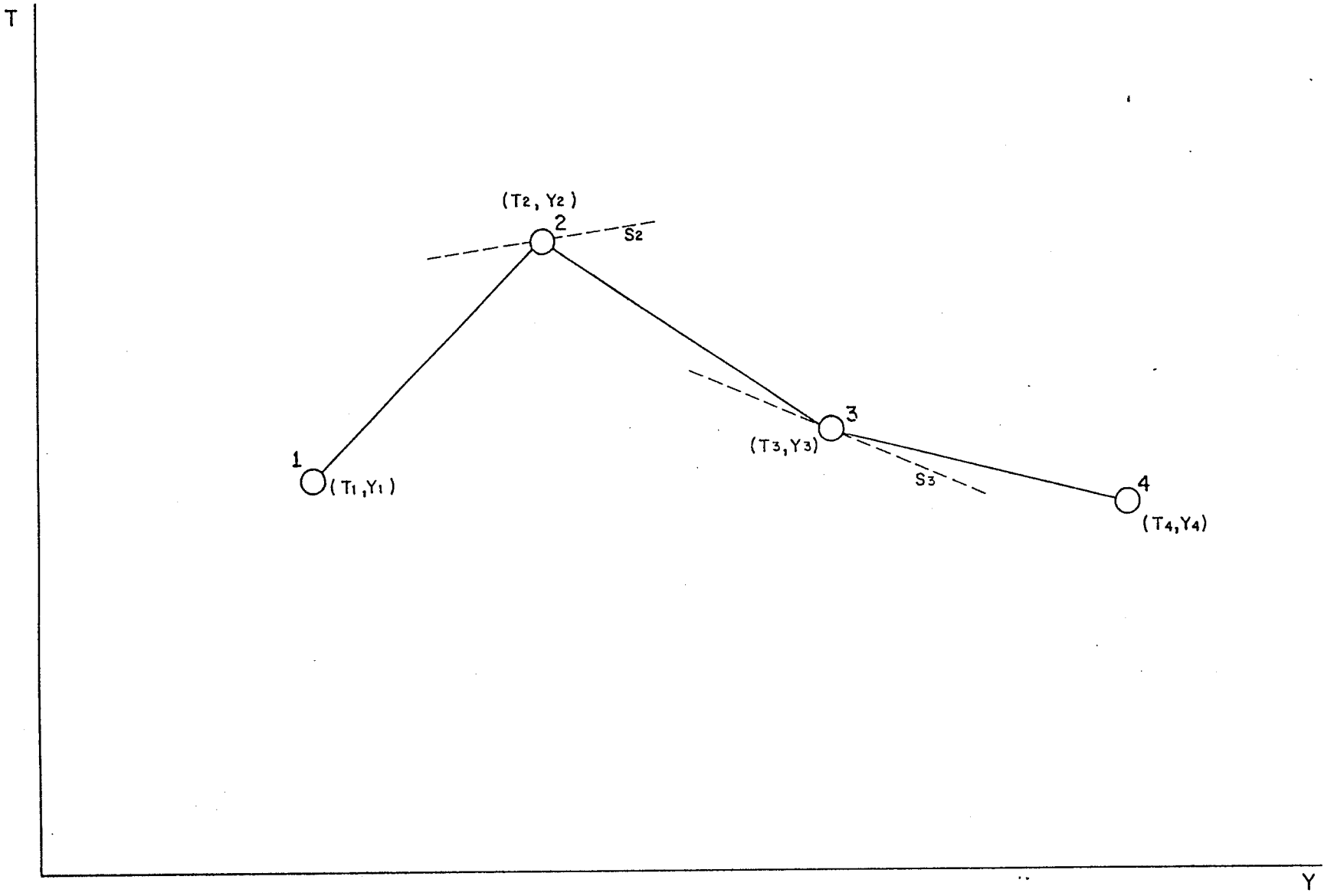


FIGURE 3

$$S_2 = \frac{1}{2}\left(\frac{T_2 - T_1}{Y_2 - Y_1} + \frac{T_3 - T_2}{Y_3 - Y_2}\right) \quad \ldots\ldots\ldots (3\text{-}2)$$

$$S_3 = \frac{1}{2}\left(\frac{T_3 - T_2}{Y_3 - Y_2} + \frac{T_4 - T_3}{Y_4 - Y_3}\right) \quad \ldots\ldots\ldots (3\text{-}3)$$

Under the boundary conditions:

$$T_2 = f(Y_2)$$

$$T_3 = f(Y_3)$$

$$S_2 = f'(Y_2)$$

$$S_3 = f'(Y_3)$$

coefficients in equation (3.1) can be solved

$$C_0 = T_2 \quad \ldots\ldots\ldots (3\text{-}4)$$

$$C_1 = S_2 \quad \ldots\ldots\ldots (3\text{-}5)$$

$$C_2 = \left(3 * \frac{T_3 - T_2}{Y_3 - Y_2} - 2S_2 - S_3\right)/(Y_3 - Y_2) \quad \ldots\ldots\ldots (3\text{-}6)$$

$$C_3 = \left(S_2 + S_3 - 2 * \frac{T_3 - T_2}{Y_3 - Y_2}\right)/(Y_3 - Y_2) \quad \ldots\ldots\ldots (3\text{-}7)$$

Using equation (3.1), with the help of equations (3.2) to (3.7) the values T can be calculated for any point between y_2 and y_3.

There are several salient points that should be mentioned here:

1) This method is superior. Since the fictitious anomalies introduced are considerably less than those introduced by other methods, such as Cubic Spline or Laplace method even when there are sudden changes in slopes.

2) The input points used for interpolation do not have to be equally spaced. However if two points are too close, the average

of these two points is used to avoid a sudden jump of the contour values.

3) The second assumption made, differs from Akima's; his method is simply a curve fitting in an x-y plane, having the x-direction and y-direction in the same scale (isotropic). In this case, the abcissa is the y-coordinate and the ordinate is the geophysical data value which do differ in units. Thus we have to deal with "slopes" instead of "angles", to avoid mixing space with geophysical quantities.

4) Between the first two and last two points, linear interpolation is used. Outside the first and last points, values are also linearly extrapolated to a distance according to the user's specification. The non-interpolated or non-extrapolated grid-corner values are set to zero.

5) Since four points are used to do the interpolation, a local anomaly (or band value) might have effects to a distance of two line spacing on each side of that point, perpendicular to the line.

6) With computer efficiency in mind, integer mode is used in computation whenever possible. Output grid values are also integers. However, to retain accuracy, a multiplication factor, which is determined by the user, is applied to all the input and output values.

Appendix C
GEOTEM® Electromagnetic System

GEOTEM[R1] ELECTROMAGNETIC SYSTEM

General

The operation of a towed-bird time-domain electromagnetic (EM) system involves the measurement of decaying secondary electromagnetic fields induced in the ground by a series of short current pulses generated from an aircraft-mounted transmitter. Variations in the decay characteristics of the secondary field (sampled and displayed as channels) are analyzed and interpreted to provide information about the subsurface geology. The response of such a system utilizing a vertical-axis transmitter dipole and a horizontal-axis receiver coil has been documented by various authors including Palacky and West (1973, Geophysics, v. 38, p. 1145-1158).

The principle of sampling the induced secondary field in the absence of the primary field (during the "off time") gives rise to an excellent signal-to-noise ratio and an increased depth of penetration compared to conventional continuous wave (frequency domain) electromagnetic systems. Such a system is also relatively free of noise due to air turbulence.

Through free-air model studies using the University of Toronto's Plate and Layered Earth programs it may be shown that the "depth of investigation" depends upon the geometry of the target. Typical depth limits would be 250 m below surface for a homogeneous half-space, 350 m for an inductively thin sheet or 200 m for a large vertical plate conductor. These depth estimates are based on the assumptions that a significant response is recorded 1.4 ms after the primary field is turned off and that the overlying or surrounding material is resistive. If a pre-selected range of channels is deemed adequate to detect or resolve a given target, then the depth of investigation increases significantly.

In addition to substantial penetration, time-domain systems respond to a wide range of conductors. With measurements taken during the off time, significant effects are seen for conductors with conductance of 0.8 S or greater, thus responding to the majority of geological feautures deemed relevant in most exploration projects.

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[1] GEOTEM[R]: Registered Trade Mark of Geoterrex Limited.

The method also offers very good discrimination of conductor geometry. The ability to distinguish between flat-lying and vertical conductors combined with excellent depth penetration results in good differentiation of bedrock conductors from surficial conductors.

Most of the preceding discussion concerns theoretical responses for all time-domain installations of similar geometry. The factor which distinguishes the various systems is their ability to faithfully and completely represent the secondary field response.

Equipment and Procedure

GEOTEM (GEOterrex Transient ElectroMagnetic system) is a time-domain towed-bird electromagnetic system incorporating a high-speed digital EM receiver. The primary electromagnetic pulses are created by a series of discontinuous sinusoidal current pulses fed into a three-turn shielded transmitting loop surrounding the aircraft and fixed to the nose, tail and wing tips. The pulse repetition rate is typically 150 Hz (300 bipolar pulses per second), 125 Hz, 90 Hz or 75 Hz. At 150 Hz, as used in this survey, each current pulse can last 1030 μs followed by 2303 μs off-time. Present peak current through the loop is 600 A resulting in a primary magnetic dipole moment of $4.5 \times 10^5 A.m^2$.

The receiver is a wire coil with a ferrite core. It is mounted horizontally in a bird which is towed by the aircraft on a 135-metre cable. The cable is demagnetized to reduce noise levels. Mean terrain clearance for the aircraft is 120 m with the bird situated 56 m below, and 123 m behind, the aircraft. The geometry of the system is displayed in Figure 1.

For each primary pulse a secondary magnetic field is produced by decaying eddy currents in the ground. These in turn induce a voltage in the receiver coil which is a measure of the electromagnetic field. Figure 2 gives a graphical display of the GEOTEM signal.

The measured signals pass through anti-aliasing filters and are then digitized with an A/D converter at sampling rates of up to 40 kHz. The digital data flows from the A/D converter into an array processor where all the numerically intensive processing tasks, such as Fourier analysis, are carried out. The array processor is under the control of a multi-tasking minicomputer which provides all of the software management.

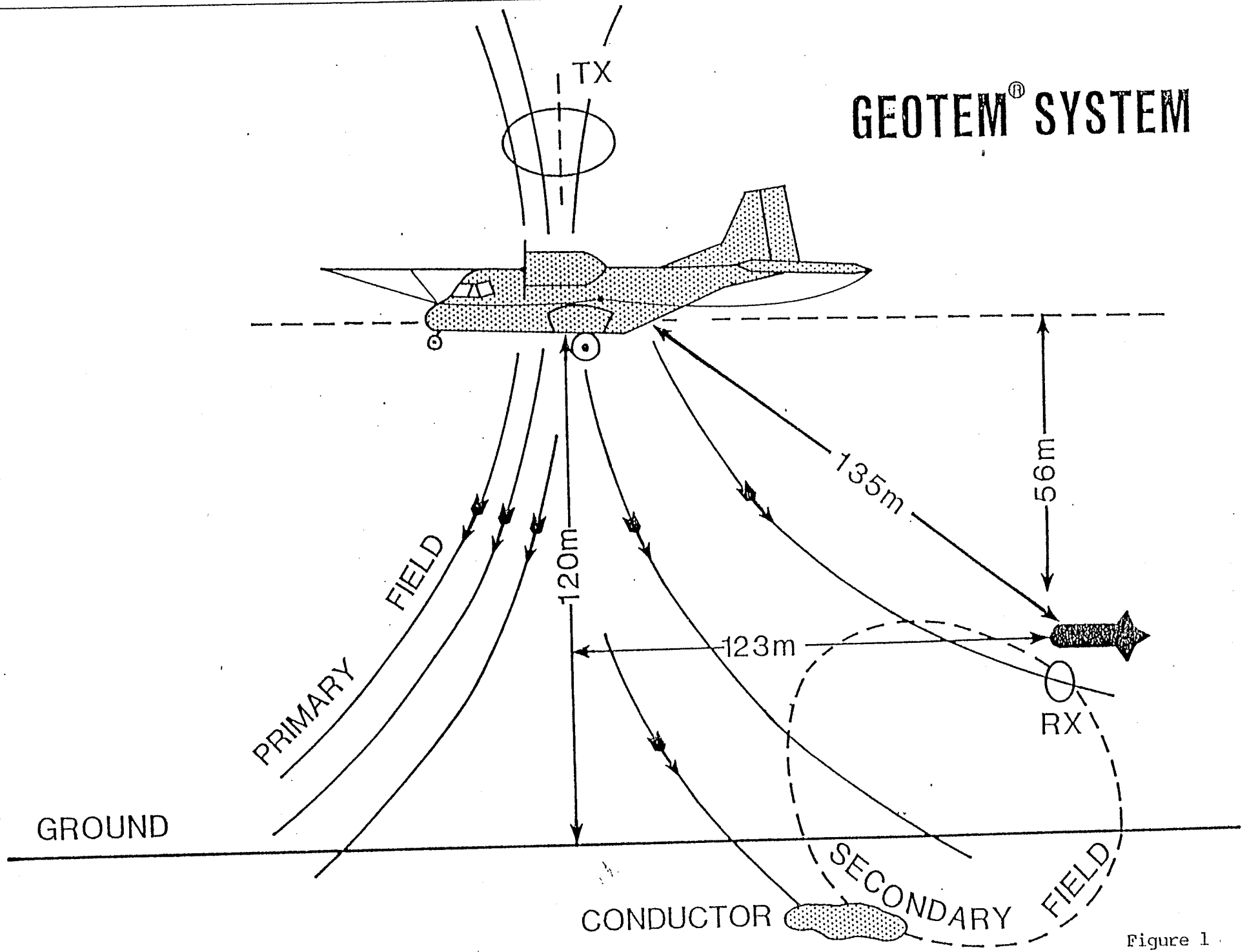

GEOTEM® SYSTEM
TX
135m
56m
120m
123m
RX
PRIMARY FIELD
GROUND
CONDUCTOR
SECONDARY FIELD

Figure 1

GEOTEM® SIGNAL

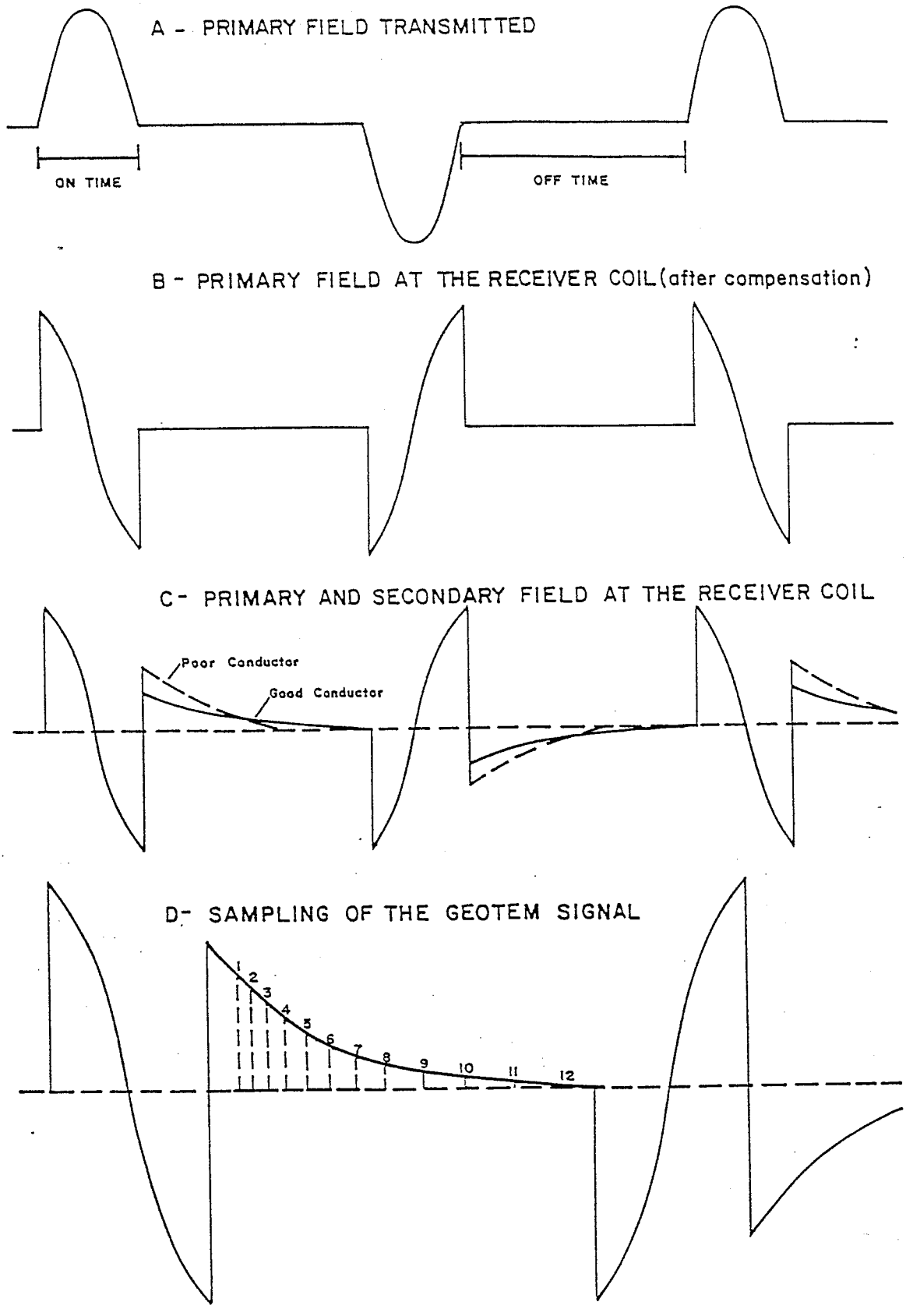


Figure 2

Operations which are carried out in the receiver are:

1. Compensation. During flight the transmitter creates eddy currents within the structure of the aircraft and these have a measurable effect at the bird. Compensation for this signal is effected numerically within the receiver by a statistical analysis of the signal detected at the bird in the absence of ground response. This is achieved by flying at an altitude such that no ground response is measurable (usually in excess of 600 m above ground level). The observed signal is used to define a compensation signal which is subtracted from the observed to produce a null and thus effectively buck out any response due to the aircraft.

2. Normalization. All EM response channels are automatically calibrated and reduced to parts per million (ppm) of the primary field in the receiver. This is achieved by dividing the measured voltage by the voltage induced by the primary field at the bird.

3. Transient Analysis. Harmonic analysis permits the separation of specific types of noise from the signal in real time.

4. Digital Stacking. Stacking is carried out to reduce the effect of broadband noise on the data.

5. Windowing of Transient Data. The GEOTEM digital receiver samples the secondary and primary electromagnetic field and stores the signal in up to 20 time gates whose centres and widths are software selectable and which may be placed anywhere within or outside the transmitter pulse. This flexibility offers the advantage of arranging the gates to suit the goals of a particular survey, ensuring that the signal is appropriately sampled through its entire dynamic range.

One of the major roles of the GEOTEM digital EM receiver is to provide diagnostic information on system functions and to allow for identification of noise events, such as spherics, which may be selectively removed from the EM signal.

The receiver automatically calibrates its received signal with reference to the primary field in ppm and hence compensates for the transmitter drift. Due to the fact that the receiver is digital, the receiver drift is minimal. These factors result in more reliable resistivity mapping where base level shifts can dramatically affect results.

GEOTEM's high digital sampling rate yields maximum resolution of the secondary field. The absence of an analog system time-constant filter results in minimal signal distortion and, therefore, superior representation of the anomaly amplitudes and shapes.

Appendix D
Calculation of Conductance and Depth from GEOTEM® Anomalies

CALCULATION OF CONDUCTANCE AND DEPTH-TO-SOURCE

FROM GEOTEM ANOMALY DECAYS

To provide a means of establishing the quality of each anomalous response, all anomalies were automatically fitted to a large vertically-dipping plate model. The rectangular vertical plate was chosen to best represent the majority of bedrock conductors in the survey environment. The response of such a model is described concisely by the response nomogram shown in Figure 1. Minimum amplitude thresholds were set for each channel to avoid fitting noise to the nomogram. The thresholds used follow:

Channel	Amplitude (ppm)
1	25
2	25
3	25
4	25
5	20
6	20
7	20
8	20
9	15
10	15
11	15
12	15

When four or more channels exceeded the thresholds, a least-squares fit of the anomaly decay to the plate nomogram resulted in a conductance and depth-to-source. Subtracting the altitude of the aircraft from the depth-to-source gives the approximate depth below surface of the conductor.

It should be noted that the parameters derived from such a model fitting are only as good as the assumption that the anomaly is due to a vertical plate-like conductor. Sources of a different shape or attitude would have modified decay characteristics.

In particular, in the case of a dipping plate which produces two anomaly peaks, a scheme has been arrived at which allows the use of a vertical plate nomogram to derive the parameters of the dipping plate. The ratio of the major to minor peak amplitudes allows the interpreter to deduce the dip from Figure 2. At the same time, application of the corresponding amplitude correction factor to the major peak results in normalization of the major peak amplitude to a vertically-dipping plate response.

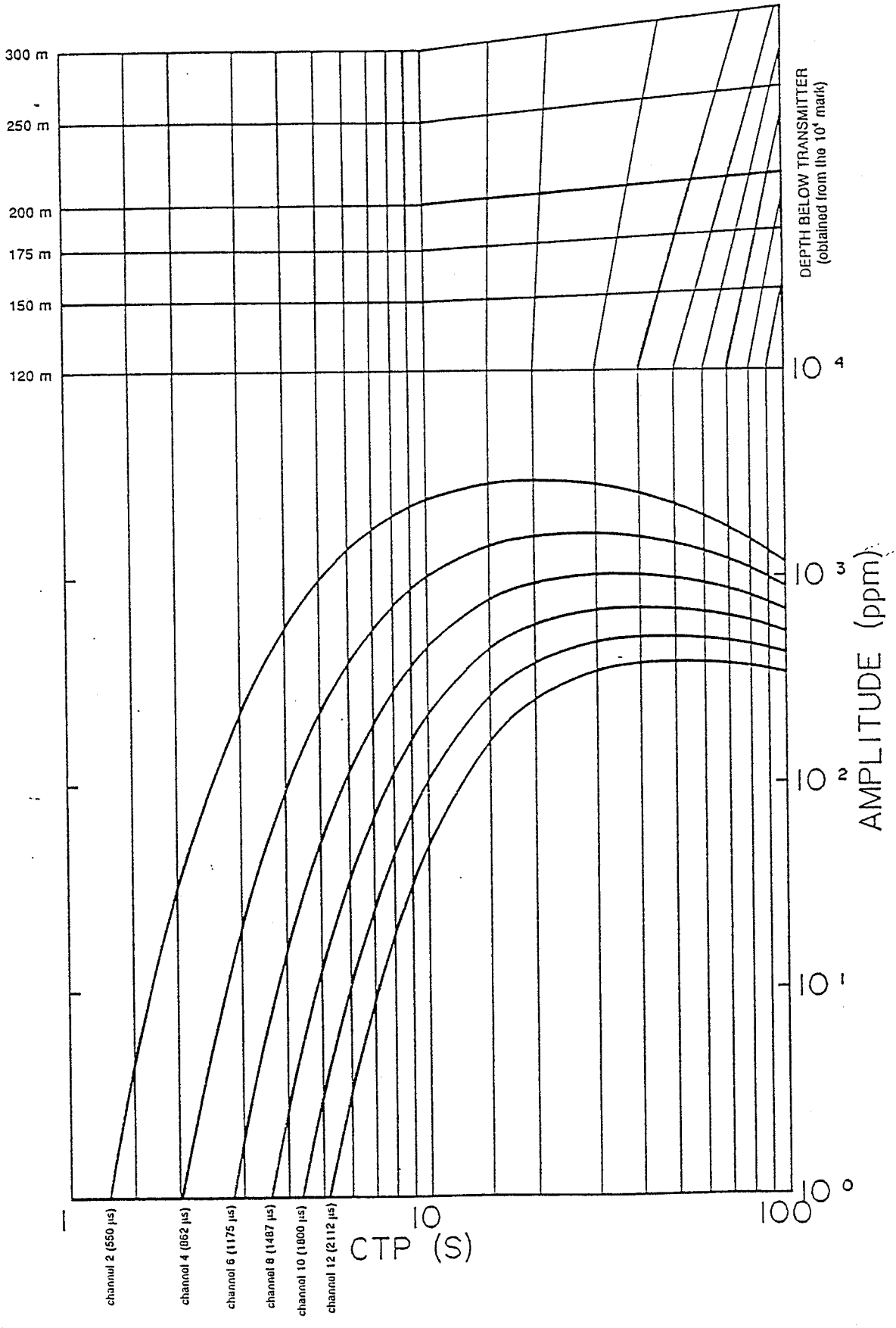
Figure 1 - **GEOTEM VERTICAL PLATE NOMOGRAM**

SYSTEM CONFIGURATION

- *Pulse repetition rate = 150 Hz*
- *Pulse width = 1070 µsec*
- *Height of Tx above ground = 120 m*
- *Rx-Tx horizontal separation = 123 m*
- *Rx-Tx vertical separation = 56 m*
- *Rx axis is horizontal*

PLATE PARAMETERS

- *Length = 600 m*
- *Depth extent = 300 m*
- *Dip = 90°*
- *Strike = 90°*



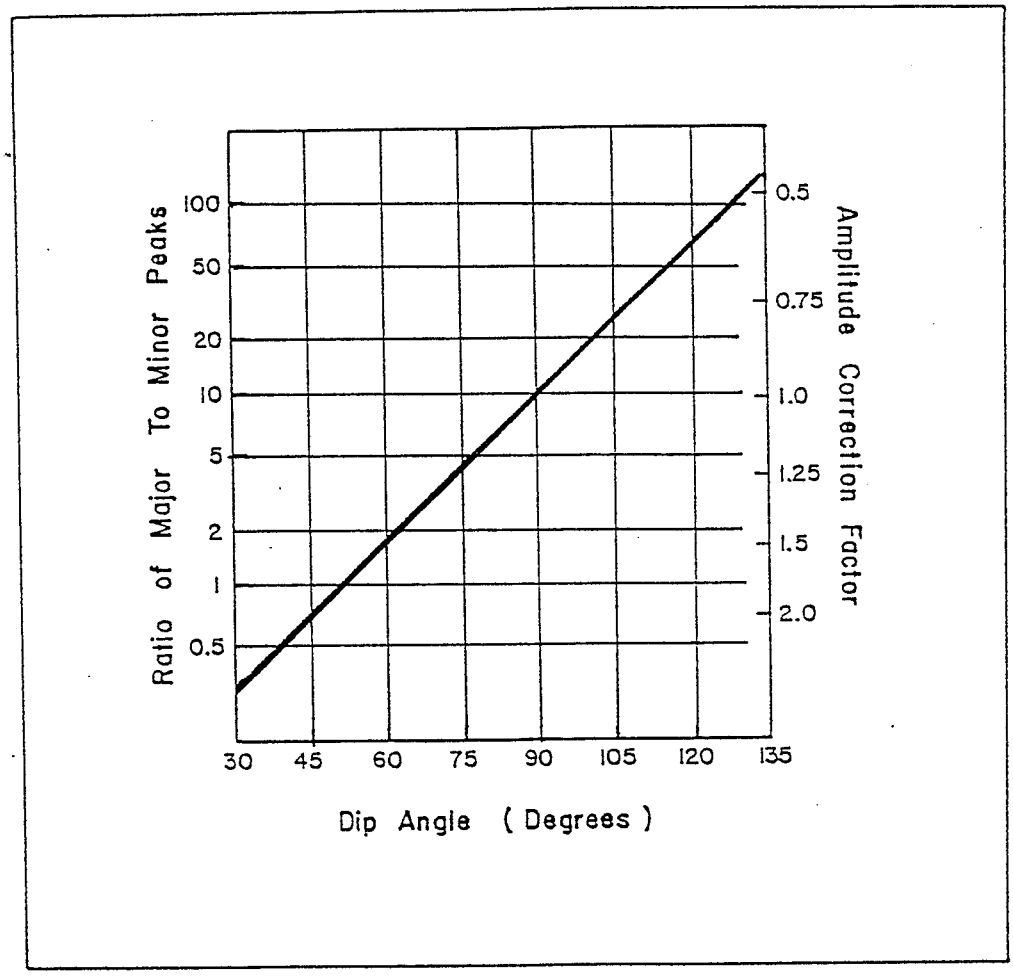


Figure 2. Estimation of dip and amplitude normalization for a dipping plate model.

Appendix E
Note on Calculation of Apparent Conductivity

CONVERSION OF GEOTEM® IN-PULSE CHANNEL 20 AMPLITUDE DATA TO APPARENT CONDUCTIVITY

A.P. Annan, M. O'Connell, D. Beattie
Geoterrex, Ottawa
July 1992

For any EM system, at low conductivities:

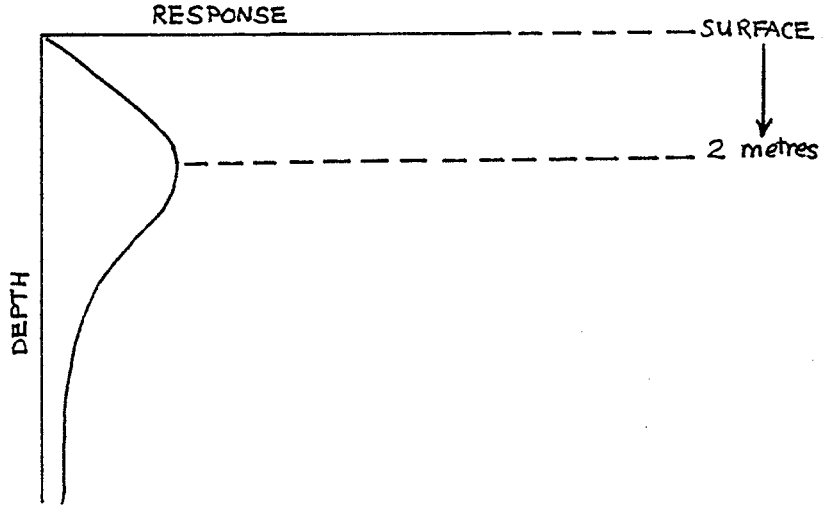
$$A \propto K\mu\sigma\emptyset[G]$$

where A = response amplitude
K = constant
μ = permeability
σ = conductivity
$\emptyset$ = effective frequency
G = geometry term

For systems such as the Geonics EM31,

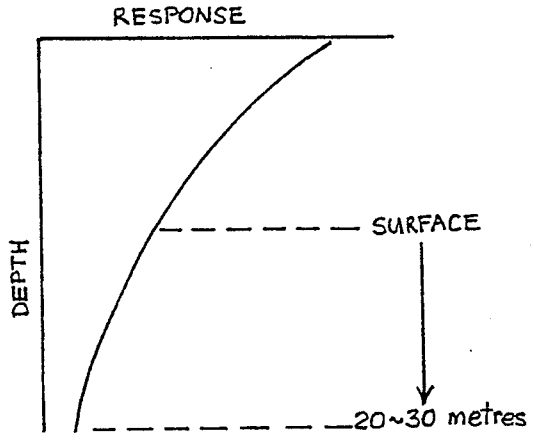
$A = K\sigma$ as $\mu \approx \mu_o$ and all other terms are known

For Geonics EM31, the system response vs. depth can be represented by the following curve:



with the final measured σ determined by integrating the contributions from all depths.

For GEOTEM®, the system response vs. depth can be represented by the following curve:

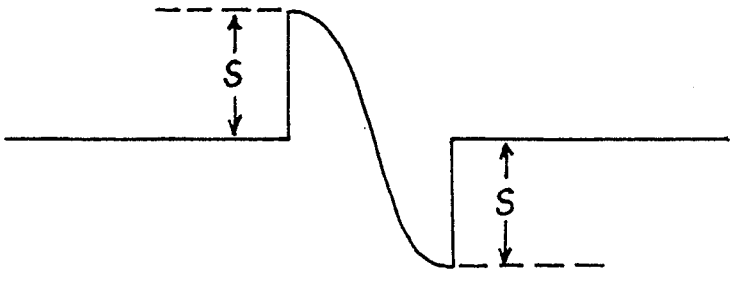


∴ The measured conductivities from GEOTEM® have greater contributions from greater depths, also the "footprint" is much larger so a much larger area is being sampled.

With a time-domain system, like GEOTEM®, having a transmitter waveform of the type:



The receiver will measure:



where S will be $\propto\sigma$ (after the Tx effects are removed) at low conductivities. With channel 20, we are effectively measuring the value S.

If we disregard altitude effects, we can say that:

$$\sigma_a^1 = A_{20}\ x\ \frac{10^{-3}}{4.5\ \epsilon}$$

where ϵ = constant dependent on coil bandwidth, filtering, etc.

Including the altitude effects, the relationship becomes:

$$\sigma_a^2 = \sigma_a^1\ x\ 0.167\ x\ \left\{1-\left[\frac{2h-z}{(x^2+(2h-z)^2)^{1/2}}\right]\right\}^{-1}$$

where h = Tx height above ground
z = Tx-Rx vertical separation
x = Tx-Rx horizontal separation

If x = 120 m, then z = 60 m

and $\sigma^2_a = \sigma^1$ for h = 120 m
$\sigma^2_a = 0.766\ \sigma^1_a$ for h = 105 m
$\sigma^2_a = 1.28\ \sigma^1_a$ for h = 135 m
$\therefore$ Altitude dependence is not a greatly significant variation.

The information displayed in the following figures represents the data used to approximate the value of ϵ.

The ground conductivity values were collected by G. Palacky of the GSC with a Geonics EM31 instrument, with the approximate position of each station plotted on a 1:50,000 preliminary copy of the channel 20 amplitude data. These station locations were digitized to get series of UTM coordinate reference points.

We can expect some scatter of the data due to the lack of precision in locating the ground stations and the likelihood that the GEOTEM® measurements are not from the exact same locations. The different penetration depths and system footprints will also contribute to the scatter.

Conclusion: The conversion of channel 20 amplitude data (ppm) to apparent conductivity (mS.m) was obtained by simply dividing by a factor of 640 (equal to the best fit slope between the two data sets).

A refinement on this conversion would be to include a term to correct for altitude variations, but the measurable effect of this would likely be slight.

FIGURES

1. Ground conductivity measurements vs. station number.

2. Radar altimeter readings vs. station number.

3. Channel 20 amplitude vs. station number.

4. EM20 amplitude (ppm vs. ground σ values.

   best fit slope = 640 ppm/mS/m

$$\sigma_a = \frac{10^{-3}A}{4.5\ \epsilon} \gg \frac{10^{-3}}{4.5\ \epsilon} = \frac{1}{640}$$

   so $\epsilon = 0.142$

5. Channel 20 vs. altitude for low ppm range.

6. Channel 20 vs. altitude for mid ppm range.

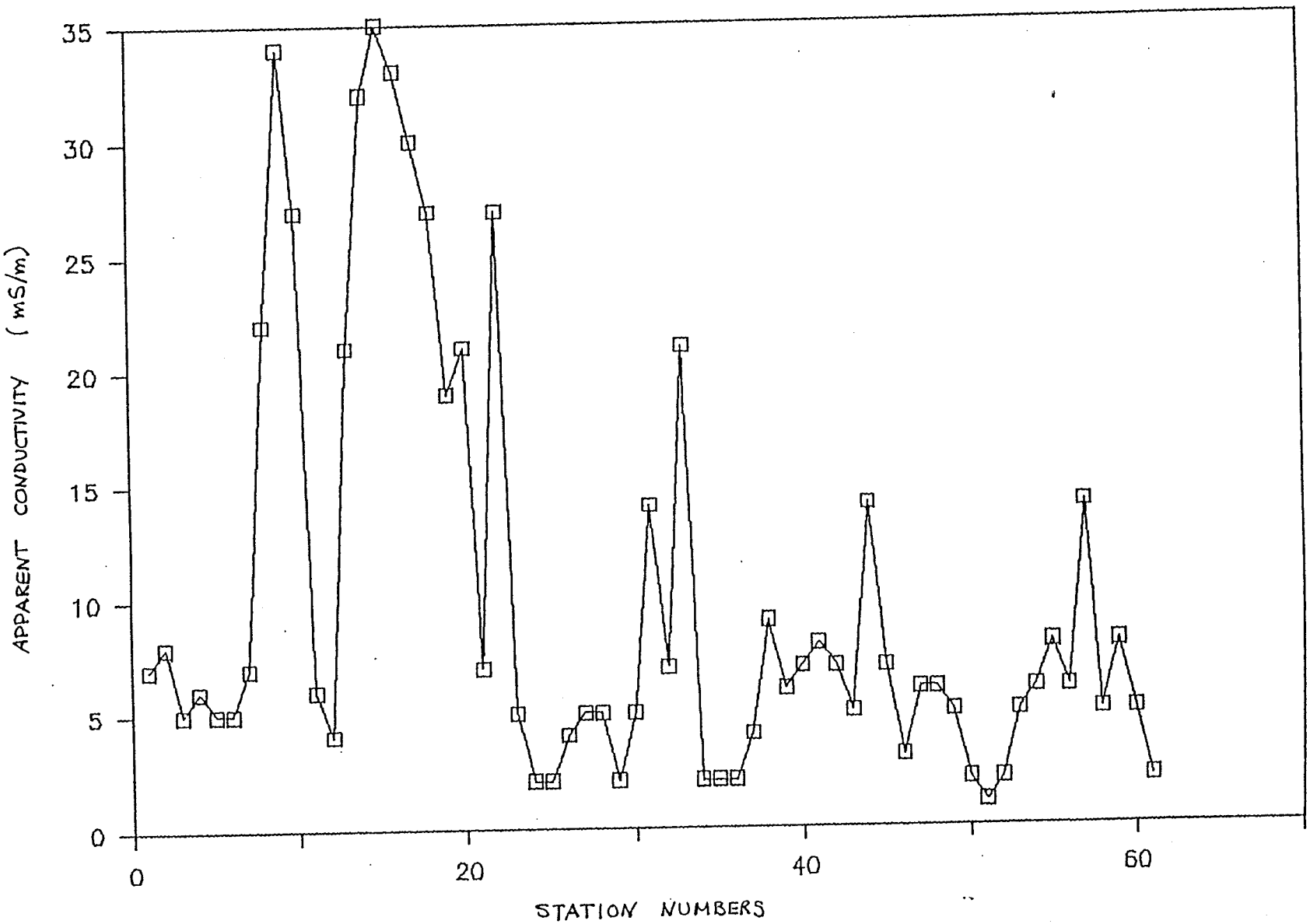
7. Channel 20 vs. altitude for high ppm range.

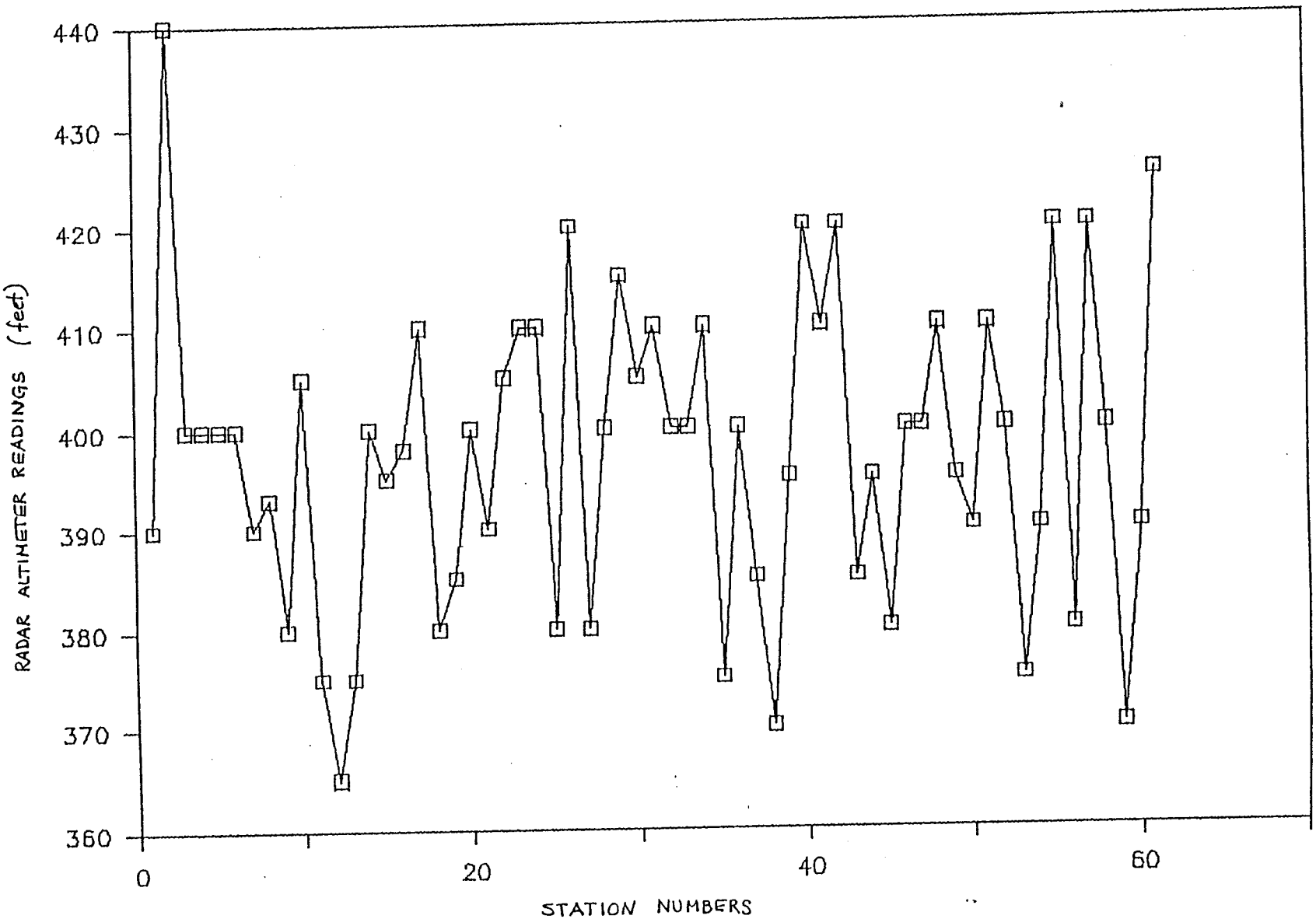
8. Mean ppm/σ vs. σ

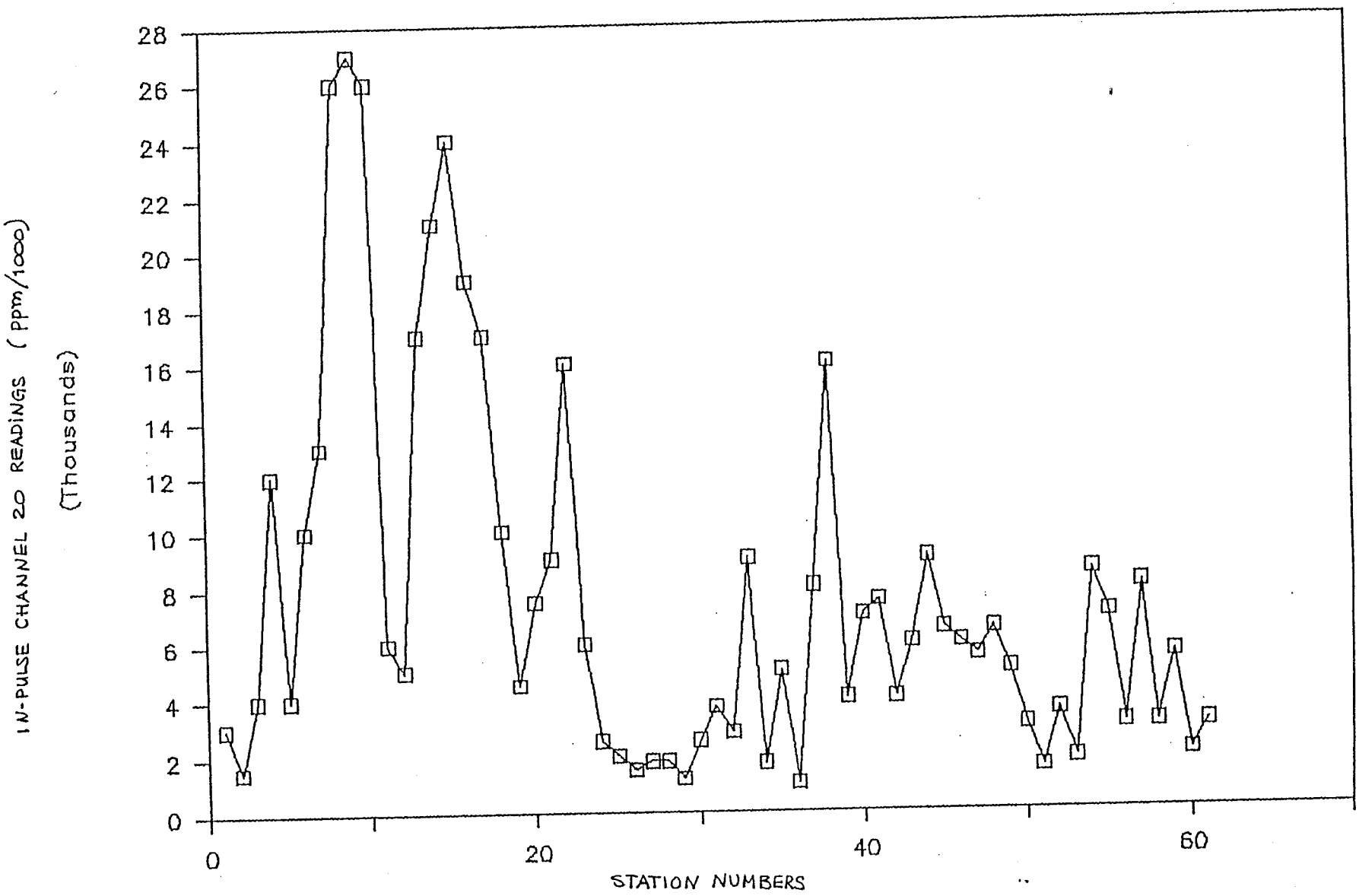
   Displays lack of linearity which again is a reflection of the inherent differences between the penetration depths and system footprints between the EM31 and GEOTEM® and the differences in the sample locations.

conductivity vs stn.

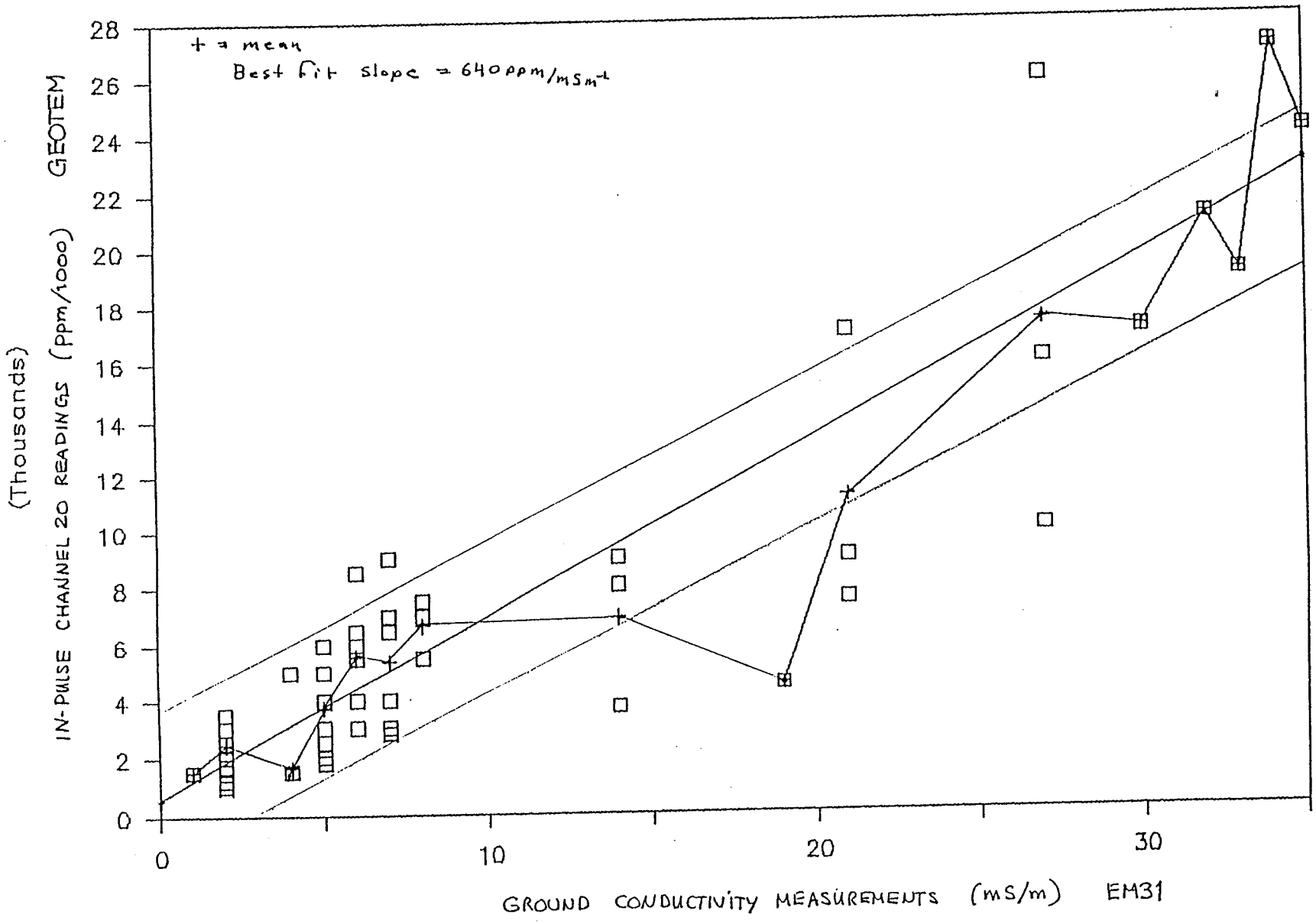
(From EM31 ground readings)



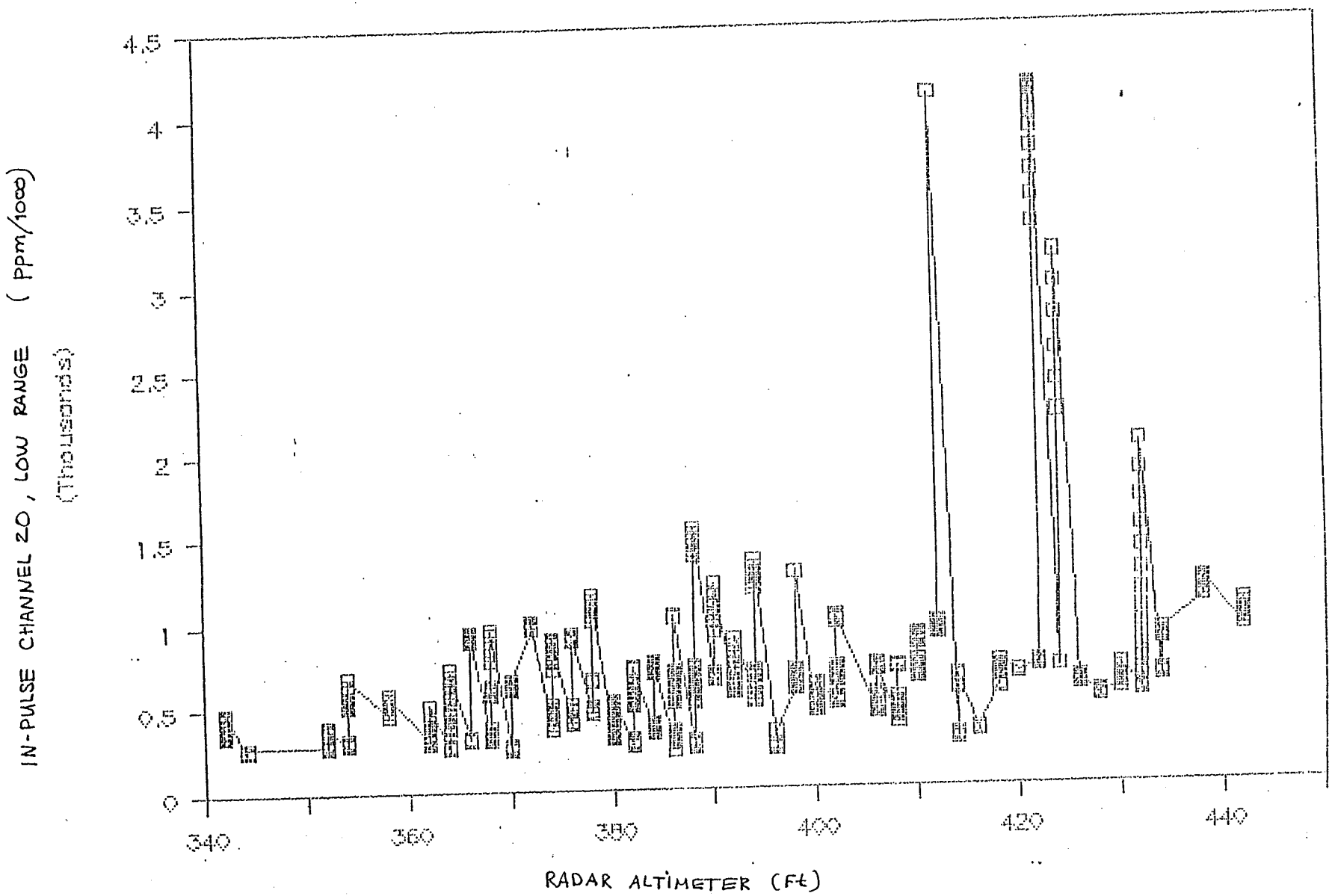

radar vs stn
RADAR ALTIMETER READINGS (feet)
440
430
420
410
400
390
380
370
360
0
20
40
60
STATION NUMBERS


ch20 vs stn
IN-PULSE CHANNEL 20 READINGS (ppm/1000)
(Thousands)
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
0
20
40
60
STATION NUMBERS

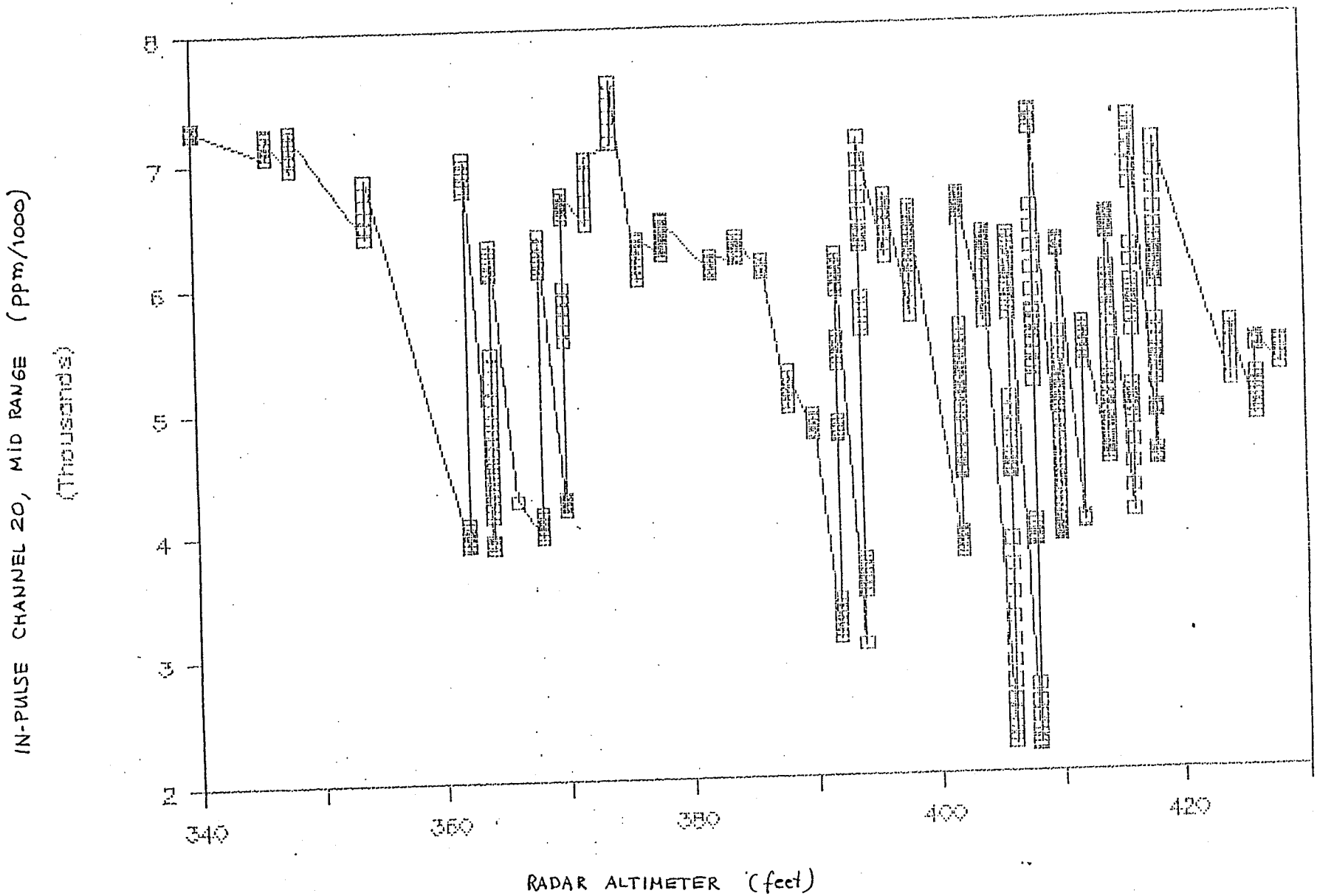
PPM VS SIGMA

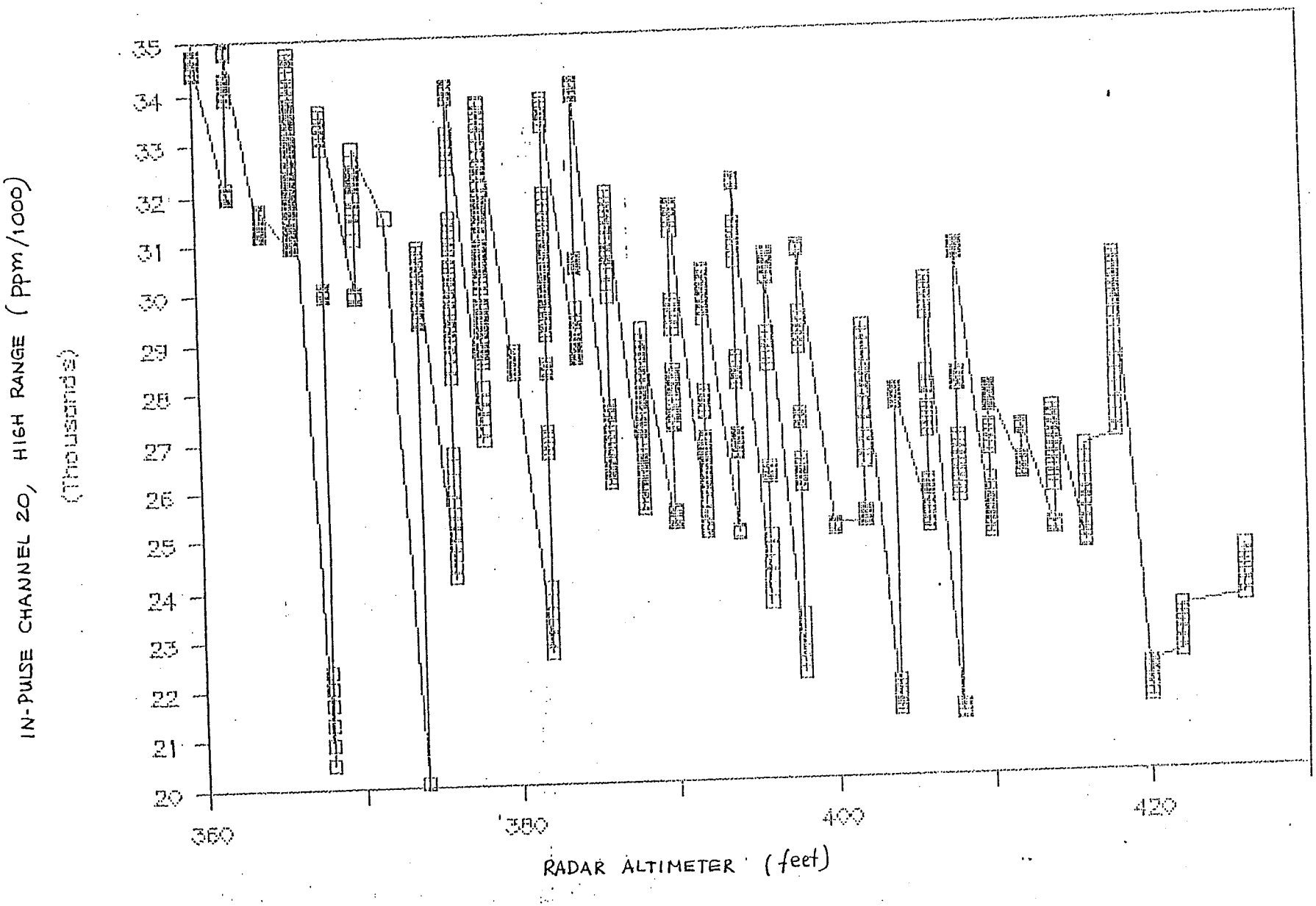

+ = mean
Best fit slope = 640 ppm/mSm⁻¹
IN-PULSE CHANNEL 20 READINGS (ppm/1000) GEOTEM
(Thousands)
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
0
10
20
30
GROUND CONDUCTIVITY MEASUREMENTS (mS/m) EM31

CH2O ppm vs ALT ft

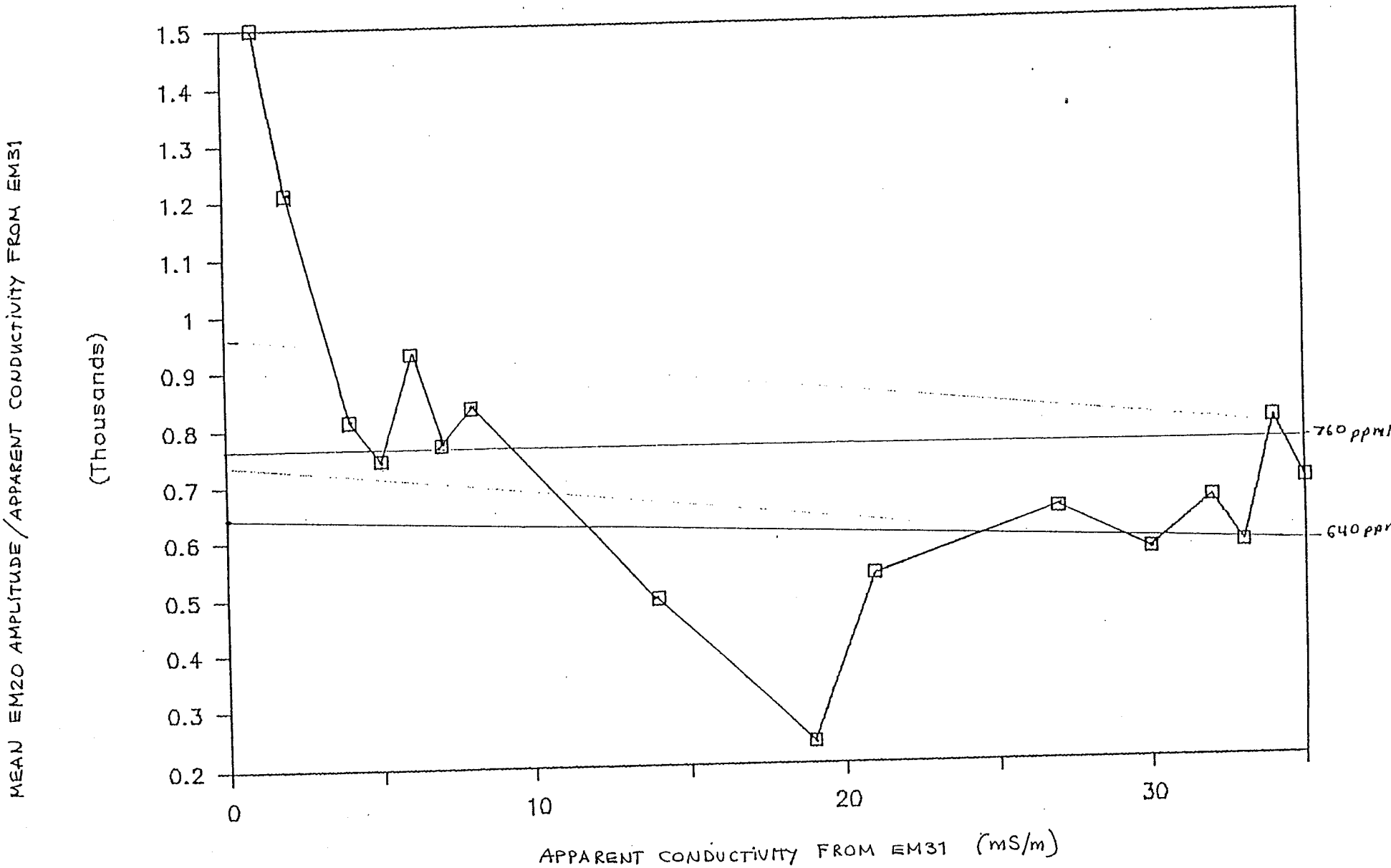


CH20 ppm vs ALT ft




CH20 ppm vs ALT ft
IN-PULSE CHANNEL 20, HIGH RANGE (ppm/1000)
(Thousands)
35
34
33
32
31
30
29
28
27
26
25
24
23
22
21
20
360
380
400
420
RADAR ALTIMETER (feet)

MEAN PPM/SIGMA VS SIGMA



Appendix F
GEOTEM® Interpretation Notes

GEOTEM[R1] INTERPRETATION

I. INTRODUCTION

The basis of the transient electromagnetic (EM) geophysical surveying technique relies on the premise that changes in the primary EM field produced in the transmitting loop will result in eddy currents being generated in any conductors in the ground. The eddy currents then decay to produce a secondary EM field which may be sensed as a voltage in the receiver coil.

GEOTEM (**GEO**terrex **T**ransient **E**lectro**M**agnetic system) is an airborne transient (or time-domain) towed-bird EM system incorporating a high-speed digital receiver which records the secondary field response with a high degree of accuracy. Most often the total magnetic field is recorded concurrently.

Although the approach to GEOTEM interpretation varies from one survey to another depending on the type of data presentation, objectives and local conditions, the following generalizations may provide the reader with some helpful background information.

The main purpose of the interpretation is to determine the probable origin of the conductors detected during the survey and to suggest recommendations for further exploration. This is possible through an objective analysis of all characteristics of the different types of conductors and associated magnetic anomalies, if any. If possible the airborne results are compared to other available data. A certitude is seldom reached, but a high probability is achieved in identifying the conductive causes in most cases. One of the most difficult problems is usually the differentiation between surface conductors and bedrock conductors.

II. TYPES OF CONDUCTORS

A. Bedrock Conductors

The different types of bedrock conductors normally encountered are the following:

1. Graphites. Graphitic horizons (including a large variety of carbonaceous rocks) occur in sedimentary formations of the Precambrian as well as in volcanic tuffs, often concentrated in shear zones. They correspond generally to long, multiple conductors lying in parallel bands. They have no magnetic expression unless associated with pyrrhotite or magnetite. Their conductivity is variable but generally high.

---

[1] GEOTEM[R]: Registered Trade Mark of Geoterrex Limited.

2. Massive sulphides. Massive sulphide deposits usually manifest themselves as short conductors of high conductivity, often with a coincident magnetic anomaly. Some massive sulphides, however, are not magnetic, others are not very conductive (discontinuous mineralization), and some may be located among formational conductors so that one must not be too rigid in applying the selection criteria.

   In addition, there are syngenetic sulphides whose conductive pattern may be similar to that of graphitic horizons but these are generally not as prevalent as graphites.

3. Magnetite and some serpentinized ultrabasics. These rocks are conductive and very magnetic.

4. Manganese oxides. This mineralization may give rise to a weak EM response.

B. Surficial Conductors

1. Beds of clay and alluvium, some swamps, and brackish ground water are usually poorly conductive to moderately conductive.

2. Lateritic formations, residual soils and the weathered layer of the bedrock may cause surface anomalous zones, the conductivity of which is generally low to medium but can occasionally be high. Their presence is often related to the underlying bedrock.

C. Cultural Conductors (Man-Made)

1. Power lines. These frequently, but not always, produce a conductive type of response on the GEOTEM record. In the case of direct radiation of its field, a power line is easily recognized by a GEOTEM anomaly which exhibits phase changes between different channels. In the case of a grounded wire, or steel pylon, the anomaly may look very much like a bedrock conductor.

2. Grounded fences or pipelines. These will invariably produce responses much like a bedrock conductor. Whenever they cannot be identified positively, a ground check is recommended.

3. General culture. Other localized sources such as certain buildings, bridges, irrigation systems, tailings ponds etc., may produce GEOTEM anomalies. Their instances, however, are rare and often they can be identified on the visual path recovery system.

III. ANALYSIS OF THE CONDUCTORS

The apparent conductivity alone is not generally a decisive criterion in the analysis of a conductor. In particular, one should note:

- its shape and size,
- all local variations of characteristics within a conductive zone,
- any associated geophysical parameter (e.g. magnetics),
- the geological environment,
- the structural context, and
- the pattern of surrounding conductors.

The first objective of the interpretation is to classify each conductive zone according to one of the three categories which best defines its probable origin. The categories are cultural, surficial and bedrock. A second objective is to assign to each zone a priority rating as to its potential as an economic prospect.

A. Cultural Conductors

The majority of cultural anomalies occur along roads and are accompanied by a response on the power line monitor. (This monitor is set to 50 or 60 Hz, depending on the local power grid.) Power lines are the most common source of the anomalies and many are recognized immediately by virtue of phase reversals or an abnormal rate of decay. A certain number yield normal GEOTEM anomalies which could be mistaken for bedrock responses. There are also some power lines which have no GEOTEM response whatsoever.

The power line monitor, of course, is of great assistance in identifying cultural anomalies of this type. It is important to note, however, that geological conductors in the vicinity of power lines may exhibit a weak response on the monitor because of current induction via the earth.

Fences, pipelines, communication lines, railways and other man-made conductors can give rise to GEOTEM responses, the strength of which will depend on the grounding of these objects.

Another facet of this analysis is the line-to-line comparison of anomaly character along suspected man-made conductors. In general, the amplitude, the rate of decay, and the anomaly width should not vary a great deal along any one conductor, except for the change in amplitude related to terrain clearance variation. A marked departure from the average response character along any given feature gives rise to the possibility of a second conductor.

In most cases a visual examination of the site will suffice to verify the presence of a man-made conductor. If a second conductor is suspected the ground check is more difficult to accomplish. The object would be to determine if there is (i) a change in the man-made construction, (ii) a difference in the grounding conditions, (iii) a second cultural source, or (iv) if there is, indeed, a geological conductor in addition to the known man-made source.

B. Surficial Conductors

This term is used for geological conductors in the overburden, either glacial or residual in origin, and in the weathered layer of the bedrock. Most surficial conductors are probably caused by clay minerals. In some environments the presence of salts will contribute to the conductivity. Other possible electrolytic conductors are residual soils, swamps, brackish ground water and alluvium such as lake or river-bottom deposits, flood plains and estuaries.

Normally, most surficial materials have low to intermediate conductivity so they are not easily mistaken for highly conductive bedrock features. Also, many of them are wide and their anomaly shapes are typical of broad horizontal sheets.

When surficial conductivity is high it is usually still possible to distinguish between a horizontal plate (more likely to be surficial material) and a vertical body (more likely to be a bedrock source) thanks to the asymmetry of the GEOTEM responses observed at the edges of a broad conductor when flying adjacent lines in opposite directions. The configuration of the system is such that the response recorded at the leading edge is more pronounced than that registered at the trailing edge. Figure 1 illustrates the "edge effect" and the resulting conductive pattern in plan view. In practice there are many variations on this very diagnostic phenomenon.

One of the more ambiguous situations as to the true source of the response is when surface conductivity is related to bedrock lithology as for example, surface alteration of an underlying bedrock unit. At times, it is also difficult to distinguish between a weak conductor within the bedrock (e.g. near-massive sulphides) and a surficial source.

In the search for massive sulphides or other bedrock targets, surficial conductivity is generally considered as interference but there are situations where the interpretation of surficial-type conductors is the primary goal. When soils, weathered or altered products are conductive, and in-situ, the GEOTEM responses are a very useful aid to geologic mapping. Shears and faults are often identified by weak, usually narrow, anomalies.

Analysis of surficial conductivity can be used in the exploration for such features as lignite deposits, kimberlites, paleochannels and ground water. In coastal or arid areas, surficial responses may serve to define the limits of fresh, brackish and salty water.

EDGE EFFECT

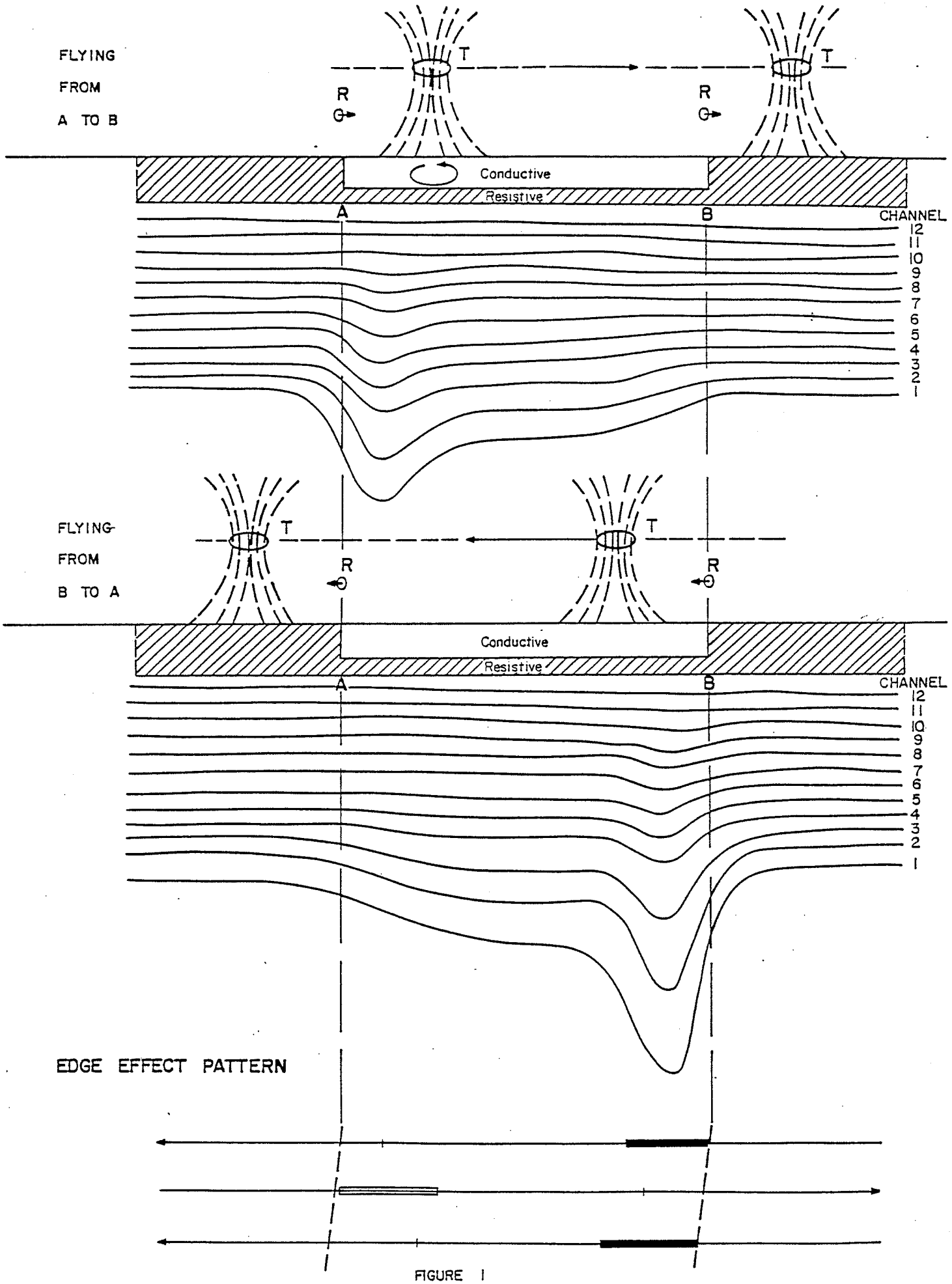


FIGURE 1

C. Bedrock Conductors

This category comprises those anomalies which cannot be classified according to the criteria established for cultural and surficial responses. It is difficult to assign a universal set of values which typify bedrock conductivity because any individual zone or anomaly might exhibit some, but not all, of these values and still be a bedrock conductor. The following criteria are considered indicative of a bedrock conductor:

1. An intermediate to high conductivity identified by a response with slow decay, with deflections most often present in the later channels.

2. The anomaly should be narrow, relatively symmetrical, with a well-defined peak.

3. There should be no serious displacement of anomaly position or change in anomaly shape (other than mirror image) with respect to flight direction, except in the case of non-vertical dipping bodies. The alternating character of the response as a result of line direction can be diagnostic of conductor geometry. Figures 2 to 6 illustrate anomalies associated with different target models.

4. A small to intermediate amplitude. Large amplitudes are normally associated with surficial conductors. The amplitude varies according to the depth of the source.

5. A degree of continuity of the EM characteristics across several lines.

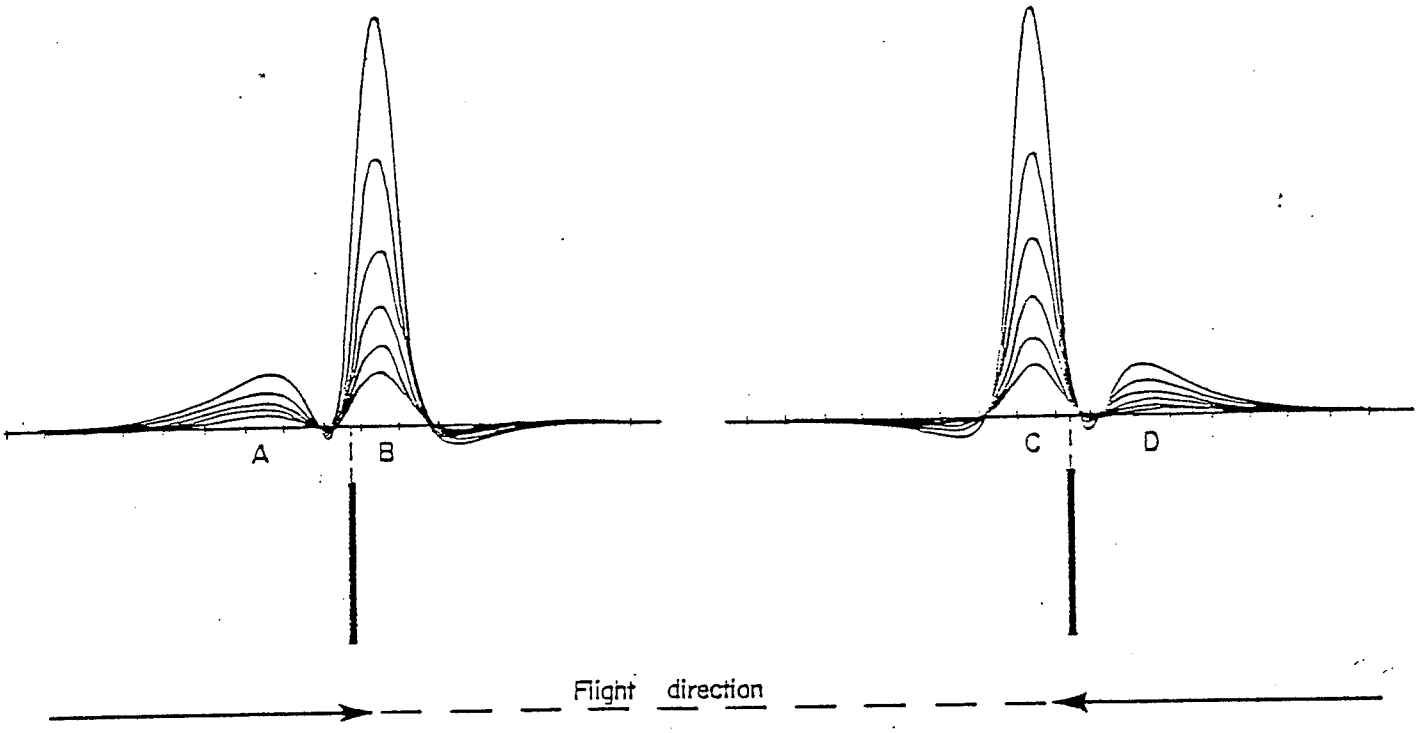
6. An associated magnetic response of similar dimensions. One should note, however, that those rocks which weather to produce a conductive upper layer will possess this magnetic association. In the absence of one or more of the characteristics defined in 1, 2, 3 and 4, the related magnetic response cannot be considered significant.

Most obvious bedrock conductors occur in long, relatively monotonous, sometimes multiple zones following formational strike. Graphitic material is usually the most probable source. Massive syngenetic sulphides extending for many kilometres are known in nature but, in general, they are not common. Long formational structures associated with a strong magnetic expression may be indicative of banded iron formations.

A bedrock conductor reflecting the presence of a massive sulphide would normally exhibit the following characteristics:

- a high conductivity,
- a good anomaly shape (narrow and well-defined peak),
- a small to intermediate amplitude,
- an isolated setting,

THE VERTICAL PLATE RESPONSE



ANOMALY MAP PRESENTATION (no lag applied)

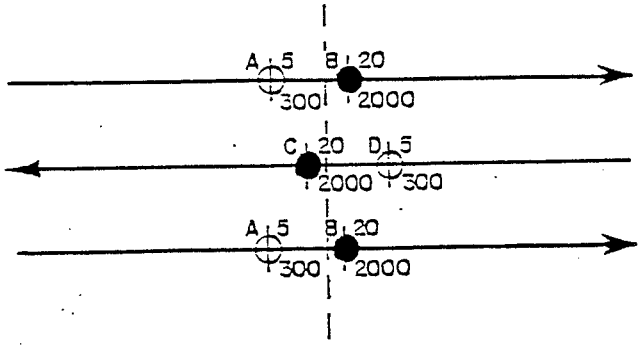
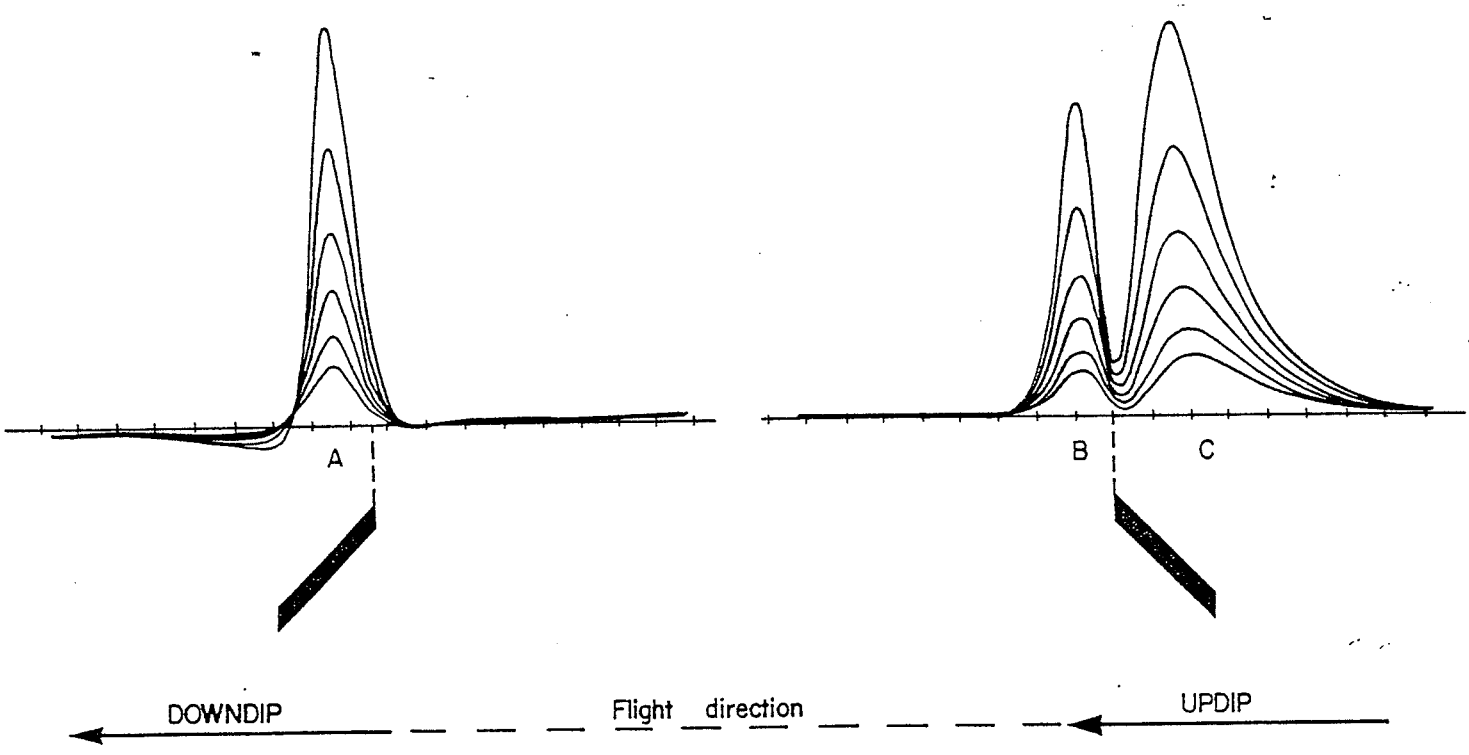


Figure 2

THE DIPPING PLATE RESPONSE



ANOMALY MAP PRESENTATION (no lag applied)

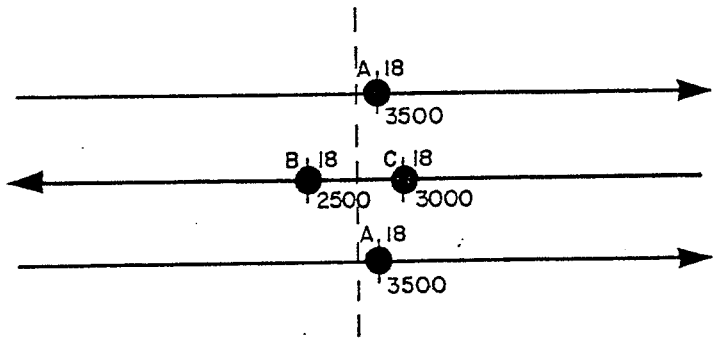
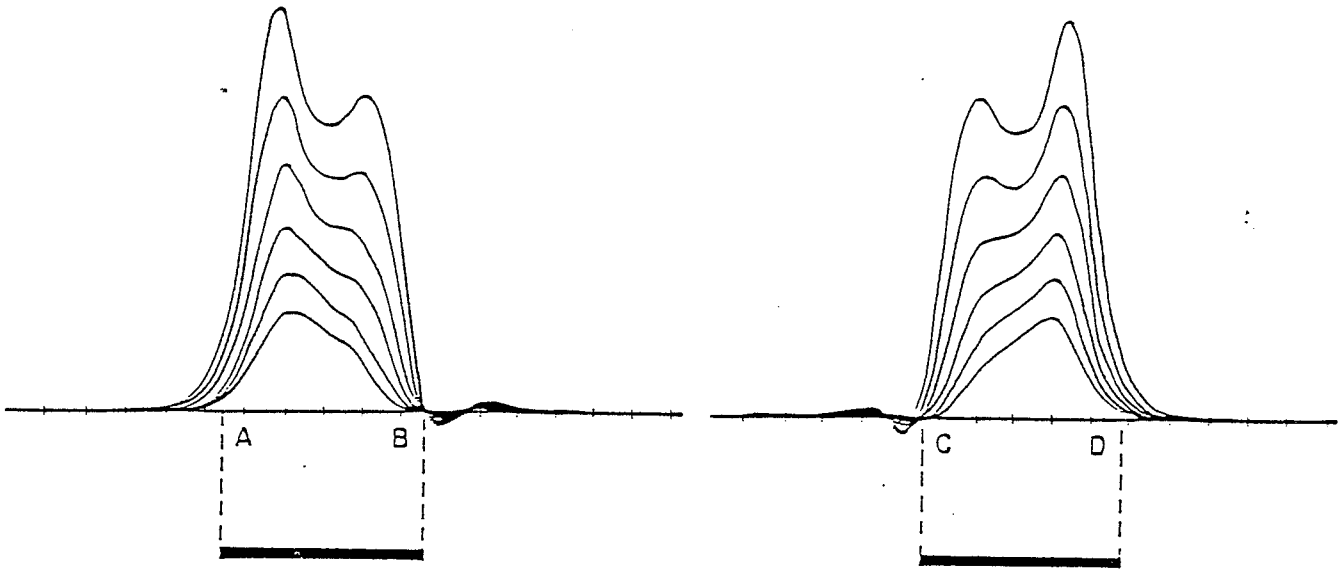
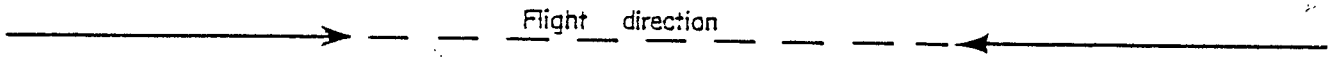


Figure 3

THE HORIZONTAL PLATE RESPONSE





ANOMALY MAP PRESENTATION (no lag applied)

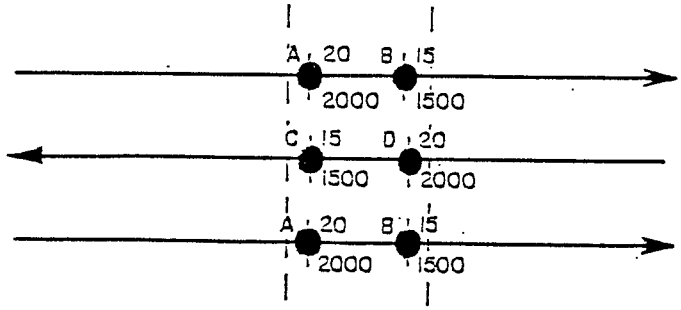
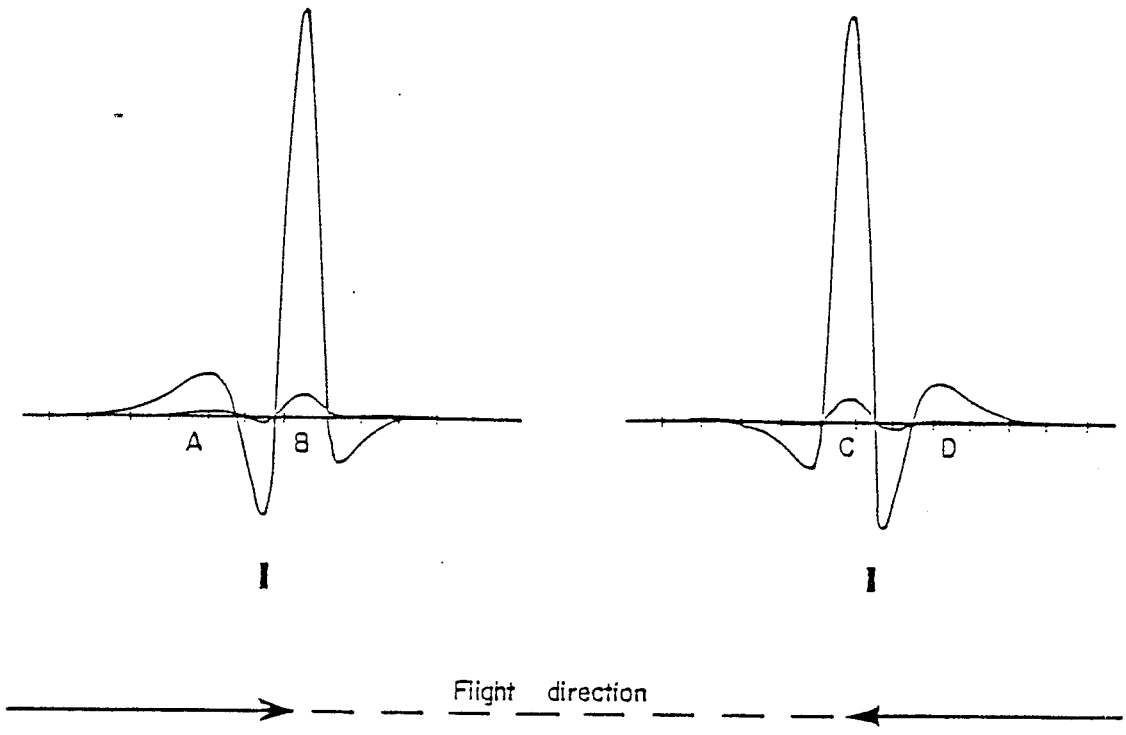


Figure 4

THE VERTICAL RIBBON RESPONSE



ANOMALY MAP PRESENTATION (no lag applied)

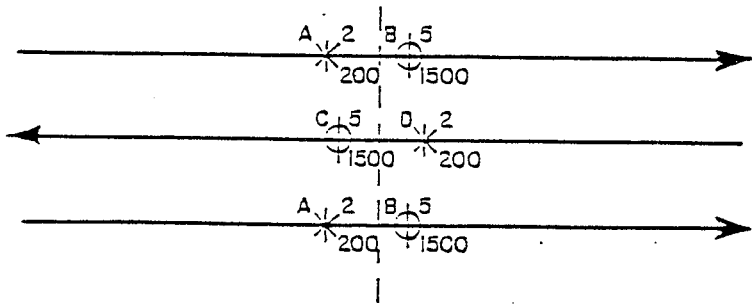
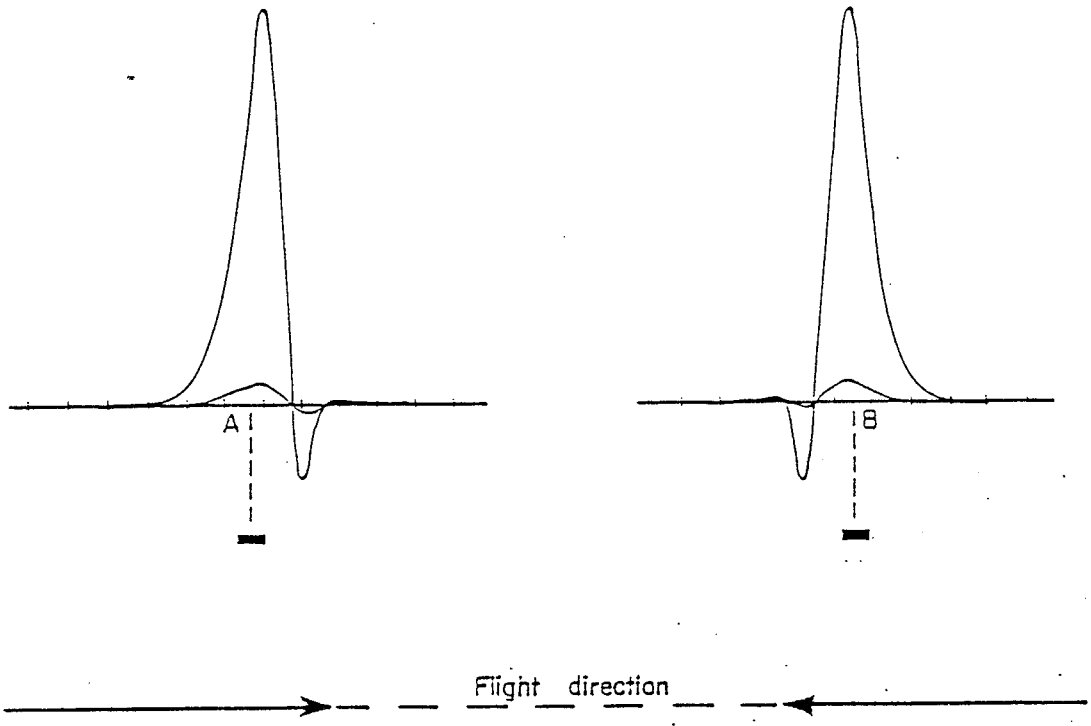


Figure 5

THE HORIZONTAL RIBBON RESPONSE



ANOMALY MAP PRESENTATION (no lag applied)

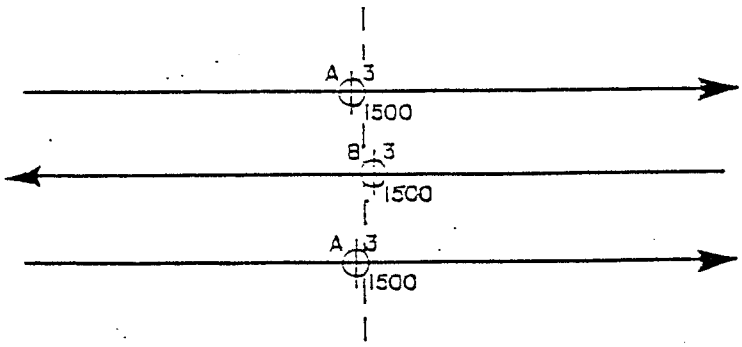


Figure 6

- a short strike length (in general, not exceeding one kilometre), and
- preferably, with a localized magnetic anomaly of matching dimensions.

The selection of targets from within extensive (formational) belts is much more difficult than in the case of isolated conductors. Local variations in the EM characteristics, such as in the amplitude, decay, shape etc., can be used as evidence for a relatively localized occurrence. Changes in the character of the EM responses, however, may be simply reflecting differences in the conductive formations themselves rather than indicating the presence of massive sulphides and, for this reason, the degree of confidence is reduced.

Another useful guide for identifying localized variations within formational conductors is to examine the magnetic data compiled as isomagnetic contours. Further study of the magnetic data can reveal the presence of faults, contacts and other features which, in turn, help define areas of potential economic interest.

Finally, once ground investigations begin, it must be remembered that the continual comparison of ground knowledge to the airborne information is an essential step in maximizing the usefulness of the GEOTEM data.

Appendix G
Digital Archive Description

ARCHIVE DATA TAPES

General Specifications

All archive tapes are:

- fully IBM compatible,
- 2400' or 1200',
- no label, ASCII,
- 9-track, formatted,
- 1600 bpi,
- block size of 5040 bytes,
- record length of 80 bytes.

Only the data header contains alphanumeric data.

The data is ordered by survey block. If any block or area requires more than one tape, the second tape is not continued in the middle of a flight line.

Each survey block contains the following files:

Line Archive	File N°1	Block header
	File N°2	Final data for each recorded point as it exists immediately prior to gridding (using appropriate null values)
Grid Archive	File N°1	Gridded data used to produce the final contour and colour interval maps
	File N°N	1 map per file

The gridded data set includes one file each of:

- total field,
- total field with IGRF removed,
- apparent conductivity,
- apparent conductance of overburden,
- apparent conductance of bedrock conductors.

Geographic coordinates in decimal of degrees are used for all positional coordinates. The Universal Transverse Mercator projection is used for creating the gridded data. The UTM zone is the same as that used on the particular topographic maps supplied for the survey area. All longitudes west of Greenwich are represented as negative degrees. Each survey grid origin is a multiple of the grid interval from the Central Meridian and 0° latitude.

Detail Specifications

Digital Line Archive for General Survey Data

Block header (File N°1)

Record N°1: Survey block number, number of sheets, GSC project number, Contractor's project number (Format (A10, I10, 2A10, 40X)) (right justified)

Record N°2 NTS Map Number (Format (A10, 70X))

Record N°3 & 4 Contain the latitude and longitude in decimal degrees consecutively, of the four map corners. (Corner 1 is the lower left corner, increasing clockwise.) (Format (4E20.10))

Records 2 to 4 are repeated for each map in the survey block on records N°5 to N^{th}.

Individual Line Segments (File N°2)

A line header identifies each line segment. It contains:

- flight number,
- line and segment number (e.g., line 1, segment 0=10, line 1, segment 1=11),
- direction code,
- traverse/control line code,
- start time,
- end time.

(Format (2I10, 10X, 2I10, 2F10.2, 10X))

Direction Codes 1 = North
2 = East
3 = South
4 = West

Traverse Code = 0
Control Line Code = 1

Data records for each recorded point contains the following in order listed:

Record #1

NAME	CONTENTS	UNITS	FORMAT	DEFAULT VALUE ADDED
TIME	Time	seconds	F10.2	N/A
LAT	Latitude coordinate	decimal degrees	F10.5	5000
LONG	Longitude coordinate	decimal degrees	F10.5	5000
MAGRAW	Edited raw total field	nT	F10.2	500,000
MAGLEV	Levelled total field	nT	F10.2	500,000
RALT	Radar altimeter	cm	F10.2	50,000
BALT	Barometric altimeter	cm	F10.2	50,000
DIURNAL 1	Edited ground magnetics	nT	F10.2	500,000

Record #2

NAME	CONTENTS	UNITS	FORMAT	NULL VALUE
DC	Decay constant	µs	F10.4	50,000
CONDO	Overburden conductivity	mS/m	F10.4	50,000
CONDB	Bedrock conductance	S	F10.4	50,000
PRIMI	Primary field intensity	%	F10.2	50,000
PL	Powerline monitor	mV	F10.2	50,000
EMW	EM noise monitor Sferics monitor	ppm	F10.2	50,000
EM 1	EM channel 1	ppm	F10.2	50,000
EM 2	EM channel 2	ppm	F10.2	50,000

Record #3

NAME	CONTENTS	UNITS	FORMAT	NULL VALUE
EM 3	EM channel 3	ppm	F10.2	50,000
EM 4	EM channel 4	ppm	F10.2	50,000
EM 5	EM channel 5	ppm	F10.2	50,000
EM 6	EM channel 6	ppm	F10.2	50,000
EM 7	EM channel 7	ppm	F10.2	50,000
EM 8	EM channel 8	ppm	F10.2	50,000
EM 9	EM channel 9	ppm	F10.2	50,000
EM 10	EM channel 10	ppm	F10.2	50,000

Record #4

NAME	CONTENTS	UNITS	FORMAT	NULL VALUE
EM 11	EM channel 11	ppm	F10.2	50,000
EM 12	EM channel 12	ppm	F10.2	50,000
EM3C	EM channel 3 culture edited	ppm	F10.2	50,000
DCED	Decay constant culture edited	μs	F10.4	50,000
INP	In-pulse channel 20	ppm	F10.2	50,000
ANOMALY L	Anomaly letter	alphabetic	A3	blank
DIP	Dip	degrees	I3	blank
DEPTH	Depth	metres	I4	blank
CONDV	Conductance	S	F10.4	blank
INTERP	Interpretation code	type	A3	blank
STRENGTH	Strength of response	channels	I3	blank
BLANK	Blank	blank	4X	blank

The end of data for each line is denoted by four (4) zero record in the same format as the data record and followed by an END OF FILE on the last line. Each new line segment starts with a new 5040 byte block for easier access.

Each field of data in the digital line archive is assigned a specific default value which is added to any value which is not used in the gridding process.

Digital line archive tape for raw EM data

In addition to the Digital Line Archive tape in ASCII code which contains data from various instrument outputs, a separate ASCII archive tape containing scans of all recorded raw EM channels was also produced. This data includes beginning and end flight EM base level calibrations out of conductive ground effect.

Grid archive

The data is ordered by map sheet, sorted by columns (south to north).

For any map sheet the number of grid values per row and column is constant for that map sheet (i.e., a full rectangle of gridded data). This infers the following:

- As the UTM projection of a map sheet boundary is not a true rectangle, the grid boundary is a rectangle which encloses the four map sheet corners.
- If any grid point cannot be given an interpolated value, then a null value (-9999.000) is assigned to that grid point.
- To ensure exact matching of contoured maps the grid is extended by 5 grid points beyond the smallest rectangle which contains the map sheet corners.

File Contents

Each map sheet data grid occupies a separate file. Each file has i) a header, and ii) the gridded data.

Header

Record N°1
- NTS map sheet number,
- Geophysical Series map number,
- grid spacing in metres,
- number of grids in X direction (columns),
- number of grids in Y direction (rows),
- Central Meridian.

(Format (2A10, F10.2, 2I10, E20.10, 10X))

Record N°2 to 5 ▸ latitude, longitude, easting, northing of four map sheet corners, with 1 corner per record

(Format (4E20.10))

Record N°6 to 9 ▸ latitude, longitude, easting, northing of four actual grid corners, with 1 corner per record

(Format (4E20.10))

Data

The above is followed by a string of grid values, a column at a time, that is, each column begins a new record:

e.g., WRITE(,) (GRID)IROW,ICOL),IROW=1,NCROWS)

note: for Magnetic Data: (Format (8F10.3))
for Conductivity and Conductance Data: (Format (8F10.4))

Each map ends with an END OF FILE.

ARCHIVE OF RAW EM DATA

THIS DATA IS NOT TO BE DISTRIBUTED

FOR INTERNAL USE ONLY.

Please consult with scientific authority Dr. George Palacky, Mineral Resources Div., GSC., if you wish access to this raw data set.

F. Kiss, Contract Surveys, Geophysics Div.

ARCHIVE OF RAW EM DATA

General Specifications

All archive tapes are:

- fully IBM compatible,
- 2400' or 1200',
- no label, ASCII,
- 9-track, formatted,
- 1600 bpi,
- block size of 5040 bytes,
- record length of 80 bytes.

The data is ordered by flight number.

Each flight contains a single file of all the raw EM data for each line of the flight, followed by the calibration data for that flight.

Geographic coordinates in decimal of degrees are used for all positional coordinates. The Universal Transverse Mercator projection is used for creating the gridded data. The UTM zone is the same as that used on the particular topographic maps supplied for the survey area. All longitudes west of Greenwich are represented as negative degrees. Each survey grid origin is a multiple of the grid interval from the Central Meridian and 0° latitude.

Detail Specifications

Digital Line Archive for Raw EM Data

A line header identifies each line segment. It contains:

- flight number,
- line and segment number (e.g., line 1, segment 0=10, line 1, segment 1=11),
- direction code,
- traverse/control line code,
- start time,

- end time.

(Format (2I10, 10X, 2I10, 2F10.2, 10X))

Direction Codes 1 = North
2 = East
3 = South
4 = West

Traverse Code = 0
Control Line Code = 1

Data records for each recorded point contains the following in order listed:

Record #1

NAME	CONTENTS	UNITS	FORMAT	DEFAULT VALUE ADDED
TIME	Time	seconds	F10.2	N/A
UTMX	UTM X value	metres	F10.2	N/A
UTMY	UTM Y value	metres	F10.2	N/A
RALT	Radar altimeter	cm	F10.2	50,000
PRIMI	Primary field intensity	%	F10.2	50,000
PL	Powerline monitor	mv	F10.2	50,000
EM1	Raw EM channel 1	ppm	F10.2	50,000
EM2	Raw EM channel 2	ppm	F10.2	500,00

Record #2

NAME	CONTENTS	UNITS	FORMAT	NULL VALUE
EM3	Raw EM channel 3	ppm	F10.2	50,000
EM4	Raw EM channel 4	ppm	F10.2	50,000
EM5	Raw EM channel 5	ppm	F10.2	50,000
EM6	Raw EM channel 6	ppm	F10.2	50,000
EM7	Raw EM channel 7	ppm	F10.2	50,000
EM8	Raw EM channel 8	ppm	F10.2	50,000
EM9	Raw EM channel 9	ppm	F10.2	50,000
EM10	Raw EM channel 10	ppm	F10.2	50,000

Record #3

NAME	CONTENTS	UNITS	FORMAT	NULL VALUE
EM 11	Raw EM channel 11	ppm	F10.2	50,000
EM 12	Raw EM channel 12	ppm	F10.2	50,000
EM 13	Raw EM channel 13	ppm	F10.2	50,000
EM 14	Raw EM channel 14	ppm	F10.2	50,000
EM 15	Raw EM channel 15	ppm	F10.2	50,000
EM 16	Raw EM channel 16	ppm	F10.2	50,000
EM 17	Raw EM channel 17	ppm	F10.2	50,000
EM 18	Raw EM channel 18	ppm	F10.2	50,000

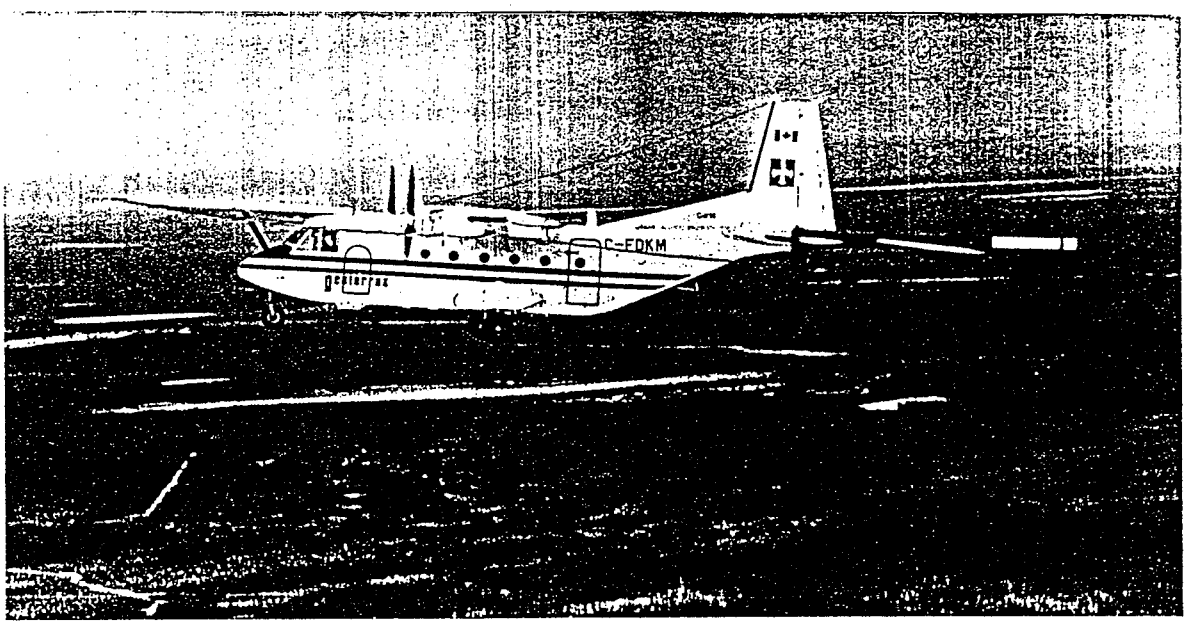
Record #4

NAME	CONTENTS	UNITS	FORMAT	NULL VALUE
EM 19	Raw EM channel 19	ppm	F10.2	50,000
EM 20	Raw EM channel 20	ppm	F10.2	50,000
			60X	

The end of data for each line is denoted by four (4) zero records in the same format at the data records and followed by an END OF FILE on the last line. Each new line segment starts with a new 5040 byte block for easier access.

Appendix H
Aircraft and Equipment Specifications

CASA 212 200 C-FDKM



WEIGHT BALANCE

• maximum take off weight	16976 lb/7700 kg
• empty weight	11950 lb/5420 kg
• maximum useful load	5026 lb/2280 kg
• maximum fuel capacity (528 US gal, 2000 L)	3500 lb
• personnel on board (3 persons)	540 lb/245 kg

CONSUMPTION

• at survey speed of 230 km/h	400 L/h

AUTONOMY

• at 295 km/h with 45 min reserve	4.5 hour

ENGINES

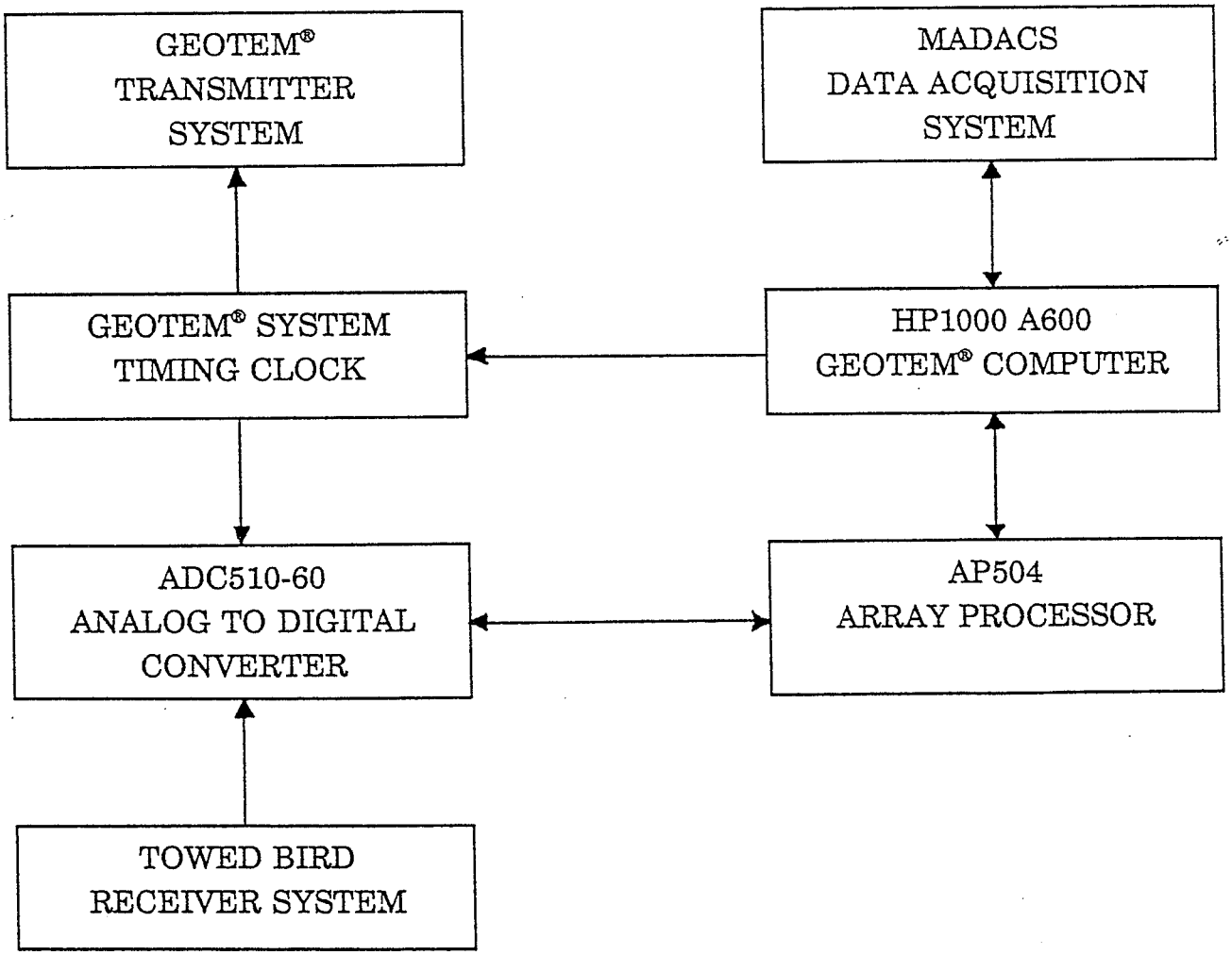
- GARRETT TPE 331-10-511C power 900 H.P.

GEOTEM® SYSTEM HARDWARE

The GEOTEM® system is an integrated whole, consisting of the CASA 212 aircraft, the onboard hardware, and the software packages controlling that hardware.

The software packages in the MADACS data acquisition system and in the HP1000-A600 GEOTEM® computer were developed in-house by Geoterrex. Likewise, certain elements of the hardware (GEOTEM® transmitter, system timing clock, towed bird receiver system) were developed in-house.

GEOTEM® BASIC BLOCK DIAGRAM



GEOTEM® COMPUTER: HEWLETT PACKARD HP1000-A600

The HP1000 is a rack mounted minicomputer capable of one million instructions per second. It acts as a controlling host for the analogic array processor. Communication between the HP1000 and array processor is via DMA transfers. The software running on the HP1000 controls the actions of the array processor, and passes the resulting output data to the MADACS DAS for display and recording.

ANALOGIC ARRAY PROCESSOR: AP504

The array processor performs the real-time processing on the EM data. It is controlled by the HP1000. Receiver data comes to the AP504 from the ADC-510-60 analog to digital converter.

ANALOGIC ANALOG TO DIGITAL CONVERTER: ADC-510-60

The ADC-510-60 digitizes the receiver coil signal. It has 16-bit resolution and can digitize 2 differential input channels at sampling rates up to 52.5 kHz.

GEOTEM® TRANSMITTER SYSTEM:

The transmitter system drives high current pulses of an appropriate shape and duration through the coils mounted on the CASA aircraft.

GEOTEM® SYSTEM TIMING CLOCK:

This subsystem provides appropriate timing signals to the transmitter, and also to the analog to digital converter, in order to produce output pulses and capture the ground response.

TOWED-BIRD RECEIVER SYSTEM:

A single coil is mounted inside a towed bird which typically is 80 metres below and 105 metres behind the aircraft. The coil axis is parallel to the longitudinal axis of the aircraft.

LIST OF EQUIPMENT

Trimble Navigation GPS Surveyor

Rosemount 1241A Barometric Altitude Transducer

Sperry C-12 Compass System

VG-14 Vertical Gyroscope

Tactical Airborne Navigation System (Tans) - Decca Doppler 71

Scintrex Cesium Vapour Magnetometer VIW2321H6

Picodas MEP-710 Cesium Base Station Magnetometer Processor

Digidata Magnetic Tape Transport 1140

RMS GR33 Graphic Recorder

'MADACS' Acquisition System

DEC System 5100

Panasonic Colour Camera WV-CL302

Panasonic AG-2400 Industrial Video Cassette Recorder

Zeta 8 Plotter

Dell 316SX

TRIMBLE NAVIGATION GPS SURVEYOR

Description

Trimble Navigation's Surveyor is a GPS receiver providing centimeter level measurements. Built around the highly regarded 4000A Locator, the Surveyor adds the capability to acquire the highest accuracy geodetic quality data using carrier phase and integrated doppler measurement techniques.

Specifications

Features:	Carrier Phase Tracking, Integrated Doppler Smoothing, Continuous and Simultaneous Tracking of 5 Satellites, Dual Interface Port, Automatic Search and Acquisition.
Outputs:	Time tagged Latitude, Longitude, Height, Speed, Heading, Raw Carrier Phase and Integrated Doppler measurements.
Accuracy:	Carrier Phase - Better than 2° in phase angle (1 mm) Integrated Doppler - Better than 3 mm Code Phase - Position fix performance depends on GPS Control Segment operation. (See 4000A specs)
Velocity:	2 cm/sec RMS (low dynamics)
Maximum Tracking Dynamics:	Maximum velocity is 250 m/s Maximum acceleration is 0.5 g
Maximum Update Rate:	Synchronized - 2.5 seconds Asynchronous - 1.0 seconds
Acquisition Time:	5 minutes (warm start), 30 minutes (cold).
I/O RS232C Port:	Dual bidirectional for computer control Simplex for printer output, 150-38,400 BAUD Carrier phase data Time tags to better than 0.5 microseconds Integrated doppler measurements Code phase pseudorange measurements Position fixes and velocity Frequency and phase offsets of local oscillator System data, NAV data
Keyboard:	16 keys on front panel for operator control and data entry.
External Frequency Input:	5 MHz, OdBm (0.25V rms into 50 ohms)
Display:	Two lines of 16 characters, vacuum fluorescent

Physical Characteristics

Dimensions & Weight:	10" x 21 1/2" x 25" rack mount option 57 pounds, without batteries Antenna 6" x 24" x 24", 15 pounds

Cable:	RG58/U 35 ft, RG2213/U 100 ft
Power:	115/230 VAC 100 VA (70 watts est.) 12 VDC 60 Watts

Environmental Characteristics

Operating:	Receiver:	0 to + 50C
Temperature:	Antenna:	-30 to +75C
Storage:	Receiver:	-20 to +60C
Temperature	Antenna:	-40 to +75C
Shock:	30g half sinewave	
Vibration:	1g, 0 to 50 Hz	

ROSEMOUNT 1241A BAROMETRIC ALTITUDE TRANSDUCER

Description

Rosemount's Model 1241A Altitude Transducers are designed to provide precise measurement of barometric altitude for high performance airborne systems operating over altitude ranges from -1000 feet to 30,000 feet.

Specifications

Resolution, Repeatability and Hysteresis:

Resolution, repeatability and hysteresis errors are constant as a function of pressure and therefore vary in a non-linear manner as a function of altitude. For Model 1241A altitude transducers, these errors are as follows for applicable altitude points.

ALTITUDE	RESOLUTION	REPEATABILITY	HYSTERESIS
Sea Level	1 foot*	3 feet*	3 feet*
30,000 feet	2.5 feet*	8 feet*	8 feet*

*Or 1 millivolt, whichever is greater.

Power Requirements: +15 VDC ± 5% at 0.050 Amperes
-15 VDC ± 5% at 0.050 Amperes
+5 VDC to +20 VDC external reference voltage at 0.001 amperes unless Option Code C is selected

Insulation Resistance: The insulation resistance between all signal and power leads tied together and case ground is 100 megohms, mimimum, at 100 VDC. (100 VDC is the voltage rating of the internal capacitors connected between signal return and case ground.)

Input-output Isolation: The 15 VDC power return and the signal return are internally connected together. It is recommended that the 15 VDC return or the singla return bee externally connected to case ground during testing andin acutal use to keep output signal noise at a minimum.

Output Impedance: Less than 50 ohms.

Output Current Capability: The altitude output amplifier is capable of supplying current to load impedances of 5000 ohms or higher.

Vibration: ±0.10" double amplitude or 10 G's peak from 5 to 500 Hz.

Humidity: 95% relative humidity or less

Operating Temperature: -55°C to +71°C

Storage Temperature: -65°C to +85°C

SPERRY C-12 COMPASS SYSTEM

Description

The System is a gyroscopically stabilized compass system which can be operated as a free directional gyro (DG) or as a slaved gyro (MAG). Table 1 lists the components and part numbers that compose a System.

System Component	Sperry Part No.
FX-120 Flux Valve or FX-270 Flux Valve	620359 1775277
CS-313 Remote Compensator	2586257-1
C-12 Directional Gyro	2586333-3
CC-161 Digital Compass Controller	258626-1
SL-120 Slaving Amplifier and Power Supply	2589226-1

TABLE 1 - System Components

The system displays a digital readout of the aircraft heading and provides synchronizing control that includes latitude control, hemisphere selection, mode selection, and a visual indication of system synchronization. It also includes compensation for index error, one- and two-cycle errors, earth rate and Coriolis error, meridian convergence error, and gimbal and turn error. four heading outputs are provided for use with other equipment.

Signal flow between the various system components is shown in figure 1.

VG-14 VERTICAL GYROSCOPE

Description

The VG-14A Vertical Gyroscope provides aircraft pitch and roll attitude reference data for use in flight director, flight instrument, automatic flight control, and radar stabilization systems.

Specifications

Performance Data

Gyro Rotor Speed:	22,000 rpm (nominal) within 5 minutes after power is applied	
Gyro Angular Momentum:	3.8 million gm-cm^2 per second	
Gyro Erection:	Vertical within 3 minutes after power is applied.	
Verticality:	(Alignment of spin axis with true vertical.) 0.25 degree (bench)	
Roll Erection Cutoff Threshold:	0.10g (6° Roll Angle Nominal)	
Erection Rate:	Fast Erection (Roll) Fast Erection (Pitch) Slow Erection (Roll & Pitch)	20 degrees/minute minimum 20 degrees/minute minimum 2.5 degrees/minute nominal

Interface Data

Excitation Voltage:	115 volts ac, 400 Hz, 1 phase	
Power Required:	Starting (Maximum) Operating (Maximum)	80 VA 40 VA

Roll and Pitch Signal Output Data, per Axis, in accordance with Arinc Standards

	GRADIENT VOLT/DEGREE	IMPEDANCE	LOAD
3-wire synchro output	0.205	Z_{ll} 19.23 + j9.1	220 + j450 wye connected
2-wire, flight director	0.205	343 + j12	1,180 ohms
2-wire, radar	0.050	85 - j235	10,400 ohms

Flag Alarm Warning Circuits

	PRESENCE OF FAULT	ABSENCE OF FAULT
Isolated three-contact sets (2 each)		
Contact 1 to common	Open	Closed
Contact 2 to common	Closed	Open
Green Lamp on gyro base	Off	On
Roll Cutoff Warning	CUTOFF	NO CUTOFF
	Ground	Open

Environmental Qualifications

Specifications:	TSO C4c (AS396B)
Temperature:	-55°C to +71°C, Operating -65°C to +71°C, Nonoperating
Virbration:	0.036 double amplitude from 5 Hz, constant 5g from 52 Hz to 500 Hz

TACTICAL AIRBORNE NAVIGATION SYSTEM (TANS) - DECCA DOPPLER 71

Description

The Tactical Air Navigation System (TANS) is a small general purpose digital computer with an integrated keyboard and display which can be set up to carry out a variety of specific functions using a fixed programme.

The computer is programmed to accept inputs from Decca Doppler Series 70, an air data transducer and thee aircraft heading and attitude systems. Data and control instructions can be inserted manually vaia the control panel.

The facilities of the TANS computer include:

- Present position (latitude/longitude, naval or UTM grid)
- Bearing/distance and heading to Steer with time to go to any one of ten waypoints, destinations or targets.
- Vectoring of waypoints.
- Pitch and roll corrections to allow full resolution into navigation axes if all three doppler velocity components are used.
- Automatic wind calculation.

System Components

Decca Doppler 71

Design characteristics tailored to suit the operational requirement of V/STOL aircraft operating below 300 knots. Velocity data is measured in three axes, along and across heading and vertical. A hovermeter which can indicate this information is available.

Antenna/Electronics Unit Type 9305

Antennae

Two antennae are used; one for transmission and the other for reception. These are mounted on the underside of the main assembly separated by a metal septum and each is covered by a fibreglass radome. The radomes form an integral part of the package.

The antennae are planar arrays of slotted waveguides and each produces three beams having beamwidths of 50° in the depression plane and 11.0° in the broadside plane. The depression angle is 67°.

Transmitter

The transmitter module is mounted on the back of the transmitting antenna and consists of a crystal controlled transistor oscillator followed by varactor multipliers providing an output power of 100mW at frequencies of 13.325 GHz and 13.314 GHz. The transmitter power is unmodulated. A small smaple of the transmitted power is fed to the receiver for use in the demodulation process.

Receiver-tracking system

Three receiving and tracking channels are used and are almost identical. A balanced crystal mixer is mounted on each of the three ports of the receiving antennae.

Each mixer is fed with 1mW of power from the appropriate varactor multiplier source. Thus the received signal at 10.7 MHz ± doppler frequency is produced, the doppler shift being positive in a forward looking beam and negative in a backward looking beam. The 10.7 MHz I.F. amplifiers and following audio amplifiers make use of microminiature modules providing compactness and high reliability. The frequency trackers are of the sine-cosine type and use an electronic oscillator controlled by an electronic integrator.

These units also use microminiature techniques. Prior to the acquisition of signal, a search signal is fed to all trackers which sweeps the voltage controlled oscillators throughout their range. On receipt of a signal the trackers lock on and the search signal is disengaged.

Ground Speed and Drift Meter Type 9308

Indicated Ground Speed:	Within 3.5 Kts at 100 Kts at 300 Kts.
Drift Measurement:	Within ± 0.5° of the true value.
Memory:	Under conditions of signal loss, the ground speed and drift indication last measured will continue to be displayed indefinitely. Manual updating of this information is possible. With the type 71, memory information is invalid for hovering operations. In the memory condition therefore, a flag is displayed on both the Hover Meter and the Ground Speed and Drift Meter.

Hover Meter type 9306

Along Heading Velocity:	Indicated on the Hover Meter with an error not exceeding one knot. Displayed along heading velocity range is -10 kts to +20 kts.
Across Heading Velocity:	Indicated on the Hover Meter with a maximum error of one knot. Displayed across heading velocity range is ± 15 kts.
Vertical Velocity:	Indicated on the Hover Meter with a maximum error of 40 ft per minute. Displayed vertical velocity range is ± 500 ft per minute.

TANS Computer Type 944D

The Tactical Air Navigation System (TANS) Computer is a low cost, highly versatile equipment designed to operate with the Type 71 Doppler in navigation systems. It is packaged in one unit to ARINC dimensions for cockpit installation.

Sizes and Weights:	Antenna/electronics Unit Type 9305 400 mm (H) x 400 mm (W) x 127 mm (D)	16.50 kg
	Hover meter type 9306 82 mm (H) x 82 mm (W) x 188 mm (D)	1.02 kg
	Ground speed and drift meter type 9308 82 mm (H) x 82 mm (W) x 154 mm (D)	1.32 kg
	TANS computer type 8447D 162 ll (H) x 146 mm (W) x 247 mm (D)	6.00 kg

SCINTREX CESIUM VAPOUR MAGNETOMETER VIW2321H6

Description

Please refer to Model 49-554

Specifications

Working Range: 20,000 - 100,000 gammas

Power Requirements: 30 V ± 2 V
1.5 amps at turn-on
.5 amps after warm-up

Output "Larmor" Frequency: 69,972 Hz @ 20,000 gammas
349,860 Hz @ 100,000 gammas
(proportionality constant 3.4986 Hz/gamma).

Sensor Orientation: (See diagram in operation section).
Optimum angle 45° between sensor head axis and magnetic field vector.

Sensor will operate with sensor head axis anywhere between 15° - 75° from parallel with magnetic field vector. This is called the "Active Zone".

Heading Error: (See diagram in operation section).
The measurements of the magnetic field strength will have small offsets which vary depending on the orientation within the active zone. The sensors are "balanced" to differennt limits depending on the model.

Model	Heading Error	Use
VIW 2321 H6		Special oriented airborne 10 foot sensors for V-201 system.
VIW 2321 H7		Special oriented airborne 10 foot sensors for V-201 system.
VIW 2321 H8	▲ 1.0 gamma 15° - 75°	General usage - 10 foot flexible cable smallhead size.

Active Zone: $15° \leq \emptyset \leq 75°$
$105° \leq \emptyset \leq 165°$

Angle $\emptyset$ is the angle between the positive direction of the earth magnetic field vector and the optical axis of the sensor optics (direction along which the pumping light propagates).

Sensitivity: ± 0.005 gammas

Output Signal to Noise:	36dB @ 70 kHZ 20dB @ 350 kHZ BW = 50 - 500 kHZ
Information Rate:	Continuous
Information Bandwidth:	20 kHZ

To determine the information bandwidth, the magnetometer is subjected to the ambient field of 20,000 gammas which is modulated to frequencies of up to Larmor frequency with the depth of modulation of less than 5%. The bandwidth is determined at -3 dB point.

Dimensions:

VIW 2321G3, G4, H6., H7

Sensor Optics:	Dia:	2.5"
	Length:	7"
Sensor Electronics:	Dia:	3"
	Length:	11"

VIW 2321H8, H9

Sensor Optics:	Dia:	2.5"
	Length:	6.25"
Sensor Electronics:	Dia:	3"
	Length:	11"

Environmental:

Operating Temp Range	-45 to 55°C
Storage Temp Range	-70°C to 70°C
Humidity	0 - 100%, Splashproof

PICODAS MEP-710 CESIUM BASE STATION MAGNETOMETER PROCESSOR

Description

The PICODAS MEP-710 is a self contained unit which interfaces directly to a Cesium Sensor and is controlled by a host computer using a serial interface. The box contains a power supply for the Cesium sensor as well as a de-coupler circuit. The box can be controlled from, and readings can be stored on any IBM PC compatible computer.

The box is provided with software for data acquisition, replot and verification.

The sensor can be positioned up to 100 metres from the box.

Specifications

Size:	6.25" x 14.75" x 3.25
Power:	12 VDC input 4 amp for 1 minute startup 2 amp max operating
Resolution:	0.01 nanotesla
Sample Rate:	10 samples per second

DIGIDATA MAGNETIC TAPE TRANSPORT 1140

Description

Storage media for MADACS Data Acquisition system.

Specifications

Recording Mode:	NRZ,PE, or both	
Number of Tracks:	7 or 9 Track NRZ, IBM, ANSI Compatible 9 Track PE, IBM, ANSI Compatible	
Data Packing Density:	800 or 1600 bpi	
Head:	Dual gap (read-after-write)	
Tape Specifications:	0.5 inch width, 1.9 mil, computer grade	
Tape Tension:	8 oz. Nominal	
Tape Buffering:	Tension arm, 30 to 60 degree arc	
BOT/EOT Sensing:	Photoelectric	
Head and Tape Guide Spacing:	IBM compatible	
Power Fail Protection:	Dynamic electrical braking, control maintained to rest.	
Electronics:	Solid State Silicon TTL Low Power Schottky	
Electrical Interface:	Line Drivers: Line Receivers:	7406/7407 buffers, open collector 7414 or equivalent with 220 ohms to V_{CC}, 330 ohms to ground
Line Voltage:	110 VAC ± 10%	
Line Frequency (AC):	49 to 400 Hz	
Input Current:	3.0 Amps Max 100-120 VAC 1.5 Amps Max 200-240 VAC 1140, 1640, and 1740 5.0 Amps Max 100-120 VAC 2.5 Amps Max 200-240 VAC 1840	
Operating Environment:	0 to 20,000 feet (6,000 m) 35 to 122 degrees F (2 to 50 degrees C)* to 95% RH without condensation	
Non-operating Environment:	0 to 50,000 feet (15,000 m) -40 to 160 degrees F (-40 to 70 degrees C)	

RMS GR33 GRAPHIC RECORDER

Description

The RMS Model GR33 Graphic Recorder is a unique and versatile data recording instrument intended for scientific, industrial and commercial data acquisition applications requiring high quality graphic records. Its modular design and 3 standard modes of operation (Alphanumeric, Raster Graphics, and Chart Recorder) permit it to easily adapt to a variety of data recording tasks.

Specifications

Record

Size:	12.4 in. (315 mm) Record on 12.625 in. (321 mm) paper
Resolution:	100 x 100 dots/in. (4 x 4 dots/mm)
Recording Method:	Fixed position monolithic thermal printhead consisting of a linear array of 1240 individual .008 in. (.2 mm) printing elements on .01 in. (.254 mm) centres.

Paper Transport

Paper Speed:	600 speeds (programmable inches/sec. or mm/sec.) up to .25 inch per second (ips) in .001 ips increments or 6.00 mm per second in .01 mm per sec. increments. Paper speed may also be determined by an external variable frequency, or any analog channel may be used to control chart speed, with the optional RMS4185 analog input module installed.
Drive Mechanism:	DC stepping motor, with an internal take-up spool.
Paper Advance:	Paper may be advanced at 1 ips (25.4 mm per sec.) without printing.
Paper Viewing Area:	3.3 in. (84 mm) when using internal take-up spool. 5.3 inc. (134.6 mm) when using writing platen.
Paper Level:	Solid state level sensor and 4 segment LED bargraph paper level indicator.

Serial Digital Interface

Signals:	EIA RS-232C or 20 mA. current loop, 8 data bits and programmable parity, RTS (request to send) and CTS (clear to send) handshake lines.
Data Rate:	300 to 9600 Baud.
Connector:	DE-9P (9 pin) located on the rear panel.

Parallel Digital Interface

Signals:	8 input lines, 8 output lines, active low or high input strobe, active low output strobe, active low and high Busy outputs, all TTL compatible.
Connector:	DB-25P (25 pin) located on the rear panel.

Installation

Size:	19.0 x 5.25 in. (482.6 x 133.4 mm) 19 inch rack mount. 19.3 in. (490 mm) overall depth,, extending 17.5 in. (445 mm) behind mounting surface.
Weight:	23 pounds (10.4 kg.) with no options installed.
Power Requirements:	GR33-2 24-32 Volts DC, 8 Amps maximum. Less than 100 Watts typical either model.
Temperature:	Operating 0° to +50°C Extreme operating condition -20°C to +55°C Storage -40° to + 60°C

'MADACS' ACQUISITION SYSTEM

by Grant Mervyn

Description

1. A universal data-logging system capable of acquiring data from all existing measuring systems in any combination and capable of handling future measuring systems which have not yet been conceived.

2. Error-free data recording and verification.

3. Flexibility without requiring hardware changes.

Hardware Features

The system is based on an Interdata model 6/16 minicomputer with 64K core memory with the following interfaces:

1. A general purose digital input/output port

This port is a "slowed-down" external bus system. The bus is capable of reading from, writing to, testing and controlling up to 16 extenral digital devicies. This permits the acquisition of up to 64 decimal digits from external devices.

The digital data does not need to be in decimal form, nor does it need to be in any of the "standard" codes, whatever the form it may be manipulated by software.

2. A general purpose 12 bit analog input module

This module has been configured to handle 8 balanced analogue channels with input amplitudes ranging between plus and minus 2.56 volts.

The same module may be re-configured to handle up to 16 single-ended analog channels by simple jumper changes on the board. It may be expanded to handle 16 balanced or 32 single-ended inputs.

3. Two each, four-channel analog output modules having 12 bit resolution

These have been configured to give analogue outputs ranging from 0 to +10 volts. This relatively high level has been selected to "swamp-out" noise on the ground bus such as that caused by the polarizing current ina proton magnetometer.

If more than eight analog outputs are required it is simply necessary to install additional four-channel modules.

4. Multichannel spectrum analyzer interface

This is a direct-meemory-access interface, requiring intervention from the processor only of the start of the sample period. This interface has been configured to handle two 8-bit (256 channel) nuclear analog to digital converters. This gives the system the capability of collecting gamma ray spectrometer data from two independent detector arrays.

5. Precision clock

This provides the basic timing for the system. Data may be collected at any multiple of 0.1 seconds.

6. Magnetic tape interface

This interface/controller is capable of handling four 9-track, NRZ1 tape transports. Tapes are written in IBM-compatable format with full parity cyclic redundancy and longitudinal check characters. Read-after-write checking ensures that data is correctly recorded.

When tape errors are sensed, the bad record is erased and a new record is written on the next section of tape. The number of re-write attempts is determined by software and is limited only by the time available. If the data cannot be correctly recorded within the allowed number of retries a diagnostic message is presented to the operator.

7. Proton magnetometer interface

A special interface has been constructed to connect a G803 magnetometer to the system. Special isolation circuits have been included to eliminate ground loops and noise induced by the pulsing magnetometer polarizing current. The magnetometer may be run under processor control or alternatively under its own internal timing circuits.

8. Doppler interface circuits

A new method of recording doppler navigation information has been implemented. This permits unambiguous recovery of flight path information and allows the pilot/navigator to use the navigation system as he chooses without affecting the validity of the recorded information.

9. Inertial navigator interface

This permits recording inertial navigation system position information. The particular inertial parameters recorded may be selected by strap options on the interface.

10. Alkali-vapour magnetometer

This interface processes the larmour frequency from cesium or rubidium vapour magnetometers providing total field measurement with a resolution of 0.01 gamma at sample intervals down to 1/2 second (more frequent sampling is possible with reduced resolution).

11. Camera controllers

The system contains interfaces for controlling both strip and frame-type flight path cameras. Cameras equipped with ledd-type displays may be annotated with any desired parameters under software control. (For example: fiducial number, or picture number, time of day, sample number etc.). This eliminates any ambiguity between information on the film and the magnetic tape.

12. Operator's console

This is a standard teletype-type keyboard and TV alphanumeric display via which the operator communicates with the system. In-flight operations are on a request-response basis with the system pre-empting the operator and rejecting all illegal responses. While on line during survey, all measured parameters are continuously displayed on the monitor unless the system senses an abnormal condition. If an abnormality is sensed, a diagnostic message andthe time sensed are displayed on the monitor. this message remains on the monitor until acknowledged by the operator.

Software Features

As mentioned earlier, the MADACS system is based on an Interdata model 6/16 minicomputer. The Interdata family of min-computers emulate IBM System 360/370 software. This permits Geoterrex to take full advantage of the powerful compilers and assemblers in their home office data centner to generate software for the MADACS system.

The MADACS software has been constructed in a modular form. In a general way, these modules may be considered as beeing in one of the following categories:

1. Operating system

This is a very fast, interruptable, fully-reeentrant, basic operating system. It contains thee mag tape handling routines, interactive console routines and mathematics subroutines used by all other modules.

2. Special device handlers

These are input/output, control and status monitoring routines for handling the various hardware devices that may be part of a particular survey system. These device handlers are included in the complete software package on an "as needed" basis depending on the particular hardware configuration.

3. Special flight-related routines

This module contains routines that would be used in an airborne data acquisition application. They would not be used for example in a data processing application.

4. Radiometrics related routines

This is a suite of routines peculiar to gamma ray spectrometry applications. In addition to the spectrometry data acquisition routines special routines are included for calibrating and balancing the gamma ray detectors, monitoring the system gain and zero stability, sensitivity, checking resolution, etc. The package contains routines which accumulatee the complete spectrum for an indefinite period while on survey thus permitting the "natural" spectrum to be displayed or drawn on analogue chart at any time.

5. Barringer INPUT system routines

This module contains routines related to the acquisition of "fast time constant" data from the Barringer INPUT system at a rate of 5 samples per second. Routines are under development for determining ratios, normalization, etc.

6. High resolution magnetometer routines

This module contains special routines related to high resolution magnetic surveys. The package includes routines associated with dynamic manoeuvre-noise compensation, 4th difference profiles for data quality monitoring etc.

7. Application routines

This module contains the routines peculiar to a specific application. This is the only module which requires "custom programming" to meet specific applications. It calls subroutines from the preceeding modules as required.

8. Test routines

In addition to the self-check procedures imbedded in the various acquisition modules, special hardware test routines are available. These routines are designed not only to fully exercise the system hardware, but also to aid the technician in servicing faulty equipment by guiding him through the test sequences. The test routines are "stand-along" programmes and are under continuing development and improvement.

DECsystem 5100

Description

The DECsystem 5100 is an RISC based computer that provides file services for a PC based Local Area Network and a UNIX processing environment.

Specifications

Processor:	MIPS Computer Systems R3000
Memory:	16 MByte
Disk:	4.75 Gbyte
Tape:	DEC TZ30 100 MByte Archive Python 1.3 GByte DAT format 4 mm cartridge
Storage:	SCSI up to seven peripherals
Terminals:	Up to 4 Asyncronous (one supporting full modem control)
Networking:	Embedded 803.3/Ethernet (Thin/Thick wire) controller
O/S:	DEC Ultrix 4.0 (DEC Unix)
Size:	15 cm x 46 cm x 40 cm
Environment:	10 - 32 degrees C, 10% - 80% humidity

PANASONIC COLOUR CAMERAS WV-CL302

Description

Colour camera for use in conjunction with VCR to record and verify flight path, time, position, and distance travelled.

Specifications

Pick-up Device:	512 (H) x 492 (V) pixels, Interline Transfer CCD
Scanning Area:	6.4 (H) x 4.8 (V) mm (Equivalent to scanning area of 1/2" pick-up tube)
Synchronization:	Internal or external (geen-lock) switchable automatically at INT position. Line locked sync at LL position for WV-CL300/WV-CL304. External (gen-lock) input: 1.0Vp-p NTSC composite (VBS) or black burst signal/75 ohms
Scanning System:	2:1 Interlace
Scanning:	525 Lines/60 Fields/30 Frames Horizontal: 15.734 KHz Vertical: 59.9 Hz
Horizontal Resolution:	330 lines at center
Video Output:	1.0Vp-p NTSC composite, 75 ohms/BNC Connector
Signal to Noise Ratio:	46 dB (AGC OFF)
Automatic Light Compensation:	40,000 - 60,000: 1 with Automatic Iris Lens
Minimum Illumination:	1 footcandle (10 lux) at Ff1.4 (AGC ON)
Recommended Illumination:	10 footcandles (100 lux) at F1.4
White Balance:	Selectable AUTO (Auto Tracing White-balance) or LOCK (Auto White Balance Setting)
Gain Control:	Selectable AGC ON (+ 12dB) or OFF
Lens Mount:	C-Mount or Special C-Mount (CS-mount)
Ambient Temperature:	14°F - 122°F (-10°C - +50°C)
Power Source:	12V DC (10.5V - 16V)
Power Consumption:	0.32A (at 12V DC)
Dimensions:	2-3/4" (W) x 2-3/4" (H) x 5-1/2" (D) (70 (W) x 70.5 (H) x 141 (D) mm)
Weight (without lens):	1.48 lb (0.67 kg)

PANASONIC AG-2400 Industrial Video Cassette Recorder

Description

Industrial VCR to record and verify flight path, time, position, and distance travelled.

Specifications

Power Source:	DC 12V
Power Consumption:	11 watts (18 watts with Camera) • 4.7 watts (at REC/PLAYBACK with Battery Pack) • 6 WATTS (at PLAYBACK)
Television System:	EIA Standard (525 lines, 60 fields) NTSC colour signal
Video Recording System:	2 rotary heads, helical scanning system Luminance: FM azimuth recording Colour signal: converted subcarrier phase shift recording
Audio Track:	1 track
Tape Format:	SP/15/16 i.p.s. (33.35 mm/s), LP (PLAYBACK only)/21/32 i.p.s. (16.67 mm/s) SLP/7/16 i.p.s. (11.12 mm/s)
Record/Playback Time:	360 min. with NV-T120 used in SLP mode
FF/REW Time:	About 4 min. with NV-T120

Input Level:

Video	VIDEO IN jack (RCA)	1.0 Vp-p,	75 ohm
	ADAPTOR (20 pin)	1.0 Vp-p,	75 ohm
	CAMERA (10 pin)	1.0 Vp-p,	75 ohm
Audio	MIC IN jack	-70 dB,	600 ohm

Output Level:

Video	VIDEO OUT jack (RCA)	1.0 Vp-p	75 ohm
Audio	AUDIO OUT jack (RCA)	-8 dB,	600 ohm
	ADAPTOR (20 pin)	-20 dB,	47 kohm
	CAMERA (10 pin)	-20 dB,	47 kohm
	Earphone jack (RCA)	-22 dB	200 ohm
RF Modulated: Channel 3 or 4		66.5 dB μ (open voltage), 75 ohm	

Video Horizontal Resolution:	Monochrome/Colour: more than 240 lines
Audio Frequency Response:	SP: 50 Hz ~10 kHz
Signal-to-Noise Ratio:	Video: better than 45 dB (Rohde & Schwarz noise meter) Audio: SP: better than 43 dB
Operating Temperature:	32°F~104°F (0°C~40°C)
Operating Humidity:	35%~80%
Weight:	Approx. 4.84 lbs. (2.2 kg) (without battery pack)
Dimensions:	8 7/16" (W) x 2 3/4" (H) x 10 3/8" (D) 215 (W) x 69.5 (H) x 263 (D) mm

ZETA 8 PLOTTER

Description

For use in plotting GPS data, flight paths, magnetic contours etc.

Specifications

Input Data:	ASCII encoded vector data
Input Data Rate (RS-232):	110,150,300,600,1200,1800,2400,4800,9600,19200 baud, asynchronous.
Interface:	One configuration is usually ordered (RS-232/GML is standard). Optionally, more than one configuration may be ordered. Protocol converters are available for different computer formats.
Resolution (Switch Selectable):	0.025 mm, 0.001 inches, 0.05 mm, 0.002 inches or 0.025 inches
Plotting Area:	297 mm by 439 m (11.7 inches by 144 feet) metric ISO A3-A4 and ANSI A-B sizes supported in software and plotting media.
Plotting Media:	Type: Roll, fan-fold. Paper: Translucent, Vellum, Glossy Bond. Other: Clear film. Special order - grid.
Pens:	Eight independent stations on one carriage-mounted pen cartridge accommodate nylon-tip, ballpoint, and liquid-roller pens. A four-station liquid ink cartridge is used.
Pen Up/Down Time:	Programmable; nominal default is 16 ms up, 10 ms down.
Speed:	Up to 25 inches per second (ips) at all angles.
Audible Annunciator:	Audible signal alerts operator of half condition such as error, programmed pause, limit, or out-of-paper. To silence annunciator, depress PAUSE pushbutton.
Physical Specifications:	61 cm (W) x 30.5 cm (D) x 25.4 cm (H) 14.5 kg
Power Requirements:	200 watts maximum. Line voltages of 100, 115, 200, 230 ± 10%, 47-63 Hz. 600 BTU/hr maximum dissipation.

DELL 316sx

Description

The DELL 316sx is a PC used for office and field processing.

Specifications

Processor:	Intel 90386sx (with an Intel 80387xs math co-processor)
Memory:	1 MByte
Disk:	100 MByte
Tape:	Core 100 MByte DC2120 format
Monitor:	VGA Colour
O/S:	DOS
Size:	52 cm x 39 cm x 16 cm
Environment:	10 - 32 degrees C, 10% - 80% humidity

Appendix I
GEOTEM® Anomaly Listing
(separate volume)

AUTOMATIC EM ANOMALY SELECTION

System configuration

Pulse repetition rate	=	150 Hz
Pulse width	=	1040 µsec
Off-time	=	2200 µsec
Receiver - transmitter horizontal separation	=	123 m
Receiver - transmitter vertical separation	=	56 m
Receiver axis - horizontal		

Model used in fitting

Vertical plate model	length = 600 m
	depth extent = 300 m
	dip = 90°
	strike = 90°

Anomaly Listing Description

Type	Blank = normal (bedrock related)
	S = Surficial
	C = Cultural
	? = questionable
Order	A,B,.....Anomaly identifier
Fid	Fiducial position of anomaly peak
P CHN	Amplitude (in ppm) of channel used to select anomaly (channel 2)
L FLD	Amplitude of a reference field (channel 6)
NC	Number of channels affected
ALT	Radar altimeter reading, in metres
X	UTM X coordinate of anomaly peak position
Y	UTM Y coordinate of anomaly peak position
CTP	Conductivity-thickness product, in siemens
D	Depth to source, relative to surface, in metres.

BLAKE RIVER SYNCLINE
PROJECT NO. 22400
PROFILE DATA FORMAT DESCRIPTION

2. FORMAT FOR PROFILE DATA VALUES:

(NOTE: 4 records per reading)

Record #1

NAME	CONTENTS	UNITS	FORMAT	DEFAULT VALUE ADDED
TIME	Time	Seconds	F10.2	N/A
LAT	Latitude Coordinate	Decimal Degrees	F10.5	5 000
LONG	Longitude Coordinate	Decimal Degrees	F10.5	5 000
MAGRAW	Edited Raw Total Field	nT	F10.2	500 000
MAGLEV	Levelled Total Field	nT	F10.2	500 000
RALT	Radar Altimeter	metres x 10^{-2}	F10.2	50 000
BALT	Barometric Altimeter	metres x 10^{-2}	F10.2	50 000
DIURNAL 1	Edited Ground Magnetics	nT	F10.2	500 000

Record #2

NAME	CONTENTS	UNITS	FORMAT	NULL VALUE
DC	Decay Constant	Microseconds	F10.4	50 000
CONDO	Overburden Conductivity	Milli-Siemens/m	F10.4	50 000
CONDB	Bedrock Conductance	Siemens	F10.4	50 000
PRIMI	Primary Field Intensity	%	F10.2	50 000
PL	Power Line Monitor	mV	F10.2	50 000
EMN	EM Noise	ppm	F10.2	50 000
EM 1	EM Channel 1	ppm	F10.2	50 000
EM 2	EM Channel 2	ppm	F10.2	50 000

BLAKE RIVER SYNCLINE
PROJECT NO. 22400
PROFILE DATA FORMAT DESCRIPTION

Record #3

NAME	CONTENTS	UNITS	FORMAT	NULL VALUE
EM 3	EM Channel 3	ppm	F10.2	50 000
EM 4	EM Channel 4	ppm	F10.2	50 000
EM 5	EM Channel 5	ppm	F10.2	50 000
EM 6	EM Channel 6	ppm	F10.2	50 000
EM 7	EM Channel 7	ppm	F10.2	50 000
EM 8	EM Channel 8	ppm	F10.2	50 000
EM 9	EM Channel 9	ppm	F10.2	50 000
EM 10	EM Channel 10	ppm	F10.2	50 000

Record #4

NAME	CONTENTS	UNITS	FORMAT	NULL VALUE
EM 11	EM Channel 11	ppm	F10.2	50 000
EM 12	EM Channel 12	ppm	F10.2	50 000
EM 3 C	EM Channel 3 Edited	ppm	F10.2	50 000
DCED	Decay Constant Edited	microseconds	F10.4	50 000
INP	In-Pulse Channel	ppm	F10.2	50 000
ANOMALY L	Anomaly Letter	alphabetic	A3	Blank
DIP	Dip	degrees	I3	Blank
DEPTH	Depth	metres	I4	Blank
CONDV	Conductance	S	F10.4	Blank
INTERP	Interpretation Code	type	A3	Blank
STRENGTH	Strength of Response	channels	I3	Blank
BLANK	Blank	blank	4X	Blank

NOTE:

1. In the above tables, the unit "S" refers to Siemens.
2. The profile data comprises 36 fields. Most records show only 33 fields since field #31 (DIP) and #32 (DEPTH) only contain data if there is a corresponding anomaly in the #30 (ANOMALY L) field. Record #36 is blank.

..... END .....

filename: 22400_01.sam
03-May-94

BLAKE RIVER SYNCLINE

PROJECT NO. 22400

FORMAT DESCRIPTION FOR PROFILE DATA

This survey dataset consists of one 80 byte record describing the flight line parameters followed by four 80 byte records for each reading. The BLOCKSIZE is 5040.

1. FORMAT FOR FLIGHT LINE PARAMETERS

NAME	CONTENTS	UNITS	FORMAT
FLIGHT	Flight Number		I10
LINE	Line Number		I10
SEGMENT	Unused		I10
DIR	Direction		I10
CODE	Line Type		I10
START	Start Time	Seconds	F10.2
END	End Time	Seconds	F10.2

NOTE: DIR - 1 = NORTH
2 = EAST
3 = SOUTH
4 = WEST

CODE - 1 = TIE LINE
0 = TRAVERSE LINE

The end of a line is indicated by null field values (0), (see description of record 1, TIME values etc. will be 0).

.....2

BLAKE RIVER SYNCLINE
PROJECT NO. 22400
PROFILE DATA FORMAT DESCRIPTION

2. FORMAT FOR PROFILE DATA VALUES:

(NOTE: 4 records per reading)

Record #1

NAME	CONTENTS	UNITS	FORMAT	DEFAULT VALUE ADDED
TIME	Time	Seconds	F10.2	N/A
LAT	Latitude Coordinate	Decimal Degrees	F10.5	5 000
LONG	Longitude Coordinate	Decimal Degrees	F10.5	5 000
MAGRAW	Edited Raw Total Field	nT	F10.2	500 000
MAGLEV	Levelled Total Field	nT	F10.2	500 000
RALT	Radar Altimeter	metres x 10^{-2}	F10.2	50 000
BALT	Barometric Altimeter	metres x 10^{-2}	F10.2	50 000
DIURNAL 1	Edited Ground Magnetics	nT	F10.2	500 000

Record #2

NAME	CONTENTS	UNITS	FORMAT	NULL VALUE
DC	Decay Constant	Microseconds	F10.4	50 000
CONDO	Overburden Conductivity	Milli-Siemens/m	F10.4	50 000
CONDB	Bedrock Conductance	Siemens	F10.4	50 000
PRIMI	Primary Field Intensity	%	F10.2	50 000
PL	Power Line Monitor	mV	F10.2	50 000
EMN	EM Noise	ppm	F10.2	50 000
EM 1	EM Channel 1	ppm	F10.2	50 000
EM 2	EM Channel 2	ppm	F10.2	50 000

BLAKE RIVER SYNCLINE
PROJECT NO. 22400
PROFILE DATA FORMAT DESCRIPTION

Record #3

NAME	CONTENTS	UNITS	FORMAT	NULL VALUE
EM 3	EM Channel 3	ppm	F10.2	50 000
EM 4	EM Channel 4	ppm	F10.2	50 000
EM 5	EM Channel 5	ppm	F10.2	50 000
EM 6	EM Channel 6	ppm	F10.2	50 000
EM 7	EM Channel 7	ppm	F10.2	50 000
EM 8	EM Channel 8	ppm	F10.2	50 000
EM 9	EM Channel 9	ppm	F10.2	50 000
EM 10	EM Channel 10	ppm	F10.2	50 000

Record #4

NAME	CONTENTS	UNITS	FORMAT	NULL VALUE
EM 11	EM Channel 11	ppm	F10.2	50 000
EM 12	EM Channel 12	ppm	F10.2	50 000
EM 3 C	EM Channel 3 Edited	ppm	F10.2	50 000
DCED	Decay Constant Edited	microseconds	F10.4	50 000
INP	In-Pulse Channel	ppm	F10.2	50 000
ANOMALY L	Anomaly Letter	alphabetic	A3	Blank
DIP	Dip	degrees	I3	Blank
DEPTH	Depth	metres	I4	Blank
CONDV	Conductance	S	F10.4	Blank
INTERP	Interpretation Code	type	A3	Blank
STRENGTH	Strength of Response	channels	I3	Blank
BLANK	Blank	blank	4X	Blank

NOTE:

1. In the above tables, the unit "S" refers to Siemens.
2. The profile data comprises 36 fields. Most records show only 33 fields since field #31 (DIP) and #32 (DEPTH) only contain data if there is a corresponding anomaly in the #30 (ANOMALY L) field. Record #36 is blank.

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FORMAT DESCRIPTION FOR PROFILE DATA

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FLIGHT	Flight Number		I10
LINE	Line Number		I10
SEGMENT	Unused		I10
DIR	Direction		I10
CODE	Line Type		I10
START	Start Time	Seconds	F10.2
END	End Time	Seconds	F10.2

NOTE: DIR - 1 = NORTH
2 = EAST
3 = SOUTH
4 = WEST

CODE - 1 = TIE LINE
0 = TRAVERSE LINE

The end of a line is indicated by null field values (0), (see description of record 1, TIME values etc. will be 0).