ST. GEORGE'S BAY AEROMAGNETIC SURVEY

DEPARTMENT OF MINES & ENERGY
LICENCE 93-106-01-EM
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Report On:

ST. GEORGE'S BAY AEROMAGNETIC SURVEY

By:
HUNT OIL COMPANY
March 9, 1993 to March 16, 1993

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DATA ACQUISITION: Sander Geophysics Limited
DATA PROCESSING: Data Processing and Interpretation Commonwealth Geophysical Development Company, Ltd.
SURVEY LOCALITY: St. George's Bay, Newfoundland 47° 58.50N, 58° 08.91'W. to 48° 59.98N., 59° 42.78'W.

July 1994

HUNT OIL COMPANY
Derek J. Gillespie, P. Eng.
Senior geophysicist

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MAGNETIC SURVEY IN ST. GEORGE'S BAY
NEWFOUNDLAND, CANADA
LATITUDE 48oN TO 49oN
LONGITUDE 57oW TO 63oW

INTERPRETATION REPORT
MAY 15, 1993

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SUMMARY

In January 1993, Hunt Oil Company engaged Commonwealth Geophysical Development Company, Ltd., to organize the data acquisition and compilation of 3,300 kilometres of aeromagnetic data in and around St. George's Bay in western Newfoundland. Accordingly, Commonwealth Geophysical engaged Sander Geophysics Ltd., to acquire these data in February and March of 1993, and compile it in March and April of 1993. This stage of the survey is described in a separate report by Sander Geophysics. Commonwealth Geophysical interpreted this data set in April and May of 1993. This report describes the interpretation procedures and some conclusions made from the aeromagnetic data.

The total field magnetic maps have a significant component of short wavelength anomalies from shallow depth (depth < 1km) sources. After filtering to remove short wavelength anomalies the maps revealed the regional trends of magnetic basement. The filtered magnetic field was reduced to the north pole and a source parameter map (scaled second derivative) was generated. The final structure map was based on these maps as well as the depths to the sources computed from the profile data. The area was divided into fault blocks, with depths averaged over the blocks. The basement is very shallow over Port au Port Peninsula and along the northwest edge. The basement depth is two to four kilometres below sea level elsewhere. There are some indications of basement trapped in overthrusted blocks and some anomalies which may be of interest in mineral exploration. These are highlighted on the final structure maps.

INTRODUCTION

The Geological Survey of Canada (GSC) has magnetic and gravity data over specific areas available for general distribution. Geoscientists associated with the GSC have analyzed these data and published their interpretations, concentrating mainly on deep crustal structure. Hunt Oil Company engaged Commonwealth Geophysical in March 1990, to study these data and derive basement structure maps. The report of this work described the processing of this aeromagnetic and gravity data, as well as an interpretation of basement structure, in an effort to demarcate areas of particular interest for hydrocarbon exploration. The aeromagnetic data had a gap in the area of St. George's Bay. Hunt Oil Company, in association with Marathon Petroleum Canada Ltd., engaged Commonwealth Geophysical to organize a survey to cover this gap and interpret the acquired data. Commonwealth Geophysical subsequently engaged Sander Geophysics Ltd., of Kanata, Ontario to acquire the data set, apply the necessary corrections and compile it into appropriate data files and total magnetic field maps. This operation is described in a separate report by Sander Geophysics.

BASIC DATA

The aeromagnetic data were acquired in February and March 1993 and compiled in March and April 1993. The flight elevation was 487m above sea level except in the high-relief area in the northeast and southern comer where data were acquired at 649m and 974m above sea level with a gentle gradation from the adjacent area. No effort was made to combine this interpretation with that of the St. Lawrence data interpretation done in 1990.

The magnetic profile data, acquired at 3 km spacing for traverse lines and 6 km spacing for tie lines, was used to create a grid with a point spacing of 375m using a minimum-curvature gridding routine. Commonwealth Geophysical processed profile data for depths of magnetic sources. Three types of maps were generated to assist in the structural interpretation: total field filtered to reduce anomalies due to shallow sources; these fields after reduction to the north pole; and source parameter maps (scaled second derivative after reduction to the pole).

GEOLOGICAL SETTING

The geological history of the Gulf of St. Lawrence and western Newfoundland is long and complex; a simplified description is given here (following Hydrocarbon Potential of the Western Newfoundland Onshore Area, Department of Energy, Government of Newfoundland and Labrador, 1989).

The Humber Zone of western Newfoundland and its extension under the Gulf of St. Lawrence is of interest for its hydrocarbon potential. The Humber Zone is the continental margin that formed the western shore of the Late Precambrian - Early Paleozoic Iapetus Ocean. The underlying Precambrian Grenvillian basement was formed about 1.1 billion years ago by a northwesterly directed compression, accompanied and followed by block faulting and intrusion by mafic dykes and anorthosites. Rifting of this Precambrian basement produced the Iapetus Ocean. Carbonate sequences were deposited on the margin in Early - Middle Ordovician time, with shale layers deposited farther offshore. Three orogenic events affected the

Humber Zone: The Taconic Orogeny (late Middle Ordovician) thrust slope to basin sediments over the shelf carbonates; the Acadian Orogeny (Middle to Upper Devonian) deformed the carbonate layers and thrust a large block of Precambrian basement over younger rocks to form the Long Range Mountains; and the Alleghenian Orogeny (Carboniferous) produced northeasterly trending faults and folds within Carboniferous rocks.

PROCESSING OF MAGNETIC DATA

Spectra

A power spectrum of the total field data, either from a profile or averaged over a grid, gives an estimate of the average depth to a group of sources. The spectrum plot (natural log of power vs. frequency) can be divided onto several linear segments. The slope of each segment gives the depth of the sources corresponding to the anomalies in this segment. Spectra computed for portions of the area, (Figure 2a, b, c for grid and 3a, b, c for profiles), indicate depth levels of about 2.3km for deep sources and 0.25 - 0.90 km for shallow sources. These shallow sources probably correspond to Precambrian basement which has intruded as in the north and northwest part of the area or has moved with the thrust faulting prevalent in the area.

The power spectra indicate that the thresholds separating deep from near-surface sources are approximately 0. 15 c/km for these data.

Filtered and Reduced to the Pole Maps

Filtered grids were computed with an appropriate filter to attenuate anomalies arising from shallow sources. These data were also reduced to the pole. Maps for the total field and filtered field reduced to the pole have been submitted separately. Low-pass filtered grids were computed by applying a filter of 0 - 0. 133 c/km on the total field grid. The filter was designed by inverse Fourier transform of the two-dimensional impulse response, and applied in the space domain. In practice, these filters succeeded in attenuating very sharp near-surface anomalies, but did not affect anomalies at depths of 1 km or more. For reduction to the pole, one operator was devised similar to the Baranov Operator (Jain, 1987, enclosed) and applied to the filtered grid. Magnetic field inclination (71.7°) and declination (21.7°), corresponding to the centre of the area, were used for the year 1993. The dimension of the operator was 7.5 km by 7.5 km, which is appropriate for the expected depths of the Precambrian and magnetic basement. The only significant effect of reduction to the pole on the filtered maps is a small northward movement of the centre of the anomalies. This is expected at high latitudes.

Source Parameter Map

The Source Parameter Map (Jain, 1974, enclosed) outlines the sources by the zero contour. The susceptibility contrast of the bodies is defined by the highest contour within the body. The sources are assumed to be vertical, semi-infinite prisms with uniform magnetization. Thus, the same map shows the anomalous source bodies by the zero contour, and the magnetization level of the magnetic basement. To minimize the impact of shallow sources, a source parameter map was computed from filtered reduced-to-the-north-pole grid, for an average depth of 2 km.

It appears that the Precambrian is outside the Port au Port Peninsula area. Over the peninsula the sources become increasingly magnetic towards the north. The weak basement in the south and west part of the area is also an indication of deep basement, perhaps significantly deeper than the 4km depth estimated by MAGDEP.

Depth Calculations

The data along the traverse and the lines were acquired at approximately 22m intervals. All of these profiles were used to compute parameters of sources at various depths, using an automatic

Werner-based program called MAGDEP (see Jain, 1976, enclosed). The data spacing for interpolated profiles was 100m. A MAGDEP profile shows the observed total field, and the horizontal gradient computed from this field, in the top half of the plot. Parameters for the source of the anomaly were computed using the total field anomaly and the horizontal gradient, and are shown in the lower half of the plot. Diurnal variations, radar and barometric altitudes are plotted in the center of the plot. An example is shown in **Figure 4**.

In the MAGDEP program, a window of seven equidistant points is used to compute one depth estimate and the window is moved by one sample point after each computation. Source locations falling within a narrow horizontal and vertical window (100 meters) are grouped together and are marked with one symbol on the plot. The length of the window determines the depth ranges of the sources included in the computation. Calculations are done for various window lengths to include all depth ranges of interest, the window length being controlled by the interval between successive points in the window. Symbol size indicates the length of the window used to calculate the parameters for that source.

The parameters computed from the total field (circles) were found assuming the source to be a thin semi-infinite dyke, and those from horizontal gradients (triangles) are computed for a semi- infinite edge. The number of sources found within a 100m range is written above the symbol plotted for the group of sources. The thin line projecting from the circle or triangle indicates the orientation of the dyke or edge, the small number at the end of the line indicates susceptibility contrast for the edges and this contrast multiplied by the thickness for the thin dykes. Some of the sources identified by the MAGDEP computations are related to susceptibility contrasts in the igneous basement, which can often be related to the top of basement rocks. However, there are not enough of these sources to permit mapping with any detail.

The equations used in MAGDEP assume the sources to extend infinite depth. The bodies whose edges are found from the horizontal gradient are assumed to be very wide, and the bodies found from the total field are assumed to be very thin. If these conditions are not met, computed depths may, in extreme circumstances, be up to 30% less than the actual depths. Another problem noted in this survey is related to deviation of flight lines from straight lines when the magnetic field has a steep gradient. These flight deviations caused spurious anomalies on the profiles which had to be screened out in the final interpretation.

Depth interpretations together with anomaly orientation were used to identify fault patterns as well as to interpret depths to magnetic basement. Sources were identified, their depths plotted on the maps, and the depth to magnetic basement was contoured. Fault-slip direction is indicated where it could be determined.

The original interpreted MAGDEP profile sections will be submitted separately to the operator.

INTERPRETATION

Maps Prepared in the Study:

All maps generated in this project were plotted at a scale of 1: 100,000. The maps included in this interpretation are:

1. Flight-line location map.

2. Total magnetic field from gridding of profile data, contoured on vellum at an interval of 5 nT. A plot in color at a scale of
   1: 1,000,000 at a 50 nT contour interval is shown in Figure 5.

3. Filtered magnetic field reduced to the north pole, contoured on vellum at an interval of 5 nT. A colour plot at a scale of 1: 1,000,000 at a 50 nT contour interval is shown in Figure 6.

4. Source-parameter map, which is a scaled second-derivative map after reduction to the pole, on a

vellum at an interval of 250 CGS units. A colour plot of this map at a scale of 1: 1,000,000 is shown in Figure 7.

5. Basement-structure map, with identified faults and estimated depths.

Flight-line and total-field maps were supplied by Sander Geophysics. Other maps were prepared by Commonwealth Geophysical. Culture boundaries were superimposed on these maps photographically.

Basement Structure Maps

The basement structure maps are based largely on fault locations identified on MAGDEP profiles and depths estimated from these profiles as they relate to the magnetic-anomaly distribution on the total field, filtered magnetic field and source parameter maps. A simplified basement structure map is shown in Figure 8.

Two sets of faults correspond to the anomaly trends; a major NNE - SSW to NE - SW trend and a subsidiary NW - SE trend. Faults identified as part of the NW - SE trend are probably younger with little vertical, but considerable lateral displacement.

The number of depth estimates available in a block was insufficient to allow contouring. Therefore, the average block depth was written. Where possible, a possible dip was indicated.

The regional change in the magnetic field in the area ranges from strong, short-wavelength anomalies in the north and northwest, to broad, weak anomalies in the southwest and southeast. High-amplitude, short-wavelength anomalies are due to Opheolites and basement intrusives, some of which are mafic. Some anomalies which may be of interest in mineral exploration are identified on the structure maps.

The trend of major magnetic anomalies is NE - SW, parallel to faults and folds created by northwest directed thrusting during formation of the Appalachians. This trend is defined by three strong positive anomalies in the eastern part of the area, separated by prominent lows. The anomalies become progressively sharper towards the northeast and their sources are at or near the surface in the eastern half of the map. To the northwest, south and southeast of these anomalies, the dominant wavelength suddenly increases to correspond to depths of 4km or greater. It must be noted that the extent of data probably restricted accurate depth estimates for deep sources and it is highly likely that the basement is deeper than 4km indicated by the MAGDEP interpretation.

Attention is drawn to a small anomaly parallel to, and approximately 12km from, the northwestern edge. This anomaly is probably due to a sliver of basement trapped in the Humber thrust.

All interpretation magnetic maps confirm the location of the boundary shown in thick lines as the edge where the basement slopes rapidly to a depth of several kilometres. Within this boundary, the basement rises from approximately 2km in the center of the area to the surface near the center of the northeast boundary of the map area.

There is another distinct indication of a weak anomaly which my indicate a basement sliver trapped and moved in the thrust faults. This is located quite close to the southwest edge of the Port au Port Peninsula at an approximate depth of 1.8km.

CONCLUSIONS

From the examination of diurnal field during flights, total field at flight line intersections, and quality of total-field and source-parameter maps, I consider the magnetic data to be most satisfactory. Some conclusions from the interpretation are:

1. The depth to sedimentary basement increases from 0 - 2km in the vicinity of Port au Port Peninsula, to

at least 4km in the south and west part of the study area.

2. There is evidence that thrust faults trapped and moved basement rocks at least in two places. These can be identified from small anomalies on the total field map.

3. There are features of hydrocarbon exploration interest in the area, as well as some distinct mineral exploration prospects.

It is strongly recommended that seismic data, if available, be incorporated in the interpretation of this data set.

Respectfully submitted,

COMMONWEALTH GEOPHYSICAL
DEVELOPMENT CO. LTD.,

Sudhir Jain

LIST OF FIGURES

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PROJECT REPORT
WEST NEWFOUNDLAND
AEROMAGNETIC SURVEY
for
Commonwealth Geophysical Development
Gerard X. Meusy, B.T.S. April 15, 1993

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INTRODUCTION

Sander Geophysics Limited (Appendix I) conducted a high-sensitivity aeromagnetic survey in the St. George's Bay area of western Newfoundland in March 1993. This survey was carried out under contract with Commonwealth Geophysical Development Company, Ltd. of Calgary, Alta. The contract was awarded on February 15, the first production flight took place on March 9 and the last one was completed on March 16, 1993. Seven flights totaling 3,436 line kilometres were required to Complete the survey.

SURVEY AREA

The survey area is comprised of one block of approximately 6,510 km2 in Southwestern Newfoundland, as illustrated on the Location Map (Figure 1). The block is contained within the following geographic coordinates, starting at the South corner and proceeding clockwise:

Table 1. Survey Area Coordinates

ST. GEORGE'S BAY

47°58.50 N	**59°09.00 W**
48°21.80 N	**59°42.78 W**
48°59.98 N	**58°42.65 W**
48°36.39 N	**58°08.91 W**

Approximately two-thirds of the survey area are over the waters of St. George's Bay and Port au Port Bay. The land part has a rugged topography with relief over 800 m. To the northeast are the Lewis Hills which culminate at 815 m and to the South are the Anguille Mountains which rise to 541 m. The centre of the survey area is occupied by the Port au Port Peninsula with maximum elevation of 354 m. Stephenville, located near the eastern corner of the survey area, has an elevation of 26 m.

SURVEY EQUIPMENT

The survey was flown using a company-owned Cessna 404 Titan, registration C-GBWE. The aircraft has been modified for high-resolution geophysical surveying and is equipped with a 2.5 m long, non-magnetic rigid stinger designed to accommodate a rnagnetometer sensor, preamplifier and wiring (Appendix II).

The following is a list of the equipment used in the aircraft:

Navigation System: Trimble 4000AX GPS Receiver
Five Channels, Analog and Digital Displays
Data Recorded: X,Y,Z in WGS-84 and UTC Time

Magnetometer: Scintrex VIW 2321 H8
Cesium Split Beam Magnetometer
Sensitivity 0.001 nT

Data Recording: Sander ABAT Computer
Data Acquisition System with 20 Mb Bernoulli Drive
Quartz Clock Control, corrected by GPS

Compensator: RMS Automatic Airborne Digital Compensator
Range 20,000 to 100,000 nT, Sensitivity 0.01 nT
Sampling Rate 10 Hz

Radar Altimeter: Honeywell HG7510CC01
Range 0 to 10,000 ft., Resolution 5 ft.
Calibrated to 1%

Barometric Altimeter: Sander BA2
Range 0 to 30,000 ft., Resolution 5 ft.
Calibrated to + / - 10 ft.

Video Tracking Panasonic DWV-5000
Camera/recorder

The following equipment was used in the ground station:

Position Reference: Trimble 4000RL GPS Receiver
Twelve Channels, Analog and Digital Displays
Data Recorded: X,Y,Z in WGS-84 and UTC Time

Magnetometer: Scintrex VIW 2321H8
Cesium Split Beam Magnetometer
Sensitivity 0.001 nT

Data Recording: Portable 286 Computer
120 Mb Hard Disk Drive

Optically Pumped, cesium split beam magnetometers manufactured by Scintrex were used both in the airplane and for the ground station. This standardization ensures that the two data sets are equivalent in terms of sensitivity (0.001 nT) and maximum noise level (0.05 nT). Furthermore, this allows for greater flexibility during field operations should sensor replacement be required. For this Survey, both magnetometers were H8 models, # 8703104 in the aircraft and # 8806101 on the ground.

Field office equipment included one Artel 486 Computer (486-1) for data processing, one Greff 386 (386-4) for archiving and one Zenith 286 (286-3) for routine plotting of flight data. These three machines were linked by a local area network. Two Fujitsu 24-pin dot matrix printers were used for plotting analog records, maps and profiles.

SURVEY SPECIFICATIONS

The flight plan included 36 traverse lines and 11 control lines (Figure 2). Traverse lines were to be flown in a N135oE direction at a mean spacing of 3 km, and control lines in a N045°E direction at a spacing of 6 km. Horizontal deviation tolerance was such that line separation could not exceed 3.25 km. The nominal survey altitude was 457 m (1,500 ft. ASL). However the topography of the survey area dictated that most of the lines over land had to be ramped up to a higher altitude. As a result, two blocks at 610 m (2000 ft.) and one at 915 m (3,000 ft.) were incorporated into the flight plan (Figure 2). Vertical deviation tolerance was + /- 30 m from the designated flight altitude over 5 km. Tolerances for diurnal variation were 15 nT per 15 min as maximum linear gradient and 5 nT per 5 min as maximum nonlinear variation. Airborne magnetometer specifications included a minimum sensitivity of 0.1 nT, a maximum noise envelope of 0.1 nT and a sampling rate of 0.10 s or no greater than 8 m in distance.

Compensation Test

A compensation test was carried out to determine the magnetic influence of aircraft maneuvers and the effectiveness of the RMS AADC compensator. These tests are done at a relatively high altitude over a magnetically quiet area. The aircraft performs pitches, rolls and yaws while flying in the four cardinal directions in survey configuration. The total compensated signal noise resulting from the 12 maneuvers is an indication of the effectiveness of the compensator and is referred to as the Figure of Merit of the aircraft. For this survey, the test was conducted on March 6 over the Port Au Port Peninsula, 3 km west of Stephenville. This resulted in a Figure of Merit of 1.59 nT, well within survey specifications. The compensation record is enclosed (Appendix III).

Altitude Setting

Data from a test flight and from the initial production flights were used to determine the differential GPS (DGPS) elevation equivalent to the nominal survey altitude of 457 m. Fifteen data points at 457 m above the water were selected from the analog records and flight video tapes. The corresponding DGPS elevations were obtained from the digital data and averaged. The result was 472 m. This figure was used for the altitude setting at the beginning of each flight. Furthermore, the DGPS elevation of each line was plotted and verified after each flight.

Radar Altimeter Test
The radar altimeter was tested systematically at the start of each flight. The intersection of the two main runways of the Stephenville airport (28 and 02) was used as a reference point. The flight video tapes were used to determine the exact time the aircraft flew over the target and the radar altimeter reading was obtained from the digital data. The CD corresponding DGPS elevation was obtained in the same manner, corrected by subtracting the altitude of the runway (also obtained in DGPS) and then plotted against the radar altimeter readings (Figure 3). Results indicate an overall accuracy of 1.75%, well within the 2.5% to required for this survey.

Navigation System Test
The accuracy of the navigation system was checked using data collected during the radar altimeter tests. DGPS coordinates obtained at the intersection of the two runways were averaged and compared with the coordinates measured on the aerodrome chart. Results show an 18 m error in northing and 7 m error in easting, well within the 50 m specification for this survey.

FIELD OPERATIONS

The base of operations was Stephenville, Newfoundland. A field office was established at the airport in the Stephenville Flying Club building. The combined magnetic/GPS ground station was located at the field office, making for a simple and efficient operation. The magnetometer sensor was positioned in an open area 100 m north of the building and the GPS antenna was mounted on a 30 ft. mast on one side of the building. The WGS-84 coordinates of the ground station were as follows:

N 48:32.7585
W 58:33.5146
Elev. 7.16 m

Weather conditions were generally poor. Five days were lost because of snowstorms and one flight was aborted because of low ceiling and bad visibility. Diurnal geomagnetic activity was high and resulted in two flights being recalled.

No significant equipment problems were encountered during the survey. The first production flight took place on March 9 and the seventh and last one on March 16. The total accepted production was 3436.2 km. Reflying totaled 331 km and was largely required because of excessive diurnal activity. Production is summarized in Table 2.

Table 2. Production Summary

FLIGHT	PRODUCTION	COMMENTS
FLT 01 (93.03.09)	186.0 km	ABORTED (DIURNALS)
FLT 02 (93.03.10)	181.4 km	
FLT 03 (93.03.11)	62.0 km	ABORTED (WEATHER)
FLT 04 (93.03.13)	925.1 km	
FLT 05 (93.03.13)	226.5 km	
FLT 06 (93.03.16)	855.2 km	ABORTED (DIURNALS)
FLT 07 (93.03.16)	Reflights	

In total, 19.8 hours of flying time were required to complete the survey.

Field operations were inspected by Dr. Sudhir Jain of Commonwealth Geophysical Development Company on March 12 and 13.

Field Operations Personnel
The following technical personnel of Sander Geophysics Limited participated in field operations:

Field Manager: Gerard Meusy March 1-19

Data Processor: Jennifer Meyer March 4-19

Pilot: Randy Forwell March 4-19

Copilot: William Heath March 4-19

DIGITAL DATA COMPILATION

Preliminary data compilation was performed in the field for on-site quality control. This included routine tracing of analog records after each flight and plotting of differential GPS data for flight path and flight altitude control. Final data compilation and map production took place at the Sander Geophysics office in Kanata. The data processing steps are illustrated on the Data Processing Flowchart (Figure 4).

Flight Path Recovery
A number of programs were executed for the compilation of navigation data in order to reformat and recalculate positions in differential GPS. Positions were transformed from the WGS-84 reference system used by GPS to the NAD-27 system used on the base maps. This involves a shift of about -206 m in northing, 80 m in easting and -19 m in elevation (Stephenville Airport). Final flight path maps were plotted at 1:100,000 scale.

Aerial Magnetometer Data
The aerial magnetometer data are recorded in flight at 10 Hz. Raw data were plotted and found to be free of spikes or noise, so that no filtering was required. The data were then corrected for diurnal variations by subtracting the ground station value from the corresponding airborne value, and adding the average ground station value back on, according to the following formula:

Corrected Total Field = Ap -Gp + G
with Ap = Airborne magnetic data,
Gp = Ground station data
and G = Average ground station value

A further correction was applied to remove the International Geomagnetic Reference Field. This was done on a point-by-point basis, using the 1990 IGRF updated to the actual time of each reading. The resulting data were rotated 45° clockwise to create a NS-EW array of residual magnetic field values. Intersections between control and traverse lines were determined from the rotated data by a program which extracts the magnetic, altitude and X and Y values of the traverse and control lines at the intersection point. Each control line was then adjusted by a specific constant value to minimize the sum for each traverse line of:

$$\Sigma \mid i - a \mid$$

where, i = (Individual intersection difference)
a = (Average intersection difference for that traverse line)

This process brings all control lines to the same datum as the average traverse line, no matter which line it actually intersects. A program allowing intersections to move within a 20 m by 20 m window was then used in order to minimize the differences remaining between traverse and control lines. Any residual difference is then corrected by levelling both traverse and control lines prior to gridding. This ensures that all intersections tie perfectly, so that only one value per intersection is used in the gridding process.

The data were rotated back to true position for levelling. Levelling was carried out by a computer program which interpolates and extrapolates levelling values for each point based on the two closest levelling values. The final levelled values were part of the data set converted to ASCII format for the line data archive.

Gridding was done on the rotated data, using the minimum curvature method. This method uses data from both control and traverse lines to create a two-dimensional grid equally incremented in X and Y directions. The algorithm produces a smooth grid by iteratively solving a set of difference equations which minimizes the total second horizontal derivative and attempts to honour input data (Briggs, I.C., 1974, Geophysics, v 39, no 1). The grid cell size used was 375 m by 375 m. The rotated grid data were extracted and converted to ASCII format as a final product.

Final contour maps were plotted at 1: 100,000 scale on one sheet using the rotated grid data. Flight lines screened at 80% and the topographic base map screened at 60% were combined with the residual magnetic field contours to produce the final map.

Ground Magnetometer Data

Minor level shifts (0.2 to 0.3 nT) of short duration (6 to 8 s) probably due to interference from the airport beacon were found in the ground magnetometer data of Flights 2 and 3. They were fixed manually using an on-screen editor. A few spikes present in the raw data were then removed automatically and the data were smoothed using a 67-point low-pass, symmetrical filter (Figure 5). The filtered data were plotted and inspected for quality and conformity to the original.

Altimeter Data

The barometric pressure altitude of the aircraft is measured constantly in flight and digitally recorded at 4 Hz. The pressure is put into ICAO standard atmosphere by fitting it to a third order polynomial equation which converts it to metres. Barometric altimeter data were filtered using a 21-point low-pass filter (Figure 6), plotted and inspected for quality and conformity to the original.

Radar Altimeter Data

The terrain clearance measured by the radar altimeter in flight is recorded in feet at 4 Hz and then converted to metres. The data were filtered to remove the high frequency noise using the same 21-point filter as for the barometric altimeter data. The filtered data were plotted and inspected for quality and conformity to the original.

Data Processing Personnel

Sander Geophysics personnel involved with the data processing of the West Newfoundland survey are as follows:

Project Geophysicist:	Stephan Sander
Software Coordinator:	Luise Sander
Geophysicist / Software Coordinator:	Bruce Coffin
Data Processing:	Jennifer Meyer
	Gerard Meusy
Plotting / Drafting:	Yves Collins
	Jeffrey Kertesz

FINAL PRODUCTS

1) Digital Data:

Line and Grid ASCII Archive on 9-track 1600 BPI tape	1 tape

2) Maps (1:100,000 Scale)

Residual Magnetic Field Contours	2 positive
Flight Paths	2 positive

3) Other Products:

Project Report	2 copies
Analog Flight Data Records (1 per flight)	7 records
Analog Ground Station Records (1 per flight)	7 records
Flight Video Tapes (1 per flight)	7 cassettes

APPENDIX I - COMPANY PROFILE (Information Sheet)

Sander Geophysics (SGL) specializes in high resolution airborne surveys for the oil and mining industries. The company carries out airborne magnetic, radiometric and VLF-EM surveys using fixed-wing aircraft and helicopters. Special attention is given to electronic navigation and flight path recovery in difficult areas. For this purpose the company has developed a navigation system "GPSNAV" which uses the Global Positioning System (GPS). This system, based on satellite instrument navigation, can be used anywhere in the world. It allows for excellent navigation and a very high accuracy of two meters in post flight recovery. It can be used with real time differential corrections for very accurate flying.

The company operates a well-equipped computing center using proprietary software to produce high resolution geophysical maps, derivatives and depth calculations. A variety of data presentation formats is available. Geophysical interpretation is carried out by an experienced professional staff.

HISTORY

SGL was founded in 1956 to provide geophysical services for the oil and mining industries. The company's first projects were land magnetic and EM surveys for mining exploration in northern Canada. The first airborne surveys were performed as early as 1958. Since then SGL has added an array of survey products for resource exploration.

SERVICES

The company currently specializes in surveys using one or more of the following methods:

* magnetic total field	* radiometric
* magnetic gradient	* VLF-EM

Digitally recorded navigation information resulting from the GPSNAV system offers greater speed in map production. It can also be used to correct satellite images and even to produce topographical maps.

All survey methods are performed using SGL's specially modified fixed-wing aircraft or helicopter.

The company is experienced in working under diverse geographical conditions from high mountains to offshore areas, from the Arctic to desert and jungle. Surveys have been conducted on five continents.

High quality data processing is an integral part of any survey performed by SGL. Careful attention is paid to maintaining all original information. Numerous methods of displaying data are available, including conventional contour maps, profiles and various forms of color and shading presentations.

SGL also offers a full range of data enhancement programs such as derivative computations, upward and downward continuation, IGRF or regional field removal and various forms of digital filtering.

Interpretation is carried out by experienced geophysicists with the aid of modeling programs, Werner depth profiles, and other related techniques. SGL provides complete interpretation of airborne geophysical data.

AIRCRAFT

SGL owns and operates fixed-wing aircraft and a helicopter for geophysical surveys. Aircraft currently available are:

Aircraft	Duration in Survey Mode (hrs with reserves)	Maximum Gross Weight (kg)
Cessna 404 Titan	8	3,810
Cessna 402B	6	2,858
Beech B80 Queenair	6	3,800
Aerospatiale AS 350 AStar (helicopter)	5	1,950

All of SGL's fixed-wing aircraft are equipped for magnetic and radiometric surveys including approved instrument racks, camera holes, and tail stingers. Extensive modifications have been performed to reduce the magnetic effect of the aircraft. These include replacement of components in the tail section of the aircraft with stainless steel parts and modification of the electrical system to reduce ground loops. Typical

Figures of Merit for SGL's fixed-wing aircraft are on the order of 1 nT after compensation, and 10 nT uncompensated.

The Beech Queenair aircraft is equipped with twin tail stingers separated by two meters to measure the vertical gradient of the magnetic field.

EQUIPMENT

SGL is engaged in an ongoing program to develop new and effective equipment for airborne geophysical surveying.

In recent years, the main area of research and development at SGL has been improved navigation equipment. A list of some of the equipment used by SGL follows:

Magnetometers

Sensor:	Scintrex H8 optically pumped cesium split beam
Compensator:	RMS 27 term digital computer based compensator for total field and gradient.
VLF-EM:	1) Hertz Totem, 2) Sander VLF-EM

Gamma-ray Spectrometers

Crystal detectors:	**Bicron** NAI, rectangle
Spectrometer:	**Exploranium** GR-820
Data acquisition:	**Sander ABAT**, Micro-computer based system
Recording	**Bernoulli** box with 90 megabyte disks

Navigation

GPS - Air:	**Novatel** 931(10 channel)
GPS - Ground:	**Trimble** 4000RL (12 channel)
Video Tracking:	**Panasonic**

FACILITIES

SGL's office is located in a modern 900 sq. m building in Kanata on the outskirts of Ottawa, Canada.

A complete electronics workshop is maintained with a complement of test equipment consistent with the research, development and production of geophysical instruments.

The SGL computer center has been operating for over 20 years and has successfully processed all data acquired in the various projects during that time. The company has developed a full suite of software for geophysical data processing.

Maps are produced to the high standard of the Geological Survey of Canada. Various forms of colour maps are available. The company operates a well equipped drafting section and its own photo laboratory.

KEY PERSONNEL

President: George W. Sander, Ph.D., P.Eng.

Chief Geophysicist: Stephan Sander, M.Sc.

Operations Manager: Reed Archer, B.Sc.

Chief, R & D: Stephen Ferguson, M.Sc.

Chief, Data Processing: Luise Archer, M.Sc.

APPENDIX II

SURVEY AIRCRAFT (Information Sheet)

GEOPHYSICAL AIRCRAFT

CESSNA 404 TITAN

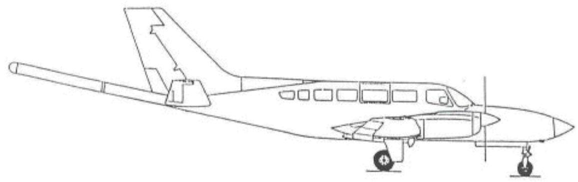
Registration: C-GBWE

Serial # 404-0624

The model 404 Titan Courier is an all metal, low wing, twin-engined aircraft powered by two turbocharged engines that drive constant speed, full-feathering propellers. The aircraft uses a fully retractable tricycle landing gear, extendable flaps and manually adjustable trim tabs on the primary controls for all three flight axes. The aircraft is equipped with full de-icing equipment and sufficient avionics for IFR and trans-oceanic flight.

The aircraft has a rigid aluminum and composite material 2.5 m tail stinger designed to accommodate a magnetometer sensor and wiring. This tail stinger can be easily removed and the aircraft can be returned to its original configuration. There is a camera hole in the floor of the aircraft.

The airframe has been extensively modified to reduce the magnetic signature of the aircraft by replacing ferromagnetic parts with those made from special nonmagnetic stainless steel or aluminum. Numerous wiring changes have also been made to the electrical system to reduce the magnetic field around the aircraft.



SPECIFICATIONS:

Crew capacity:	2 pilots
Fuselage:	8 seat, semi-monocoque
Wings:	-low wing
	-outboard ailerons
	-extendable flaps
Tail:	-conventional stabilizers
	-elevators rudder and trim tabs
Powerplants:	Two Teledyne Continental GTSIO-520-M2B, 375 HP, six cylinder, horizontally-opposed, air cooled, turbocharged, reciprocating engines
	-two three-blade fully-feathering, non-reversible hydraulically activated constant-speed propellers
Systems:	-dual flight controls with IFR instruments and avionics with an integrated flight control system and full 3 axes autopilot
	-airframe and propeller de-icing
	-weather radar
	-HF radio
	-extended range auxiliary fuel tanks
	-removable ferry tank, 200 L
Dimensions:	-wing span.................14.23 m
	-exterior length...........12 m
	-interior usable length..3 m
	-interior usable width..1.4 m
	-interior height.............1.3 m
Weights:	-empty........................2,396 kg (without passenger seats or survey equipment)
	-maximum take off......3,810 kg
Performance:	-cruise airspeed..........170 kts (315 km/hr.)

-stall airspeed.............70 kts (130 km/hr.)

-service ceiling...........7, 625 m

-take off run..............915 m

-landing run................671 m

-fuel capacity without ferry tank...1,378 L

-fuel flow (cruise at 65% power)....144 L/hr.

Engine overhaul: 1,600 hrs.

Propeller overhaul: 1,600 hrs. or 5 years

PROVISIONS FOR GEOPHYSICAL SURVEYING:

- **Tail stinger**, 2.54 m long and 18 cm in diameter, capable of housing a 5.5 kg sensor
- **HF radio**
- **Camera mount** and a 8 cm diameter glass covered opening in the belly of the aircraft
- **Two instrument racks**, standard 48 cm/19 in.
- **Radar altimeter**, 0-3,000 m
- **28VD** at 150 amp
- **Static inverter**, 115VAC 400 Hz
- **Provisions to mount an Inertial Navigation System**
- **Provisions to mount a GPS receiver and antenna**

APPENDIX III

AIRCRAFT COMPENSATION RECORD

Magnetometer Calibration Statistics (pdf - 109kb)

APPENDIX IV

ASCII DATA TAPE FORMAT

GENERAL TAPE SPECIFICATIONS

All archive tapes are:

- fully IBM compatible
- 2400' or 1200'
- no label ASCII
- 9-track, formatted

- 1600 bi
- block size of 5040 bytes
- record length of 80 bytes

Only the block header contains alphanumeric data.

The following files were submitted:

(i) **Line Archive**

File No.1 Block header
File No.2 Final data for each recorded point as it exists immediately prior to gridding.

Each archive contains a block header, then the final data used for each recorded point as it exists immediately prior to gridding.

(ii) **Grid Archive**

File No.1 Gridded data with header used to produce the final contour maps.

This archive contains a header and the gridded data used to produce the final contour maps. The grid archive was created from data rotated 45o.

All positional coordinates are in decimal of degrees and UTM projection was used for creating the gridded data.

LINE ARCHIVE OUTLINE

File No. 1 Block header

Contains basic information about the survey project and a description of the ASCII line archive format.

File No. 2 Final data for each recorded point

Line header for each line segment

Record 1: A,B,C,D,E,F,G Format (5|10,2F10.2,10X)

A = flight number
B = line number

C = segment number

D = direction code (1 = north, 2 = east, 3 = south, 4 = west)

E = control line code (0 = traverse line, 1 = control line)

F = start time of line segment (seconds)

G = end time segment (seconds)

Data for each line

Record 2: H,I,J,K,L,M,N,O,P   Format (F11.2,F11.5,F10.5,3F7.1,3F9.2)

H = time (seconds)

I = latitude coordinate, final position (decimal degrees)

J = longitude coordinate, final position (decimal degrees (negative - west of Greenwich)

K = altitude (metres)

L = radar altimeter (metres)

M = barometric altimeter (metres)

N = residual levelled magnetics (nanotesla)

O = edited raw total field (nanotesla)

P = edited ground station magnetics (nanotesla)

Note: There is a data record for each data point on the line.

The end of data for each line is denoted by two zero records in the same format as the data record and is followed by an END OF FILE on the last line.

Each new line segment starts with a new 5040 bytes block.

Unused data were nulled out by adding a constant number to the existing value.

GRID ARCHIVE OUTLINE

Header

Record 1: A, B, C, D, E, F   Format (2A10, F10.1, 1,2|10, E20.10, 10X)

Record 2: G, H, I, J   Format (4E20.10)

Record 3: K, L, M, N   Format (4E20.10)

Record 4: O, P, Q, R   Format (4E20.10)

Record 5: S, T, U, V   Format (4E20.10)

Record 6: W, X, Y, Z   Format (4E20.10)

Record 7: AA, BB, CC, DD Format (4E20.10)
Record 8: EE, FF, GG, HH Format (4E20.10)
Record 9: II, JJ, KK, LL Format (4E20.10)

A = NTS map sheet number
B = geophysical series map number
C = grid spacing (metres)
D = number of grid cells in X direction, number of columns
E = number of grid cells in Y direction, number of rows
F = central meridian
G = latitude of south west map sheet corner
H = longitude of south west map sheet corner
I = easting of south west map sheet corner
J = northing of south west map sheet corner
K = latitude of north west map sheet corner
L = longitude of north west map sheet corner
M = easting of north west map sheet corner
N = northing of north west map sheet corner
O = latitude of north east map sheet corner
P = longitude of north east map sheet corner
Q = easting of north east map sheet corner
R = northing of north east map sheet corner
S = latitude of south east map sheet corner
T = longitude of south east map sheet corner
U = easting of south east map sheet corner
V = northing of south east map sheet corner
W = latitude of south west grid sheet corner
X = longitude of south west grid sheet corner
Y = easting of south west grid sheet corner
Z = northing of south west grid sheet corner
AA = latitude of north west grid sheet corner
BB = longitude of north west grid sheet corner
CC = easting of north west grid sheet corner
DD = northing of north west grid sheet corner
EE = latitude of north east grid sheet corner
FF = longitude of north east grid sheet corner
GG = easting of north east grid sheet corner
HH = northing of north east grid sheet corner
II = latitude of south east grid sheet corner

JJ = longitude of south east grid sheet corner

KK = easting of south east grid sheet corner

LL = northing of south east grid sheet corner

Gridded data

Records 10 - nth: MM Format (8F10.3)

MM = string of grid values (nT) - each row begins a new record

Note: The grid is rotated clockwise 45°, corners stipulated in the header correspond to the rotated data.

For any map sheet, the numbers of grid values per row and column are constant for that map sheet (i.e. a full rectangle of gridded data).

If a grid point could not be given an interpolated value, then a null value (-9999.000) was assigned to that grid point.

ASCII DATA SPECIFICATIONS

FORMAT	NULL*	DATA TYPE	UNITS
F11.2	5000000.0	Time	seconds
F11.5	5000.0	Latitude coordinate	decimal degrees
F10.5	5000.0	Longitude coordinate	decimal degrees
F7.1	50000.0	Altitude	metres
F7.1	50000.0	Radar altimeter	metres
F7.1	50000.0	Barometric altimeter	metres
F9.2	500000.0	Residual leveled magnetics	nT
F9.2	500000.0	Edited raw total field	nT
F9.2	500000.0	Edited ground station magnetics	nT

***Null** = The value added to unused data

APPENDIX V
SURVEY LOG

Survey Log 1 (pdf - 147kb)   Survey Log 2 (pdf - 78kb)

APPENDIX VI
FLIGHT LOG

Flight # 1 (pdf - 63kb)   Flight # 2 (pdf - 107kb)   Flight # 3 (pdf - 53kb)

Flight # 4 (pdf - 92kb)   Flight # 5 (pdf - 60kb)   Flight # 6 (pdf - 84kb)

Flight # 7 (pdf - 51kb)