Technical Report

Acquisition of Airborne Geophysical Survey Data, South-Central Newfoundland

Newfoundland and Labrador
2019

for

Geological Survey, Department of Natural Resources, Newfoundland and Labrador

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1. EXECUTIVE SUMMARY

Sander Geophysics Limited (SGL) conducted a fixed-wing high resolution airborne magnetic gradient, gamma ray, and VLF ("Very Low Frequency") electromagnetic survey of the Twillick Brook area in South-Central Newfoundland for Natural Resources, Government of Newfoundland. Please refer to Appendix I for a company profile of SGL.

The traverse lines were oriented at 135° and spaced at 150 m, while the control lines were oriented at 045° and spaced at 1000 m. A drape surface was created taking into account the terrain and the performance of the aircraft at the expected altitudes and estimated temperatures. The survey was flown with a target clearance of survey 90 m above ground level. The target average ground speed was 67 m/s, or 130 knots.

The survey was flown using SGL's Cessna Grand Caravan 208B, registration C-GSGL operating from Gander. Production flights commenced on October 17, 2019 and data acquisition was completed on November 10, 2019. A total of 15 flights were carried out during the survey to complete the planned 9,899 line kilometres and a total of 6 SGL staff were employed on the field operations. The survey was completed without significant incident.

Final processing of the data was completed at SGL's head quarters in Ottawa Canada. Digital data products were delivered to the client on December 23, 2019. A total of 6 SGL staff were involved on the data reduction.

Picture 1: Survey aircraft

2. INTRODUCTION

This report describes the airborne survey of the Twillick Brook area that Sander Geophysics Limited (SGL) flew for the Department of Natural Resources, Government of Newfoundland in the fall of 2019 over South-Central Newfoundland. Magnetic gradient, gamma ray and VLF data were gathered during this survey.

The instruments used to collect the data are described in this report (Section 5. SURVEY EQUIPMENT) as well as the tests performed to calibrate instruments and to ensure optimal data quality (Section 6. SYSTEM TESTS).

Information relating field operations at the survey location including the airport used, reference stations established and any logistical problems encountered during the survey are provided (Section 7. FIELD OPERATIONS). Re-flights are listed as well as the field crew members.

Details of data processing performed from data acquisition to final product creation are described (Section 8. DIGITAL DATA COMPILATION).

A full description of the data formats delivered to the client are described (Section 9. FINAL PRODUCTS). One page colour maps of all the survey data types are included (Appendix VIII) and give a meaningful overview of the extensive data gathered.

The project brief in Table 2.1 gives a quick reference of the details of the survey.

Picture 2: Survey aircraft in flight

Table 2.1: Project Brief

Survey Details	
Survey Title	Airborne Geophysical Survey, South-Central Newfoundland
Client	Natural Resources, Government of Newfoundland
Survey Location	Twillick Brook, South-Central Newfoundland
Survey Start Date	October 17, 2019
Survey End Date	November 10, 2019
Contact	Gerry Kilfoil (gerry.kilfoil@gov.nl.ca)
Field Office Location	The Albatross Hotel, Gander, Newfoundland
Airport Used	Gander Airport
Aircraft Type & Registrations	Cessna Grand Caravan 208B, registration C-GSGL
Total line kilometres	9,899
Survey Flying Particulars	
Traverse Line numbers	1001-1276
Traverse Line direction	135°
Traverse Line spacing	150 m
Control Line numbers	101-159
Control Line direction	045°
Control Line spacing	1000 m
Survey Altitude	90 m
Digital Terrain Source	SRTM
Number of Flights (and flight numbers)	15 (1001-1015)
Aircraft Target Ground Speed	130 knots / 67 m/s
Data	
Survey Base Parking Location (Datum WGS-84)	N48:56:30.85/W54:33:21.02/124.0m
GPS Base Station Locations (Datum WGS-84)	REF1: N48:56:28.01/W54:33:17.88/142.72 m REF2: N48:56:27.99/W54:33:17.89/142.74 m
Data Delivery Datum	NAD-83
Data Delivery Projection	Universal Transverse Mercator Zone 21 North

3. SURVEY AREA

The survey area covers the Twillick Brook area, southeast of the town of Gander, where operations were based. The survey area is fairly flat, with some hills. There is a moderate amount of tree cover interspersed with many open areas having peat bog or low bush cover. The survey area is all onshore, although there are several lakes within the block, with Jeddore Lake being the largest. The altitude of the survey area varies from approximately 90 m above mean sea level (MSL) to approximately 440 m above MSL. There is no significant infrastructure within the block, nor any hazards. Typical Fall weather in the area is cool, with temperatures in the -2°C to 10°C range for October and November, often with significant precipitation around 83 mm per month.

The block is bounded by the coordinates provided in Table 3.1. The survey was flown as a single block. Figure 3.1 and Figure 3.2 show the geographical location of the survey area. The planned survey lines are illustrated in Figure 3.3 and are listed in (Appendix II).

Survey Area Map

Figure 3.1: Survey Area location

Figure 3.2: Survey Area location

Saint Alban's
© 2019 Google
Image © 2020 Maxar Technologies
Image © 2020 CNES / Airbus
Image © 2020 Maxar Technologies
Google earth

Figure 3.3: Planned survey lines

Table 3.1: Survey block boundary (WGS-84, Latitude/Longitude)

Latitude (Deg:Min:Sec)	Longitude (Deg:Min:Sec)
N47:50:55.9358	W55:30:05.7669
N48:00:38.6043	W55:44:02.2381
N48:00:11.5774	W55:44:43.8535
N48:01:21.3754	W55:46:24.5828
N48:00:10.3802	W55:48:13.7687
N48:01:20.1309	W55:49:54.5774
N48:00:12.4615	W55:51:38.4902
N48:01:22.1629	W55:53:19.3771
N48:00:11.0569	W55:55:08.4077
N48:02:34.9684	W55:58:37.1532
N48:03:22.4142	W55:57:24.4710
N48:04:32.0290	W55:59:05.5909
N48:04:38.8070	W55:58:55.2046
N48:05:02.0074	W55:59:28.9282
N48:05:15.5675	W55:59:08.1525
N48:05:38.7668	W55:59:41.8843
N48:05:59.1059	W55:59:10.7151
N48:06:22.3051	W55:59:44.4551
N48:06:29.0840	W55:59:34.0639
N48:06:52.2812	W56:00:07.8122
N48:06:59.0640	W55:59:57.4196
N48:07:22.2593	W56:00:31.1763
N48:07:42.6020	W55:59:59.9953
N48:08:05.7971	W56:00:33.7597
N48:08:29.5279	W55:59:57.3728
N48:08:52.7233	W56:00:31.1457
N48:09:13.0658	W55:59:59.9489
N48:09:36.2609	W56:00:33.7300
N48:09:59.9948	W55:59:57.3251
N48:10:23.1901	W56:00:31.1138
N48:10:43.5324	W55:59:59.9021
N48:11:06.7276	W56:00:33.6991
N48:11:30.4612	W55:59:57.2762
N48:11:53.6566	W56:00:31.0817

Latitude (Deg:Min:Sec)	Longitude (Deg:Min:Sec)
N48:12:13.9986	W55:59:59.8541
N48:12:37.1938	W56:00:33.6679
N48:12:54.1447	W56:00:07.6396
N48:13:17.3393	W56:00:41.4612
N48:13:41.0733	W56:00:05.0132
N48:14:04.2681	W56:00:38.8434
N48:14:24.6104	W56:00:07.5944
N48:14:47.8050	W56:00:41.4328
N48:16:40.7875	W55:57:47.7012
N48:15:07.9358	W55:55:32.4053
N48:15:21.4798	W55:55:11.5443
N48:14:58.2586	W55:54:37.7416
N48:15:21.9599	W55:54:01.2274
N48:14:58.7329	W55:53:27.4336
N48:15:22.4280	W55:52:50.9104
N48:14:59.1921	W55:52:17.1255
N48:15:22.8809	W55:51:40.5933
N48:14:59.6426	W55:51:06.8172
N48:15:23.3250	W55:50:30.2760
N48:15:00.0811	W55:49:56.5088
N48:15:20.3743	W55:49:25.1808
N48:14:57.1218	W55:48:51.4225
N48:15:20.7922	W55:48:14.8646
N48:14:57.5374	W55:47:41.1152
N48:15:21.2014	W55:47:04.5483
N48:14:57.9409	W55:46:30.8077
N48:15:24.9758	W55:45:49.0063
N48:15:01.7093	W55:45:15.2747
N48:15:25.3570	W55:44:38.6886
N48:15:02.0848	W55:44:04.9660
N48:15:25.7295	W55:43:28.3708
N48:15:02.4516	W55:42:54.6570
N48:15:29.4644	W55:42:12.8229
N48:15:06.1805	W55:41:39.1186
N48:17:21.1669	W55:38:09.7668
N48:16:34.5571	W55:37:02.3882

Latitude (Deg:Min:Sec)	Longitude (Deg:Min:Sec)
N48:18:05.5876	W55:34:40.9057
N48:15:45.6244	W55:31:18.9844
N48:15:48.9903	W55:31:13.7419
N48:14:10.9579	W55:28:52.5792
N48:13:33.9264	W55:29:50.2316
N48:13:10.5830	W55:29:16.6426
N48:12:47.0143	W55:29:53.3183
N48:12:23.6713	W55:29:19.7373
N48:12:03.4703	W55:29:51.1656
N48:11:40.1271	W55:29:17.5926
N48:11:19.9262	W55:29:49.0136
N48:10:56.5829	W55:29:15.4487
N48:10:33.0139	W55:29:52.0971
N48:10:09.6709	W55:29:18.5402
N48:09:49.4696	W55:29:49.9455
N48:09:26.1264	W55:29:16.3966
N48:09:02.5603	W55:29:53.0271
N48:08:39.2174	W55:29:19.4862
N48:08:19.0159	W55:29:50.8753
N48:07:55.6728	W55:29:17.3429
N48:07:32.1031	W55:29:53.9547
N48:07:08.7603	W55:29:20.4298
N48:06:48.5585	W55:29:51.8038
N48:06:25.2156	W55:29:18.2869
N48:06:05.0138	W55:29:49.6536
N48:05:41.6708	W55:29:16.1447
N48:05:18.1007	W55:29:52.7298
N48:04:54.7580	W55:29:19.2293
N48:04:34.5558	W55:29:50.5800
N48:04:11.2129	W55:29:17.0875
N48:03:47.6457	W55:29:53.6543
N48:03:24.2999	W55:29:20.1693
N48:03:10.8350	W55:29:41.0605
N47:58:30.5324	W55:22:59.8927
N47:58:00.2708	W55:23:46.8789
N47:57:36.9000	W55:23:13.5019

Latitude (Deg:Min:Sec)	Longitude (Deg:Min:Sec)
N47:53:48.1049	W55:29:08.0099
N47:53:24.7592	W55:28:34.6364
N47:52:40.9870	W55:29:42.3104
N47:52:17.6441	W55:29:08.9444
N47:51:54.0753	W55:29:45.3704
N47:51:30.7327	W55:29:12.0126
N47:50:55.9358	W55:30:05.7669

Picture 3: View of the survey area from the survey aircraft

4. SURVEY SPECIFICATIONS

Data Recording

In the aircraft:

- GPS positional data (time, latitude, longitude, altitude and raw range from each satellite being tracked) at 10 readings per second;
- Altitude as measured by the barometric altimeter at 10 readings per second;
- Terrain clearance as measured by the radar altimeter at 10 readings per second;
- Terrain clearance as measured by the laser rangefinder at 1000 readings per second;
- Total magnetic field recorded at 160 readings per second from the port wing tip sensor (#1), the starboard wing tip sensor (#2), and the tail stinger sensor (#3);
- Airborne gamma ray data recorded in windowed and 1024 channel spectral format at 1 reading per second;
- Outside air temperature at 10 readings per second;
- Digital video at 30 frames per second.

At the base and remote magnetic/GPS reference stations:

- Total magnetic field at 11 readings per second;
- GPS positional data (time, latitude, longitude, and raw range from each satellite being tracked) at 10 readings per second.

Technical Specifications

The following technical specifications were adhered to:

Survey speed

- The ground speed for the survey aircraft, flying traverse or control lines will be limited to a range between 200 km/h and 270 km/h (~108 to 145 KN), (~55 to 75 m/s).

Survey altitude and tolerances

- The survey flying height will be 90 m NTC (nominal terrain clearance) except in areas where Transport Canada regulations prevent flying at this height. In areas where obstacles or topography conflict with the planned terrain clearance, the pilot's judgment shall prevail within reason. The survey height must be controlled according to the pre-defined smooth drape surface.
- Where the above exceptions do not apply, traverse lines and control lines must be flown to within +/- 15 metres of the pre-planned drape surface.

Flight lines

- Parts of traverse lines reflown to complete a traverse line must cross control lines at either end and join the original traverse line at a low angle at a point where the data conforms to the technical specifications. All segments of a traverse line must begin and end by crossing control lines. Conversely, segments of a control line must start and end by crossing a common traverse line. All traverse lines must intersect a minimum of two (2) control lines. Outside survey boundaries, all traverse lines must start or end by intersecting a control line. If that intersection is within the 1 km overfly zone, then the traverse must extend to the next control line. No perimeter lines are to be flown. No gaps will be accepted in the final products.
- For each survey flight, adjacent lines must be flown consecutively and in opposite directions. Racetrack flying pattern will not be permitted.
- The flights should be carried out during optimum diurnal and gamma-ray spectrometry data acquisition conditions as gamma-ray spectrometry will be required along control and traverse

lines.

Diurnal limits

- A maximum tolerance of 3.0 nT (peak to peak) deviation from a long chord equivalent to a period of 60 seconds for each base station.
- A maximum tolerance of 0.5 nT (peak to peak) deviation from a long chord equivalent to a period of 15 seconds for each base station – in order to limit ULF waves (micropulsations).
- These specifications must be verified in the field prior to demobilization.

Precipitation Limitations

- Varying ground moisture conditions affect the airborne radioactivity measurements. No survey flying should be undertaken during or for 3 hours after measurable precipitation. In the event of heavy precipitation yielding more than 2 cm of ground soaking rain, flying should be suspended for at least 12 hours after end of precipitation or until soil returns to its "normal" moisture level.

Magnetometers

- Magnetometer data must be compensated for system orientation effects. Three sensors are required and must be rigidly attached to the aircraft. Two will be mounted along the transverse axis on the wingtips with a minimum separation of 5 m. The third magnetometer will be mounted on the longitudinal axis of the aircraft and there shall be a minimum longitudinal separation between the two transversely-mounted magnetometers and the longitudinally-mounted magnetometer of 5 m.

Gamma-ray Spectrometer

- The gamma-ray detectors must be positioned in the aircraft such that shielding of the detectors by the fuel tanks is minimal.
- Systems which use multiple detectors independently digitized and combined to a single output spectrum must preserve the Poisson distribution in all output spectrum channels.

GPS

- Real time differential GPS sensors must be deployed on the cockpit and tail ends of the longitudinal axis of the aircraft, as well as on one of the wingtips. An alternate method of determining aircraft roll, pitch and yaw may be substituted at the discretion of the Scientific Authority.
- Post-flight differential correction of the raw GPS data is mandatory.

Radar Altimeter

- Radar altimeter, with digital output and a precise radar display, must form part of the ancillary equipment for the survey aircraft.
- Radar Altimeter
  Minimum range: 0-800 m
  Accuracy (minimal) 5%

Barometer and Thermometer

- The barometer must be capable of measuring the absolute air pressure to 0.1 kPa. The thermometer must be capable of measuring the external ambient temperature to 1°C

Video Camera

- Recording speed must be set to Standard Play (SP) mode if using VHS, or equivalent resolution if using digital camera technology. The image overlay must show time to tenths of seconds, position and image centre cross-hair.

Ground Magnetometer Stations

- At least one base station is required in proximity to the survey area. The base station must record data at a rate of 1 sample per second and record GPS time with each magnetic base station reading.

Flight Line Specifications

The survey target average ground speed was 67 m/s (130 knots).

The survey area flight line specifications are provided in Table 4.1. Survey lines are planned as straight in the UTM reference frame and the line direction is given with respect to UTM North.

Table 4.1: Flight line specifications

	Line Direction	Line Spacing (m)
Traverse Lines	135	150
Control Lines	045	1000

The target survey altitude above ground ("clearance") was 90 m.

A pre-planned drape surface was prepared to guide the aircraft over the topography in a consistent manner, as close to the target clearance as possible. The drape surface was prepared with 1 Arc second resolution digital elevation model (DEM) data obtained from the Shuttle Radar Topography Mission as follows:

https: //earthexplore.usgs.gov

The DEM data included an extension beyond the survey boundary to allow the aircraft to achieve the drape clearance before coming on line.

The drape surface was created with climb and descent rate of 5.9% (360 ft/NM) at sea level and 6.2% (375 ft/NM) at an altitude of 440 m (1444 feet) above sea level taking into account the survey aircraft configuration and expected climatic conditions. Interpolation or extrapolation was used to calculate climb and descent rates for the smooth surface for all expected survey elevations. The temperature component used for the calculation was based on published weather history. The gentle drape surface created was below the maximum climbing and descending capabilities of the survey aircraft and guided the aircraft as close to the target height of 90 m above the terrain as possible in all locations whilst retaining reasonable safety margins.

Picture 4: Some of the survey crew at Gander Airport

5. SURVEY EQUIPMENT

SGL provided the following instrumentation for this survey; see *Appendix III* for further details:

Airborne Navigation and Data Acquisition System

Sander Geophysics Data Acquisition System (SGDAS)

The SGDAS is the latest version of airborne navigation and data acquisition computers developed by SGL. It is the data gathering core for all the different types of survey data. The computer incorporates an altimeter analog to digital converter and a NovAtel GPS multi-frequency receiver (see the GNSS and GPS Receivers section below for the details) which automatically provides the UTC time base for the recorded data. The system acquires the different data streams from the sensors and receives and processes GPS signals from the GPS antenna. Navigation information from the navigation side of the computer guides the pilots along the pre-planned flight path in all three dimensions. Profiles of the incoming data are displayed in real-time to the pilots for continuous monitoring. The data are recorded in database format on redundant solid-state data storage modules.

Aerial and Ground Magnetometers

Geometrics G-822A

Both the ground and airborne systems used a non-oriented (strap-down) optically-pumped cesium split-beam sensor. These magnetometers have a sensitivity of 0.005 nT and a range of 20,000 to 100,000 nT with a sensor noise of less than 0.0005 nT. One airborne sensor designated as #3 was mounted in a fibreglass stinger extending from the tail of the aircraft. The system included two additional sensors, #1 and #2, housed in each wingtip pod to record the horizontal magnetic gradient. Total magnetic field measurements were recorded at 160 Hz in the aircraft, then later down sampled to 10 Hz in the processing. The ground systems recorded magnetic data at 11 Hz.

Picture 5: Ground magnetic sensor installation

Magnetic Compensation System

Sander Geophysics AIRComp

SGL's own hardware and software system, AIRComp, was used to remove the effects of the aircraft and its manoeuvres from the recorded magnetic data. This system records the magnetic field measured by up to 4 cesium magnetometers, as well as the three axis output of a fluxgate magnetometer. These data are recorded for post-processing. Calibration of the magnetic effects of the aircraft is carried out as described in Section 6 – SYSTEM TESTS. Coefficients to be used for compensation are derived by processing the calibration flight data. The compensation coefficients are applied to data recorded during normal survey operations to produce compensated magnetic data.

Airborne Gamma Ray Spectrometer System

Sander Geophysics SGLSpec with crystal detector packs SGX-4/5

The Sander Geophysics spectrometer system includes an Advanced Digital Spectrometer (ADS) for each crystal providing real-time signal processing and analysis, and allowing automatic gain control for individual crystals using the natural thorium peak, and multi-channel recording and analysis. The system utilizes a NaI(Tl) detector volume of 58.8 L consisting of 12 downward-looking and 2 upward-looking parallelepiped crystals of 4.2 L each, housed in 3 detector packs. Data were recorded in 1024 channel spectral mode and windowed data mode at an interval of 1 Hz.

Very Low Frequency (VLF) Electro-Magnetic Instrumentation

Herz Totem 2A

The Herz Totem 2A VLF-EM receiver consists of three orthogonal coils mounted in a 2.5 m fibreglass stinger installed on the tail of the aircraft. The instrument simultaneously measures the total field strength (from all three coils) and the vertical quadrature component (from the vertical coil only) of the magnetic field induced by two different selected VLF stations designated as Line and Ortho, for a total of four channels of data. The Line station is selected to be in a direction more or less parallel to the primary survey lines, whilst the Ortho station is selected to be more or less perpendicular to the primary survey lines, depending on availability and proximity of operating VLF stations with respect to the survey area. Prior to each flight, the frequency of the Line and Ortho channels, which may lie between 15.0 to 24.3 kHz, are selected individually using three digital thumb-wheel switches. For this survey, the VLF stations in Cutler, Maine, and LaMoure, North Dakota were used as Line stations whilst Rhauderfehn, Germany, and Skelton, U.K. were used as Ortho stations. The Cutler station operates at a frequency of 24.0 kHz, LaMoure at 25.2 kHz, Rhauderfehn at 23.4 kHz, and Skelton at 22.1 kHz.

A nominal primary total and quadrature field strength for each frequency is determined pre-flight whilst the aircraft is parked, and all measurements are recorded as a percentage of these values. The output scale is plus 100 % = 1.0 V. The receiver is tuned to the selected frequency and the gain is adjusted such that the voltage reads 1 V, corresponding to 100 % primary field strength (all measurements are relative to this value). All total field measurements (only) are offset by -1.0 V to read 0 V for 100 % signal.

Reference Station Acquisition System

Sander Geophysics MSGRef

The MSGRef (mini SGRef) consists of a data acquisition computer and a GNSS receiver (see the GNSS Receivers section below for the details). All data are displayed on an LCD flat panel monitor. The GNSS data, sampled at 10 Hz, are recorded on the internal hard drive of the computer and the removable hard drive simultaneously for transfer to the processing computers in the field office. The entire reference data acquisition system is fully automatic and was set for

unattended recording.

GNSS Receivers

NovAtel OEM4 receiver boards

The OEM4 is a high performance, high accuracy, dual-frequency GPS receiver that is capable of receiving and tracking the L1 C/A code, L1 and L2 carrier phase, and L2 P-code (or encrypted Y-code) of up to 24 channels. The GPS data are recorded at 10 Hz. OEM4 receivers are employed in one of the MSGRef ground stations and airborne CDAC.

NovAtel OEMV-3 receiver board

The NovAtel OEMV-3, multi-frequency GNSS (Global Navigation Satellite System) receiver is configurable up to 72 channels with the tracking of GPS (L1, L2, L5), GLONASS (L1, L2), SBAS, and L-band satellites and signals. It provides averaged position and raw range information of all satellites in view. GNSS positional data are recorded at 10 Hz. An OEMV-3 receiver is employed in one of the MSGRef ground stations.

Digital Video System

Sander Geophysics SGDIS - Digital Imaging System

The video camera is mounted in the floor of the aircraft and oriented to look vertically below while in flight. The system automatically records the position, time (fiducials), line and flight number on the digital video. The data are stored, by flight line, in Audio Video Interleave (AVI) format, viewable by any commercial media player.

Altimeters

SGLas-P – MDL ILM-1500-R Laser Rangefinder

The MDL laser altimeter uses a single optical laser beam to measure distance to the ground. It is effective over water and is eye safe. This profilometer has a range of 1500 m, a resolution of 0.01 m with an accuracy of 10 cm and a 1000 Hz data rate.

TRT ERT 530A Digital Radar Altimeter

The TRT uses radio wave echoing to determine the height above ground. It will generally "see through" foliage. The TRT radar altimeter has a resolution of 0.5 m, an accuracy of 1%, a range of 1 to 2,440 m and a 10 Hz data rate.

Bendix/King KRA-10A Radar Altimeter

The Bendix-King radar altimeter has a resolution of 0.5 m, an accuracy of 5%, a range of 6 to 760 m, and a 10 Hz data rate. This system is employed as a backup system and not actively employed for survey guidance or data processing.

Sensotec Digital Barometric Pressure Sensor

The barometric pressure sensor measures static pressure to an accuracy of ± 4 m and resolution of 2 m over a range up to 30,000 ft above sea level. The barometric altimeter data is sampled at 10 Hz.

Air Temperature Sensor

Omega RTD-805 Outside Air Temperature Probe

The outside air temperature is measured at 10 Hz with a resolution of 0.1 °C. The temperature sensor has a range of +/-100 °C and an accuracy of +/-0.2 °C. The temperature sensor is mounted in an air inlet duct at the point where the wing strut attaches to the right hand wing.

Survey Aircraft

Cessna 208B Grand Caravan (C-GSGL)

The Cessna 208B Grand Caravan is an all metal, high wing single-engine aircraft powered by a Pratt & Whitney Canada PT6A-114A engine driving a constant speed, full feathering, reversible propeller. The aircraft has fixed gear, extendable flaps, manually adjustable trim tabs, full de-icing equipment, and sufficient avionics for instrument flying. The Grand Caravan is equipped with a rigid aluminium and composite material 3 m tail stinger designed to accommodate the magnetometer sensor. The belly of the aircraft has a 14 cm diameter glass opening allowing for the laser altimeter and video camera. The airframe has been extensively modified to reduce the magnetic signature of the aircraft by replacing ferromagnetic parts with those made from special non-magnetic stainless steel or aluminium. Several wiring changes have also been made to the electrical system to reduce the magnetic field variations around the aircraft. Other alterations have been made to the Grand Caravan allowing for gravity, spectrometer, LiDAR and methane sensing surveys. All survey modifications are certified to meet the requirements of the Canadian Aviation Regulations (CARs). A complete description of this survey aircraft is given in *Appendix IV*.

Data Processing Hardware and Software

Compilation of the data was performed on high performance desktop and laptop computers optimized for data processing tasks. SGL's proprietary geophysical software was used for data processing.

6. SYSTEM TESTS

Altimeter System, Position and Digital Terrain Model Tests

Radar and Laser Altimeter Calibration

A test flight to calibrate the radar and laser altimeters was flown on October 5, 2019 over the runway at Gatineau Airport Quebec, east of Ottawa. 10 passes were conducted over the runway at heights from 90 to 460 m above ground at various levels. The average altimeter values per pass were compared to post-processed GPS altitude. An ideal altimeter would yield a slope of 1 and an intercept of 0. The TRT radar altimeter slope is 0.9938 and the intercept is 0.0969 m. The laser altimeter slope is 0.990 and the intercept is -1.7658 m. The King radar altimeter slope is 1.0571 and the intercept is -0.1700 m. These results are well within the expected accuracy of the altimeters. Please refer to Figure 6.1 which illustrates the results of the altimeter test.

Figure 6.1: Altimeter test results, October 5, 2019

A post-survey altimeter test was performed on November 23 over Gatineau Airport to verify the calibration coefficients.

6 passes were conducted over the runway at heights from 60 to 360 m above ground at various levels. The average altimeter values per pass were compared to post-processed GPS altitude. The TRT radar altimeter slope is 1.0023 and the intercept is 0.3796 m. The laser altimeter slope is 0.9981 and the intercept is 0.1596 m. The King radar altimeter slope is 0.9928 and the intercept is 0.1596 m. The improvement in the King altimeter result reflects changes made to the calibration coefficients following the October 5 test. Please refer to Figure 6.2 which illustrates the results of the altimeter test.

Figure 6.2: Altimeter test results, November 23, 2019

Magnetometer System Tests

Compensation Calibration

Compensation calibrations determine the magnetic influence of aircraft and its maneuvers. During the compensation calibration flight, the aircraft performs sets of three pitches (+/-5 degree), rolls (+/-10 degree), and yaws (+/-5 degree), while flying in the four flight line directions at high altitude over a magnetically quiet area. The coefficients calculated from the calibration are applied to the acquired magnetometer data to measure the effectiveness of the compensation system in mitigating the magnetic interference.

The total compensated signal noise resulting from the twelve maneuvers, referred to as the Figure of Merit (FOM), is calculated from the maximum peak-to-peak value resulting from each maneuver. A new compensation calibration must be performed after any aircraft or system modifications that may affect the aircraft's magnetic field interference.

Compensation calibration flights at 10,000 feet were performed in the field location on October 23 and again on November 5, following a change of the starboard magnetometer. See Figures 6.3 - 6.8 for illustrations of the compensated and uncompensated data acquired during the compensation calibrations. Table 6.1 lists the compensation calibration tests performed and the results.

Figure 6.3: Compensator calibration – Port #1 – C-GSGL – October 23, 2019

Figure 6.4: Compensator calibration – Starboard #2 – C-GSGL – October 23, 2019

Figure 6.5: Compensator calibration – Tail #3– C-GSGL – October 23, 2019

Figure 6.6: Compensator calibration – Port #1– C-GSGL – November 5, 2019

Figure 6.7: Compensator calibration – Starboard #2– C-GSGL – November 5, 2019

Figure 6.8: Compensator calibration – Tail #3 – C-GSGL – November 5, 2019

Table 6.1: Magnetic compensation calibration tests and results

Date	Flight	Sensor	FOM (nT)	Used for Flights
October 23, 2019	9002	Port #1	0.36	1001-1013
		Starboard #2	0.69	
		Tail #3	1.65	
November 5, 2019	9004	Port #1	0.34	1014-1015
		Starboard #2	0.41	
		Tail #3	0.29	

Magnetometer Heading Test

A test was performed to measure the heading error of the magnetic system in the survey aircraft. The test was performed by flying a "cloverleaf" pattern over a known point at survey altitude. The cloverleaf consists of passes over the known point flown in the orientation of the traverse and control lines in opposite directions. A total of eight passes were flown, twice in each direction.

The heading test was flown on October 5 over the Geological Survey of Canada magnetic observatory at Morewood, Ontario along lines described in Table 6.2 and illustrated in Figure 6.9. The heading test was performed at a fixed altitude of 457 meters (1500 feet) above ground. Reference ground magnetic data were obtained from NRCan's magnetic observatory at Ottawa, Ontario.

Table 6.2: Magnetometer Heading Test Line location (datum WGS-84)

	Latitude (Deg: Min: Sec)	Longitude (Deg: Min: Sec)
Test Line Number 2001.00 Start	N45°10'22"	W75°14'53"
Test Line Number 2001.00 End	N45°07'45"	W75°12'55"
Test Line Number 201.00 Start	N45°08'20"	W75°15'50"
Test Line Number 201.00 End	N45°09'47"	W75°11'60"

Figure 6.9: Heading test

The results of the heading test for all three sensors are presented in Tables 6.3 - 6.5. The test determined average north-south heading errors of 0.37, -0.90 and 0.94 nT and average east-west heading errors of -0.24, 0.16 and 0.29 nT for the Port #1, Starboard #2 and Tail #3 sensors respectively. The heading errors remain consistent through the duration of the survey, and are fully corrected in the normal airborne magnetic data during processing.

Table 6.3: Port #1 magnetometer heading test

Aircraft type:	Cessna Grand Caravan 208B	Date:	October 9, 2019
Registration:	C-GSGL	Height above ground:	457 m
		Magnetometer type:	Geometrics G-822A
		Compensator:	SGL AIRComp
		Sampling rate:	10/s

Dir	Line #	GMT	Total Field Aircraft	Ground Mag	Calculated	Error Value	Variation from Average
NW	1	19:13:27	53,418.48	54,054.0	53413.9	4.60	0.08
SE	2	19:05:34	53,417.96	54,053.6	53413.5	4.48	-0.04
NE	3	19:09:45	53,419.19	54,054.7	53414.6	4.57	0.05
SW	4	19:17:23	53,419.33	54,055.1	53415.0	4.37	-0.15
NW	5	19:28:45	53,420.56	54,055.8	53415.7	4.89	0.37
SE	6	19:21:15	53,419.22	54,055.1	53415.0	4.27	-0.25
NE	7	19:25:11	53,418.41	54,054.4	53414.3	4.13	-0.39
SW	8	19:32:22	53,421.39	54,056.7	53416.6	4.82	0.30
					Total	36.13	
					Average	4.52	
Average North-South Heading Error					0.37 nT		
Average East-West Heading Error					-0.24 nT		

Table 6.4: Starboard #2 magnetometer heading test

Aircraft type:	Cessna Grand Caravan 208B	Date:	October 9, 2019
Registration:	C-GSGL	Height above ground:	457 m
		Magnetometer type:	Geometrics G-822A
		Compensator:	SGL AIRComp
		Sampling rate:	10/s

Dir	Line #	GMT	Total Field Aircraft	Ground Mag	Calculated	Error Value	Variation from Average
NW	1	19:13:27	53,423.00	54,054.0	53413.9	9.12	0.28
SE	2	19:05:34	53,422.20	54,053.6	53413.5	8.72	-0.12
NE	3	19:09:45	53,423.69	54,054.7	53414.6	9.07	0.23
SW	4	19:17:23	53,423.48	54,055.1	53415.0	8.52	-0.32
NW	5	19:28:45	53,423.39	54,055.8	53415.7	7.72	-1.12
SE	6	19:21:15	53,424.87	54,055.1	53415.0	9.92	1.08
NE	7	19:25:11	53,422.98	54,054.4	53414.3	8.70	-0.14
SW	8	19:32:22	53,425.50	54,056.7	53416.6	8.93	0.09
					Total	70.70	
					Average	8.84	
Average North-South Heading Error					-0.90 nT		
Average East-West Heading Error					0.16 nT		

Table 6.5: Tail #3 magnetometer heading test

Aircraft type:	Cessna Grand Caravan 208B	Date:	October 9, 2019
Registration:	C-GSGL	Height above ground:	457 m
		Magnetometer type:	Geometrics G-822A
		Compensator:	SGL AIRComp
		Sampling rate:	10/s

Dir	Line #	GMT	Total Field Aircraft	Ground Mag	Calculated	Error Value	Variation from Average
NW	1	19:13:27	53,430.17	54,067.4	53427.3	2.88	0.66
SE	2	19:05:34	53,427.97	54,066.2	53426.1	1.83	-0.39
NE	3	19:09:45	53,429.28	54,067.2	53427.1	2.22	0.00
SW	4	19:17:23	53,429.45	54,067.6	53427.5	2.00	-0.22
NW	5	19:28:45	53,431.08	54,068.5	53428.4	2.64	0.42
SE	6	19:21:15	53,429.02	54,067.3	53427.2	1.81	-0.41
NE	7	19:25:11	53,429.75	54,067.5	53427.4	2.36	0.14
SW	8	19:32:22	53,430.79	54,068.9	53428.8	2.00	-0.22
					Total	17.74	
					Average	2.22	
Average North-South Heading Error					0.94 nT		
Average East-West Heading Error					0.29 nT		

Magnetometer Lag

The lag in the magnetic data is a well-known speed-dependent dynamic lag due to the physical offset of the magnetometer and the GPS antenna. The dynamic lag is equal to the offset of the sensors, known to be 1.13 m for the Port #1 and Starboard #2 magnetometers and 11.18 m for the Tail #3 magnetomer respectively, divided by the flying speed 67 m/s. For this test the dynamic lag averaged 0.01, 0.02 and 0.18 s for the port, starboard and tail magnetomers respectively.

The lag test was flown in Ottawa prior to mobilization on October 9 and again when the aircraft returned to Ottawa following survey completion on November 23 along a line described in Table 6.6 and illustrated in Figure 6.10. The test utilizes a strong magnetic anomaly generated by a disused railway bridge over the Ottawa River west of Ottawa. The results are shown in Figures 6.11 - 6.16. Lag corrections are applied in the first step of magnetic data compilation.

Table 6.6: Magnetometer Lag Test Line location (datum WGS-84)

	Latitude (Deg: Min: Sec)	Longitude (Deg: Min: Sec)
Test Line Number 4001.00 Start	N45°27'56"	W76°17'21"
Test Line Number 4001.00 End	N45°28'02"	W76°16'59"

Figure 6.10: Lag test

Figure 6.11: Lag Test – Port #1 – C-GSGL - Flight 1388 October 5, 2019

Figure 6.12: Lag Test – Starboard #2 – C-GSGL - Flight 1388 October 5, 2019

Figure 6.13: Lag Test – Tail #3 – C-GSGL - Flight 1392 October 9, 2019

Figure 6.14: Lag Test – Port #1 – C-GSGL - Flight 1413 November 23, 2019

Figure 6.15: Lag Test – Starboard #2 – C-GSGL - Flight 1413 November 23, 2019

Figure 6.16: Lag Test – Tail #3 – C-GSGL - Flight 1413 November 23, 2019

Spectrometer System Tests

Stripping Ratio Calibration

The stripping ratios for the SGLSpec gamma ray spectrometer were determined before the aircraft departed for the survey on October 3, 2019. The Geological Survey of Canada calibration pads, which are stored at the SGL hangar in Ottawa, were used. The tests were performed with the detectors installed in survey configuration on board the aircraft. Each detector was tested separately and the test results were averaged to create stripping ratios for the full system.

The following procedure was carried out:

- Cesium stabilization
- Thorium stabilization
- Pre-pads source test, one thorium source below pack
- Pads test carried out in order: background, potassium, uranium, thorium, and background
- Post-pads source test, one thorium source below pack

See Table 6.7 for a list of stripping ratios.

Table 6.7: Spectrometer stripping ratios

Thorium into Uranium (α)	0.3308
Thorium into Potassium (β)	0.4331
Uranium into Potassium (γ)	0.7937
Uranium into Thorium (a)	0.0454
Potassium into Thorium (b)	-0.0026
Potassium into Uranium (g)	0.0069

The negative result for the "b" coefficient is the result of errors associated with the random nature of gamma ray radiation, and this coefficient is effectively zero.

Attenuation Test

The exponential height attenuation coefficients for the spectrometer were calculated using data acquired during a pre-survey test flight over the 10 km long Geological Survey of Canada test range at Breckenridge, Quebec on October 5, 2019. The calibration flights were carried out from approximately 145 m to 250 m mean terrain clearance at 15 m intervals. A series of background measurements were made by flying the same altitudes over the Ottawa River to determine the background due to cosmic radiation, radon decay products in the air and the radioactivity of the aircraft and equipment. Background corrected data for each gamma ray region of interest are given in Table 6.8 along with the radar altitude above ground adjusted to effective height at standard pressure and temperature (Section 8 - DATA COMPILATION, Gamma Ray Data).

After correction for background and stripping, the variation in count rate with effective height was used to determine the attenuation coefficients shown in Table 6.9.

Table 6.8: Spectrometer calibration test data

Effective Height (m)	Total Counts (cps)	Potassium (cps)	Uranium (cps)	Thorium (cps)
146.11	1562.20	135.70	10.10	37.40
160.89	1405.50	116.50	8.10	36.10
174.01	1274.20	104.50	9.80	29.80
188.08	1182.30	92.20	7.40	29.10
202.37	1073.20	83.00	7.80	25.00
244.55	819.20	57.30	5.80	19.30

Table 6.9: Spectrometer attenuation coefficients

Region of Interest	Coefficients
Total	-0.006499
Potassium	-0.008632
Uranium	-0.005814
Thorium	-0.006963

The uranium coefficient appears erroneously low compared to the other radio elements, most probably due to the impact of uncorrected radon. A value of 0.007798 based on the average of Potassium and Thorium is used instead, and was verified during data processing.

System Sensitivity

A pre-survey test flight was carried out over the Geological Survey of Canada test range at Breckenridge, Quebec on October 5, 2019. The test flight served to determine system sensitivities through comparison of airborne data with data acquired on the ground, as well as to determine the variation of the window counts with aircraft altitude (see Attenuation Test above).

The ground measurements were made using an Exploranium portable gamma ray spectrometer, acquired at 20 different sites along the 10 km length of the calibration range. Measurements were also made using the portable spectrometer over the Ottawa River to determine background radiation due to cosmic radiation, radon decay products in the air and any radioactivity of the equipment. The background was subtracted from the ground measurements and the ground concentrations of potassium, uranium and thorium were determined by calibration of the portable spectrometer using the Geological Survey of Canada calibration pads located at Ottawa Airport.

The sensitivities of the airborne system for potassium, equivalent uranium, and equivalent thorium were calculated by dividing the average count rates corrected to an effective height of 90 m above ground by the measured ground concentrations. The results are presented in Table 6.10.

Table 6.10: Spectrometer system sensitivities

Radio Element	Average counts at 90 m (cps)	Ground Concentrations	Sensitivities
Potassium	212.7	1.9669 %	108.1267
Equivalent Uranium	25.7	1.3670 ppm	18.7660
Equivalent Thorium	56.9	8.0176 ppm	7.0976

Cosmic and Aircraft Background

A cosmic and aircraft background test was performed for the spectrometer on October 23, 2019, at the field location just west of Gander. The test flight consisted of flying at heights of 1800 m to 3500 m above ground level at 300 m intervals, recording approximately 6 minutes of data at each altitude. Coefficients are determined by linear regression of cosmic counts versus each spectral window as described in the IAEA Report 323 (1991); the slope of the regression provides the cosmic coefficient and the intercept with the region of interest axis provides the aircraft background. Figure 6.17 shows the cosmic test results and Table 6.11 lists the computed cosmic and aircraft background coefficients.

Figure 6.17: Cosmic Test Results

Table 6.11: Cosmic coefficients and Aircraft Background

Region of Interest	Cosmic Stripping Factor	Aircraft Background
Total	3.0380	89.1219
Potassium	0.1551	18.3365
Uranium	0.1289	2.8311
Thorium	0.1561	-4.1894
Upward	0.0234	0.4230

The negative Thorium background value is the result of errors associated with the random nature of gamma ray radiation, and this coefficient is effectively zero.

Radon Background Calibration

Radon background was monitored through the use of upward looking detectors. Coefficients relating the count rate in the uranium window from the upward detectors to the count rate in the potassium, uranium, thorium and total count regions of interest from the downward facing detectors were determined using data acquired from a water test line flown repeatedly at different times during the survey.

The water test line was established in the middle of Gander Lake along a line described in Table 6.12 and illustrated in Figure 6.18.

Table 6.12: Water Test Line location (datum WGS-84)

	Latitude (Deg: Min: Sec)	Longitude (Deg: Min: Sec)
Test Line Number 4001 Start	N48°55’16.79”	W54°59’58.72”
Test Line Number 4001 End	N48°56’24.71”	W54°39’26.47”

Figure 6.18: Water test line location over Gander Lake

The cosmic and background corrected data from each of the up (ur), thorium (Tr), potassium (Kr) and total (Ir) windows are plotted against the counts in the uranium (Ur) window for each over water line flown. Linear regressions of these plots provide the radon coefficients to be used in the radiometric data processing are shown in Figures 6.19 - 6.22. The coefficients determined for this survey are presented in Table 6.13.

Table 6.13: Radon correction coefficients

	a	*b*
$I_r = a_I U_r + b_I$	15.3633	29.0195
$K_r = a_K U_r + b_K$	0.8154	4.7425
$T_r = a_T U_r + b_T$	-0.0194	1.4046
$u_r = a_u U_r + b_u$	0.2004	0.2083

The negative "a" coefficient for Thorium is the result of errors associated with the random nature of gamma ray radiation, and this coefficient is effectively zero.

Figure 6.19: Linear regressions - Total vs Uranium

Figure 6.20: Linear regressions - Potassium vs Uranium

Figure 6.21: Linear regressions - Thorium vs Uranium

Figure 6.22: Linear regressions - Up vs Uranium

Ground Component

The ground component coefficients are used to quantify the response of the upward looking detector to radiation from the ground using the technique described in IAEA Report 323 using the on-line survey data.

The ground component coefficients used for this project are listed in Table 6.14.

Table 6.14: Spectrometer ground component coefficients

a_1 (Uranium)	a_2 (Thorium)
0.021080	0.028874

Pre- and Post-Flight Gamma Ray Test Lines

Overland test lines were flown at survey height and survey speed before and after almost every survey production flight. The overland test line was just west of the airport and north of Gander Lake along a line described in Table 6.15 and illustrated in Figure 6.23.

Table 6.15: Overland Test Line location (datum WGS-84)

	Latitude (Deg: Min: Sec)	Longitude (Deg: Min: Sec)
Test Line Number 3001 Start	N48°56'38.73"	W54°49'08.70"
Test Line Number 3001 End	N49°01'54.02"	W54°44'42.21"

Figure 6.23: Land test line location near Gander

Background corrected thorium data for the test lines were generally within +/- 10% of the average, see Figure 6.24.

Figure 6.24: Corrected average thorium data for the test lines

Thorium Source Tests

Thorium source tests were performed at the start and end of each production day. A source was positioned beneath each crystal pack. Data from the thorium, and background windows were recorded for 300 seconds during each test. Recorded data were dead-time and background corrected and statistics were compiled. Thorium source test results were well within +/-5 % of the mean value, see Figure 6.24. The post flight result from flight 1001 is omitted due to a procedural error. The coherence of the data indicates that the system is operating correctly.

Figure 6.25: Thorium source test results

7. FIELD OPERATIONS

Operational Base

Operations were conducted from Gander airport, Gander, Newfoundland and Labrador, Canada. The survey required 15 production flights, from October 17, 2019 to November 10, 2019.

Mobilization of the SGL crew and equipment to Gander began with the arrival of the crew on October 13, followed by Cessna Grand Caravan 208B C-GSGL on October 14. The field office was located at The Albatross Hotel. The Gander airport features 2 runways: runway 13/31 which is 8,900 ft × 200 ft (2,713 m × 61 m), and runway 03/21 (changed from 04/22 in August 2004) which measures 10,500 ft × 200 ft (3,200 m × 61 m) and a fire service. Mobilization was completed on October 14, with the combined magnetometer ground and GPS reference stations installed at the Gander Airport on that day.

Pre-survey tests started on October 15 with a compensation flight. A reconnaisiance flight was performed on October 16. Another compensation flight followed by a cosmic calibration was performed on October 23.

When not survey flying the aircraft was parked on the airport ramp across from Gander Aviation. Each survey flight departed and returned to this location. Table 7.1 shows the position of the aircraft in the WGS-84 datum. Figure 7.1 shows the parking location on a satellite image of the airport.

Table 7.1: Aircraft parking location (datum WGS-84)

Parking Location	Aircraft	Latitude	Longitude	Elevation (m)
1	C-GSGL	N48:56:30.85	W54:33:21.02	124.0

Figure 7.1: parking location on a satellite image of Gander airport

The average production rate was about 2000 kilometers per week. There were several down days due to weather, in particular low clouds and rain. Weekly Reports that detail day to day operations and progress are provided in *Appendix V*.

The survey flying, including all necessary re-flights, was completed on November 12. Demobilization started immediately and was completed on November 14 when the aircraft departed.

Coordinates and times of the actual lines flown are listed in *Appendix VI*.

Reference Stations

The reference stations were set-up outside the fence at Gander Aviation in Gander on October 14. Table 7.2 shows the WGS-84 coordinates of the reference station GPS antennas.

Table 7.2: Locations of reference stations (datum WGS-84)

Station #	Latitude (Deg:Min:Sec)	Longitude (Deg:Min:Sec)	Elevation (m)
REF1	N48:56:28.01	W54:33:17.88	142.72
REF2	N48:56:27.99	W54:33:17.89	142.74

The position of the reference station GPS antennas were calculated using Precise Point Positioning (PPP) corrections using the algorithm developed by the Natural Resources Canada (NRCAN) (http://webapp.geod.nrcan.gc.ca/geod/tools-outils/ppp.php) that has been incorporated in to SGL's suite of software.

Magnetometers were connected to the same computers as those housing the GPS antennae. Each magnetometer was housed in a non-magnetic shell mounted on a 2m high pole that was erected in a magnetically quiet area outside the fence at Gander Aviation away from electrical interference and moving metal objects such as cars. Power was supplied from a nearby building. Figure 7.2 shows the installation location of the GPS and magnetic sensors on a satellite image of the airport, and the setup is shown in Figure 7.3.

Figure 7.2: installation location of the GPS reference and magnetic ground sensors on a satellite image of the airport

Figure 7.3: Magnetic ground and GPS reference station installation at Gander airport

Re-flights

Table 7.3 shows a list of re-flights and the reasons they were required.

Table 7.3: Re-flight list

Original Flight		Re-Flights		
Line	Flight	Line	Flight	Reason
120.00	1003	120.01	1009	Magnetic data
1232.00	1014	1232.01	1015	VLF data
1257.00	1003	1257.01	1009	Accidental reflight

Field Personnel

Table 7.4 shows a list of SGL technical personnel who participated in the field operations.

Table 7.4: Survey field crew

	Name	Dates in Field
Project Manager	Kevin Charles	N/A
Crew Chief	Keith Wells	Oct 12 – Nov 14
Data Processor	Luis Vargas	Oct 12 – Oct 24
Lead Pilot	Jean Deschenes	Oct 14 – Nov 14
Pilot	Aymeric Douerin	Oct 14 – Oct 24
Pilot	Sarah Newland	Oct 25 – Nov 14
Technician	Angella Farr	Oct 12 – Oct 24

8. DIGITAL DATA COMPILATION

Radar, Barometric, and Laser Altimeter Data

Barometric pressure data were recorded at 10 Hz. The pressure data, smoothed with a low pass frequency domain filter, (cosine taper between 42 and 47 points), was used to adjust height above ground to standard pressure and temperature to derive the effective height used in gamma ray data processing.

The terrain clearance measured by the radar altimeter were recorded at 10 Hz. The radar data does not always penetrate the canopy of the trees in the survey area as it records the first return within the footprint of its signal. The radar altimeter data were filtered to remove high-frequency noise using a 21-point low pass filter (Appendix VII).

The laser altimeter recorded terrain clearance at 1000 Hz. Even though the laser altimeter can record returns from more than 300 m above the ground with a high degree of certainty, some laser data dropouts occurred due to areas of poor reflectivity and the effect of clouds. Short sections of poor laser or missing data were replaced using TRT radar data. Both GPS and altimeter data are adjusted so they are referenced to a standard reference point within the aircraft to ensure they are at a consistent level. A digital elevation model is derived with respect to Mean Sea Level (MSL) by subtracting the gap filled laser altimeter data from the GPS elevation above MSL. The DEM is provided as a grid with a 35 m cell size.

The laser data were also processed with an iterative asymmetric de-spiking routine designed to remove early laser returns assumed to be mainly from trees. This version of the laser data is processed the same way as described above and used to derive a "bare earth" version of the DEM. The bare earth DEM is provided as a grid with a 35 m cell size.

Positional Data

A positional data flowchart is presented in Figure 8.1. A number of programs were executed for the compilation of navigation data in order to reformat and recalculate positions from raw 10 Hz range data obtained from the moving (airborne) receivers using combinations of L1 and L2 phase signal. PPP processing (described below) was used for all flights except 1009 which required the use of low inclination satellites, and therefore used DGPS processing (described below).

DGPS Processing

Accurate locations of the airborne GPS antenna were determined by differentially correcting the airborne GPS data with respect to the SGL reference station positions for flight 1009 only. This technique provides a final receiver location with an accuracy of better than 5 cm.

Figure 8.1: DGPS Positional data processing flowchart

PPP Processing

A PPP Positional data flowchart is presented in Figure 8.2.

Accurate locations of the airborne GPS antenna for all flights except 1009 were determined through Precise Point Positioning (PPP) corrections using the algorithm developed by the Natural Resources Canada (NRCAN) (http://webapp.geod.nrcan.gc.ca/geod/tools-outils/ppp.php) adapted to run under SGL's suite of software. This technique provides a final receiver location with an accuracy of better than 5 cm.

Datum and Projection

Positional data (x, y, z) were recorded and all data processing was performed in the WGS-84 datum. The delivered data were provided in x, y locations in UTM projection zone 21N with respect to the NAD-83 datum. Please see Table 8.1 for ellipsoid parameters.

Table 8.1: Ellipsoid parameters for WGS-84

Ellipsoid	WGS-84
Semi-major axis	6378137.0
1/flattening	298.257223563

Table 8.2: Ellipsoid parameters for NAD-83

Ellipsoid	GRS-80
Semi-major axis	6378137.0
1/flattening	298.257222101

Table 8.3: Datum conversion parameters from WGS-84 to NAD-83

x shift (m)	0.991
y shift (m)	-1.9072
z shift (m)	-0.5129
x rotation (rad)	1.2581E-7
y rotation (rad)	0.3599E-7
z rotation (rad)	0.5607E-7

Elevation data were recorded relative to the GRS-80 ellipsoid and transformed to mean sea level (MSL) with respect to the Canadian Geodetic Vertical Datum 2013.

For the purpose of calculating a digital terrain model (DEM), the x, y, z coordinates of the GPS antenna are adjusted in vertical height to a reference point located on the floor level of the aircraft interior. Altimeter data is adjusted to the same reference point to assure consistency of reference when the data source are combined to calculate the DEM.

Figure 8.2: PPP Positional data flowchart

Figure 8.3: Magnetic data flowchart

Magnetometer Data

This section describes the data processing of the primary Tail #3 sensor only.

A magnetic data flowchart is presented in Figure 8.3.

Reference Station Data

Magnetometer data from the reference station were inspected for cultural interference and edited where necessary using comparison of data from the two stations as a guide. All reference station magnetometer data were filtered using a 369-point low pass filter (see Appendix VII) to remove any high frequency interference, but retain the diurnal variations.

A correction for the International Geomagnetic Reference Field (IGRF) year 2015 model, was extrapolated for all ground magnetometer data using the fixed ground station location (see Section 7 – FIELD OPERATIONS) and the recorded date for each flight. The mean residual value of the reference station calculated to be 147.333nT and 355.099 nT for ground stations 1 and 2 respectively was subtracted to remove any bias from the local anomalous field.

Data were recorded on a 24 hour basis, and are provided as such in a separate data base in which the best available data from either ground station is selected.

Compensation and Lag Correction

The airborne magnetometer data were recorded at 160 Hz, compensated for aircraft manoeuvre noise (see Section 6 - SYSTEM TESTS, Magnetometer) and down sampled to 10 Hz for processing. All magnetic data were plotted and checked for any spikes or noise. A dynamic lag correction varying from between 0.22 s and 0.24 s depending on the instantaneous velocity of the aircraft was applied to each data point. The aircraft speed dependent dynamic lag was calculated using SGL's Dynlag software.

Diurnal Correction

Diurnal variations in the airborne magnetometer data were removed by subtracting the corrected reference station data. Ground station 1 was used to correct all production lines.

Height Correction

At low altitudes, even relatively small differences in altitude may result in significant changes in spectral content of the magnetic data. Amplitude of magnetic signal drops off with height at an exponential rate proportional to the frequency of the signal, so that high frequency signal in particular changes rapidly with small changes in altitude close to the ground. Correcting for such changes using traditional levelling methods can be challenging since there is no way to properly extrapolate corrections from miss-ties at intersections due to altitude differences. Therefore, there is an advantage to correcting the airborne data for height variation before attempting levelling.

In order to correct magnetic data for altitude variation, we first need to define a consistent surface that will be used as a reference height. This can be a surface of constant height with respect to the ellipsoid or a drape surface. The drape surface approach has the advantage of retaining as much of the recorded signal content as possible whilst achieving consistency of height at intersections and smoothly varying heights between adjacent lines. Therefore the drape approach was adopted, and was based on a climb and descent rate of between 360 and 375 ft/NM. The difference between the drape reference surface and the recorded altitude is the height difference to be accounted for.

The magnetic field intensity that would have been recorded at the different altitude was predicted based on a Taylor expansion that sums the derivatives of the field as follows:

$$T + (T' h)/1! + (T'' h^2)/2! + (T''' h^3)/3! + (T'''' h^4)/4! \ldots\ldots$$

where, T is the total magnetic intensity (TMI) at any given point,

T' is the first vertical derivative of the TMI, T'' is the second vertical derivative etc.

$1!$ is the factorial of 1, 2! is the factorial of 2 etc.

The series is infinite, but in practise there is no need to calculate the factors beyond the 4th derivative.

The calculation was calculated and applied to the time series data in one dimension which does not account for the cross line gradients.

Levelling

Intersections between control and traverse lines were determined by a program which extracts the magnetic, altitude, and x and y values of the traverse and control lines at each intersection point. Each control line was adjusted by a constant value to minimize the intersection differences, calculated as follows:

$\Sigma\ |i - a|$ summed over all traverse lines

where, i = (individual intersection difference)

a = (average intersection difference for that traverse line).

This is an iterative process. The variation of each intersection difference from the average intersection difference for each traverse line are calculated. The average of these intersection variation values are then derived for each control line, and the control line is adjusted up or down by that amount. The variation of each intersection from the average intersection difference for each traverse line are then recalculated, and another set of control line adjustments are derived accordingly. The procedure continues to iterate in this manner, but the adjustments become progressively smaller until the average adjustment falls below a pre-set threshold of <0.1nT.

Adjusted control lines were further corrected locally to minimize any residual differences. Traverse line levelling was carried out by a program that interpolates and extrapolates levelling values for each point based on the two closest levelling values. After traverse lines have been levelled, the control lines are matched to them. This ensures that all intersections tie perfectly and permits the use of all data in the final products.

CLEVEL provides a curved correction using a function similar to spline interpolation. A third degree polynomial is used to interpolate between two intersections and the two values and two derivatives are chosen to determine the polynomial. CLEVEL is an improved method as it allows intersection points to be preserved with no mismatch and interpolation is smooth with the first derivative continuously approaching the same value from both sides of the intersection points.

The levelling procedure was verified through inspection of magnetic anomaly and vertical derivative grids (see below for derivative calculation), plotting profiles of corrections along lines, and examining levelling statistics to check for steep correction gradients.

Micro-Levelling

Micro-levelling was applied to remove any residual diurnal effects from the data. This was achieved by using directional filters to identify and remove artifacts that are long wavelengths parallel to survey lines and short wavelengths perpendicular to survey lines. A limit of +/- 0.8 nT was set for all micro-levelling corrections. A second microlevel with limits of +/- 4.5 nT was used in some high gradient areas where the control lines run parallel to the strong magnetic features, illustrated in Figure 8.4

Figure 8.4: Survey area magnetic data with areas requiring additional micro-levelling indicated by three black polygons

IGRF Correction

The airborne magnetometer data were corrected for the IGRF using the location of each point. IGRF values were calculated using the year 2015 model extrapolated forward to a constant date of 2019.384 (Nov 1, 2019). The altitude data used for the IGRF corrections is a fixed height of 313 meters above the GRS-80 ellipsoid, corresponding to the average survey height. Removal of the IGRF from the magnetic data transforms it from Total Magnetic Intensity (TMI) to magnetic anomaly data.

Gridding

The grid of the magnetic anomaly was made using a minimum curvature algorithm to create a two-dimensional grid equally sampled in the x and y directions. The algorithm produces a

smooth grid by iteratively solving a set of difference equations minimizing the total second horizontal derivative while attempting to honour the input data (Briggs, I.C, 1974, Geophysics, v 39, no. 1).

The final grids of the magnetic data were created with 35 m grid cell size appropriate for survey lines spaced at 150 m. The strong geological trends on the grids were enhanced by SGL's Gtrend software, which adds interpolated data values between survey lines along strong magnetic anomalies during the gridding procedure. This technique reduces the 'bubbling' effect which may occur when gridding high gradient data sets.

Vertical Derivatives of the Magnetic Anomaly

Vertical derivatives act as high pass filters that enhance the high frequency content of the data and suppress low frequency/long wavelength signal. The first vertical derivative (n=1) enhances rapid changes in the gravity or magnetic field at the edges of anomalies, and therefore it is useful for delimiting the extents of causative bodies.

If kx and ky are the wave numbers of the potential field in the two dimensional frequency domain, the nth vertical derivative of a potential field is easily derived in the Fourier domain by applying the following filter:

$F(k_x, k_y) = (-k)^n$, where $k = \sqrt{(k_x^2 + k_y^2)}$

The first vertical derivative of the magnetic anomaly is provided.

Figure 8.5: Magnetic gradient data flowchart

Magnetometer Gradient Data

A magnetic gradient data flowchart is presented in Figure 8.5

The measured lateral and longitudinal gradients provide an improved rendition of the shorter wavelengths in magnetic field than the total magnetic field measured by the tail sensor (#3) alone. This is because the direction and amplitude of the field's total horizontal gradient can be determined using the two measured gradients, providing information regarding the behaviour of the magnetic field in between traverse lines. The array of magnetometers employed is illustrated in Figure 8.6.

Figure 8.6: Array of magnetometers

Raw Gradient Calculation

Initially, the magnetic gradients are derived with respect to the aircraft frame. The across-aircraft gradient data is derived from the difference in total magnetic intensity recorded at the wingtip sensors on the port side (#1) and starboard side (#2) divided by the separation of the magnetometers across the wings as follows,

#2-#1/lateral separation

where the lateral separation for the survey aircraft is 19.02 m
The along-aircraft gradient is derived from all sensors, being the difference in total magnetic intensity between the mean value of the wingtip sensors #1 and #2 and the tail sensor #3 divided by the longitudinal separation along the aircraft body as follows,

(((#2+#1)/2) - #3) / longitudinal separation between #1&2 and #3

where the longitudinal separation for the survey aircraft is 10.04 m

Lag Correction

Lag corrections were applied to the magnetic gradients to reference the data to the GPS antenna located on the roof of the aircraft cabin.

A dynamic lag correction equivalent to the offset of 1.13 m as measured along the long axis of the aircraft from the GPS antenna to the line between #1 and #2 was applied to the lateral gradient.

A dynamic lag correction equivalent to the offset of 6.15 m as measured along the long axis of the aircraft from the GPS antenna to the point that lies half way from the line between #1 and #2 and the tail sensor #3 was applied to the longitudinal gradient.

The lag correction is applied to each data point dependent on the instantaneous velocity of the aircraft, so for example when flying exactly at the target speed of 130 Knots, or 67 m/s, the correction is equal to the offset listed above divided by 67 m/s. The aircraft speed dependent dynamic lag was calculated using SGL's Dynlag software.

Bias and Orientation Correction

Due to the different properties of the magnetic sensors employed on the aircraft, there is an inherent directional bias in the horizontal gradients. Initial bias correction is performed by subtracting the average of each line base on "anomaly free" areas, and adding back the average of all lines. By comparing data flown in opposite directions along the test line, and from adjacent lines, the biases were adjusted and applied as listed in Table 8.4.

Table 8.4: Gradient bias corrections

Lateral Bias (nT/m)	Longitudinal Bias (nT/m)	Range of Flight Numbers
-0.176	-0.355	1001-1001
-0.187	-0.365	1002-1002
-0.178	-0.342	1003-1003
-0.173	-0.342	1004-1006
-0.190	-0.335	1007-1007
-0.181	-0.325	1008-1008
-0.184	-0.325	1009-1009
-0.180	-0.325	1010-1010
-0.162	-0.330	1011-1012
-0.164	-0.313	1013-1013
-0.133	-0.245	1014-1014
-0.131	-0.245	1015-1015

The across and along the aircraft gradients and the azimuth of the aircraft, available from the aircraft avionics, are combined to calculate the lateral and longitudinal gradients with respect to the survey lines so that positive gradients are eastward and northward respectively. For this purpose the azimuth data is first smoothed using a 7 point averaging filter applied to 10Hz data to prevent noise

in the azimuth data from contaminating the gradients.

Levelling

Lateral and longitudinal gradients were "levelled" to gradients derived from the tail sensor #3 to account for minor bias variations that occur along a survey line. This is in part due to the fact that pitch and roll of the aircraft are not accounted for since no measured vertical gradient was acquired. Levelling was achieved by applying a 91 point averaging filter to the difference between the tail sensor #3 derived gradients and measured lateral gradients equivalent to 600 m at average survey speed, and by applying a 91 point averaging filter equivalent to 600 m to the difference of the longitudinal gradients. The differences are applied to the measured gradients. This process combines the longer wavelength data that is well sampled and represented by the #3 sensor derived gradients for wavelengths of four times the survey line spacing or longer (ie. 600 m or more) with the detailed short wavelength gradients best represented by the measured gradients, and helps to reconcile minor line-by-line differences not accounted for by the zero order corrections alone.

Gridding

Grids of the lateral and longitudinal gradients were made using a minimum curvature algorithm to create a two-dimensional grid equally sampled in the x and y directions. The algorithm produces a smooth grid by iteratively solving a set of difference equations minimizing the total second horizontal derivative while attempting to honour the input data (Briggs, I.C, 1974, Geophysics, v 39, no. 1). A cell size of 35 m was employed.

Calculation of Enhanced Magnetic Anomaly

The two levelled horizontal gradient grids, lateral gradient and longitudinal, can be utilized to create a first vertical derivative grid using the Hilbert transform relationship (Nabighian, M.N. 1984, Geophysics v.49 p.780-786). Once the Hilbert transform has been applied to the lateral and longitudinal gradient grids, the outputs are summed to create a first vertical derivative grid. The first vertical derivative grid is then integrated to create a grid of gradient-enhanced magnetic anomaly.

However the integrated gradient enhanced magnetic anomaly grid does not contain the long wavelength signal that is well sampled and retained in the single #3 sensor magnetic anomaly data. To account for this the long wavelength magnetic anomaly must be recovered. This was achieved by analysis of the difference between these two versions of the residual magnetic anomaly grid and a low pass filter is applied to the difference to isolate the missing long wavelengths that can then be added to the integrated magnetic anomaly. A 2nd order Butterworth filter with a cut off of 3 km was found to match the two magnetic anomaly grid versions well whilst retaining the enhancement of the short wavelengths from the measured gradients. Since this grid based method is restricted in resolution to the grid cell size (35m), the difference between the enhanced and single #3 sensor magnetic anomaly grids is extracted along survey lines and applied as a correction to the higher resolution 10Hz single #3 sensor magnetic anomaly channel to provide a channel of gradient enhanced magnetic anomaly. Note however that it is not possible to re-grid this channel to recreate the enhanced magnetic anomaly grid since this does not reproduce the between line interpolation achieved by the procedure described above.

Due to relatively large rolls of the aircraft exceeding 20 degrees to both port and starboard upon intercepting line 1152, the gradient data is compromised for a short segment corresponding to times 53201 to 53224 seconds. To avoid artifacts in the data, the gradient data for these segments are nulled prior to generating the grid of enhanced magnetic data, and the channel of enhanced magnetic data is replaced with standard single magnetic data for this period of time to provide

complete coverage.

The vertical derivative of the enhanced magnetic anomaly is derived in the same way as described earlier for the single magnetic sensor data. The grid of the first vertical derivative of enhanced magnetic anomaly is extracted along survey lines to provide an equivalent channel.

Spectrometer Data

A spectrometer data compilation flowchart is presented in Figure 8.7. The data were recorded at 1 Hz in asynchronous mode, and subsequently interpolated to 1 Hz synchronous data on the exact second. A 0.5 second lag correction was applied to all data to correct for the time delay between detection and recording of the airborne data.

Figure 8.7: spectrometer data compilation flowchart

Spectral Component Analysis

Raw 256 channel spectrometer data were analyzed using noise adjusted singular value decomposition (NASVD; J. Hovgaard and R L. Grasty paper 98; Geophysics and Geochemistry at the Millennium, Proceedings of the 4th Decennial International Conference on Mineral Exploration, 1997). Normalization with respect to the count rate is achieved by dividing each measured spectrum by the square root of the best fit of the mean spectra, i.e. component zero. The NASVD method determines the components in order of significance with respect to the amount of variance in the data they describe. Each component is a spectrum with 1024 channels. In theory, there are as many components as there are channels, and the amount of variance in the data accounted for by a component decreases as the number of the component increases. Variation in the natural signal is generally accounted for by a relatively small number of low order components, and variation due to noise is primarily accounted for by the higher order components. Spectra are reconstructed from a selection of low order natural signal related components, and the count rates in the standard windows are recalculated.

Individual spectra are inspected to determine if they describe natural signal through the presence of photo-peaks known to be related to radioactive isotopes of either Potassium, Uranium or Thorium. Through such an analysis, it was determined to retain components 0 to 3.

Figures 8.8 – 8.11 show charts of the first 4 NASVD components

Figure 8.8: Spectral Component zero

Figure 8.9: Spectral Component 1st

Figure 8.10: Spectral Component 2nd

Figure 8.11: Spectral Component 3rd

Standard Corrections

Spectrometer data were corrected as documented in the Geological Survey of Canada Open File No. 109 and the IAEA report "Airborne gamma-ray spectrometer surveying; Technical Report Series No. 323 (International Atomic Energy Agency, Vienna). The gamma-ray spectroscopy processing parameters are shown in Table 8.5. The parameters employed are based on those determined through calibration tests (Section 6 - SYSTEM TESTS – Spectrometer) but adjusted through observation of their impact on the survey data.

Table 8.5: Spectrometer processing parameters

Spectrometer Processing Parameters		
Window	Cosmic Stripping Ratio (b)	Aircraft Background (a)
Total	2.3380	69.12
Potassium	0.1301	12.34
Uranium	0.0850	2.50
Thorium	0.1101	0.00
Upward	0.0183	0.00
Radon Component	a	b
Total (I_r)	16.3446	10.7000
Potassium (K_r)	1.0000	2.5872
Thorium (T_r)	0.0000	0.4227
Up (u_r)	0.2256	0.1000
Ground Component	a_1	a_2
Up (u_g)	0.02108	0.02887
Stripping Ratios	Contribution on the Ground	Effective Height Adjustment (m^{-1})
α	0.3008	0.00049
β	0.4331	0.00065
γ	0.7937	0.00069
a	0.0454	0
b	0.0000	0
g	0.0069	0
Attenuation Coefficients (m^{-1})		
Total	-0.006499	
Potassium	-0.008632	
Uranium	-0.007798	
Thorium	-0.006963	
Sensitivities		
Potassium	110.2551	
Uranium	12.5271	
Thorium	8.0176	

The following corrections were applied to the spectrometer data in the following order.

a) Calculation of effective height above ground level (AGL)

A 21 point low pass filter (see Appendix VII) was applied to 10 Hz radar altimeter data, and a low pass frequency domain filter, (cosine taper between 42 and 47 points) was applied to 10 Hz barometric altimeter data. The barometric altimeter data was then converted to equivalent pressure and used with the digitally recorded temperature to convert the radar altimeter data to effective height at standard pressure and temperature (STP) as follows:

$$h_e = h \times \frac{273.15}{T + 273.15} \times \frac{P}{101.325}$$

where, h_e = the effective height

h = the observed radar altitude in metres

T = the observed air temperature in degrees Celsius and

P = the observed barometric pressure in kPa.

b) Removal of cosmic radiation and aircraft background radiation

A 67-point low pass filter (see Appendix VII) is applied to 1 Hz cosmic data to reduce statistical noise. Cosmic radiation and aircraft background radiation are removed from each spectral window using the cosmic coefficients and aircraft background values determined from test flight data using the following equation:

$$N = a + b\,C$$

where, N = the combined cosmic and aircraft background in each spectral window,

a = the aircraft background in the window,

b = the cosmic stripping factor for the window, and

C = the cosmic channel count.

c) Radon background corrections

A 199-point average low pass filter is applied to 1 Hz downward uranium, downward thorium and upward uranium count data for the purposes of the radon correction only. The radon component in the uranium window is calculated using the radon coefficients determined from the survey data using the following equation:

$$U_r = \frac{u - a_1\,U - a_2\,T + a_2\,b_T - b_u}{a_u - a_1 - a_2\,a_T}$$

where, U_r = the radon background measured in the downward uranium window,

u = the filtered observed count in the upward uranium window,

U = the filtered observed count in the downward uranium window,

T = the filtered observed count in the downward thorium window,

a_1 and a_2 = the ground component coefficients,

a_u and b_u = the radon coefficients for uranium,

a_T and b_T = the radon coefficients for thorium.

The radon counts in the uranium upward window and the potassium, thorium and total count downward windows are calculated from Ur using the following equations:

$$
\begin{aligned}
u_r &= a_u U_r + b_u \\
K_r &= a_K U_r + b_K \\
T_r &= a_T U_r + b_T \\
I_r &= a_I U_r + b_I
\end{aligned}
$$

Where ur is the radon component in the upward uranium window, Kr, Ur, Tr and Ir are the radon components in the various windows of the downward detectors, and a and b are the radon calibration coefficients.

d) Stripping

The stripping ratios for the spectrometer system are determined experimentally. The stripped count rates for the potassium, uranium and thorium downward windows are calculated using the following equations:

$$N_K = \frac{n_{Th}\ (\alpha\ \gamma - \beta) + n_U\ (a\ \beta - \gamma) + n_K\ (1 - a\ \alpha)}{A}$$

$$N_U = \frac{n_{Th}\ (g\ \beta - \alpha) + n_U\ (1 - b\ \beta) + n_K\ (b\ \alpha - g)}{A}$$

$$N_{Th} = \frac{n_{Th}\ (1 - g\ \gamma) + n_U\ (b\ \gamma - a) + n_K\ (a\ g - b)}{A}$$

where A has the value:

$$A = 1 - g\ \gamma - a\ (\alpha - g\ \beta) - b\ (\beta - \alpha\ \gamma)$$

and where,

n_K, n_U and n_{Th} = the unstripped potassium, uranium and thorium downward windows counts,

N_K, N_U and N_{Th} = the stripped potassium, uranium and thorium downward windows counts,

α, β, and γ = the forward stripping ratios, and

a, b and g = the reverse stripping ratios.

α, β, and γ are adjusted for effective height (as calculated above) by standard factors given in Table 8.5 *Spectrometer Processing Parameters.*

e) Altitude attenuation correction
This correction normalizes the data to a constant terrain clearance of 90 m above ground level (AGL) at standard temperature and pressure (STP). Attenuation coefficients for each of the downward windows were determined from test flights. The measured count rate is related to the actual count rate at the nominal survey altitude by the equation:

$$N_s = N_m \left(e^{\mu (h_o - h)} \right)$$

where, N_s = the count rate normalized to the nominal survey altitude, h_o,

N_m = the background corrected, stripped count rate at effective height h,

μ = the attenuation coefficient for that window,

h_o = the nominal survey altitude, and

h = the effective height.

The effective height was determined as described above.

The temperature sensor was malfunctioning during Flight 1001. Data was obtained from the weather station at the Gander airport and adjusted for the height of the aircraft above ground according to the International Civil Aviation Organization temperature lapse rate.

f) Conversion to radio element concentration
Sensitivities are determined experimentally from the test flight data. The units of the count rates in each spectral window are converted to "apparent radio element concentrations" using the following equation:

$$C = \frac{N}{S}$$

where, C = the concentration of the element(s)

N = the count rate for the window after correction for dead-time, background, stripping and attenuation

S = the broad source sensitivity for the window

Potassium concentration is expressed as a percentage and equivalent uranium and thorium as parts per million of the accepted standards. Uranium and thorium are described as "equivalent" since their presence is inferred from gamma-ray radiation from daughter elements (214Bi for uranium, 208Th for thorium).

g) Correction for effects of uncorrected radon background
The survey test line averages for thorium were consistent throughout the duration of the survey. No correction for effects of precipitation was deemed necessary. Adjustments to the upward detector and the corrected uranium were carried out to remove the impact of uncorrected radon. Tables 8.6

to 8.7 show which lines and flights were corrected together with the correction value.

Table 8.6: Flights with upward detector adjustment

Flight	Scale factor
1002	1.10
1009 (first sortie)	1.05
1009 (second sortie)	1.10
1010	1.10
1011	1.08
1013	1.05

Table 8.7: Lines corrected for uranium

Line Number	Flight	Correction value (ppm)
1214.0.0	1015	0.10
1215.0.0	1015	0.10
1216.0.0	1015	0.10
1217.0.0	1015	0.10
1218.0.0	1015	0.10
1219.0.0	1015	0.10
1220.0.0	1015	0.10
1221.0.0	1015	0.10
1222.0.0	1015	0.10
1223.0.0	1015	0.10
1224.0.0	1015	0.10
1225.0.0	1015	0.10
1226.0.0	1015	0.10
1227.0.0	1015	0.10
1228.0.0	1015	0.10
1229.0.0	1015	0.10
1230.0.0	1015	0.10
1231.0.0	1015	0.10
1231.0.0	1015	0.10
1232.0.1	1015	0.10
139.0.0	1015	0.10
141.0.0	1015	0.10
145.0.0	1015	0.10
146.0.0	1015	0.10
147.0.0	1015	0.10
148.0.0	1015	0.10
150.0.0	1015	0.10

h) Levelling

Following the method of Beiki et. al (2010, Geophysics, Vol. 75, No. 1, L13-L23) differential polynomial levelling was used to correct for residual radon effects in the measured uranium channel. The algorithm is based on polynomial fitting of data points in 1D and 2D sliding windows. The levelling error is taken as the difference between 1D and 2D polynomial fitted data at the centre of the windows. Polynomials of order 1 were used along with a search radius of 450 metres. The corrections were limited to +/- 0.10 ppm and then filtered with a low pass frequency domain filter, (cosine taper between 18 and 218 points) before being applied.

Data gridding

Grids were made using a minimum curvature algorithm to create a two-dimensional grid equally sampled in the x and y directions. The algorithm produces a smooth grid by iteratively solving a set of difference equations minimizing the total second horizontal derivative while attempting to honour the input data (Briggs, 1974). The final grids of the radiometric data were created with 35 m grid cell size appropriate for survey lines spaced at 150 m.

Ratio Grids

Ratios of concentrations of Thorium to Potassium, Uranium to Thorium, and Uranium to Potassium were calculated, in grid form, using a procedure originally designed by the Geological Survey of Canada.

In order to eliminate calculation of ratios at those locations most likely to be over water, an initial standard is required at each grid cell before a ratio is calculated. The potassium concentration must be ≥ 0.10 percent. Otherwise the ratio for that cell is set to null.

In order to reduce fluctuations caused by limited statistical certainty in the final radioelement concentrations, further minimum standards are set for each ratio calculation. These are somewhat arbitrarily selected to equate to a corrected ROI count rate of about 100 counts/second for each element. For this spectrometer survey these numbers are derived from the average sensitivities of the spectrometer employed and have the following values:

$K \geq 0.9067$ %

$eTh \geq 12.4725$ ppm

$eU \geq 7.9827$ ppm

where:

K is the concentration of potassium (%),

eTh is the equivalent concentration of thorium (ppm),

eU is the equivalent concentration of uranium (ppm).

In order to extend ratio values to those grid cells that fall below these minimum standards, a simple variable length filter was applied prior to ratio calculation. This consists of summing data from adjacent cells on each side of the initial grid cell, for both numerator and denominator, and checking to see if both now meet the required minimum. If so, the ratio was calculated. If not, this process was continued to the next adjacent cells until a successful check is achieved or until a maximum distance to adjacent cells is reached. This maximum distance to adjacent cells has been set to 300 m for this survey. Any adjacent cells that already failed the 0.10 % potassium concentration limit are

not considered. If the minimum check fails after the maximum number of cells have been added, the ratio is set to null at the subject grid cell.

The data channels of ratios are derived by sampling of the equivalent ratio grids along survey lines.

Ternary Radioelement Map

The ternary radioelement map is generated along the lines described in the IAEA-TECDOC-1363 "Guidelines for radioelement mapping using gamma ray spectrometry data" (IAEA 2003). The ternary map is a colour composite image in which the relative concentrations of potassium, equivalent uranium and equivalent thorium determine the colour hue whilst the overall intensity of the hue is determined by the total radioactivity.

Total Radioactivity (TR) is calculated as follows:

$$TR = K + eU + \frac{eTh}{4}$$

where K is expressed as a percentage and eU and eTh are expressed in ppm.

Total radioactivity is split into five levels that together span the full range of values from zero to the maximum total radioactivity encountered. The intensity of the colours used increases for each higher level of total radioactivity.

Relative concentrations of each radioelement are calculated as follows:

$$K_n = \frac{K}{(K + eU + eTh/4)}$$
$$U_n = \frac{U}{(K + eU + eTh/4)}$$
$$Th_n = \frac{(Th/4)}{(K + eU + eTh/4)}$$

This normalizes the data with respect to average crustal concentrations. Each relative concentration is expressed as a percentage of the total radioactivity, and together they sum up to 100%. The relative saturation of magenta, cyan and yellow is determined by the percentage of relative concentration of potassium, uranium and thorium respectively. For example, 100% potassium will be represented by pure magenta. Within each level of total radioactivity the full range of possible colours is assigned to achieve an equal area distribution so that all colours appear in equal abundance on the ternary image. This approach preserves the most detailed resolution of the data in the ternary image.

Figure 8.12: VLF data flowchart

Very Low Frequency (VLF) Electromagnetic Data Processing

A VLF data flowchart is presented in Figure 8.12.

VLF Station Selection

For this survey, the four VLF stations listed in Table 8.8 were employed.

Table 8.8: VLF stations used during survey

VLF Station	Location	Frequency (kHz)	Instrument Tuning
Cutler (NAA)	Maine, USA	24.0	Line
LaMoure, (NML)	North Dakota, USA	25.2	Line or Orthogonal
Rhauderfehn (DHO38)	Germany	23.4	Line or Orthogonal
Skelton (GQD)	United Kingdom	22.1	Orthogonal

Since VLF stations are not always in operation, the stations were selected based on signal strength and expected reliability using real time data recorded at Todmorden in the UK available from the following on-line portal:

http://abelian.org/vlf/spectrum.shtml

Stations that are in a direction approximately parallel to the survey lines are tuned to be received by the Line sensor, those in a direction that is approximately at right angles to the survey lines are tuned to the orthogonal sensor, whilst those in between may be tuned to either the Line or the Orthogonal sensor, as shown in Table 8.8. Only one of each Line or Orthogonal station can be tuned to at any given time, and a selection is made based on signal strength of the selected stations at the start of each flight whilst parked on the ramp prior to take off. A summary of the VLF transmitters used for each flight is provided in Table 8.9.

Table 8.9: VLF stations used for each flight

Flight	Line Station	Orthogonal Station
1001	NAA	NML
1002	NAA	NML
1003	NAA	NML
1004	NAA	NML
1005	NML	GQD
1006	NML	DHO38
1007	NML	DHO38
1008	NML	GQD
1009	NML	DHO38
1010	DHO38	GQD
1011	DHO38	GQD
1012	NML	GQD
1013	DHO38	GQD
1014	NML	DHO38
1015	NML	DHO38

Due to a lack of signal recorded from both selected transmitters, no VLF data were collected along lines T1233.0.0 and T1235.0.0 on flight 1014. The VLF data collected with the Orthogonal sensor (tuned to GQD) on lines T1169.0.0 and T1170.0.0 from flight 1013 have been discarded because visual inspection of the data indicated that the transmitter signal strength was too variable. For flights 1001-1004, the Line sensor was tuned to NAA, however, this station was not operating at that time and so the Line data from these flights are also discarded, and NAA was not employed after these flights. A full list of lines for which the different stations did not provide useable data is provided in Appendix VIII.

VLF Data Processing

Four raw VLF data channels are recorded:

- Line Total Field
- Line Quadrature
- Orthogonal Total Field
- Orthogonal Quadrature

The raw VLF data are recorded as a voltage relative to a reference value determined at the beginning of each flight before take off by tuning the sensor to the selected station. This reference voltage value corresponds to the signal strength resulting from the primary field emitted from the selected station transmitter at that time and place. The total field data quantifies the change in the vector sum of the field measured by all three sensors for the two selected frequencies (Line and Orthogonal) relative to the primary field strength as calibrated at the start of the flight. This value is expressed as a fraction of 1 V (e.g., 0.5 V is 50% of the primary field strength). For the total field data, 1 is subtracted from the total field data before it is recorded such that the measurements are offset by -1.0 V and read 0 V for 100% signal and -1 V

for 0% signal. This is the "TF_Raw" data. The vertical quadrature data quantifies the relative strength of the vertical quadrature component of the field measured by the vertical sensor only for the two selected frequencies (Line and Orthogonal), however, the quantity also provides information regarding the polarity of the signal. The vertical quadrature component is not offset by -1.0 V, so a recorded reading of 1 V corresponds to 100% signal strength (for positive polarity) and a reading of -1.0 V corresponds to 100% signal strength, but of opposite polarity. For a line flown in opposite directions, the quadrature component will demonstrate opposite polarity depending on the direction in which the line is flown. This is the "Quad_Raw" data.

A static lag correction of 1.6 s was applied to each data point for all four channels. The data were then low-pass filtered using a 67-point filter (Appendix VII) to remove high frequency noise. Data from flights 1007 (DHO38), 1008 (GQD), and lines T1158.0.0 to T1168.0.0 of flight 1012 (GQD) were additionally filtered using a cosine tapered frequency domain low pass filter with 0% pass below 38 points (~228 m) and 100% pass above 75 points (~450 m). This extra filter was necessary to remove some noise likely due to weak/variable transmitter signal strength or poor tuning of the sensor.

Once the data were filtered, a 600 point rolling mean and standard deviation was calculated for each data point. Prior to calculation of the rolling statistics, outliers were removed on a line-by-line basis based on a comparison of the deviation of the value from the median value for the line and the standard deviation. Data that deviated from the median by more than two times the line standard deviation were removed and replaced by the median value. The total field and quadrature data from each station including outliers were DC shifted by the re-calculated mean value and scaled by the re-calculated standard deviation, yielding data with a mean of 0% and standard deviation of 1 (ignoring outliers). To yield total field data with an average of 100%, 100 was added to this value.

The processed quadrature data only was then convolved with a five-point Fraser filter:

$$[-1, -1, 0, 1, 1]$$

The Fraser filter effectively calculates the first derivative of the profiled quadrature data, and remedies the issue of opposite polarity for lines flown in opposite directions. The quadrature highs occur directly over the maximum positive or negative gradients.

Due to the sensitivity of the measured response to the orientation of conducting structures with respect to the direction of the transmitter, total field data from NML were considered separately, but data from DHO38 and GQD that are in a similar direction from the survey block were combined, as they demonstrated similar trends in both the total field and quadrature data. For flights in which both DHO38 and GQD data were obtained, the DHO38 were preferentially combined into the merged data set.

The trends demonstrated in the Fraser filtered quadrature were similar between all three stations, except for the polarity of the northern power-line is reversed for NML data when compared to DHO38 and GQD data. Therefore to provide a grid with complete quadrature coverage of the survey block, the Fraser filtered quadrature data from either DHO38 or GQD was used to fill gaps in the Fraser filtered quadrature data from NML that was considered superior as it is more coherent.

Levelling & Data Gridding

Differential polynomial fitting was used to level the processed total field data and the Fraser filtered quadrature data (Beiki et al., 2010, Geophysics, v.75(1), L13-L23) to yield fully processed data that was gridded using minimum curvature (Briggs, I.C, 1974, Geophysics, v 39, no. 1) and a cell size of 35m. Due to various lines having no useable VLF data at different times from different stations, gaps are apparent in the grids that correspond to the lines listed in Appendix VIII. Note that when a single isolated line has no data, no gap appears due to grid interpolation. These lines are as follows: 1054, 1233 and 1235 from all stations, and 1122 from Lamoure (NML) only.

Raw Data

To provide comparable raw data to the processed data in the delivered data base, the recorded raw total field data were adjusted to allow for the subtraction of 1 described above and then both total field and quadrature are expressed as a percentage, so total field data are adjusted as (TF_raw + 1)*100), quadrature data are scaled by 100 (Quad_raw*100).

9. FINAL PRODUCTS

Digital Data Archives

Digital data are delivered in Geosoft Data Base format (.gdb) and Geosoft compatible ASCII format (.xyz). Details of the fields of data provided for each data type are provided below:

Magnetic and VLF Data Channels

A listing of the magnetic and VLF data channels delivered with a sampling rate of 10 Hz can be found in Table 9.1.

Table 9.1: Magnetic line data channels and format

Name	Units	Field Length	Null	Description
LINE	08	-	-	Line Number XXXX.YY where XXXX is line number and YY is segment number
TIME	10	sec	*	Seconds Past Midnight UTC
GPSTIME	14	sec	*	GPS Week Seconds
FIDCOUNT	10	sec	*	Fiducial Seconds
LONG	13	degree	*	Longitude, NAD83
LAT	13	degree	*	Latitude, NAD83
EASTING	11	m	*	Easting, NAD83 UTM ZONE 21N
NORTHING	11	m	*	Northing, NAD83 UTM ZONE 21N
RALTRAW	11	m	*	Raw Radar altitude (Terrain Clearance)
LALTRAW	11	m	*	Raw Laser altitude (Terrain Clearance)
RALT	11	m	*	Radar altitude (Terrain Clearance)
LALT	11	m	*	Laser altitude (Terrain Clearance)
BALT	11	m	*	Barometric altitude
SURFACE	11	m	*	Drape surface
GPSALTR	11	m	*	Raw GPS altitude, WGS-84
GPSALT	11	m	*	GPS altitude, MSL (above CGVD2013 Geoid)
DEM	11	m	*	Digital Elevation Model, MSL (above CGVD2013 Geoid)
BAREEARTH	11	m	*	Bare Earth Digital Elevation Model, MSL (above CGVD2013 Geoid)
MAGUNCOMP	11	nT	*	Raw uncompensated, unlagged magnetic total field
MAGCOM	11	nT	*	Raw compensated, unlagged, un-edited magnetic total field
MAGRAW	11	nT	*	Raw magnetic total field (compensated, lagged, edited)

Name	Units	Field Length	Null	Description
DIURNRAW	11	nT	*	Raw Diurnal / ground magnetics base station 1
DIUR2RAW	11	nT	*	Raw Diurnal / ground magnetics base station 2
DIURNAL	11	nT	*	Edited Diurnal / ground magnetics (main base)
MAGDIU	11	nT	*	Magnetic total field diurnal corrected
ALTCOR	11	nT	*	Altitude correction to magnetic field
MAGALT	11	nT	*	Magnetic total field altitude corrected
MAGTLCOR	11	nT	*	Tie-line levelling corrections to magnetic field
MGMLVCOR	11	nT	*	Corrugation corrections to magnetic field
SRVMGLEV	11	nT	*	Magnetic total field, levelled to survey
IGRF	11	nT	*	IGRF (International Geomagnetic Reference Field)
SRVMGRES	11	nT	*	Residual magnetic field, levelled to survey
AZIMUTH	11	degree	*	The horizontal direction of the aircraft expressed as the angular distance between North (0 degrees) and the direction of the flight line.
LMAGUCOM	11	nT	*	Left sensor, raw uncompensated, unlagged, un-edited magnetic total field
LMAGCOM	11	nT	*	Left sensor, raw compensated, unlagged, un-edited magnetic total field
LMAGLAG	11	nT	*	Left sensor, raw compensated, Lagged magnetic total field
RMAGUCOM	11	nT	*	Right sensor, raw uncompensated, unlagged, un-edited magnetic total field
RMAGCOM	11	nT	*	Right sensor, raw compensated, unlagged, un-edited magnetic total field
RMAGLAG	11	nT	*	Right sensor, raw compensated, Lagged magnetic total field
TMAGUCOM	11	nT	*	Tail sensor, raw uncompensated, unlagged, un-edited magnetic total field
TMAGCOM	11	nT	*	Tail sensor, raw compensated, unlagged, un-edited magnetic total field
TMAGLAG	11	nT	*	Tail sensor, raw compensated, Lagged magnetic total field
PITCH	11	degree	*	Aircraft pitch
ROLL	11	degree	*	Aircraft roll
YAW	11	degree	*	Aircraft yaw
FLUXLONG	11	nT	*	Longitudinal vector of magnetic field (Fluxgate X component used for compensation)
FLUXTRAN	11	nT	*	Transverse vector of magnetic field (Fluxgate Y component used for compensation)
FLUXVERT	11	nT	*	Vertical vector of magnetic field (Fluxgate vertical component used for compensation)
HG_OCOM	11	nT/m	*	Raw Horizontal magnetic Gradient, Orthogonal (transverse/lateral), compensated, unlagged

Name	Units	Field Length	Null	Description
HG_OLAG	11	nT/m	*	Raw Horizontal magnetic Gradient, Orthogonal (transverse/lateral), compensated and lagged
HG_OROT	11	nT/m	*	Orthogonal (transverse/lateral) magnetic gradient, attitude corrected (Rotated) using pitch, roll, and yaw
HG_OLEV	11	nT/m	*	Levelled Horizontal magnetic Gradient, Orthogonal (transverse/lateral)
HG_LCOM	11	nT/m	*	Raw Horizontal magnetic Gradient, Line (longitudinal), compensated, unlagged
HG_LLAG	11	nT/m	*	Raw Horizontal magnetic Gradient, Line (longitudinal), compensated and lagged
HG_LROT	11	nT/m	*	Line (longitudinal) magnetic gradient, attitude corrected (Rotated) using pitch, roll, and yaw
HG_LLEV	11	nT/m	*	Levelled Horizontal magnetic Gradient, Line (longitudinal)
HGEA_ST	11	nT/m	*	Horizontal magnetic gradient East direction
HGNORTH	11	nT/m	*	Horizontal magnetic gradient North direction
ENHANAMF	11	nT	*	Horizontal magnetic gradient enhanced residual magnetic field
ENHANFVD	11	nT/m	*	Horizontal magnetic gradient enhanced first vertical derivative of the residual magnetic field
LINESTN	08	-	-	VLF station LINE sensor tuned to (1 - NAA, 2 - NML, 3 - DHO38, 4 - GQD)
ORTHOSTN	09	-	-	VLF station ORTHO sensor tuned to (1 - NAA, 2 - NML, 3 - DHO38, 4 - GQD)
V1TOT_RAW	10	%	*	VLF EM total field, NML, Raw
V1QUAD_RAW	11	%	*	VLF EM quadrature, NML, Raw
V2TOT_RAW	10	%	*	VLF EM total field, DHO38, Raw
V2QUAD_RAW	11	%	*	VLF EM quadrature, DHO38, Raw
V3TOT_RAW	10	%	*	VLF EM total field, GQD, Raw
V3QUAD_RAW	11	%	*	VLF EM quadrature, GQD, Raw
V1TOT_PROC	11	%	*	VLF EM total field, NML, Proc
V1QUAD_PROC	12	%	*	VLF EM quadrature, NML, Proc
V2TOT_PROC	11	%	*	VLF EM total field, DHO38, Proc
V2QUAD_PROC	12	%	*	VLF EM quadrature, DHO38, Proc
V3TOT_PROC	11	%	*	VLF EM total field, GQD, Proc
V3QUAD_PROC	12	%	*	VLF EM quadrature, GQD, Proc
V1QUAD_FF	10	FF%	*	Fraser filtered VLF EM quadrature, NML, expressed as Fraser filtered %
V2QUAD_FF	10	FF%	*	Fraser filtered VLF EM quadrature, DHO38, expressed as Fraser filtered %
V3QUAD_FF	10	FF%	*	Fraser filtered VLF EM quadrature, GQD, expressed as Fraser filtered %
V1TOT_LEV	10	%	*	VLF EM total field, NML, levelled
V23TOT_LEV	11	%	*	VLF EM total field, DHO38 and GQD, levelled
V1FF_LEV	10	FF%	*	Fraser filtered VLF EM quadrature, NML, levelled, expressed as Fraser filtered %
V23FF_LEV	10	FF%	*	Fraser filtered VLF EM quadrature, DHO38 and GQD,

Name	Units	Field Length	Null	Description
				levelled, expressed as Fraser filtered %
MERFF_LEV	10	FF%	*	Fraser filtered VLF EM quadrature, NML and DHO38 and GQD, levelled, expressed as Fraser filtered %
DATE	10	yyyymmd	-	Date of flight line
FLIGHT	06	-	-	Flight number
LINETYPE	06	-	-	Line type. L=Traverse, T=Tie, B=Background line
LINENAME	06	-	-	Line name. An alpha-numeric string, or LINETYPE + LINE

Diurnal Magnetic Data

A listing of the ground station diurnal magnetic data delivered with a sampling rate of 10 Hz can be found in Table 9.2.

Table 9.2: Ground station diurnal magnetic data

Name	Size	Units	Null	Description
YEAR	06	-	-	Year
DOY	05	-	-	Day of Year
DATE	12	YYYY/MM/DD	-	Date (Year-Month-Day)
TIME	12	HH:MM:SS.ss	*	UTC Time
FIDCOUNT	10	sec	*	Fiducial Seconds Past UTC Midnight
DIURNRAW_1	11	nT	*	Raw Diurnal / base station 1 - Unedited
DIURNEDT_1	11	nT	*	Edited Diurnal / base station 1 - Edited to remove cultural interference where selected (see below)
IGRFCOR_1	11	nT	*	IGRF / base station 1 - International Geomagnetic Reference Field
DIURNRES_1	11	nT	*	Residual Diurnal / base station 1 - IGRF and background mean (-144.638nT) removed
DIURNRAW_2	11	nT	*	Raw Diurnal / base station 2 - Unedited
DIURNEDT_2	11	nT	*	Edited Diurnal / base station 2 - Edited to remove cultural interference where selected (see below)
IGRFCOR_2	11	nT	*	IGRF / base station 2 - International Geomagnetic Reference Field
DIURNRES_2	11	nT	*	Residual Diurnal / base station 2 - IGRF and background mean (-354.137nT) removed
DIURNFIN	11	nT	*	Final Diurnal - Final selection of either station 1 or 2
STN_ID	06	-	*	Base Station Identifier (1 or 2) - Base station selected for Final Diurnal

Gamma Ray Data Format

A listing of the gamma ray data channels delivered with a sampling rate of 1 Hz can be found in Table 9.3.

Table 9.3: Gamma ray line data channels and format

Name	Units	Field Length	Null	Description
LINE	08	-	-	Line Number XXXX.YY where XXXX is line number and YY is segment number
TIME	10	sec	*	Seconds Past Midnight UTC
GPSTIME	14	sec	*	GPS Week Seconds
FIDCOUNT	10	sec	*	Fiducial Seconds
LONG	13	degree	*	Longitude, NAD83
LAT	13	degree	*	Latitude, NAD83
EASTING	11	m	*	Easting, NAD83 UTM ZONE 21N
NORTHING	11	m	*	Northing, NAD83 UTM ZONE 21N
SURFACE	11	m	*	Drape surface
RALT	09	m	*	Radar altitude (Terrain Clearance)
BALT	09	m	*	Barometric altitude
GPSALT	09	m	*	GPS altitude, MSL (above CGVD2013 Geoid)
DEM	11	m	*	Digital Elevation Model, MSL (above CGVD2013 Geoid)
TEMP	09	°C	*	Temperature
BARO_PR	09	kPa	*	Barometric Pressure
R_LIVE	09	ms	*	Live Time
R_COS	09	cps	*	Raw Cosmic count
R_UPU	09	cps	*	Raw Upward-looking Uranium count
SPECTRUM	05	cps	*	Measured spectrum, 1024 channel array
R_TOT	09	cps	*	Raw Total Count
R_POT	09	cps	*	Raw Potassium count
R_THO	09	cps	*	Raw Thorium count
R_URA	09	cps	*	Raw Uranium count
R_RDN	09	cps	*	Computed Radon Background
F_NADR	09	nGy/h	*	Natural Air Absorbed Dose Rate
F_POT	09	%	*	Final corrected Potassium concentration

Name	Units	Field Length	Null	Description
F_THO	09	ppm	*	Final corrected Thorium concentration
F_URA	09	ppm	*	Final corrected Uranium concentration
F_RTK	09	ppm/%	*	Equivalent Thorium / Potassium
F_RUK	09	ppm/%	*	Equivalent Uranium / Potassium
F_RUT	09	-	*	Equivalent Uranium / Equivalent Thorium
DATE	08	yyyymmdd	-	Date of flight line
FLIGHT	08	-	-	Flight number
LINETYPE	08	-	-	Line type. L=Traverse, T=Tie, B=Background line.
LINENAME	06	-	-	Line name. An alpha-numeric string, or LINETYPE + LINE.

GPS Data

All Airborne GPS data is provided in RINEX (Receiver Independent Exchange Format) Version 2.1 data format, on a flight by flight basis.

Digital Grids

Digital grids are provided as digital grids in the following formats:

- Geosoft Binary (.grd) with associated Geographic Information (.gi) files

The grids have the following properties:

Datum:	NAD83
Projection:	Universal Transverse Mercator Zone 21 North
Cell size (m):	35

A list of all digital grids delivered can be found in Table 9.4.

Table 9.4: Delivered digital grids

Grid File Name	Units	Description
MAG	nT	Residual Magnetic Anomaly
FVD	nT/m	First Vertical Derivative of Residual Magnetic Anomaly
Enhanced_MAG	nT	Gradient Enhanced Residual Magnetic Anomaly
Enhanced_FVD	nT/m	Gradient Enhanced First Vertical Derivative of the Residual Magnetic Anomaly
Orthogonal_Levelled	nT/m	Levelled Orthogonal Magnetic Gradient
Longitudinal_Levelled	nT/m	Levelled Longitudinal Magnetic Gradient
East_Gradient	nT/m	Horizontal Magnetic Gradient, East Direction
North_Gradient	nT/m	Horizontal Magnetic Gradient, North Direction
Bare_Earth_DEM	m	Bare Earth Digital Elevation Model (DEM), MSL (above CGVD2013 Geoid)
DEM	m	Digital Elevation Model (DEM), MSL (above CGVD2013 Geoid)
NML_TOT	%	Levelled VLF EM total field, NML
DHO_GQD_TOT	%	Levelled VLF EM total field, DHO and GQD
NML_FFQUAD	FF%	Levelled Fraser filtered VLF EM quadrature, NML, expressed as Fraser filtered %
DHO_GQD_FFQUAD	FF%	Levelled Fraser filtered VLF EM quadrature, DHO and GQD, expressed as Fraser filtered %
NML_DHO_GQD_FFQUAD	FF%	Levelled Fraser filtered VLF EM quadrature, NML, DHO and GQD, expressed as Fraser filtered %
AADR	nGy/h	Natural Air Absorbed Dose Rate
POT	%	Potassium
URA	ppm	Equivalent Uranium
THO	ppm	Equivalent Thorium
RUT	ppm/ppm	Uranium/Thorium ratio
RUK	ppm/%	Uranium/Potassium ratio
RTK	ppm/%	Thorium/Potassium ratio

Maps

Maps are provided as digital grids in the following formats:

- Geosoft Packed Map
- PDF

The maps have the following properties:

Datum:	NAD83
Projection:	Universal Transverse Mercator Zone 21 North
Map Scale:	1:75000

A list of all digital maps delivered can be found in Table 9.5.

Table 9.5: Delivered maps, hard copy and digitally

Map Name	Description
2020-01	Residual Total Magnetic Field (Gradient Enhanced)
2020-02	First Vertical Derivative of the magnetic field (Gradient Enhanced)
2020-03	Potassium Percent
2020-04	Uranium ppm
2020-05	Thorium ppm
2020-06	Thorium/Potassium Ratio
2020-07	Uranium/Potassium Ratio
2020-08	Uranium/Thorium Ratio
2020-09	Natural Air Absorbed Dose Rate
2020-10	Ternary Radioelement Map
2020-11	VLF-EM Total Field – 25.2 KHz (LaMoure, ND)
2020-12	VLF-EM Total Field – 23.4 & 22.1 KHz (Rhauderfehn, Germany & Skelton, UK)
2020-13	VLF-EM Quadrature – 25.2, 23.4 & 22.1 KHz (LaMoure, ND, Rhauderfehn, Germany & Skelton, UK)

See Appendix IX for report size maps.

Appendix I

Company Profile

ABOUT US

Sander Geophysics Limited (SGL) provides worldwide airborne geophysical surveys for petroleum and mineral exploration, and geological and environmental mapping. Services offered include high resolution airborne gravity, magnetic, electromagnetic, and radiometric surveys, using fixed-wing aircraft and helicopters.

SGL head office in Ottawa, Canada

Dr. George W. Sander (1924-2008) founded SGL in 1956 to provide ground geophysical surveys. The first airborne surveys were performed as early as 1958, and by 1967 airborne geophysical surveys were the company's main focus. Operations have expanded steadily since SGL was founded 60 years ago. The company is led by co-Presidents Luise Sander and Stephan Sander.

WORLDWIDE OPERATIONS

SGL's head office and aircraft maintenance hangar are located at the International Airport in Ottawa, Canada. Sander Geophysics has operated on every continent including Antarctica, over diverse conditions ranging from the tropics to deserts, mountains and offshore.

Facilities at the head office include a state of the art data processing department with an integrated digital cartographic department and a fully equipped electronics workshop for research, development and production of geophysical instruments. A Transport Canada Approved Maintenance Organization (AMO) for fixed-wing aircraft and helicopters allows most aircraft maintenance and modifications to be performed in-house.

SERVICES

AIRBORNE SURVEYS

- **Gravity (AIRGrav)**
- **Magnetic Total Field**
- **Magnetic Gradient**
- **Electromagnetic**
- **Gamma-ray Spectrometer**
- **Scanning LiDAR**

SGL offers gravity surveys with **AIRGrav** (Airborne Inertially Referenced Gravimeter), which was designed specifically for the unique characteristics of the airborne environment and is the highest resolution airborne gravimeter available. **AIRGrav** can be flown in an efficient survey aircraft during normal daytime conditions and is routinely flown in combination with magnetometer systems in SGL's airplanes and helicopters.

***AIRGrav** data: 3d image of the first vertical derivative of terrain corrected Bouguer gravity*

DATA PROCESSING

Immediate data processing is part of SGL's standard quality control procedure, and provides clients with rapid results for evaluation while a survey is in progress. Sander Geophysics offers a full range of data enhancement programs and integrated interpretation services by experienced geoscientists. Available products in digital and/or hard copy include:

- **Contour, colour or shaded relief maps of any parameter or combination of parameters**
- **NASVD processed gamma-ray spectrometer data**

- **Filtered line or grid products such as vertical or horizontal gradients, frequency slices, high/low-pass or band-pass filtered, amplitude of the analytic signal, reduction to the pole, upward or downward continuation**
- **Computed depth to basement**
- **Calculated digital terrain models**
- **Two- or three-dimensional modelling**
- **Cultural editing**
- **Complete geophysical interpretative reports**

ENVIRONMENTAL MONITORING

The company also provides environmental monitoring services using gamma-ray spectrometers and specialized processing to detect and quantify natural and anthropogenic radiation.

HEALTH & SAFETY

Sander Geophysics is a founding and active executive member of the International Airborne Geophysics Safety Association (IAGSA), which promotes the safe operation of helicopters and fixed-wing aircraft on airborne geophysical surveys.

SGL has developed and implemented a Safety Management System (SMS) and comprehensive Health, Safety and Environment (HSE) policies that govern all aspects of company operations. Safety initiatives include:

- **Project-specific Aviation Risk Analysis (ARA) and Personnel Risk Analysis (PRA) for all surveys**
- **Real-time satellite tracking of SGL aircraft**
- **HSE and first aid training for all field personnel**
- **Low-level flight and aircraft simulator training for pilots**
- **Advanced safety training appropriate to the survey location, such as water-egress, wilderness survival, etc.**

SGL's excellent safety record reflects the quality and experience of its survey crews. This, combined with management's ongoing commitment to safety, helps to ensure that Sander Geophysics is a safe and reliable choice for airborne geophysical surveys.

PERSONNEL

Sander Geophysics has over 160 experienced permanent employees, including geophysicists, software and hardware engineers, aircraft maintenance engineers and pilots.

AIRCRAFT

SGL owns and operates thirteen aircraft, including eight Cessna Grand Caravans and a Twin Otter all equipped for geophysical surveys.

The Grand Caravans have been modified to allow the installation of a tri-axial magnetic gradiometer system. The company's fleet also includes a de Havilland DHC-6 Twin Otter for airborne magnetic, gravity, radiometric and frequency-domain EM surveys, and two AS350 B3 helicopters equipped for gravity, magnetic and radiometric surveys. Extensive modifications have been made to all of the survey aircraft to accommodate geophysical instruments and to reduce the aircraft's magnetic field. Typical Figures of Merit (FOM) for Sander Geophysics' fixed-wing aircraft are less than 1 nT. The company's aircraft are flown and maintained by licensed and experienced permanent employees of Sander Geophysics.

SGL aircraft

RESEARCH & DEVELOPMENT

Nearly one-third of the company's resources are devoted to developing new and more efficient instrumentation for airborne geophysical surveying, and to further refine its full suite of software for geophysical data processing.

SGL

Appendix II

PLANNED SURVEY LINES
DATUM NAD-83

SEGMENT	START		END		LENGTH	
NO	LAT	LONG	LAT	LONG	NM	KM
C0101.0	N48:14.76	W056:00.63	N48:16.64	W055:57.74	2.70	5.00
C0102.0	N48:14.03	W056:00.59	N48:16.25	W055:57.17	3.19	5.90
C0103.0	N48:13.25	W056:00.63	N48:15.87	W055:56.61	3.75	6.95
C0104.0	N48:12.58	W056:00.50	N48:15.48	W055:56.05	4.16	7.70
C0105.0	N48:11.86	W056:00.46	N48:15.32	W055:55.14	4.97	9.20
C0106.0	N48:11.07	W056:00.51	N48:15.33	W055:53.96	6.10	11.30
C0107.0	N48:10.35	W056:00.46	N48:15.34	W055:52.79	7.15	13.25
C0108.0	N48:09.57	W056:00.51	N48:15.34	W055:51.62	8.29	15.35
C0109.0	N48:08.84	W056:00.46	N48:15.35	W055:50.45	9.34	17.30
C0110.0	N48:08.06	W056:00.51	N48:15.30	W055:49.36	10.39	19.25
C0111.0	N48:07.33	W056:00.46	N48:15.31	W055:48.19	11.45	21.20
C0112.0	N48:06.83	W056:00.07	N48:15.31	W055:47.02	12.18	22.55
C0113.0	N48:06.33	W055:59.68	N48:15.38	W055:45.76	12.99	24.05
C0114.0	N48:05.61	W055:59.64	N48:15.38	W055:44.59	14.04	26.00
C0115.0	N48:04.99	W055:59.43	N48:15.39	W055:43.42	14.93	27.65
C0116.0	N48:04.50	W055:59.04	N48:15.45	W055:42.16	15.74	29.15
C0117.0	N48:04.11	W055:58.48	N48:17.31	W055:38.11	18.98	35.15
C0118.0	N48:03.72	W055:57.91	N48:16.93	W055:37.54	18.98	35.15
C0119.0	N48:02.54	W055:58.56	N48:18.05	W055:34.63	22.30	41.30
C0120.0	N48:02.16	W055:58.00	N48:17.67	W055:34.06	22.30	41.30
C0121.0	N48:01.77	W055:57.44	N48:17.28	W055:33.50	22.30	41.30
C0122.0	N48:01.38	W055:56.88	N48:16.89	W055:32.94	22.30	41.30
C0123.0	N48:01.00	W055:56.32	N48:16.50	W055:32.38	22.30	41.30
C0124.0	N48:00.61	W055:55.76	N48:16.11	W055:31.82	22.30	41.30
C0125.0	N48:00.22	W055:55.20	N48:15.78	W055:31.17	22.38	41.45
C0126.0	N48:01.02	W055:52.82	N48:15.39	W055:30.61	20.68	38.30
C0127.0	N48:00.63	W055:52.26	N48:15.00	W055:30.05	20.68	38.30
C0128.0	N48:00.25	W055:51.70	N48:14.61	W055:29.49	20.68	38.30
C0129.0	N48:00.99	W055:49.41	N48:14.22	W055:28.93	19.06	35.30
C0130.0	N48:00.60	W055:48.85	N48:13.22	W055:29.33	18.17	33.65
C0131.0	N48:00.21	W055:48.29	N48:12.43	W055:29.38	17.60	32.60
C0132.0	N48:01.01	W055:45.91	N48:11.71	W055:29.35	15.42	28.55
C0133.0	N48:00.62	W055:45.35	N48:10.98	W055:29.31	14.93	27.65
C0134.0	N48:00.23	W055:44.79	N48:10.20	W055:29.36	14.36	26.60
C0135.0	N48:00.29	W055:43.53	N48:09.47	W055:29.33	13.23	24.50
C0136.0	N47:59.91	W055:42.98	N48:08.69	W055:29.38	12.66	23.45
C0137.0	N47:59.52	W055:42.42	N48:07.97	W055:29.34	12.18	22.55
C0138.0	N47:59.13	W055:41.86	N48:07.19	W055:29.40	11.61	21.50
C0139.0	N47:58.74	W055:41.30	N48:06.46	W055:29.36	11.12	20.60
C0140.0	N47:58.35	W055:40.74	N48:05.73	W055:29.32	10.64	19.70
C0141.0	N47:57.97	W055:40.18	N48:04.95	W055:29.38	10.07	18.65
C0142.0	N47:57.58	W055:39.62	N48:04.23	W055:29.34	9.58	17.75
C0143.0	N47:57.19	W055:39.06	N48:03.44	W055:29.39	9.02	16.70
C0144.0	N47:56.80	W055:38.51	N48:02.83	W055:29.18	8.69	16.10
C0145.0	N47:56.41	W055:37.95	N48:02.44	W055:28.62	8.69	16.10
C0146.0	N47:56.02	W055:37.39	N48:02.05	W055:28.07	8.69	16.10
C0147.0	N47:55.64	W055:36.83	N48:01.66	W055:27.51	8.69	16.10
C0148.0	N47:55.25	W055:36.28	N48:01.27	W055:26.95	8.69	16.10
C0149.0	N47:54.86	W055:35.72	N48:00.88	W055:26.39	8.69	16.10
C0150.0	N47:54.47	W055:35.16	N48:00.50	W055:25.84	8.69	16.10
C0151.0	N47:54.08	W055:34.60	N48:00.11	W055:25.28	8.69	16.10
C0152.0	N47:53.69	W055:34.05	N47:59.72	W055:24.72	8.69	16.10
C0153.0	N47:53.30	W055:33.49	N47:59.33	W055:24.17	8.69	16.10
C0154.0	N47:52.92	W055:32.93	N47:58.94	W055:23.61	8.69	16.10
C0155.0	N47:52.53	W055:32.38	N47:58.55	W055:23.05	8.69	16.10
C0156.0	N47:52.14	W055:31.82	N47:57.65	W055:23.28	7.96	14.75
C0157.0	N47:51.75	W055:31.26	N47:53.45	W055:28.63	2.46	4.55
C0158.0	N47:51.36	W055:30.71	N47:52.33	W055:29.20	1.40	2.60
C0159.0	N47:50.97	W055:30.15	N47:51.55	W055:29.26	0.84	1.55
T1001.0	N48:02.62	W055:58.56	N48:00.22	W055:55.08	3.35	6.20
T1002.0	N48:02.68	W055:58.48	N48:00.28	W055:55.00	3.35	6.20
T1003.0	N48:02.73	W055:58.39	N48:00.33	W055:54.91	3.35	6.20
T1004.0	N48:02.79	W055:58.30	N48:00.39	W055:54.82	3.35	6.20
T1005.0	N48:02.85	W055:58.22	N48:00.45	W055:54.74	3.35	6.20
T1006.0	N48:02.90	W055:58.13	N48:00.50	W055:54.65	3.35	6.20
T1007.0	N48:02.96	W055:58.04	N48:00.56	W055:54.56	3.35	6.20

PLANNED SURVEY LINES
DATUM NAD-83

SEGMENT	START		END		LENGTH	
NO	LAT	LONG	LAT	LONG	NM	KM
T1008.0	N48:03.02	W055:57.96	N48:00.62	W055:54.48	3.35	6.20
T1009.0	N48:03.07	W055:57.87	N48:00.67	W055:54.39	3.35	6.20
T1010.0	N48:03.13	W055:57.78	N48:00.73	W055:54.30	3.35	6.20
T1011.0	N48:03.19	W055:57.70	N48:00.79	W055:54.22	3.35	6.20
T1012.0	N48:03.24	W055:57.61	N48:00.84	W055:54.13	3.35	6.20
T1013.0	N48:03.30	W055:57.52	N48:00.90	W055:54.04	3.35	6.20
T1014.0	N48:03.35	W055:57.44	N48:00.96	W055:53.96	3.35	6.20
T1015.0	N48:04.57	W055:59.04	N48:01.01	W055:53.87	4.97	9.20
T1016.0	N48:04.63	W055:58.95	N48:01.07	W055:53.78	4.97	9.20
T1017.0	N48:05.07	W055:59.42	N48:01.12	W055:53.70	5.51	10.20
T1018.0	N48:05.13	W055:59.34	N48:01.18	W055:53.61	5.51	10.20
T1019.0	N48:05.18	W055:59.25	N48:01.24	W055:53.52	5.51	10.20
T1020.0	N48:05.24	W055:59.16	N48:01.29	W055:53.44	5.51	10.20
T1021.0	N48:05.68	W055:59.64	N48:01.35	W055:53.35	6.05	11.20
T1022.0	N48:05.74	W055:59.55	N48:00.25	W055:51.58	7.67	14.20
T1023.0	N48:05.80	W055:59.47	N48:00.30	W055:51.50	7.67	14.20
T1024.0	N48:05.85	W055:59.38	N48:00.36	W055:51.41	7.67	14.20
T1025.0	N48:05.91	W055:59.29	N48:00.41	W055:51.32	7.67	14.20
T1026.0	N48:05.97	W055:59.21	N48:00.47	W055:51.24	7.67	14.20
T1027.0	N48:06.41	W055:59.68	N48:00.53	W055:51.15	8.21	15.20
T1028.0	N48:06.47	W055:59.60	N48:00.58	W055:51.06	8.21	15.20
T1029.0	N48:06.91	W056:00.07	N48:00.64	W055:50.98	8.75	16.20
T1030.0	N48:06.97	W055:59.99	N48:00.70	W055:50.89	8.75	16.20
T1031.0	N48:07.41	W056:00.46	N48:00.75	W055:50.80	9.29	17.20
T1032.0	N48:07.47	W056:00.38	N48:00.81	W055:50.72	9.29	17.20
T1033.0	N48:07.52	W056:00.29	N48:00.87	W055:50.63	9.29	17.20
T1034.0	N48:07.58	W056:00.20	N48:00.92	W055:50.54	9.29	17.20
T1035.0	N48:07.63	W056:00.12	N48:00.98	W055:50.46	9.29	17.20
T1036.0	N48:07.69	W056:00.03	N48:01.03	W055:50.37	9.29	17.20
T1037.0	N48:08.13	W056:00.50	N48:01.09	W055:50.28	9.83	18.20
T1038.0	N48:08.19	W056:00.42	N48:01.15	W055:50.20	9.83	18.20
T1039.0	N48:08.25	W056:00.33	N48:01.20	W055:50.11	9.83	18.20
T1040.0	N48:08.30	W056:00.25	N48:01.26	W055:50.03	9.83	18.20
T1041.0	N48:08.36	W056:00.16	N48:01.32	W055:49.94	9.83	18.20
T1042.0	N48:08.42	W056:00.07	N48:00.21	W055:48.17	11.45	21.20
T1043.0	N48:08.47	W055:59.99	N48:00.27	W055:48.09	11.45	21.20
T1044.0	N48:08.92	W056:00.46	N48:00.32	W055:48.00	11.99	22.20
T1045.0	N48:08.97	W056:00.37	N48:00.38	W055:47.91	11.99	22.20
T1046.0	N48:09.03	W056:00.29	N48:00.44	W055:47.83	11.99	22.20
T1047.0	N48:09.09	W056:00.20	N48:00.49	W055:47.74	11.99	22.20
T1048.0	N48:09.14	W056:00.11	N48:00.55	W055:47.65	11.99	22.20
T1049.0	N48:09.20	W056:00.03	N48:00.61	W055:47.57	11.99	22.20
T1050.0	N48:09.64	W056:00.50	N48:00.66	W055:47.48	12.53	23.20
T1051.0	N48:09.70	W056:00.42	N48:00.72	W055:47.39	12.53	23.20
T1052.0	N48:09.76	W056:00.33	N48:00.77	W055:47.31	12.53	23.20
T1053.0	N48:09.81	W056:00.24	N48:00.83	W055:47.22	12.53	23.20
T1054.0	N48:09.87	W056:00.16	N48:00.89	W055:47.13	12.53	23.20
T1055.0	N48:09.92	W056:00.07	N48:00.94	W055:47.05	12.53	23.20
T1056.0	N48:09.98	W055:59.98	N48:01.00	W055:46.96	12.53	23.20
T1057.0	N48:10.42	W056:00.46	N48:01.06	W055:46.87	13.07	24.20
T1058.0	N48:10.48	W056:00.37	N48:01.11	W055:46.79	13.07	24.20
T1059.0	N48:10.54	W056:00.29	N48:01.17	W055:46.70	13.07	24.20
T1060.0	N48:10.59	W056:00.20	N48:01.22	W055:46.61	13.07	24.20
T1061.0	N48:10.65	W056:00.11	N48:01.28	W055:46.53	13.07	24.20
T1062.0	N48:10.71	W056:00.03	N48:01.34	W055:46.44	13.07	24.20
T1063.0	N48:11.15	W056:00.50	N48:00.23	W055:44.67	15.23	28.20
T1064.0	N48:11.21	W056:00.42	N48:00.29	W055:44.59	15.23	28.20
T1065.0	N48:11.26	W056:00.33	N48:00.34	W055:44.50	15.23	28.20
T1066.0	N48:11.32	W056:00.24	N48:00.40	W055:44.41	15.23	28.20
T1067.0	N48:11.38	W056:00.16	N48:00.46	W055:44.33	15.23	28.20
T1068.0	N48:11.43	W056:00.07	N48:00.51	W055:44.24	15.23	28.20
T1069.0	N48:11.49	W055:59.98	N48:00.57	W055:44.15	15.23	28.20
T1070.0	N48:11.93	W056:00.46	N48:00.62	W055:44.07	15.77	29.20
T1071.0	N48:11.99	W056:00.37	N47:50.97	W055:30.04	29.27	54.20
T1072.0	N48:12.04	W056:00.29	N47:51.03	W055:29.95	29.27	54.20
T1073.0	N48:12.10	W056:00.20	N47:51.08	W055:29.86	29.27	54.20

PLANNED SURVEY LINES
DATUM NAD-83

SEGMENT	START		END		LENGTH	
NO	LAT	LONG	LAT	LONG	NM	KM
T1074.0	N48:12.16	W056:00.11	N47:51.14	W055:29.78	29.27	54.20
T1075.0	N48:12.21	W056:00.03	N47:51.19	W055:29.69	29.27	54.20
T1076.0	N48:12.66	W056:00.50	N47:51.25	W055:29.60	29.81	55.20
T1077.0	N48:12.71	W056:00.42	N47:51.31	W055:29.52	29.81	55.20
T1078.0	N48:12.77	W056:00.33	N47:51.36	W055:29.43	29.81	55.20
T1079.0	N48:12.83	W056:00.24	N47:51.42	W055:29.34	29.81	55.20
T1080.0	N48:12.88	W056:00.16	N47:51.47	W055:29.26	29.81	55.20
T1081.0	N48:13.33	W056:00.63	N47:51.92	W055:29.73	29.81	55.20
T1082.0	N48:13.38	W056:00.55	N47:51.98	W055:29.64	29.81	55.20
T1083.0	N48:13.44	W056:00.46	N47:52.03	W055:29.55	29.81	55.20
T1084.0	N48:13.50	W056:00.37	N47:52.09	W055:29.47	29.81	55.20
T1085.0	N48:13.55	W056:00.29	N47:52.14	W055:29.38	29.81	55.20
T1086.0	N48:13.61	W056:00.20	N47:52.20	W055:29.29	29.81	55.20
T1087.0	N48:13.67	W056:00.11	N47:52.26	W055:29.21	29.81	55.20
T1088.0	N48:14.11	W056:00.59	N47:52.70	W055:29.68	29.81	55.20
T1089.0	N48:14.17	W056:00.50	N47:52.76	W055:29.59	29.81	55.20
T1090.0	N48:14.22	W056:00.42	N47:52.81	W055:29.50	29.81	55.20
T1091.0	N48:14.28	W056:00.33	N47:52.87	W055:29.42	29.81	55.20
T1092.0	N48:14.33	W056:00.24	N47:52.93	W055:29.33	29.81	55.20
T1093.0	N48:14.39	W056:00.16	N47:52.98	W055:29.24	29.81	55.20
T1094.0	N48:14.83	W056:00.63	N47:53.04	W055:29.16	30.35	56.20
T1095.0	N48:14.89	W056:00.55	N47:53.09	W055:29.07	30.35	56.20
T1096.0	N48:14.95	W056:00.46	N47:53.15	W055:28.98	30.35	56.20
T1097.0	N48:15.00	W056:00.37	N47:53.21	W055:28.90	30.35	56.20
T1098.0	N48:15.06	W056:00.29	N47:53.26	W055:28.81	30.35	56.20
T1099.0	N48:15.12	W056:00.20	N47:53.32	W055:28.72	30.35	56.20
T1100.0	N48:15.17	W056:00.11	N47:53.38	W055:28.64	30.35	56.20
T1101.0	N48:15.23	W056:00.02	N47:53.82	W055:29.10	29.81	55.20
T1102.0	N48:15.29	W055:59.94	N47:53.88	W055:29.02	29.81	55.20
T1103.0	N48:15.34	W055:59.85	N47:53.93	W055:28.93	29.81	55.20
T1104.0	N48:15.40	W055:59.76	N47:53.99	W055:28.84	29.81	55.20
T1105.0	N48:15.46	W055:59.68	N47:54.04	W055:28.76	29.81	55.20
T1106.0	N48:15.51	W055:59.59	N47:54.10	W055:28.67	29.81	55.20
T1107.0	N48:15.57	W055:59.50	N47:54.16	W055:28.58	29.81	55.20
T1108.0	N48:15.63	W055:59.42	N47:54.21	W055:28.50	29.81	55.20
T1109.0	N48:15.68	W055:59.33	N47:54.27	W055:28.41	29.81	55.20
T1110.0	N48:15.74	W055:59.24	N47:54.33	W055:28.32	29.81	55.20
T1111.0	N48:15.79	W055:59.16	N47:54.38	W055:28.24	29.81	55.20
T1112.0	N48:15.85	W055:59.07	N47:54.44	W055:28.15	29.81	55.20
T1113.0	N48:15.91	W055:58.98	N47:54.49	W055:28.06	29.81	55.20
T1114.0	N48:15.96	W055:58.90	N47:54.55	W055:27.98	29.81	55.20
T1115.0	N48:16.02	W055:58.81	N47:54.61	W055:27.89	29.81	55.20
T1116.0	N48:16.08	W055:58.72	N47:54.66	W055:27.80	29.81	55.20
T1117.0	N48:16.13	W055:58.64	N47:54.72	W055:27.72	29.81	55.20
T1118.0	N48:16.19	W055:58.55	N47:54.77	W055:27.63	29.81	55.20
T1119.0	N48:16.25	W055:58.46	N47:54.83	W055:27.54	29.81	55.20
T1120.0	N48:16.30	W055:58.37	N47:54.89	W055:27.46	29.81	55.20
T1121.0	N48:16.36	W055:58.29	N47:54.94	W055:27.37	29.81	55.20
T1122.0	N48:16.42	W055:58.20	N47:55.00	W055:27.28	29.81	55.20
T1123.0	N48:16.47	W055:58.11	N47:55.05	W055:27.19	29.81	55.20
T1124.0	N48:16.53	W055:58.03	N47:55.11	W055:27.11	29.81	55.20
T1125.0	N48:16.59	W055:57.94	N47:55.17	W055:27.02	29.81	55.20
T1126.0	N48:16.64	W055:57.85	N47:55.22	W055:26.93	29.81	55.20
T1127.0	N48:15.15	W055:55.51	N47:55.28	W055:26.85	27.65	51.20
T1128.0	N48:15.21	W055:55.42	N47:55.34	W055:26.76	27.65	51.20
T1129.0	N48:15.26	W055:55.34	N47:55.39	W055:26.67	27.65	51.20
T1130.0	N48:15.32	W055:55.25	N47:55.45	W055:26.59	27.65	51.20
T1131.0	N48:14.99	W055:54.60	N47:55.50	W055:26.50	27.11	50.20
T1132.0	N48:15.05	W055:54.51	N47:55.56	W055:26.41	27.11	50.20
T1133.0	N48:15.10	W055:54.43	N47:55.62	W055:26.33	27.11	50.20
T1134.0	N48:15.16	W055:54.34	N47:55.67	W055:26.24	27.11	50.20
T1135.0	N48:15.22	W055:54.25	N47:55.73	W055:26.15	27.11	50.20
T1136.0	N48:15.27	W055:54.17	N47:55.78	W055:26.07	27.11	50.20
T1137.0	N48:15.33	W055:54.08	N47:55.84	W055:25.98	27.11	50.20
T1138.0	N48:15.00	W055:53.43	N47:55.90	W055:25.89	26.57	49.20
T1139.0	N48:15.05	W055:53.34	N47:55.95	W055:25.80	26.57	49.20

PLANNED SURVEY LINES
DATUM NAD-83

SEGMENT	START		END		LENGTH	
NO	LAT	LONG	LAT	LONG	NM	KM
T1140.0	N48:15.11	W055:53.25	N47:56.01	W055:25.72	26.57	49.20
T1141.0	N48:15.17	W055:53.17	N47:56.06	W055:25.63	26.57	49.20
T1142.0	N48:15.22	W055:53.08	N47:56.12	W055:25.54	26.57	49.20
T1143.0	N48:15.28	W055:52.99	N47:56.18	W055:25.46	26.57	49.20
T1144.0	N48:15.34	W055:52.91	N47:56.23	W055:25.37	26.57	49.20
T1145.0	N48:15.01	W055:52.26	N47:56.29	W055:25.28	26.03	48.20
T1146.0	N48:15.06	W055:52.17	N47:56.34	W055:25.20	26.03	48.20
T1147.0	N48:15.12	W055:52.08	N47:56.40	W055:25.11	26.03	48.20
T1148.0	N48:15.17	W055:52.00	N47:56.46	W055:25.02	26.03	48.20
T1149.0	N48:15.23	W055:51.91	N47:56.51	W055:24.94	26.03	48.20
T1150.0	N48:15.29	W055:51.82	N47:56.57	W055:24.85	26.03	48.20
T1151.0	N48:15.34	W055:51.73	N47:56.62	W055:24.76	26.03	48.20
T1152.0	N48:15.01	W055:51.08	N47:56.68	W055:24.67	25.49	47.20
T1153.0	N48:15.07	W055:51.00	N47:56.74	W055:24.59	25.49	47.20
T1154.0	N48:15.13	W055:50.91	N47:56.79	W055:24.50	25.49	47.20
T1155.0	N48:15.18	W055:50.82	N47:56.85	W055:24.41	25.49	47.20
T1156.0	N48:15.24	W055:50.74	N47:56.91	W055:24.33	25.49	47.20
T1157.0	N48:15.29	W055:50.65	N47:56.96	W055:24.24	25.49	47.20
T1158.0	N48:15.35	W055:50.56	N47:57.02	W055:24.15	25.49	47.20
T1159.0	N48:15.02	W055:49.91	N47:57.07	W055:24.07	24.95	46.20
T1160.0	N48:15.08	W055:49.83	N47:57.13	W055:23.98	24.95	46.20
T1161.0	N48:15.13	W055:49.74	N47:57.19	W055:23.89	24.95	46.20
T1162.0	N48:15.19	W055:49.65	N47:57.24	W055:23.80	24.95	46.20
T1163.0	N48:15.25	W055:49.56	N47:57.30	W055:23.72	24.95	46.20
T1164.0	N48:15.30	W055:49.48	N47:57.35	W055:23.63	24.95	46.20
T1165.0	N48:14.97	W055:48.83	N47:57.41	W055:23.54	24.41	45.20
T1166.0	N48:15.03	W055:48.74	N47:57.47	W055:23.46	24.41	45.20
T1167.0	N48:15.08	W055:48.65	N47:57.52	W055:23.37	24.41	45.20
T1168.0	N48:15.14	W055:48.57	N47:57.58	W055:23.28	24.41	45.20
T1169.0	N48:15.20	W055:48.48	N47:58.02	W055:23.75	23.87	44.20
T1170.0	N48:15.25	W055:48.39	N47:58.08	W055:23.67	23.87	44.20
T1171.0	N48:15.31	W055:48.31	N47:58.14	W055:23.58	23.87	44.20
T1172.0	N48:14.98	W055:47.66	N47:58.19	W055:23.49	23.33	43.20
T1173.0	N48:15.03	W055:47.57	N47:58.25	W055:23.40	23.33	43.20
T1174.0	N48:15.09	W055:47.48	N47:58.30	W055:23.32	23.33	43.20
T1175.0	N48:15.15	W055:47.40	N47:58.36	W055:23.23	23.33	43.20
T1176.0	N48:15.20	W055:47.31	N47:58.42	W055:23.14	23.33	43.20
T1177.0	N48:15.26	W055:47.22	N47:58.47	W055:23.06	23.33	43.20
T1178.0	N48:15.32	W055:47.13	N48:03.20	W055:29.66	16.85	31.20
T1179.0	N48:14.98	W055:46.48	N48:03.26	W055:29.57	16.31	30.20
T1180.0	N48:15.04	W055:46.40	N48:03.31	W055:29.48	16.31	30.20
T1181.0	N48:15.10	W055:46.31	N48:03.37	W055:29.39	16.31	30.20
T1182.0	N48:15.15	W055:46.22	N48:03.81	W055:29.87	15.77	29.20
T1183.0	N48:15.21	W055:46.14	N48:03.87	W055:29.78	15.77	29.20
T1184.0	N48:15.27	W055:46.05	N48:03.93	W055:29.69	15.77	29.20
T1185.0	N48:15.32	W055:45.96	N48:03.98	W055:29.60	15.77	29.20
T1186.0	N48:15.38	W055:45.87	N48:04.04	W055:29.52	15.77	29.20
T1187.0	N48:15.05	W055:45.23	N48:04.09	W055:29.43	15.23	28.20
T1188.0	N48:15.10	W055:45.14	N48:04.15	W055:29.34	15.23	28.20
T1189.0	N48:15.16	W055:45.05	N48:04.59	W055:29.81	14.69	27.20
T1190.0	N48:15.22	W055:44.96	N48:04.65	W055:29.73	14.69	27.20
T1191.0	N48:15.27	W055:44.88	N48:04.71	W055:29.64	14.69	27.20
T1192.0	N48:15.33	W055:44.79	N48:04.76	W055:29.55	14.69	27.20
T1193.0	N48:15.39	W055:44.70	N48:04.82	W055:29.47	14.69	27.20
T1194.0	N48:15.05	W055:44.05	N48:04.88	W055:29.38	14.15	26.20
T1195.0	N48:15.11	W055:43.97	N48:05.32	W055:29.85	13.61	25.20
T1196.0	N48:15.17	W055:43.88	N48:05.38	W055:29.76	13.61	25.20
T1197.0	N48:15.22	W055:43.79	N48:05.43	W055:29.68	13.61	25.20
T1198.0	N48:15.28	W055:43.71	N48:05.49	W055:29.59	13.61	25.20
T1199.0	N48:15.33	W055:43.62	N48:05.54	W055:29.50	13.61	25.20
T1200.0	N48:15.39	W055:43.53	N48:05.60	W055:29.41	13.61	25.20
T1201.0	N48:15.06	W055:42.88	N48:05.66	W055:29.33	13.07	24.20
T1202.0	N48:15.12	W055:42.79	N48:06.10	W055:29.80	12.53	23.20
T1203.0	N48:15.17	W055:42.71	N48:06.16	W055:29.71	12.53	23.20
T1204.0	N48:15.23	W055:42.62	N48:06.21	W055:29.62	12.53	23.20
T1205.0	N48:15.28	W055:42.53	N48:06.27	W055:29.54	12.53	23.20

PLANNED SURVEY LINES
DATUM NAD-83

SEGMENT	START		END		LENGTH	
NO	LAT	LONG	LAT	LONG	NM	KM
T1206.0	N48:15.34	W055:42.45	N48:06.33	W055:29.45	12.53	23.20
T1207.0	N48:15.40	W055:42.36	N48:06.38	W055:29.36	12.53	23.20
T1208.0	N48:15.45	W055:42.27	N48:06.83	W055:29.83	11.99	22.20
T1209.0	N48:15.12	W055:41.62	N48:06.88	W055:29.75	11.45	21.20
T1210.0	N48:15.18	W055:41.54	N48:06.94	W055:29.66	11.45	21.20
T1211.0	N48:15.23	W055:41.45	N48:07.00	W055:29.57	11.45	21.20
T1212.0	N48:15.29	W055:41.36	N48:07.05	W055:29.49	11.45	21.20
T1213.0	N48:15.35	W055:41.27	N48:07.11	W055:29.40	11.45	21.20
T1214.0	N48:15.40	W055:41.19	N48:07.55	W055:29.87	10.91	20.20
T1215.0	N48:15.46	W055:41.10	N48:07.61	W055:29.78	10.91	20.20
T1216.0	N48:15.52	W055:41.01	N48:07.67	W055:29.70	10.91	20.20
T1217.0	N48:15.57	W055:40.93	N48:07.72	W055:29.61	10.91	20.20
T1218.0	N48:15.63	W055:40.84	N48:07.78	W055:29.52	10.91	20.20
T1219.0	N48:15.68	W055:40.75	N48:07.83	W055:29.43	10.91	20.20
T1220.0	N48:15.74	W055:40.66	N48:07.89	W055:29.35	10.91	20.20
T1221.0	N48:15.80	W055:40.58	N48:08.34	W055:29.82	10.37	19.20
T1222.0	N48:15.85	W055:40.49	N48:08.39	W055:29.73	10.37	19.20
T1223.0	N48:15.91	W055:40.40	N48:08.45	W055:29.64	10.37	19.20
T1224.0	N48:15.97	W055:40.32	N48:08.50	W055:29.56	10.37	19.20
T1225.0	N48:16.02	W055:40.23	N48:08.56	W055:29.47	10.37	19.20
T1226.0	N48:16.08	W055:40.14	N48:08.62	W055:29.38	10.37	19.20
T1227.0	N48:16.13	W055:40.05	N48:09.06	W055:29.85	9.83	18.20
T1228.0	N48:16.19	W055:39.97	N48:09.12	W055:29.77	9.83	18.20
T1229.0	N48:16.25	W055:39.88	N48:09.17	W055:29.68	9.83	18.20
T1230.0	N48:16.30	W055:39.79	N48:09.23	W055:29.59	9.83	18.20
T1231.0	N48:16.36	W055:39.70	N48:09.29	W055:29.51	9.83	18.20
T1232.0	N48:16.42	W055:39.62	N48:09.34	W055:29.42	9.83	18.20
T1233.0	N48:16.47	W055:39.53	N48:09.40	W055:29.33	9.83	18.20
T1234.0	N48:16.53	W055:39.44	N48:09.84	W055:29.80	9.29	17.20
T1235.0	N48:16.58	W055:39.36	N48:09.90	W055:29.72	9.29	17.20
T1236.0	N48:16.64	W055:39.27	N48:09.96	W055:29.63	9.29	17.20
T1237.0	N48:16.70	W055:39.18	N48:10.01	W055:29.54	9.29	17.20
T1238.0	N48:16.75	W055:39.09	N48:10.07	W055:29.45	9.29	17.20
T1239.0	N48:16.81	W055:39.01	N48:10.12	W055:29.37	9.29	17.20
T1240.0	N48:16.87	W055:38.92	N48:10.57	W055:29.84	8.75	16.20
T1241.0	N48:16.92	W055:38.83	N48:10.63	W055:29.75	8.75	16.20
T1242.0	N48:16.98	W055:38.74	N48:10.68	W055:29.66	8.75	16.20
T1243.0	N48:17.03	W055:38.66	N48:10.74	W055:29.58	8.75	16.20
T1244.0	N48:17.09	W055:38.57	N48:10.79	W055:29.49	8.75	16.20
T1245.0	N48:17.15	W055:38.48	N48:10.85	W055:29.40	8.75	16.20
T1246.0	N48:17.20	W055:38.40	N48:10.91	W055:29.32	8.75	16.20
T1247.0	N48:17.26	W055:38.31	N48:11.35	W055:29.79	8.21	15.20
T1248.0	N48:17.32	W055:38.22	N48:11.41	W055:29.70	8.21	15.20
T1249.0	N48:16.59	W055:37.01	N48:11.46	W055:29.61	7.13	13.20
T1250.0	N48:16.65	W055:36.92	N48:11.52	W055:29.53	7.13	13.20
T1251.0	N48:16.71	W055:36.84	N48:11.58	W055:29.44	7.13	13.20
T1252.0	N48:16.76	W055:36.75	N48:11.63	W055:29.35	7.13	13.20
T1253.0	N48:16.82	W055:36.66	N48:12.08	W055:29.82	6.59	12.20
T1254.0	N48:16.88	W055:36.57	N48:12.13	W055:29.74	6.59	12.20
T1255.0	N48:16.93	W055:36.49	N48:12.19	W055:29.65	6.59	12.20
T1256.0	N48:16.99	W055:36.40	N48:12.24	W055:29.56	6.59	12.20
T1257.0	N48:17.04	W055:36.31	N48:12.30	W055:29.47	6.59	12.20
T1258.0	N48:17.10	W055:36.22	N48:12.36	W055:29.39	6.59	12.20
T1259.0	N48:17.16	W055:36.14	N48:12.80	W055:29.86	6.05	11.20
T1260.0	N48:17.21	W055:36.05	N48:12.86	W055:29.77	6.05	11.20
T1261.0	N48:17.27	W055:35.96	N48:12.91	W055:29.68	6.05	11.20
T1262.0	N48:17.33	W055:35.88	N48:12.97	W055:29.60	6.05	11.20
T1263.0	N48:17.38	W055:35.79	N48:13.03	W055:29.51	6.05	11.20
T1264.0	N48:17.44	W055:35.70	N48:13.08	W055:29.42	6.05	11.20
T1265.0	N48:17.49	W055:35.61	N48:13.14	W055:29.34	6.05	11.20
T1266.0	N48:17.55	W055:35.53	N48:13.58	W055:29.81	5.51	10.20
T1267.0	N48:17.61	W055:35.44	N48:13.64	W055:29.72	5.51	10.20
T1268.0	N48:17.66	W055:35.35	N48:13.70	W055:29.63	5.51	10.20
T1269.0	N48:17.72	W055:35.26	N48:13.75	W055:29.55	5.51	10.20
T1270.0	N48:17.77	W055:35.18	N48:13.81	W055:29.46	5.51	10.20
T1271.0	N48:17.83	W055:35.09	N48:13.86	W055:29.37	5.51	10.20

PLANNED SURVEY LINES
DATUM NAD-83

SEGMENT	START		END		LENGTH	
NO	LAT	LONG	LAT	LONG	NM	KM
T1272.0	N48:17.89	W055:35.00	N48:13.92	W055:29.28	5.51	10.20
T1273.0	N48:17.94	W055:34.91	N48:13.98	W055:29.20	5.51	10.20
T1274.0	N48:18.00	W055:34.83	N48:14.03	W055:29.11	5.51	10.20
T1275.0	N48:18.06	W055:34.74	N48:14.09	W055:29.02	5.51	10.20
T1276.0	N48:15.78	W055:31.29	N48:14.15	W055:28.93	2.27	4.20

Total control line length = 714.21 nautical miles
= 1322.71 kilometers.

Total traverse line length = 4631.32 nautical miles
= 8577.20 kilometers.

Total length of all lines = 5345.52 nautical miles
= 9899.91 kilometers.

SGL

Appendix III

Equipment List

Part	Serial No.	Description	Manufacturer
Aircraft- C-GSGL	208B-0783	Cessna 208B Grand Caravan,engine Pratt & Whitney Canada,mod. PT6A-114A, S/N PCE-PC0719	Cessna
Barometric Sensor	1335789	Barometric Transducer Honeywell Model THE absolute	Honeywell
Data Acquisition Computer	CDAC-17	CPCI Data Acquisition computer	SGL
Fluxgate Magnetometer	877	Model TFM100G2-1E, ThreeAxis Magnetic Field Sensor	Billingsly
GPS Antenna	512C-5986	Model 512C, L1/L2	Aero Antenna
GPS Antenna	NAE11450093	Model 702-GGL,L1/L2 Kinematic GPS Ant.	Novatel
GPS Antenna	NAE10170022	Model 702-GG,L1/L2 Kinematic GPS Ant.	Novatel
GPS Receiver	DAB08180095	OEMV-3, 72-ch, L1/L2	Novatel
GPS Receiver	DAB08400111	OEMV-3, 72-ch, L1/L2	Novatel
GPS Receiver	DVA10370115	OEM4,-G2-L1/L2	Novatel
Ground Data Acquisition Computer	M-SGREF-53	CPCI Data Acquisition computer	SGL
Ground Data Acquisition Computer	M-SGREF-67	CPCI Data Acquisition computer	SGL
Laser Profilometer	9800114003	Standard Range Finder, RS232,12V, 9Hz, +-5cm, 1cmResolution.Received	Renishaw PLC
Magnetometer Sensor	75100-C1014	Model G-822A,Starboard Wing Mag	Geometrics
Magnetometer Sensor	75231-C020	Model G-822A, Tail	Geometrics
Magnetometer Sensor	75421-C1961	Model G-822A, Port Wing	Geometrics
Magnetometer Sensor	75308-C1320	Model G-822A,	Geometrics
Radar Tranceiver	11158	Model KRA 10A	Bendix King
Radar Tranceiver	1225	Model ERT-530A	Thomson TRT defense
Relative Humidity Sensor	E2340009	0-5V output 0-98%RH w/M8 conn.	Vaisala

Spectrometer Crystal Pack	SGL crystal pack 001	1024 Channel NaI(Th) 5 crystal Spec Pack	SGL
Spectrometer Crystal Pack	SGL crystal pack 002	1024 Channel NaI(Th) 5 crystal Spec Pack	SGL
Spectrometer Crystal Pack	SGL crystal pack 003	1024 Channel NaI(Th) 4 crystal Spec Pack	SGL
VLF Receiver	3206703	TOTEM 2A VLF	Vaisala

SGL

Appendix IV

GEOPHYSICAL SURVEY AIRCRAFT

Cessna 208B Grand Caravan

Registration	C-GSGW	C-GSGY	C-GSGZ	C-GSGL	C-GSGV	C-GSGU	C-GSGJ	C-GSGA
Serial #	208B0646	208B0600	208B0493	208B0783	208B0524	208B0747	208B1187	208B1228

The Cessna 208B Grand Caravan is an all metal, high wing, single-engine aircraft powered by a Pratt & Whitney Canada PT6A-114A engine. This engine drives a constant speed, fully feathering, reversible propeller. The aircraft has fixed gear, extendable flaps and manually adjustable trim tabs on the primary controls for the roll and pitch axis and full rudder trim for the yaw axes. The aircraft is equipped with full de-icing equipment and sufficient avionics for instrument flying including a flight control system and weather radar. Supplementary fuel can be added for transoceanic flight. The Caravan is certified for IFR flights in known icing conditions.

GEOPHYSICAL SURVEYING

SGL aircraft have a rigid aluminum and composite material 3 m tail stinger designed to accommodate the magnetometer sensor. The stinger can be easily removed and the aircraft returned to its original configuration. There is a camera hole in the belly of the aircraft and provisions for other survey and navigation systems.

The Cessna Grand Caravan uses the extremely reliable Pratt & Whitney Canada PT6 turbine engine. These engines have recorded tens of millions of hours of flight time and with virtually no in-flight engine stoppages due to mechanical failure. Over 2,000 Caravans are in use around the world. Because the Caravan has one engine, fixed landing gear, and no single engine control speed limitations, it is considered an easy and very safe aircraft to fly. The PT6 turbine engine provides ample power for climbing over terrain, working at altitudes up to 7,000 m and can withstand frequent rapid power changes. The low stall speeds and abundant available power, mean that the Caravan is a safe and effective aircraft for surveys which require low airspeeds, drape flying over rough topography, or flights at high altitudes.

CESSNA 208B GRAND CARAVAN SPECIFICATIONS

Crew Capacity:

- 2 pilots, 1 operator (optional)

Fuselage:

- semi-monocoque

Wings:

- strut braced, high wing
- outboard ailerons with spoiler and trim tab

Tail:

- conventional stabilizers
- elevator and rudder with trim tabs

Power Plant:

- Pratt & Whitney Canada PT6A-114A, 675 shp, free-turbine gas engine, overhaul 4,600 hours
- three-blade, fully-feathering, constant-speed, reversible propeller, overhaul 4,000 hours or 10 years

Systems:

- dual flight controls with IFR instruments and avionics
- 2 axis autopilot
- weather radar
- full airframe and propeller de-icing

Dimensions:

Wing span	52 ft 1in	16.11 m
Exterior length	41 ft 7 in	12.68 m
Exterior height	15 ft 5.5 in	4.72 m
Interior usable length	15 ft 10 in	4.83 m
Interior usable width	5 ft 4 in	1.63 m
Interior height	4 ft 6 in	1.37 m
Usable fuel capacity (with survey tank)	519 US gal	2,011 l

Weights:

Empty	4,237 lb	1,926 kg
Maximum take-off	9,062 lb	4,119 kg

Performance (2000 ft ASL, standard day, maximum take-off weight, 1900 rpm, 1375 ft-lb tq):

Range, maximum range power (plus reserve)	1,450 nm	2,685 km
Cruise speed at maximum range power	155 kt	287 km/h
Fuel flow at maximum range power	50 US gal/h	189 l/h
Stall airspeed, landing configuration	61 kt	113 km/h
Service ceiling	25,000 ft	7,620 m
Minimum required runway length	2,500 ft	765 m
Rate of climb	975 ft/min	297 m/min
Maximum sustained climb gradient	650 ft/nm	107 m/km

Type of Aviation Fuel: Jet A, A-1, B, JP-1, 4, 5, 8

Maximum Endurance: 8 hours plus 1 hour reserve at maximum range power

GEOPHYSICAL CAPABILITIES

AIRGrav, SGL airborne gravimeter

Magnetic total field

Tri-axial magnetic gradient

Gamma-ray spectrometer, up to 63 litres (3,840 in^3) of detector crystals

SGMethane, methane gas sensing

Additional Features:

- Tail stinger, 3 m long, 21 cm in diameter, capable of housing a 5.5 kg sensor
- HF radio
- Video camera mount with 14 cm diameter glass covered opening in the belly of the aircraft
- Two instrument racks, standard 48 cm (19 in) width
- Radar altimeter, 0-3,000 m
- Electrical power capacity, 28 VDC at 200 amp
- Static inverters, 115 VAC - 400 Hz, 110 VAC - 60 Hz
- GPS receiver and antenna plus data link for real-time corrections
- Cabin fuel tank certified for a normal production flying

v2.0

SGL

Appendix V

SANDER GEOPHYSICS AIRBORNE GEOPHYSICAL SURVEY

260 Hunt Club Road, Ottawa, ON K1V 1C1 Canada Tel: +1 613-521-9626 Fax: +1 613-521-0215 www.sgl.com

SURVEY DETAILS			
Survey Name	Airborne Geophysical Survey, South-Central Newfoundland	**Client Name**	Natural Resources, Government of Newfoundland
Survey Location	Newfoundland	**Contact Name**	Gerry Kilfoil
Project Code	NatRes19.NL	**Contact Phone**	709-729-2169
Total km	9899	**Client Address**	
Line Spacing	150m/1000m		
Survey Type	Gradient Mag, Spec and VLF	**Email**	gerrykilfoil@gov.nl.ca

SURVEY PRODUCTION SUMMARY			
Production This Week (km)	0.0	**Total km Flown to Date**	0.0
Total Remaining (km)	9899.9	**km Reflown This Week**	0.0
Percent Complete (%)	0.0	**Flight Time This Week (h)**	3.4
Prod km/Day This Week	0.0	**Prod km/Flt Hour This Week**	0.0

WEEKLY PRODUCTION

Week 1			**Flight No.**	**Flight Time**	**No. of Lines Flown**	**No. Reflight Lines Flown**	**Production (km)**	**Reflown (km)**
TOTALS				**3.4**	**0.0**	**0.0**	**0.0**	**0.0**
7-Oct	**Mon**	C-GSGL		0.0	0.0	0.0	0.0	0.0
Weather				**Remarks**				
Geomag								
8-Oct	**Tue**	C-GSGL		0.0	0.0	0.0	0.0	0.0
Weather				**Remarks**				
Geomag								
9-Oct	**Wed**	C-GSGL		0.0	0.0	0.0	0.0	0.0
Weather				**Remarks**				
Geomag								
10-Oct	**Thu**	C-GSGL		0.0	0.0	0.0	0.0	0.0
Weather				**Remarks**				
Geomag								
11-Oct	**Fri**	C-GSGL		0.0	0.0	0.0	0.0	0.0
Weather				**Remarks**				
Geomag								
12-Oct	**Sat**	C-GSGL		0.0	0.0	0.0	0.0	0.0
Weather				**Remarks**	Mobilization Begins. Crew depart Ottawa.			
Geomag								
13-Oct	**Sun**	C-GSGL	FF	3.4	0.0	0.0	0.0	0.0
Weather				**Remarks**	Crew arrive in Gander. C-GSGL departs Ottawa and lands in Gaspe Bay.			
Geomag								
Comments	Mobilization under way. Crew arrive in Gander and begin set-up of ground equipment.							
Signed								

Week 1 Page 2

PERSONNEL ON SITE THIS WEEK						
Name	**Position**	**Arrival This Week**	**Departure This Week**	**On Site?**	**Days On Site This Week**	**Days on Site To Date**
Keith Wells	Crew Chief	12-Oct-19		ON SITE	2	2
Luis Vargas	Data Analyst	12-Oct-19		ON SITE	2	2
Angella Farr	Technician	12-Oct-19		ON SITE	2	2

HSE Statistic	This Week	Project Total
SGL Person Hours	45.0	45.0
Inductions		0.0
Near Miss		0.0
First Aid Case (FAC)		0.0
Medical Treatment Case (MTC)		0.0
Restricted Work Case (RWC)		0.0
Lost Time Injuries (LTI)		0.0

WEEKLY PRODUCTION KILOMETRES AND HOURS FLOWN

SANDER GEOPHYSICS AIRBORNE GEOPHYSICAL SURVEY

260 Hunt Club Road, Ottawa, ON K1V 1C1 Canada Tel: +1 613-521-9626 Fax: +1 613-521-0215 www.sgl.com

SURVEY DETAILS			
Survey Name	Airborne Geophysical Survey, South-Central Newfoundland	**Client Name**	Natural Resources, Government of Newfoundland
Survey Location	Newfoundland	**Contact Name**	Gerry Kilfoil
Project Code	NatRes19.NL	**Contact Phone**	709-729-2169
Total km	9899	**Client Address**	
Line Spacing	150m/1000m		
Survey Type	Gradient Mag, Spec and VLF	**Email**	gerrykilfoil@gov.nl.ca

SURVEY PRODUCTION SUMMARY			
Production This Week (km)	1506.2	**Total km Flown to Date**	1506.2
Total Remaining (km)	8393.7	**km Reflown This Week**	0.0
Percent Complete (%)	15.2	**Flight Time This Week (h)**	20.6
Prod km/Day This Week	215.2	**Prod km/Flt Hour This Week**	73.1

WEEKLY PRODUCTION

Week 2			Flight No.	Flight Time	No. of Lines Flown	No. Reflight Lines Flown	Production (km)	Reflown (km)
TOTALS				**20.6**	**65.0**	**0.0**	**1506.2**	**0.0**
14-Oct	**Mon**	C-GSGL	FF	3.5	0.0	0.0	0.0	0.0
Weather				**Remarks**	C-GSGL arrives in Gander.			
Geomag								
15-Oct	**Tue**	C-GSGL	9001.0	1.6	0.0	0.0	0.0	0.0
Weather	Clear in the afternoon			**Remarks**	Morning rain and low cloud. Weather cleared in the afternoon and a compensation flight was flown.			
Geomag	Quiet							
16-Oct	**Wed**	C-GSGL		1.8	0.0	0.0	0.0	0.0
Weather	Clear in the afternoon			**Remarks**	Morning rain and low cloud. Weather cleared in the afternoon and a recon flight was flown.			
Geomag	Quiet							
17-Oct	**Thu**	C-GSGL	1001.0	9.1	26.0	0.0	1106.3	0.0
Weather	Clear, warm, calm			**Remarks**	Production flight .			
Geomag	Quiet							
18-Oct	**Fri**	C-GSGL		0.0	0.0	0.0	0.0	0.0
Weather	Overcast, rain			**Remarks**	No production due to weather.			
Geomag	Quiet							
19-Oct	**Sat**	C-GSGL	1002.0	4.6	39.0	0.0	399.9	0.0
Weather	Overcast, warm, calm			**Remarks**	Production flight.			
Geomag	Quiet							
20-Oct	**Sun**	C-GSGL		0.0	0.0	0.0	0.0	0.0
Weather	Rain			**Remarks**	No production due to weather.			
Geomag	Quiet							
Comments	Crew arrived in Gander, equipment was set up and production commenced.							
Signed	Keith Wells							

Week 2 Page 2

PERSONNEL ON SITE THIS WEEK						
Name	**Position**	**Arrival This Week**	**Departure This Week**	**On Site?**	**Days On Site This Week**	**Days on Site To Date**
Keith Wells	Crew Chief			ON SITE	7	9
Luis Vargas	Data Analyst			ON SITE	7	9
Angella Farr	Technician			ON SITE	7	9
Jean Deschenes	Lead Pilot	14-Oct-19		ON SITE	7	7
Aymeric Douerin	Pilot	14-Oct-19		ON SITE	7	7

HSE Statistic	This Week	Project Total
SGL Person Hours	262.5	307.5
Inductions		0.0
Near Miss		0.0
First Aid Case (FAC)		0.0
Medical Treatment Case (MTC)		0.0
Restricted Work Case (RWC)		0.0
Lost Time Injuries (LTI)		0.0

WEEKLY PRODUCTION KILOMETRES AND HOURS FLOWN

SANDER GEOPHYSICS AIRBORNE GEOPHYSICAL SURVEY

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SURVEY DETAILS			
Survey Name	Airborne Geophysical Survey, South-Central Newfoundland	**Client Name**	Natural Resources, Government of Newfoundland
Survey Location	Newfoundland	**Contact Name**	Gerry Kilfoil
Project Code	NatRes19.NL	**Contact Phone**	709-729-2169
Total km	9899	**Client Address**	
Line Spacing	150m/1000m		
Survey Type	Gradient Mag, Spec and VLF	**Email**	gerrykilfoil@gov.nl.ca

SURVEY PRODUCTION SUMMARY			
Production This Week (km)	1582.9	**Total km Flown to Date**	3089.1
Total Remaining (km)	6810.8	**km Reflown This Week**	0.0
Percent Complete (%)	31.2	**Flight Time This Week (h)**	20.4
Prod km/Day This Week	226.1	**Prod km/Flt Hour This Week**	77.6

WEEKLY PRODUCTION

Week 3			Flight No.	Flight Time	No. of Lines Flown	No. Reflight Lines Flown	Production (km)	Reflown (km)
TOTALS				**20.4**	**59.0**	**0.0**	**1582.9**	**0.0**
21-Oct	**Mon**	C-GSGL	1003.0	5.2	27.0	0.0	601.4	0.0
Weather	Scattered Clouds, cool			**Remarks**	Production flight.			
Geomag	Quiet							
22-Oct	**Tue**	C-GSGL	1004.0	4.6	21.0	0.0	478.6	0.0
Weather	Clear, cool			**Remarks**	Production flight.			
Geomag	Quiet							
23-Oct	**Wed**	C-GSGL	9002.0	4.3	0.0	0.0	0.0	0.0
Weather	Overcast, cool			**Remarks**	No production due to weather in the survey area. Compensation and cosmic test flown.			
Geomag	Quiet							
24-Oct	**Thu**	C-GSGL		0.0	0.0	0.0	0.0	0.0
Weather	Low ceilings, rain			**Remarks**	No production due to weather.			
Geomag	Quiet							
25-Oct	**Fri**	C-GSGL	1005.0	2.6	4.0	0.0	157.6	0.0
Weather	Scattered Clouds, cool			**Remarks**	Production flight.			
Geomag	Quiet							
26-Oct	**Sat**	C-GSGL	1006.0	3.7	7.0	0.0	345.3	0.0
Weather	Clear, calm, cool			**Remarks**	Production flight.			
Geomag	Quiet							
27-Oct	**Sun**	C-GSGL		0.0	0.0	0.0	0.0	0.0
Weather	Snow, low cloud			**Remarks**	No production due to weather.			
Geomag	Quiet							
Comments	Production continued with weather continuing to limit our production flights. Crew did a good job of making the most of the opportunities when the weather was suitable for flying.							
Signed	Keith Wells							

Week 3 Page 2

PERSONNEL ON SITE THIS WEEK						
Name	**Position**	**Arrival This Week**	**Departure This Week**	**On Site?**	**Days On Site This Week**	**Days on Site To Date**
Keith Wells	Crew Chief			ON SITE	7	16
Luis Vargas	Data Analyst			ON SITE	7	16
Angella Farr	Technician		24-Oct-19	ON SITE	4	13
Jean Deschenes	Lead Pilot			ON SITE	7	14
Aymeric Douerin	Pilot		24-Oct-19	ON SITE	4	11
Sarah Newland	Pilot	25-Oct-19		ON SITE	3	3

HSE Statistic	This Week	Project Total
SGL Person Hours	240.0	547.5
Inductions		0.0
Near Miss		0.0
First Aid Case (FAC)		0.0
Medical Treatment Case (MTC)		0.0
Restricted Work Case (RWC)		0.0
Lost Time Injuries (LTI)		0.0

WEEKLY PRODUCTION KILOMETRES AND HOURS FLOWN

SANDER GEOPHYSICS AIRBORNE GEOPHYSICAL SURVEY

260 Hunt Club Road, Ottawa, ON K1V 1C1 Canada Tel: +1 613-521-9626 Fax: +1 613-521-0215 www.sgl.com

SURVEY DETAILS			
Survey Name	Airborne Geophysical Survey, South-Central Newfoundland	**Client Name**	Natural Resources, Government of Newfoundland
Survey Location	Newfoundland	**Contact Name**	Gerry Kilfoil
Project Code	NatRes19.NL	**Contact Phone**	709-729-2169
Total km	9899	**Client Address**	
Line Spacing	150m/1000m		
Survey Type	Gradient Mag, Spec and VLF	**Email**	gerrykilfoil@gov.nl.ca

SURVEY PRODUCTION SUMMARY			
Production This Week (km)	3498.3	**Total km Flown to Date**	6587.4
Total Remaining (km)	3312.5	**km Reflown This Week**	24.2
Percent Complete (%)	66.5	**Flight Time This Week (h)**	32.1
Prod km/Day This Week	499.8	**Prod km/Flt Hour This Week**	109.0

WEEKLY PRODUCTION

Week 4			Flight No.	Flight Time	No. of Lines Flown	No. Reflight Lines Flown	Production (km)	Reflown (km)
TOTALS				**32.1**	**94.0**	**0.3**	**3498.3**	**24.2**
28-Oct	**Mon**	C-GSGL	1007.0	4.9	20.0	0.0	546.4	0.0
Weather	Overcast, cool, windy			**Remarks**	Production flight			
Geomag	Quiet							
29-Oct	**Tue**	C-GSGL		0.0	0.0	0.0	0.0	0.0
Weather	Overcast, cool			**Remarks**	No production due to weather			
Geomag	Quiet							
30-Oct	**Wed**	C-GSGL	1008.0	8.8	17.0	0.0	891.5	0.0
Weather	Clear, warm, calm			**Remarks**	Production flight.			
Geomag	Quiet							
31-Oct	**Thu**	C-GSGL	1009.0	10.2	37.0	0.3	1049.4	24.2
Weather	Overcast, warm, calm			**Remarks**	Production flight			
Geomag	Quiet							
1-Nov	**Fri**	C-GSGL		0.0	0.0	0.0	0.0	0.0
Weather	High winds, rain			**Remarks**	No production due to weather			
Geomag	Quiet							
2-Nov	**Sat**	C-GSGL	1010, 1011	8.2	20.0	0.0	1011.0	0.0
Weather	Clear, warm, calm			**Remarks**	Production flights			
Geomag	Quiet							
3-Nov	**Sun**	C-GSGL		0.0	0.0	0.0	0.0	0.0
Weather	Heavy rain, cool			**Remarks**	No production due to weather			
Geomag	Quiet							
Comments	Good week of production. Pilots maximized good weather days by flying two flights.							
Signed	Keith Wells							

Week 4 Page 2

PERSONNEL ON SITE THIS WEEK						
Name	**Position**	**Arrival This Week**	**Departure This Week**	**On Site?**	**Days On Site This Week**	**Days on Site To Date**
Keith Wells	Crew Chief			ON SITE	7	23
Luis Vargas	Data Analyst			ON SITE	7	23
Jean Deschenes	Lead Pilot			ON SITE	7	21
Sarah Newland	Pilot			ON SITE	7	10

HSE Statistic	This Week	Project Total
SGL Person Hours	210.0	757.5
Inductions		0.0
Near Miss		0.0
First Aid Case (FAC)		0.0
Medical Treatment Case (MTC)		0.0
Restricted Work Case (RWC)		0.0
Lost Time Injuries (LTI)		0.0

WEEKLY PRODUCTION KILOMETRES AND HOURS FLOWN

SANDER GEOPHYSICS AIRBORNE GEOPHYSICAL SURVEY

260 Hunt Club Road, Ottawa, ON K1V 1C1 Canada Tel: +1 613-521-9626 Fax: +1 613-521-0215 www.sgl.com

SURVEY DETAILS			
Survey Name	Airborne Geophysical Survey, South-Central Newfoundland	**Client Name**	Natural Resources, Government of Newfoundland
Survey Location	Newfoundland	**Contact Name**	Gerry Kilfoil
Project Code	NatRes19.NL	**Contact Phone**	709-729-2169
Total km	9899	**Client Address**	
Line Spacing	150m/1000m		
Survey Type	Gradient Mag, Spec and VLF	**Email**	gerrykilfoil@gov.nl.ca

SURVEY PRODUCTION SUMMARY			
Production This Week (km)	3312.5	**Total km Flown to Date**	9899.9
Total Remaining (km)	0.0	**km Reflown This Week**	18.2
Percent Complete (%)	100.0	**Flight Time This Week (h)**	28.3
Prod km/Day This Week	473.2	**Prod km/Flt Hour This Week**	117.0

WEEKLY PRODUCTION

Week 5			Flight No.	Flight Time	No. of Lines Flown	No. Reflight Lines Flown	Production (km)	Reflown (km)
TOTALS				**28.3**	**117.0**	**0.0**	**3312.5**	**18.2**
4-Nov	**Mon**	C-GSGL	1012.0	8.6	24.0	0.0	1125.7	0.0
Weather	Clear, Cool			**Remarks**	Production flight			
Geomag	Quiet							
5-Nov	**Tue**	C-GSGL	1013, 9004	6.1	18.0	0.0	659.5	0.0
Weather	Clear, cool, calm			**Remarks**	Production flight and compensation flight.			
Geomag	Quiet							
6-Nov	**Wed**	C-GSGL		0.0	0.0	0.0	0.0	0.0
Weather	Rain, cloudy			**Remarks**	No production due to weather.			
Geomag	Quiet							
7-Nov	**Thu**	C-GSGL		0.0	0.0	0.0	0.0	0.0
Weather	High Winds			**Remarks**	No production due to weather.			
Geomag	Quiet							
8-Nov	**Fri**	C-GSGL		0.0	0.0	0.0	0.0	0.0
Weather	Rain, snow, fog			**Remarks**	No production due to weather.			
Geomag	Quiet							
9-Nov	**Sat**	C-GSGL	1014.0	4.2	23.0	0.0	398.6	0.0
Weather	Windy, Clouds, cool			**Remarks**	Production flight			
Geomag	Quiet							
10-Nov	**Sun**	C-GSGL	1015.0	9.4	52.0	0.0	1128.7	18.2
Weather	Clear, calm, cool			**Remarks**	Production flight.			
Geomag	Quiet							
Comments	Pilots did a great job of making the most of good weather days. All production flying was completed on Sunday.							
Signed	Keith Wells							

Week 5 Page 2

PERSONNEL ON SITE THIS WEEK						
Name	**Position**	**Arrival This Week**	**Departure This Week**	**On Site?**	**Days On Site This Week**	**Days on Site To Date**
Keith Wells	Crew Chief			ON SITE	7	30
Luis Vargas	Data Analyst			ON SITE	7	30
Jean Deschenes	Lead Pilot			ON SITE	7	28
Sarah Newland	Pilot			ON SITE	7	17

HSE Statistic	This Week	Project Total
SGL Person Hours	210.0	967.5
Inductions		0.0
Near Miss		0.0
First Aid Case (FAC)		0.0
Medical Treatment Case (MTC)		0.0
Restricted Work Case (RWC)		0.0
Lost Time Injuries (LTI)		0.0

WEEKLY PRODUCTION KILOMETRES AND HOURS FLOWN

SGL

Appendix VI

FLOWN LINES - Magnetic and VLF
UTM Zone 21N, Datum NAD-83

LINE	START TIME (seconds)	END TIME (seconds)	START X (m)	END X (m)	START Y (m)	END Y (m)	FLIGHT	DAY	YEAR
1001.00	53784.80	53889.90	576286	580751.4	5321770	5317229	1002	292	2019
1002.00	53999.40	54091.10	580859.1	576375.2	5317317	5321818	1002	292	2019
1003.00	54201.70	54304.50	576483.1	580964.9	5321922	5317444	1002	292	2019
1004.00	54403.60	54496.60	581069.4	576589.5	5317543	5322026	1002	292	2019
1005.00	54601.90	54703.10	576694	581174.3	5322134	5317654	1002	292	2019
1006.00	54809.50	54906.60	581282.7	576799.7	5317752	5322242	1002	292	2019
1007.00	55012.80	55114.80	576907.5	581386.2	5322347	5317866	1002	292	2019
1008.00	55215.40	55308.50	581492.5	577012.6	5317968	5322460	1002	292	2019
1009.00	55417.30	55518.90	577120.5	581601.4	5322547	5318073	1002	292	2019
1010.00	55619.10	55716.30	581706.3	577223.3	5318182	5322673	1002	292	2019
1011.00	55825.00	55931.40	577333.4	581811.6	5322762	5318285	1002	292	2019
1012.00	56036.50	56135.30	581918.4	577437.4	5318393	5322877	1002	292	2019
1013.00	56245.60	56347.70	577544.3	582022.8	5322979	5318497	1002	292	2019
1014.00	56455.50	56550.20	582130.2	577650.6	5318605	5323094	1002	292	2019
1015.00	56690.90	56845.90	575636.2	582236.1	5325303	5318710	1002	292	2019
1016.00	56967.60	57104.40	582340.6	575740	5318816	5325425	1002	292	2019
1017.00	57217.90	57377.00	575139.2	582448.5	5326240	5318929	1002	292	2019
1018.00	57479.90	57634.40	582555.8	575244.9	5319023	5326330	1002	292	2019
1019.00	57742.20	57898.70	575352.2	582659	5326442	5319138	1002	292	2019
1020.00	58000.70	58154.90	582766.3	575457.8	5319233	5326548	1002	292	2019
1021.00	58246.80	58420.00	574855.8	582873.9	5327368	5319348	1002	292	2019
1022.00	58543.20	58756.30	585101.8	574964.3	5317334	5327468	1002	292	2019
1023.00	46982.00	47206.70	585203.4	575069	5317435	5327575	1003	294	2019
1024.00	47338.30	47551.10	575173.9	585313.5	5327684	5317544	1003	294	2019
1025.00	47669.60	47904.20	585417.9	575281	5317651	5327790	1003	294	2019
1026.00	48029.50	48243.30	575384.5	585525.1	5327899	5317756	1003	294	2019
1027.00	48362.20	48609.60	585630	574784.8	5317863	5328711	1003	294	2019
1028.00	48710.80	48937.90	574889.6	585737.6	5328827	5317974	1003	294	2019
1029.00	49048.20	49307.00	585840.4	574290.5	5318081	5329625	1003	294	2019
1030.00	49408.70	49651.30	574396.1	585948.8	5329727	5318183	1003	294	2019
1031.00	49772.20	50055.10	586053	573794.6	5318293	5330567	1003	294	2019
1032.00	50149.30	50405.30	573899.9	586161.4	5330662	5318391	1003	294	2019
1033.00	50529.40	50817.90	586284.9	574007	5318477	5330763	1003	294	2019
1034.00	50932.00	51184.40	574115.5	586373.2	5330861	5318602	1003	294	2019
1035.00	51293.80	51571.80	586478.6	574218	5318708	5330979	1003	294	2019
1036.00	51671.50	51925.70	574324	586605.1	5331081	5318800	1003	294	2019
1037.00	47615.10	47910.40	586691.8	573722.8	5318933	5331894	1004	295	2019
1038.00	47218.60	47496.50	573831.6	586797.1	5331997	5319031	1004	295	2019
1039.00	48438.40	48724.40	586902.6	573935.3	5319138	5332096	1004	295	2019
1040.00	48022.40	48311.70	574044.6	587009.4	5332208	5319238	1004	295	2019
1041.00	49257.30	49535.80	587115.4	574150.4	5319352	5332313	1004	295	2019

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LINE	START TIME (seconds)	END TIME (seconds)	START X (m)	END X (m)	START Y (m)	END Y (m)	FLIGHT	DAY	YEAR
1042.00	48823.70	49138.70	574256.9	589339.6	5332416	5317337	1004	295	2019
1043.00	50118.30	50446.50	589445.7	574363.4	5317440	5332521	1004	295	2019
1044.00	49655.30	49990.90	573758.4	589551.7	5333339	5317549	1004	295	2019
1045.00	51047.80	51385.50	589663.1	573866.9	5317642	5333447	1004	295	2019
1046.00	50575.60	50904.70	573970.4	589765.5	5333554	5317762	1004	295	2019
1047.00	51927.80	52283.90	589875	574080.5	5317862	5333657	1004	295	2019
1048.00	51484.40	51811.10	574183.5	589980.4	5333758	5317967	1004	295	2019
1049.00	52842.40	53196.80	590085	574288.5	5318084	5333874	1004	295	2019
1050.00	52386.20	52733.30	573690.1	590189.5	5334678	5318179	1004	295	2019
1051.00	53769.60	54130.70	590296.5	573795.9	5318296	5334788	1004	295	2019
1052.00	53303.30	53640.50	573900.3	590404.1	5334893	5318399	1004	295	2019
1053.00	57412.50	57805.60	590510.9	574006.6	5318492	5335004	1007	301	2019
1054.00	55484.90	55830.50	574112.1	590614.4	5335106	5318608	1004	295	2019
1055.00	58359.00	58756.70	590720	574220.4	5318711	5335213	1007	301	2019
1056.00	57890.30	58229.10	574323.8	590826.9	5335333	5318817	1007	301	2019
1057.00	59354.70	59761.10	590931.7	573722.7	5318932	5336137	1007	301	2019
1058.00	58873.90	59223.90	573832.7	591036.4	5336213	5319024	1007	301	2019
1059.00	60422.40	60841.60	591145.5	573935.3	5319146	5336354	1007	301	2019
1060.00	59883.00	60262.30	574045.3	591249.9	5336448	5319240	1007	301	2019
1061.00	61462.70	61879.40	591359.4	574147.4	5319353	5336568	1007	301	2019
1062.00	60975.80	61340.70	574254	591464.7	5336651	5319464	1007	301	2019
1063.00	62496.90	62956.30	593689.4	573652.9	5317445	5337483	1007	301	2019
1064.00	61967.30	62386.60	573762.1	593798.3	5337584	5317554	1007	301	2019
1065.00	63632.80	64112.70	593905	573864.7	5317655	5337693	1007	301	2019
1066.00	63049.80	63472.30	573974.1	594010.2	5337822	5317769	1007	301	2019
1067.00	64822.50	65294.40	594116.6	574078	5317862	5337907	1007	301	2019
1068.00	64242.90	64670.80	574185	594222.1	5338036	5317982	1007	301	2019
1069.00	65908.70	66380.50	594326.4	574291.7	5318078	5338122	1007	301	2019
1070.00	65376.00	65797.70	573691.8	594432	5338950	5318187	1007	301	2019
1071.00	51986.30	52805.80	612217	573795.7	5300611	5339030	1008	303	2019
1072.00	52941.40	53743.70	573900.1	612321.2	5339147	5300730	1008	303	2019
1073.00	48499.70	49303.60	574006.8	612427.3	5339251	5300817	1006	299	2019
1074.00	51036.40	51846.70	574112.5	612535	5339343	5300928	1008	303	2019
1075.00	46506.70	47306.10	574221.8	612643.3	5339455	5301028	1006	299	2019
1076.00	47446.50	48356.50	612749.9	573620.6	5301136	5340273	1006	299	2019
1077.00	45395.70	46231.60	612854.9	573724	5301247	5340380	1006	299	2019
1078.00	66483.20	67304.40	573829.8	612959.3	5340490	5301352	1007	301	2019
1079.00	43240.00	44101.80	613064.9	573938.5	5301462	5340594	1006	299	2019
1080.00	44216.70	45013.80	574042.7	613173.2	5340671	5301564	1006	299	2019
1081.00	54177.50	55080.30	612570.3	573441.1	5302367	5341506	1005	298	2019
1082.00	53194.30	54043.90	573547.6	612675.3	5341616	5302491	1005	298	2019

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LINE	START TIME (seconds)	END TIME (seconds)	START X (m)	END X (m)	START Y (m)	END Y (m)	FLIGHT	DAY	YEAR
1083.00	69347.80	70140.00	612781.7	573656.2	5302607	5341719	1001	290	2019
1084.00	68400.40	69247.40	573760.4	612890.7	5341825	5302687	1001	290	2019
1085.00	67496.40	68285.30	612994.1	573866.4	5302768	5341933	1001	290	2019
1086.00	66569.40	67384.70	573973	613101.3	5342038	5302914	1001	290	2019
1087.00	65670.50	66448.80	613204.6	574079.7	5303007	5342139	1001	290	2019
1088.00	44419.70	45271.70	573479.2	612606	5342952	5303818	1001	290	2019
1089.00	45380.90	46192.50	612712.9	573584.9	5303913	5343059	1001	290	2019
1090.00	46304.30	47169.50	573688.5	612819.1	5343165	5304038	1001	290	2019
1091.00	47290.20	48094.10	612925.2	573795.4	5304143	5343271	1001	290	2019
1092.00	48211.60	49058.70	573899.6	613032	5343381	5304249	1001	290	2019
1093.00	49165.40	49975.50	613138.9	574008.5	5304351	5343487	1001	290	2019
1094.00	50075.00	50939.20	573407.9	613242.2	5344299	5304470	1001	290	2019
1095.00	51032.90	51846.10	613350.2	573512.5	5304562	5344406	1001	290	2019
1096.00	51958.30	52844.50	573616.6	613455.2	5344503	5304675	1001	290	2019
1097.00	52952.40	53761.00	613562.1	573724.2	5304781	5344627	1001	290	2019
1098.00	53876.30	54733.60	573828.5	613667.2	5344728	5304888	1001	290	2019
1099.00	54838.40	55630.60	613772.1	573937.8	5304988	5344833	1001	290	2019
1100.00	55746.70	56600.70	574042.4	613879	5344936	5305105	1001	290	2019
1101.00	70600.30	71434.10	574148.5	613276.8	5345045	5305919	1001	290	2019
1102.00	54779.90	55597.00	574253.8	613385	5345146	5306019	1008	303	2019
1103.00	53858.50	54668.00	613492.2	574360.1	5306122	5345256	1008	303	2019
1104.00	56661.50	57459.80	574466.9	613597.5	5345367	5306226	1008	303	2019
1105.00	55720.20	56532.30	613700.8	574575.6	5306339	5345465	1008	303	2019
1106.00	58458.90	59272.90	574679.5	613805.6	5345577	5306444	1008	303	2019
1107.00	57557.00	58354.20	613915.2	574785.2	5306554	5345694	1008	303	2019
1108.00	60344.40	61146.60	574889.4	614019.3	5345790	5306637	1008	303	2019
1109.00	59419.60	60224.20	614127.2	574999.3	5306765	5345893	1008	303	2019
1110.00	68226.90	69025.10	575106.4	614232.9	5345998	5306866	1008	303	2019
1111.00	67294.60	68093.20	614336.2	575211	5306992	5346101	1008	303	2019
1112.00	70007.80	70796.70	575315.3	614443.6	5346207	5307077	1008	303	2019
1113.00	69121.30	69910.30	614549.6	575419.9	5307158	5346319	1008	303	2019
1114.00	47621.90	48413.70	575526.5	614657.9	5346413	5307289	1009	304	2019
1115.00	70926.90	71722.80	614764.6	575634.2	5307389	5346525	1008	303	2019
1116.00	49435.50	50228.00	575739.4	614868.5	5346639	5307504	1009	304	2019
1117.00	48514.60	49315.40	614973.1	575845	5307606	5346741	1009	304	2019
1118.00	51243.90	52029.90	575950.4	615083.1	5346855	5307713	1009	304	2019
1119.00	50338.20	51141.70	615188.3	576060.4	5307819	5346964	1009	304	2019
1120.00	54860.50	55654.50	576164.4	615291.2	5347056	5307934	1009	304	2019
1121.00	52115.40	52919.30	615399.4	576271.2	5308038	5347158	1009	304	2019
1122.00	46438.40	47359.00	615504.3	576378.3	5308142	5347261	1010	306	2019
1123.00	53974.30	54773.90	615610.3	576480.3	5308255	5347381	1009	304	2019

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LINE	START TIME (seconds)	END TIME (seconds)	START X (m)	END X (m)	START Y (m)	END Y (m)	FLIGHT	DAY	YEAR
1124.00	53043.30	53839.60	576589.9	615714.7	5347482	5308363	1009	304	2019
1125.00	62319.80	63124.40	615825.1	576692.6	5308419	5347593	1009	304	2019
1126.00	47499.30	48322.60	576800.1	615929.1	5347693	5308576	1010	306	2019
1127.00	48466.30	49319.30	616036.6	579735.3	5308682	5344980	1010	306	2019
1128.00	49420.90	50181.00	579839.9	616143.9	5345091	5308773	1010	306	2019
1129.00	50302.40	51168.10	616246.7	579945.9	5308889	5345185	1010	306	2019
1130.00	51315.90	52077.00	580055.3	616356.2	5345281	5308995	1010	306	2019
1131.00	52220.30	53055.70	616460	580867.6	5309101	5344696	1010	306	2019
1132.00	53147.00	53866.50	580972.1	616564.8	5344803	5309210	1010	306	2019
1133.00	53977.70	54808.50	616672	581080.1	5309309	5344898	1010	306	2019
1134.00	62182.70	62905.30	581186.6	616777.9	5345008	5309416	1011	306	2019
1135.00	63049.00	63850.70	616883.9	581291.6	5309524	5345125	1011	306	2019
1136.00	63947.90	64670.30	581398.3	616989.6	5345225	5309631	1011	306	2019
1137.00	64774.60	65560.50	617095.6	581502	5309729	5345332	1011	306	2019
1138.00	65665.90	66371.60	582314.9	617202.1	5344728	5309840	1011	306	2019
1139.00	66493.20	67252.80	617308.2	582424.8	5309943	5344831	1011	306	2019
1140.00	67352.30	68058.30	582529.1	617413.3	5344846	5310042	1011	306	2019
1141.00	68158.60	68905.70	617522.4	582633.7	5310155	5345046	1011	306	2019
1142.00	69002.40	69718.00	582741.1	617627.2	5345161	5310260	1011	306	2019
1143.00	69839.80	70590.00	617731.1	582846.3	5310379	5345258	1011	306	2019
1144.00	70688.90	71399.30	582952.3	617837.4	5345354	5310469	1011	306	2019
1145.00	47473.30	48195.20	617944.1	583767.9	5310588	5344765	1012	308	2019
1146.00	48299.90	48989.70	583872.9	618050.9	5344866	5310689	1012	308	2019
1147.00	49113.00	49826.30	618158.2	583978.3	5310792	5344971	1012	308	2019
1148.00	49937.60	50633.00	584085.1	618263.4	5345072	5310899	1012	308	2019
1149.00	50739.80	51453.60	618367	584188.4	5311001	5345194	1012	308	2019
1150.00	51555.30	52244.40	584294.9	618475.8	5345304	5311118	1012	308	2019
1151.00	52362.80	53077.50	618582.2	584401.3	5311218	5345394	1012	308	2019
1152.00	53201.10	53885.50	585226.2	618687.2	5344833	5311319	1012	308	2019
1153.00	54006.40	54717.30	618792.4	585320.5	5311427	5344902	1012	308	2019
1154.00	54828.50	55500.80	585426.5	618900	5345006	5311535	1012	308	2019
1155.00	55619.90	56328.10	619003.4	585532.3	5311633	5345116	1012	308	2019
1156.00	56427.00	57100.30	585640	619109.7	5345213	5311750	1012	308	2019
1157.00	57218.30	57928.10	619218.5	585743.8	5311855	5345334	1012	308	2019
1158.00	63954.50	64626.50	585851.1	619323.9	5345429	5311962	1012	308	2019
1159.00	64742.40	65416.80	619431.8	586665.4	5312068	5344828	1012	308	2019
1160.00	65515.40	66174.00	586772.2	619537.3	5344942	5312165	1012	308	2019
1161.00	66281.20	66966.30	619643.7	586874.8	5312278	5345042	1012	308	2019
1162.00	67076.60	67734.90	586985.9	619749.7	5345147	5312389	1012	308	2019
1163.00	67851.10	68523.90	619852.5	587088.1	5312496	5345264	1012	308	2019
1164.00	68632.70	69290.90	587196.8	619960.6	5345352	5312589	1012	308	2019

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LINE	START TIME (seconds)	END TIME (seconds)	START X (m)	END X (m)	START Y (m)	END Y (m)	FLIGHT	DAY	YEAR
1165.00	69389.30	70041.30	620066.2	588007.9	5312709	5344756	1012	308	2019
1166.00	70137.10	70778.10	588113.9	620169.3	5344866	5312804	1012	308	2019
1167.00	70869.30	71518.80	620276.9	588221.9	5312910	5344969	1012	308	2019
1168.00	71632.90	72279.50	588328.4	620385.5	5345073	5313025	1012	308	2019
1169.00	49823.80	50469.90	619783.9	588433	5313841	5345182	1013	309	2019
1170.00	49065.60	49717.00	588540.7	619886.1	5345284	5313942	1013	309	2019
1171.00	51353.30	51998.30	619993	588646.1	5314047	5345394	1013	309	2019
1172.00	50599.40	51225.30	589457	620101.1	5344797	5314162	1013	309	2019
1173.00	52832.70	53472.20	620208	589565.4	5314252	5344888	1013	309	2019
1174.00	52103.30	52737.00	589672.9	620312.5	5345002	5314361	1013	309	2019
1175.00	54300.50	54932.60	620420.1	589778.1	5314460	5345110	1013	309	2019
1176.00	53553.40	54180.10	589884	620525.5	5345205	5314584	1013	309	2019
1177.00	55734.50	56371.80	620632	589986.8	5314680	5345332	1013	309	2019
1178.00	55052.70	55498.90	590095.1	612254.9	5345423	5323280	1013	309	2019
1179.00	57000.30	57444.30	612358.9	590905.5	5323375	5344826	1013	309	2019
1180.00	56465.40	56897.90	591015.6	612465.4	5344927	5323491	1013	309	2019
1181.00	58126.70	58564.90	612570.8	591121.2	5323591	5345026	1013	309	2019
1182.00	57568.00	57987.30	591225.8	611972.2	5345144	5324405	1013	309	2019
1183.00	59190.60	59617.90	612076	591330.8	5324512	5345256	1013	309	2019
1184.00	58682.50	59101.00	591438.5	612182.2	5345351	5324617	1013	309	2019
1185.00	60224.80	60644.50	612289.3	591545.3	5324720	5345476	1013	309	2019
1186.00	59709.30	60136.80	591650.8	612394.8	5345560	5324834	1013	309	2019
1187.00	44531.30	44930.90	612499.8	592463.2	5324938	5344974	1015	314	2019
1188.00	45044.10	45446.40	592569.5	612605.9	5345077	5325045	1015	314	2019
1189.00	45570.20	45958.60	612006.9	592677.2	5325853	5345181	1015	314	2019
1190.00	46070.50	46457.10	592779.8	612108.9	5345287	5325965	1015	314	2019
1191.00	46577.40	46964.60	612215.1	592886	5326076	5345400	1015	314	2019
1192.00	47074.40	47459.50	592994.5	612323.3	5345498	5326172	1015	314	2019
1193.00	47565.20	47952.10	612429.7	593100.8	5326285	5345609	1015	314	2019
1194.00	48062.20	48435.00	593914.6	612533.2	5344998	5326396	1015	314	2019
1195.00	48547.10	48901.90	611935.7	594021	5327201	5345127	1015	314	2019
1196.00	49018.80	49378.60	594123.4	612041.1	5345207	5327308	1015	314	2019
1197.00	49488.80	49844.30	612148.3	594228.4	5327400	5345332	1015	314	2019
1198.00	49951.80	50313.50	594339.9	612252.9	5345426	5327527	1015	314	2019
1199.00	50412.30	50768.00	612360.6	594445	5327620	5345538	1015	314	2019
1200.00	50872.70	51230.90	594548.5	612451.6	5345643	5327739	1015	314	2019
1201.00	51328.80	51667.50	612571.1	595361.9	5327841	5345047	1015	314	2019
1202.00	51774.80	52104.70	595469.9	611967.9	5345150	5328653	1015	314	2019
1203.00	52205.80	52534.20	612077.8	595572.3	5328755	5345254	1015	314	2019
1204.00	52639.70	52969.80	595678.3	612179.6	5345360	5328860	1015	314	2019
1205.00	53070.80	53396.10	612289.6	595784.7	5328967	5345470	1015	314	2019

FLOWN LINES - Magnetic and VLF
UTM Zone 21N, Datum NAD-83

LINE	START TIME (seconds)	END TIME (seconds)	START X (m)	END X (m)	START Y (m)	END Y (m)	FLIGHT	DAY	YEAR
1206.00	53494.10	53827.80	595891	612394.2	5345576	5329075	1015	314	2019
1207.00	53922.70	54248.20	612500.1	595999.1	5329181	5345681	1015	314	2019
1208.00	54346.00	54661.30	596107	611901.1	5345772	5329985	1015	314	2019
1209.00	54768.50	55067.90	612004.4	596915.4	5330097	5345186	1015	314	2019
1210.00	55174.60	55474.90	597026.3	612108.7	5345282	5330204	1015	314	2019
1211.00	55562.00	55858.10	612215	597128.9	5330313	5345415	1015	314	2019
1212.00	55967.20	56270.40	597237.5	612325.2	5345495	5330418	1015	314	2019
1213.00	56372.40	56673.50	612428	597343.3	5330516	5345614	1015	314	2019
1214.00	62105.50	62392.50	597448.9	611828.4	5345710	5331330	1015	314	2019
1215.00	62487.80	62772.30	611934.5	597554.7	5331442	5345826	1015	314	2019
1216.00	62875.00	63163.70	597660.2	612039.2	5345925	5331544	1015	314	2019
1217.00	63260.70	63546.90	612147.7	597767.4	5331651	5346037	1015	314	2019
1218.00	63807.90	64096.80	597872.9	612254.3	5346142	5331760	1015	314	2019
1219.00	64198.40	64483.40	612359.6	597978.2	5331849	5346241	1015	314	2019
1220.00	64582.30	64870.80	598085.3	612464.4	5346358	5331969	1015	314	2019
1221.00	64971.50	65240.80	611862.1	598189.7	5332776	5346459	1015	314	2019
1222.00	65348.70	65621.90	598297.1	611969.6	5346556	5332885	1015	314	2019
1223.00	65715.80	65985.20	612077.4	598402.6	5332995	5346674	1015	314	2019
1224.00	66082.50	66359.90	598506.9	612184	5346780	5333098	1015	314	2019
1225.00	66459.30	66729.10	612286.4	598616.6	5333218	5346880	1015	314	2019
1226.00	66836.50	67109.60	598719.4	612395.9	5346997	5333313	1015	314	2019
1227.00	67234.40	67492.80	611794.7	598829.7	5334119	5347098	1015	314	2019
1228.00	67598.40	67861.10	598934.2	611897.8	5347194	5334223	1015	314	2019
1229.00	67959.40	68215.10	612003.3	599039.9	5334329	5347302	1015	314	2019
1230.00	68322.00	68579.40	599145.7	612111.1	5347404	5334441	1015	314	2019
1231.00	68673.00	68927.20	612214.6	599249.6	5334540	5347528	1015	314	2019
1232.01	69038.50	69294.60	599355.7	612324.2	5347631	5334655	1015	314	2019
1233.00	58472.60	58804.00	612427.7	599462.4	5334760	5347736	1014	313	2019
1234.00	54262.20	54529.30	599568	611826.6	5347841	5335577	1014	313	2019
1235.00	57715.20	58012.20	611935.9	599675.4	5335690	5347954	1014	313	2019
1236.00	53530.50	53787.50	599782.6	612039.3	5348048	5335787	1014	313	2019
1237.00	53897.60	54191.70	612146.6	599886	5335904	5348159	1014	313	2019
1238.00	52817.60	53070.30	599992.9	612250.3	5348267	5335992	1014	313	2019
1239.00	53173.60	53451.20	612360.3	600100	5336113	5348372	1014	313	2019
1240.00	52114.20	52354.30	600207.1	611758.5	5348477	5336920	1014	313	2019
1241.00	52465.80	52750.50	611862.4	600312.8	5337031	5348588	1014	313	2019
1242.00	51437.80	51674.60	600419.1	611971.3	5348682	5337133	1014	313	2019
1243.00	51786.30	52048.20	612075.8	600524.9	5337225	5348797	1014	313	2019
1244.00	50716.10	50959.60	600631.1	612182.6	5348892	5337353	1014	313	2019
1245.00	51077.60	51342.90	612288.3	600736.9	5337456	5349015	1014	313	2019
1246.00	50005.30	50249.00	600841.1	612394.9	5349106	5337557	1014	313	2019

FLOWN LINES – Magnetic and VLF
UTM Zone 21N, Datum NAD-83

LINE	START TIME (seconds)	END TIME (seconds)	START X (m)	END X (m)	START Y (m)	END Y (m)	FLIGHT	DAY	YEAR
1247.00	50376.00	50633.10	611791.1	600946.6	5338371	5349219	1014	313	2019
1248.00	67426.80	67669.90	601053.5	611897.1	5349314	5338475	1009	304	2019
1249.00	49648.20	49878.50	612006.4	602575.7	5338582	5348016	1014	313	2019
1250.00	66843.40	67038.00	602681.6	612111	5348120	5338684	1009	304	2019
1251.00	67143.70	67337.70	612217.7	602785.9	5338787	5348227	1009	304	2019
1252.00	66245.40	66440.10	602893.9	612324.5	5348335	5338894	1009	304	2019
1253.00	66555.70	66733.80	611720.5	602997.9	5339717	5348437	1009	304	2019
1254.00	65542.70	65722.00	603106.7	611826.6	5348535	5339829	1009	304	2019
1255.00	65876.00	66054.10	611932.8	603212.2	5339925	5348651	1009	304	2019
1256.00	63672.70	63850.60	603315.2	612041.9	5348755	5340032	1009	304	2019
1257.00	57628.30	57805.20	603425.8	612144.8	5348864	5340144	1003	294	2019
1258.00	57952.20	58158.90	612253.3	603530.3	5340242	5348970	1003	294	2019
1259.00	45757.60	45948.20	611651.8	603634.7	5341062	5349068	1003	294	2019
1260.00	57308.20	57496.90	611757.8	603742.3	5341171	5349175	1003	294	2019
1261.00	61423.40	61596.20	611863.7	603846.9	5341271	5349281	1002	292	2019
1262.00	61143.30	61307.30	603955.5	611971.5	5349382	5341381	1002	292	2019
1263.00	60859.10	61026.80	612074.7	604057.5	5341473	5349489	1002	292	2019
1264.00	60578.50	60748.80	604165	612179.7	5349599	5341588	1002	292	2019
1265.00	60292.00	60470.70	612285.4	604270.4	5341690	5349712	1002	292	2019
1266.00	60037.60	60202.20	604377.1	611689.1	5349818	5342501	1002	292	2019
1267.00	59777.50	59932.30	611792.4	604483.4	5342617	5349918	1002	292	2019
1268.00	59505.90	59672.40	604589.6	611900.3	5350033	5342722	1002	292	2019
1269.00	52685.70	52840.20	612005.7	604695.9	5342821	5350133	1002	292	2019
1270.00	52430.20	52582.80	604802.9	612112.7	5350243	5342922	1002	292	2019
1271.00	52163.50	52316.80	612216.2	604909	5343043	5350351	1002	292	2019
1272.00	51909.70	52063.20	605013.3	612324.1	5350455	5343138	1002	292	2019
1273.00	51653.80	51803.20	612429.8	605122.2	5343252	5350559	1002	292	2019
1274.00	51387.90	51546.50	605224.7	612535.3	5350668	5343358	1002	292	2019
1275.00	51077.20	51234.20	612641	605333.4	5343453	5350767	1002	292	2019
1276.00	45575.60	45640.10	609680.8	612749.3	5346628	5343564	1003	294	2019
101.00	70358.50	70441.30	573404.9	577037.6	5344059	5347695	1001	290	2019
102.00	43914.10	43999.50	577744.7	573476.7	5346985	5342718	1001	290	2019
103.00	47369.00	47471.80	573443.7	578454.3	5341269	5346279	1009	304	2019
104.00	47139.80	47252.30	579160.2	573619.5	5345574	5340033	1009	304	2019
105.00	46890.40	47025.10	573689	580289.1	5338681	5345277	1009	304	2019
106.00	50744.30	50914.20	581741.6	573652.3	5345339	5337244	1008	303	2019
107.00	46256.00	46445.90	573723.1	583189.4	5335884	5345352	1009	304	2019
108.00	46564.40	46788.00	584641	573687.3	5345382	5334449	1009	304	2019
109.00	45486.10	45734.80	573761.1	586092	5333097	5345440	1009	304	2019
110.00	45872.30	46149.30	587435.3	573727.3	5345374	5331650	1009	304	2019
111.00	52519.90	52872.90	588881.9	573796.8	5345406	5330317	1005	298	2019

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LINE	START TIME (seconds)	END TIME (seconds)	START X (m)	END X (m)	START Y (m)	END Y (m)	FLIGHT	DAY	YEAR
112.00	44468.80	44797.60	590331.3	574292.3	5345435	5329397	1009	304	2019
113.00	54939.70	55301.50	591888.5	574783.6	5345575	5328474	1004	295	2019
114.00	55401.10	55785.40	574856.9	593336	5327122	5345605	1005	298	2019
115.00	46583.90	46984.30	594785.6	575139.5	5345643	5325996	1004	295	2019
116.00	54357.40	54828.00	575635.2	596344.2	5325077	5345788	1004	295	2019
117.00	53184.40	53735.50	601291.9	576342.5	5349317	5324369	1002	292	2019
118.00	58936.80	59452.00	577046.8	602002.1	5323661	5348614	1002	292	2019
119.00	53602.90	54220.30	576271.8	605570.8	5321466	5350773	1003	294	2019
120.00	46109.40	46567.40	606280	585458.2	5350076	5329258	1003	294	2019
120.01	45085.60	45268.30	585496.8	576977.1	5329282	5320776	1009	304	2019
121.00	52157.80	52777.70	577683.8	606987.1	5320061	5349360	1003	294	2019
122.00	52883.00	53503.70	607690.6	578393.6	5348648	5319353	1003	294	2019
123.00	55076.50	55691.90	579098.9	608397.8	5318642	5347934	1003	294	2019
124.00	54328.10	54953.50	609108	579806	5347270	5317935	1003	294	2019
125.00	56496.10	57111.10	580512.9	609919.4	5317231	5346629	1003	294	2019
126.00	55769.60	56340.20	610625.5	583446.6	5345915	5318749	1003	294	2019
127.00	64560.50	65104.90	584152.7	611332.1	5318039	5345212	1009	304	2019
128.00	56039.50	56661.10	584863.1	612040.1	5317342	5344512	1004	295	2019
129.00	68325.70	68829.00	587691.7	612750.1	5318740	5343809	1009	304	2019
130.00	56605.60	57096.40	612286.4	588396.2	5341934	5318027	1007	301	2019
131.00	69545.60	70016.60	589105.2	612250.4	5317346	5340475	1009	304	2019
132.00	63949.90	64371.90	612325	592036.3	5339141	5318856	1009	304	2019
133.00	70681.70	71080.70	592746.7	612395.5	5318140	5337788	1009	304	2019
134.00	67749.00	68159.70	612360.5	593452.6	5336346	5317453	1009	304	2019
135.00	55155.00	55509.30	595010.7	612430.5	5317592	5335011	1014	313	2019
136.00	69020.10	69383.40	612395	595717.5	5333556	5316869	1009	304	2019
137.00	56166.70	56494.00	596420.3	612464.4	5316149	5332221	1014	313	2019
138.00	70213.70	70542.70	612429.3	597130.1	5330757	5315451	1009	304	2019
139.00	69383.60	69687.40	612498.7	597839.6	5329424	5314762	1015	314	2019
140.00	54665.90	55031.40	612571.8	598544.4	5328079	5314048	1014	313	2019
141.00	69772.60	70038.00	599253.3	612534.1	5313344	5326613	1015	314	2019
142.00	55713.00	56035.70	612607.8	599958.7	5325258	5312636	1014	313	2019
143.00	57043.20	57285.70	600664.9	612570.4	5311927	5323838	1014	313	2019
144.00	56690.40	56987.00	612846.4	601372.7	5322764	5311217	1014	313	2019
145.00	70486.10	70713.40	602081.2	613559.3	5310486	5321984	1015	314	2019
146.00	70154.60	70391.10	614270.3	602786.7	5321289	5309801	1015	314	2019
147.00	71130.10	71355.80	603496.1	614973.9	5309104	5320575	1015	314	2019
148.00	70800.40	71038.90	615683.4	604203.2	5319875	5308386	1015	314	2019
149.00	56218.20	56450.70	604906.6	616388.6	5307687	5319156	1009	304	2019
150.00	71437.70	71677.10	617097.1	605615.5	5318460	5306985	1015	314	2019
151.00	67577.80	67849.30	606321.2	617804.2	5306249	5317763	1007	301	2019

FLOWN LINES - Magnetic and VLF
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LINE	START TIME (seconds)	END TIME (seconds)	START X (m)	END X (m)	START Y (m)	END Y (m)	FLIGHT	DAY	YEAR
152.00	61875.00	62117.10	618512.6	607030	5317044	5305565	1009	304	2019
153.00	42734.30	42987.70	619219.4	607735.6	5316334	5304857	1006	299	2019
154.00	55877.50	56115.90	619924.5	608443.6	5315628	5304152	1009	304	2019
155.00	56775.20	57012.10	609149.1	620631	5303442	5314919	1001	290	2019
156.00	64952.00	65170.70	620382.5	609859.8	5313264	5302728	1001	290	2019
157.00	65255.80	65326.30	610566.7	613877.9	5302054	5305336	1001	290	2019
158.00	65417.00	65456.90	613208.6	611274.6	5303251	5301324	1001	290	2019
159.00	65547.30	65572.00	611980.5	613172.8	5300617	5301806	1001	290	2019

FLOWN LINES - Spectrometer
UTM Zone 21N, Datum NAD-83

LINE	START TIME (seconds)	END TIME (seconds)	START X (m)	END X (m)	START Y (m)	END Y (m)	FLIGHT	DAY	YEAR
1001.00	53785.50	53889.50	576302.7	580735.2	5321735	5317245	1002	292	2019
1002.00	53999.50	54090.50	580854.8	576404.9	5317322	5321788	1002	292	2019
1003.00	54202.50	54304.50	576519.2	580964.9	5321886	5317444	1002	292	2019
1004.00	54403.50	54496.50	581073.8	576594.3	5317538	5322022	1002	292	2019
1005.00	54602.50	54702.50	576720.3	581149.8	5322108	5317679	1002	292	2019
1006.00	54809.50	54906.50	581282.6	576804.4	5317752	5322237	1002	292	2019
1007.00	55013.50	55114.50	576937.1	581373.4	5322316	5317879	1002	292	2019
1008.00	55215.50	55308.50	581488.1	577012.5	5317973	5322460	1002	292	2019
1009.00	55417.50	55518.50	577129.6	581584.2	5322538	5318090	1002	292	2019
1010.00	55619.50	55715.50	581687.2	577261.3	5318196	5322635	1002	292	2019
1011.00	55825.50	55931.50	577354.4	581815.7	5322741	5318281	1002	292	2019
1012.00	56036.50	56134.50	581918.4	577476.4	5318393	5322839	1002	292	2019
1013.00	56245.50	56347.50	577539.9	582014.3	5322984	5318506	1002	292	2019
1014.00	56455.50	56549.50	582130.2	577685.9	5318605	5323059	1002	292	2019
1015.00	56691.50	56845.50	575660.1	582219.2	5325279	5318727	1002	292	2019
1016.00	56967.50	57104.50	582344.7	575735.2	5318812	5325429	1002	292	2019
1017.00	57218.50	57376.50	575165.4	582426.5	5326213	5318951	1002	292	2019
1018.00	57480.50	57634.50	582529.8	575240	5319049	5326335	1002	292	2019
1019.00	57742.50	57898.50	575365.6	582649.9	5326428	5319148	1002	292	2019
1020.00	58001.50	58154.50	582731.7	575477.9	5319268	5326528	1002	292	2019
1021.00	58247.50	58419.50	574887.4	582851.7	5327336	5319370	1002	292	2019
1022.00	58543.50	58755.50	585088.1	575003.1	5317346	5327430	1002	292	2019
1023.00	46982.50	47206.50	585179.3	575078.3	5317458	5327566	1003	294	2019
1024.00	47338.50	47550.50	575183.1	585286.4	5327675	5317571	1003	294	2019
1025.00	47669.50	47903.50	585422.1	575312.2	5317647	5327758	1003	294	2019
1026.00	48029.50	48242.50	575384.5	585487.5	5327899	5317794	1003	294	2019
1027.00	48362.50	48609.50	585617.3	574789.2	5317875	5328706	1003	294	2019
1028.00	48711.50	48937.50	574921.7	585719	5328794	5317992	1003	294	2019
1029.00	49048.50	49306.50	585827	574312.8	5318094	5329603	1003	294	2019
1030.00	49409.50	49650.50	574433.5	585910.4	5329690	5318220	1003	294	2019
1031.00	49772.50	50054.50	586039.9	573821.8	5318306	5330540	1003	294	2019
1032.00	50149.50	50404.50	573909.1	586124.8	5330653	5318428	1003	294	2019
1033.00	50530.50	50817.50	586239.2	574024.5	5318523	5330745	1003	294	2019
1034.00	50932.50	51184.50	574138.1	586377.7	5330838	5318597	1003	294	2019
1035.00	51294.50	51571.50	586448.3	574231.6	5318739	5330965	1003	294	2019
1036.00	51671.50	51924.50	574324	586547.1	5331081	5318856	1003	294	2019
1037.00	47615.50	47910.50	586673.9	573718.6	5318951	5331898	1004	295	2019
1038.00	47218.50	47496.50	573827.3	586797.2	5332002	5319031	1004	295	2019
1039.00	48438.50	48724.50	586898.2	573931.1	5319142	5332100	1004	295	2019
1040.00	48022.50	48311.50	574048.7	587000.5	5332204	5319246	1004	295	2019
1041.00	49257.50	49535.50	587106.1	574164.2	5319361	5332299	1004	295	2019

FLOWN LINES - Spectrometer
UTM Zone 21N, Datum NAD-83

LINE	START TIME (seconds)	END TIME (seconds)	START X (m)	END X (m)	START Y (m)	END Y (m)	FLIGHT	DAY	YEAR
1042.00	48824.50	49138.50	574292.9	589329.4	5332381	5317347	1004	295	2019
1043.00	50118.50	50446.50	589436.2	574363.4	5317449	5332521	1004	295	2019
1044.00	49655.50	49990.50	573767.1	589532.1	5333330	5317569	1004	295	2019
1045.00	51048.50	51385.50	589630	573866.8	5317675	5333447	1004	295	2019
1046.00	50576.50	50904.50	574010.5	589755.6	5333514	5317772	1004	295	2019
1047.00	51928.50	52283.50	589842.1	574098.9	5317895	5333639	1004	295	2019
1048.00	51484.50	51810.50	574187.9	589951.2	5333754	5317997	1004	295	2019
1049.00	52842.50	53196.50	590080.5	574302.3	5318088	5333860	1004	295	2019
1050.00	52386.50	52732.50	573704.3	590149.8	5334664	5318218	1004	295	2019
1051.00	53769.50	54130.50	590301.4	573805.6	5318291	5334778	1004	295	2019
1052.00	53303.50	53640.50	573910.2	590404	5334883	5318399	1004	295	2019
1053.00	57412.50	57805.50	590510.9	574011.2	5318492	5334999	1007	301	2019
1054.00	55485.50	55830.50	574142.1	590614.3	5335078	5318608	1004	295	2019
1055.00	58359.50	58756.50	590699.1	574229	5318732	5335205	1007	301	2019
1056.00	57890.50	58228.50	574333.3	590797.6	5335323	5318847	1007	301	2019
1057.00	59355.50	59760.50	590898.4	573747.6	5318966	5336111	1007	301	2019
1058.00	58874.50	59223.50	573861	591015.9	5336190	5319045	1007	301	2019
1059.00	60422.50	60841.50	591141.8	573939.6	5319149	5336349	1007	301	2019
1060.00	59883.50	60261.50	574068.8	591213.9	5336425	5319277	1007	301	2019
1061.00	61463.50	61878.50	591326.2	574185.6	5319386	5336529	1007	301	2019
1062.00	60976.50	61340.50	574289.3	591455.8	5336620	5319473	1007	301	2019
1063.00	62497.50	62955.50	593665.7	573689	5317468	5337447	1007	301	2019
1064.00	61967.50	62386.50	573771.7	593793.7	5337574	5317559	1007	301	2019
1065.00	63633.50	64112.50	593880	573873	5317679	5337684	1007	301	2019
1066.00	63050.50	63471.50	574008.1	593973.1	5337792	5317807	1007	301	2019
1067.00	64822.50	65294.50	594116.7	574073.7	5317862	5337911	1007	301	2019
1068.00	64243.50	64670.50	574210.3	594207.3	5338008	5317996	1007	301	2019
1069.00	65909.50	66380.50	594295.3	574291.7	5318109	5338122	1007	301	2019
1070.00	65376.50	65797.50	573718.7	594422.2	5338931	5318198	1007	301	2019
1071.00	51986.50	52805.50	612208.5	573810	5300619	5339016	1008	303	2019
1072.00	52941.50	53743.50	573904.7	612311.1	5339142	5300740	1008	303	2019
1073.00	48500.50	49303.50	574053.1	612422.5	5339224	5300822	1006	299	2019
1074.00	51036.50	51846.50	574117	612525.1	5339339	5300938	1008	303	2019
1075.00	46507.50	47305.50	574261.2	612613.9	5339416	5301058	1006	299	2019
1076.00	47446.50	48356.50	612749.9	573620.6	5301136	5340273	1006	299	2019
1077.00	45396.50	46231.50	612817.1	573728.7	5301284	5340375	1006	299	2019
1078.00	66483.50	67304.50	573846.4	612964.3	5340474	5301347	1007	301	2019
1079.00	43240.50	44101.50	613044.8	573952.4	5301482	5340580	1006	299	2019
1080.00	44217.50	45013.50	574080.2	613157.8	5340629	5301578	1006	299	2019
1081.00	54177.50	55079.50	612570.3	573472.4	5302367	5341475	1005	298	2019
1082.00	53194.50	54043.50	573555.8	612656.2	5341608	5302510	1005	298	2019

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LINE	START TIME (seconds)	END TIME (seconds)	START X (m)	END X (m)	START Y (m)	END Y (m)	FLIGHT	DAY	YEAR
1083.00	69348.50	70139.50	612746.4	573681.1	5302638	5341695	1001	290	2019
1084.00	68400.50	69246.50	573764.7	612849.4	5341821	5302729	1001	290	2019
1085.00	67496.50	68284.50	612989.9	573905.7	5302773	5341893	1001	290	2019
1086.00	66569.50	67384.50	573977.3	613092.1	5342034	5302923	1001	290	2019
1087.00	65670.50	66448.50	613204.7	574094.6	5303007	5342124	1001	290	2019
1088.00	44420.50	45271.50	573515.1	612597.8	5342916	5303826	1001	290	2019
1089.00	45381.50	46192.50	612687.3	573584.8	5303943	5343059	1001	290	2019
1090.00	46304.50	47169.50	573697.3	612819.2	5343156	5304038	1001	290	2019
1091.00	47290.50	48093.50	612910.6	573824.2	5304157	5343242	1001	290	2019
1092.00	48212.50	49058.50	573941.7	613022.8	5343340	5304258	1001	290	2019
1093.00	49165.50	49975.50	613134.5	574008.4	5304355	5343487	1001	290	2019
1094.00	50075.50	50938.50	573429.6	613209.7	5344277	5304502	1001	290	2019
1095.00	51033.50	51845.50	613324.3	573543.5	5304589	5344375	1001	290	2019
1096.00	51958.50	52844.50	573625.7	613455.1	5344494	5304675	1001	290	2019
1097.00	52952.50	53760.50	613557.8	573748.5	5304786	5344602	1001	290	2019
1098.00	53876.50	54733.50	573837.3	613662.5	5344719	5304893	1001	290	2019
1099.00	54838.50	55630.50	613767.5	573942.7	5304992	5344828	1001	290	2019
1100.00	55747.50	56600.50	574078.3	613869.6	5344901	5305115	1001	290	2019
1101.00	70600.50	71433.50	574157.4	613249	5345036	5305947	1001	290	2019
1102.00	54780.50	55596.50	574283.9	613360.3	5345116	5306044	1008	303	2019
1103.00	53858.50	54667.50	613492.2	574384.7	5306122	5345232	1008	303	2019
1104.00	56661.50	57459.50	574466.9	613582.4	5345367	5306241	1008	303	2019
1105.00	55720.50	56531.50	613687.2	574614.4	5306353	5345427	1008	303	2019
1106.00	58459.50	59272.50	574708.9	613786.3	5345547	5306463	1008	303	2019
1107.00	57557.50	58353.50	613892.6	574819.1	5306575	5345660	1008	303	2019
1108.00	60344.50	61146.50	574894	614014.8	5345785	5306642	1008	303	2019
1109.00	59419.50	60223.50	614131.7	575033	5306760	5345858	1008	303	2019
1110.00	68227.50	69024.50	575137.7	614203.3	5345968	5306896	1008	303	2019
1111.00	67294.50	68092.50	614341.5	575244.4	5306988	5346068	1008	303	2019
1112.00	70008.50	70796.50	575350.8	614433.6	5346171	5307087	1008	303	2019
1113.00	69121.50	69909.50	614539.7	575459.1	5307166	5346278	1008	303	2019
1114.00	47622.50	48413.50	575555.1	614648.3	5346384	5307299	1009	304	2019
1115.00	70927.50	71722.50	614738.3	575649.2	5307415	5346510	1008	303	2019
1116.00	49435.50	50227.50	575739.7	614844.2	5346639	5307529	1009	304	2019
1117.00	48514.50	49315.50	614977.8	575840.6	5307601	5346745	1009	304	2019
1118.00	51244.50	52029.50	575979.3	615062.5	5346826	5307734	1009	304	2019
1119.00	50338.50	51141.50	615174.1	576069.2	5307833	5346955	1009	304	2019
1120.00	54860.50	55654.50	576164.6	615291.6	5347057	5307935	1009	304	2019
1121.00	52115.50	52918.50	615394.6	576309.2	5308043	5347121	1009	304	2019
1122.00	46438.50	47358.50	615499.7	576399.2	5308147	5347240	1010	306	2019
1123.00	53974.50	54773.50	615600.8	576500	5308265	5347362	1009	304	2019

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LINE	START TIME (seconds)	END TIME (seconds)	START X (m)	END X (m)	START Y (m)	END Y (m)	FLIGHT	DAY	YEAR
1124.00	53043.50	53839.50	576600	615710.1	5347474	5308368	1009	304	2019
1125.00	62320.50	63124.50	615794.9	576688	5308458	5347598	1009	304	2019
1126.00	47499.50	48322.50	576808.7	615924.2	5347685	5308581	1010	306	2019
1127.00	48466.50	49318.50	616028.1	579769.3	5308690	5344946	1010	306	2019
1128.00	49421.50	50180.50	579866.3	616118.4	5345065	5308798	1010	306	2019
1129.00	50302.50	51167.50	616242.4	579971	5308893	5345160	1010	306	2019
1130.00	51316.50	52076.50	580080.4	616333.3	5345256	5309019	1010	306	2019
1131.00	52220.50	53055.50	616451.7	580876.6	5309110	5344687	1010	306	2019
1132.00	53147.50	53866.50	580995.8	616564.8	5344778	5309210	1010	306	2019
1133.00	53978.50	54808.50	616635.9	581080.1	5309345	5344898	1010	306	2019
1134.00	62183.50	62904.50	581227	616738.4	5344968	5309457	1011	306	2019
1135.00	63049.50	63850.50	616862.5	581300.1	5309546	5345116	1011	306	2019
1136.00	63948.50	64669.50	581426.4	616949.9	5345197	5309671	1011	306	2019
1137.00	64774.50	65560.50	617100.4	581502	5309724	5345332	1011	306	2019
1138.00	65666.50	66371.50	582345.3	617197.1	5344698	5309845	1011	306	2019
1139.00	66493.50	67252.50	617295.5	582439.1	5309956	5344817	1011	306	2019
1140.00	67352.50	68057.50	582541.7	617373.5	5344838	5310083	1011	306	2019
1141.00	68158.50	68905.50	617527	582643.5	5310151	5345036	1011	306	2019
1142.00	69002.50	69717.50	582745.5	617601.2	5345157	5310285	1011	306	2019
1143.00	69840.50	70589.50	617701.6	582870.4	5310406	5345233	1011	306	2019
1144.00	70689.50	71398.50	582981	617795	5345326	5310511	1011	306	2019
1145.00	47473.50	48194.50	617935.4	583802.9	5310596	5344728	1012	308	2019
1146.00	48300.50	48989.50	583899.3	618041.1	5344840	5310699	1012	308	2019
1147.00	49113.50	49825.50	618137.1	584019.6	5310813	5344930	1012	308	2019
1148.00	49937.50	50632.50	584080.5	618239.4	5345076	5310923	1012	308	2019
1149.00	50740.50	51453.50	618335.6	584193.6	5311032	5345189	1012	308	2019
1150.00	51555.50	52244.50	584304.2	618480.9	5345293	5311113	1012	308	2019
1151.00	52363.50	53077.50	618551.4	584401.3	5311248	5345394	1012	308	2019
1152.00	53201.50	53885.50	585230.3	618687.3	5344813	5311319	1012	308	2019
1153.00	54006.50	54716.50	618788.1	585358	5311431	5344865	1012	308	2019
1154.00	54828.50	55500.50	585426.5	618884.8	5345006	5311551	1012	308	2019
1155.00	55620.50	56327.50	618978.6	585559.8	5311658	5345088	1012	308	2019
1156.00	56427.50	57099.50	585663.2	619070.8	5345190	5311789	1012	308	2019
1157.00	57218.50	57927.50	619210	585772.9	5311863	5345306	1012	308	2019
1158.00	63954.50	64626.50	585851.1	619324	5345429	5311962	1012	308	2019
1159.00	64742.50	65416.50	619427.4	586679	5312072	5344814	1012	308	2019
1160.00	65515.50	66173.50	586777	619511.7	5344937	5312191	1012	308	2019
1161.00	66281.50	66965.50	619630.2	586910.9	5312292	5345007	1012	308	2019
1162.00	67076.50	67734.50	586981.2	619729.7	5345152	5312409	1012	308	2019
1163.00	67851.50	68523.50	619834.5	587106.1	5312516	5345246	1012	308	2019
1164.00	68633.50	69290.50	587233.2	619939.9	5345316	5312610	1012	308	2019

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LINE	START TIME (seconds)	END TIME (seconds)	START X (m)	END X (m)	START Y (m)	END Y (m)	FLIGHT	DAY	YEAR
1165.00	69389.50	70040.50	620057.2	588044.6	5312718	5344716	1012	308	2019
1166.00	70137.50	70777.50	588134.6	620138.3	5344845	5312835	1012	308	2019
1167.00	70869.50	71518.50	620267	588236.6	5312920	5344955	1012	308	2019
1168.00	71633.50	72279.50	588358.7	620385.6	5345042	5313025	1012	308	2019
1169.00	49824.50	50469.50	619752.7	588451.9	5313872	5345163	1013	309	2019
1170.00	49065.50	49716.50	588535.5	619860.8	5345289	5313967	1013	309	2019
1171.00	51353.50	51997.50	619985.3	588683.7	5314054	5345357	1013	309	2019
1172.00	50599.50	51224.50	589461.9	620060.5	5344792	5314202	1013	309	2019
1173.00	52833.50	53471.50	620173.6	589603.2	5314286	5344855	1013	309	2019
1174.00	52103.50	52736.50	589682.6	620287.1	5344993	5314387	1013	309	2019
1175.00	54300.50	54932.50	620420.2	589783	5314460	5345105	1013	309	2019
1176.00	53553.50	54179.50	589889	620496	5345200	5314615	1013	309	2019
1177.00	55734.50	56371.50	620632	590002.2	5314680	5345317	1013	309	2019
1178.00	55053.50	55498.50	590132.3	612236.2	5345386	5323300	1013	309	2019
1179.00	57000.50	57443.50	612350.1	590942.4	5323384	5344790	1013	309	2019
1180.00	56465.50	56897.50	591020.2	612445.9	5344923	5323509	1013	309	2019
1181.00	58127.50	58564.50	612533.2	591139.7	5323629	5345007	1013	309	2019
1182.00	57568.50	57986.50	591249	611934.6	5345122	5324443	1013	309	2019
1183.00	59190.50	59617.50	612080.7	591349.2	5324507	5345238	1013	309	2019
1184.00	58682.50	59100.50	591438.7	612159	5345352	5324641	1013	309	2019
1185.00	60225.50	60644.50	612255	591545.4	5324755	5345476	1013	309	2019
1186.00	59709.50	60136.50	591659	612380.8	5345552	5324848	1013	309	2019
1187.00	44531.50	44930.50	612489.6	592482.2	5324949	5344955	1015	314	2019
1188.00	45044.50	45446.50	592588.8	612610.6	5345058	5325040	1015	314	2019
1189.00	45570.50	45958.50	611992.3	592682.1	5325868	5345176	1015	314	2019
1190.00	46070.50	46456.50	592780	612079.9	5345287	5325994	1015	314	2019
1191.00	46577.50	46964.50	612210	592891	5326081	5345395	1015	314	2019
1192.00	47074.50	47459.50	592999.2	612323.3	5345493	5326172	1015	314	2019
1193.00	47565.50	47951.50	612414.1	593129.5	5326300	5345580	1015	314	2019
1194.00	48062.50	48434.50	593930	612506.7	5344982	5326420	1015	314	2019
1195.00	48547.50	48901.50	611915.2	594040.5	5327222	5345107	1015	314	2019
1196.00	49019.50	49378.50	594160.3	612036.2	5345173	5327313	1015	314	2019
1197.00	49489.50	49843.50	612113.1	594267.3	5327437	5345293	1015	314	2019
1198.00	49952.50	50313.50	594375.3	612253	5345391	5327527	1015	314	2019
1199.00	50412.50	50767.50	612350.5	594469.5	5327630	5345513	1015	314	2019
1200.00	50873.50	51230.50	594588.2	612431.6	5345602	5327757	1015	314	2019
1201.00	51329.50	51667.50	612536.1	595361.9	5327877	5345047	1015	314	2019
1202.00	51775.50	52104.50	595505.1	611958.1	5345115	5328662	1015	314	2019
1203.00	52206.50	52533.50	612042.3	595607.1	5328791	5345220	1015	314	2019
1204.00	52640.50	52969.50	595717.9	612165.1	5345320	5328874	1015	314	2019
1205.00	53071.50	53395.50	612252.9	595814.1	5329004	5345440	1015	314	2019

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LINE	START TIME (seconds)	END TIME (seconds)	START X (m)	END X (m)	START Y (m)	END Y (m)	FLIGHT	DAY	YEAR
1206.00	53494.50	53827.50	595910.4	612379.9	5345556	5329089	1015	314	2019
1207.00	53923.50	54247.50	612460.2	596034	5329222	5345646	1015	314	2019
1208.00	54346.50	54660.50	596131.4	611859.9	5345748	5330025	1015	314	2019
1209.00	54768.50	55067.50	612004.4	596935.2	5330097	5345166	1015	314	2019
1210.00	55174.50	55474.50	597021	612088.1	5345287	5330223	1015	314	2019
1211.00	55562.50	55857.50	612189	597157.1	5330339	5345382	1015	314	2019
1212.00	55967.50	56269.50	597252.7	612280.5	5345479	5330464	1015	314	2019
1213.00	56372.50	56673.50	612423	597343.3	5330522	5345614	1015	314	2019
1214.00	62105.50	62392.50	597448.9	611828.5	5345710	5331330	1015	314	2019
1215.00	62488.50	62771.50	611899	597593.8	5331476	5345787	1015	314	2019
1216.00	62875.50	63163.50	597683.6	612029	5345900	5331554	1015	314	2019
1217.00	63261.50	63546.50	612107.6	597787.3	5331691	5346018	1015	314	2019
1218.00	63808.50	64096.50	597901.3	612239.3	5346115	5331774	1015	314	2019
1219.00	64198.50	64483.50	612354.5	597973.3	5331854	5346247	1015	314	2019
1220.00	64582.50	64870.50	598094.9	612449.5	5346348	5331985	1015	314	2019
1221.00	64971.50	65240.50	611862.2	598204.7	5332776	5346445	1015	314	2019
1222.00	65349.50	65621.50	598335.6	611948.8	5346517	5332905	1015	314	2019
1223.00	65716.50	65984.50	612041.4	598437.8	5333031	5346639	1015	314	2019
1224.00	66082.50	66359.50	598507	612163.8	5346780	5333118	1015	314	2019
1225.00	66459.50	66728.50	612276.1	598646.7	5333227	5346849	1015	314	2019
1226.00	66836.50	67109.50	598719.3	612390.7	5346997	5333318	1015	314	2019
1227.00	67234.50	67492.50	611790.1	598845	5334123	5347082	1015	314	2019
1228.00	67598.50	67860.50	598939	611868.5	5347189	5334252	1015	314	2019
1229.00	67959.50	68214.50	611998.3	599070.8	5334334	5347271	1015	314	2019
1230.00	68322.50	68579.50	599170.7	612116	5347379	5334437	1015	314	2019
1231.00	68673.50	68926.50	612190.5	599284.9	5334565	5347492	1015	314	2019
1232.00	69038.50	69294.50	599355.7	612319.3	5347631	5334660	1015	314	2019
1232.01	69038.50	69294.50	599355.7	612319.3	5347631	5334660	1015	314	2019
1233.00	58472.50	58803.50	612431.7	599481.5	5334756	5347716	1014	313	2019
1234.00	54262.50	54528.50	599580.2	611789.3	5347828	5335613	1014	313	2019
1235.00	57715.50	58011.50	611924.3	599703.5	5335702	5347925	1014	313	2019
1236.00	53530.50	53787.50	599782.2	612039.3	5348048	5335788	1014	313	2019
1237.00	53897.50	54191.50	612150.2	599894.6	5335900	5348151	1014	313	2019
1238.00	52817.50	53069.50	599988.2	612211.6	5348272	5336031	1014	313	2019
1239.00	53173.50	53450.50	612364.1	600130.3	5336109	5348341	1014	313	2019
1240.00	52114.50	52353.50	600217.7	611719.1	5348464	5336958	1014	313	2019
1241.00	52466.50	52750.50	611835.6	600313	5337059	5348588	1014	313	2019
1242.00	51438.50	51674.50	600451.3	611966.3	5348650	5337137	1014	313	2019
1243.00	51786.50	52047.50	612068	600555.8	5337233	5348766	1014	313	2019
1244.00	50716.50	50959.50	600647.5	612177.6	5348874	5337358	1014	313	2019
1245.00	51077.50	51342.50	612292.3	600755.5	5337452	5348997	1014	313	2019

FLOWN LINES – Spectrometer
UTM Zone 21N, Datum NAD-83

LINE	START TIME (seconds)	END TIME (seconds)	START X (m)	END X (m)	START Y (m)	END Y (m)	FLIGHT	DAY	YEAR
1246.00	50005.50	50248.50	600849.5	612372	5349097	5337579	1014	313	2019
1247.00	50376.50	50632.50	611770.3	600974.3	5338392	5349191	1014	313	2019
1248.00	67427.50	67669.50	601083.4	611879.7	5349284	5338493	1009	304	2019
1249.00	49648.50	49878.50	611994.7	602575.8	5338593	5348016	1014	313	2019
1250.00	66843.50	67037.50	602686.1	612088.3	5348116	5338709	1009	304	2019
1251.00	67144.50	67337.50	612178.9	602795.7	5338828	5348217	1009	304	2019
1252.00	66245.50	66439.50	602898.9	612295.7	5348330	5338922	1009	304	2019
1253.00	66556.50	66733.50	611681.6	603011.6	5339756	5348423	1009	304	2019
1254.00	65543.50	65721.50	603140.5	611802.2	5348500	5339853	1009	304	2019
1255.00	65876.50	66053.50	611907.7	603240.7	5339948	5348622	1009	304	2019
1256.00	63673.50	63850.50	603352.5	612037.4	5348718	5340037	1009	304	2019
1257.00	57628.50	57804.50	603435.5	612110.3	5348854	5340178	1003	294	2019
1257.01	65267.50	65444.50	612099.7	603439.1	5340190	5348836	1009	304	2019
1258.00	57952.50	58158.50	612239.6	603545.4	5340256	5348955	1003	294	2019
1259.00	45757.50	45947.50	611656.1	603661.3	5341058	5349041	1003	294	2019
1260.00	57308.50	57496.50	611745.2	603757.5	5341183	5349160	1003	294	2019
1261.00	61423.50	61595.50	611859	603877.6	5341276	5349251	1002	292	2019
1262.00	61143.50	61306.50	603964.8	611932.4	5349373	5341420	1002	292	2019
1263.00	60859.50	61026.50	612055.3	604071	5341493	5349476	1002	292	2019
1264.00	60578.50	60748.50	604165	612165.4	5349599	5341602	1002	292	2019
1265.00	60292.50	60470.50	612261.8	604278.8	5341712	5349703	1002	292	2019
1266.00	60037.50	60201.50	604372.5	611657.7	5349823	5342532	1002	292	2019
1267.00	59777.50	59931.50	611792.4	604519.8	5342617	5349882	1002	292	2019
1268.00	59506.50	59671.50	604613.3	611858.8	5350009	5342763	1002	292	2019
1269.00	52686.50	52839.50	611968.7	604727.8	5342858	5350101	1002	292	2019
1270.00	52430.50	52582.50	604816.6	612098	5350229	5342936	1002	292	2019
1271.00	52163.50	52316.50	612216.3	604922.9	5343043	5350337	1002	292	2019
1272.00	51910.50	52062.50	605050.9	612289.8	5350417	5343173	1002	292	2019
1273.00	51654.50	51802.50	612394.8	605156	5343286	5350524	1002	292	2019
1274.00	51388.50	51546.50	605252.6	612535.3	5350640	5343358	1002	292	2019
1275.00	51077.50	51233.50	612626.7	605366.8	5343468	5350734	1002	292	2019
1276.00	45575.50	45639.50	609676.3	612721.4	5346633	5343592	1003	294	2019
101.00	70358.50	70440.50	573404.9	577000.9	5344059	5347659	1001	290	2019
102.00	43914.50	43999.50	577724.5	573476.7	5346965	5342718	1001	290	2019
103.00	47369.50	47471.50	573467.1	578440.3	5341293	5346264	1009	304	2019
104.00	47140.50	47251.50	579125.4	573659.5	5345539	5340074	1009	304	2019
105.00	46890.50	47024.50	573693.8	580259.7	5338686	5345248	1009	304	2019
106.00	50744.50	50913.50	581732.1	573685.3	5345330	5337278	1008	303	2019
107.00	46256.50	46445.50	573747.8	583169.4	5335909	5345332	1009	304	2019
108.00	46564.50	46787.50	584636.2	573711.9	5345378	5334473	1009	304	2019
109.00	45486.50	45734.50	573781	586076.8	5333117	5345425	1009	304	2019

FLOWN LINES – Spectrometer
UTM Zone 21N, Datum NAD-83

LINE	START TIME (seconds)	END TIME (seconds)	START X (m)	END X (m)	START Y (m)	END Y (m)	FLIGHT	DAY	YEAR
110.00	45872.50	46148.50	587426.2	573768.5	5345365	5331692	1009	304	2019
111.00	52520.50	52872.50	588857.8	573815	5345381	5330335	1005	298	2019
112.00	44469.50	44797.50	590297.6	574297	5345402	5329402	1009	304	2019
113.00	54940.50	55301.50	591850.9	574783.5	5345535	5328474	1004	295	2019
114.00	55401.50	55785.50	574876.2	593340.9	5327141	5345610	1005	298	2019
115.00	46584.50	46983.50	594755	575179.6	5345613	5326035	1004	295	2019
116.00	54357.50	54827.50	575639.2	596324.1	5325081	5345768	1004	295	2019
117.00	53184.50	53735.50	601287.4	576342.5	5349313	5324369	1002	292	2019
118.00	58937.50	59451.50	577080	601978.6	5323693	5348590	1002	292	2019
119.00	53603.50	54219.50	576299.9	605530.1	5321496	5350733	1003	294	2019
120.00	46109.50	46567.50	606275.4	585453.6	5350071	5329253	1003	294	2019
120.01	45085.50	45267.50	585501.3	577018.3	5329287	5320815	1009	304	2019
121.00	52158.50	52777.50	577714.2	606978.1	5320091	5349351	1003	294	2019
122.00	52883.50	53503.50	607668.8	578403.5	5348626	5319363	1003	294	2019
123.00	55076.50	55691.50	579098.9	608378.8	5318642	5347915	1003	294	2019
124.00	54328.50	54953.50	609094.6	579805.9	5347251	5317935	1003	294	2019
125.00	56496.50	57110.50	580530.7	609891.5	5317249	5346601	1003	294	2019
126.00	55769.50	56339.50	610629.9	583478.5	5345919	5318781	1003	294	2019
127.00	64560.50	65104.50	584153	611311.7	5318039	5345192	1009	304	2019
128.00	56039.50	56660.50	584863.1	612013.3	5317342	5344486	1004	295	2019
129.00	68326.50	68828.50	587731.1	612725.3	5318778	5343784	1009	304	2019
130.00	56605.50	57096.50	612291.4	588391.7	5341939	5318022	1007	301	2019
131.00	69545.50	70016.50	589100.5	612245.5	5317341	5340470	1009	304	2019
132.00	63950.50	64371.50	612296.7	592056.6	5339113	5318876	1009	304	2019
133.00	70682.50	71080.50	592785.2	612385.2	5318178	5337777	1009	304	2019
134.00	67749.50	68159.50	612344.1	593461.7	5336324	5317461	1009	304	2019
135.00	55155.50	55508.50	595034.5	612391.2	5317616	5334971	1014	313	2019
136.00	69020.50	69383.50	612376.2	595712.9	5333537	5316864	1009	304	2019
137.00	56167.50	56493.50	596459	612439.8	5316185	5332196	1014	313	2019
138.00	70214.50	70542.50	612393.6	597140.2	5330719	5315461	1009	304	2019
139.00	69383.50	69687.50	612503.6	597834.6	5329428	5314757	1015	314	2019
140.00	54666.50	55031.50	612547.4	598540.1	5328055	5314044	1014	313	2019
141.00	69772.50	70037.50	599249.3	612508.3	5313339	5326587	1015	314	2019
142.00	55713.50	56035.50	612589.2	599967.5	5325241	5312645	1014	313	2019
143.00	57043.50	57285.50	600678.6	612560.8	5311941	5323828	1014	313	2019
144.00	56690.50	56986.50	612843.4	601391.1	5322759	5311236	1014	313	2019
145.00	70486.50	70713.50	602099.9	613564.8	5310506	5321989	1015	314	2019
146.00	70154.50	70390.50	614275.1	602815.3	5321293	5309831	1015	314	2019
147.00	71130.50	71355.50	603515.7	614958.1	5309122	5320560	1015	314	2019
148.00	70800.50	71038.50	615678.8	604222.6	5319870	5308405	1015	314	2019
149.00	56218.50	56450.50	604921.9	616379.4	5307701	5319147	1009	304	2019

FLOWN LINES – Spectrometer
UTM Zone 21N, Datum NAD-83

LINE	START TIME (seconds)	END TIME (seconds)	START X (m)	END X (m)	START Y (m)	END Y (m)	FLIGHT	DAY	YEAR
150.00	71438.50	71676.50	617060.6	605644	5318422	5307014	1015	314	2019
151.00	67578.50	67848.50	606345.6	617771	5306283	5317729	1007	301	2019
152.00	61875.50	62116.50	618488.4	607059.8	5317020	5305594	1009	304	2019
153.00	42734.50	42987.50	619210.8	607744.9	5316326	5304866	1006	299	2019
154.00	55877.50	56115.50	619924.6	608462.9	5315628	5304172	1009	304	2019
155.00	56775.50	57011.50	609163.6	620600	5303457	5314887	1001	290	2019
156.00	64952.50	65170.50	620359.1	609869.6	5313241	5302738	1001	290	2019
157.00	65256.50	65325.50	610597.3	613837.5	5302082	5305296	1001	290	2019
158.00	65417.50	65456.50	613185	611294.6	5303229	5301345	1001	290	2019
159.00	65547.50	65571.50	611990.4	613149.4	5300627	5301783	1001	290	2019

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Appendix VII

FILTER 21
COEFFICIENTS

.0181004100
.0090731840
-.0033823890
-.0236237500
-.0393873800
-.0341412800
.0037196630
.0722507900
.1533358000
.2191219000
.2444045000

FILTER 67 COEFFICIENTS

-.0073813819
.0017786870
.0022008393
.0028708524
.0036799926
.0044552023
.0050366484
.0052816825
.0050482578
.0042355750
.0028043608
.0007561474
.0018169265
-.0047570802
-.0078405226
-.010776499
-.013235446
-.014878507
-.015358825
-.014386294
-.011729066
-.0072475690
-.0009241524
.0071362499
.016706382
.027417007
.038819272
.050368667
.061476381
.071564890
.080079578
.086310541
.090552829
.091944844

369 POINT FILTER
WAVELENGTH IN READINGS / CYCLE
100.0
50.0
33.3
25.0
20.0
100
80
60
40
20
0
PERCENTAGE PASSED
97.22% at 200 READINGS/CYCLE
0.02% at 66.7 READINGS/CYCLE
0.000
0.010
0.020
0.030
0.040
0.050
FREQUENCY IN CYCLES / READING

SGL

Appendix VIII

VLF Outages

Lines for which VLF data were not acquired by station.
Note that no usable data was acquired from the Cutler (NAA) station.

Lamoure	**Skelton**			**Rhauderfehn**			
NML	**GQD**			**DHO38**			
1054	1001	1084	1259	1001	1060	1197	1256
1122	1002	1085	1260	1002	1061	1198	1257
1126	1003	1086	1261	1003	1062	1199	1258
1127	1004	1087	1262	1004	1063	1200	1259
1128	1005	1088	1263	1005	1064	1201	1260
1129	1006	1089	1264	1006	1065	1202	1261
1130	1007	1090	1265	1007	1066	1203	1262
1131	1008	1091	1266	1008	1067	1204	1263
1132	1009	1092	1267	1009	1068	1205	1264
1133	1010	1093	1268	1010	1069	1206	1265
1134	1011	1094	1269	1011	1070	1207	1266
1135	1012	1095	1270	1012	1073	1208	1267
1136	1013	1096	1271	1013	1075	1209	1268
1137	1014	1097	1272	1014	1076	1210	1269
1138	1015	1098	1273	1015	1077	1211	1270
1139	1016	1099	1274	1016	1078	1212	1271
1140	1017	1100	1275	1017	1079	1213	1272
1141	1018	1101	1276	1018	1080	1214	1273
1142	1019	1102		1019	1083	1215	1274
1143	1020	1103		1020	1084	1216	1275
1144	1021	1104		1021	1085	1217	1276
1169	1022	1105		1022	1086	1218	
1170	1023	1106		1023	1087	1219	
1171	1024	1107		1024	1088	1220	
1172	1025	1108		1025	1089	1221	
1173	1026	1109		1026	1090	1222	
1174	1027	1110		1027	1091	1223	
1175	1028	1111		1028	1092	1224	
1176	1029	1112		1029	1093	1225	
1177	1030	1113		1030	1094	1226	
1178	1031	1115		1031	1095	1227	
1179	1032	1145		1032	1096	1228	
1180	1033	1146		1033	1097	1229	
1181	1034	1147		1034	1098	1230	
1182	1035	1148		1035	1099	1231	
1183	1036	1149		1036	1100	1232	
1184	1037	1150		1037	1101	1233	
1185	1038	1151		1038	1114	1234	
1186	1039	1152		1039	1116	1235	
1233	1040	1153		1040	1117	1236	
1235	1041	1154		1041	1118	1237	
	1042	1155		1042	1119	1238	
	1043	1156		1043	1120	1239	
	1044	1157		1044	1121	1240	
	1045	1158		1045	1123	1241	
	1046	1159		1046	1124	1242	
	1047	1160		1047	1125	1243	
	1048	1161		1048	1169	1244	
	1049	1162		1049	1170	1245	
	1050	1163		1050	1187	1246	
	1051	1164		1051	1188	1247	
	1052	1165		1052	1189	1248	
	1054	1166		1053	1190	1249	
	1071	1167		1054	1191	1250	
	1072	1168		1055	1192	1251	
	1074	1233		1056	1193	1252	
	1081	1235		1057	1194	1253	
	1082	1257		1058	1195	1254	
	1083	1258		1059	1196	1255	

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Appendix IX

Topographic contour interval: 30 metres

MAP 2020-01
TWILLICK BROOK
NTS MAP AREA 2D/04 AND PARTS OF 1M/13, 1M/14, 2D/03 AND 2D/05

Flown and compiled by:

SANDER GEOPHYSICS
255 Hunt Club Road
Ottawa, Ontario, Canada K1V 1C1
Tel: (613) 731-8686
www.sgl@sgl.com
sgl.com

Scale 1:75000

1000 0 1000 2000 3000 4000 5000 6000
(metres)
NAD83 / UTM zone 21N

Digital topographic data provided by Geomatics Canada, Natural Resources Canada

Newfoundland Labrador
NATURAL RESOURCES

AIRBORNE GEOPHYSICAL SURVEY OF THE TWILLICK BROOK REGION, NEWFOUNDLAND

NTS MAP AREA 2D/04 AND PARTS OF 1M/13, 1M/14, 2D/03 AND 2D/05,

RESIDUAL MAGNETIC INTENSITY

MAP 2020-01
OPEN FILE NFLD/3383
Map 1 of 13

G.J. Kilfoil

ABOUT THE SURVEY

Introduction
A high resolution gamma-ray spectrometric, aeromagnetic and VLF-Electromagnetic airborne geophysical survey of Twillick Brook region, Newfoundland, was completed by Sander Geophysics Limited. The survey was flown from October 17th to November 10th, 2019 using a single Cessna 208 Caravan (C-GSGJ). The nominal traverse and control line spacings were, respectively, 150 m and 1500 m. The survey was flown at a nominal terrain clearance of 100 m. Navigation was provided by Global Positioning System receivers operated 24h with orthogonal control lines. The flight path was recovered following post-flight Precise Point Positioning (PPP) corrections using precise ephemerides applied to rare data recorded by a Global Positioning System.

Gamma-ray Spectrometric Data
The airborne gamma-ray measurements were made with a Sander Geophysics GSLSpec gamma-ray spectrometer using fourteen 616 cubic inch (10.1 litres) NaI(Tl) crystals. Twelve crystals were mounted in a single array and two in a tail boom. The total active volume 8.4 litres), shielded by the main array, were used to detect variations in background radiation caused by atmospheric radon. The system continuously adjusted the gain of each crystal by monitoring the natural potassium, uranium, and thorium peaks. Upward crystals were provided a small vacuum source to supplemented the three natural peaks.

Potassium is measured directly from the 1460 keV gamma-ray photons emitted by K-40. Uranium and thorium are measured indirectly from the gamma-ray photons emitted by their daughters. The 1760 keV photons from Bismuth-214 in the Uranium series are for down their respective decay chains, they are assumed to be in equilibrium with their parents, thus gamma-ray spectrometric measurements of uranium and thorium are referred to as equivalent uranium and equivalent thorium, i.e. eU and eTh. The energy windows used to measure potassium, uranium and thorium are respectively (370 -1570 keV, 1660-1860 keV and 2410-2810 keV.

Gamma-ray spectra were recorded at one-second intervals. Data processing followed standard procedures as described in IAEA, 1991 and Grasty, 1997. Corrections were made for the effects of aircraft and cosmic background radiation, channel overlap and radon. Counts from the radon detectors were recorded in a 1860 - 1980 keV window and radiation at energies greater than 3000 keV was recorded in the cosmic window. The window counts were corrected for background activity from cosmic radiation, radioactivity of the aircraft and radon emanation. The radon window was used to estimate the radon contribution in the other windows. The stripping ratios and coefficients for deviations from the planned terrain clearance and for variation of temperature and pressure were made prior to conversion to ground concentrations of potassium, uranium and thorium, using factors determined from flights over the Breckenridge, Quebec calibration range.

Corrected data were interpolated to a 30 m grid interval. The results of an airborne gamma-ray spectrometric survey represent the average surface concentrations that are influenced by varying amounts of outcrop, overburden, vegetation cover, soil moisture and snow cover. The data are also influenced by atmospheric radon concentrations, which are monitored by observations. The total air absorbed dose rate in nanograys per hour was produced from measured counts between 400 and 2810 keV.

Magnetic Data
The magnetic field was sampled 10 times per second using three spill-beam cesium vapour magnetometers (sensitivity = 0.005 nT) mounted inside the tail boom and two wingtip pods of the aircraft. This array of sensors form a fixed-wing gradiometer with a lateral separation of 2.5 m between the wingtip sensors and a longitudinal separation of 7.5 m between the wingtip sensors and the tail boom sensor. The tail boom sensor was computer-balanced to obtain a mutually levelled set of flight-line magnetic data. The International Geomagnetic Reference Field (IGRF) defined at the average GPS altitude of 310 m for the date November 1st was then removed. Removal of the IGRF ensures that the data sets for the survey area are free of the regional effects of the Earth's core and long wavelength sources within the Earth's crust. An enhanced version of the levelled magnetic data is calculated by averaging horizontal and longitudinal gradients to better define short wavelength signal, which is then interpolated to a 30 m grid interval.

The first vertical derivative of the magnetic field is the rate of change of the magnetic field in the vertical direction. Computation of the first vertical derivative removes long wavelength features of the magnetic field and significantly improves the resolution of closely spaced magnetic anomalies. Because the first vertical derivative maps is the coincidence of the zero-value contour with vertical contacts of magnetic units at high magnetic latitudes (Hood, 1965).

VLF-EM
Very low frequency (VLF) electro-magnetic data was measured using a Herz Totem 2A VLF-EM receiver mounted in a 2.5 m fibreglass stinger installed on the tail of the aircraft. For this survey, the VLF station in Lualualei, North Dakota (22.2 kHz) provided Line data and Rhumbatrons. Rhumbatrons (Fraser, 1972) were calculated from the Line data using a 3 point filter (Karous and Hjelt, 1983) and a 9 point filter (Fraser, 1969). VLF coverage of the survey area was not achieved. Variation in signal quality is also apparent in the data as bands of less coherent data.

Additional Information
Data compilation and map production were performed by Sander Geophysics Limited, Ottawa, Ontario.
Contract and project management was provided by the Newfoundland and Labrador Department of Natural Resources.

Copies of this map may be obtained from the Geological Survey, Department of Natural Resources,
Government of Newfoundland and Labrador, P.O. Box 8700, St. John's, NL, Canada, A1B 4J6.

This map is subject to revision and modification. Comments to the author concerning errors or omissions are invited.

Department Website: http://www.nr.gov.nl.ca/nr/
Geological Survey Website: http://www.nr.gov.nl.ca/nr/
Email: gsl@gov.nl.ca

References
Hood, P.J.
1965: Gradient measurements in aeromagnetic surveying. Geophysics, vol. 30, p. 891-902.

PLANIMETRIC SYMBOLS

Topographic contours
Drainage
Road
Flight line
Building
Transmission line

ISOMAGNETIC LINES

250nT
50nT
10nT
5nT
Magnetic depression

LOCATION MAP

NATIONAL TOPOGRAPHIC SYSTEM REFERENCE AND GEOPHYSICAL MAP INDEX

Recommended Citation
Kilfoil, G.J.
2020: Airborne Geophysical Survey of the Twillick Brook region, Newfoundland (NTS Map Area 2D/04 and parts of 1M/13, 1M/14, 2D/03 and 2D/05). Residual Magnetic Intensity. Geological Survey, Department of Natural Resources, Government of Newfoundland and Labrador, Map 2020-01; Open File NFLD/3383.

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Topographic contour interval: 30 metres

Digital topographic data provided by Geomatics Canada, Natural Resources Canada

MAP 2020-02
TWILLICK BROOK
NTS MAP AREA 2D/04 AND PARTS OF 1M/13, 1M/14, 2D/03 AND 2D/05

Scale 1:75000

1000 0 1000 2000 3000 4000 5000 6000
(metres)
NAD83 / UTM zone 21N

Flown and compiled by:

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Ottawa, Ontario, Canada K1V 1C1
Tel: (613) 521-3421
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Newfoundland Labrador
NATURAL RESOURCES

AIRBORNE GEOPHYSICAL SURVEY OF THE TWILLICK BROOK REGION, NEWFOUNDLAND

NTS MAP AREA 2D/04 AND PARTS OF 1M/13, 1M/14, 2D/03 AND 2D/05,

FIRST VERTICAL DERIVATIVE OF THE MAGNETIC FIELD

MAP 2020-02
OPEN FILE NFLD/3383
Map 2 of 13

G.J. Kilfoil

ABOUT THE SURVEY

Introduction
An airborne gamma-ray spectrometric, aeromagnetic and VLF-Electromagnetic airborne geophysical survey of Twillick Brook region, Newfoundland, was completed by Sander Geophysics Limited. The survey was flown from October 17th to November 10th, 2019 using a single Cessna 208 Caravan (C-GSGU). The nominal traverse and control line spacings were, respectively, 150 m and 1000 m. The nominal terrain clearance was 100 m. Magnetic and electromagnetic data were sampled at 10 Hz. Survey lines were oriented 135° with orthogonal control lines. The flight path was recovered following post-flight Precise Point Positioning (PPP) corrections using precise ephemerides applied to raw data recorded by a Global Positioning System.

Gamma-ray Spectrometric Data
The airborne gamma-ray measurements were made with a Sander Geophysics GSLSpec gamma-ray spectrometer using fourteen 4.2-litre (256 cubic inch) NaI(Tl) crystals. Twelve crystals were mounted in a single wing pod, and two 4.2-litre crystals plus two 4.2-litre crystals, shielded by the main array, were used to detect variations in background radiation caused by atmospheric radon. The system continuously adjusted the gain of each crystal by monitoring the natural potassium, uranium, and thorium peaks. Upward crystals were provided a small vacuum source to supplement the three natural peaks.

Potassium is measured directly from the 1460 keV gamma-ray photons emitted by K-40 ; whereas uranium and thorium are measured indirectly by measurements of daughter products in the U-238 and Th-232 decay series. The U-238 series is in "secular equilibrium" if all daughters are far down their respective decay chains, they are assumed to be in equilibrium with their parents, thus gamma-ray spectrometric measurements of uranium and thorium are referred to as equivalent uranium and equivalent thorium, i.e. eU and eTh. The energy windows used to measure potassium, uranium and thorium are respectively (370 - 1570 keV, 1660-1860 keV and 2410-2810 keV.

Gamma-ray spectra were recorded at one-second intervals. Data processing followed standard procedures as described in IAEA, 1991 and Grasty, 1997. Spectral data were corrected for live time, background radiation, cosmic radiation, radon, channel overlap and Compton scatter. Counts from the native detection were recorded in a 1860 - 1960 keV window and radiation at energies greater than 3000 keV was recorded in the cosmic window. The window counts were corrected for background activity from cosmic radiation, radioactivity of the aircraft and radon emanation. The radon background was estimated using the upward crystals and the cosmic window. The data were also corrected for deviations from the planned terrain clearance and for variation of temperature and pressure were made prior to conversion to ground concentrations of potassium, uranium and thorium, using factors determined from flights over the Blackbridge, Quebec calibration range.

Corrected data were interpolated to a 30 m grid interval. The results of an airborne gamma-ray spectrometric survey represent the average surface concentrations that are influenced by varying amounts of outcrop, overburden, vegetation cover, soil moisture and depth of snow. The data are also influenced by variations in the effective flight height and detector concentrations. The total air absorbed dose rate in nanograys per hour was produced from measured counts between 400 and 2810 keV.

Magnetic Data
The magnetic field was sampled 10 times per second using three split-beam cesium vapour magnetometers (sensitivity = 0.005 nT) mounted inside the tail boom and two wingtip pods of the aircraft. This array of sensors form a fixedwindled gradiometer with a lateral separation of 2.5 m between the wingtip sensors and 7.5 m between the tail boom sensor and the average position of the wingtip sensors. Traverse lines were computer-assisted to obtain a mutually levelled set of flight-line magnetic data. The International Geomagnetic Reference Field (IGRF) defined at the average GPS altitude of 313 m for the date November 1st, was then removed. Removal of the IGRF ensures that the data sets for all surveys, regardless of the date or altitude, are comparable and represent the magnetic field within the Earth's crust. An enhanced version of the levelled magnetic data is calculated by averaging horizontal and longitudinal gradients to better define short wavelength signal, which is then interpolated to a 30 m grid interval.

The first vertical derivative of the magnetic field is the rate of change of the magnetic field in the vertical direction. Computation of the first vertical derivative removes long wavelength features of the magnetic field and significantly improves the resolution of closely spaced magnetic anomalies caused by shallow sources. The derivative maps is the coincidence of the zero-value contour with vertical contacts of magnetic units at high magnetic latitudes (Hood, 1965).

VLF-EM
Very low frequency (VLF) electro-magnetic data was measured using a Herz Totem 2A VLF-EM receiver mounted in a 2.5 m fibreglass stinger installed on the tail of the aircraft. For this survey, the VLF station in Cutler, North Dakota (25.2 kHz) provided Line data and Rhumbatron, Quebec (27.1 kHz) provided Cross data. Data was recorded in the form of the in-phase and quadrature components as a percent of the primary field. Due to the orientation of the survey lines with respect to the VLF transmitters, variation in signal quality is also apparent in the data as bands of less coherent data.

Additional Information
Data compilation and map production were performed by Sander Geophysics Limited, Ottawa, Ontario.
Contract and project management was provided by the Newfoundland and Labrador Department of Natural Resources.

Copies of this map may be obtained from the Geological Survey, Department of Natural Resources,
Government of Newfoundland and Labrador, P.O. Box 8700, St. John's, NL, Canada, A1B 4J6.

This map is subject to revision and modification. Comments to the author concerning errors or omissions are invited.

Department Website: http://www.nr.gov.nl.ca/nr/
Geological Survey Website: http://www.nr.gov.nl.ca/nr
Email: gsdl@gov.nl.ca

References
Hood, P.J.
1965: Gradient measurements in aeromagnetic surveying. Geophysics, vol. 30, p. 891-902.

PLANIMETRIC SYMBOLS

Topographic contours
Drainage
Road
Flight line
Building
Transmission line

LOCATION MAP

NATIONAL TOPOGRAPHIC SYSTEM REFERENCE AND GEOPHYSICAL MAP INDEX

Recommended Citation
Kilfoil, G.J.
2020: Airborne Geophysical Survey of the Twillick Brook region, Newfoundland (NTS Map Area 2D/04 and parts of 1M/13, 1M/14, 2D/03 and 2D/05). First Vertical Derivative of the Magnetic Field; Geological Survey, Department of Natural Resources, Government of Newfoundland and Labrador, Map 2020-02, Open File NFLD/3383.

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Topographic contour interval: 30 metres

MAP 2020-03
TWILLICK BROOK
NTS MAP AREA 2D/04 AND PARTS OF 1M/13, 1M/14, 2D/03 AND 2D/05

Scale 1:75000

Digital topographic data provided by Geomatics Canada, Natural Resources Canada

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Newfoundland Labrador
NATURAL RESOURCES

AIRBORNE GEOPHYSICAL SURVEY OF THE TWILLICK BROOK REGION, NEWFOUNDLAND

NTS MAP AREA 2D/04 AND PARTS OF 1M/13, 1M/14, 2D/03 AND 2D/05,

PERCENT POTASSIUM

MAP 2020-03
OPEN FILE NFLD/3383
Map 3 of 13

G.J. Kilfoil

ABOUT THE SURVEY

Introduction
A high resolution gamma-ray spectrometric, aeromagnetic and VLF-Electromagnetic airborne geophysical survey of Twillick Brook region, Newfoundland, was completed by Sander Geophysics Limited. The survey was flown from October 17th to November 10th, 2018 using a single Cessna 208 Caravan (C-GSGL). The nominal traverse and control line spacings were, respectively, 150 m and 1500 m. The nominal terrain clearance was 100 m. Magnetic and electromagnetic data were recorded at 10 Hz. Survey lines were oriented 135° with orthogonal control lines. The flight path was recovered following post-flight Precise Point Positioning (PPP) corrections using precise ephemerides applied to raw data recorded by a Global Positioning System.

Gamma-ray Spectrometric Data
The airborne gamma-ray measurements were made with a Sander Geophysics GSLZero gamma-ray spectrometer using fourteen 616 cubic inches (10.1 litres) NaI(Tl) crystals. The spectrometer was calibrated at the Pembroke, Ontario, GSL calibration pad. Four volume 5.4-litres, shielded by the main array, were used to detect variations in background radiation caused by atmospheric radon. The system continuously adjusted the gain of each crystal by monitoring the natural potassium, uranium, and thorium peaks. Upward crystals were provided a small vacuum source to supplement the three natural peaks.

Potassium is measured directly from the 1460 keV gamma-ray photons emitted by K-40. Uranium and thorium are measured indirectly from the gamma-ray photons emitted by their daughter products. The 1760 keV peak of Bi-214 and the 2614 keV peak of Tl-208 are for down their respective decay chains, they are assumed to be in equilibrium with their parents, thus gamma-ray spectrometric measurements of uranium and thorium are referred to as equivalent uranium and equivalent thorium, i.e. eU and eTh. The energy windows used to measure potassium, uranium and thorium are respectively (370 -1570 keV, 1660-1860 keV and 2410-2810 keV.

Gamma-ray spectra were recorded at one-second intervals. Data processing followed standard procedures as described in IAEA, 1991 and IAEA, 2003. Spectral data were corrected for dead time, background radiation, channel overlapping, and cosmic ray interference. Counts from the radon detection were recorded in a 1860 - 1960 keV window and radiation at energies greater than 3000 keV was recorded in the cosmic window. The window counts were corrected for background activity from cosmic radiation, radioactivity of the aircraft and atmospheric radon. The radon window was used to estimate the radon component in the other windows. The data were also corrected for deviations from the planned terrain clearance and for variation of temperature and pressure were made prior to conversion to ground concentrations of potassium, uranium and thorium, using factors determined from flights over the Breckenridge, Quebec calibration range.

Corrected data were interpolated to a 30 m grid interval. The results of an airborne gamma-ray spectrometric survey represent the average surface concentrations that are influenced by varying amounts of outcrop, overburden, vegetation cover, soil moisture and radon activity. The data are also influenced by variations in the effective flight height and detector characteristics. The total air absorbed dose rate in nanograys per hour was produced from measured counts between 400 and 2810 keV.

Magnetic Data
The magnetic field was sampled 10 times per second using three spin-beam cesium vapour magnetometers (sensitivity = 0.005 nT) mounted inside the tail boom and two wingtip pods of the aircraft. This array of sensors form a fixedwind gradiometer with a lateral separation of 3.3 m and a longitudinal separation of 8.5 m. The three sensors provide three independent measurements of the transverse field were computer-analysed to obtain a mutually levelled out of flight-line magnetic data. The International Geomagnetic Reference Field (IGRF) defined at the average GPS altitude of 313 m for the date November 1st was then removed. Removal of the IGRF ensures that the data sets for the various surveys in a regional aeromagnetic survey have consistent background values within the Earth's crust. An enhanced version of the levelled magnetic data is calculated by averaging horizontal and longitudinal gradients to better define short wavelength signal, which is then interpolated to a 30 m grid interval.

The first vertical derivative of the magnetic field is the rate of change of the magnetic field in the vertical direction. Computation of the first vertical derivative removes long wavelength features of the magnetic field and significantly improves the resolution of closely spaced magnetic anomalies. Shading of the first vertical derivative maps is the coincidence of the zero-value contour with vertical contacts of magnetic units at high magnetic latitudes (Hood, 1965).

VLF-EM
Very low frequency (VLF) electro-magnetic data was measured using a Herz Totem 2A VLF-EM receiver mounted in a 2.5 m fibreglass stinger installed on the tail of the aircraft. For this survey, the VLF station in Lualualei, North Dakota (22.2 kHz) provided Line data and Rhumbatron data (22.0 kHz) was used as a backup. The Rhumbatron data was used to fill in the Lualualei data where signal strength was less than 10%. VLF coverage of the survey area was not achieved. Variation in signal quality is also apparent in the data as bands of less coherent data.

Additional Information
Data compilation and map production were performed by Sander Geophysics Limited, Ottawa, Ontario.
Contract and project management was provided by the Newfoundland and Labrador Department of Natural Resources.

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Government of Newfoundland and Labrador, P.O. Box 8700, St. John's, NL, Canada, A1B 4J6.

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Geological Survey Website: http://www.nr.gov.nl.ca/nr/mines/geology/
Email: gsdept@gov.nl.ca

References
Hood, P.J.
1965: Gradient measurements in aeromagnetic surveying. Geophysics, vol. 30, p. 891-902.

PLANIMETRIC SYMBOLS

Topographic contours
Drainage
Road
Flight line
Building
Transmission line

LOCATION MAP

NATIONAL TOPOGRAPHIC SYSTEM REFERENCE AND GEOPHYSICAL MAP INDEX

Recommended Citation
Kilfoil, G.J.
2020: Airborne Geophysical Survey of the Twillick Brook region, Newfoundland (NTS Map Area 2D/04 and parts of 1M/13, 1M/14, 2D/03 and 2D/05). Percent Potassium. Geological Survey, Department of Natural Resources, Government of Newfoundland and Labrador, Map 2020-03; Open File NFLD/3383.

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Topographic contour interval: 30 metres

Digital topographic data provided by Geomatics Canada, Natural Resources Canada

MAP 2020-04
TWILLICK BROOK
NTS MAP AREA 2D/04 AND PARTS OF 1M/13, 1M/14, 2D/03 AND 2D/05

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Newfoundland Labrador
NATURAL RESOURCES

AIRBORNE GEOPHYSICAL SURVEY OF THE TWILLICK BROOK REGION, NEWFOUNDLAND

NTS MAP AREA 2D/04 AND PARTS OF 1M/13, 1M/14, 2D/03 AND 2D/05,

EQUIVALENT URANIUM

MAP 2020-04
OPEN FILE NFLD/3383
Map 4 of 13

G.J. Kilfoil

ABOUT THE SURVEY

Introduction
A high resolution gamma-ray spectrometric, aeromagnetic and VLF-Electromagnetic airborne geophysical survey of Twillick Brook region, Newfoundland, was completed by Sander Geophysics Limited. The survey was flown from October 17th to November 10th, 2019 using a single Cessna 208 Caravan (C-GSGU). The nominal traverse and control line spacings were, respectively, 150 m and 1500 m. The survey was flown at a nominal terrain clearance of 100 m. Navigation was by GPS. Flight path was recovered and stacked GIS with orthogonal control lines. The flight path was recovered following post-flight Precise Point Positioning (PPP) corrections using precise ephemerides applied to raw data recorded by a Global Positioning System.

Gamma-ray Spectrometric Data
The airborne gamma-ray measurements were made with a Sander Geophysics GSLZero gamma-ray spectrometer using fourteen Radiation Solutions RS-500 Series 256 channel spectrometers. Twenty-eight downward-looking 4.2 litre (256 cubic inch) NaI crystal volume 5-4-Array, shielded by the main array, were used to detect variations in background radiation caused by atmospheric radon. The system continuously adjusted the gain of each crystal by monitoring the natural potassium, uranium, and thorium peaks. Upward crystals were provided a small vacuum source to supplement the three natural peaks.

Potassium is measured directly from the 1460 keV gamma-ray photons emitted by K-40. Uranium and thorium are measured indirectly from the daughter products of U-238 and Th-232 decay series. The U-238 series is represented by Bi-214 and Th-232 series by Tl-208 and for down-hole radioactive decay chains, they are assumed to be in equilibrium with their parents, thus gamma-ray spectrometric measurements of uranium and thorium are referred to as equivalent uranium and equivalent thorium, i.e. eU and eTh. The energy windows used to measure potassium, uranium and thorium are respectively (370 -1570 keV, 1660-1860 keV and 2410-2810 keV.

Gamma-ray spectra were recorded at one-second intervals. Data processing followed standard procedures as described in IAEA, 1991 and IAEA, 2003. Spectra were stripped of the effects of cosmic radiation, background radiation, radon, and channel overlap. Counts from the radon detection were recorded in a 1860 - 1960 keV window and radiation at energies greater than 3000 keV was recorded in the cosmic window. The window counts were corrected for background activity from cosmic radiation, radioactivity of the aircraft and radon activity. Radon activity is measured in the upward looking crystals and is assumed to be the same in the other 26 crystals. Corrections for deviations from the planned terrain clearance and for variations in temperature and pressure were made prior to conversion to ground concentrations of potassium, uranium and thorium, using factors determined from flights over the Breckenridge, Quebec calibration range.

Corrected data were interpolated to a 30 m grid interval. The results of an airborne gamma-ray spectrometric survey represent the average surface concentrations that are influenced by varying amounts of outcrop, overburden, vegetation cover, soil moisture and radon activity. The data are also influenced by variations in the effective flight height and detector responsiveness. The total air absorbed dose rate in nanograys per hour was produced from measured counts between 400 and 2810 keV.

Magnetic Data
The magnetic field was sampled 10 times per second using three split-beam cesium vapour magnetometers (sensitivity = 0.005 nT) mounted inside the tail boom and two winglip pods of the aircraft. This array of sensors form a fixedwindled gradiometer with a lateral baseline of 2.3 m and a longitudinal baseline of 8.5 m. The three magnetic field measurements were used to compute a magnetic vector which was computer-analysed to obtain a mutually levelled out of flight-line magnetic data. The International Geomagnetic Reference Field (IGRF) defined at the average GPS altitude of 313 m for the date November 1st was then removed. Removal of the IGRF ensures that the data sets for all lines and all surveys will be compatible when merged into a regional compilation of data within the Earth's crust. An enhanced version of the levelled magnetic data is calculated by averaging horizontal and longitudinal gradients to better define short wavelength signal, which is then interpolated to a 30 m grid interval.

The first vertical derivative of the magnetic field is the rate of change of the magnetic field in the vertical direction. Computation of the first vertical derivative removes long wavelength features of the magnetic field and significantly improves the resolution of closely spaced magnetic anomalies caused by shallow sources. The derivative maps is the coincidence of the zero-value contour with vertical contacts of magnetic units at high magnetic latitudes (Hood, 1965).

VLF-EM
Very low frequency (VLF) electro-magnetic data was measured using a Herz Totem 2A VLF-EM receiver mounted in a 2.5 m fibreglass stinger installed on the tail of the aircraft. For this survey, the VLF station in Lualualei, North Dakota (22.2 kHz) provided Line data and Rhumbatron data (22.0 kHz) was used for Cross-line data. Data was recorded in the 4 channels of the receiver in-phase and quadrature (Line and Cross). VLF coverage of the survey area was not achieved. Variation in signal quality is also apparent in the data as bands of less coherent data.

Additional Information
Data compilation and map production were performed by Sander Geophysics Limited, Ottawa, Ontario.
Contract and project management was provided by the Newfoundland and Labrador Department of Natural Resources.

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This map is subject to revision and modification. Comments to the author concerning errors or omissions are invited.

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Geological Survey Website: http://www.nr.gov.nl.ca/nr
Email: gsdept@gov.nl.ca

References
Hood, P.J.
1965: Gradient measurements in aeromagnetic surveying. Geophysics, vol. 30, p. 891-902.

PLANIMETRIC SYMBOLS

Topographic contours
Drainage
Road
Flight line
Building
Transmission line

LOCATION MAP

NATIONAL TOPOGRAPHIC SYSTEM REFERENCE AND GEOPHYSICAL MAP INDEX

2 D/11
2 D/12
2 D/14
2 D/13
2 D/05
2 D/04
2 D/03
1 M/14
1 M/13
1 L/14
1 L/13
Grand Falls-Windsor
Gander
Bonavista
Clarenville
Marystown
Burgeo
Stephenville
Corner Brook
St. Anthony
Labrador City
Wabush
Goose Bay
Cartwright
Nain
Hopedale
Makkovik
Rigolet
Nain
Hopedale
Makkovik
Rigolet
Cape Harrison
Cape Mugford
Cape Harrison
Cape Mugford
Cape Harrison
Cape Mugford

Topographic contour interval: 30 metres

Digital topographic data provided by Geomatics Canada, Natural Resources Canada

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sgl.com

MAP 2020-05
TWILLICK BROOK
NTS MAP AREA 2D/04 AND PARTS OF 1M/13, 1M/14, 2D/03 AND 2D/05

Scale 1:75000

1000 0 1000 2000 3000 4000 5000 6000

(metres)

NAD83 / UTM zone 21N

Newfoundland Labrador
NATURAL RESOURCES

AIRBORNE GEOPHYSICAL SURVEY OF THE TWILLICK BROOK REGION, NEWFOUNDLAND

NTS MAP AREA 2D/04 AND PARTS OF 1M/13, 1M/14, 2D/03 AND 2D/05,

EQUIVALENT THORIUM

MAP 2020-05
OPEN FILE NFLD/3383
Map 5 of 13

G.J. Kilfoil

ABOUT THE SURVEY

Introduction
A high resolution gamma-ray spectrometric, aeromagnetic and VLF-Electromagnetic airborne geophysical survey of Twillick Brook region, Newfoundland, was completed by Sander Geophysics Limited. The survey was flown from October 17th to November 10th, 2019 using a single Cessna 208 Caravan (C-GSGU). The nominal traverse and control line spacings were, respectively, 150 m and 1500 m. The survey was flown at a nominal terrain clearance of 100 m and a nominal airspeed of 185 km/h. Flying in the area was started 100' with orthogonal control lines. The flight path was recovered following post-flight Precise Point Positioning (PPP) corrections using precise ephemerides applied to raw data recorded by a Global Positioning System.

Gamma-ray Spectrometric Data
The airborne gamma-ray measurements were made with a Sander Geophysics GSLZ[ero] gamma-ray spectrometer using fourteen NaI(Tl) crystals, with a total 616 cubic inch (10.1 litres) volume, mounted in a pod on the wing tip. The pod also carried a NaI(Tl) crystal (volume 5.4 litres), shielded by the main array, were used to detect variations in background radiation caused by atmospheric radon. The system continuously adjusted the gain of each crystal by monitoring the natural potassium, uranium, and thorium peaks. Upward crystals were provided a small vacuum source to supplement the three natural peaks.

Potassium is measured directly from the 1460 keV gamma-ray photons emitted by K-40. Uranium and thorium are measured indirectly by measuring the gamma-ray photons emitted by the daughters of the U-238 and Th-232 series. The U-238 series daughters are for down their respective decay chains, they are assumed to be in equilibrium with their parents, thus gamma-ray spectrometric measurements of uranium and thorium are referred to as equivalent uranium and equivalent thorium, i.e. eU and eTh. The energy windows used to measure potassium, uranium and thorium are respectively (370 -1570 keV, 1660-1860 keV and 2410-2810 keV.

Gamma-ray spectra were recorded at one-second intervals. Data processing followed standard procedures as described in IAEA, 1991 and IAEA, 2003. Corrections for the effects of cosmic radiation, radon, aircraft background, and Compton scattering were applied. Counts from the radon detection were recorded in a 1860 - 1960 keV window and radiation at energies greater than 3000 keV was recorded in the cosmic window. The window counts were corrected for background activity from cosmic radiation, radioactivity of the aircraft and radon activity in the air. The radon window was used to estimate the contribution of radon to the U, Th and K windows. The U window was corrected for contamination from the adjacent Th window. Calibrations for attenuation and processed were made prior to conversion to ground concentrations of potassium, uranium and thorium, using factors determined from flights over the Breckenridge, Quebec calibration range.

Corrected data were interpolated to a 30 m grid interval. The results of an airborne gamma-ray spectrometric survey represent the average surface concentrations that are influenced by varying amounts of outcrop, overburden, vegetation cover, soil moisture and radon activity. The data represent approximately the top 30 cm of the ground for potassium concentrations. The total air absorbed dose rate in nanograys per hour was produced from measured counts between 400 and 2810 keV.

Magnetic Data
The magnetic field was sampled 10 times per second using three spin-beam cesium vapour magnetometers (sensitivity = 0.005 nT) mounted inside the tail boom and two wingtip pods of the aircraft. This array of sensors form a fixed-wing gradiometer with a lateral separation of 2.5 m between the wingtip sensors and a longitudinal separation of 7.5 m between the wingtip sensors and the tail boom sensor. The tail boom sensor was computer-balanced to obtain a mutually levelled out of flight-line magnetic data. The International Geomagnetic Reference Field (IGRF) defined at the average GPS altitude of 313 m for the date November 1st, was then removed. Removal of the IGRF ensures that the data sets for the survey area will mesh with those of adjacent regions and accurately represent the magnetic field within the Earth's crust. An enhanced version of the levelled magnetic data is calculated by averaging horizontal and longitudinal gradients to better define short wavelength signal, which is then interpolated to a 30 m grid interval.

The first vertical derivative of the magnetic field is the rate of change of the magnetic field in the vertical direction. Computation of the first vertical derivative removes long wavelength features of the magnetic field and significantly improves the resolution of closely spaced magnetic anomalies caused by shallow sources. The derivative maps is the coincidence of the zero-value contour with vertical contacts of magnetic units at high magnetic latitudes (Hood, 1965).

VLF-EM
Very low frequency (VLF) electro-magnetic data was measured using a Herz Totem 2A VLF-EM receiver mounted in a 2.5 m fibreglass stinger installed on the tail of the aircraft. For this survey, the VLF station in Lualualei, North Dakota (22.2 kHz) provided Line data and Rhumbatron data (22.4 kHz) was used as a backup. The Rhumbatron data was used to fill in the Line data where the signal was weak. Typically, 90% - 95% VLF coverage of the survey area was not achieved. Variation in signal quality is also apparent in the data on bands of less coherent data.

Additional Information
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Contract and project management was provided by the Newfoundland and Labrador Department of Natural Resources.

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Email: mineral@gov.nl.ca

References
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6.3060
5.2582
4.8043
4.4505
4.2771
4.0714
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3.5044
3.4033
3.3141
3.2766
3.2030
3.1228
3.0485
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2.6200
2.5524
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0.8262
0.8002
0.5818
0.5396
0.5399
0.2550
0.1569
0.1132
0.0812
0.0512
0.0255
0.0000

ppm

PLANIMETRIC SYMBOLS

Topographic contours
Drainage
Road
Flight line
Building
Transmission line

LOCATION MAP

NATIONAL TOPOGRAPHIC SYSTEM REFERENCE AND GEOPHYSICAL MAP INDEX

Recommended Citation
Kilfoil, G.J.
2020: Airborne Geophysical Survey of the Twillick Brook region, Newfoundland (NTS Map Area 2D/04 and parts of 1M/13, 1M/14, 2D/03 and 2D/05). Equivalent Thorium. Geological Survey, Department of Natural Resources, Government of Newfoundland and Labrador, Map 2020-05; Open File NFLD/3383.

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Topographic contour interval: 30 metres

Digital topographic data provided by Geomatics Canada, Natural Resources Canada

MAP 2020-06
TWILLICK BROOK
NTS MAP AREA 2D/04 AND PARTS OF 1M/13, 1M/14, 2D/03 AND 2D/05

Scale 1:75000

1000 0 1000 2000 3000 4000 5000 6000

(metres)

NAD83 / UTM zone 21N

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Newfoundland Labrador
NATURAL RESOURCES

AIRBORNE GEOPHYSICAL SURVEY OF THE TWILLICK BROOK REGION, NEWFOUNDLAND

NTS MAP AREA 2D/04 AND PARTS OF 1M/13, 1M/14, 2D/03 AND 2D/05,

RATIO OF EQUIVALENT THORIUM TO PERCENT POTASSIUM

MAP 2020-06
OPEN FILE NFLD/3383
Map 6 of 13

G.J. Kilfoil

ABOUT THE SURVEY

Introduction
A high resolution gamma-ray spectrometric, aeromagnetic and VLF-Electromagnetic airborne geophysical survey of Twillick Brook region, Newfoundland, was completed by Sander Geophysics Limited. The survey was flown from October 17th to November 10th, 2018 using a single Cessna 208 Caravan (C-GSGL). The nominal traverse and control line spacings were, respectively, 150 m and 1500 m. The nominal terrain clearance was 100 m. Magnetic and electromagnetic data were recorded at 10 Hz. Survey lines were oriented 135° with orthogonal control lines. The flight path was recovered following post-flight Precise Point Positioning (PPP) corrections using precise ephemerides applied to raw data recorded by a Global Positioning System.

Gamma-ray Spectrometric Data
The airborne gamma-ray measurements were made with a Sander Geophysics GSLZgam gamma-ray spectrometer using fourteen Radiation Solutions RS-500 NaI(Tl) detectors, with a total combined volume of 33.6 litres (2100 cu. in.). Twelve of the detectors, total volume 8.4 litres, shielded by the main array, were used to detect variations in background radiation caused by atmospheric radon. The system continuously adjusted the gain of each crystal by monitoring the natural potassium, uranium, and thorium peaks. Upward crystals were provided a small vacuum source to supplement the three natural peaks.

Potassium is measured directly from the 1460 keV gamma-ray photons emitted by K-40 ; whereas uranium and thorium are measured indirectly by their daughter products, Bismuth-214 and Thallium-208 respectively. Since the U-238 and Th-232 series are not in equilibrium with their ancestors and far down their respective decay chains, they are assumed to be in equilibrium with their ancestor, thus gamma-ray spectrometric measurements of uranium and thorium are referred to as equivalent uranium and equivalent thorium, i.e. eU and eTh. The energy windows used to measure potassium, uranium and thorium are respectively (370 - 1570 keV, 1660-1860 keV and 2410-2810 keV.

Gamma-ray spectra were recorded at one-second intervals. Data processing followed standard procedures as described in IAEA, 1991 and IAEA, 2003. Spectral data were corrected for live time, background radiation, channel overlapping, and radon contamination. Counts from the radon detection were recorded in a 1860 - 1980 keV window and radiation at energies greater than 3000 keV was recorded in the cosmic window. The window counts were corrected for background activity from cosmic radiation, radioactivity of the aircraft and atmospheric radon. The stripping ratios used were determined from calibrations flown at Calibration Range 2A in Ottawa, Ontario. The data were corrected for deviations from the potassium window clearance and for variation of temperature and pressure were made prior to conversion to ground concentrations of potassium, uranium and thorium, using factors determined from flights over the Breckenridge, Quebec calibration range.

Corrected data were interpolated to a 30 m grid interval. The results of an airborne gamma-ray spectrometric survey represent the average surface concentrations that are influenced by varying amounts of outcrop, overburden, vegetation cover, soil moisture and radon emanation. The data are presented as contour maps, colour ratio maps, and individual channel concentrations. The total air absorbed dose rate in nanograys per hour was produced from measured counts between 400 and 2810 keV.

Magnetic Data
The magnetic field was sampled 10 times per second using three split-beam cesium vapour magnetometers (sensitivity = 0.005 nT) mounted inside the tail boom and two winglip pods of the aircraft. This array of sensors form a fixedwindled gradiometer with a lateral separation of 2.3 m between the wingtip sensors and 8.0 m between the wingtip sensors and the tail sensor. Three orthogonal fluxgate boom mounted on the tail boom were used to obtain a mutually levelled out of flight-line magnetic data. The International Geomagnetic Reference Field (IGRF) defined at the average GPS altitude of 313 m for the date November 1st, was then removed. Removal of the IGRF ensures that the data set is free of the effects of the Earth's core and long wavelength magnetic field variations originating within the Earth's crust. An enhanced version of the levelled magnetic data is calculated by averaging horizontal and longitudinal gradients to better define short wavelength signal, which is then interpolated to a 30 m grid interval.

The first vertical derivative of the magnetic field is the rate of change of the magnetic field in the vertical direction. Computation of the first vertical derivative removes long wavelength features of the magnetic field and significantly improves the resolution of closely spaced magnetic anomalies. Because of the effects of the Earth's magnetic field, derivative maps is the coincidence of the zero-value contour with vertical contacts of magnetic units at high magnetic latitudes (Hood, 1965).

VLF-EM
Very low frequency (VLF) electro-magnetic data was measured using a Herz Totem 2A VLF-EM receiver mounted in a 2.0 m fibreglass stinger installed on the tail of the aircraft. Five stations, the VLF stations Cutler, North Dakota (24.0 kHz) provided Line data and Rhosgoch, United Kingdom (24.0 kHz), Lualualei, Hawaii (23.4 kHz), Jim Creek, Washington (24.8 kHz) and Yosami, Japan (22.2 kHz) were used. Due to the VLF coverage of the survey area was not achieved, variation in signal quality is also apparent in the data on bands of less coherent data.

Additional Information
Data compilation and map production were performed by Sander Geophysics Limited, Ottawa, Ontario.
Contract and project management was provided by the Newfoundland and Labrador Department of Natural Resources.

Copies of this map may be obtained from the Geological Survey, Department of Natural Resources,
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Department Website: http://www.nr.gov.nl.ca/nr/
Geological Survey Website: http://www.nr.gov.nl.ca/nr
Email: gsdet@gov.nl.ca

References
Hood, P.J.
1965: Gradient measurements in aeromagnetic surveying; Geophysics, vol. 30, p. 891-902.

PLANIMETRIC SYMBOLS

Topographic contours
Drainage
Road
Flight line
Building
Transmission line

LOCATION MAP

NATIONAL TOPOGRAPHIC SYSTEM REFERENCE AND GEOPHYSICAL MAP INDEX

-59°30'
-58°00'
-56°30'
-55°00'
48°30'
48°15'
48°00'
47°45'
47°30'
2 D/12
2 D/11
2 D/05
2 D/06
2 D/03
2 D/02
1 M/14
1 M/13
Twillick Brook
Gander River
Gander Lake
Appleton
Glenwood
Lewisporte
Pilley's Island
Fogo
Change Islands
Farmers Arm
Summerford
Cobbler Arm
Indian Arm
Little Burnt Bay
Point Leamington
Tizzard Harbour
Sandy Cove
Pacquet
Comfort Cove-Newstead
Nipper's Harbour
Coachman's Cove
Triton
Long Island
Herbert
Moreton's Harbour
Tilting
Fogo Island
Joe Batt's Arm
Barr'd Islands
Shoal Bay
Stoneman Bay
Seldom-by-the-Sea
Musgrave Harbour
Eastport
Deadman's Bay
Clarenville
Terra Nova National Park
Glovertown
Gambo
Traverse Bay
Dover
Salmonier Nature Park
Colinet
Fox Harbour
Long Harbour
Placentia
Argentia
Marystown
Grand Bank
Fortune
Belleoram
Pool's Island
Harbour Breton
Gaultois
Rencontre East
Bay d'Espoir
Conne River
Hermitage
Sandy Lake
Grand Falls-Windsor
Buchans
Red Indian Lake
Millertown
Badger
Norris Arm
Botwood
Peterview
Leading Tickles
Beothuk Lake
Red Rocks
Long Point
Point Rosie
Seal Cove
White Bay
Jackson's Arm
Baie Verte
Westbrook
Coy Pond
Sops Arm
Springdale
Nippers Harbour
Anderson's Cove
Pacquet Harbour
Terrenceville
Fortune Harbour
Grand Bay West
Flat Bay
Big Brook
St. Georges
Stephenville
Port au Port
Lourdes
Black Duck Brook
Daniels Harbour
Roddickton
Bird Cove
Conche
St. Lunaire-Griquet
Englee
Reidville
Flat Bay
Boswarlos
Main Brook
Sandy Lake
Gillams
Dunfield
Rocky Harbour
Norris Point
Woody Point
Trout River
Lourdes
Parsons Pond
Hawke Bay
Port au Choix
Plum Point
St. Anthony
Goose Bay
Port Hope Simpson
Cape Ann
Mount Moriah
Pistolet Bay
Shoal Harbour
Anchor Point
Ship Cove
Quirpon
Lower Cove
Loon Bay
Bear Cove
Williams Harbour
Point Rich
Ship Harbour
Long Beach
Tilt Cove
Mount Clut
Sandy Lake
Oderin
Offer Wadham Islands
Long Island
Placentia Bay
Grand Bank
Port aux Basques
Bay du Nord
Wilderness Area
Funk Island Bay
Great Sandy Island
Red Indian Lake
Notre Dame Bay
Green Bay
Exploits River
Bonavista Bay
Trinity Bay
Conception Bay
St. Mary's Bay
Placentia Bay
Fortune Bay
Hermitage Bay
Bonne Bay
St. George's Bay
St. Lawrence Bay
Hare Bay
Notre Dame Bay
Green Bay
Bay d'Espoir
Fortune Bay
Placentia Bay
Conception Bay
Trinity Bay
Bonavista Bay
Notre Dame Bay
Green Bay
Exploits River
Red Indian Lake
Grand Falls-Windsor
Gander Lake
Gander River
Terra Nova National Park
Glovertown
Clarenville
Bonavista
Trinity
Carbonear
Harbour Grace
Placentia
Marystown
Grand Bank
Fortune
Burgeo
Port aux Basques
Stephenville
Corner Brook
Deer Lake
Springdale
Baie Verte
Lewisporte
Gander
Grand Falls-Windsor
Buchans

Topographic contour interval: 30 metres

MAP 2020-07
TWILLICK BROOK
NTS MAP AREA 2D/04 AND PARTS OF 1M/13, 1M/14, 2D/03 AND 2D/05

Scale 1:75000

1000 0 1000 2000 3000 4000 5000 6000

(metres)

NAD83 / UTM zone 21N

Digital topographic data provided by Geomatics Canada, Natural Resources Canada

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Newfoundland Labrador
NATURAL RESOURCES

AIRBORNE GEOPHYSICAL SURVEY OF THE TWILLICK BROOK REGION, NEWFOUNDLAND

NTS MAP AREA 2D/04 AND PARTS OF 1M/13, 1M/14, 2D/03 AND 2D/05,

RATIO OF EQUIVALENT URANIUM TO PERCENT POTASSIUM

MAP 2020-07
OPEN FILE NFLD/3383
Map 7 of 13

G.J. Kilfoil

ABOUT THE SURVEY

Introduction
A helicopter gamma-ray spectrometric, aeromagnetic and VLF-Electromagnetic airborne geophysical survey of Twillick Brook region, Newfoundland, was completed by Sander Geophysics Limited. The survey was flown from October 17th to November 10th, 2018 using a single Cessna 208 Caravan (C-GSGL). The nominal traverse and control line spacings were, respectively, 150 m and 1500 m. The traverse lines were oriented 090°/270° and control lines were oriented 000°/180°. Flying heights for traverse lines were nominal 100 m with orthogonal control lines. The flight path was recovered following post-flight Precise Point Positioning (PPP) corrections using precise ephemerides applied to raw data recorded by a Global Positioning System.

Gamma-ray Spectrometric Data
The airborne gamma-ray measurements were made with a Sander Geophysics GSLSpec gamma-ray spectrometer using fourteen 616 cubic inch (10.1 litres) NaI(Tl) crystals. The system was calibrated at the Calibration Pad in Ottawa, Ontario. The fourteen crystals, total volume 8.4 litres, shielded by the main array, were used to detect variations in background radiation caused by atmospheric radon. The system continuously adjusted the gain of each crystal by monitoring the natural potassium, uranium, and thorium peaks. Upward crystals were provided a small vacuum source to supplement the three natural peaks.

Potassium is measured directly from the 1460 keV gamma-ray photons emitted by K-40. Uranium and thorium are measured indirectly from the gamma-ray photons emitted by their daughter products. The 1760 keV peak for Bismuth-214 and the 2614 keV peak for Thallium-208 are used to measure uranium and thorium, respectively. The Bismuth and Thallium peaks are used because they are far down their respective decay chains, they are assumed to be in equilibrium with their parents, thus gamma-ray spectrometric measurements of uranium and thorium are referred to as equivalent uranium and equivalent thorium, i.e. eU and eTh. The energy windows used to measure potassium, uranium and thorium are respectively (370 - 1570 keV, 1660-1860 keV and 2410-2810 keV.

Gamma-ray spectra were recorded at one-second intervals. Data processing followed standard procedures as described in IAEA, 1991 and IAEA, 2003. Spectra were stripped of the contribution from cosmic radiation, atmospheric radon, and airborne fuel and structure. Counts from the radon detection were recorded in a 1860 - 1980 keV window and radiation at energies greater than 3000 keV was recorded in the cosmic window. The window counts were corrected for background activity from cosmic radiation, radioactivity of the aircraft and atmospheric radon. The stripped data was then corrected for the effects of attenuation and height. The data was then corrected for deviations from the planned terrain clearance and for variation of temperature and pressure were made prior to conversion to ground concentrations of potassium, uranium and thorium, using factors determined from flights over the Breckenridge, Quebec calibration range.

Corrected data were interpolated to a 30 m grid interval. The results of an airborne gamma-ray spectrometric survey represent the average surface concentrations that are influenced by varying amounts of outcrop, overburden, vegetation cover, soil moisture and snow cover. The data represents approximately the uppermost 30 cm of the ground for average terrain conditions. The total air absorbed dose rate in nanograys per hour was produced from measured counts between 400 and 2810 keV.

Magnetic Data
The magnetic field was sampled 10 times per second using three split-beam cesium vapour magnetometers (sensitivity = 0.005 nT) mounted inside the tail boom and two winglip pods of the aircraft. This array of sensors forms a fixedwindled gradiometer with a lateral separation of 2.3 m between the wingtip sensors and 8.0 m between the tail boom sensor and the average position of the wingtip sensors. The barycentre lines were computed and applied to obtain a mechanically levelled set of flight-line magnetic data. The International Geomagnetic Reference Field (IGRF) defined at the average GPS altitude of 310 m for the date November 1st was then removed. Removal of the IGRF ensures that the data sets for all surveys in a region are compatible and that the residual magnetic field represents only sources within the Earth's crust. An enhanced version of the levelled magnetic data is calculated by averaging horizontal and longitudinal gradients to better define short wavelength signal, which is then interpolated to a 30 m grid interval.

The first vertical derivative of the magnetic field is the rate of change of the magnetic field in the vertical direction. Computation of the first vertical derivative removes long wavelength features of the magnetic field and significantly improves the resolution of closely spaced magnetic anomalies caused by shallow sources. The derivative maps is the coincidence of the zero-value contour with vertical contacts of magnetic units at high magnetic latitudes (Hood, 1965).

VLF-EM
Very low frequency (VLF) electro-magnetic data was measured using a Herz Totem 2A VLF-EM receiver mounted in a 2.0 m fibreglass stinger installed on the tail of the aircraft. For this survey, the VLF station in Lualualei, North Dakota (22.2 kHz) provided Line data and Rhumbatron data (22.0 kHz) was used as a backup. The Rhumbatron data was used to fill in the Lualualei data where signal strength was less than 10%. VLF coverage of the survey area was not achieved. Variation in signal quality is also apparent in the data as bands of less coherent data.

Additional Information
Data compilation and map production were performed by Sander Geophysics Limited, Ottawa, Ontario.
Contract and project management was provided by the Newfoundland and Labrador Department of Natural Resources.

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Geological Survey Website: http://www.nr.gov.nl.ca/nr
Email: gsdet@gov.nl.ca

References
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PLANIMETRIC SYMBOLS

Topographic contours
Drainage
Road
Flight line
Building
Transmission line

LOCATION MAP

NATIONAL TOPOGRAPHIC SYSTEM REFERENCE AND GEOPHYSICAL MAP INDEX

Recommended Citation
Kilfoil, G.J.
2020: Airborne Geophysical Survey of the Twillick Brook region, Newfoundland (NTS Map Area 2D/04 and parts of 1M/13, 1M/14, 2D/03 and 2D/05). Ratio of Equivalent Uranium to Percent Potassium; Geological Survey, Department of Natural Resources, Government of Newfoundland and Labrador, Map 2020-07, Open File NFLD/3383.

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Topographic contour interval: 30 metres

MAP 2020-08
TWILLICK BROOK
NTS MAP AREA 2D/04 AND PARTS OF 1M/13, 1M/14, 2D/03 AND 2D/05

Scale 1:75000

1000 0 1000 2000 3000 4000 5000 6000

(metres)

NAD83 / UTM zone 21N

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Newfoundland Labrador
NATURAL RESOURCES

AIRBORNE GEOPHYSICAL SURVEY OF THE TWILLICK BROOK REGION, NEWFOUNDLAND

NTS MAP AREA 2D/04 AND PARTS OF 1M/13, 1M/14, 2D/03 AND 2D/05,

EQUIVALENT URANIUM / EQUIVALENT THORIUM RATIO

MAP 2020-08
OPEN FILE NFLD/3383
Map 8 of 13

G.J. Kilfoil

ABOUT THE SURVEY

Introduction
A helicopter gamma-ray spectrometric, aeromagnetic and VLF-Electromagnetic airborne geophysical survey of Twillick Brook region, Newfoundland, was completed by Sander Geophysics Limited. The survey was flown from October 17th to November 10th, 2019 using a single Cessna 208 Caravan (C-GSGL). The nominal traverse and control line spacings were, respectively, 150 m and 1500 m. The nominal terrain clearance was 100 m. Ancillary equipment included a Piper PA-31 Navajo (C-FSAR). Survey lines were oriented 030° with orthogonal control lines. The flight path was recovered following post-flight Precise Point Positioning (PPP) corrections using precise ephemerides applied to raw data recorded by a Global Positioning System.

Gamma-ray Spectrometric Data
The airborne gamma-ray measurements were made with a Sander Geophysics GSLSpec gamma-ray spectrometer using fourteen 16.8-litre (256 cubic inch) NaI(Tl) crystals. Twelve crystals were mounted in a 1.68 cubic metre (100 cubic inch) array and four crystals (5.4-litres), shielded by the main array, were used to detect variations in background radiation caused by atmospheric radon. The system continuously adjusted the gain of each crystal by monitoring the natural potassium, uranium, and thorium peaks. Upward crystals were provided a small vacuum source to supplement the three natural peaks.

Potassium is measured directly from the 1460 keV gamma-ray photons emitted by K-40, whereas uranium and thorium are measured indirectly from the gamma-ray photons emitted by daughter products of the U-238 and Th-232 series. The U-238 series daughters are for seven their respective decay chains, they are assumed to be in equilibrium with their parents, thus gamma-ray spectrometric measurements of uranium and thorium are referred to as equivalent uranium and equivalent thorium, i.e. eU and eTh. The energy windows used to measure potassium, uranium and thorium are respectively (370 -1570 keV, 1660-1860 keV and 2410-2810 keV.

Gamma-ray spectra were recorded at one-second intervals. Data processing followed standard procedures as described in IAEA, 1991 and Grasty, 1997. Corrections were made for the effects of aircraft and cosmic background radiation, radon background, and Compton scattering. Counts from the radon detection were recorded in a 1860 - 1960 keV window and radiation at energies greater than 3000 keV was recorded in the cosmic window. The window counts were corrected for background activity from cosmic radiation, radioactivity of the aircraft and radon emanation. The radon window was used to estimate the radon background in the other windows. The U-238 series radon daughters for deviations from the planned terrain clearance and for variation of temperature and pressure were made prior to conversion to ground concentrations of potassium, uranium and thorium, using factors determined from flights over the Blackcrowe, Quebec calibration range.

Corrected data were interpolated to a 30 m grid interval. The results of an airborne gamma-ray spectrometric survey represent the average surface concentrations that are influenced by varying amounts of outcrop, overburden, vegetation cover, soil moisture and other factors. The data represent approximately the uppermost 30 cm of the ground for typical survey concentrations. The total air absorbed dose rate in nanograys per hour was produced from measured counts between 400 and 2810 keV.

Magnetic Data
The magnetic field was sampled 10 times per second using three split-beam cesium vapour magnetometers (sensitivity = 0.005 nT) mounted inside the tail boom and two wingtip pods of the aircraft. This array of sensors forms a fixedwindled gradiometer with a lateral separation of 2.5 m between the wingtip sensors and 7.5 m between the wingtip sensors and the tail sensor. The three magnetic field traverse lines were computer-analysed to obtain a mutually levelled set of flight-line magnetic data. The International Geomagnetic Reference Field (IGRF) defined at the average GPS altitude of 313 m for the date November 1st was then removed. Removal of the IGRF ensures that the data sets for the survey area will mesh with those of adjacent regions and accurately represent the magnetic field within the Earth's crust. An enhanced version of the levelled magnetic data is calculated by averaging horizontal and longitudinal gradients to better define short wavelength signal, which is then interpolated to a 30 m grid interval.

The first vertical derivative of the magnetic field is the rate of change of the magnetic field in the vertical direction. Computation of the first vertical derivative removes long wavelength features of the magnetic field and significantly improves the resolution of closely spaced magnetic anomalies (Hood, P.J., 1965; Henderson, R.G., 1960). Derivative maps is the coincidence of the zero-value contour with vertical contacts of magnetic units at high magnetic latitudes (Hood, 1965).

VLF-EM
Very low frequency (VLF) electro-magnetic data was measured using a Herz Totem 2A VLF-EM receiver mounted in a 2.5 m fibreglass stinger installed on the tail of the aircraft. For this survey, the VLF station in Jackfish, North Dakota (25.2 kHz) provided Line data and Rhombenporth, Cornwall (24.0 kHz) provided Cross data. Line data is the vertical component of the magnetic field measured in the direction of the VLF station. Cross data is the component of the magnetic field perpendicular to the Line data. Due to the orientation of the survey lines, VLF coverage of the survey area was not achieved. Variation in signal quality is also apparent in the data on bands of less coherent data.

Additional Information
Data compilation and map production were performed by Sander Geophysics Limited, Ottawa, Ontario.
Contract and project management was provided by the Newfoundland and Labrador Department of Natural Resources.

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Topographic contour interval: 30 metres

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MAP 2020-09
TWILLICK BROOK
NTS MAP AREA 2D/04 AND PARTS OF 1M/13, 1M/14, 2D/03 AND 2D/05

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Scale 1:75000

1000 0 1000 2000 3000 4000 5000 6000

(metres)

NAD83 / UTM zone 21N

Newfoundland Labrador
NATURAL RESOURCES

AIRBORNE GEOPHYSICAL SURVEY OF THE TWILLICK BROOK REGION, NEWFOUNDLAND

NTS MAP AREA 2D/04 AND PARTS OF 1M/13, 1M/14, 2D/03 AND 2D/05,

NATURAL AIR ABSORBED DOSE RATE

MAP 2020-09
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Map 9 of 13

G.J. Kilfoil

ABOUT THE SURVEY

Introduction
A helicopter gamma-ray spectrometric, aeromagnetic and VLF-Electromagnetic airborne geophysical survey of Twillick Brook region, Newfoundland, was completed by Sander Geophysics Limited. The survey was flown from October 17th to November 10th, 2018 using a single Cessna 208 Caravan (C-GSGU). The nominal traverse and control line spacings were, respectively, 150 m and 1500 m. The survey was flown at a nominal terrain clearance of 100 m. Approximately 1,800 line-km of high-resolution data were collected GPS with orthogonal control lines. The flight path was recovered following post-flight Precise Point Positioning (PPP) corrections using precise ephemerides applied to raw data recorded by a Global Positioning System.

Gamma-ray Spectrometric Data
The airborne gamma-ray measurements were made with a Sander Geophysics GDL32en gamma-ray spectrometer using fourteen Radiation Solutions RS-500 CsI(Tl) detectors with a combined nominal volume of 33.6 litres (2.4 litres each). The detectors, total volume 5.4 litres, shielded by the main array, were used to detect variations in background radiation caused by atmospheric radon. The system continuously adjusted the gain of each crystal by monitoring the natural potassium, uranium, and thorium peaks. Upward crystals were provided a small vacuum source to supplement the three natural peaks.

Potassium is measured directly from the 1460 keV gamma-ray photons emitted by K-40. Uranium and thorium are measured indirectly from the daughter products of U-238 and Th-232 decay series. The U-238 series is represented by Bi-214 and the daughters are for down their respective decay chains, they are assumed to be in equilibrium with their parents, thus gamma-ray spectrometric measurements of uranium and thorium are referred to as equivalent uranium and equivalent thorium, i.e. eU and eTh. The energy windows used to measure potassium, uranium and thorium are respectively (370 - 1570 keV, 1660-1860 keV and 2410-2810 keV.

Gamma-ray spectra were recorded at one-second intervals. Data processing followed standard procedures as described in IAEA, 1991 and IAEA, 2003. Spectral data were corrected for the effects of cosmic radiation, detector background, radon background, and Compton scattering from the native detectors were recorded in a 1860 - 1960 keV window and radiation at energies greater than 3000 keV was recorded in the cosmic window. The window counts were corrected for background activity from cosmic radiation, radioactivity of the aircraft and radioactivity of the detectors. The effects of radon were removed using the method of Grasty, 1979 and Grasty, 1997. The data were corrected for deviations from the planned terrain clearance and for variation of temperature and pressure were made prior to conversion to ground concentrations of potassium, uranium and thorium, using factors determined from flights over the Breckenridge, Quebec calibration range.

Corrected data were interpolated to a 30 m grid interval. The results of an airborne gamma-ray spectrometric survey represent the average surface concentrations that are influenced by varying amounts of outcrop, overburden, vegetation cover, soil moisture and radon. The data are a valid representation of the near surface geology for use in regional geochemistry. The total air absorbed dose rate in nanograys per hour was produced from measured counts between 400 and 2810 keV.

Magnetic Data
The magnetic field was sampled 10 times per second using three split-beam cesium vapour magnetometers (sensitivity = 0.005 nT) mounted inside the tail boom and two wingtip pods of the aircraft. This array of sensors form a fixedwindled gradiometer with a lateral baseline of 2.3 m and a longitudinal baseline of 8.5 m. The three sensors were used to compensate the magnetic field for aircraft manoeuvres. Barrow lines were computer-analysed to obtain a mutually levelled set of flight-line magnetic data. The International Geomagnetic Reference Field (IGRF) defined at the average GPS altitude of 313 m for the date November 1st, was then removed. Removal of the IGRF ensures that the data sets for all surveys, regardless of survey specifications, will be compatible when merged or compared within the Earth's crust. An enhanced version of the levelled magnetic data is calculated by averaging horizontal and longitudinal gradients to better define short wavelength signal, which is then interpolated to a 30 m grid interval.

The first vertical derivative of the magnetic field is the rate of change of the magnetic field in the vertical direction. Computation of the first vertical derivative removes long wavelength features of the magnetic field and significantly improves the resolution of closely spaced magnetic anomalies. Because the first vertical derivative maps is the coincidence of the zero-value contour with vertical contacts of magnetic units at high magnetic latitudes (Hood, 1965).

VLF-EM
Very low frequency (VLF) electro-magnetic data was measured using a Herz Totem 2A VLF-EM receiver mounted in a 2.0 m fibreglass stinger installed on the tail cone of the aircraft. Five stations, the VLF stations in Cutler, North Dakota (25.2 kHz) provided Line data and Rhumbatrons, Cutler (25.2 kHz), Lualualei, Hawaii (23.4 kHz), Jim Creek, Washington (24.8 kHz), Seattle, Washington (25.5 kHz) and Annapolis, Maryland (24.0 kHz), were used to monitor the VLF-EM signal. Because the VLF transmitters are located in the USA, the VLF coverage of the survey area was not achieved. Variation in signal quality is also apparent in the data on bands of less coherent data.

Additional Information
Data compilation and map production were performed by Sander Geophysics Limited, Ottawa, Ontario.
Contract and project management was provided by the Newfoundland and Labrador Department of Natural Resources.

Copies of this map may be obtained from the Geological Survey, Department of Natural Resources,
Government of Newfoundland and Labrador, P.O. Box 8700, St. John's, NL, Canada, A1B 4J6.

This map is subject to revision and modification. Comments to the author concerning errors or omissions are invited.

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Geological Survey Website: http://www.nr.gov.nl.ca/nr/
Email: gsdept@gov.nl.ca

References
Hood, P.J.
1965: Gradient measurements in aeromagnetic surveying. Geophysics, vol. 30, p. 891-902.

PLANIMETRIC SYMBOLS

Topographic contours
Drainage
Road
Flight line
Building
Transmission line

LOCATION MAP

NATIONAL TOPOGRAPHIC SYSTEM REFERENCE AND GEOPHYSICAL MAP INDEX

2 D/11
2 D/12
2 D/14
2 D/13
2 D/04
2 D/05
1 M/14
1 M/13
Labrador City
Wabush
Fermont
Lake Jeannette
Mount Reed
Gagnon
Lake Walmsley
Fire Lake
Lac Le Fer
Lac Le Moyne
Lac Le Blanc
Lac Le Gros

Topographic contour interval: 30 metres

MAP 2020-10
TWILLICK BROOK
NTS MAP AREA 2D/04 AND PARTS OF 1M/13, 1M/14, 2D/03 AND 2D/05

Scale 1:75000

1000 0 1000 2000 3000 4000 5000 6000

(metres)

NAD83 / UTM zone 21N

Flown and compiled by:

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255 Terst Oak Road
Ottawa, Ontario, Canada K1V 1Z1
Tel: 613-737-7932
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sgl.com

Digital topographic data provided by Geomatics Canada, Natural Resources Canada

Newfoundland Labrador
NATURAL RESOURCES

AIRBORNE GEOPHYSICAL SURVEY OF THE TWILLICK BROOK REGION, NEWFOUNDLAND

NTS MAP AREA 2D/04 AND PARTS OF 1M/13, 1M/14, 2D/03 AND 2D/05,

TERNARY RADIOELEMENT IMAGE

MAP 2020-10
OPEN FILE NFLD/3383
Map 10 of 13

G.J. Kilfoil

ABOUT THE SURVEY

Introduction
A high resolution gamma-ray spectrometric, aeromagnetic and VLF-Electromagnetic airborne geophysical survey of Twillick Brook region, Newfoundland, was completed by Sander Geophysics Limited. The survey was flown from October 17th to November 10th, 2018 using a single Cessna 208 Caravan (C-GSGL). The nominal traverse and control line spacings were, respectively, 150 m and 1500 m. The nominal terrain clearance was 100 m. Magnetic and electromagnetic data were sampled at 10 Hz. Survey lines were oriented 135° with orthogonal control lines. The flight path was recovered following post-flight Precise Point Positioning (PPP) corrections using precise ephemerides applied to raw data recorded by a Global Positioning System.

Gamma-ray Spectrometric Data
The airborne gamma-ray measurements were made with a Sander Geophysics GSLSpec gamma-ray spectrometer using fourteen 4.2-litre (616 cubic inch) NaI(Tl) crystals. Four additional crystals were used in the tail stinger. The total 58.8-litre (3,588 cubic inch) volume 5.4-litre), shielded by the main array, were used to detect variations in background radiation caused by atmospheric radon. The system continuously adjusted the gain of each crystal by monitoring the natural potassium, uranium, and thorium peaks. Upward crystals were provided a small vacuum source to supplement the three natural peaks.

Potassium is measured directly from the 1460 keV gamma-ray photons emitted by K-40. Uranium and thorium are measured indirectly from the daughter products of U-238 and Th-232 decay series. The U-238 series is represented by Bi-214 and Th-232 by Tl-208. These nuclides are for down their respective decay chains, they are assumed to be in equilibrium with their parents, thus gamma-ray spectrometric measurements of uranium and thorium are referred to as equivalent uranium and equivalent thorium, i.e. eU and eTh. The energy windows used to measure potassium, uranium and thorium are respectively (370 - 1570 keV, 1660-1860 keV and 2410-2810 keV.

Gamma-ray spectra were recorded at one-second intervals. Data processing followed standard procedures as described in IAEA, 1991 and IAEA, 2003. Spectral stripping ratios were calculated using a calibration facility at Goldstream airport, near Carp, Ontario. Counts from the native detectors were recorded in a 1860 - 1980 keV window and radiation at energies greater than 3000 keV was recorded in the cosmic window. The window counts were corrected for background activity from cosmic radiation, radioactivity of the aircraft and radioactivity of the air. The air radon component was estimated using the upward crystals and the tail stinger. The data were corrected for deviations from the planned terrain clearance and for variation of temperature and pressure were made prior to conversion to ground concentrations of potassium, uranium and thorium, using factors determined from flights over the Breckenridge, Quebec calibration range.

Corrected data were interpolated to a 30 m grid interval. The results of an airborne gamma-ray spectrometric survey represent the average surface concentrations that are influenced by varying amounts of outcrop, overburden, vegetation cover, soil moisture and radon in the air. The data are presented as concentrations of potassium, uranium and thorium, and total dose rate. The total air absorbed dose rate in nanograys per hour was produced from measured counts between 400 and 2810 keV.

Magnetic Data
The magnetic field was sampled 10 times per second using three split-beam cesium vapour magnetometers (sensitivity = 0.005 nT) mounted inside the tail boom and two wingtip pods of the aircraft. This array of sensors form a fixedwindled gradiometer with a lateral separation of 2.5 m between the wingtip sensors and 3.5 m between the tail sensor and the nearest wingtip sensor. The three lateral traverse lines were computer-analysed to obtain a mutually levelled out of flight-line magnetic data. The International Geomagnetic Reference Field (IGRF) defined at the average GPS altitude of 313 m for the date November 1st, was then removed. Removal of the IGRF ensures that the data sets for the various survey blocks will be compatible with adjacent regional aeromagnetic data sets within the Earth's crust. An enhanced version of the levelled magnetic data is calculated by averaging horizontal and longitudinal gradients to better define short wavelength signal, which is then interpolated to a 30 m grid interval.

The first vertical derivative of the magnetic field is the rate of change of the magnetic field in the vertical direction. Computation of the first vertical derivative removes long wavelength features of the magnetic field and significantly improves the resolution of closely spaced magnetic anomalies. Because the first vertical derivative maps is the coincidence of the zero-value contour with vertical contacts of magnetic units at high magnetic latitudes (Hood, 1965).

VLF-EM
Very low frequency (VLF) electro-magnetic data was measured using a Herz Totem 2A VLF-EM receiver mounted in a 2.5 m fibreglass stinger installed on the tail cone of the aircraft. The Cutler, Maine, VLF station (24.0 kHz), North Dakota (25.2 kHz) provided Line data and Whidbey, Washington (24.8 kHz) provided Cross data. The Line data was recorded in the direction of the survey lines and the Cross data was recorded at 90°. VLF coverage of the survey area was not achieved. Variation in signal quality is also apparent in the data on bands of less coherent data.

Additional Information
Data compilation and map production were performed by Sander Geophysics Limited, Ottawa, Ontario.
Contract and project management was provided by the Newfoundland and Labrador Department of Natural Resources.

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Government of Newfoundland and Labrador, P.O. Box 8700, St. John's, NL, Canada, A1B 4J6.

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Geological Survey Website: http://www.nr.gov.nl.ca/nr
Email: gsdept@gov.nl.ca

References
Hood, P.J.
1965: Gradient measurements in aeromagnetic surveying. Geophysics, vol. 30, p. 891-902.

PLANIMETRIC SYMBOLS

Topographic contours
Drainage
Road
Flight line
Building
Transmission line

LOCATION MAP

NATIONAL TOPOGRAPHIC SYSTEM REFERENCE AND GEOPHYSICAL MAP INDEX

Recommended Citation
Kilfoil, G.J.
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Topographic contour interval: 30 metres

Digital topographic data provided by Geomatics Canada, Natural Resources Canada

MAP 2020-11
TWILLICK BROOK
NTS MAP AREA 2D/04 AND PARTS OF 1M/13, 1M/14, 2D/03 AND 2D/05

Scale 1:75000

1000 0 1000 2000 3000 4000 5000 6000

(metres)

NAD83 / UTM zone 21N

Flown and compiled by:

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Newfoundland Labrador
NATURAL RESOURCES

AIRBORNE GEOPHYSICAL SURVEY OF THE TWILLICK BROOK REGION, NEWFOUNDLAND

NTS MAP AREA 2D/04 AND PARTS OF 1M/13, 1M/14, 2D/03 AND 2D/05,

VLF-EM TOTAL FIELD - 25.2 KHz (LaMoure, ND)

MAP 2020-11
OPEN FILE NFLD/3383
Map 11 of 13

G.J. Kilfoil

ABOUT THE SURVEY

Introduction
A high resolution gamma-ray spectrometric, aeromagnetic and VLF-Electromagnetic airborne geophysical survey of Twillick Brook region, Newfoundland, was completed by Sander Geophysics Limited. The survey was flown from October 17th to November 10th, 2018 using a single Cessna 208 Caravan (C-GSGL). The nominal traverse and control line spacings were, respectively, 150 m and 1500 m. The survey was flown at a nominal terrain clearance of 100 m. Nominal ground speed was 215 km/h. Survey lines were oriented 135° with orthogonal control lines. The flight path was recovered following post-flight Precise Point Positioning (PPP) corrections using precise ephemerides applied to raw data recorded by a Global Positioning System.

Gamma-ray Spectrometric Data
The airborne gamma-ray measurements were made with a Sander Geophysics GSLZ[ram] gamma-ray spectrometer using fourteen 616 cubic inch (16.8 litres) NaI(Tl) crystals. Four additional crystals were used to detect cosmic radiation. The total array, with a total volume 8.4 litres, shielded by the main array, were used to detect variations in background radiation caused by atmospheric radon. The system continuously adjusted the gain of each crystal by monitoring the natural potassium, uranium, and thorium peaks. Upward crystals were provided a small vacuum source to supplement the Radon natural peaks.

Potassium is measured directly from the 1460 keV gamma-ray photons emitted by K-40. Uranium and thorium are measured indirectly from the gamma-ray photons emitted by their daughter products. The 1760 keV peak of U-238 is used to quantify uranium and for down their respective decay chains, they are assumed to be in equilibrium with their parents, thus gamma-ray spectrometric measurements of uranium and thorium are referred to as equivalent uranium and equivalent thorium, i.e. eU and eTh. The energy windows used to measure potassium, uranium and thorium are respectively (370 - 1570 keV, 1660-1860 keV and 2410-2810 keV.

Gamma-ray spectra were recorded at one-second intervals. Data processing followed standard procedures as described in IAEA, 1991 and Grasty, 1997. Spectral data were corrected for live time, background radiation, channel overlap, and channel sensitivities. Counts from the radon detection were recorded in a 1660 - 1860 keV window and radiation at energies greater than 3000 keV was recorded in the cosmic window. The window counts were corrected for background activity from cosmic radiation, radioactivity of the aircraft and radon emanation. The effect of radon in the airborne environment was measured using the upward crystal. The data were also corrected for deviations from the planned terrain clearance and for variation of temperature and pressure were made prior to conversion to ground concentrations of potassium, uranium and thorium, using factors determined from flights over the Breckenridge, Grafton calibration range.

Corrected data were interpolated to a 30 m grid interval. The results of an airborne gamma-ray spectrometric survey represent the average surface concentrations that are influenced by varying amounts of outcrop, overburden, vegetation cover, soil moisture and snow cover. The data are also influenced by atmospheric radon, cosmic radiation, and instrument noise. The total air absorbed dose rate in nanograys per hour was produced from measured counts between 400 and 2810 keV.

Magnetic Data
The magnetic field was sampled 10 times per second using three split-beam cesium vapour magnetometers (sensitivity = 0.005 nT) mounted inside the tail boom and two winglip pods of the aircraft. This array of sensors form a fixed-wing gradiometer with a lateral separation of 2.5 m between the wing-tip sensors and 8.5 m between the wing-tip sensors and the tail sensor. Three orthogonal fluxgate traverse lines were computed and subtracted to obtain a residually levelled out of flight-line magnetic data. The International Geomagnetic Reference Field (IGRF) defined at the average GPS altitude of 310 m for the date November 1st, was then removed. Removal of the IGRF ensures that the data sets from adjacent areas will match and that the residual magnetic field represents magnetic sources within the Earth's crust. An enhanced version of the levelled magnetic data is calculated by averaging horizontal and longitudinal gradients to better define short wavelength signal, which is then interpolated to a 30 m grid interval.

The first vertical derivative of the magnetic field is the rate of change of the magnetic field in the vertical direction. Computation of the first vertical derivative removes long wavelength features of the magnetic field and significantly improves the resolution of closely spaced magnetic anomalies caused by shallow sources. The derivative maps is the coincidence of the zero-value contour with vertical contacts of magnetic units at high magnetic latitudes (Hood, 1965).

VLF-EM
Very low frequency (VLF) electro-magnetic data was measured using a Herz Totem 2A VLF-EM receiver mounted in a 2.5 m fibreglass stinger installed on the tail cone of the aircraft. For this survey, the VLF station in LaMoure, North Dakota (25.2 kHz) provided Line data and Rhumbatron data (25.2 kHz), respectively. The Line data is recorded in the direction of the survey line and the Rhumbatron data is in the vertical plane. VLF coverage of the survey area was not achieved. Variation in signal quality is also apparent in the data on bands of less coherent data.

Additional Information
Data compilation and map production were performed by Sander Geophysics Limited, Ottawa, Ontario.
Contract and project management was provided by the Newfoundland and Labrador Department of Natural Resources.

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This map is subject to revision and modification. Comments to the author concerning errors or omissions are invited.

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Geological Survey Website: http://www.nr.gov.nl.ca/nr
Email: gsdpg@gov.nl.ca

References
Hood, P.J.
1965: Gradient measurements in aeromagnetic surveying; Geophysics, vol. 30, p. 891-902.

PLANIMETRIC SYMBOLS

Topographic contours.....
Drainage.....
Road.....
Flight line.....
Building.....
Transmission line.....

LOCATION MAP

NATIONAL TOPOGRAPHIC SYSTEM REFERENCE AND GEOPHYSICAL MAP INDEX

2 D/12
2 D/11
2 D/05
2 D/04
2 D/03
2 D/02
1 M/14
1 M/13
1 L/16
1 L/15
Lake Melville
Goose Bay
North Mountain
Cartwright
Sandwich Bay
Hopedale
Nain
Makkovik
Postville
Rigolet
Cape Harrison
Mount Caribou
Mount Jacques Cartier
Mount Tetagouche
Mount Ashuanipi
Mount Wightman
Mount Ungava
Mount Ruth
Mount Thomas
Mount Ingrid
Mount Ingrid
Mount Ingrid

Topographic contour interval: 30 metres

Digital topographic data provided by Geomatics Canada, Natural Resources Canada

MAP 2020-12
TWILLICK BROOK
NTS MAP AREA 2D/04 AND PARTS OF 1M/13, 1M/14, 2D/03 AND 2D/05

Scale 1:75000

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Newfoundland Labrador
NATURAL RESOURCES

AIRBORNE GEOPHYSICAL SURVEY OF THE TWILLICK BROOK REGION, NEWFOUNDLAND

NTS MAP AREA 2D/04 AND PARTS OF 1M/13, 1M/14, 2D/03 AND 2D/05,

VLF-EM TOTAL FIELD - 23.4 & 22.1 KHz (Rhauderfehn, Germany & Skelton, UK)

MAP 2020-12
OPEN FILE NFLD/3383
Map 12 of 13

G.J. Kilfoil

ABOUT THE SURVEY

Introduction
A combined gamma-ray spectrometric, aeromagnetic and VLF-Electromagnetic airborne geophysical survey of Twillick Brook region, Newfoundland, was completed by Sander Geophysics Limited. The survey was flown from October 17th to November 10th, 2019 using a single Cessna 208 Caravan (C-GSGU). The nominal traverse and control line spacings were, respectively, 150 m and 1500 m. The nominal terrain clearance was 100 m. Ancillary equipment consisted of a Cessna 172 (C-FSRX) for flying tie lines and a Bell 206L (C-GSFW) with orthogonal control lines. The flight path was recovered following post-flight Precise Point Positioning (PPP) corrections using precise ephemerides applied to raw data recorded by a Global Positioning System.

Gamma-ray Spectrometric Data
The airborne gamma-ray measurements were made with a Sander Geophysics GDL2ten gamma-ray spectrometer using fourteen NaI(Tl) crystals with a total 33.6 litres (2100 cubic inches) of effective detector volume. The 33.6 litres of NaI(Tl) crystals, total volume 5.4 litres), shielded by the main array, were used to detect variations in background radiation caused by atmospheric radon. The system continuously adjusted the gain of each crystal by monitoring the natural potassium, uranium, and thorium peaks. Upward crystals were provided a small vacuum source to supplement the fibres natural peaks.

Potassium is measured directly from the 1460 keV gamma-ray photons emitted by K-40. Uranium and thorium are measured indirectly from the gamma-ray photons emitted by daughter products of the U-238 and Th-232 series. The U-238 series daughters are for down their respective decay chains, they are assumed to be in equilibrium with their parents, thus gamma-ray spectrometric measurements of uranium and thorium are referred to as equivalent uranium and equivalent thorium, i.e. eU and eTh. The energy windows used to measure potassium, uranium and thorium are respectively (370 -1570 keV, 1660-1860 keV and 2410-2810 keV.

Gamma-ray spectra were recorded at one-second intervals. Data processing followed standard procedures as described in IAEA, 1991 and IAEA, 2003. Spectral data were corrected for live time, background radiation, channel overlapping, and instrument dead time. Counts from the radon detectors were recorded in a 1860 - 1960 keV window and radiation at energies greater than 3000 keV was recorded in the cosmic window. The window counts were corrected for background activity from cosmic radiation, radioactivity of the aircraft and radioactivity of radon in the air. The effects of radon were removed using the method described in IAEA, 2003. The data were corrected for deviations from the planned terrain clearance and for variation of temperature and pressure were made prior to conversion to ground concentrations of potassium, uranium and thorium, using factors determined from flights over the Breckenridge, Quebec calibration range.

Corrected data were interpolated to a 30 m grid interval. The results of an airborne gamma-ray spectrometric survey represent the average surface concentrations that are influenced by varying amounts of outcrop, overburden, vegetation cover, soil moisture and radon in the air. The data are presented as contour maps and colour images of the ground concentrations. The total air absorbed dose rate in nanograys per hour was produced from measured counts between 400 and 2810 keV.

Magnetic Data
The magnetic field was sampled 10 times per second using three split-beam cesium vapour magnetometers (sensitivity = 0.005 nT) mounted inside the tail boom and two winglip pods of the aircraft. This array of sensors form a fixedwindled gradiometer with a lateral separation of 2.5 m and a longitudinal separation of 4.5 m between the sensors. Magnetic compensation was performed on the traverse lines were computer-assisted to obtain a mostly levelled out of flight-line magnetic data. The International Geomagnetic Reference Field (IGRF) defined at the average GPS altitude of 313 m for the date November 1st, was then removed. Removal of the IGRF ensures that the data sets from the various surveys can be combined and subsequently interpreted without regional trends within the Earth's crust. An enhanced version of the levelled magnetic data is calculated by averaging horizontal and longitudinal gradients to better define short wavelength signal, which is then interpolated to a 30 m grid interval.

The first vertical derivative of the magnetic field is the rate of change of the magnetic field in the vertical direction. Computation of the first vertical derivative removes long-wavelength features of the magnetic field and significantly improves the resolution of closely spaced magnetic anomalies. Interpretation of the first vertical derivative maps is the coincidence of the zero-value contour with vertical contacts of magnetic units at high magnetic latitudes (Hood, 1965).

VLF-EM
Very low frequency (VLF) electro-magnetic data was measured using a Herz Totem 2A VLF-EM receiver mounted in a 2.5 m fibreglass stinger installed on the tail of the aircraft. For this survey, the VLF stations Rhauderfehn, North Germany (23.4 kHz) provided Line data and Rhauderfehn, Germany (23.4 kHz), and Skelton, U.K. (22.1 kHz) provided Cross data. Line data was recorded in phase quadrature, and Cross data in phase. The VLF coverage of the survey area was not achieved, variation in signal quality is also apparent in the data on bands of less coherent data.

Additional Information
Data compilation and map production were performed by Sander Geophysics Limited, Ottawa, Ontario.
Contract and project management was provided by the Newfoundland and Labrador Department of Natural Resources.

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Email: gsdg@gov.nl.ca

References
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PLANIMETRIC SYMBOLS

Topographic contours
Drainage
Road
Flight line
Building
Transmission line

LOCATION MAP

NATIONAL TOPOGRAPHIC SYSTEM REFERENCE AND GEOPHYSICAL MAP INDEX

Recommended Citation
Kilfoil, G.J.
2020: Airborne Geophysical Survey of the Twillick Brook region, Newfoundland (NTS Map Area 2D/04 and parts of 1M/13, 1M/14, 2D/03 and 2D/05). VLF-EM Total Field - 23.4 & 22.1 KHz (Rhauderfehn, Germany & Skelton, UK). Geological Survey, Department of Natural Resources, Government of Newfoundland and Labrador, Map 2020-12, Open File NFLD/3383.

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Topographic contour interval: 30 metres

MAP 2020-13
TWILLICK BROOK
NTS MAP AREA 2D/04 AND PARTS OF 1M/13, 1M/14, 2D/03 AND 2D/05

Scale 1:75000

1000 0 1000 2000 3000 4000 5000 6000
(metres)
NAD83 / UTM zone 21N

Flown and compiled by:

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Tel: 613-521-3445
www.sgl-sgl.com
sgl.com

Digital topographic data provided by Geomatics Canada, Natural Resources Canada

Newfoundland Labrador
NATURAL RESOURCES

AIRBORNE GEOPHYSICAL SURVEY OF THE TWILLICK BROOK REGION, NEWFOUNDLAND

NTS MAP AREA 2D/04 AND PARTS OF 1M/13, 1M/14, 2D/03 AND 2D/05,

VLF-EM QUADRATURE - 25.2, 23.4 & 22.1 KHz (LaMoure, ND, Rhauderfehn, Germany & Skelton, UK)

MAP 2020-13
OPEN FILE NFLD/3383
Map 13 of 13

G.J. Kilfoil

ABOUT THE SURVEY

Introduction
A high resolution gamma-ray spectrometric, aeromagnetic and VLF-Electromagnetic airborne geophysical survey of Twillick Brook region, Newfoundland, was completed by Sander Geophysics Limited. The survey was flown from October 17th to November 10th, 2019 using a single Cessna 208 Caravan (C-GSGU). The nominal traverse and control line spacings were, respectively, 150 m and 1500 m. The survey was flown at a nominal terrain clearance of 100 m. Navigation was provided by the Canada-wide DGPS network (WAAS) and stitched GPS with orthogonal control lines. The flight path was recovered following post-flight Precise Point Positioning (PPP) corrections using precise ephemerides applied to raw data recorded by a Global Positioning System.

Gamma-ray Spectrometric Data
The airborne gamma-ray measurements were made with a Sander Geophysics GSLZ*pro gamma-ray spectrometer using fourteen Radiation Solutions RS-500 NaI(Tl) detectors, with a total combined volume of 33.6 litres (2100 cu. in.). Twelve of the detectors (total volume 8.4 litres), shielded by the main array, were used to detect variations in background radiation caused by atmospheric radon. The system continuously adjusted the gain of each crystal by monitoring the natural potassium, uranium, and thorium peaks. Upward crystals were provided a small vacuum source to supplement the Radon natural peaks.

Potassium is measured directly from the 1460 keV gamma-ray photons emitted by K-40. Uranium and thorium are measured indirectly from the gamma-ray photons emitted by daughter products of the U-238 and Th-232 series. The U-238 series is represented by Bi-214 and the Th-232 series by Tl-208. Since these gamma-ray spectrometric measurements of uranium and thorium are referred to as equivalent uranium and equivalent thorium, i.e. eU and eTh. The energy windows used to measure potassium, uranium and thorium are respectively (370 - 1570 keV, 1660-1860 keV and 2410-2810 keV.

Gamma-ray spectra were recorded at one-second intervals. Data processing followed standard procedures as described in IAEA, 1991 and EC, 1991. Data were corrected for live time of the spectrometers, background radiation, cosmic radiation, radon, aircraft and Compton scatter. Counts from the radon detectors were recorded in a 1860 - 1860 keV window and radiation at energies greater than 3000 keV was recorded in the cosmic window. The window counts were corrected for background activity from cosmic radiation, radioactivity of the aircraft and radon activity in the air mass. The radon corrections were made using the method described in IAEA, 1991 and EC, 1991. Data were corrected for deviations from the planned terrain clearance and for variation of temperature and pressure were made prior to conversion to ground concentrations of potassium, uranium and thorium, using factors determined from flights over the Breckenridge, Grafton calibration range.

Corrected data were interpolated to a 30 m grid interval. The results of an airborne gamma-ray spectrometric survey represent the average surface concentrations that are influenced by varying amounts of outcrop, overburden, vegetation cover, soil moisture and other factors. As a result, the airborne measurements may differ significantly from ground measurements. The total air absorbed dose rate in nanograys per hour was produced from measured counts between 400 and 2810 keV.

Magnetic Data
The magnetic field was sampled 10 times per second using three split-beam cesium vapour magnetometers (sensitivity = 0.005 nT) mounted inside the tail boom and two wingtip pods of the aircraft. This array of sensors form a fixedwindled gradiometer with a lateral separation of 2.5 m and a longitudinal separation of 8.5 m. The three magnetic field measurements were used to compute a total field traverse (tmv) were computer-assisted to obtain a manually levelled out of flight-line magnetic data. The International Geomagnetic Reference Field (IGRF) defined at the average GPS altitude of 313 m for the date November 1st, was then removed. Removal of the IGRF ensures that the data sets for all surveys, regardless of the date or altitude, are comparable and represent the magnetic field within the Earth's crust. An enhanced version of the levelled magnetic data is calculated by averaging horizontal and longitudinal gradients to better define short wavelength signal, which is then interpolated to a 30 m grid interval.

The first vertical derivative of the magnetic field is the rate of change of the magnetic field in the vertical direction. Computation of the first vertical derivative removes long wavelength features of the magnetic field and significantly improves the resolution of closely spaced magnetic anomalies. Contrast is improved and the interpretive maps is the coincidence of the zero-value contour with vertical contacts of magnetic units at high magnetic latitudes (Hood, 1965).

VLF-EM
Very low frequency (VLF) electro-magnetic data was measured using a Herz Totem 2A VLF-EM receiver mounted in a 2.5 m fibreglass stinger installed on the tail cone of the aircraft. The VLF stations in Lafleur, North Dakota (25.2 kHz) provided Line data and Rhauderfehn, Germany (23.4 kHz), and Skelton, U.K. (22.1 kHz) provided Cross data. Data was recorded at a sampling rate of 0.1 seconds. Typically, VLF coverage of the survey area was not achieved. Variation in signal quality is also apparent in the data on bands of less coherent data.

Additional Information
Data compilation and map production were performed by Sander Geophysics Limited, Ottawa, Ontario.
Contract and project management was provided by the Newfoundland and Labrador Department of Natural Resources.

Copies of this map are obtained directly from the Geological Survey, Department of Natural Resources,
Government of Newfoundland and Labrador, P.O. Box 8700, St. John's, NL, Canada, A1B 4J6

This map is subject to revision and modification. Comments to the author concerning errors or omissions are invited.

Department Website: http://www.nr.gov.nl.ca/nr/
Geological Survey Website: http://www.nr.gov.nl.ca/nr
Email: mail@gov.nl.ca

References
Hood, P.J.
1965: Gradient measurements in aeromagnetic surveying. Geophysics, vol. 30, p. 891-902.

3.187
0.881
0.823
0.764
0.405
0.370
0.346
0.311
0.293
0.281
0.242
0.229
0.206
0.190
0.175
0.163
0.152
0.134
0.127
0.117
0.105
0.096
0.085
0.075
0.064
0.054
0.046
0.037
0.029
0.019
0.003
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-0.016
-0.027
-0.037
-0.048
-0.058
-0.071
-0.082
-0.096
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-0.117
-0.130
-0.141
-0.148
-0.160
-0.170
-0.181
-0.194
-0.209
-0.223
-0.237
-0.255
-0.274
-0.293
-0.320
-0.347
-0.376
-0.406
-0.442
-0.500
-3.00
%

PLANIMETRIC SYMBOLS

Topographic contours
Drainage
Road
Flight line
Building
Transmission line

LOCATION MAP

NATIONAL TOPOGRAPHIC SYSTEM REFERENCE AND GEOPHYSICAL MAP INDEX

-58°30'
-58°00'
-57°30'
-56°30'
48°30'
48°15'
48°00'
47°45'
47°30'
2 D/12
2 D/11
2 D/05
2 D/04
2 D/03
1 M/14
1 M/13
Grand Falls-Windsor
Gander
Bonavista
Clarenville
Marystown
Burgeo
Stephenville
Corner Brook
Deer Lake
St. Anthony
Port aux Basques
Labrador City
Wabush
Churchill Falls
Happy Valley-Goose Bay
Nain
Cartwright
Hopedale
Makkovik
Postville
Rigolet
Nain
Natuashish
Sept-Îles
Baie-Comeau
Blanc-Sablon
Schefferville
Kuujjuaq
Kuujjuarapik
Chibougamau
Chapais
Matagami
Lac Mistassini
Oujé-Bougoumou
Waskaganish
Eastmain
Wemindji
Chisasibi
Nemaska
Lac Albanel
Mistissini
Obedjiwan
Roberval
Saint-Michel-des-Saints
Pointe-Bleue
Alma
Dolbeau-Mistassini
Saguenay
La Tuque
Jonquière
Chicoutimi
Québec
Baie-Comeau
Forestville
Tadoussac
Natashquan
Port-Menier
Havre-Saint-Pierre
Fermont
Schefferville
Kuujjuaq
Kuujjuarapik
Radisson
Chibougamau
Chapais
Matagami