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GEOPHYSICAL SURVEY REPORT
AIRBORNE MAGNETIC AND HELITEM^2 SURVEY
CAPE SMITH BELT
PROJECT 2100109B
KOBOLD METALS CO.

September 28, 2022

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Introduction

This report describes the logistics, data acquisition, processing and presentation of results of a HELITEM^2 electromagnetic and magnetic airborne geophysical survey carried out for KoBold Metals Co. over six properties in Nunavik, Québec. The breakdown of kilometres flown, line direction and spacing are shown in Table 1.

Block	Line Numbers	Line direction	Line Spacing	Line km
1	L10010 - 11360	0°/180°	200 m	1430.4
	T19005 – 19070	90°/270°	1700 m	137.2
2	L20010 – 21180	0°/180°	200 m	885.8
	T29010 – 29071	90°/270°	2000 m	76.5
5	L50010 – 50270	90°/270°	200 m	55.6
8	L80235 – 82015	90°/270°	200 m	918.1
	T89000 – 89090	0°/180°	1475 m	149.5
9	L90420 – 90840	0°/180°	200 m	219.5
10	L100230 – 100530	0°/180°	200 m	116.6
	T109000 - 109030	90°/270°	1450 m	18.5
Total				4007.7 km

Table 1 Flown line kilometre summary

The purpose of the survey was to map the geology and structure of the area and is a continuation of acquisition started in 2021. Data were acquired using a HELITEM^2 electromagnetic system supplemented by a high-sensitivity cesium magnetometer. The information from these sensors was processed to produce maps and images that display the magnetic and conductive properties of the survey area. A GPS electronic navigation system ensured accurate positioning of the geophysical data with respect to the base map coordinates.

The survey was performed by Xcalibur MPH (Canada) Ltd. Grids and data in digital format are provided with this report.

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Survey Area Description

Location of the Survey Area

Six blocks in Nunavik, Québec (Figure 1) were flown between June 18 and August 24, 2022, with Kangiqsujuaq airport as the base of operations. Survey coverage consisted of 3626.0 km of traverse lines flown with a spacing of 200 m and 381.7 km of tie lines ranging between 1450 and 2000 m spacing for a total of 4007.7 km.

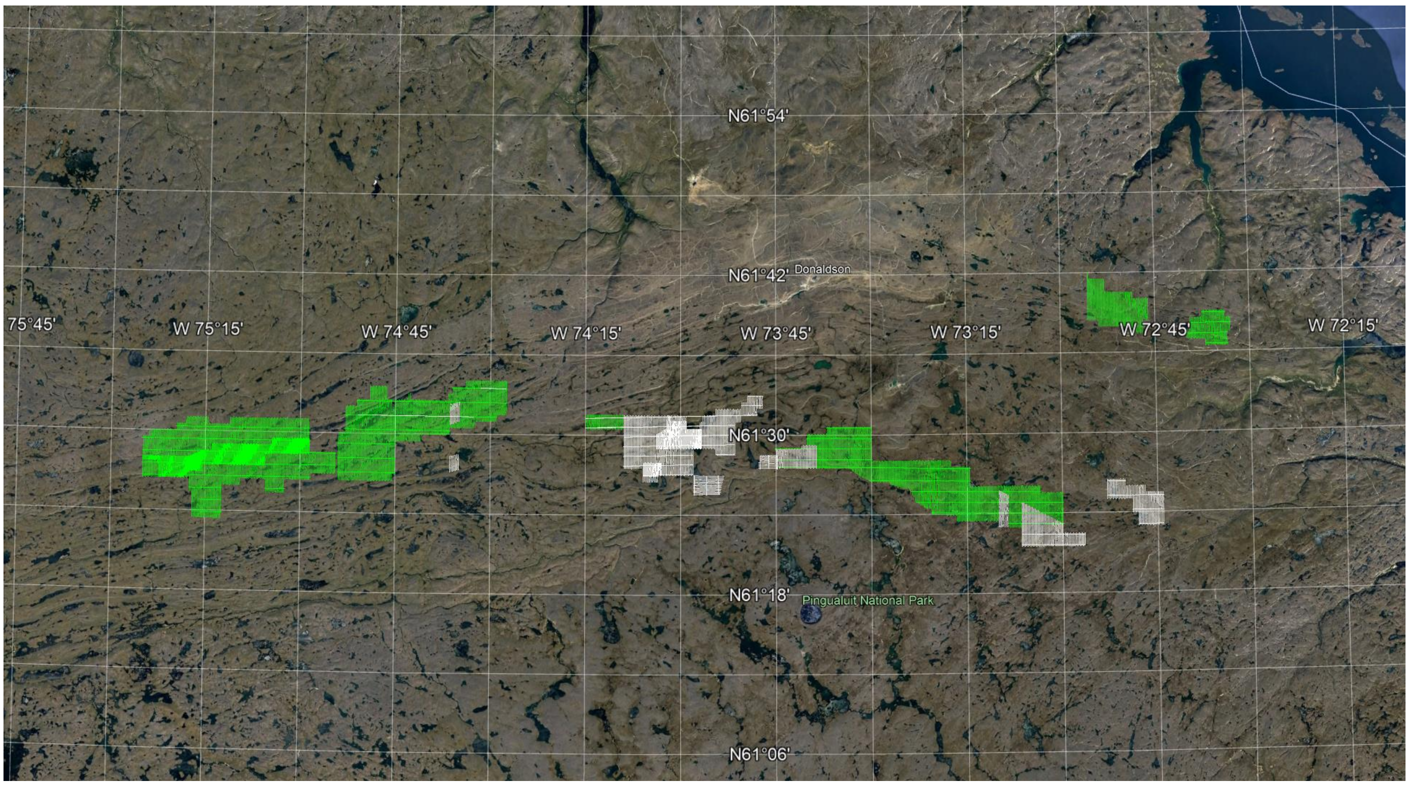

Figure 1 Cape Smith Belt - Location Map
2021 survey lines (white), 2022 survey lines (green)

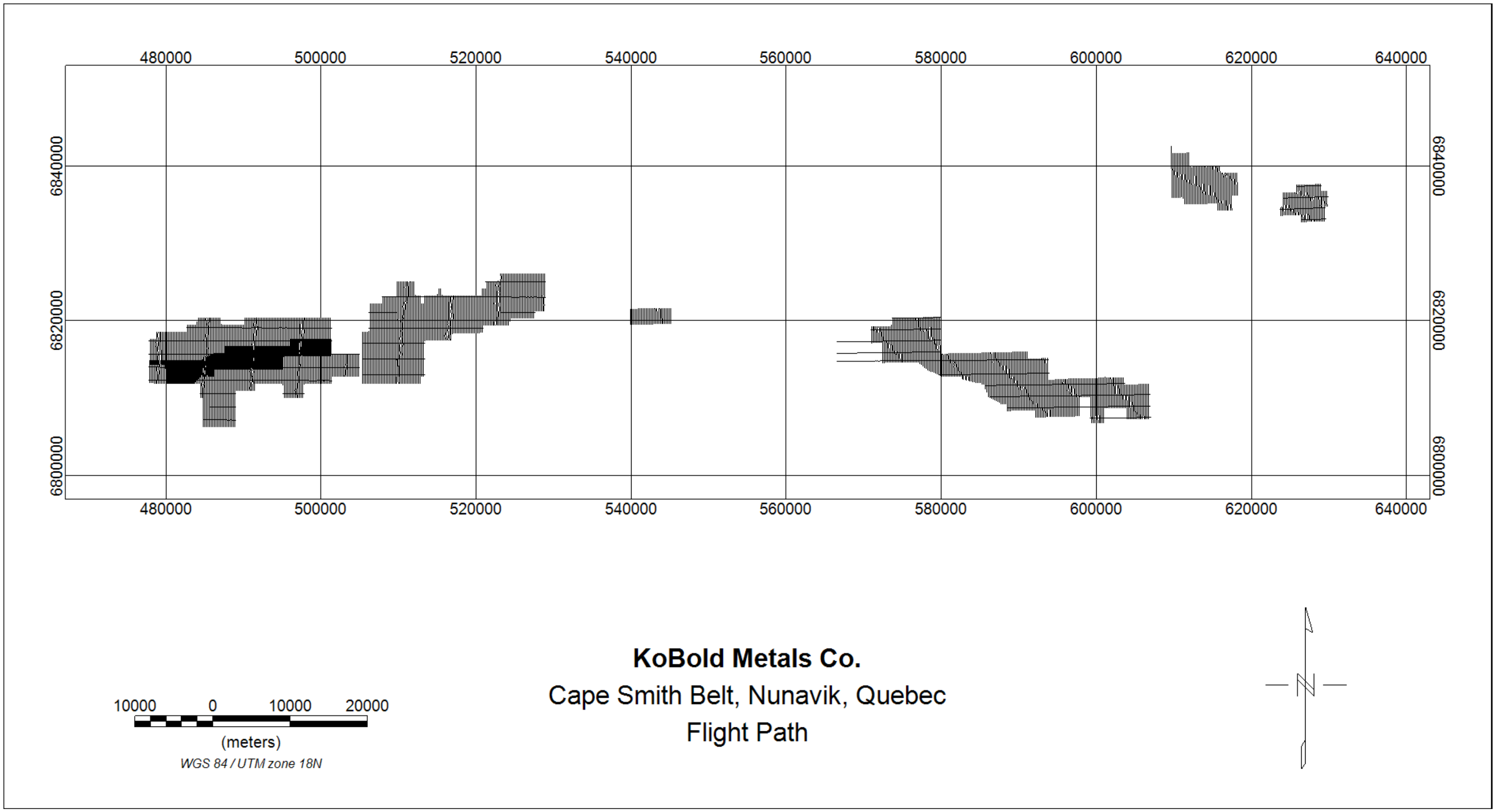

Figure 2 Cape Smith Belt – 2022 Flight Path Map

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Table 2 contains the coordinates of the corner points for the survey block.

Block 1 North	
X-UTM (E)	Y-UTM (N)
480000	6812037
480014	6814424
477792	6814434
477809	6817624
478701	6817619
478707	6818547
482699	6818525
482704	6819453
484034	6819447
484038	6820375
487142	6820362
487139	6819434
490243	6819424
490246	6820352
501330	6820338
501332	6815554
495124	6815563
495120	6813858
486228	6813868
486226	6812939
484449	6812947
483546	6812013

Block 5	
X-UTM (E)	X-UTM (E)
539910	539910
539894	539894
545198	545198
545237	545237

Block 1 South	
X-UTM (E)	Y-UTM (N)
477778	6812052
477794	6814834
484456	6814803
486237	6815725
487569	6815719
487572	6816647
496005	6816628
496006	6817556
501331	6817554
501332	6815697
504884	6815701
504888	6812916
501333	6812912
501333	6811984
497778	6811985
497777	6810128
495109	6810131
495111	6811996
491555	6811995
491553	6811066
488886	6811073
488870	6806433
484850	6806447
484857	6807368
485759	6807367
485770	6810173
484447	6810168
484445	6811091
488886	6811073
488889	6811976

Block 2	
X-UTM (E)	Y-UTM (N)
505333	6811988
505323	6818486
506210	6818487
506203	6822200
507976	6822204
507974	6823129
509696	6823135
509696	6825000
512000	6825000
512000	6823144
512848	6823147
512851	6822217
513294	6822216
513290	6823149
515063	6823156
515061	6824081
515504	6824081
515506	6823158
520828	6823186
520829	6824121
521257	6824116
521258	6825045
523017	6825063
523018	6825982
528809	6826028
528803	6821394
527489	6821383
527487	6820455
524382	6820419
524380	6819510
520841	6819501
520840	6818558
516857	6818523
516861	6817594
513313	6817579
513325	6812929
512890	6812928
512890	6812005

Block 9	
X-UTM (E)	Y-UTM (N)
605857	6839603
605800	6841458
607122	6841499
607093	6842427
609737	6842511
609766	6841583
611970	6841654
612030	6839798
615999	6839929
616030	6839001
618236	6839076
618331	6836293
617448	6836262
617511	6834407
615745	6834347
615714	6835275
611298	6835129
611268	6836057
607295	6835932
607266	6836860
609032	6836915
608944	6839699

Block 10	
X-UTM (E)	X-UTM (E)
623728	6833695
623694	6834623
624136	6834639
624069	6836494
625835	6836558
625801	6837486
628890	6837600
628925	6836672
629807	6836706
629877	6834850
629436	6834833
629505	6832978
626412	6832863
626378	6833791

Block 8	
X-UTM (E)	Y-UTM (N)
570918	6817230
566576	6817168
566574	6817362
570916	6817423
570890	6819227
573661	6819266
573646	6820348
579855	6820415
579931	6815688
591067	6815967
591079	6815078
593754	6815116
593795	6812320
597796	6812527
603582	6812608
603595	6811724
606807	6811769
606916	6807427
603863	6807384
603842	6808874
601043	6808835
601067	6806951
599257	6806899
599210	6810272
597819	6810252
597854	6807793
592121	6807643
592108	6808533

Block 8	
X-UTM (E)	Y-UTM (N)
588521	6808483
588508	6809386
587801	6809376
586127	6810323
585578	6811842
585357	6811879
585343	6812102
584629	6812085
582666	6812613
582661	6812966
580035	6812905
579632	6813191
578477	6813649
577289	6814537
577288	6814700
577081	6814697
577020	6814742
572824	6814714
572375	6814639
572375	6814698
566614	6814656
566614	6814856
572372	6814898
572360	6815768
566604	6815687
566602	6815887
572357	6815968
572339	6817251

Table 2 Area Corners
WGS84 UTM Zone 18N

System Information

Figure 3 HELITEM^2 System

The HELITEM^2 system is composed of a 40 m cable to which is attached the transmitter loop (Figure 4). The top of the cable is attached to a helicopter and when in flight it drags to form a 25-degree angle from the vertical putting the transmitter coil approximately 35 m below the helicopter. The receiver platform and the receiver coil are located at the centre of the 35 m diameter transmitter loop approximately 0.1 m above the centre of the transmitter plane. The real time navigation GPS antenna is on the tail boom of the helicopter. The barometric altimeter, radar altimeter, laser altimeter, video camera and data recorder are all installed in the helicopter. GPS antennae are attached to the transmitter loop to give positional information and transmitter orientation. An IMU was mounted on the front of the transmitter loop to measure receiver pitch, roll, and yaw. The values mentioned above and provide in the figure below are nominal, measured values will differ slightly.

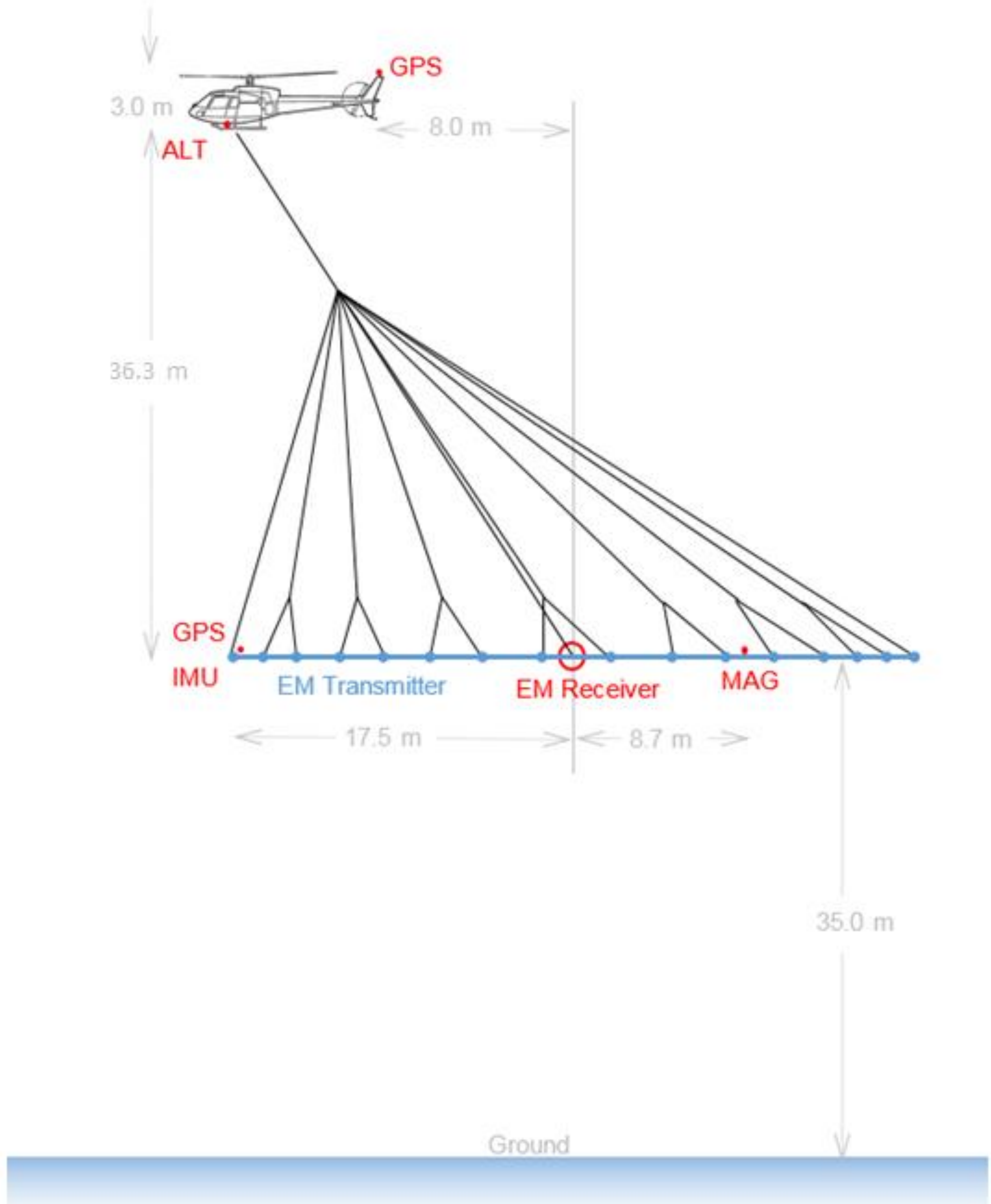


Figure 4 Nominal Geometry of the HELITEM^2 System

Aircraft and Geophysical On-Board Equipment

Helicopter:	AS350 B3
Operator:	Helicarrier and Acasta Heliflight
Registration:	C-FHCH and C-GUTI
EM System:	HELITEM^2 35m diameter loop
Transmitter:	Vertical axis loop slung below helicopter
Loop area:	961 m^2
Number of turns:	4
Nominal height above ground:	35 m
Receiver:	Multicoil system (X, Y and Z components) with a final recording rate of 10 samples per second, 25 channels of data normalised to a coil effective area of 1 m^2.
Inflight Vertical Rx-Tx separation (m)	0.1 m
Nominal height above ground:	35 m
Helicopter-Loop Separation:	35.8 m, calculated using GPS located on the helicopter and transmitter loop
Base frequency:	7.5 Hz
Pulse width:	33.9030 ms
Off-time:	32.7637 ms
Transmitter Current:	146.0 A
Dipole moment:	5.61×10^5 A·m^2
Digital Acquisition:	Xcalibur HeliDAS
Video:	Logitech C615 USB Camera mounted to the exterior bottom of the helicopter between the forward skid tubes
Magnetometer:	CS-3 Scintrex Cesium Vapour, mounted in the plane of the transmitter loop; Operating Range: 15,000 to 100,000 nT Operating Limit: -40°C to 50°C Accuracy: ±0.002 nT Measurement Precision: 0.001 nT Sampling rate: 10.0 Hz

Radar Altimeter:	Honeywell Sperry RT300 Altimeter System. Radar antennas are mounted to the exterior bottom of the helicopter Operating Range: 0 – 2500ft Operating Limit: -55°C to 70°C Accuracy: ± 3% (100 – 500ft above obstacle) ± 4% (500 – 2500ft above obstacle) Measurement Precision: 1 ft Sample Rate: 10.0 Hz
Laser Altimeter:	LTI - TruSense-S200 mounted on the helicopter; Operating Range: 0.2 to 750 m Operating Limit: -10°C to 45°C Accuracy: ±5 cm (10°C to 30°C) ±10 cm (-10°C to 45°C) Measurement Precision: 4 cm Sample Rate: 10.0 Hz
Transmitter Loop attitude:	VN-300 mounted on the front of the transmitter loop; Operating Range (Heading, Roll): ±180° Operating Range (Pitch): ±90° Dynamic Accuracy (Heading): 0.3° RMS Dynamic Accuracy (Pitch/Roll): 0.1° RMS Operating Limit: -40°C to 85°C Sample Rate: 10 Hz
Aircraft Navigation:	NovAtel OEM4 Card with an Aero antenna mounted on the tail of the helicopter; Operating Limit: -40°C to 85°C Real-Time Accuracy: 1.8m CEP (L1) Real-Time Measurement Precision: 6 cm RMS Sample Rate: 2.0 Hz
Transmitter Loop Positional Data:	NovAtel OEM4 with Aero Antenna mounted on the loop transmitter. Operating Limit: -40°C to 85°C Real-Time Accuracy: 1.8m CEP (L1) Real-Time Measurement Precision: 6 cm RMS Sample Rate: 2.0 Hz
Barometric Altimeter:	Motorola MPX4115AP analog pressure sensor mounted in the helicopter Operating Range: 55 kPa to 108 kPa Operating Limit: -40°C to 125°C Accuracy: ± 1.5 kPa (0°C to 85°C) ± 3.0 kPa (-20°C to 0°C, 85°C to 105°C) ± 4.5 kPa (-40°C to -20°C, 105°C to 125°C) Measurement Precision: 0.01 kPa Sampling Rate = 10.0 Hz

Temperature: Analog Devices 592 sensor mounted on the camera box
Operating Range: -40°C to + 75°C
Operating Limit: -40°C to + 75°C
Accuracy: ± 1.5°C
Measurement Precision: 0.03°C
Sampling Rate = 10.0 Hz

Base Station Equipment

Magnetometer: Xcalibur CF1 using Scintrex cesium vapour sensor with Marconi GPS card and antenna for measurement synchronization to GPS. The base station also collects barometric pressure and outside temperature.
Magnetometer Operating Range: 15,000 to 100,000 nT
Barometric Operating Range: 55kPa to 108 kPa
Temperature Operating Range: -40°C to 75°C
Sample Rate: 1.0 Hz

GPS Receiver: NovAtel OEM4 Card with an Aero antenna

Real-Time Accuracy:
1.8m CEP (L1)
Sample Rate: 1.0 Hz

During the survey GPS base stations were set up to collect data to allow post processing of the positional data for increased accuracy. The location of the GPS base stations is shown in Table 3.

Status	Location Name	WGS84 Latitude (deg-min-sec)	WGS84 Longitude (deg-min-sec)	Ellipsoidal Height (m)	Date Set Up	Date Torn Down
Primary	Fuel Cache 4	61° 28' 58.26336" N	75° 01' 29.41741" W	483.187	17-Jun-22	17-Jul-22
Primary	Fuel Cache 3	61° 27' 39.49485" N	73° 27' 58.32930" W	484.059	17-Jul-22	06-Aug-22
Primary	Fuel Cache 5	61° 38' 35.36616" N	72° 48' 37.94422" W	636.968	06-Aug-22	25-Aug-22

Table 3 GPS Base Station Location

Pulse Configuration and Sampling windows

At 7.5 Hz one half cycle of the HELITEM^2 system is made up of a square pulse (on-time) of approximately thirty-four milliseconds in duration followed by approximately thirty-four milliseconds of off-time before the pulse is repeated with the opposite polarity. Figure 5 is a graphic of what the receiver coils measure during the half cycle. After acquisition the measured data are windowed into twenty-five ranges called “gates”. Gate widths increase as time after turn-off increases because as the energy from the transmitter decays a wider sample must be taken to get a valid average. The gates used for this project are documented in Table 4. The position of the first off-time gate is selected after examining several flights of data and is as close to the transmitter turn off as possible. The power of the pulse causes eddy currents in the system after the turn off and the first off-time gate cannot start until these have died away. The earliest data has had less time to penetrate the subsurface and so contains information from the near surface.

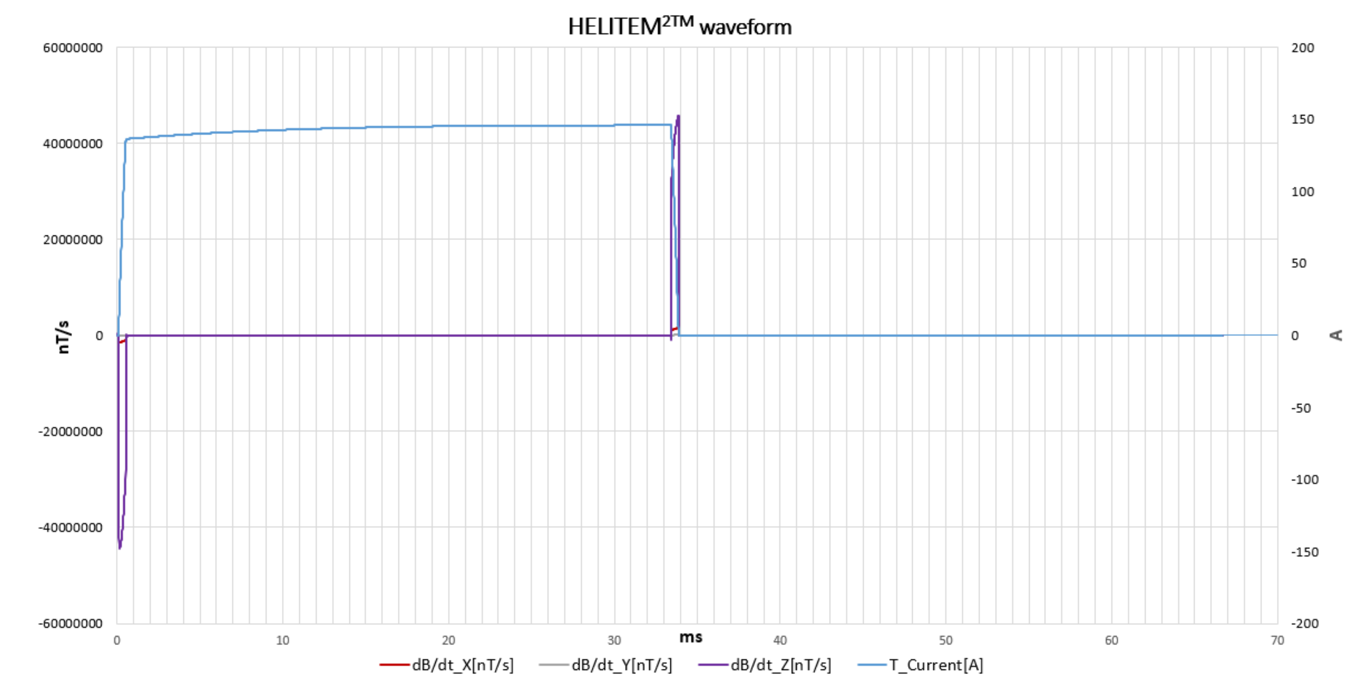


Figure 5 Typical HELITEM^2 System Waveform for one half cycle

HELITEM^2 Gate positions 7.5 Hz / 34 ms pulse width				
Gate	**Start time after Pulse (ms)**	**End Time after Pulse (ms)**	**Midpoint (ms)**	**Width (ms)**
1	0.0570	0.0732	0.0651	0.0163
2	0.0732	0.0977	0.0854	0.0244
3	0.0977	0.1221	0.1099	0.0244
4	0.1221	0.1546	0.1383	0.0326
5	0.1546	0.2035	0.1790	0.0488
6	0.2035	0.2604	0.2319	0.0570
7	0.2604	0.3337	0.2970	0.0732
8	0.3337	0.4313	0.3825	0.0977
9	0.4313	0.5534	0.4924	0.1221
10	0.5534	0.7161	0.6348	0.1628
11	0.7161	0.9277	0.8219	0.2116
12	0.9277	1.1963	1.0620	0.2686
13	1.1963	1.5462	1.3713	0.3499
14	1.5462	1.9938	1.7700	0.4476
15	1.9938	2.5716	2.2827	0.5778
16	2.5716	3.3203	2.9460	0.7487
17	3.3203	4.2806	3.8005	0.9603
18	4.2806	5.5176	4.8991	1.2370
19	5.5176	7.1126	6.3151	1.5951
20	7.1126	9.1715	8.1421	2.0589
21	9.1715	11.8327	10.5021	2.6611
22	11.8327	15.2669	13.5498	3.4342
23	15.2669	19.6940	17.4805	4.4271
24	19.6940	25.3988	22.5464	5.7048
25	25.3988	32.7637	29.0812	7.3649

Table 4 HELITEM^2 Gate Positions

Survey Specifications and Data Quality Control

Digital data for each flight were transferred to the office, in order to verify data quality and completeness. A database was created and updated using Geosoft Oasis Montaj and proprietary Xcalibur Atlas software. This allowed the processor to calculate, display and verify both the positional (flight path) and geophysical data. The initial database was examined as a preliminary assessment of the data acquired for each flight.

Daily processing of Xcalibur survey data consists of differential corrections to the airborne GPS data, verification of EM calibrations, drift correction of the raw airborne EM data, spike rejection and filtering of all geophysical and ancillary data, verification of the digital video, calculation of preliminary resistivity data, and diurnal correction of magnetic data.

All data, including base station records, were checked on a daily basis to ensure compliance with the survey contract specifications. Re-flights were required if any of the following specifications were not met.

Navigation

A specialized GPS system provided in-flight navigation control. The system determined the absolute position of the helicopter by monitoring the range information of twelve channels (satellites). The Novatel OEM4 receiver was used for this application. In North America, the OEM4 receiver is WAAS-enabled (Wide Area Augmentation System) providing better real-time positioning.

A Novatel OEM4 GPS base station was used to record pseudo-range, carrier phase, ephemeris, and timing information of all available GPS satellites in view at a one second interval. These data are used to improve the conversion of aircraft raw ranges to differentially corrected aircraft position. The GPS antenna was set-up in a location that allowed for clear sight of the satellites above. The set-up of the antenna also considered surfaces that could cause signal reflection around the antenna that could be a source of error to the received data measurements.

Flight Path

Flight lines did not deviate from the intended flight path by more than 25% of the line spacing over a distance of more than 1 kilometre. Except where the pilot used their judgement to fly safely around man-made structures or other safety reasons. Flight specifications were based on GPS positional data recorded at the helicopter.

Survey Elevation

The survey elevation is defined as the measurement of the helicopter radar altimeter to the tallest obstacle in the helicopter path. An obstacle is any structure or object which will impede the path of the helicopter to the ground and is not limited to and includes tree canopy, towers and power lines.

Survey elevations may vary based on the pilot's judgement of safe flying conditions around man-made structures or in rugged terrain.

The ideal survey elevation for the helicopter and instrumentation during data collection was:

Helicopter	70 metres
Magnetometer	35 metres
HELITEM^2 Receiver	35 metres
HELITEM^2 Transmitter	35 metres

Survey elevations did not deviate by more than ±15 m from the contracted/revised elevation over a distance of 2 km.

Airborne High Sensitivity Magnetometer

To assess the noise quality of the collected airborne magnetic data, Xcalibur monitors the 4th difference results during flight which is verified post flight by the processor. The contracted specification for the collected airborne magnetic data was that the normalized 4th difference would not exceed 0.05 nT over a continuous distance of 1 kilometre excluding areas where this specification was exceeded due to natural anomalies.

Magnetic Base Station

Ground magnetic base stations were set-up to measure the total intensity of the earth's magnetic field. The base stations were placed in a magnetically quiet area, away from power lines and moving metallic objects. The contracted specification for the collected ground magnetic data was the non-linear variations in the magnetic data were not to exceed 10 nT per minute.

Electromagnetic Data

The noise envelopes of the EM data, as calculated from the last off-time channel shall not exceed the following tolerances continuously over a horizontal distance of 500 metres under normal survey conditions:

dB/dt X < 1.20 nT/s
dB/dt Z < 0.35 nT/s

The EM noise level is defined as the standard deviation of Z dB/dt square wave secondary field collected during high altitude backgrounds of the last time channel.

Flying was not performed when spheric pulses became sufficiently intense and frequent that digital data processing techniques could not recover useful data.

The HELITEM^2 EM system includes a power line channel for noise monitoring. There are no power transmission lines or electric fences evident within in the survey areas.

In-Flight EM System Calibration

The calibration consists of measuring the system characteristics out of ground effect and compensation of the electromagnetic data for these measured effects. The reference waveforms recorded during the pre-flight calibration form an important part of the delivered data and are critical to accurate inversion of the data. During the pre-flight calibration, a minimum of 30 seconds of data is collected out-of-ground-effect to monitor the effectiveness of the calibration and the accuracy to the base levels. During any post-flight calibration, a minimum of 30 seconds of data is collected out-of-ground-effect; these data are compared with the pre-flight calibration data to quantify drift.

Measurements of in-flight noise levels, out of ground effect, are made at the high-altitude portions of each flight. Static or hover noise levels are not directly related to those seen in flight due to geometry and compensation considerations that are only addressed in a dynamic situation.

Data Gaps

Isolated errors, spikes and narrow non-sequential data gaps were corrected by interpolation providing no similar data gaps existed on nearby sections of adjacent flight lines.

Cape Smith Belt 2022 Acquisition

Below is a summary of any data issues or information of interest.

- Due to weather survey acquisition was terminated before all lines were flown in block 9.
- EM X-component data for flight 28 was considered not useable and was not processed or archived.
- Flights 30, 31 and 32 did not have transmitter GPS or laser altimeter data recorded. The positional data was estimated based on the helicopter positional data and the radar altimeter.

Data Processing

Flight Path Recovery

To check the quality of the positional data the speed of the bird is calculated using the differentially corrected x, y and z data. Any sharp changes in the speed are used to flag possible problems with the positional data. Where speed jumps occur, the data are inspected to determine the source of the error. The erroneous data are deleted and splined if less than five seconds in length. If the error is greater than five seconds the raw data are examined and if acceptable, may be shifted and used to replace the bad data. The GPS-Z component is the most common source of error. When it shows problems that cannot be corrected by recalculating the differential correction, the barometric altimeter is used as a guide to assist in making the appropriate correction. The corrected WGS84 longitude and latitude coordinates were transformed to WGS84 UTM's.

Datum:	WGS84
Ellipsoid:	WGS84
Projection:	UTM Zone 18N
Central meridian:	75° West
False Easting:	500000 metres
False Northing:	0 metres
Scale factor:	0.9996
WGS84 to Local Conversion:	Molodensky
Dx,Dy,Dz:	0, 0, 0

Recorded video flight path may also be linked to the data and used for verification of the flight path. Fiducial numbers are recorded continuously and are displayed on the margin of each digital image. This procedure ensures accurate correlation of data with respect to visible features on the ground. The fiducials appearing on the video frames and the corresponding fiducials in the digital profile database originate from the data acquisition system and are based on incremental time from start-up. Along with the acquisition system time, UTC time is also recorded in parallel and displayed (Figure 6).

Altitude Data

Laser altimeter data are despiked and filtered using an alpha-trim filter. The laser altimeter data are then subtracted from the GPS elevation to create a digital elevation model that is examined in grid format for spurious values. The height above ground based on laser altimeter was used in the conductivity calculations.

Flight Number **Heading (°)** **Fiducial (UTC HH:MM:SS.S)**

Speed (m/s) **Latitude DD:MM:SS.SS** **Longitude: DD:MM:SS.SS (WGS84)**

Figure 6 Flight path video

Magnetics

Magnetic Base Station Diurnal

The raw diurnal data are sampled at 1 Hz and imported into a database. A non-linear variation was then calculated and a flag channel is created to indicate where the variation exceeds the survey tolerance. The data are filtered with a 51 second median filter and then a 51 second Hanning filter to remove spikes and smooth short wavelength variations. Acceptable diurnal data are interpolated to a 10 Hz sample rate and then a local regional field value was removed to leave the diurnal variation. This diurnal variation is then ready to be removed during the processing of the airborne magnetic data based on the assumption that both the static ground observatory and (nearby) airborne magnetometer are subject to equivalent temporal magnetic variation from solar wind interactions with the magnetosphere.

Total Magnetic Intensity

The Total Magnetic Field (TMF) data collected in flight were profiled on screen along with a fourth difference channel calculated from the TMF. Spikes were removed manually where indicated by the fourth difference. The despiked data were then corrected for lag by 2.3 seconds. The diurnal variation that was extracted from the filtered ground station data was then removed from the despiked and lagged TMF. The IGRF was calculated using the 2020 IGRF model for the specific survey location, date and altitude of the sensor and removed from the TMF to obtain the Residual Magnetic Intensity (RMI). The results were then levelled using tie and traverse line intercepts. Manual adjustments were applied to any lines that required levelling, as indicated by shadowed images of the gridded magnetic data. The manually levelled data were then subjected to a microlevelling filter. The IGRF was calculated a second time using the specific survey location and a fixed date and altitude. The result was added back to the levelled Residual Magnetic Intensity to calculate the levelled Total Magnetic Intensity.

Calculated Vertical Magnetic Gradient

The levelled, Total Magnetic Intensity grid was subjected to a processing algorithm that enhances the response of magnetic bodies in the upper 500 metres and attenuates the response of deeper bodies. The resulting calculated vertical gradient grid provides better definition and resolution of near-surface magnetic units. It also identifies weak magnetic features that may not be quite as evident in the RMI data. Regional magnetic variations and changes in lithology, however, may be better defined on the Residual Magnetic Intensity.

Electromagnetics

dB/dt Data

The X and Z component data are processed from the raw stream to produce the 25 raw channels at 10 samples per second from the square pulse.

The following processing steps are applied to the dB/dt data from all coil sets:

- The raw stream data is re-processed post-flight using start-of-flight and end-of-flight calibrations to remove spheric spikes, system drift, and to filter VLF noise.
- High frequency incoherent noise was identified in the stackedhalfwave through analysis of the odd harmonic base frequency spectrum. The dominant (peak) frequency was extracted and used for suppressing the noise in the stacked halfwave.
- Noise filtering is done using an Alpha-trim and Hanning that is tapered between the early and late times. Filter lengths of 1.5 to 3.0 seconds were used for the alpha-trim and 1.5 to 1.5 seconds used for the Hanning filter.
- Incoherent noise is removed using an exponential decomposition[1] that calculates apparent rates of decay to identify incoherent noise. Incoherent areas in the decay which are below the specified amplitude constraint, set on the order of the system noise level, are then filtered down decay to improve coherency.
- The filtered X and Z component data are then levelled in flight form for any residual and nonlinear drift that was not adequately corrected during the drift correction.
- Finally, line-based levelling and microlevelling are applied as required.

B-field Data

The data acquisition system produces 25 B-field channels each for X and Z component in real-time during flight, however these channels are only used for field QC. For delivery, mapping and generation of derived products, the final B-field channels are derived from the final levelled dB/dt data.

The advantage of B-field data compared with dB/dt data are that it enhances the slow decaying response of good conductors while suppressing the rapid decaying response of less conductive overburden. B-field data can also be used to enhance conductors hidden below thick conductive overburden

[1] Chen, Hodges, and Smiarowski, 2015, Extracting subtle IP responses from airborne time domain electromagnetic data: SEG Technical Program Expanded Abstracts 2015, 2061-2066.

Because B-field is a derived product, all B-field anomalies should be reviewed with the dB/dt data to verify the response.

Apparent Conductivity from Z data

Xcalibur has developed an algorithm that converts the response in any measurement window (on-time or off-time) into an apparent conductivity. This is performed using a look-up table that contains the response at a range of half-space conductivities and altimeter heights. The apparent conductivity is calculated by fitting all channels of the Z-coil response of the dB/dt component to the homogeneous-half-space model.

Differential Conductivity™

Differential Conductivity™ is a simple, relatively accurate resistivity section developed by Xcalibur to be derived from airborne electromagnetic data (Huang and Fraser, 1996[1]). This type of resistivity section is fast and robust and provides a good picture of resistivity conditions in the earth. It can be derived from both frequency[2] domain and time domain EM data.

Differential Conductivity™ is derived from a homogeneous halfspace model of the resistivity calculated for each time channel, each at an approximate depth of maximum induced current flow. The early time channel provides a measure of the shallow conductivity, and the deeper (later time) halfspace conductivities are modified using the shallow information to give a more accurate measure of the conductivity at depth. The depth of investigation for each time channel is adjusted as well.

It is very important to recognize that Differential Conductivity™ sections, like conductivity-depth images or layered-earth inversions, assume that the earth is made of uniform layers. Any feature in the earth which is not much wider than the footprint of the airborne EM system will not be properly represented (generally they are too deep) and the contrast will be reduced.

Differential Conductivity™ sections tend to smooth sharply defined layers (compared to layered-earth inversions) but provide an excellent model of the resistivity, quickly and without the complex processing necessary for inversions, and without the dependence on accurate starting models.

Time Constant (TAU)

Time constant values are obtained for windows consisting of four consecutive gates starting with the first off-time using the equation below. Each window is shifted by one gate until the last channel is reached and from this series of windows the maximum detectable Tau for each measurement point is chosen.

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

where A is amplitude at time zero, t is time in microseconds and τ is the time constant, expressed in microseconds. A semi-log plot of this exponential function will be displayed as a straight line, the slope of which will reflect the rate of decay and therefore the strength of the conductivity. A slow rate of decay, reflecting a high conductivity, will be represented by a high time constant.

As a single parameter, the time constant provides more useful information than the amplitude data of any given single channel, as it indicates not only the peak position of the response but also the relative strength of the conductor. It also allows better discrimination of conductive axes within a broad formational group of conductors.

[2] Huang, Haoping and Fraser, Douglas, 1996, The differential parameter method for multifrequency airborne resistivity mapping, Geophysics Vol 61, No 1, January-February 1996, P 100-109.

dB/dt Fraser Filtered X Data

For a vertical conductor, the X component response reaches a maximum as the system approaches the conductor, rapidly decreases to zero near the top of the conductor and reaches a negative minimum on the other side of the conductor. The shape of the X component response over a discrete conductor depends on both the dipping angle of the conductor and the flight direction, which renders a grid image of the X component responses over discrete conductors complicated and hard to interpret. The Fraser Filter is a gradient filter which, when applied to the X component data, highlights the steep gradients near the zero crossing of the response on top of discrete conductors and suppresses the responses from the half-space earth. Thus, the Fraser filtered X component data are simplified with anomalous features indicating the existence and location of discrete conductors or edges of broad conductive bodies.

Digital Elevation

The laser altimeter values are subtracted from the differentially corrected and de-spiked GPS-Z values to produce profiles of the height above mean sea level along the survey lines. These values are gridded to produce contour maps showing approximate elevations within the survey area. Any subtle line-to-line discrepancies are manually removed. After the manual corrections are applied, the digital terrain data are filtered with a microlevelling algorithm.

The accuracy of the elevation calculation is directly dependent on the accuracy of the two input parameters, laser altimeter and GPS-Z. The GPS-Z value is primarily dependent on the number of available satellites. Although post-processing of GPS data will yield X and Y accuracies in the order of 1-2 metres, the accuracy of the Z value is usually much less, sometimes in the ±5 metre range. Further inaccuracies may be introduced during the interpolation and gridding process.

Because of the inherent inaccuracies of this method, no guarantee is made or implied that the information displayed is a true representation of the height above sea level. Although this product may be of some use as a general reference, THIS PRODUCT MUST NOT BE USED FOR NAVIGATION PURPOSES.

Gridding

The magnetic and conductivity data are interpolated onto a regular grid using a modified Akima spline technique. The grid cell size is 20% of the line separation (40 metre cells).

The resulting grids are suitable for image processing and generation of contour maps.

CONCLUSIONS AND RECOMMENDATIONS

This report provides a very brief description of the survey results and describes the equipment, data processing procedures and logistics of the airborne survey over the Cape Smith Belt site, near Nunavik, Québec. The various maps included with this report display the magnetic, and conductive properties of the survey area.

It is recommended that the survey results be assessed and fully evaluated in conjunction with all other available geophysical, geological and geochemical information. In particular, structural analysis of the data should be undertaken and areas of interest should be selected. It is important that careful examination of these areas be carried out on the ground in order to eliminate possible man-made sources of the EM anomalies. An attempt should be made to determine the geophysical “signatures” over any known zones of mineralization in the survey areas or their vicinity.

The anomalous resistivity and magnetic targets defined by the survey should be subjected to further investigation using appropriate surface exploration techniques. Any inferred contacts and structural breaks are considered to be of particular interest as they may have influenced or controlled mineral deposition within the survey area. Anomalies that are currently considered to be of moderately low priority may require upgrading if follow-up results are favourable, or if they occur in areas of favourable geology.

It is also recommended that image processing of existing geophysical data be considered, in order to extract the maximum amount of information from the survey results. Current software and imaging techniques often provide valuable information on structure and lithology, which may not be clearly evident on the contour and colour maps. These techniques can yield images that define subtle, but significant, structural details.

Respectfully submitted,

Xcalibur MPH (Canada)

R2100109B

CERTIFICATE OF REVIEWER

I, Mihai Szentesy, do hereby certify that:

1. I am residing at 511- 2100 Rue Du Coliseé, Longueuil, J4N 0C7, Québec, Canada.

2. I am temporary employed as Senior Geophysical Data Processor for the Toronto office of the geophysical survey firm Xcalibur MULTIPHYSICS (Canada) Ltd.

3. I hold the following academic qualifications: B.Sc., Geology and Geophysics (1982), University of Babes-Bolyai, Cluj-Napoca, Romania.

4. I am a member in good standing of the Ordre des géologues du Québec (OGQ) since January 15th, 2013, member number #01747.

5. I have worked as a geologist for 10 years and in geophysical data processing for 11 years.

6. I have had no prior involvement with the Property that forms the subject of this Report.

7. I am not aware of any material fact or material change with respect to the subject matter of the Report that is not reflected in the Report, the omission to disclose which makes the Report misleading.

I have reviewed the Report titled "GEOPHYSICAL SURVEY REPORT AIRBORNE MAGNETIC AND HELITEM^2 SURVEY, CAPE SMITH BELT, PROJECT 2100109B" dated September 28, 2022, and prepared for Kobold Metals Co

.
Dated this 28th Day of September 2022.

Respectfully Submitted

____

Mihai Szentesy, Géologue Restrictif (1G3, #01747)

Appendix A List of Personnel

List of Personnel:

The following personnel were involved in the acquisition, processing, interpretation and presentation of data, relating to a HELITEM^2 airborne geophysical survey carried out for KoBold Metals Co. over the Cape Smith Belt near Nunavik, Québec.

Acquisition:

Brett Robinson	Project Manager
Keith Lavalley	Crew Leader/Electronics Technician
Johan van Rooyen	Electronics Technician
Abhishek Goyal	Electronics Technician
Zak Deen	Electronics Technician
Frebin Baby	Electronics Technician
Jeff McArthur	Pilot (Helicarrier)
Rachel Trottier	AME (Helicarrier)
Glenn Charbonneau	Pilot (Acasta Heliflight)
Alvaro Lopez	AME (Acasta Heliflight)
Travis Booker	AME (Acasta Heliflight)
Robert O’Halloran	Pilot (Acasta Heliflight)
Glenn Burritt	AME (Acasta Heliflight)

Processing:

Elizabeth Bowslaugh	Geophysicist
Graham Konieczny	Geophysicist
Mihai Szentesy	Geophysicist

All personnel were employees of Xcalibur MPH, except where indicated.

Appendix B Data Archive Description

Data Archive Description:

Survey Details:

Survey Area Name:	Cape Smith Belt
Project number:	2100109B
Client:	KoBold Metals Co.
Survey Company Name:	Xcalibur MPH (Canada) Ltd.
Flown Dates:	June 18 to August 24, 2022
Archive Creation Date:	September 28, 2022

Geodetic Information for map products:

Datum:	WGS84
Ellipsoid:	WGS84
Projection:	UTM Zone 18N
Central meridian:	75° West
False Easting:	500000 metres
False Northing:	0 metres
Scale factor:	0.9996
WGS84 to Local Conversion:	Molodensky
Dx,Dy,Dz:	0, 0, 0

Geosoft Grids, GeoTiffs and kmz:

File	Description	Units
dtm	Digital Terrain Model	m
tmi	Total Magnetic Intensity	nT
tmi_1vd	Calculated Vertical Magnetic Gradient	nT/m
each_conductivity_db_z_early	Apparent conductivity dB/dt Z at 0.0651 ms after turn-off	mS/m
each_conductivity_db_z_mid	Apparent conductivity dB/dt Z at 0.8219 ms after turn-off	mS/m
each_conductivity_db_z_late	Apparent conductivity dB/dt Z at 10.5021 ms after turn-off	mS/m
tcon	Time constant dB/dt Z maximum detectable	µs
emx_db_ff	Fraser filtered dB/dt X at 10.5021 ms after turn-off	nT/s/m
dcon_db_z_100m	Differential conductivity depth slice dB/dt Z at 100 m	mS/m
dcon_db_z_200m	Differential conductivity depth slice dB/dt Z at 200 m	mS/m
dcon_db_z_300m	Differential conductivity depth slice dB/dt Z at 300 m	mS/m
Dcon_*line*	Differential conductivity depth section dB/dt for each line	mS/m

Disclaimer: Google Earth Accuracy
Xcalibur provides images of geophysical data in .KML or .KMZ format for viewing in Google Earth as a convenient product to our clients. It is important to recognize that the horizontal and vertical positional accuracy of Google Earth is not sufficient for close location of targets for drilling, verifying outcrop, etc. Xcalibur makes no warranty as to the accuracy of apparent positioning of Xcalibur data when converted and displayed in Google Earth.

Geosoft Database:

Variable	Description	Units
line	Line	-
flight	Flight Number	-
date	Flight Date	yyyymmdd
fid	HELIDAS Fiducial Counter	seconds
time_ssm	Universal Time (Seconds Since Midnight)	seconds
easting_WGS84	Helicopter Easting (X) in WGS84 UTM Zone 18N	metres
northing_WGS84	Helicopter Northing (Y) in WGS84 UTM Zone 18N	metres
latitude_WGS84	Helicopter Latitude in WGS84	degrees
longitude_WGS84	Helicopter Longitude in WGS84	degrees
easting_tx_WGS84	Transmitter Loop Easting (X) in WGS84 UTM Zone 18N	metres
northing_tx_WGS84	Transmitter Loop Northing (Y) in WGS84 UTM Zone 18N	metres
latitude_tx_WGS84	Transmitter Loop Latitude in WGS84	degrees
longitude_tx_WGS84	Transmitter Loop Longitude in WGS84	degrees
radar	Helicopter Height Above Surface from Radar Altimeter	metres
laser	Helicopter Height Above Surface from Laser Altimeter	metres
height_tx	Transmitter Height Above Surface	metres
gpsz	Helicopter Height Referenced to Mean Sea Level	metres
gpsz_tx	Transmitter Height Referenced to Mean Sea Level	metres
DTM	Digital Terrain Model Referenced to Mean Sea Level	m
diur	Measured Base Station Ground Magnetic Intensity	nT
mag_lag	Total Magnetic Field – corrected for lag	nT
IGRF	International Geomagnetic Reference Field	nT
mag_rmi	Final Residual Magnetic Intensity	nT
mag_tmi	Final Total Magnetic Intensity	nT
powerline	Power Line Monitor	V
tx_current	Transmitter Peak Current	amp
emx_db	Final dB/dt X Component Channels 1 - 25	nT/s
emz_db	Final dB/dt Z Component Channels 1 – 25	nT/s
emx_bf	Final B field X Component Channels 1 – 25	pT
emz_bf	Final B field Z Component Channels 1 – 25	pT
emx_db_ff	Fraser Filtered dB/dt X Channels 1 - 25	nT/s/m
tcon	Time Constant dB/dt Z Maximum Detectable	µs
each_conductivity_db_z	Apparent Conductivity dB/dt Z Channels 1 to 25	mS/m
dcon_db_z_500m_by5m	Differential Conductivity Depth Section dB/dt Z, 5 m slicing to 500 m	mS/m

Note – Null values in the GDB archive are displayed as *.

Report:

A logistics and processing report for Project #2100109B in PDF format:

R2100109B.pdf

Video:

Digital video in .MOV format for survey flights.

EM Reference Waveform Description:

The information shown below is a sample.

```
/Calibration Data [FLT 1 Cal# 2 Start FID 65088 End Fid 65149]
/Base Frequency: 7.50 Hz
/Sample Interval: 8.1380208 µs

/-------------------------------------------------------------------------------
/XYZ REF WAVEFORM EXPORT
/SAMPLE  T_Current[A] dB/dt_X[nT/s] dB/dt_Y[nT/s] dB/dt_Z[nT/s]
      0         0.000         5.861        -2.892        -2.560
      1         0.000         5.382       -20.113        -4.593
      2        -0.000        -7.168       -11.549       -13.703
      3         0.000       -15.048        17.050       -92.976
      4        -0.012       131.507       -10.387      3804.561
      |             |             |             |             |
      |             |             |             |             |
      |             |             |             |             |
      |             |             |             |             |
   8188        -0.000         0.162         0.040         0.054
   8189        -0.000         0.159         0.040         0.059
   8190        -0.000         0.159         0.043         0.054
   8191        -0.000         0.159         0.043
```

The first column is the sample number. There are a total of 8192 samples representing a half-wave cycle or one pulse. The subsequent columns are: transmitter current, measured X primary field, measured Y primary field, and measured Z primary field for dB/dt.

Appendix C Map Product Grids

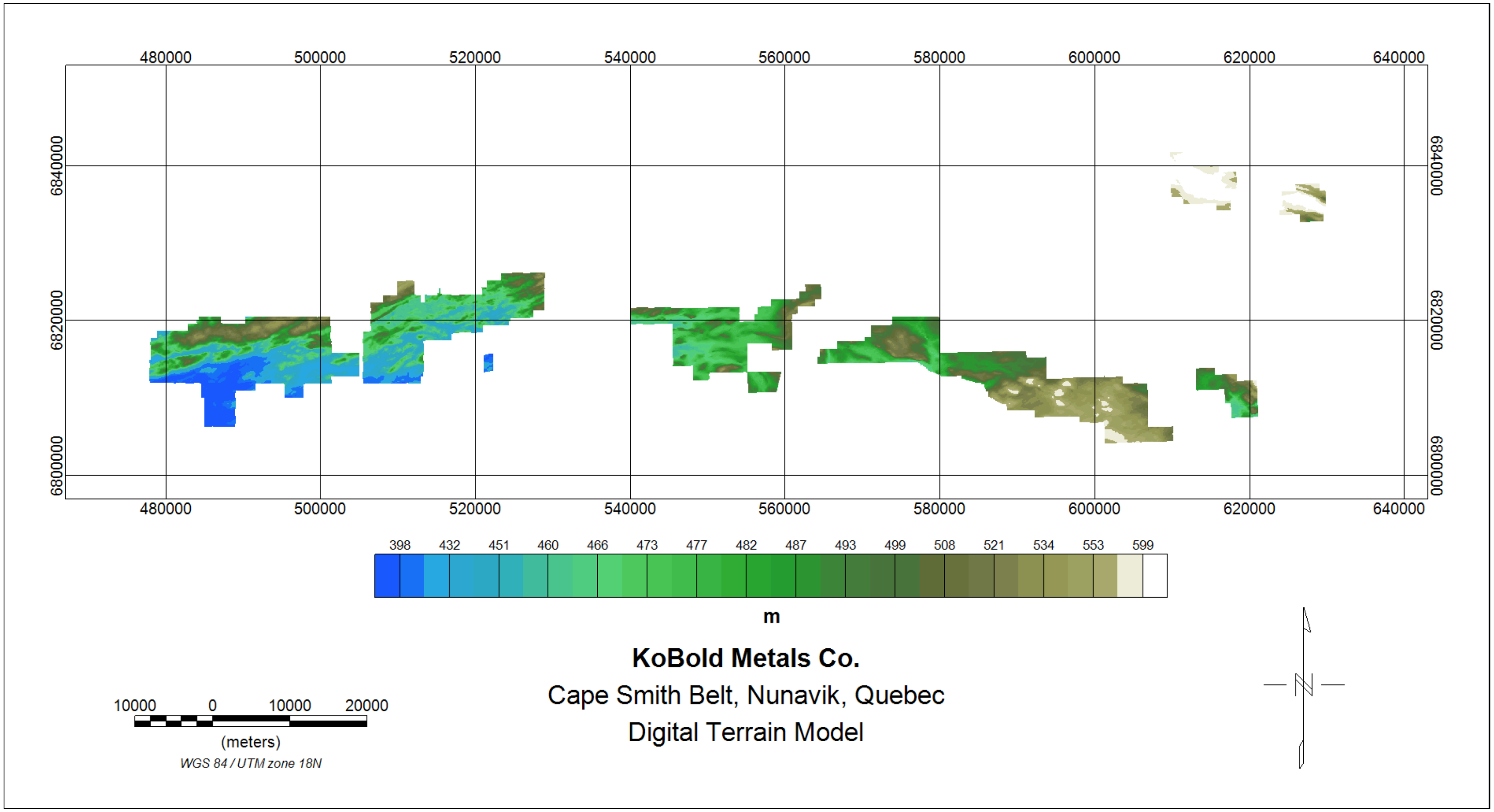
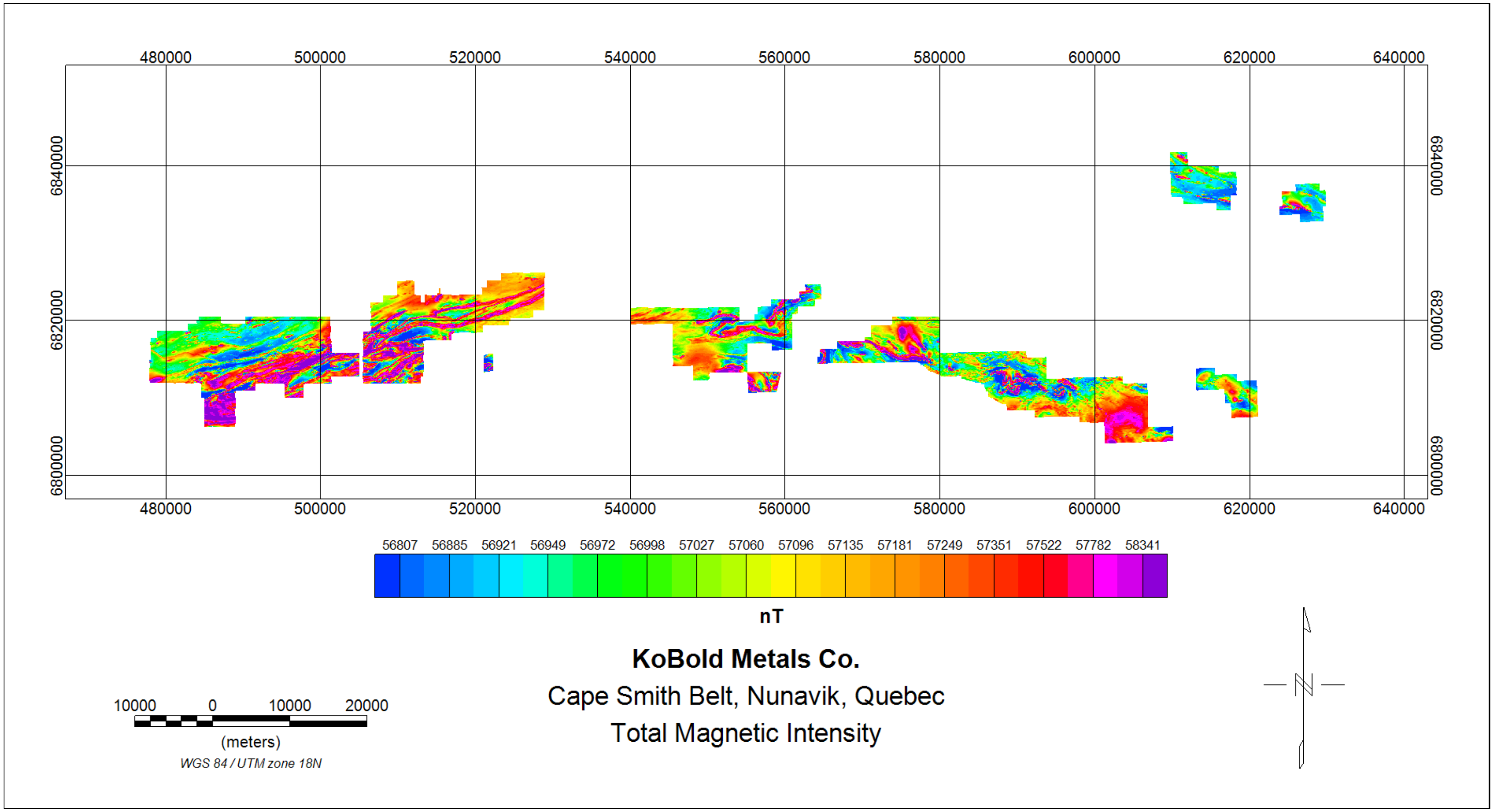


Figure 7 Digital Terrain Model
2021 and 2022 survey data shown

Figure 8 Total Magnetic Intensity
2021 and 2022 survey data shown



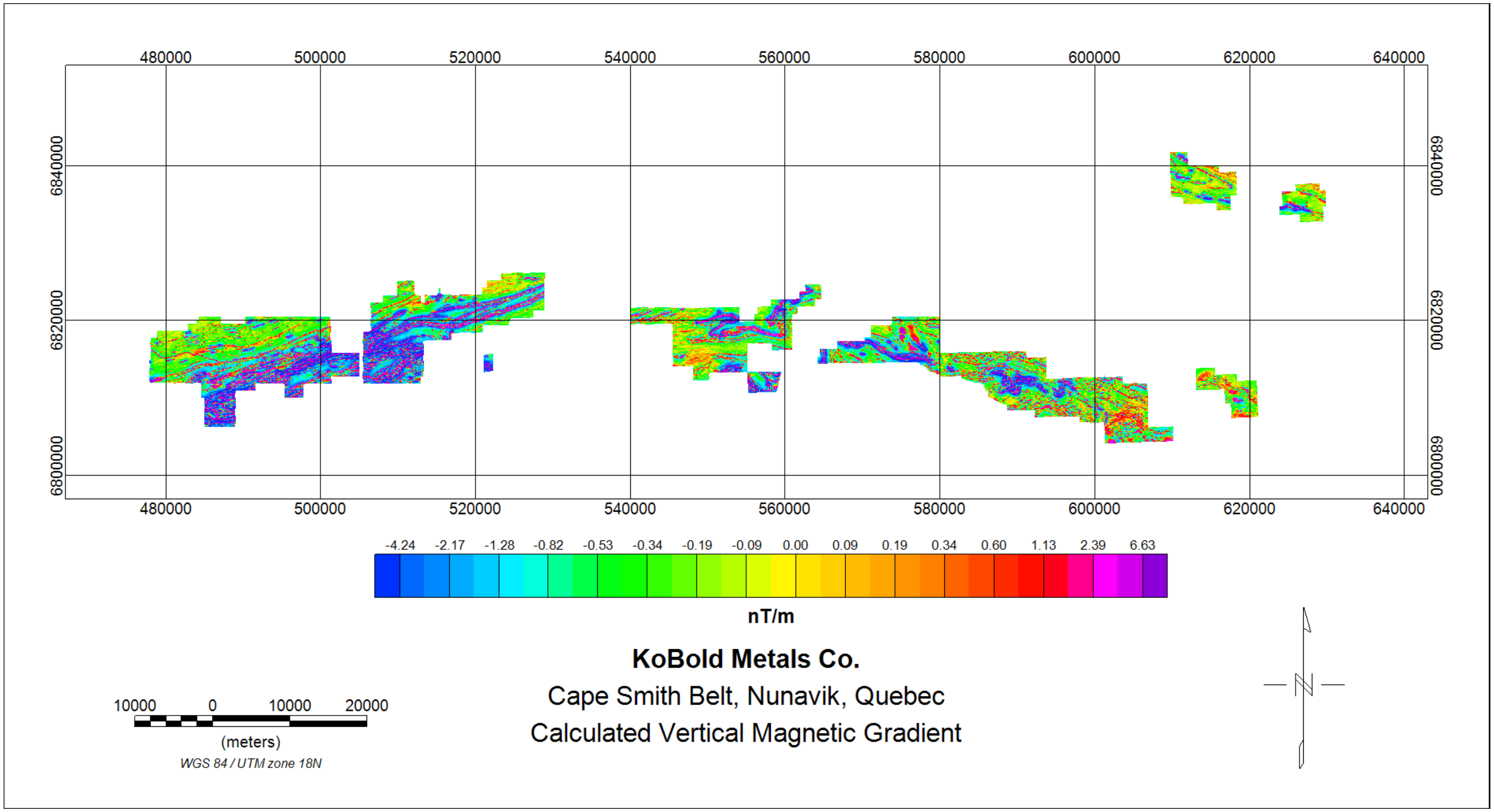


Figure 9 Calculated First Vertical Derivative of the TMI
2021 and 2022 survey data shown

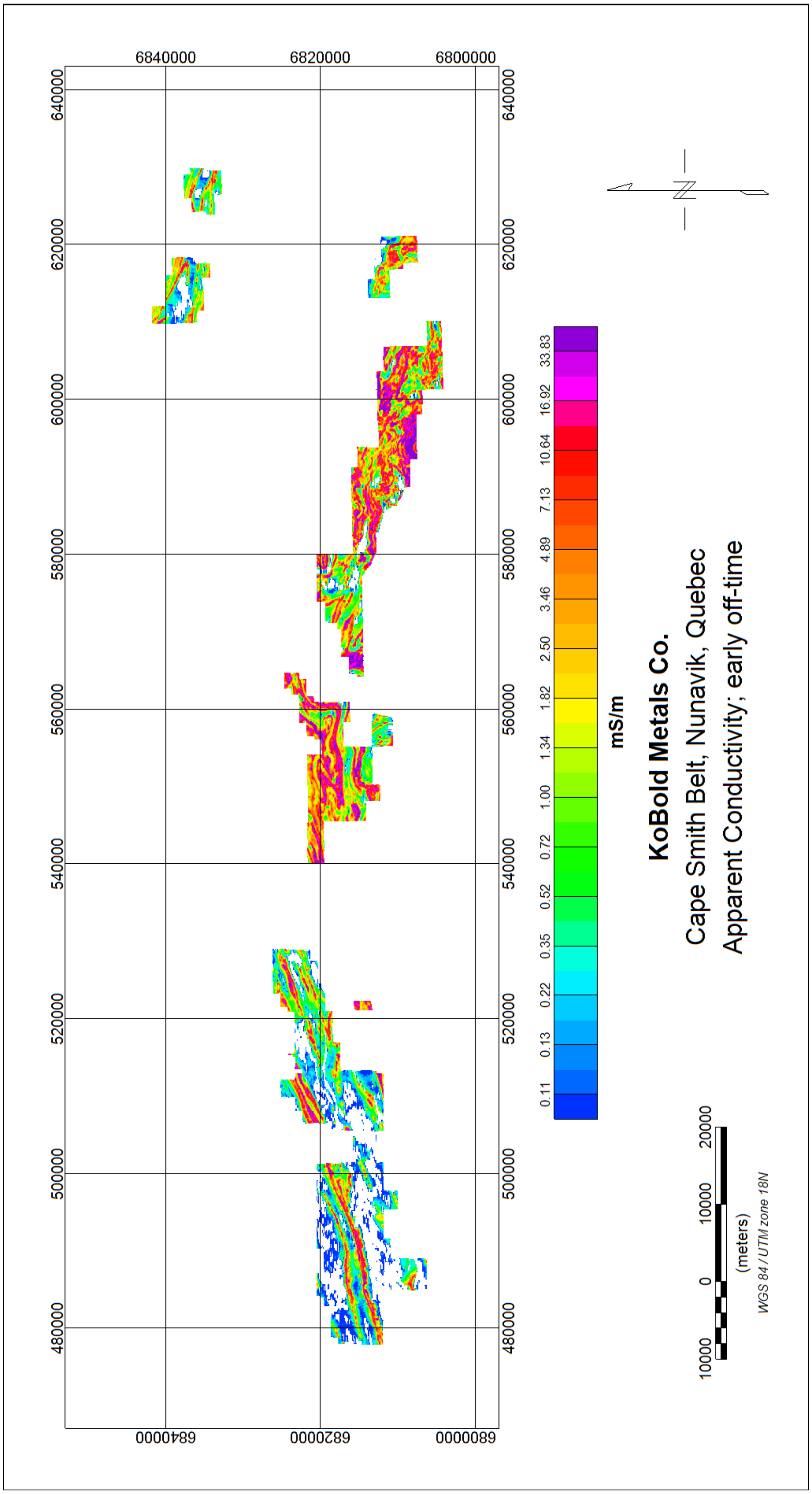


Figure 10 Apparent Conductivity early off-time
2021 and 2022 survey data shown

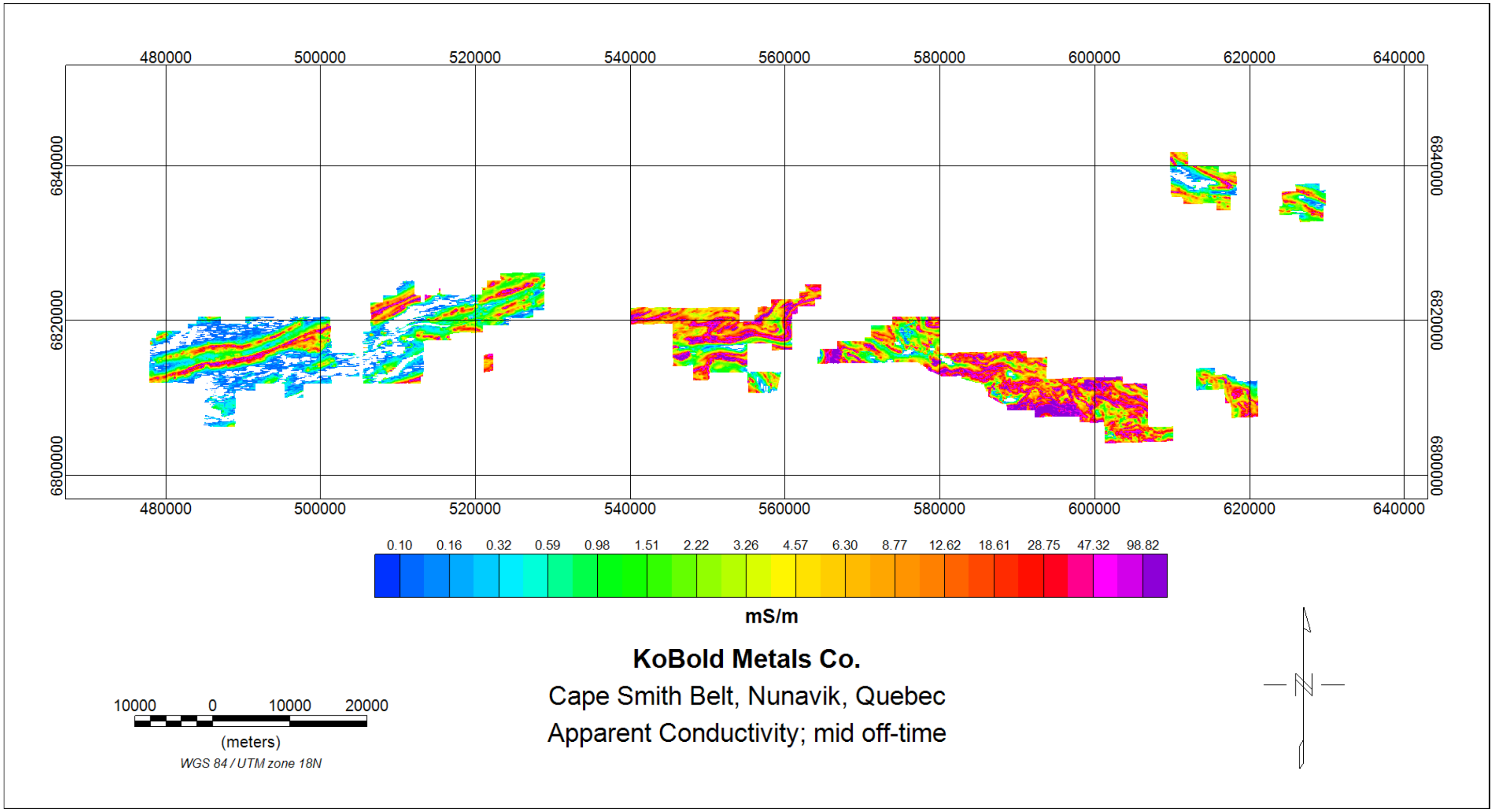


Figure 11 Apparent Conductivity mid off-time
2021 and 2022 survey data shown

Xcalibur
MULTIPHYSICS

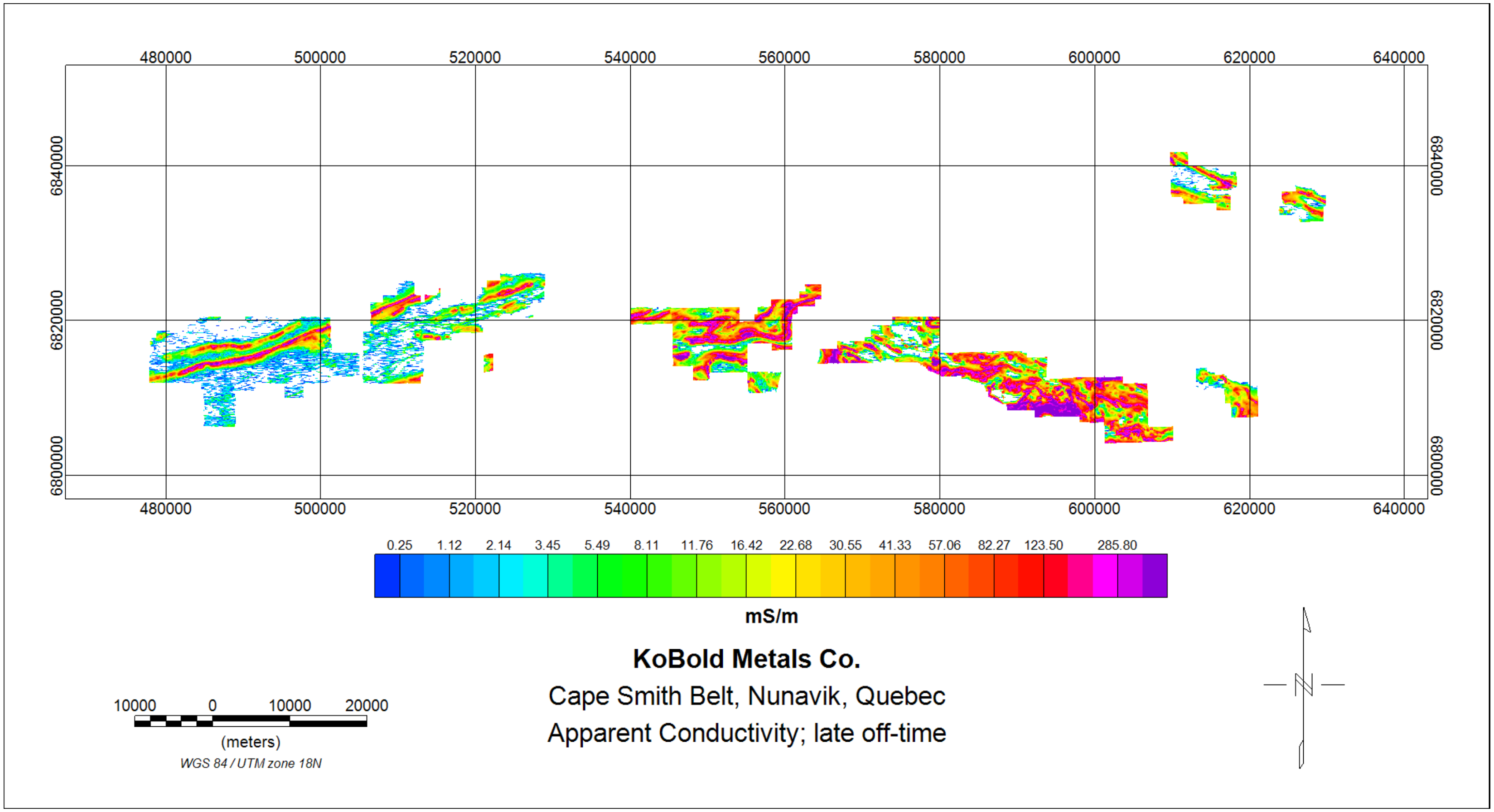


Figure 12 Apparent Conductivity late off-time
2021 and 2022 survey data shown

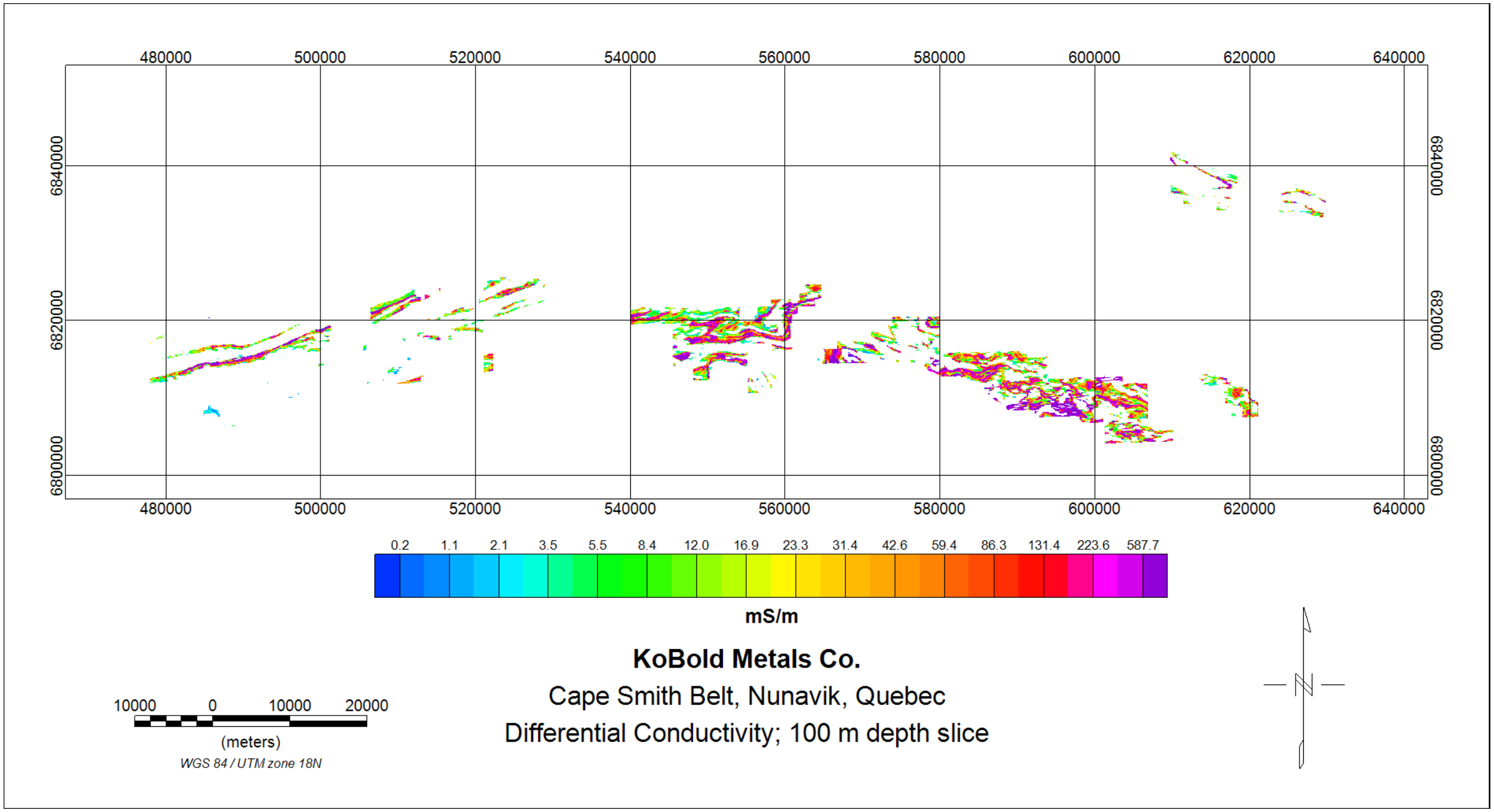


Figure 13 Differential Conductivity 100 m depth slice
2021 and 2022 survey data shown

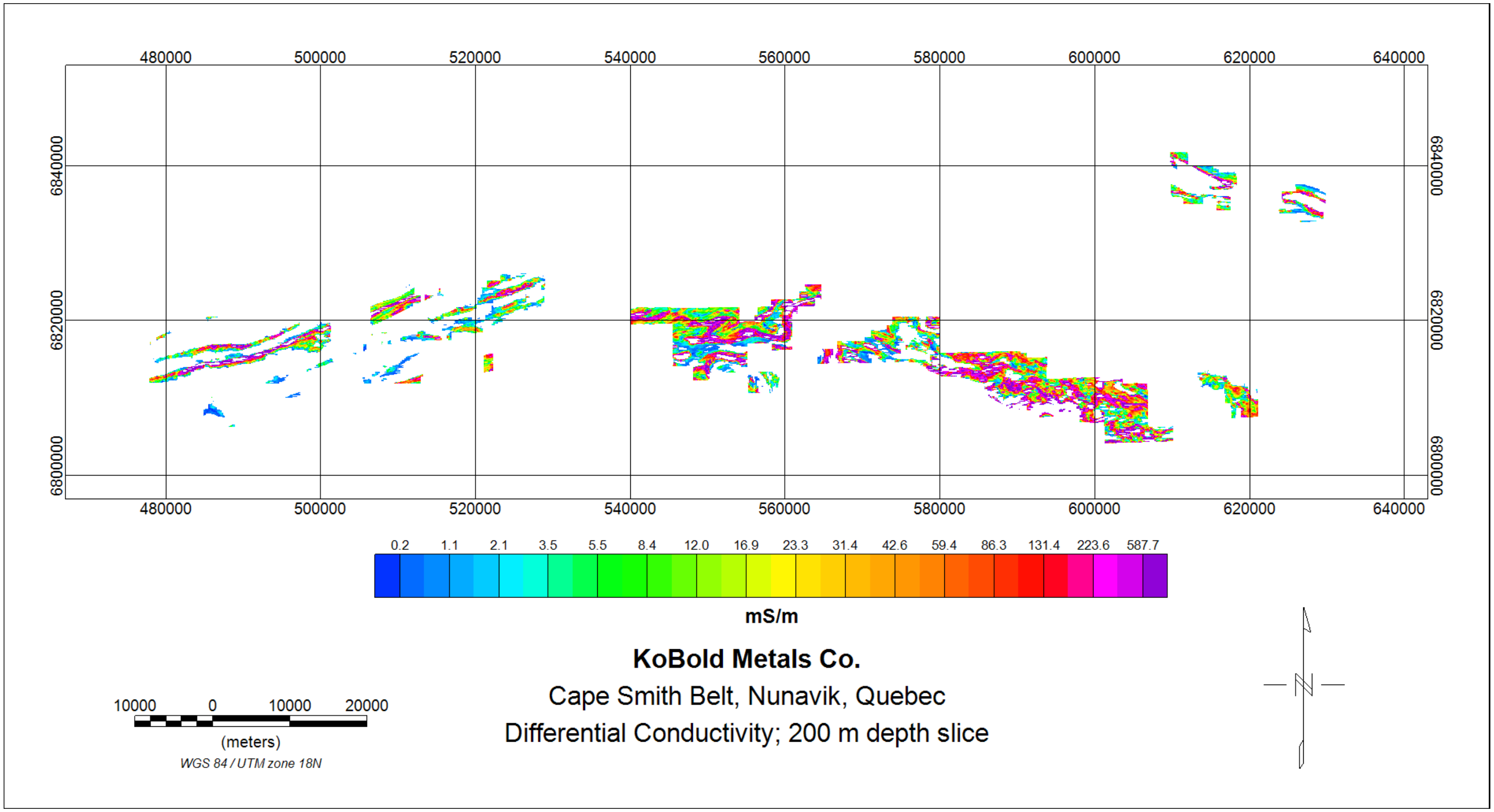


Figure 14 Differential Conductivity 200 m depth slice
2021 and 2022 survey data shown

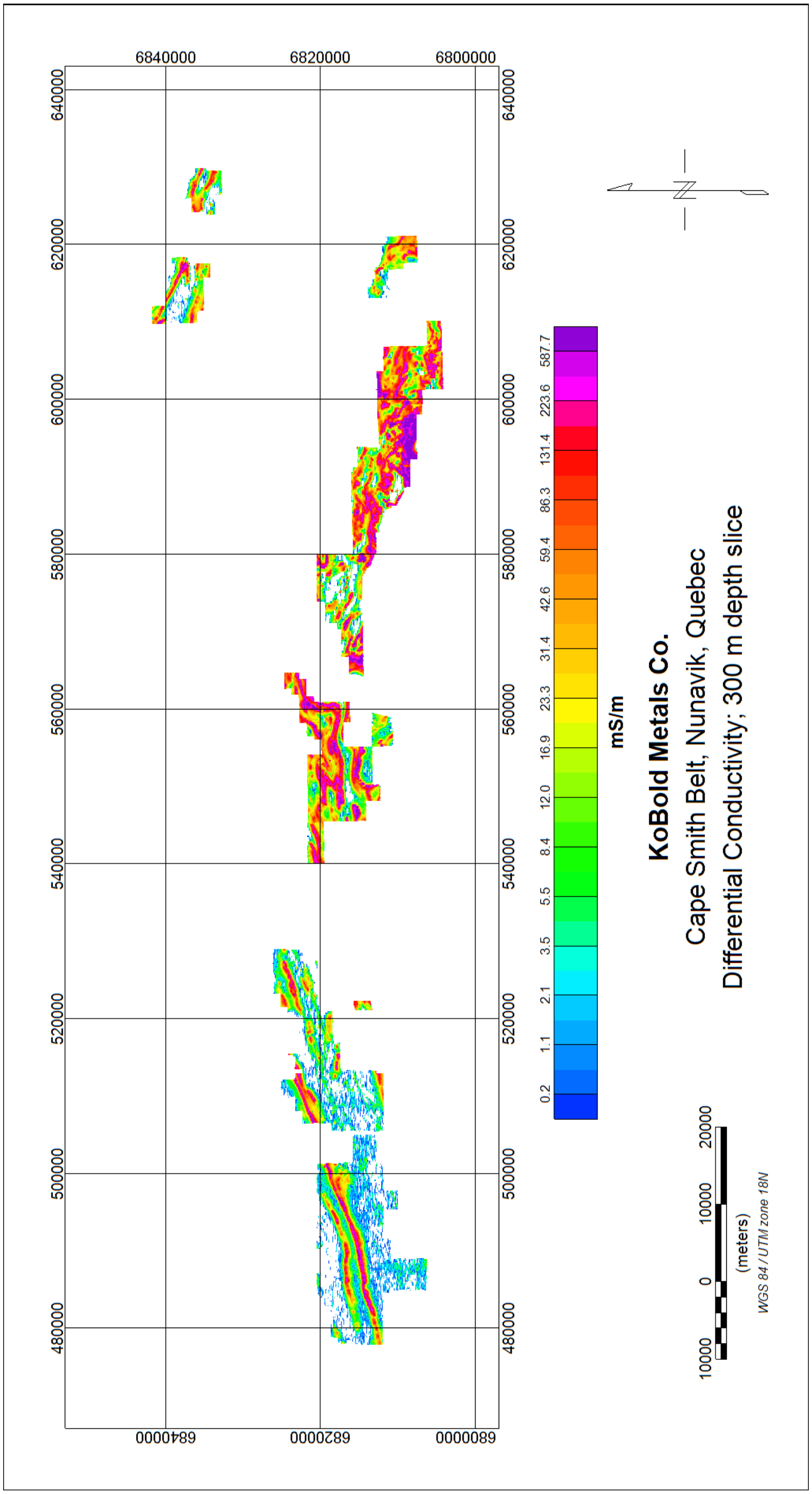
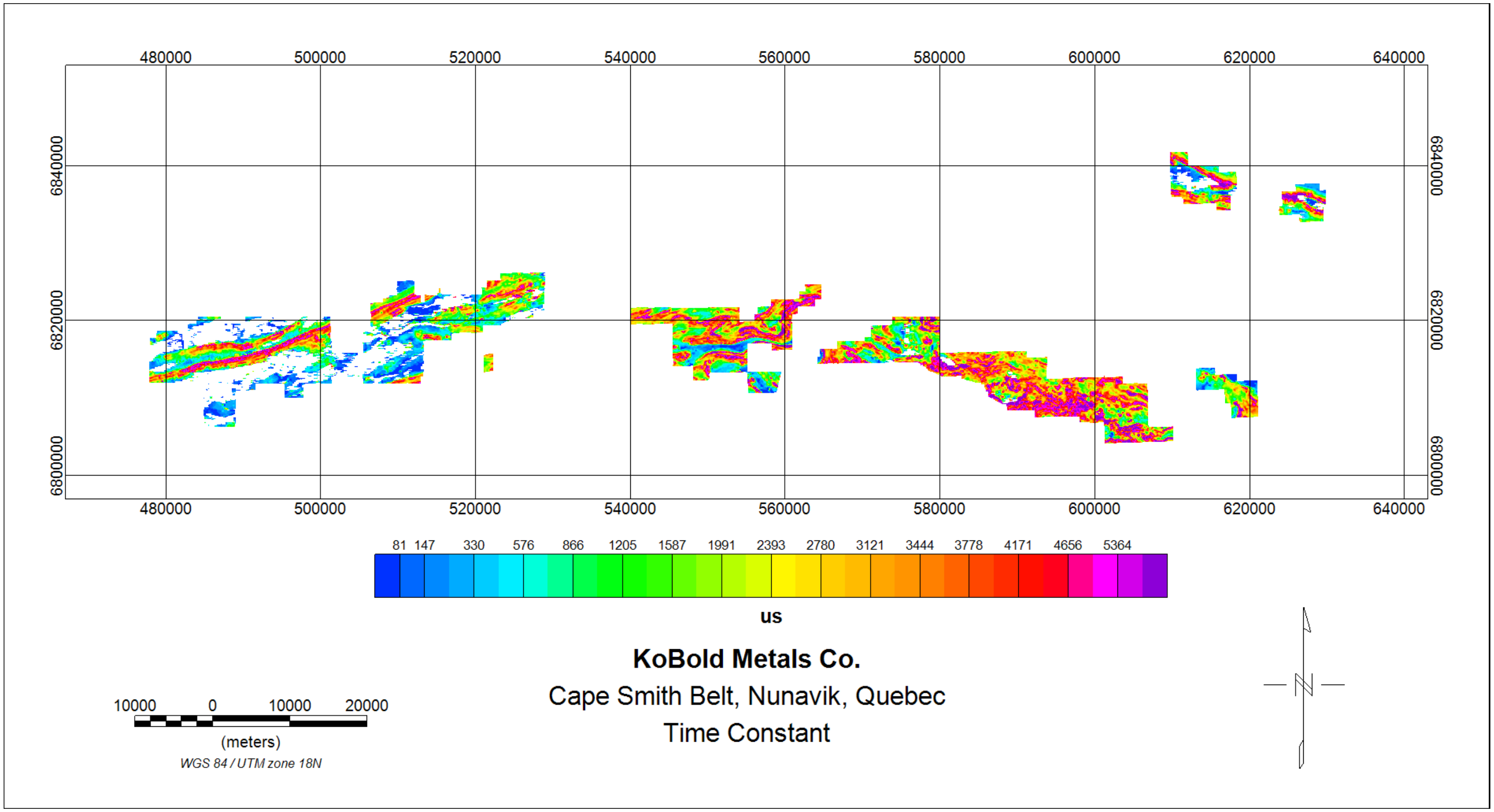


Figure 15 Differential Conductivity 300 m depth slice
2021 and 2022 survey data shown

Figure 16 Time constant
2021 and 2022 survey data shown



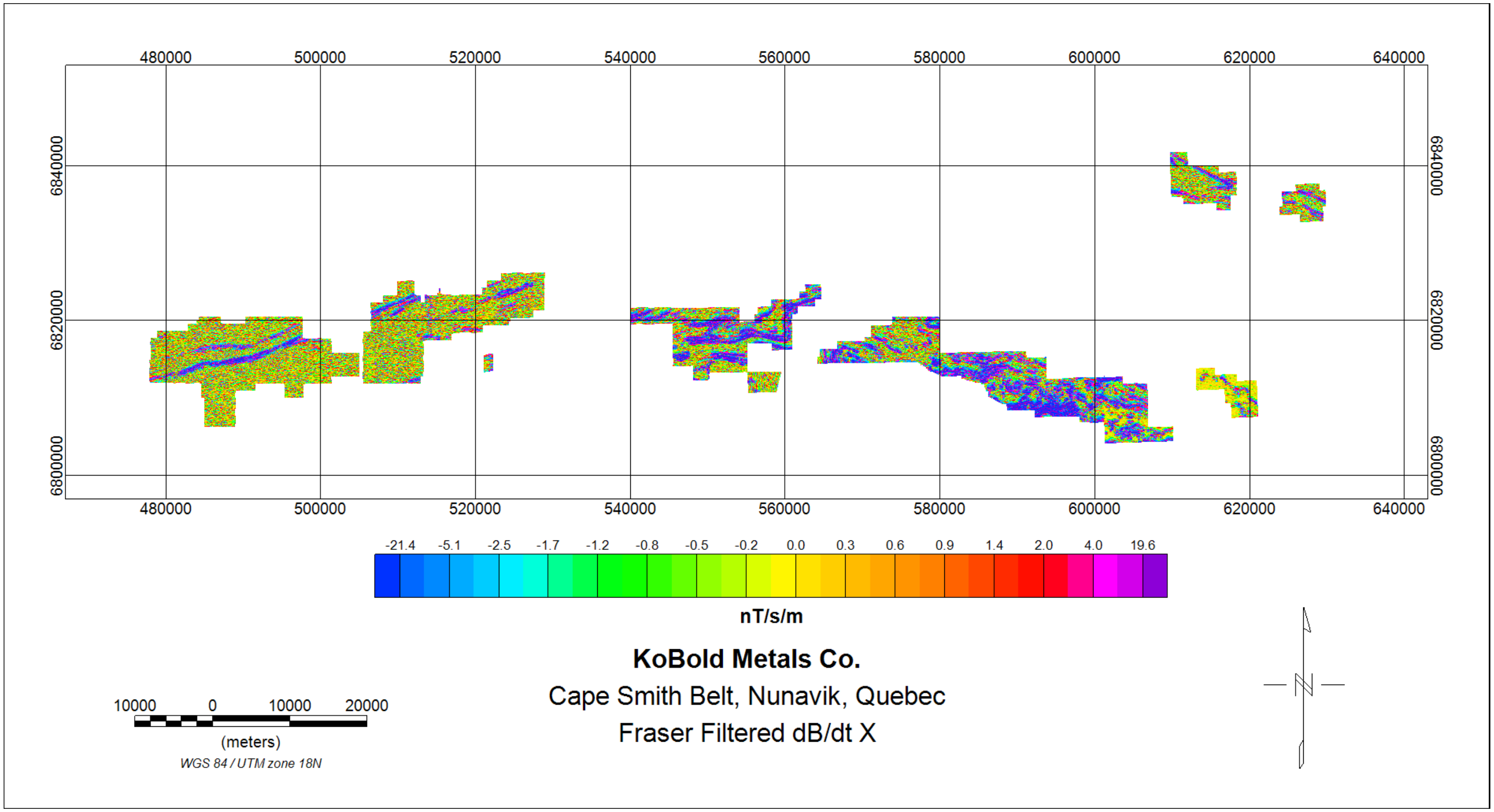


Figure 17 Fraser Filtered dB/dt X
2021 and 2022 survey data shown

Appendix D Helicopter Airborne Electromagnetic Systems

General

The operation of a helicopter time-domain electromagnetic system (HELITEM™) involves the measurement of decaying secondary electromagnetic fields induced in the ground by a series of short current pulses generated from a towed transmitter. Variations in the decay characteristics of the secondary field (sampled and displayed as windows) are analyzed and interpreted to provide information about the subsurface geology.

A number of factors combine to give the helicopter platforms good signal-to-noise ratio, depth of penetration and excellent resolution: 1) the principle of sampling the induced secondary field in the absence of the primary field (during the "off-time"), 2) the large dipole moment 3) the low flying height of the system and spatial proximity of the transmitter and receiver. Such a system is also relatively insensitive to noise due to air turbulence. However, sampling in the "on-time" can also result in excellent sensitivity for mapping very resistive features and very conductive geologic features (Annan et al, 1991, Geophysics v.61, p. 93-99).

Methodology

The Xcalibur time-domain helicopter electromagnetic system (HELITEM™) uses a high-speed digital EM receiver. The primary electromagnetic pulses are created by a series of discontinuous square current pulses fed into a transmitting loop towed below the helicopter. The base frequency rate is selectable, with 6.25, 7.5, 12.5, 15, 25, 30, 75 and 90 currently being available. The length of the pulse can be tailored to suit the targets. Standard pulse widths can be tailored to anywhere from 4 ms to 40ms. The amount of off-time is dependent on the pulse frequency. The dipole moment depends on the pulse width and base frequency used on the survey. The specific dipole moment, waveform and gate settings for this survey are given in the main body of the report.

The receiver sensor is a three-axis (x, y & z) induction coil set housed in a platform suspended on the tow cable below the helicopter and above the transmitter. The tow cable is non-magnetic to reduce noise levels. The tow cable is 40 m long. The receiver is 0.1 m above and 0.0 m ahead of the transmitter in flight.

For each primary pulse a secondary magnetic field is produced by decaying eddy currents in the ground. These in turn induce a voltage in the receiver coils, which is the electromagnetic response. Good conductors decay slowly, poorer conductors more rapidly.

Operations, which are carried out in the receiver, are:

1. *Primary-field removal:* In addition to measuring the secondary response from the ground, the receiver sensor coils also measure the primary response from the transmitter. During flight, the receiver sensor position and orientation changes slightly, and this has a very strong effect on the magnitude of the total response (primary plus secondary) measured at the receiver coils. The variable primary field response is distracting because it is unrelated to the ground response. The primary field is measured by flying at an altitude such that no ground response is measurable. These calibration signals are used to define the shape of the primary waveform. By definition this primary field includes the response of the current in the transmitter loop plus the response of any slowly decaying eddy currents induced in the helicopter. We assume that the shape of the primary will not change as the receiver sensor position changes, but that the amplitude will vary. The primary-field-removal procedure involves solving for the amplitude of the primary field in the measured response and removing this from the total response to leave a secondary response. Note that this procedure removes any "in-phase" response from the ground which has the same shape as the primary field.

2. *Digital Stacking:* Stacking is carried out to reduce the effect of broadband noise in the data.

3. *Windowing of data*: The digital receiver samples the secondary and primary electromagnetic field at 2048, 4096 or 8192 points per EM pulse and windows the signal in up to 30 square time gates whose

centres and widths are software selectable and which may be placed anywhere within or outside the transmitter pulse. This flexibility offers the advantage of arranging the gates to suit the goals of a particular survey, ensuring that the signal is appropriately sampled through its entire dynamic range.

4. *Primary Field:* The primary field at the receiver sensor is measured for each stack and recorded as a separate data channel to assess the variation in coupling between the transmitter and the receiver sensor induced by changes in system geometry.

One of the major roles of the digital receiver is to provide diagnostic information on system functions and to allow for identification of noise events, such as sferics, which may be selectively removed from the EM signal. The high digital sampling rate yields maximum resolution of the secondary field.

System Hardware

The airborne EM system consists of the helicopter, the on-board hardware, and the software packages controlling the hardware.

Transmitter System

The transmitter system drives high-current pulses of an appropriate shape and duration through the coils towed below the helicopter.

System Timing Clock

This subsystem provides appropriate timing signals to the transmitter, and also to the analog-to-digital converter, in order to produce output pulses and capture the ground response. All systems are synchronized to GPS time.

Platform Systems

A three-axis induction coil sensor is mounted inside a platform on the tow cable. The platform is connected to the transmitter loop through a network of cables to ensure a more robust and better stability of the transmitter-receiver geometry. A magnetometer sensor is attached to the transmitter loop near its centre.

Appendix E Airborne Transient EM Interpretation

Introduction

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

The HELITEM™ airborne transient (or time-domain) EM system incorporates a high-speed digital receiver which records the secondary field response with a high degree of accuracy. Most often the earth's total magnetic field is recorded concurrently.

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

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

Types of Conductors

Bedrock Conductors

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

1. *Graphites*. Graphitic horizons (including a large variety of carbonaceous rocks) occur in sedimentary formations of the Precambrian as well as in volcanic tuffs, often concentrated in shear zones. They correspond generally to long, multiple conductors lying in parallel bands. They have no magnetic expression unless associated with pyrrhotite or magnetite. Their conductivity is variable but generally high.
2. *Massive sulphides*. Massive sulphide deposits usually manifest themselves as short conductors of high conductivity, often with a coincident magnetic anomaly. Some massive sulphides, however, are not magnetic, others are not very conductive (discontinuous mineralization or sphalerite), and some may be located among formational conductors so that one must not be too rigid in applying the selection criteria.

   In addition, there are syngenetic sulphides whose conductive pattern may be similar to that of graphitic horizons but these are generally not as prevalent as graphites.
3. *Magnetite and some serpentinized ultrabasics*. These rocks are conductive and very magnetic.
4. *Manganese oxides*. This mineralization may give rise to a weak EM response.

Surficial Conductors

1. Beds of clay and alluvium, some swamps, and brackish ground water are usually poorly conductive to moderately conductive.
2. Lateritic formations, residual soils and the weathered layer of the bedrock may cause surface anomalous zones, the conductivity of which is generally low to medium but can occasionally be high. Their presence is often related to the underlying bedrock.

Cultural Conductors (Man-Made)

3. *Power lines*. These frequently, but not always, produce a conductive type of response. In the case when the radiated field is not removed by the power line comb filter, the anomalous response can exhibit phase changes between different windows. In the case of current induced by the EM system in a grounded wire, or steel pylon, the anomaly may look very much like a bedrock conductor.

   The power line monitor gives the amplitude of the received signal at the power line frequency (50 or 60 Hz). Appropriate selection of the base frequency (such that the power line frequency is an even harmonic of the base frequency) and tapered stacking combine to strongly attenuate power line signals. When passing directly over a power line, the rapid lateral variations in the strength and direction of the magnetic fields associated with the power line can result in imperfect cancellation of the power line response during stacking. Some power line related interference can manifest itself in a form that is similar to the response of a discrete conductor. The exact form of the monitor profile over a power line depends on the flight line direction, power line direction, power line current, and receiver component, but the monitor will show a general increase in amplitude approaching the power line.

   Grids (or images) of the power line monitor reveal the location of the transmission lines. Note that the X component (horizontal receiver coil axis parallel with the flight line direction) does not register any response from power lines parallel to the flight line direction since the magnetic fields associated with power lines only vary in a direction perpendicular to the power line. Note also that the Y component (horizontal receiver coil axis perpendicular to the flight line direction) is sensitive to power lines parallel to the flight direction.

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

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

Analysis of the Conductors

The rate of decay of a conductor is generally indicative of the conductivity of the anomalous material. However, the decay rate alone is not generally a decisive criterion in the analysis of a conductor. In particular, one should note:

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

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

Bedrock Conductors

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

1. An intermediate to high conductivity identified by a response with slow decay, with an anomalous response present in the later windows.

2. For vertical conductors, the anomaly should be narrow, relatively symmetrical, with two well-defined z-component peaks and a null between the peaks.
3. If the conductor is thin, the response characteristics varies as a function of depth and dips. If the conductor is wider, the responses might look more similar to the sphere responses.

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

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

6. An associated magnetic response of similar dimensions. One should note, however, that those magnetic rocks which weather to produce a conductive upper layer will possess this magnetic association. In the absence of one or more of the characteristics defined in 1, 2, 3, 4 and 5, the related magnetic response cannot be considered significant.

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

In summary, a bedrock conductor reflecting the presence of a massive sulphide would normally exhibit the following characteristics:

- a high conductivity,
- an appropriate anomaly shape,
- a small to intermediate amplitude,
- an isolated setting,
- a short strike length (in general, not exceeding one kilometre), and
- preferably, with a localized magnetic anomaly of matching dimensions.

Surficial Conductors

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

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

When surficial conductivity is high it is usually still possible to distinguish between a horizontal plate (more likely to be surficial material) and a vertical body (more likely to be a bedrock source) thanks to the characteristic shapes of the two anomalies and the differences in the x-component responses.

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

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

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

Cultural Conductors

The majority of cultural anomalies occur along roads and are accompanied by a response on the power line monitor. This monitor is set to 50 or 60 Hz, depending on the local power grid. In some cases, the current induced in the power line results in anomalies which could be mistaken for bedrock responses. There are also some power lines which have no response whatsoever.

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

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

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

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

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

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

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

Appendix F Multicomponent Modeling

PLATE MODELING

The CSIRO Leroi plate program has been used to generate synthetic responses over a number of plate models with a burial depth of 50 m and varying dips (0, 45, 90 and 135 degrees). The geometry of the HELITEM™ system is with the receiver located in the centre of the loop with a 0.1 m vertical separation above the loop. In all cases the plate has a strike length of 300 m perpendicular to flight direction. The depth extent of the plate is 100 m. As the flight path traverses the center of the plate, the Y component is zero and has not been plotted.

The plate responses are plotted using the receiver location. GPS position in the data archive is referenced to the helicopter tail, 8.0 m in front of the receiver.

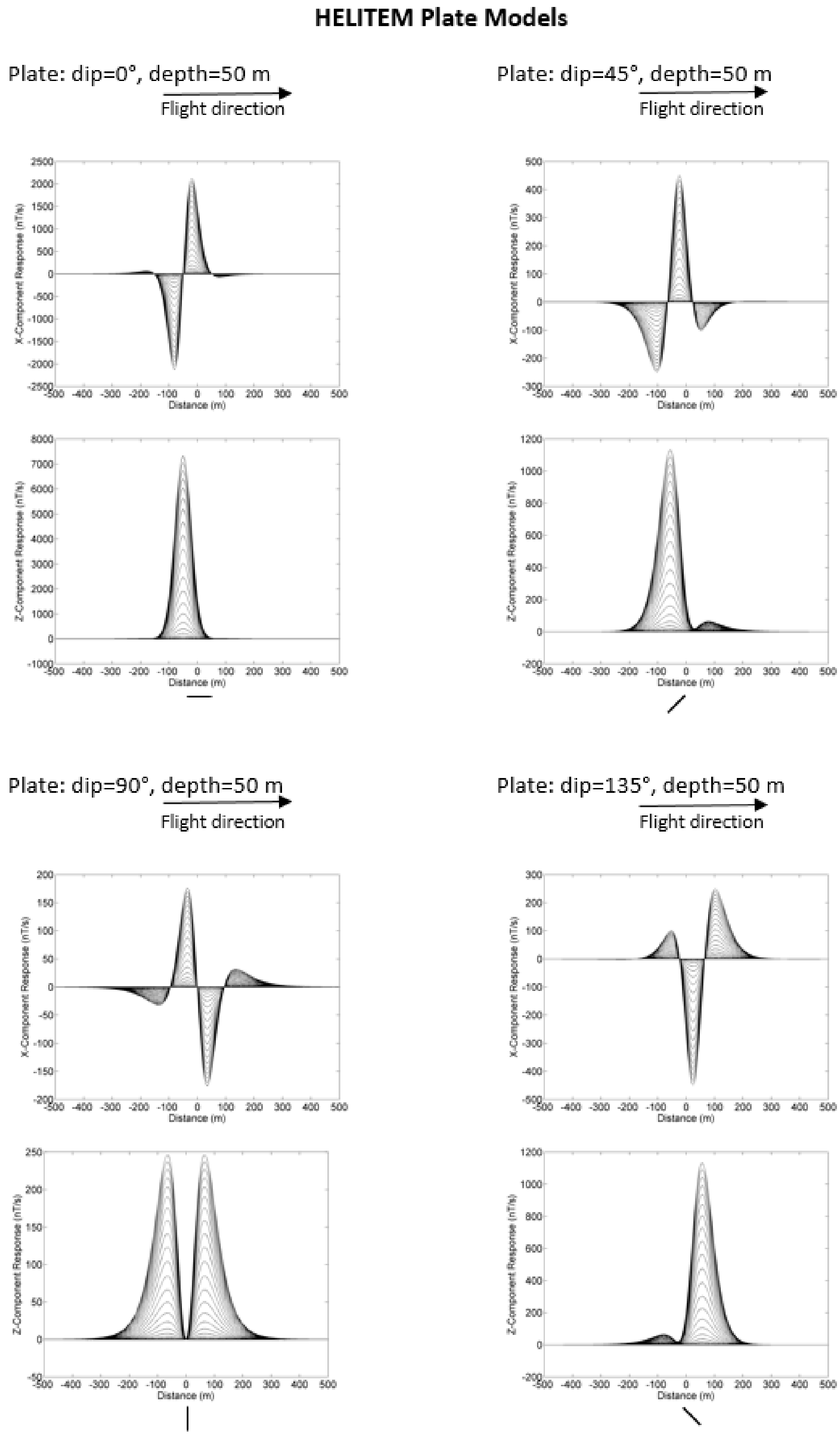


Figure 18 Plate model with a flying direction of left to right

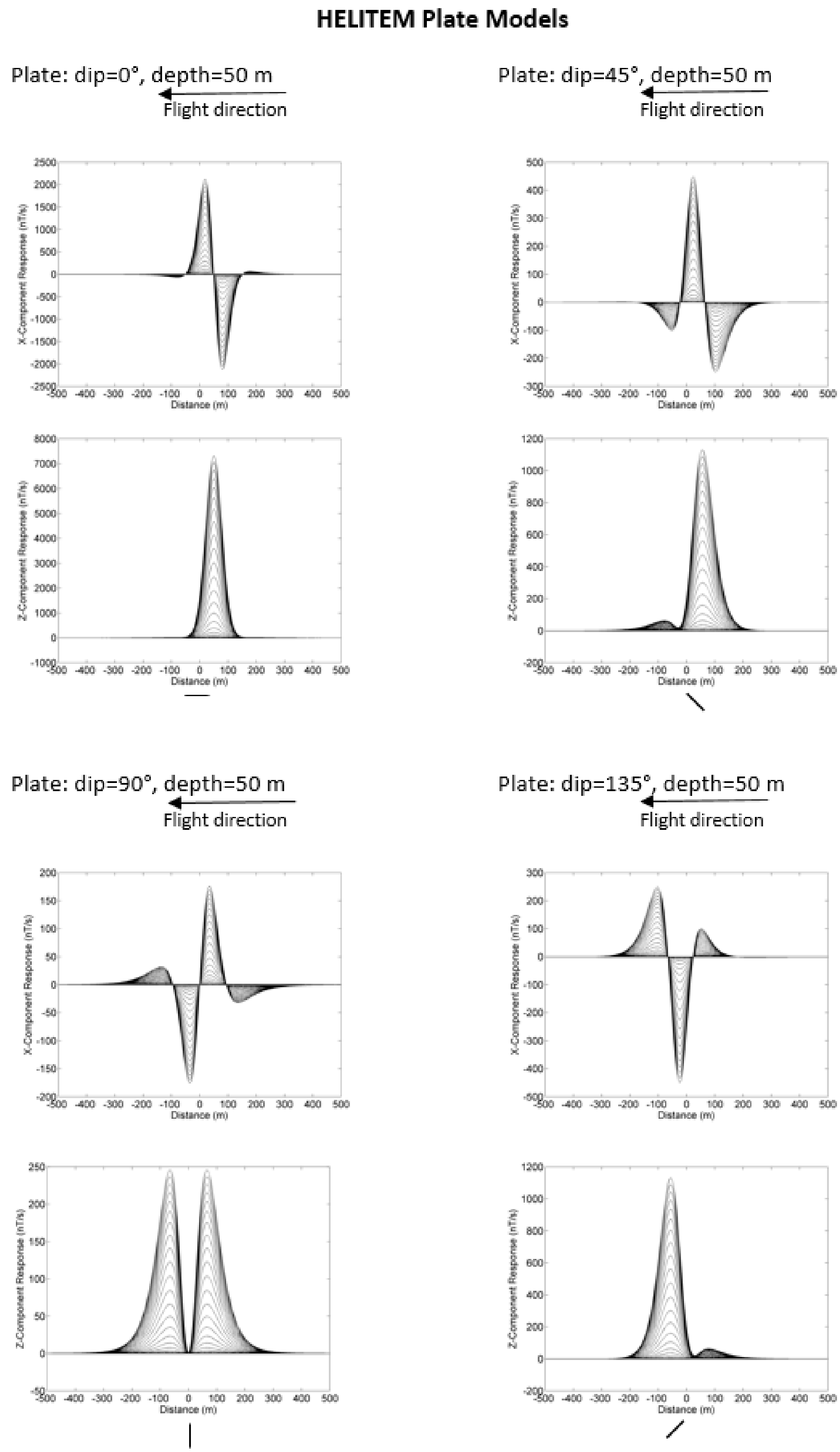


Figure 19 Plate model with flying direction from right to left

Appendix G Glossary

Xcalibur GLOSSARY OF AIRBORNE GEOPHYSICAL TERMS

accelerometer: an instrument that measures both acceleration (due to motion) and acceleration due to ***gravity***.

altitude attenuation: the absorption of gamma rays by the atmosphere between the earth and the detector. The number of gamma rays detected by a system decreases as the altitude increases.

AGG: Airborne ***gravity gradiometer.***

AGS: Airborne ***gamma-ray spectrometry***.

amplitude: The strength of the total electromagnetic field. In ***frequency domain*** it is most often the sum of the squares of ***in-phase*** and ***quadrature*** components. In multi-component electromagnetic surveys it is generally the sum of the squares of all three directional components.

analytic signal: The total amplitude of all the directions of magnetic ***gradient***. Calculated as the sum of the squares.

anisotropy: Having different ***physical parameters*** in different directions. This can be caused by layering or fabric in the geology. Note that a unit can be anisotropic, but still **homogeneous**.

anomaly: A localized change in the geophysical data characteristic of a discrete source, such as a conductive or magnetic body: something locally different from the **background**.

apparent- : the ***physical parameters*** of the earth measured by a geophysical system are normally expressed as apparent, as in "apparent ***resistivity*****"**. This means that the measurement is limited by assumptions made about the geology in calculating the response measured by the geophysical system. Apparent resistivity calculated with ***HEM***, for example, generally assumes that the earth is a ***homogeneous half-space*** – not layered.

attitude: the orientation of a geophysical system relative to the earth. Some surveys assume the instrument attitudes are constant, and other surveys measure the attitude and correct the data for the changes in response because of attitude.

B-field: In time-domain **electromagnetic** surveys, the magnetic field component of the (electromagnetic) **field**. This can be measured directly, although more commonly it is calculated by integrating the time rate of change of the magnetic field **dB/dt**, as measured with a receiver coil.

background: The "normal" response in the geophysical data – that response observed over most of the survey area. **Anomalies** are usually measured relative to the background. In airborne gamma-ray spectrometric surveys the term defines the **cosmic**, radon, and aircraft responses in the absence of a signal from the ground.

base-level: The measured values in a geophysical system in the absence of any outside signal. All geophysical data are measured relative to the system base level.

base frequency: The frequency of the pulse repetition for a ***time-domain electromagnetic*** system. Measured between subsequent positive pulses.

base magnetometer: A stationary magnetometer used to record the ***diurnal*** variations in the earth's magnetic field; to be used to correct the survey magnetic data.

bird: A common name for the pod towed beneath or behind an aircraft, carrying the geophysical sensor array.

bucking: The process of removing the strong ***signal*** from the ***primary field*** at the ***receiver*** from the data, to measure the ***secondary field***. It can be done electronically or mathematically. This is done in ***frequency-domain EM***, and to measure ***on-time*** in ***time-domain EM***.

calibration: a procedure to ensure a geophysical instrument is measuring accurately and repeatably. Most often applied in ***EM*** and ***gamma-ray spectrometry***.

calibration coil: A wire coil of known size and dipole moment, which is used to generate a field of known ***amplitude*** and ***phase*** or ***decay constant*** in the receiver, for system calibration. Calibration coils can be external, or internal to the system. Internal coils may be called Q-coils.

coaxial coils: **[CX]** Coaxial coils in an HEM system are in the vertical plane, with their axes horizontal and collinear in the flight direction. These are most sensitive to vertical conductive objects in the ground, such as thin, steeply dipping conductors perpendicular to the flight direction. Coaxial coils generally give the sharpest anomalies over localized conductors. (See also ***coplanar coils***)

coil: A multi-turn wire loop used to transmit or detect electromagnetic fields. Time varying ***electromagnetic*** fields through a coil induce a voltage proportional to the strength of the field and the rate of change over time.

compensation: Correction of airborne geophysical data for the changing effect of the aircraft. This process is generally used to correct data in ***fixed-wing time-domain electromagnetic*** surveys (where the transmitter is on the aircraft and the receiver is moving), and magnetic surveys (where the sensor is on the aircraft, turning in the earth's magnetic field.

component: In ***frequency domain electromagnetic*** surveys this is one of the two **phase** measurements – ***in-phase or quadrature***. In "multi-component" electromagnetic surveys it is also used to define the measurement in one geometric direction (vertical, horizontal in-line and horizontal transverse – the Z, X and Y components).

Compton scattering: gamma ray photons will bounce off electrons as they pass through the earth and atmosphere, reducing their energy and then being detected by ***radiometric*** sensors at lower energy levels. See also ***stripping***.

conductance: See ***conductivity thickness***

conductivity: [σ] The facility with which the earth or a geological formation conducts electricity. Conductivity is usually measured in milli-Siemens per metre (mS/m). It is the reciprocal of ***resistivity***.

conductivity-depth imaging: see ***conductivity-depth transform***.

conductivity-depth transform: A process for converting electromagnetic measurements to an approximation of the conductivity distribution vertically in the earth, assuming a ***layered earth***. (Macnae and Lamontagne, 1987; Wolfgram and Karlik, 1995)

conductivity thickness: [σ**t**] The product of the ***conductivity***, and thickness of a large, tabular body. (It is also called the "conductivity-thickness product"). In electromagnetic geophysics, the response of a thin plate-like conductor is proportional to the conductivity multiplied by thickness. For example, a 10-metre thickness of 20 Siemens/m mineralization will be equivalent to 5 metres of 40 S/m; both have 200 S conductivity thickness. Sometimes referred to as conductance.

conductor: Used to describe anything in the ground more conductive than the surrounding geology. Conductors are most often clays or graphite, or hopefully some type of mineralization, but may also be man-made objects, such as fences or pipelines.

continuation: mathematical procedure applied to ***potential field*** geophysical data to approximate data collected at a different altitude. Data can be continued upward to a higher altitude or downward to a lower altitude.

coplanar coils: **[CP]** In HEM, the coplanar coils lie in the horizontal plane with their axes vertical, and parallel. These coils are most sensitive to massive conductive bodies, horizontal layers, and the ***halfspace***.

cosmic ray: High energy sub-atomic particles from outer space that collide with the earth's atmosphere to produce a shower of gamma rays (and other particles) at high energies.

counts (per second): The number of ***gamma-rays*** detected by a gamma-ray ***spectrometer*****.** The rate depends on the geology, but also on the size and sensitivity of the detector.

culture: A term commonly used to denote any man-made object that creates a geophysical anomaly. Includes, but not limited to, power lines, pipelines, fences, and buildings.

current channelling: See current gathering.

current gathering: The tendency of electrical currents in the ground to channel into a conductive formation. This is particularly noticeable at higher frequencies or early time channels when the formation is long and parallel to the direction of current flow. This tends to enhance anomalies relative to inductive currents (see also ***induction***). Also known as current channelling.

daughter products: The radioactive natural sources of gamma-rays decay from the original "parent" element (commonly potassium, uranium, and thorium) to one or more lower-energy "daughter" elements. Some of these lower energy elements are also radioactive and decay further. ***Gamma-ray spectrometry*** surveys may measure the gamma rays given off by the original element or by the decay of the daughter products.

dB/dt: As the ***secondary electromagnetic field*** changes with time, the magnetic field [**B**] component induces a voltage in the receiving ***coil***, which is proportional to the rate of change of the magnetic field over time.

decay: In ***time-domain electromagnetic*** theory, the weakening over time of the ***eddy currents*** in the ground, and hence the ***secondary field*** after the ***primary field*** electromagnetic pulse is turned off. In ***gamma-ray spectrometry***, the radioactive breakdown of an element, generally potassium, uranium, thorium, into their ***daughter*** products.

decay constant: see time constant.

decay series: In ***gamma-ray spectrometry***, a series of progressively lower energy ***daughter products*** produced by the radioactive breakdown of uranium or thorium.

depth of exploration: The maximum depth at which the geophysical system can detect the target. The depth of exploration depends very strongly on the type and size of the target, the contrast of the target with the surrounding geology, the homogeneity of the surrounding geology, and the type of geophysical system. One measure of the maximum depth of exploration for an electromagnetic system is the depth at which it can detect the strongest conductive target – generally a highly conductive horizontal layer.

differential resistivity: A process of transforming ***apparent resistivity*** to an approximation of layer resistivity at each depth. The method uses multi-frequency HEM data and approximates the effect of shallow layer ***conductance*** determined from higher frequencies to estimate the deeper conductivities (Huang and Fraser, 1996)

dipole moment: [NIA] For a transmitter, the product of the area of a ***coil***, the number of turns of wire, and the current flowing in the coil. At a distance significantly larger than the size of the coil, the magnetic field from a coil will be the same if the dipole moment product is the same. For a receiver coil, this is the product of the area and the number of turns. The sensitivity to a magnetic field (assuming the source is far away) will be the same if the dipole moment is the same.

diurnal: The daily variation in a natural field, normally used to describe the natural fluctuations (over hours and days) of the earth's magnetic field.

dielectric permittivity: **[ε]** The capacity of a material to store electrical charge, this is most often measured as the relative permittivity [ε_r], or ratio of the material dielectric to that of free space. The effect of high permittivity may be seen in HEM data at high frequencies over highly resistive geology as a reduced or negative ***in-phase***, and higher ***quadrature*** data.

dose rate: see **exposure rate**.

drape: To fly a survey following the terrain contours, maintaining a constant altitude above the local ground surface. Also applied to re-processing data collected at varying altitudes above ground to simulate a survey flown at constant altitude.

drift: Long-time variations in the base-level or calibration of an instrument.

eddy currents: The electrical currents induced in the ground, or other conductors, by a time-varying ***electromagnetic field*** (usually the ***primary field***). Eddy currents are also induced in the aircraft's metal frame and skin; a source of ***noise*** in EM surveys.

electromagnetic: **[EM]** Comprised of a time-varying electrical and magnetic field. Radio waves are common electromagnetic fields. In geophysics, an electromagnetic system is one which transmits a time-varying ***primary field*** to induce ***eddy currents*** in the ground, and then measures the ***secondary field*** emitted by those eddy currents.

energy window: A broad spectrum of ***gamma-ray*** energies measured by a spectrometric survey. The energy of each gamma-ray is measured and divided up into numerous discrete energy levels, called windows.

equivalent (thorium or uranium): The amount of radioelement calculated to be present, based on the gamma-rays measured from a **daughter** element. This assumes that the ***decay series*** is in equilibrium – progressing normally.

exposure rate: in radiometric surveys, a calculation of the total exposure rate due to gamma rays at the ground surface. It is used as a measurement of the concentration of all the **radioelements** at the surface. Sometimes called "dose rate".See also: **natural exposure rate**.

fiducial, or fid: Timing mark on a survey record. Originally these were timing marks on a profile or film; now the term is generally used to describe 1-second interval timing records in digital data, and on maps or profiles.

Figure of Merit: **(FOM)** A sum of the 12 distinct magnetic noise variations measured by each of four flight directions, and executing three aircraft attitude variations (yaw, pitch, and roll) for each direction. The flight directions are generally parallel and perpendicular to planned survey flight directions. The FOM is used as a measure of the **manoeuvre noise** before and after **compensation.**

fixed-wing: Aircraft with wings, as opposed to "rotary wing" helicopters.

flight: a continuous interval of survey data collection, generally between stops at base to refuel.

flight-line: a single line of data across the survey area. Surveys are generally comprised of many parallel flight lines to cover the survey area, with wider-spaced ***tie lines*** perpendicular. Flight lines are generally separated by ***turn-arounds*** when the aircraft is outside the survey area.

footprint: This is a measure of the area of sensitivity under the aircraft of an airborne geophysical system. The footprint of an ***electromagnetic*** system is dependent on the altitude of the system, the orientation of the transmitter and receiver and the separation between the receiver and transmitter, and the conductivity of the ground. The footprint of a ***gamma-ray spectrometer*** depends mostly on the altitude. For all geophysical systems, the footprint also depends on the strength of the contrasting ***anomaly***.

frequency domain: An ***electromagnetic*** system which transmits a harmonic ***primary field*** that oscillates over time (e.g., sinusoidal), inducing a similarly varying electrical current in the ground. These systems generally measure the changes in the ***amplitude*** and ***phase*** of the ***secondary field*** from the ground at different frequencies by measuring the **in-phase** and **quadrature** phase components. See also ***time-domain***.

full-stream data: Data collected and recorded continuously at the highest possible sampling rate. Normal data are stacked (see ***stacking***) over some time interval before recording.
gamma-ray: A very high-energy photon, emitted from the nucleus of an atom as it undergoes a change in energy levels.

gamma-ray spectrometry: Measurement of the number and energy of natural (and sometimes man-made) gamma-rays across a range of photon energies.

GGI: gravity gradiometer instrument. An airborne gravity gradiometer (AGG) consists of a GGI mounted in an inertial platform together with a temperature control system.

gradient: In magnetic surveys, the gradient is the change of the magnetic field over a distance, either vertically or horizontally in either of two directions. Gradient data can be measured or calculated from the total magnetic field data because it changes more quickly over distance than the ***total magnetic field***, and so may provide a more precise measure of the location of a source. See also ***analytic signal***.

gradiometer, gradiometry: instrument and measurement of the gradient, or change in a field with location usually for ***gravity*** or ***magnetic*** surveys. Used to provide higher resolution of ***targets***, better ***interpretation*** of ***target*** geometry, independence from drift and absolute field and, for ***gravity***, accelerations of the aircraft.

gravity: Survey collecting measurements of the earth's gravitational field strength. Denser objects in the earth create stronger gravitational pull above them.

ground effect: The response from the earth. A common ***calibration*** procedure in many geophysical surveys is to fly to altitude high enough to be beyond any measurable response from the ground, and there establish ***base levels*** or ***backgrounds***.

half-space: A mathematical model used to describe the earth – as infinite in width, length, and depth below the surface. The most common halfspace models are ***homogeneous*** and ***layered earth***.

heading error: A slight change in the magnetic field measured when flying in opposite directions.

HEM: Helicopter ElectroMagnetic, This designation is most commonly used for helicopter-borne, ***frequency-domain*** electromagnetic systems. At present, the transmitter and receivers are normally mounted in a ***bird*** carried on a sling line beneath the helicopter.

herringbone pattern: A pattern created in geophysical data by an asymmetric system, where the **anomaly** may be extended to either side of the source, in the direction of flight. Appears like fish bones, or like the teeth of a comb, extending either side of centre, each tooth an alternate flight line.

homogeneous: This is a geological unit that has the same ***physical parameters*** throughout its volume. This unit will create the same response to an HEM system anywhere, and the HEM system will measure the same apparent ***resistivity*** anywhere. The response may change with system direction (see ***anisotropy***).

HFEM: Helicopter Frequency-domain ElectroMagnetic, This designation is used for helicopter-borne, **frequency-*domain*** electromagnetic systems. Formerly most often called HEM.

HTEM: Helicopter Time-domain ElectroMagnetic, This designation is used for the new generation of helicopter-borne, ***time-domain*** electromagnetic systems.

in-phase: the component of the measured ***secondary field*** that has the same phase as the transmitter and the ***primary field***. The in-phase component is stronger than the ***quadrature*** phase over relatively higher ***conductivity***.

induction: Any time-varying electromagnetic field will induce (cause) electrical currents to flow in any object with non-zero ***conductivity***. (see ***eddy currents***)

induction number: also called the “response parameter”, this number combines many of the most significant parameters affecting the ***EM*** response into one parameter against which to compare responses. For a ***layered earth*** the response parameter is $\mu\omega\sigma h^2$ and for a large, flat, ***conductor*** it is $\mu\omega\sigma t h$, where μ is the ***magnetic permeability***, ω is the angular ***frequency***, σ is the **conductivity**, t is the thickness (for the flat conductor) and h is the height of the system above the conductor.

inductive limit: When the frequency of an EM system is very high, or the **conductivity** of the target is very high, the response measured will be entirely **in-phase** with no **quadrature** (**phase** angle =0). The in-phase response will remain constant with further increase in conductivity or frequency. The system can no longer detect changes in conductivity of the target.

infinite: In geophysical terms, an “infinite’ dimension is one much greater than the ***footprint*** of the system, so that the system does not detect changes at the edges of the object.

International Geomagnetic Reference Field: **[IGRF]** An approximation of the smooth magnetic field of the earth, in the absence of variations due to local geology. Once the IGRF is subtracted from the measured magnetic total field data, any remaining variations are assumed to be due to local geology. The IGRF also predicts the slow changes of the field up to five years in the future.

inversion, or **inverse modeling**: A process of converting geophysical data to an earth model, which compares theoretical models of the response of the earth to the data measured, and refines the model until the response closely fits the measured data (Huang and Palacky, 1991)

layered earth: A common geophysical model which assumes that the earth is horizontally layered – the ***physical parameters*** are constant to ***infinite*** distance horizontally but change vertically.

lead-in: approach to a ***flight line*** outside of survey area to establish proper track and stabilize instrumentations. The lead-in for a helicopter survey is generally shorter than required for fixed-wing.

line source, or line current: a long narrow object that creates an ***anomaly*** on an ***EM*** survey. Generally man-made objects like fences, power lines, and pipelines (***culture***).

mag: common abbreviation for ***magnetic.***

magnetic: ("**mag**") a survey measuring the strength of the earth's magnetic field, to identify geology and targets by their effect on the field.

magnetic permeability: **[μ]** This is defined as the ratio of magnetic induction to the inducing magnetic field. The relative magnetic permeability [μ_r] is often quoted, which is the ratio of the rock permeability to the permeability of free space. In geology and geophysics, the ***magnetic susceptibility*** is more commonly used to describe rocks.

magnetic susceptibility: **[k]** A measure of the degree to which a body is magnetized. In SI units this is related to relative ***magnetic permeability*** by $k=\mu_r-1$, and is a dimensionless unit. For most geological material, susceptibility is influenced primarily by the percentage of magnetite. It is most often quoted in units of 10^{-6}. In HEM data this is most often apparent as a negative ***in-phase*** component over high susceptibility, high ***resistivity*** geology such as diabase dikes.

manoeuvre noise: variations in the magnetic field measured caused by changes in the relative positions of the magnetic sensor and magnetic objects or electrical currents in the aircraft. This type of noise is generally corrected by magnetic **compensation**.

model: Geophysical theory and applications generally have to assume that the geology of the earth has a form that can be easily defined mathematically, called the model. For example, steeply dipping **conductor**s are generally modeled as being **infinite** in horizontal and depth extent, and very thin. The earth is generally modeled as horizontally layered, each layer infinite in extent and uniform in characteristic. These models make the mathematics to describe the response of the (normally very complex) earth practical. As theory advances, and computers become more powerful, the useful models can become more complex.

natural exposure rate: in radiometric surveys, a calculation of the total exposure rate due to natural-source gamma rays at the ground surface. It is used as a measurement of the concentration of all the natural **radioelements** at the surface. See also: **exposure rate**.

natural source: any geophysical technique for which the source of the energy is from nature, not from a man-made object. Most commonly applied to natural source ***electromagnetic*** surveys.

noise: That part of a geophysical measurement that the user does not want. Typically this includes electronic interference from the system, the atmosphere (***sferics***), and man-made sources. This can be a subjective judgment, as it may include the response from geology other than the target of interest. Commonly the term is used to refer to high frequency (short period) interference. See also ***drift***.

Occam's inversion: an ***inversion*** process that matches the measured ***electromagnetic*** data to a theoretical model of many, thin layers with constant thickness and varying resistivity (Constable et al, 1987).

off-time: In a ***time-domain electromagnetic*** survey, the time after the end of the ***primary field pulse***, and before the start of the next pulse.

on-time: In a ***time-domain electromagnetic*** survey, the time during the ***primary field pulse***.

overburden: In engineering and mineral exploration terms, this most often means the soil on top of the unweathered bedrock. It may be sand, glacial till, or weathered rock.

Phase, phase angle: The angular difference in time between a measured sinusoidal electromagnetic field and a reference – normally the primary field. The phase is calculated from $\tan^{-1}$(***in-phase / quadrature***).

physical parameters: These are the characteristics of a geological unit. For electromagnetic surveys, the important parameters are ***conductivity, magnetic permeability*** (or ***susceptibility***) and ***dielectric permittivity***; for magnetic surveys the parameter is magnetic susceptibility, and for gamma ray spectrometric surveys it is the concentration of the major radioactive elements: potassium, uranium, and thorium.

permittivity: see ***dielectric permittivity***.

permeability: see ***magnetic permeability***.

potential field: A field that obeys Laplace's Equation. Most commonly used to describe ***gravity*** and ***magnetic*** measurements.

primary field: the EM field emitted by a transmitter. This field induces ***eddy currents*** in (energizes) the conductors in the ground, which then create their own ***secondary* fields**.

pulse: In time-domain EM surveys, the short period of intense ***primary*** field transmission. Most measurements (the ***off-time***) are measured after the pulse. **On-time** measurements may be made during the pulse.

quadrature: that component of the measured ***secondary field*** that is phase-shifted 90° from the ***primary field***. The quadrature component tends to be stronger than the ***in-phase*** over relatively weaker ***conductivity***.

Q-coils: see ***calibration coil***.

radioelements: This normally refers to the common, naturally-occurring radioactive elements: potassium (K), uranium (U), and thorium (Th). It can also refer to man-made radioelements, most often cobalt (Co) and cesium (Cs)

radiometric: Commonly used to refer to ***gamma ray*** spectrometry.

radon: A radioactive daughter product of uranium and thorium, radon is a gas which can leak into the atmosphere, adding to the non-geological background of a gamma-ray spectrometric survey.

receiver: the ***signal*** detector of a geophysical system. This term is most often used in active geophysical systems – systems that transmit some kind of signal. In airborne ***electromagnetic*** surveys it is most often a ***coil***. (see also, ***transmitter***)

resistivity: **[ρ]** The strength with which the earth or a geological formation resists the flow of electricity, typically the flow induced by the ***primary field*** of the electromagnetic transmitter. Normally expressed in ohm-metres, it is the reciprocal of ***conductivity***.

resistivity-depth transforms: similar to ***conductivity depth transforms***, but the calculated ***conductivity*** has been converted to ***resistivity***.

resistivity section: an approximate vertical section of the resistivity of the layers in the earth. The resistivities can be derived from the ***apparent resistivity***, the ***differential resistivities***, ***resistivity-depth transforms***, or ***inversions***.

response parameter: another name for the **induction number**.

secondary field: The field created by conductors in the ground, as a result of electrical currents induced by the ***primary field*** from the ***electromagnetic*** transmitter. Airborne ***electromagnetic*** systems are designed to create and measure a secondary field.

Sengpiel section: a ***resistivity section*** derived using the ***apparent resistivity*** and an approximation of the depth of maximum sensitivity for each frequency.

sferic: Lightning, or the ***electromagnetic*** signal from lightning, it is an abbreviation of "atmospheric discharge". These appear to magnetic and electromagnetic sensors as sharp "spikes" in the data. Under some conditions lightning storms can be detected from hundreds of kilometres away. (see ***noise***)

signal: That component of a measurement that the user wants to see – the response from the targets, from the earth, etc. (See also ***noise***)

skin depth: A measure of the depth of penetration of an electromagnetic field into a material. It is defined as the depth at which the primary field decreases to 1/e of the field at the surface. It is calculated by approximately 503 x √(resistivity/frequency). Note that depth of penetration is greater at higher ***resistivity*** and/or lower ***frequency***.

spec: common abbreviation for *gamma-ray spectrometry*.

spectrometry: Measurement across a range of energies, where ***amplitude*** and energy are defined for each measurement. In gamma-ray spectrometry, the number of gamma rays are measured for each energy ***window***, to define the ***spectrum***.

spectrum: In ***gamma ray spectrometry***, the continuous range of energy over which gamma rays are measured. In ***time-domain electromagnetic*** surveys, the spectrum is the energy of the **pulse** distributed across an equivalent, continuous range of frequencies.

spheric: see ***sferic***.

stacking: Summing repeat measurements over time to enhance the repeating ***signal***, and minimize the random ***noise***.

stinger: A boom mounted on an aircraft to carry a geophysical sensor (usually ***magnetic***). The boom moves the sensor farther from the aircraft, which might otherwise be a source of ***noise*** in the survey data.

stripping: Estimation and correction for the gamma ray photons of higher and lower energy that are observed in a particular ***energy window***. See also ***Compton scattering***.

susceptibility: See ***magnetic susceptibility***.
tau: [τ] Often used as a name for the ***decay time constant***.

TDEM: ***time domain electromagnetic***.

thin sheet: A standard model for electromagnetic geophysical theory. It is usually defined as a thin, flat-lying conductive sheet, ***infinite*** in both horizontal directions. (see also ***vertical plate***)

tie-line: A survey line flown across most of the ***traverse lines***, generally perpendicular to them, to assist in measuring ***drift*** and ***diurnal*** variation. In the short time required to fly a tie-line it is assumed that the drift and/or diurnal will be minimal, or at least changing at a constant rate.

time constant: The time required for an ***electromagnetic*** field to decay to a value of 1/e of the original value. In ***time-domain*** electromagnetic data, the time constant is proportional to the size and ***conductance*** of a tabular conductive body. Also called the decay constant.

Time channel: In ***time-domain electromagnetic*** surveys the decaying ***secondary field*** is measured over a period of time, and the divided up into a series of consecutive discrete measurements over that time.

time-domain: ***Electromagnetic*** system which transmits a pulsed, or stepped ***electromagnetic*** field. These systems induce an electrical current (***eddy current***) in the ground that persists after the ***primary field*** is turned off, and measure the change over time of the ***secondary field*** created as the currents ***decay***. See also ***frequency-domain***.

total energy envelope: The sum of the squares of the three ***components*** of the ***time-domain electromagnetic secondary field***. Equivalent to the ***amplitude*** of the secondary field.

transient: Time-varying. Usually used to describe a very short period pulse of ***electromagnetic*** field.

transmitter: The source of the ***signa***l to be measured in a geophysical survey. In airborne ***EM*** it is most often a **coil** carrying a time-varying electrical current, transmitting the ***primary field***. (see also ***receiver***)

traverse line: A normal geophysical survey line. Normally parallel traverse lines are flown across the property in spacing of 50 m to 500 m, and generally perpendicular to the target geology. Also called a **flight line**.

turn-arounds: The time the aircraft is turning between one ***traverse*** or ***tie line*** and the next. Turn-arounds are generally outside the survey area, and the data collected during this time generally are not useable, because of aircraft ***manoeuvre noise***.

vertical plate: A standard model for electromagnetic geophysical theory. It is usually defined as thin conductive sheet, ***infinite*** in horizontal dimension and depth extent. (see also ***thin shee***t)

waveform: The shape of the ***electromagnetic pulse*** from a ***time-domain*** electromagnetic transmitter.

window: A discrete portion of a ***gamma-ray spectrum*** or ***time-domain electromagnetic decay***. The continuous energy spectrum or ***full-stream*** data are grouped into windows to reduce the number of samples, and reduce ***noise***.

zero, or zero level: The ***base level*** of an instrument, with no ***ground effect*** or ***drift***. Also, the act of measuring and setting the zero level.

Common Symbols and Acronyms

k	Magnetic susceptibility
ε	Dielectric permittivity
μ, μ_r	Magnetic permeability, relative permeability
ρ, ρ_a	Resistivity, apparent resistivity
σ,σ_a	Conductivity, apparent conductivity
σt	Conductivity thickness
τ	Tau, or time constant
Ωm	ohm-metres, units of resistivity
AGS	Airborne gamma ray spectrometry.
CDT	Conductivity-depth transform, conductivity-depth imaging (Macnae and Lamontagne, 1987; Wolfgram and Karlik, 1995)
CPI, CPQ	Coplanar in-phase, quadrature
CPS	Counts per second
CTP	Conductivity thickness product
CXI, CXQ	Coaxial, in-phase, quadrature
FOM	Figure of Merit
fT	femtoteslas, common unit for measurement of B-Field in time-domain EM
EM	Electromagnetic
keV	kilo electron volts – a measure of gamma-ray energy
MeV	mega electron volts – a measure of gamma-ray energy 1MeV = 1000keV
NIA	dipole moment: turns x current x Area
nT	nanotesla, a measure of the strength of a magnetic field
nT/s	nanoteslas/second; standard unit of measurement of secondary field dB/dt in time domain EM.
nG/h	nanoGreys/hour – gamma ray dose rate at ground level
ppm	parts per million – a measure of secondary field or noise relative to the primary or radioelement concentration.
pT	picoteslas: standard unit of measurement of B-Field in time-domain EM
pT/s	picoteslas per second: Units of decay of secondary field, dB/dt
S	siemens – a unit of conductance
x:	the horizontal component of an EM field parallel to the direction of flight.
y:	the horizontal component of an EM field perpendicular to the direction of flight.
z:	the vertical component of an EM field.

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