Acquiring VLF-EM data with the hand-held Geonics EM-16 receiver

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Department of Industry, Energy and Technology

Outline

- Basic principles – EM method
- EM-16 use/demo & survey set-up
- Data presentation, Fraser Filter
- Basic interpretation

Electromagnetics (EM)

Theory

Passing a current (AC) through a wire induces a primary magnetic field in the vicinity of the wire.

The primary magnetic field induces currents in bedrock conductors (if present).

The currents in the conductor induce a secondary magnetic field.

The secondary field is measured by a receiver

Electromagnetics (EM)

Uses

To detect buried metal in urban settings.

To map conductive geological strata, fault zones.

To delineate mineralized horizons (if conductive)

There are several types of EM surveys.

VLF-EM (Very Low Frequency)

The primary signal field induces a secondary field in a conductor in the bedrock.

A conductor can be

Metallic body,
Graphitic horizons,
Faults,
Contacts between different bedrock units.

Conductor = Continuous body

VLF-EM

Submarine communications systems use VLF transmitter stations at

Cutler, Maine
Annapolis, Maryland
Seattle, Washington
Rugby, England
Bordeaux, France
(and others around the globe)

VLF-EM

Uses:

- **Primarily used for locating/mapping near vertical mineralized beds or structures.**
- Depth of penetration approx. 50 m

VLF-EM

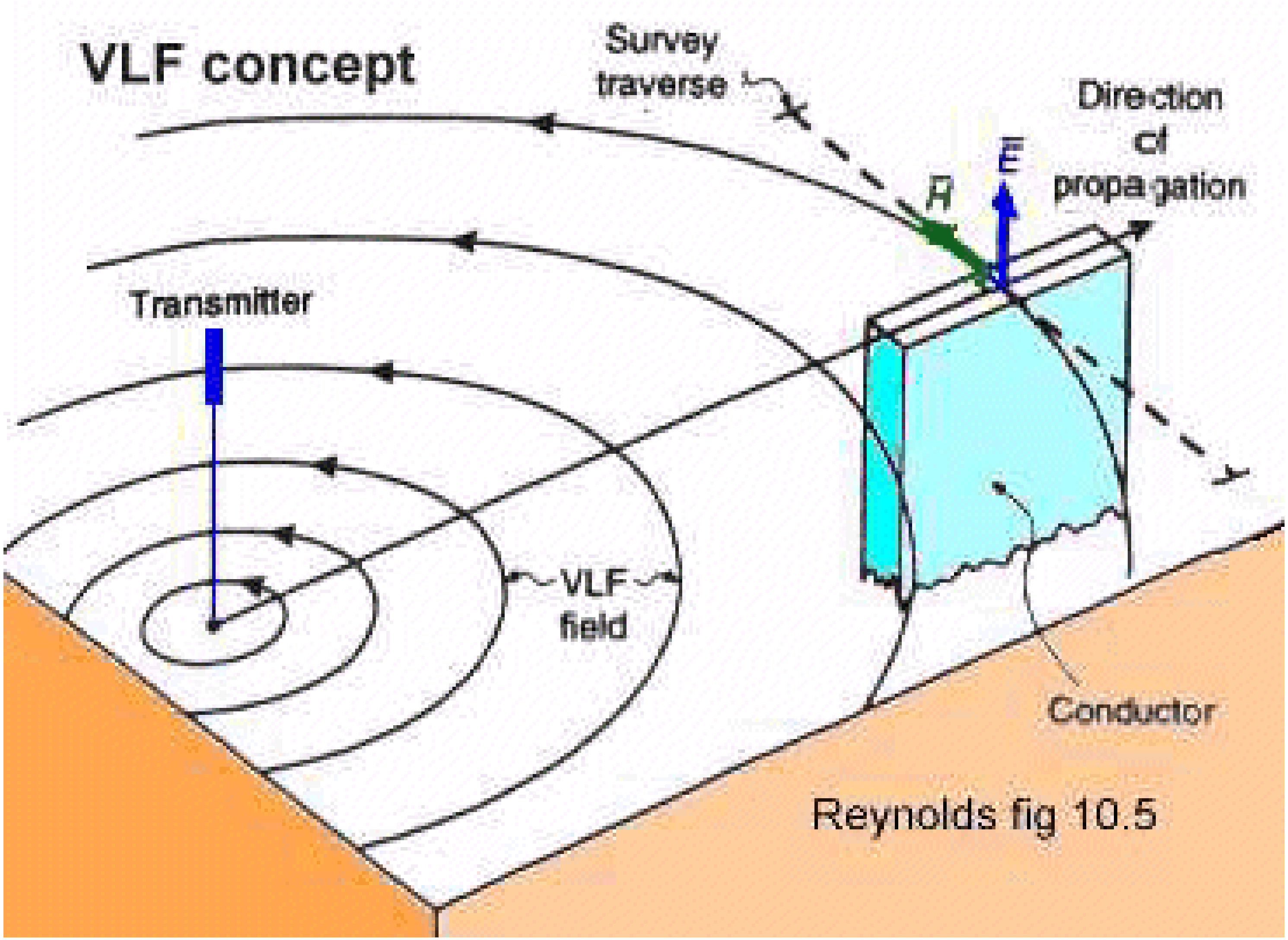
Advantages:

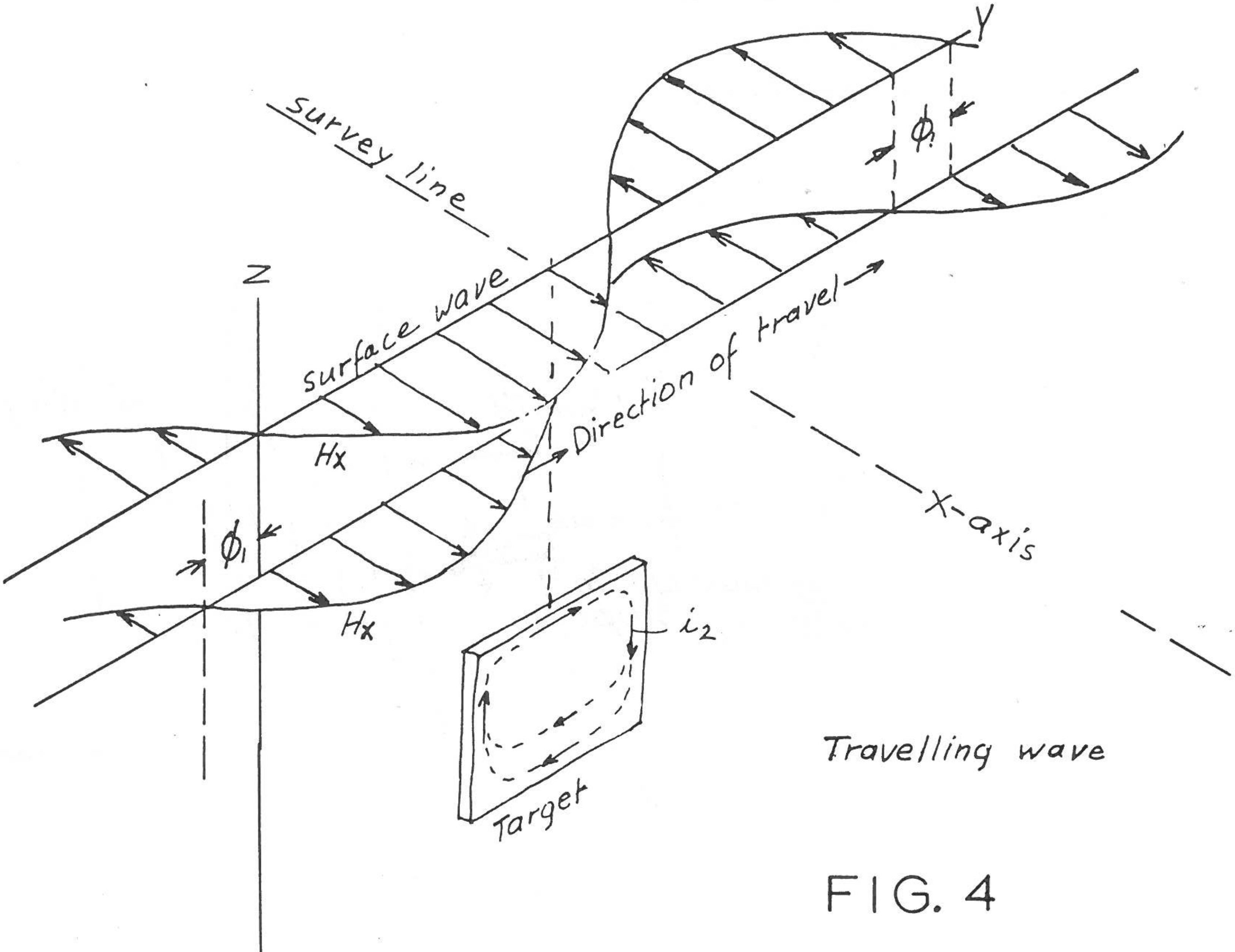
- Measurements are easily acquired;
- Relatively cheap and good for reconnaissance;
- Uses an existing transmitter source;
- Does not require ground contact;
- Can provide relatively deep measurements.

VLF-EM

Ineffective if

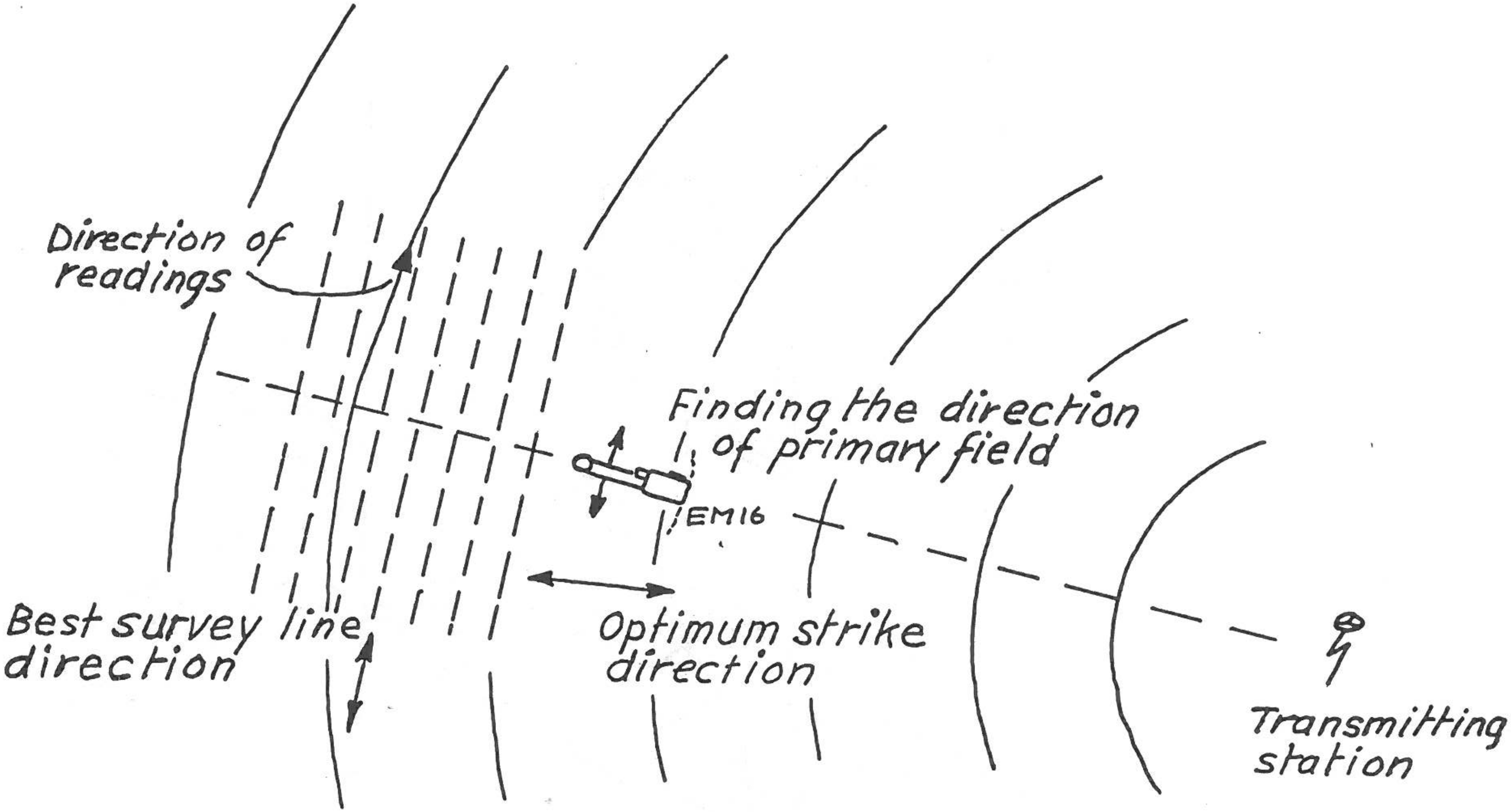
- Rock layers are horizontal
- Soil is electrically conductive
- Body not aligned approx. towards transmitter
- Metal pipes, cables, power lines etc nearby
- Loss of signal from the VLF transmitter!!


VLF concept
Survey traverse
Direction of propagation
R
E
Transmitter
VLF field
Conductor
Reynolds fig 10.5



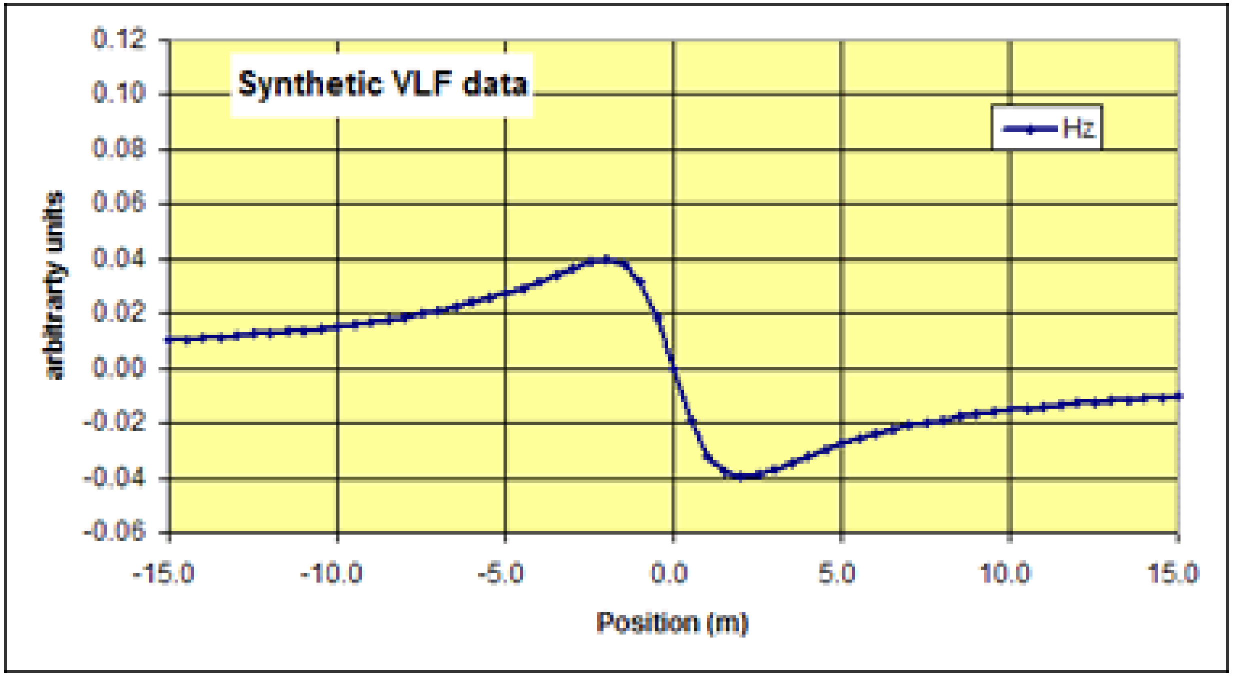
Travelling wave

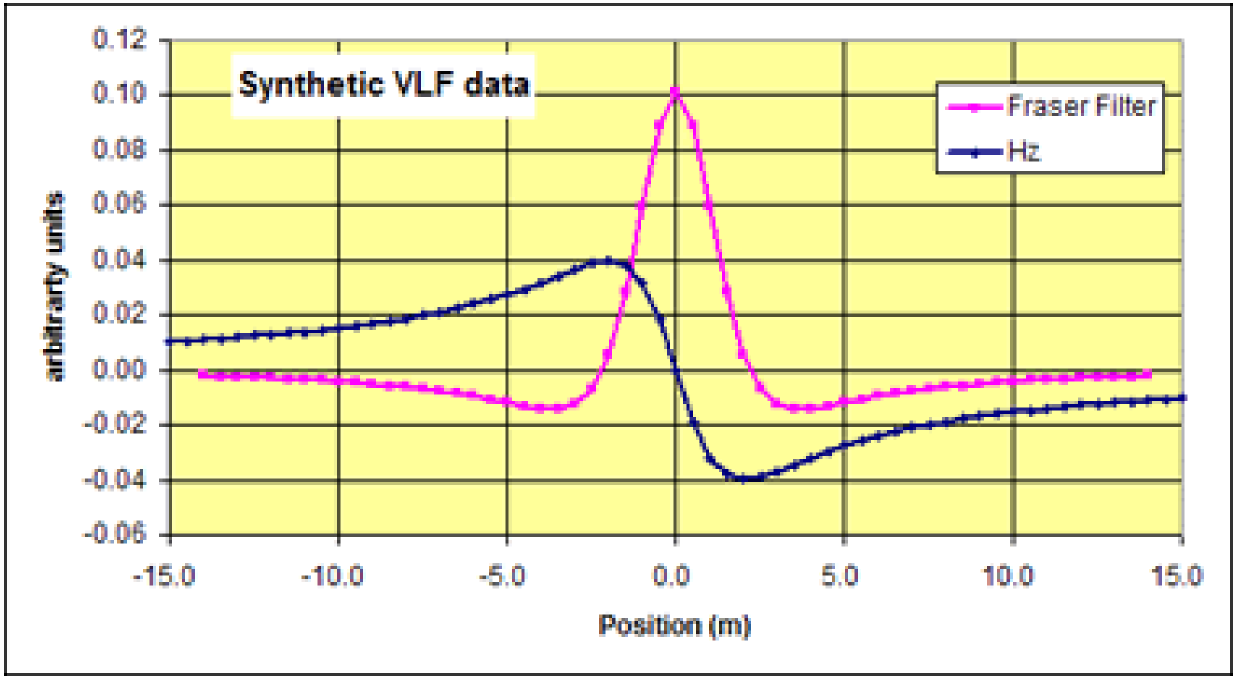
FIG. 4



Planning of survey

FIG. 3


Synthetic VLF data
Hz
arbitrarty units
Position (m)
0.12
0.10
0.08
0.06
0.04
0.02
0.00
-0.02
-0.04
-0.06
-15.0
-10.0
-5.0
0.0
5.0
10.0
15.0


Synthetic VLF data
Fraser Filter
Hz
arbitrarty units
Position (m)
0.12
0.10
0.08
0.06
0.04
0.02
0.00
-0.02
-0.04
-0.06
-15.0
-10.0
-5.0
0.0
5.0
10.0
15.0

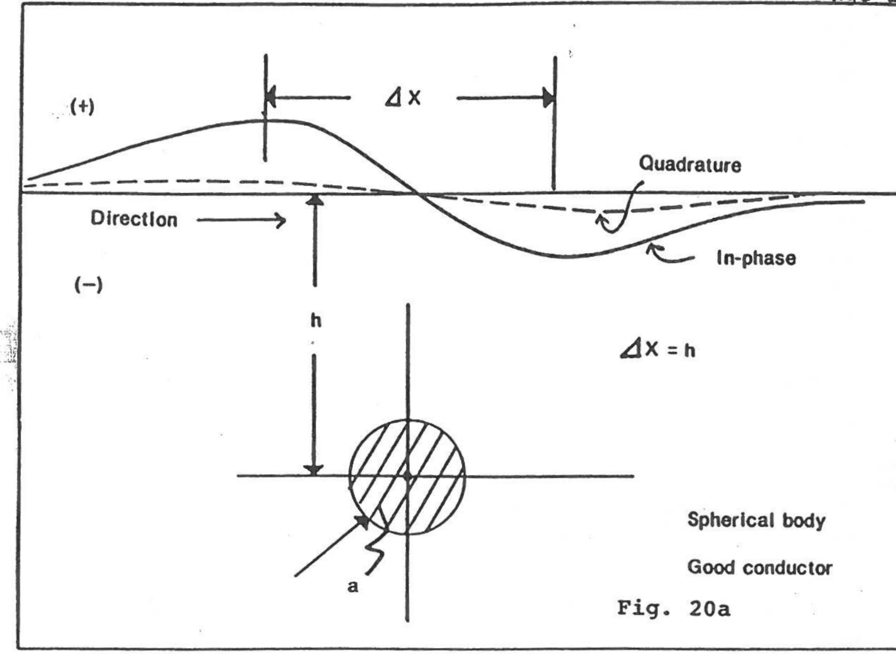


Fig. 20a

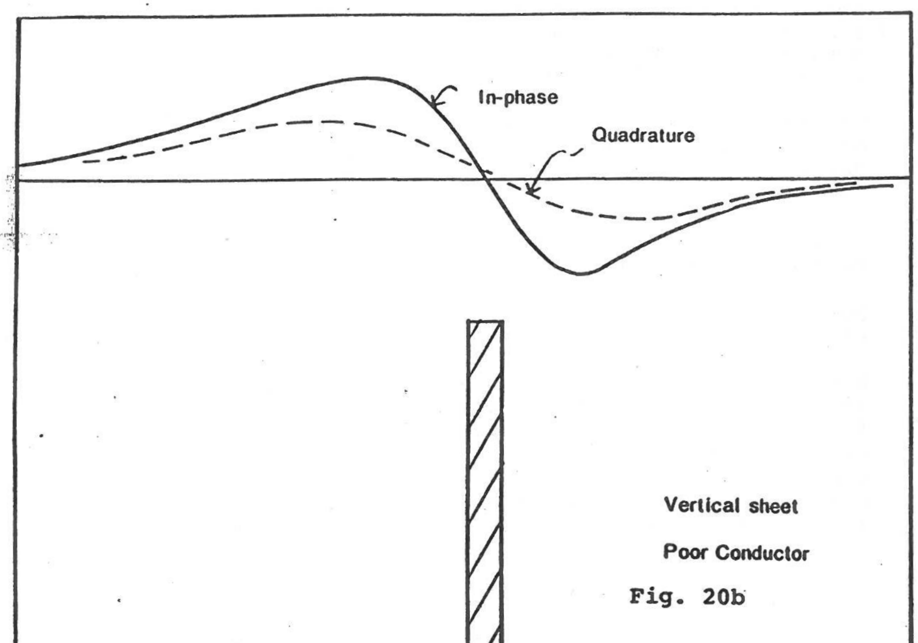


Fig. 20b

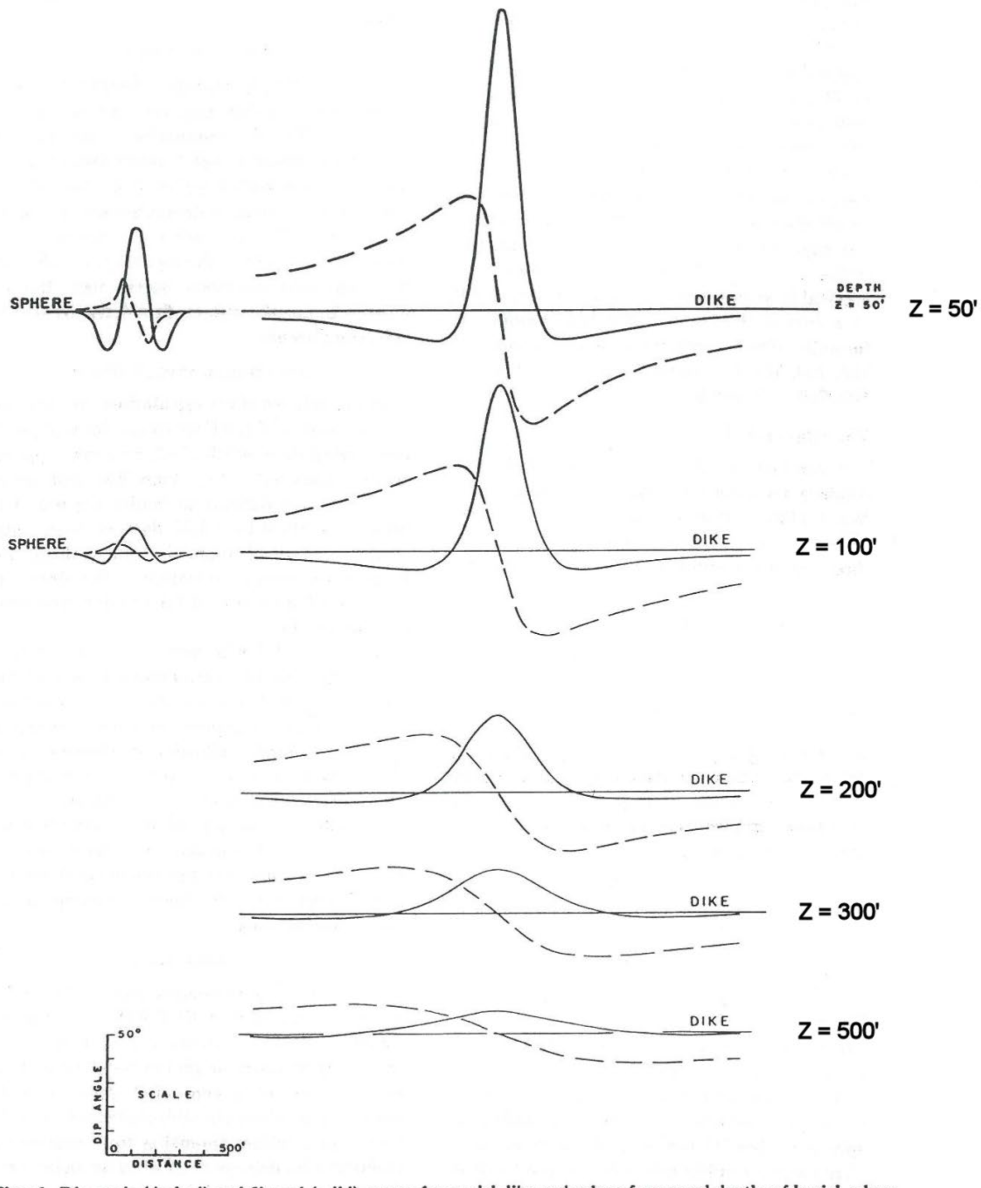
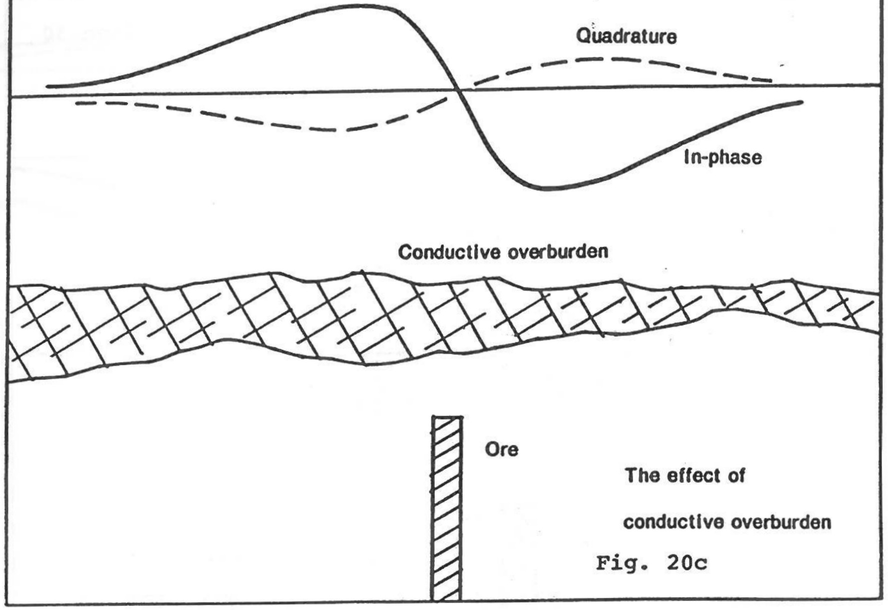


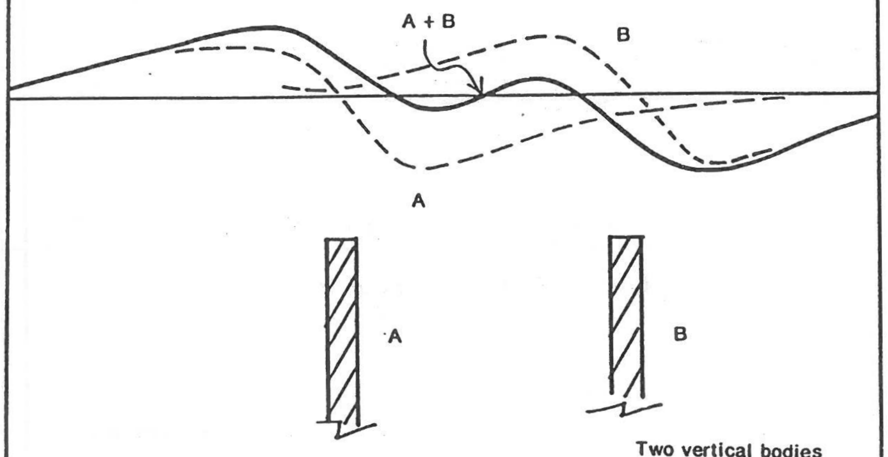
FIG. 6. Dip-angle (dashed) and filtered (solid) curves for model dike and sphere for several depths of burial, where z is depth to top of dike and to center of sphere.

(Fraser, 1969)



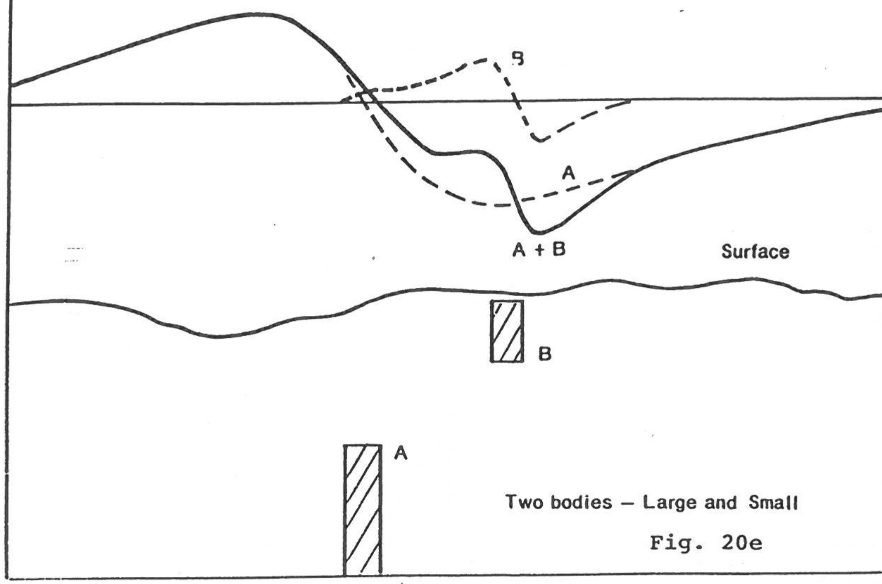
The effect of conductive overburden

Fig. 20c



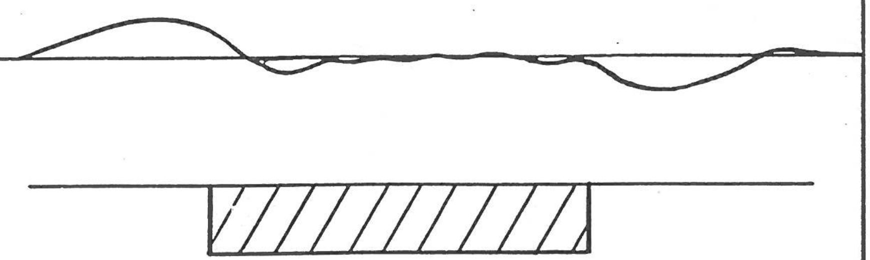
Two vertical bodies

Fig. 20d.



Two bodies – Large and Small

Fig. 20e



Horizontal slab

Fig. 20f

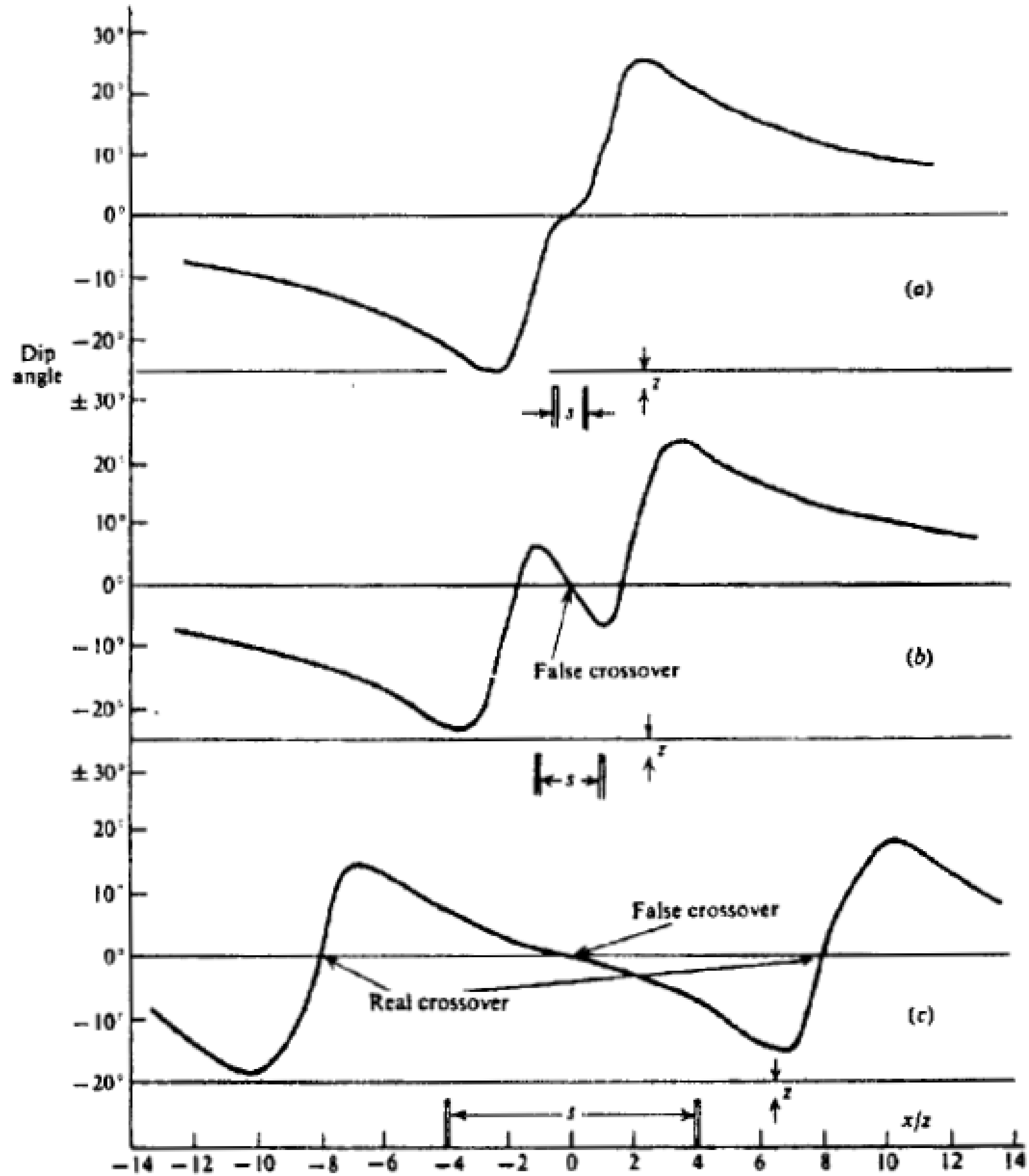


Figure 7.39. VLF profiles over two identical semiinfinite vertical sheets as a function of distance between the sheets. (a) s = 2z. (b) s = 4z. (c) s = 16z.

(Telford et al., 1990)

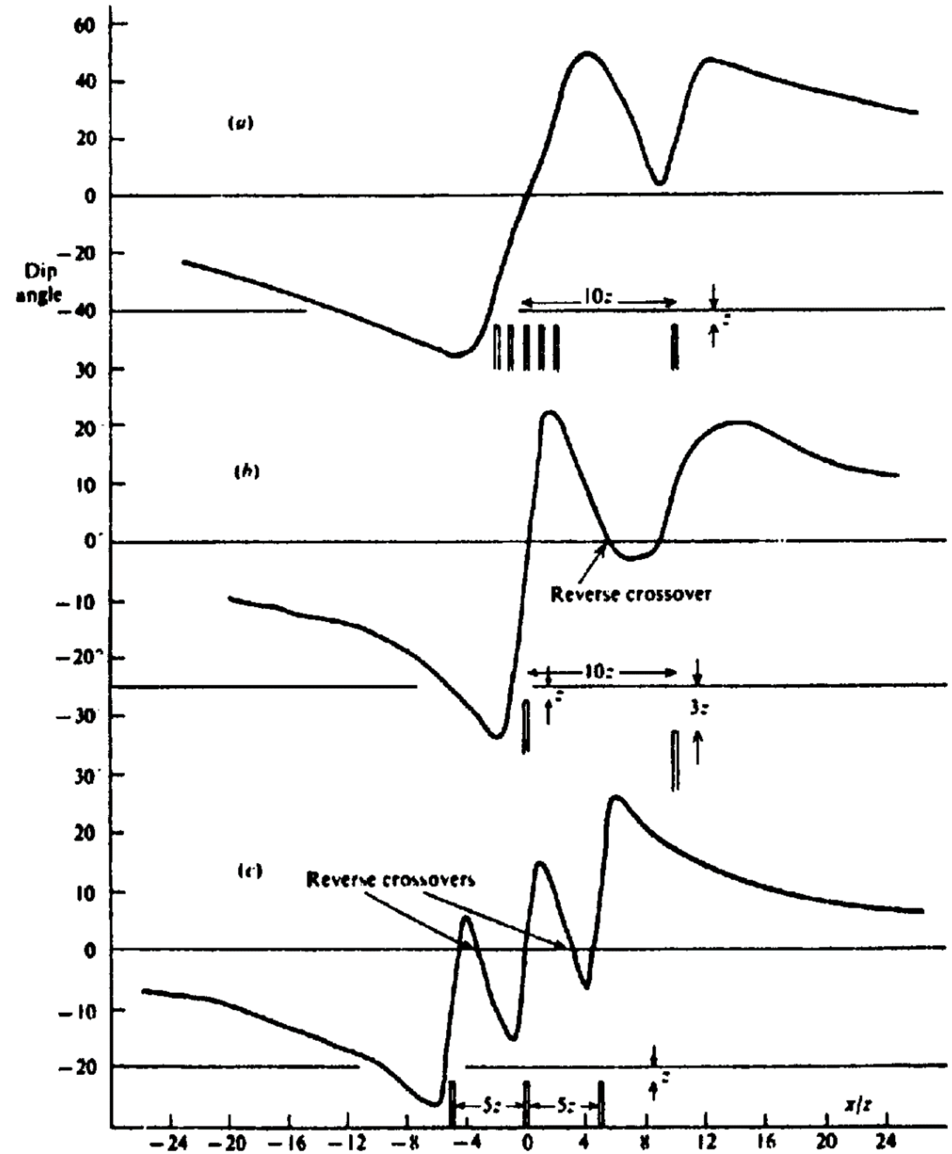
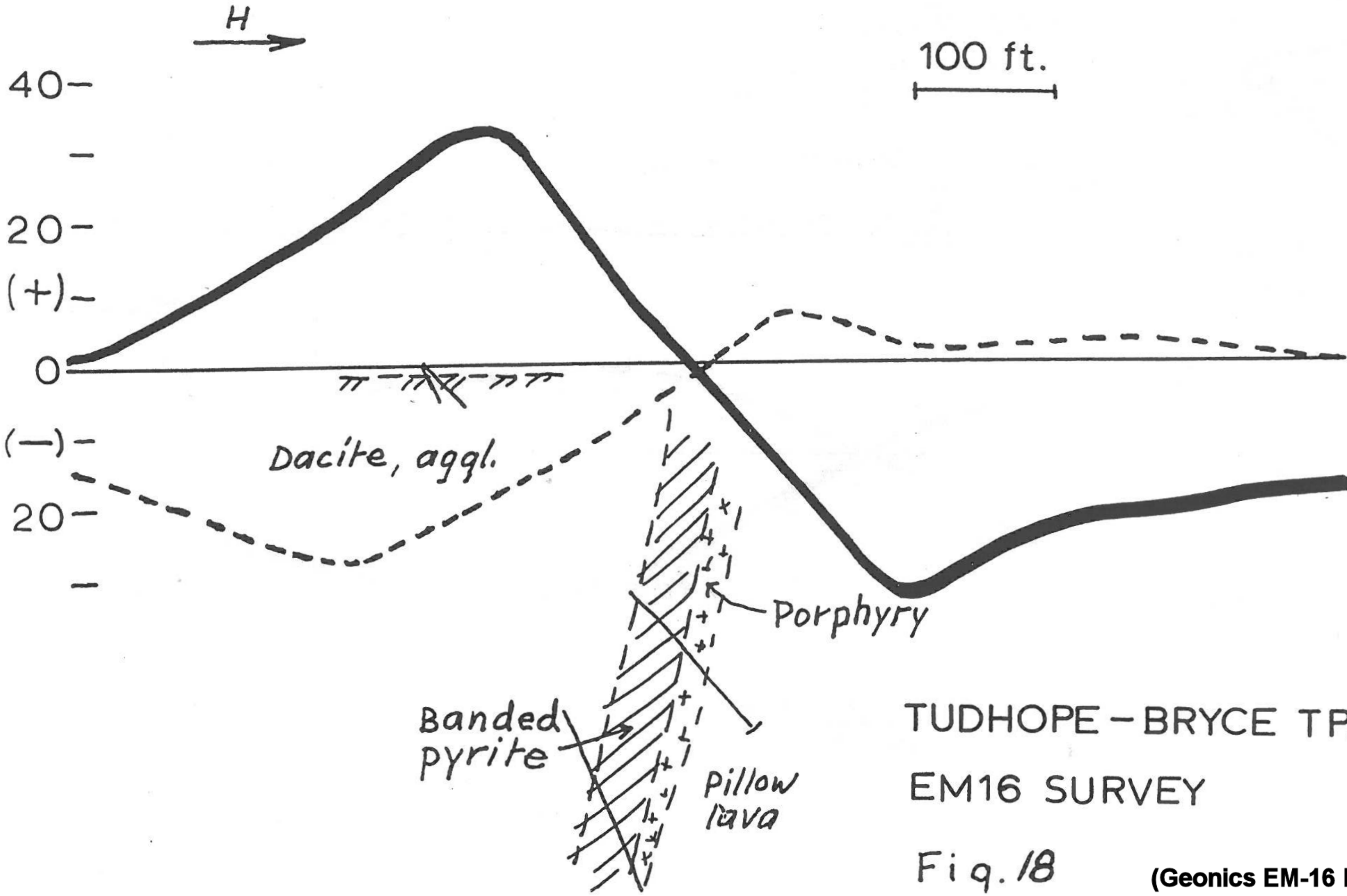


Figure 7.40. VLF profiles over multiple vertical-sheet conductors. (a) Five sheets spaced z apart plus one sheet distant 10z from the midpoint of the five sheets, all at depth z. (b) Two sheets at depths of z and 3z, spaced 10z apart. (c) Three sheets at depth z and spaced 5z apart.

(Telford et al., 1991)



TUDHOPE – BRYCE TP.
EM16 SURVEY
Fig. 18

(Geonics EM-16 Manual)

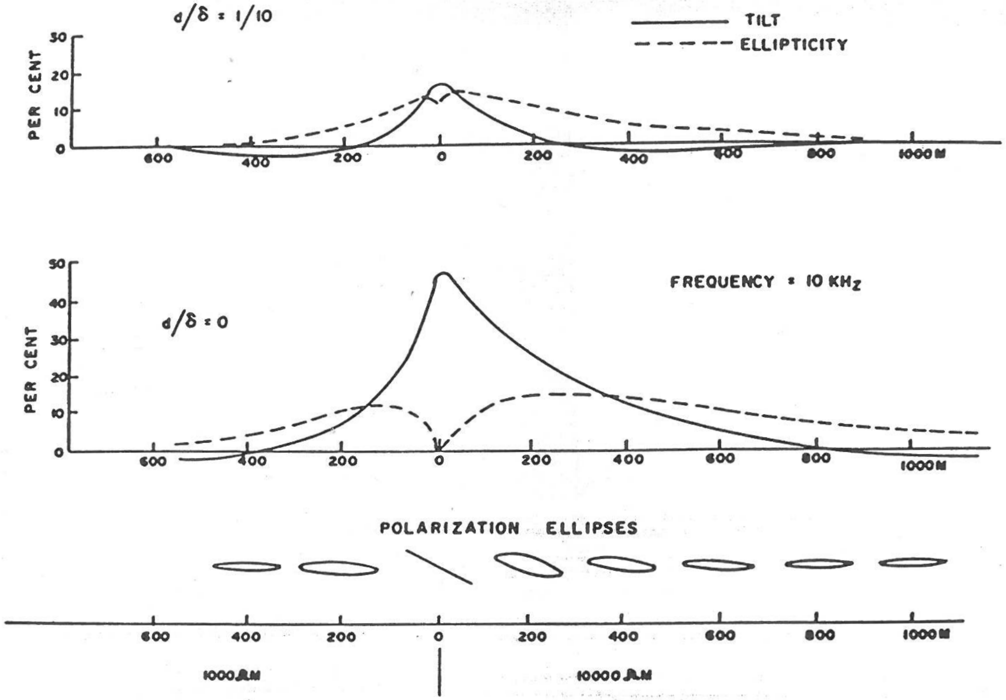
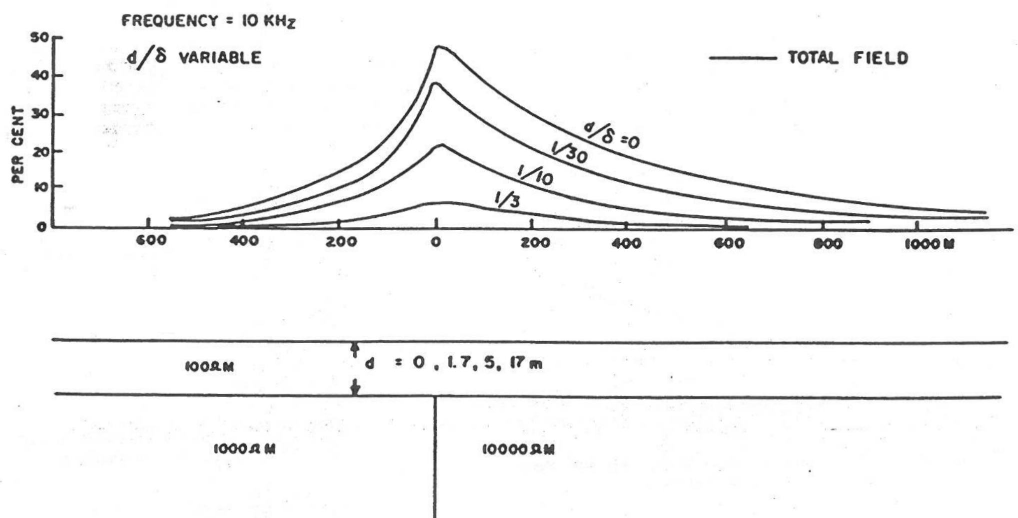
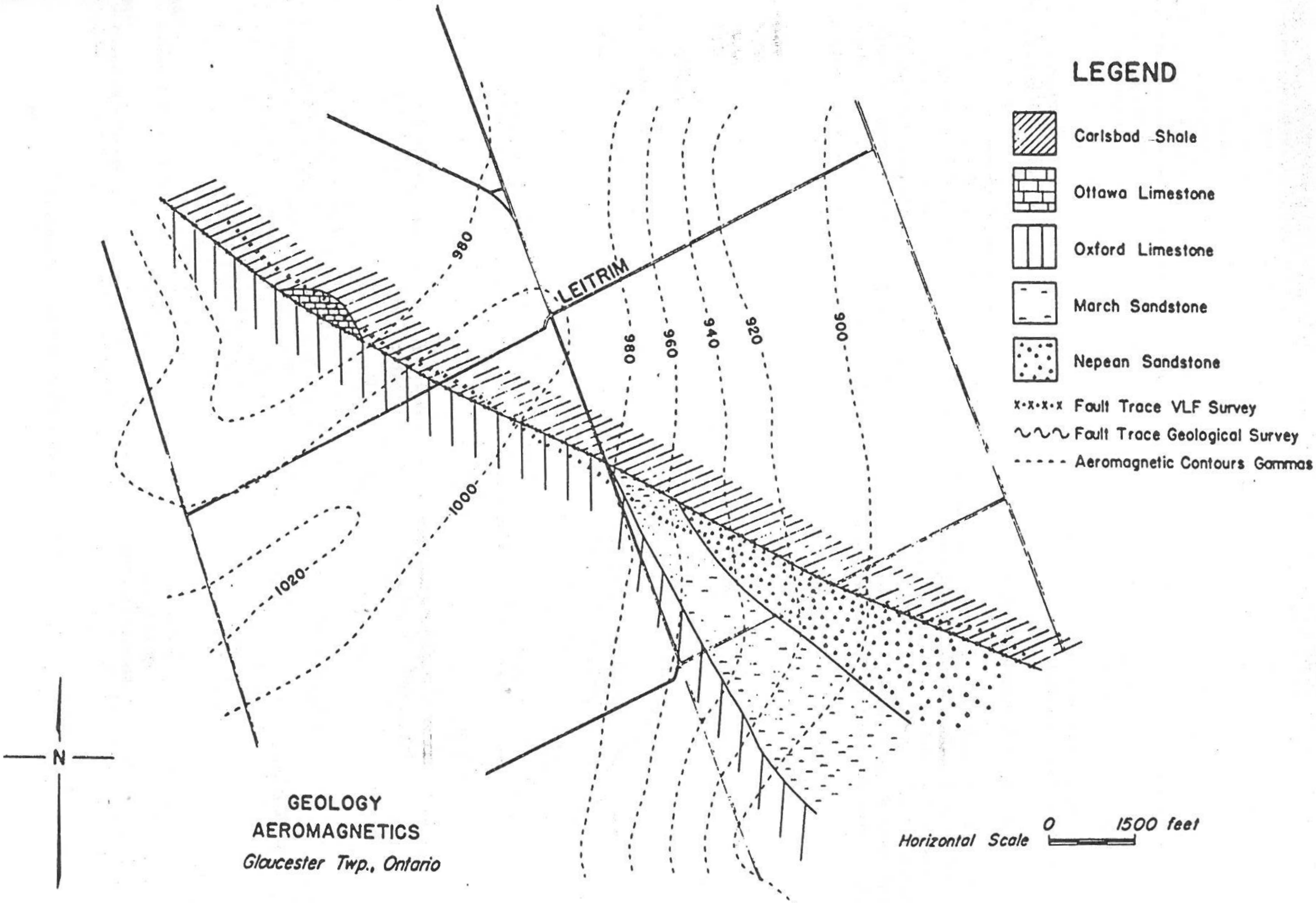


Figure 4. Tilt and ellipticity profiles for d/δ = 1/10, 0 for the structure of Figure 2.



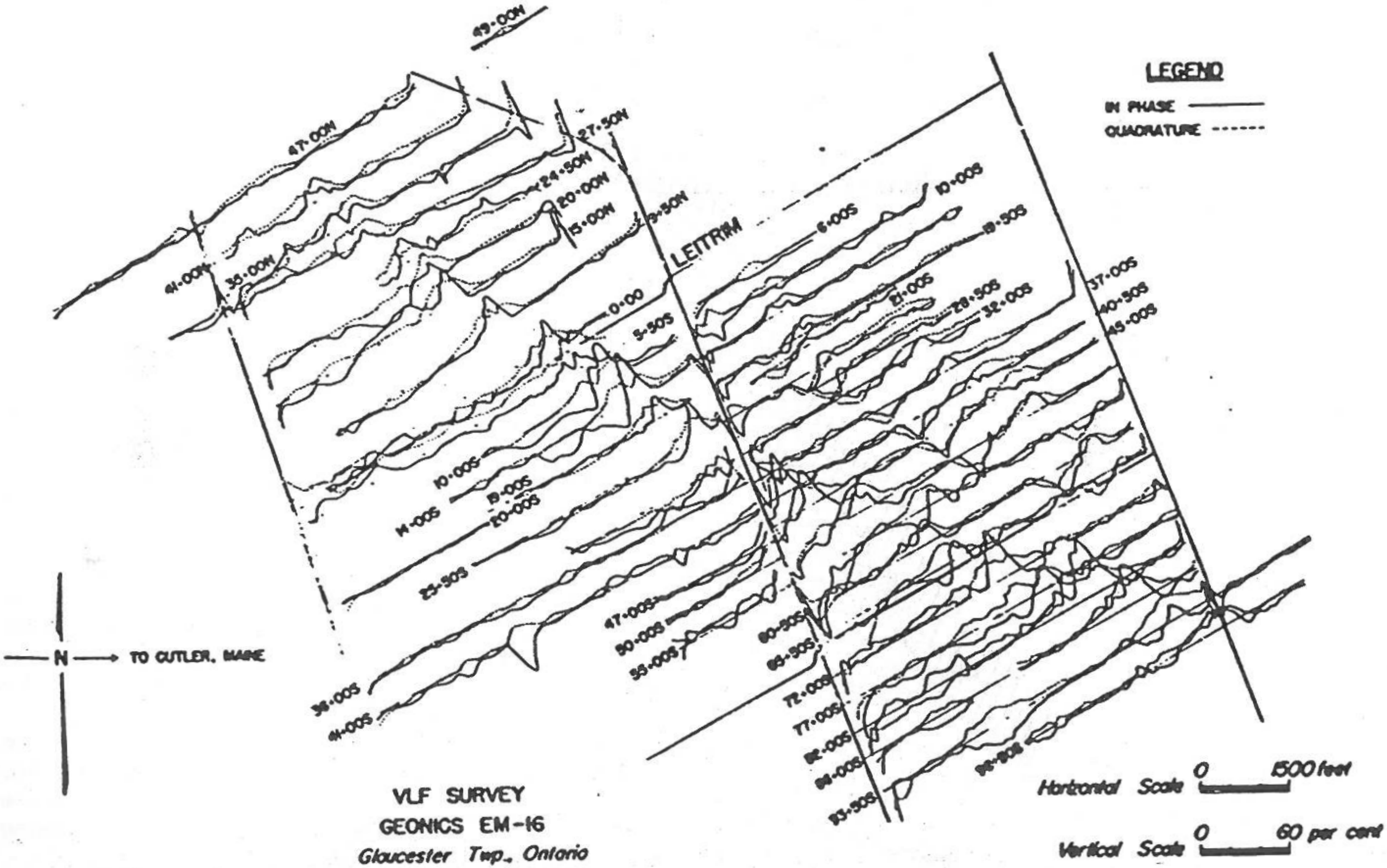
(Geonics EM-16 Manual)

Figure 5. Total field, $|H_z/H_x|$, profiles over the structure of Figure 2 with d/δ = 0, 1/30, 1/10, 1/3.



(Geonics EM-16 Manual)

Figure 10. Geology and aeromagnetic contours, Leitrim area.



(Geonics EM-16 Manual)

Figure 11. VLF in-phase and quadrature profiles, Leitrim area.

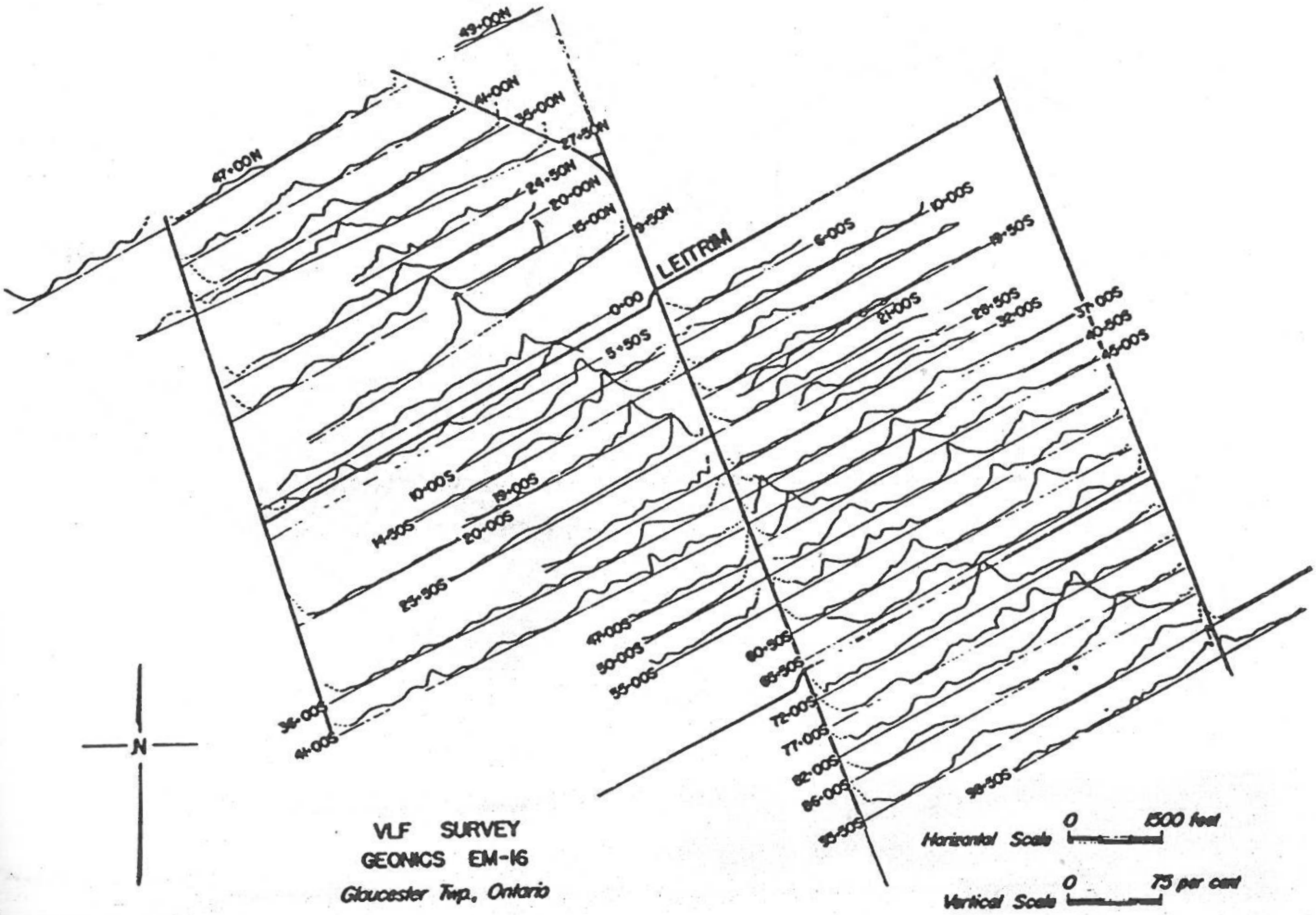


Figure 12. VLF total field profiles, Leitrim area.

(Geonics EM-16 Manual)

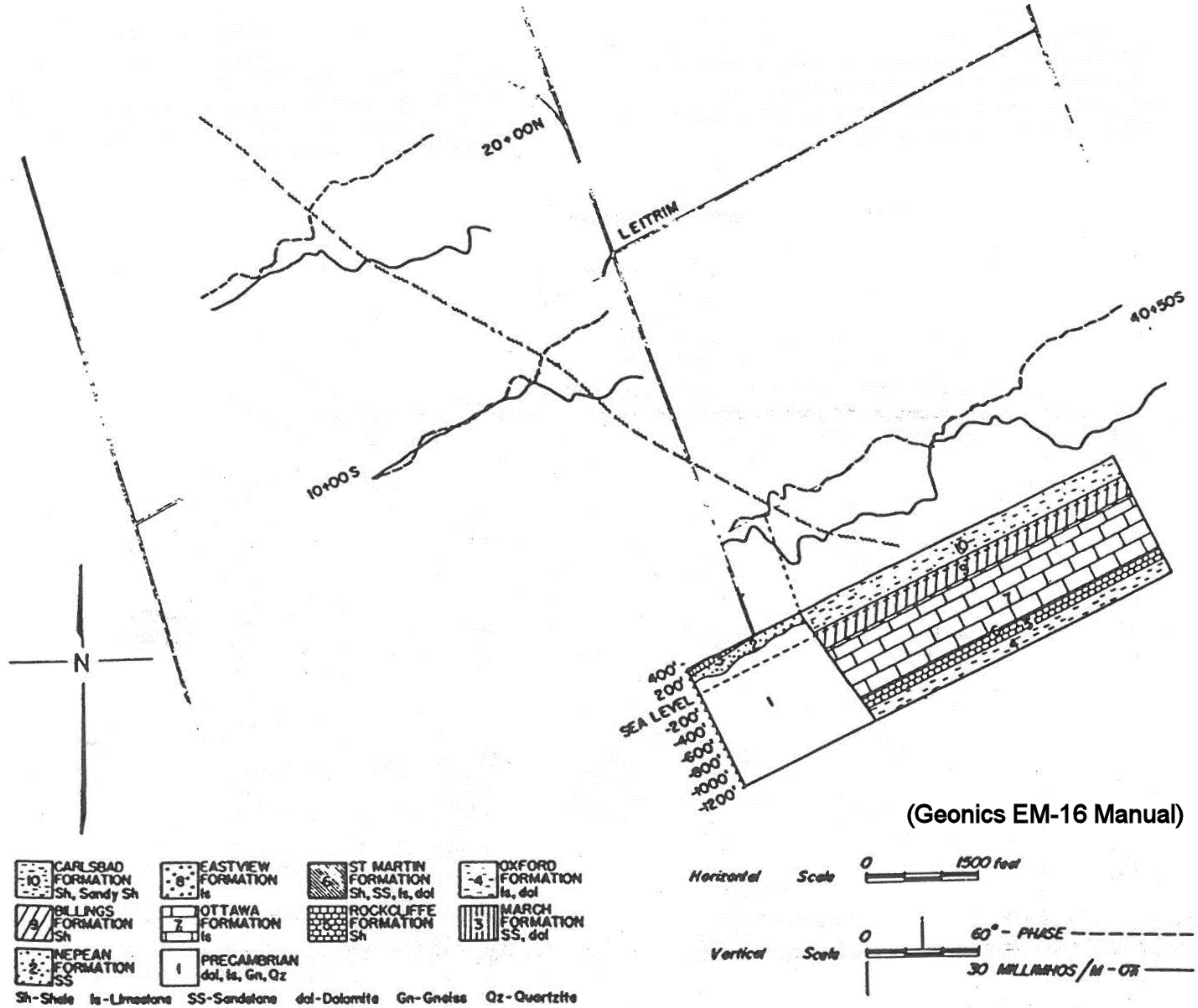


Figure 13. Apparent conductivity (σ_a) and phase (ϕ) profiles on lines 20+00N, 10+00S, and 40+50S, Leitrim area.

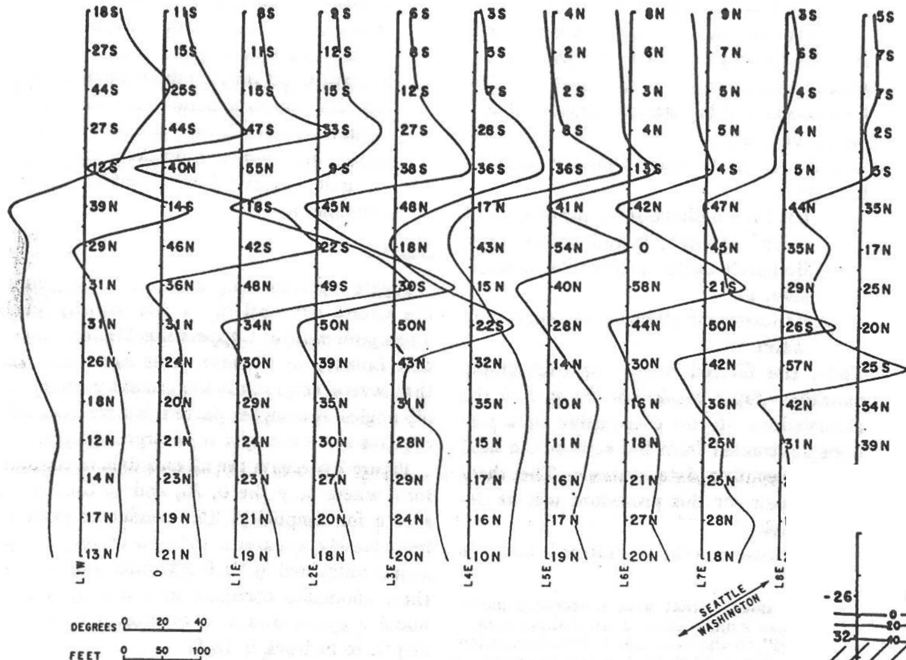


FIG. 1. Dip-angle data in the vicinity of the Temagami mine. The arrow defines the VLF-EM primar from the transmitter at Seattle, Washington.

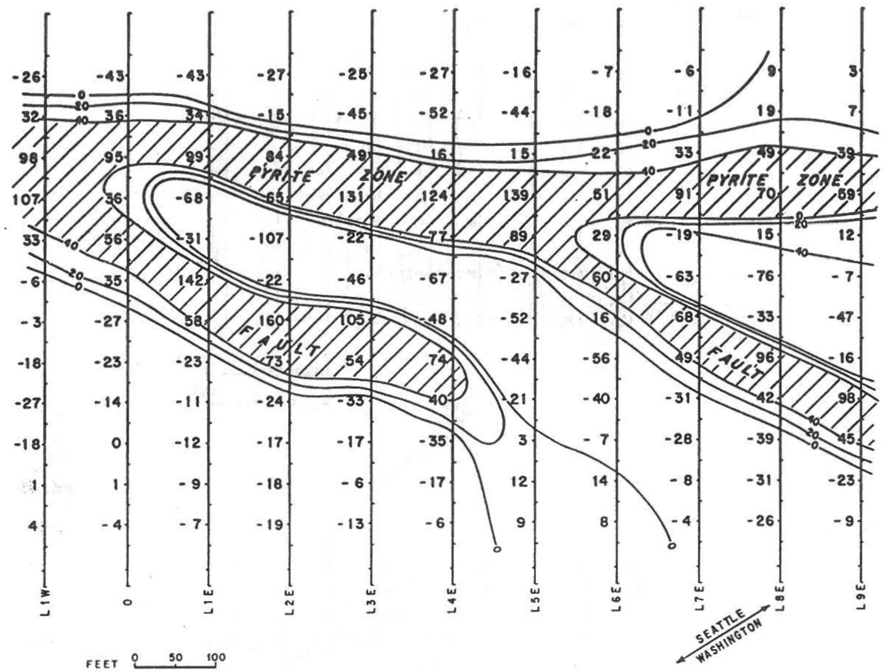


FIG. 2. Filtered data computed from the map of Figure 1.

EM-16
Receiver

FIG. I EM 16

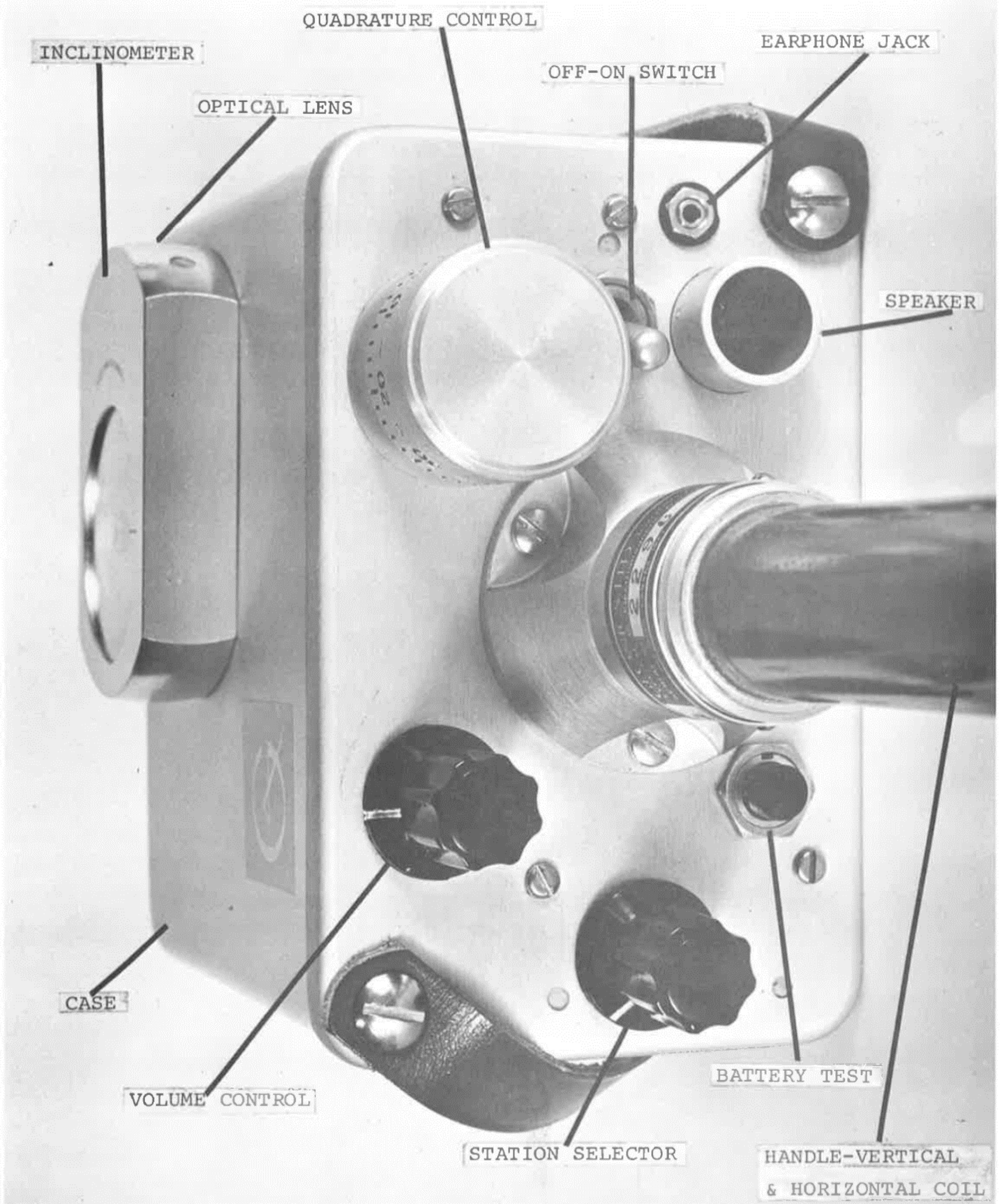

QUADRATURE CONTROL
INCLINOMETER
EARPHONE JACK
OFF-ON SWITCH
OPTICAL LENS
SPEAKER
CASE
BATTERY TEST
VOLUME CONTROL
STATION SELECTOR
HANDLE-VERTICAL
& HORIZONTAL COIL

Fig.10

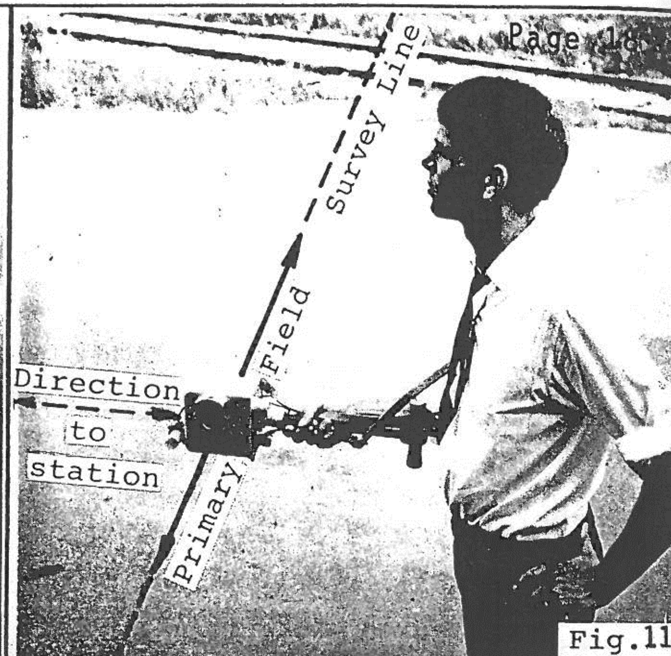


Fig.11

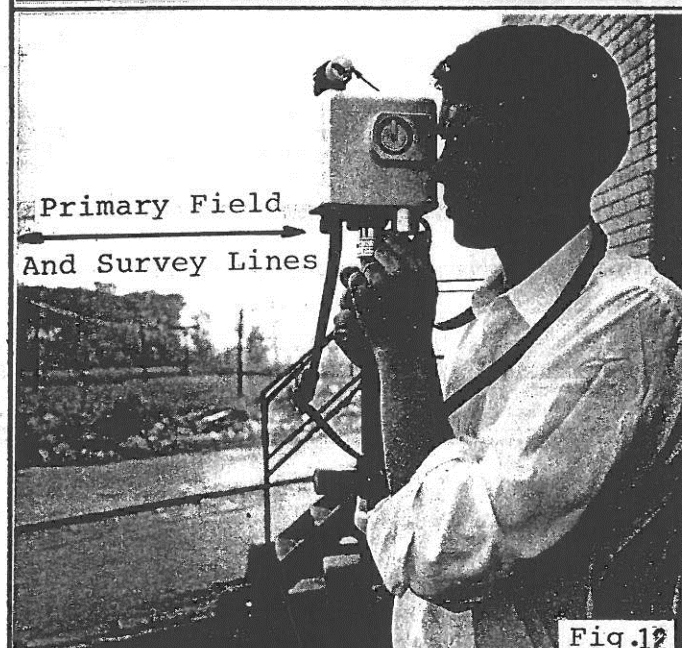


Fig.12

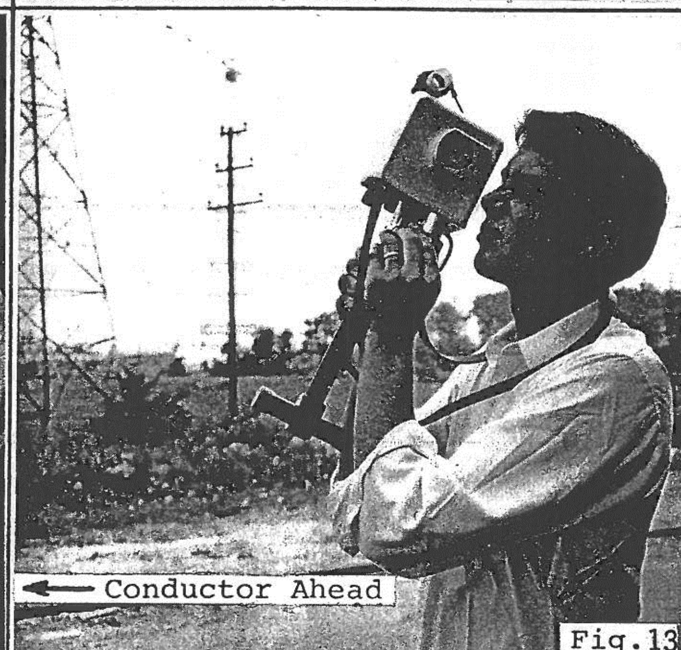


Fig.13


Conductor Behind →

Fig.14

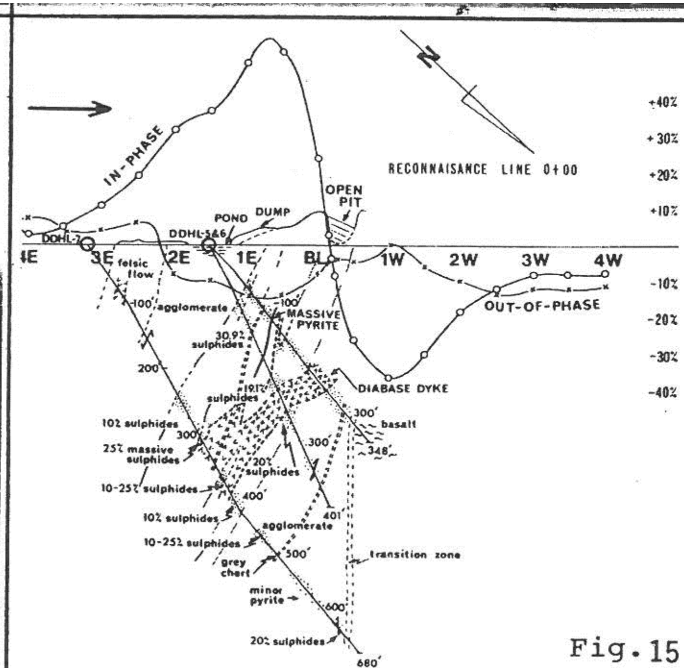

IN-PHASE
N
RECONNAISANCE LINE 0+00
+40%
+30%
+20%
+10%
-10%
-20%
-30%
-40%
OPEN PIT
POND
DUMP
DDHL-2
DDHL-5&6
4E
3E
2E
1E
BL
1W
2W
3W
4W
felsic flow
100
agglomerate
MASSIVE PYRITE
30.9% sulphides
OUT-OF-PHASE
200
DIABASE DYKE
19.1% sulphides
10% sulphides
300'
basalt
25% massive sulphides
300
348'
20% sulphides
10-25% sulphides
400'
401
10% sulphides
agglomerate
10-25% sulphides
500'
transition zone
grey chert
minor pyrite
600
20% sulphides
680'

Fig.15


Omni Plus Magnetometer / VLF-EM

VLF-EM
Data Recording and Plotting

Great Gull Lake #1

wade

FIELD BOOK
CAT.NO. 515/8671100
HEAVY DUTY

JOB Weir's Pond North
DATE June 04, 1987 PAGE

JOB Clouds in A.M. Sunny + still by noon
DATE June 04, 1987 PAGE [illegible] 200

Pos	Tilt	Quad	Mag	
0.0	+10	+6	56236.7	Edge of cliff
20.0	+6	+2	55527.7	
10.0	+6	+1	55870.8	
40.0	+8	+6	54942.8	
60.0	0	+6	54878.1	
80.0	-17	+1	54653.4	
70.0	-10	+3		
100.0	-21	-4	539571	[illegible] Swamp
90.0			543436	
120.0	-11.5	-6	54238.6	Larch tree
140.0	+5.5	-3	54643.1	
160.0	+29.0	+4	54904.2	Edge of East bog
150.0	+16.0	0.0		
180.0	+14.0	-4.0	53458.2	[illegible] bog
170.0			53660.0	
200.0	-2.0	-8.0	53595.4	
220.0	-6.0	-3.0	54494.0	
240.0	+1.5	+2.0	55150.1	
260.0	-0.5	+5.5	55239.1	E. end of Bog - at the
280.0	+1.0	+0.0	55162.8	[illegible]
300.0	-3.0	+10.0	55042.9	
320.0	+1.0	+10.0	54648.5	
310.0			54789.3	

PARTY CHIEF

WEATHER

nw wade


Omni Plus Magnetometer / VLF-EM

OMNI-PLUS Tie-line MAG/VLF R22N Ser #428061
VLF TOTAL FIELD DATA uncorrected
Date 18 JUL 89
Operator: 3001
Records: 712
Bat: 17.6 Volt Lithium: 3.48 Volt
Last time update: 7/16 5:15:00
Start of print: 7/18 18:44:17

Line 000 E Date 18 JUL 89 24.0 #1

POSITION	I/P	QUAD	T.FLD	TILT	TIME	CULT S	DIR	4-FRA	5-FRA
#1	-71.5	-0.1	2461.	-8.0	7:23:34	99	0.0		
#2	7.3	-24.2	19.23	4.4	7:24:37	69	17.8		
#3	7.3	-22.3	19.42	4.4	7:24:56	69	6.4		
#4	6.1	-22.1	19.24	3.7	7:25:13	59	-8.8		

Line 1200 E Date 18 JUL 89 24.0 #5

POSITION	I/P	QUAD	T.FLD	TILT	TIME	CULT S	DIR	4-FRA	5-FRA
2100 N	-28.7	-7.0	42.55	-16.1	9:54:32	65	16.4		
20875N	-20.0	-3.4	44.64	-11.3	9:55:21	44	13.2		
2075 N	-8.7	-0.2	45.41	-4.9	9:55:40	69	18.5		
20625N	-1.8	2.7	40.81	-1.0	9:56:00	59	11.6	21.5	
2050 N	-3.6	1.2	39.10	-2.1	9:56:24	49	16.6	13.1	17.3
20375N	-11.3	-4.0	38.47	-6.4	9:56:53	58	13.3	-2.6	5.2
2025 N	-14.3	-7.2	41.04	-8.1	9:57:11	58	15.7	-11.4	-7.0
20125N	-7.0	-4.4	44.27	-4.0	9:57:47	49	4.9	-3.6	-7.5
2000 N	3.9	1.1	43.39	2.2	9:58:05	59	10.6	12.7	4.5
19875N	7.9	4.3	38.91	4.5	9:58:25	59	10.4	18.8	15.7
1975 N	5.0	2.0	37.26	2.8	9:58:40	49	11.3	9.1	13.9
19625N	3.2	0.8	36.54	1.8	9:59:01	49	7.0	-2.1	3.5

1875S	42.6	-25.5	26.90	24.2	8:09:41	49	15.1	-8.7	-6.5
200 S	37.0	-25.9	26.09	21.5	8:10:02	49	23.3	-10.5	-9.6
2125S	31.3	-26.6	25.73	18.5	8:10:20	59	17.6	-11.2	-10.9
225 S	25.3	-27.1	25.49	15.2	8:10:38	49	15.7	-12.0	-11.6
2375S	20.5	-27.1	25.27	12.4	8:11:02CROP	59	18.2	-12.4	-12.2
250 S	18.3	-25.6	25.84	11.0	8:11:31	69	17.9	-10.3	-11.4
2625S	16.9	-24.2	25.37	10.1	8:11:51	59	15.9	-6.5	-8.4
275 S	15.3	-22.4	25.40	9.1	8:12:07	49	13.5	-4.2	-5.4
2875S	14.3	-21.1	25.27	8.5	8:12:26	59	16.5	-3.5	-3.9
300 S	11.7	-20.6	25.25	7.0	8:12:48CREC	59	19.2	-3.7	-3.6

Line 1100 E Date 18 JUL 89 24.0 #146

POSITION	I/P	QUAD	T.FLD	TILT	TIME	CULT S	DIR	4-FRA	5-FRA
2375S	16.0	-18.1	27.08	9.4	8:46:29	56	14.8		
225 S	19.1	-18.6	27.12	11.2	8:47:14	56	16.4	0.6	
2125S	23.6	-18.8	27.33	13.7	8:47:37	55	12.3	-3.7	-1.6
200 S	28.0	-18.2	27.30	16.1	8:47:55	44	16.5	-9.2	-6.5
1875S	32.4	-18.0	28.35	18.4	8:48:14	54	13.0	-9.6	-9.4
175 S	38.7	-17.4	28.72	21.6	8:48:32	42	12.2	-10.2	-9.9
1625S	40.3	-18.6	29.53	22.5	8:48:53	55	13.8	-9.6	-9.9
150 S	46.5	-17.0	30.88	25.4	8:49:11	64	16.0	-7.9	-8.8
1375S	54.1	-15.7	32.92	28.8	8:49:31	64	16.0	-10.1	-9.0
125 S	61.2	-13.2	34.79	31.7	8:49:46	52	20.2	-12.6	-11.4
1125S	67.3	-12.5	40.63	34.2	8:50:09	54	10.9	-11.7	-12.2
100 S	70.3	-10.7	46.56	35.3	8:50:24	52	9.6	-9.0	-10.4
0875S	57.0	-10.3	60.00	29.9	8:50:42	63	13.9	0.7	-4.2
075 S	18.6	-10.8	71.55	10.6	8:51:02	55	17.0	29.0	14.8
0625S	-5.7	-0.8	59.82	-3.3	8:51:22	59	11.0	57.9	43.4
050 S	-9.9	1.8	55.35	-5.6	8:51:39	49	13.9	49.4	53.6
0375S	-14.4	6.6	52.23	-8.2	8:51:56	59	5.2	21.1	35.2
025 S	-21.8	3.9	49.66	-12.3	8:52:14	49	7.9	11.6	16.3

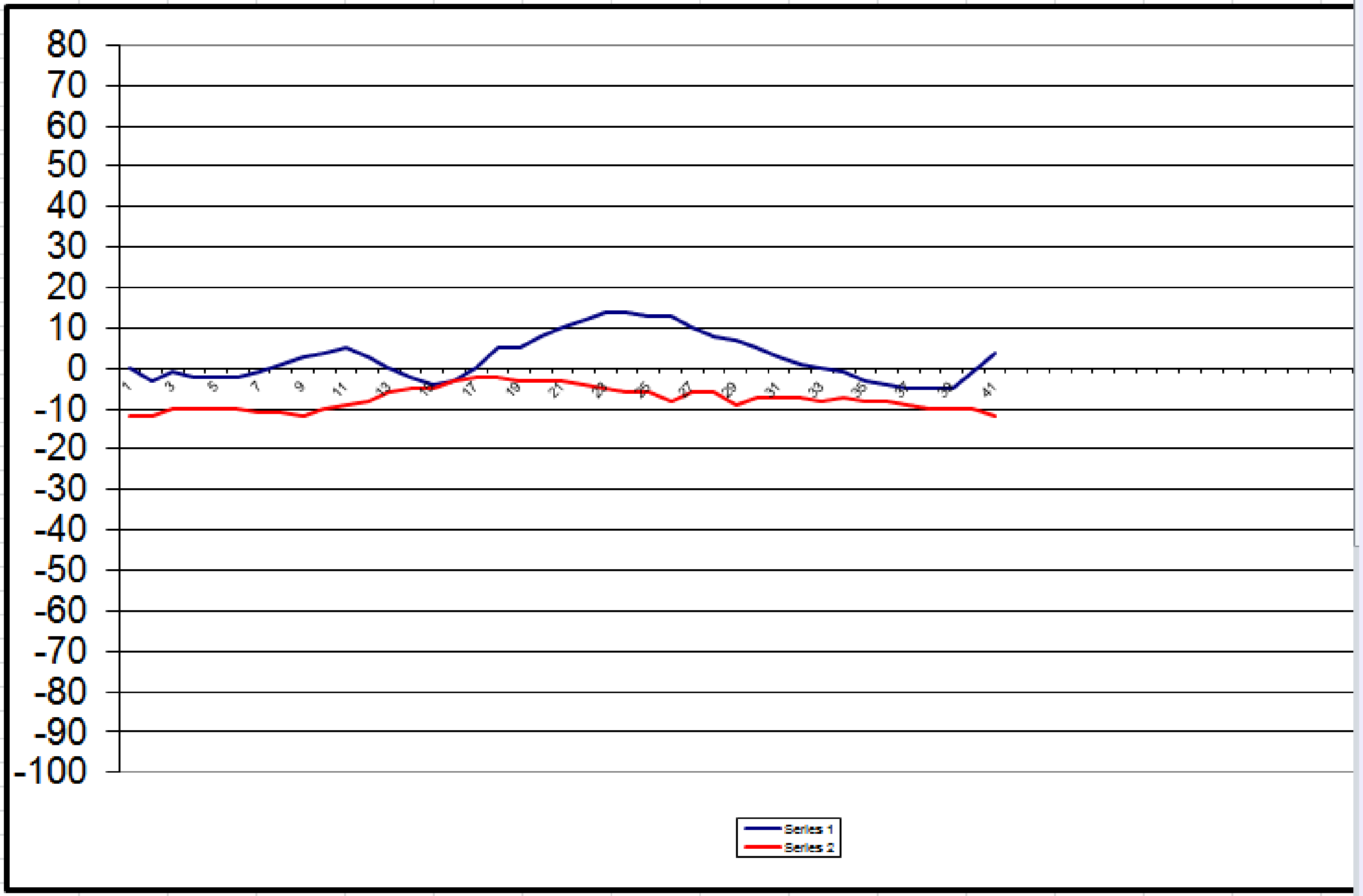
Esker Road EM-16 Survey (April--2001)

Line # 3 West--East along ridge south of big lake @ 25 meter intervals facing East.

Start at Grid--20U-0339904--UTM--5963994.

	Series 1	Series 2	
1	0	-12	
2	-3	-12	
3	-1	-10	
4	-2	-10	
5	-2	-10	
6	-2	-10	
7	-1	-11	
8	1	-11	
9	3	-12	
10	4	-10	
11	5	-9	
12	3	-8	
13	0	-6	X
14	-2	-5	
15	-4	-5	
16	-3	-3	
17	0	-2	
18	5	-2	
19	5	-3	
20	8	-3	
21	10	-3	
22	12	-4	
23	14	-5	
24	14	-6	
25	13	-6	
26	13	-8	
27	10	-6	
28	8	-6	
29	7	-9	
30	5	-7	
31	3	-7	
32	1	-7	
33	0	-8	X
34	-1	-7	
35	-3	-8	
36	-4	-8	
37	-5	-9	
38	-5	-10	
39	-5	-10	
40	-1	-10	
41	4	-12	

West



Note: All reading are taken at 25 Meter Intervals Facing East.

Crossover Location @ reading # 13-- Grid--20U-0340186--UTM--5963994

#33 --Grid--20U--0340677--UTM--5963912.

Paste | Cut | Copy | Format Painter | Clipboard

11 | Font

Wrap Text | Merge & Center | Alignment

Number | $ % | Number

Conditional Formatting | Format Table

SUM | =(D3+D4)-(D5+D6)

	A	B	C	D	E	F	G	H	I	J
1		Grid X	Mag	In-Phase	Quad	Fraser Filter	FF_interp	Grid_X+1/2	Easting	Northing
2	Line	9900								
3	9900.0	9700.0	397.0	-2.2	-3.0				549386.46	5394762.01
4	9900.0	9712.5	400.7	-8.6	-7.3		13.5	9706.3	549397.55	5394756.24
5	9900.0	9725.0	372.4	-11.7	-10.4	=(D3+D4)-(D5	-6.1	9718.8	549408.64	5394750.47
6	9900.0	9737.5	364.4	-3.7	-7.5	-16.7	-13.6	9731.3	549419.72	5394744.69
7	9900.0	9750.0	358.2	0.1	-5.6	-10.4	-3.6	9743.8	549430.81	5394738.92
8	9900.0	9762.5	328.1	-5.1	-9.2	3.3	-0.1	9756.3	549441.90	5394733.15
9	9900.0	9775.0	500.2	-1.8	-9.0	-3.4	-5.7	9768.8	549452.99	5394727.38
10	9900.0	9787.5	392.6	0.2	-9.1	-7.9	-5.8	9781.3	549464.07	5394721.61
11	9900.0	9800.0	379.9	0.8	-10.4	-3.7	-3.4	9793.8	549475.16	5394715.84
12	9900.0	9812.5	375.7	1.3	-10.9	-3.1	-4.0	9806.3	549486.25	5394710.06
13	9900.0	9825.0	371.3	2.8	-11.2	-4.9	-4.7	9818.8	549497.34	5394704.29
14	9900.0	9837.5	364.2	4.2	-12.0	-4.5	-4.8	9831.3	549508.42	5394698.52
15	9900.0	9850.0	363.0	4.4	-12.5	-5.0	-7.7	9843.8	549519.51	5394692.75
16	9900.0	9862.5	341.3	7.6	-12.3	-10.3	-11.7	9856.3	549530.60	5394686.98
17	9900.0	9875.0	332.2	11.3	-11.6	-13.1	-10.7	9868.8	549541.69	5394681.20
18	9900.0	9887.5	318.8	13.8	-11.0	-8.3	-5.7	9881.3	549552.77	5394675.43
19	9900.0	9900.0	282.9	13.4	-12.4	-3.1	-3.2	9893.8	549563.86	5394669.66
20	9900.0	9912.5	333.8	14.8	-13.3	-3.2	-4.8	9906.3	549574.95	5394663.89
21	9900.0	9925.0	719.9	15.6	-15.5	-6.3	-8.3	9918.8	549586.04	5394658.12
22	9900.0	9937.5	687.2	18.9	-15.4	-10.3	-13.2	9931.3	549597.12	5394652.35
23	9900.0	9950.0	702.7	21.8	-15.3	-16.0	-16.9	9943.8	549608.21	5394646.57
24	9900.0	9962.5	1031.1	28.7	-12.5	-17.8	-15.0	9956.3	549619.30	5394640.80
25	9900.0	9975.0	558.5	29.8	-14.2	-12.2	-10.2	9968.8	549630.39	5394635.03
26	9900.0	9987.5	454.2	32.9	-13.8	-8.2	-7.3	9981.3	549641.47	5394629.26

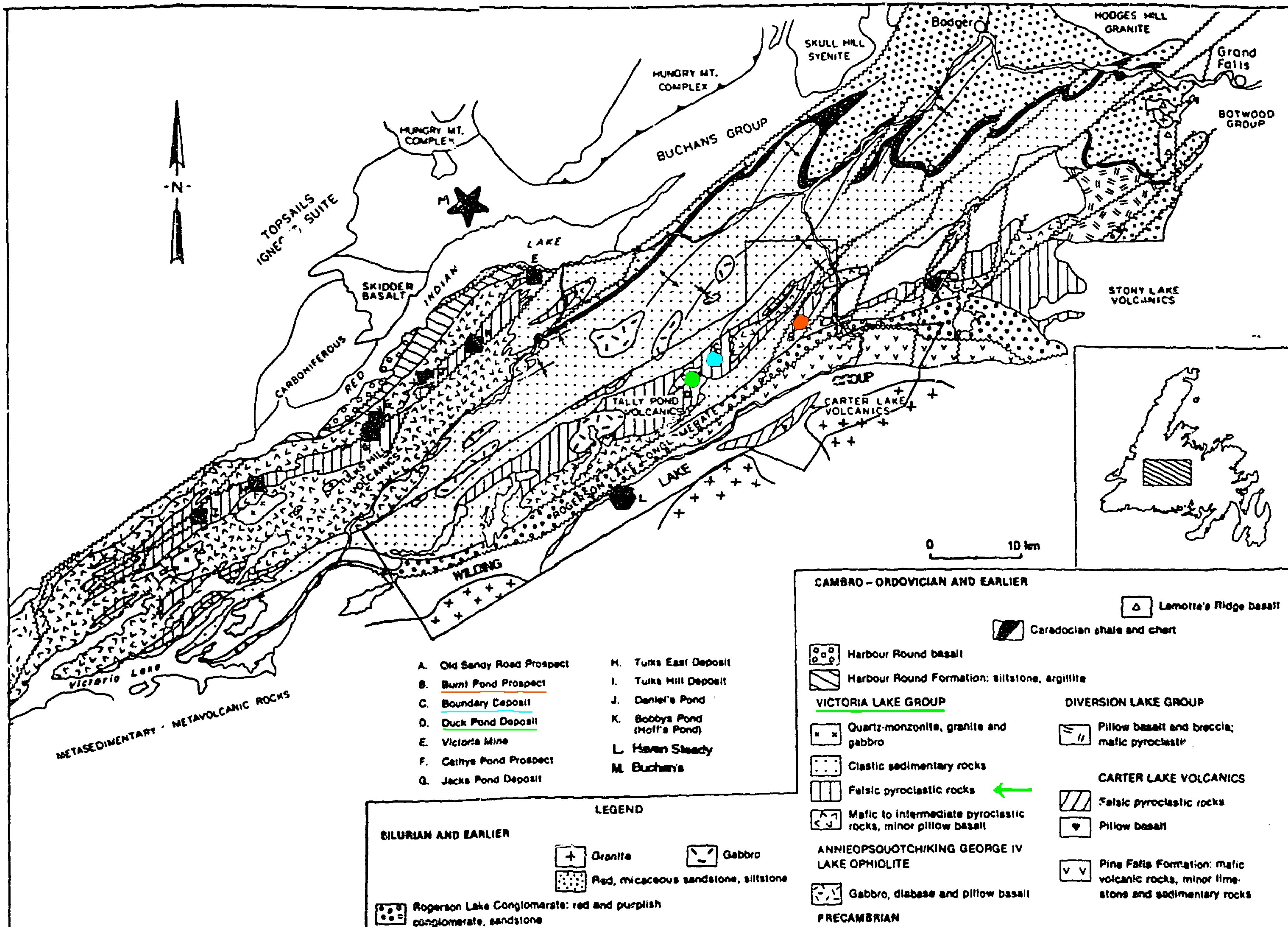


FIGURE 3 (after Evans et al,1990.)

SCANNED IMAGE

012A/09/0606
MAP- 012A/09/0606/1-16

CONFIDENTIAL

Fourth Year Assessment Report

Burnt Pond Property (6777)

NTS 12A/9

Licence 3881, 3107, 3108

by

Chris Collins, P.Geo.

for

Noranda Exploration Company, Limited

(No Personal Liability)

September, 1991

SCANNED IMAGE

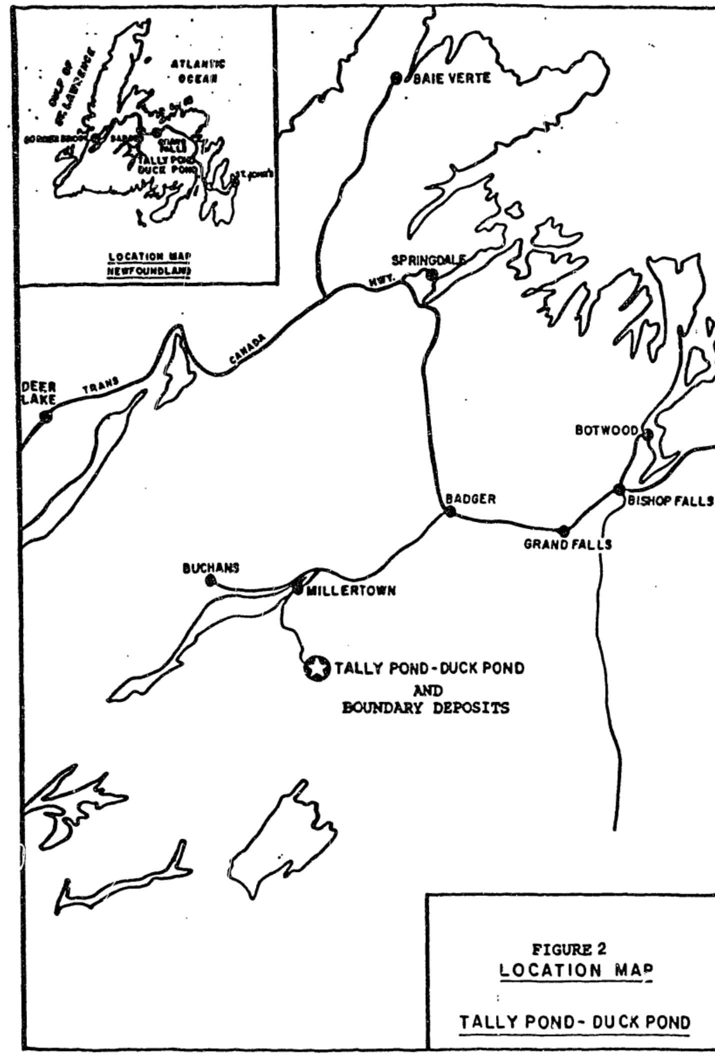
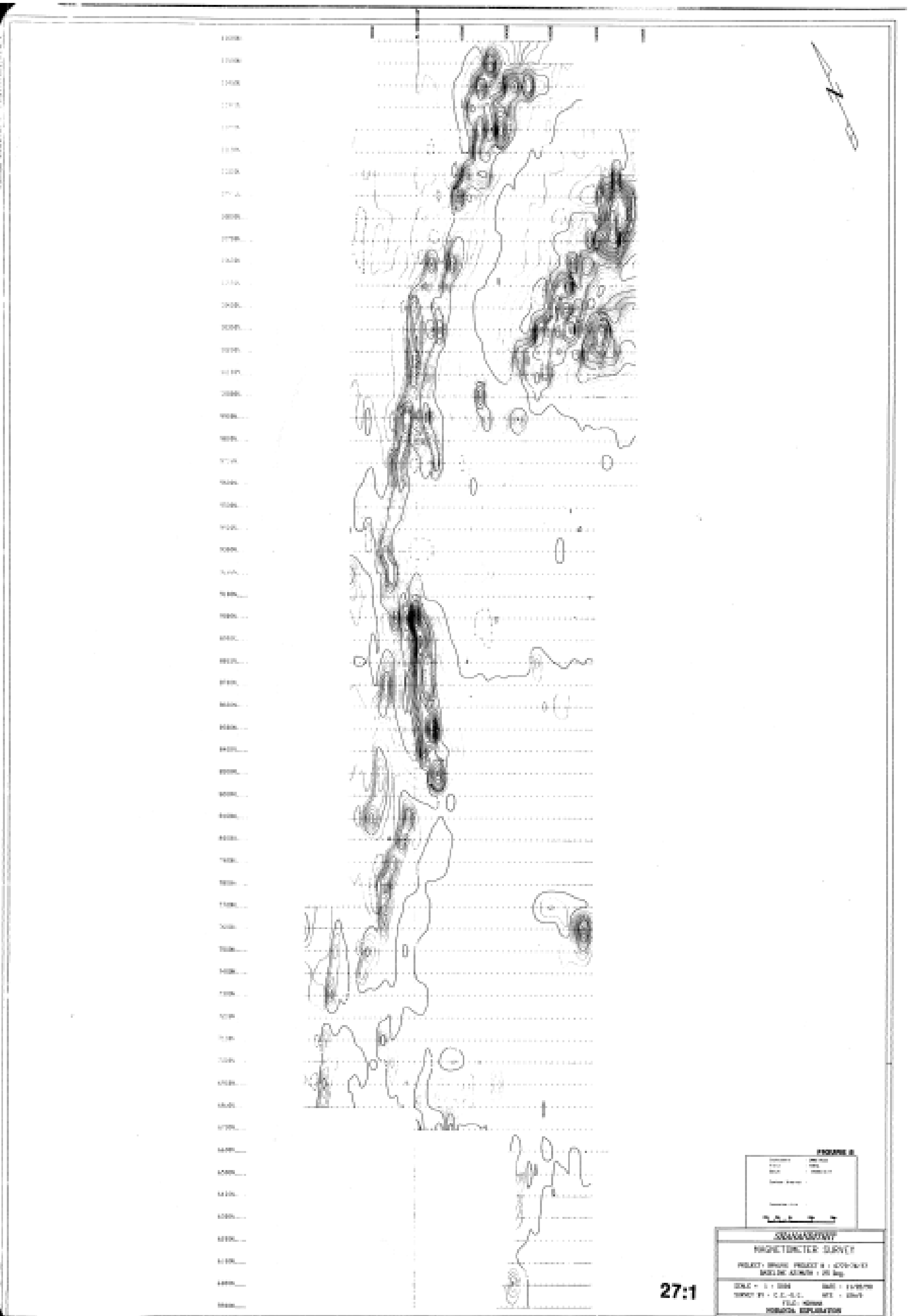
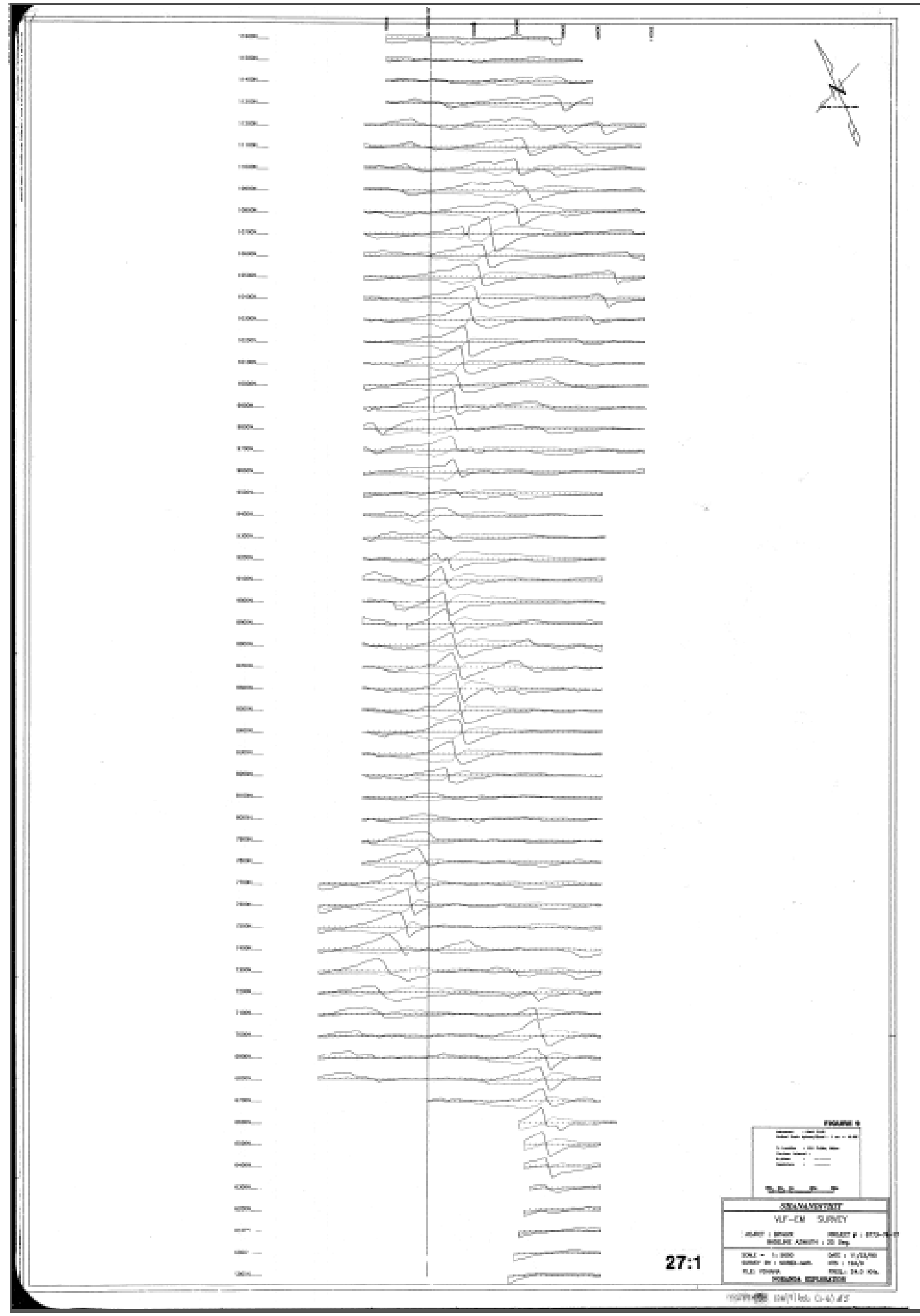
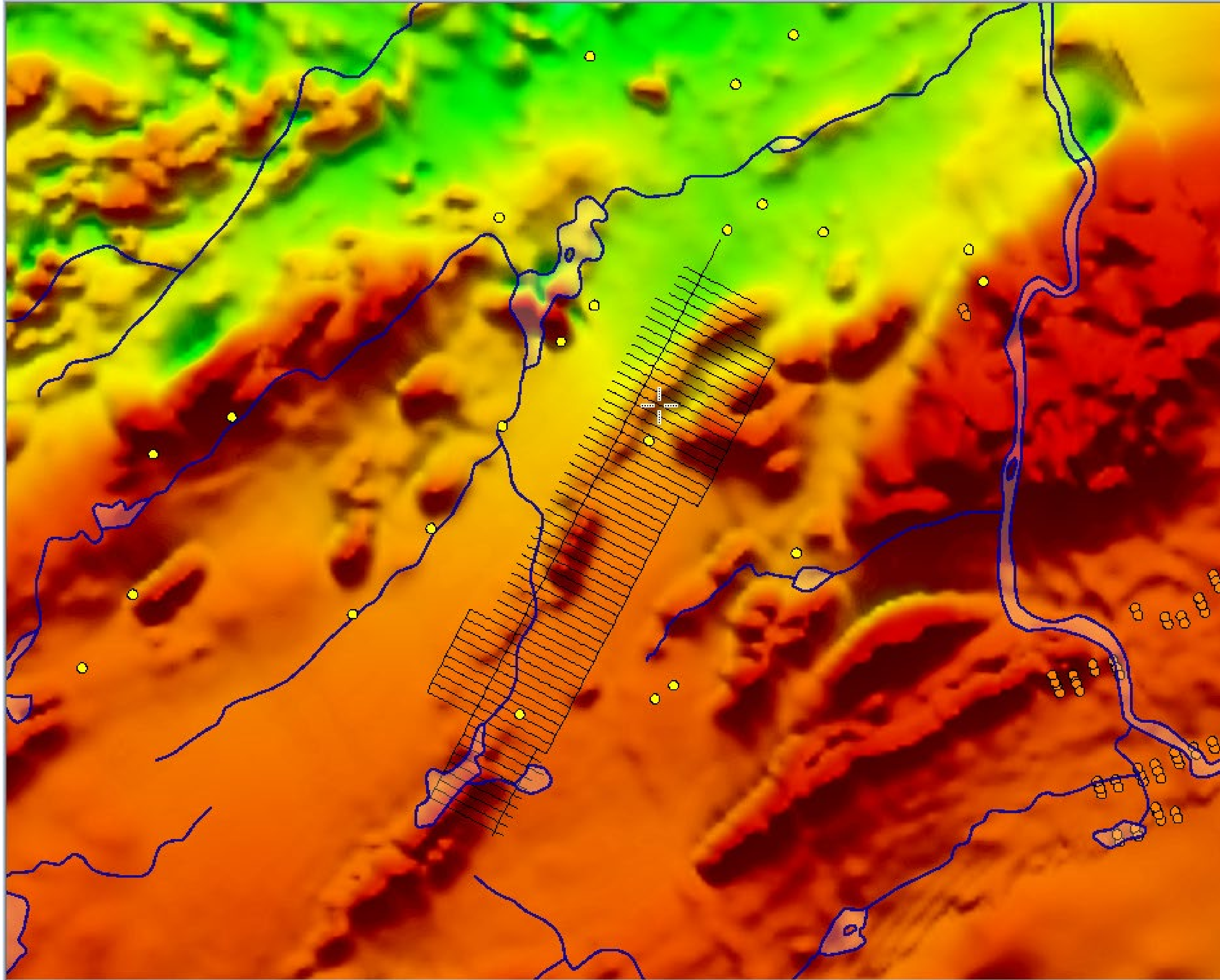
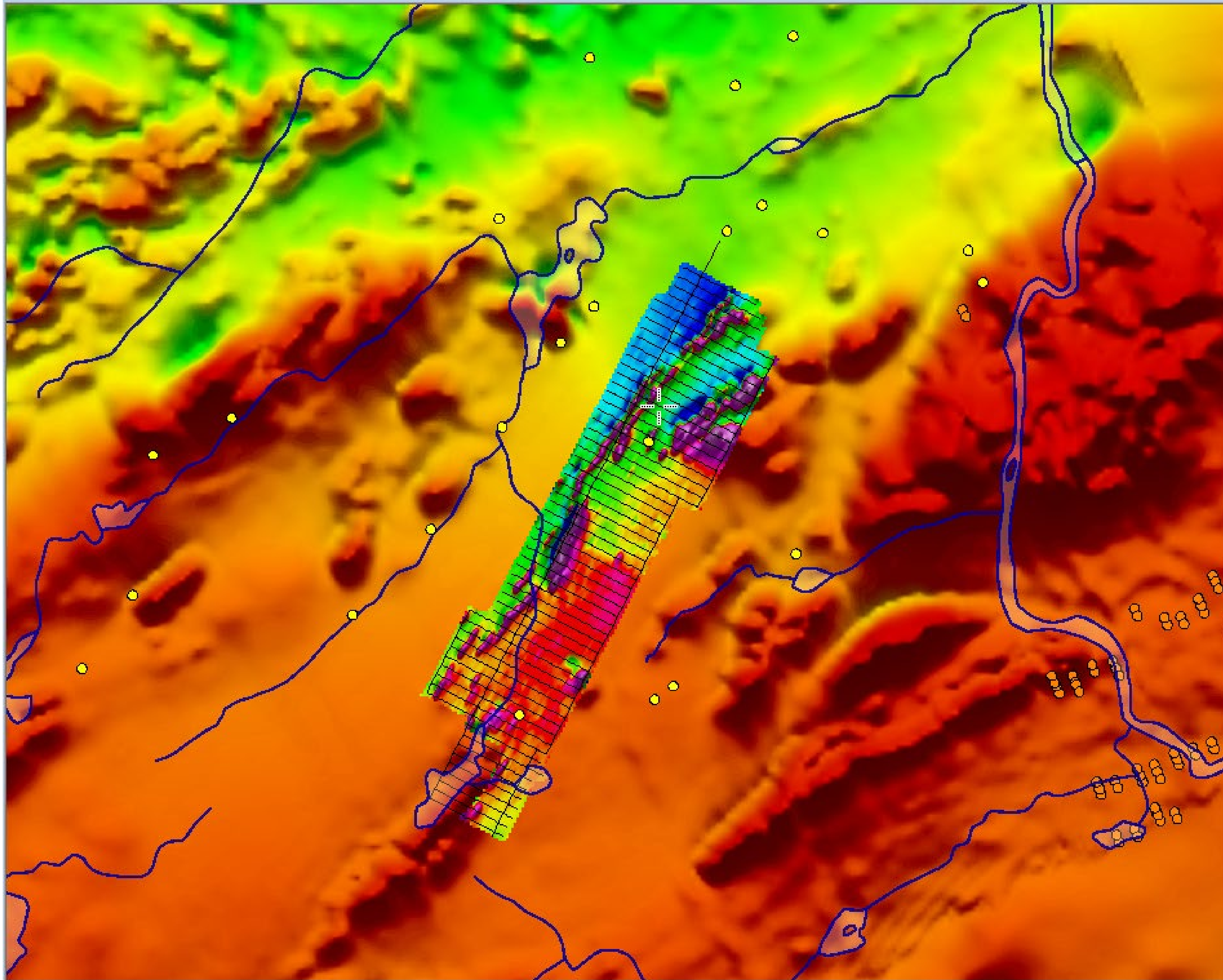


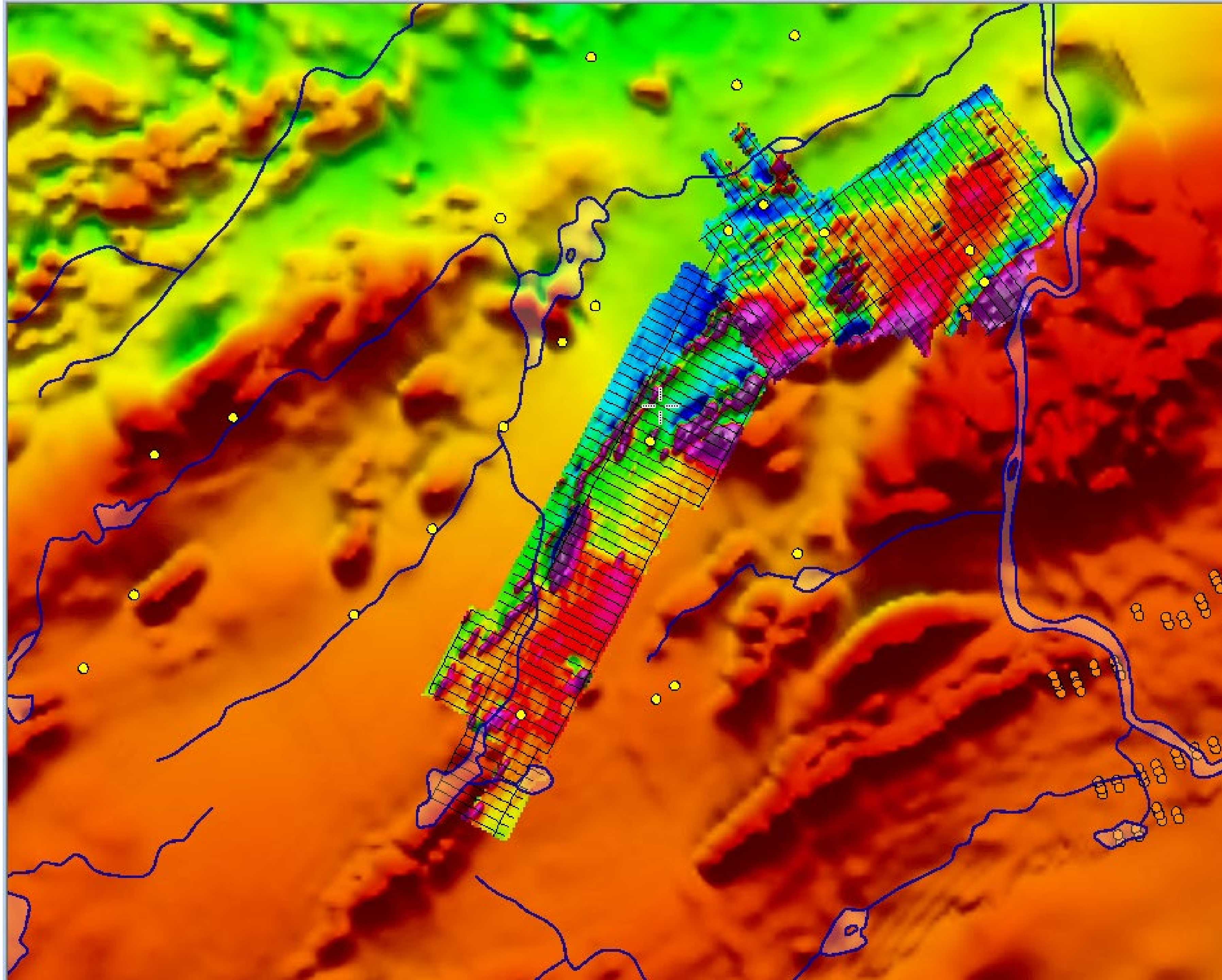
FIGURE 2
LOCATION MAP
TALLY POND - DUCK POND

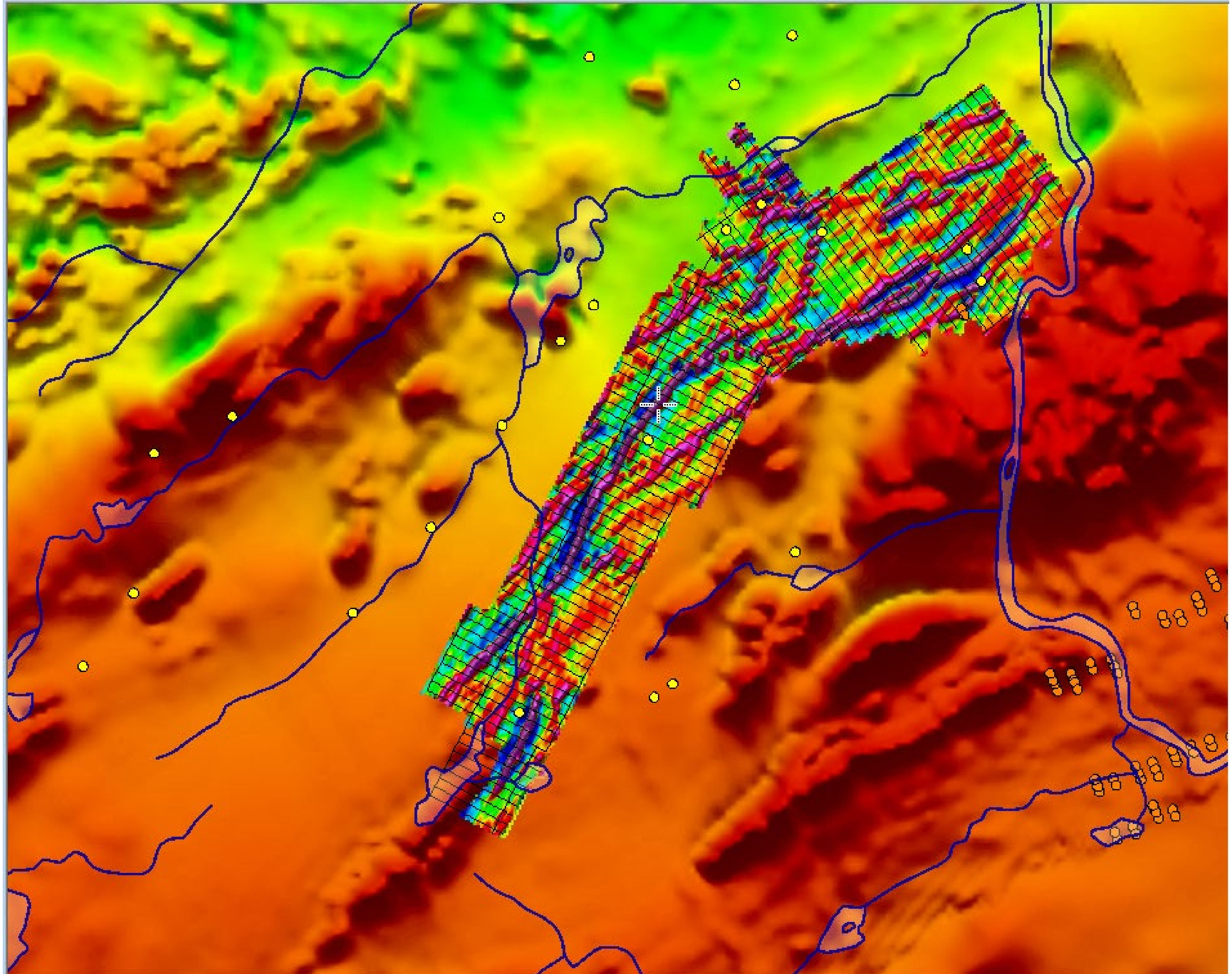

MAGNETOMETER SURVEY
27:1

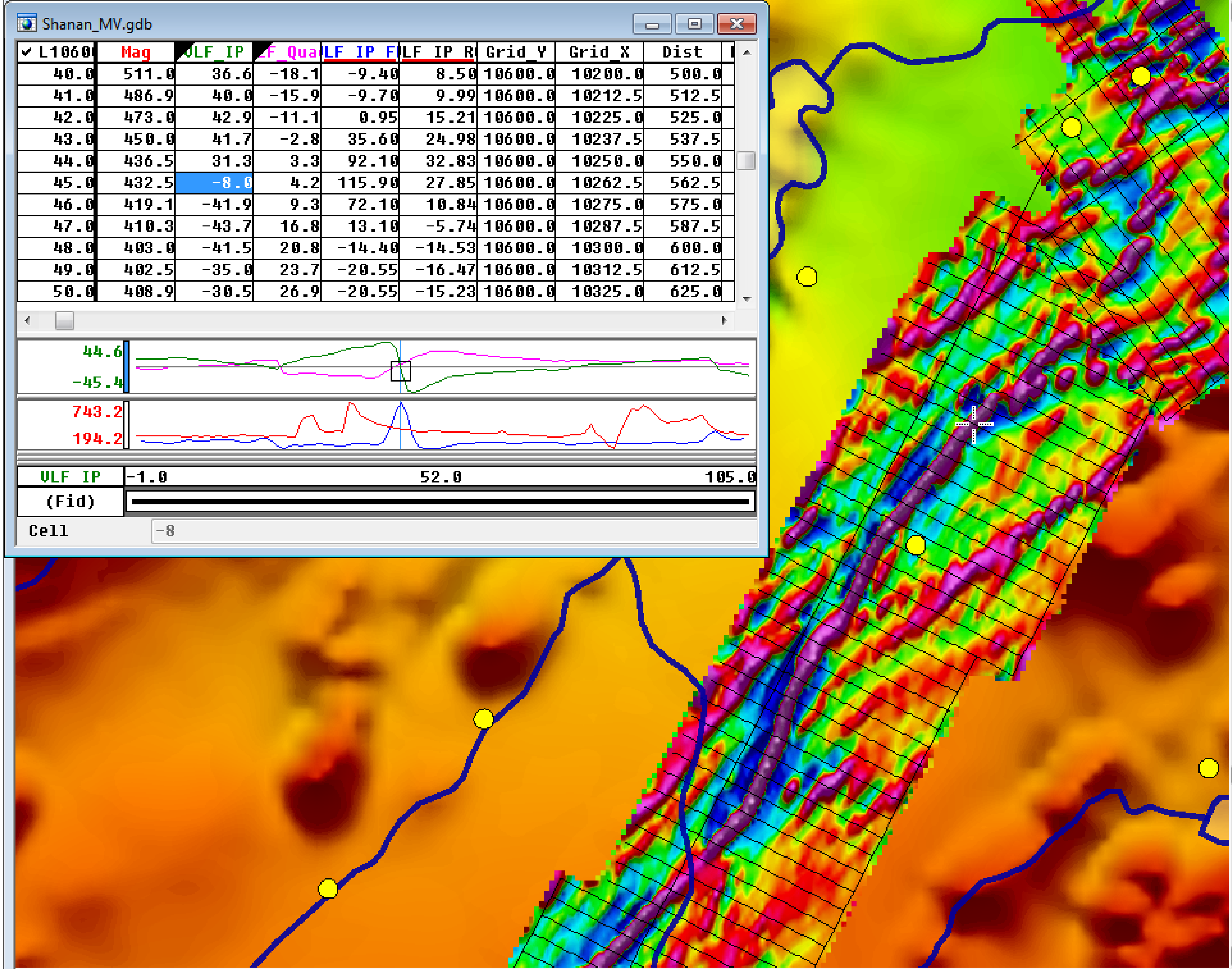

VLF-EM SURVEY
27:1



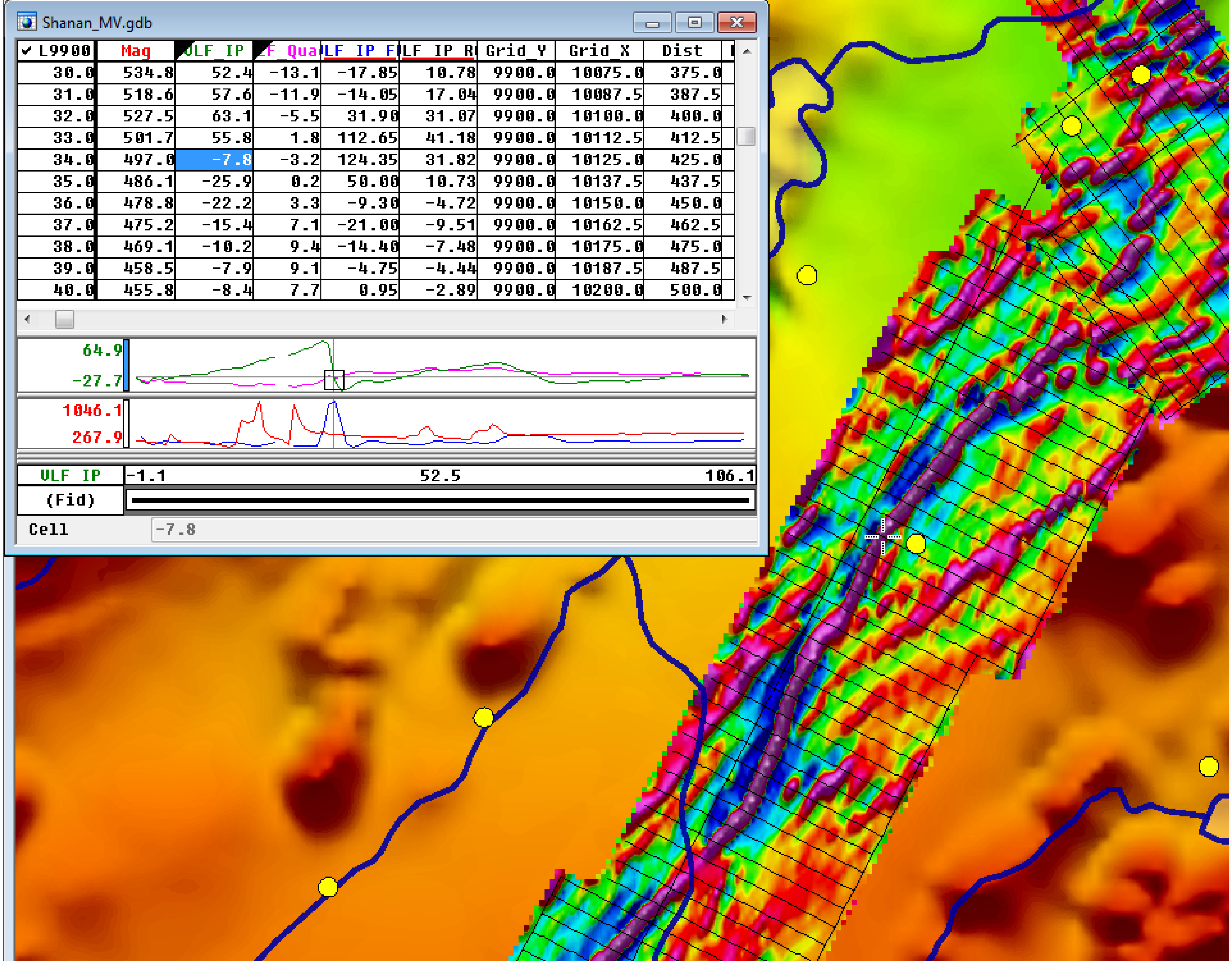


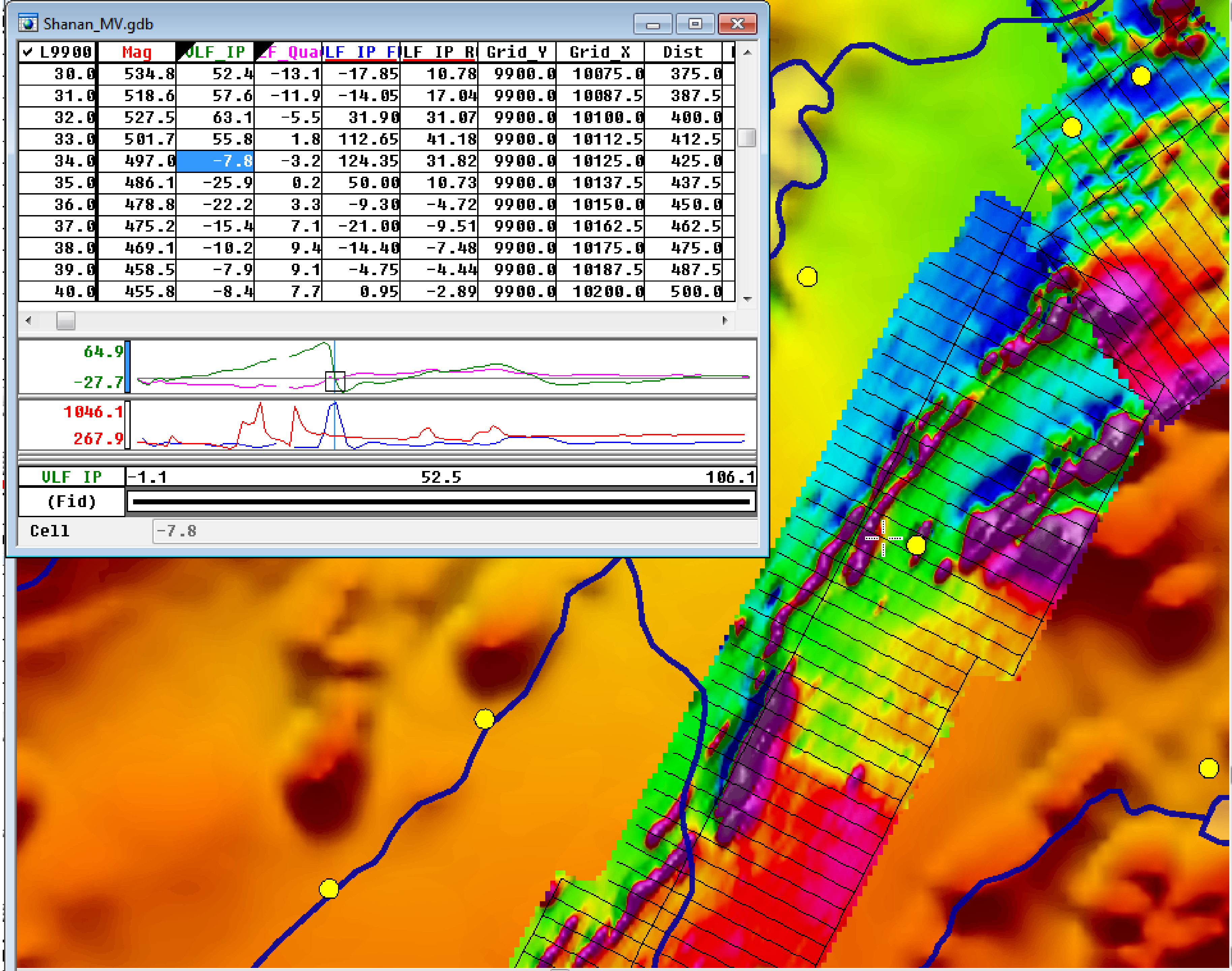




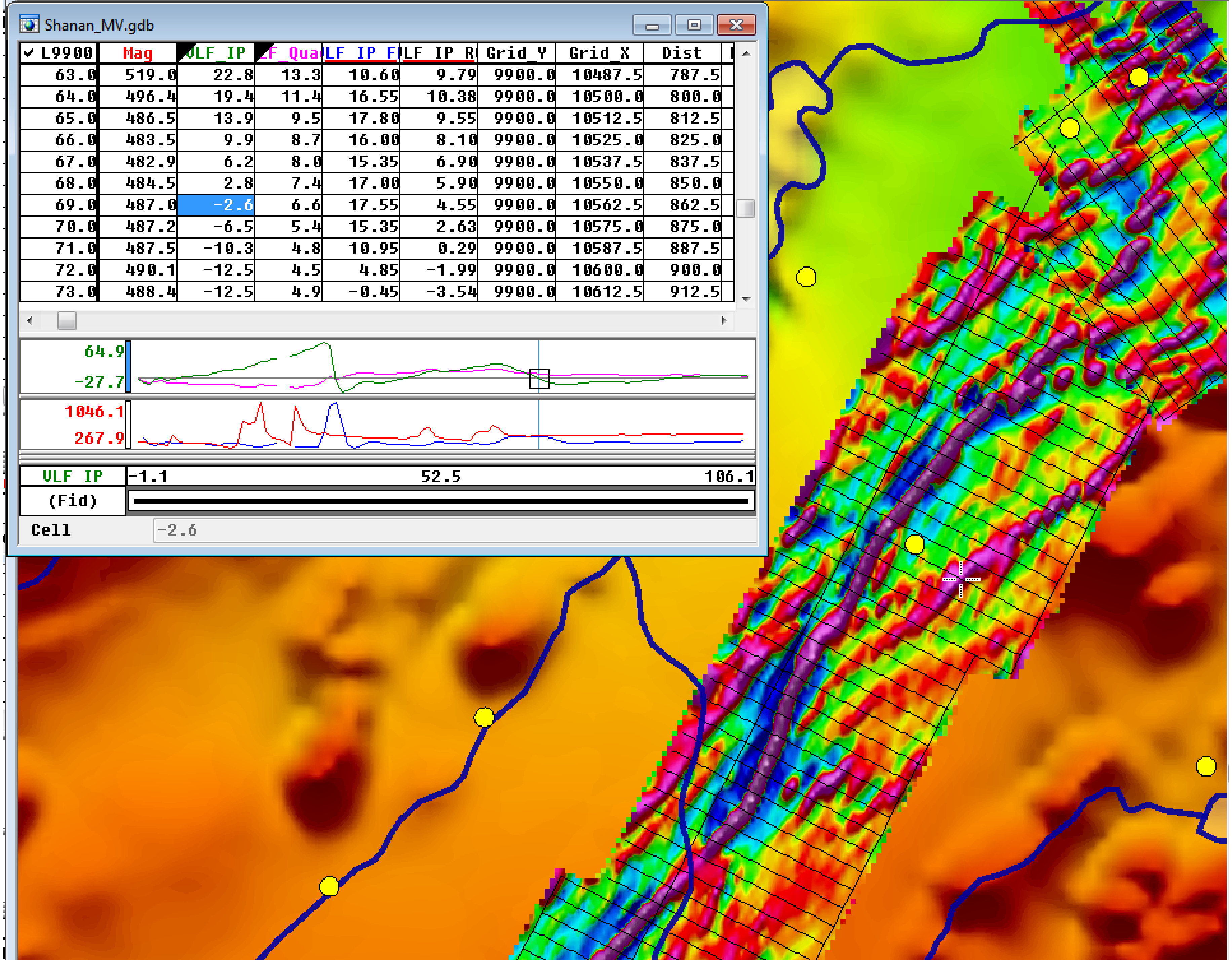


L1060	Mag	VLF_IP	LF_Qua	LF_IP_F	LF_IP_R	Grid_Y	Grid_X	Dist
40.0	511.0	36.6	-18.1	-9.40	8.50	10600.0	10200.0	500.0
41.0	486.9	40.0	-15.9	-9.70	9.99	10600.0	10212.5	512.5
42.0	473.0	42.9	-11.1	0.95	15.21	10600.0	10225.0	525.0
43.0	450.0	41.7	-2.8	35.60	24.98	10600.0	10237.5	537.5
44.0	436.5	31.3	3.3	92.10	32.83	10600.0	10250.0	550.0
45.0	432.5	-8.0	4.2	115.90	27.85	10600.0	10262.5	562.5
46.0	419.1	-41.9	9.3	72.10	10.84	10600.0	10275.0	575.0
47.0	410.3	-43.7	16.8	13.10	-5.74	10600.0	10287.5	587.5
48.0	403.0	-41.5	20.8	-14.40	-14.53	10600.0	10300.0	600.0
49.0	402.5	-35.0	23.7	-20.55	-16.47	10600.0	10312.5	612.5
50.0	408.9	-30.5	26.9	-20.55	-15.23	10600.0	10325.0	625.0

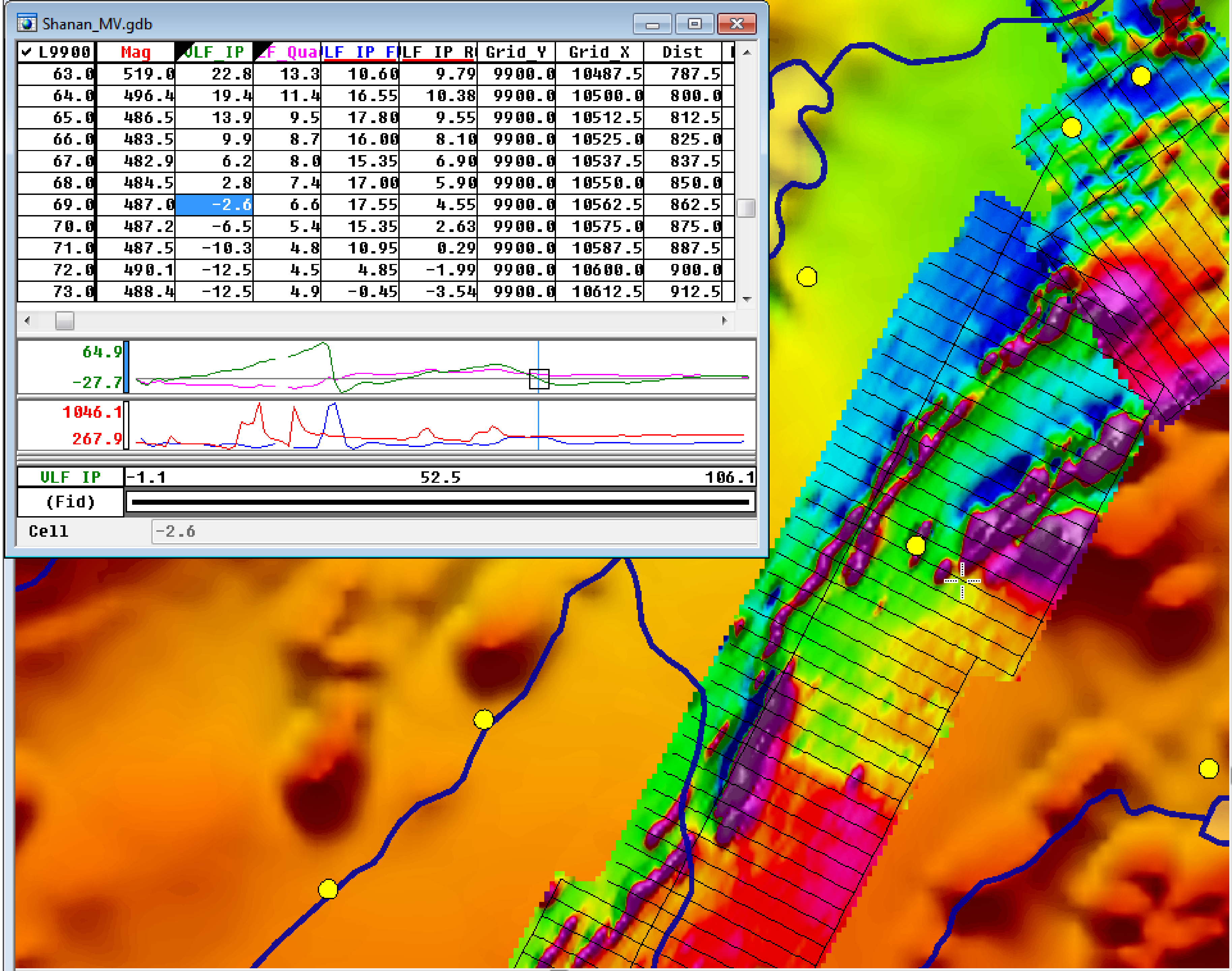

Shanan_MV.gdb
L9900 Mag VLF_IP F_Qua LF_IP_F LF_IP_R Grid_Y Grid_X Dist
30.0 534.8 52.4 -13.1 -17.85 10.78 9900.0 10075.0 375.0
31.0 518.6 57.6 -11.9 -14.05 17.04 9900.0 10087.5 387.5
32.0 527.5 63.1 -5.5 31.90 31.07 9900.0 10100.0 400.0
33.0 501.7 55.8 1.8 112.65 41.18 9900.0 10112.5 412.5
34.0 497.0 -7.8 -3.2 124.35 31.82 9900.0 10125.0 425.0
35.0 486.1 -25.9 0.2 50.00 10.73 9900.0 10137.5 437.5
36.0 478.8 -22.2 3.3 -9.30 -4.72 9900.0 10150.0 450.0
37.0 475.2 -15.4 7.1 -21.00 -9.51 9900.0 10162.5 462.5
38.0 469.1 -10.2 9.4 -14.40 -7.48 9900.0 10175.0 475.0
39.0 458.5 -7.9 9.1 -4.75 -4.44 9900.0 10187.5 487.5
40.0 455.8 -8.4 7.7 0.95 -2.89 9900.0 10200.0 500.0
64.9
-27.7
1046.1
267.9
VLF_IP -1.1 52.5 106.1
(Fid)
Cell -7.8



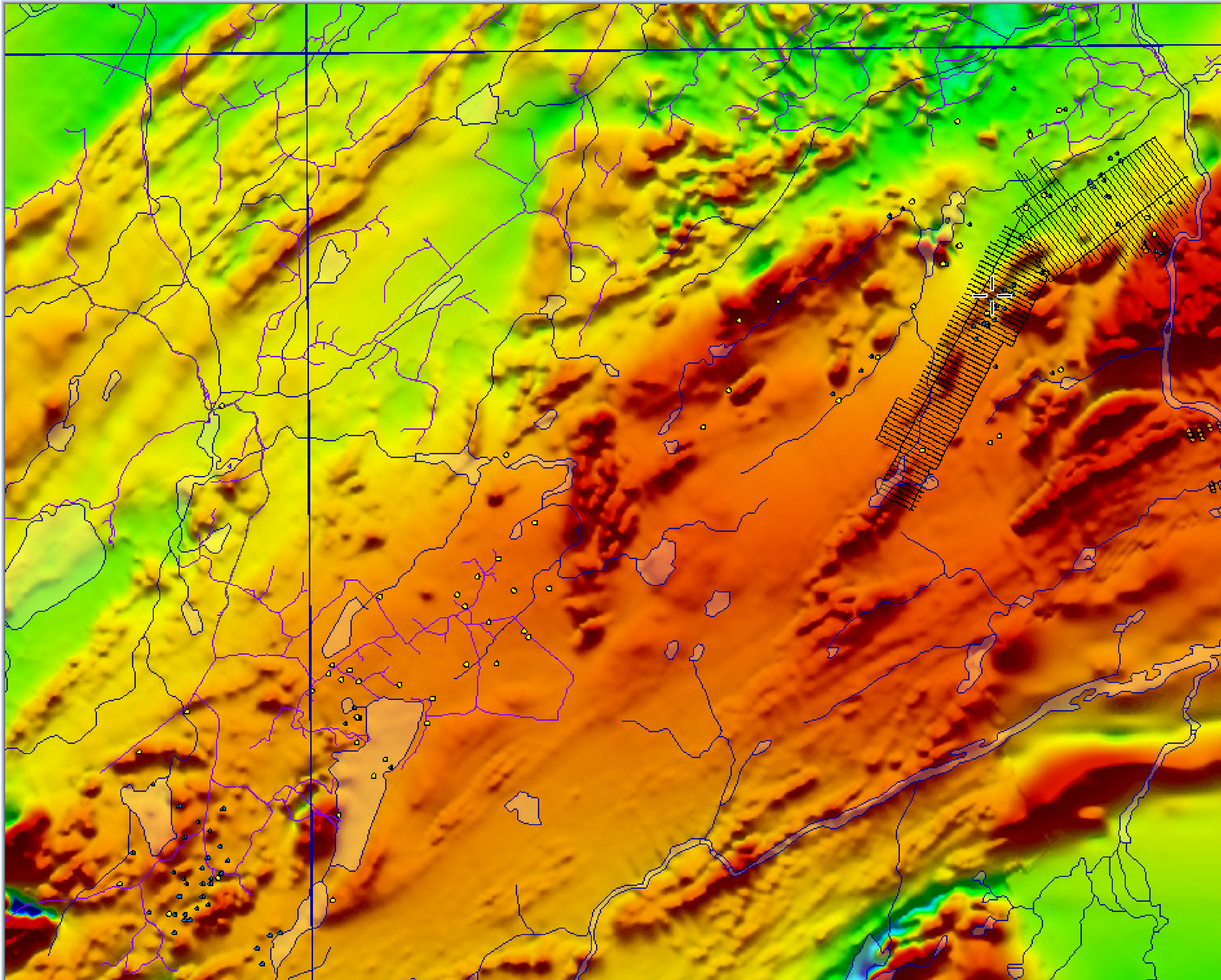
✓ L9900	Mag	VLF_IP	F_Qua	LF_IP_F	LF_IP_R	Grid_Y	Grid_X	Dist
30.0	534.8	52.4	-13.1	-17.85	10.78	9900.0	10075.0	375.0
31.0	518.6	57.6	-11.9	-14.05	17.04	9900.0	10087.5	387.5
32.0	527.5	63.1	-5.5	31.90	31.07	9900.0	10100.0	400.0
33.0	501.7	55.8	1.8	112.65	41.18	9900.0	10112.5	412.5
34.0	497.0	-7.8	-3.2	124.35	31.82	9900.0	10125.0	425.0
35.0	486.1	-25.9	0.2	50.00	10.73	9900.0	10137.5	437.5
36.0	478.8	-22.2	3.3	-9.30	-4.72	9900.0	10150.0	450.0
37.0	475.2	-15.4	7.1	-21.00	-9.51	9900.0	10162.5	462.5
38.0	469.1	-10.2	9.4	-14.40	-7.48	9900.0	10175.0	475.0
39.0	458.5	-7.9	9.1	-4.75	-4.44	9900.0	10187.5	487.5
40.0	455.8	-8.4	7.7	0.95	-2.89	9900.0	10200.0	500.0

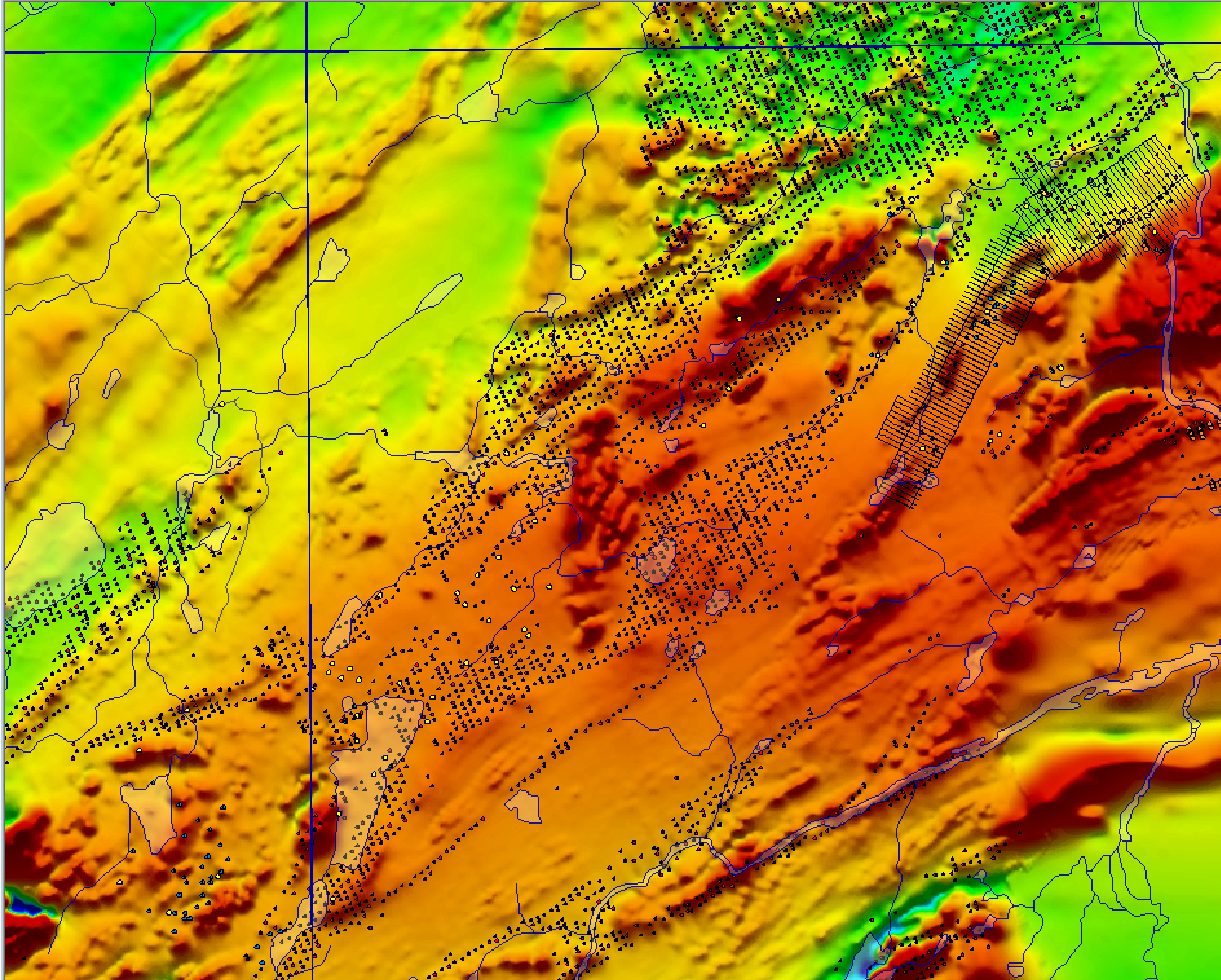


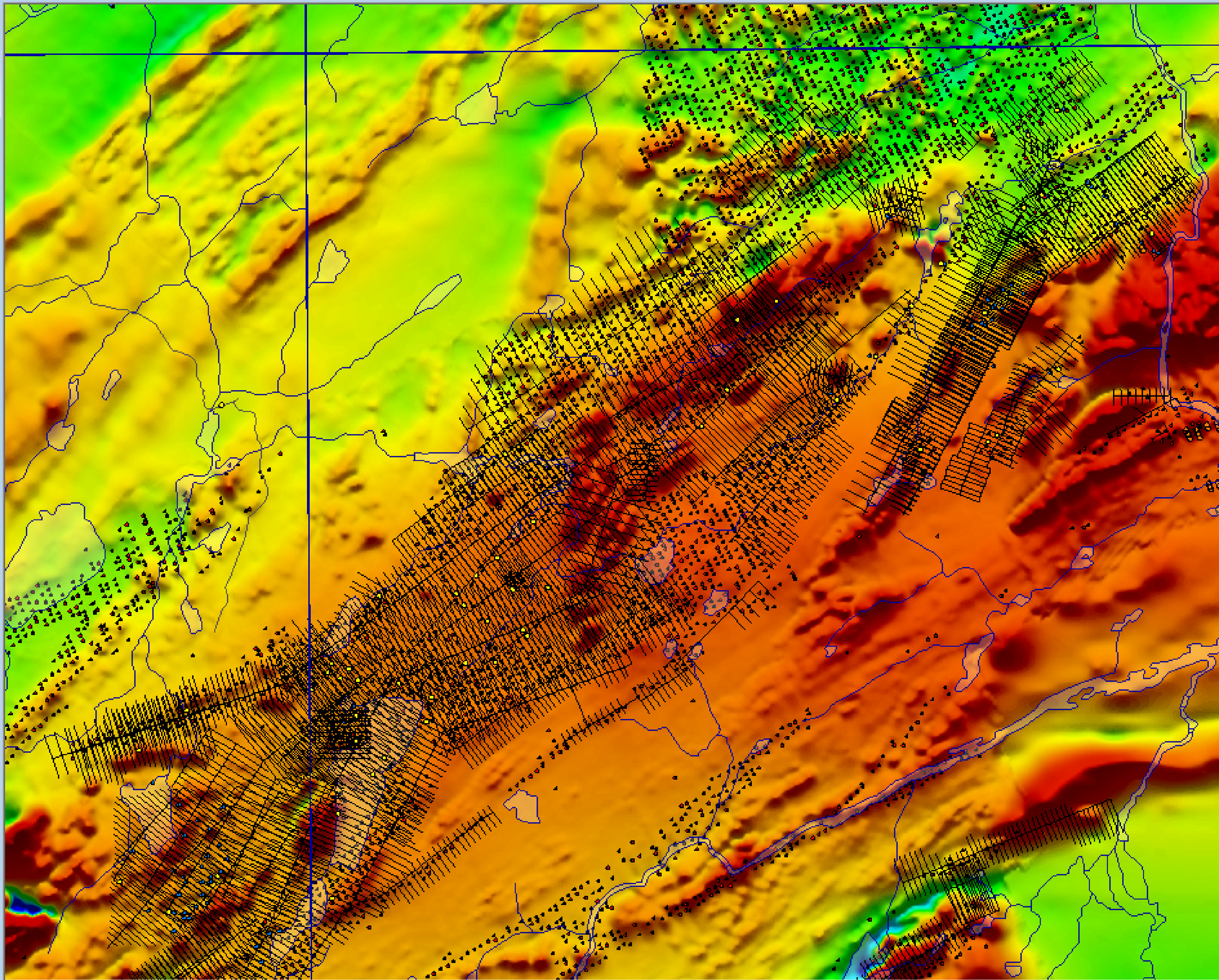
L9900	Mag	VLF_IP	F_Qua	LF_IP_F	LF_IP_R	Grid_Y	Grid_X	Dist
63.0	519.0	22.8	13.3	10.60	9.79	9900.0	10487.5	787.5
64.0	496.4	19.4	11.4	16.55	10.38	9900.0	10500.0	800.0
65.0	486.5	13.9	9.5	17.80	9.55	9900.0	10512.5	812.5
66.0	483.5	9.9	8.7	16.00	8.10	9900.0	10525.0	825.0
67.0	482.9	6.2	8.0	15.35	6.90	9900.0	10537.5	837.5
68.0	484.5	2.8	7.4	17.00	5.90	9900.0	10550.0	850.0
69.0	487.0	-2.6	6.6	17.55	4.55	9900.0	10562.5	862.5
70.0	487.2	-6.5	5.4	15.35	2.63	9900.0	10575.0	875.0
71.0	487.5	-10.3	4.8	10.95	0.29	9900.0	10587.5	887.5
72.0	490.1	-12.5	4.5	4.85	-1.99	9900.0	10600.0	900.0
73.0	488.4	-12.5	4.9	-0.45	-3.54	9900.0	10612.5	912.5



✔ L9900	Mag	VLF_IP	F_Qua	LF_IP_F	LF_IP_R	Grid_Y	Grid_X	Dist
63.0	519.0	22.8	13.3	10.60	9.79	9900.0	10487.5	787.5
64.0	496.4	19.4	11.4	16.55	10.38	9900.0	10500.0	800.0
65.0	486.5	13.9	9.5	17.80	9.55	9900.0	10512.5	812.5
66.0	483.5	9.9	8.7	16.00	8.10	9900.0	10525.0	825.0
67.0	482.9	6.2	8.0	15.35	6.90	9900.0	10537.5	837.5
68.0	484.5	2.8	7.4	17.00	5.90	9900.0	10550.0	850.0
69.0	487.0	-2.6	6.6	17.55	4.55	9900.0	10562.5	862.5
70.0	487.2	-6.5	5.4	15.35	2.63	9900.0	10575.0	875.0
71.0	487.5	-10.3	4.8	10.95	0.29	9900.0	10587.5	887.5
72.0	490.1	-12.5	4.5	4.85	-1.99	9900.0	10600.0	900.0
73.0	488.4	-12.5	4.9	-0.45	-3.54	9900.0	10612.5	912.5

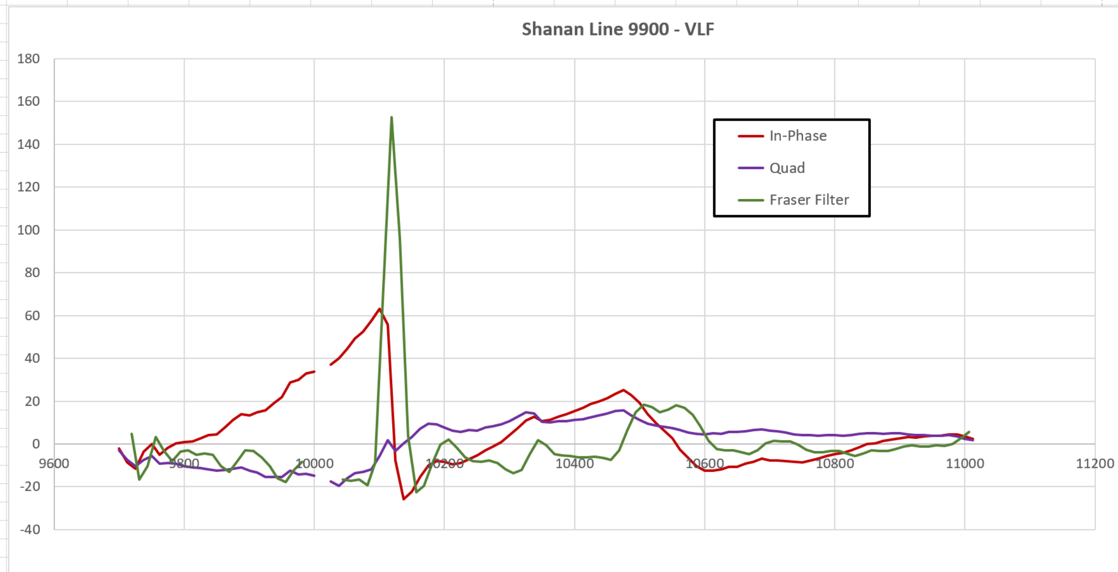






F37 =(D35+D36)-(D37+D38)

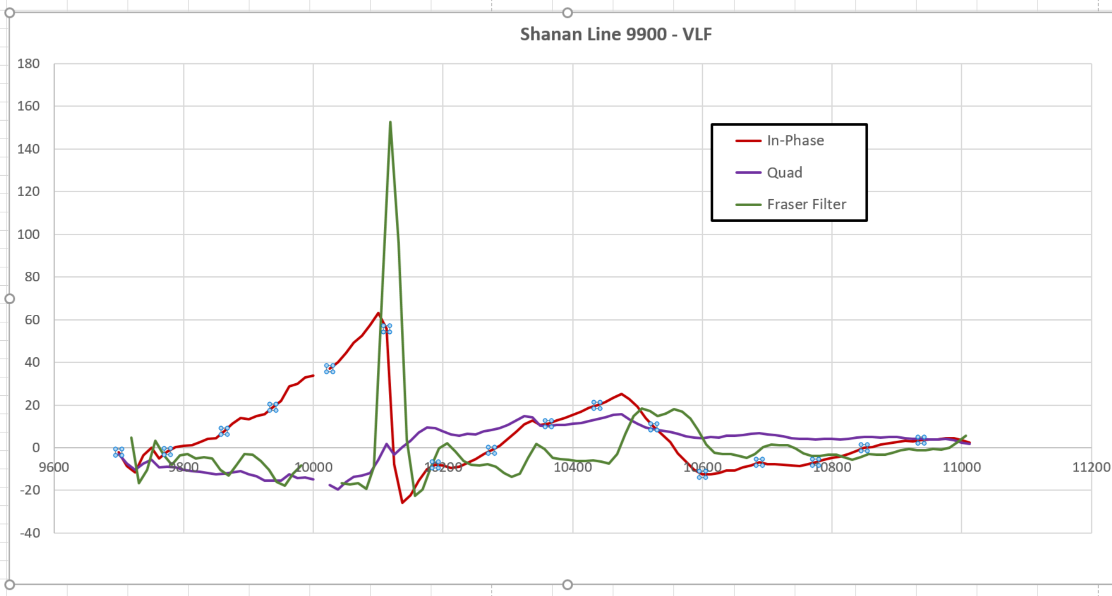
	A	B	C	D	E	F	G	H	I	J
1		Grid X	Mag	In-Phase	Quad	Fraser Filter	FF_interp	Grid_X+1/2	Easting	Northing
2	Line	9900								
3	9900.0	9700.0	397.0	-2.2	-3.0				549386.46	5394762.01
4	9900.0	9712.5	400.7	-8.6	-7.3		13.5	9706.3	549397.55	5394756.24
5	9900.0	9725.0	372.4	-11.7	-10.4	4.6	-6.1	9718.8	549408.64	5394750.47
6	9900.0	9737.5	364.4	-3.7	-7.5	-16.7	-13.6	9731.3	549419.72	5394744.69
7	9900.0	9750.0	358.2	0.1	-5.6	-10.4	-3.6	9743.8	549430.81	5394738.92
8	9900.0	9762.5	328.1	-5.1	-9.2	3.3	-0.1	9756.3	549441.90	5394733.15
9	9900.0	9775.0	500.2	-1.8	-9.0	-3.4	-5.7	9768.8	549452.99	5394727.38
10	9900.0	9787.5	392.6	0.2	-9.1	-7.9	-5.8	9781.3	549464.07	5394721.61
11	9900.0	9800.0	379.9	0.8	-10.4	-3.7	-3.4	9793.8	549475.16	5394715.84
12	9900.0	9812.5	375.7	1.3	-10.9	-3.1	-4.0	9806.3	549486.25	5394710.06
13	9900.0	9825.0	371.3	2.8	-11.2	-4.9	-4.7	9818.8	549497.34	5394704.29
14	9900.0	9837.5	364.2	4.2	-12.0	-4.5	-4.8	9831.3	549508.42	5394698.52
15	9900.0	9850.0	363.0	4.4	-12.5	-5.0	-7.7	9843.8	549519.51	5394692.75
16	9900.0	9862.5	341.3	7.6	-12.3	-10.3	-11.7	9856.3	549530.60	5394686.98
17	9900.0	9875.0	332.2	11.3	-11.6	-13.1	-10.7	9868.8	549541.69	5394681.20
18	9900.0	9887.5	318.8	13.8	-11.0	-8.3	-5.7	9881.3	549552.77	5394675.43
19	9900.0	9900.0	282.9	13.4	-12.4	-3.1	-3.2	9893.8	549563.86	5394669.66
20	9900.0	9912.5	333.8	14.8	-13.3	-3.2	-4.8	9906.3	549574.95	5394663.89
21	9900.0	9925.0	719.9	15.6	-15.5	-6.3	-8.3	9918.8	549586.04	5394658.12
22	9900.0	9937.5	687.2	18.9	-15.4	-10.3	-13.2	9931.3	549597.12	5394652.35
23	9900.0	9950.0	702.7	21.8	-15.3	-16.0	-16.9	9943.8	549608.21	5394646.57
24	9900.0	9962.5	1031.1	28.7	-12.5	-17.8	-15.0	9956.3	549619.30	5394640.80
25	9900.0	9975.0	558.5	29.8	-14.2	-12.2	-10.2	9968.8	549630.39	5394635.03
26	9900.0	9987.5	454.2	32.9	-13.8	-8.2	-7.3	9981.3	549641.47	5394629.26
27	9900.0	10000.0	428.2	33.8	-14.7		-6.0	9993.8	549652.56	5394623.49
28	9900.0	10012.5	401.5					10006.3	549663.65	5394617.71
29	9900.0	10025.0	337.9	36.9	-17.4			10018.8	549674.74	5394611.94
30	9900.0	10037.5	970.1	40.0	-19.5		-14.4	10031.3	549685.83	5394606.17
31	9900.0	10050.0	695.7	44.4	-15.9	-16.6	-16.9	10043.8	549696.91	5394600.40
32	9900.0	10062.5	573.1	49.1	-13.7	-17.1	-16.8	10056.3	549708.00	5394594.63
33	9900.0	10075.0	534.8	52.4	-13.1	-16.5	-17.9	10068.8	549719.09	5394588.86
34	9900.0	10087.5	518.6	57.6	-11.9	-19.2	-14.1	10081.3	549730.18	5394583.08
35	9900.0	10100.0	527.5	63.1	-5.5	-8.9	31.9	10093.8	549741.26	5394577.31
36	9900.0	10112.5	501.7	55.8	1.8	72.7	112.7	10106.3	549752.35	5394571.54
37	9900.0	10125.0	497.0	-7.8	-3.2	152.6	124.4	10118.8	549763.44	5394565.77
38	9900.0	10137.5	486.1	-25.9	0.2	96.1	50.0	10131.3	549774.53	5394560.00
39	9900.0	10150.0	478.8	-22.2	3.3	3.9	-9.3	10143.8	549785.61	5394554.22
40	9900.0	10162.5	475.2	-15.4	7.1	-22.5	-21.0	10156.3	549796.70	5394548.45
41	9900.0	10175.0	469.1	-10.2	9.4	-19.5	-14.4	10168.8	549807.79	5394542.68
42	9900.0	10187.5	458.5	-7.9	9.1	-9.3	-4.8	10181.3	549818.88	5394536.91
43	9900.0	10200.0	455.8	-8.4	7.7	-0.2	1.0	10193.8	549829.96	5394531.14
44	9900.0	10212.5	452.1	-9.5	6.2	2.1	0.1	10206.3	549841.05	5394525.37
45	9900.0	10225.0	448.7	-8.9	5.6	-1.9	-4.0	10218.8	549852.14	5394519.59
46	9900.0	10237.5	450.2	-7.1	6.4	-6.1	-7.0	10231.3	549863.23	5394513.82
47	9900.0	10250.0	446.1	-5.2	6.3	-7.9	-8.1	10243.8	549874.31	5394508.05
48	9900.0	10262.5	435.7	-2.9	7.8	-8.2	-8.0	10256.3	549885.40	5394502.28
49	9900.0	10275.0	427.4	-1.2	8.4	-7.7	-8.3	10268.8	549896.49	5394496.51
50	9900.0	10287.5	482.7	0.8	9.3	-8.9	-10.4	10281.3	549907.58	5394490.73
51	9900.0	10300.0	476.6	4.0	10.7	-11.9	-12.8	10293.8	549918.66	5394484.96
52	9900.0	10312.5	585.9	7.5	12.6	-13.7	-12.9	10306.3	549929.75	5394479.19
53	9900.0	10325.0	623.3	11.0	14.9	-12.1	-8.4	10318.8	549940.84	5394473.42
54	9900.0	10337.5	465.2	12.6	14.2	-4.7	-1.5	10331.3	549951.93	5394467.65



Shanan_MV_L99.xlsx - Excel

Chart 1 =SERIES(" In-Phase",Shanan_MV_L99!$B$3:$B$108,Shanan_MV_L99!$D$3:$D$108,1)

	A	B	C	D	E	F	G	H	I	J
1		Grid X	Mag	In-Phase	Quad	Fraser Filter	FF_interp	Grid_X+1/2	Easting	Northing
2	Line	9900								
3	9900.0	9700.0	397.0	-2.2	-3.0				549386.46	5394762.01
4	9900.0	9712.5	400.7	-8.6	-7.3		13.5	9706.3	549397.55	5394756.24
5	9900.0	9725.0	372.4	-11.7	-10.4	4.6	-6.1	9718.8	549408.64	5394750.47
6	9900.0	9737.5	364.4	-3.7	-7.5	-16.7	-13.6	9731.3	549419.72	5394744.69
7	9900.0	9750.0	358.2	0.1	-5.6	-10.4	-3.6	9743.8	549430.81	5394738.92
8	9900.0	9762.5	328.1	-5.1	-9.2	3.3	-0.1	9756.3	549441.90	5394733.15
9	9900.0	9775.0	500.2	-1.8	-9.0	-3.4	-5.7	9768.8	549452.99	5394727.38
10	9900.0	9787.5	392.6	0.2	-9.1	-7.9	-5.8	9781.3	549464.07	5394721.61
11	9900.0	9800.0	379.9	0.8	-10.4	-3.7	-3.4	9793.8	549475.16	5394715.84
12	9900.0	9812.5	375.7	1.3	-10.9	-3.1	-4.0	9806.3	549486.25	5394710.06
13	9900.0	9825.0	371.3	2.8	-11.2	-4.9	-4.7	9818.8	549497.34	5394704.29
14	9900.0	9837.5	364.2	4.2	-12.0	-4.5	-4.8	9831.3	549508.42	5394698.52
15	9900.0	9850.0	363.0	4.4	-12.5	-5.0	-7.7	9843.8	549519.51	5394692.75
16	9900.0	9862.5	341.3	7.6	-12.3	-10.3	-11.7	9856.3	549530.60	5394686.98
17	9900.0	9875.0	332.2	11.3	-11.6	-13.1	-10.7	9868.8	549541.69	5394681.20
18	9900.0	9887.5	318.8	13.8	-11.0	-8.3	-5.7	9881.3	549552.77	5394675.43
19	9900.0	9900.0	282.9	13.4	-12.4	-3.1	-3.2	9893.8	549563.86	5394669.66
20	9900.0	9912.5	333.8	14.8	-13.3	-3.2	-4.8	9906.3	549574.95	5394663.89
21	9900.0	9925.0	719.9	15.6	-15.5	-6.3	-8.3	9918.8	549586.04	5394658.12
22	9900.0	9937.5	687.2	18.9	-15.4	-10.3	-13.2	9931.3	549597.12	5394652.35
23	9900.0	9950.0	702.7	21.8	-15.3	-16.0	-16.9	9943.8	549608.21	5394646.57
24	9900.0	9962.5	1031.1	28.7	-12.5	-17.8	-15.0	9956.3	549619.30	5394640.80
25	9900.0	9975.0	558.5	29.8	-14.2	-12.2	-10.2	9968.8	549630.39	5394635.03
26	9900.0	9987.5	454.2	32.9	-13.8	-8.2	-7.3	9981.3	549641.47	5394629.26
27	9900.0	10000.0	428.2	33.8	-14.7		-6.0	9993.8	549652.56	5394623.49
28	9900.0	10012.5	401.5					10006.3	549663.65	5394617.71
29	9900.0	10025.0	337.9	36.9	-17.4			10018.8	549674.74	5394611.94
30	9900.0	10037.5	970.1	40.0	-19.5		-14.4	10031.3	549685.83	5394606.17
31	9900.0	10050.0	695.7	44.4	-15.9	-16.6	-16.9	10043.8	549696.91	5394600.40
32	9900.0	10062.5	573.1	49.1	-13.7	-17.1	-16.8	10056.3	549708.00	5394594.63
33	9900.0	10075.0	534.8	52.4	-13.1	-16.5	-17.9	10068.8	549719.09	5394588.86
34	9900.0	10087.5	518.6	57.6	-11.9	-19.2	-14.1	10081.3	549730.18	5394583.08
35	9900.0	10100.0	527.5	63.1	-5.5	-8.9	31.9	10093.8	549741.26	5394577.31
36	9900.0	10112.5	501.7	55.8	1.8	72.7	112.7	10106.3	549752.35	5394571.54
37	9900.0	10125.0	497.0	-7.8	-3.2	152.6	124.4	10118.8	549763.44	5394565.77
38	9900.0	10137.5	486.1	-25.9	0.2	96.1	50.0	10131.3	549774.53	5394560.00
39	9900.0	10150.0	478.8	-22.2	3.3	3.9	-9.3	10143.8	549785.61	5394554.22
40	9900.0	10162.5	475.2	-15.4	7.1	-22.5	-21.0	10156.3	549796.70	5394548.45
41	9900.0	10175.0	469.1	-10.2	9.4	-19.5	-14.4	10168.8	549807.79	5394542.68
42	9900.0	10187.5	458.5	-7.9	9.1	-9.3	-4.8	10181.3	549818.88	5394536.91
43	9900.0	10200.0	455.8	-8.4	7.7	-0.2	1.0	10193.8	549829.96	5394531.14
44	9900.0	10212.5	452.1	-9.5	6.2	2.1	0.1	10206.3	549841.05	5394525.37
45	9900.0	10225.0	448.7	-8.9	5.6	-1.9	-4.0	10218.8	549852.14	5394519.59
46	9900.0	10237.5	450.2	-7.1	6.4	-6.1	-7.0	10231.3	549863.23	5394513.82
47	9900.0	10250.0	446.1	-5.2	6.3	-7.9	-8.1	10243.8	549874.31	5394508.05
48	9900.0	10262.5	435.7	-2.9	7.8	-8.2	-8.0	10256.3	549885.40	5394502.28
49	9900.0	10275.0	427.4	-1.2	8.4	-7.7	-8.3	10268.8	549896.49	5394496.51
50	9900.0	10287.5	482.7	0.8	9.3	-8.9	-10.4	10281.3	549907.58	5394490.73
51	9900.0	10300.0	476.6	4.0	10.7	-11.9	-12.8	10293.8	549918.66	5394484.96
52	9900.0	10312.5	585.9	7.5	12.6	-13.7	-12.9	10306.3	549929.75	5394479.19
53	9900.0	10325.0	623.3	11.0	14.9	-12.1	-8.4	10318.8	549940.84	5394473.42
54	9900.0	10337.5	465.2	12.6	14.2	-4.7	-1.5	10331.3	549951.93	5394467.65



	A	B	C	D	E	F	G	H	I	J
1		Grid X	Mag	In-Phase	Quad	Fraser Filter	FF_interp	Grid_X+1/2	Easting	Northing
2	Line	9900								
3	9900.0	9700.0	397.0	-2.2	-3.0				549386.46	5394762.01
4	9900.0	9712.5	400.7	-8.6	-7.3		13.5	9706.3	549397.55	5394756.24
5	9900.0	9725.0	372.4	-11.7	-10.4	4.6	-6.1	9718.8	549408.64	5394750.47
6	9900.0	9737.5	364.4	-3.7	-7.5	-16.7	-13.6	9731.3	549419.72	5394744.69
7	9900.0	9750.0	358.2	0.1	-5.6	-10.4	-3.6	9743.8	549430.81	5394738.92
8	9900.0	9762.5	328.1	-5.1	-9.2	3.3	-0.1	9756.3	549441.90	5394733.15
9	9900.0	9775.0	500.2	-1.8	-9.0	-3.4	-5.7	9768.8	549452.99	5394727.38
10	9900.0	9787.5	392.6	0.2	-9.1	-7.9	-5.8	9781.3	549464.07	5394721.61
11	9900.0	9800.0	379.9	0.8	-10.4	-3.7	-3.4	9793.8	549475.16	5394715.84
12	9900.0	9812.5	375.7	1.3	-10.9	-3.1	-4.0	9806.3	549486.25	5394710.06
13	9900.0	9825.0	371.3	2.8	-11.2	-4.9	-4.7	9818.8	549497.34	5394704.29
14	9900.0	9837.5	364.2	4.2	-12.0	-4.5	-4.8	9831.3	549508.42	5394698.52
15	9900.0	9850.0	363.0	4.4	-12.5	-5.0	-7.7	9843.8	549519.51	5394692.75
16	9900.0	9862.5	341.3	7.6	-12.3	-10.3	-11.7	9856.3	549530.60	5394686.98
17	9900.0	9875.0	332.2	11.3	-11.6	-13.1	-10.7	9868.8	549541.69	5394681.20
18	9900.0	9887.5	318.8	13.8	-11.0	-8.3	-5.7	9881.3	549552.77	5394675.43
19	9900.0	9900.0	282.9	13.4	-12.4	-3.1	-3.2	9893.8	549563.86	5394669.66
20	9900.0	9912.5	333.8	14.8	-13.3	-3.2	-4.8	9906.3	549574.95	5394663.89
21	9900.0	9925.0	719.9	15.6	-15.5	-6.3	-8.3	9918.8	549586.04	5394658.12
22	9900.0	9937.5	687.2	18.9	-15.4	-10.3	-13.2	9931.3	549597.12	5394652.35
23	9900.0	9950.0	702.7	21.8	-15.3	-16.0	-16.9	9943.8	549608.21	5394646.57
24	9900.0	9962.5	1031.1	28.7	-12.5	-17.8	-15.0	9956.3	549619.30	5394640.80
25	9900.0	9975.0	558.5	29.8	-14.2	-12.2	-10.2	9968.8	549630.39	5394635.03
26	9900.0	9987.5	454.2	32.9	-13.8	-8.2	-7.3	9981.3	549641.47	5394629.26
27	9900.0	10000.0	428.2	33.8	-14.7		-6.0	9993.8	549652.56	5394623.49
28	9900.0	10012.5	401.5					10006.3	549663.65	5394617.71
29	9900.0	10025.0	337.9	36.9	-17.4			10018.8	549674.74	5394611.94
30	9900.0	10037.5	970.1	40.0	-19.5		-14.4	10031.3	549685.83	5394606.17
31	9900.0	10050.0	695.7	44.4	-15.9	-16.6	-16.9	10043.8	549696.91	5394600.40
32	9900.0	10062.5	573.1	49.1	-13.7	-17.1	-16.8	10056.3	549708.00	5394594.63
33	9900.0	10075.0	534.8	52.4	-13.1	-16.5	-17.9	10068.8	549719.09	5394588.86
34	9900.0	10087.5	518.6	57.6	-11.9	-19.2	-14.1	10081.3	549730.18	5394583.08
35	9900.0	10100.0	527.5	63.1	-5.5	-8.9	31.9	10093.8	549741.26	5394577.31
36	9900.0	10112.5	501.7	55.8	1.8	72.7	112.7	10106.3	549752.35	5394571.54
37	9900.0	10125.0	497.0	-7.8	-3.2	152.6	124.4	10118.8	549763.44	5394565.77
38	9900.0	10137.5	486.1	-25.9	0.2	96.1	50.0	10131.3	549774.53	5394560.00
39	9900.0	10150.0	478.8	-22.2	3.3	3.9	-9.3	10143.8	549785.61	5394554.22
40	9900.0	10162.5	475.2	-15.4	7.1	-22.5	-21.0	10156.3	549796.70	5394548.45
41	9900.0	10175.0	469.1	-10.2	9.4	-19.5	-14.4	10168.8	549807.79	5394542.68
42	9900.0	10187.5	458.5	-7.9	9.1	-9.3	-4.8	10181.3	549818.88	5394536.91
43	9900.0	10200.0	455.8	-8.4	7.7	-0.2	1.0	10193.8	549829.96	5394531.14
44	9900.0	10212.5	452.1	-9.5	6.2	2.1	0.1	10206.3	549841.05	5394525.37
45	9900.0	10225.0	448.7	-8.9	5.6	-1.9	-4.0	10218.8	549852.14	5394519.59
46	9900.0	10237.5	450.2	-7.1	6.4	-6.1	-7.0	10231.3	549863.23	5394513.82
47	9900.0	10250.0	446.1	-5.2	6.3	-7.9	-8.1	10243.8	549874.31	5394508.05
48	9900.0	10262.5	435.7	-2.9	7.8	-8.2	-8.0	10256.3	549885.40	5394502.28
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51	9900.0	10300.0	476.6	4.0	10.7	-11.9	-12.8	10293.8	549918.66	5394484.96
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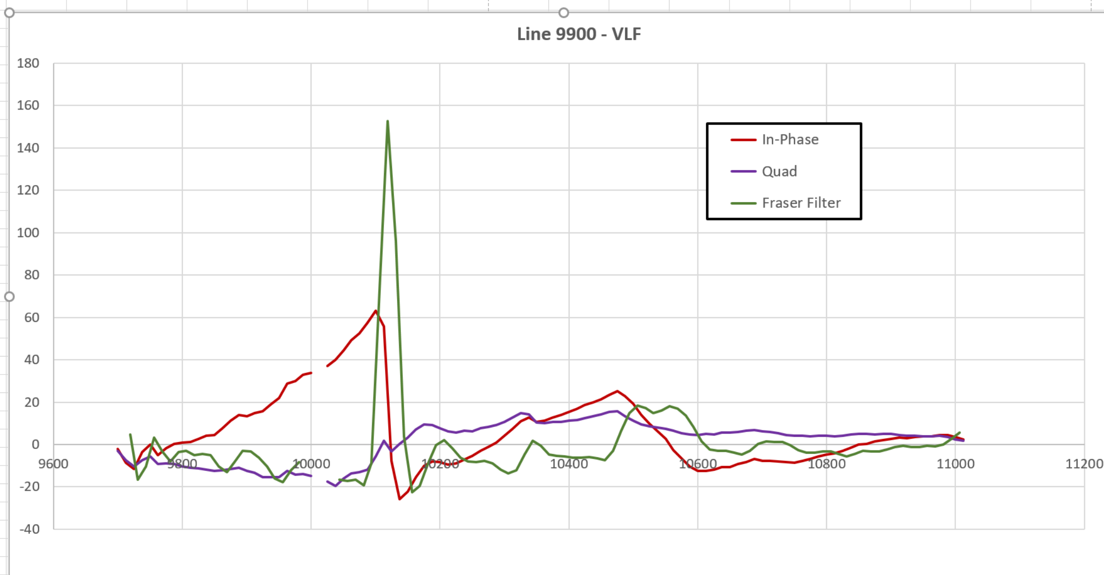
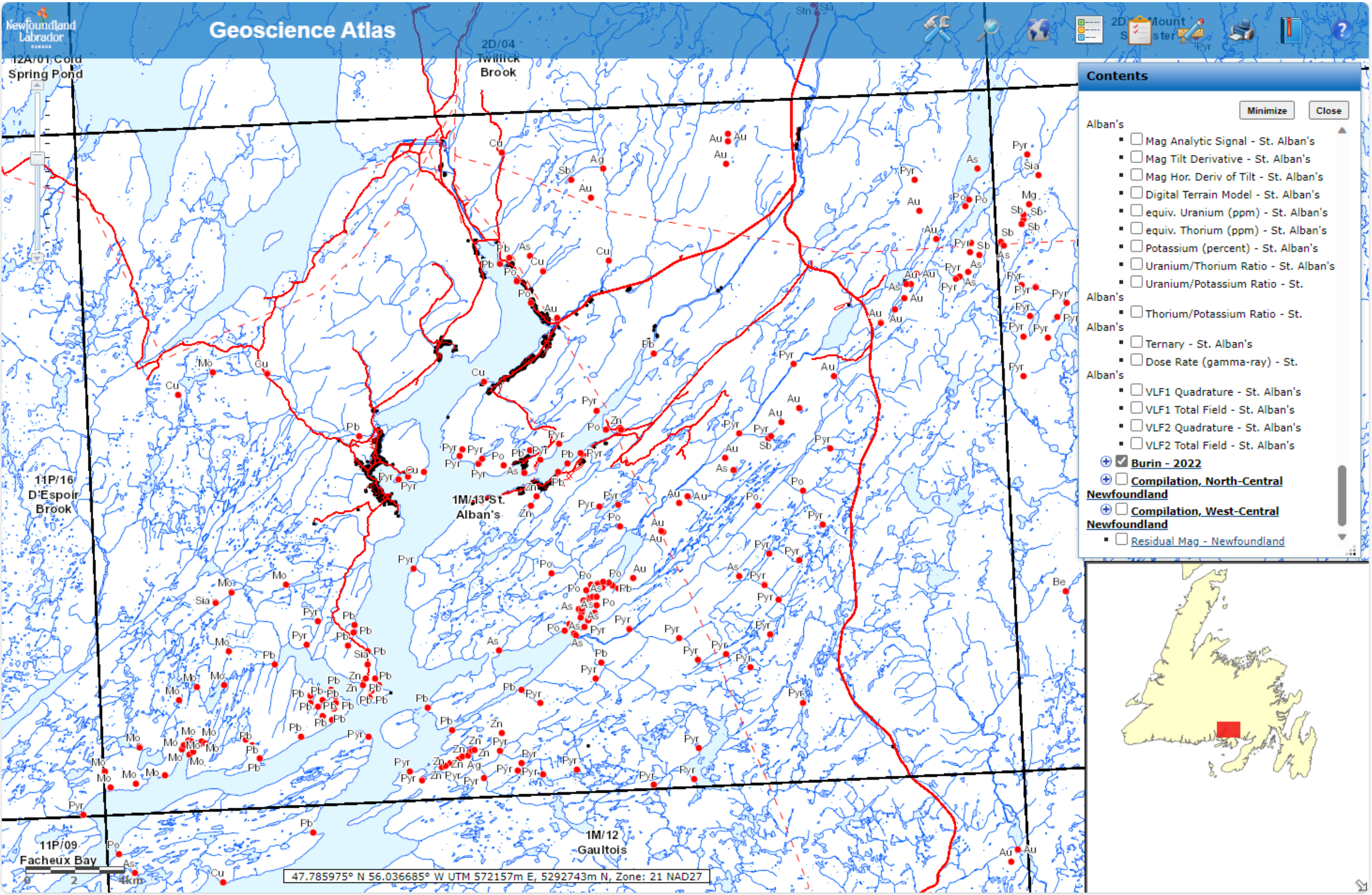


Shanan_MV_L99

Pitfalls for VLF-EM

- Recording the sign (+/-) of the numbers correctly
- Switching the facing direction or orientation during survey
- Presence of cultural features – power lines, cables fences, culverts, rebar, asphalt roadways, etc.
- Unforeseen causes of anomalies – *eg.* Permafrost contacts, conductive surficial sediments

VLF-EM
St. Alban’s
Airborne Survey


Geoscience Atlas
Newfoundland Labrador CANADA
12A/01 Cold Spring Pond
2D/04 Twillick Brook
11P/16 D'Espoir Brook
1M/13 St. Alban's
11P/09 Facheux Bay
1M/12 Gaultois
Contents
Minimize
Close
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Mag Tilt Derivative - St. Alban's
Mag Hor. Deriv of Tilt - St. Alban's
Digital Terrain Model - St. Alban's
equiv. Uranium (ppm) - St. Alban's
equiv. Thorium (ppm) - St. Alban's
Potassium (percent) - St. Alban's
Uranium/Thorium Ratio - St. Alban's
Uranium/Potassium Ratio - St. Alban's
Thorium/Potassium Ratio - St. Alban's
Ternary - St. Alban's
Dose Rate (gamma-ray) - St. Alban's
VLF1 Quadrature - St. Alban's
VLF1 Total Field - St. Alban's
VLF2 Quadrature - St. Alban's
VLF2 Total Field - St. Alban's
Burin - 2022
Compilation, North-Central Newfoundland
Compilation, West-Central Newfoundland
Residual Mag - Newfoundland
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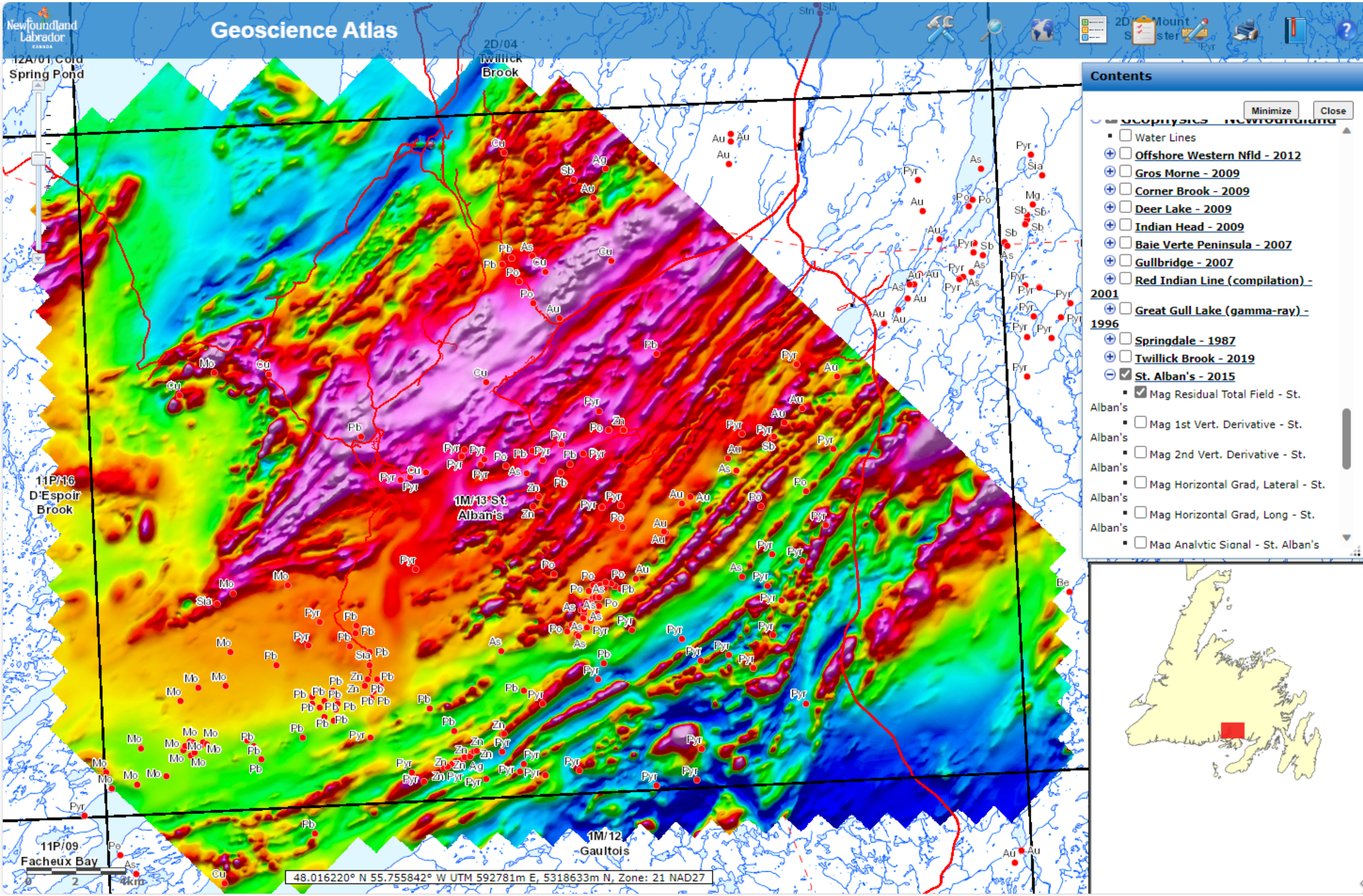
0 2 4km


Newfoundland Labrador
CANADA
Geoscience Atlas
12A/01 Cold Spring Pond
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Water Lines
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Gros Morne - 2009
Corner Brook - 2009
Deer Lake - 2009
Indian Head - 2009
Baie Verte Peninsula - 2007
Gullbridge - 2007
Red Indian Line (compilation) - 2001
Great Gull Lake (gamma-ray) - 1996
Springdale - 1987
Twillick Brook - 2019
St. Alban's - 2015
Mag Residual Total Field - St. Alban's
Mag 1st Vert. Derivative - St. Alban's
Mag 2nd Vert. Derivative - St. Alban's
Mag Horizontal Grad, Lateral - St. Alban's
Mag Horizontal Grad, Long - St. Alban's
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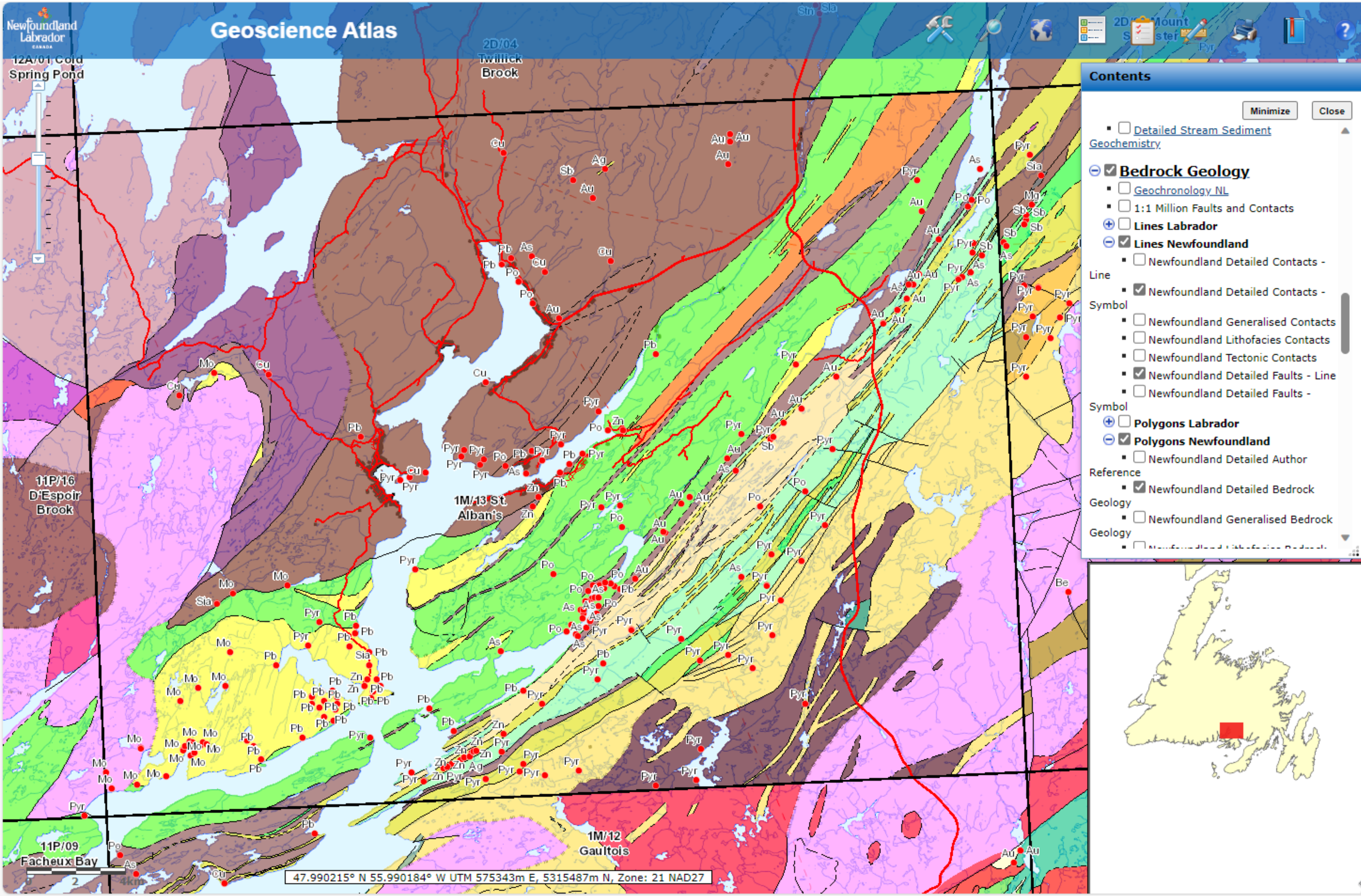
2
4km


Newfoundland Labrador
Geoscience Atlas
12A/01 Cold Spring Pond
2D/04 Twillick Brook
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1M/13 St. Alban's
11P/09 Facheux Bay
1M/12 Gaultois
47.990215° N 55.990184° W UTM 575343m E, 5315487m N, Zone: 21 NAD27
Contents
Minimize
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Bedrock Geology
Geochronology NL
1:1 Million Faults and Contacts
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Lines Newfoundland
Newfoundland Detailed Contacts - Line
Newfoundland Detailed Contacts - Symbol
Newfoundland Generalised Contacts
Newfoundland Lithofacies Contacts
Newfoundland Tectonic Contacts
Newfoundland Detailed Faults - Line
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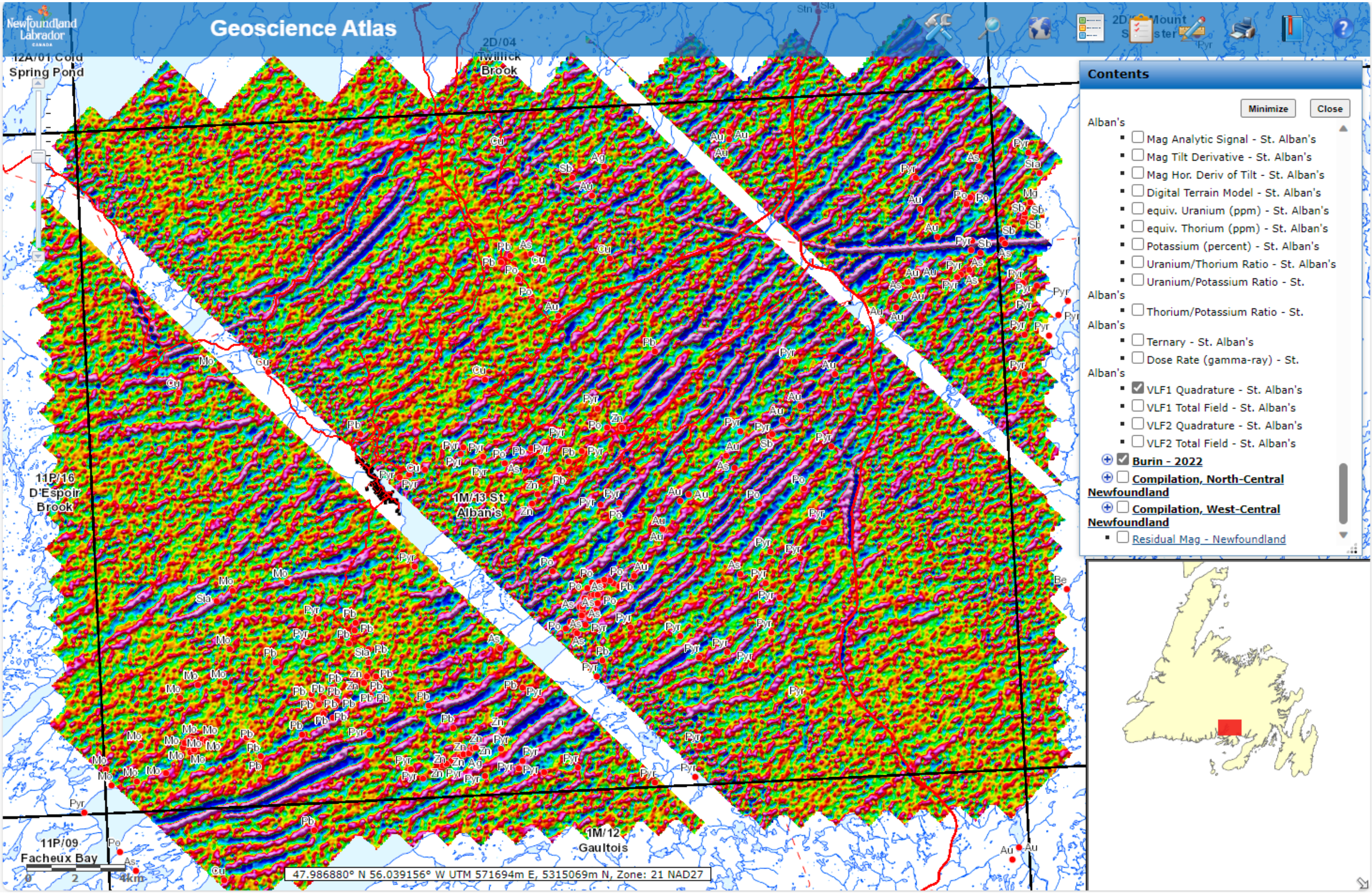
Polygons Labrador
Polygons Newfoundland
Newfoundland Detailed Author Reference
Newfoundland Detailed Bedrock Geology
Newfoundland Generalised Bedrock Geology


Newfoundland Labrador
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12A/01 Cold Spring Pond
2D/04 Twillick Brook
11P/16 D'Espoir Brook
1M/13 St. Alban's
11P/09 Facheux Bay
1M/12 Gaultois
0 2 4km
47.986880° N 56.039156° W UTM 571694m E, 5315069m N, Zone: 21 NAD27
Contents
Minimize
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Alban's
Mag Analytic Signal - St. Alban's
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Mag Hor. Deriv of Tilt - St. Alban's
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equiv. Thorium (ppm) - St. Alban's
Potassium (percent) - St. Alban's
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Uranium/Potassium Ratio - St. Alban's
Thorium/Potassium Ratio - St. Alban's
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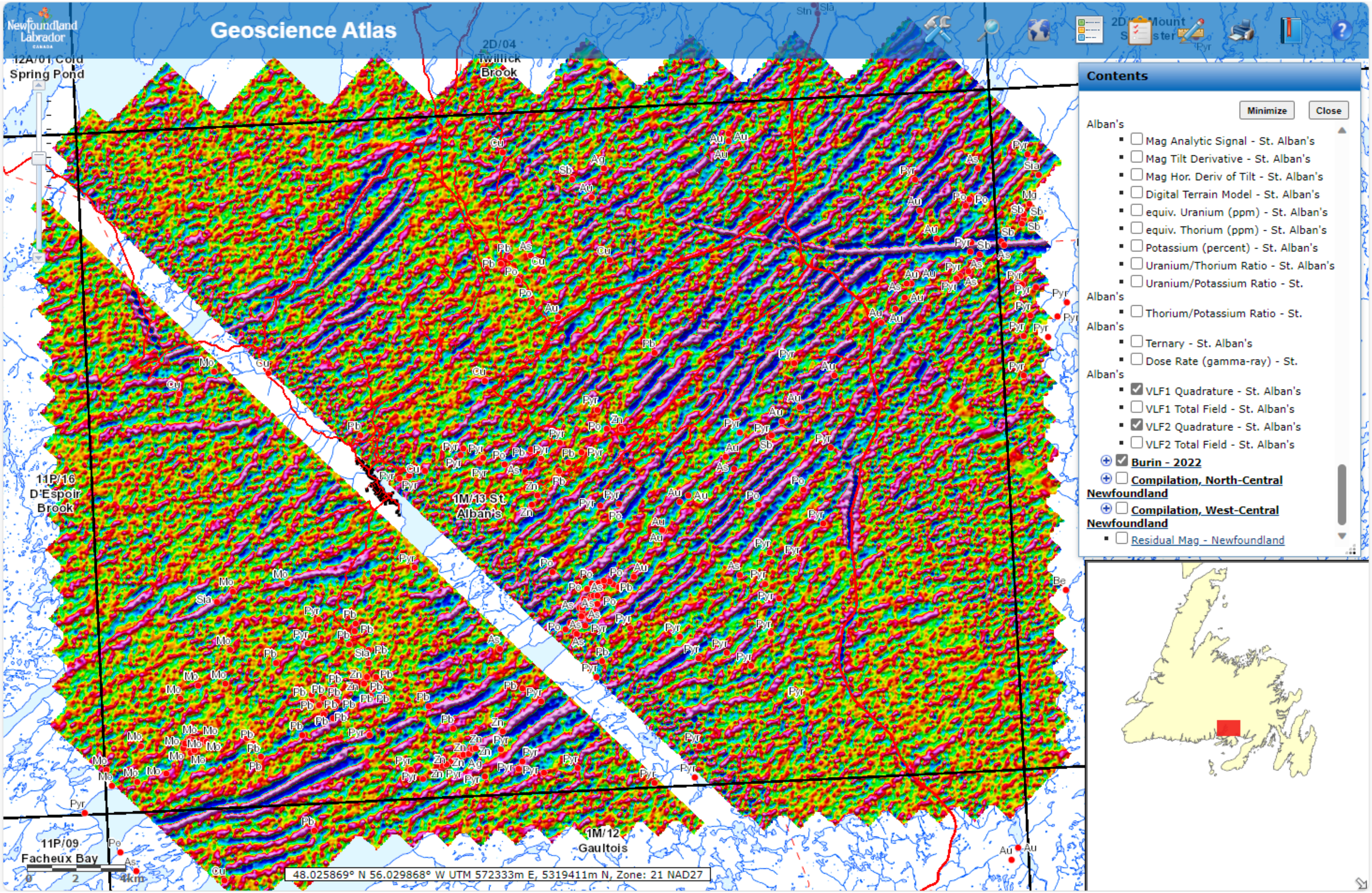
Dose Rate (gamma-ray) - St. Alban's
VLF1 Quadrature - St. Alban's
VLF1 Total Field - St. Alban's
VLF2 Quadrature - St. Alban's
VLF2 Total Field - St. Alban's
Burin - 2022
Compilation, North-Central Newfoundland
Compilation, West-Central Newfoundland
Residual Mag - Newfoundland



Newfoundland Labrador
Geoscience Atlas
12A/01 Cold Spring Pond
2D/04 Twillick Brook
11P/16 D'Espoir Brook
1M/13 St Albans
11P/09 Facheux Bay
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Potassium (percent) - St. Alban's
Uranium/Thorium Ratio - St. Alban's
Uranium/Potassium Ratio - St. Alban's
Thorium/Potassium Ratio - St. Alban's
Ternary - St. Alban's
Dose Rate (gamma-ray) - St. Alban's
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VLF1 Total Field - St. Alban's
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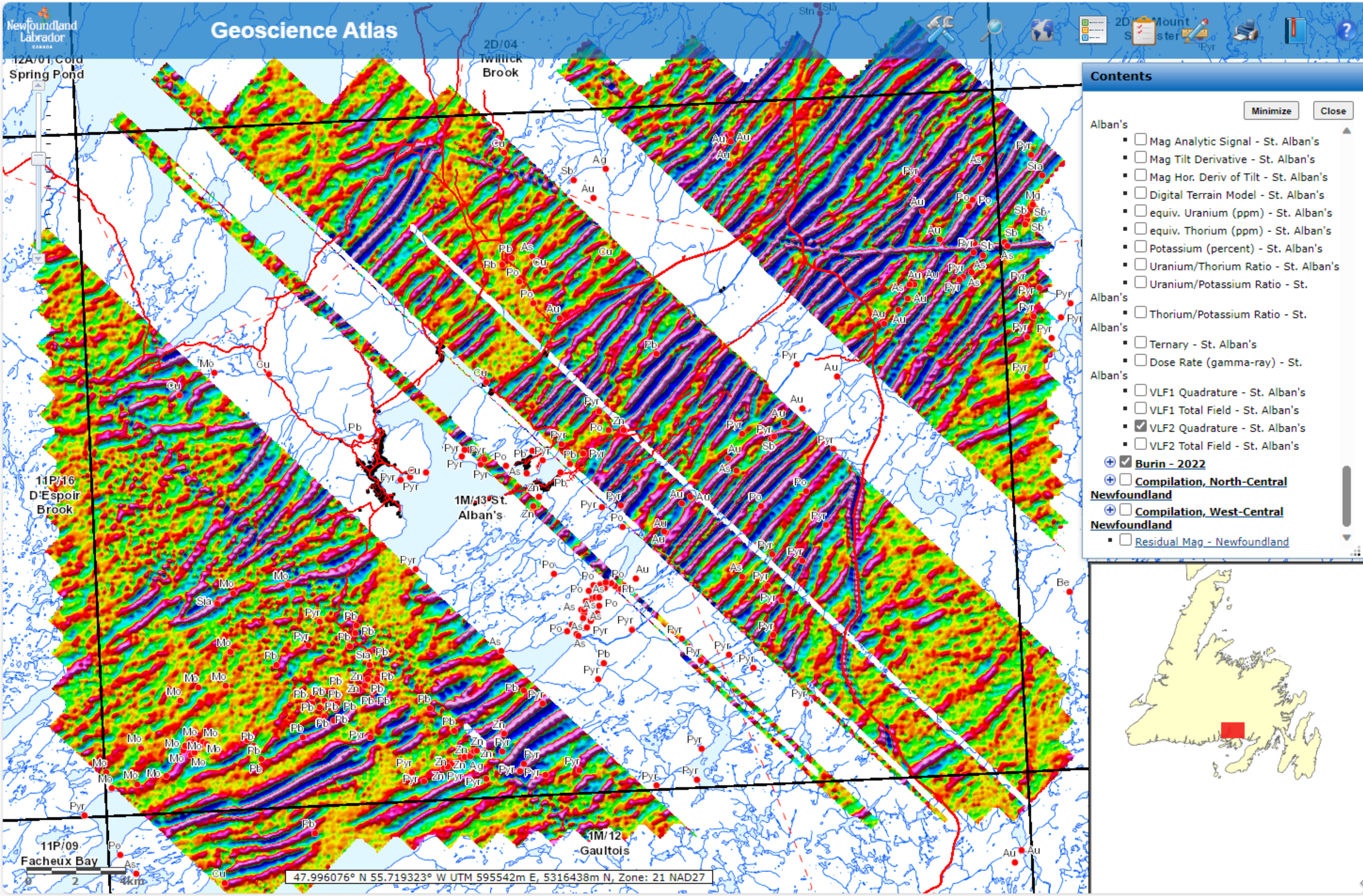

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11P/09 Facheux Bay
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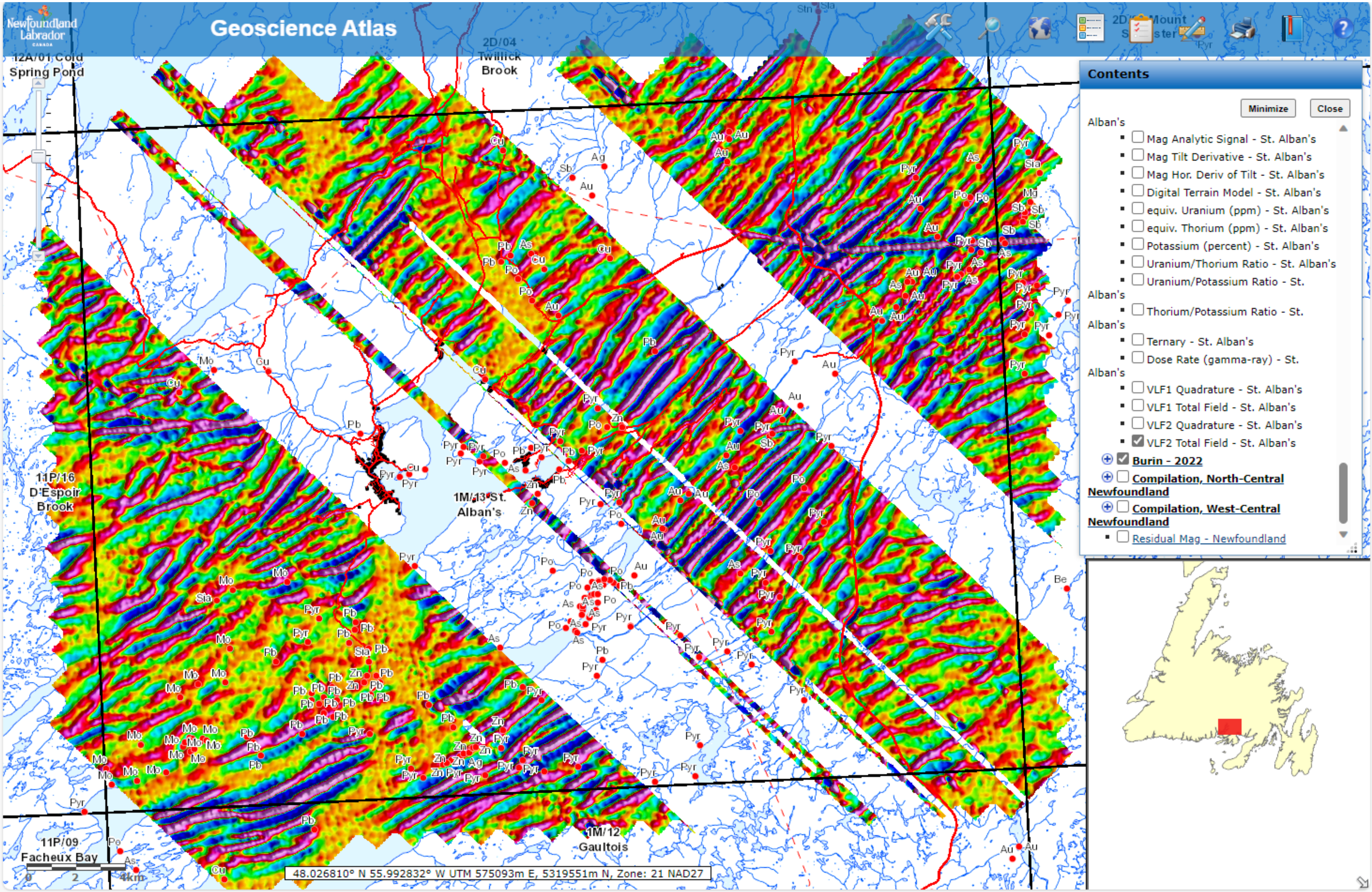
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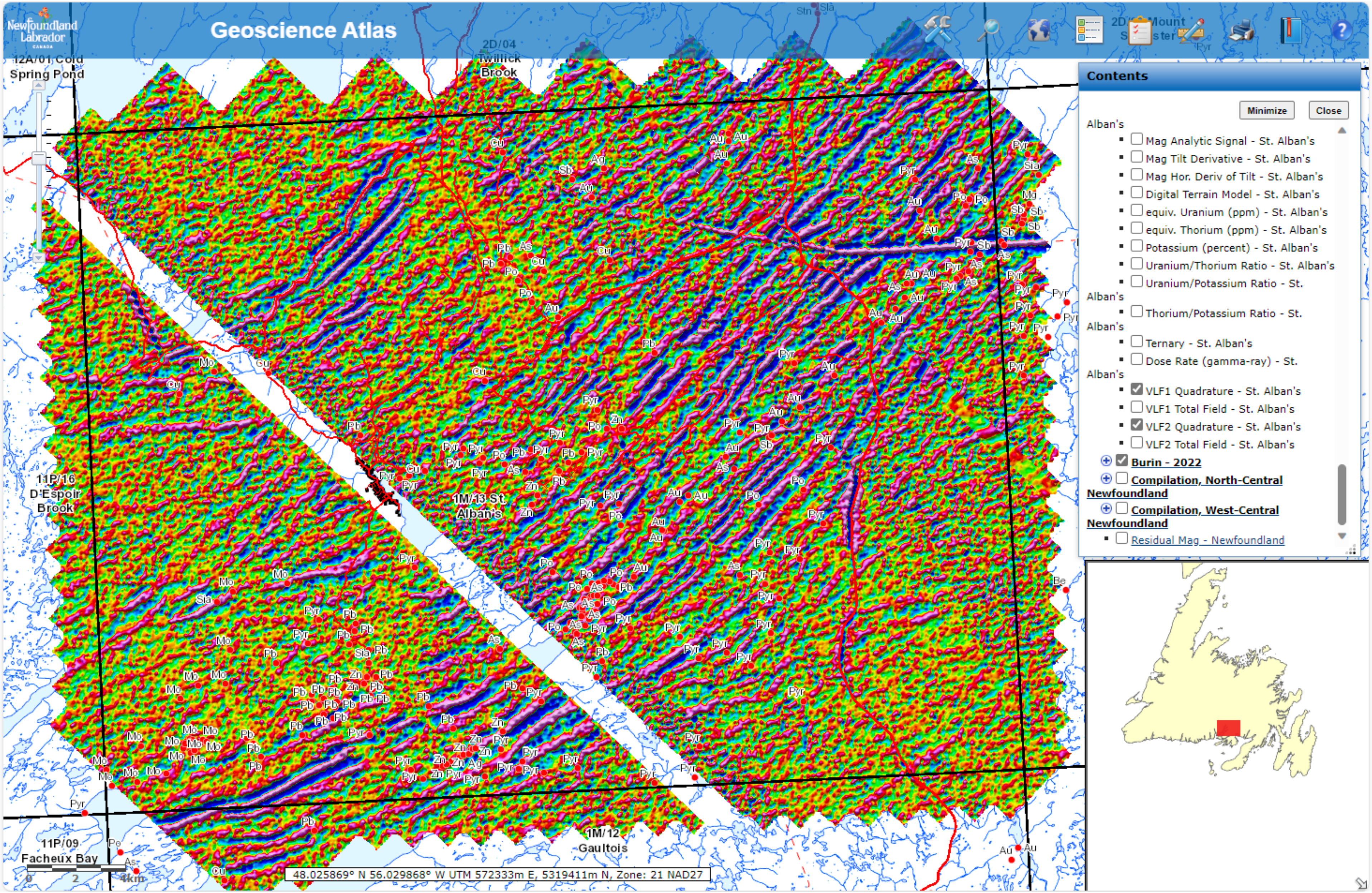
Residual Mag - Newfoundland



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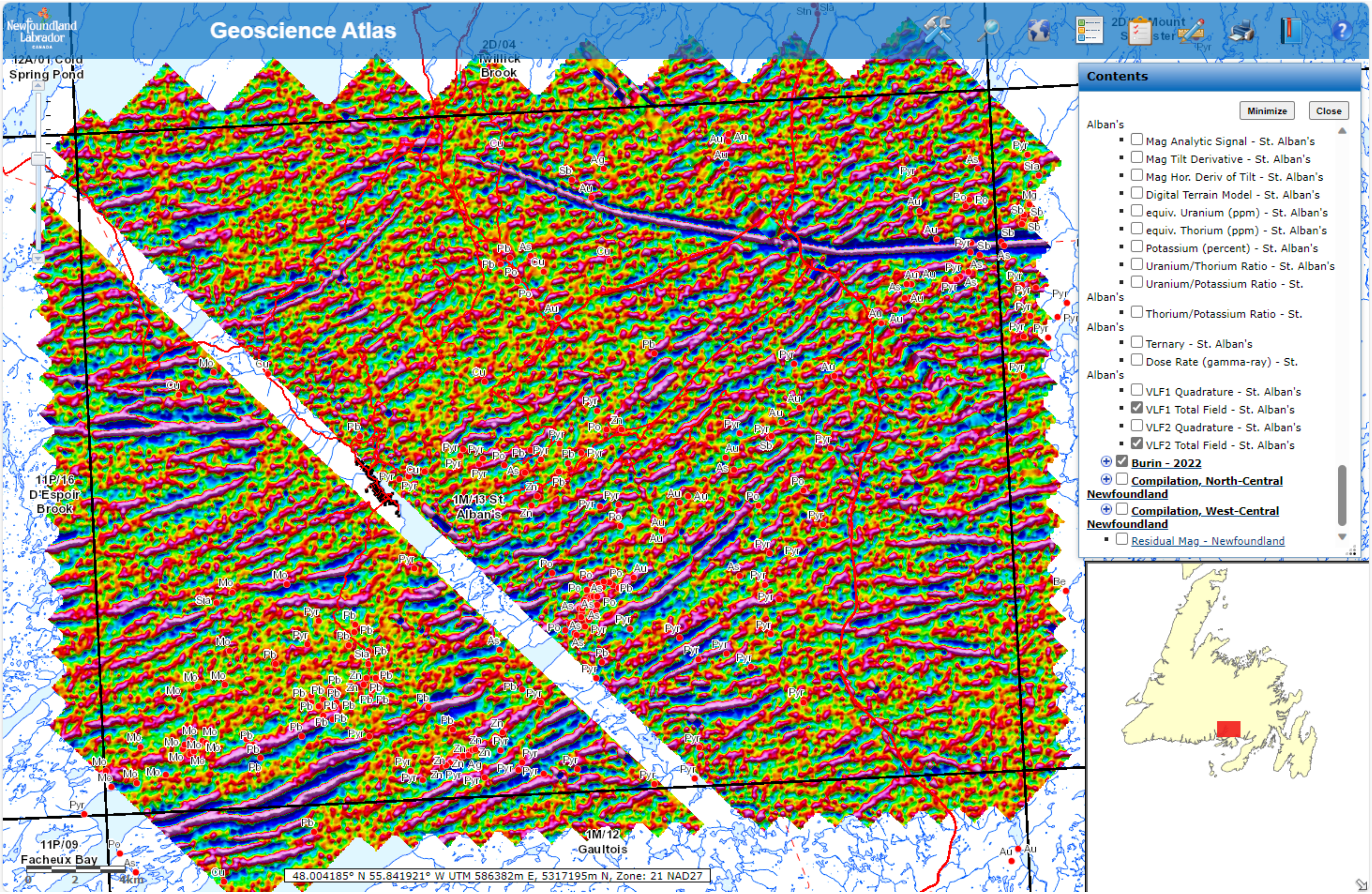
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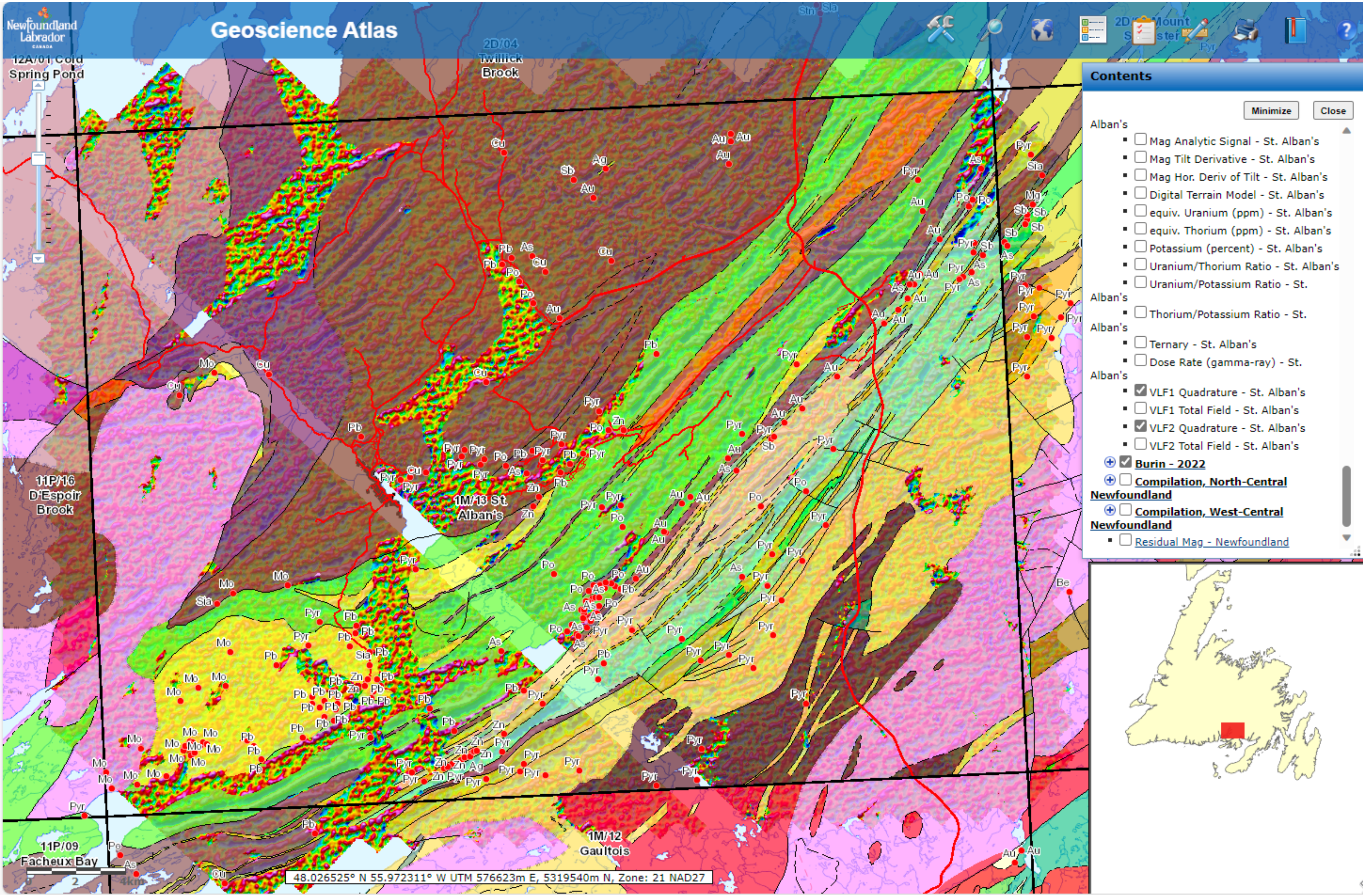
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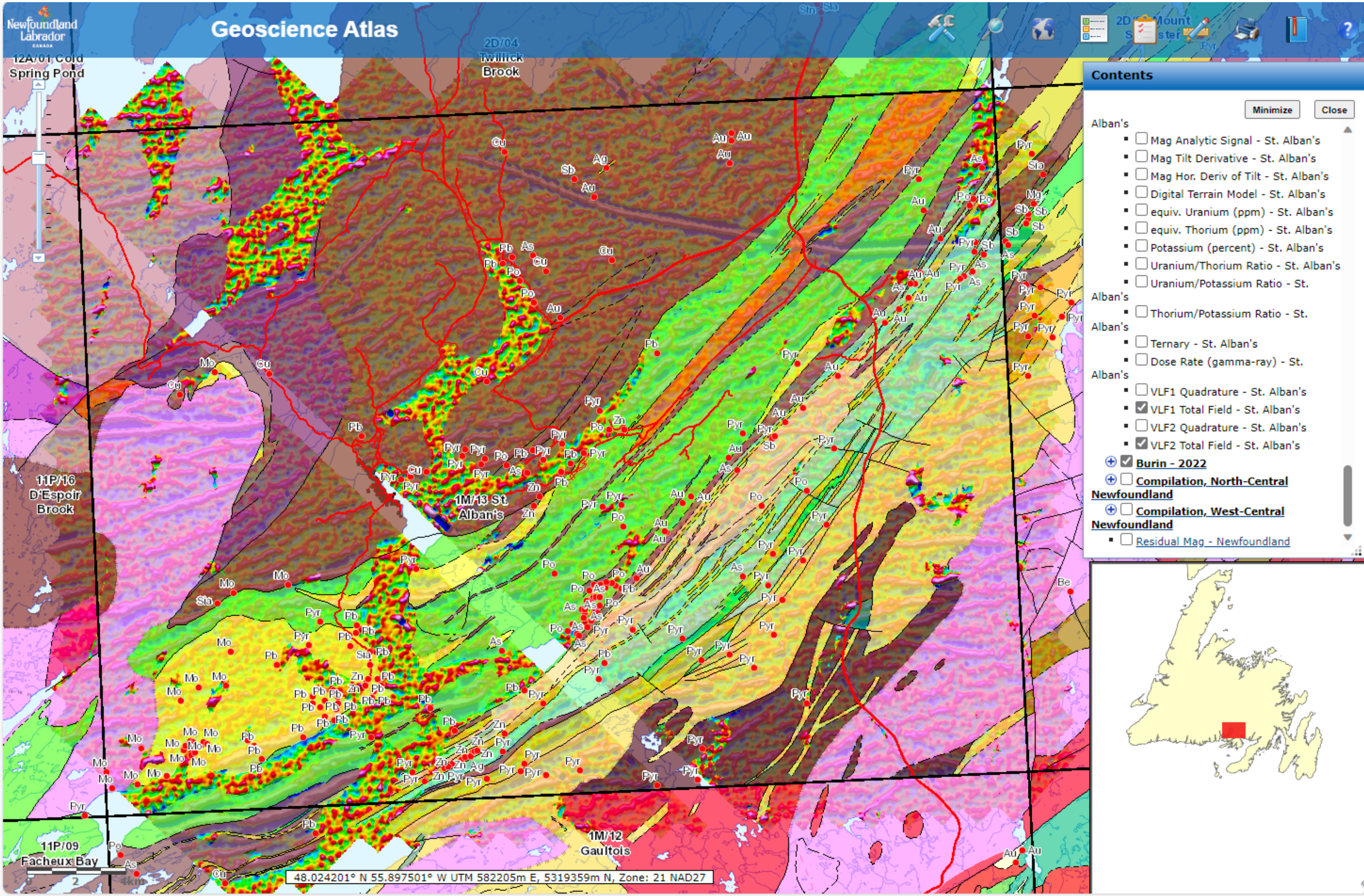
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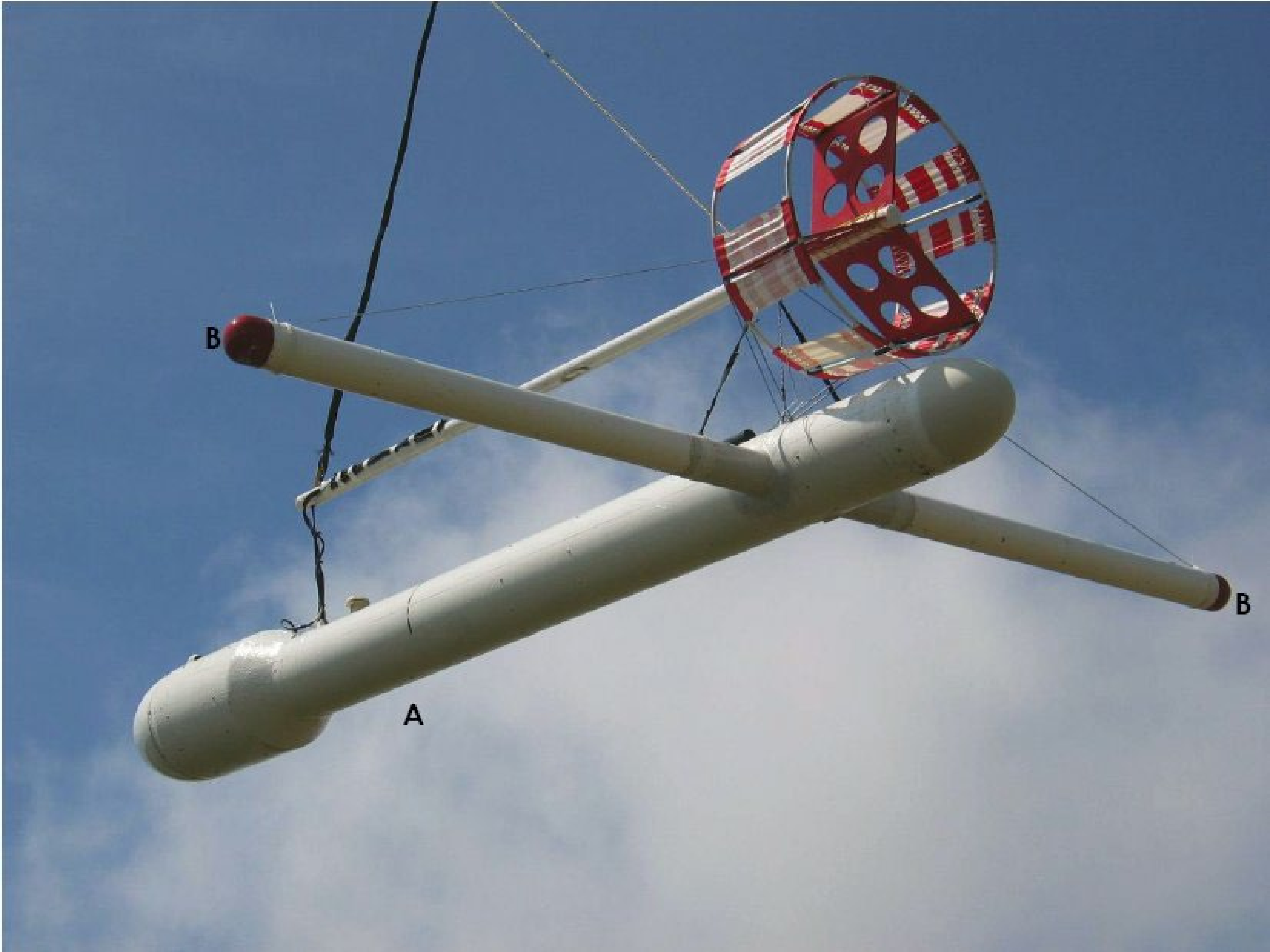
Residual Mag - Newfoundland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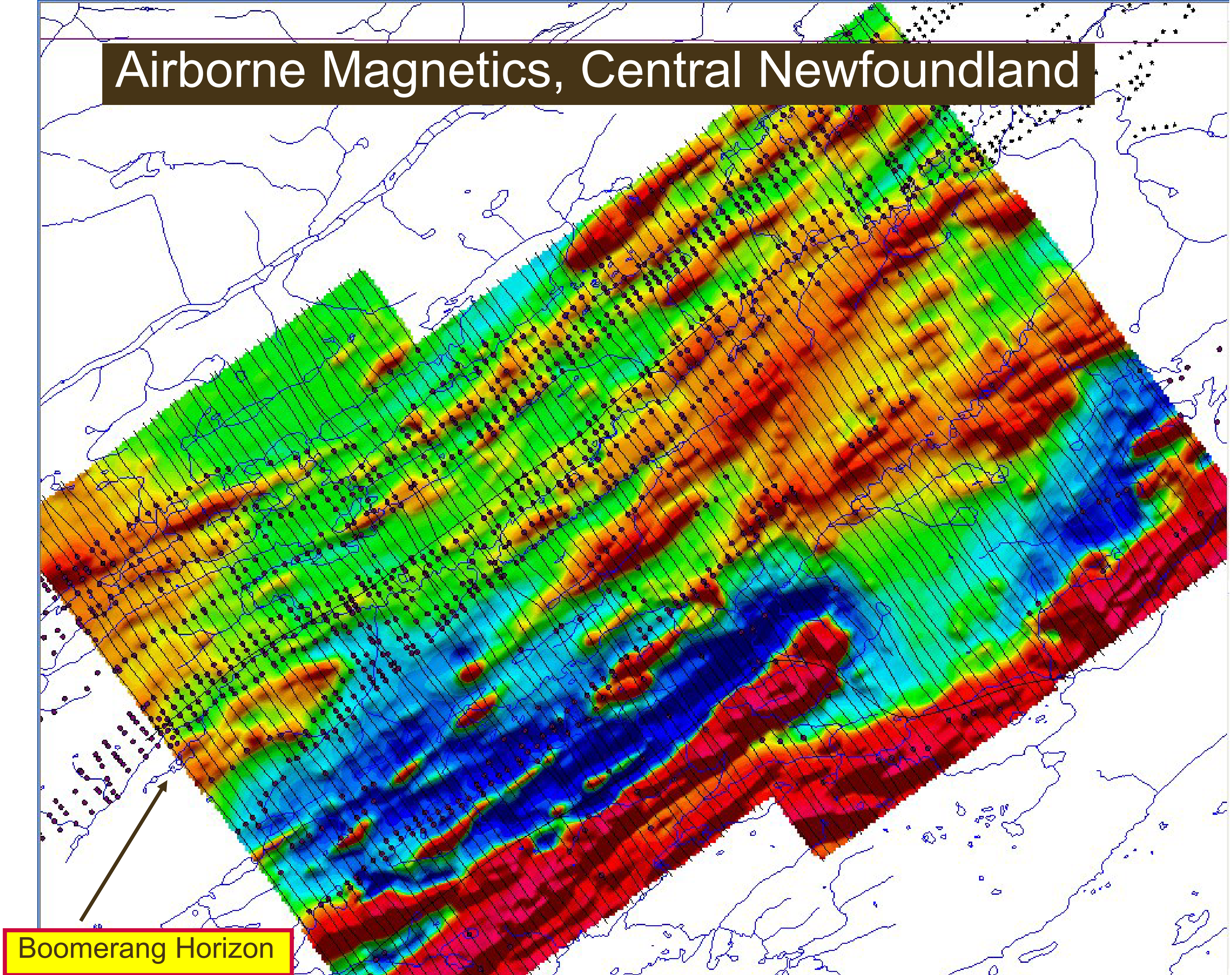
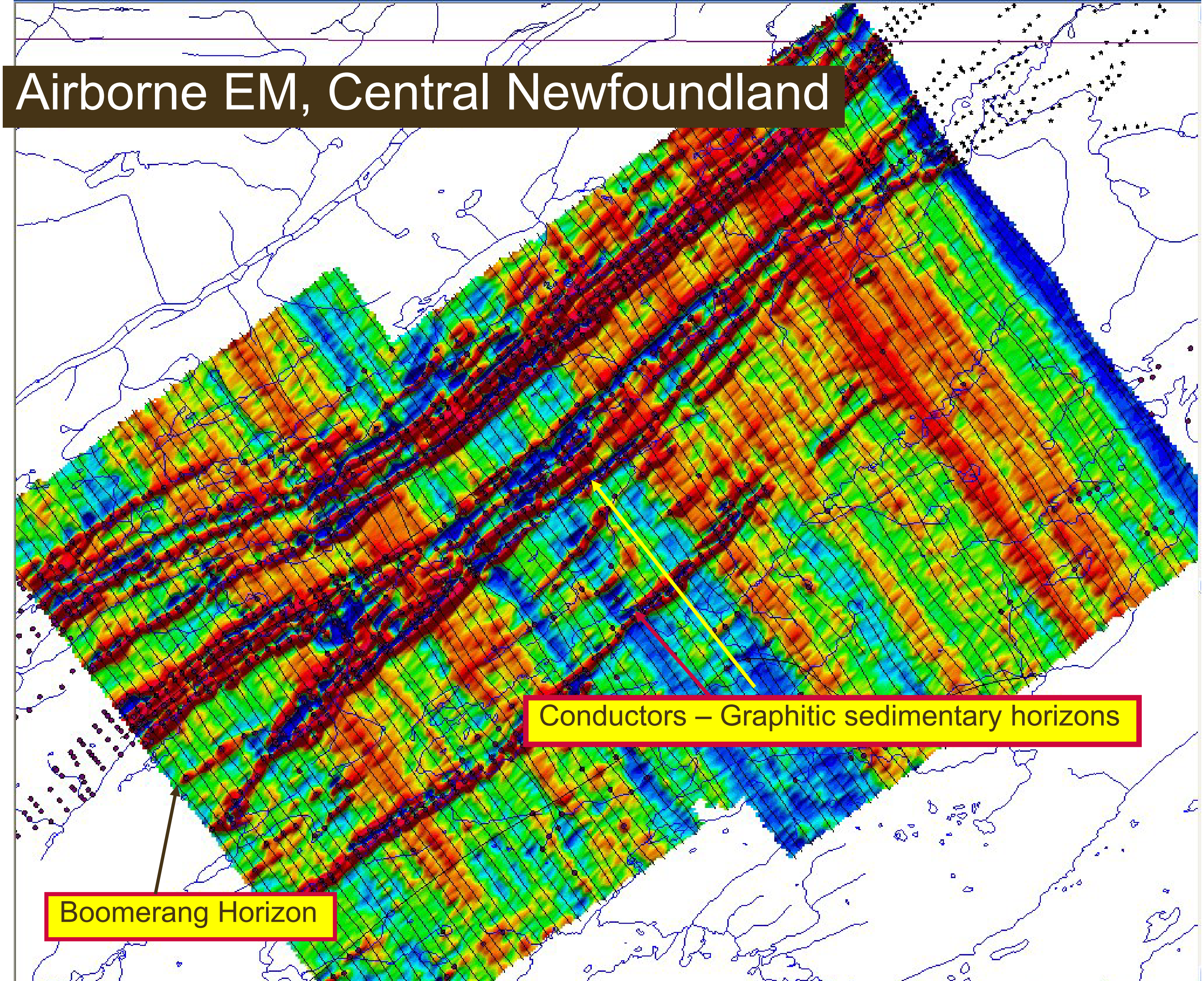
Airborne Magnetics, Central Newfoundland



Airborne EM, Central Newfoundland



Normally the sample will be equivalent to a resistance and capacitance in parallel. In some cases it may be necessary to interchange the series and parallel arms of the bridge.

5.4 Typical values of electrical constants of rocks and minerals

5.4.1 *Resistivities of rocks and minerals*

Of all the physical properties of rocks and minerals, electrical resistivity shows the greatest variation. While the range in density, elastic wave velocity and radioactive content is quite small, in magnetic susceptibility it may be as large as 10^5. However, the resistivity of metallic minerals may be as small as 10^{-5} Ωm, that of dry, close-grained rocks like gabbro as large as 10^7 Ωm. The maximum possible range is even greater, from native silver ($1{\cdot}6 \times 10^{-8}$ Ωm) to pure sulphur (10^{16} Ωm).

A *conductor* is usually defined as a material of resistivity less than 10^{-5} Ωm, while an *insulator* is one having a resistivity greater than 10^7 Ωm. Between these limits lie the so-called *semiconductors*. Within this grouping the metals and graphite are all conductors; they contain a large number of free electrons whose mobility is very great. The semiconductors also carry current by mobile electrons but have fewer of them. The insulators are characterized by ionic bonding so that the valence electrons are not free to move; the charge carriers are ions which must overcome larger barrier potentials than exist either in the semiconductors or conductors.

A further difference between conductors and semiconductors is found in their respective variation with temperature. The former vary inversely with temperature and have their highest conductivities in the region of 0°*K*. The semiconductors, on the other hand, are practically insulators at low temperatures.

In a looser classification, rocks and minerals are considered to be good, intermediate and poor conductors within the following ranges:

(*a*) minerals of resistivity 10^{-8} to about 1 Ωm,
(*b*) minerals and rocks of resistivity 1 to 10^7 Ωm,
(*c*) minerals and rocks of resistivity above 10^7 Ωm.

Group (*a*) includes the metals, graphite, the sulphides except for sphalerite, cinnabar and stibnite, all the arsenides and sulpho-arsenides except $SbAs_2$, the antimonides except for some lead compounds, the tellurides and some oxides such as magnetite, manganite, pyrolusite and ilmenite. Most oxides, ores and porous rocks containing water are intermediate conductors. The common rock-forming minerals, silicates, phosphates and the carbonates, nitrates, sulphates, borates, etc., are poor conductors.

The following tables list characteristic resistivities for various minerals and rocks. The data are from various sources, including Heiland (1940), Keller (1966), Parasnis (1956, 1966), Jakosky (1950) and Parkhomenko (1967).

The variation in resistivity of particular minerals is enormous, as can be seen from table 5.2. Among the more common minerals, pyrrhotite and graphite appear to be the most consistent good conductors, while pyrite, galena and magnetite are often poor conductors in bulk form, although the individual crystals have high conductivity. Hematite and sphalerite, in pure form, are practically insulators, but when combined with impurities may have resistivities as low as 0·1 Ωm. Graphite is often the connecting link in mineral zones which makes them good conductors.

Table 5.1. *Resistivities of metals and elements*

Element	Resistivity (Ωm)		Element	Resistivity (Ωm)	
	Range	Average		Range	Average
Antimony		$4{\cdot}5 \times 10^{-7}$	Molybdenum		$5{\cdot}7 \times 10^{-8}$
Arsenic		$2{\cdot}2 \times 10^{-7}$	Nickel		$7{\cdot}8 \times 10^{-8}$
Bismuth		$1{\cdot}2 \times 10^{-6}$	Platinum		10^{-7}
Copper		$1{\cdot}7 \times 10^{-8}$	Silver		$1{\cdot}6 \times 10^{-8}$
Gold		$2{\cdot}4 \times 10^{-8}$	Sulphur	10^7–10^{16}	10^{14}
Graphite	5×10^{-7}–10	10^{-3}	Tellurium	10^{-4}–2×10^{-3}	10^{-3}
Iron		10^{-7}	Tin		$1{\cdot}1 \times 10^{-7}$
Lead		$2{\cdot}2 \times 10^{-7}$	Uranium		3×10^{-7}
Mercury		$9{\cdot}6 \times 10^{-7}$	Zinc		$5{\cdot}8 \times 10^{-8}$

Table 5.2. *Resistivities of minerals*

Mineral	Formula	Resistivity (Ωm)	
		Range	Average
Argentite	Ag_2S	2×10^{-3}–10^4	$1{\cdot}7 \times 10^{-3}$
Bismuthinite	Bi_2S_3	18–570	
Covellite	CuS	3×10^{-7}–8×10^{-5}	2×10^{-5}
Chalcocite	Cu_2S	3×10^{-5}–$0{\cdot}6$	10^{-4}
Chalcopyrite	$CuFeS_2$	$1{\cdot}2 \times 10^{-5}$–$0{\cdot}3$	4×10^{-3}
Bornite	Cu_5FeS_4	$2{\cdot}5 \times 10^{-5}$–$0{\cdot}5$	3×10^{-3}
Marcasite	FeS_2	10^{-3}–$3{\cdot}5$	5×10^{-2}
Pyrite	FeS_2	$2{\cdot}9 \times 10^{-5}$–$1{\cdot}5$	3×10^{-1}
Pyrrhotite	Fe_nS_m	$6{\cdot}5 \times 10^{-6}$–5×10^{-2}	10^{-4}
Cinnabar	HgS		2×10^7
Molybdenite	MoS_2	10^{-3}–10^6	10
Galena	PbS	3×10^{-5}–3×10^2	2×10^{-3}
Millerite	NiS		3×10^{-7}
Stannite	Cu_2FeSnS_2	10^{-3}–6×10^3	
Stibnite	Sb_2S_3	10^5–10^{12}	5×10^6
Sphalerite	ZnS	$1{\cdot}5$–10^7	10^2
Cobaltite	$CoAsS$	$3{\cdot}5 \times 10^{-4}$–10^{-1}	
Smaltite	$CoAs_2$		5×10^{-5}
Arsenopyrite	$FeAsS$	2×10^{-5}–15	10^{-3}
Niccolite	$NiAs$	10^{-7}–2×10^{-3}	2×10^{-5}
Sylvanite	$AgAuTe_4$	4×10^{-6}–2×10^{-5}	
Bauxite	$Al_2O_3 . nH_2O$	2×10^2–6×10^3	

Mineral	Formula	Resistivity (Ωm) Range	Average
Braunite	Mn_2O_3	0·16–1·2	
Cuprite	Cu_2O	10^{-3}–300	30
Chromite	$FeCr_2O_4$	1–10^{6}	
Specularite	Fe_2O_3		6×10^{-3}
Hematite	Fe_2O_3	$3·5 \times 10^{-3}$–10^{7}	
Limonite	$2Fe_2O_3 . 3H_2O$	10^{3}–10^{7}	
Magnetite	Fe_3O_4	5×10^{-5}–$5·7 \times 10^{3}$	
Ilmenite	$FeTiO_3$	10^{-3}–50	
Wolframite	Fe, Mn, WO_4	10–10^{5}	
Manganite	MnO(OH)	10^{-2}–0·3	
Pyrolusite	MnO_2	5×10^{-3}–10	
Quartz	SiO_2	4×10^{10}–2×10^{14}	
Cassiterite	SnO_2	4×10^{-4}–10^{4}	0·2
Rutile	TiO_2	30–1000	500
Uraninite (Pitchblende)	UO_2	1–200	
Anhydrite	$CaSO_4$		10^{9}
Calcite	$CaCO_3$		2×10^{12}
Fluorite	CaF_2		8×10^{13}
Siderite	$Fe_2(CO_3)_3$		70
Rock salt	NaCl	30–10^{13}	
Sylvite	KCl	10^{11}–10^{12}	
Diamond	C	10–10^{14}	
Serpentine		2×10^{2}–3×10^{3}	
Hornblende		2×10^{2}–10^{6}	
Mica		9×10^{2}–10^{14}	
Biotite		2×10^{2}–10^{6}	
Phlogopite		10^{11}–10^{12}	
Bitum. coal		0·6–10^{5}	
Coals (various)		10–10^{11}	
Anthracite		10^{-3}–2×10^{5}	
Lignite		9–200	
Fire clay			30
Meteoric waters		30–10^{3}	
Surface waters (ign. rocks)		0·1–3×10^{3}	
Surface waters (sediments)		10–100	
Soil waters			100
Natural waters (ign. rocks)		0·5–150	9
Natural waters (sediments)		1–100	3
Sea water			0·2
Saline waters, 3%			0·15
Saline waters, 20%			0·05

The range of resistivities of various waters is notably smaller than for solid minerals; the actual resistivities are also lower than those of a great many minerals.

Table 5.3 lists resistivities for a variety of ores, from Parkhomenko (1967). In

general it appears that pyrrhotite in massive form has the lowest resistivity, that the resistivity of zinc ores is surprisingly low (possibly due to the presence of lead and copper fractions) and that molybdenite, chromite and iron ores have values in the range of many rocks.

Table 5.3. *Resistivities of various ores*

Ore	Other minerals	Gangue	ρ(Ωm)
Pyrite			
18%	2% (chalco)	80%	300
40	20%	40	130
60	5% (ZnS) + 15%	20	0·9
75	10% (ZnS) + 5%	10	0·14
95	5% (ZnS)		1·0
95		5	7·0
Pyrrhotite			
41%		59%	$2·2 \times 10^{-4}$
58		42	$2·3 \times 10^{-4}$
79		21	$1·4 \times 10^{-5}$
82		18	$8·5 \times 10^{-5}$
95		5	$1·4 \times 10^{-5}$
SbS_2 in quartz			4×10^{3}–3×10^{7}
FeAsS 60%	FeS 20%	20% SiO_2	0·39
FeAsS			10^{-4}–10^{-2}
Cu_5FeS_4			3×10^{-3}
Cu_5FeS_4 40%		60% SiO_2	7×10^{-2}
Fe, Mn, WO_4 80%			2×10^{4}
Fe, Mn, WO_4	CoAsS		10^{3}–10^{7}
PbS, massive			7×10^{-2}
PbS, near massive			0·8
PbS 50–80%			10^{-2}–3
Fe_2O_3			0·1–300
Fe_2O_3, massive			$2·5 \times 10^{3}$
Iron			
Fe_3O_4 60%			45
Fe_3O_4 from contact met.			0·5–10^{2}
Diss. brown iron oxide			8×10^{2}–3×10^{6}
75% brown iron oxide		25%	2×10^{4}–8×10^{5}
Fe_2O_3 fine grained			$2·5 \times 10^{3}$
Fe_3O_4			5×10^{3}–8×10^{3}
Fe_3O_4 in pegmatite			7×10^{3}–2×10^{5}
Zinc			
30%	5% PbS, 15% FeS	50%	0·75
70%	3% chalco, 17% PbS, 10% FeS		20
80	10% PbS, 10% FeS		$1·7 \times 10^{3}$
80	2% chalco, 1% PbS, 2% FeS	15%	1·3
90	5% PbS	5%	130

Ore	Other minerals	Gangue	$\rho(\Omega m)$
Graphitic slate			0·13
Graphite, massive			10^{-4}–5 × 10^{-3}
MoS_2			2 × 10^2–4 × 10^3
MnO_2 colloidal ore			1·6
Cu_2S			3 × 10^{-2}
$CuFeS_2$			10^{-4}–1
$CuFeS_2$ 80%	10% FeS	10%	0·66
$CuFeS_2$ 90%	2% FeS	8% SiO_2	0·65
$FeCr_2O_4$			10^3
$FeCr_2O_4$ 95%		5% Serp.	1·2 × 10^4

Tables 5.4 and 5.5 list typical values for rocks and unconsolidated formations. The ranges here are quite similar to water, which obviously is the controlling factor in many rocks.

Table 5.4. *Resistivities of igneous and metamorphic rocks*

Rock type	Resistivity range (Ωm)
Granite	3 × 10^2–10^6
Granite porphyry	4·5 × 10^3 (wet)–1·3 × 10^6 (dry)
Feldspar porphyry	4 × 10^3 (wet)
Albite	3 × 10^2 (wet)–3·3 × 10^3 (dry)
Syenite	10^2–10^6
Diorite	10^4–10^5
Diorite porphyry	1·9 × 10^3 (wet)–2·8 × 10^4 (dry)
Porphyrite	10–5 × 10^4 (wet)–3·3 × 10^3 (dry)
Carbonatized porphyry	2·5 × 10^3 (wet)–6 × 10^4 (dry)
Quartz porphyry	3 × 10^2–9 × 10^5
Quartz diorite	2 × 10^4–2 × 10^6 (wet)–1·8 × 10^5 (dry)
Porphyry (various)	60–10^4
Dacite	2 × 10^4 (wet)
Andesite	4·5 × 10^4 (wet)–1·7 × 10^2 (dry)
Diabase porphyry	10^3 (wet)–1·7 × 10^5 (dry)
Diabase (various)	20–5 × 10^7
Lavas	10^2–5 × 10^4
Gabbro	10^3–10^6
Basalt	10–1·3 × 10^7 (dry)
Olivine norite	10^3–6 × 10^4 (wet)
Peridotite	3 × 10^3 (wet)–6·5 × 10^3 (dry)
Hornfels	8 × 10^3 (wet)–6 × 10^7 (dry)
Schists (calcareous and mica)	20–10^4
Tuffs	2 × 10^3 (wet)–10^5 (dry)
Graphite schist	10–10^2
Slates (various)	6 × 10^2–4 × 10^7
Gneiss (various)	6·8 × 10^4 (wet)–3 × 10^6 (dry)
Marble	10^2–2·5 × 10^8 (dry)
Skarn	2·5 × 10^2 (wet)–2·5 × 10^8 (dry)
Quartzites (various)	10–2 × 10^8

Table 5.5. *Resistivities of sediments*

Rock type	Resistivity range (Ωm)
Consolidated shales	20–2 × 10^3
Argillites	10–8 × 10^2
Conglomerates	2 × 10^3–10^4
Sandstones	1–6·4 × 10^8
Limestones	50–10^7
Dolomite	3·5 × 10^2–5 × 10^3
Unconsolidated wet clay	20
Marls	3–70
Clays	1–100
Alluvium and sands	10–800
Oil sands	4–800

Very roughly, igneous rocks have the highest resistivity, sediments the lowest, with metamorphic rocks intermediate. However, there is considerable overlapping, as in other physical properties. In addition, the resistivities of particular rock types vary directly with age and lithology, since the porosity of the rock and salinity of the contained water are affected by both. For example, the resistivity range of Precambrian volcanics is 200–5000 Ωm, while for Quaternary rocks of the same kind it is 10–200 Ωm.

The effect of water content on the bulk resistivity of rocks has been frequently mentioned and is evident from table 5.4. Further data are listed in table 5.6, where samples with variable amounts of water are shown. In all cases a small change in the percentage of water effects the resistivity enormously.

Table 5.6. *Variation of rock resistivity with water content*

Rock	% H_2O	$\rho(\Omega m)$	Rock	% H_2O	$\rho(\Omega m)$
Siltstone	0·54	1·5 × 10^4	Pyrophyllite	0·76	6 × 10^6
Siltstone	0·44	8·4 × 10^6	Pyrophyllite	0·72	5 × 10^7
Siltstone	0·38	5·6 × 10^8	Pyrophyllite	0·7	2 × 10^8
Coarse grain SS	0·39	9·6 × 10^5	Pyrophyllite	0	10^{11}
Coarse grain SS	0·18	10^8	Granite	0·31	4·4 × 10^3
Medium grain SS	1·0	4·2 × 10^3	Granite	0·19	1·8 × 10^6
Medium grain SS	1·67	3·2 × 10^6	Granite	0·06	1·3 × 10^8
Medium grain SS	0·1	1·4 × 10^8	Granite	0	10^{10}
Graywacke SS	1·16	4·7 × 10^3	Diorite	0·02	5·8 × 10^5
Graywacke SS	0·45	5·8 × 10^4	Diorite	0	6 × 10^6
Arkosic SS	1·26	10^3	Basalt	0·95	4 × 10^4
Arkosic SS	1·0	1·4 × 10^3	Basalt	0·49	9 × 10^5
Organic limestone	11	0·6 × 10^3	Basalt	0·26	3 × 10^7
Dolomite	2	5·3 × 10^3	Basalt	0	1·3 × 10^8
Dolomite	1·3	6 × 10^3	Olivine-pyrox.	0·028	2 × 10^4
Dolomite	0·96	8 × 10^3	Olivine-pyrox.	0·014	4 × 10^5
Peridotite	0·1	3 × 10^3	Olivine-pyrox.	0	5·6 × 10^7
Peridotite	0·03	2 × 10^4			
Peridotite	0·016	10^6			
Peridotite	0	1·8 × 10^7			

Pitfalls for VLF-EM

- Recording the sign (+/-) of the numbers correctly
- Switching the facing direction or orientation during survey
- Presence of cultural features – power lines, cables fences, culverts, rebar, asphalt roadways, etc.
- Unforeseen causes of anomalies – *eg.* Permafrost contacts

Technique	Passive/ active	Physical property utilised	Source/signal
Magnetics	Passive	Magnetic susceptibility/ remanence	Earth's magnetic field
Gravity	Passive	Density	Earth's gravitational field
Continuous Wave and Time-Domain Electromagnetics (EM)	Active/ passive	Electrical conductivity/ resistivity	Hz/kHz band electromagnetic waves
Resistivity Imaging/ Sounding	Active	Electrical resistivity	DC electric current
Induced Polarisation	Active	Electrical resistivity/ complex resistivity and chargeability	Pulsed electric current
Self potential (SP)	Passive	Redox and electrokinetic	Redox, streaming and diffusion potentials
Seismic Refraction and Reflection/ Sonic	Active/ passive	Density/elasticity	Explosives, weight drops, vibrations, earthquakes, sonic transducers
Radiometrics	Active/ passive	Radioactivity	Natural or artificial radioactive sources
Ground Penetrating Radar (GPR)	Active	Dielectric properties (permittivity)	Pulsed or stepped frequency microwave EM (50–2000 MHz)
Wireline Logging	Active/ passive	Various	Various