TDEM applications for exploring for magmatic Ni-Cu-PGE deposits – Zooming in to the "brownfield" scale

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Canadian Royalties Inc.

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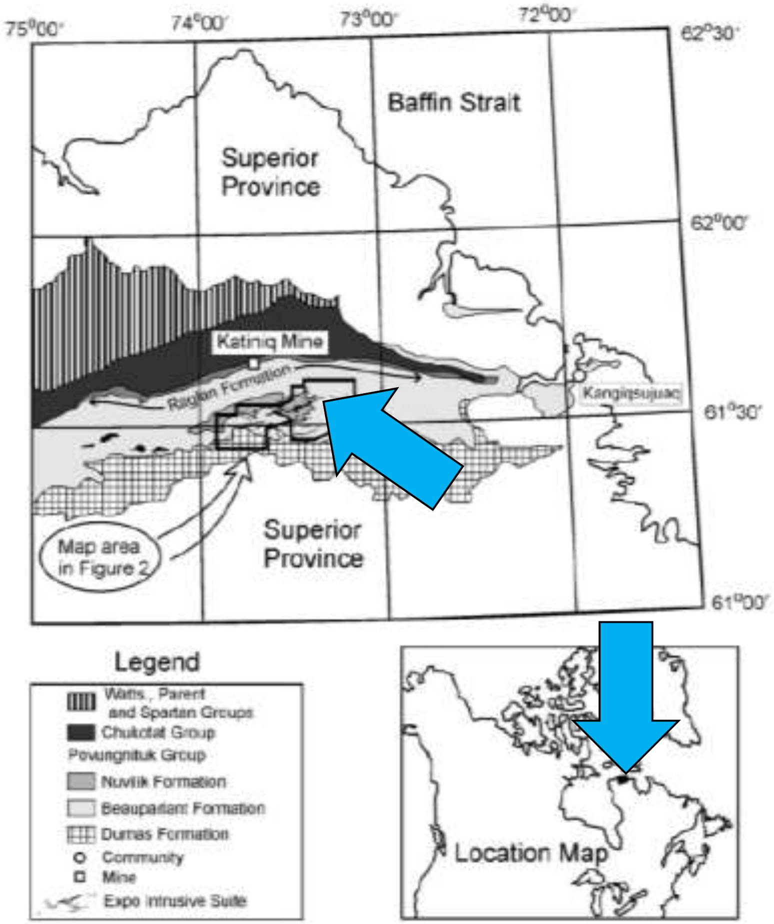
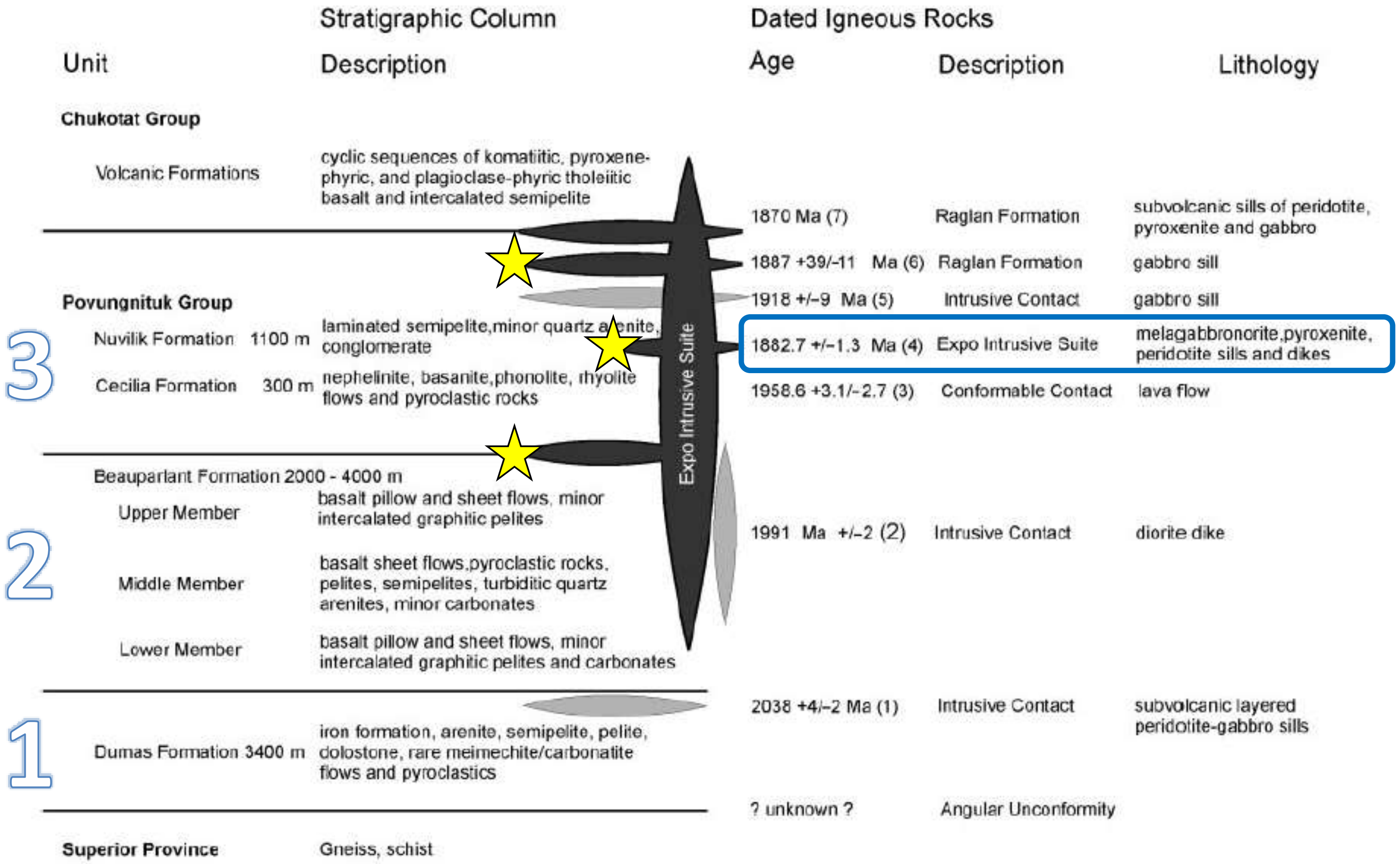
1. Geological setting at Nunavik Nickel

NUNAVIK NICKEL





(From Mungall, 2007)

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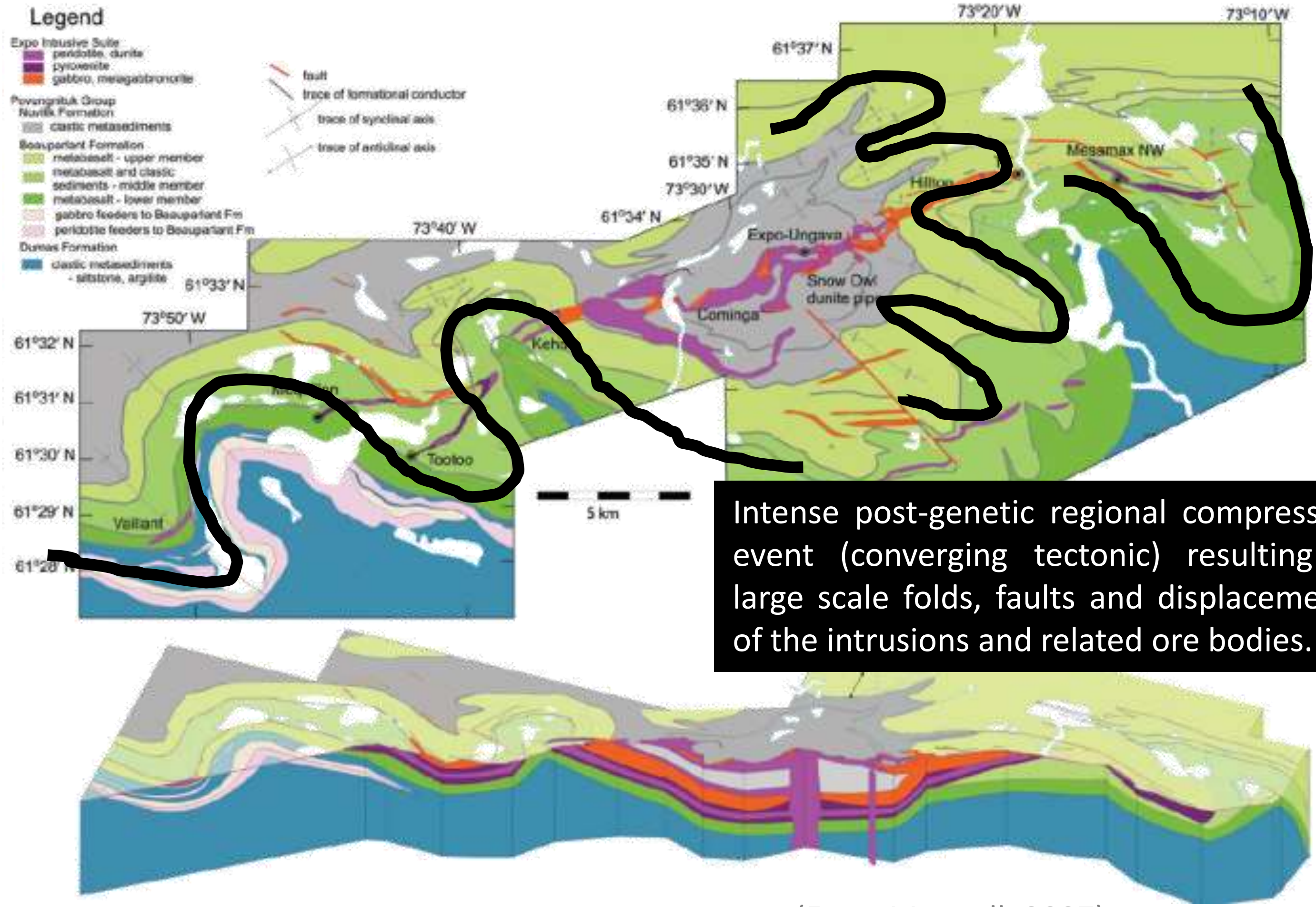
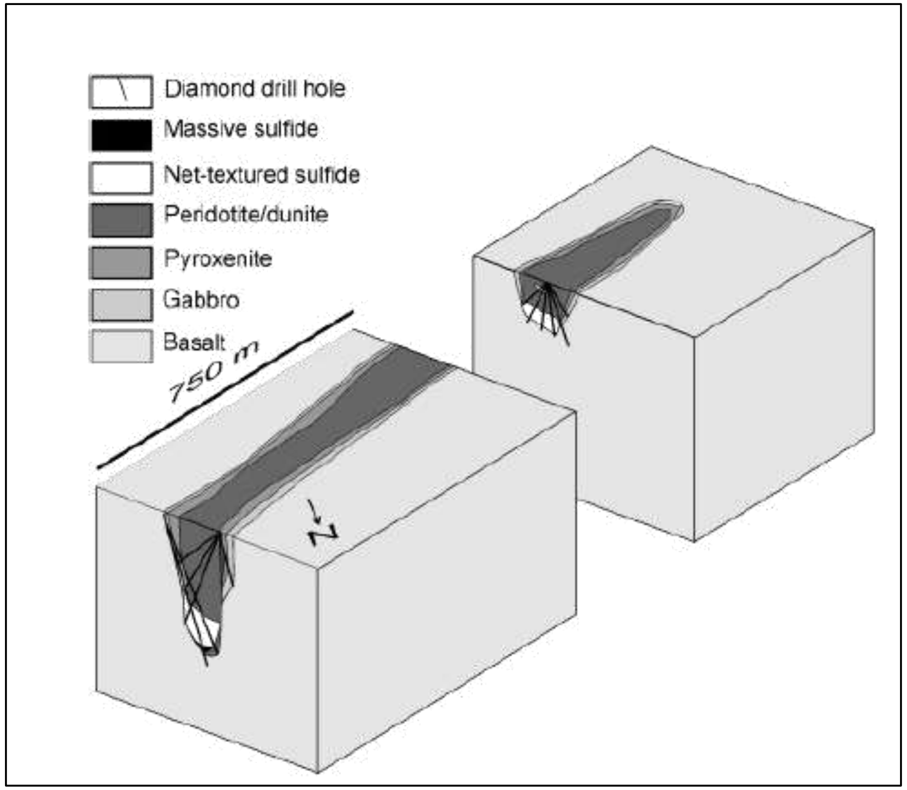
1. Geological setting at Nunavik Nickel



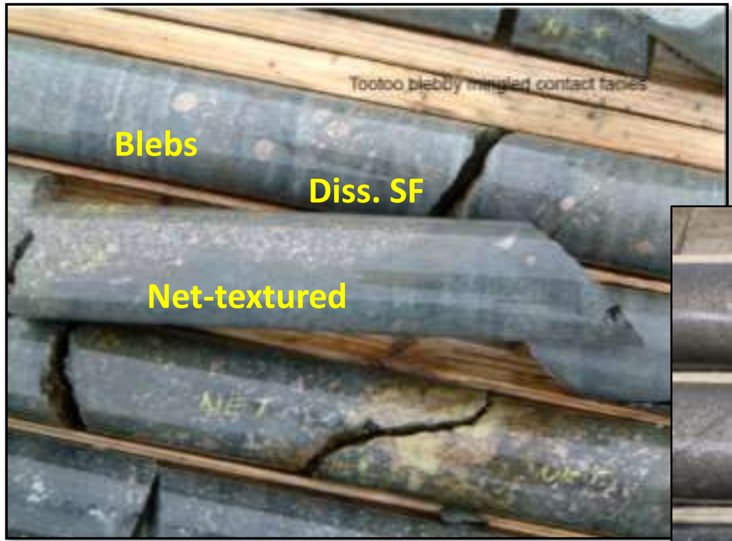
Intense post-genetic regional compression event (converging tectonic) resulting in large scale folds, faults and displacements of the intrusions and related ore bodies.

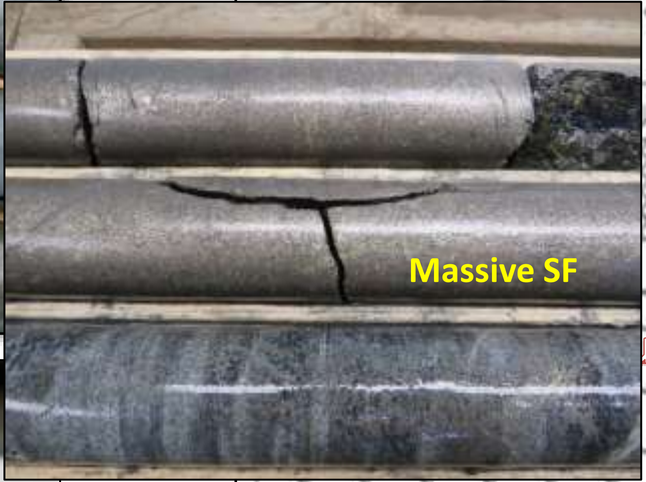
(From Mungall, 2007)

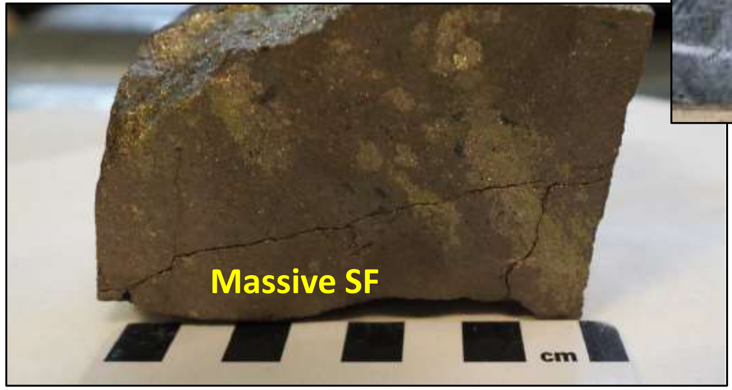
Typical shape of UM intrusion crosscutting the volcano-sedimentary basin



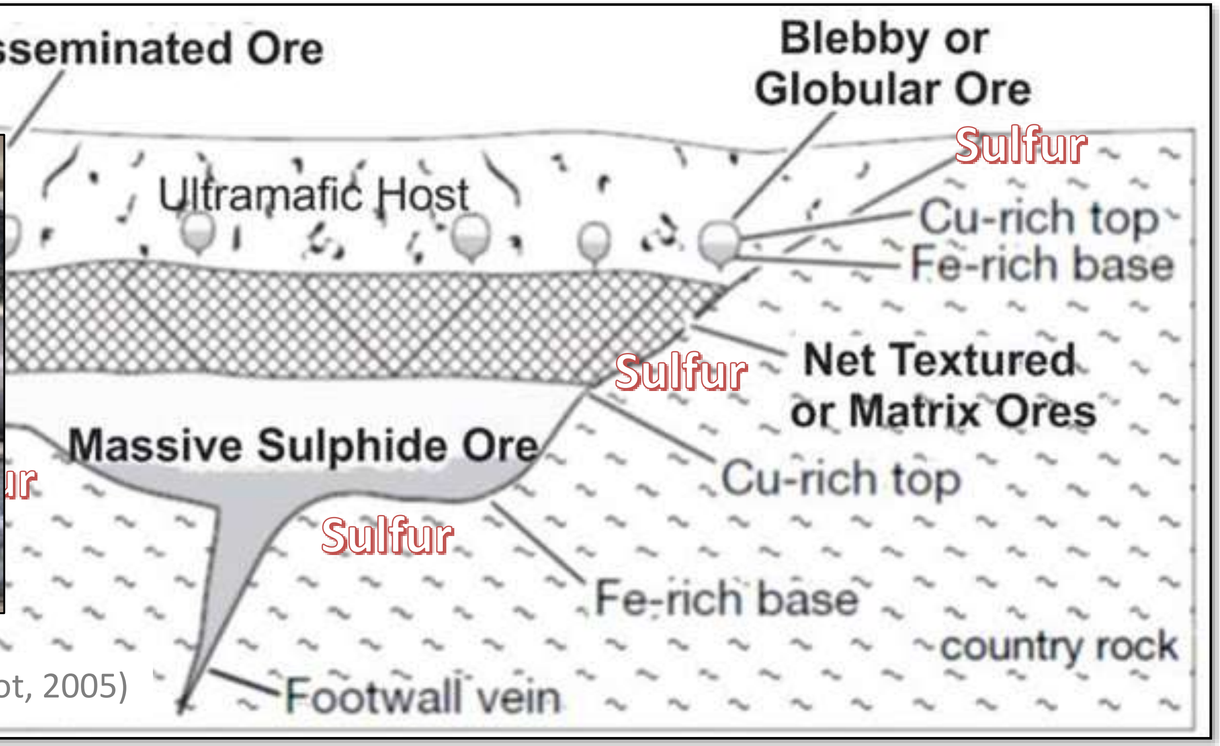
1. Geological setting at Nunavik Nickel







Cross-section of typical Ni-Cu-PGE ore body

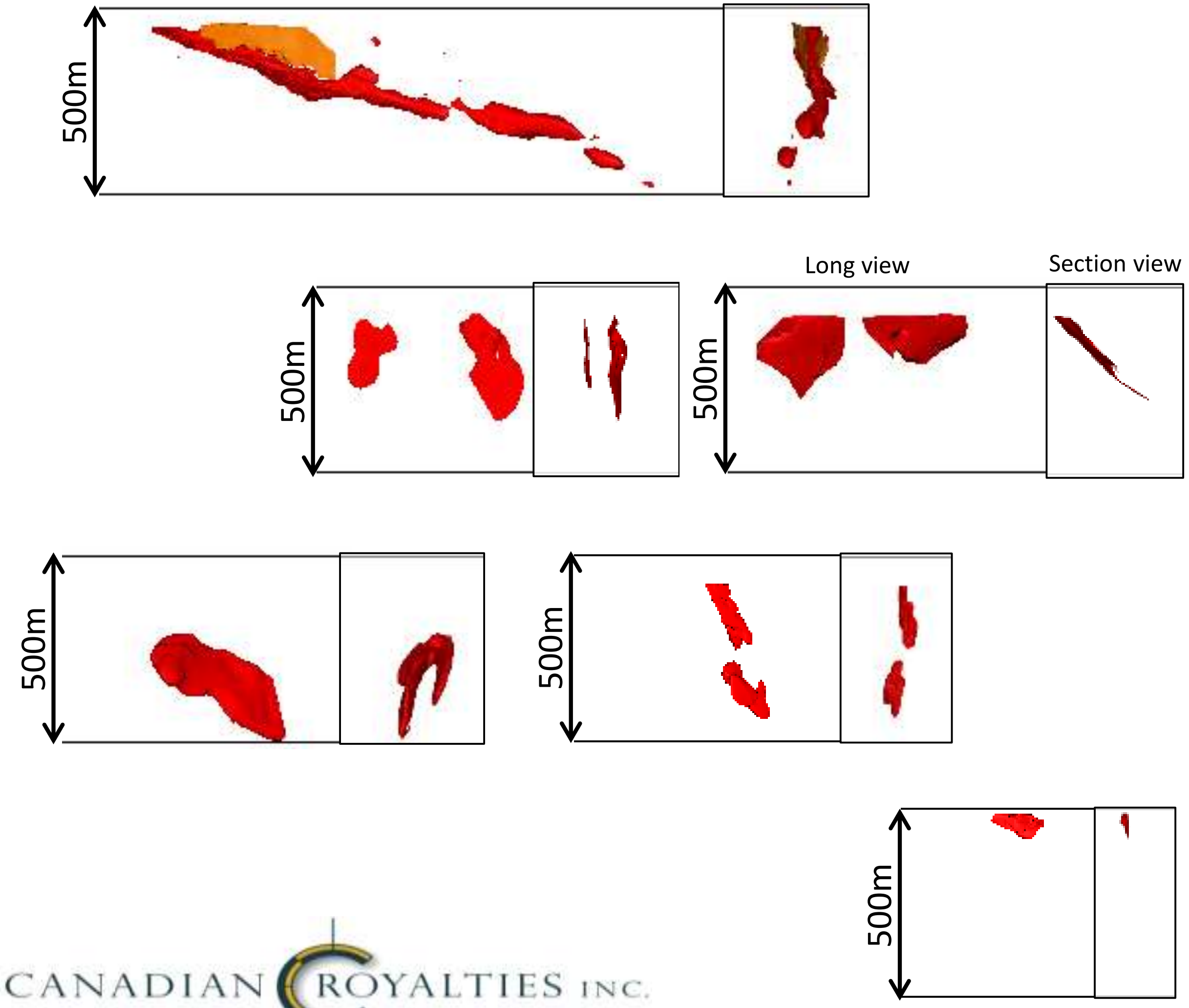


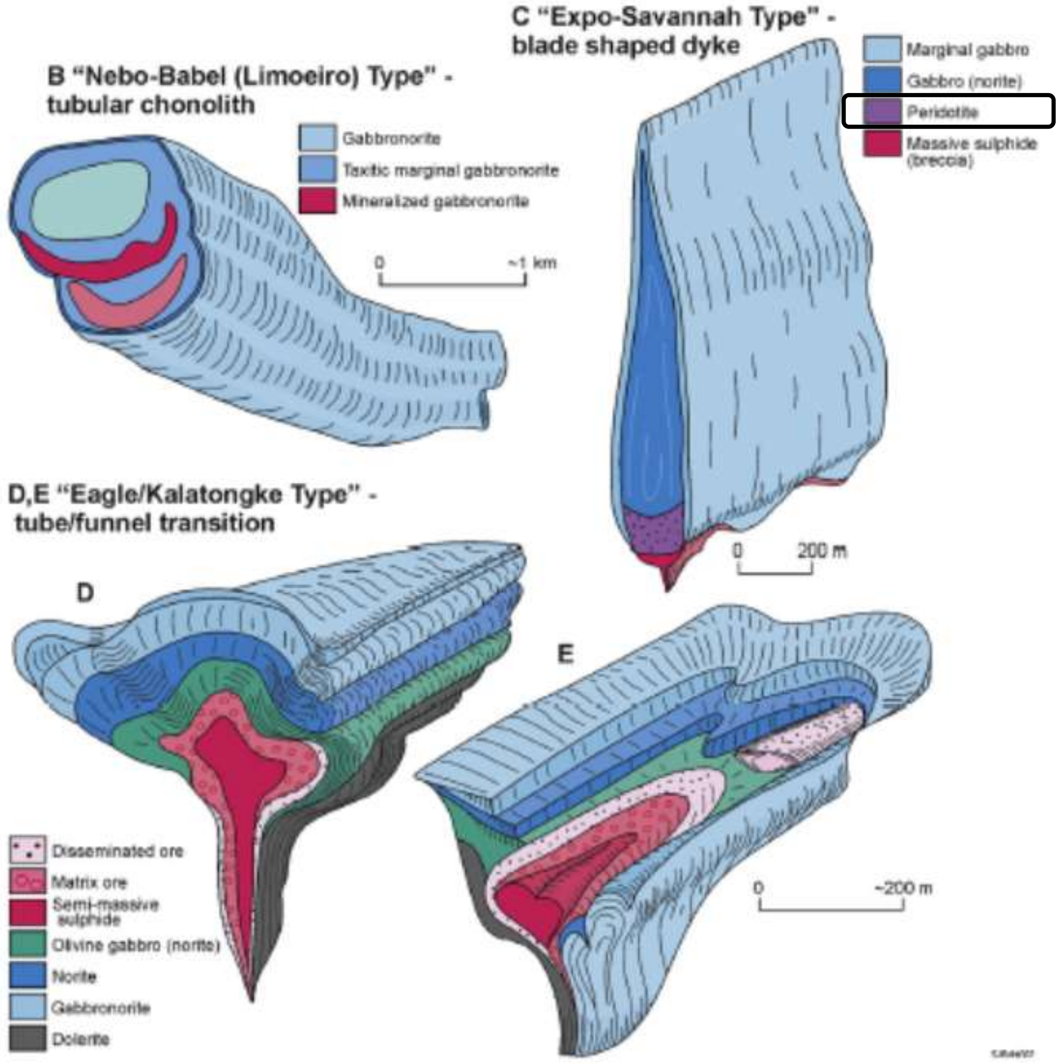
(From Barnes & Lightfoot, 2005)

1. Geological setting at Nunavik Nickel

NUNAVIK NICKEL

Cross-section of typical Ni-Cu-PGE ore body





(From Barnes et al., 2015)

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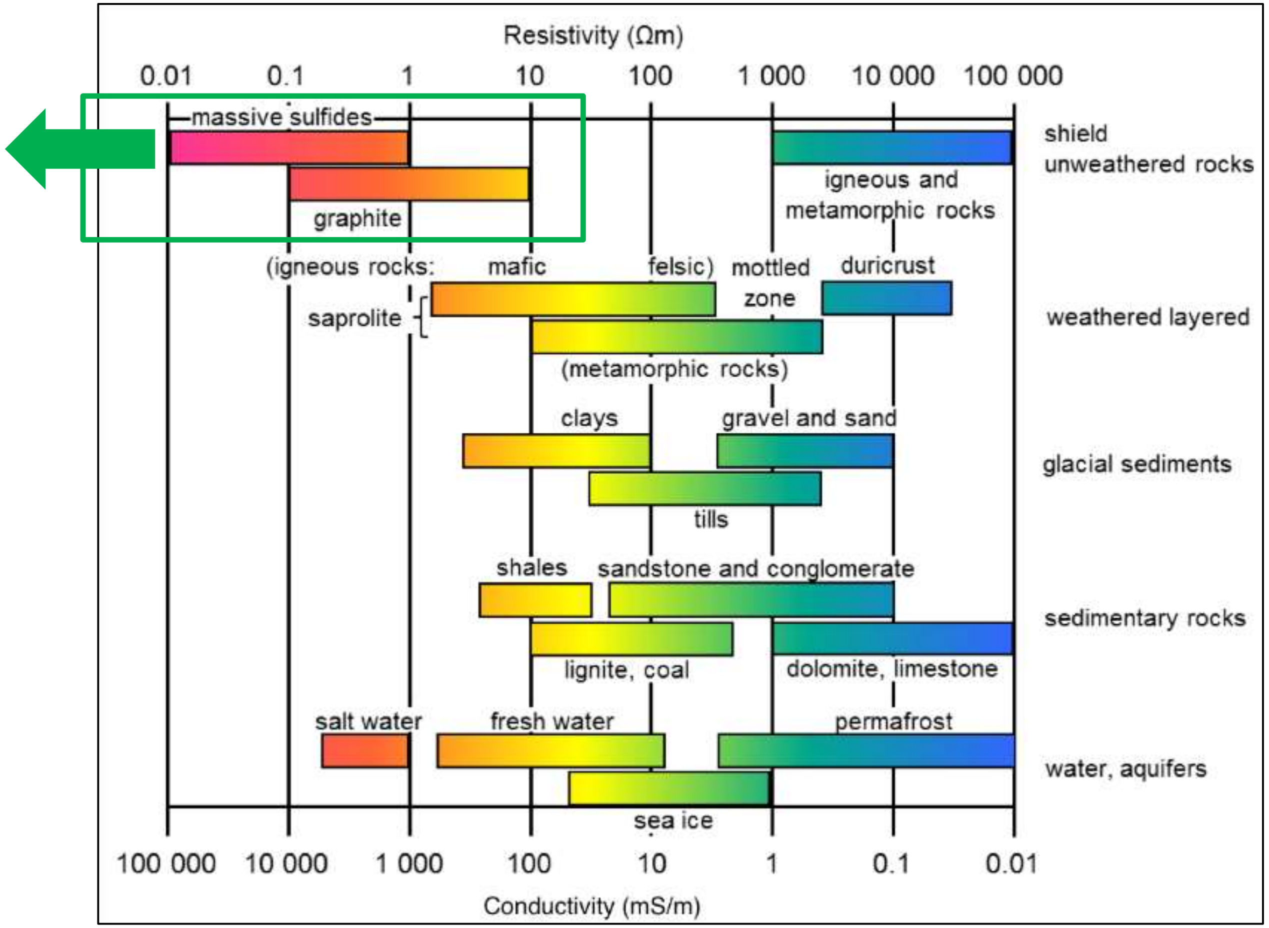
2. Physical Rock Properties

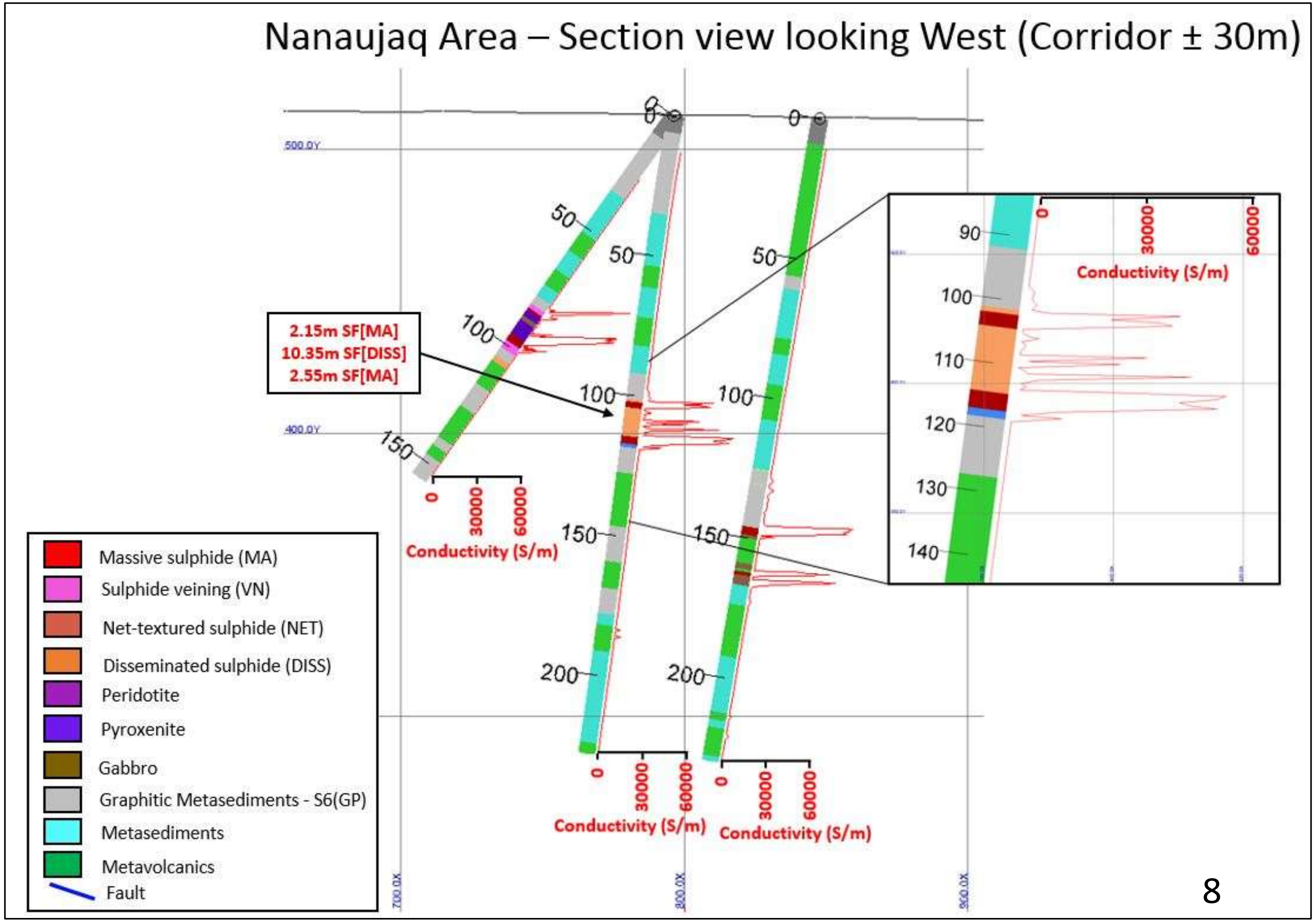


https://em.geosci.xyz/

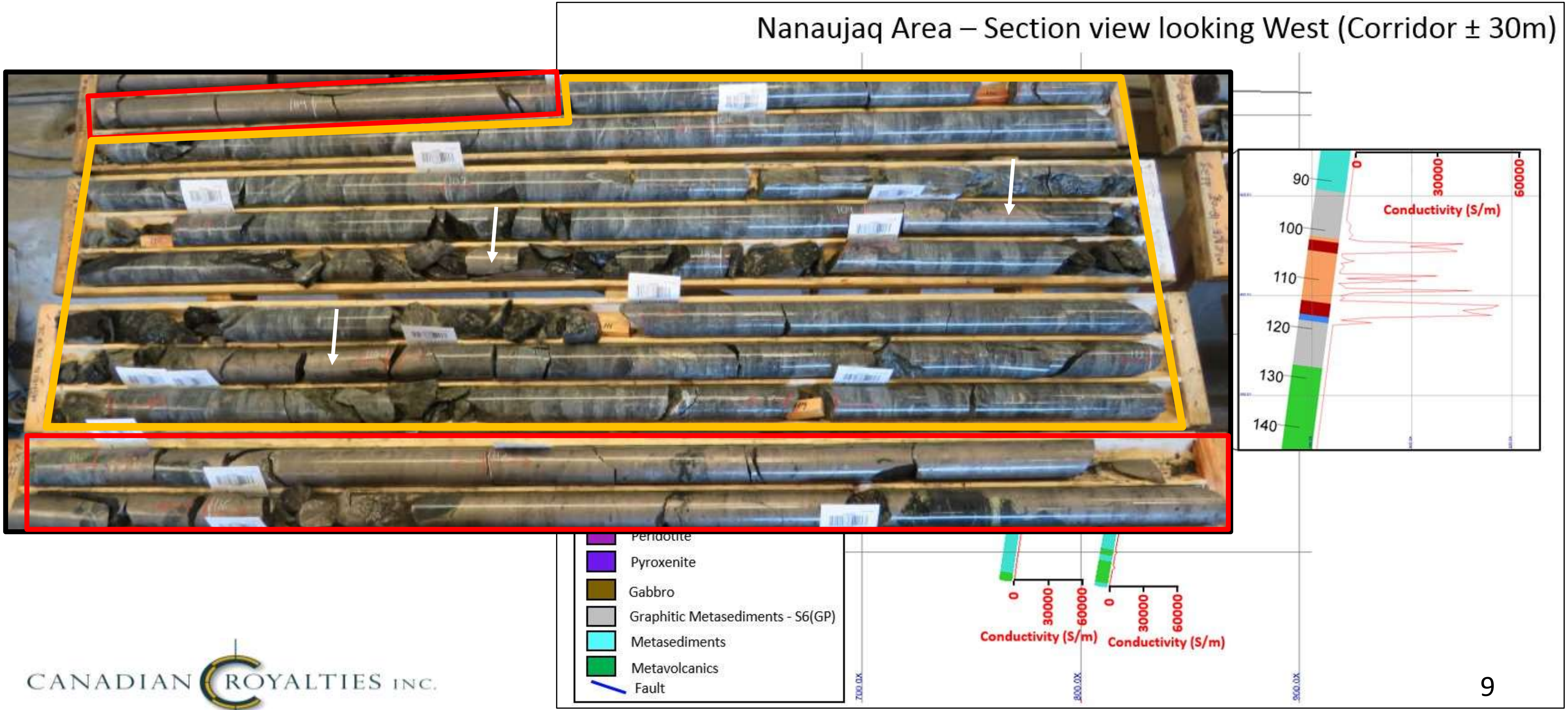
	EM Conductivity over Core (Nunavik Nickel)	
	Mean (S/m)	Range (S/m)
Massive sulfides - SF(MA)	35,000	22,000 – 70,000
Net-textured – SF(NET)	3000	100 - 6300
Disseminated Sulfides – SF(DISS)	0	-
Sulfides in veins – S6(PO)	9000	1000 – 26,000
GP-rich Sediments – S6(GP)	500	10 – 2000

Comparison between (left) theoretical Conductivity values (Palacky, 1988) and (right) *in-situ* measurements from the Nunavik Nickel Project

2. Physical Rock Properties



2. Physical Rock Properties



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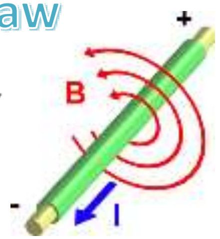
3. Time-Domain Electromagnetics – Theory

https://lenergie-solaire.net/electricite/lois

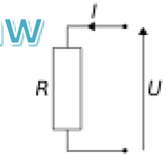
Ampère's Law

$$\oint \vec{B}\, d\vec{l} = \mu_0 I_T$$



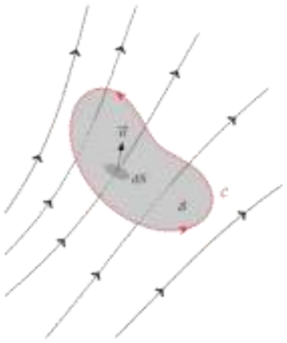
Ohm's Law

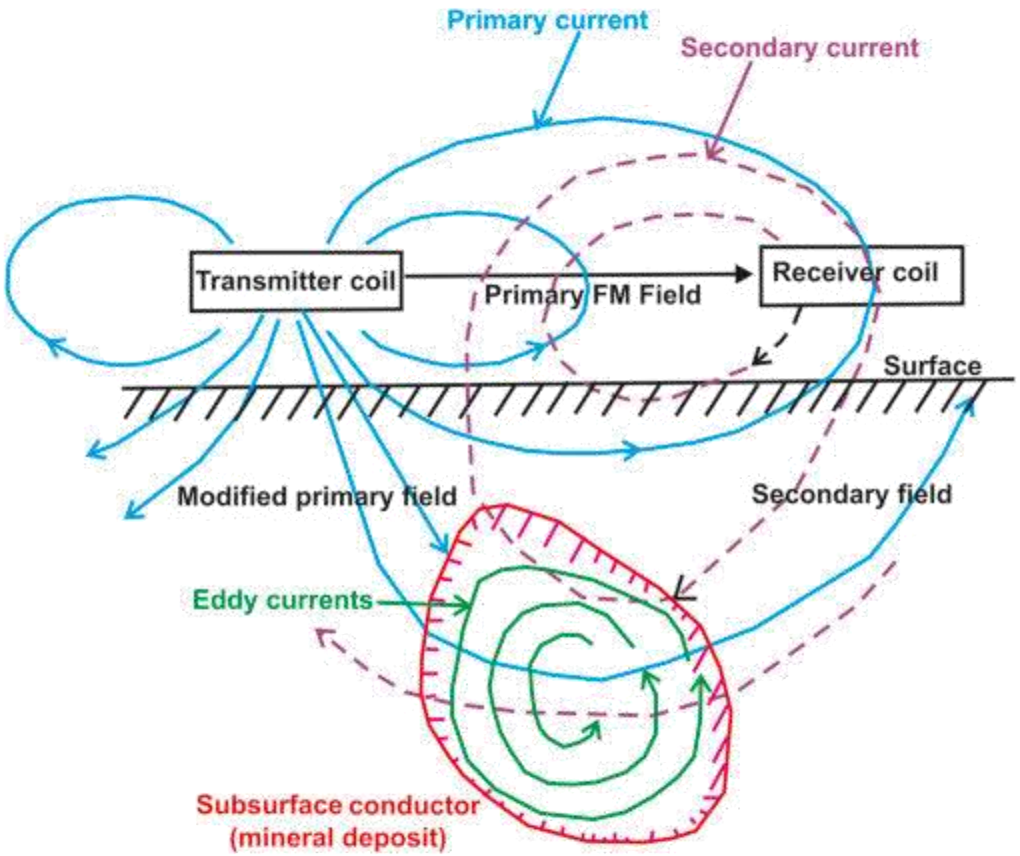
U = R ◦ I



Faraday's Law

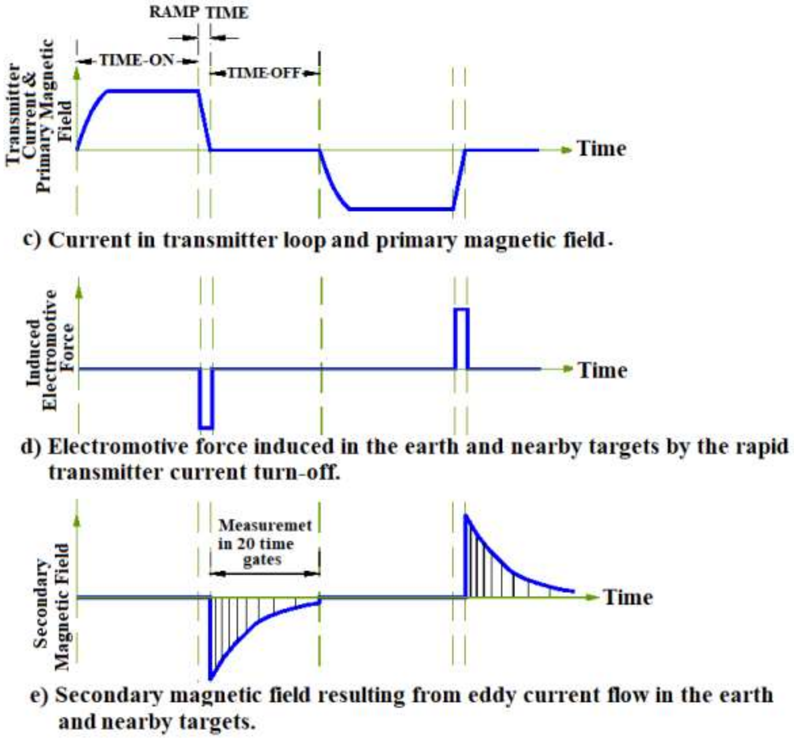
$$\mathcal{E} = -N\frac{d\Phi_B}{dt}$$





https://www.sciencedirect.com/topics/earth-and-planetary-sciences/electromagnetic-survey

Figure 6.18. Conceptual diagram of electromagnetic induction processing system generating eddy currents in subsurface conductive mass.



Journal of Geoscience and Environment Protection, 2020, 8, 195-206

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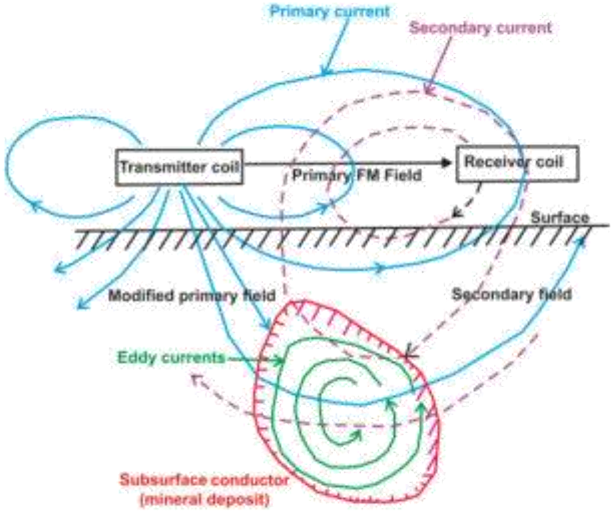
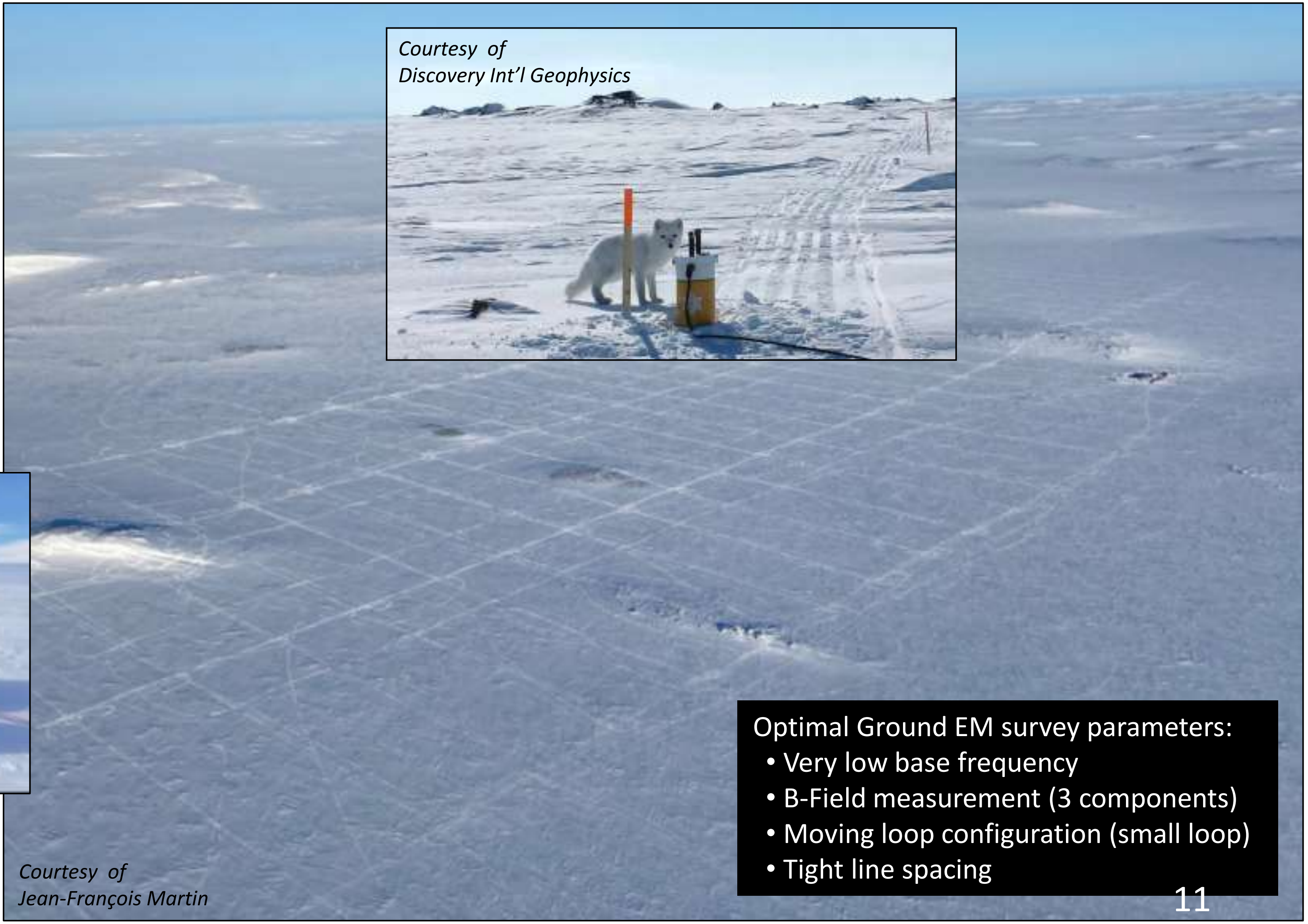
3. Time-Domain Electromagnetics – Theory



Courtesy of
Discovery Int'l Geophysics

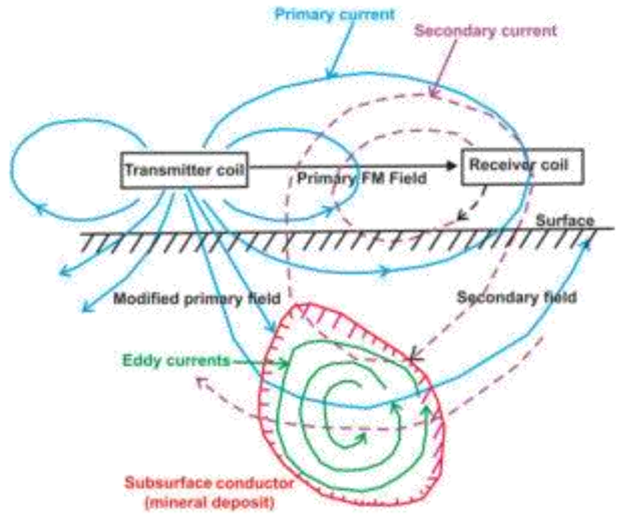


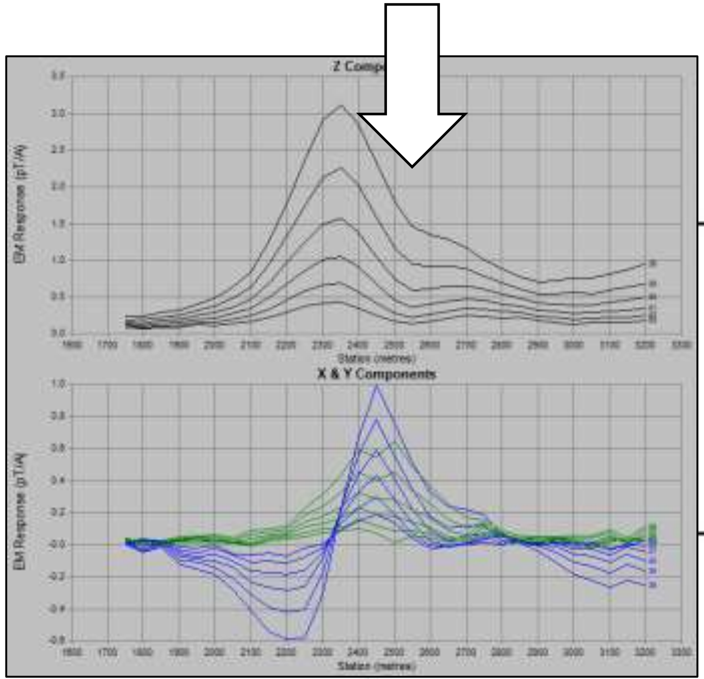
Courtesy of
Jean-François Martin

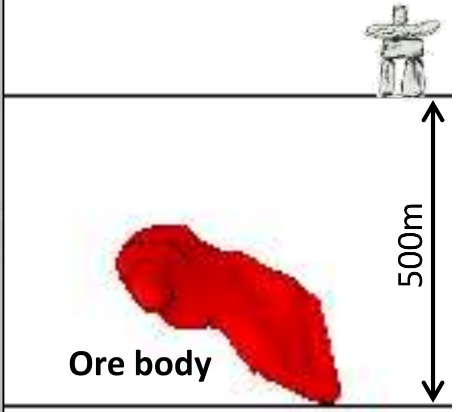
Courtesy of
Discovery Int'l Geophysics

Optimal Ground EM survey parameters:
- Very low base frequency
- B-Field measurement (3 components)
- Moving loop configuration (small loop)
- Tight line spacing

3. Time-Domain Electromagnetics – Theory





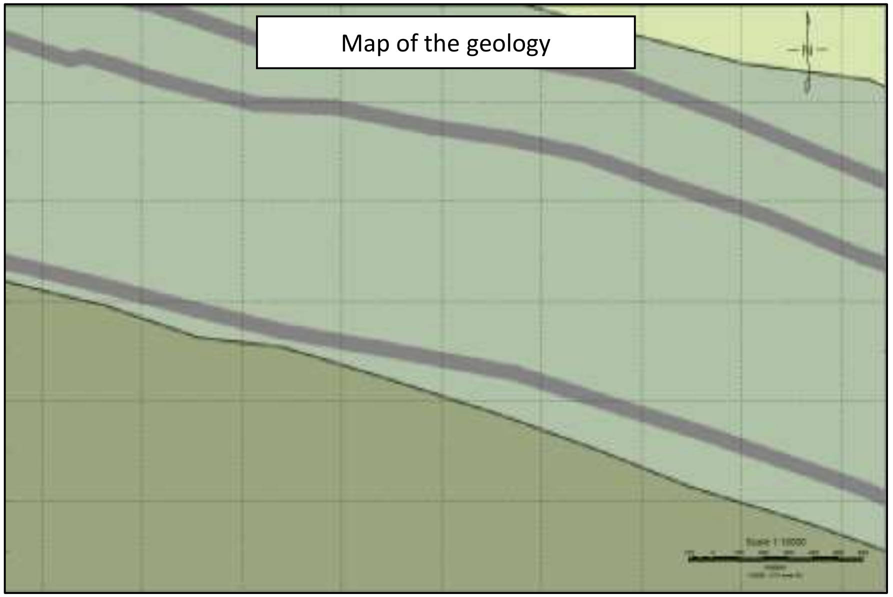


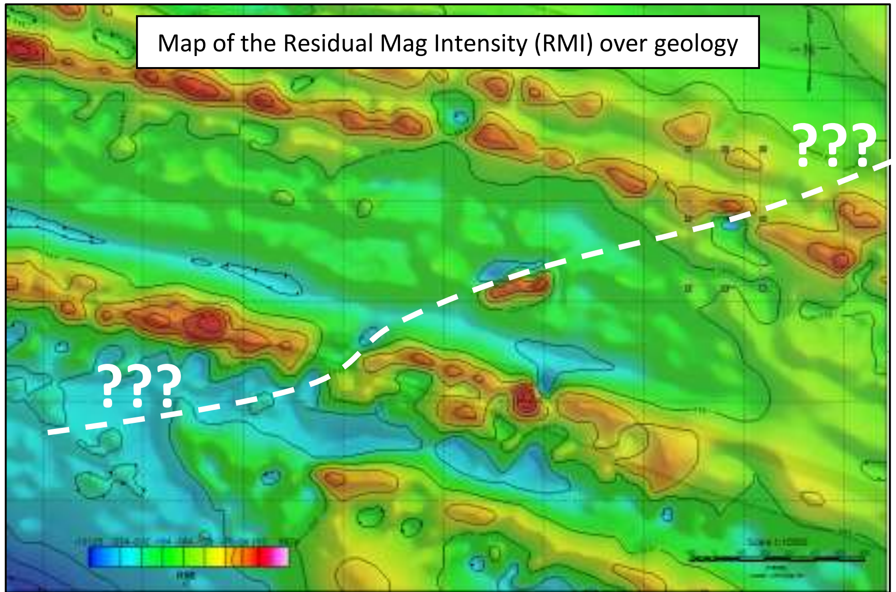
Timing settings
Transmitter current
Sensor sensitivity
Loop configuration
TX loop size & location

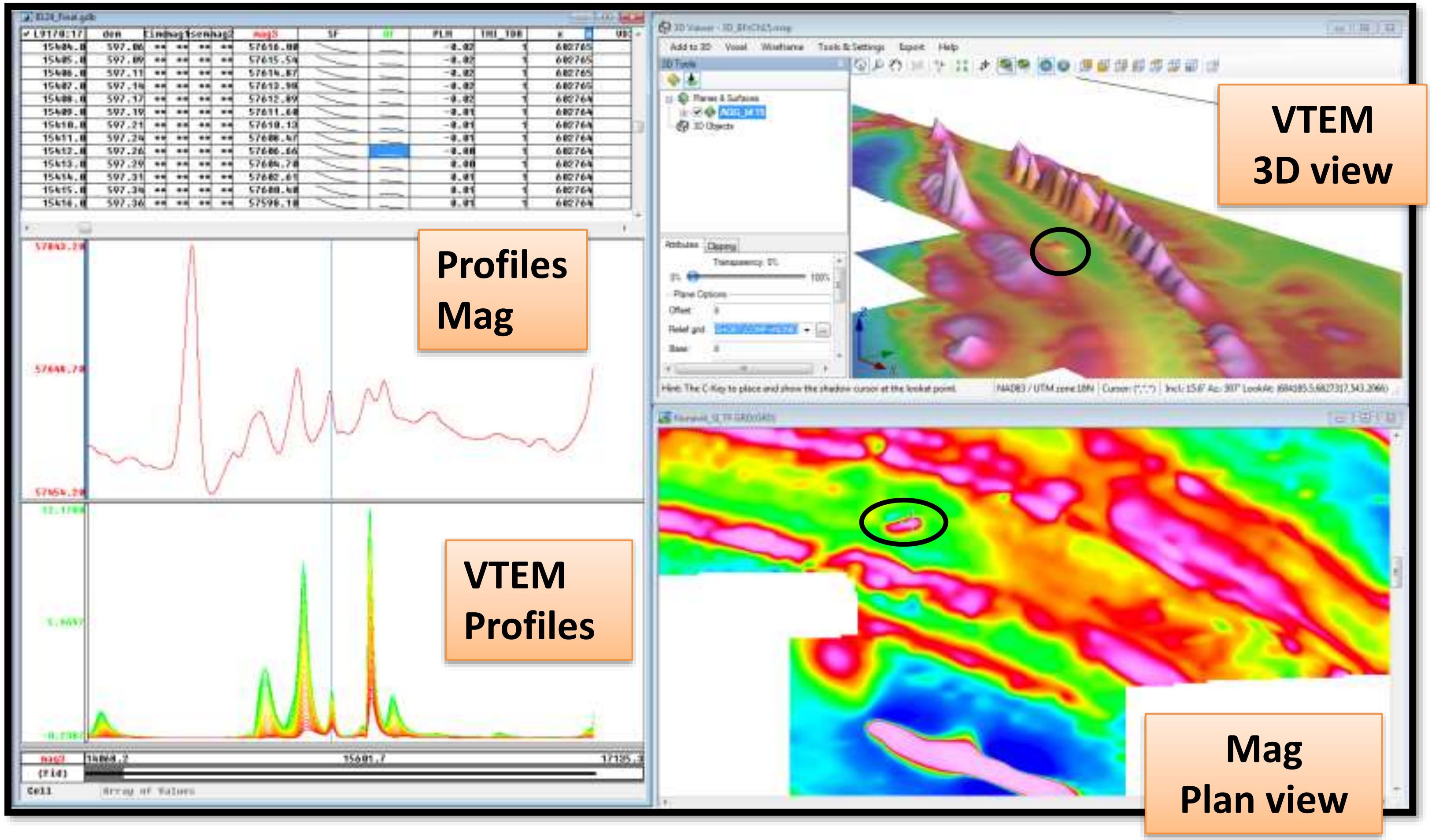
Nature & texture of exploration target
Shape of exploration target
Size & depth of exploration target
Geological setting

Infrastructures & cultural noise

4. Time-Domain Electromagnetics – Easy one #1







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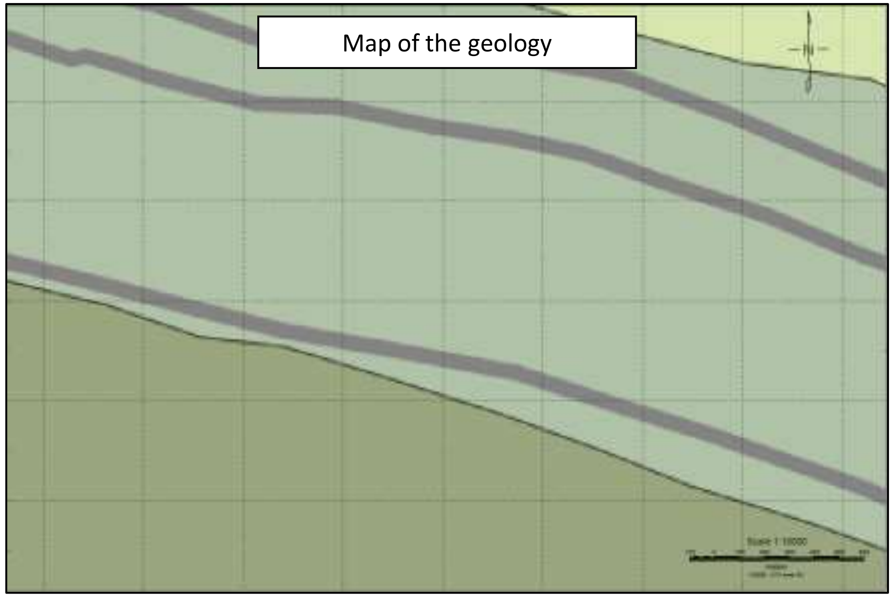

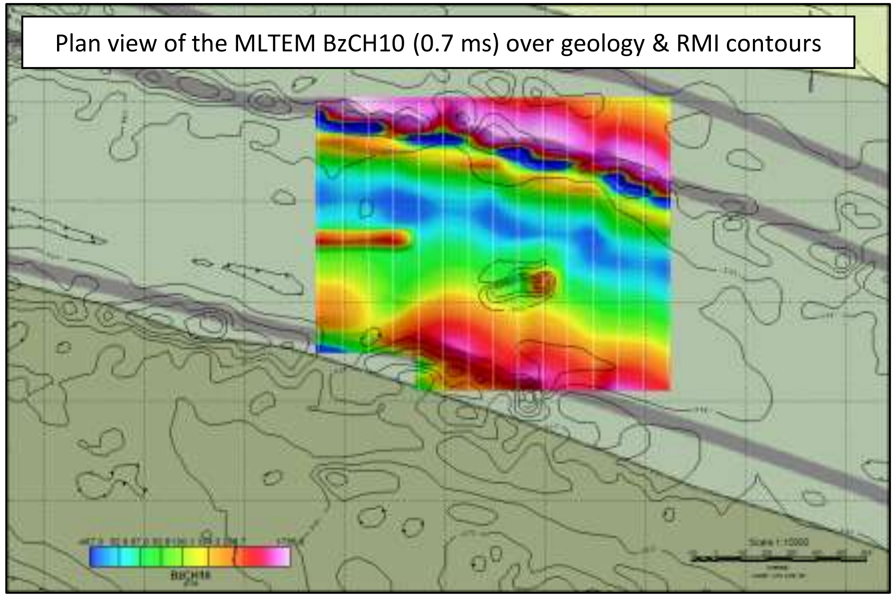

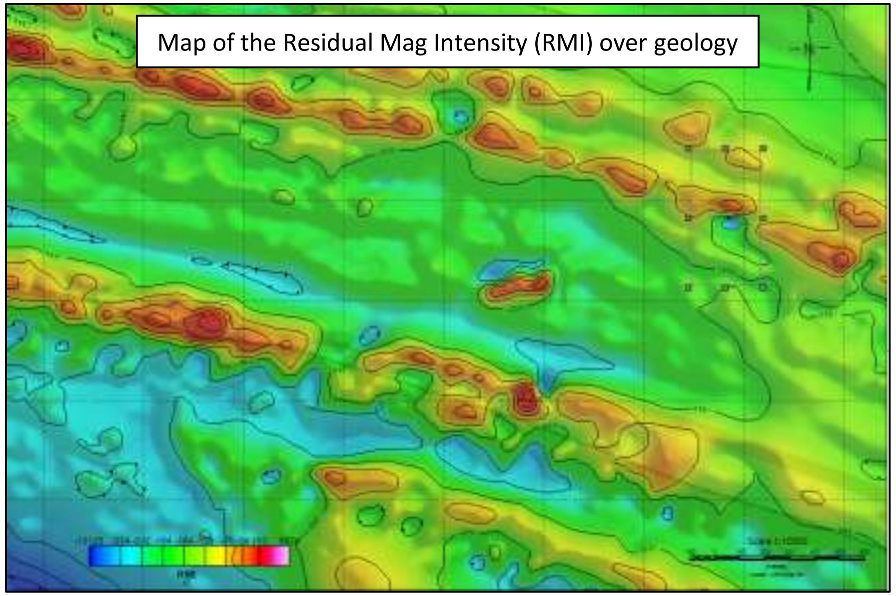

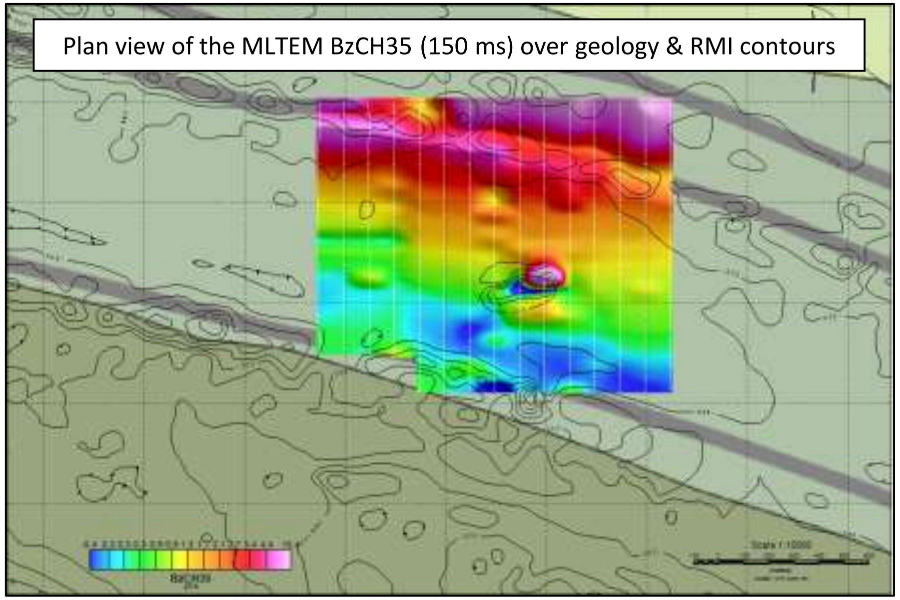

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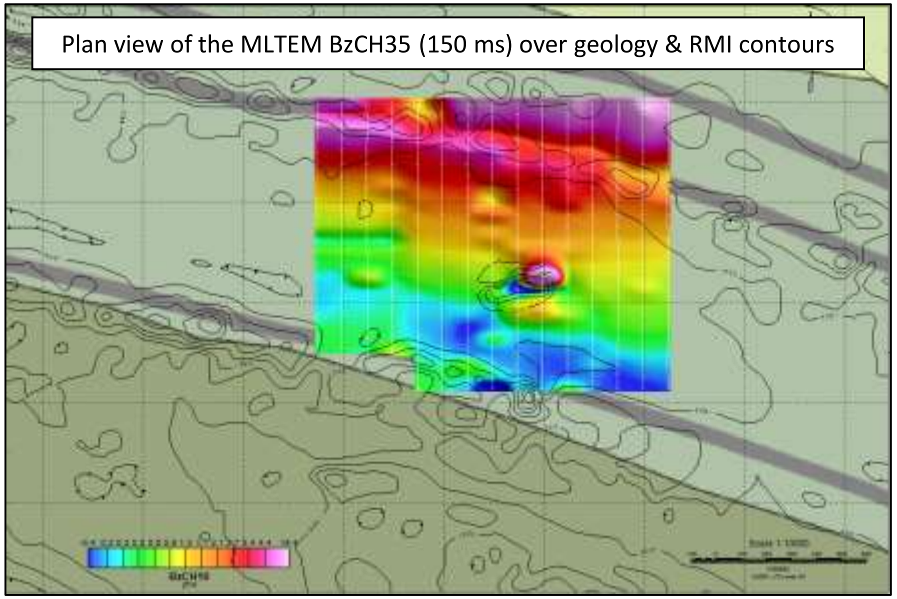
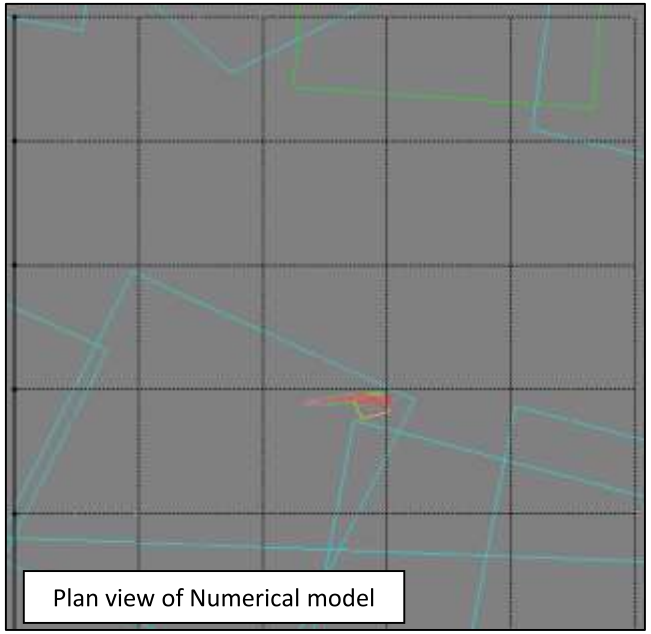
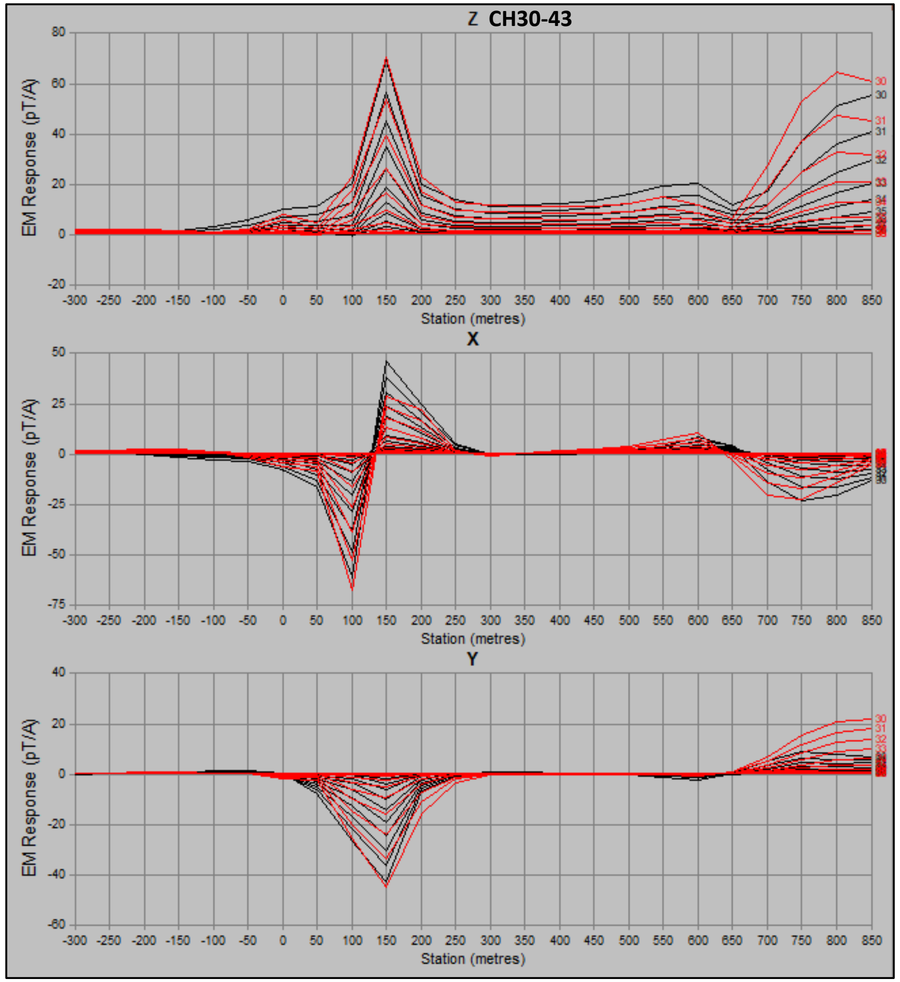


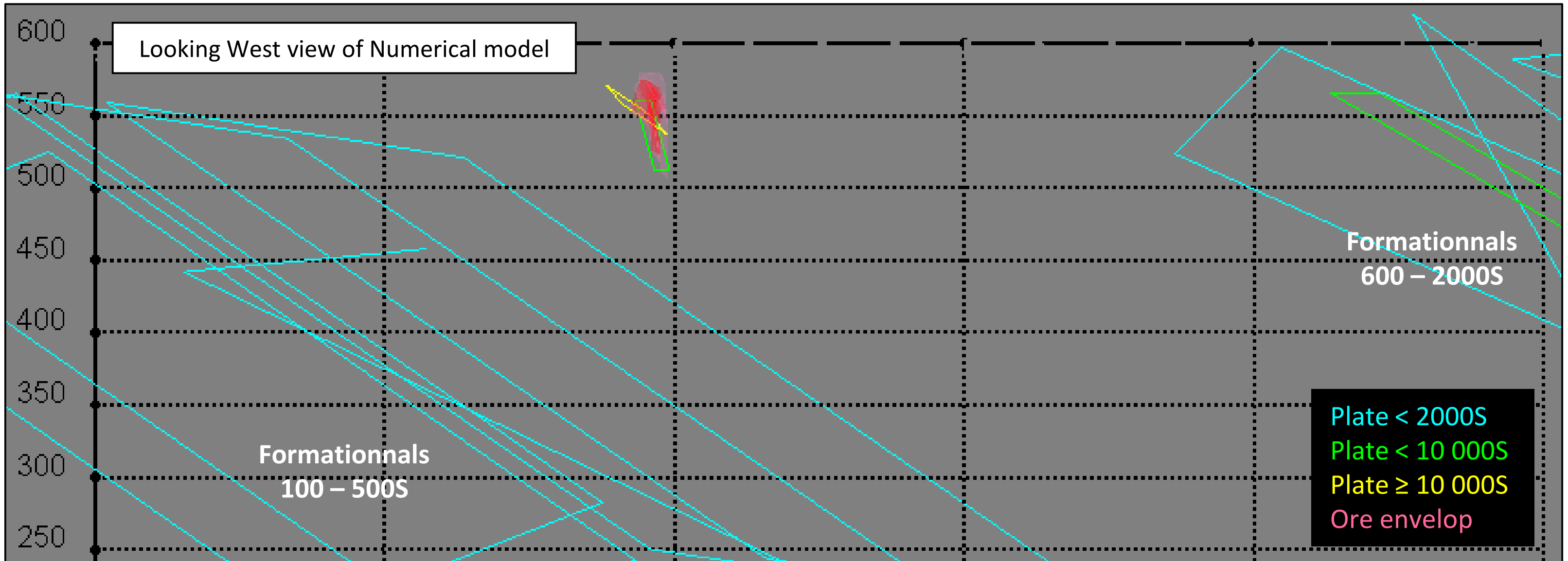
Plan view of the MLTEM BzCH35 (150 ms) over geology & RMI contours



Plan view of Numerical model

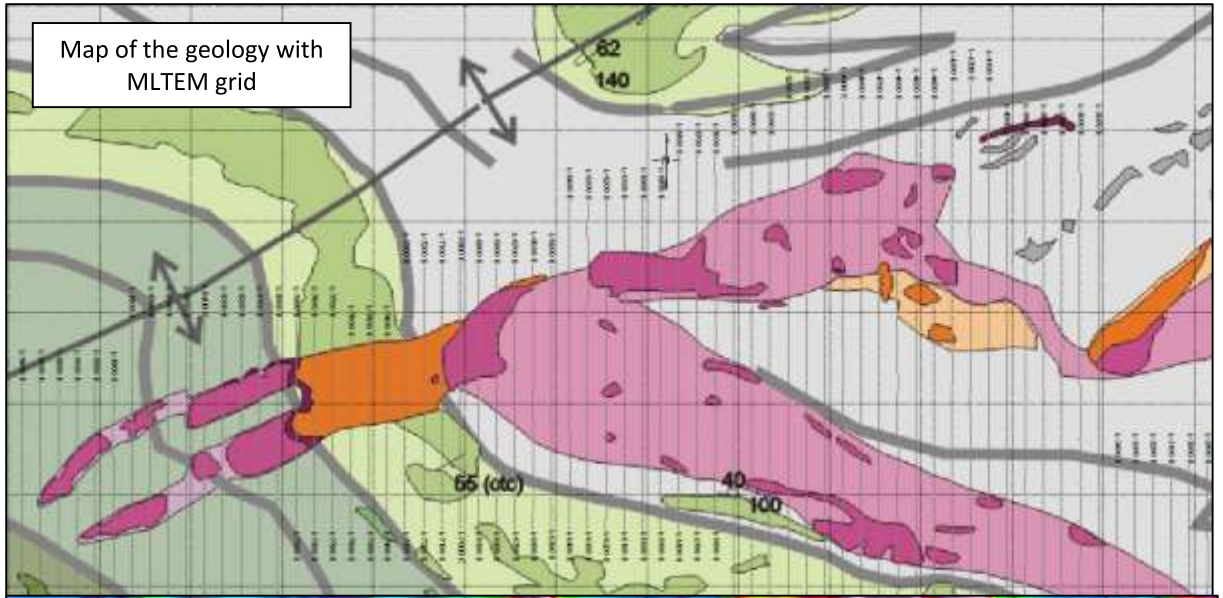
Observed (black) and Calculated (red) MLTEM profiles – CH30-43

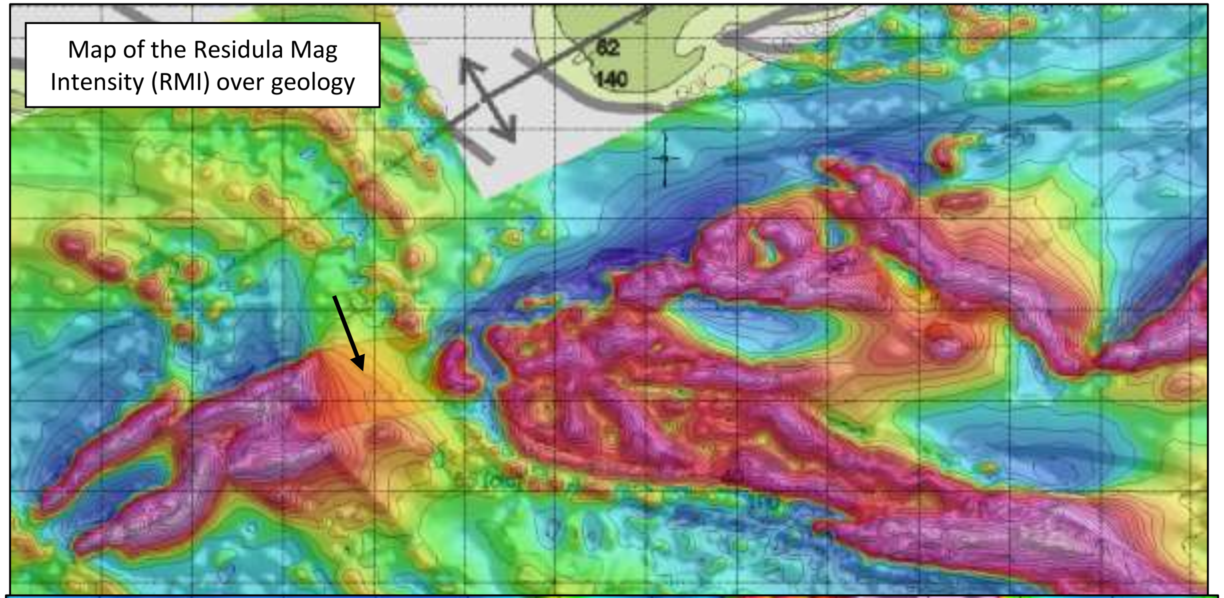


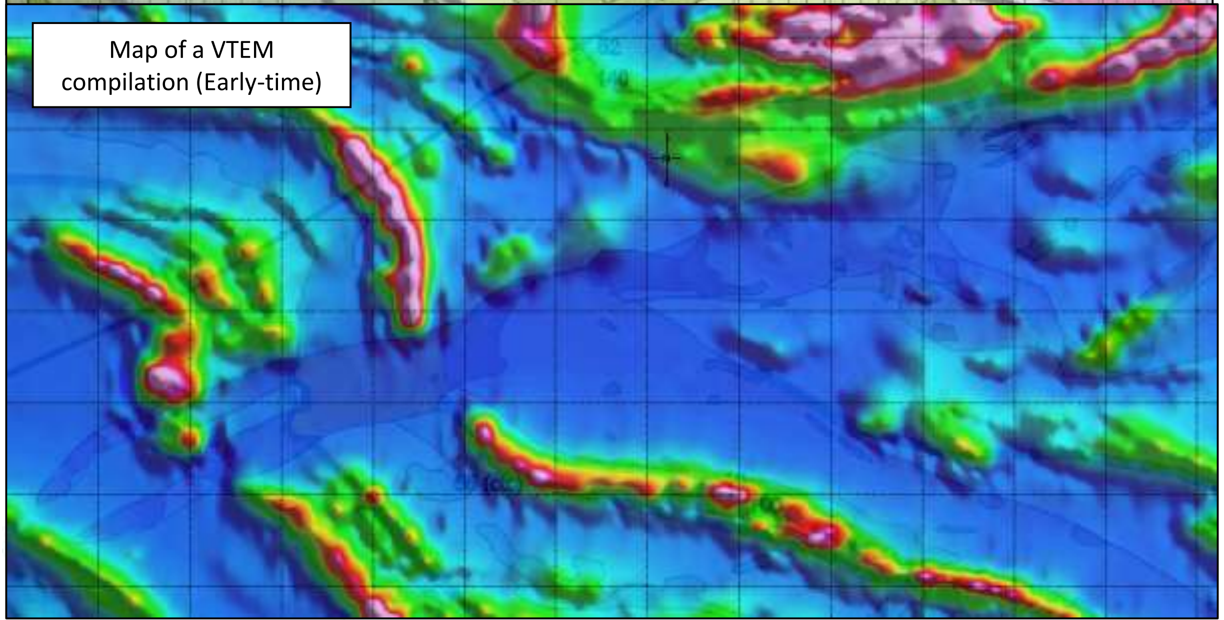


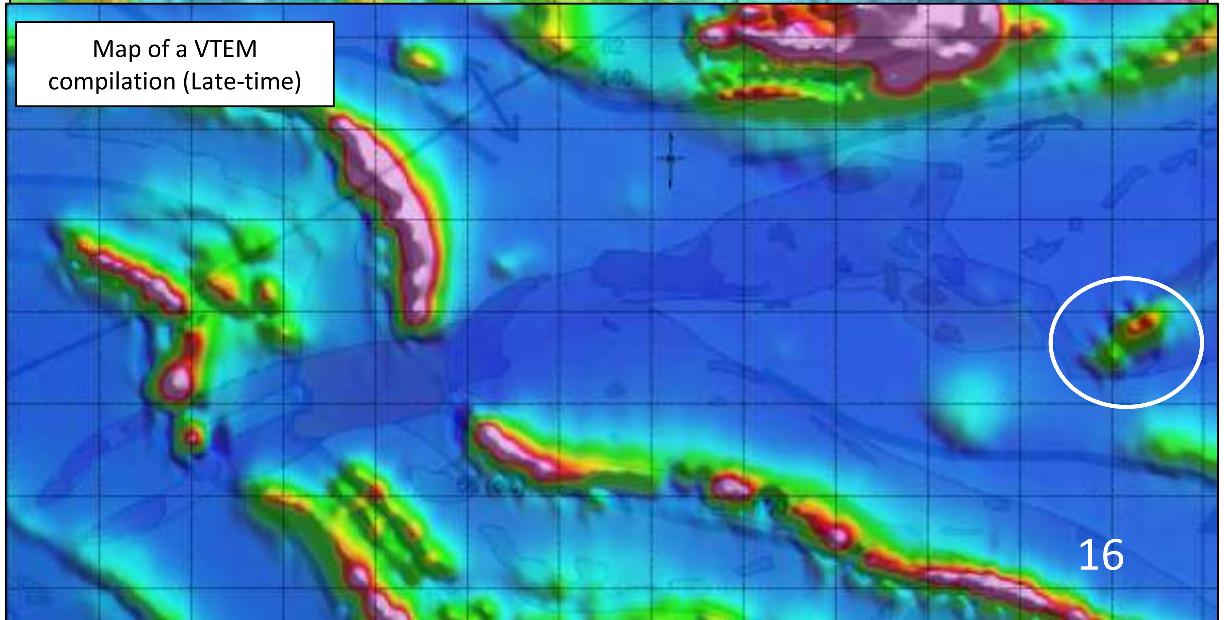
Looking West view of Numerical model

4. Time-Domain Electromagnetics – Easy one #2

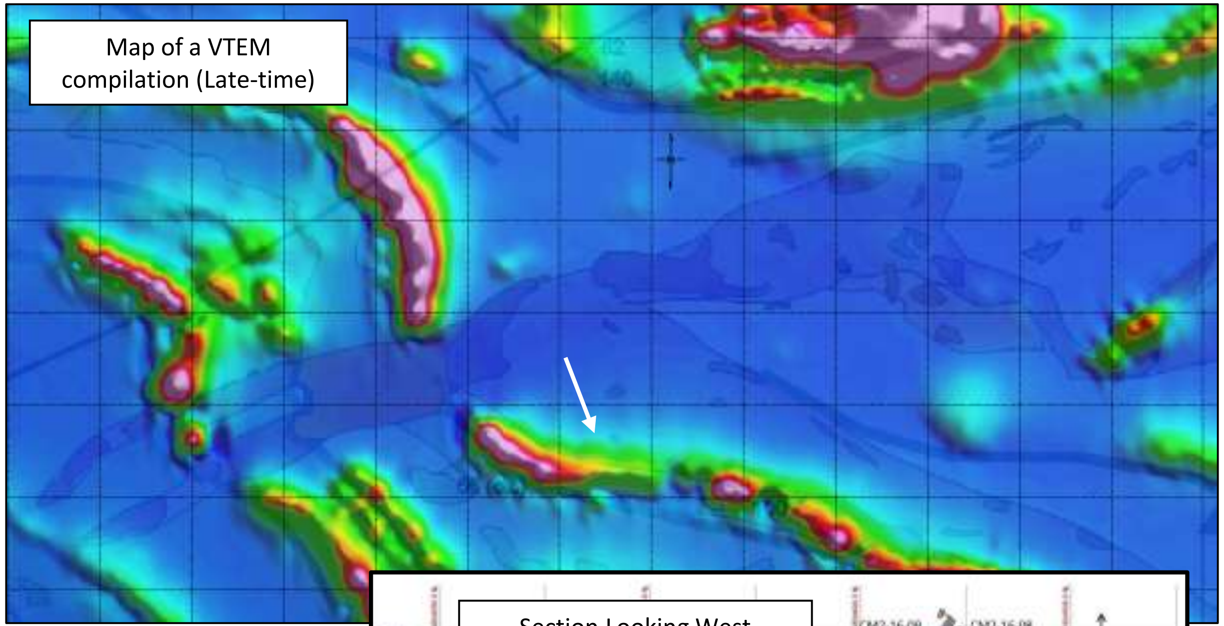


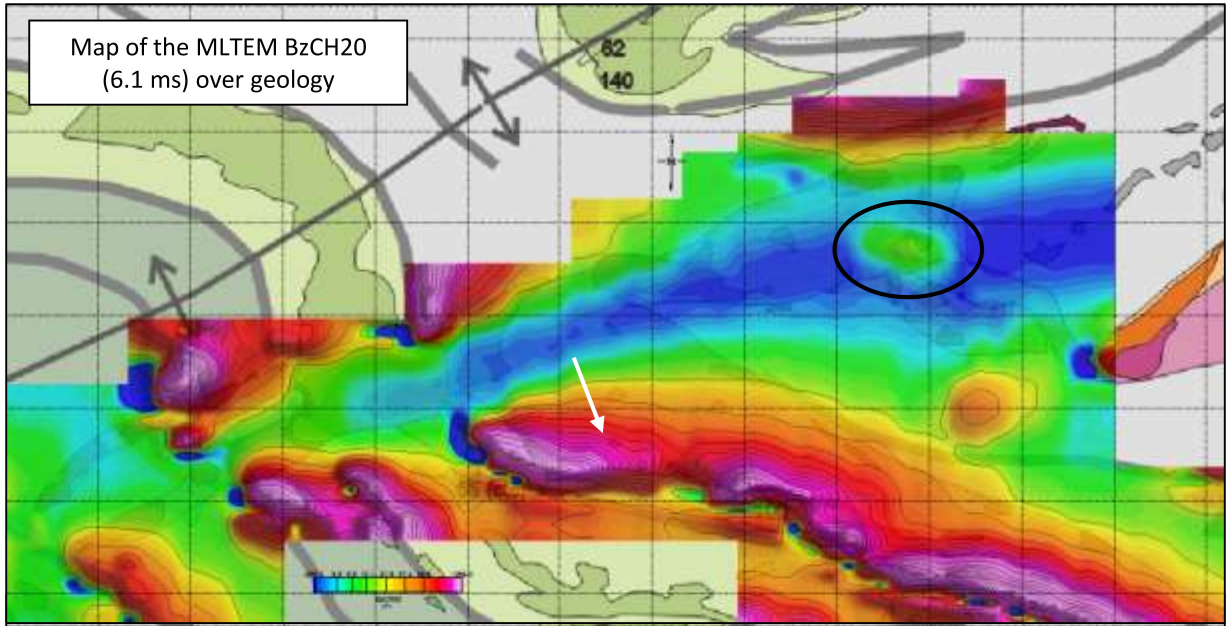


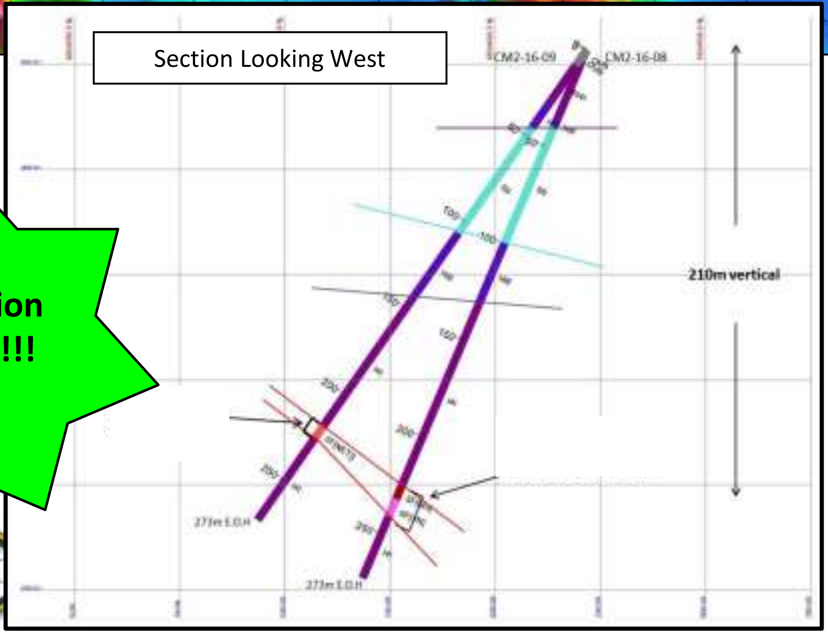




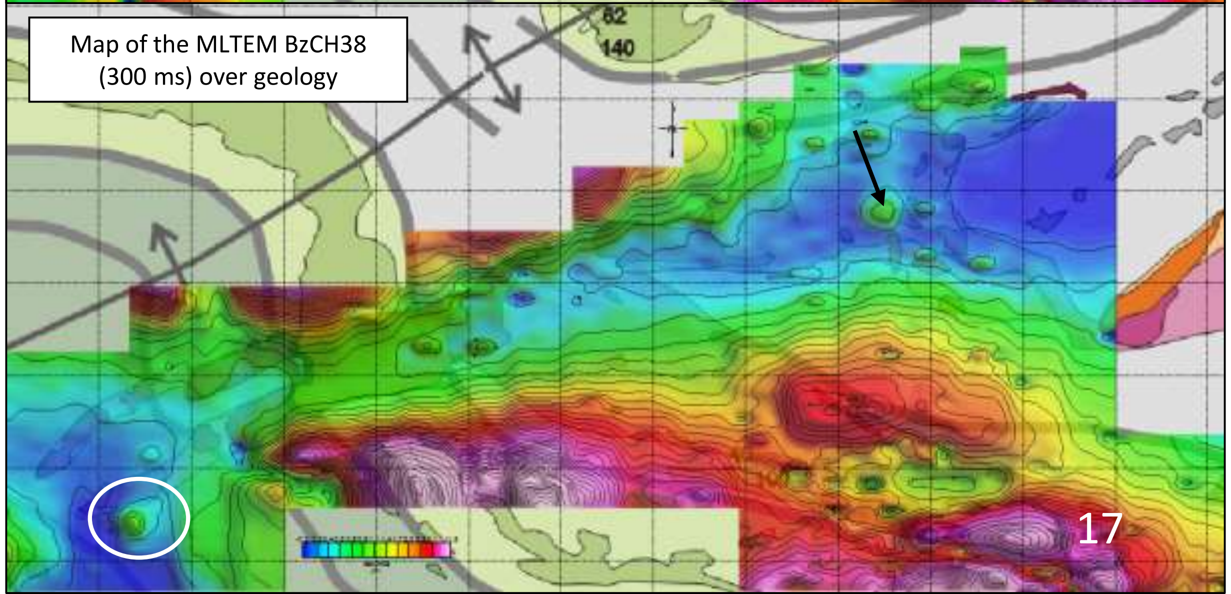
4. Time-Domain Electromagnetics – Easy one #2





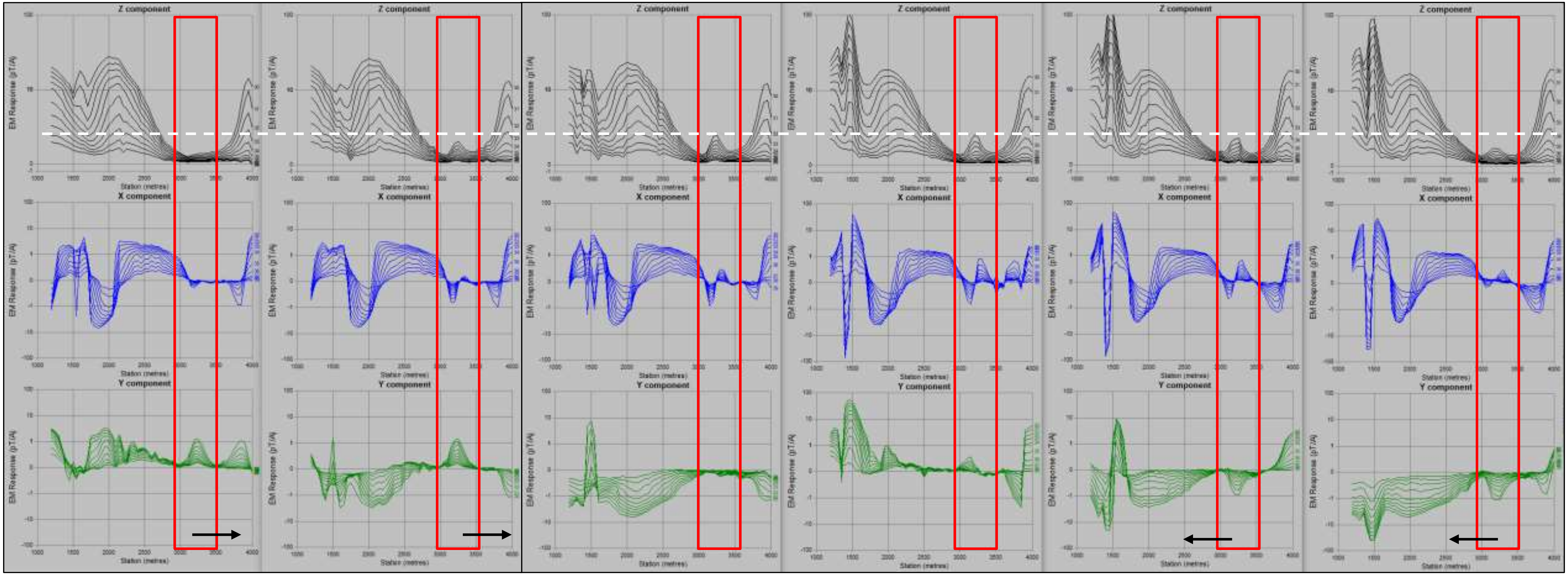


Exploration Success !!!



4. Time-Domain Electromagnetics – Easy one #2

MLTEM profiles (CH30-39)



- Low amplitude EM anomalies (<2pT/A) vs formationals
- Isolated conductor (ore) i.e. fair distance away from formationnals
- Interpretation of conducteur's center with Y component

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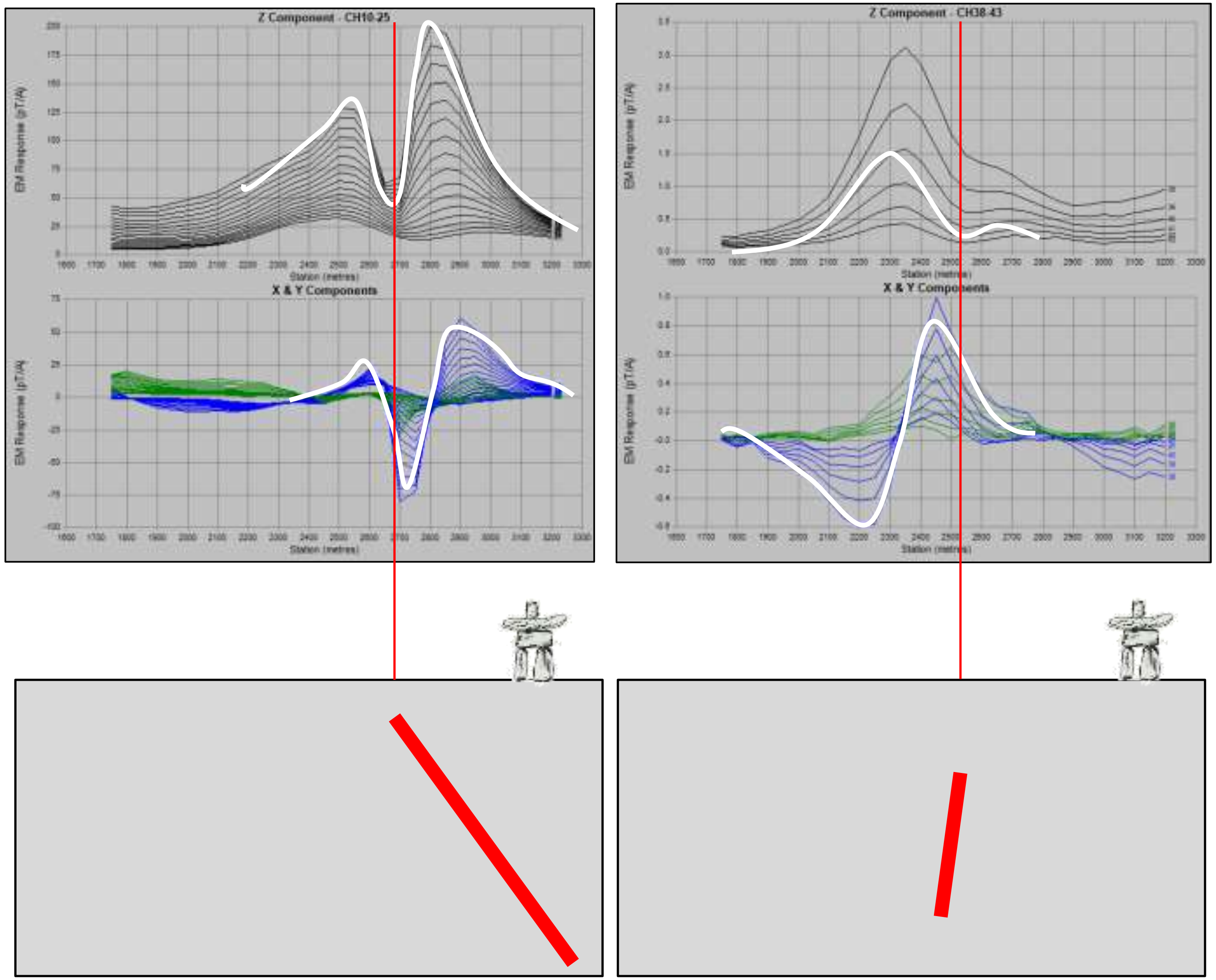
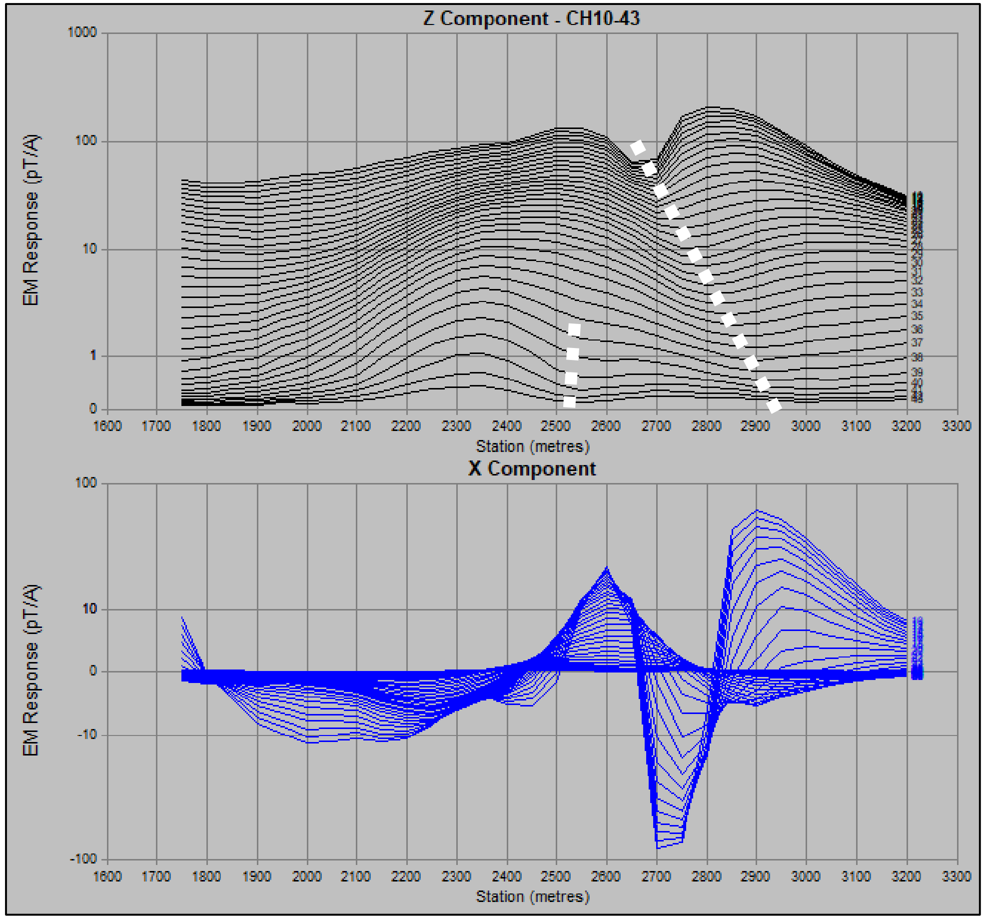
5. Time-Domain Electromagnetics – Stacked anomalies example #1





5. Time-Domain Electromagnetics – Stacked anomalies example #1

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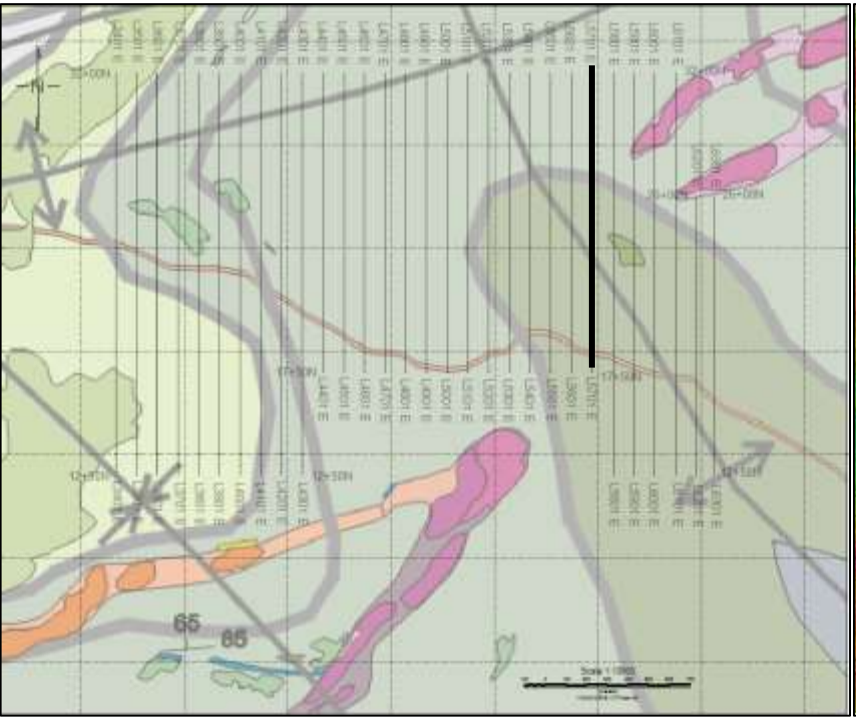
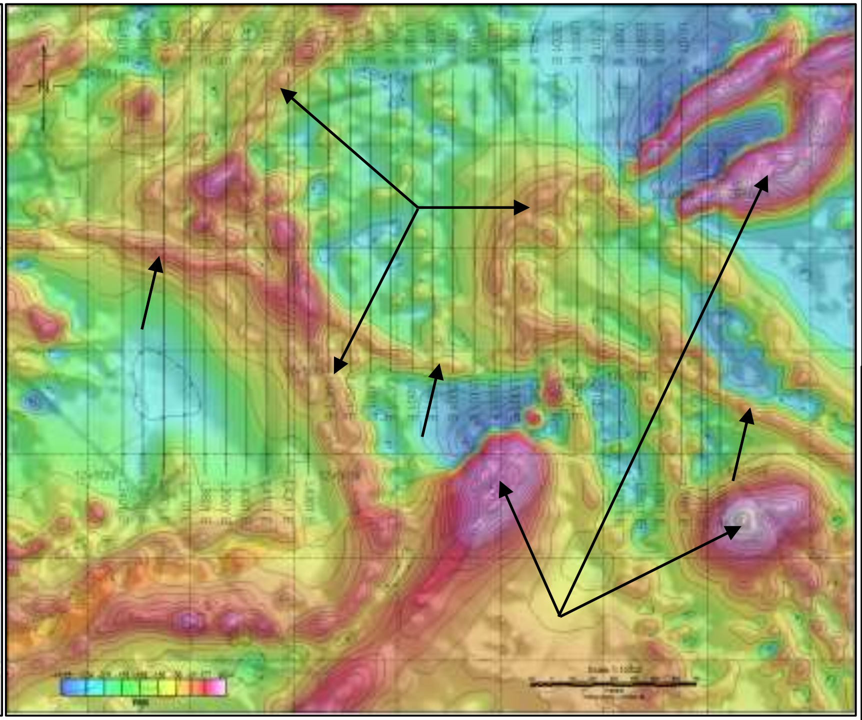
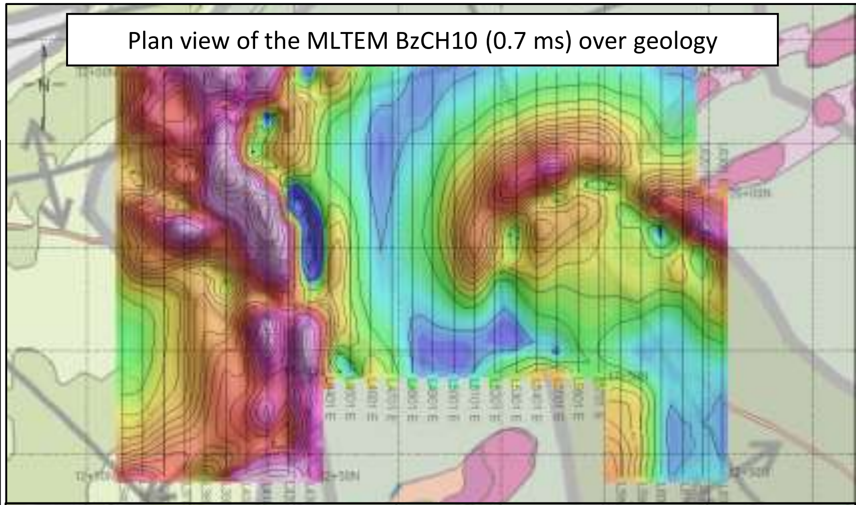
Geological map with MLTEM survey grid

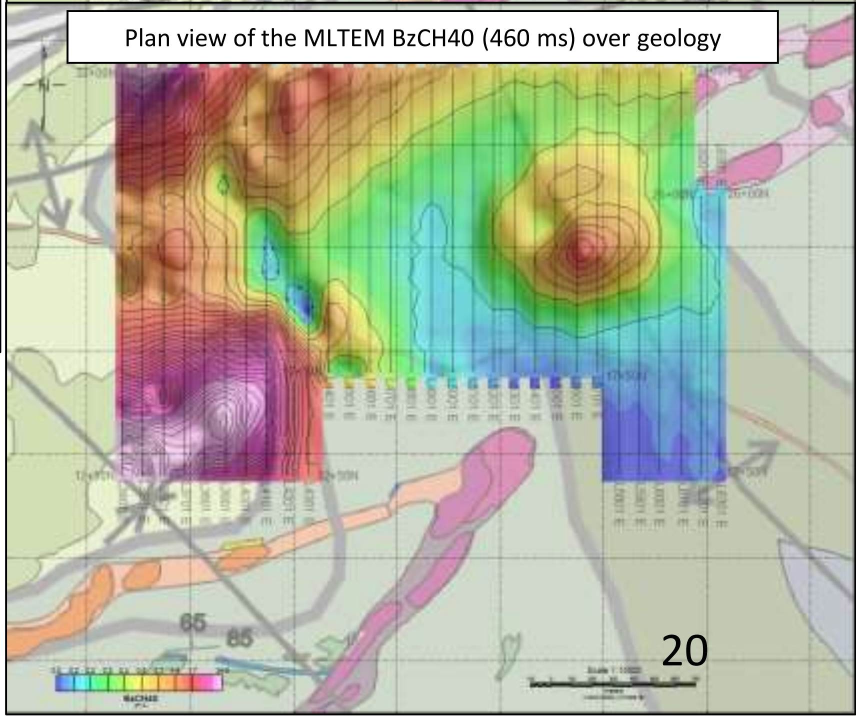


Plan view of the Residual Mag Intensity (RMI) over geology with MLTEM survey grid





Plan view of the MLTEM BzCH10 (0.7 ms) over geology



Plan view of the MLTEM BzCH40 (460 ms) over geology

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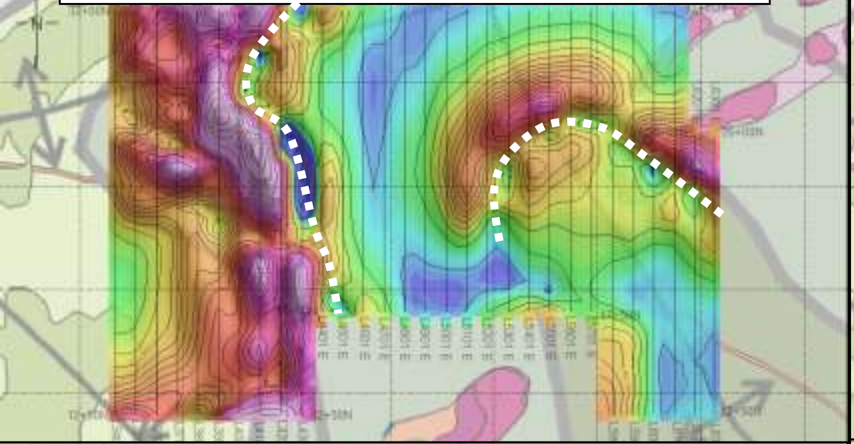
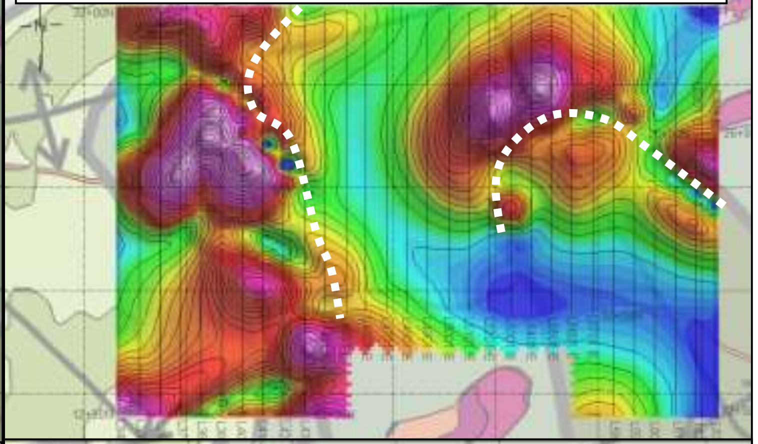
5. Time-Domain Electromagnetics – Stacked anomalies example #1

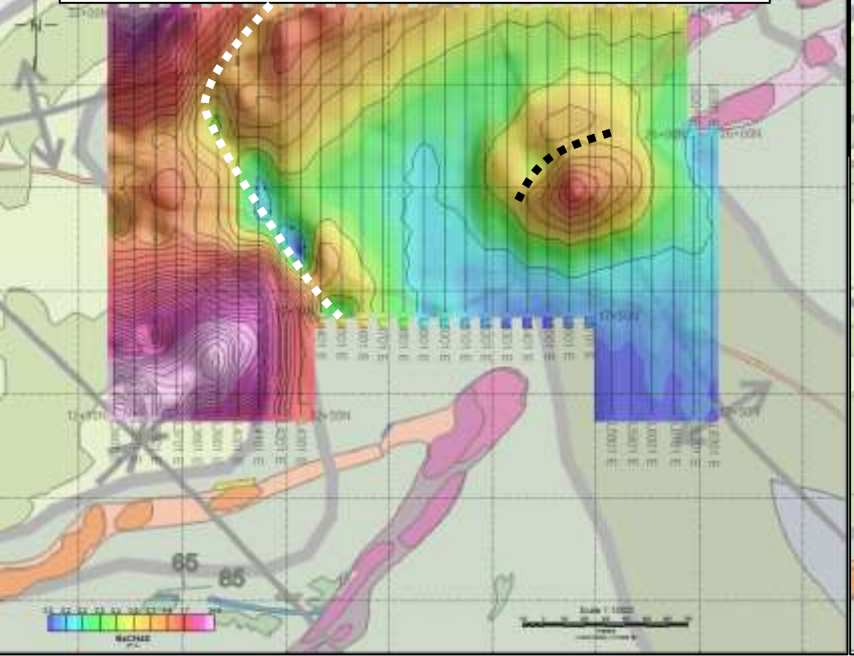
Plan view of the MLTEM BzCH10 (0.7 ms) over geology



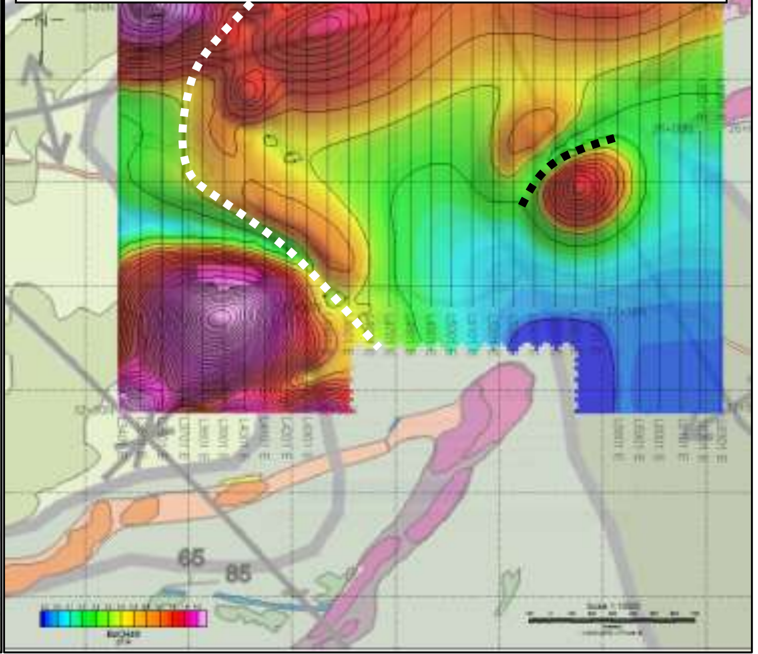
Plan view of the Plate model BzCH10 (0.7 ms) over geology



Plan view of the MLTEM BzCH40 (460 ms) over geology



Plan view of the Plate model BzCH40 (460 ms) over geology



Plan view of the Plate model with constrained MAG inversion iso-contour (0.03 SI)

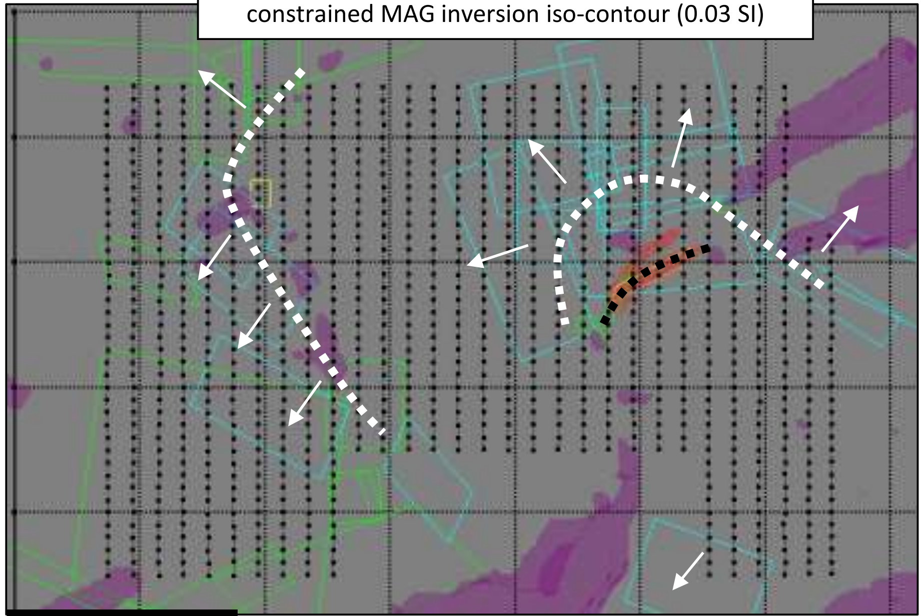
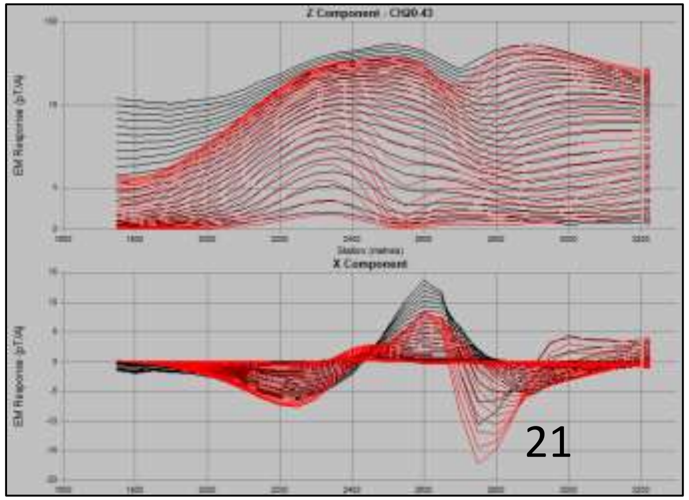


Plate < 2000S
Plate < 10 000S
Plate ≥ 10 000S
MAG INVc 0.03 SI



5. Time-Domain Electromagnetics - Stacked anomalies example #2

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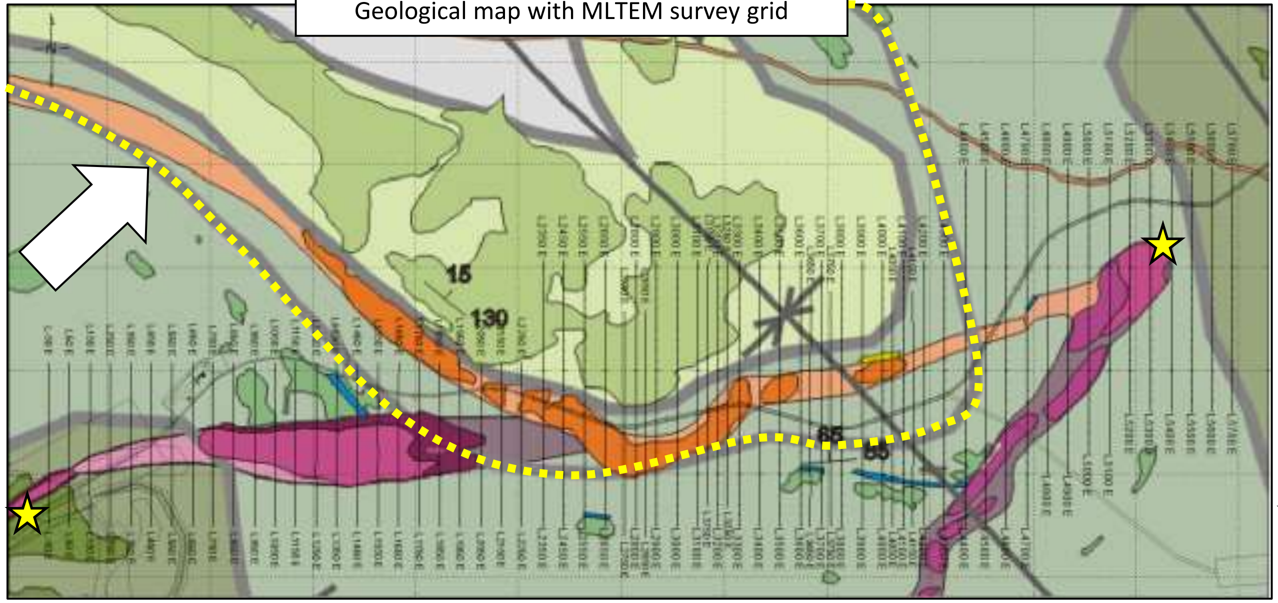
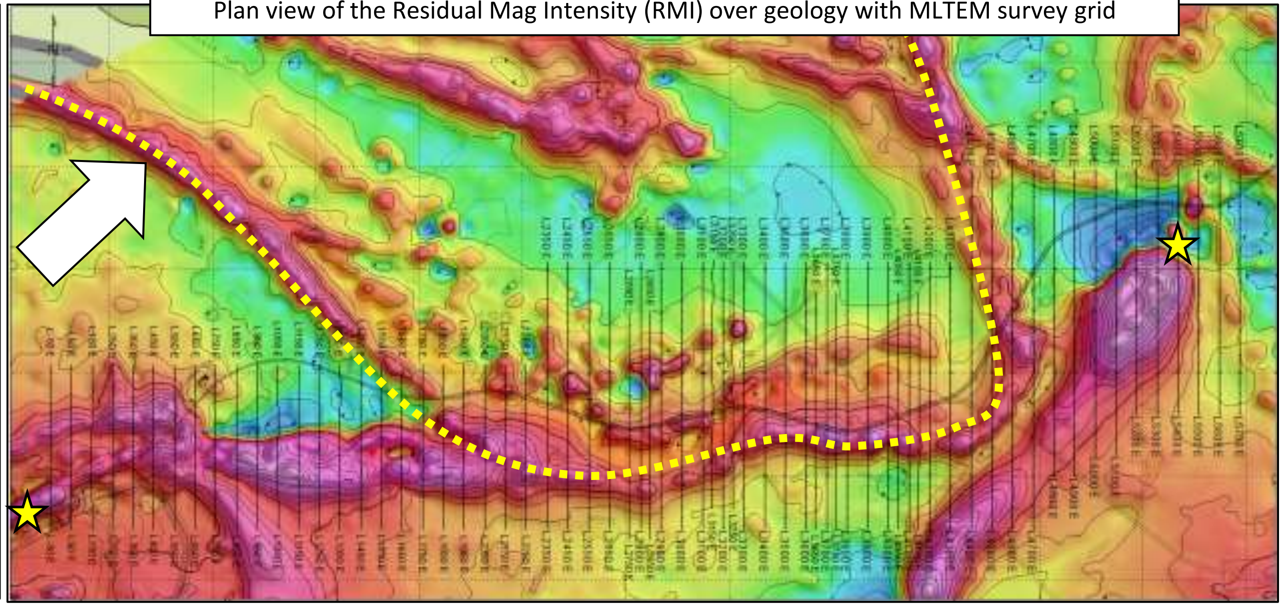


Geological map with MLTEM survey grid



Plan view of the Residual Mag Intensity (RMI) over geology with MLTEM survey grid

Argilites with PO-rich veins and GP

	Magnetic Susceptibility over Core (Nunavik Nickel)	
	Mean (SI)	Range (SI)
Peridotite (I4I)	51×10^{-3}	$[7 – 155] \times 10^{-3}$
Pyroxenite (I4B)	2.1×10^{-3}	$[0.8 – 2.4] \times 10^{-3}$
Gabbro (I3A)	1.2×10^{-3}	$[0.6 – 1.3] \times 10^{-3}$
Sediments (S6)	1.1×10^{-3}	$[0.4 – 2] \times 10^{-3}$
Gp-PO-rich Sediments (S6)	5.7×10^{-3}	$[1.6 – 15] \times 10^{-3}$
Basalte (V3)	2.3×10^{-3}	$[1.2 – 2.6] \times 10^{-3}$

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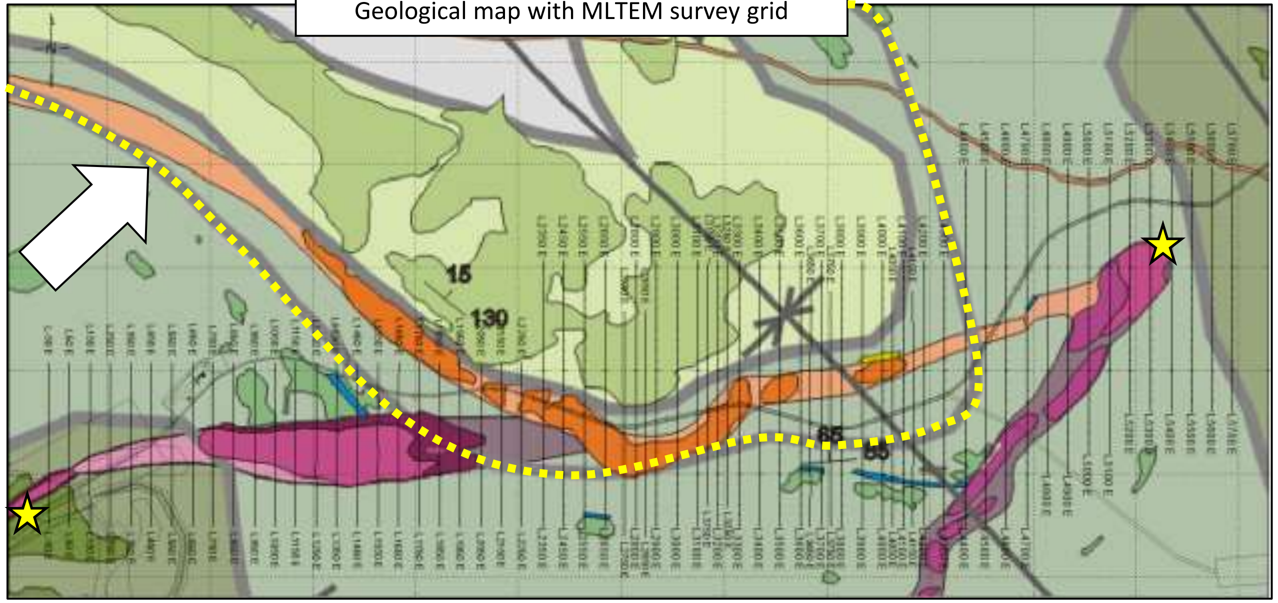
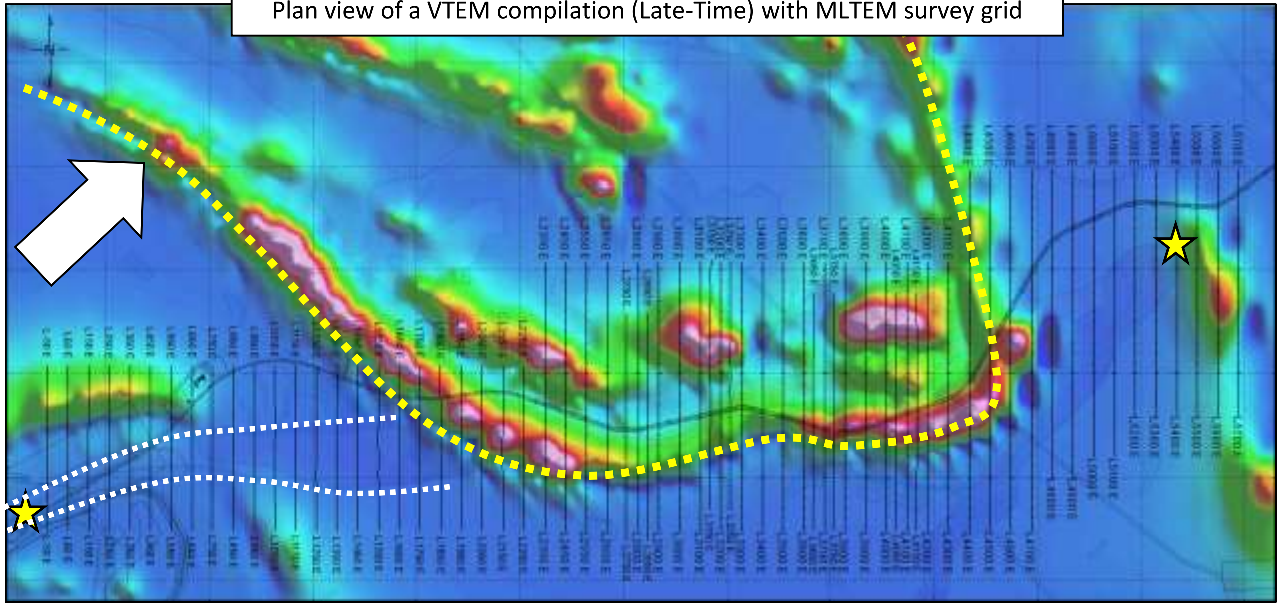
5. Time-Domain Electromagnetics - Stacked anomalies example #2

Geological map with MLTEM survey grid

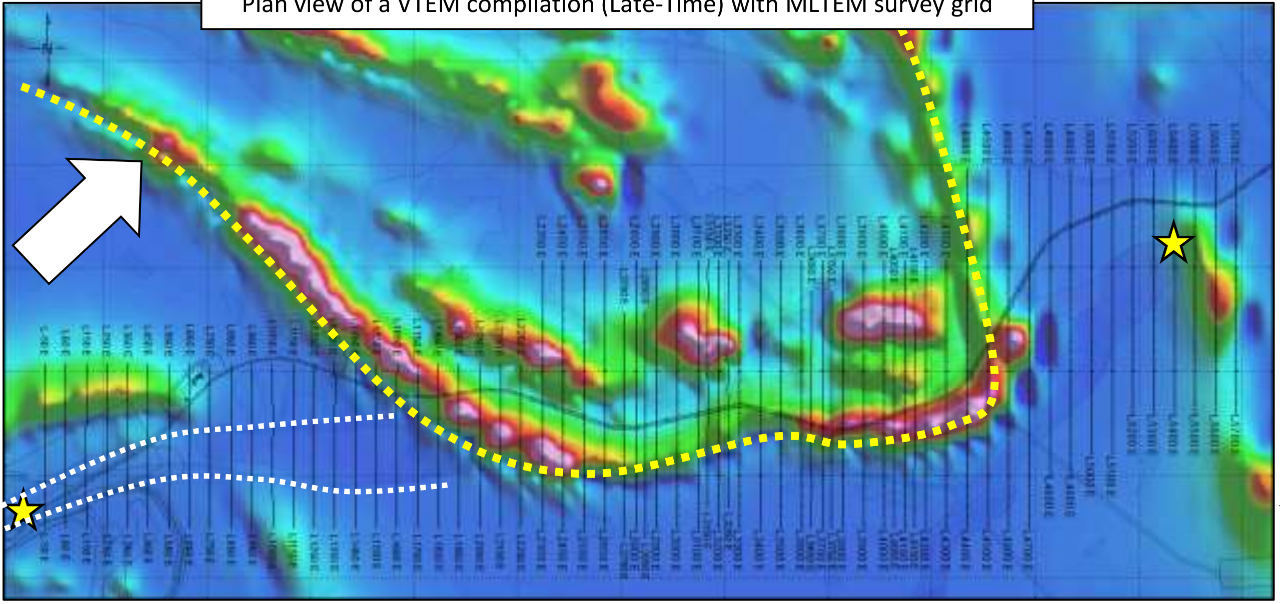


Plan view of a VTEM compilation (Late-Time) with MLTEM survey grid

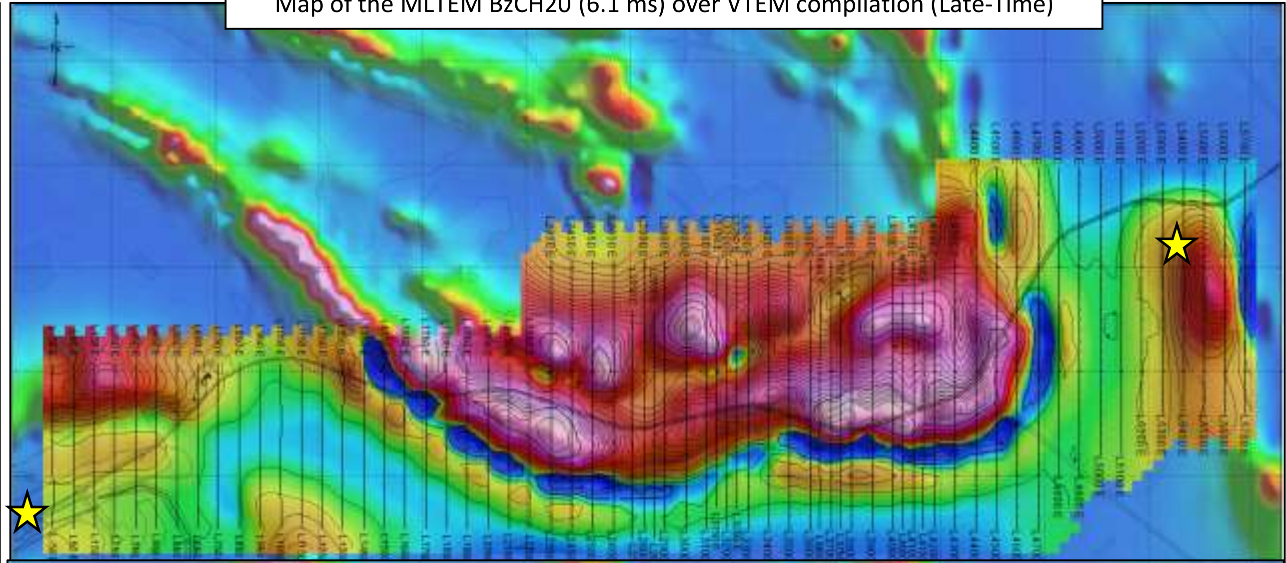


5. Time-Domain Electromagnetics - Stacked anomalies example #2

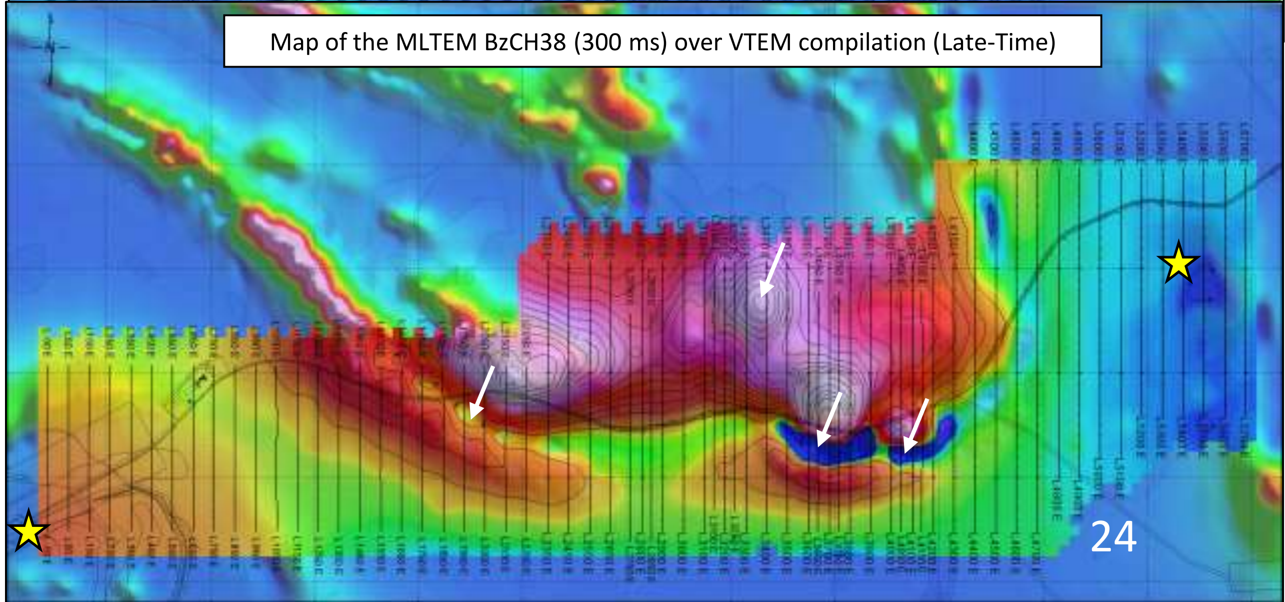
Plan view of a VTEM compilation (Late-Time) with MLTEM survey grid

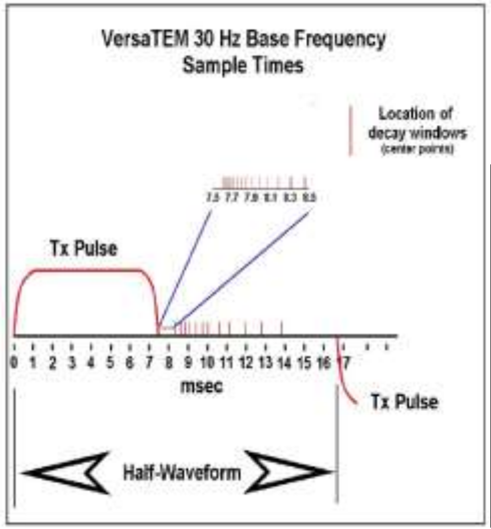


Map of the MLTEM BzCH20 (6.1 ms) over VTEM compilation (Late-Time)

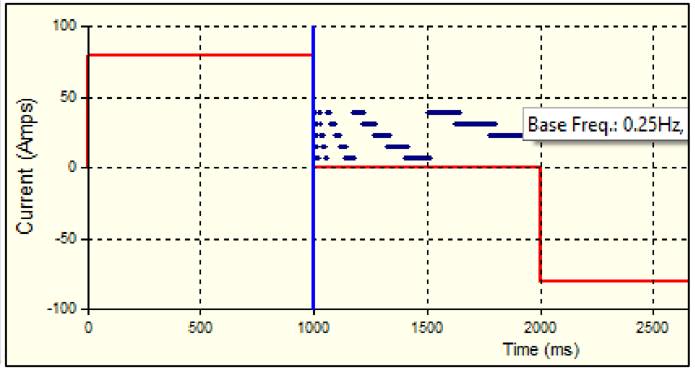


Map of the MLTEM BzCH38 (300 ms) over VTEM compilation (Late-Time)



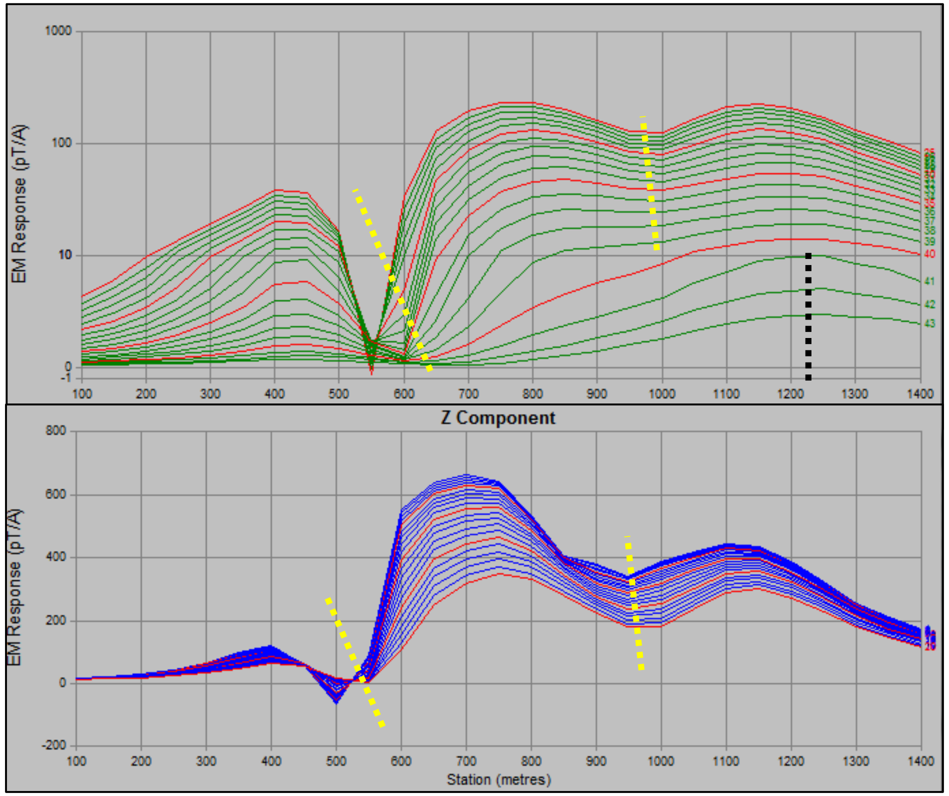


Waveform comparison between VTEM at 30Hz (2007) and MLTEM at 0.25Hz

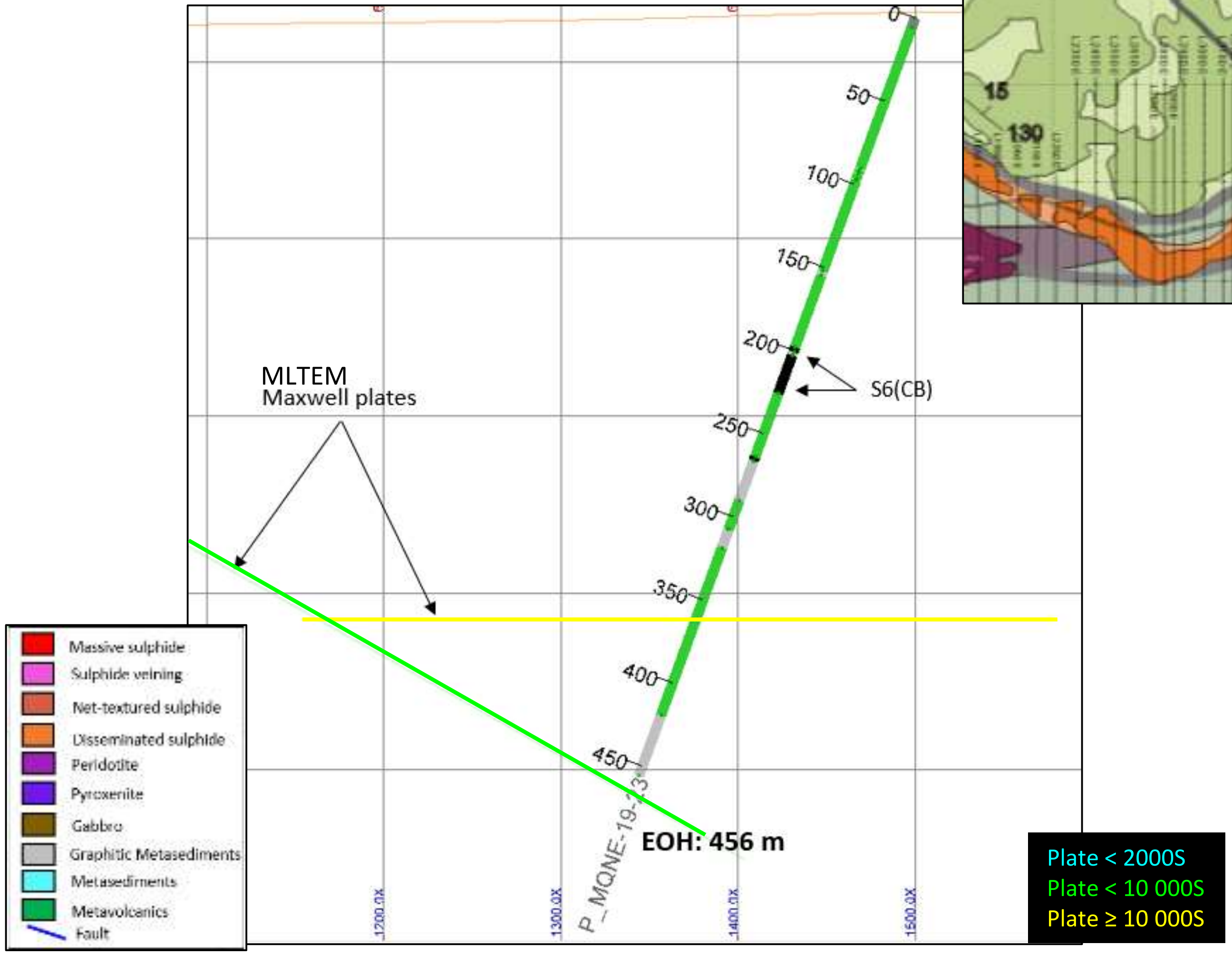


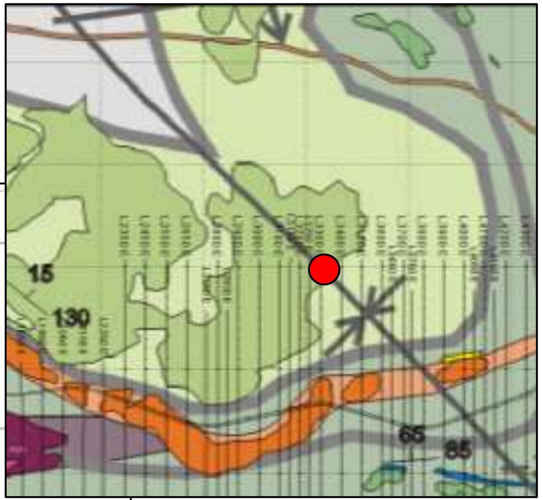
5. Time-Domain Electromagnetics - Stacked anomalies example #2

(Top) MLTEM Profiles of BzCH25-43 (Lin-Log scale) and (Bottom) MLTEM Profiles of BzCH1-20 (Lin scale – 30Hz equivalent)



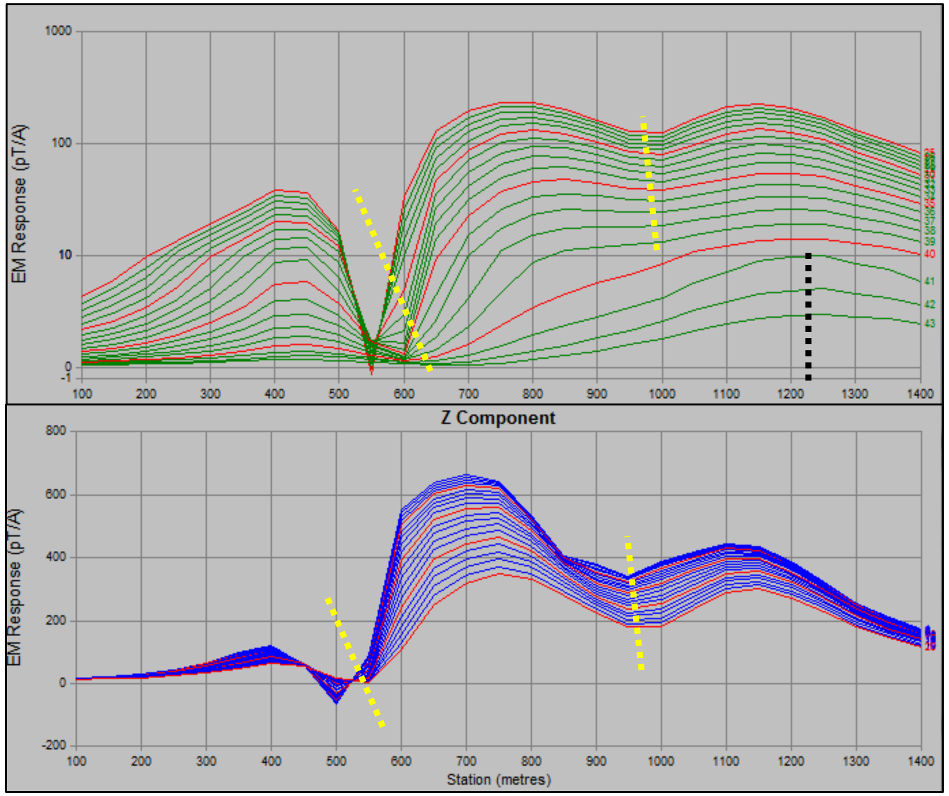
Section view Looking West



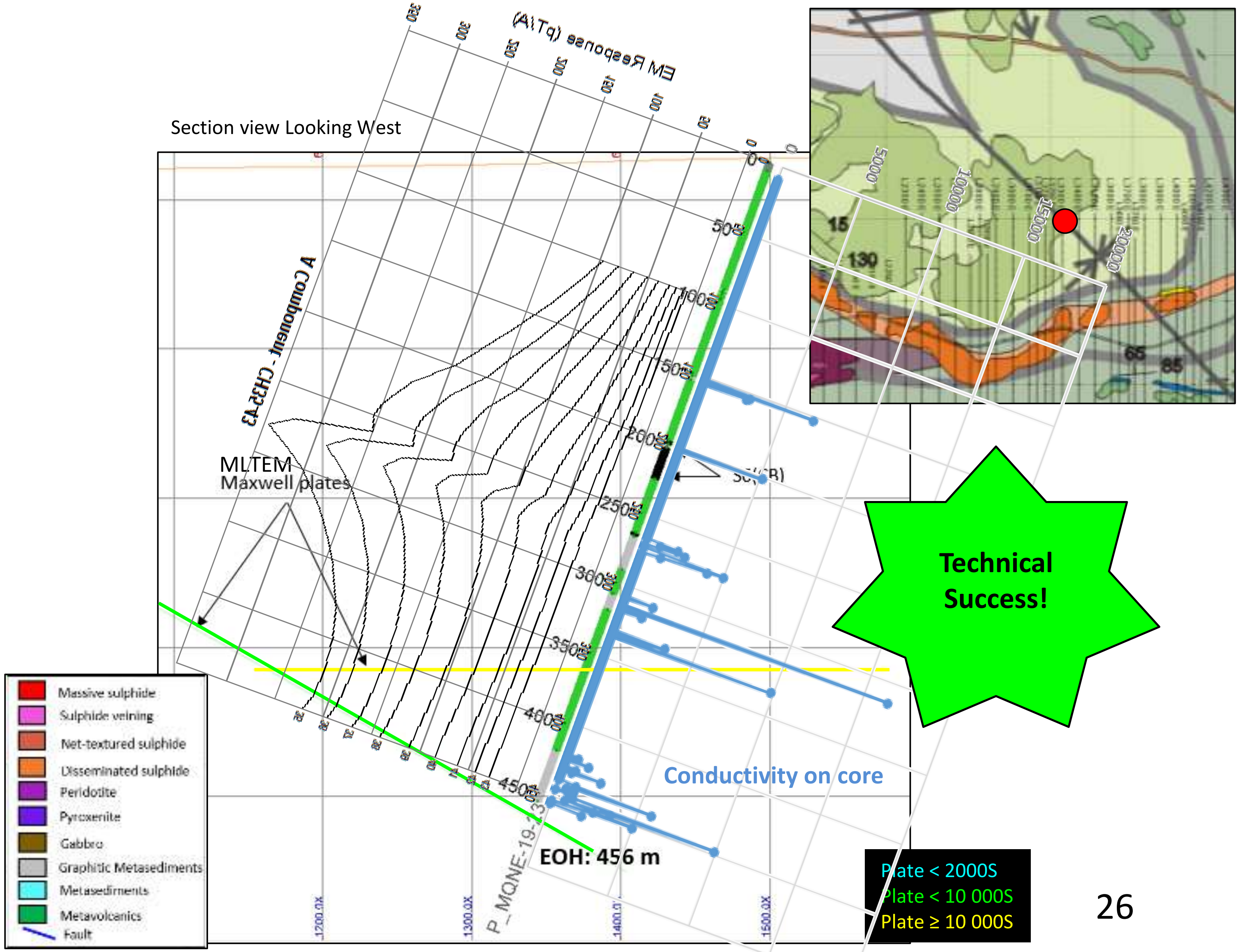


5. Time-Domain Electromagnetics - Stacked anomalies example #2

(Top) MLTEM Profiles of BzCH25-43 (Lin-Log scale) and (Bottom) MLTEM Profiles of BzCH1-20 (Lin scale – 30Hz equivalent)



Section view Looking West

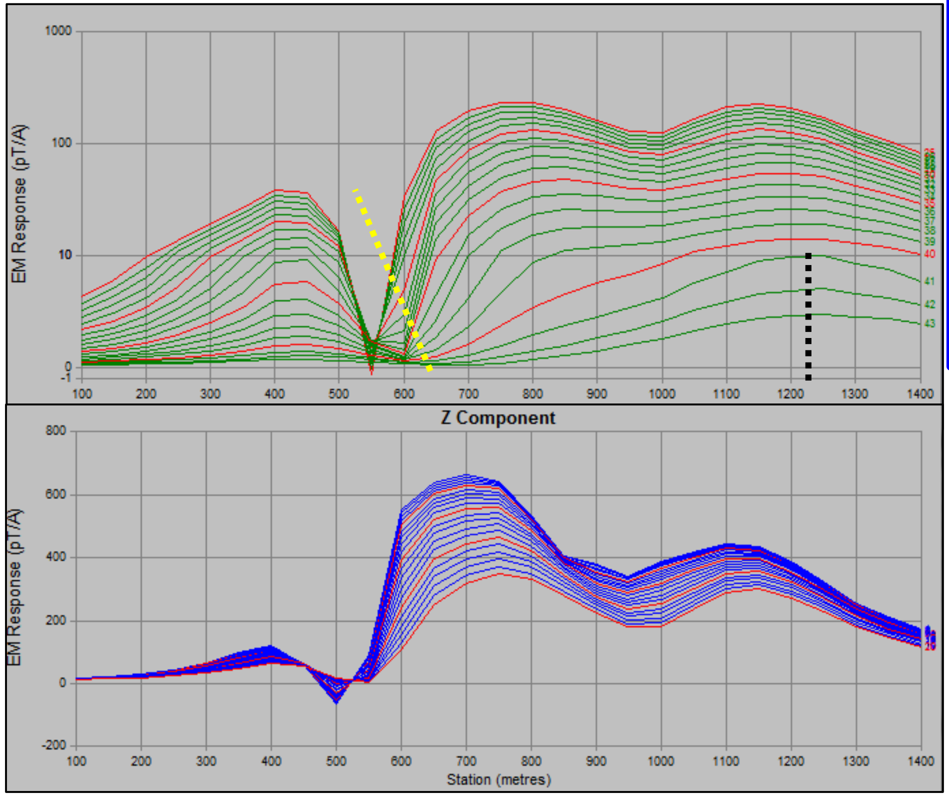


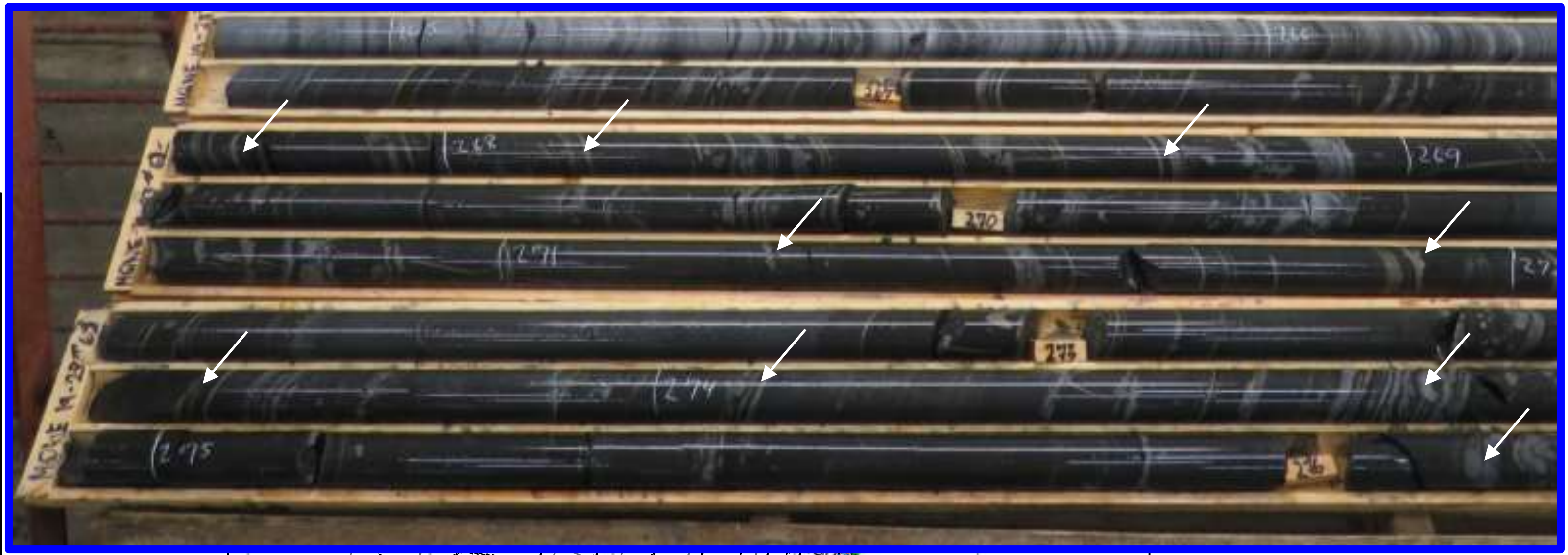
Technical Success!

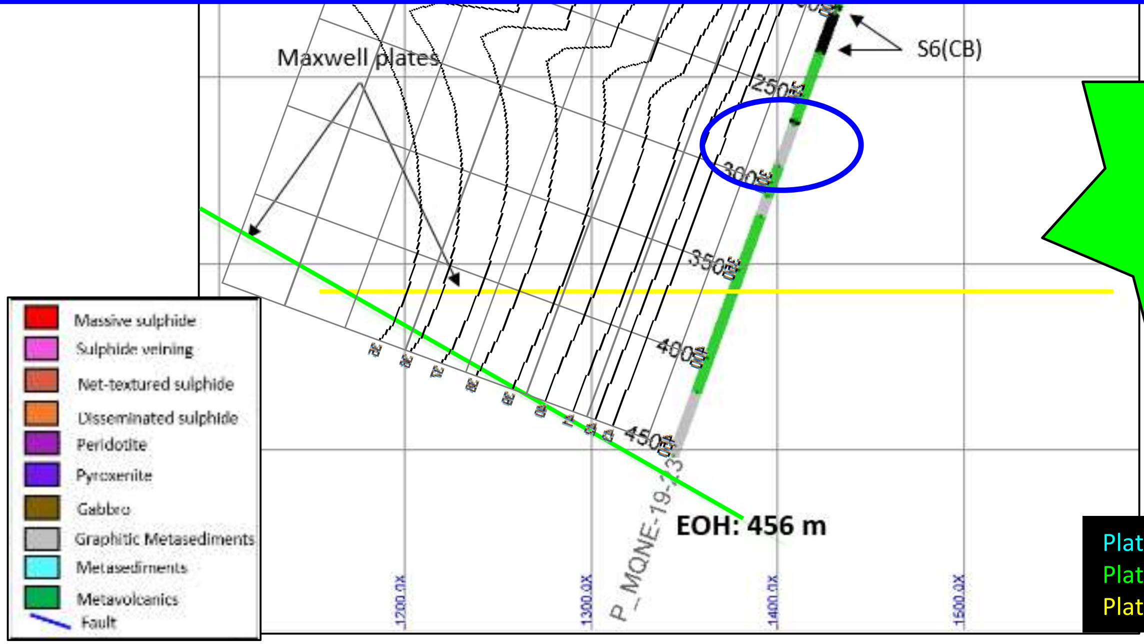
Plate < 2000S
Plate < 10 000S
Plate ≥ 10 000S

5. Time-Domain Electromagnetics - Stacked anomalies example #2

(Top) MLTEM Profiles of BzCH25-43 (Lin-Log scale) and (Bottom) MLTEM Profiles of BzCH1-20 (Lin scale – 30Hz pseudo-equivalent)



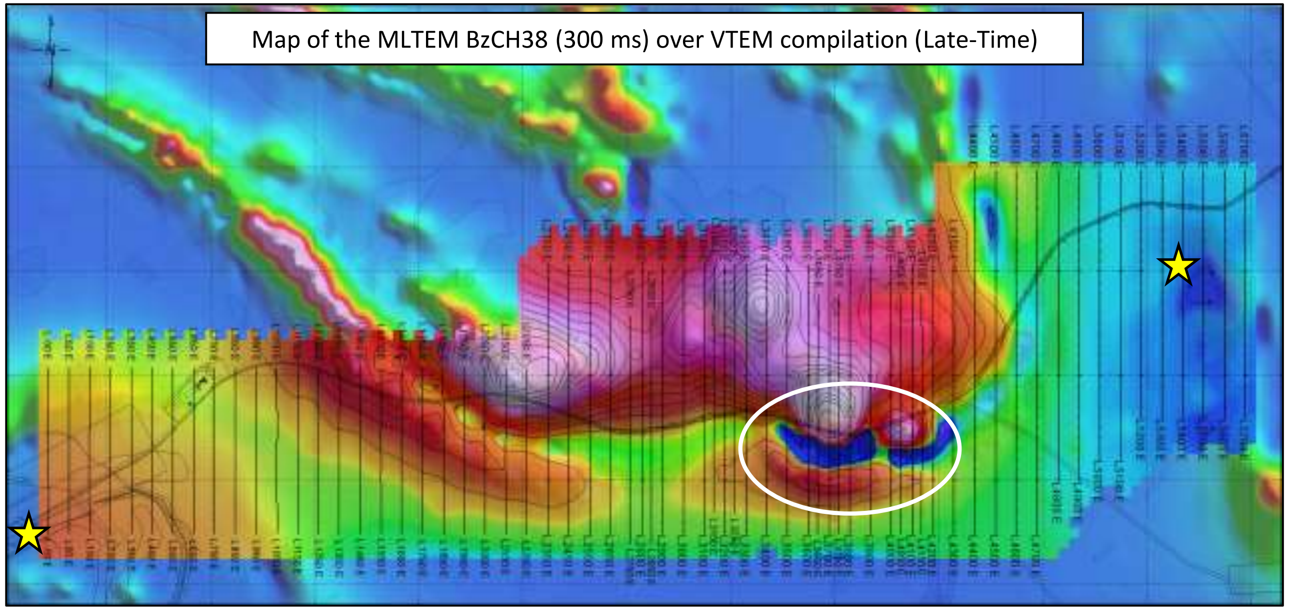


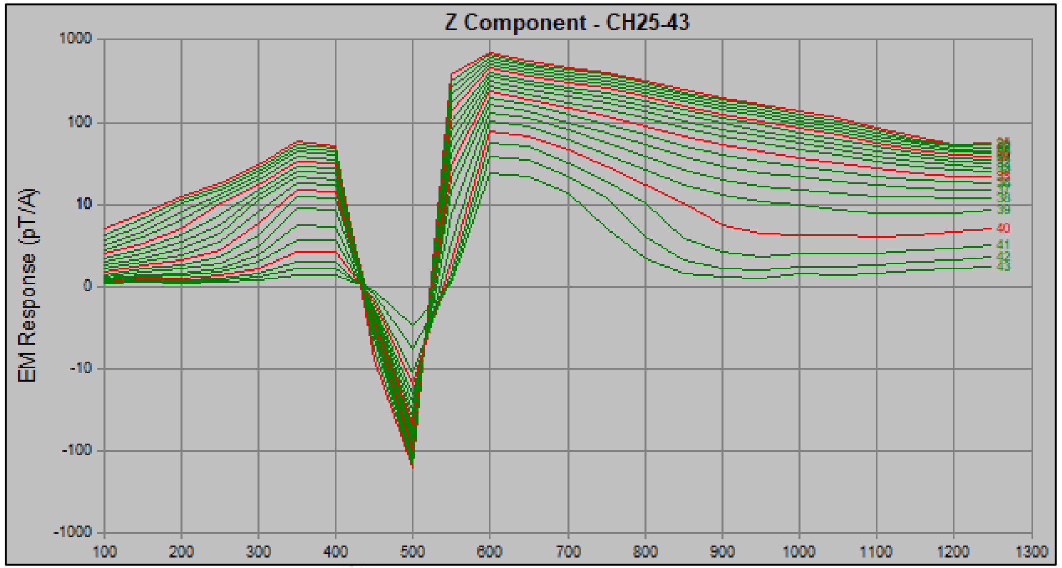


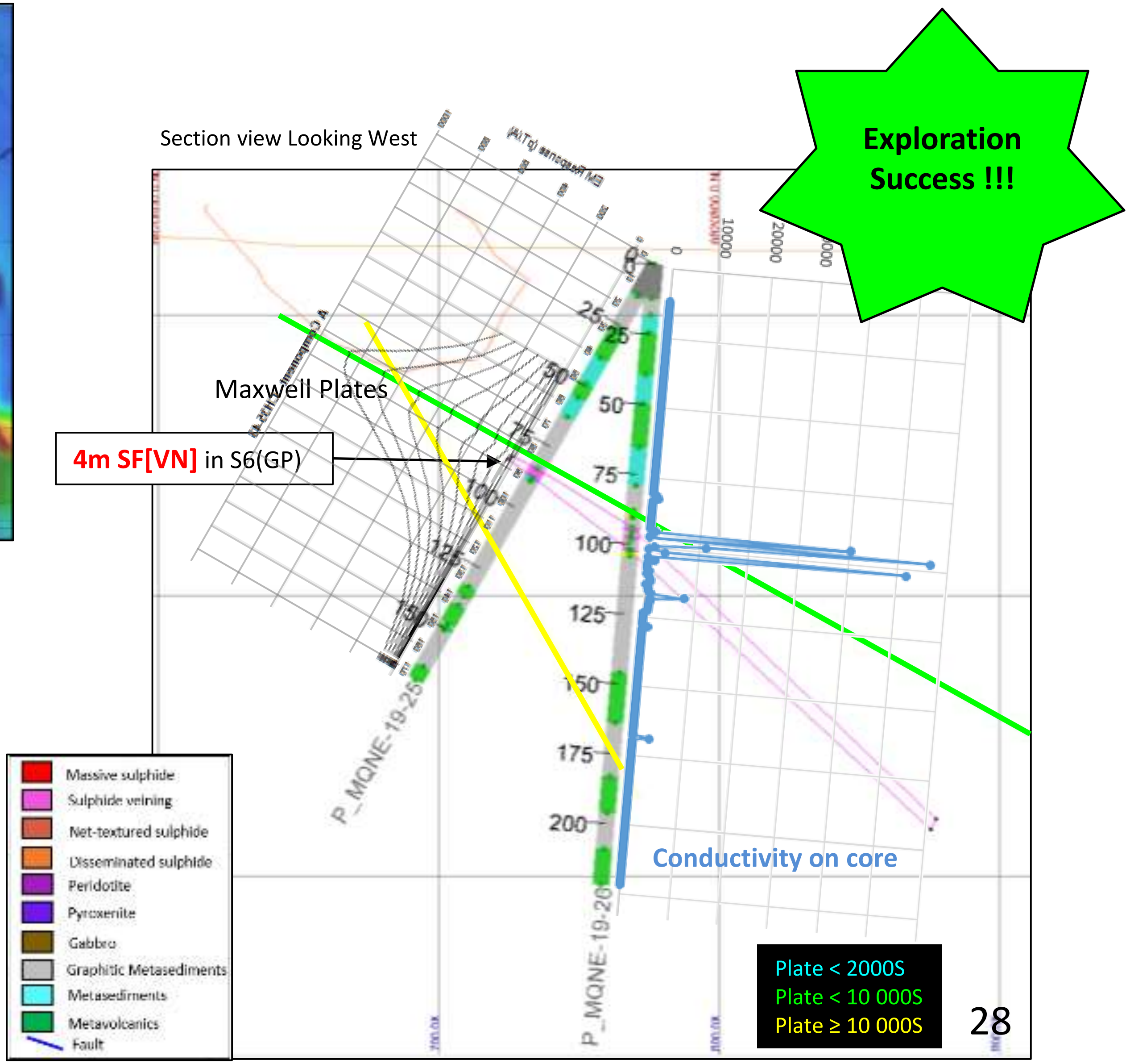
Technical Success!

Plate < 2000S
Plate < 10 000S
Plate ≥ 10 000S

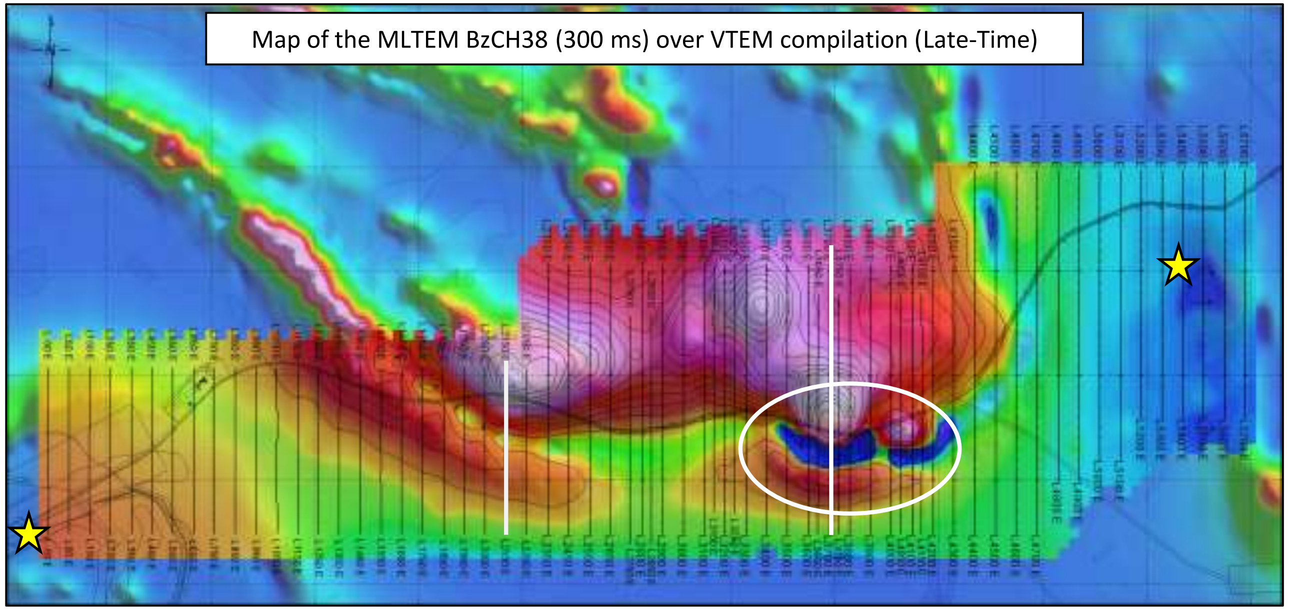
5. Time-Domain Electromagnetics - Stacked anomalies example #2

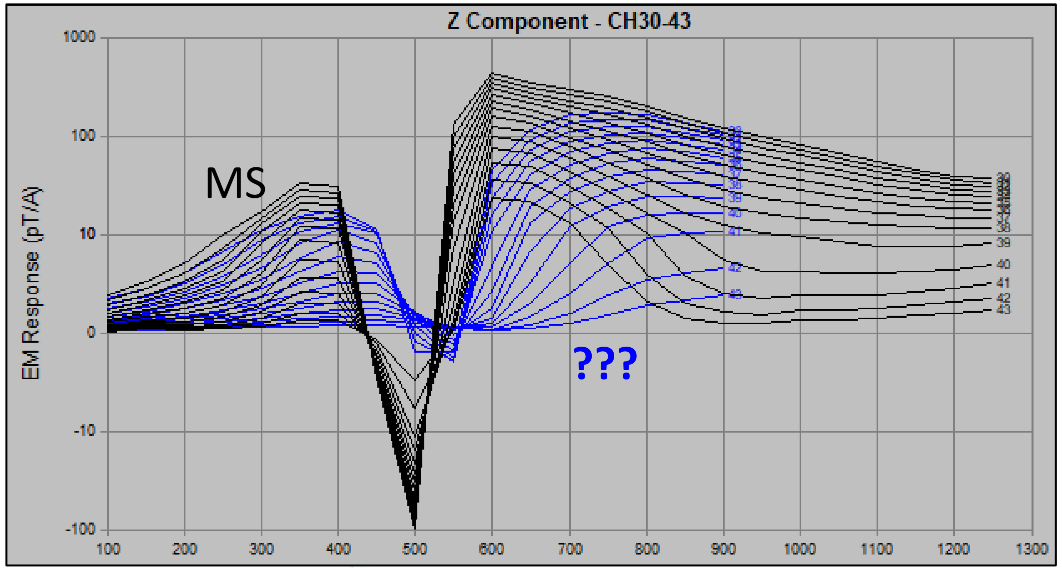


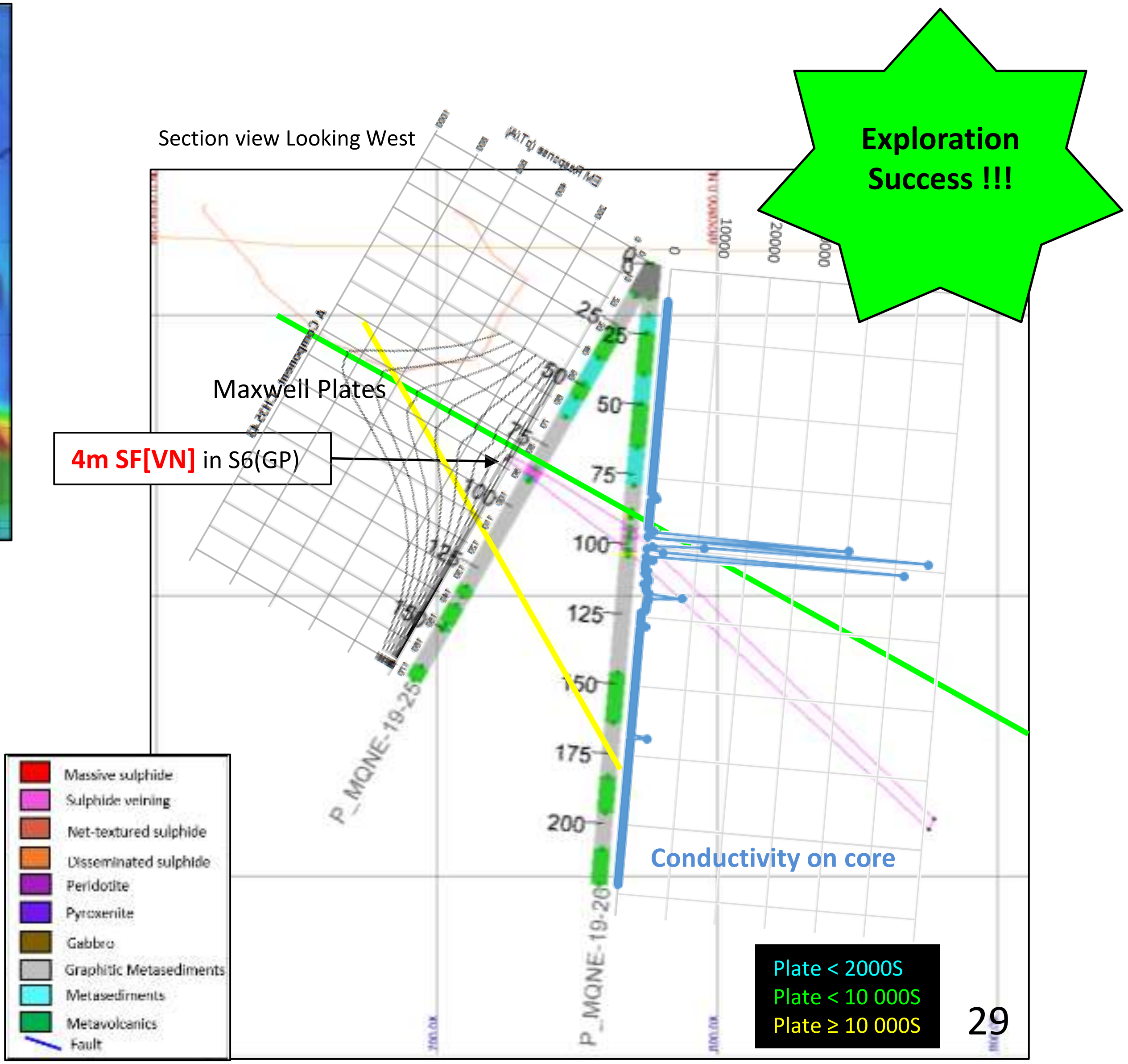




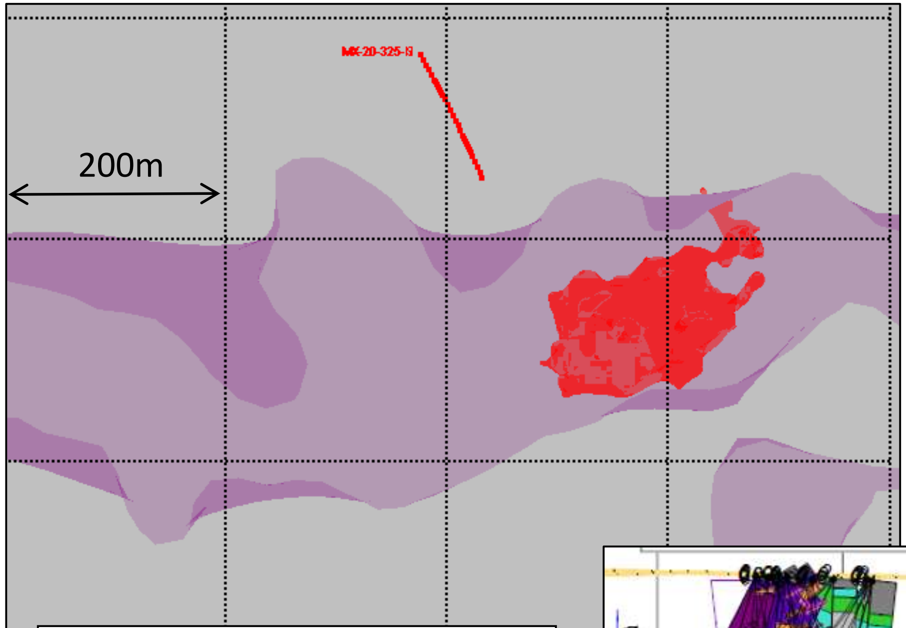
5. Time-Domain Electromagnetics - Stacked anomalies example #2





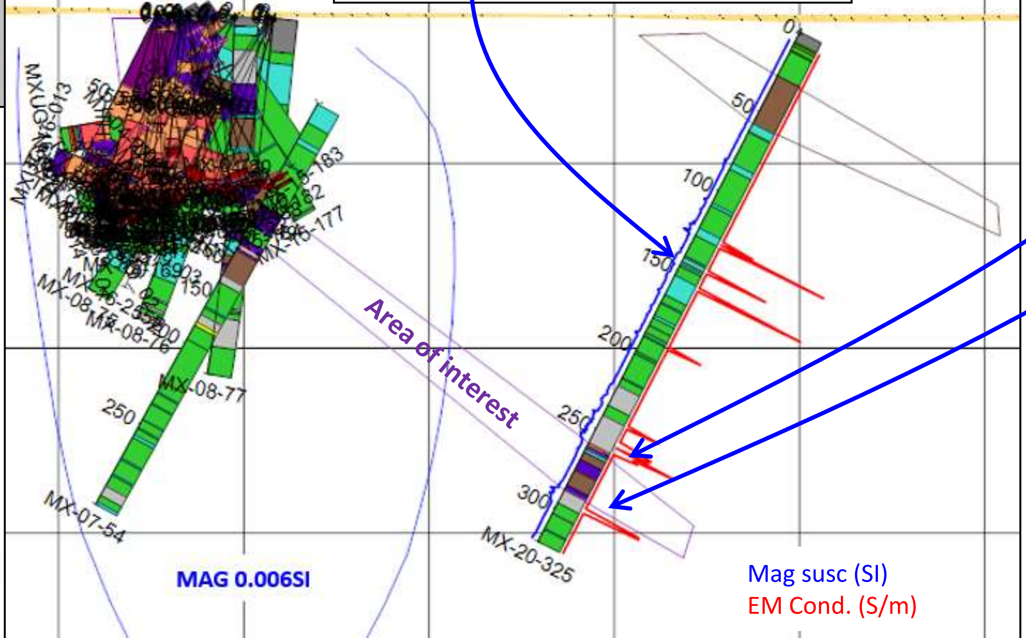


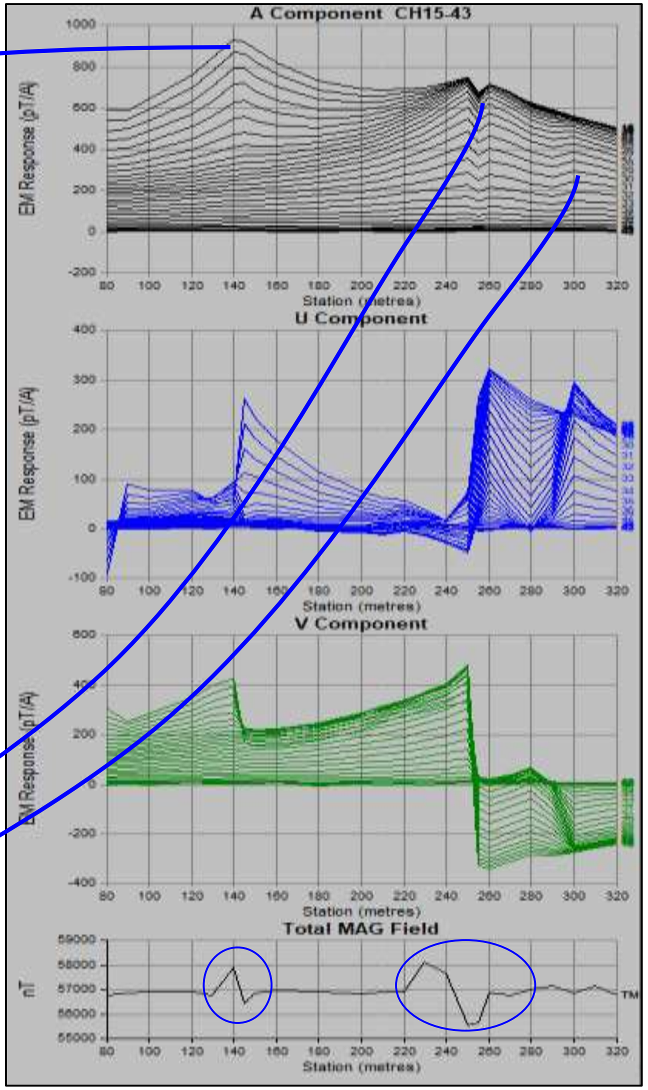
5b. Time-Domain Electromagnetics – Sandwich-style challenge



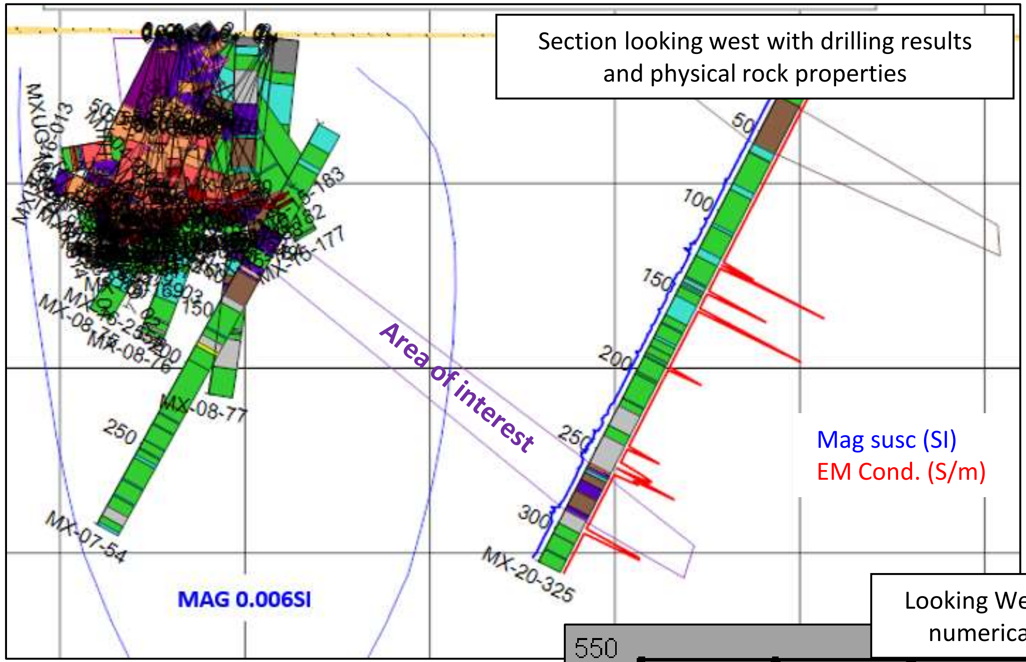
Plan view of a known ore deposit with inferred UM from MAG inv (0.0065 SI)

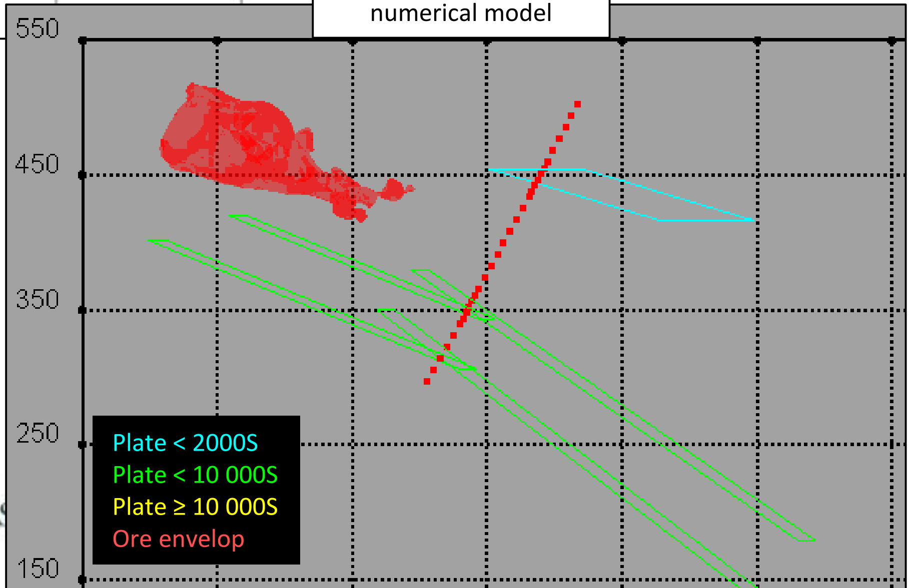
Section looking west with drilling results and physical rock properties

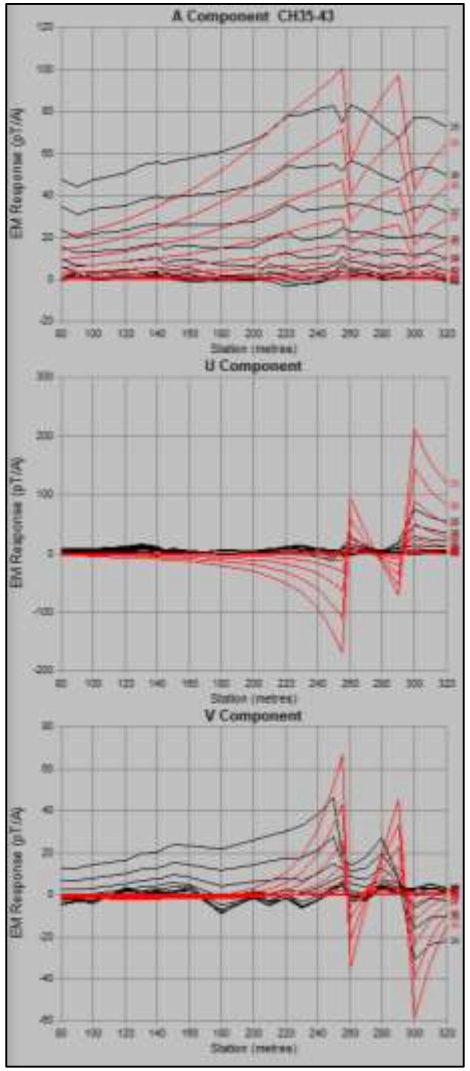




5b. Time-Domain Electromagnetics – Sandwich-style challenge







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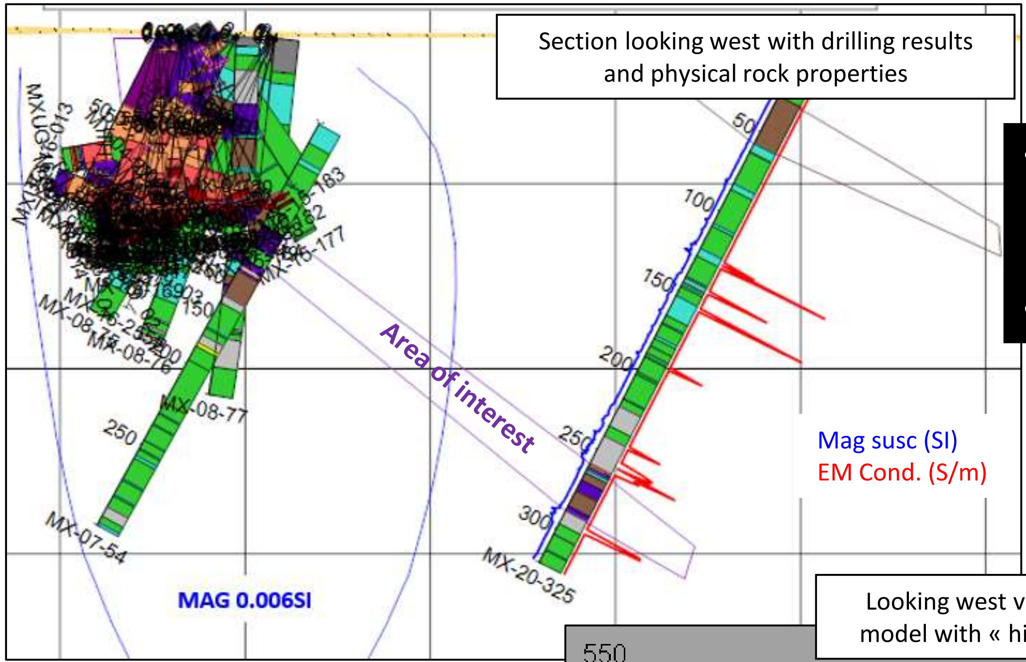
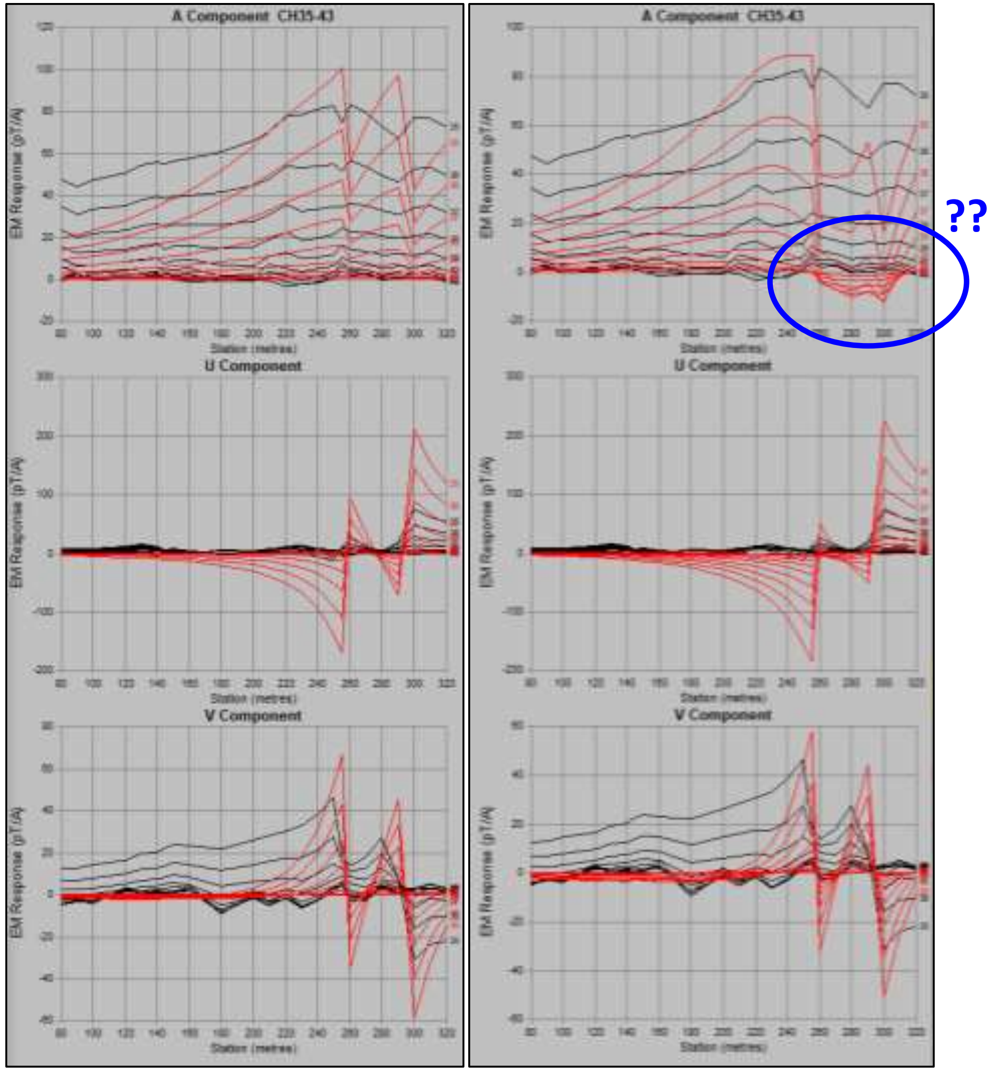
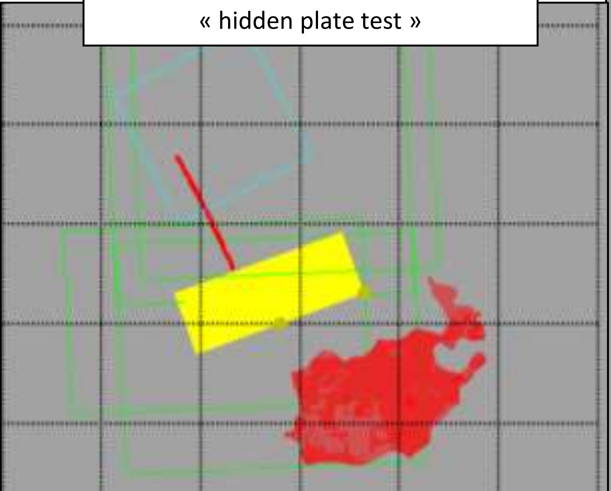
5b. Time-Domain Electromagnetics – Sandwich-style challenge



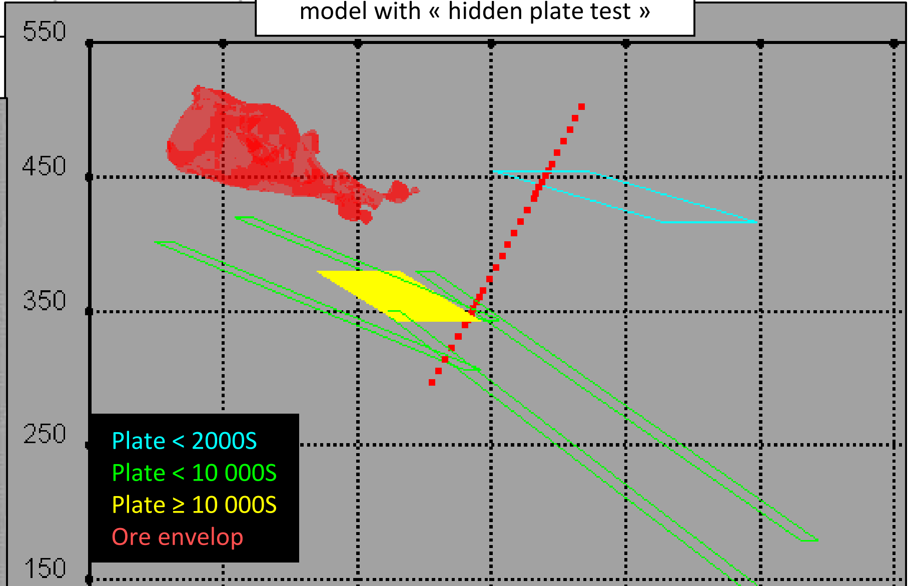
Section looking west with drilling results and physical rock properties

- Numerical modelling used to estimate BHEM investigation radius;
- Hidden plates scenarios



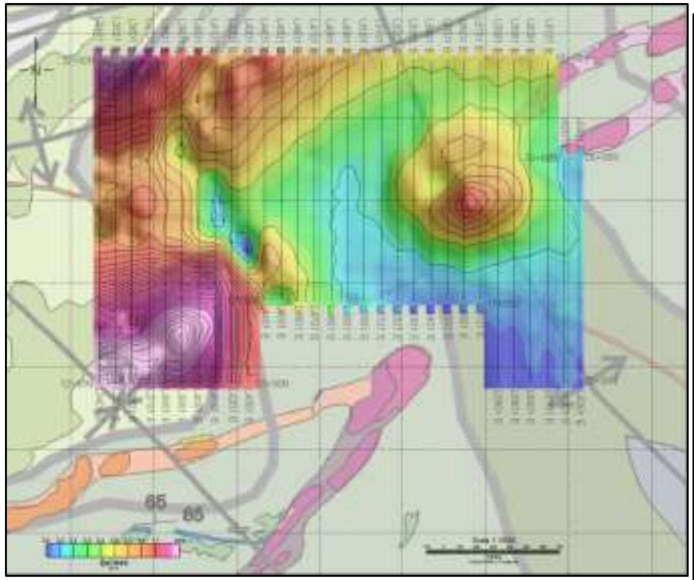


Plan view of numerical model with « hidden plate test »

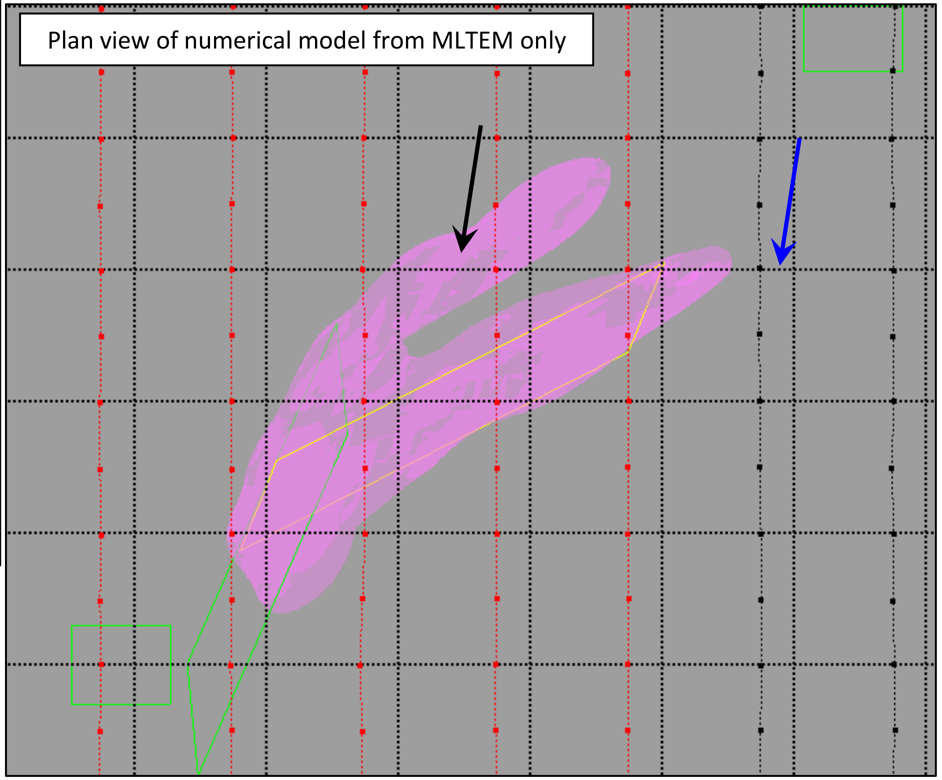


Looking west view of numerical model with « hidden plate test »

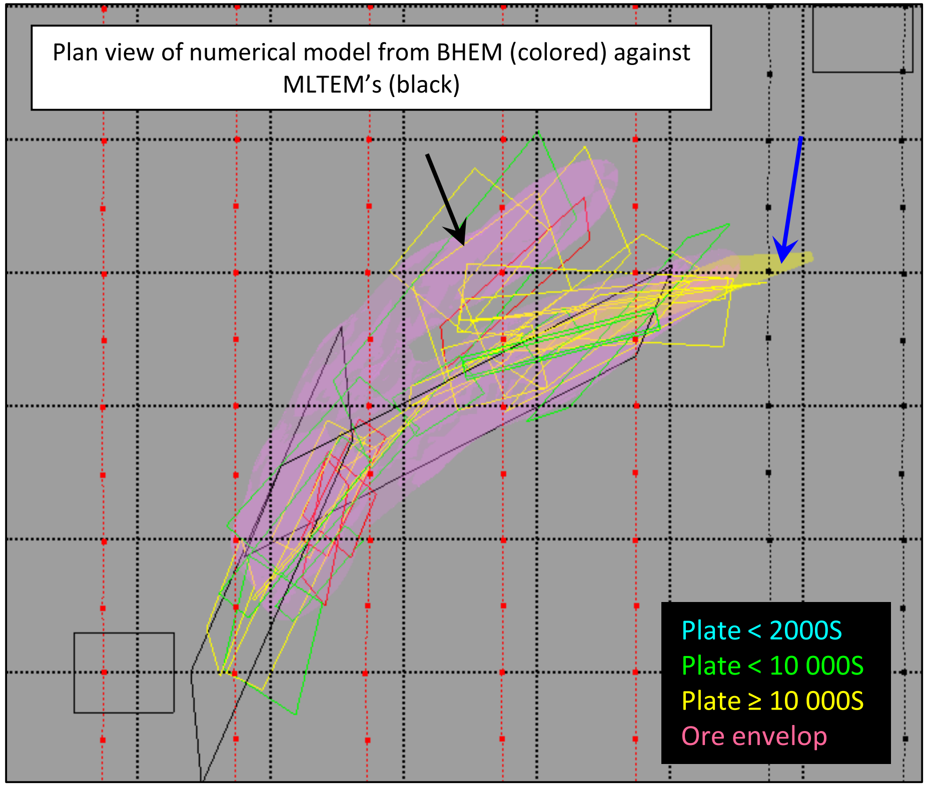
6. Time-Domain Electromagnetics – MLTEM model vs BHEM model #1



Plan view of the MLTEM BzCH40 (460 ms) over geology



Plan view of numerical model from MLTEM only

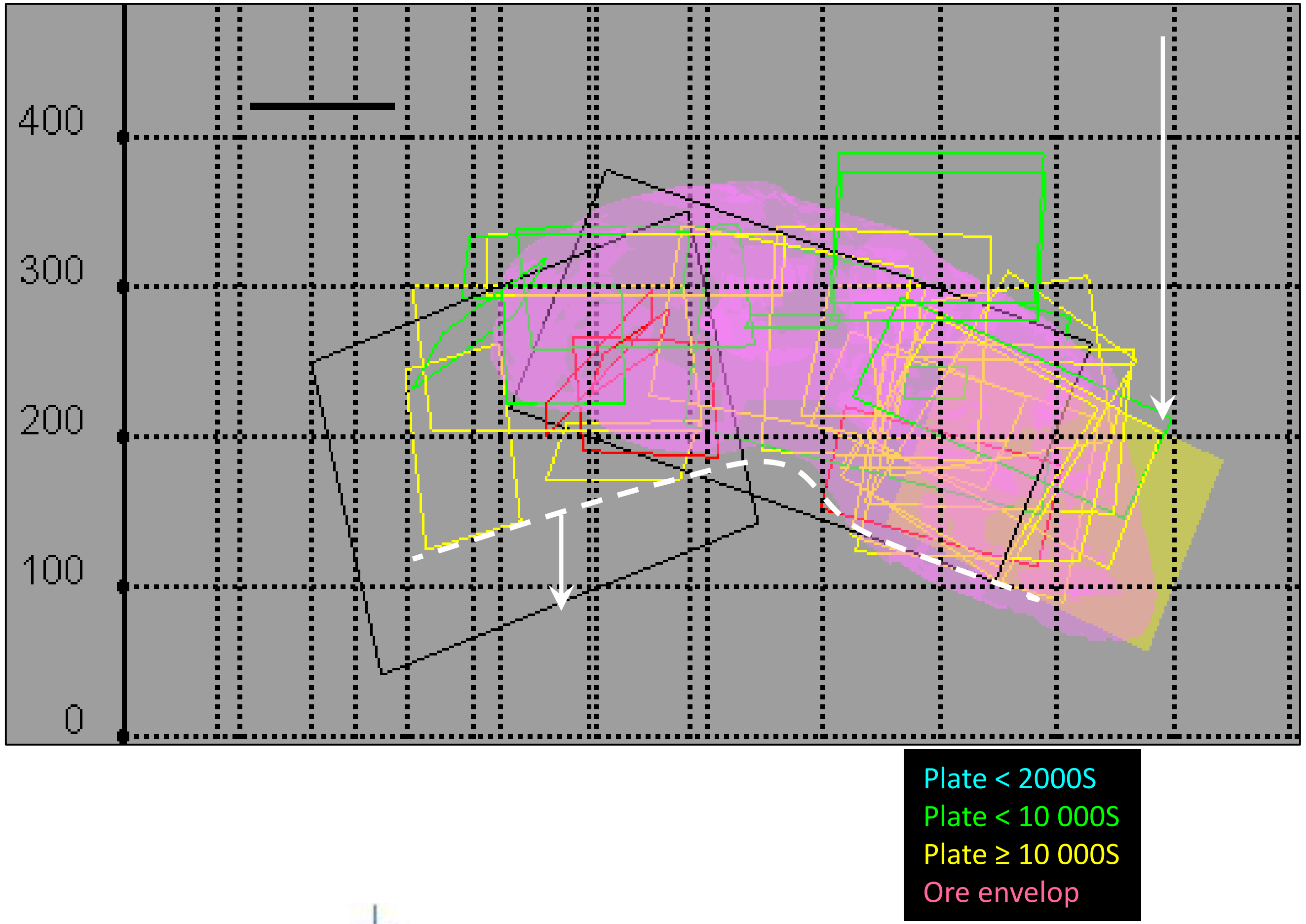


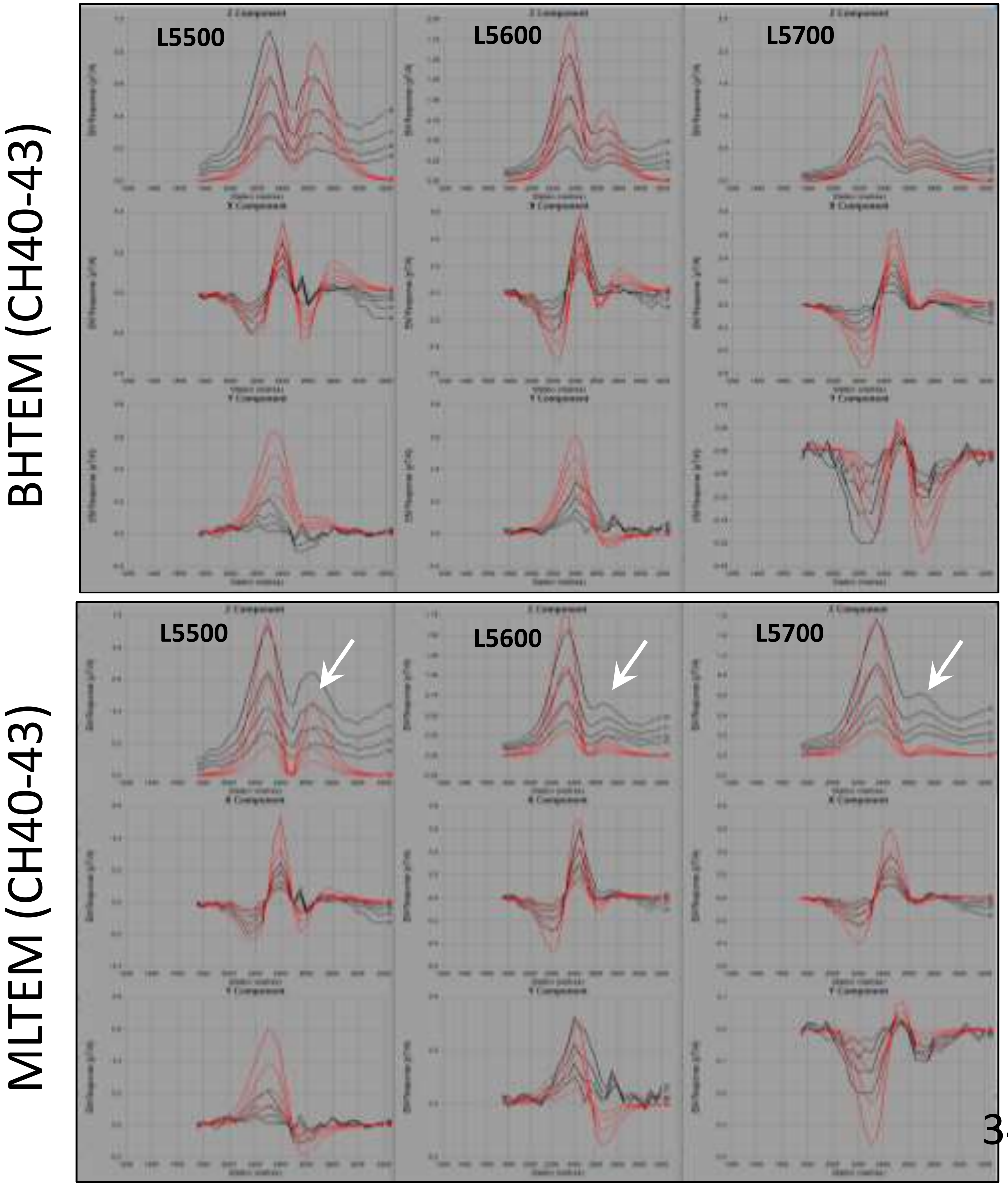
Plan view of numerical model from BHEM (colored) against MLTEM's (black)

- MLTEM & BHEM station spacing;
- Sensor location (surface vs underground);
- Heterogeneous nature of Ni-Cu deposits (SFDISS, SFNET, SFMA)

6. Time-Domain Electromagnetics – MLTEM model vs BHEM model #1

View looking NW of numerical model from BHEM (colored) against MLTEM's (black)





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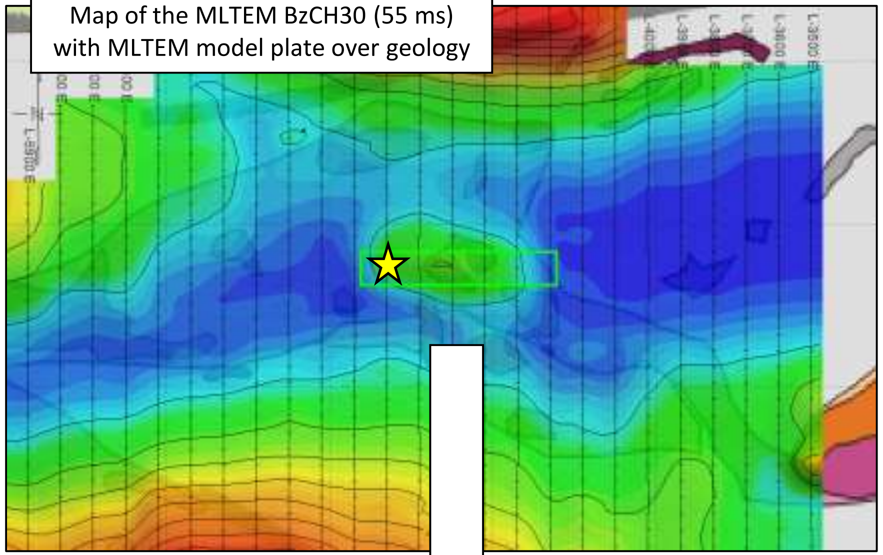
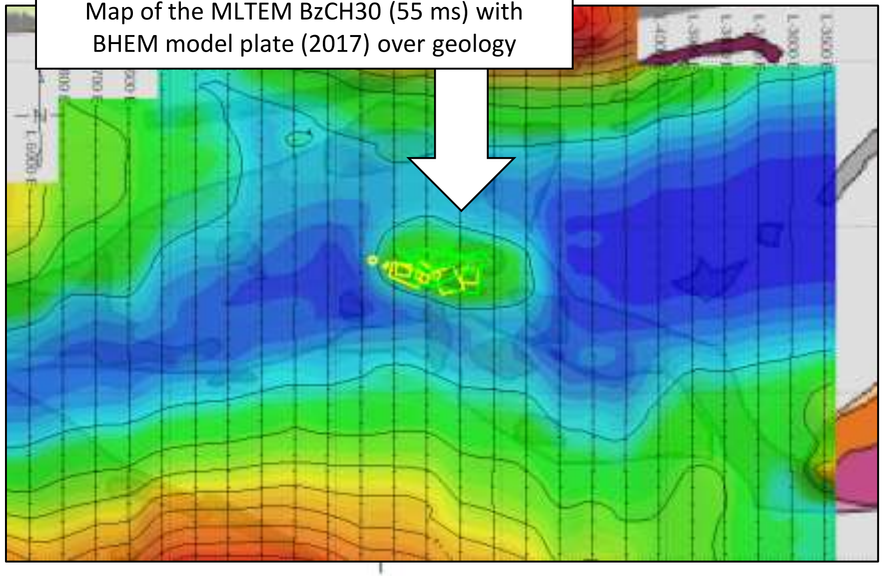
6. Time-Domain Electromagnetics – MLTEM model vs BHEM model #2

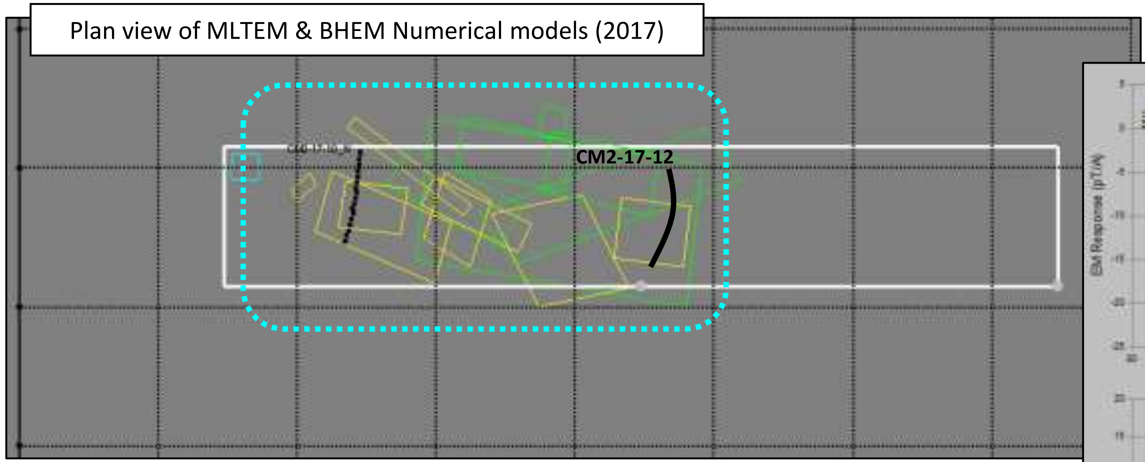
Map of the MLTEM BzCH30 (55 ms) with MLTEM model plate over geology



Map of the MLTEM BzCH30 (55 ms) with BHEM model plate (2017) over geology



Plan view of MLTEM & BHEM Numerical models (2017)



Looking North view of MLTEM & BHEM Numerical models (2017)

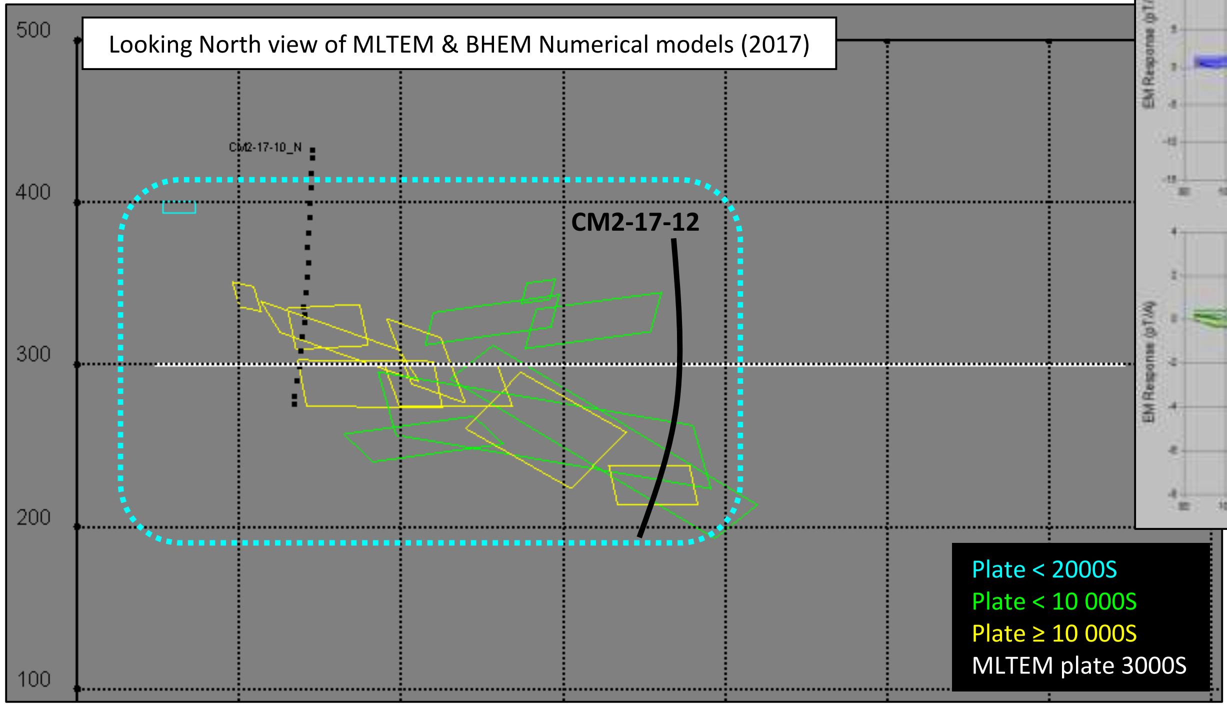
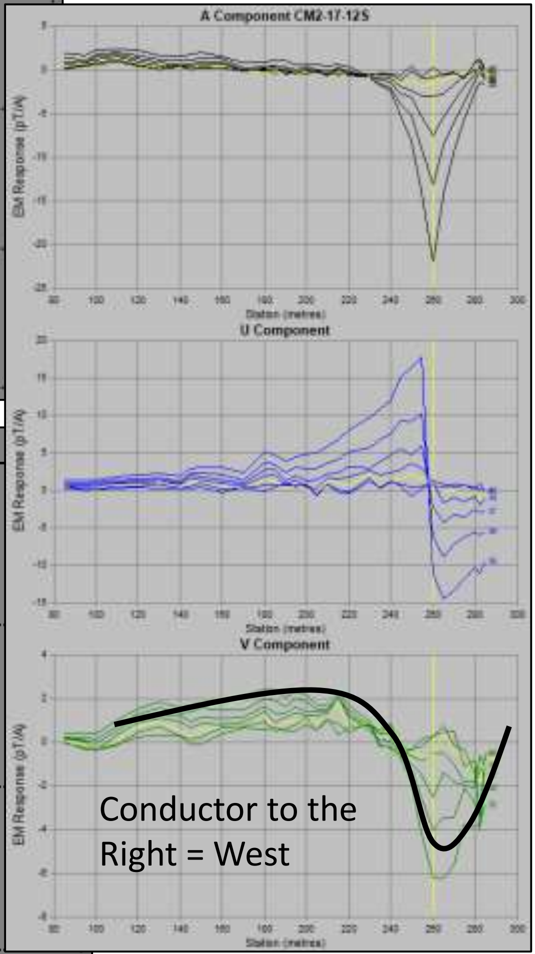
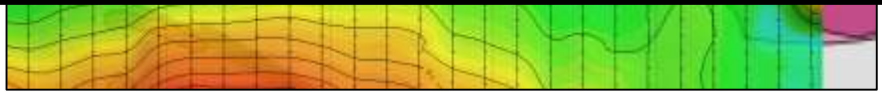


Plate < 2000S
Plate < 10 000S
Plate ≥ 10 000S
MLTEM plate 3000S

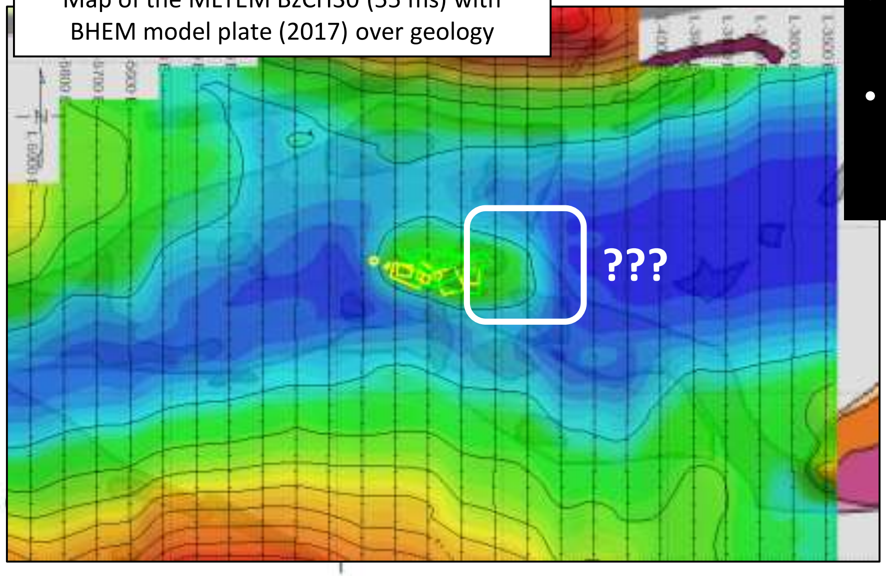
CM2-17-12



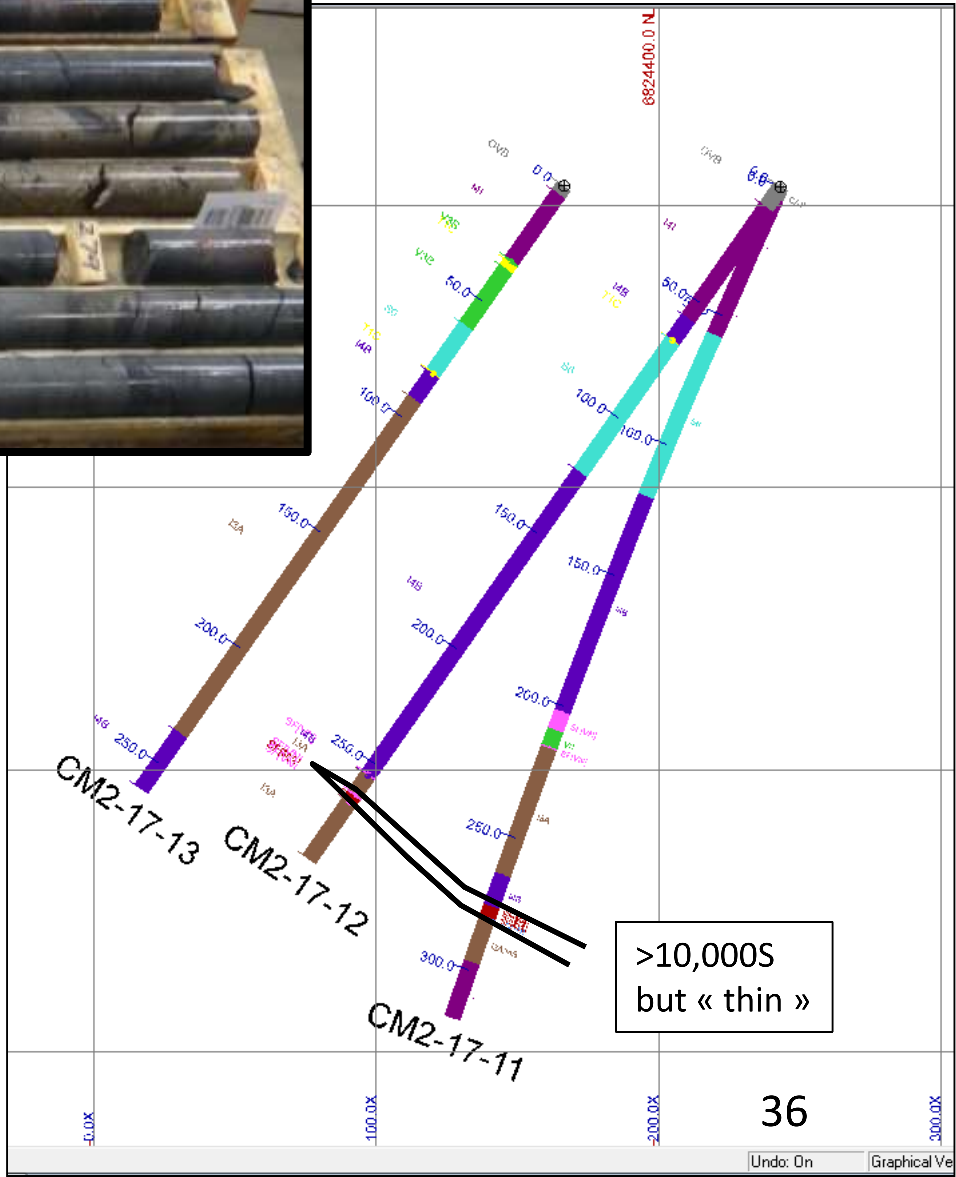
6. Time-Domain Electromagnetics – MLTEM model vs BHEM model #2



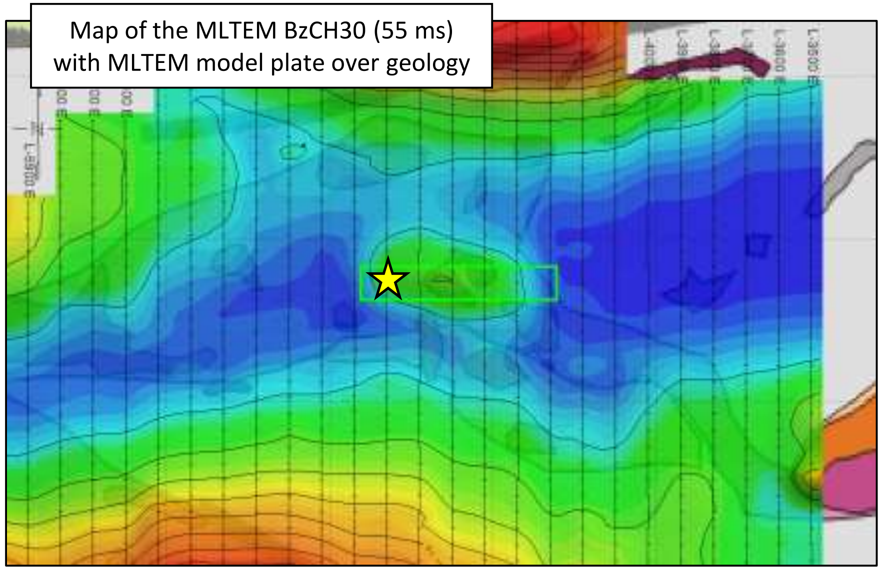
Map of the MLTEM BzCH30 (55 ms) with BHEM model plate (2017) over geology

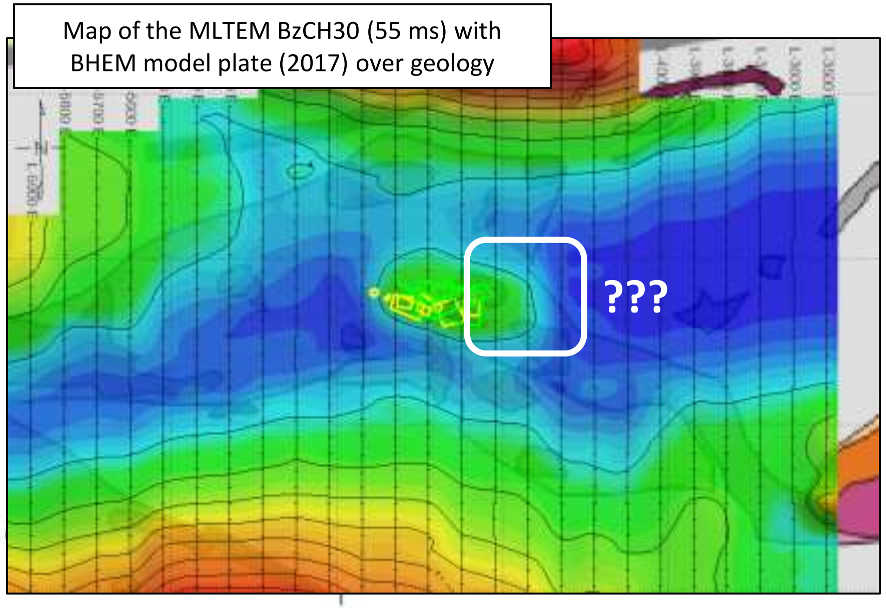


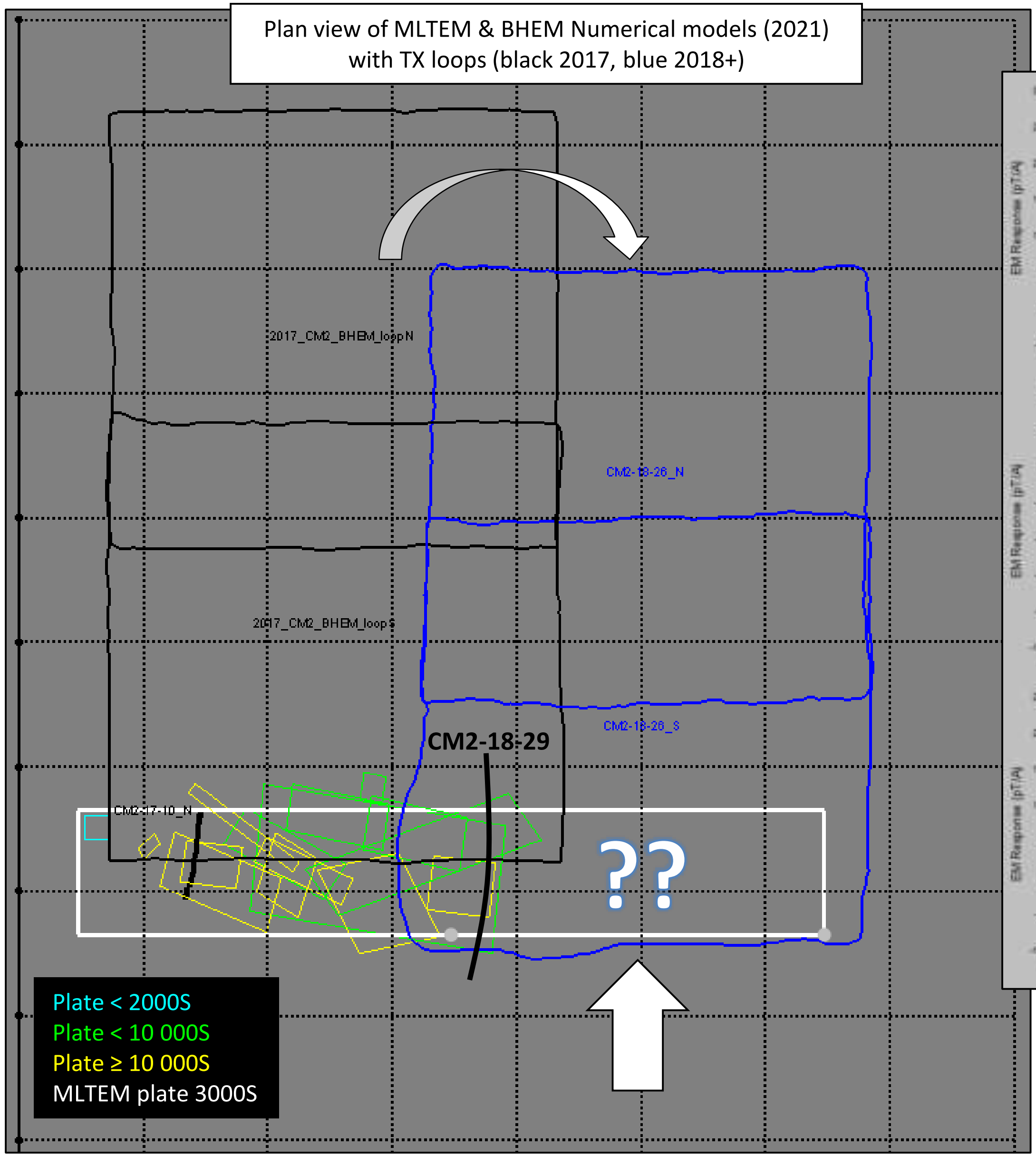
- Location of the BHEM loops to induce potential ore extensions;
- Perpetual challenge with the estimation of a conductor's thickness vs conductance and value for follow-up drilling…



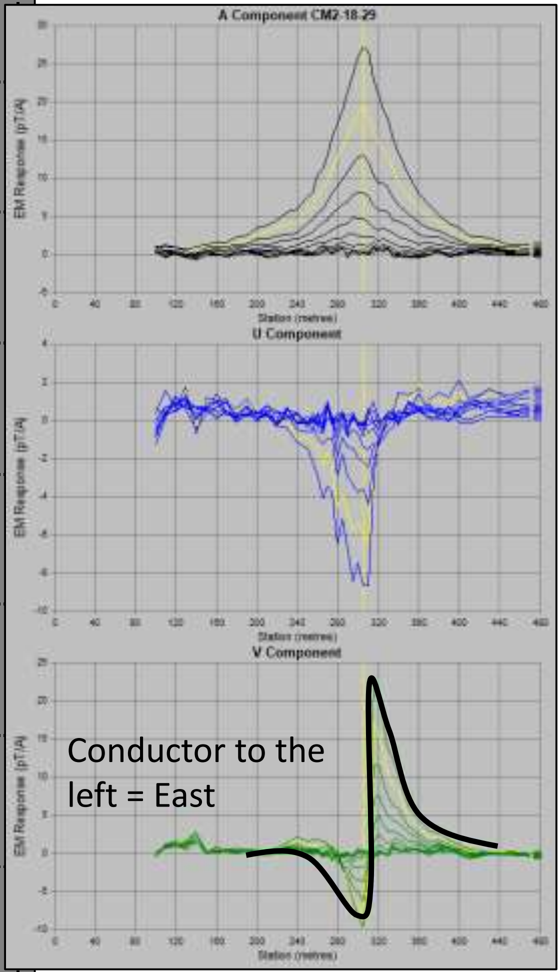
6. Time-Domain Electromagnetics – MLTEM model vs BHEM model #2



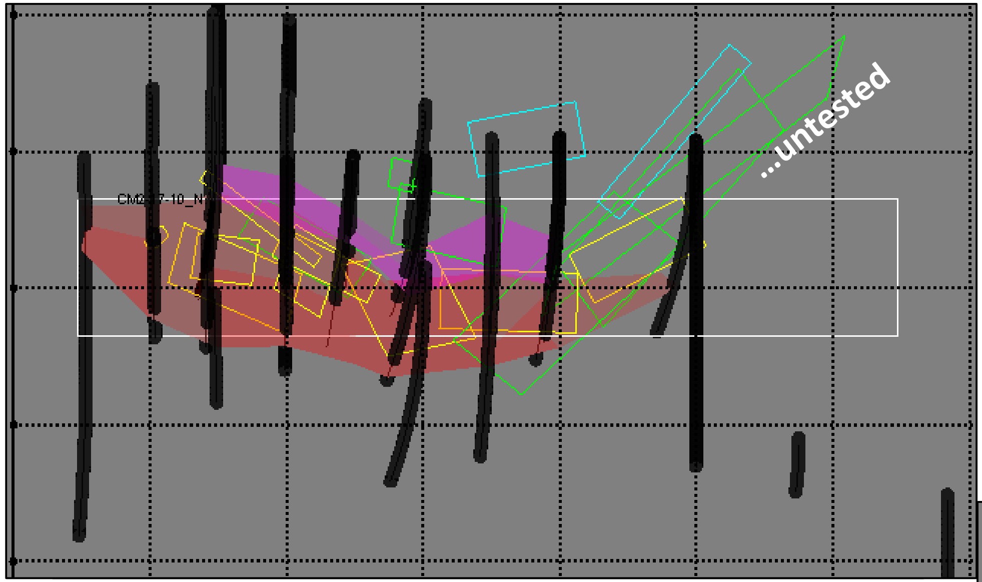


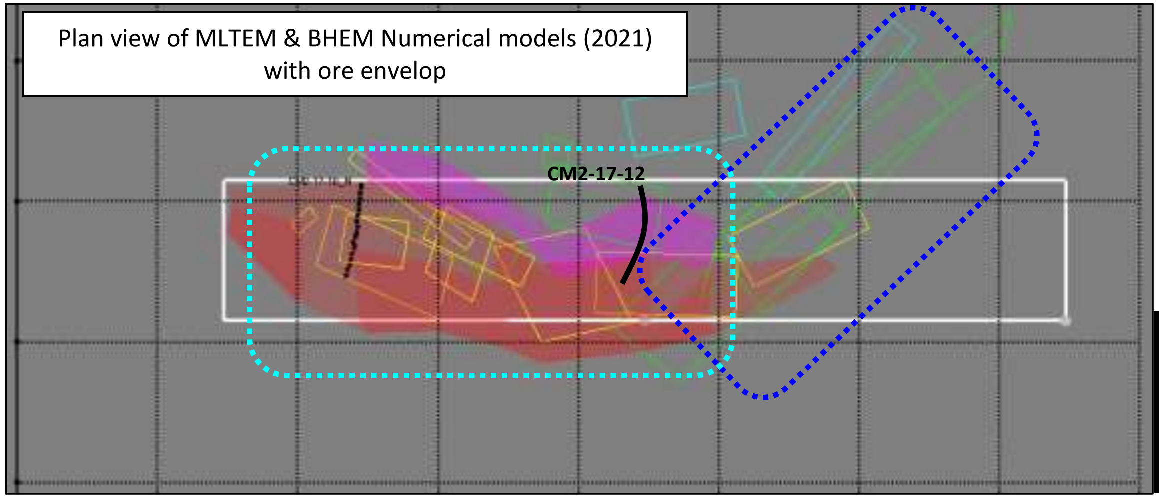


CM2-18-29



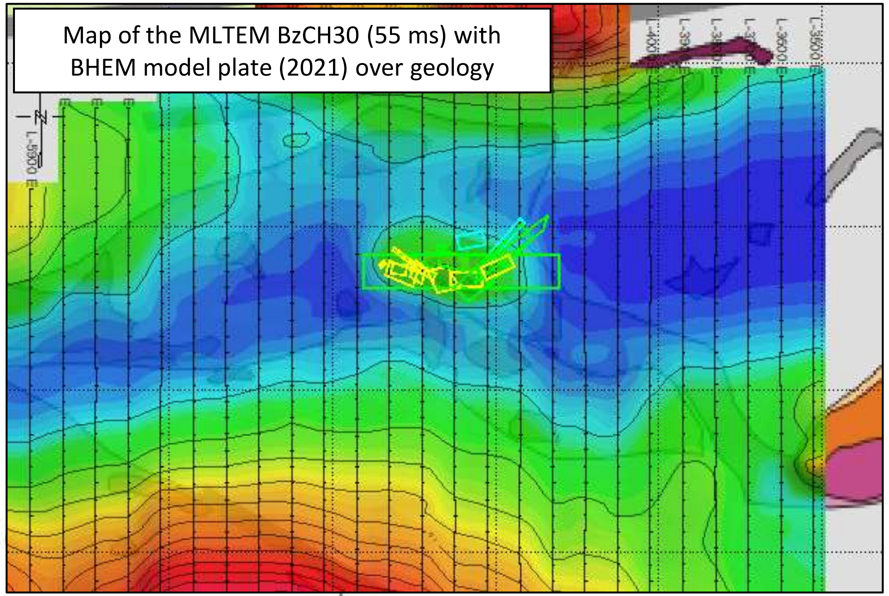
6. Time-Domain Electromagnetics – MLTEM model vs BHEM model #2



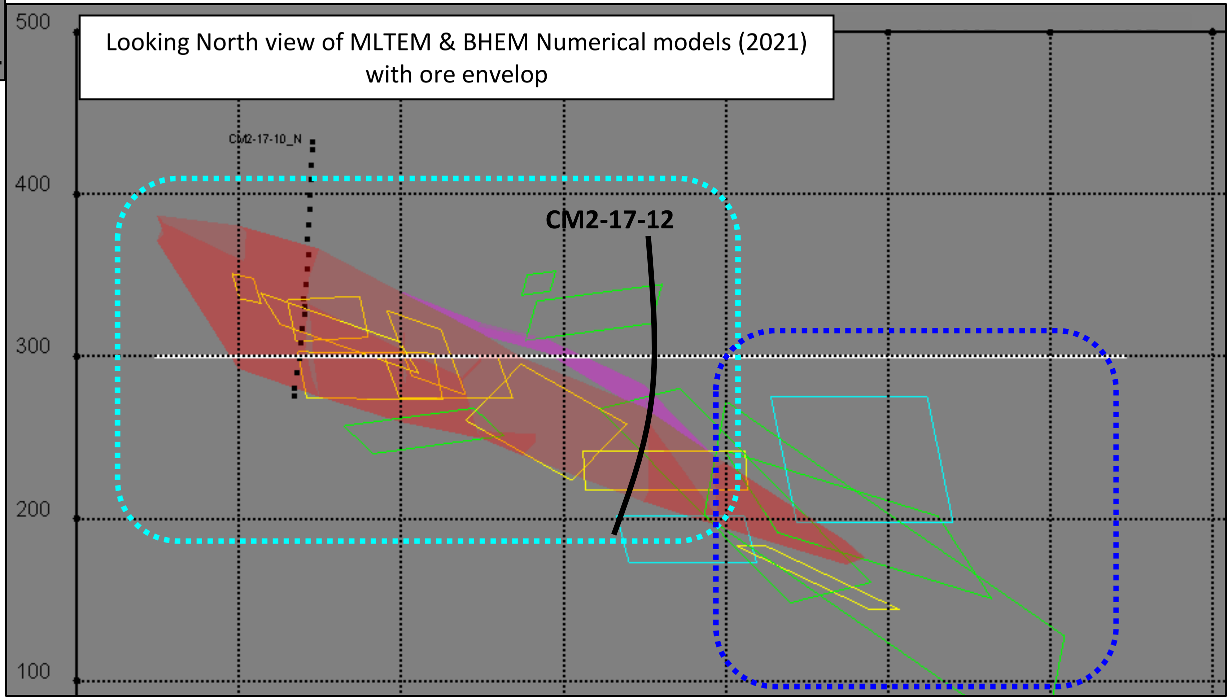


Plan view of MLTEM & BHEM Numerical models (2021) with ore envelop

Plate < 2000S
Plate < 10 000S
Plate ≥ 10 000S
MLTEM plate 3000S
Ore envelop



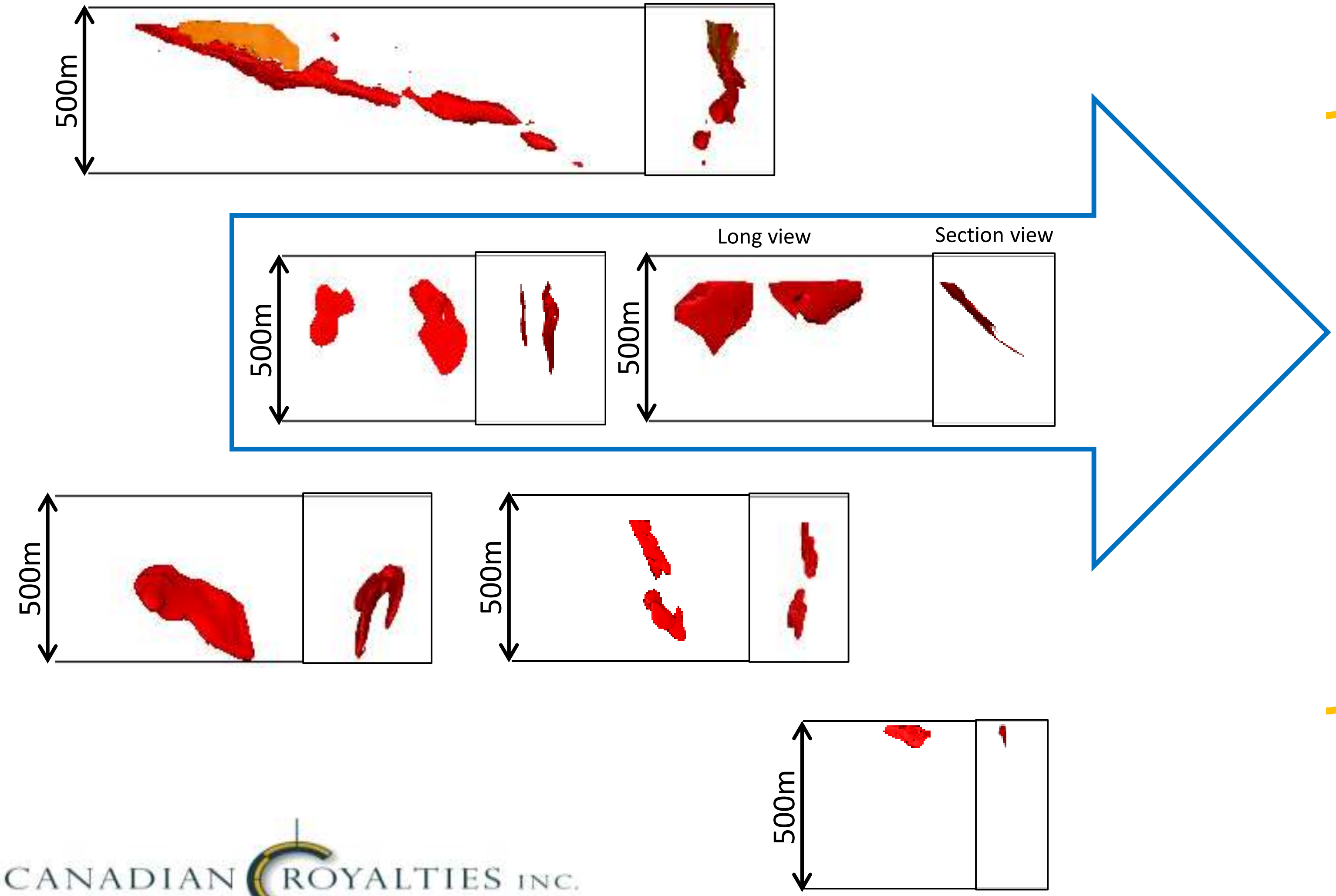
Map of the MLTEM BzCH30 (55 ms) with BHEM model plate (2021) over geology

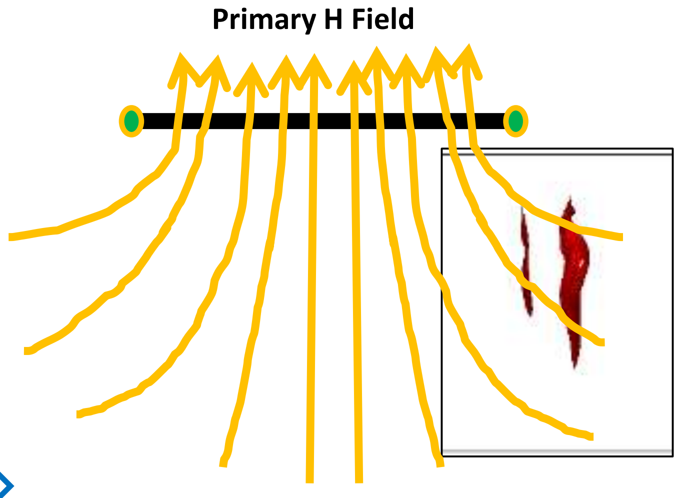


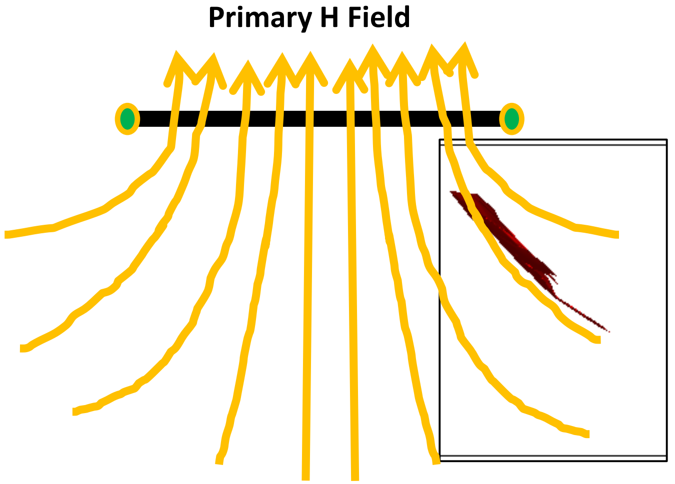
Looking North view of MLTEM & BHEM Numerical models (2021) with ore envelop

7. Time-Domain Electromagnetics – A word about BHEM loops

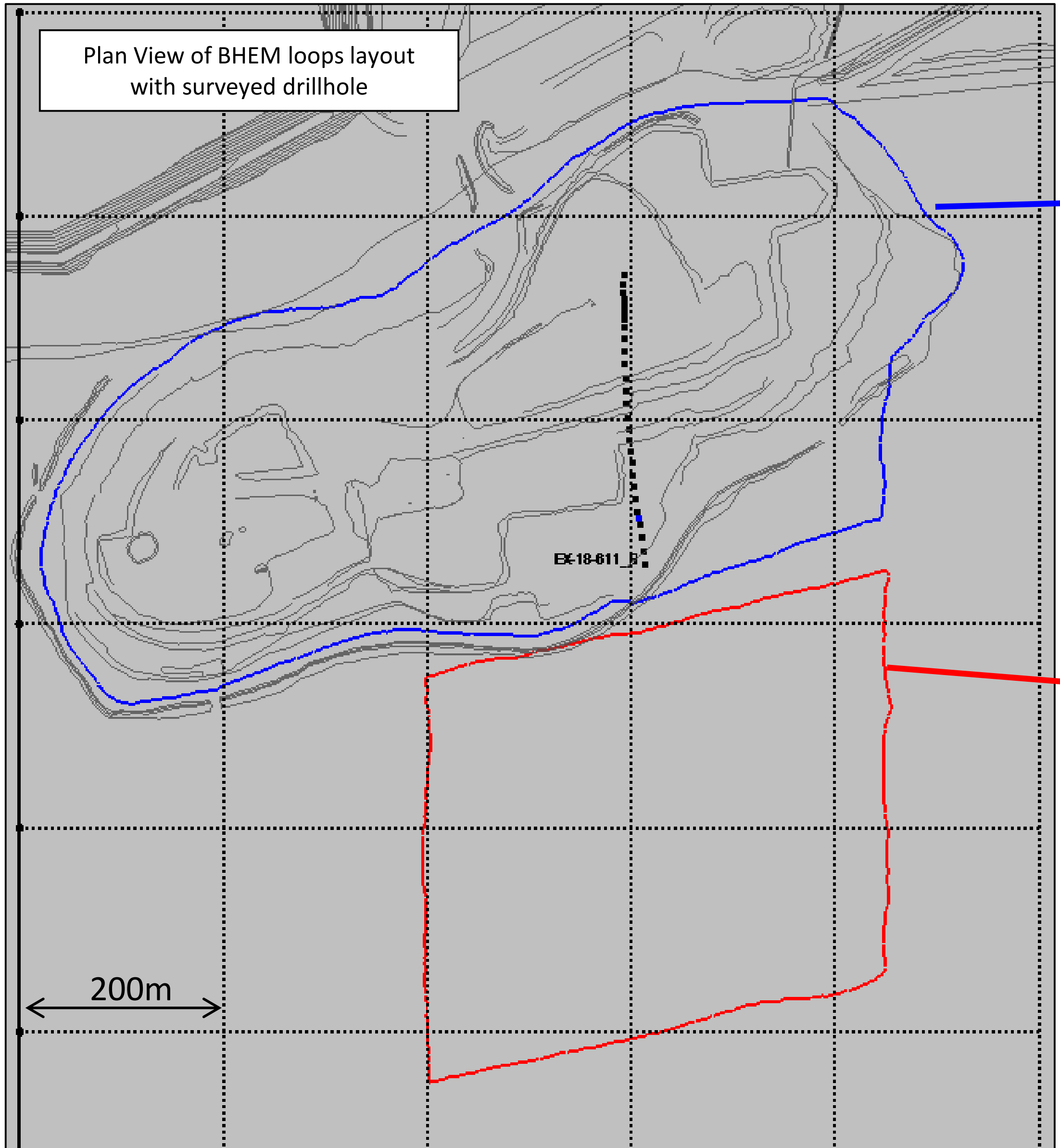
Cross-section of typical Ni-Cu-PGE ore body

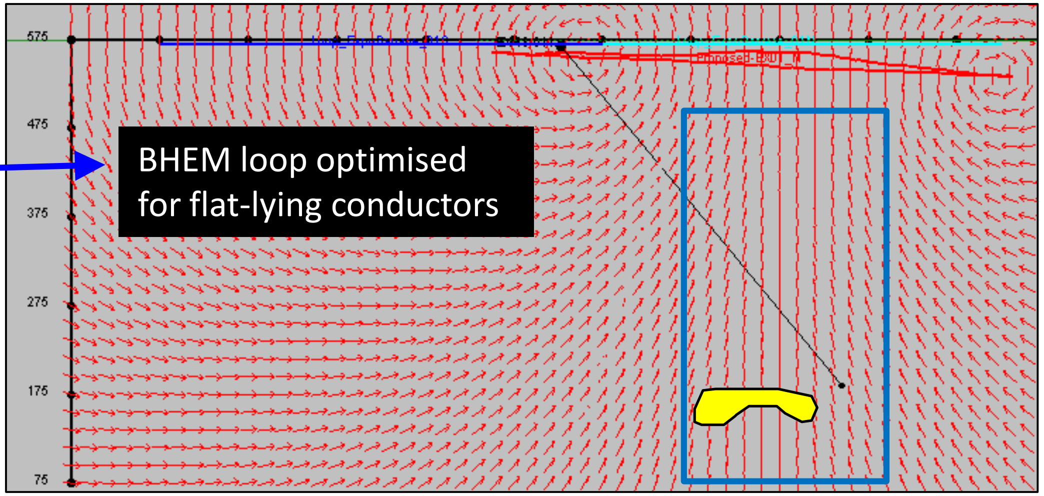


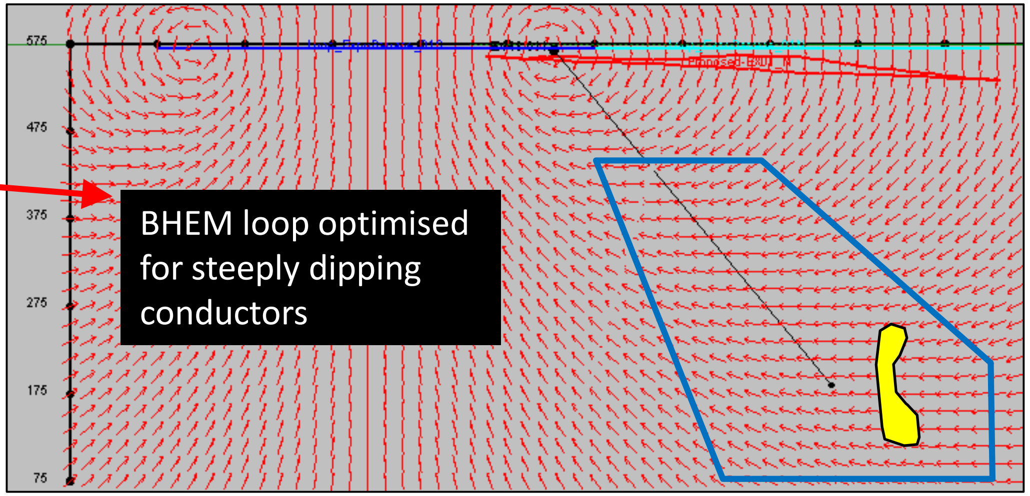




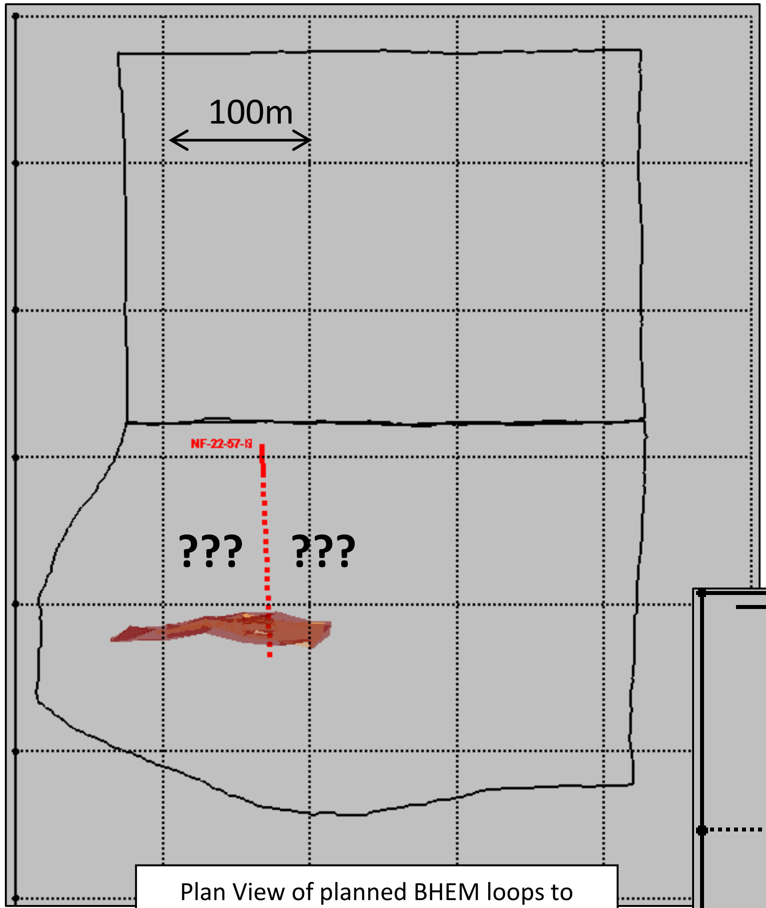
7. Time-Domain Electromagnetics – A word about BHEM loops







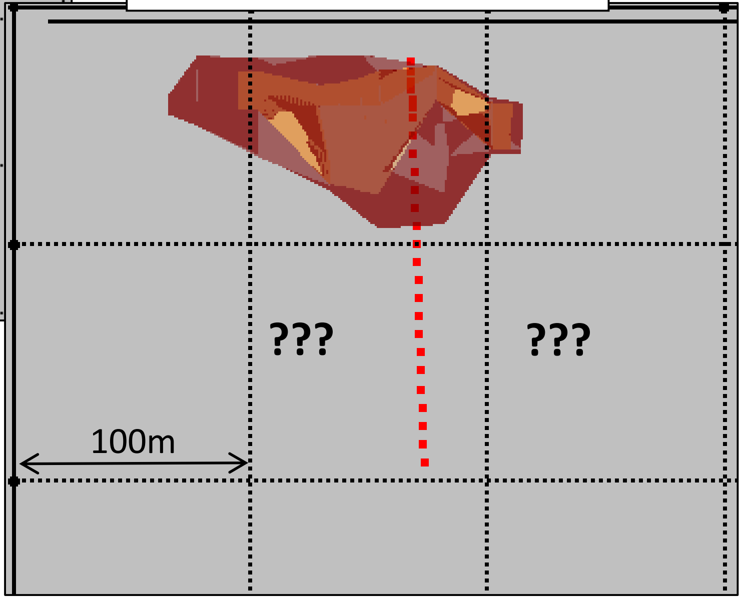
7. Time-Domain Electromagnetics – A word about BHEM loops



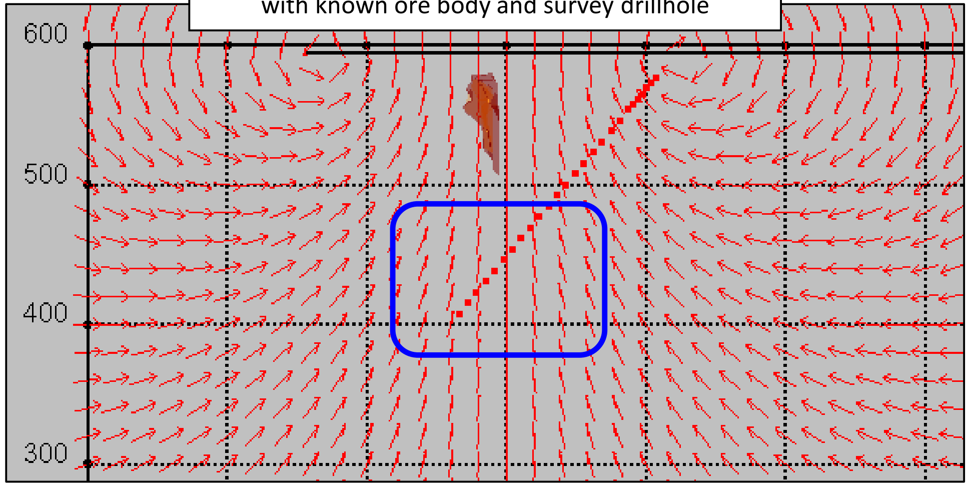
Plan View of planned BHEM loops to explore for satellite ore bodies

For brownfield exploration, “blinding” known ore body is key to improve BHEM scanning performance

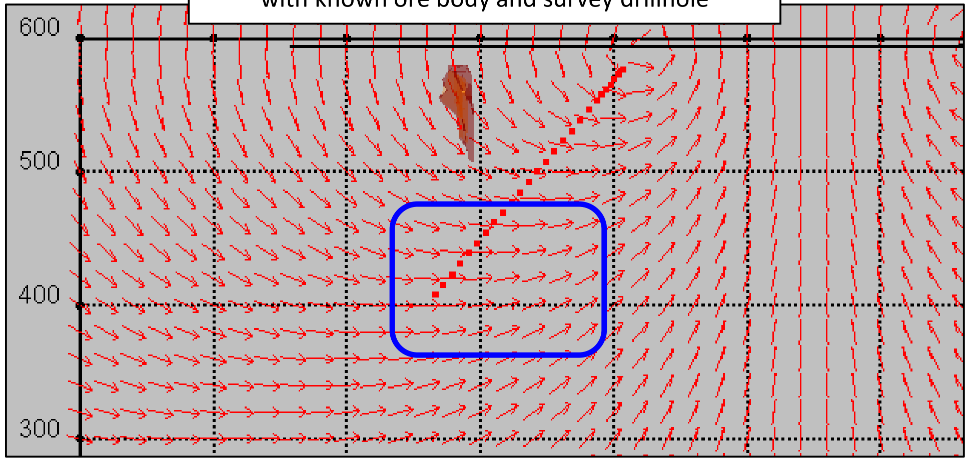
Looking North view of known ore body with location of survey drillhole



Looking West view of South loop primary field with known ore body and survey drillhole



Looking West view of North loop primary field with known ore body and survey drillhole



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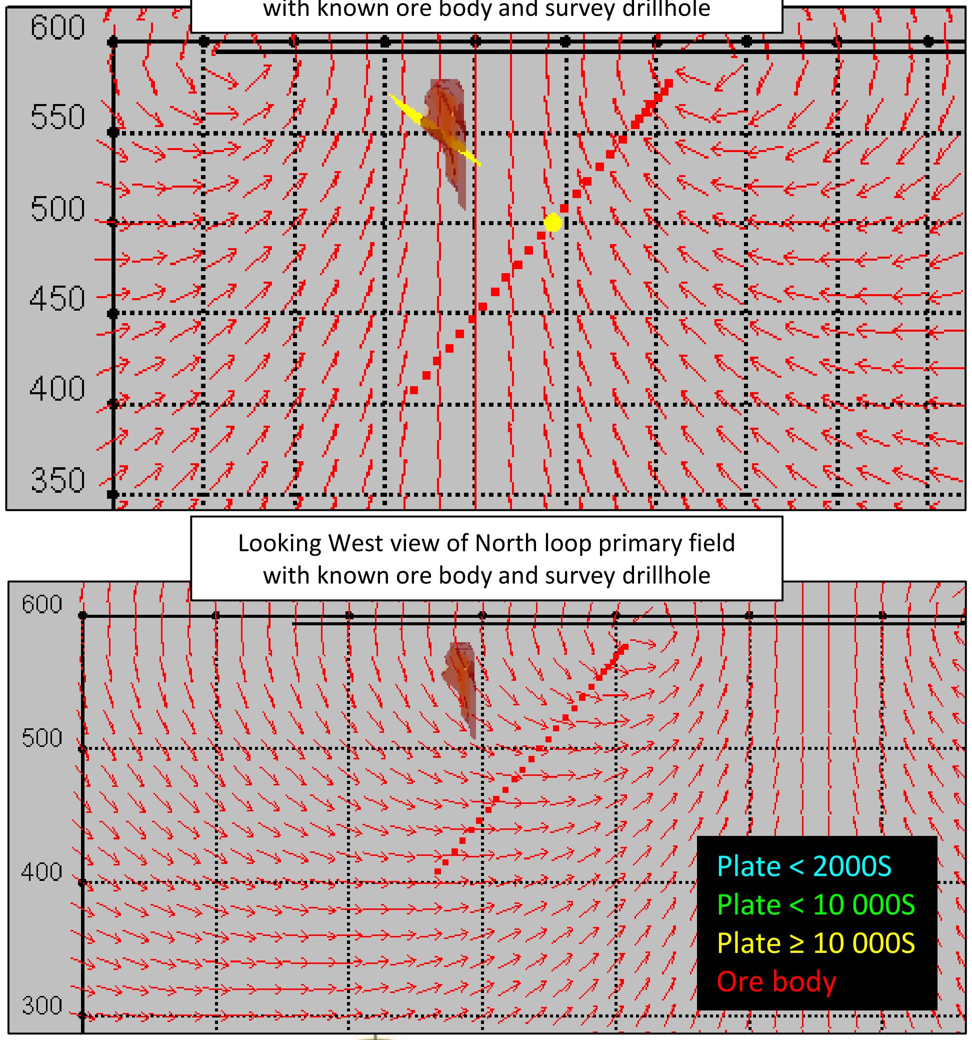
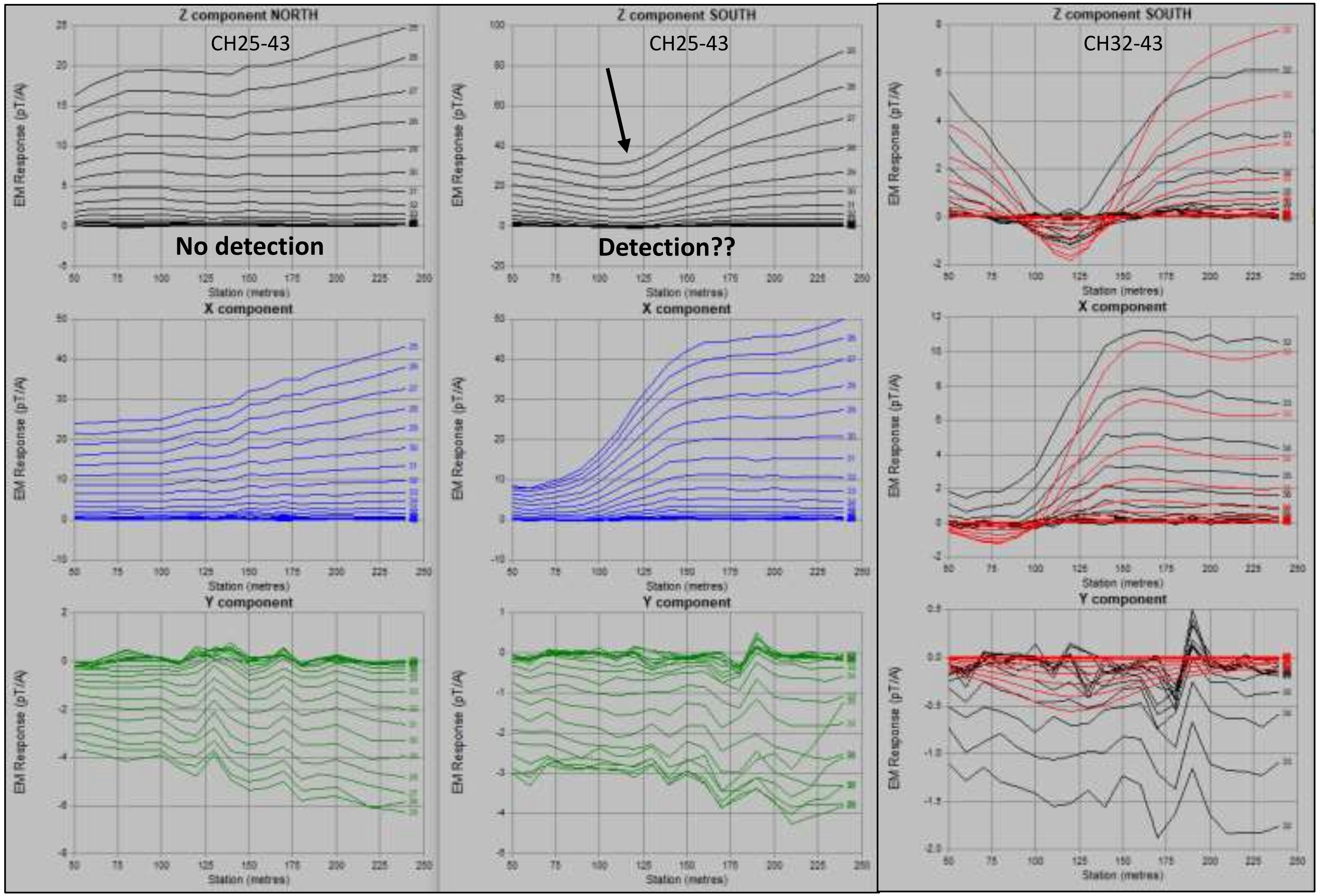
7. Time-Domain Electromagnetics – A word about BHEM loops

Looking West view of South loop primary field with known ore body and survey drillhole

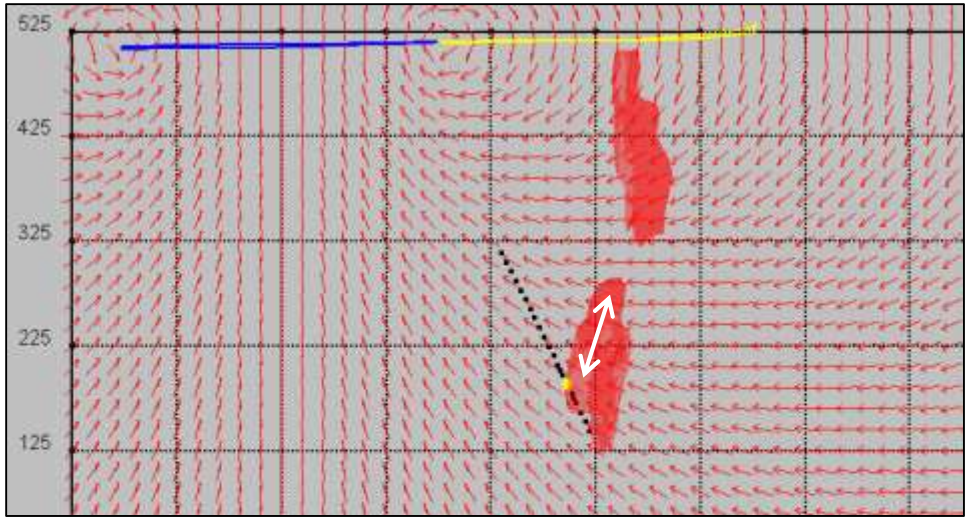


Looking West view of North loop primary field with known ore body and survey drillhole

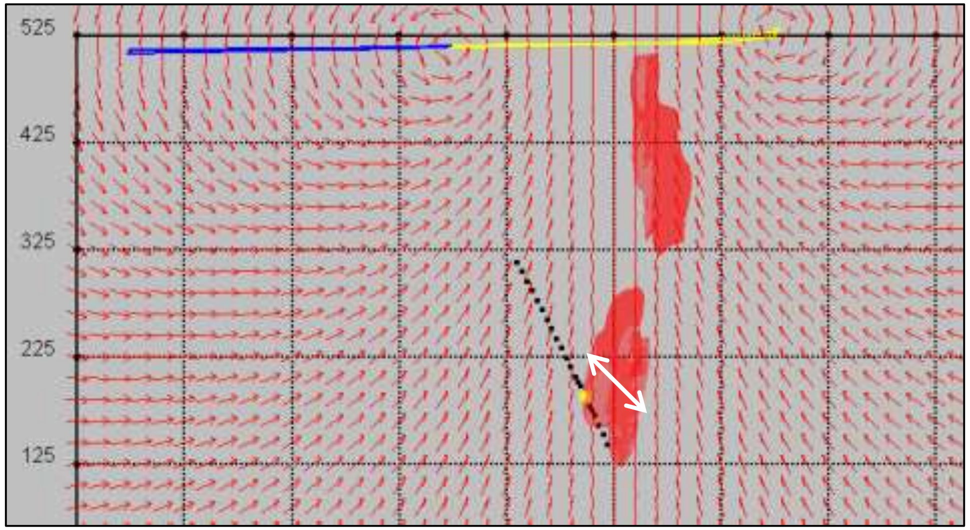


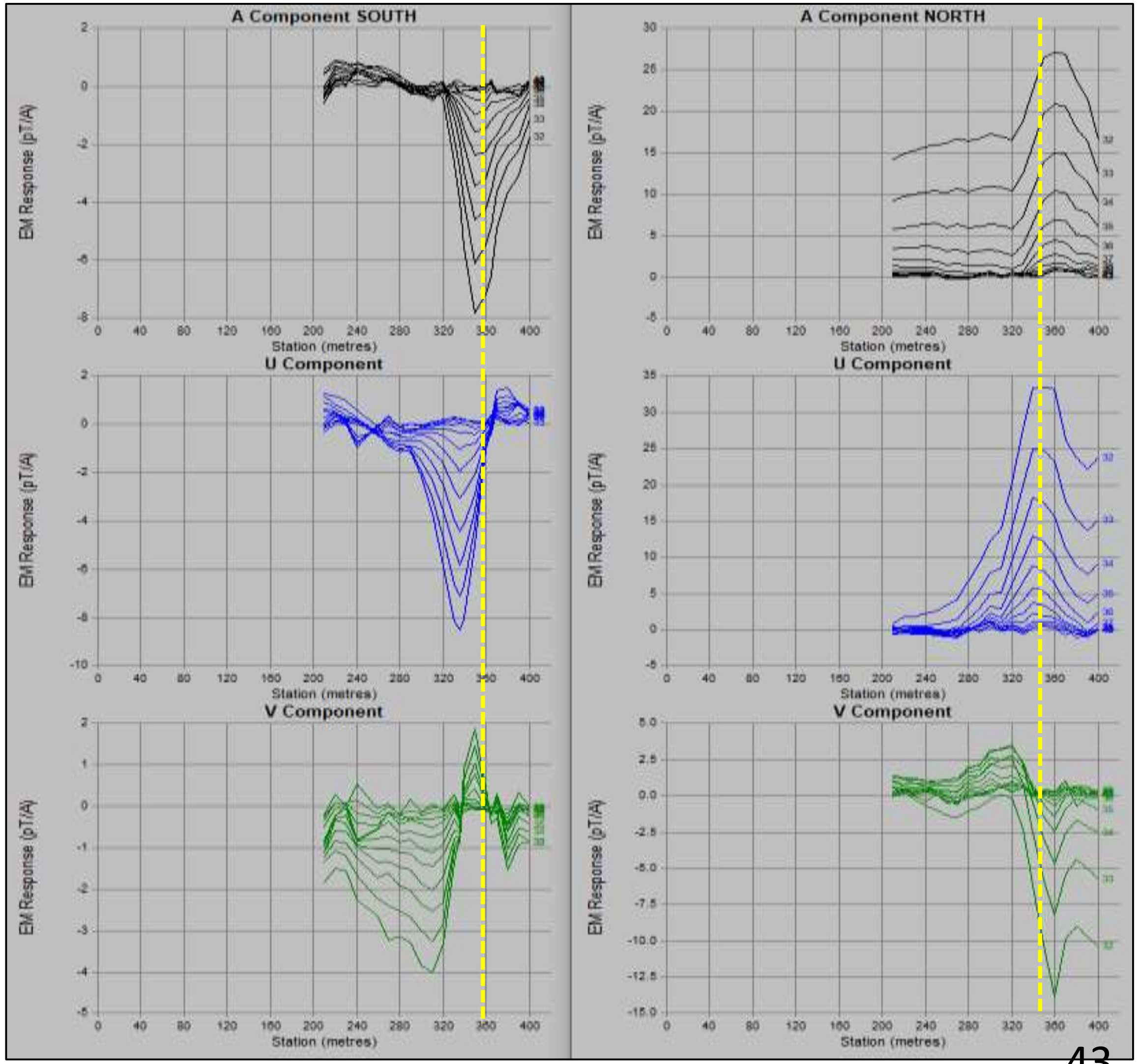
7. Time-Domain Electromagnetics – A word about BHEM loops

Looking West view of South loop primary field with known ore body and survey drillhole

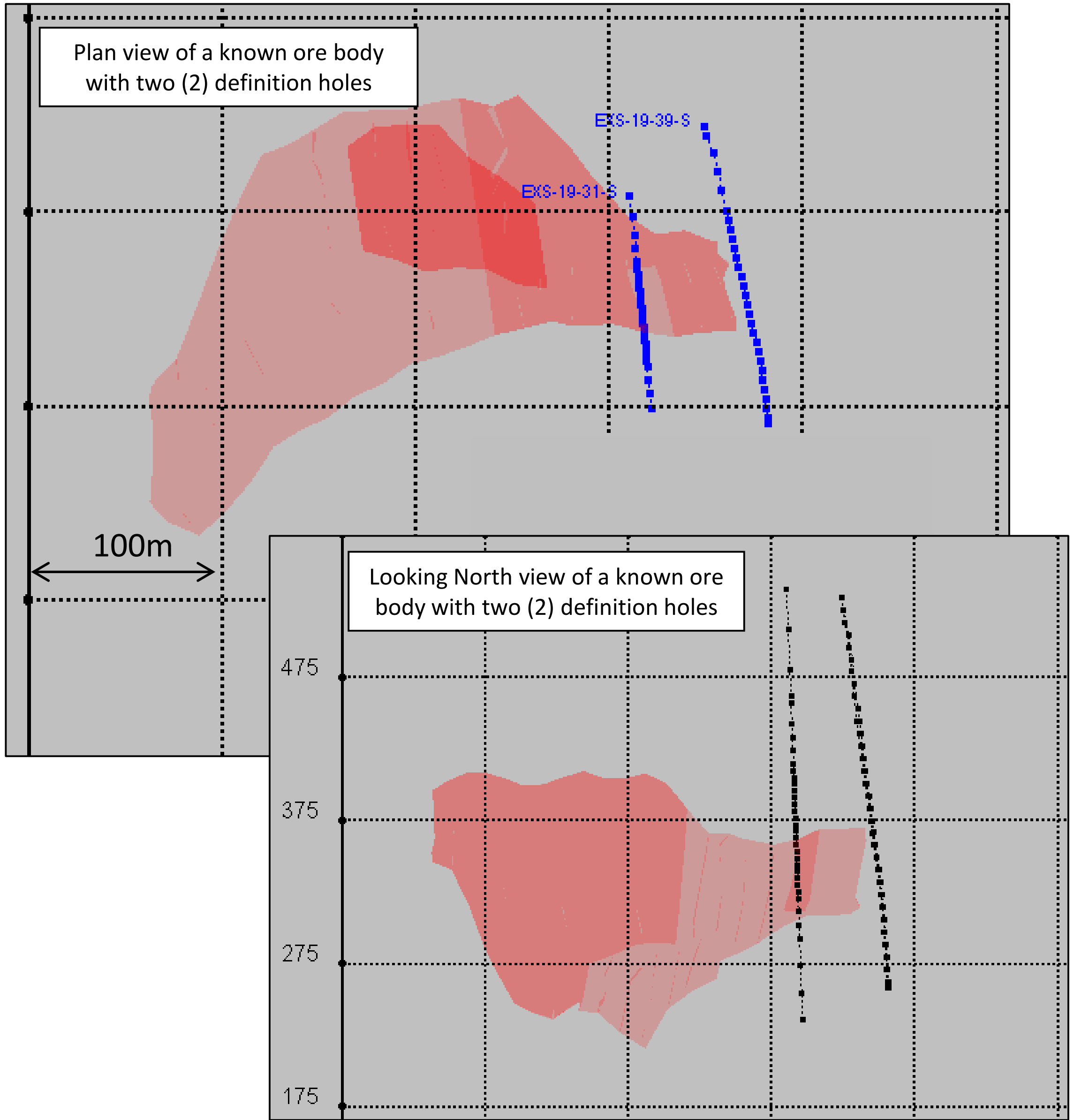


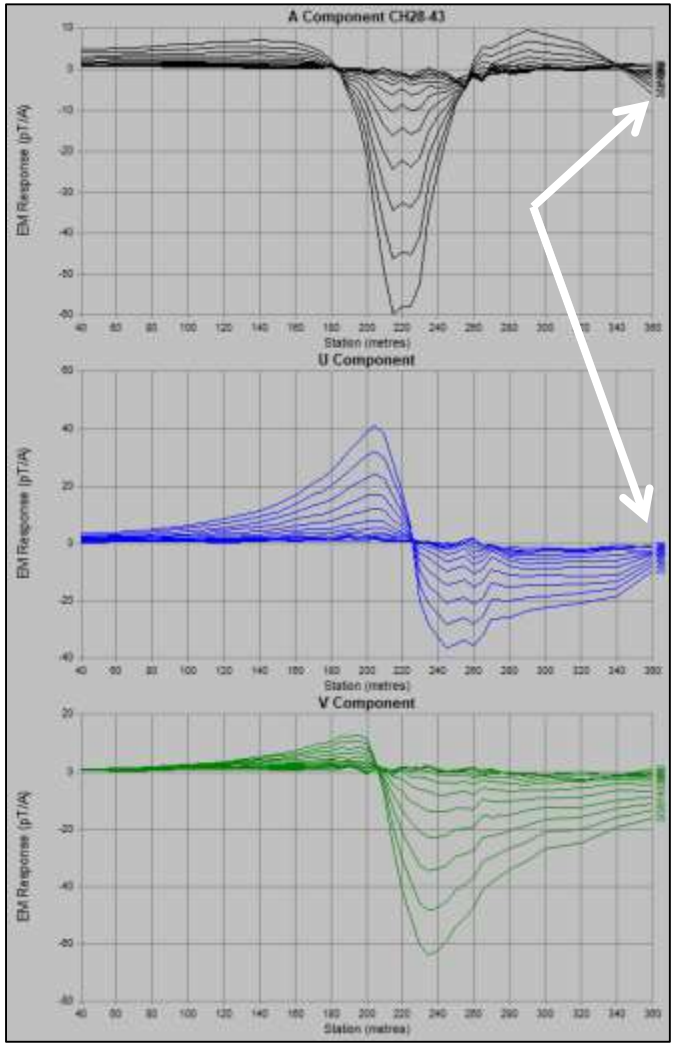
Looking West view of North loop primary field with known ore body and survey drillhole

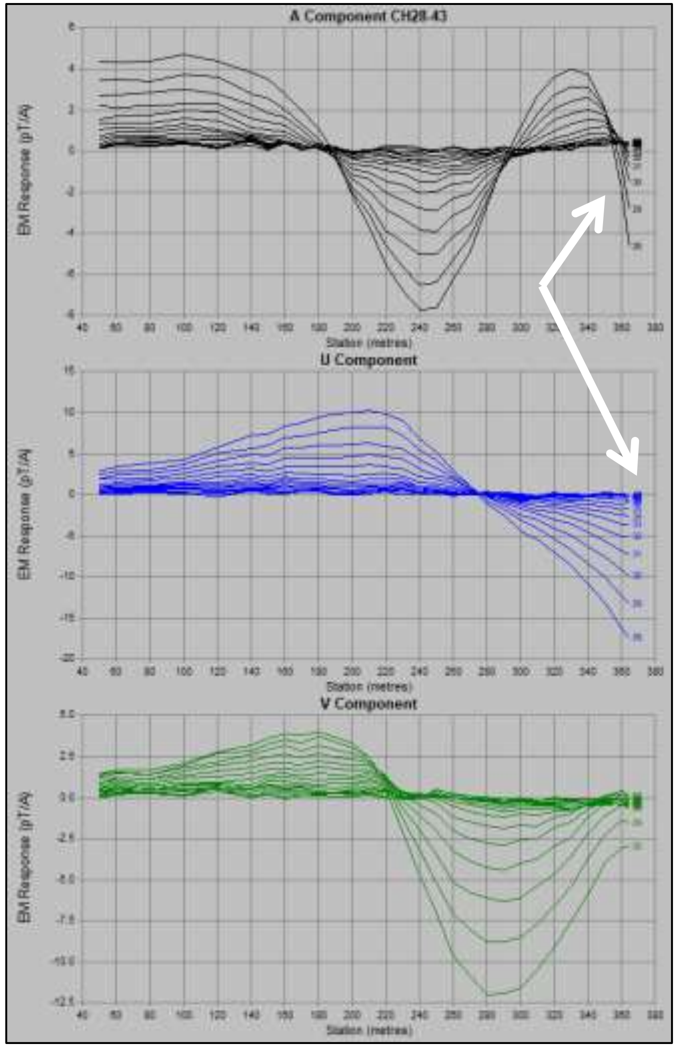




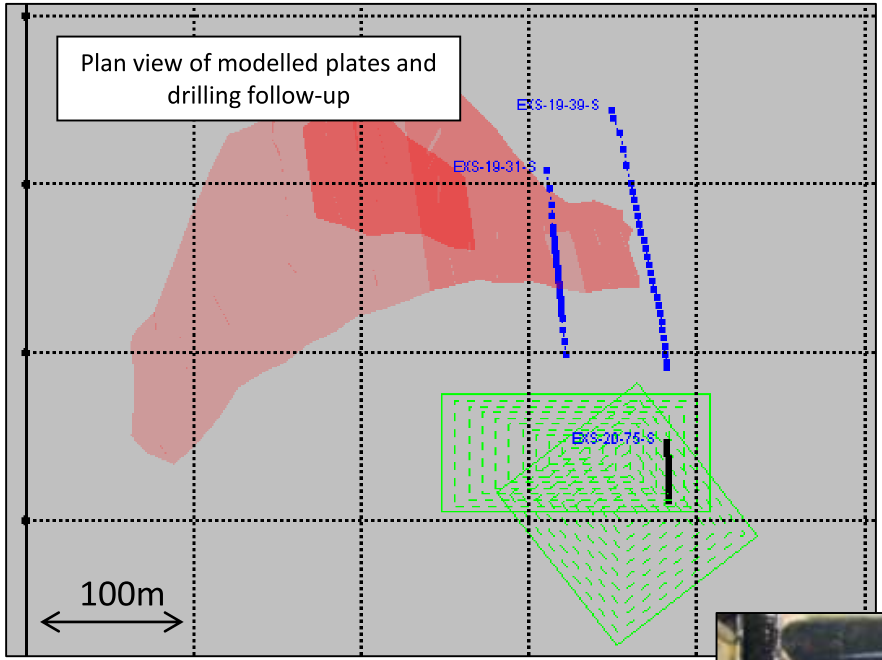
8. Time-Domain Electromagnetics – Concerning EOH Build-Ups







8. Time-Domain Electromagnetics – Concerning EOH Build-Ups



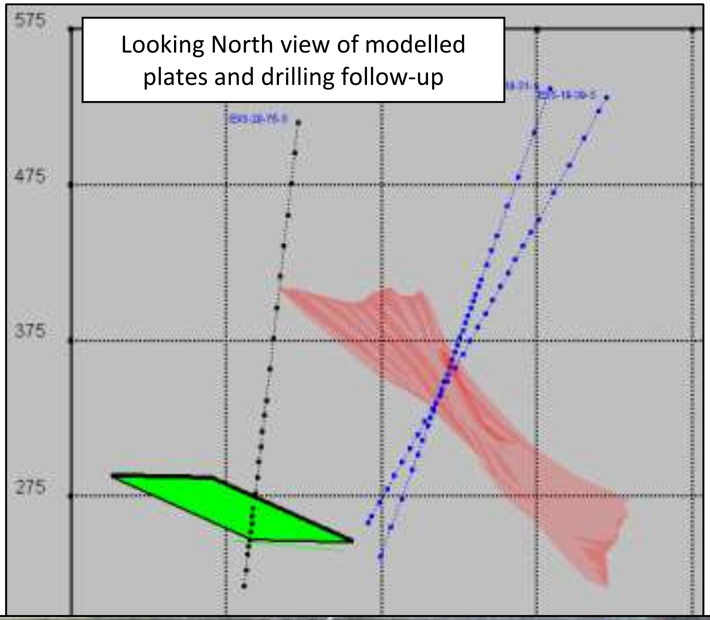


Plate < 2000S
Plate < 10 000S
Plate ≥ 10 000S
Ore body

6.1m SF[DISS]
3.5m SF[ST] + SF[VN]
3.15m SF[MA]

Exploration Success !!!

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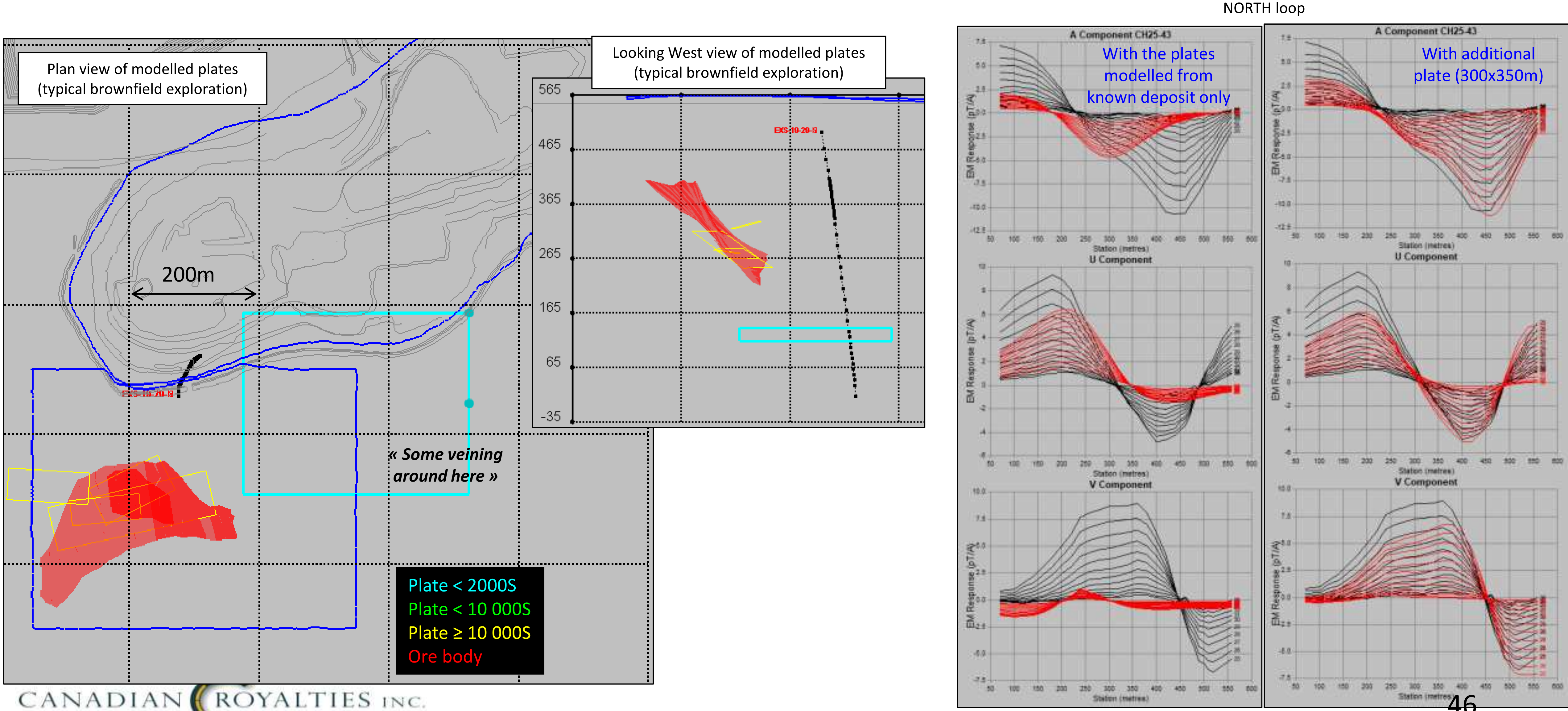
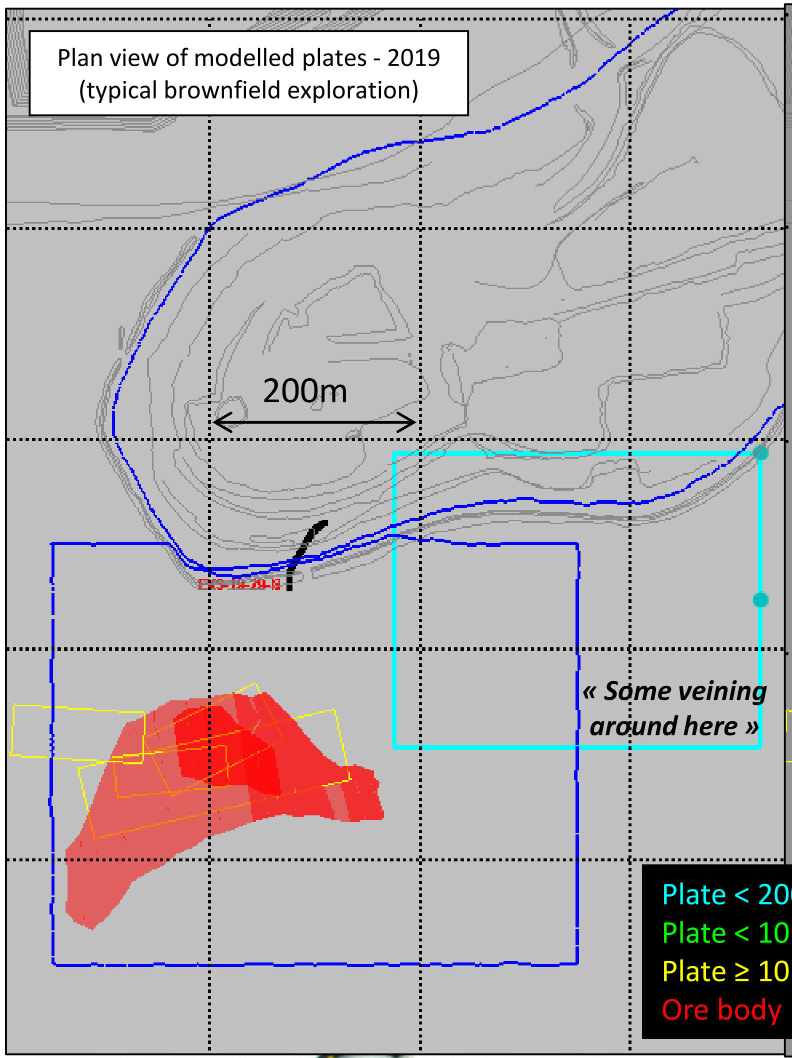
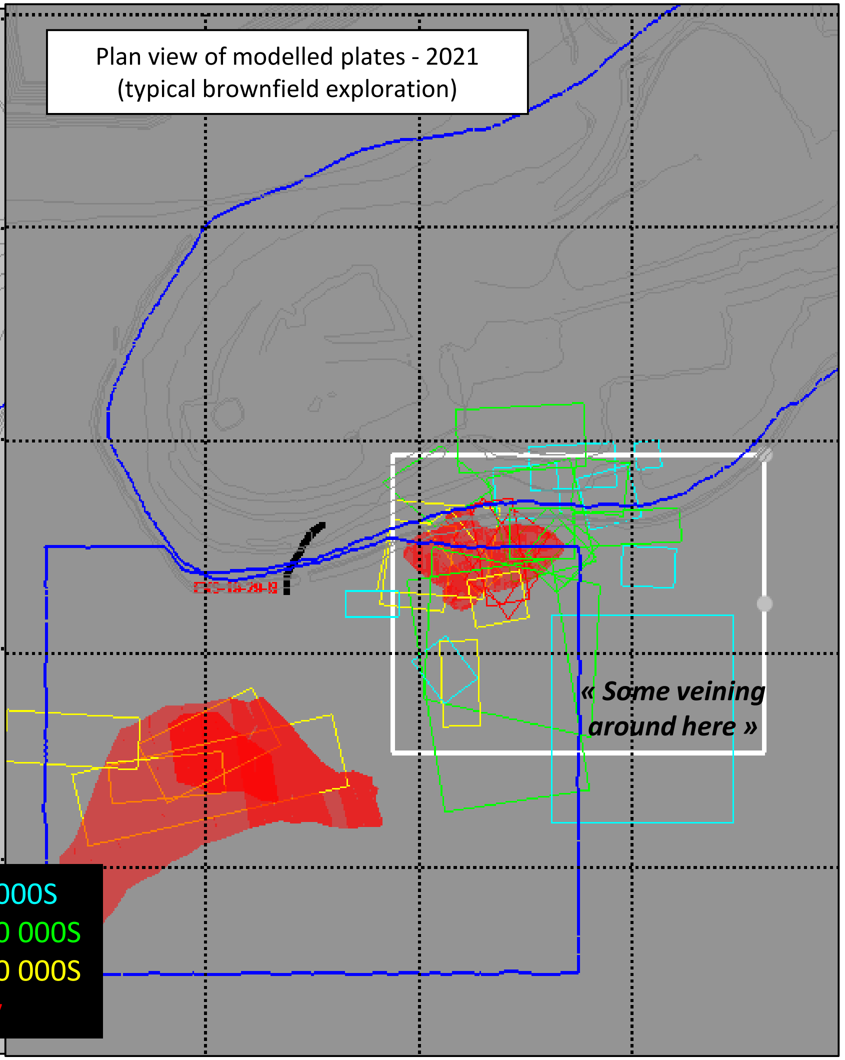
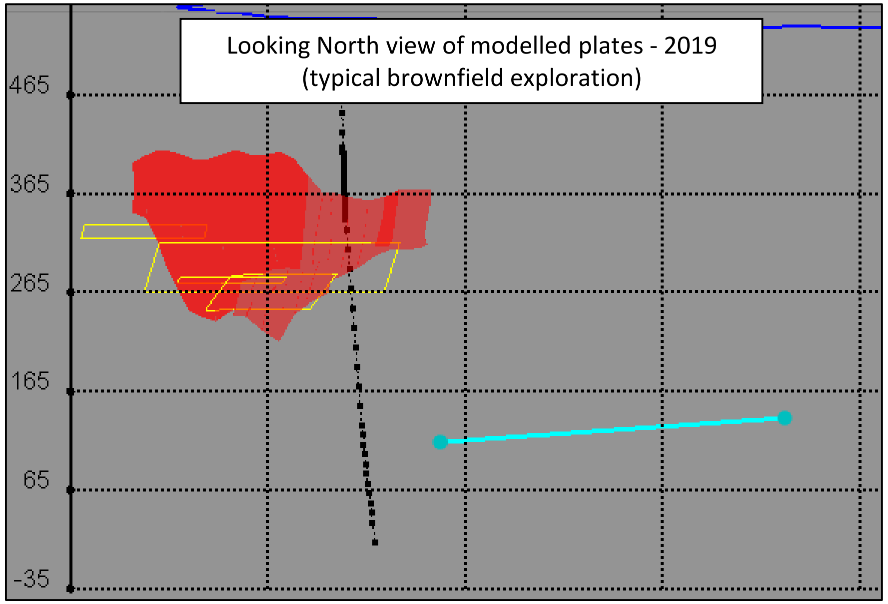
9. Time-Domain Electromagnetics – Underestimated signatures

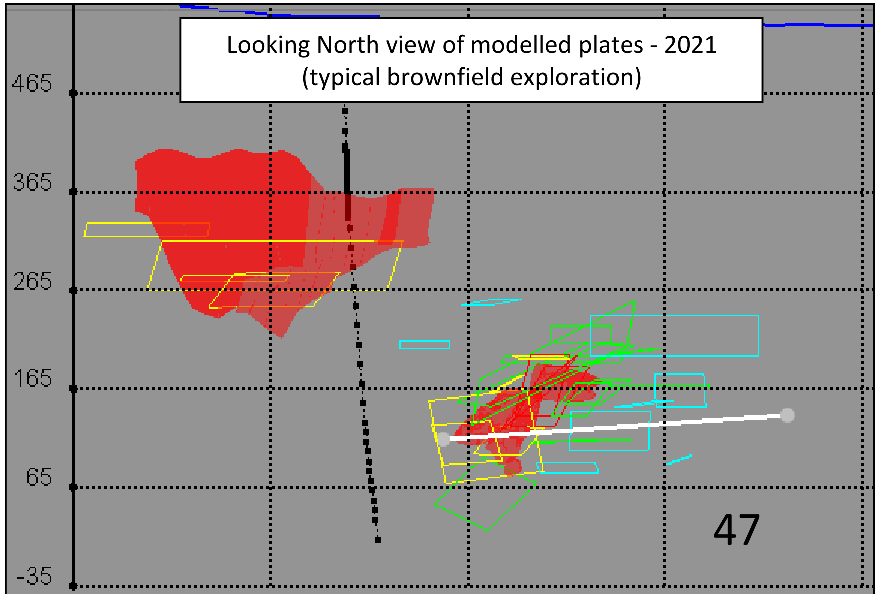


9. Time-Domain Electromagnetics – Underestimated signatures

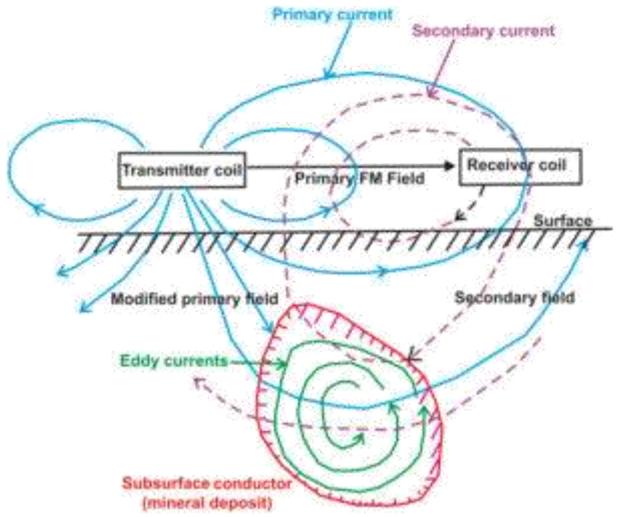


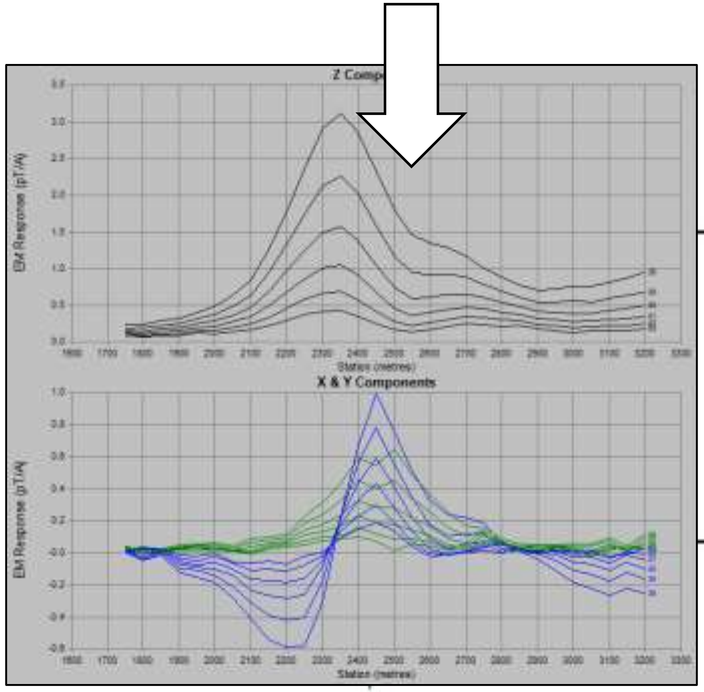


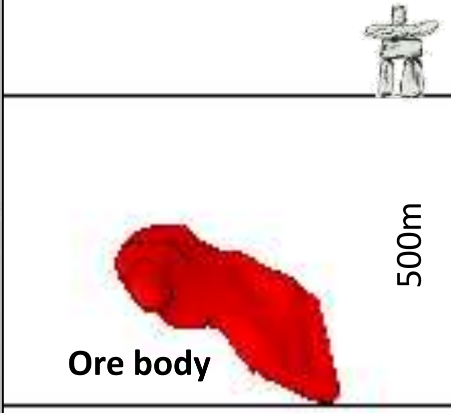




In conclusion







Timing settings
Transmitter current
Sensor sensitivity
Loop configuration
TX loop size & location

Nature & texture of exploration target
Shape of exploration target
Size & depth of exploration target
Geological setting

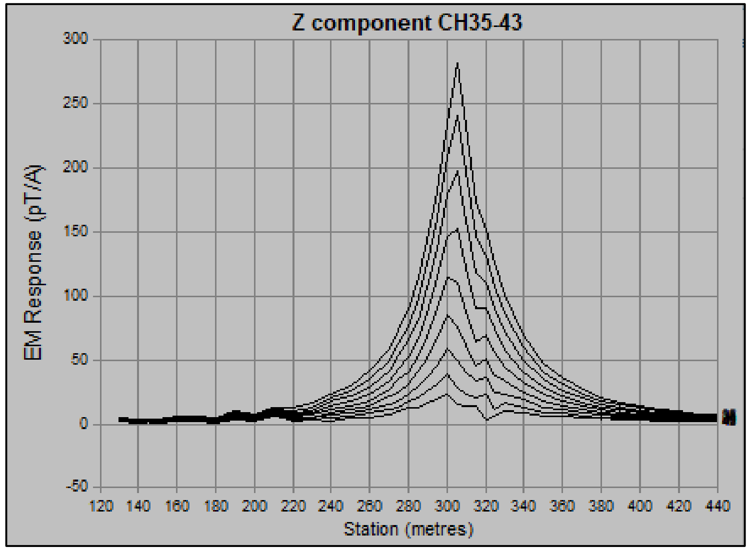
Infrastructures & cultural noise

Acknowledgements

Canadian Royalties inc.
Yueshi Lei, Maxim Boisvert & CRI Exploration team

MTNet - EMinars

Discovery Int'l Geophysics
MIRA Geoscience
& ALL our exploration partners



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