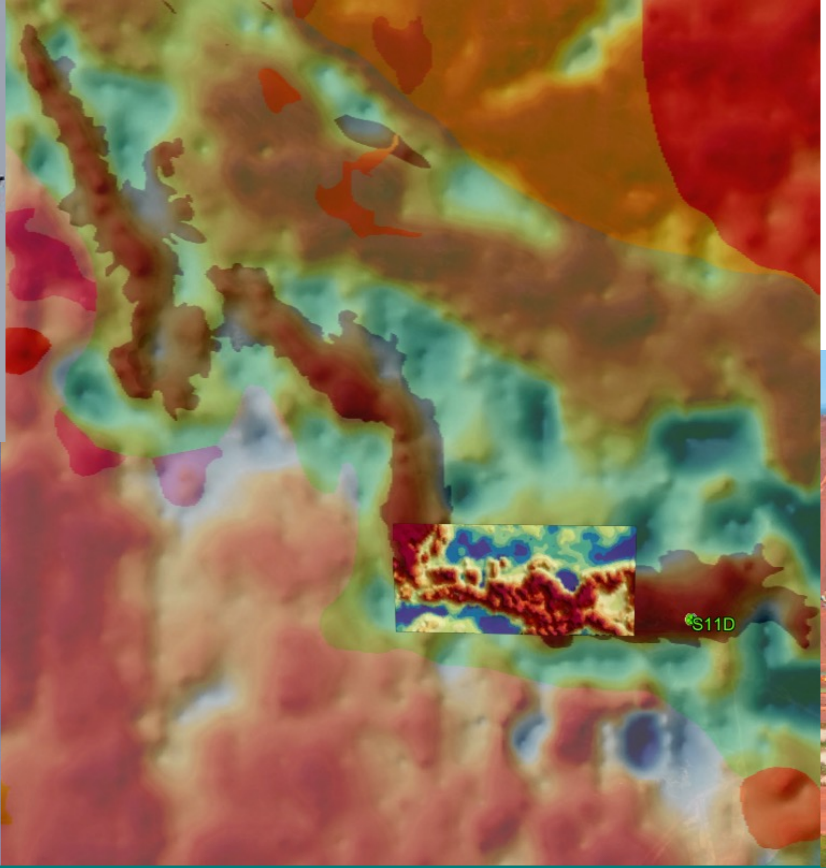
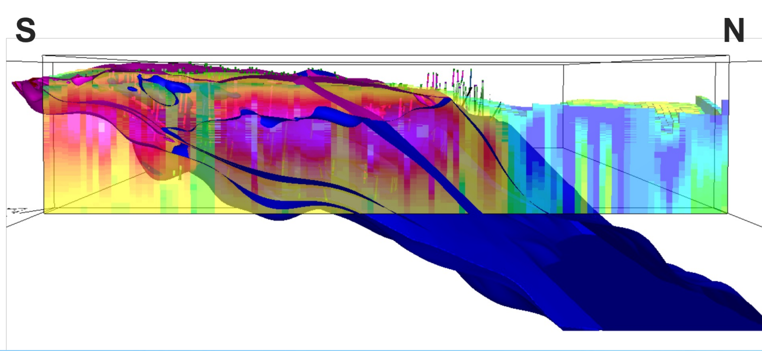




AEM Surveys Applied for Iron Formation Mapping: A Proxy for Iron Ore Exploration

Marco Antonio Couto Jr (marco.junior1@vale.com), Dionísio Uendro Carlos, Raphael Fernandes Prieto

Geophysics Team

Geological Data Governance and Technical Services

15/11/2023

3DEM 7th Edition

Nov 13 - 15, 2023

Vancouver, BC

VALE

Our Team - Innovation / Geophysics

Area of **specialists** that aims to promote **integration** between **geology**, **geophysics**, and **technological innovation** in the value chain of geosciences.

Our Mission:

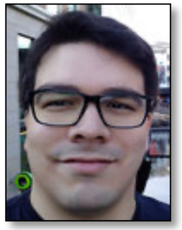
To develop and implement technological solutions:

- Optimization of geological/geophysical data acquisition processes;
- Improvement of the quality of acquired data, information and its availability;
- Reduction of risks in data acquisition tasks;
- Reduction of uncertainties in different geological processes through increased geological knowledge by integrating geoscience disciplines.

People:

PhD Dionísio Carlos
Master Geophysicist

MBA Debora Rossi
Master Geologist

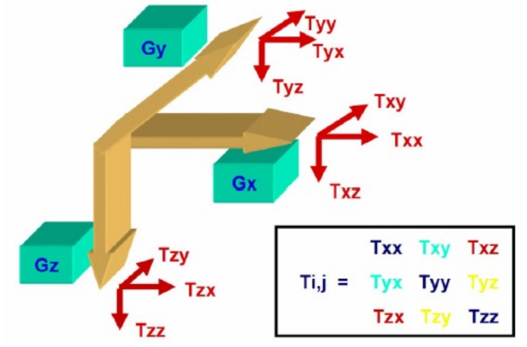


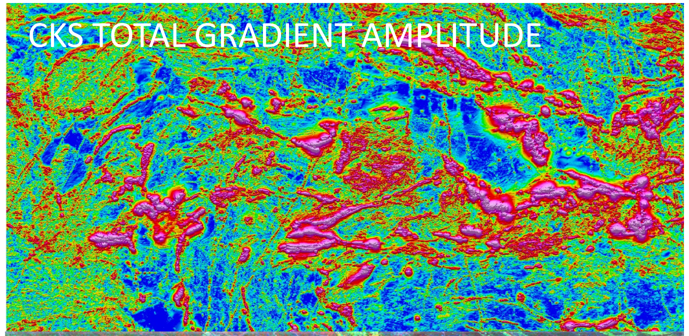
PhD Marco Junior
Master Geophysicist

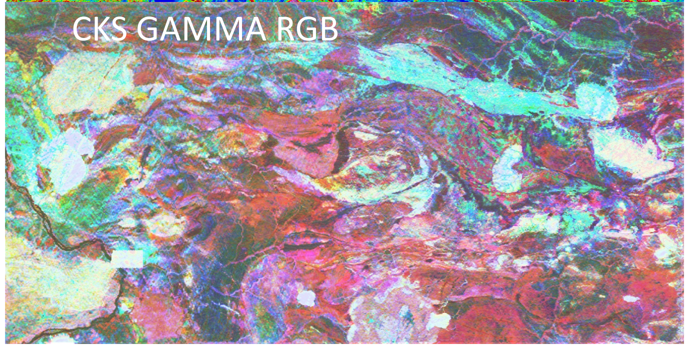
MSc Raphael Prieto
Master Geophysicist

BSc Hugo Oliveira
Intern

AIRBORNE GEOPHYSICS







Airborne Gravity Gradiometry (AGG)

FTG & FALCON

Regional Magnetics and Radiometrics

AEM (FDEM & TEM)

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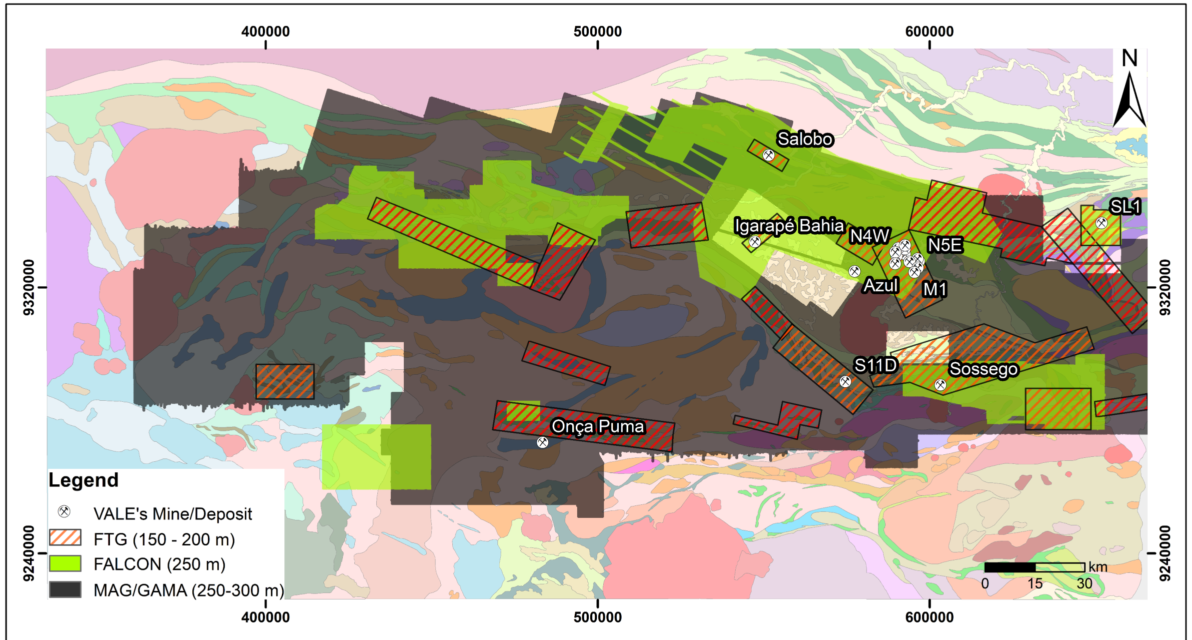
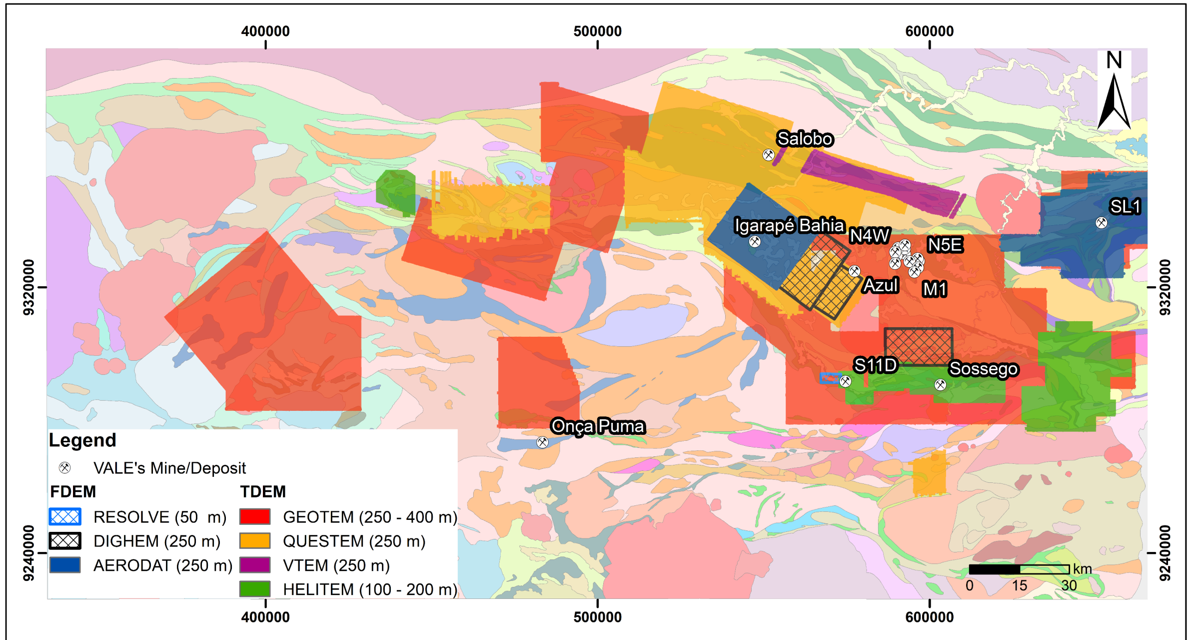
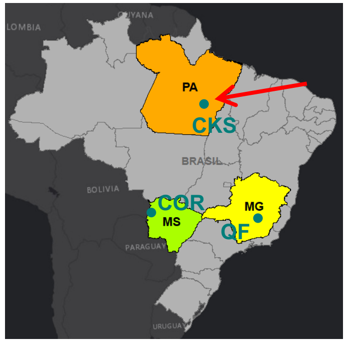
AIRBORNE GEOPHYSICS – CARAJÁS (CKS) MINERAL PROVINCE



Magnetics, Gamma and AGG (Falcon & FTG)

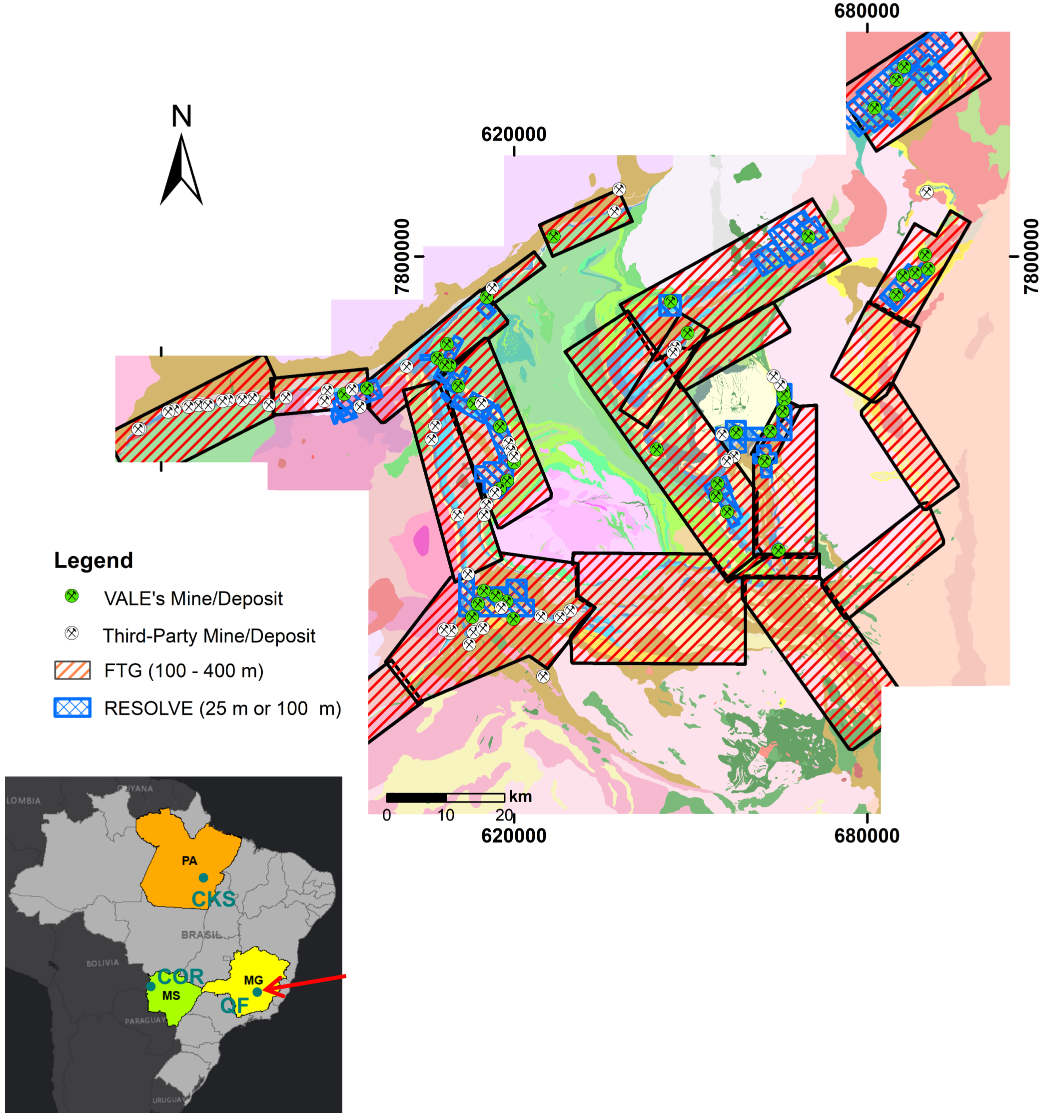


AEM (FDEM & TDEM)



	AEM System	Line - km	Line Sep. (m)	Year
TEM	GEOTEM	37587.2	250	1990's
	QUESTEM	16535.4	250	1990's
	VTEM	1197.1	250	2003
	Helitem	9338.2	200	2016, 2022
FDEM	Aerodat-5	6041.9	250	1990's
	DIGHEM-V	2311.0	250	1990's
	RESOLVE	327.0	50	2021

AIRBORNE GEOPHYSICS – QUADRILÁTERO FERRÍFERO (QF) MINERAL PROVIN

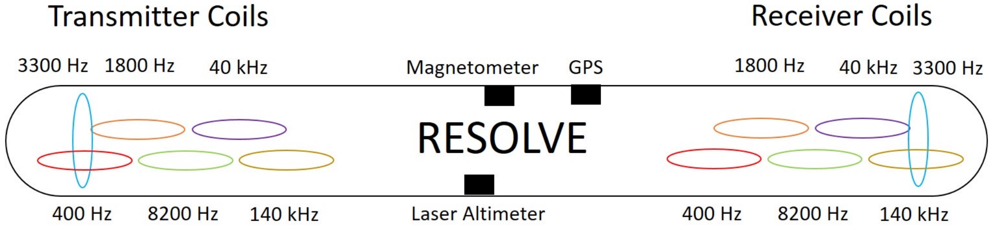


AGG (Falcon & FTG) and Magnetics

AEM (FDEM)

AEM System	Line - km	Line Sep. (m)	Year
RESOLVE	18658..0	25 or 100	2020-2021

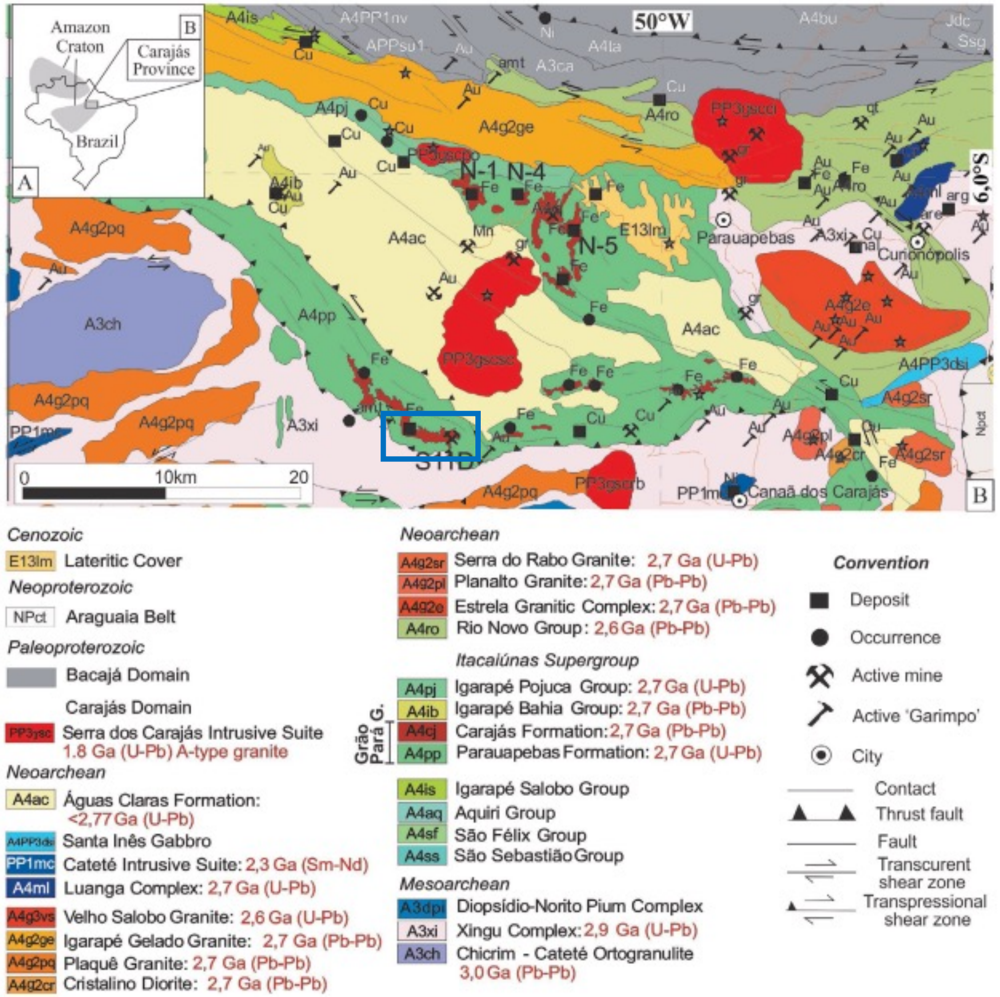
RESOLVE BIRD AND COILS



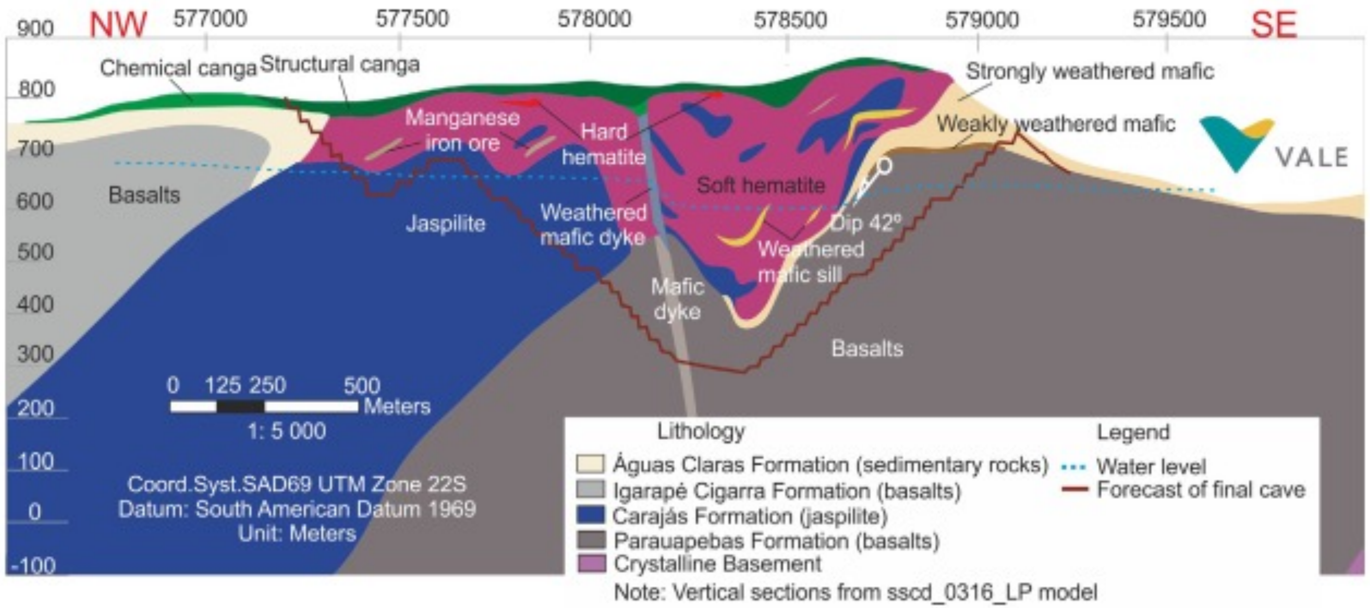
From http://em.geosci.xyz

S11D STUDY CASE

CARAJÁS REGIONAL GEOLOGY



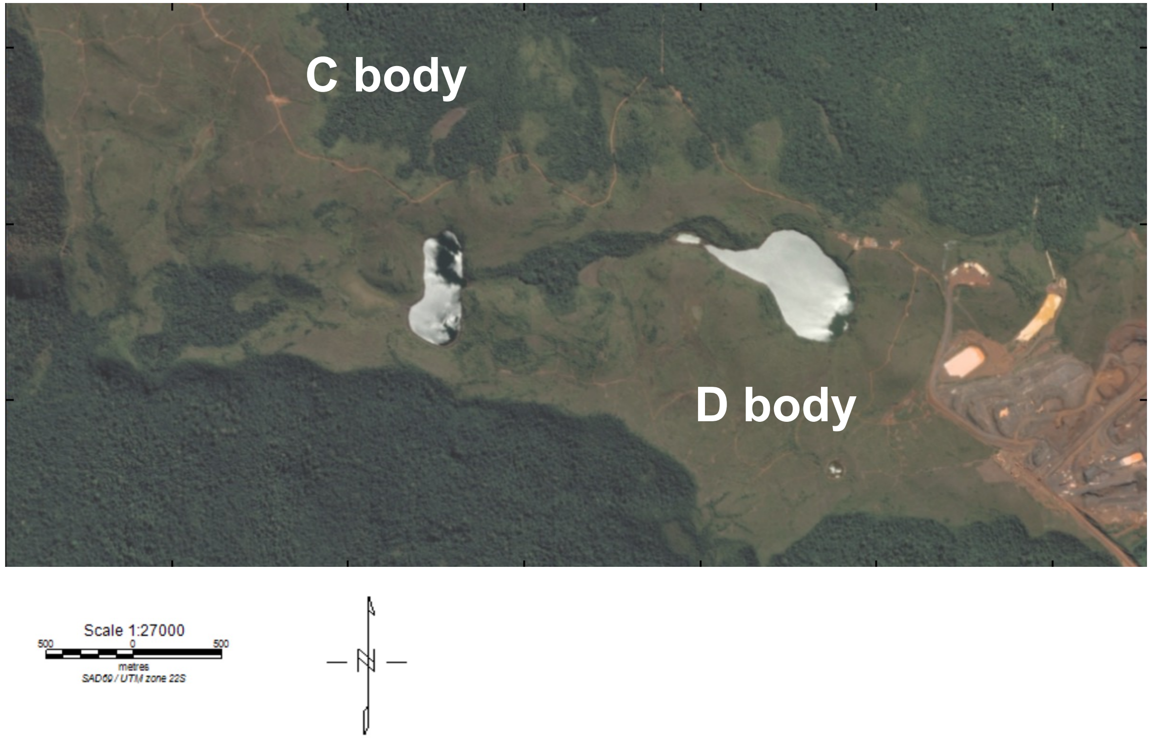
S11D LOCAL GEOLOGY



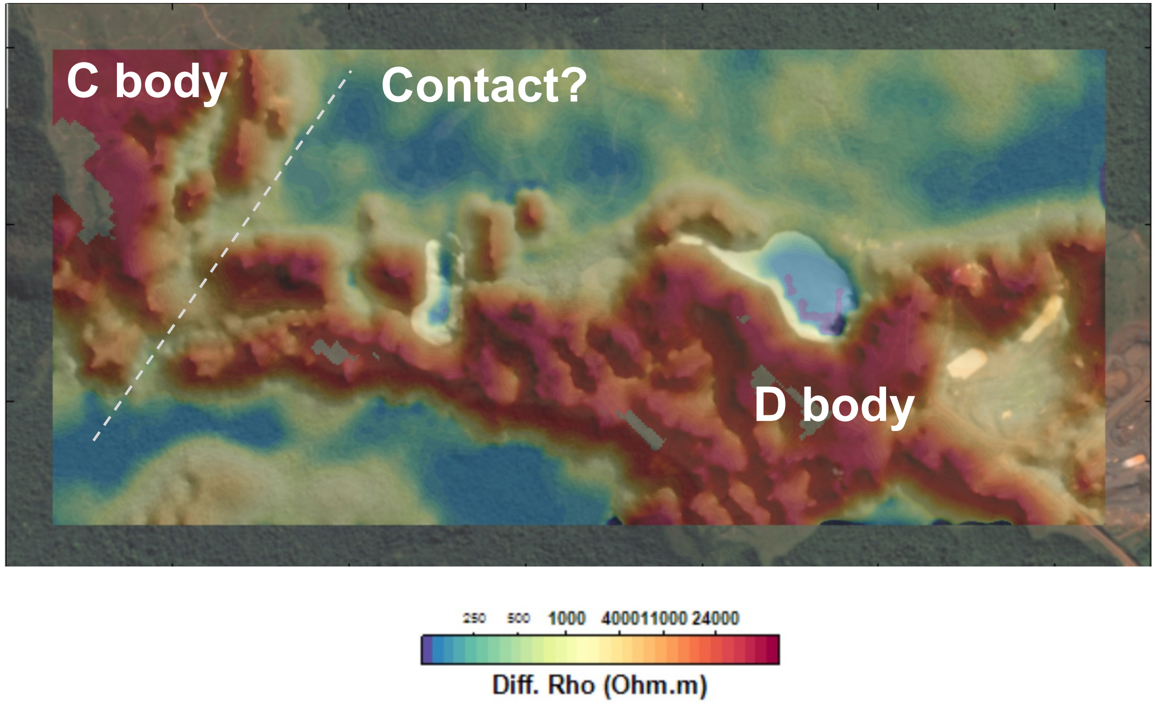
Supergene iron ore

Silva & Costa (2020)

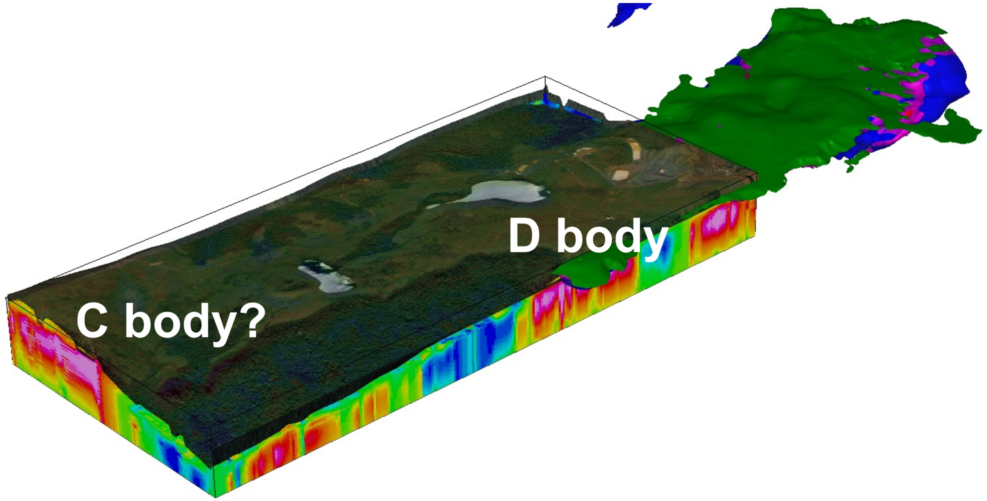
S11D STUDY CASE – RESOLVE SURVEY

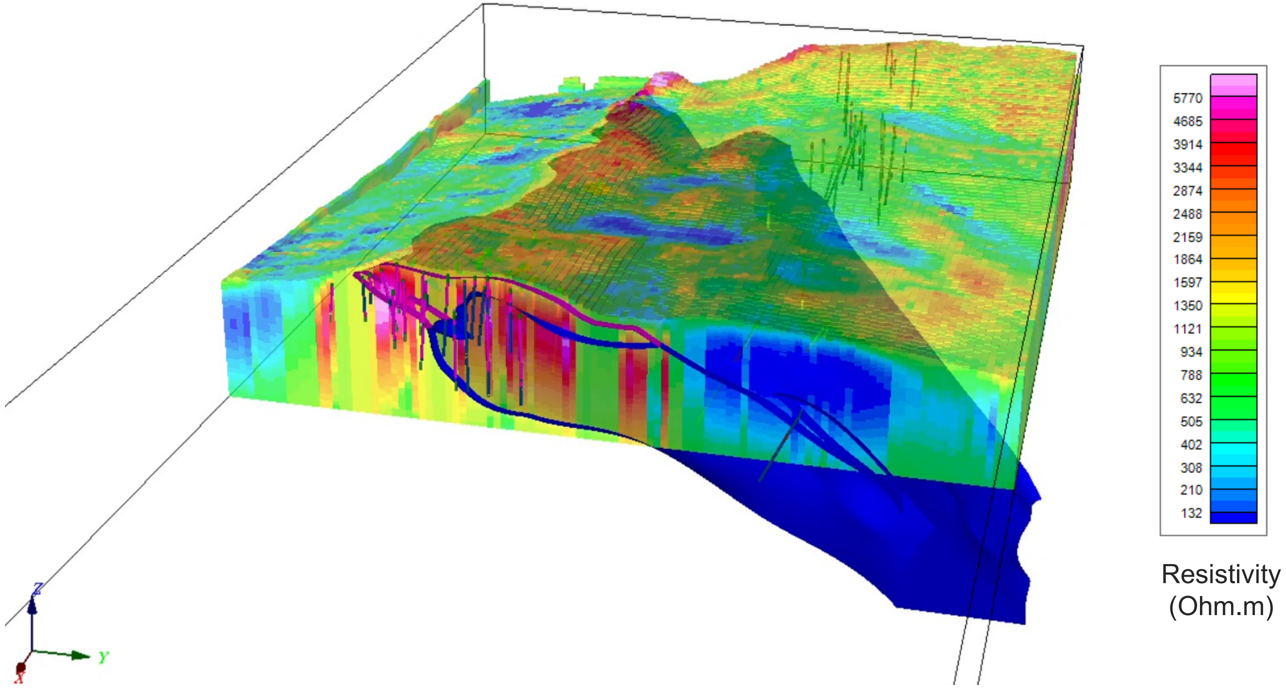


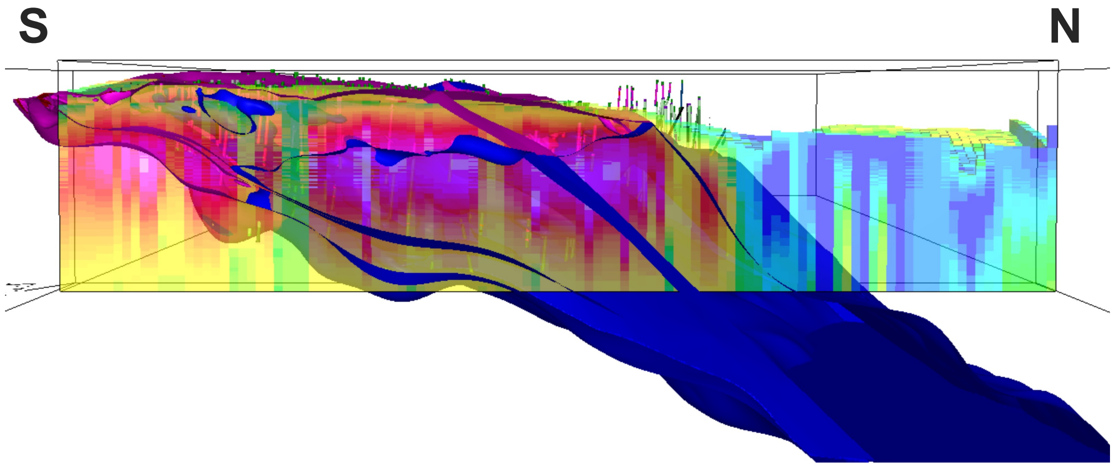
40 kHz

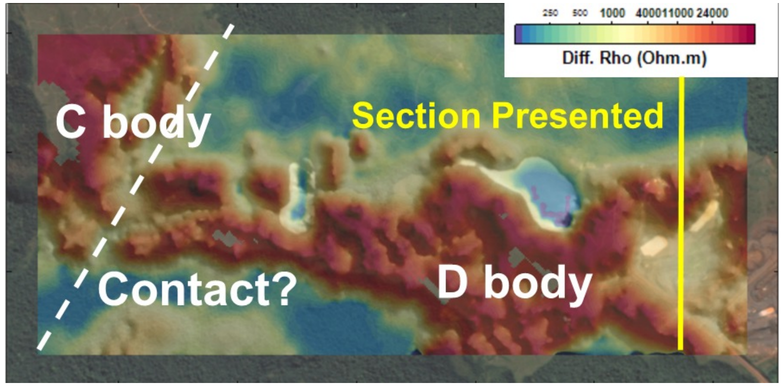


S11D STUDY CASE – RESOLVE SURVEY









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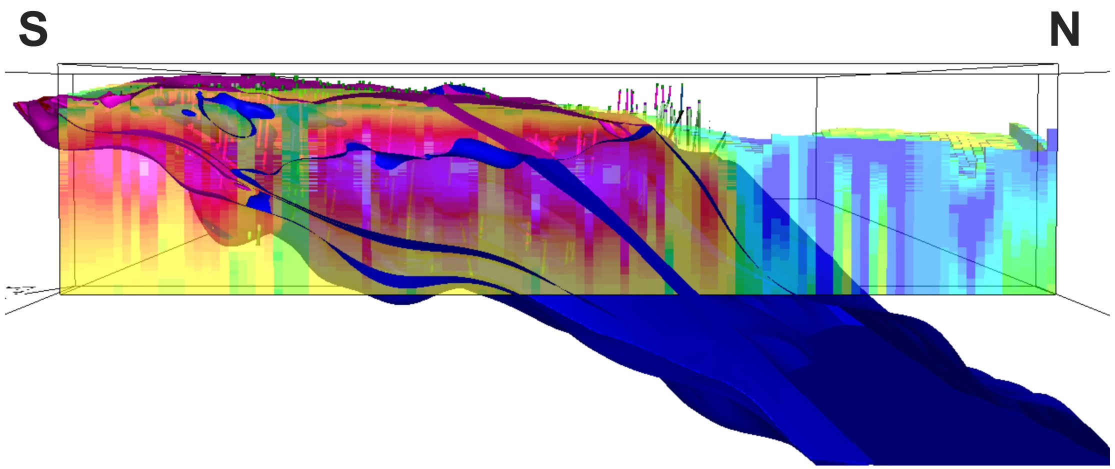
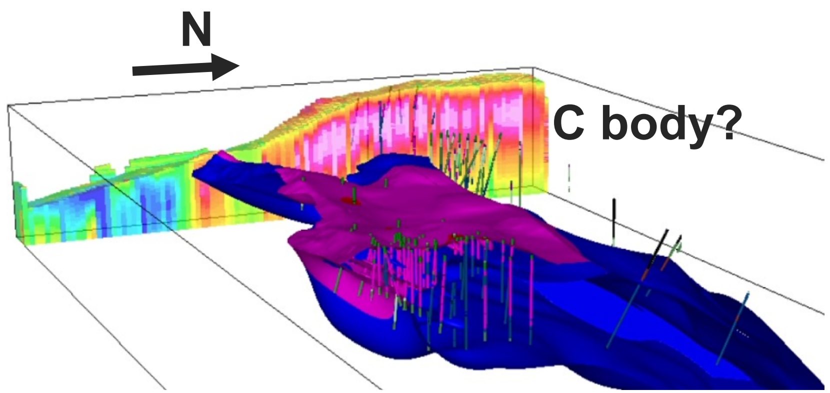
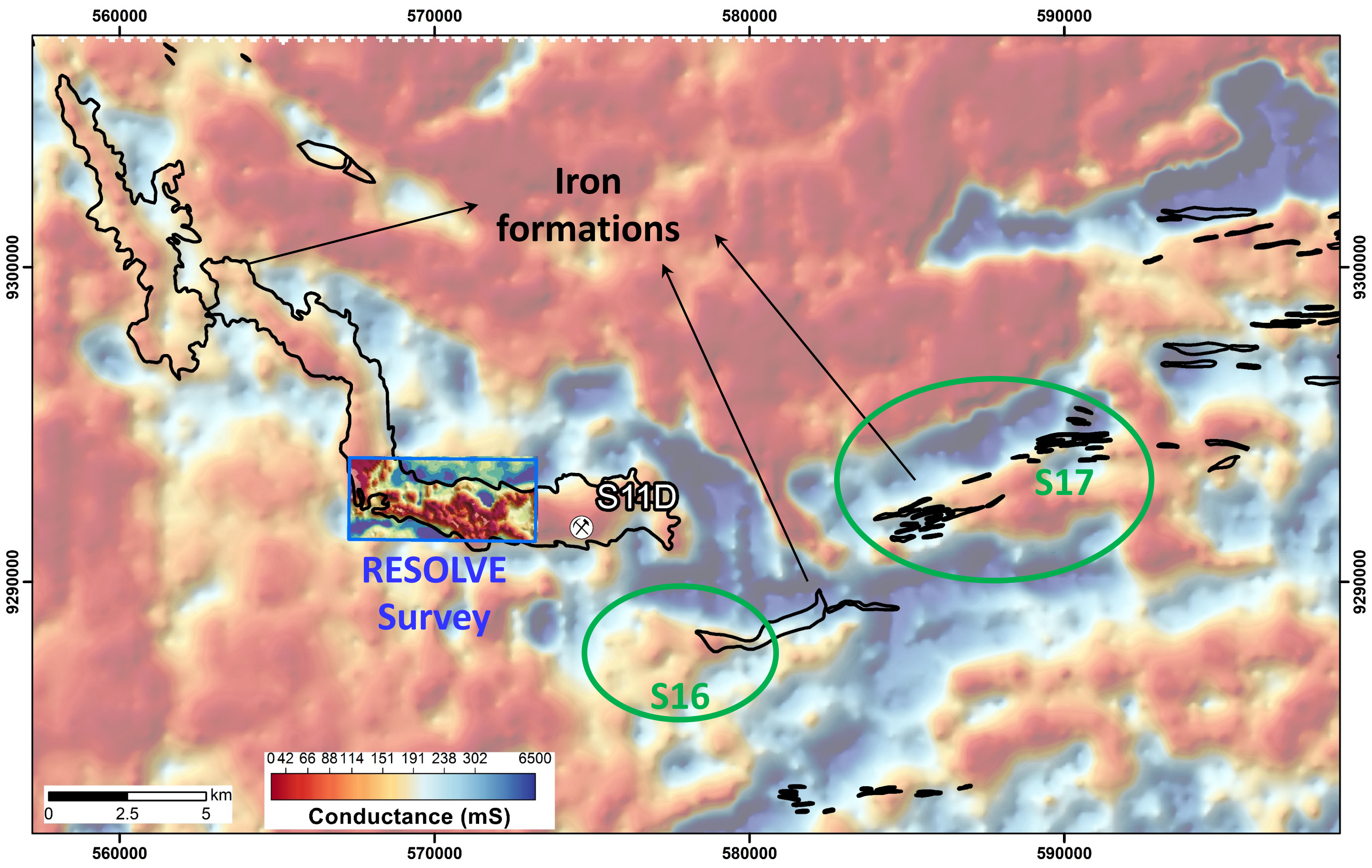
S11D STUDY CASE – RESOLVE SURVEY

- Good spatial correlation between RESOLVE resistive domains and the banded iron formation. However, it could not distinguish between friable hematite (magenta) and compact jaspilite (blue);
- It maps the contact between mafic (conductive domain) and iron formation (resistive domain);
- New targets indication beyond the known geological model;
- Contact between C and D bodies?





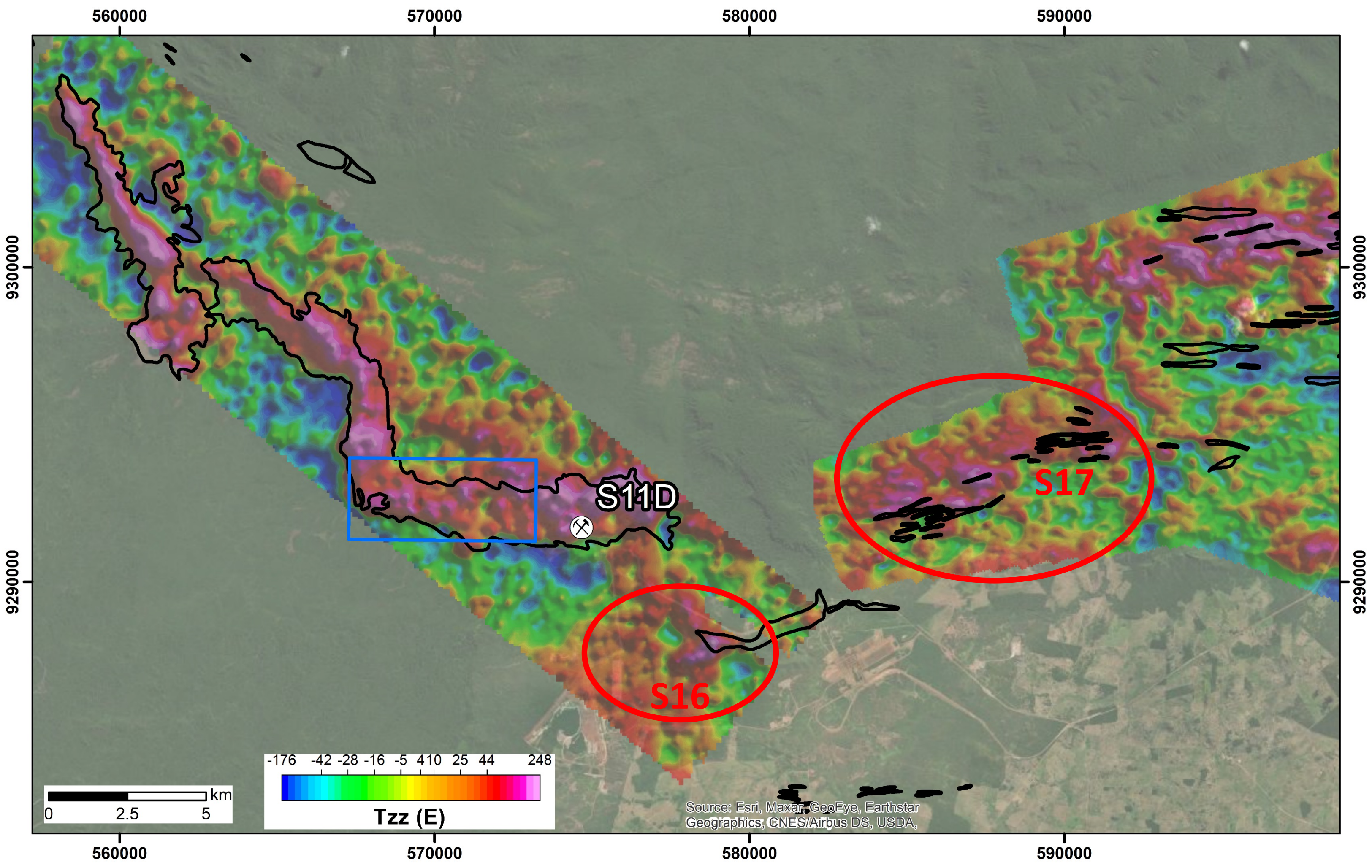
S11D STUDY CASE – AEM, AGG & AMAG



GEOTEM and RESOLVE

- The whole S11 iron formation is marked by a strong resistor by the apparent conductance data from the GEOTEM survey.
- RESOLVE high resistive anomaly in good agreement with the resistive domain in S11D.
- S16 and S17 targets are correlated with high resistive regions as well.

S11D STUDY CASE – AEM, AGG & AMAG



Full Tensor Gravity Gradiometry (FTG)

- The standard approach in terms of iron ore exploration.
- Iron formations are well marked by high density anomalies.
- Strong spatial correlation between higher values of Tzz and resistive zones.

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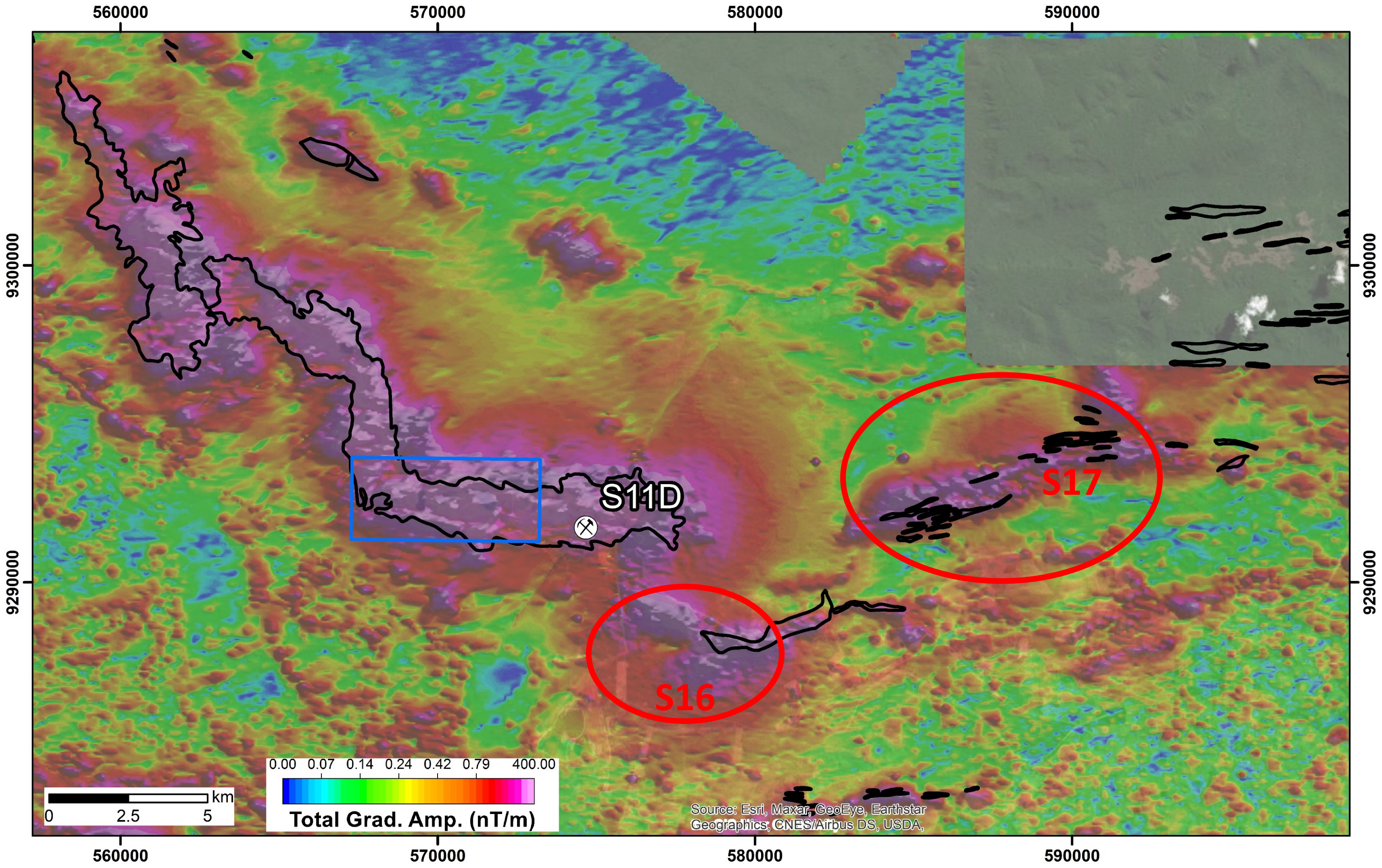
S11D STUDY CASE – AEM, AGG & AMAG



Airborne Magnetivcs (AMAG)

- Important ancillary for the AGG data.
- Good spatial correlation with known iron bodies.
- It is also well spatially correlated with AEM and AGG data.

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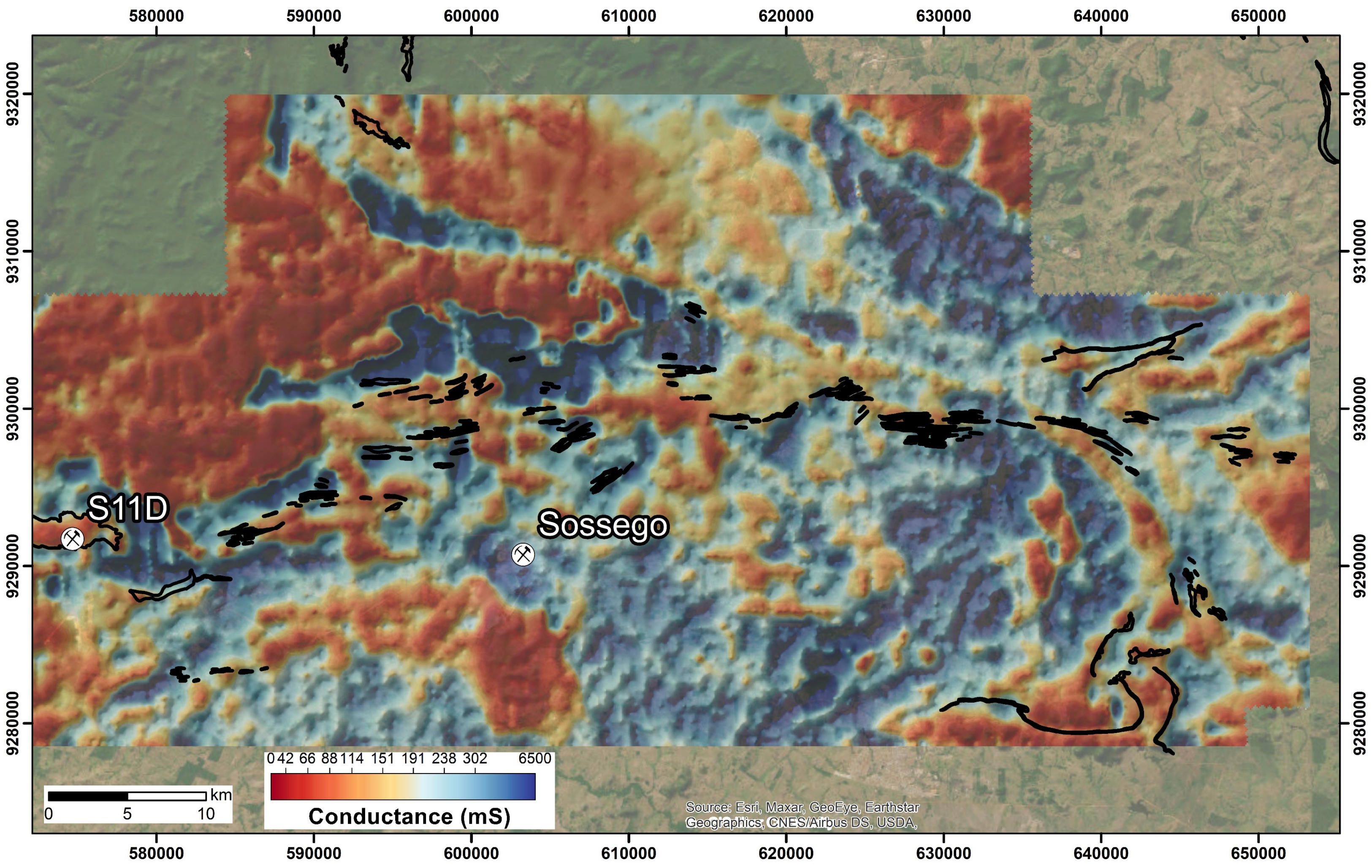
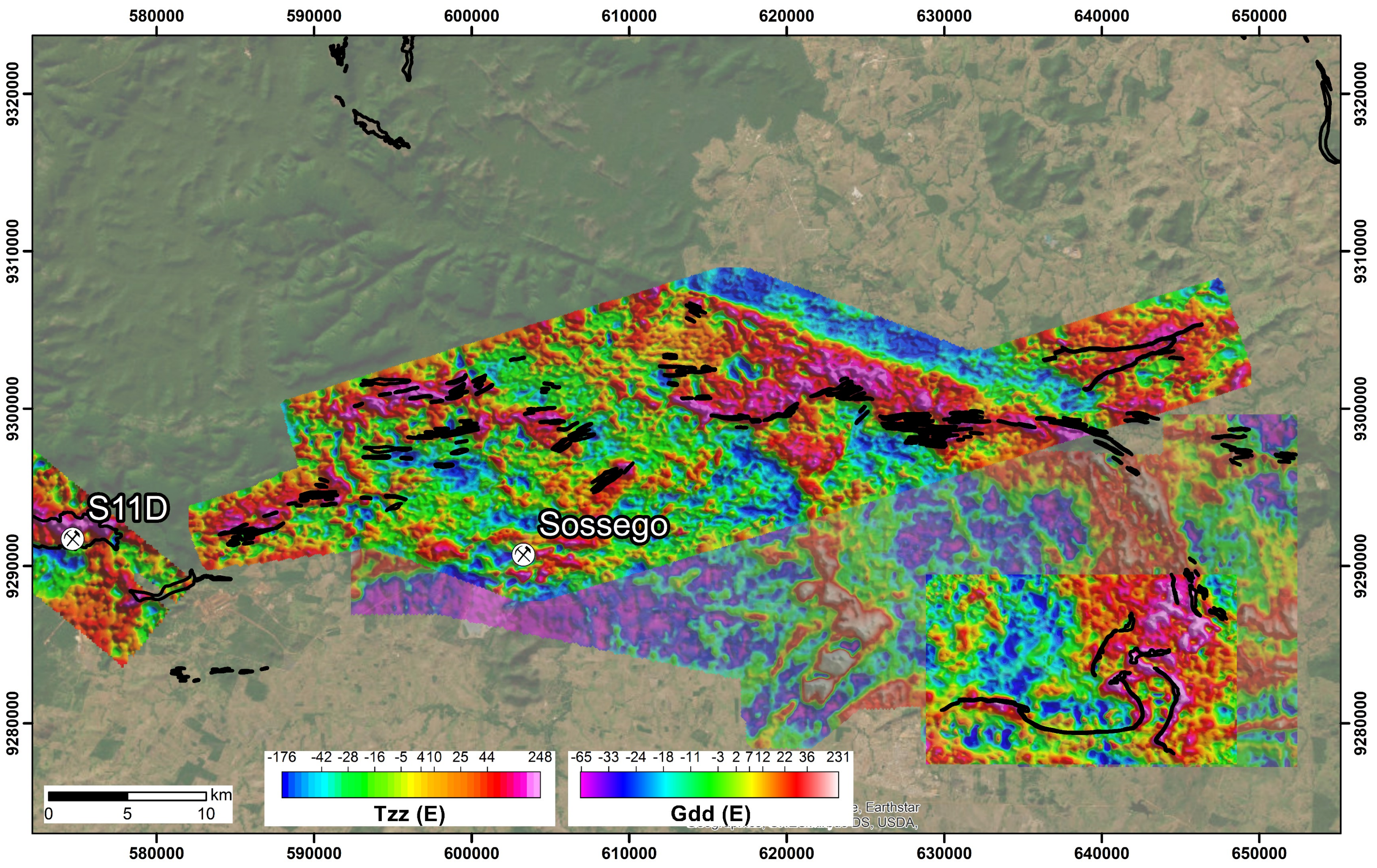
CARAJÁS PROVINCE –AEM, AGG & AMAG (SOUTHERN AREA)



Regional Anomalies

- The pattern about resistive anomalies related to known iron formation stands in a regional sense.
- This also holds for AGG and AMAG anomalies.

CARAJÁS PROVINCE –AEM, AGG & AMAG (SOUTHERN AREA)



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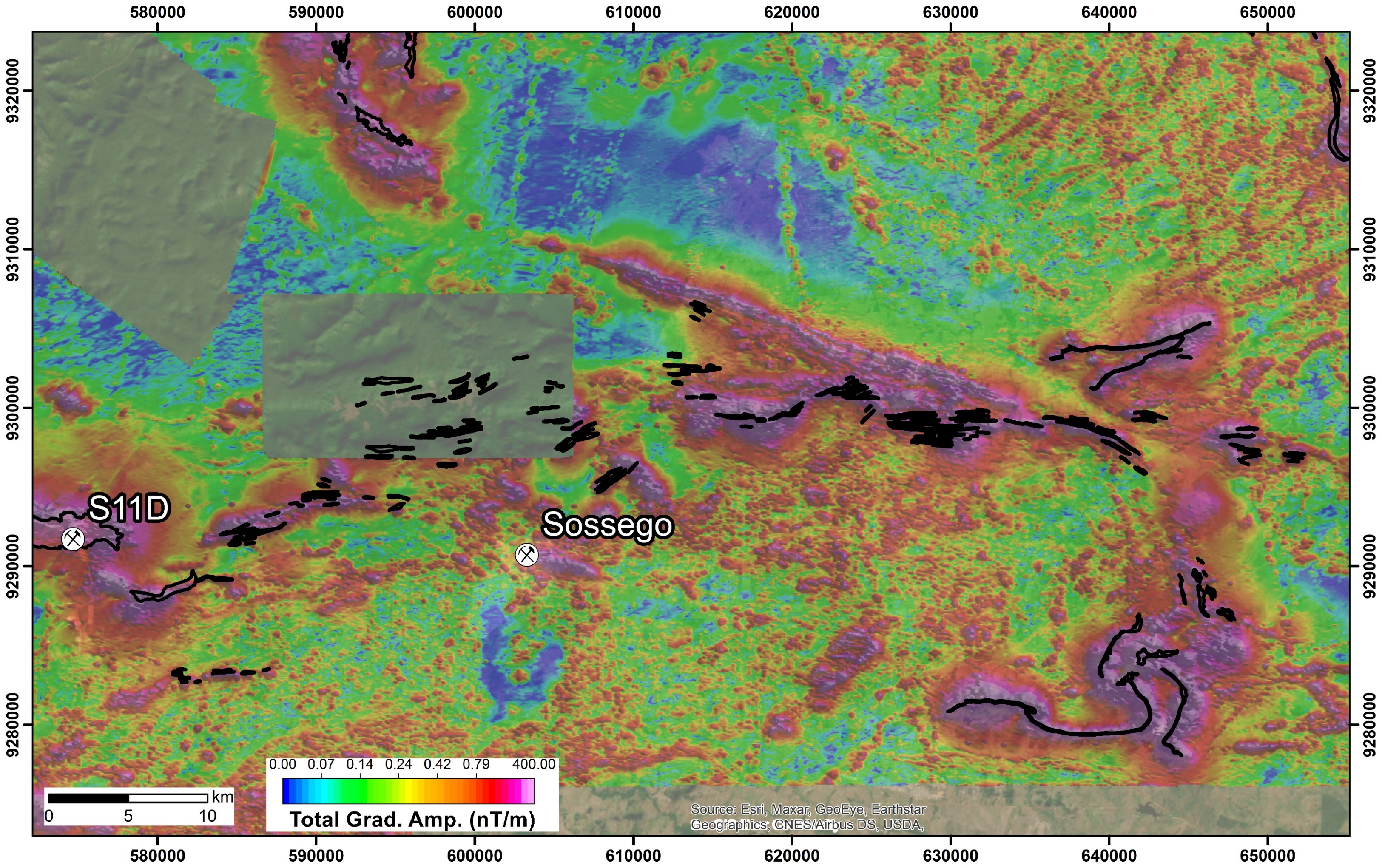
CARAJÁS PROVINCE –AEM, AGG & AMAG (SOUTHERN AREA)



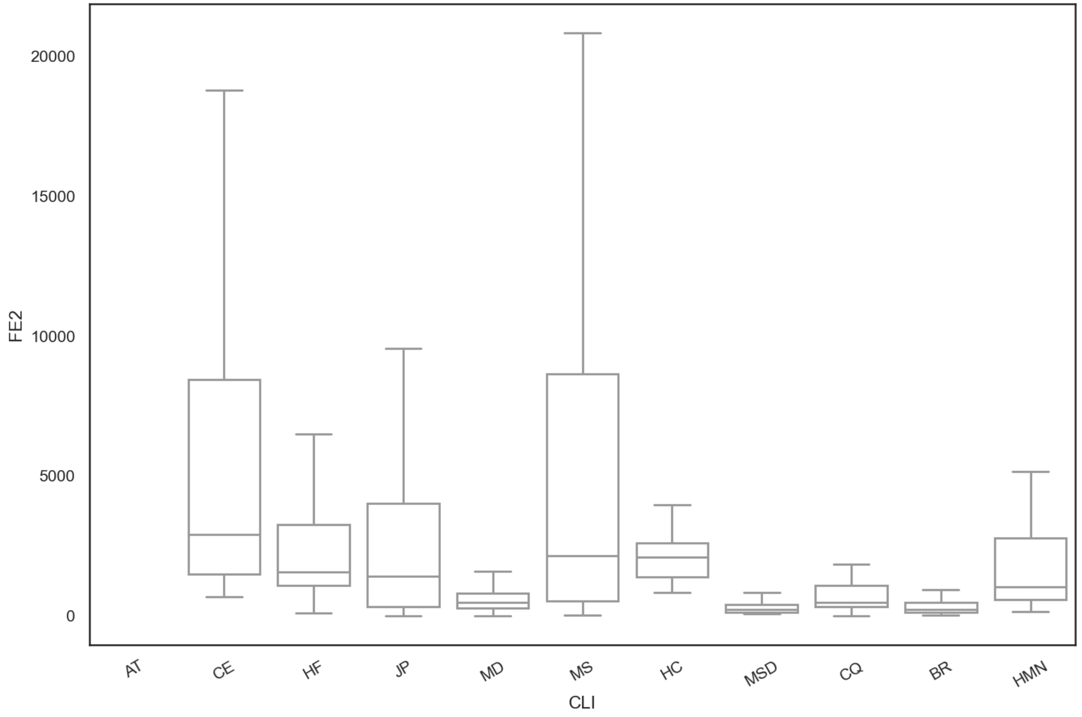
Regional Anomalies

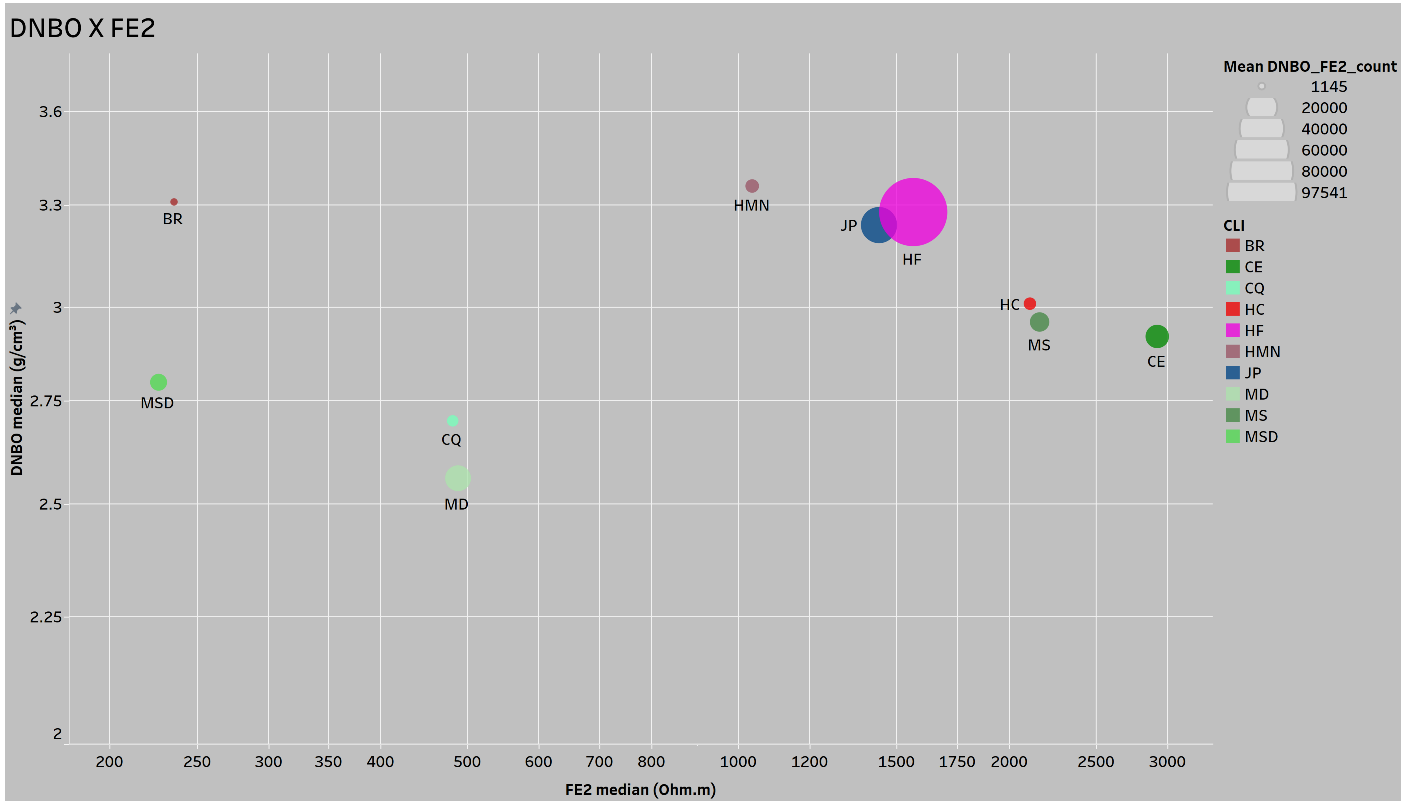
- The pattern about resistive anomalies related to known iron formation stands in a regional sense.
- This also holds for AGG and AMAG anomalies.

WHAT DOES THE PETROPHYSICS TELL US?

- **Database:** Multitools Borehole Geophysics
- 18 boreholes – 6899.44 m sampling interval
- **Measurements:**
  - Gamma-gamma density (DNBO);
  - Laterolog (FE2);

WHAT DOES THE PETROPHYSICS TELL US?





Legend

CE – Structural canga
CQ – Chemical canga
HF – Friable hematite
HC – Compact hematite
HMN – Manganese-hematite

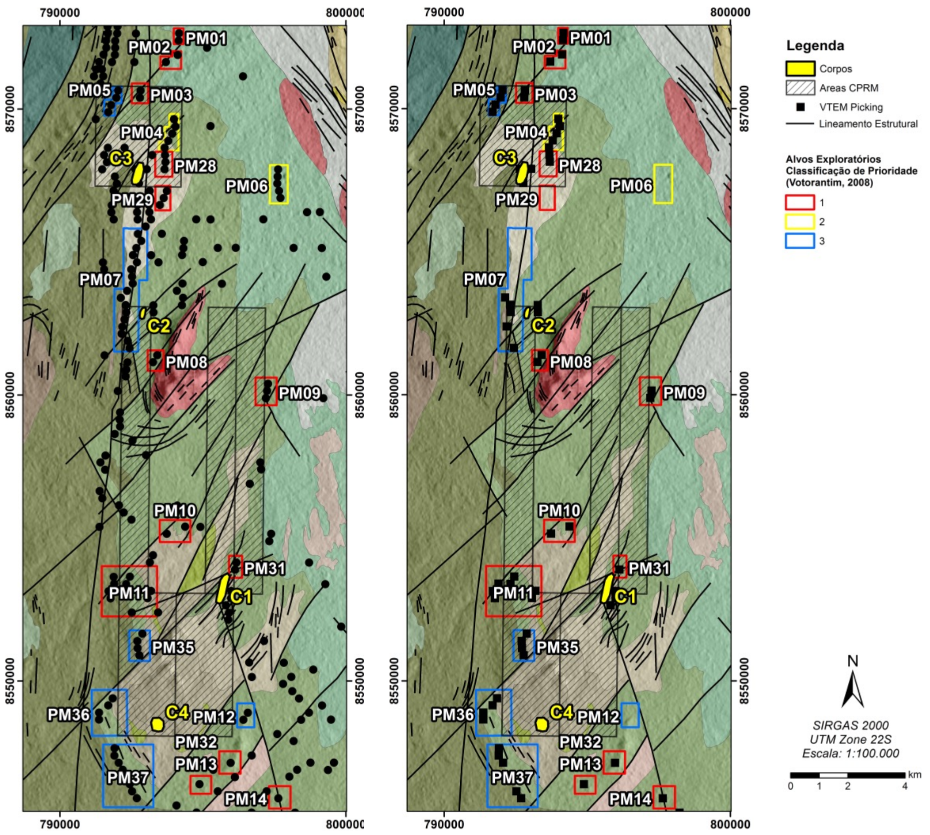
JP – Jaspilite
MD – Weathered mafic rock
MSD – Partially weathered mafic rock
MS – Preserved mafic rock
BR – Breccia

SO... HIGH RESISTIVE ANOMALIES MATTER!

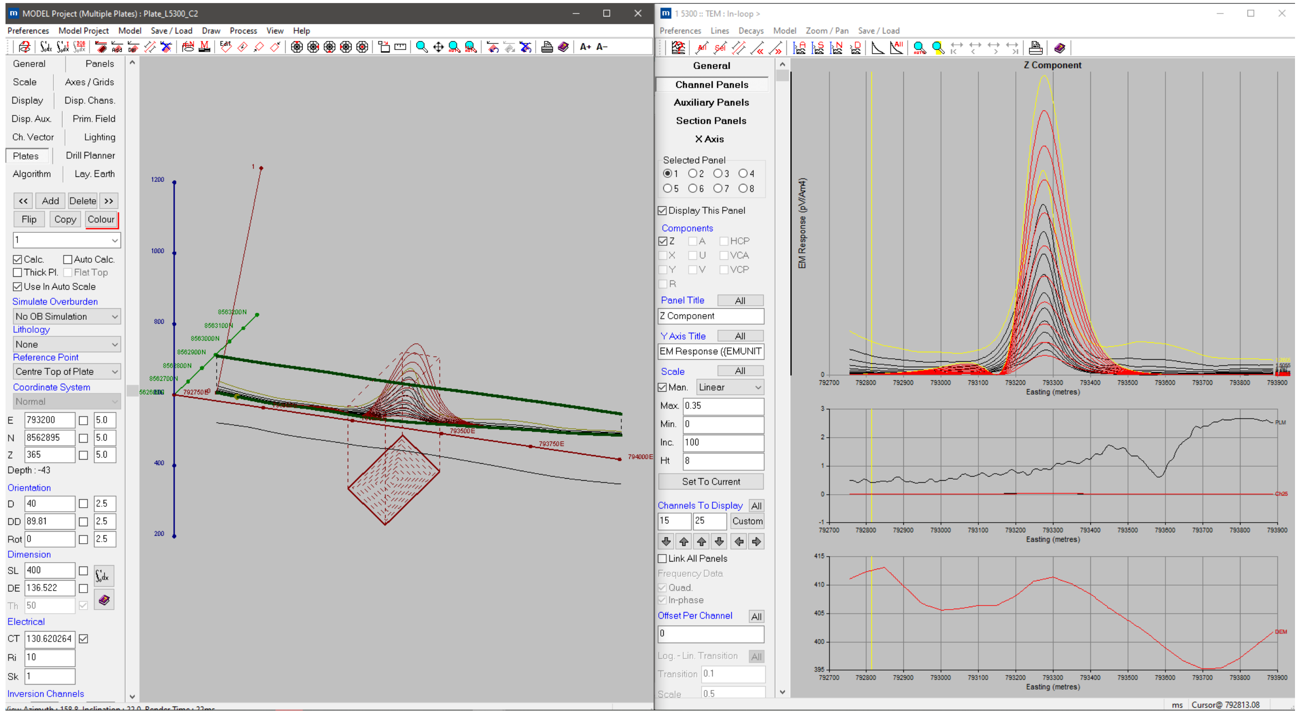
OK... BUT WHAT IS THE BEST WAY TO DEAL WITH AEM DATA THEN?

Standard Approach: Conductors Picking & Parametric Modeling (Palmeirópolis Case)

Conductive Picking Selection



Parametric Modeling

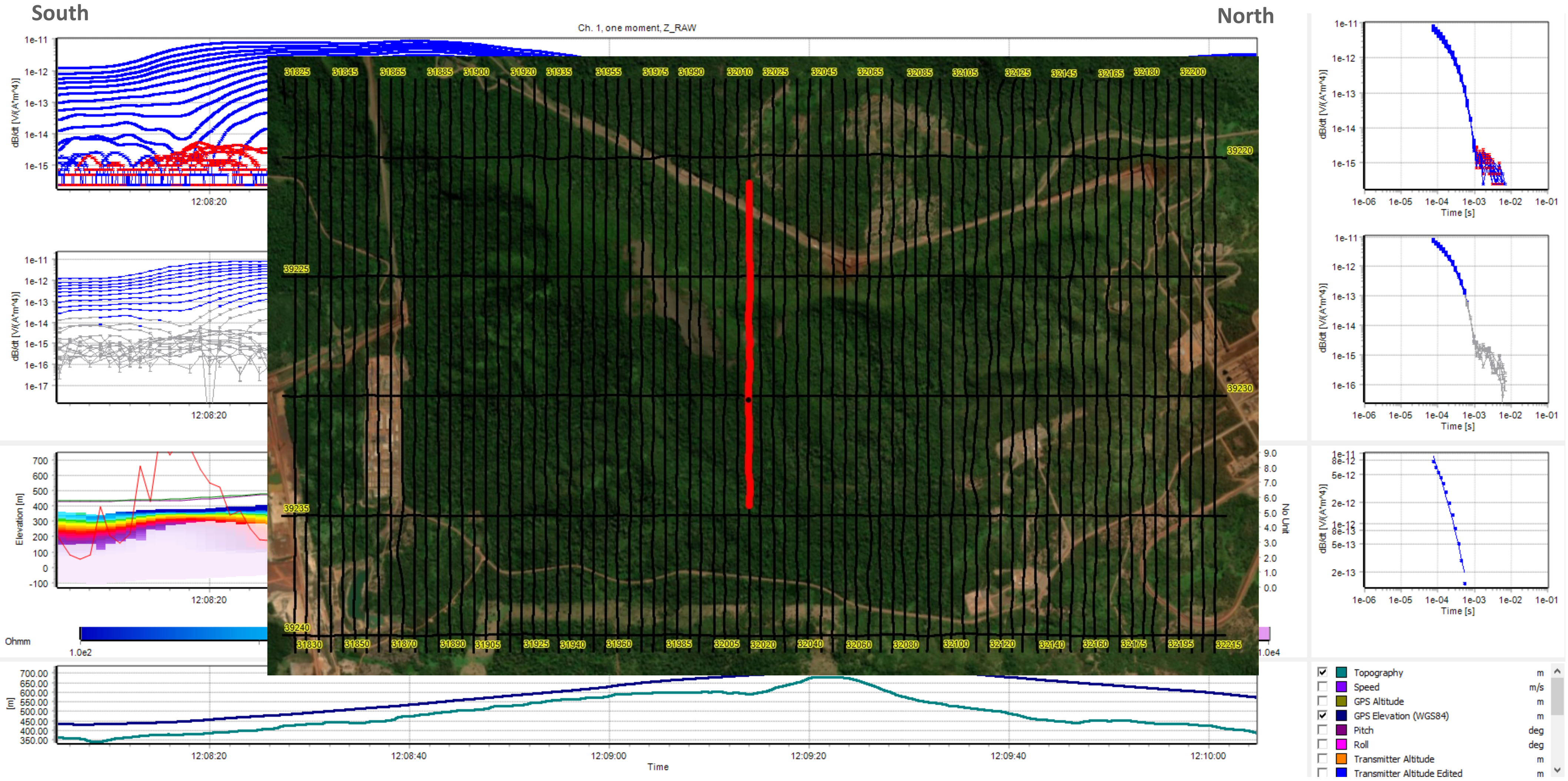


Couto et al. (2020)

OK... BUT WHAT IS THE BEST WAY TO DEAL WITH AEM DATA THEN?

- Yep... It works quite good for conductos. But we are dealing with very resistive environment.
- We need to address the resistivity model properly.
- 1D inversions? – LCI or SCI?
- 3D inversions???
- What about IP effect?
- Lots of magnetite... Is superparamagnetic effect relevant?

OK... BUT WHAT IS THE BEST WAY TO DEAL WITH AEM DATA THEN?



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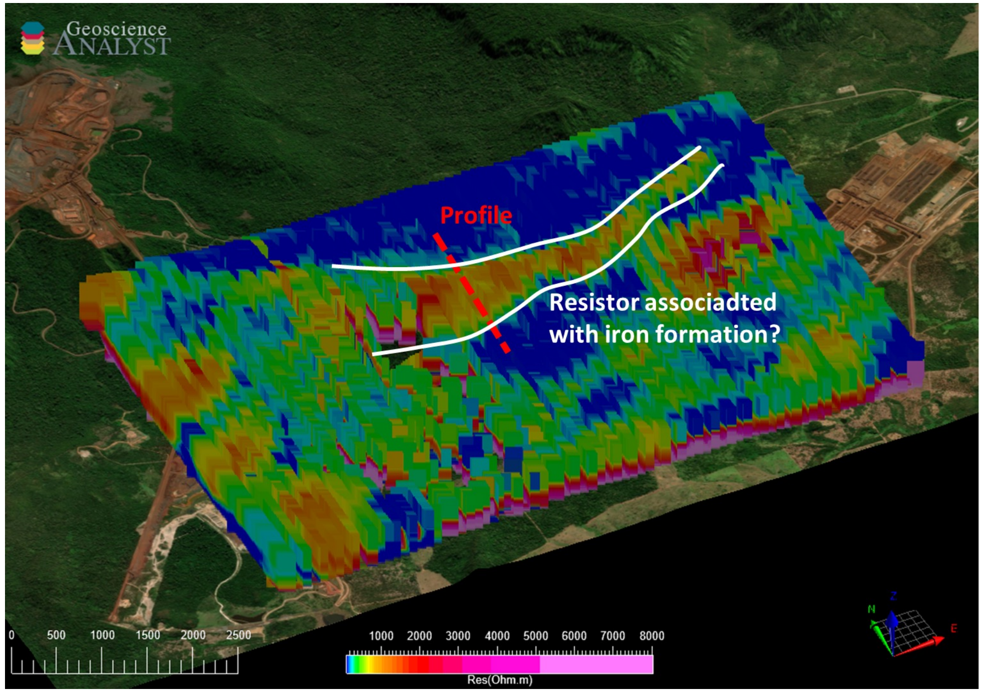
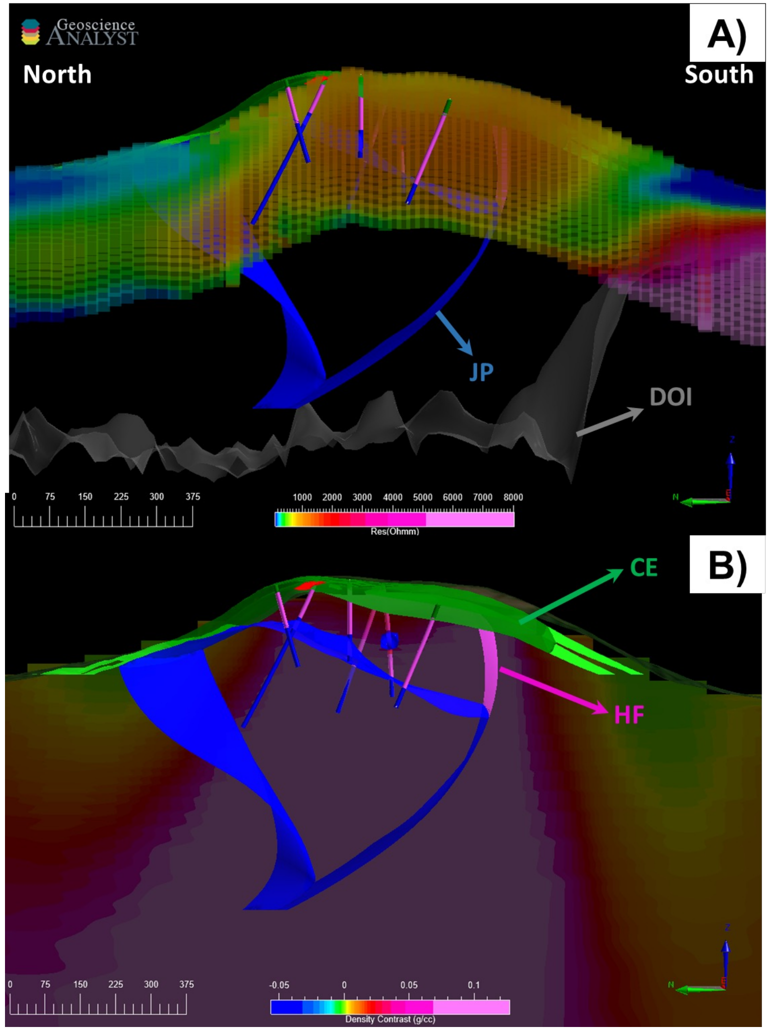
S16 TARGET STUDY CASE – HELITEM SURVEY

OK... BUT WHAT IS THE BEST WAY TO DEAL WITH AEM DATA THEN?





Accelerated Development for Geoscience Analyst. It covered:

- AEM Data Processing.
- Joint Inversions – AGG, AEM and AMAG (Cross-Gradient)
- Case Study: S16 Target

Mira Geoscience
...modelling the earth

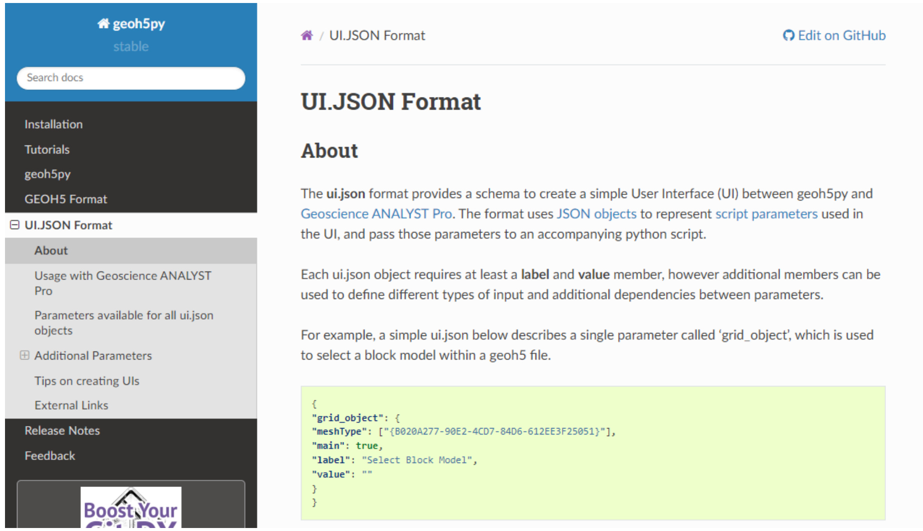
Geoscience ANALYST

GitHub

Vale-RnD repo

python™ jupyter

Development and Documentation



UI.JSON format to run all in GA

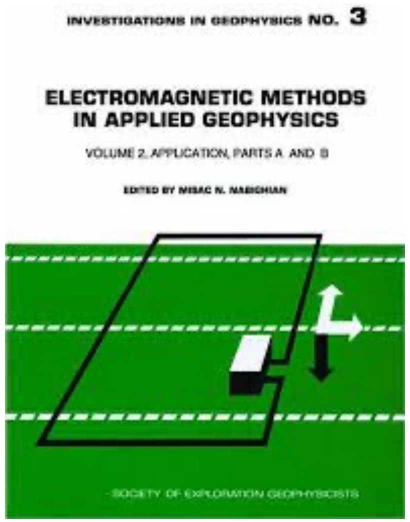
Ideas based on:

CSIRO PUBLISHING
www.publish.csiro.au/journals/eg
Exploration Geophysics, 2009, 40, 184–192

An integrated processing scheme for high-resolution airborne electromagnetic surveys, the SkyTEM system

Esben Auken[1,5] Anders Vest Christiansen[2] Joakim H. Westergaard[3]
Casper Kirkegaard[1] Nikolaj Foged[1] Andrea Viezzoli[4]

[1]The Hydrogeophysics Group, Department of Earth Sciences, University of Aarhus, Høegh-Guldbergs Gade 2, DK-8000 Aarhus C, Denmark.
[2]Geological Survey of Denmark and Greenland – GEUS, Department of Groundwater Mapping, Lyseng Alle 1, DK-8270, Højbjerg, Denmark.
[3]Orbicon A/S, Department of Water Resources and Applied Geophysics, Jens Juuls Vej 16, DK-8260, Viby J, Denmark.
[4]Aarhus Geophysics, Høegh-Guldbergs Gade 2, DK-8000 Aarhus C, Denmark.
[5]Corresponding author. Email: esben.auken@geo.au.dk



... and other papers...

Airborne EM Processing

This chapter covers the various tools developed for the processing of airborne electromagnetic data.

Table of content

Jupyter Notebooks Docs

jupyter Quit Logout

Files | Running | Clusters

Select items to perform actions on them.

Upload | New | ⟳

0 / airborne_em

Name		Last Modified	File size
..		há poucos segundos	
images		há 10 dias	
altitude_correction.ipynb	Running	há 4 dias	21.7 kB
altitude_correction.py		há 10 dias	14.3 kB
apparent_resistivity.ipynb	Running	há 10 dias	19.1 kB
apparent_resistivity.py		há 10 dias	13.5 kB
convolution_filters.ipynb	Running	há 5 horas	777 kB
convolution_filters.py		há 10 dias	15.4 kB
decay_constant.ipynb	Running	há 10 dias	18.5 kB
decay_constant.py		há 10 dias	11.9 kB
decay_slope_filter.ipynb	Running	há 10 dias	29.9 kB
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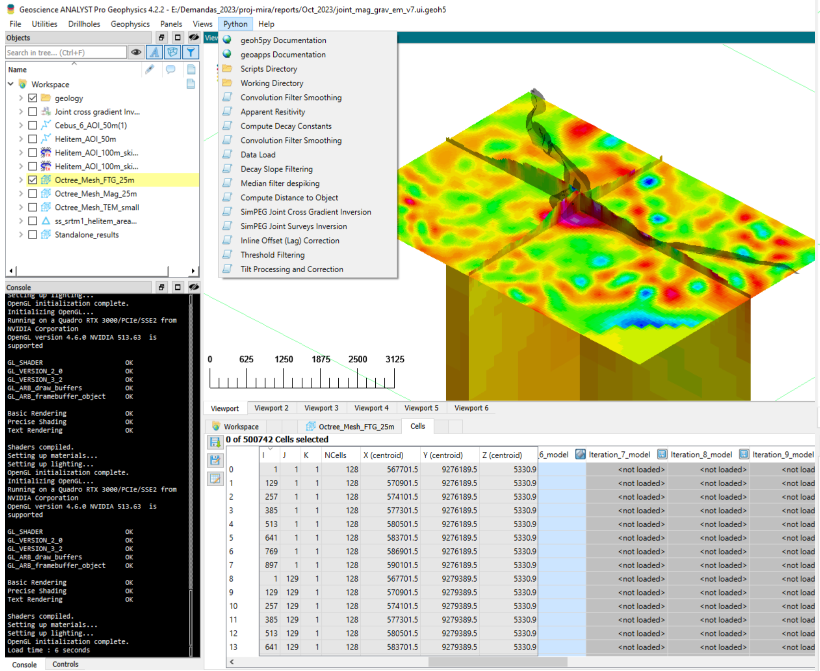
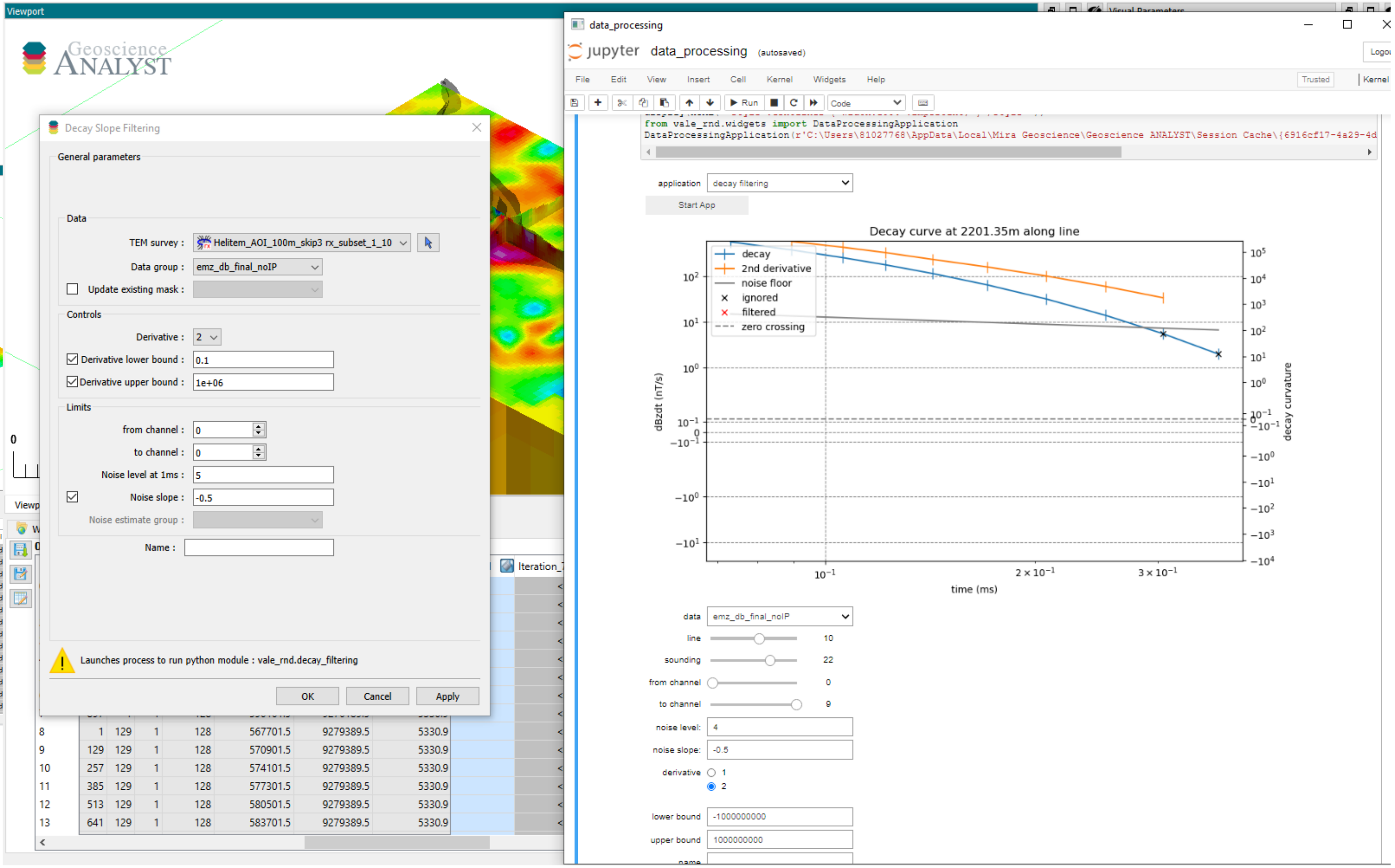
despiking.ipynb	Running	há 10 dias	24 kB
despiking.py		há 10 dias	17.4 kB
index.ipynb	Running	há 10 dias	4.14 kB
index.py		há 10 dias	3.1 kB
lag_correction.ipynb		há 10 dias	13.6 kB
lag_correction.py		há 10 dias	9.23 kB
threshold_filter.ipynb	Running	há 10 dias	15 kB
threshold_filter.py		há 10 dias	10.6 kB
tilt_correction.ipynb	Running	há 3 dias	17.4 kB
tilt_correction.py		há 10 dias	9.71 kB

UI.JSON in action!



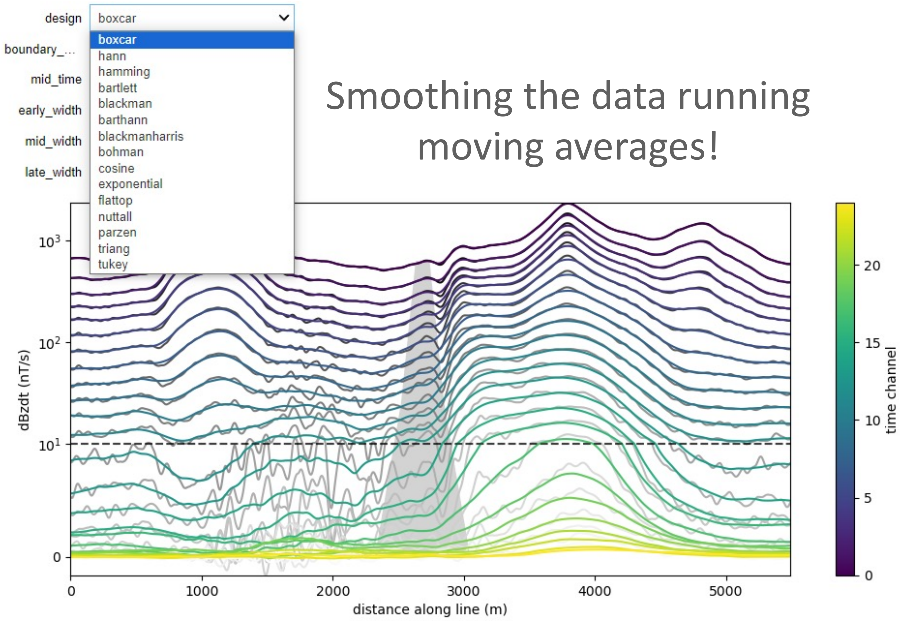
Pick the processing mode in the Python menu.



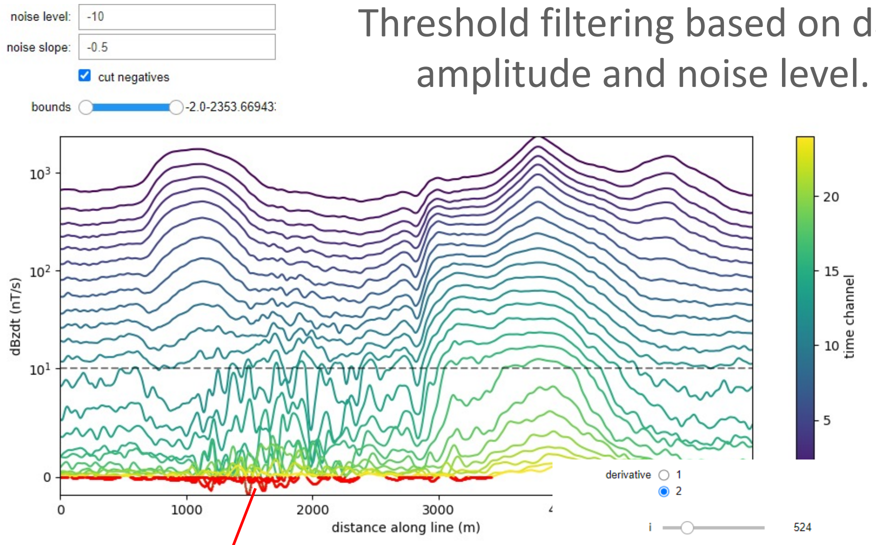
Then, you can setup/test parameters and run for the whole survey interval.

Some of the cool stuff we can do!

Smoothing the data running moving averages!

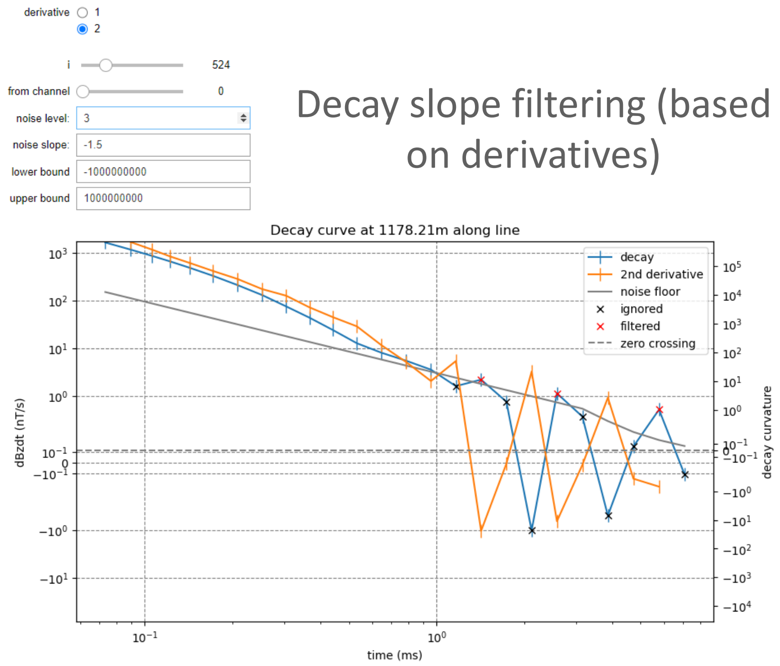


Threshold filtering based on data amplitude and noise level.

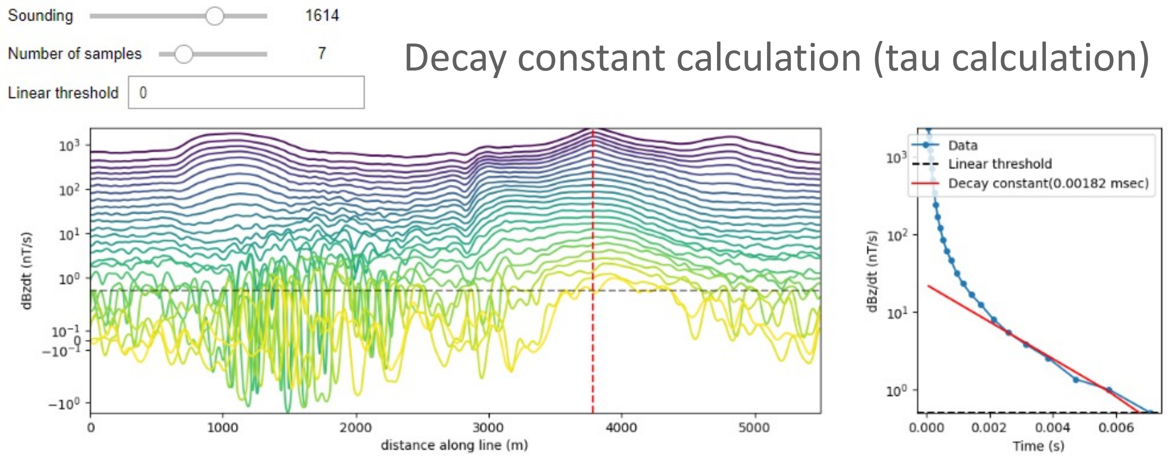


Negatives!

Decay slope filtering (based on derivatives)



Decay constant calculation (tau calculation)



- We are using SimPEG to run these joint invertion for AGG, AEM and AMAG

- So far, we are using the cross-gradient technique (Gallardo & Meju, 2003):

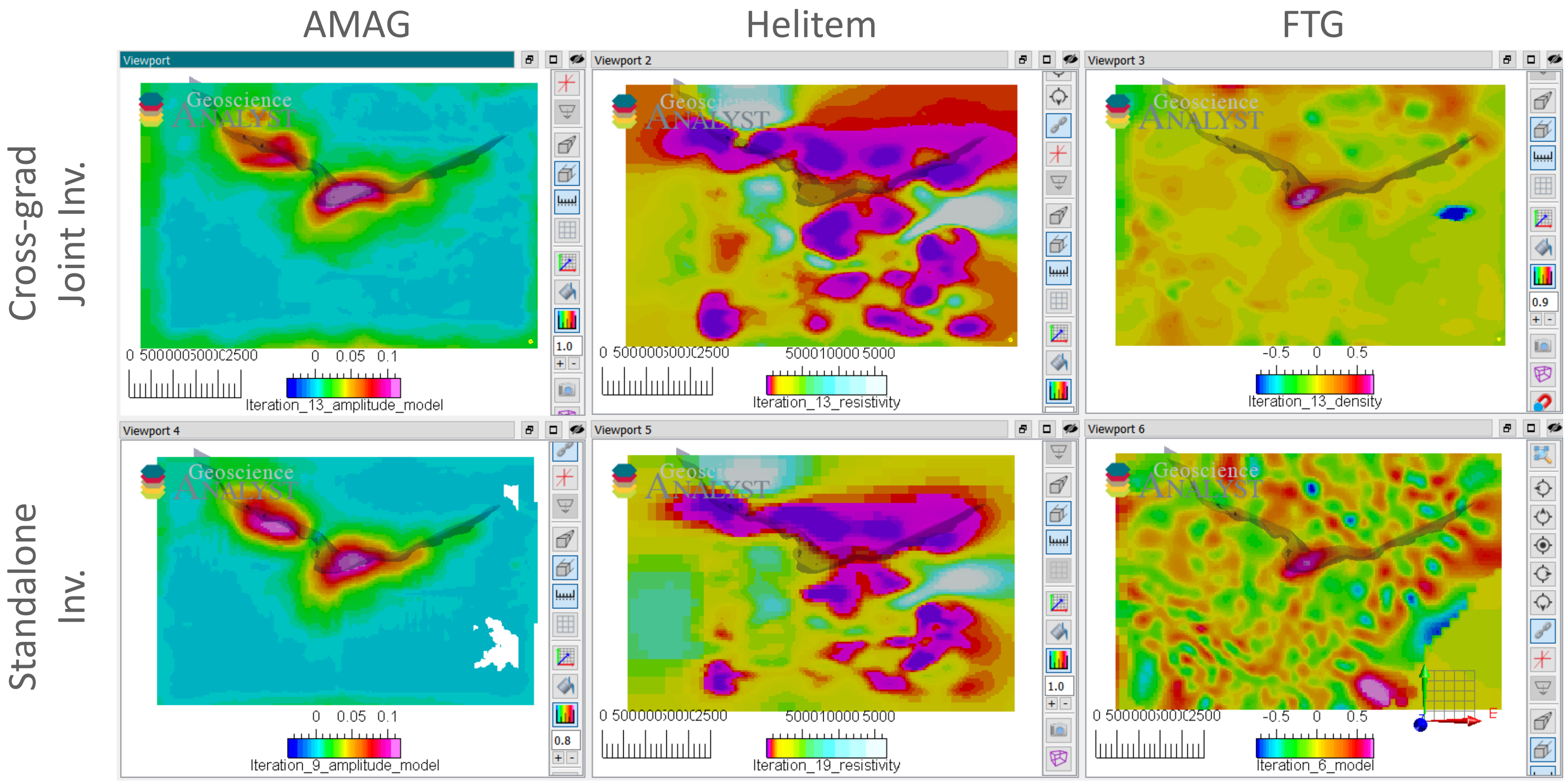
$$\phi_c(\boldsymbol{m}_A, \boldsymbol{m}_B) = \sum_{i=1}^{M} \|\nabla \boldsymbol{m}_{A\,i} \times \nabla \boldsymbol{m}_{B\,i}\|^2$$

(Cross-gradient objective function)

$$\phi_{Total}(\boldsymbol{m}_A, \boldsymbol{m}_B, \boldsymbol{m}_C\ ) = \alpha_{AB}\phi_c(\boldsymbol{m}_A, \boldsymbol{m}_B) + \alpha_{AC}\phi_c(\boldsymbol{m}_A, \boldsymbol{m}_C) + \alpha_{BC}\phi_c(\boldsymbol{m}_B, \boldsymbol{m}_C)$$

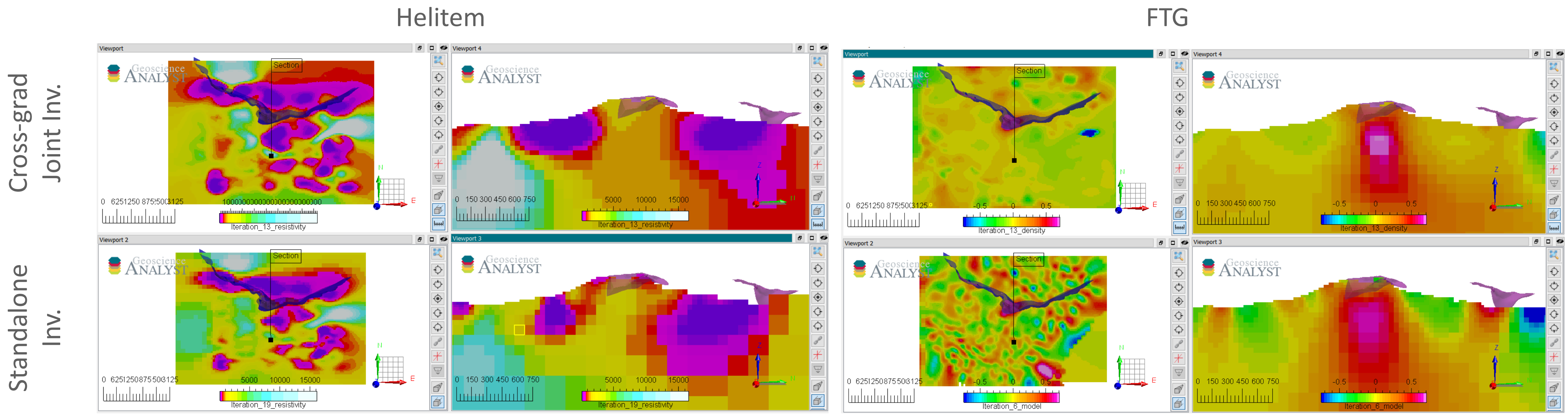
(Total objective function)

- S16 target case study



- FTG: joint inv. decreased high frequency noisy solutions.
- Helitem: joint inv. delimited better resistivity contrasts between iron formation (host rock) and bedrock (mafic unit).

- S16 target case study



TAKE AWAYS AND NEXT STEPS

- AEM data are usefull for mapping/modeling high grade supergene iron formation;

- Recovering good resistivity models are crucial for its application. We need to address all distortions related to the data (noisy data, EM couplings, IP, superparamagnetic?) – MIRA's accelerated development comes handy for this;

- FDEM data might allow to recover the magnetic susceptibility distribution within the iron bodies (we are investigating);

- Integrating AEM data with potential field methods (AGG and MAG) are quite relevant for iron ore exploration:
  - Joint inversion approaches;
  - Predictive models based on all these methodologies (MPM`s);

There is still a lot do!!!

ACKNOWLEDGEMENTS

- VALE S.A. for the permission of this publication.
- Seequent for the AGS Workbench trial license to run the Helitem inversions.
- MIRA Geoscience for the collaboration in the accelerated development project (Dominique Fournier).

VALE

REFERENCES

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