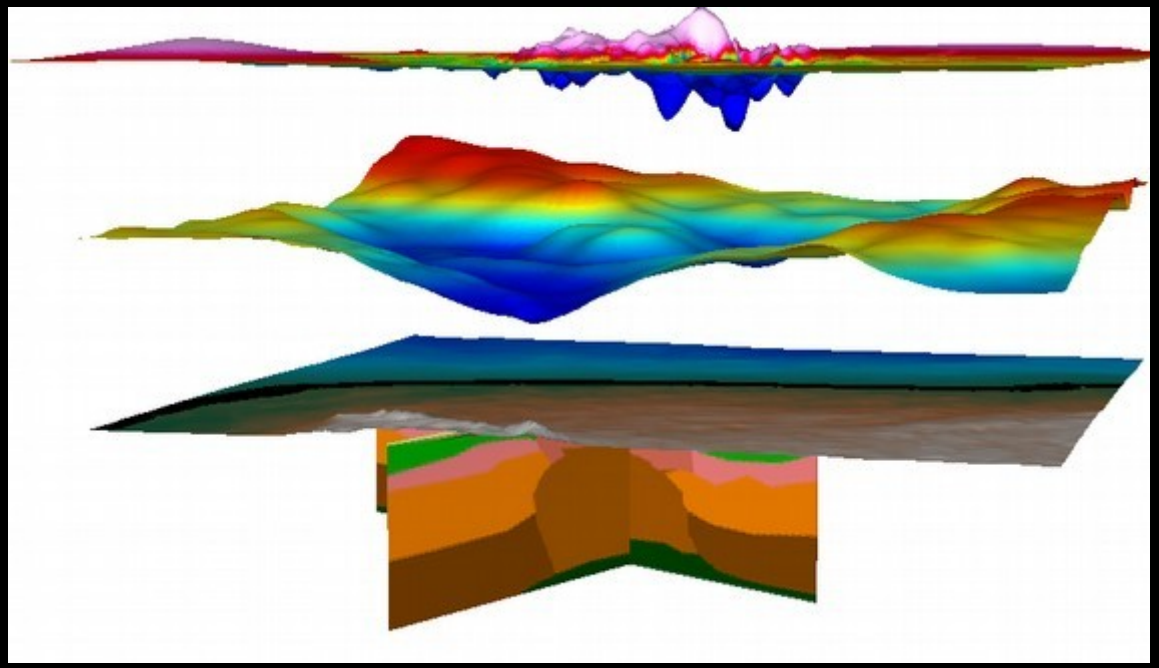
Exemples terrestres et planétaires de modélisation contrainte par des données de champs potentiels



Y. Quesnel
CEREGE, Aix-en-Provence

Potential-field data → anomaly → constraints

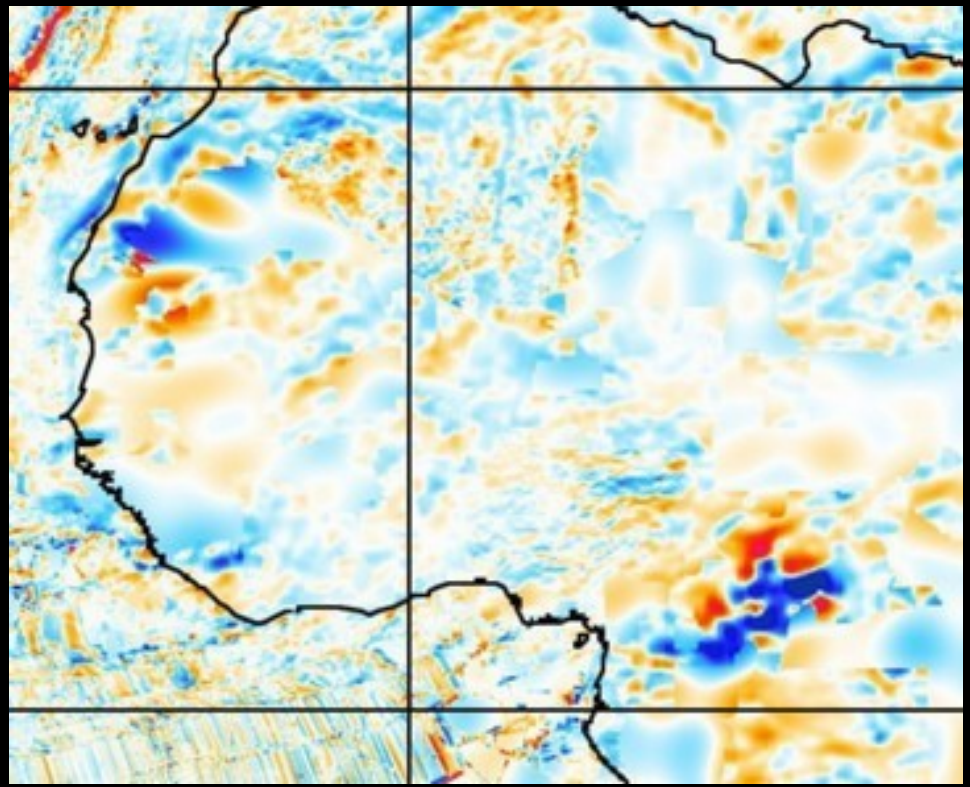
	Magnetic field	Gravity field
Local survey	Remove core and external fields → TF or (bx,by,bz) anomaly	Classical processing… → FA anomaly → Bouguer anomaly
Models	- WDMAM 2.0 (Dyment et al., 2015) - GRIMM (Lesur et al., 2010) - SWARM data (Thébault et al., 2016)	- EGM08 (Pavlis et al., 2012) - WGM12 (Bonvalot et al., 2012)

Case of WDMAM 2.0: lateral variations of initial data

1) airborne and marine data grids

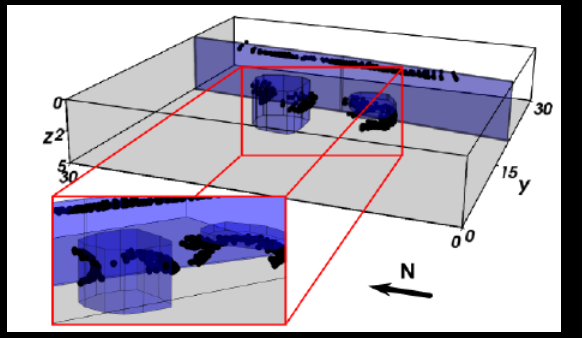
2) predictions from seafloor magnetization model

3) predictions from satellite magnetic field model



Modeling of geological sources

‘Extended’ data processing (spectral domain) : pseudo-gravity, analytic signal, Euler deconvolution (Blakely, 1995)



Uieda et al., 2014

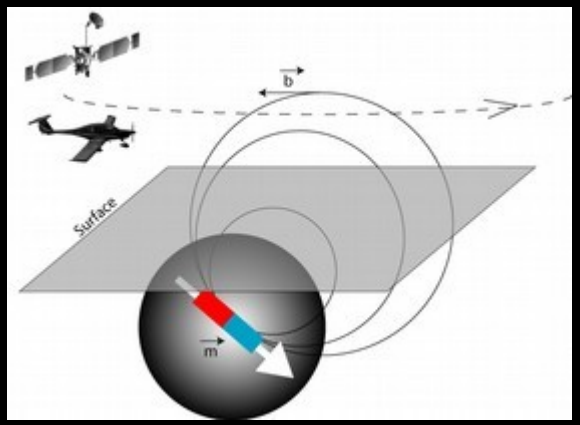
Observations

Inverse modeling →

← Forward modeling

Source parameters

Case of magnetizated sources



Can be reduced by assuming :
- uniform shapes (prisms, spheres,...)
- known thicknesses
- homogeneous dipole grid

A lot of parameters!

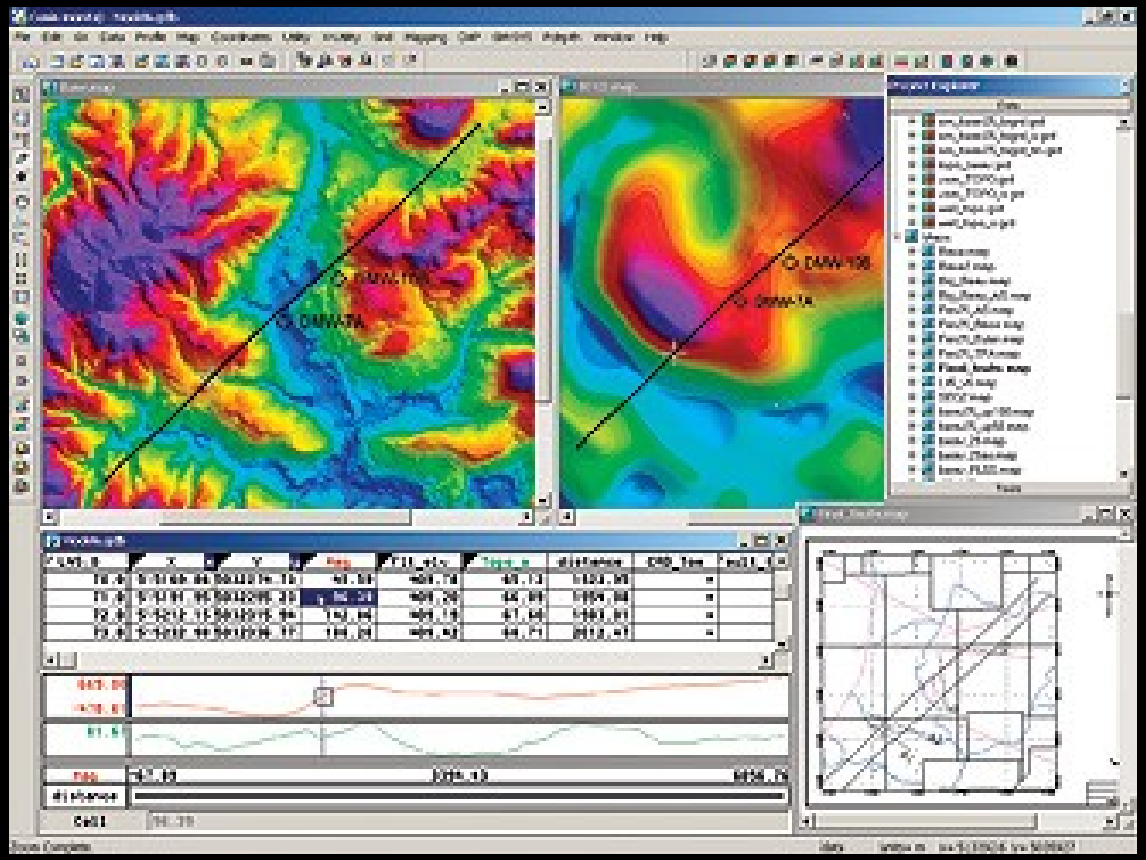
$$\vec{B}_{obs} = \sum_{i}^{N} \vec{B}^{i}_{obs} = \sum_{i}^{N} f\left(x_i, y_i, z_i, \vec{M}^{i}_{x}, \vec{M}^{i}_{y}, \vec{M}^{i}_{z}, shape_i, volume_i\right)$$

N sources affect the measurement ; (Mx, My, Mz): <u>total</u> magnetization components of each sources.

Modeling of geological sources

Some potential-field modeling softwares (non-exhaustive list)

- Geophysical Software Solutions: geoss.com.au
- IGMAS+: potentialgs.com
- USGS Potential-Field Geophysical Software: pubs.usgs.gov/fs/fs-0076-95/ → freeware
- QuickMag: pitneybowes.com/pbencom
- ModelVision: tensor-research.com.au
- Mag3D: eoas.ubc.ca/ubcgif/iag/sftwrdocs/mag3d/index.htm
- GEOSOFT Oasis montaj with GM-SYS (2D-3D) module: geosoft.com/products/oasis-montaj



geosoft.com

Oasis montaj allows to easily:

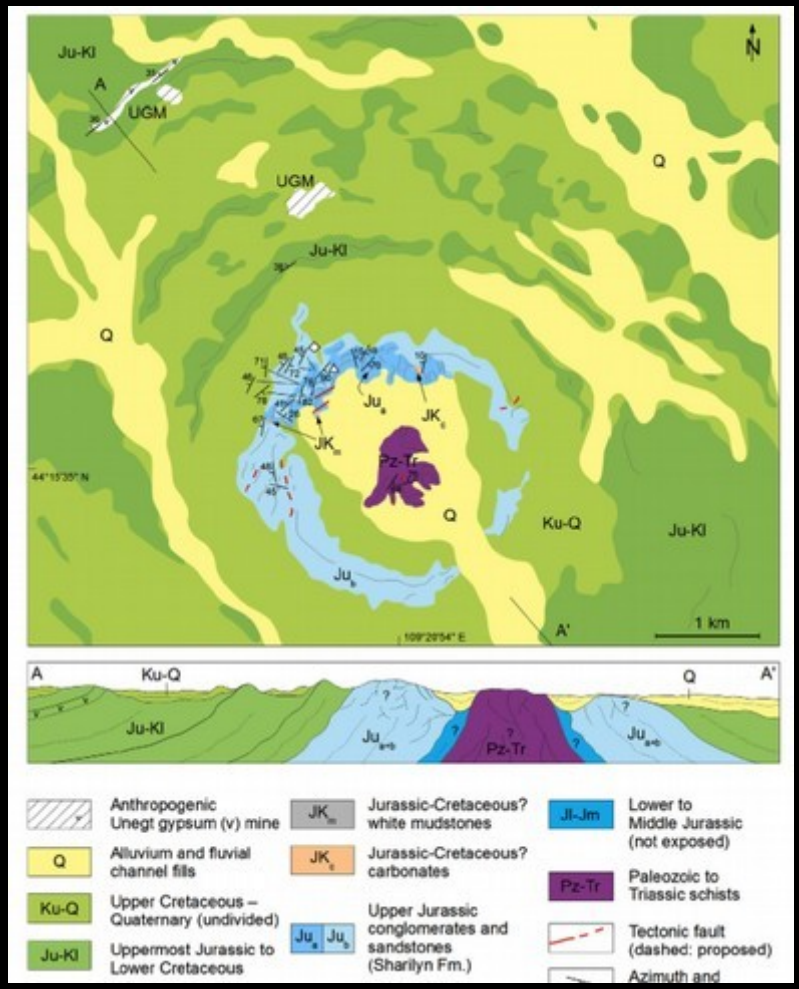
- manage databases
- interactively visualize data
- build profiles and maps like GIS projects
- integrate external data (if connected)
- perform all kind of data processing (including filtering)
- apply all potential field data transformations

...and has several very interesting additionnal modules/extensions...

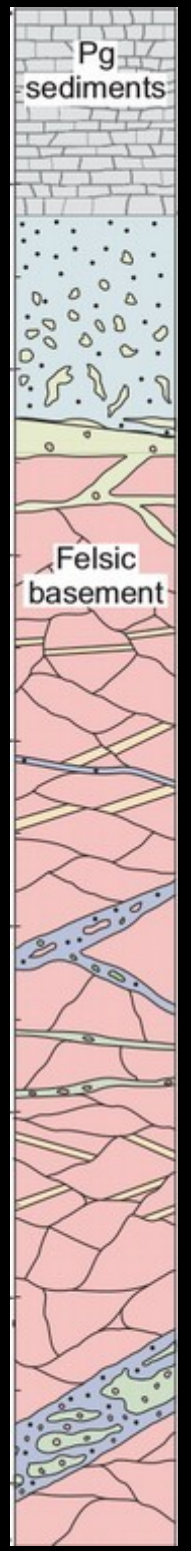
Other constraints

- Geological maps and cross-sections
- Seismic data
- Resistivity data
- MT data
- Geological well data
- Geophysical logs
- Petrophysical data on samples

Superconducting magnetometer



Uneged Uul expected impact structure (Schmieder et al., 2013)

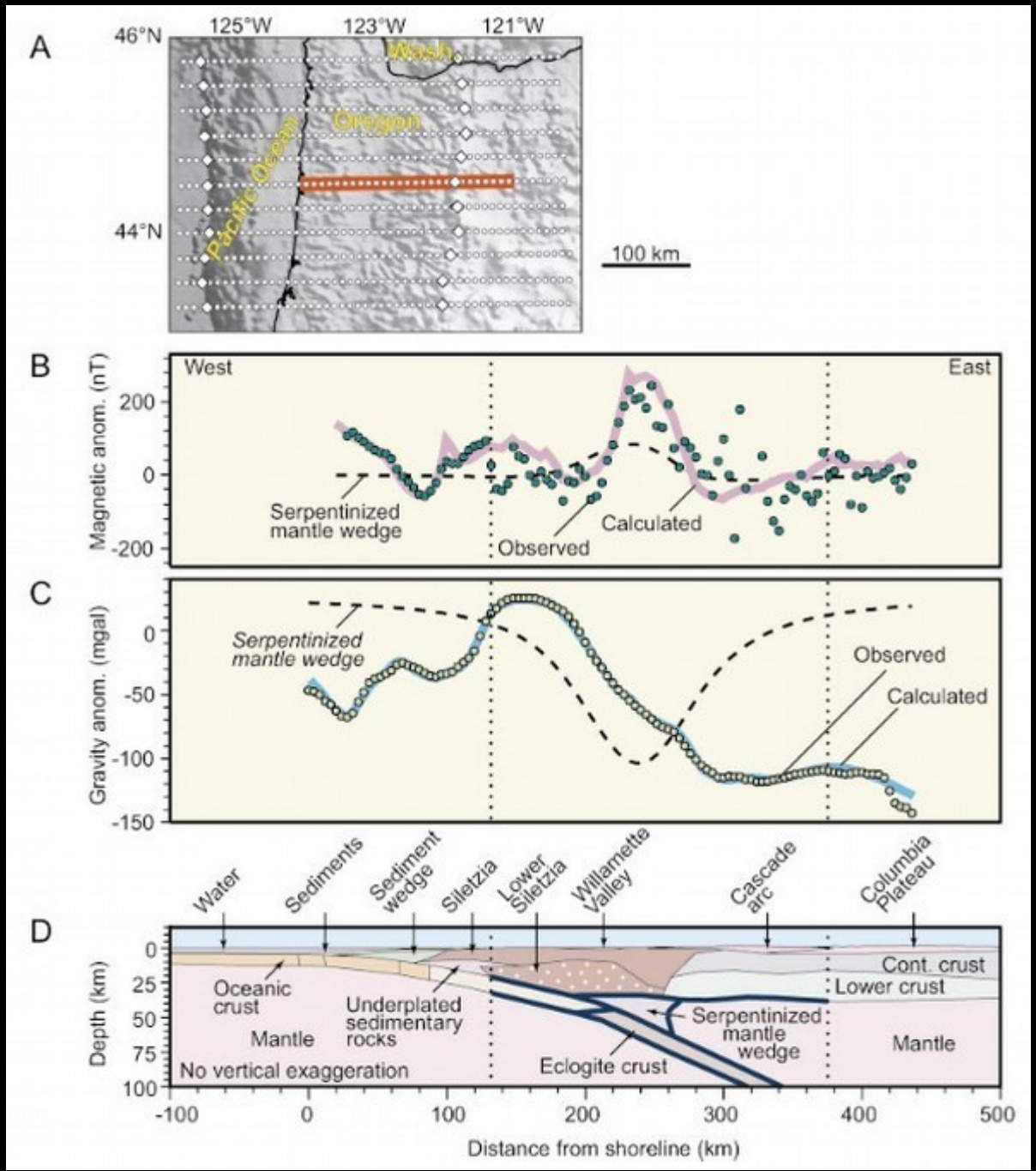


Chicxulub IODP Exp 364 well (Morgan et al., 2016)

Subduction zones

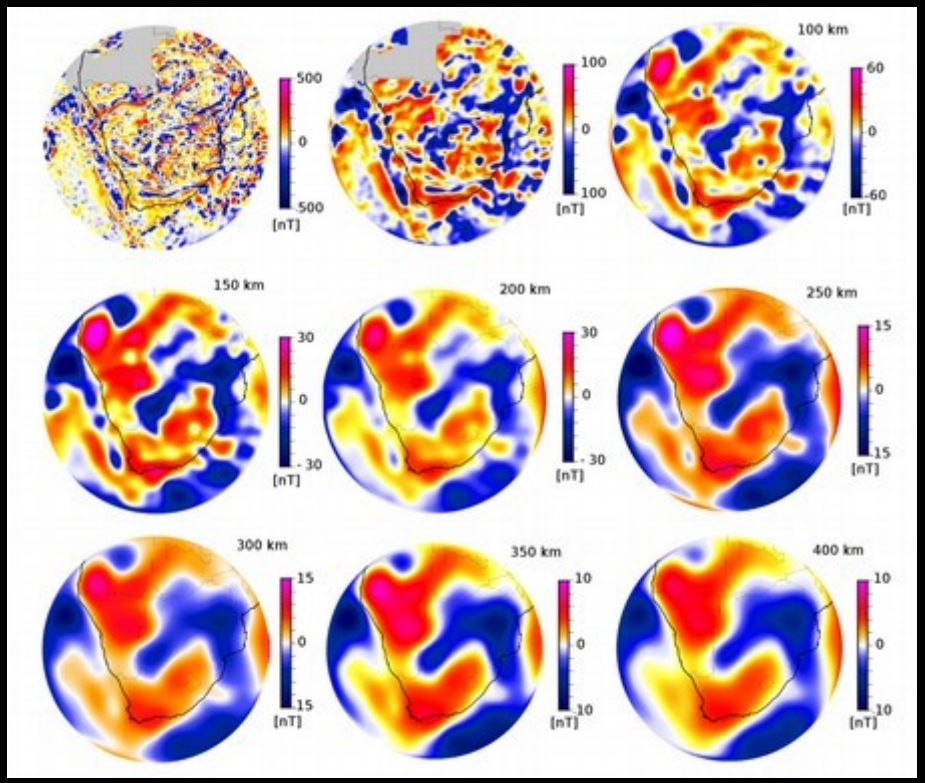
Forward modeling of gravity and magnetic field data using seismic constraints

Reveals magnetization of serpentinized mantle wedge



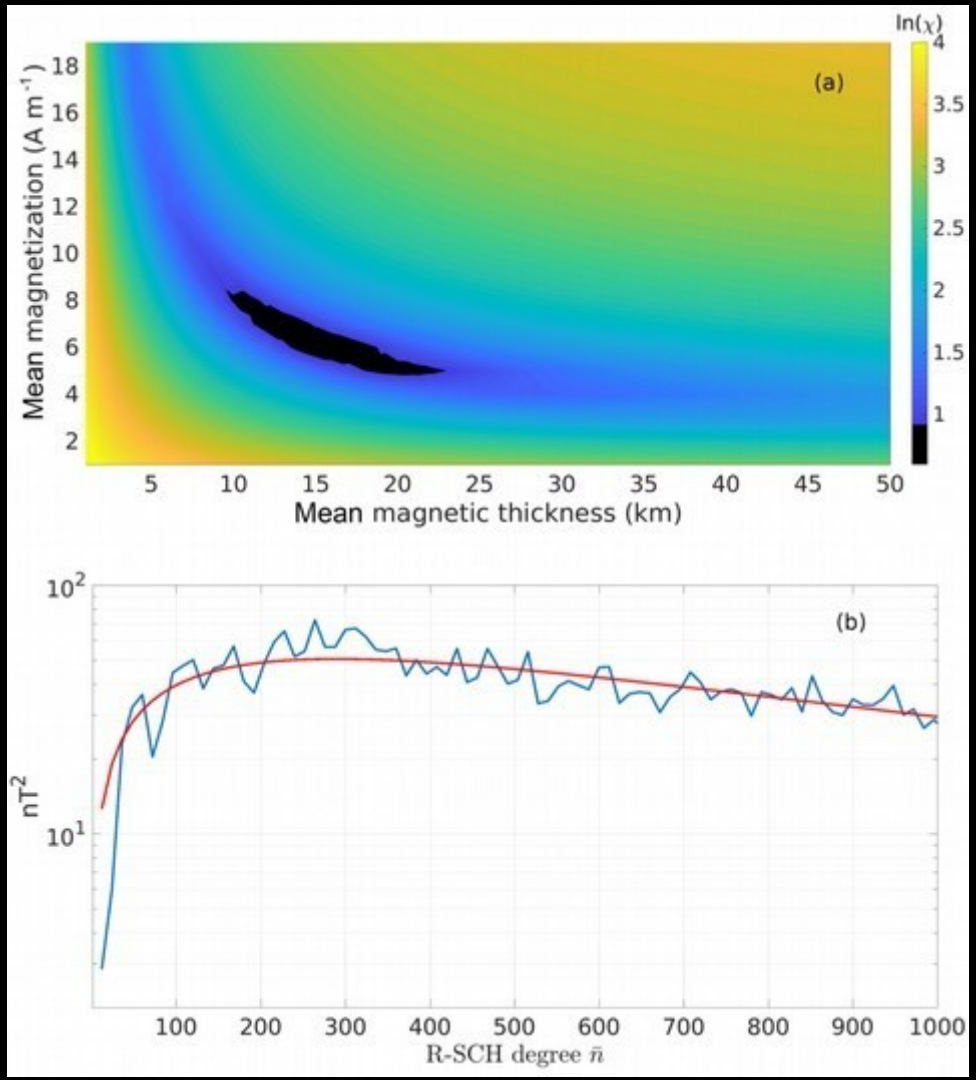
Blakely et al., 2005

Inversion using magnetic field data only



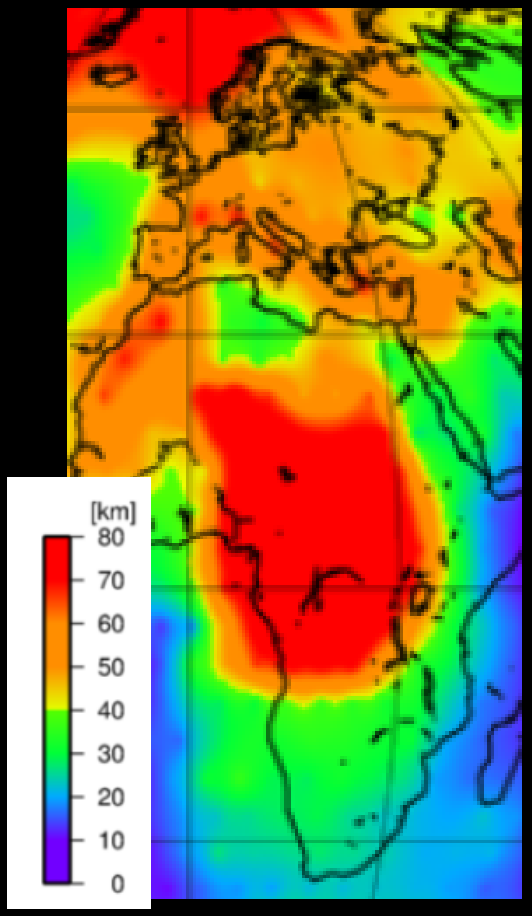
Lithospheric magnetic field anomaly model over South Africa

Vervelidou et al., 2018



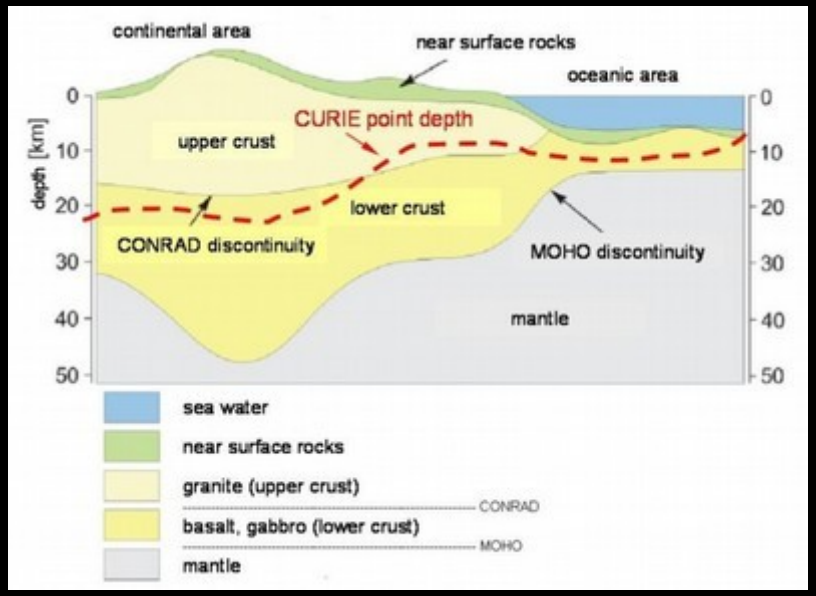
Estimation of magnetization intensity and magnetized thickness using power spectra

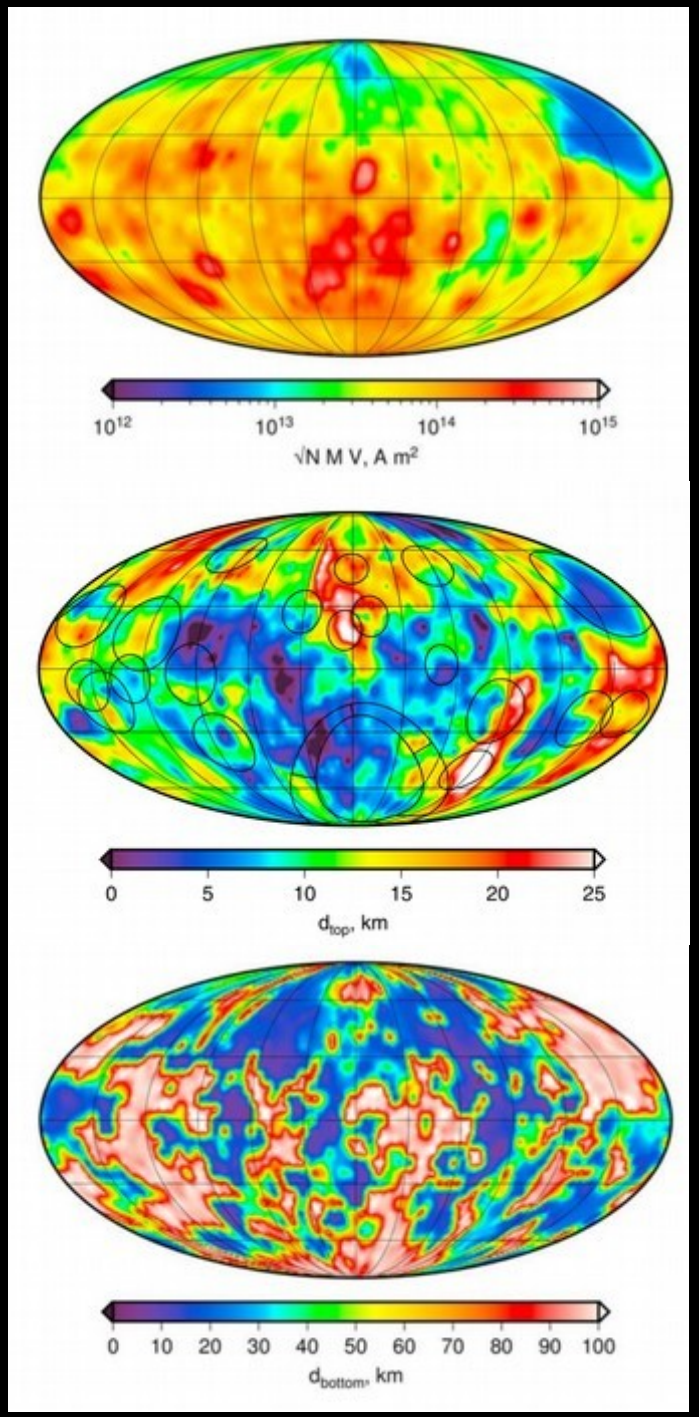
Inversion using magnetic field data only



Estimated thickness over Africa (Vervelidou and Thébault, 2015)

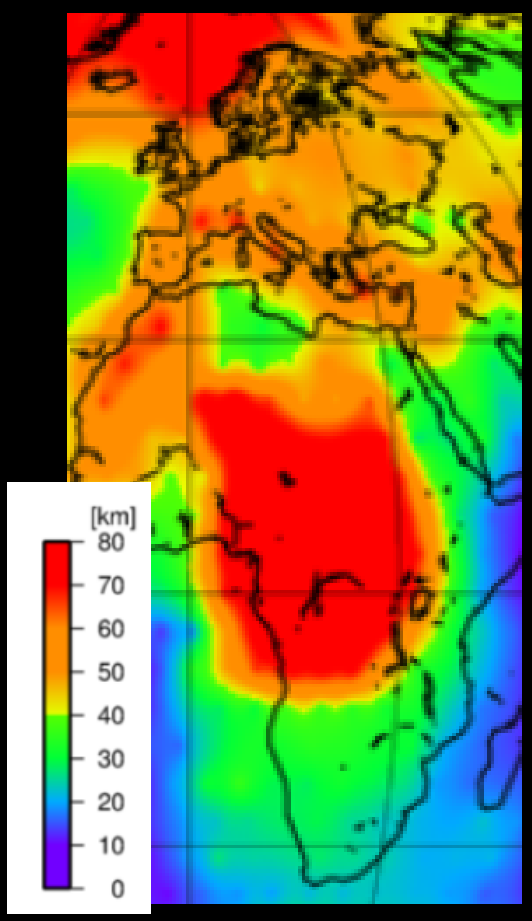
Geological ‘truth’?



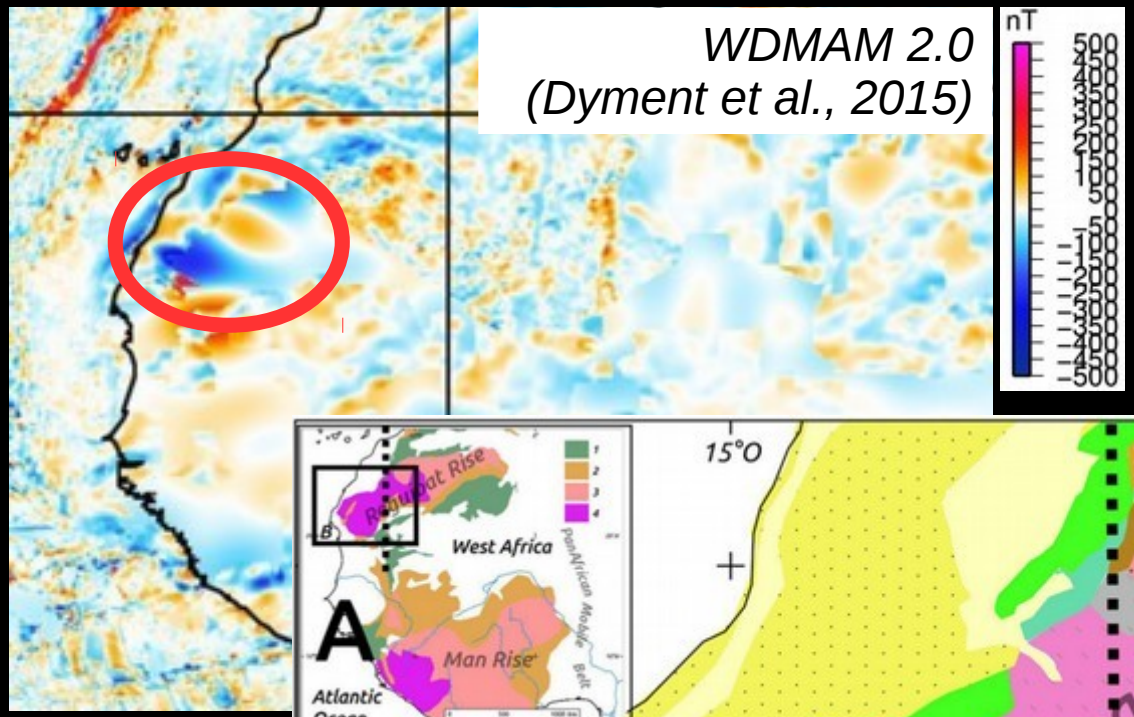


Estimation of lunar magnetization intensity and magnetized thickness using power spectra (Wieczorek, 2018)

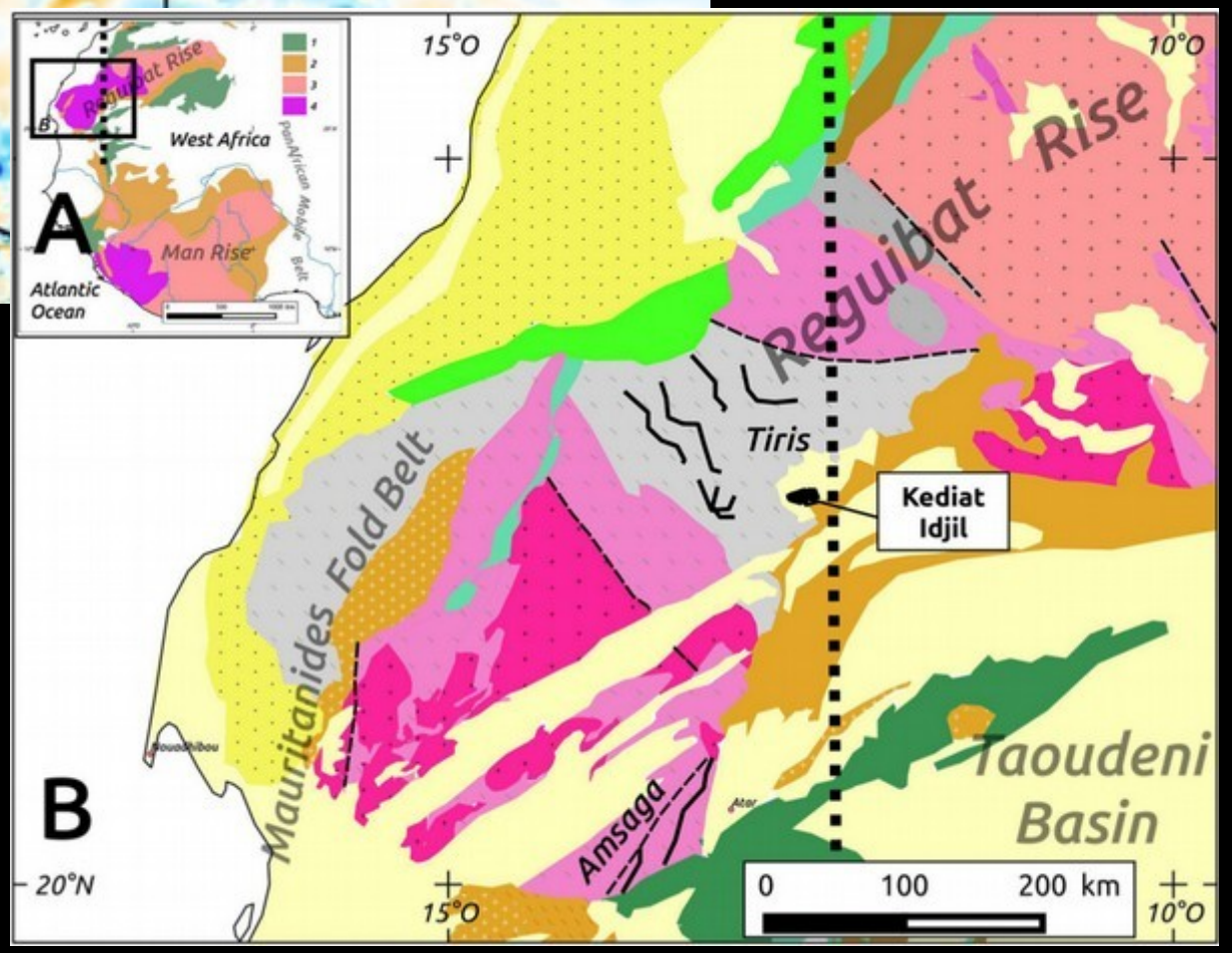
West African Magnetic Anomaly



Estimated thickness over Africa (Vervelidou and Thébault, 2015)

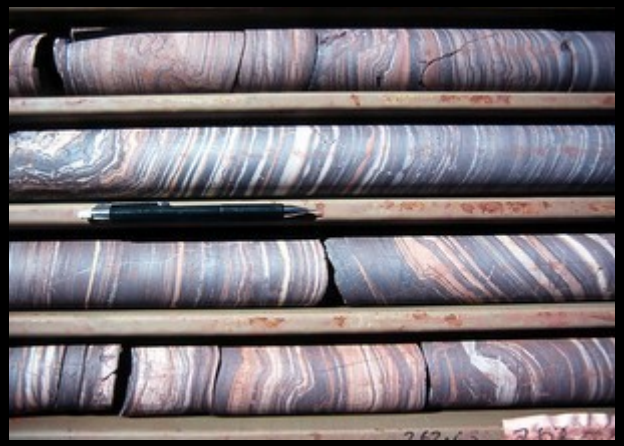


WDMAM 2.0 (Dyment et al., 2015)

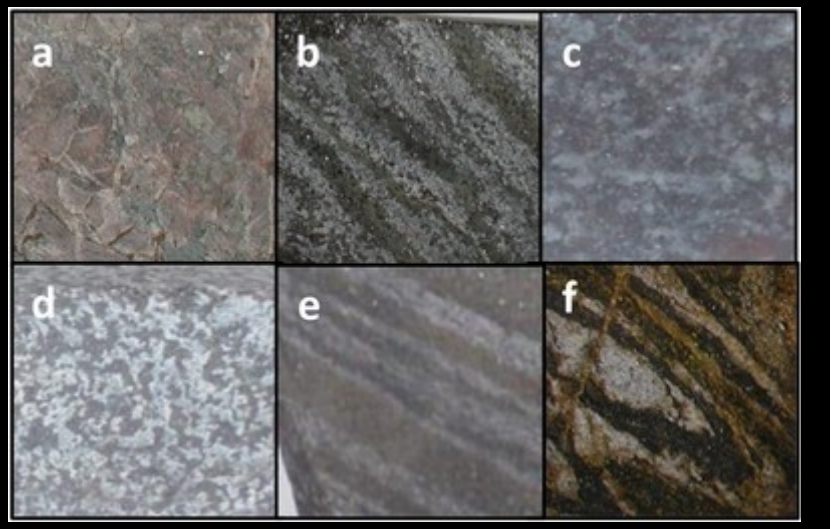


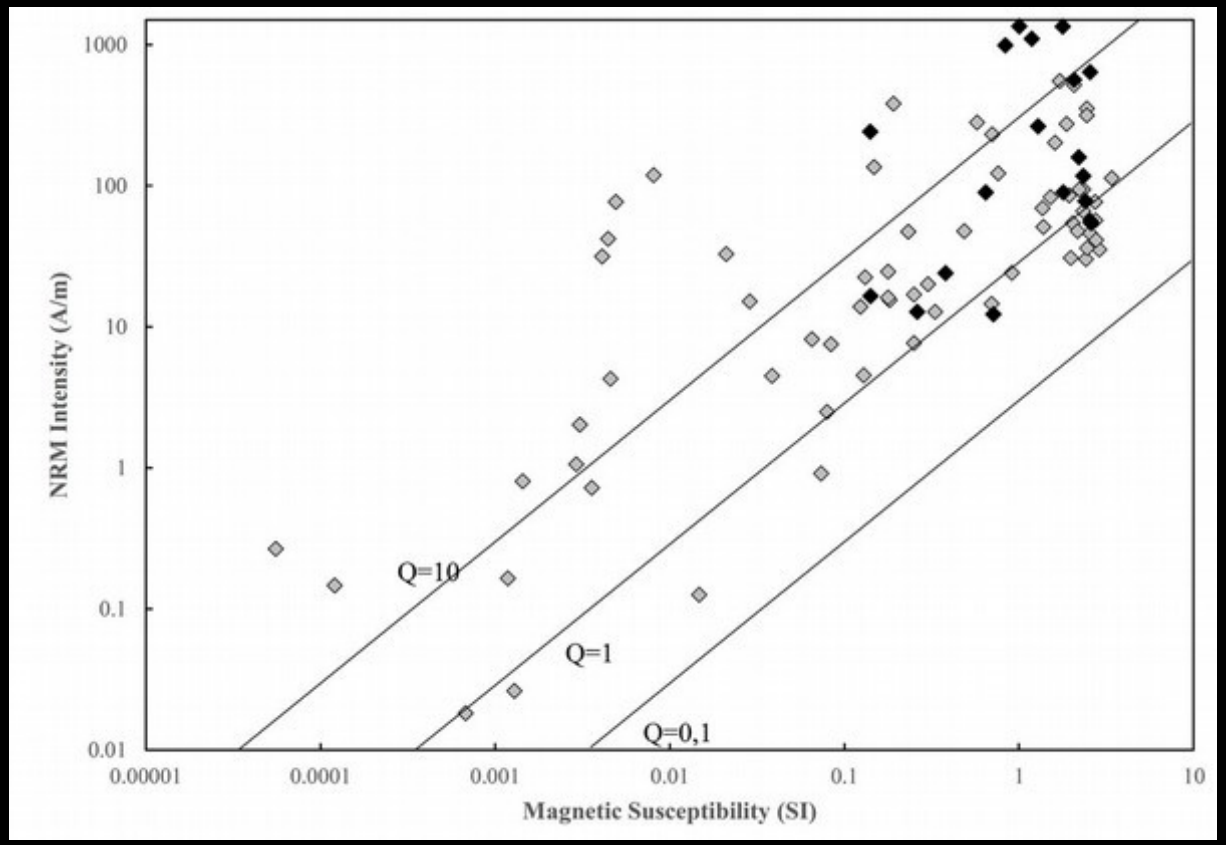
Launay et al., 2018

West African Magnetic Anomaly



All BIF facies + other metamorphic lithologies
from Kediat Idjil, Tiris and Amsaga areas (Mauritania)

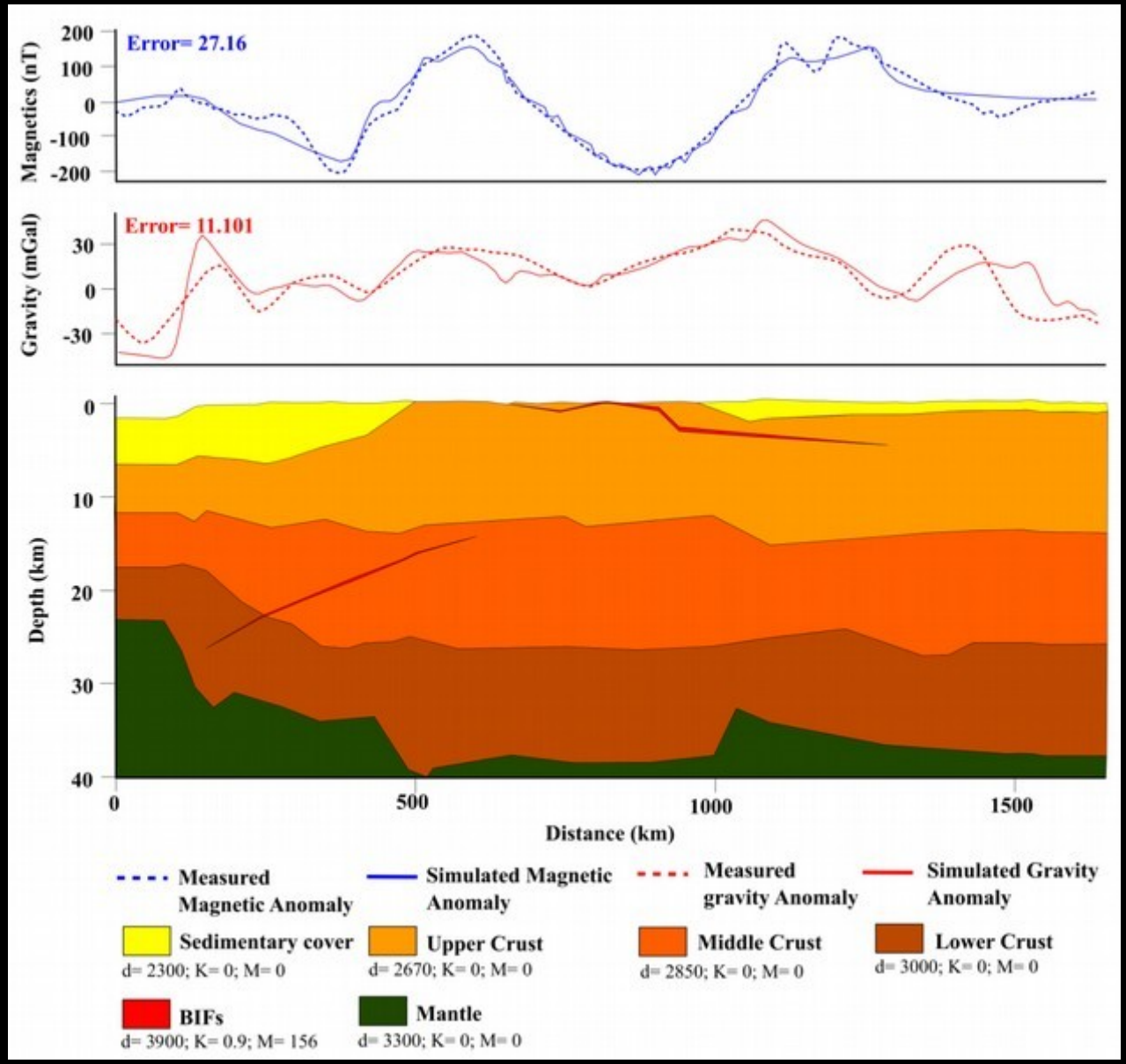




Remanence >> Induction
(Launay et al., 2018)

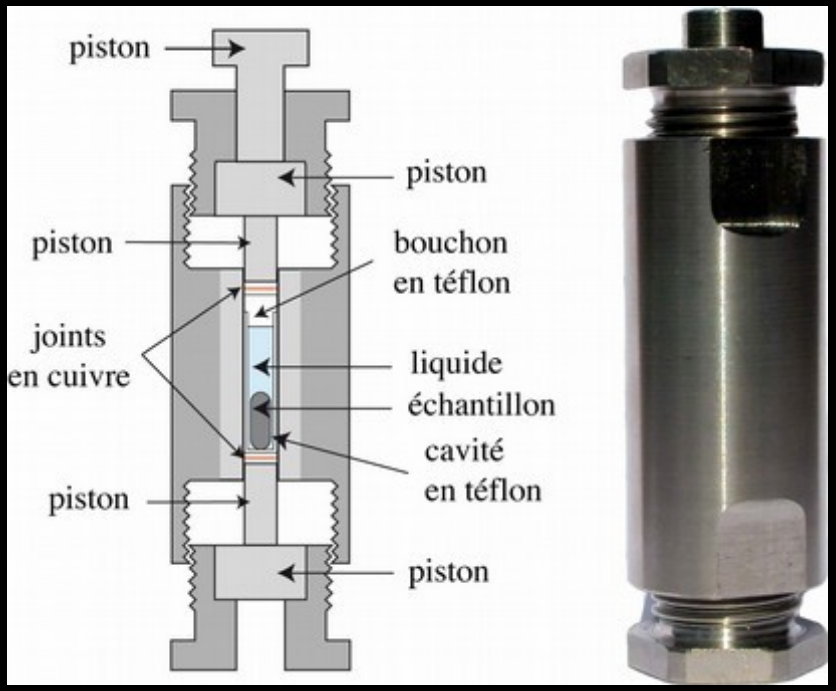
West African Magnetic Anomaly

2D forward modeling using gravity and magnetic field data + constraints from rock mag measurements and large seismic models (Launay, 2018)

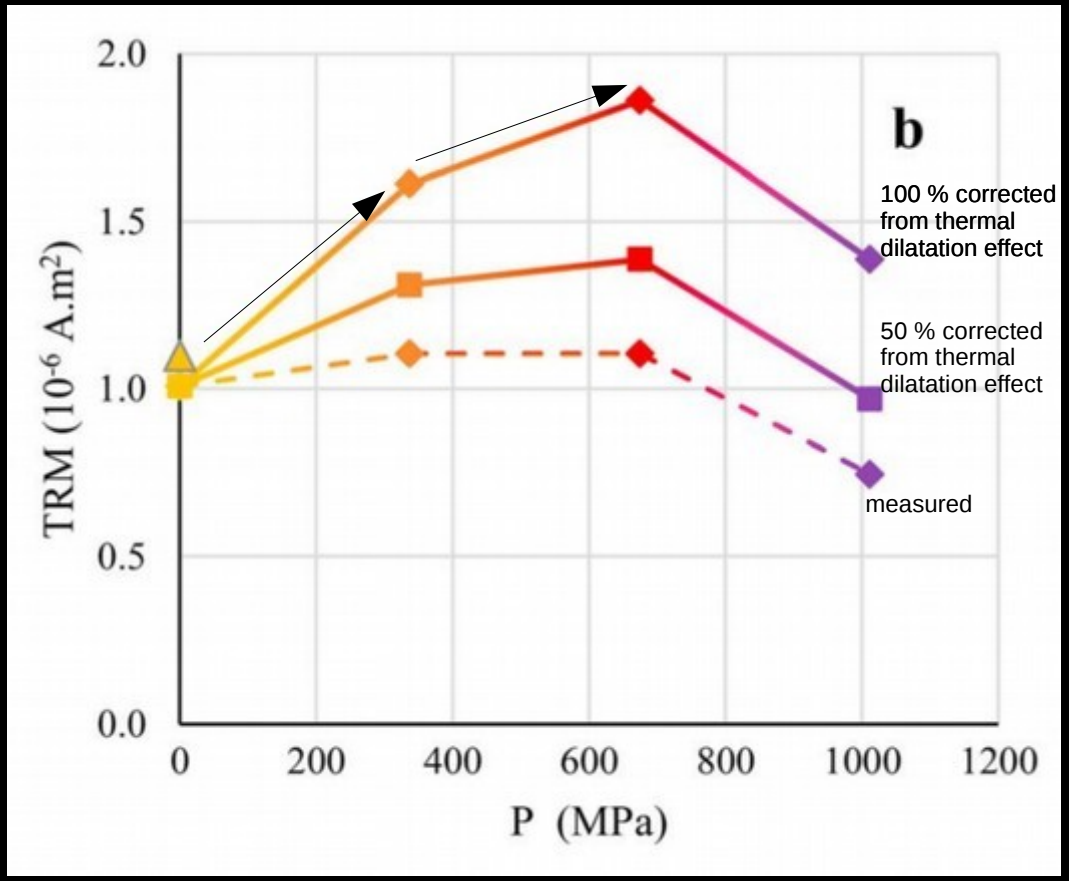


Strongly-magnetized BIF layers are necessary and can reach large crustal depths

Magnetization at depth?



Amagnetic pressure cell (up to 2 GPa) (Bezaeva et al., 2015)



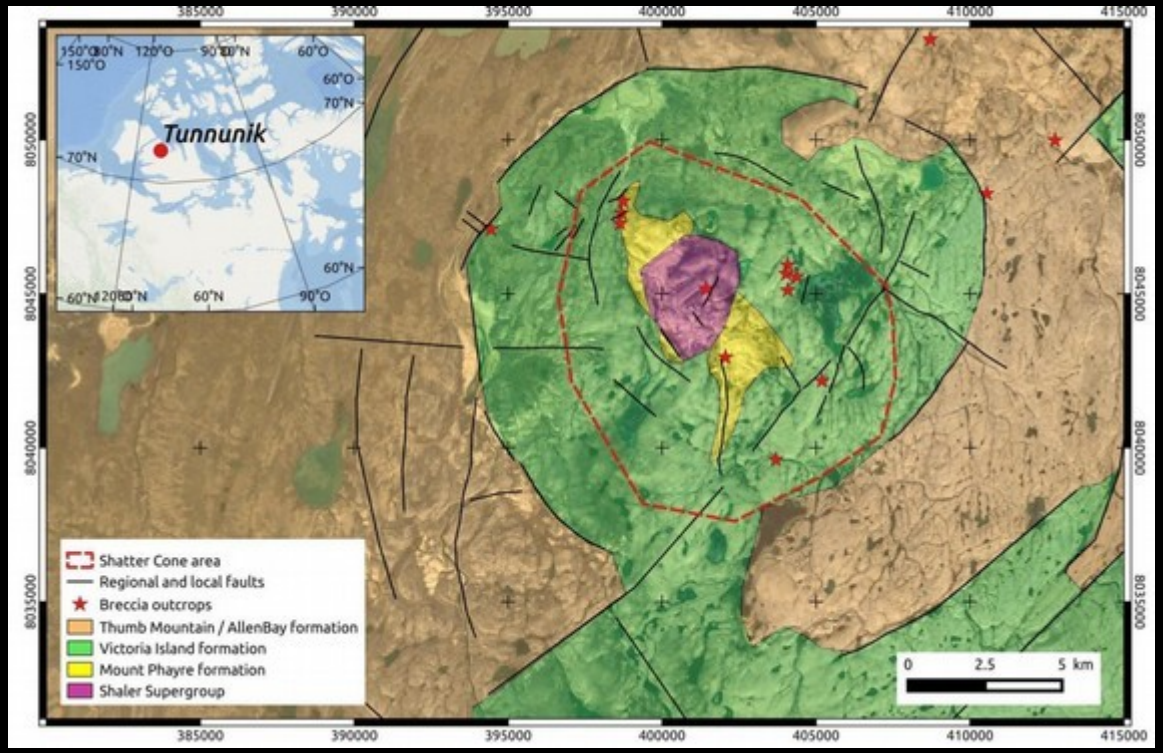
Magnetization intensity increases at crustal depths (Launay et al., 2017)

Crustal pressures may increase remanence effect
→ this can reduce the magnetized thickness to explain large magnetic anomalies

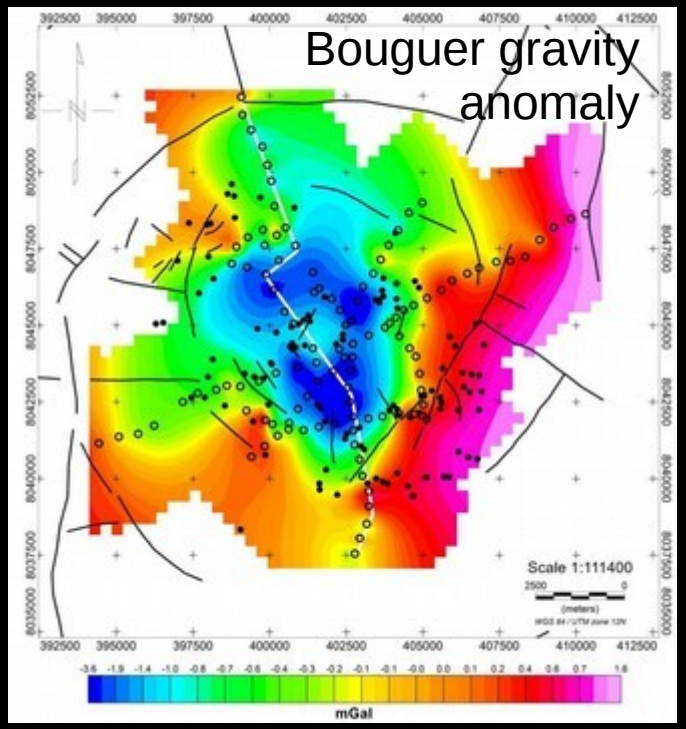
→ Experimental constraints

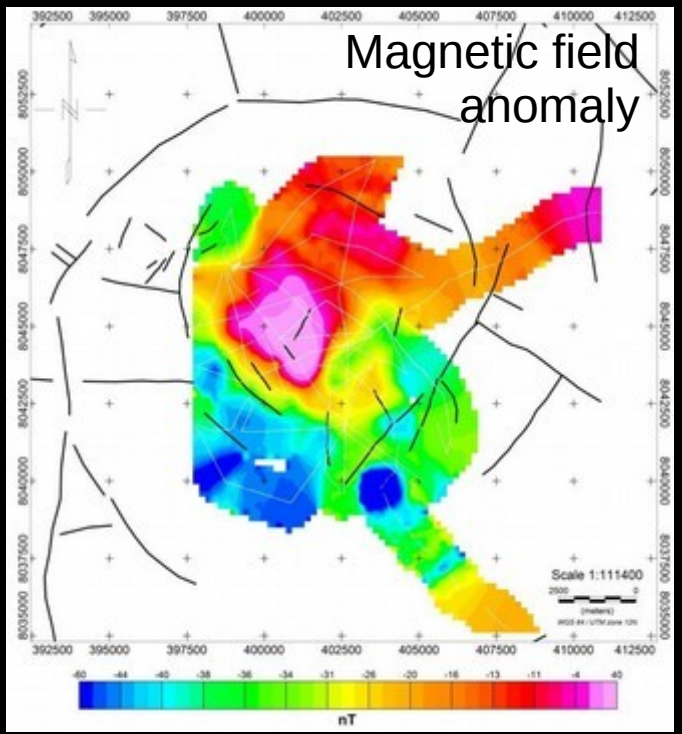
Tunnunik impact structure

First ground gravity and magnetic field measurements



Geological map (Quesnel et al., in prep.)



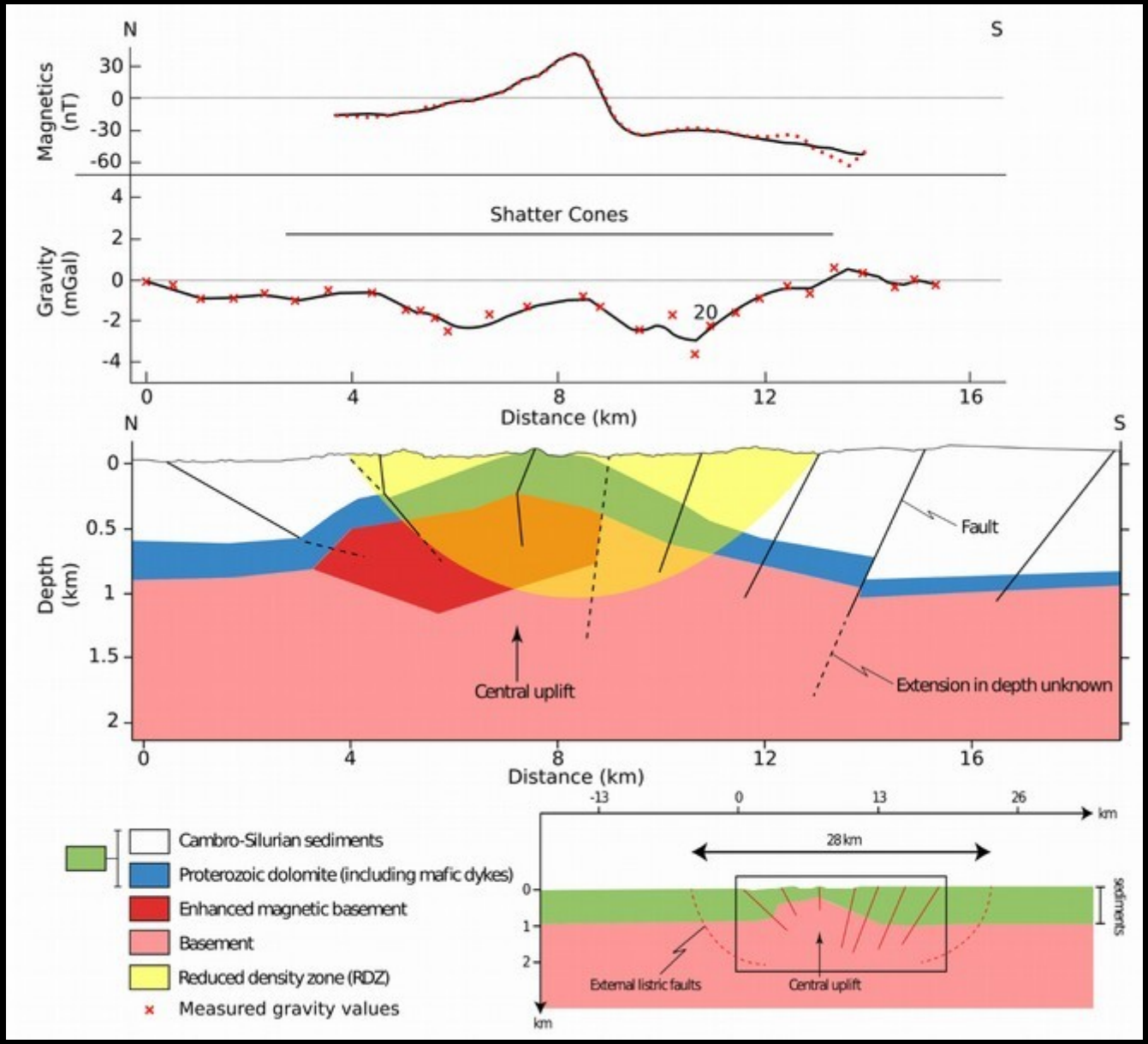


Significant potential-field anomalies

Tunnunik impact structure

Forward modeling using petrophysical constraints from surface samples, and using geological mapping

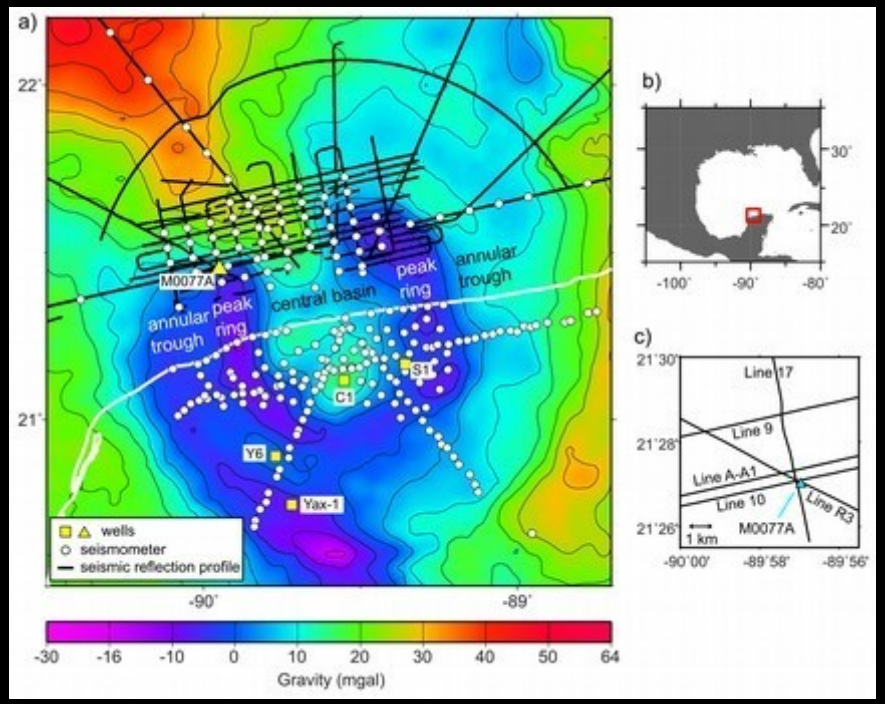
Still a 500 m central uplift?



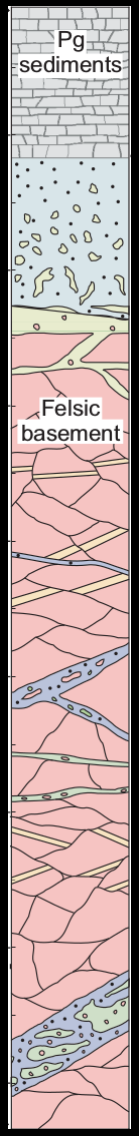
Quesnel et al., in prep.

Chicxulub impact structure

Potential field + seismic data



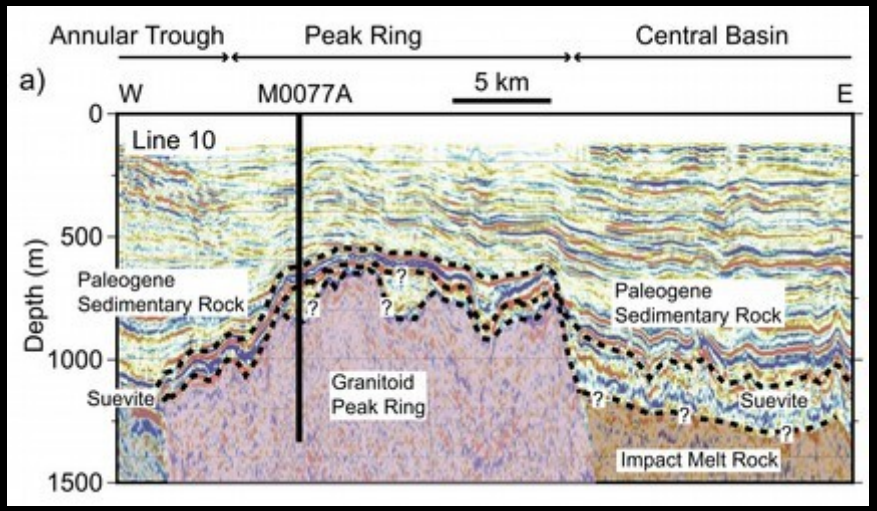
Gulick et al., 2013



Well data

Morgan et al., 2016

Example of seismic data interpretation

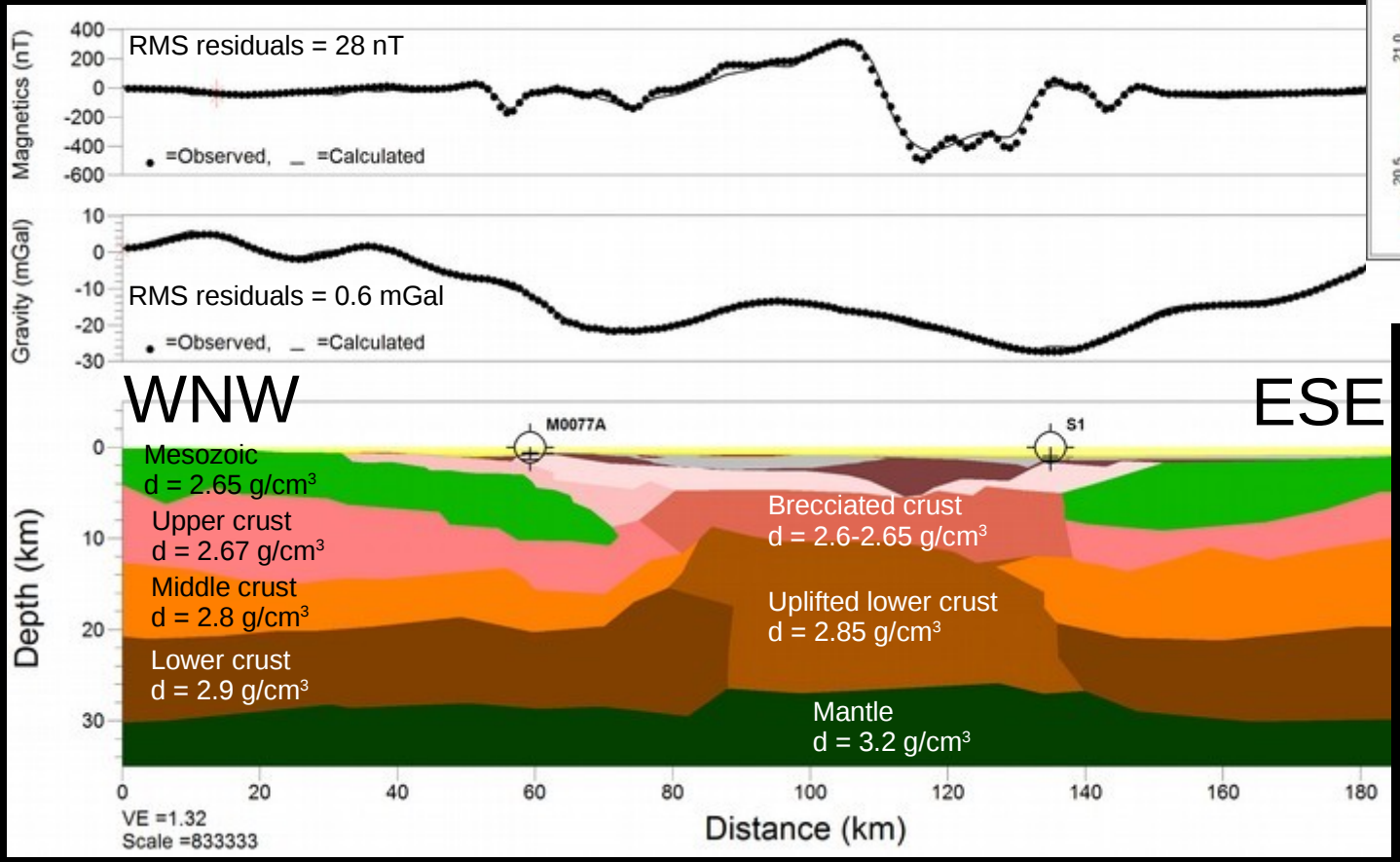


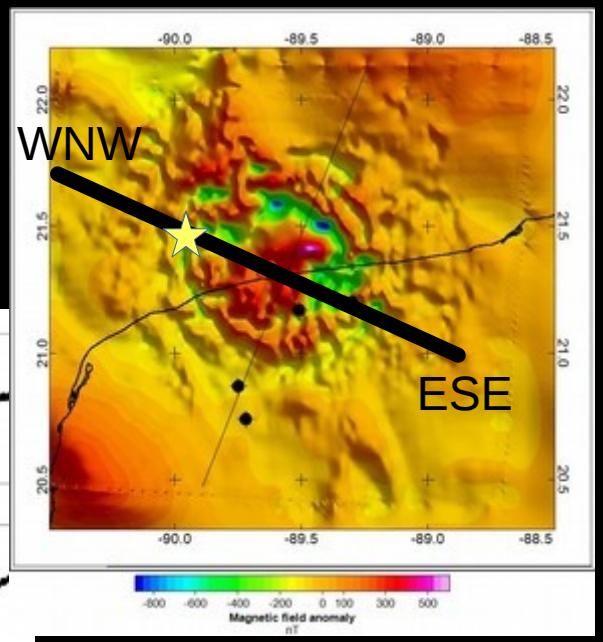
Christeson et al., 2018

→ First access to the central IMR and brecciated crustal rocks

Chicxulub impact structure

W-E cross-section (including M0077A)





→ Suevite and IMR layer 'alternately' thicker towards center

Quesnel et al., in prep.

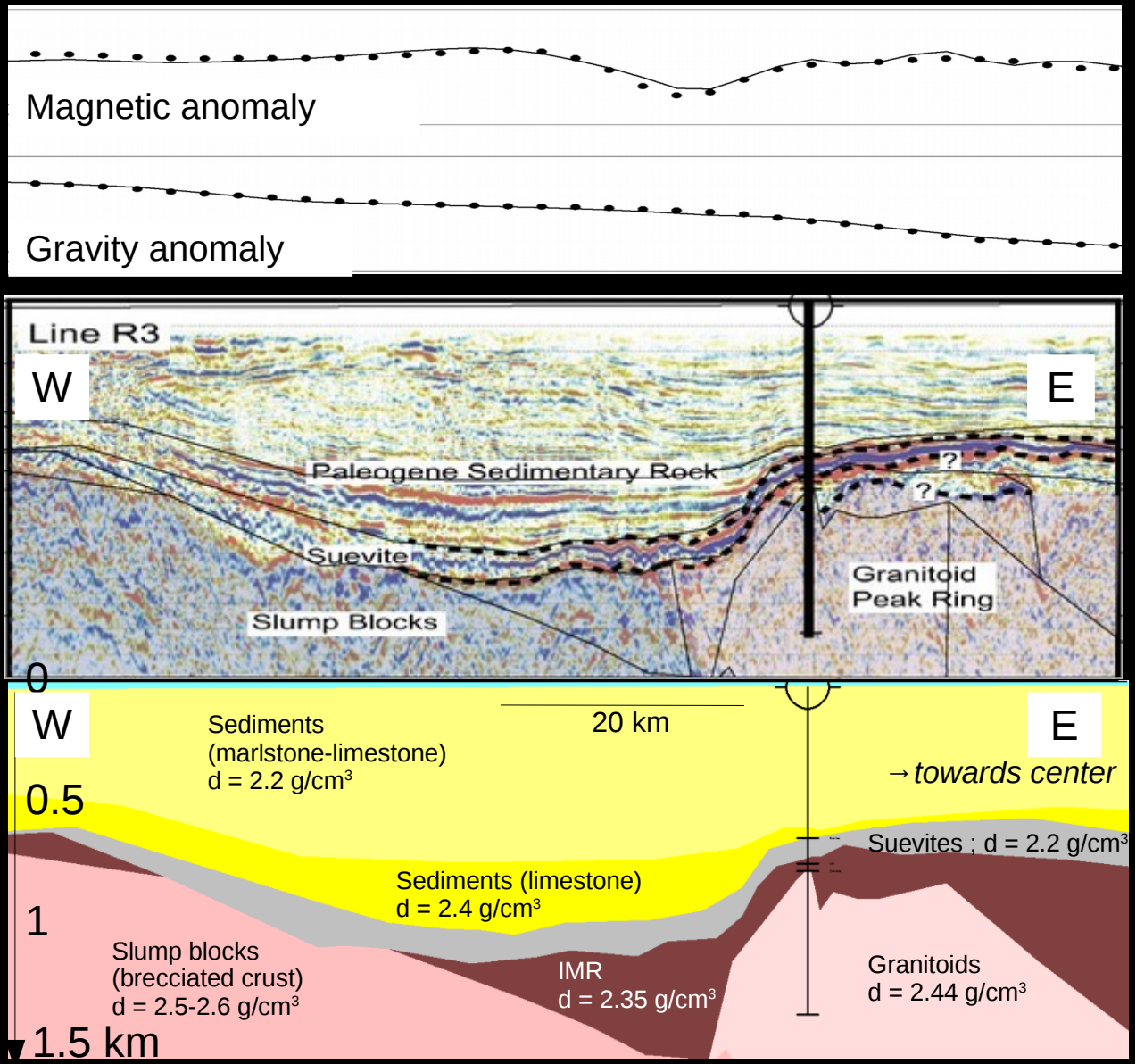
Rock	*d (g/cm³)*	*χ (10⁻³ SI)*	*NRM (A/m)*	*I (°)*
Suevite	2.1-2.2	10	0.1-1	-30
Impact Melt Rock	2.3-2.4	10	1-8	-38
Brecciated Granitoids	2.4-2.5	1	0.1	-52

Chicxulub impact structure

W-E cross-section (zoom in PR)

→ fits seismic data interpretations (Christeson et al., EPSL, 2018)

→ respects lithological transitions observed in hole M0077A



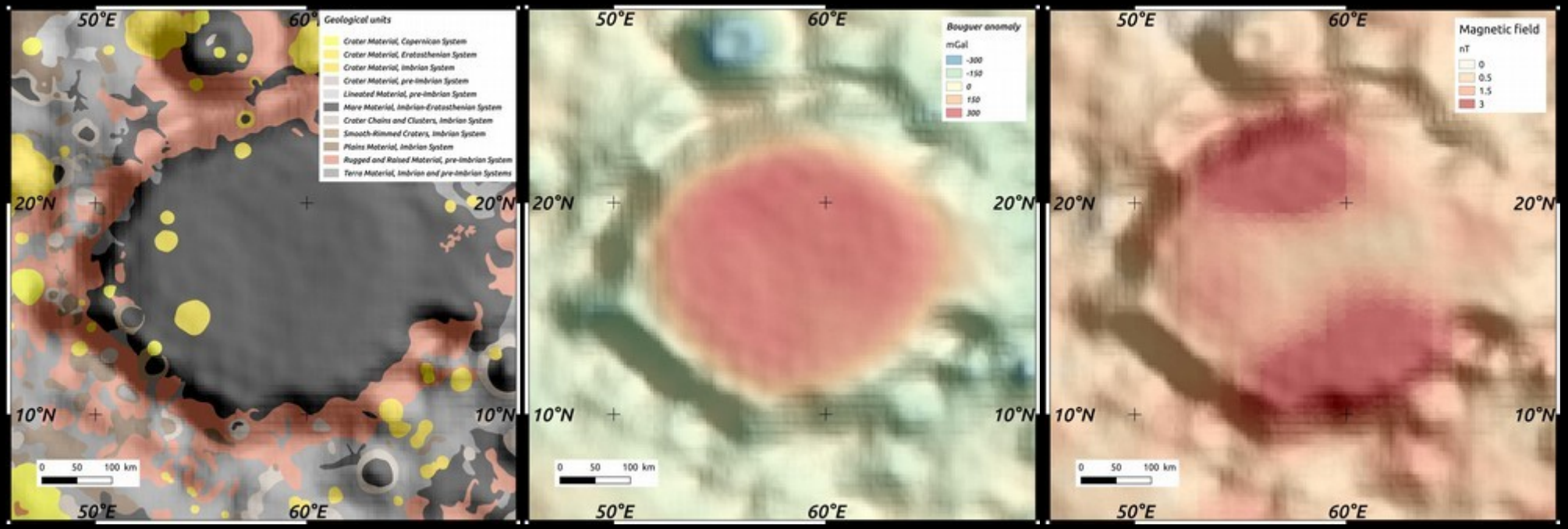
Quesnel et al., in prep.

Around M0077A → larger IMR layer

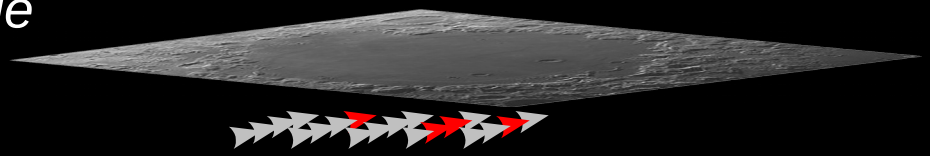
Crisium impact structure

Diameter: ~560 km
Age: 3.86 Ga
Type: basin
Target: anorthosite

airandspace.si.edu

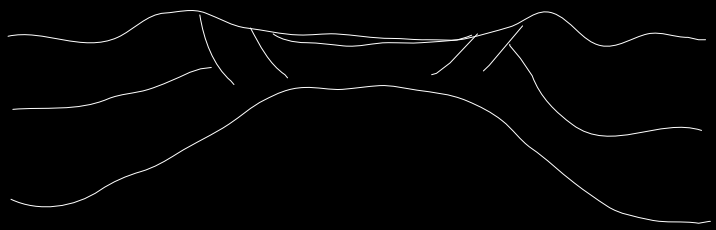


Inversion of a dipole grid

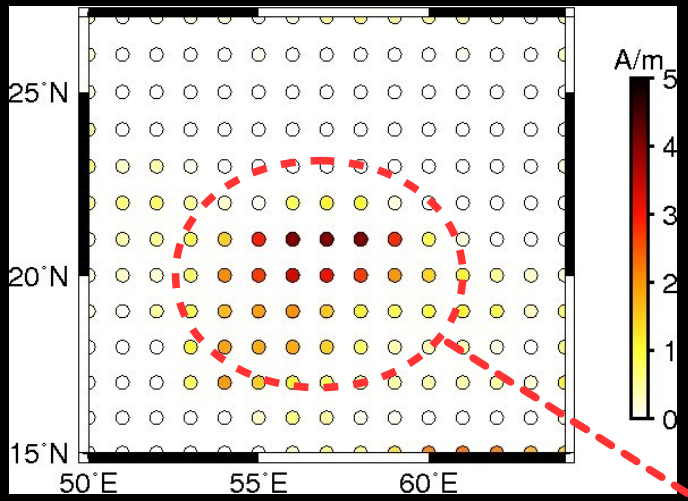


Depth and intensity estimations of magnetized sources

2D grav-mag forward modeling

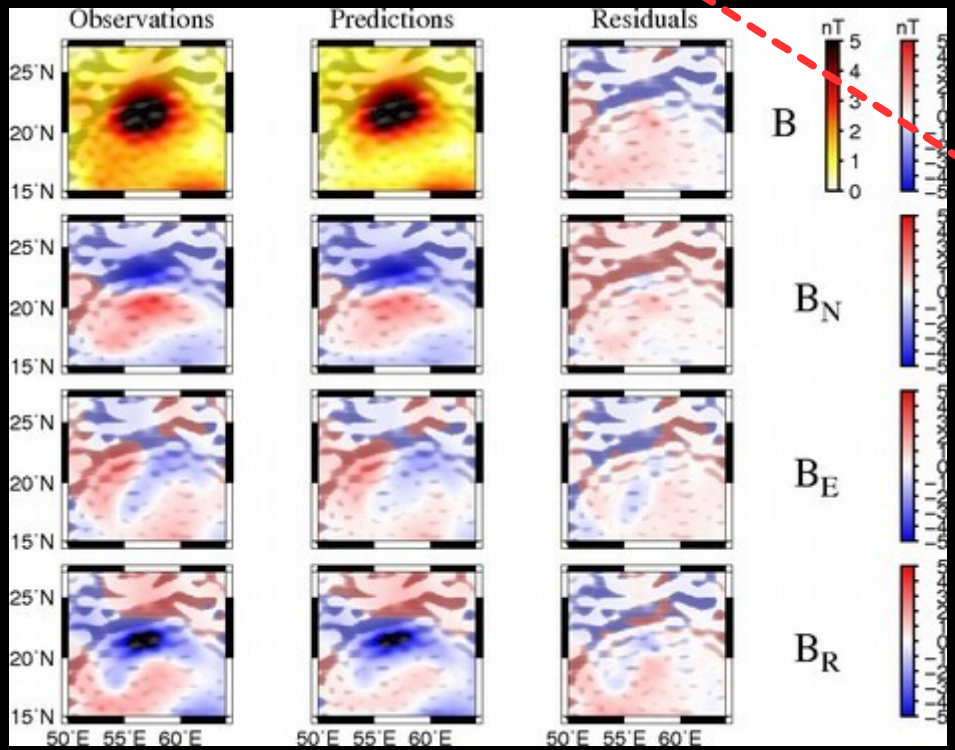


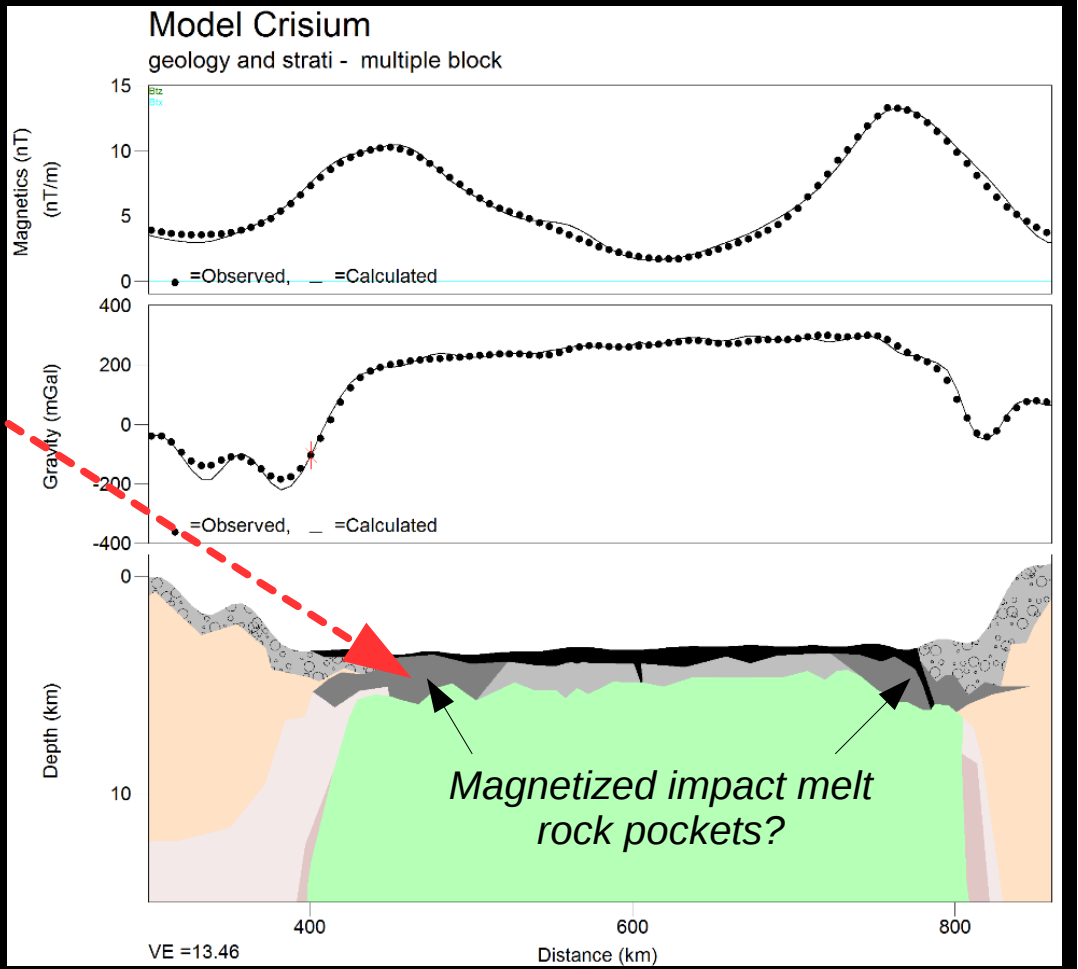
Crisium impact structure



North anomaly: dipole grid at 5 km depth
→ magnetizations up to 4 A/m

Quesnel et al., in prep.





Conclusions

- Potential-field data constrain density, magnetization and/or shape of geological formations
- Grav-Mag anomaly correlation: not systematically (also true for impacts…)
- Rare cases of true ‘joint’ modeling or inversion → often grav-mag forward modeling using other constraints (seismic, petrophysics, wells)
- Even well-eroded and/or buried, impact structures can be revealed by potential-field data acquisition and modeling
- Some specific geological processes can be unveiled by magnetized source models: hydrothermalism