Software for Remanence Estimation

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Introduction

- Vector relationships in remanence estimation
- Applicable software resources
- Limitations for all methods
- Thomson Orogen case history
- Parametric modelling & inversion focus

Calculating vector amplitudes

Known

Partial

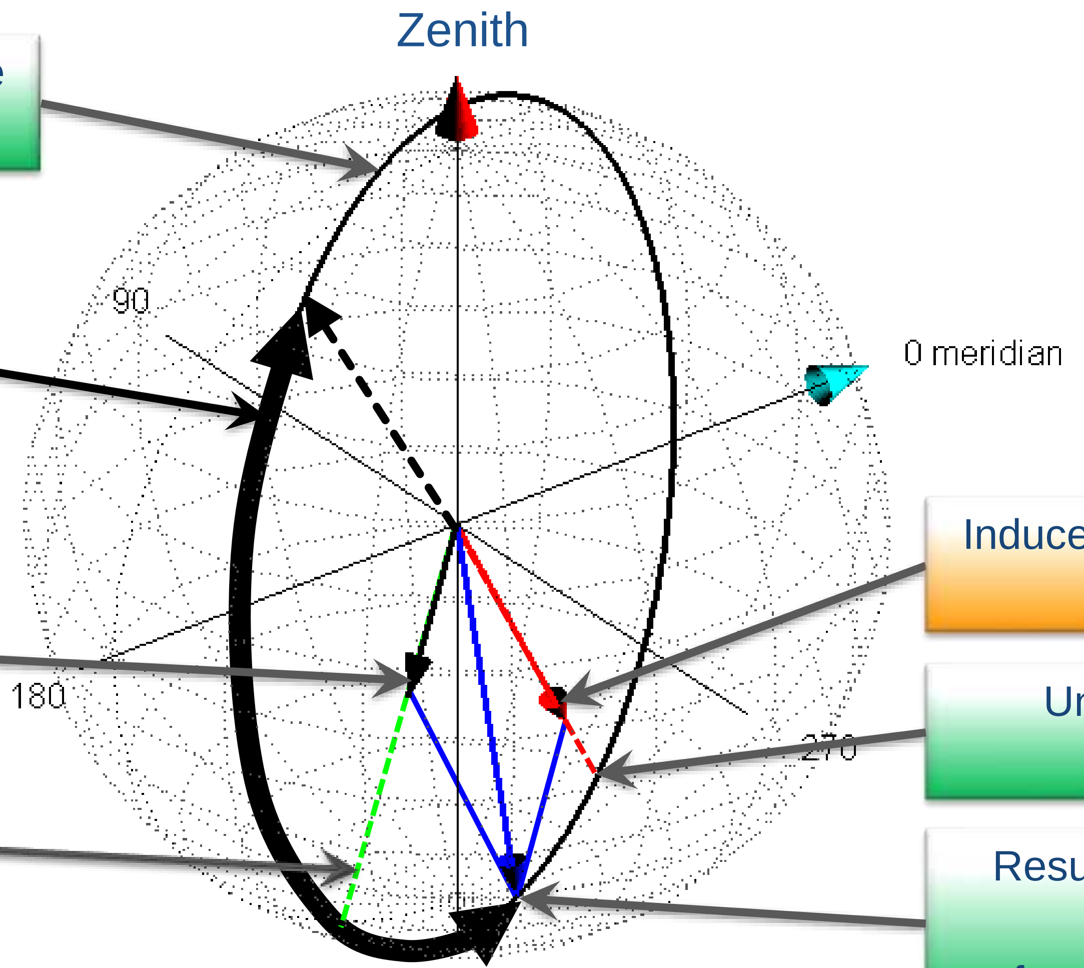
Unknown

Great circle
GC

Remanent vector range

Remanent vector
B_{nrm}

Unit vector i_{nrm}
Polar wander



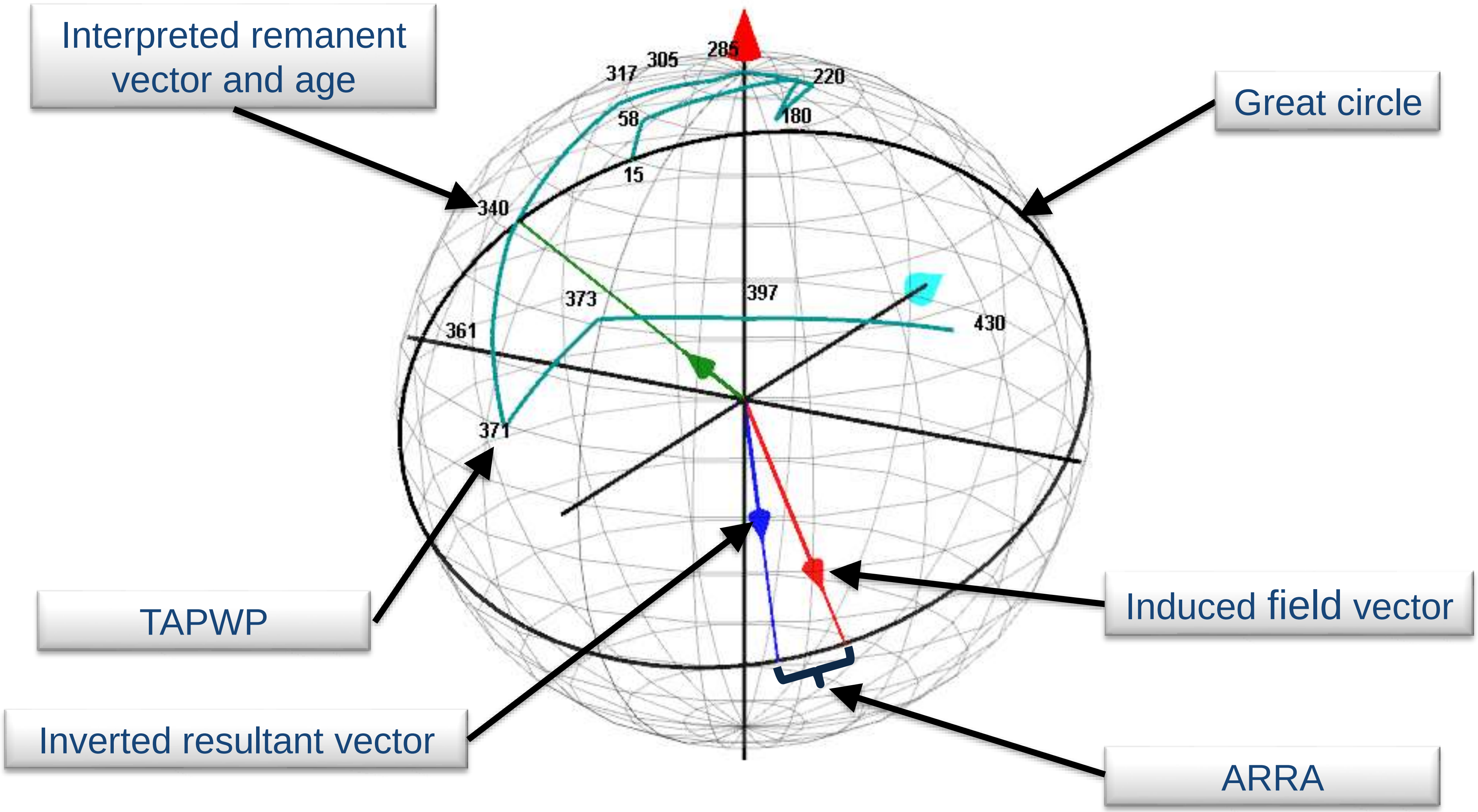
Induced field vector
B_{ind}

Unit vector
i_{ind}

Resultant vector
B_{res}
from inversion

or unit vector
i_{res}

RRE – using polar wander data



Important outcomes

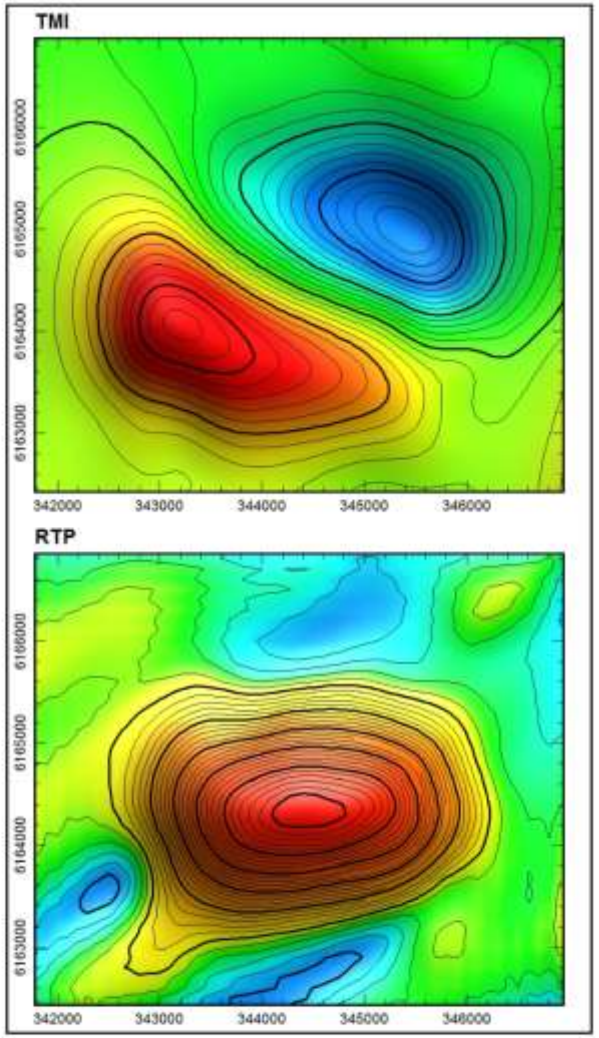
- Resultant magnetization method
  - Magnetization vector amplitude & direction
  - Apparent resultant rotation angle ARRA
- RRE method
  - Remanent & induced vectors
  - Remote determination of Q
  - Improved precision for bulk magnetic susceptibility
  - More confidence in spatial parameters such as shape & dip
  - Target age

Applicable software resources

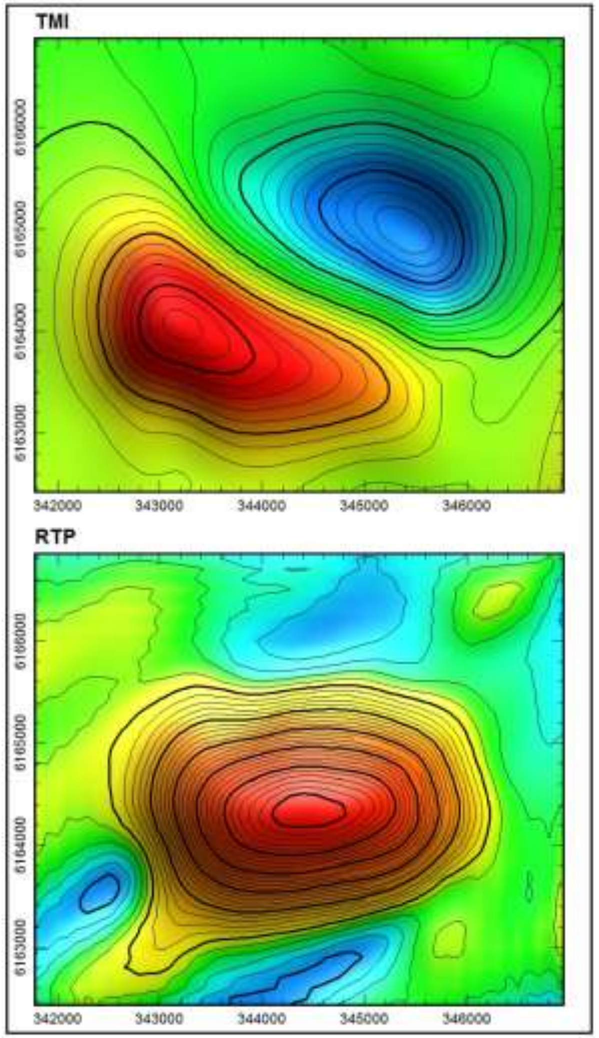
- Magnetization unit vector direction estimation
  - Helbig magnetic moment (Helbig, Schmidt & Clark, Foss)
  - Max-Min (Fedi, Florio & Rapolla)
- Magnetization vector direction & amplitude inversion
  - ModelVision (Pratt et.al. 2012, 2013)
  - VPmg 3D# (Fullagar et.al., 2016) & VOXI # (Ellis &MacLeod, 2013)
- Remanence estimation methods
  - VPMA for Q & age from unit vector (Cordani & Shukowsky, 2009)
  - RRE for Q, susc., remanence vector & age (Pratt et.al. 2012)

Magnetization unit vector (Max-Min)

- Max-Min method by Fedi et.al.
- Remove regional background
- Upward continue (optional)
- Iterate magnetization direction to maximise the minimum
- Matlab code from Cordani



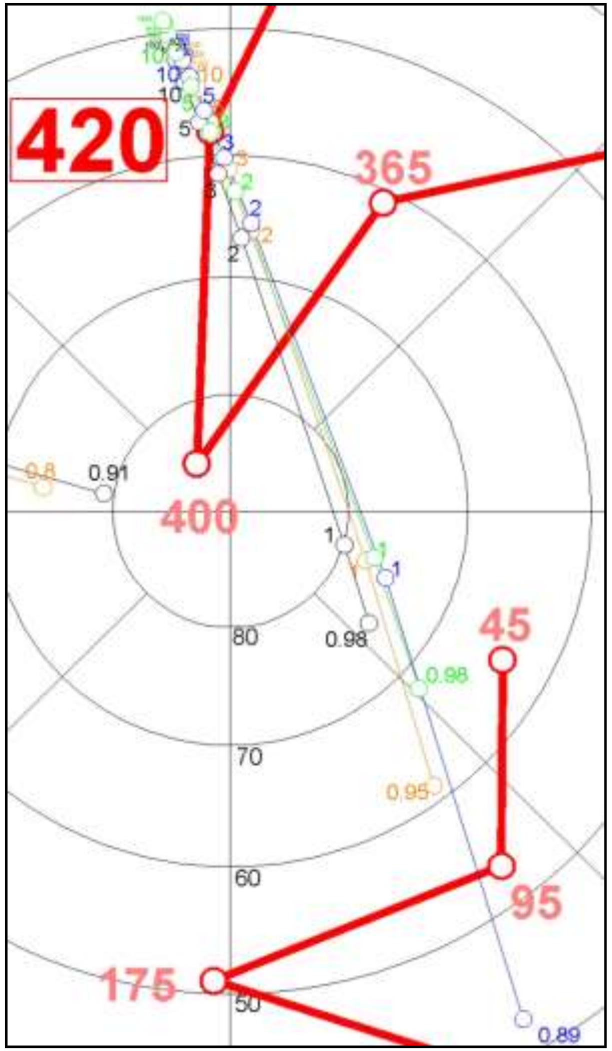
Q & age estimation Cordani & Shukowsky



Max-Min method gives the magnetization unit vector

$$\vec{J} = \vec{J}i + \vec{J}r$$

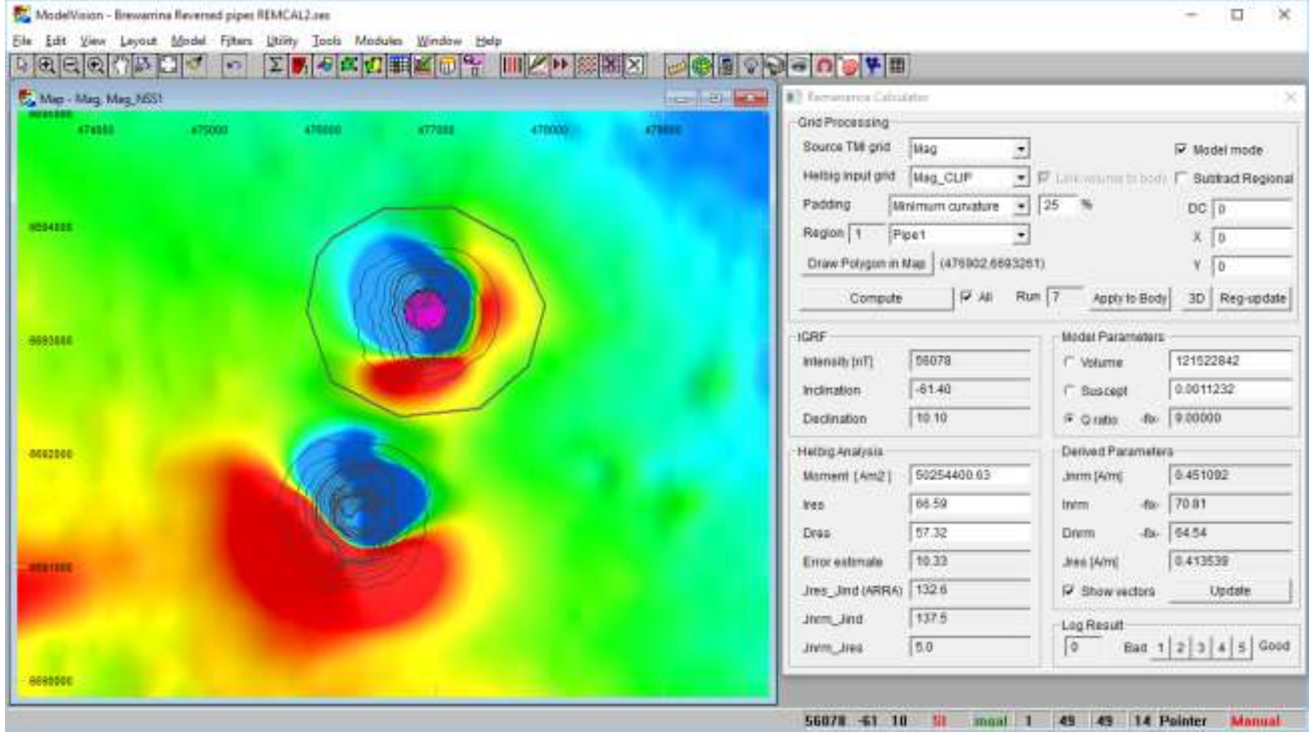
Solve for multiple Q & age intersection



Cordani & Shukowsky, 2009

Magnetization unit vector (ModelVision)

- Helbig (1963) surface integral method
- Based on Schmidt & Clark (1998)
- Compact source requirement (dipole)
- Remove regional
- Integrate Bx, By, Bz
  from FFT transformation
  of residual TMI



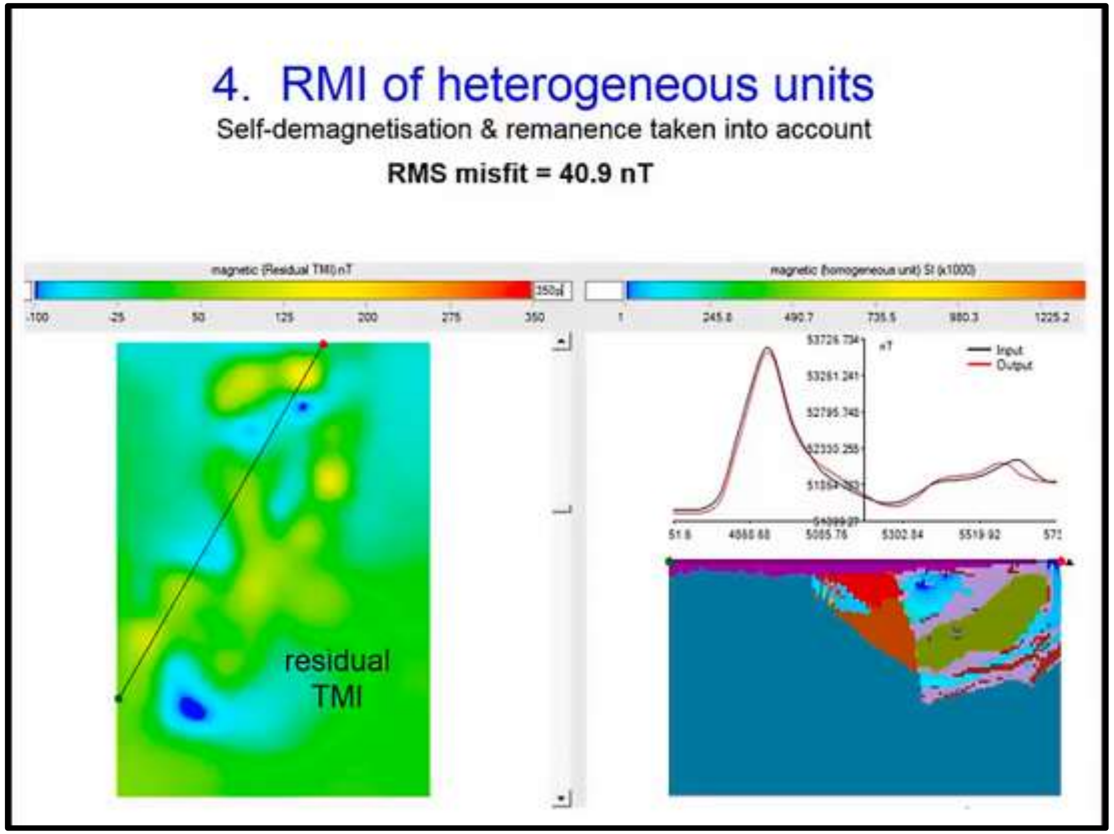
VPmg 3D

Fullagar & Pears 2016 YouTube video -

Remanent Magnetisation Inversion at Cannington, Queensland, fully constrained. BC Geophysical Society (BCGS) Fall Symposium Presentations- 2016

VPmg 3D - Supported by Mira Geoscience

For details of the methodology see:
Remanent magnetisation inversion, Fullagar & Pears, 2015
ASEG-PESA 2015 – Perth, Australia



https://www.youtube.com/watch?v=afbyB20az6o

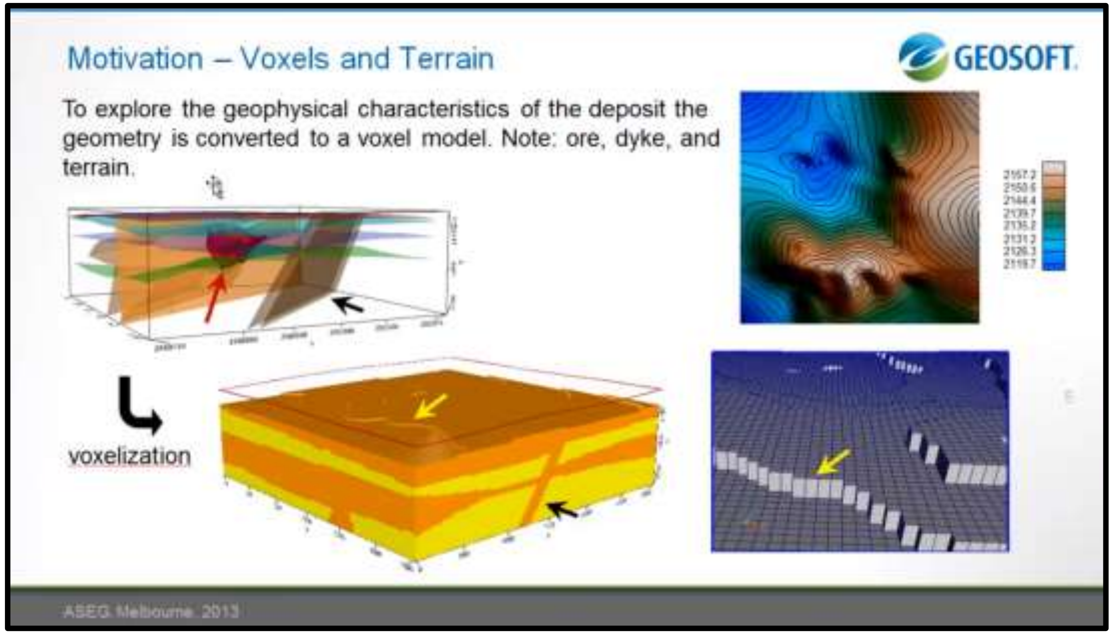
VOXI

Ellis & MacLeod 2013 YouTube video -

The Cartesian cut cell method and constrained inversion.

ASEG Melbourne Conference

Developed & supported by Geosoft



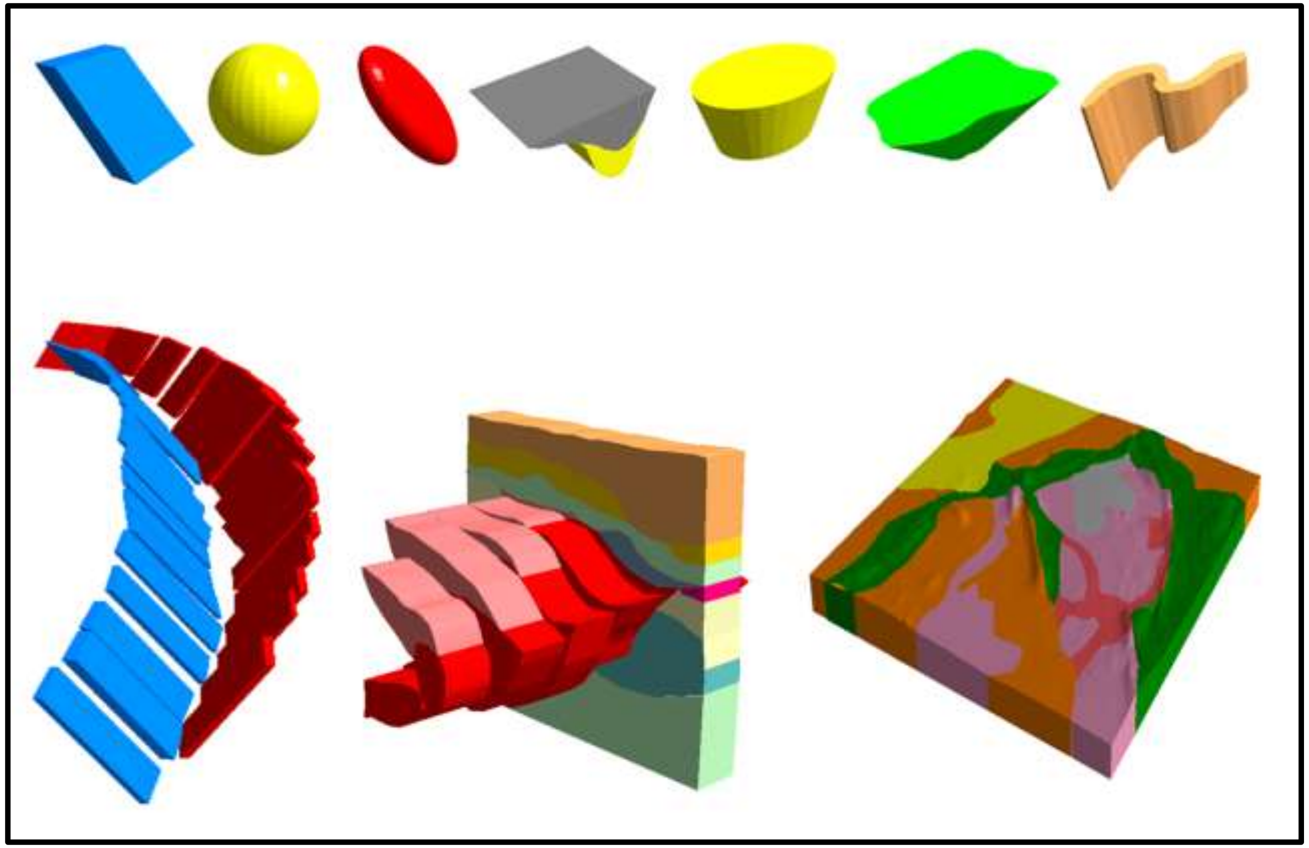
https://www.youtube.com/watch?v=ypRnQwcoU1s

Parametric modelling with ModelVision

Constrained modelling and inversion.

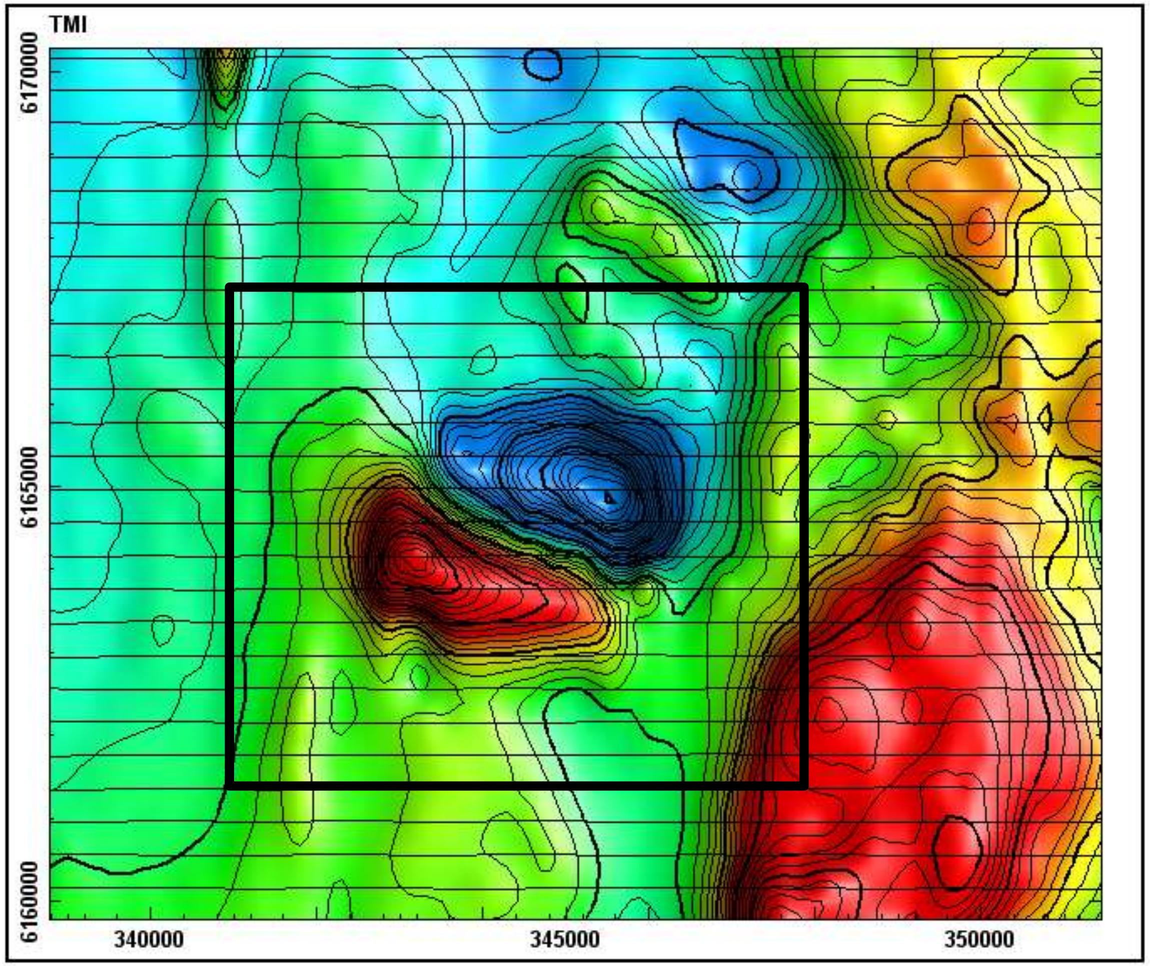
Simple shapes that are created interactively and combined to build realistic geological models for anomaly complexes.

Developed & supported by Tensor Research



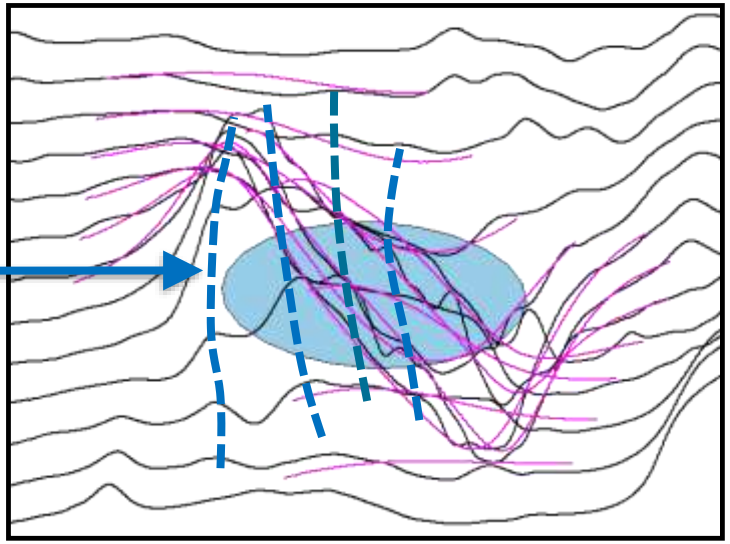
Magnetization estimation (ModelVision)

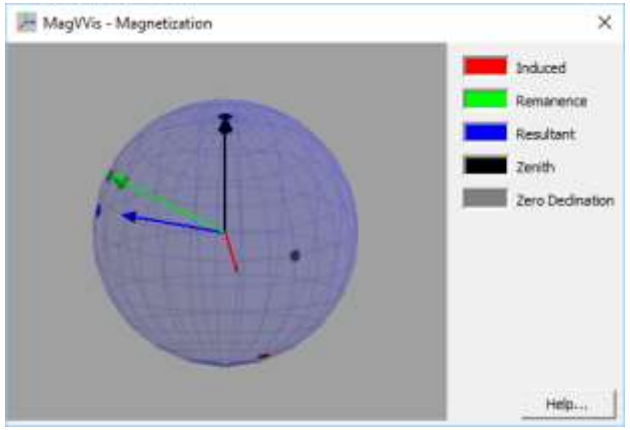
Magnetic image of Area “C”



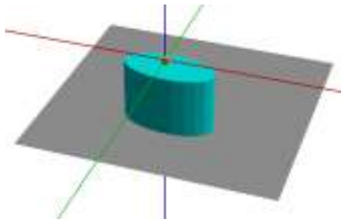
B_m inversion match

Younger dyke anomalies





Jres = 10.8 A/m
Ires = 9.5 deg
Dres = 234



Validation of RRE method

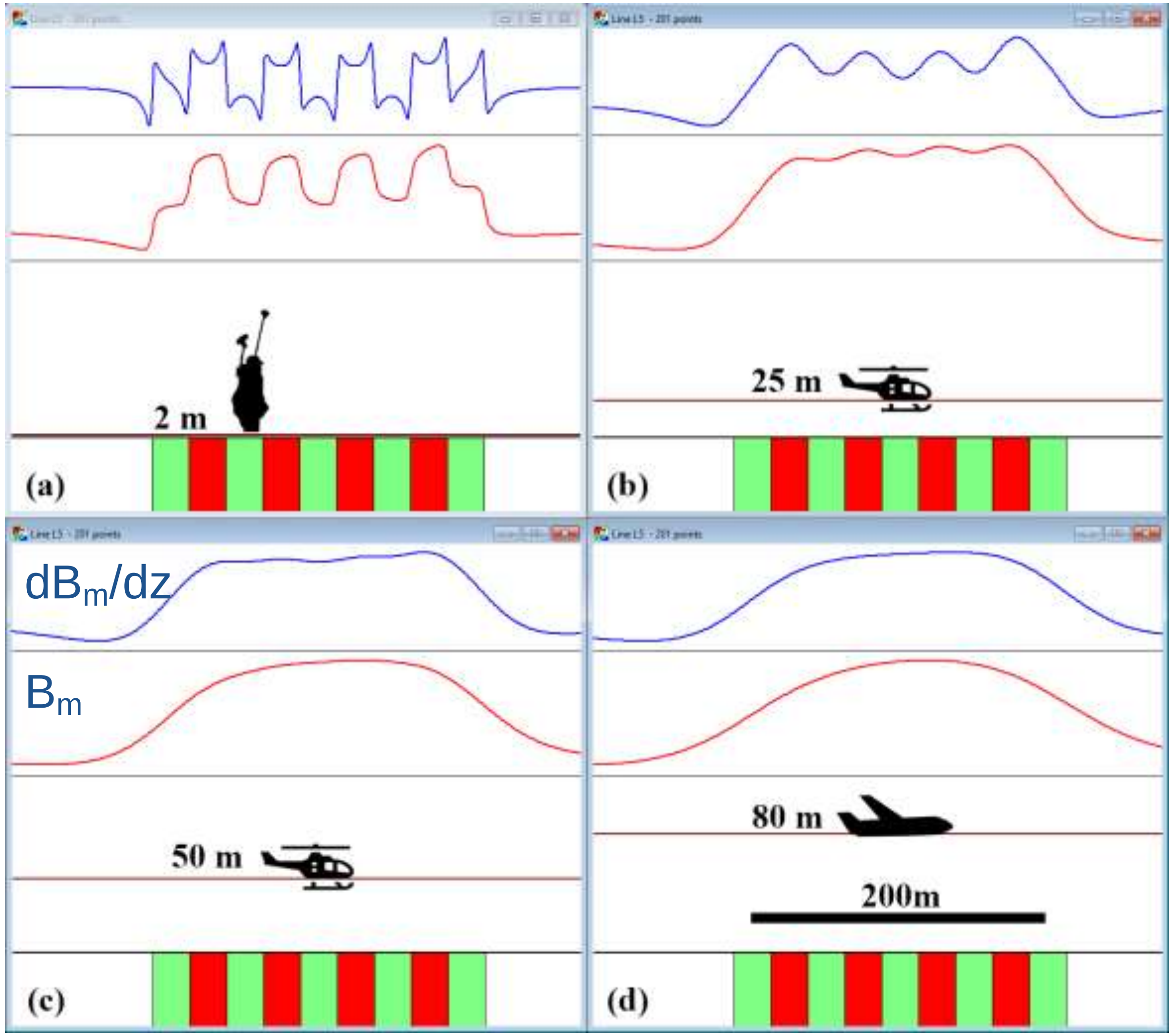
Source	Method	Dec. (deg)	Inc. (deg)
This study	Res inv	234	9
Foss & McKenzie, 2006	Res inv	232	8
Foss & McKenzie, 2006	MM 1	233	12
Foss & McKenzie, 2006	MM 2	223	6
Rajagapolan et al, 1995	Pmag	221	8
Schmidt et al, 1993	Pmag 1	223	9
Schmidt et al, 1993	Pmag 2	231	20
This study using BH Norite B_{nrm}	RRE	230	18

Inherent limitations (all methods)

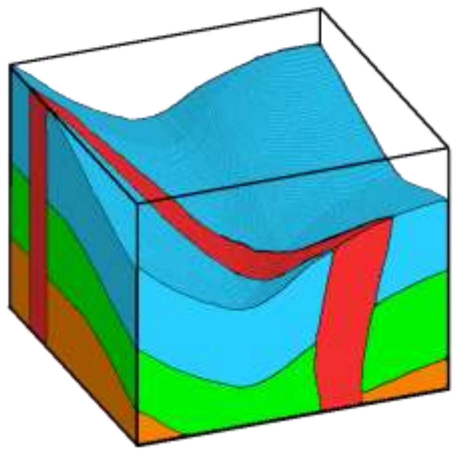
- Lateral resolution
- Vertical resolution
- Compact source requirement (implications for voxel methods)
- Equivalent source solutions & degrees of freedom
- Polar wander information (RRE & VPMA methods)

Lateral resolution

- 25m wide formations 0.005 & 0.01SI
- Parametric models
  - Ability to focus on each anom.
  - Complexity limited
- Voxel models
  - Voxels size usually larger than available resolution

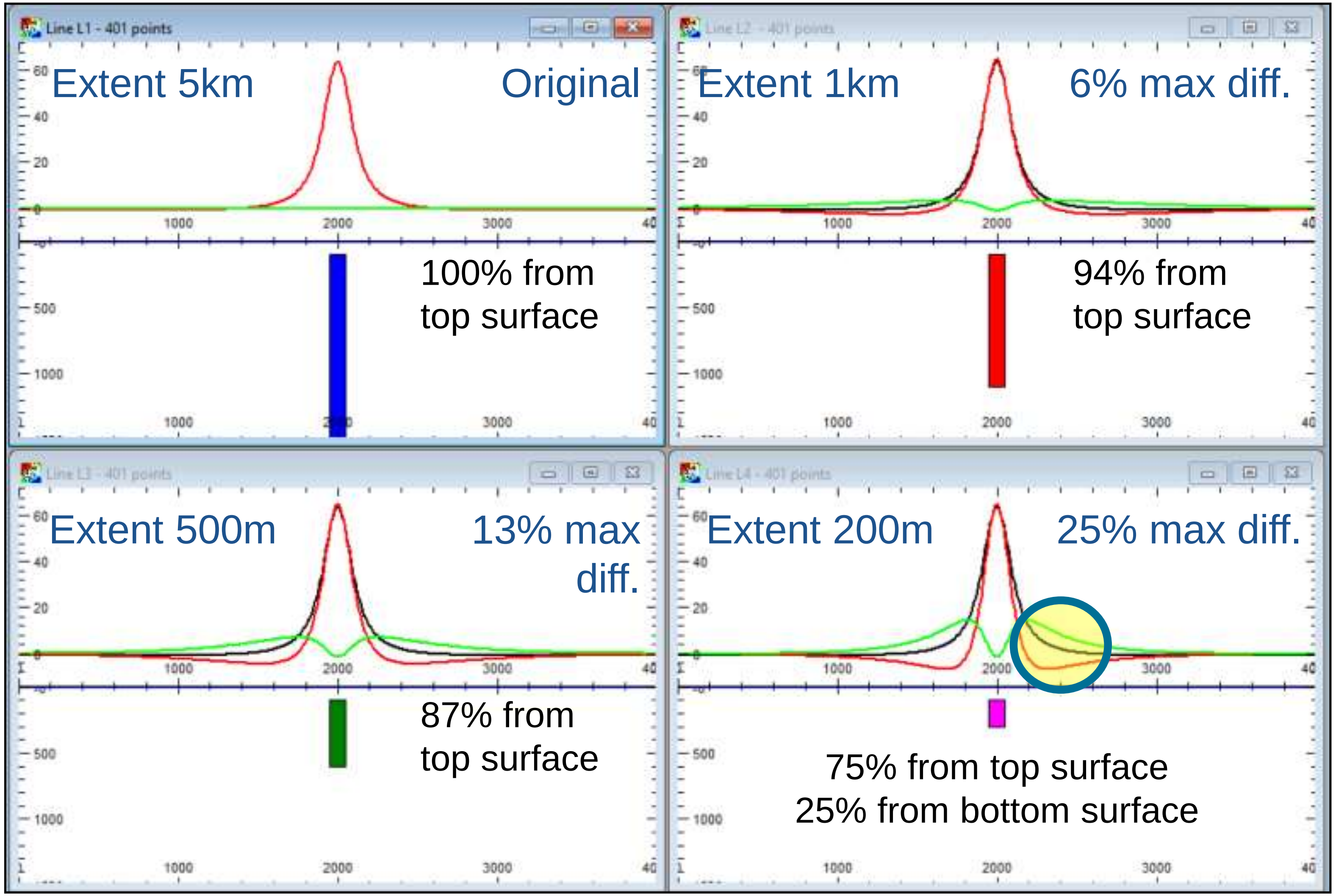


Vertical resolution



Pure property inversion

The original **model top is 100m** below the surface and inversion of models with different depth extents reveal the dominance of the top surface (unconformity).



Black =TMI, Red = Inversion, Green = Residual

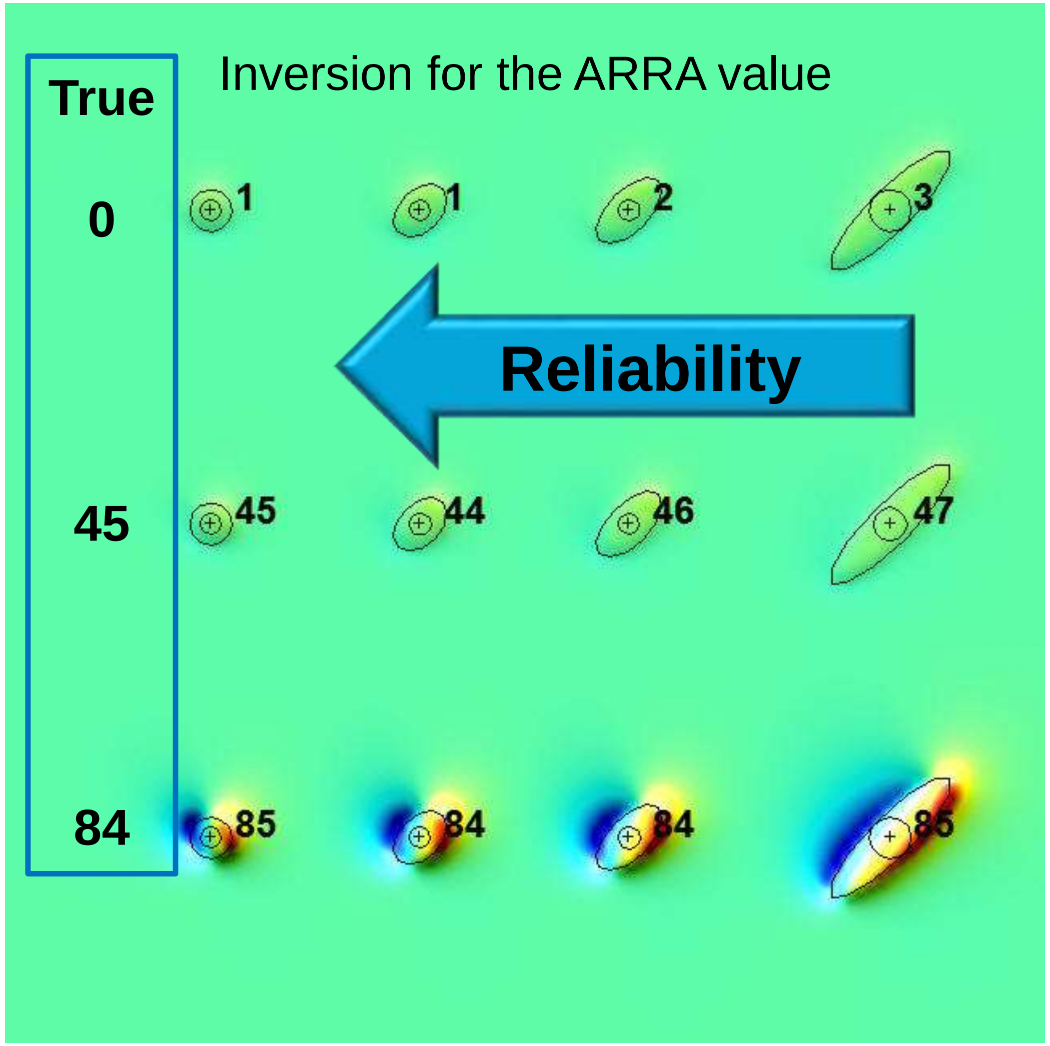
Compact source requirement (ModelVision)

Row	Q	Inrm	Dnrm	Ires	Dres	ARRA
1	0	-60	0.0	0.0	0.0	0.0
2	1	0	90.0	-37.8	63.4	45.0
3	10	0	90.0	-4.9	87.1	84.3

A ‘compact source’ describes a distribution of magnetization which has no extent in any direction greater than twice the distance between the magnetic sensor and the shortest distance to the source (Foss 2017). It should look like a dipole source at the sensor.

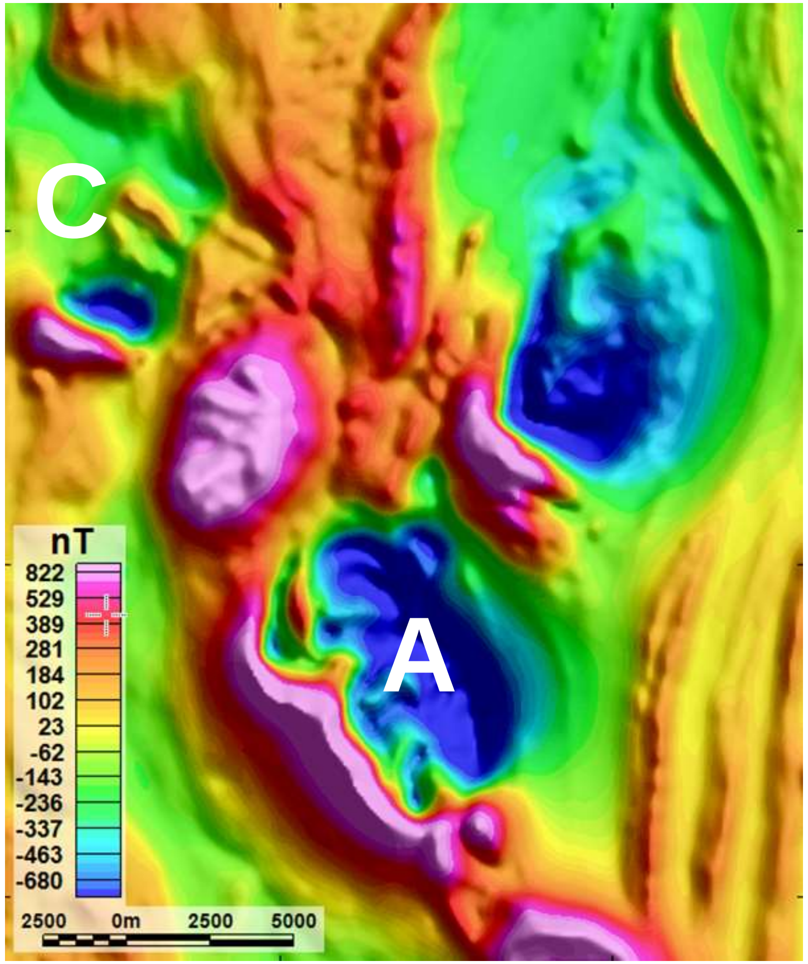
Our experiments suggest this is conservative, but it is a reasonable starting point based on the Helbig theory.

Unconstrained voxel models cannot comply with this rule.



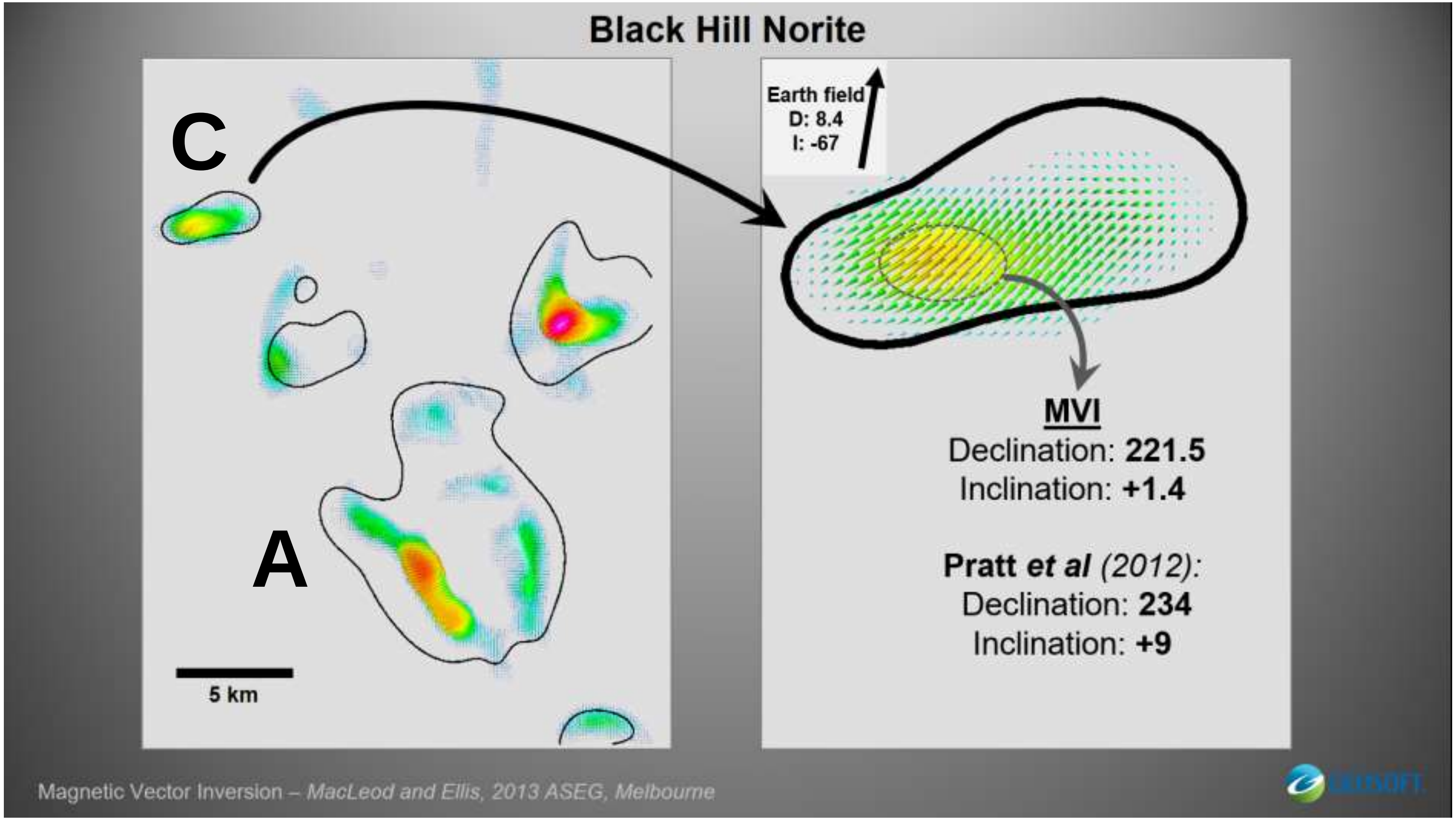
Reliability Black Hill Norite

- Parametric models
  - Dipolar
  - Limited strike length
  - Control shallow interference
  - Homogeneous at dipole scale
- Unconstrained voxel models
  - Equivalent source solution
  - Trends toward the true direction if compact
  - Compact source rules A (no), C (yes)
  - No control over artefacts



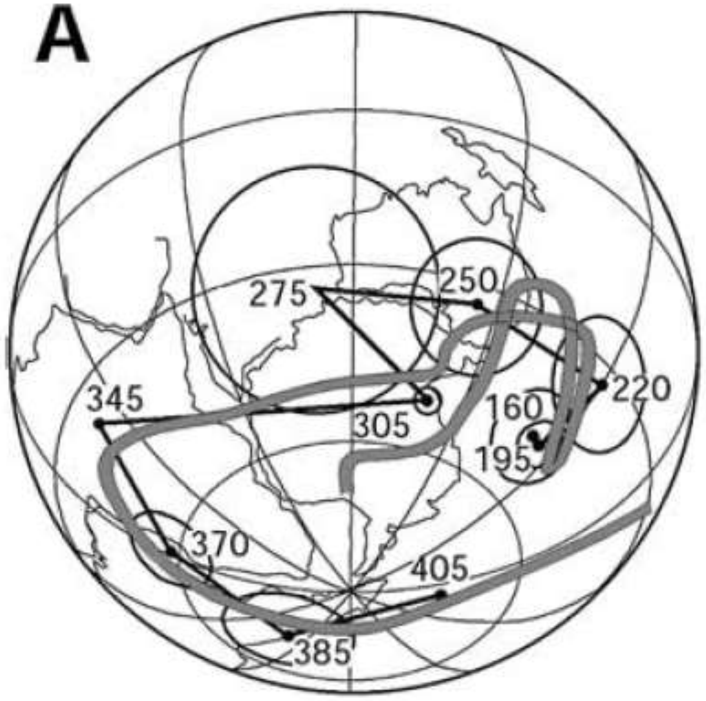
MacLeod and Ellis, 2013 ASEG, Melbourne

Magnetization estimation MVI (VOXI)



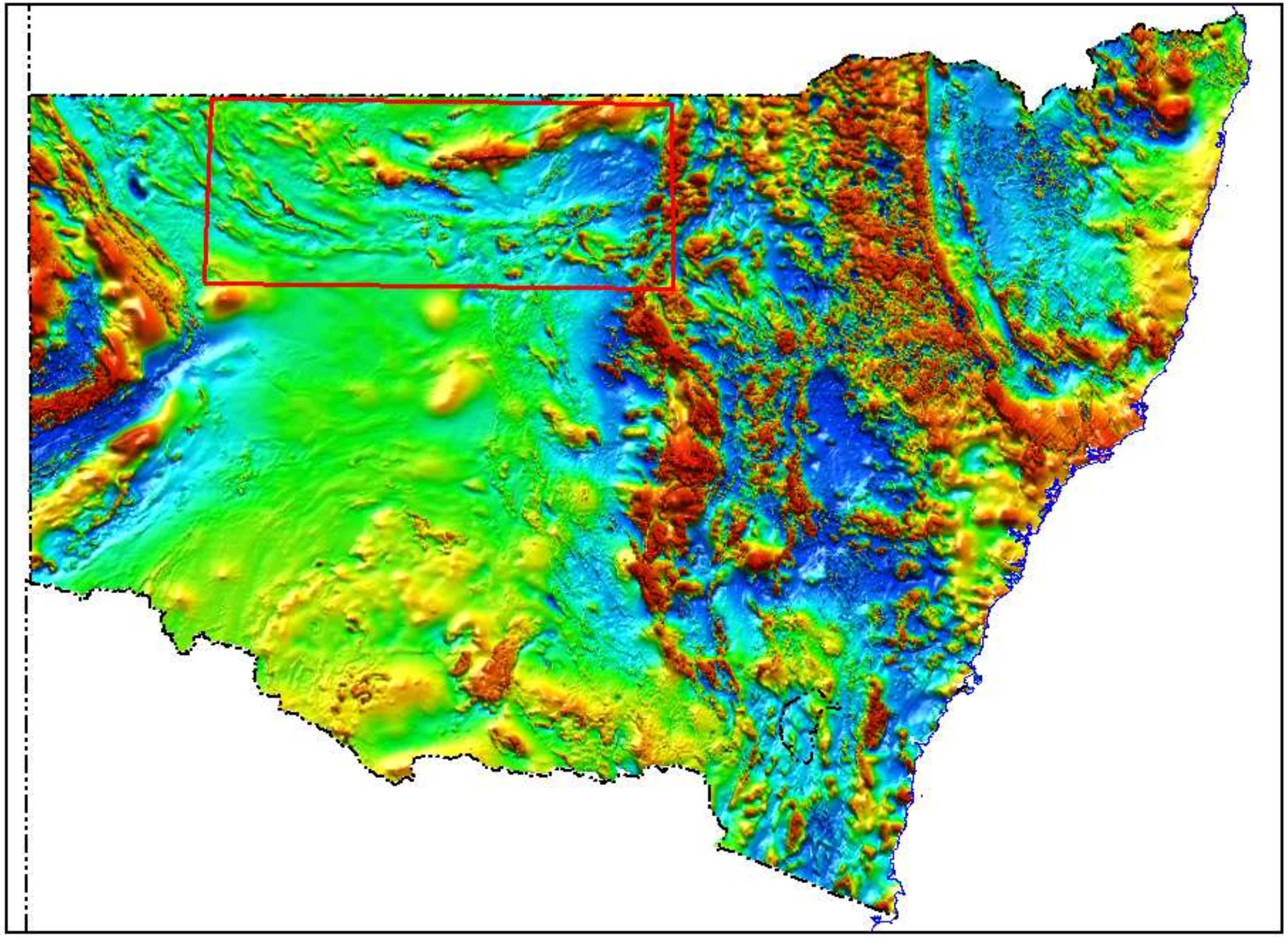
Polar wander data limitations

- Data availability
- Interpolation uncertainty
- Structural adjustment for tilt
- Secular variation & cooling time

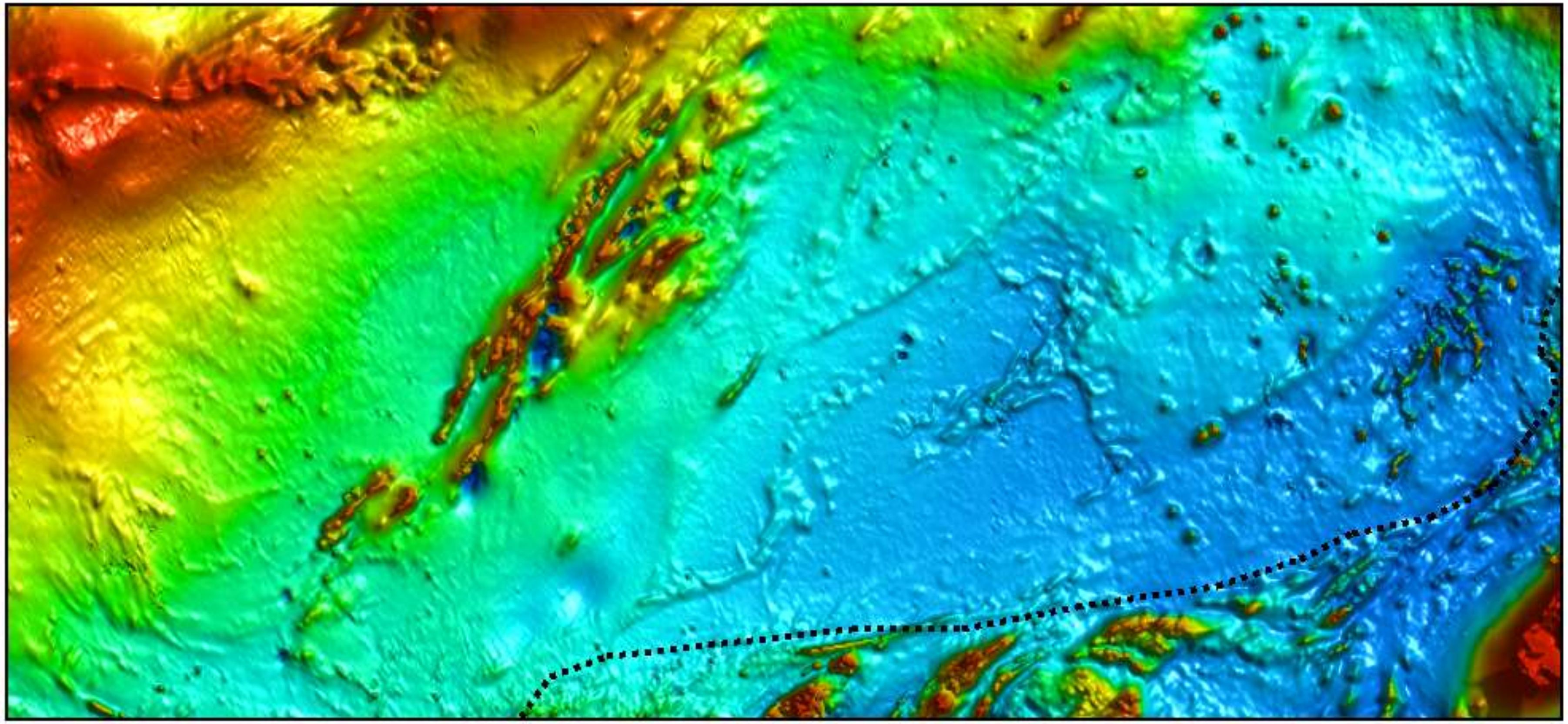


Clarke & Lackie 2003

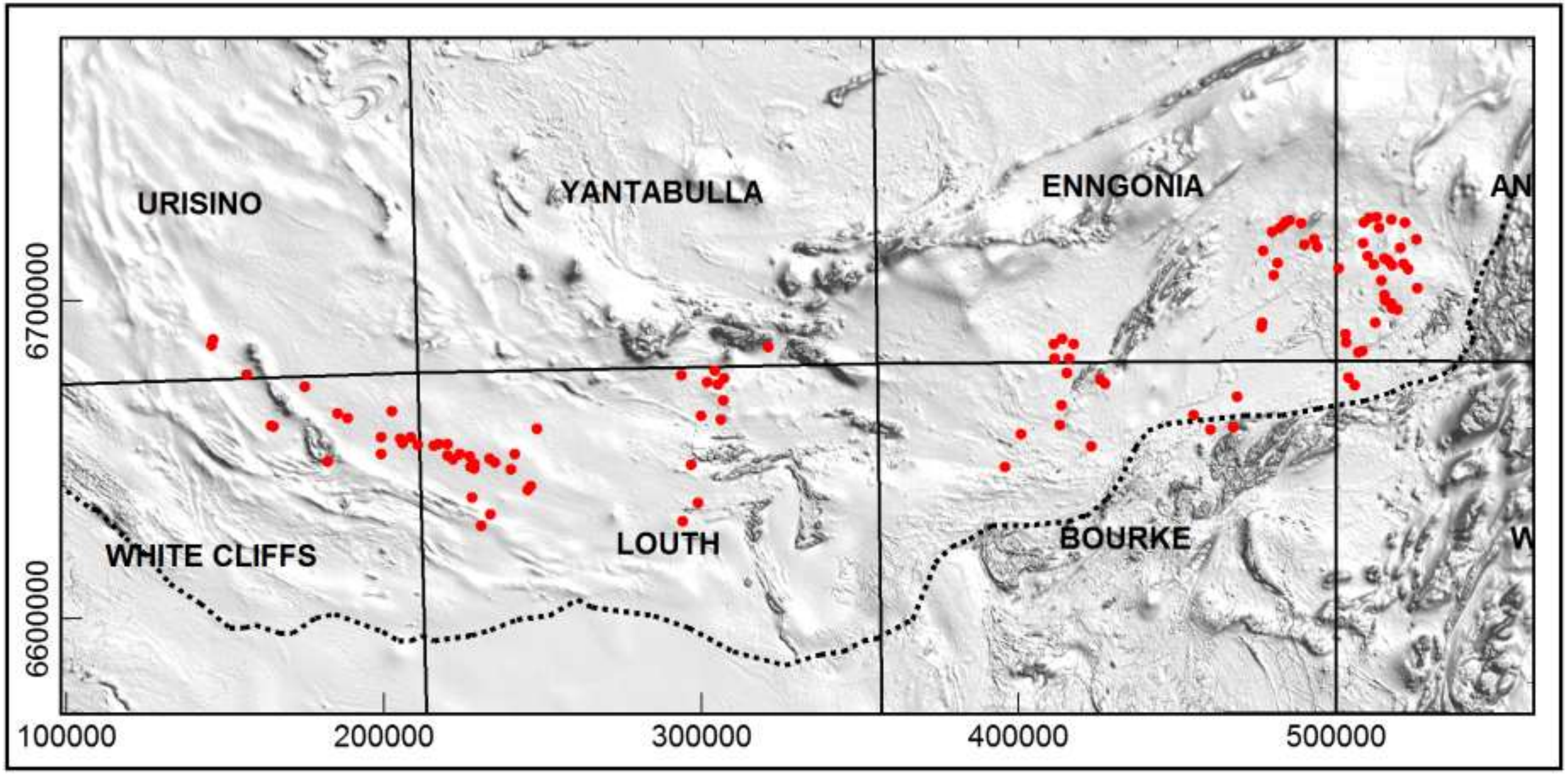
RRE - Thomson Orogen NSW, Australia



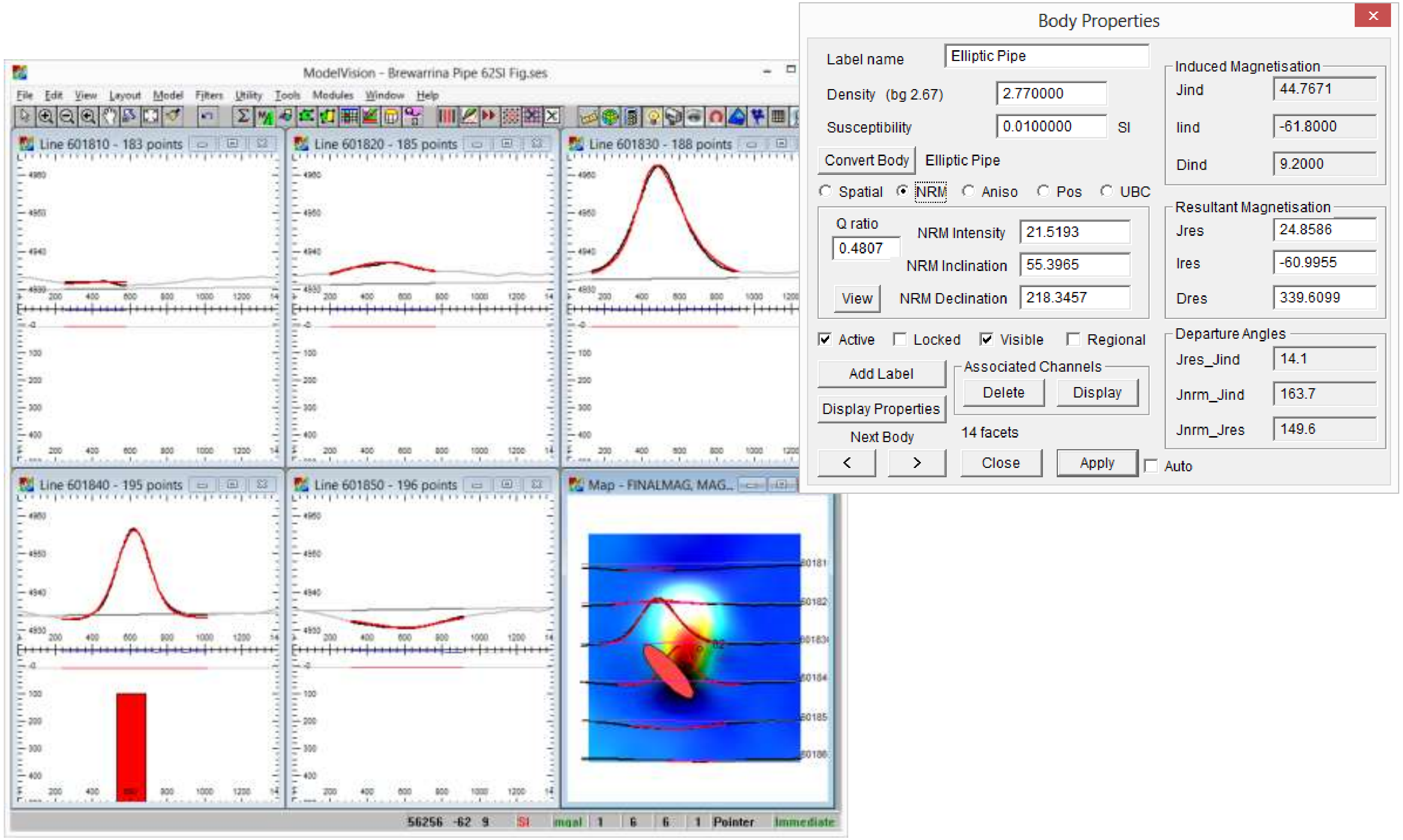
Thomson pipes (east section)



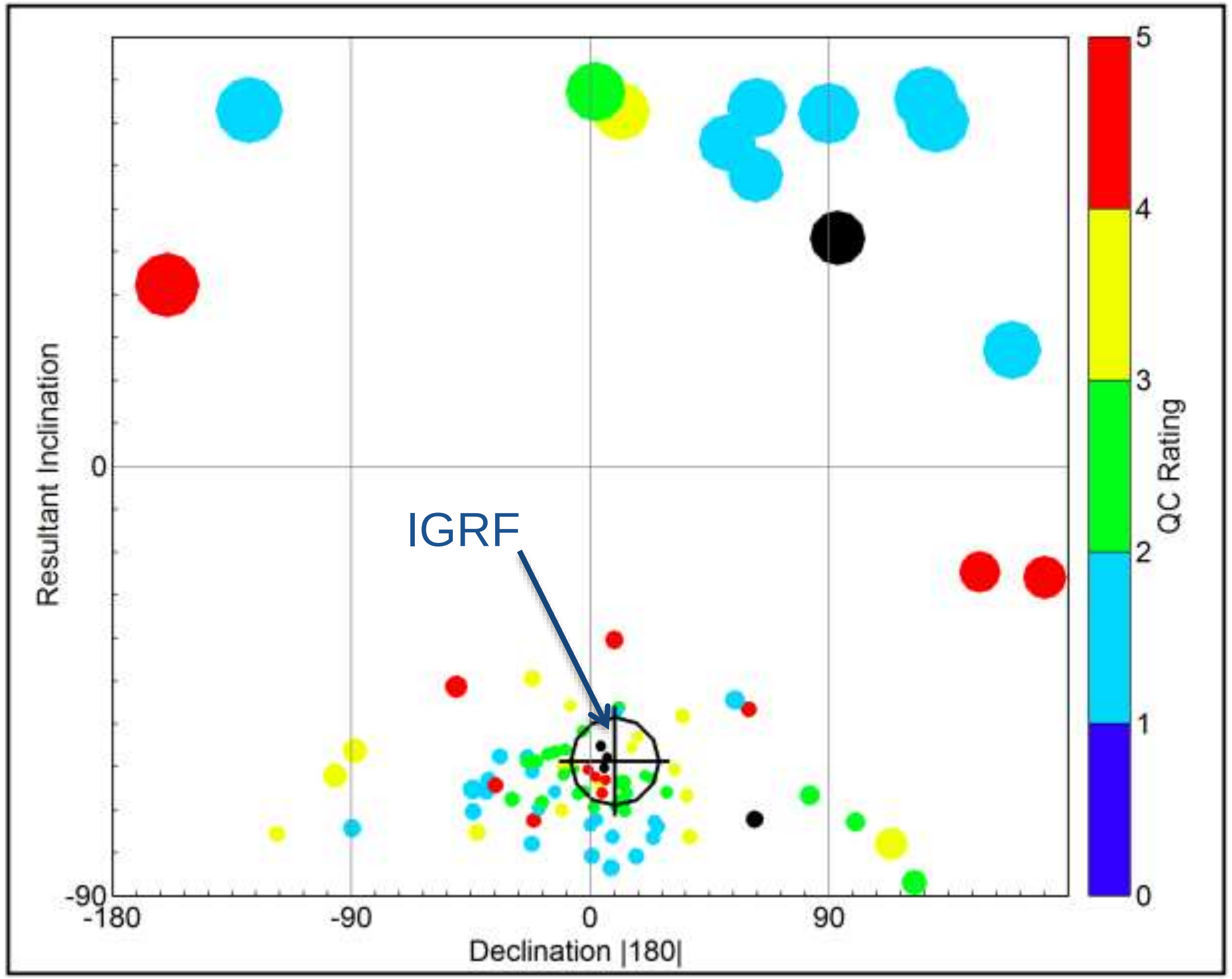
Thomson pipe distribution



ModelVision inversion

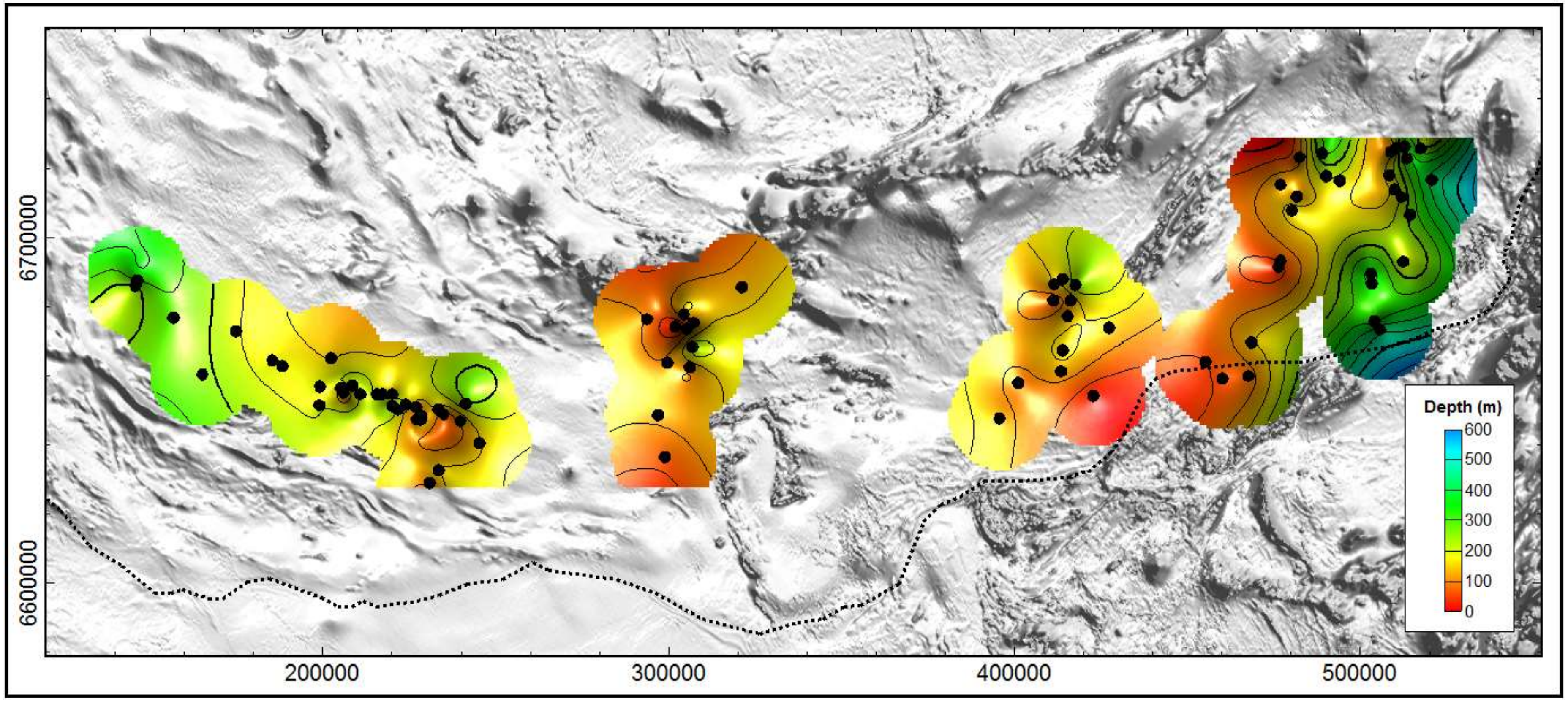


Thomson resultant vectors



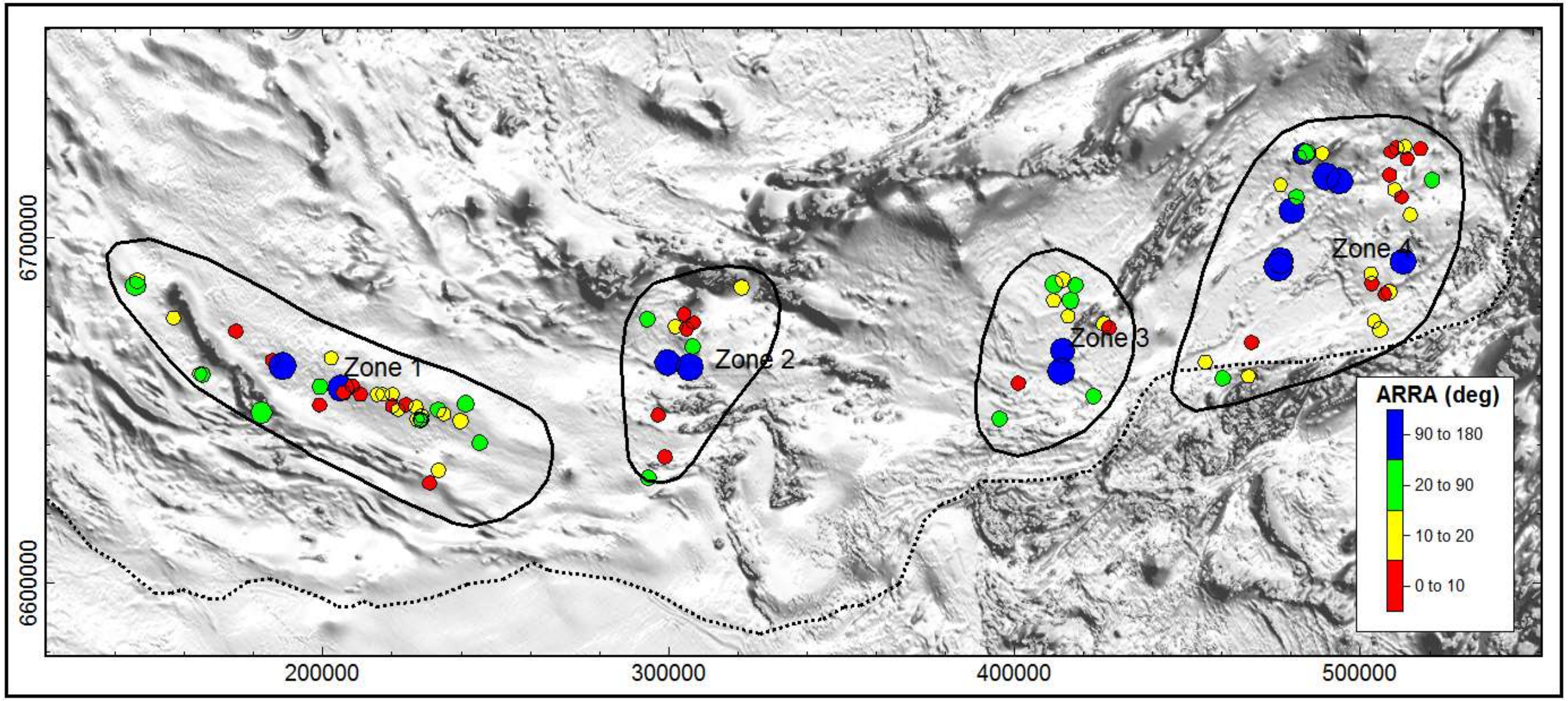
Symbol size = ARRA Symbol colour = QC rating

Pipe inversion depths



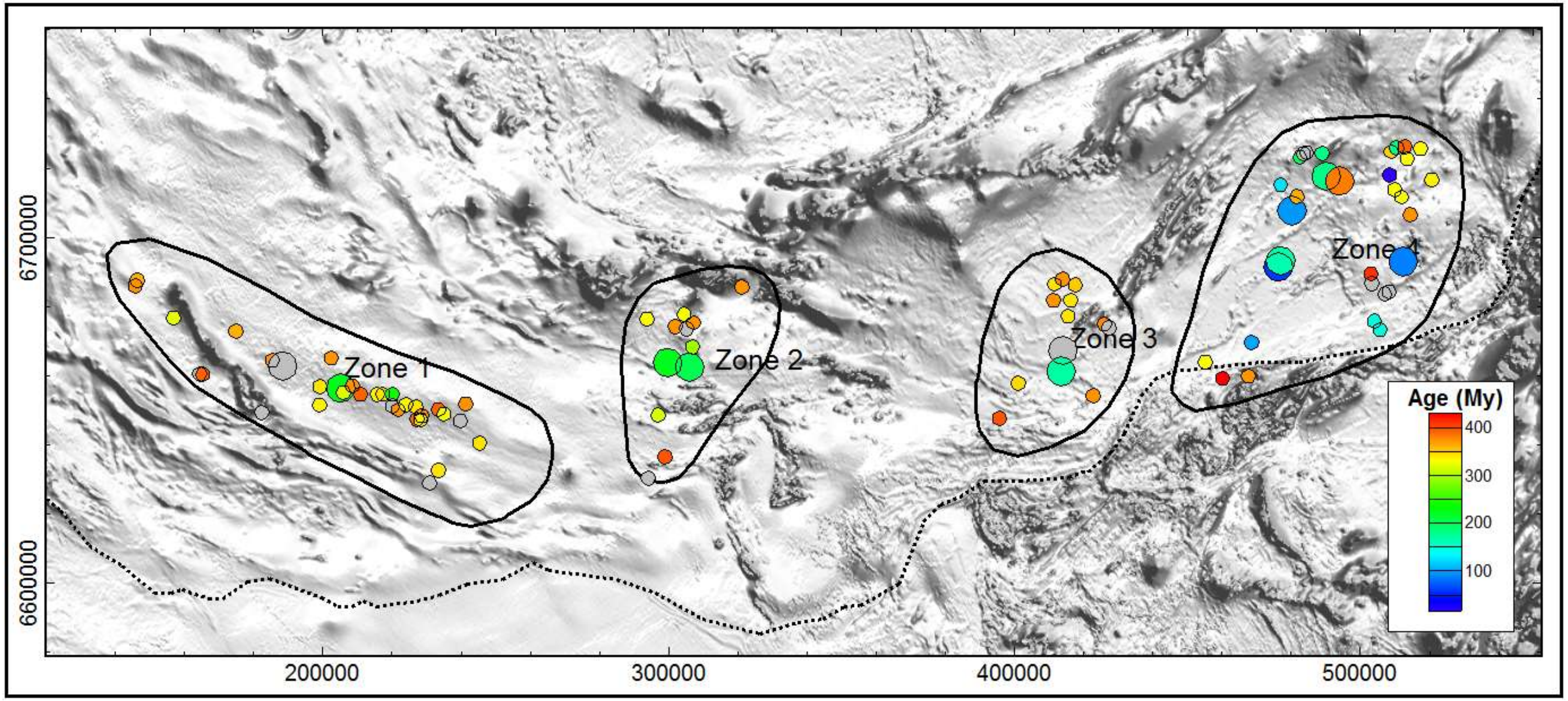
Symbol size = ARRA Symbol colour = QC rating

Pipe ARRA distribution



Symbol size = ARRA, Symbol colour = ARRA (deg.) (● = reversal)

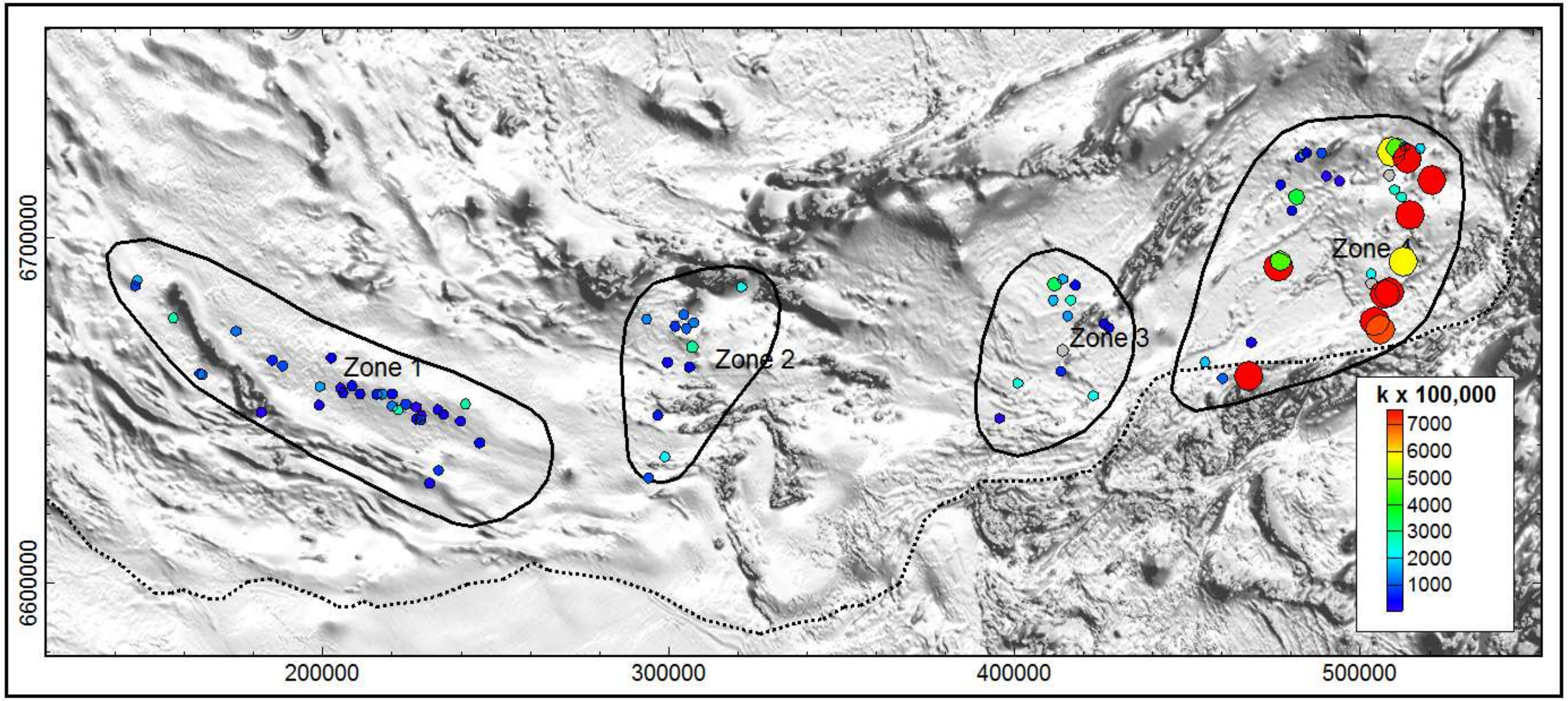
Pipe age distribution



Symbol size = polarity, Symbol colour = age

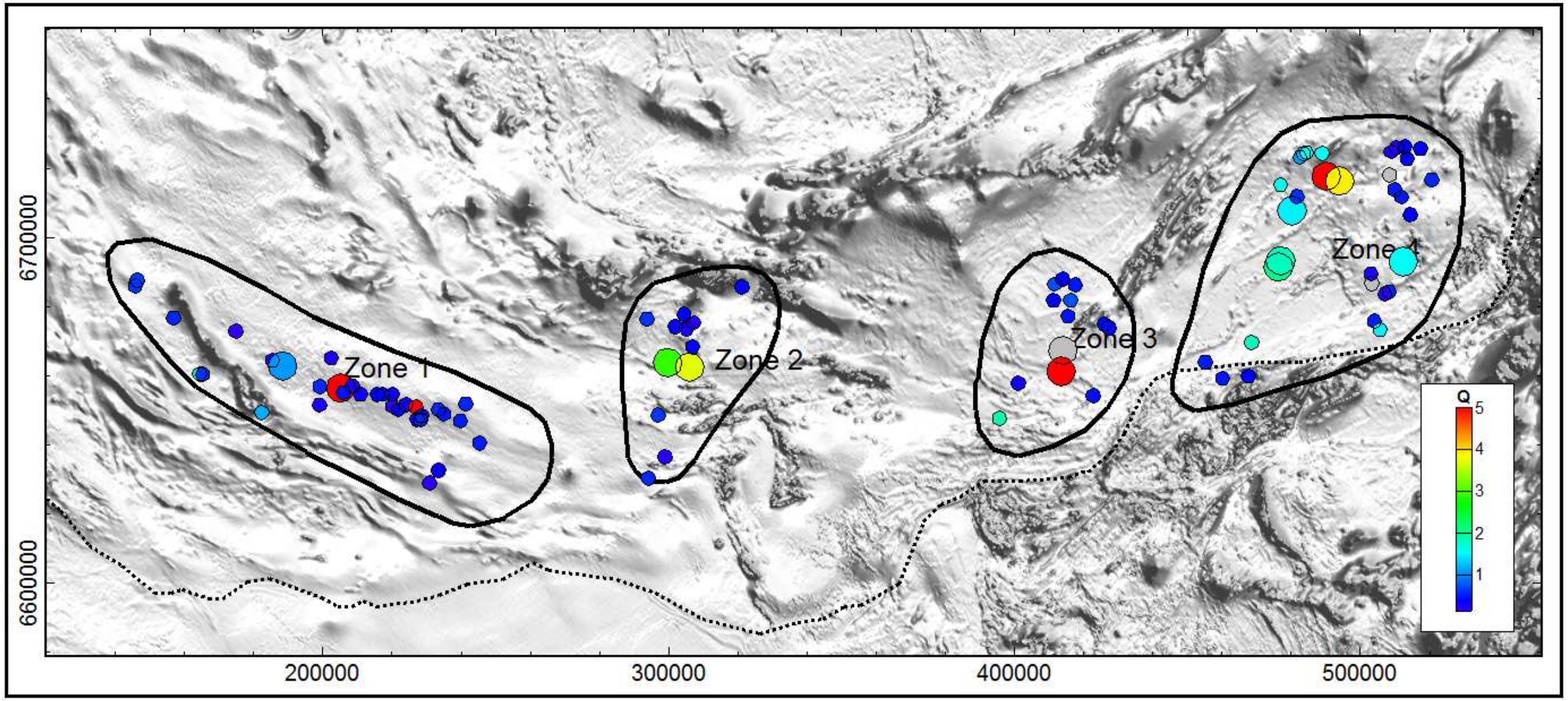
Mid to Upper Devonian = red
Carbonif.- Up. Devonian = yellow-orange
Jurassic = blue & cyan

Pipe corrected susceptibilities (SI)



Symbol size = susceptibility, Symbol colour = susceptibility

Pipe Koenigsberger ratios (Q)



Symbol size = polarity, Symbol colour = Q

Summary

- **Constrained** inversion is essential for magnetization calc.
- The **compact source** rule must be applied.
- Parametric methods are fast and constrained for individual or compound targets plus easy to separate irrelevant sources.
- The surface integral & max-min are easy to use but cannot remove noise sources & require regional removal.
- Voxel inversion must be constrained and observe the compact source rule.

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