Australian Government

Geoscience Australia

Developments and directions in 3D mapping of mineral systems using geophysics

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Geoscience Australia

The DARPA Transparent Earth Project 2010-2015 has a vision that eloquently describes what we want to do!

“… determine the physical, chemical, and dynamic properties of the Earth down to 5 km depth”

- A global 3D volumetric model of physical/chemical properties and their variations with time
- Data from multiple sensors inverted to estimate the properties
- Changes determined at local scales and propagated back into the global model

(N.B. DARPA = US Department of Defense - Defense Advanced Research Projects Agency)

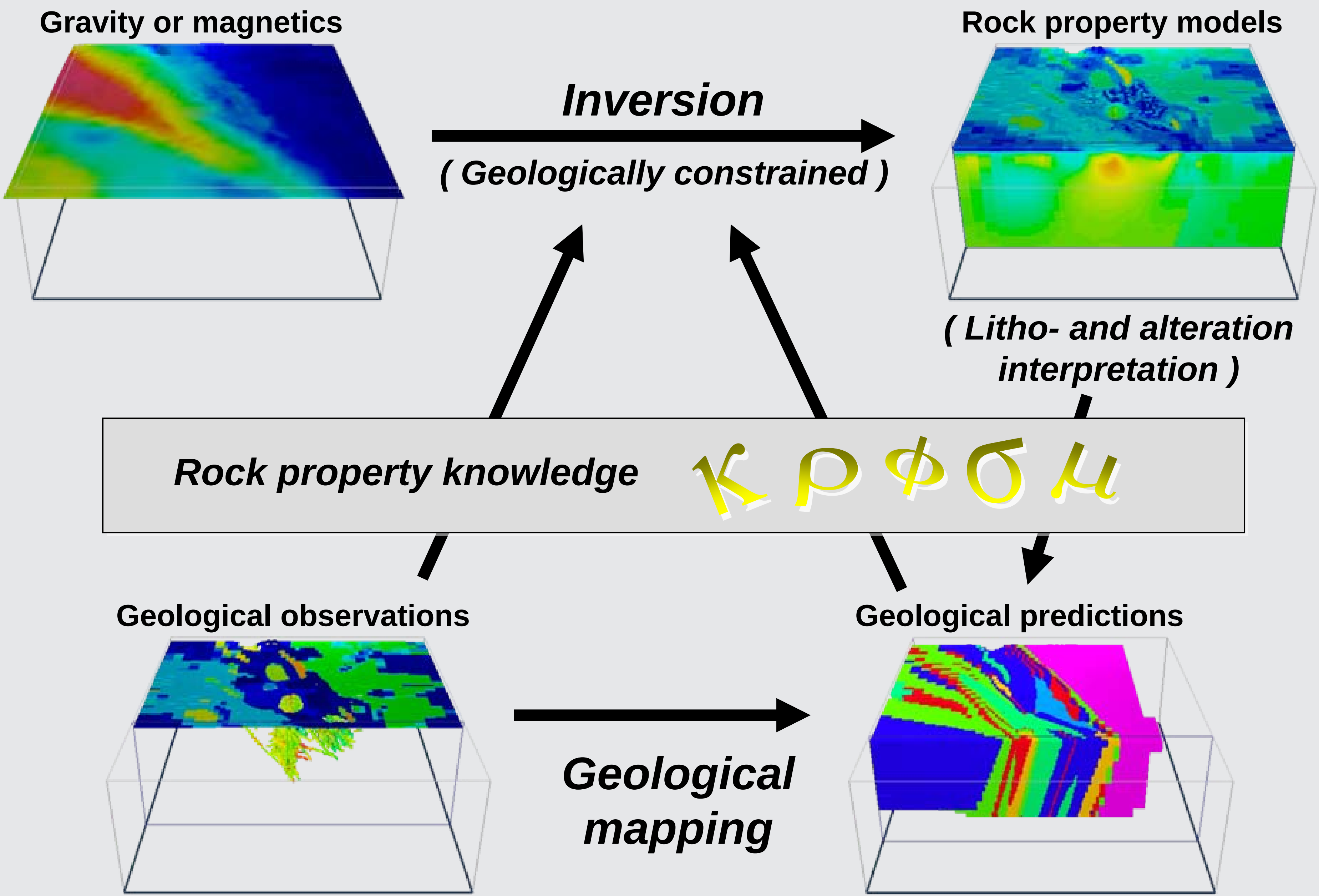
These are the separate chapters in this presentation but the issues are all interrelated

1. **Modelling and interpretation methods / Rock properties**
2. **Next generation geophysical data acquisition**
3. **Computing challenges**
   - High performance computing (HPC)
   - Data and software interoperability
   - Visualisation and communication of 3D objects

1. Modelling and interpretation methods / Rock properties

Rock properties are the key

They are the link between geophysics and geology



(Adapted from slide by Nick Williams)

GA carry out <u>lithological and alteration mapping</u> **using several different methods.**

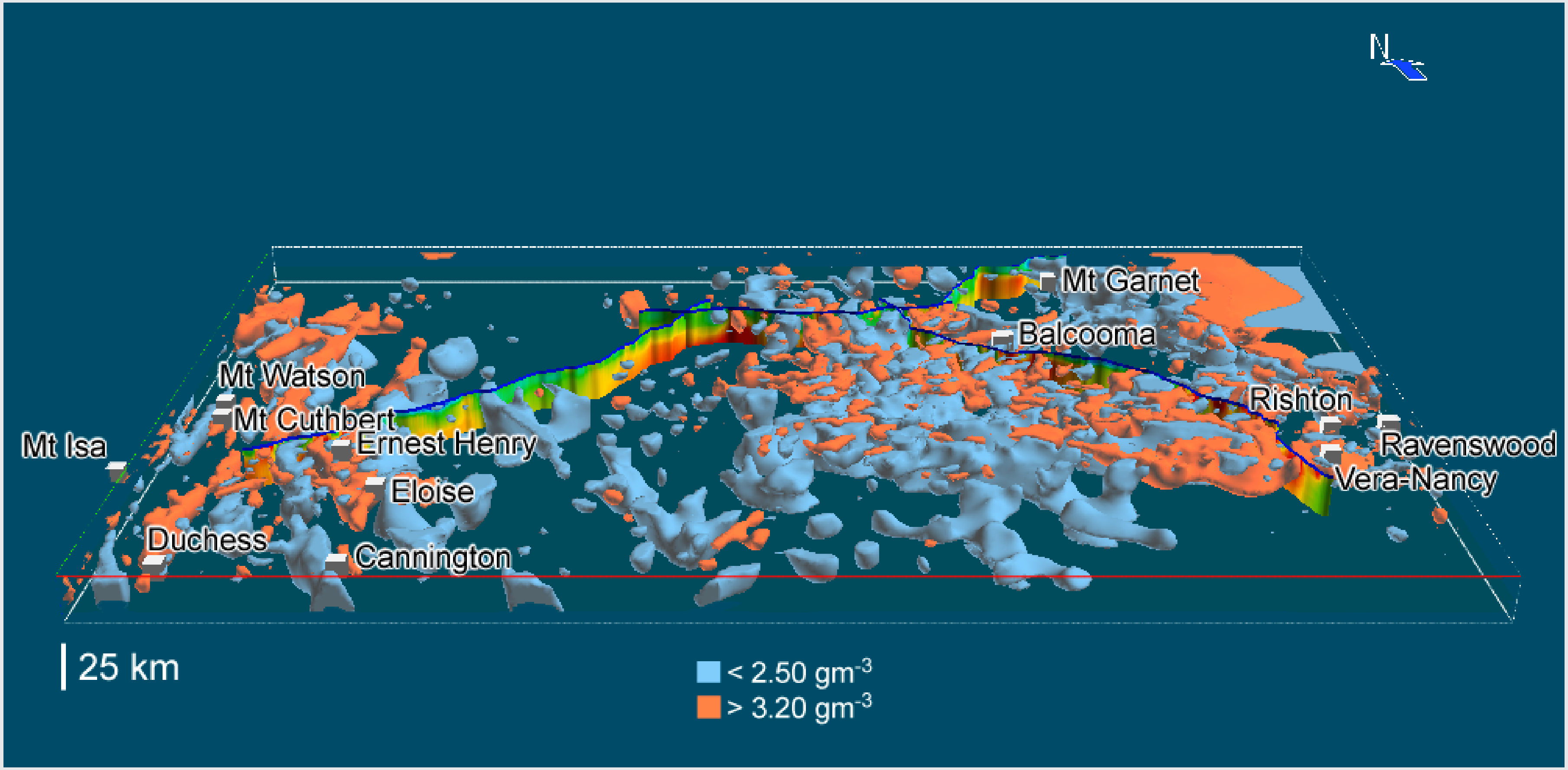
Some are based on *<u>property models</u>* derived though inversion

a. Thresholding
b. Qualitative alteration mapping
c. Quantitative alteration mapping
d. Multi-property litho-classification

Others are based on *<u>litho-modelling</u>* methods that use geological subdivisions rather than properties as the primary variables

e.g., GeoModeller, VPmg, IGMAS, ModelVision, etc

Thresholding of density inversion results from NW Queensland



Blue = low density ≈ granite

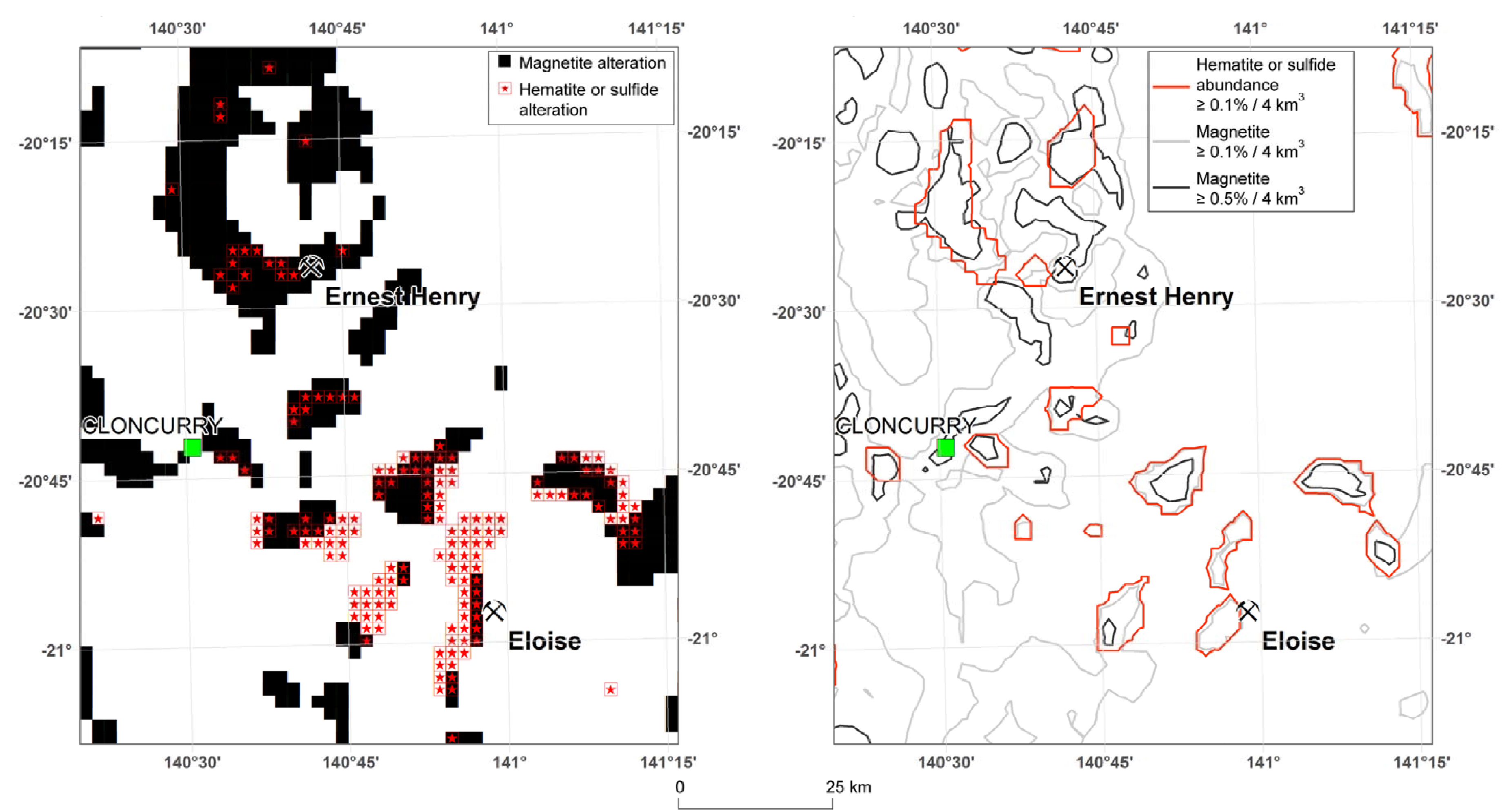
Orange = high density ≈ mafic/ultramafic/Fe-rich/sulphides

(Adapted from slide by Richard Chopping)

Qualitative and *quantitative alteration mapping* results for the Ernest Henry-Eloise area

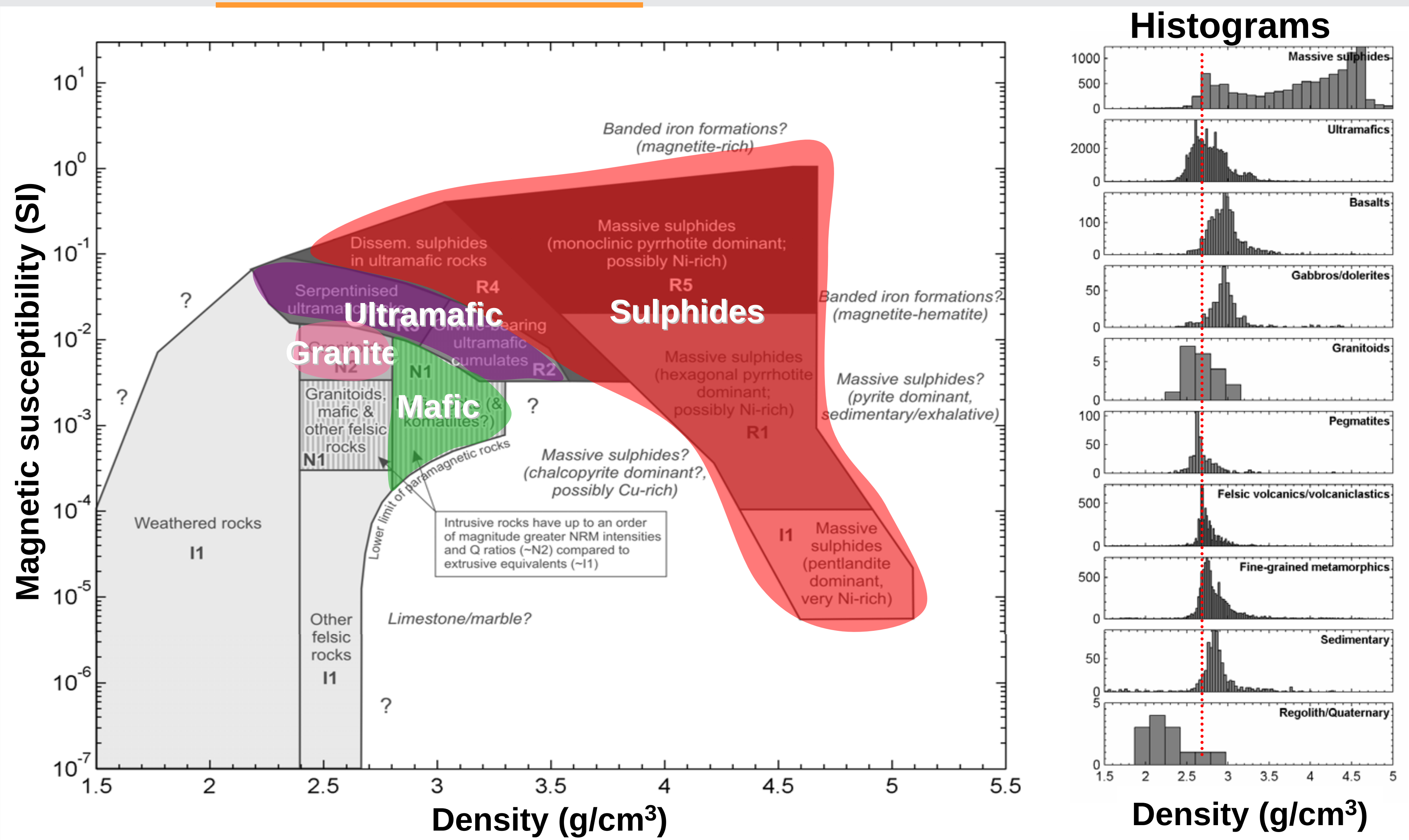
Qualitative method

Quantitative method

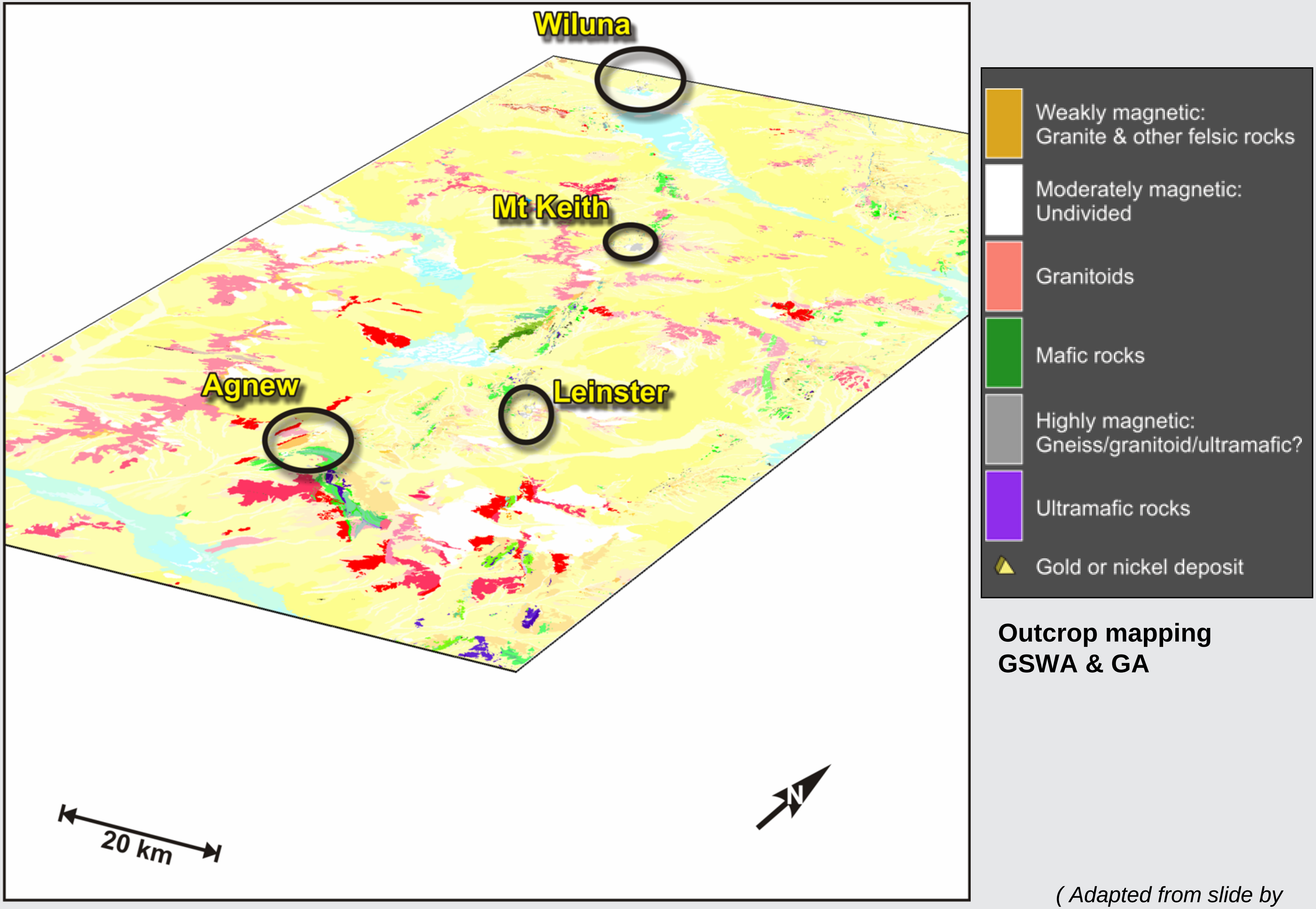


(Adapted from slide by Richard Chopping)

Measurements of complementary rock properties allow multi-property regions to be defined for each rock type for use in ***litho-classification***.

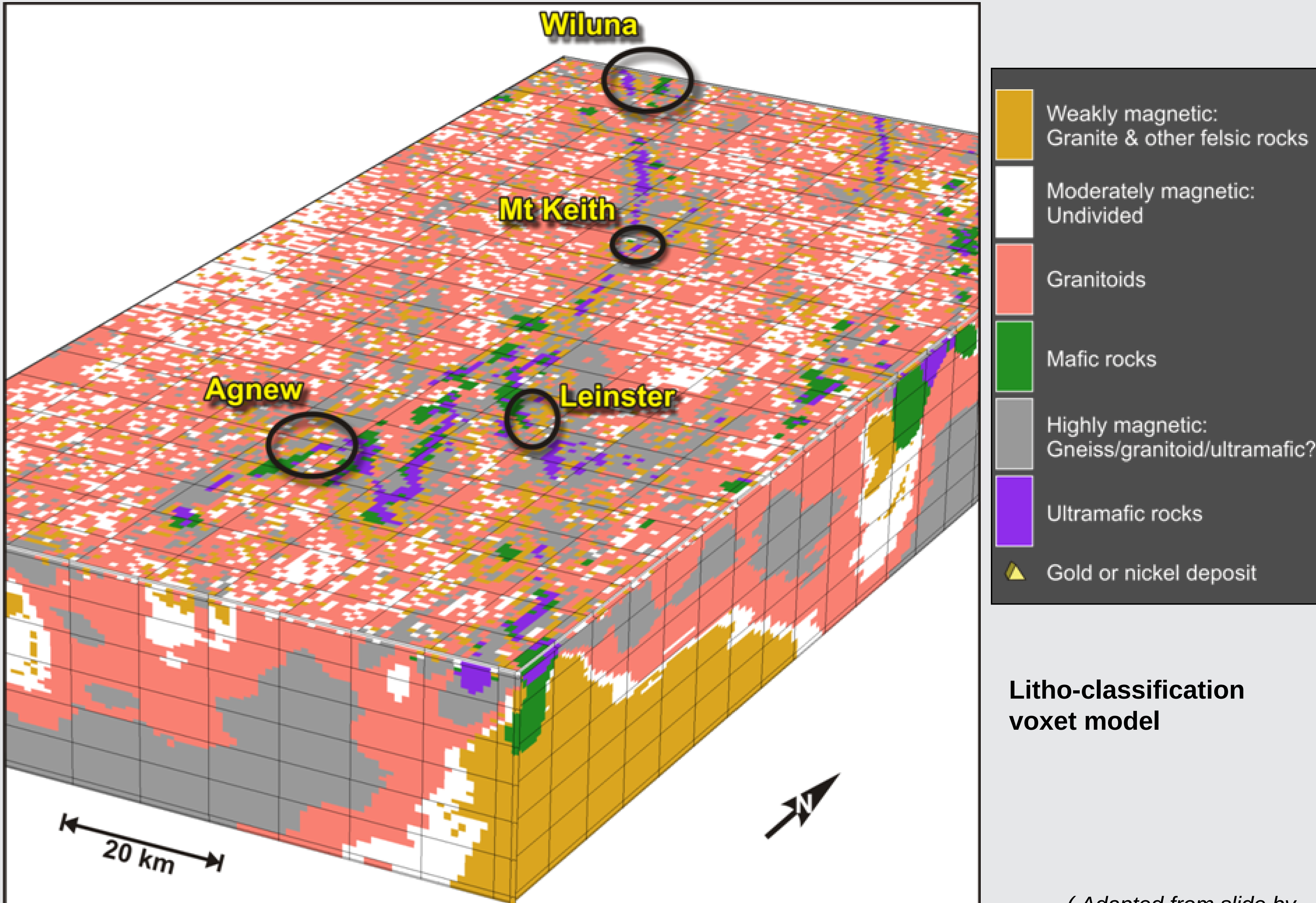


(Adapted from slide by Nick Williams)



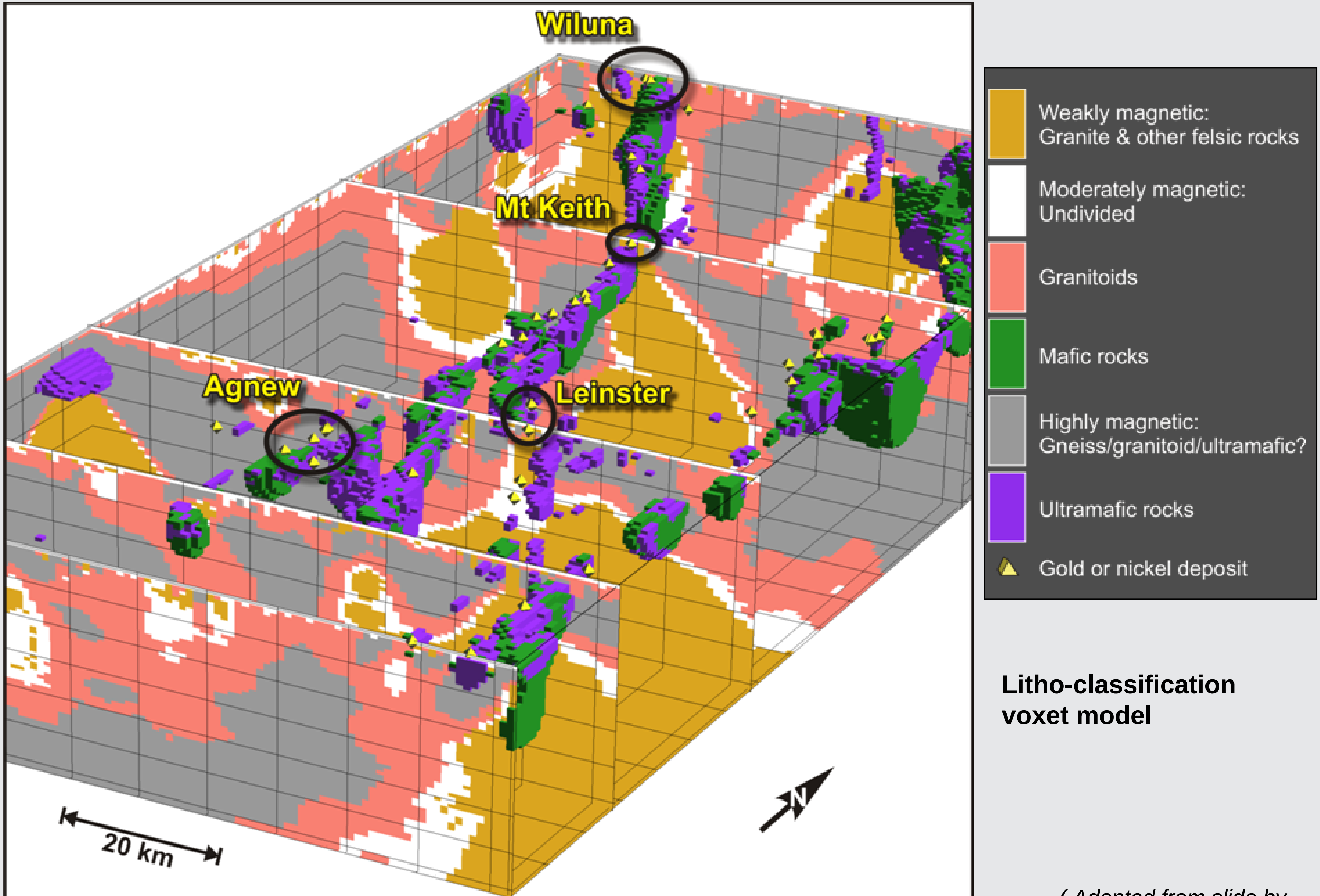
Outcrop mapping
GSWA & GA

(Adapted from slide by Nick Williams)



Litho-classification voxet model

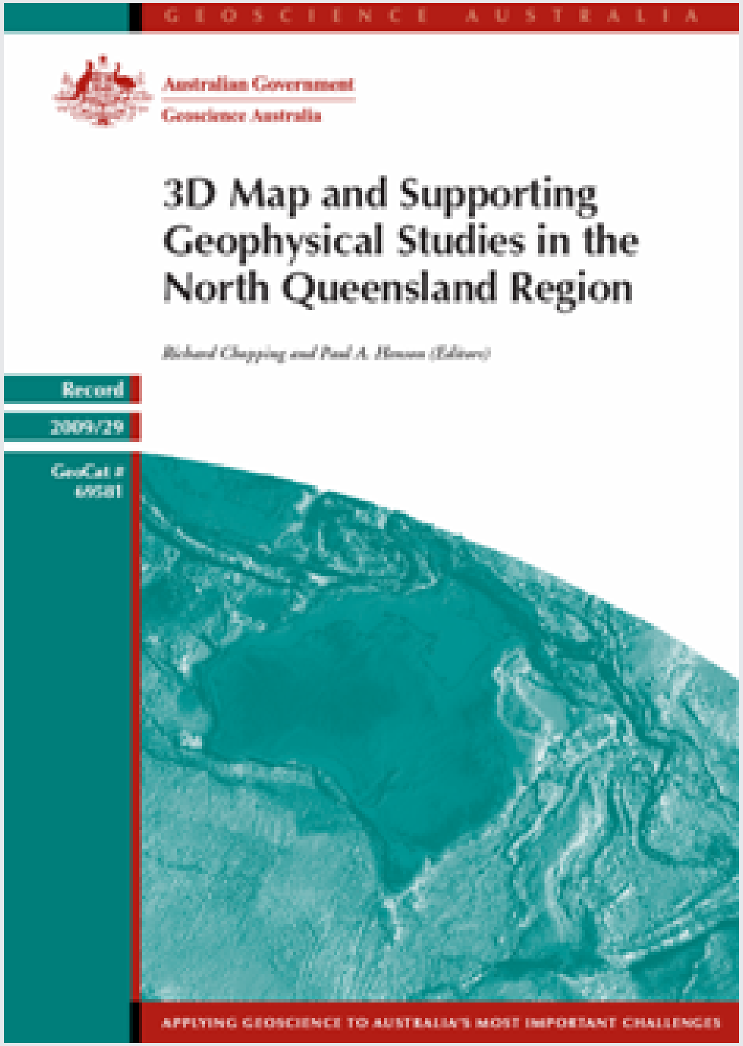
(Adapted from slide by Nick Williams)



Litho-classification voxet model

(Adapted from slide by Nick Williams)

Some useful references for the work shown above.



GA Record 2009/29
https://www.ga.gov.au/products/servlet/controller?event=GEOCAT_DETAILS&catno=69581

Ph.D. thesis by Nick Williams

Williams, N. C., 2008, Geologically-constrained UBC–GIF gravity and magnetic inversions with examples from the Agnew-Wiluna greenstone belt, Western Australia: Ph.D. thesis, University of British Columbia, 478p. http://hdl.handle.net/2429/2744

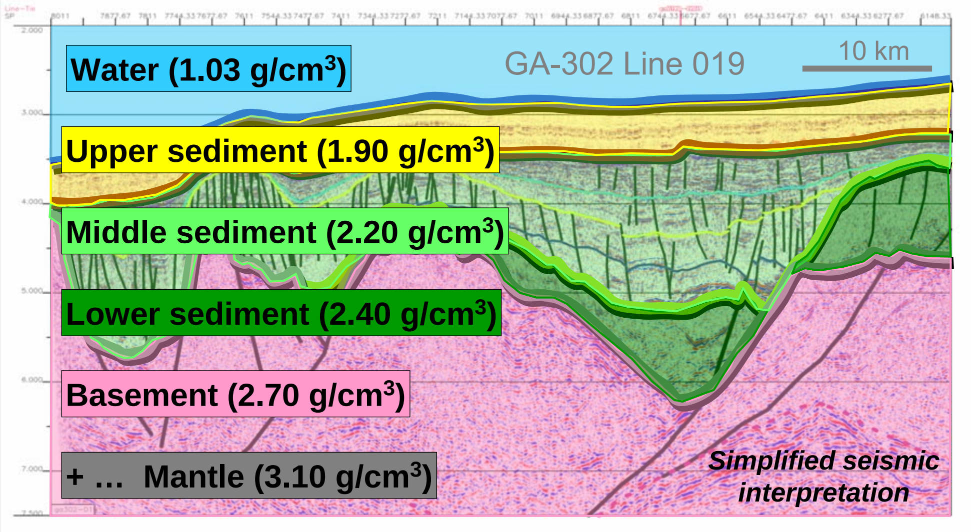
Selected papers

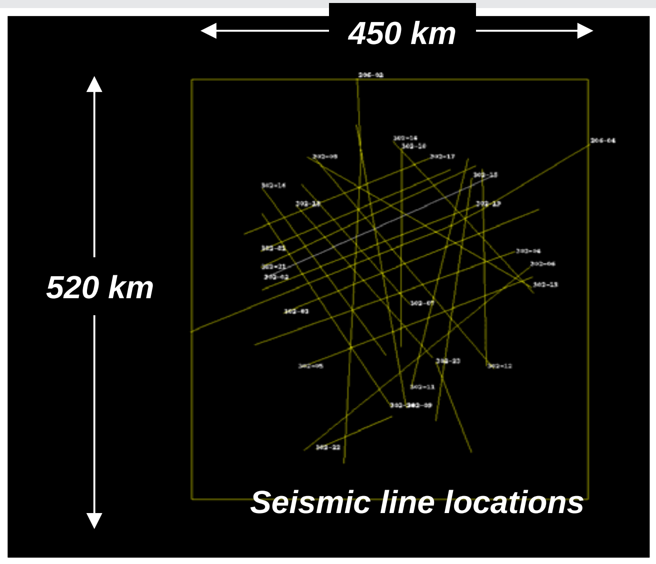
Williams, N. C., 2009, Mass and magnetic properties for 3D geological and geophysical modelling of the southern Agnew–Wiluna Greenstone Belt and Leinster nickel deposits, Western Australia: AJES, 56, 1111 – 1142.

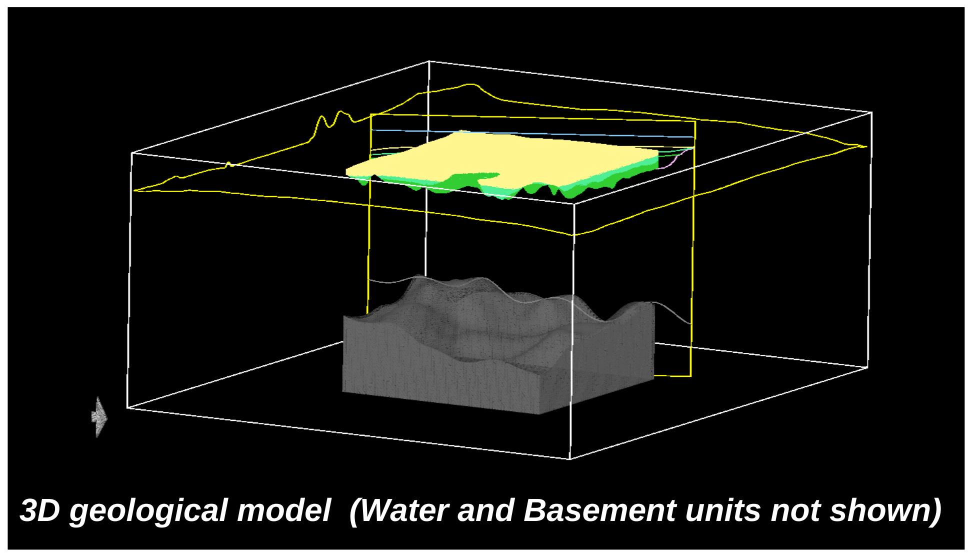
Williams, N.C., and Dipple, G.M., 2007, Mapping subsurface alteration using gravity and magnetic inversion models: In Milkereit, B., Proceedings of Exploration 07: Fifth Decennial International Conference on Mineral Exploration, 461-472.

GeoModeller 3D geological mapping and ***litho-inversion*** example : Capel and Faust Basins

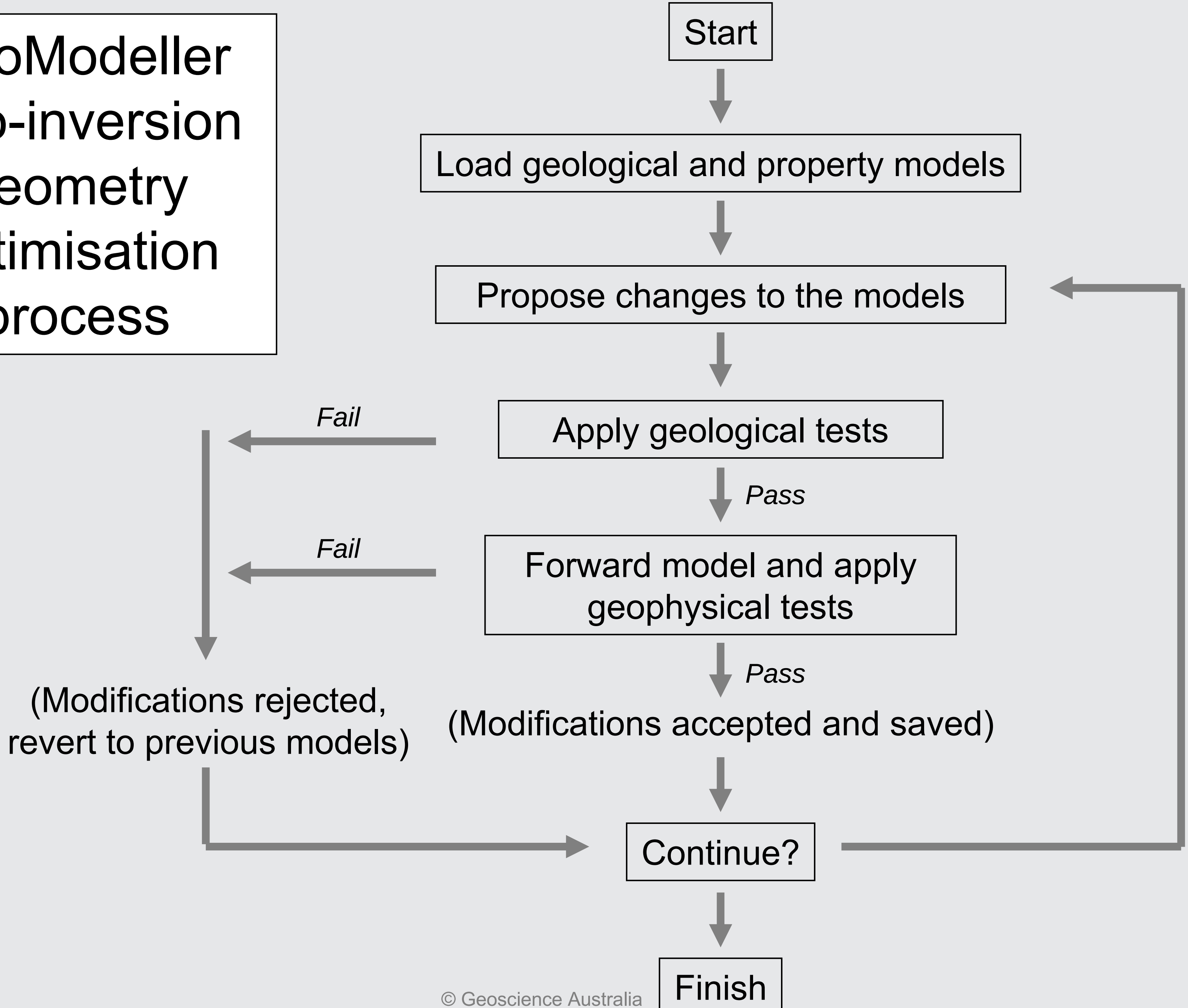
- Build a 3D geological model from each generation of 2D seismic interpretation
- Use 3D visualisation to aid structural analysis
- Evaluate each model using gravity data and litho-inversion

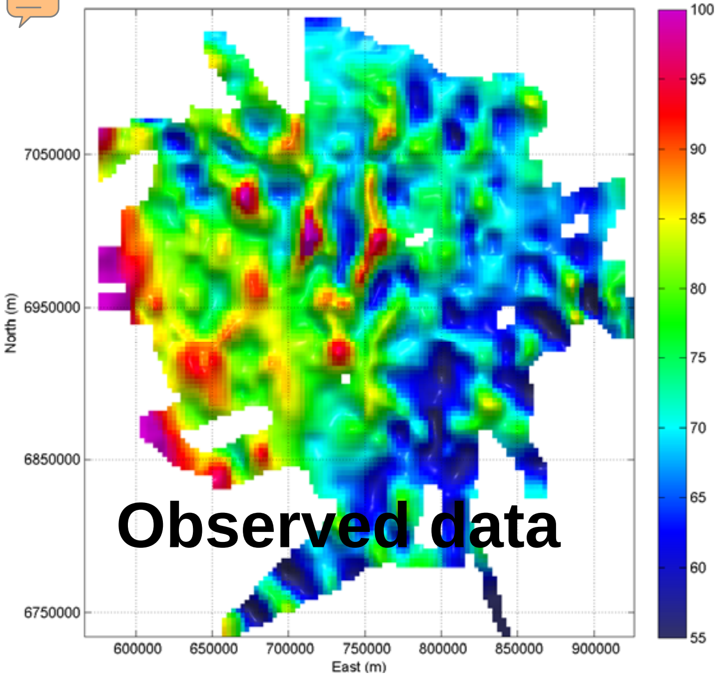


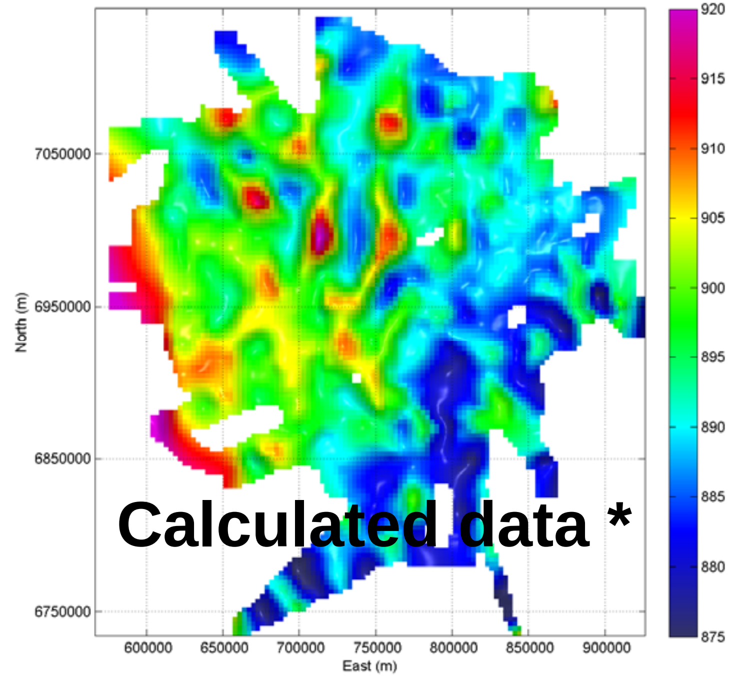




GeoModeller litho-inversion geometry optimisation process

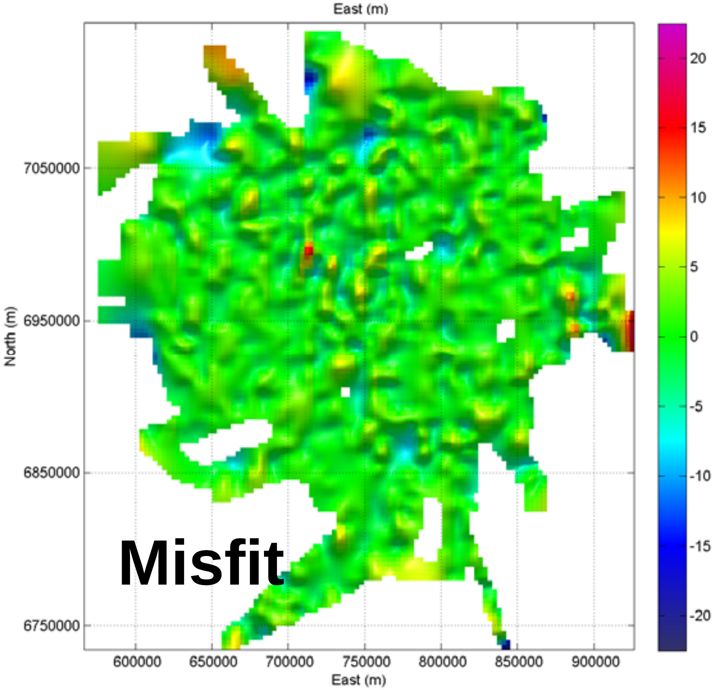






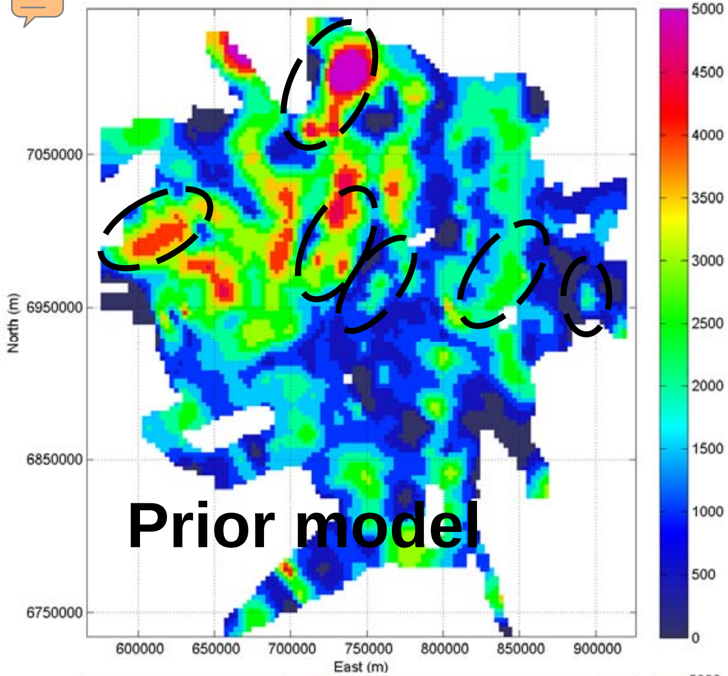
200 km

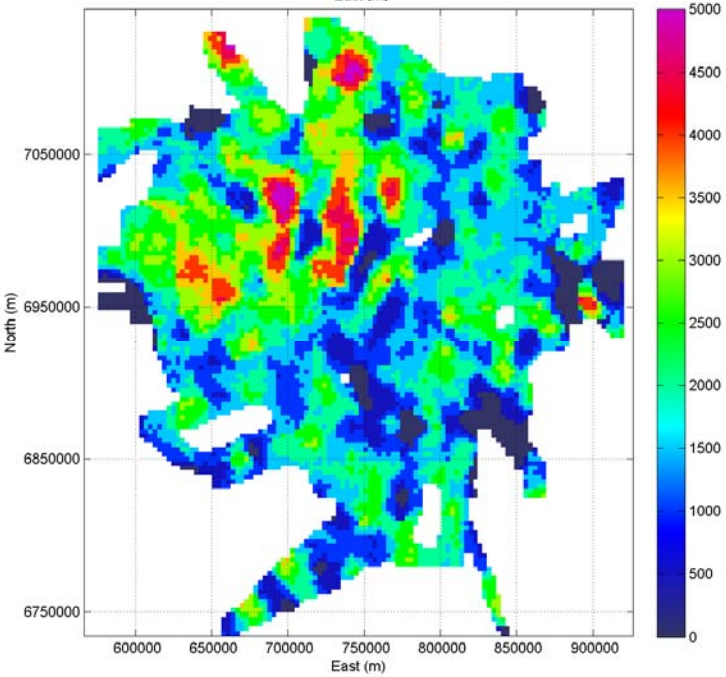
Colour range of 45 mGal for each image



**** Based on the model at proposal 4 million***

Geometry optimisation of vertical gravity to refine basin thickness (and Moho interface) (mGal)

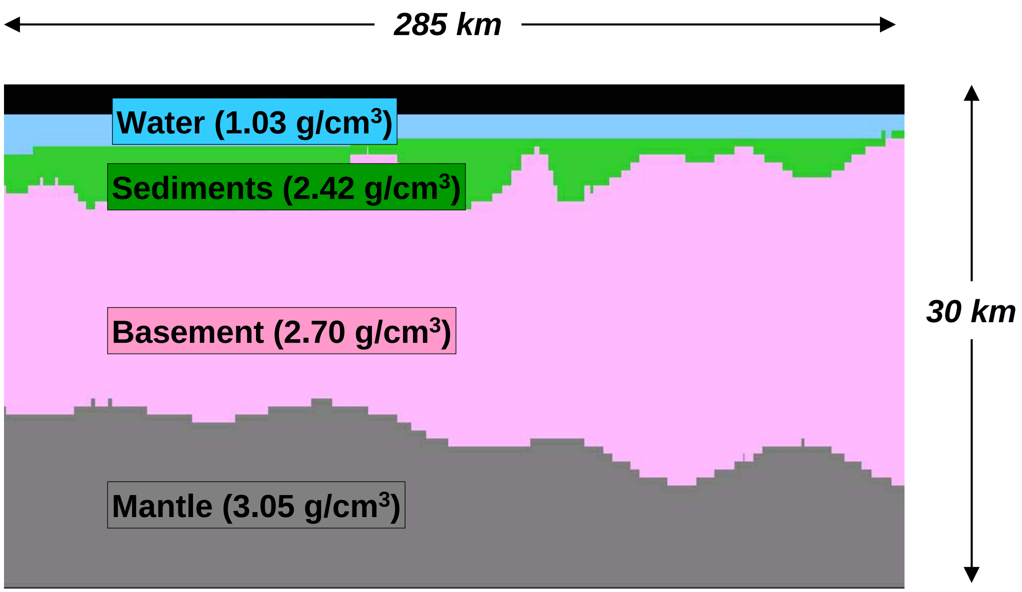




Geometry optimisation to refine basin thickness (and Moho interface)

Images of basin thickness (m)

Colour range of 0 to 5 km shown in both images



Animation of model evolution

Frames at 20k intervals, 0 to 4M proposals
Vertical section 302-02, Vertical exaggeration 5 : 1

2. Next generation geophysical data acquisition

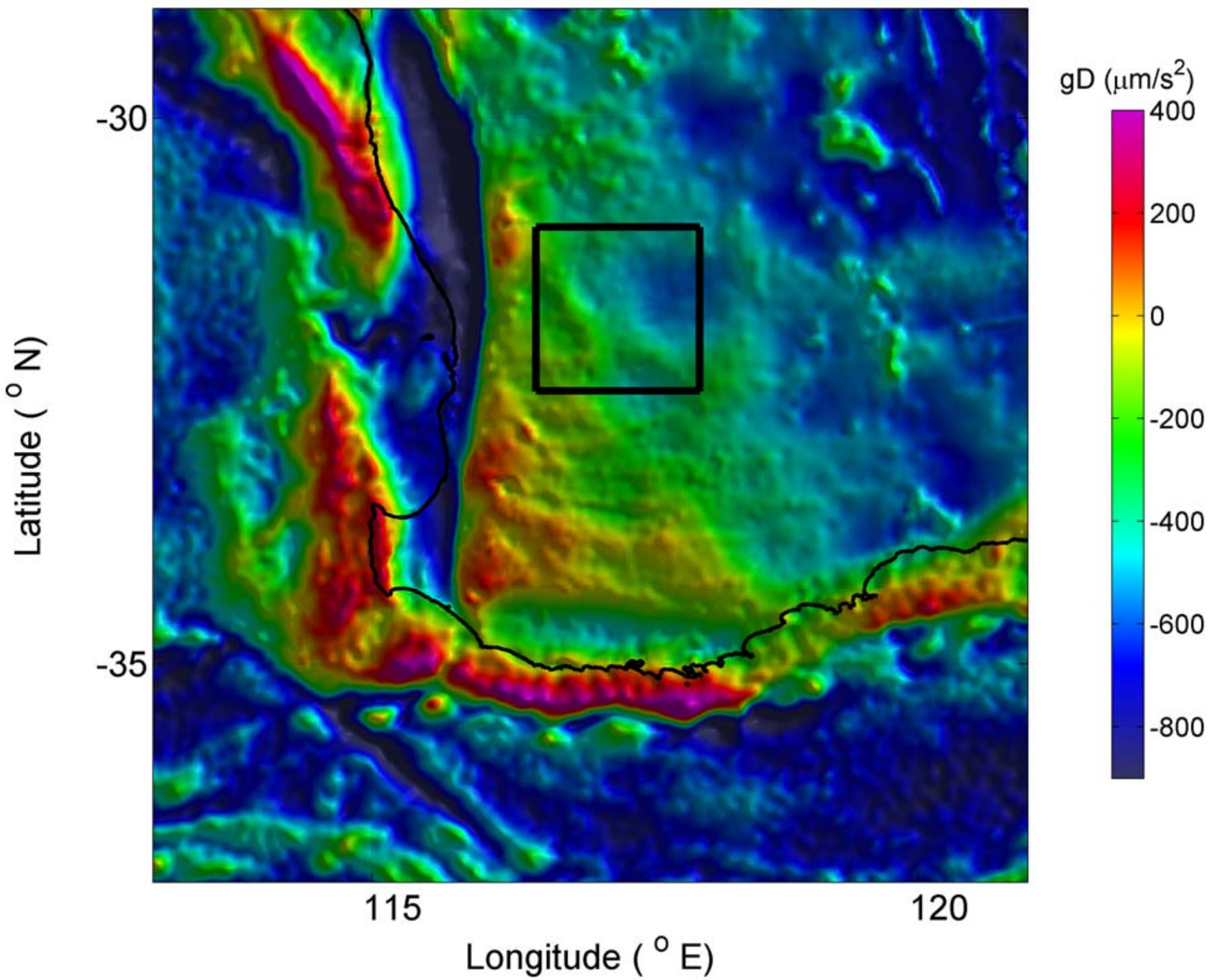
Regional airborne electromagnetic surveys (AEM)

Airborne gravity surveys (AG)

Airborne gravity gradiometer surveys (AGG)

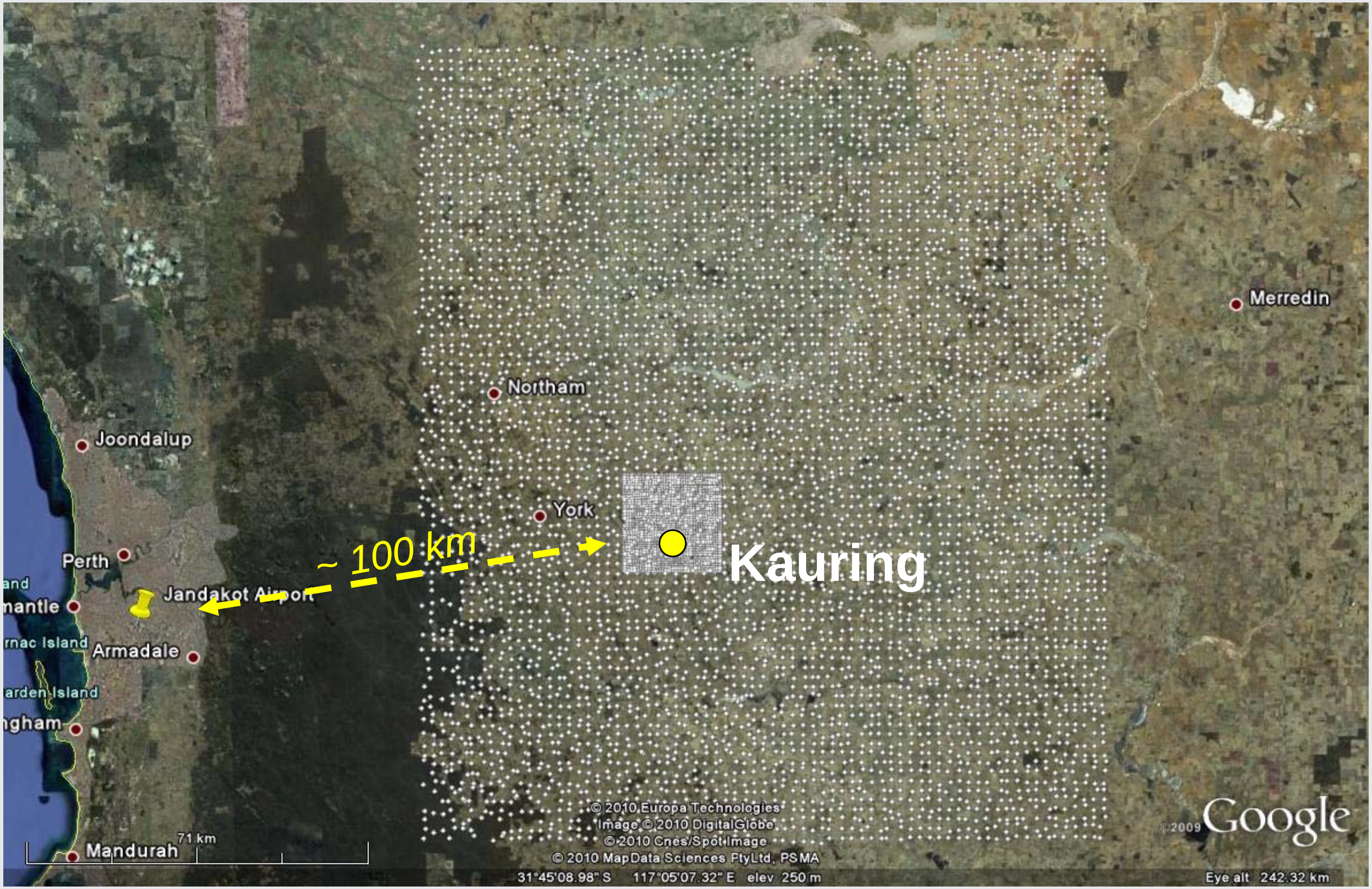
We require better facilities and methods to characterise the many different systems that are available or under development

Location of the Kauring Test Site shown on a regional vertical gravity image.

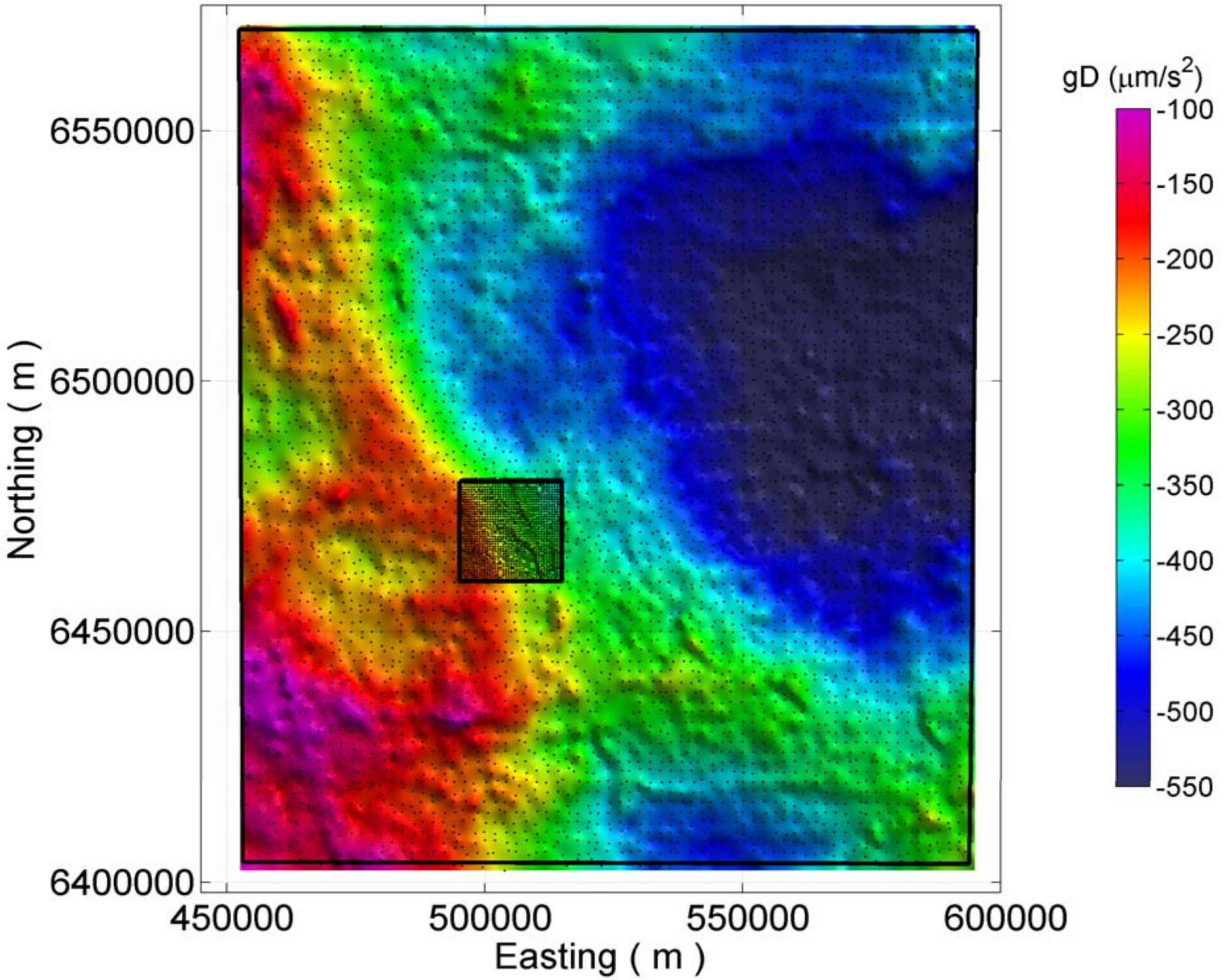


(Geodetic projection, GRS80 Spheroid, GDA94 Datum)

A ground gravity survey was carried out in 2009 to provide high quality semi-regional and detailed data for the Kauring Test Site, WA.

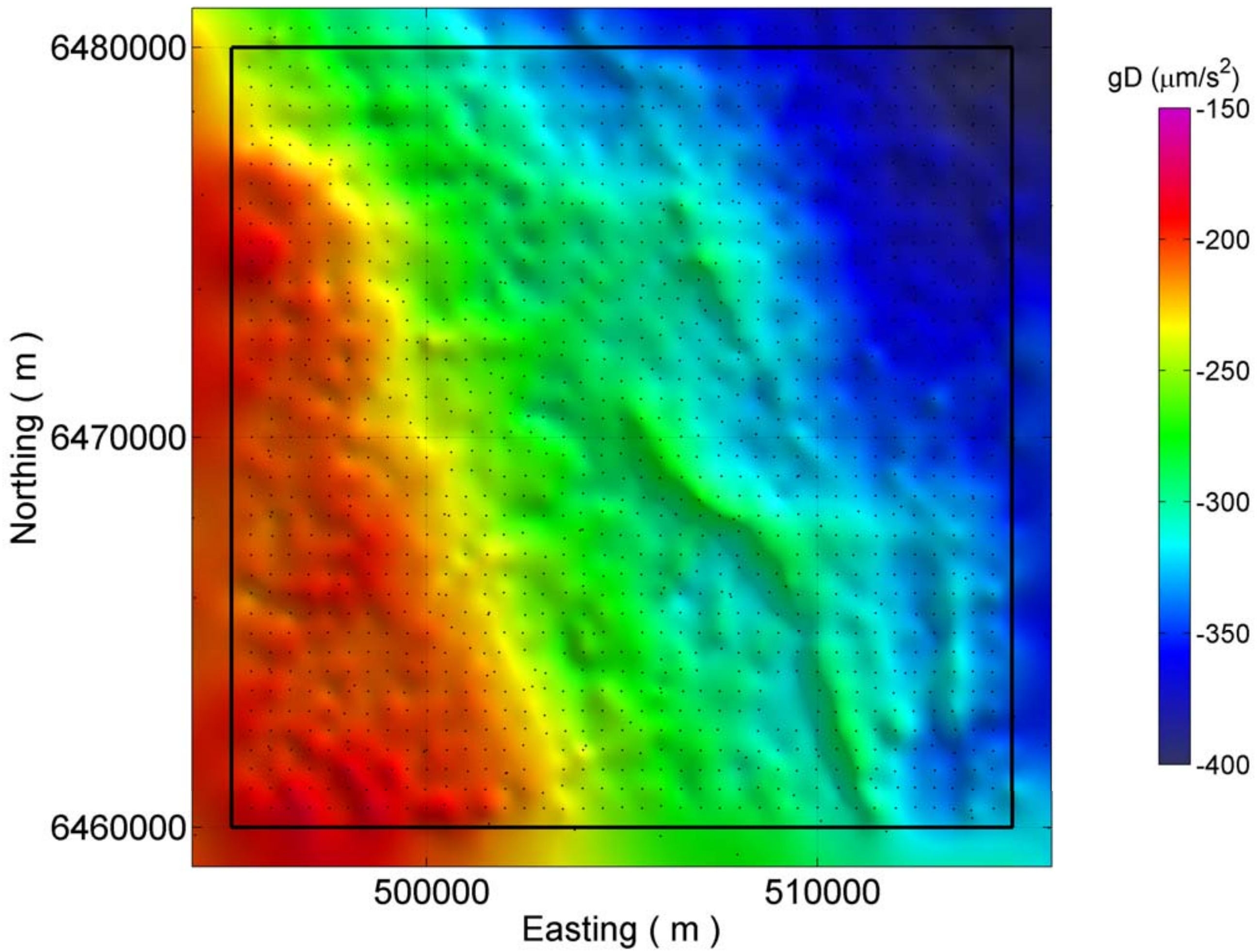


A regional view of the ground gravity data (~150 x 150 km, 2 km spacing) reveals terrain boundaries and broad geological subdivisions.



(MGA50 projection, GDA94 Datum)

A semi-regional view of the ground gravity data (~20 x 20 km, 500 m spacing) reveals geological units with higher resolution.



(MGA50 projection, GDA94 Datum)

"Airborne Gravity 2010" Workshop

Part of the 2010 ASEG-PESA Conference

22nd August 2010 in the Blackwattle Bay Room, Level 1 Crown Plaza Darling Harbour

Register on http://www.aseg-pesa2010.com.au/

Themes

- Operating airborne gravity and gravity gradiometry systems
- Systems under development
- Advances in processing and interpretation software
- Complementary technologies

3. Some of the computing challenges …

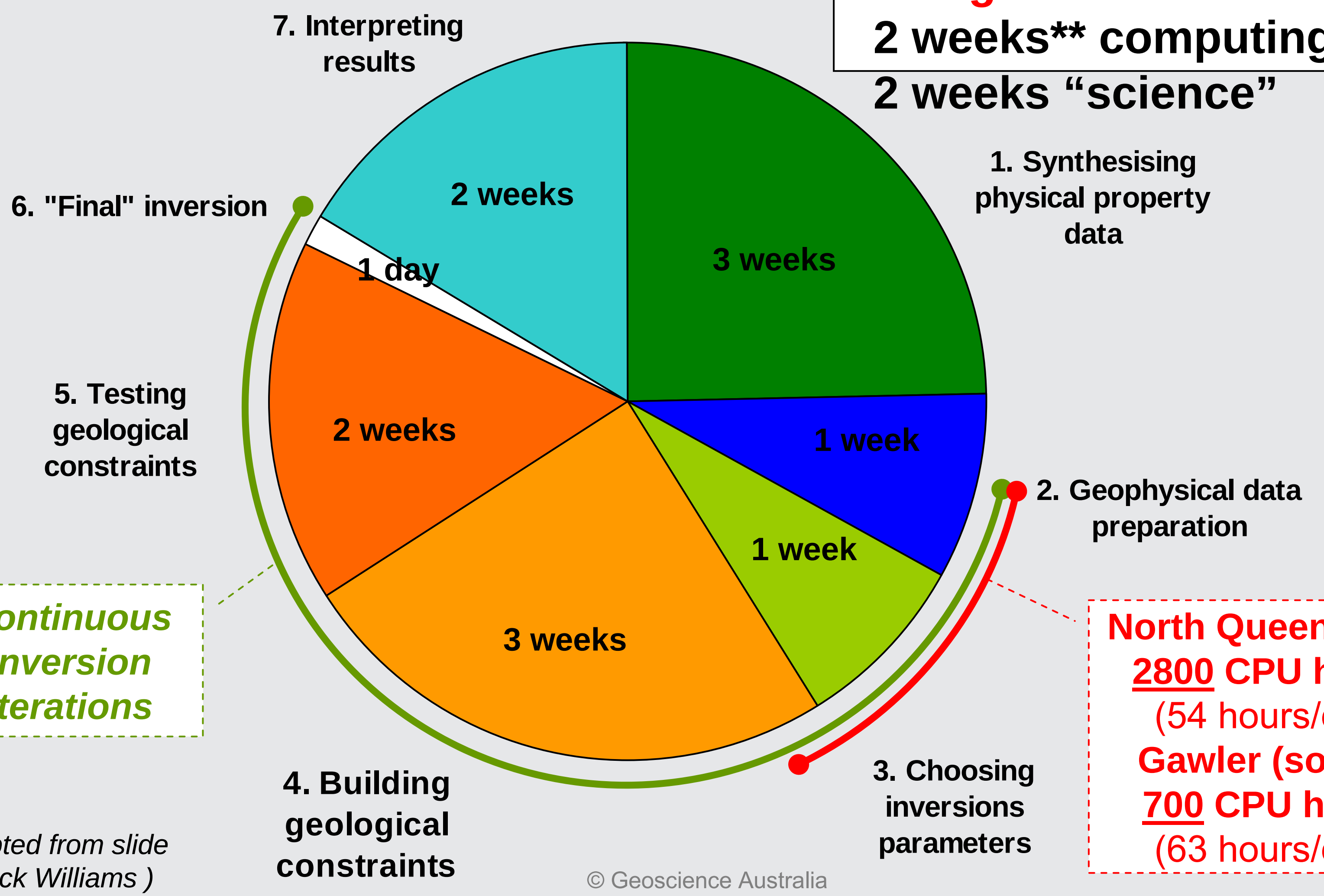
High performance computing (HPC)

Data and software interoperability

Visualisation and communication

Time required for regional gravity and magnetic inversions

TOTAL: ~3 months
2 months data management
2 weeks computing time**
2 weeks "science"



Continuous inversion iterations

North Queensland:
2800 CPU hours
(54 hours/day)
Gawler (so far):
700 CPU hours
(63 hours/day)

(Adapted from slide by Nick Williams)

Data stores
(Local computer, local network, online)
Geology
Geophysics
Rock properties

User
Knowledge / Experience
Background prior information

Computing Resources
(Local computer, local network, online)

How do I navigate through this?

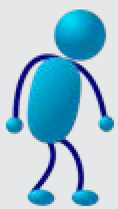
Probabilistic 3D geological model
(consistent with all data)

Provenance
(Metadata / Audit Trail etc.)

Data processing

Geosoft | *MATLAB* | *Intrepid* | *Others …*

DET CRC Mineralogy / Lithology / Rock property software



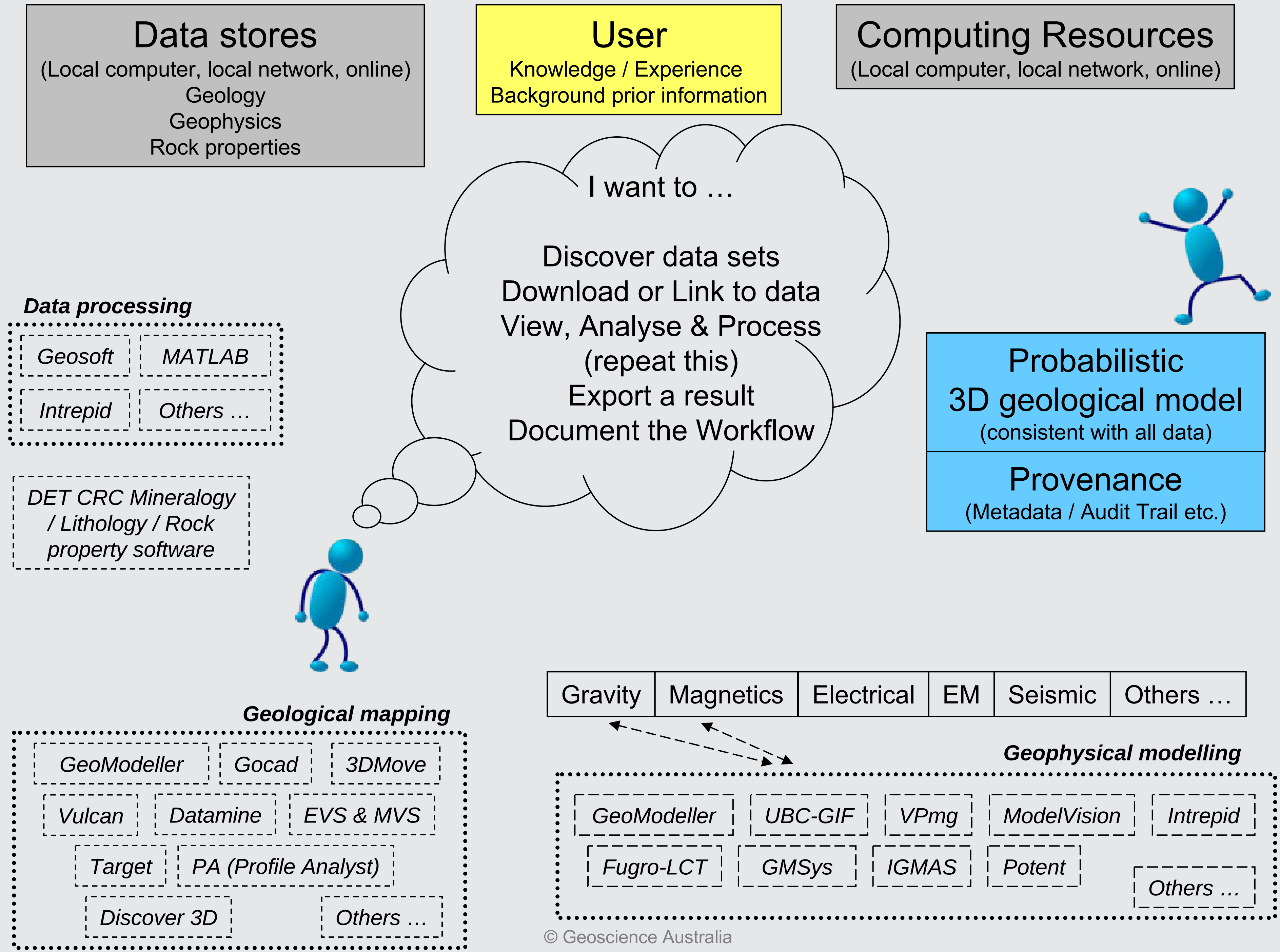
Geological mapping

GeoModeller | *Gocad* | *3DMove* | *Vulcan* | *Datamine* | *EVS & MVS* | *Target* | *PA (Profile Analyst)* | *Discover 3D* | *Others …*

Gravity | Magnetics | Electrical | EM | Seismic | Others …

Geophysical modelling

GeoModeller | *UBC-GIF* | *VPmg* | *ModelVision* | *Intrepid* | *Fugro-LCT* | *GMSys* | *IGMAS* | *Potent* | *Others …*


Data stores
(Local computer, local network, online)
Geology
Geophysics
Rock properties
User
Knowledge / Experience
Background prior information
Computing Resources
(Local computer, local network, online)
I want to …
Discover data sets
Download or Link to data
View, Analyse & Process
(repeat this)
Export a result
Document the Workflow
Data processing
Geosoft
MATLAB
Intrepid
Others …
DET CRC Mineralogy / Lithology / Rock property software
Probabilistic 3D geological model
(consistent with all data)
Provenance
(Metadata / Audit Trail etc.)
Geological mapping
GeoModeller
Gocad
3DMove
Vulcan
Datamine
EVS & MVS
Target
PA (Profile Analyst)
Discover 3D
Others …
Gravity
Magnetics
Electrical
EM
Seismic
Others …
Geophysical modelling
GeoModeller
UBC-GIF
VPmg
ModelVision
Intrepid
Fugro-LCT
GMSys
IGMAS
Potent
Others …
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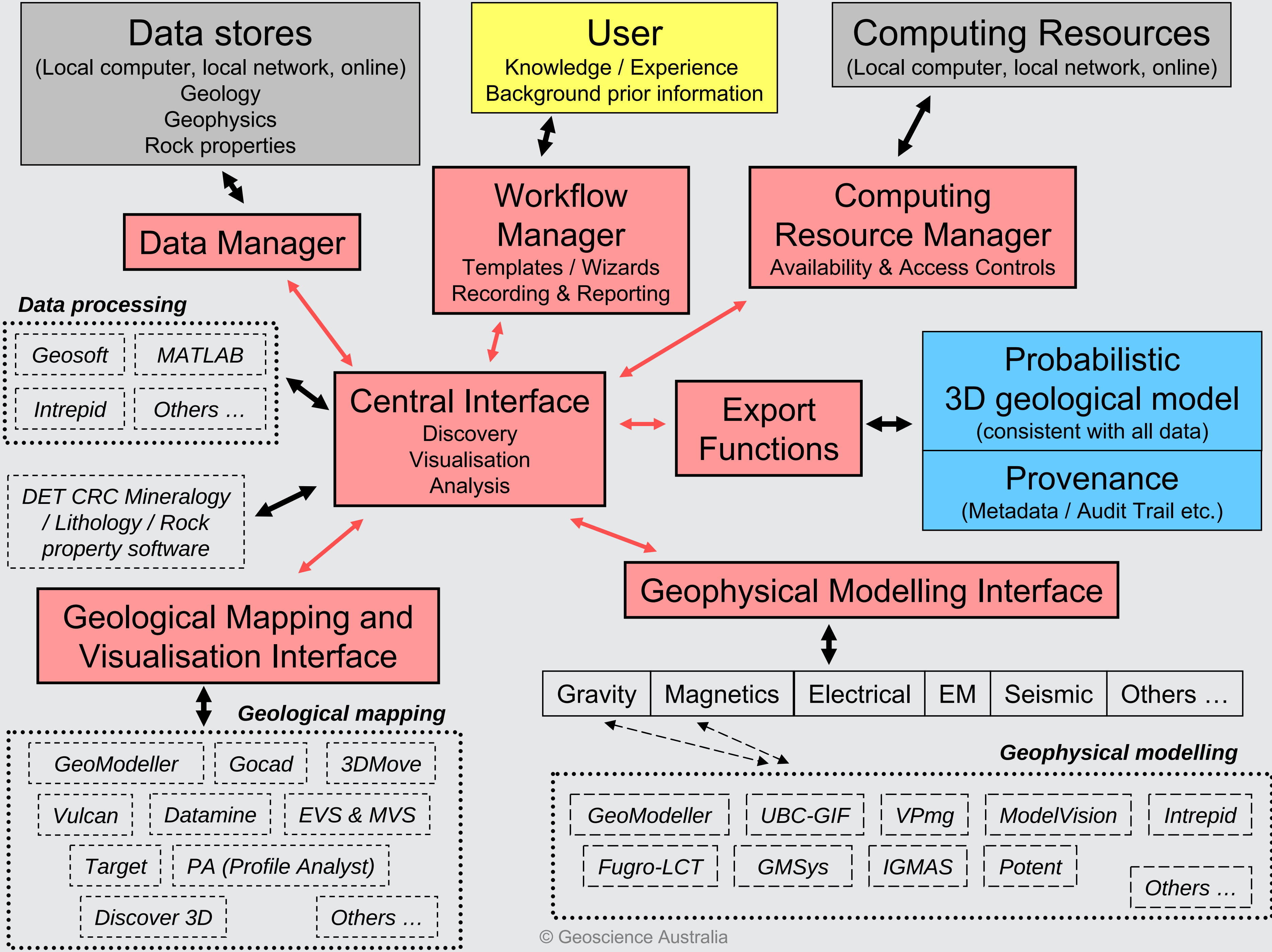
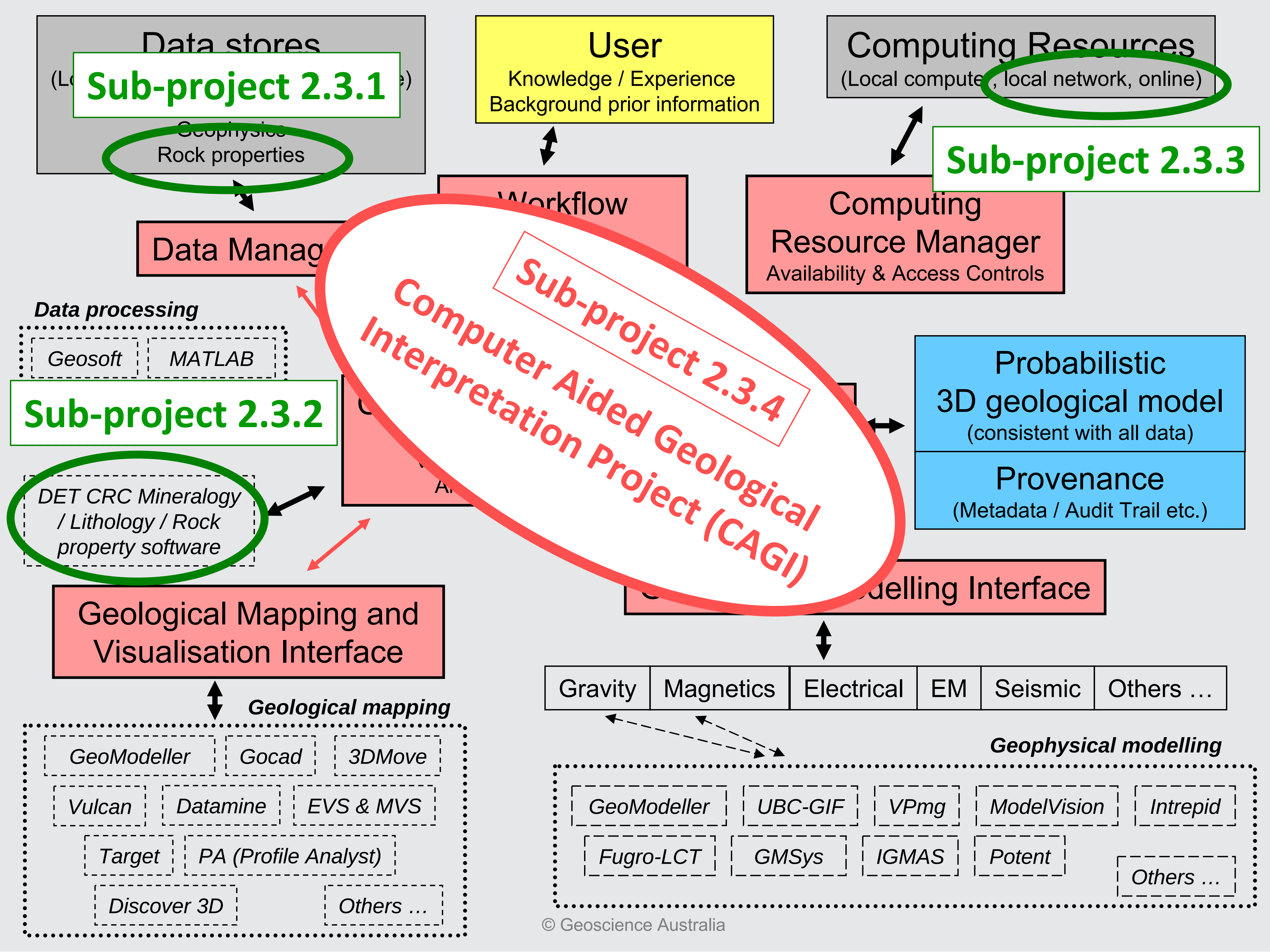

Data stores
(Local computer, local network, online)
Geology
Geophysics
Rock properties
User
Knowledge / Experience
Background prior information
Computing Resources
(Local computer, local network, online)
Data Manager
Workflow Manager
Templates / Wizards
Recording & Reporting
Computing Resource Manager
Availability & Access Controls
Data processing
Geosoft
MATLAB
Intrepid
Others …
Central Interface
Discovery
Visualisation
Analysis
Export Functions
Probabilistic 3D geological model
(consistent with all data)
Provenance
(Metadata / Audit Trail etc.)
DET CRC Mineralogy / Lithology / Rock property software
Geological Mapping and Visualisation Interface
Geophysical Modelling Interface
Gravity
Magnetics
Electrical
EM
Seismic
Others …
Geological mapping
GeoModeller
Gocad
3DMove
Vulcan
Datamine
EVS & MVS
Target
PA (Profile Analyst)
Discover 3D
Others …
Geophysical modelling
GeoModeller
UBC-GIF
VPmg
ModelVision
Intrepid
Fugro-LCT
GMSys
IGMAS
Potent
Others …

CRC for Deep Exploration Technologies

“To improve deep ore discovery by opening up both greenfields and brownfields search space through quicker, more effective exploration at depth and through cover”


Data stores
Sub-project 2.3.1
Geophysics
Rock properties
User
Knowledge / Experience
Background prior information
Computing Resources
(Local compute, local network, online)
Sub-project 2.3.3
Workflow
Computing
Resource Manager
Availability & Access Controls
Data Manag
Sub-project 2.3.4
Computer Aided Geological Interpretation Project (CAGI)
Data processing
Geosoft
MATLAB
Sub-project 2.3.2
Probabilistic
3D geological model
(consistent with all data)
Provenance
(Metadata / Audit Trail etc.)
DET CRC Mineralogy / Lithology / Rock property software
delling Interface
Geological Mapping and Visualisation Interface
Geological mapping
GeoModeller
Gocad
3DMove
Vulcan
Datamine
EVS & MVS
Target
PA (Profile Analyst)
Discover 3D
Others …
Gravity
Magnetics
Electrical
EM
Seismic
Others …
Geophysical modelling
GeoModeller
UBC-GIF
VPmg
ModelVision
Intrepid
Fugro-LCT
GMSys
IGMAS
Potent
Others …
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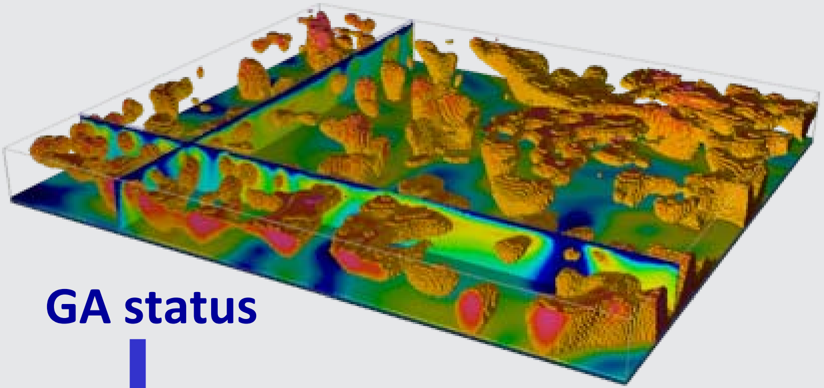
Computation blowout



Standard GA study:

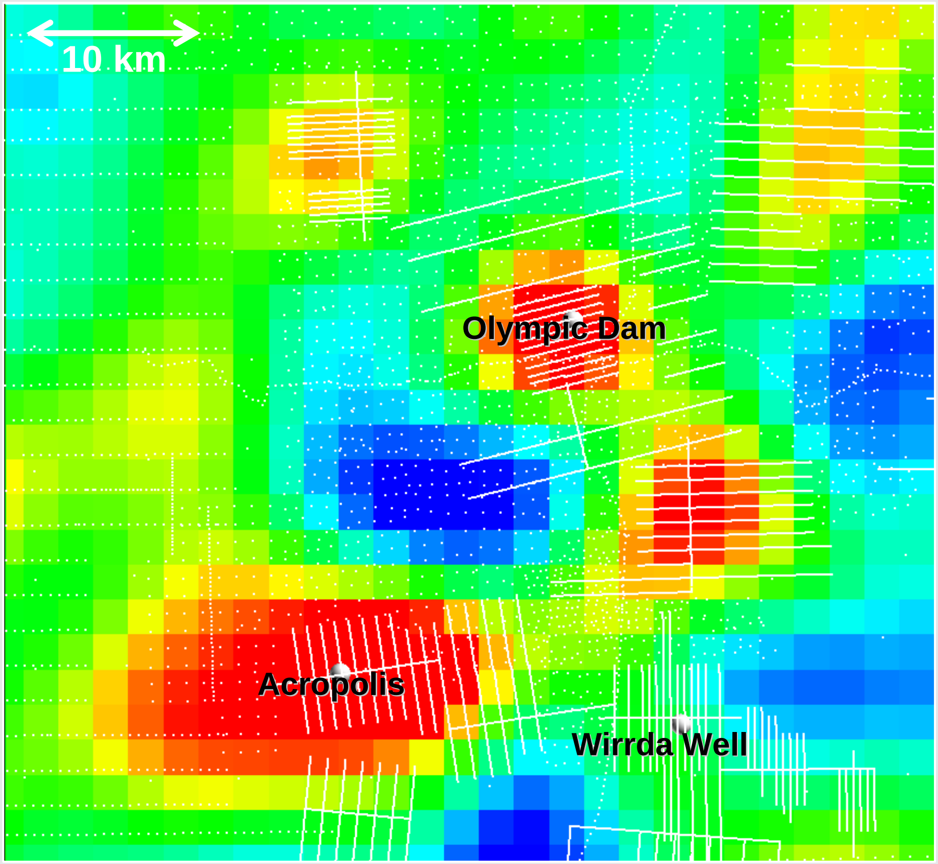
- 3D gravity & magnetic inversions
- <u>600 km x 600 km</u> to <u>25 km depth</u>

GA status

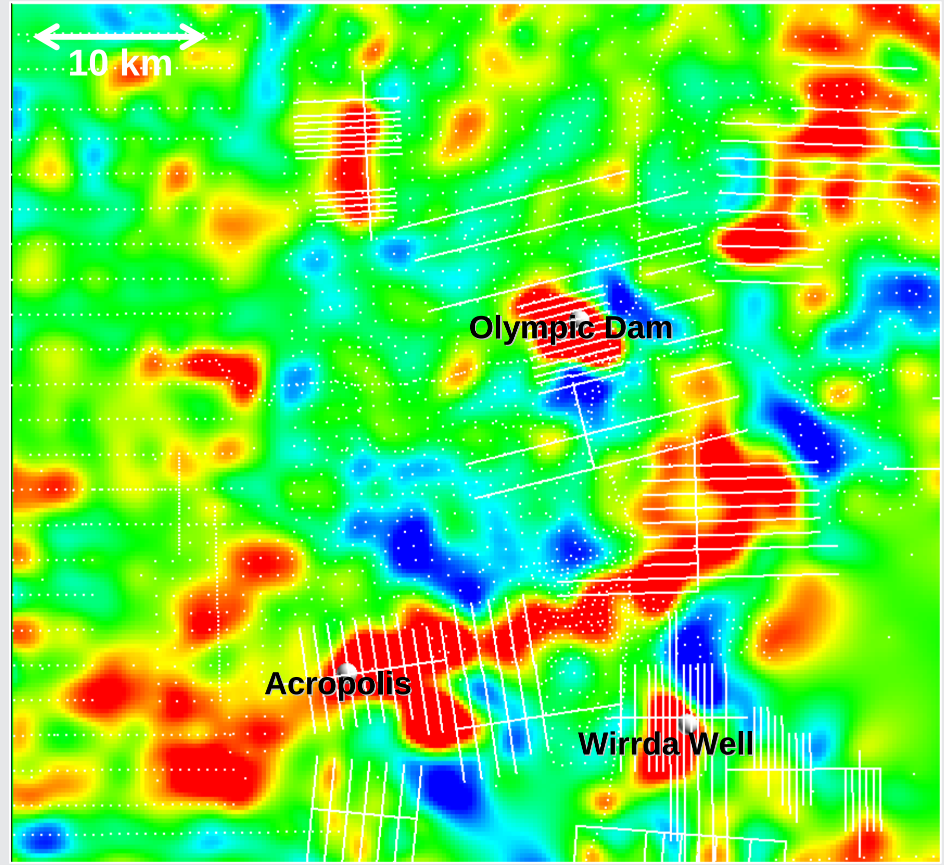
	Stone Age (<u>Desktop</u>)	**Bronze Age (<u>Condor</u>)**	**Iron Age (<u>NCI</u>)**	**“Petascale” Age?**
	Largest on single PC	**@ current resolution**	**@ higher resolution**	**@ ideal resolution**
Data spacing/ model cell size	3.75 km x 3.75 km (1 obs. / 14 km^2)	2 km x 2 km (1 obs. / 4 km^2)	400 m x 400 m (6 obs. / km^2)	80 m x 80 m (156 obs. / km^2)
Number of data	25,600	90,000	2.25 million	56.25 million
Number of model cells	640,000	2.25 million	281.25 million	35.1 billion
Memory required	3.2 GB	40 GB	115 TB	351 PB
Required CPU time	4 hours	48 hours	**17 years**	**52,500 years**
Run time	2 CPUs: 2 hours	24 CPUs: 2 hours	6,000 CPUs: 12 hours	???
			100 CPUs: 62 days	???

(Adapted from slide by Nick Williams)

Gravity example : Olympic Dam, SA



Cell size: 2 km x 2 km x 1 km



Cell size: 250 m x 250 m x 200 m

1 cell = *320 cells*

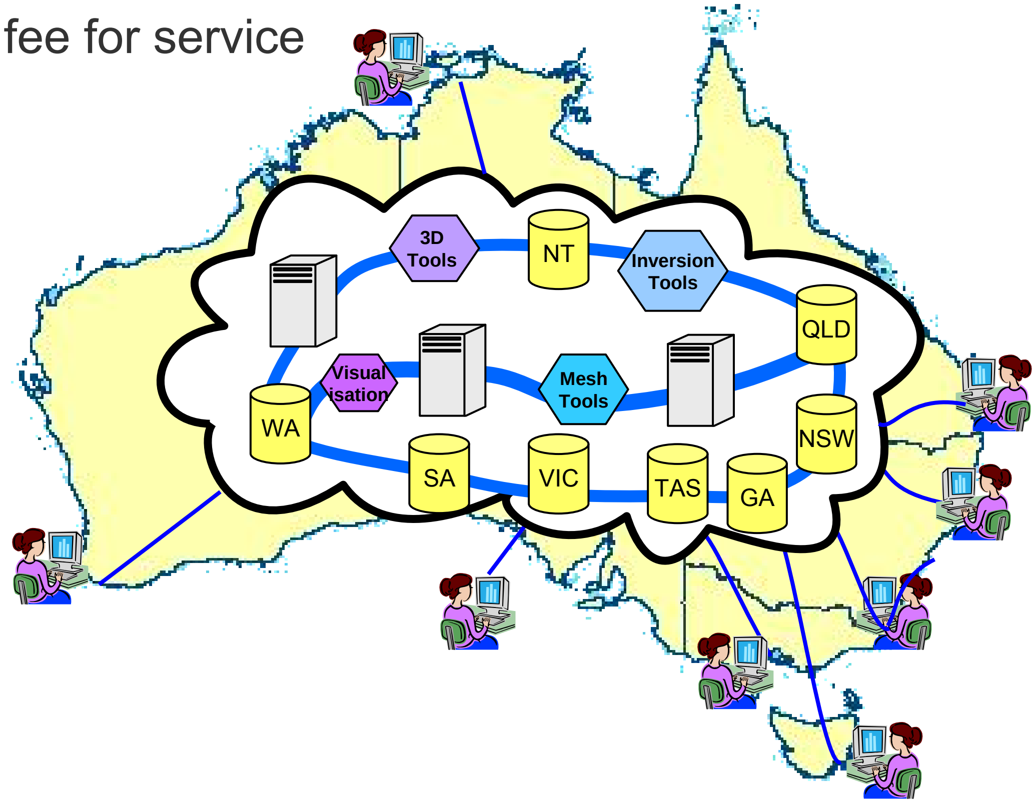
(Adapted from slide by Nick Williams)

Virtual Exploration Geophysics (Computing) Laboratory

Combination of data stores, software and computers

Based on the ‘Cloud Computing’ paradigm

- Users do not need to know where data is stored
- Resources are available as a fee for service



Extend the concept to commercial cloud facilities

- e.g., Google cloud services, Amazon EC2 and S3, Microsoft Azure, etc.

(Adapted from slide by Lesley Wyborn)

Visualisation and communication of 3D geological maps and geophysical models remains a challenge.

Full 3D mapping and GIS programs

e.g., gOcad

Viewers

e.g., Geocando, ParaviewGeo

Customised interfaces

e.g., VRML, X3D

Other

e.g., Movies, 3D PDF

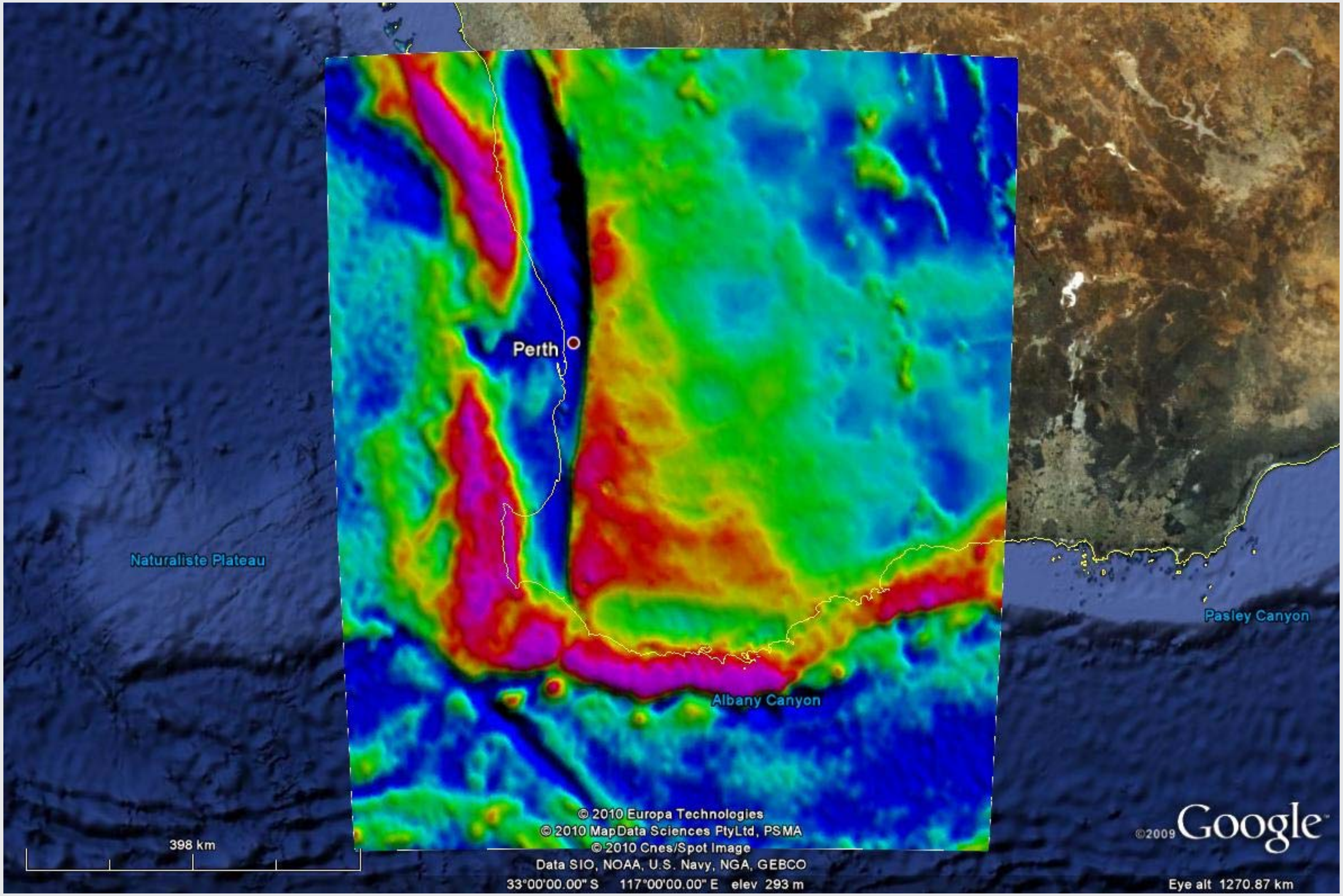
Virtual globes

e.g., Google Earth, WorldWind

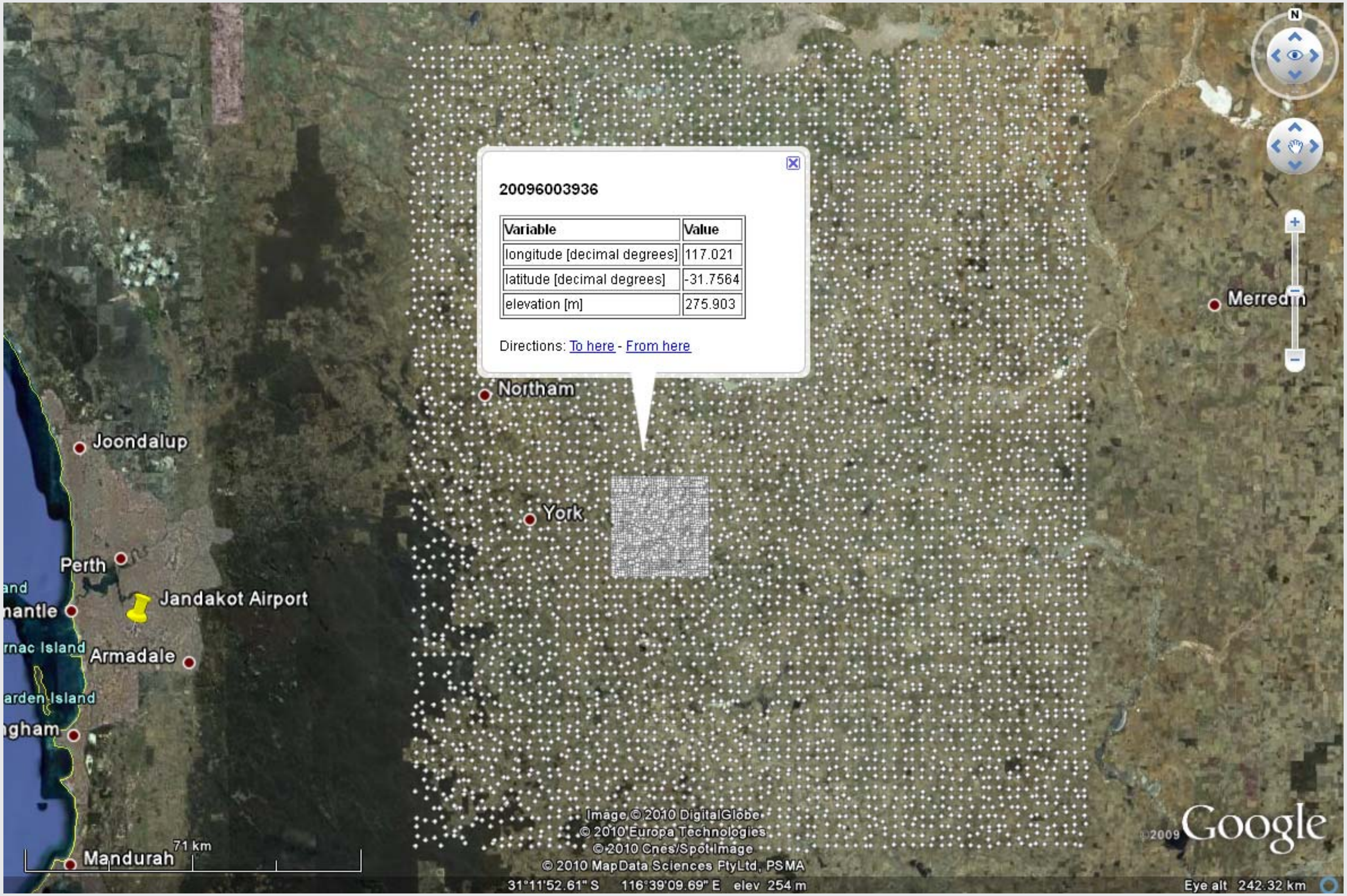
Pro et contra for Google Earth

- **Provides location and scale context for the content**
- **Input data are in an international OGC standard format**
  - KML and KMZ
- **Spherical geometry**
  - Latitude, longitude, and elevation (m)
  - Simple cylindrical projection (Plate Carrée, or EPSG:4326 projection) with WGS84 datum
- **Includes the 4th dimension (time)**
- **Supports multi-resolution data views**
- **Supports point, line, polygon, and image feature types**
- **Supports use of cloud-based data files**
- **Very large client base**
- **Good interface**
- **Lacks true 3D volumetric object support**
- **Standard viewer does not support sub-surface data**

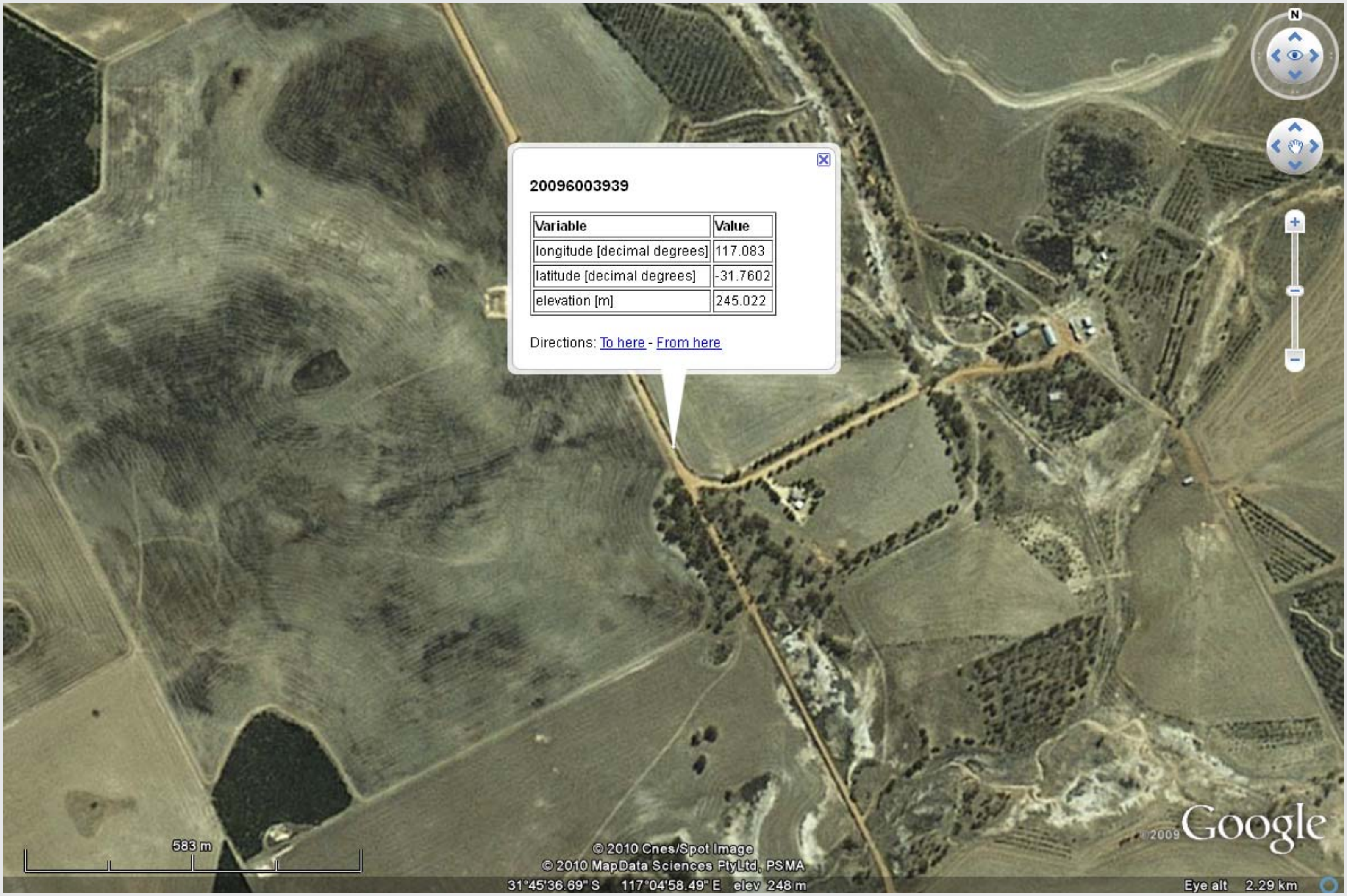
Google Earth example : Kauring Test Site regional vertical gravity image



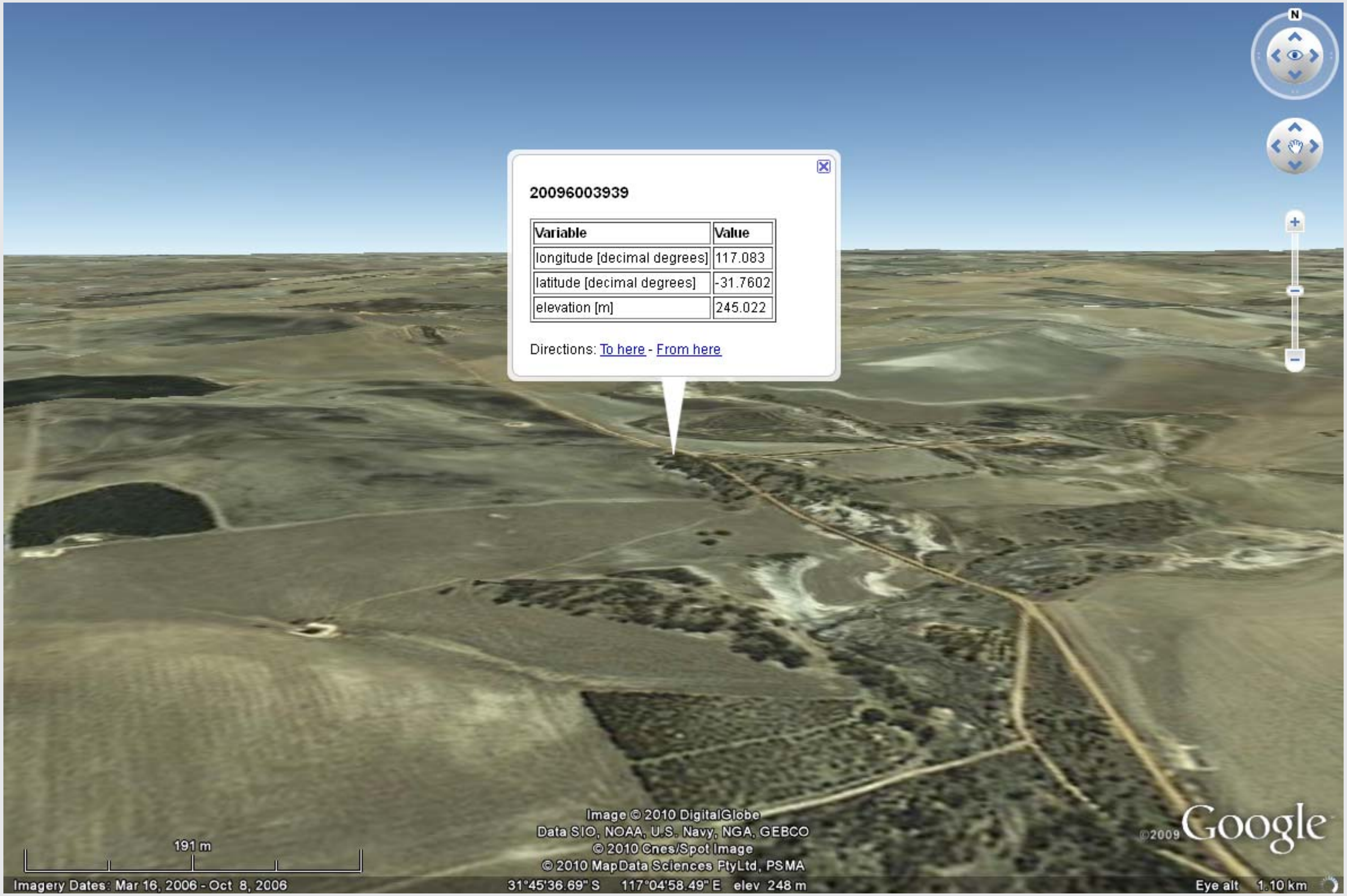
Google Earth example : Kauring Test Site regional and semi-regional ground gravity observation sites



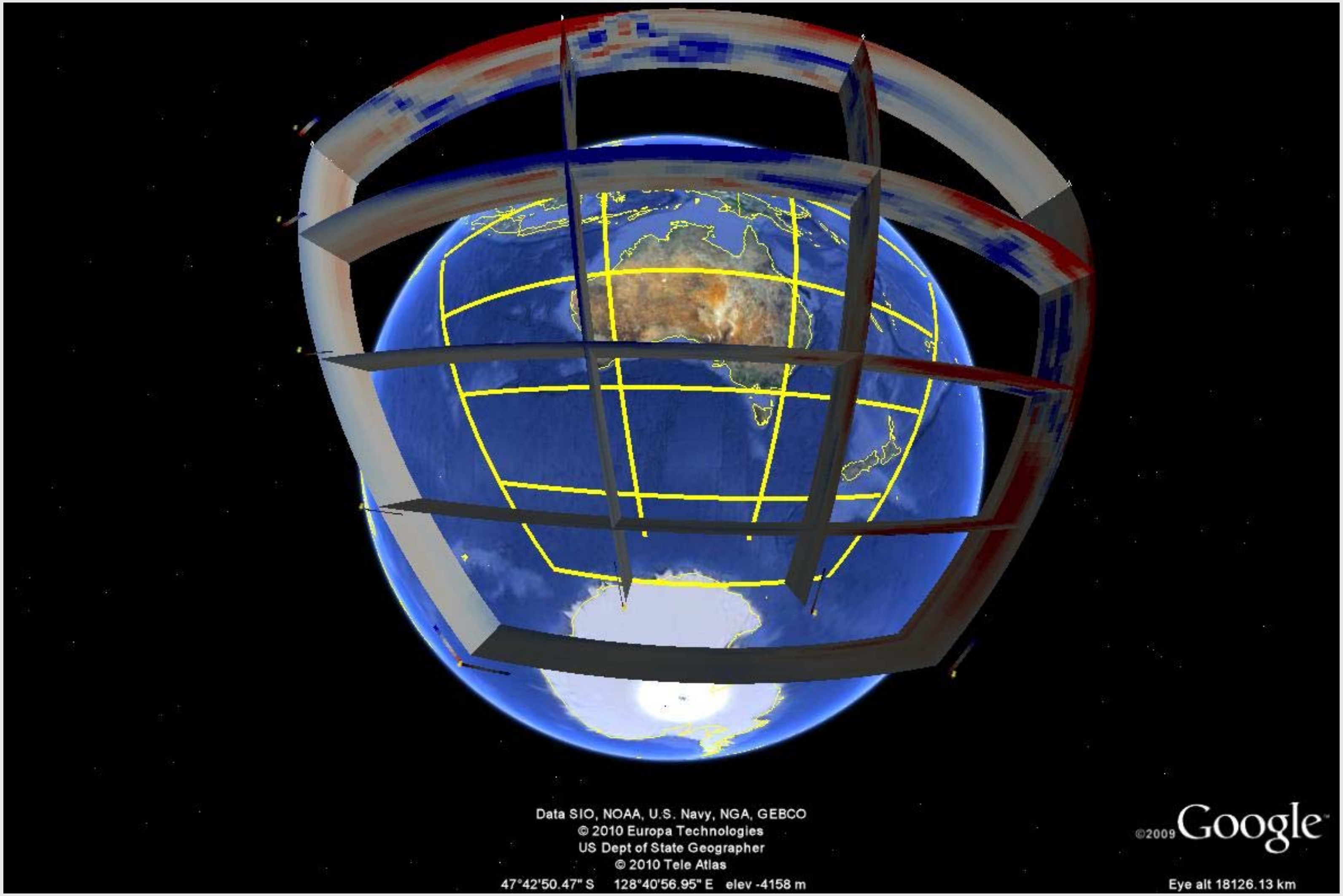
Google Earth example : Kauring Test Site regional and semi-regional ground gravity observation sites



Google Earth example : Kauring Test Site regional and semi-regional ground gravity observation sites

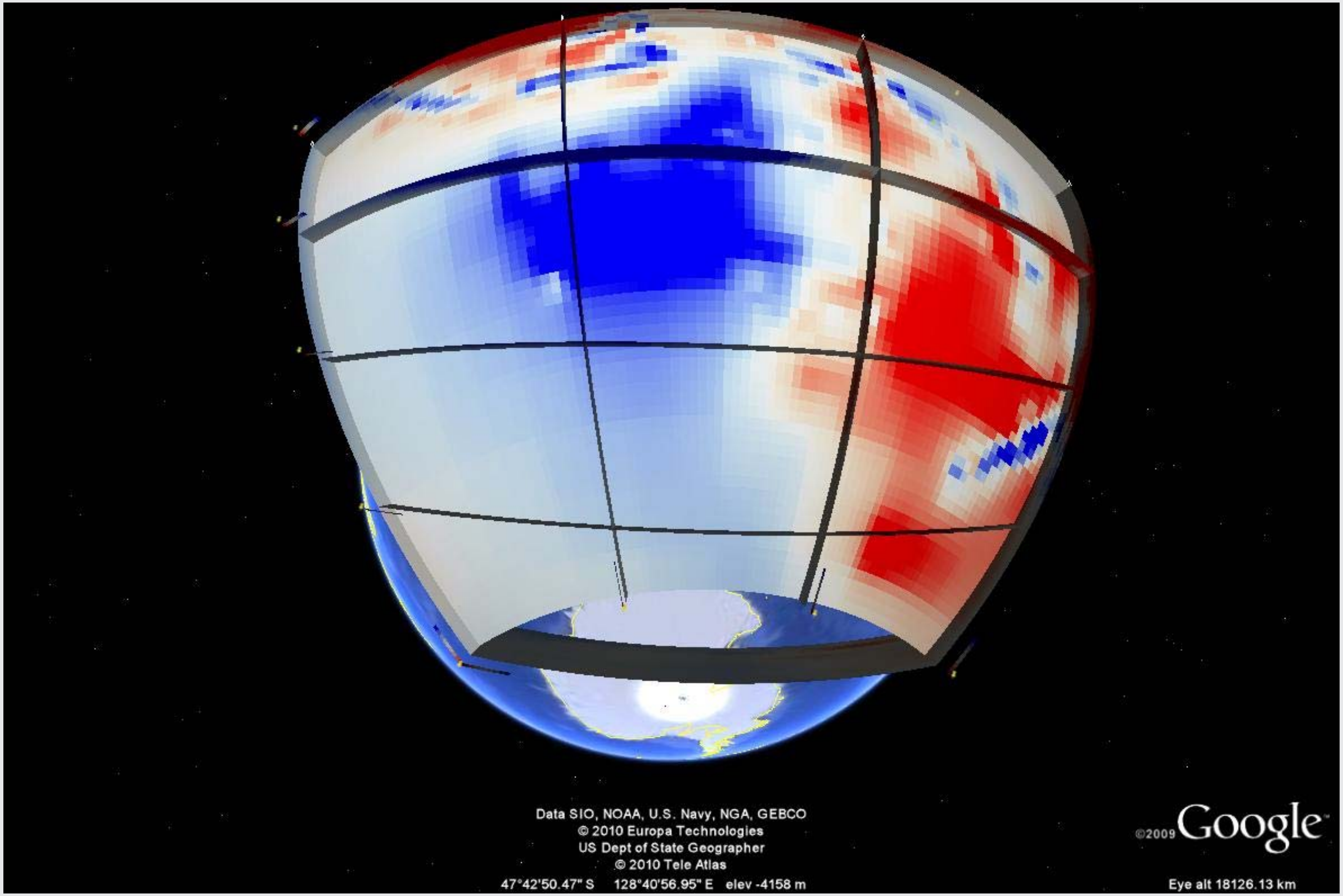


Google Earth example : GAP-P1 global P-wave seismic tomography model sections and slices



(GAP-P1 model - See Obayashi et al., 2006)

Google Earth example : GAP-P1 global P-wave seismic tomography model sections and slices



(GAP-P1 model - See Obayashi et al., 2006)

We have reviewed various developments and directions in 3D geological mapping using geophysical modelling

We have seen that a number of interrelated issues are being addressed.

- Modelling and interpretation methods
- Rock properties
- Data
- High performance computing
- Data and software interoperability
- Visualisation and communication