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Down hole rock properties and their application to geological and geophysical interpretation

AIG/ADIA: Drill for geology seminar – Aug 1, 2014

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Presentation Outline

- Rock properties
  - Importance of rock properties for interpretation
  - What are they
  - Measuring rock properties

- Rock property applications and interpretation.
- Case study - 3D lithological interpretation from rock properties
- Conclusions

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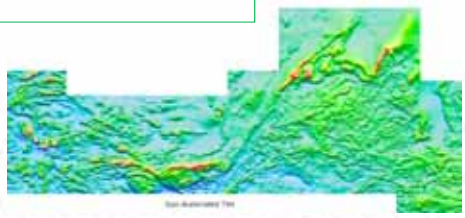
Geophysical interpretation

- Measured (remote survey) geophysical responses are governed by rock properties of the Earth
- If there is a physical contrast in the properties of rock, geophysical interpretation may be able to map these rocks.

Rock Property	Geophysical survey
• Density	→ Gravity surveys
• Magnetic susceptibility	→ Magnetic surveys
• Conductivity/Resistivity	→ EM and Electrical surveys
• Chargeability	→ DCIP surveys.
• Velocity and Density	→ Seismic surveys
• Natural radiation	→ Radiometric surveys



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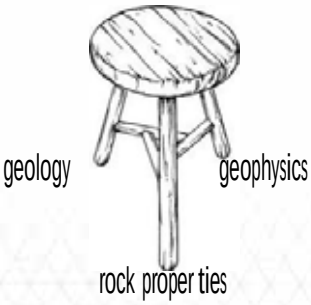
Geophysical interpretation

- Geophysical interpretation is subject to non-uniqueness and modern exploration challenges (deep, under cover) require sophisticated analysis of geophysical data: forward modelling and geologically-constrained inversion in complex ore-hosting environments.
- Physical rock properties provide the only quantitative connection between geological description and geophysical data.
- Understanding physical rock properties is paramount to interpreting geology from geophysical surveys.



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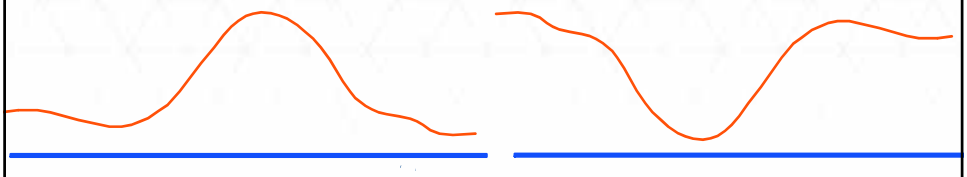
Contrast in physical properties is the key



2.5 g/cc 2.6 2.6 2.7 g/cc

Same source producing diverse anomalies

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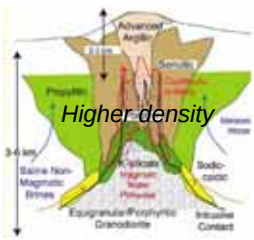
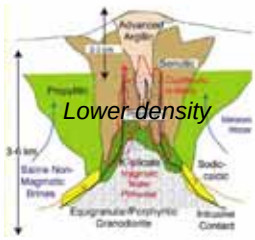
Contrast in physical properties is the key





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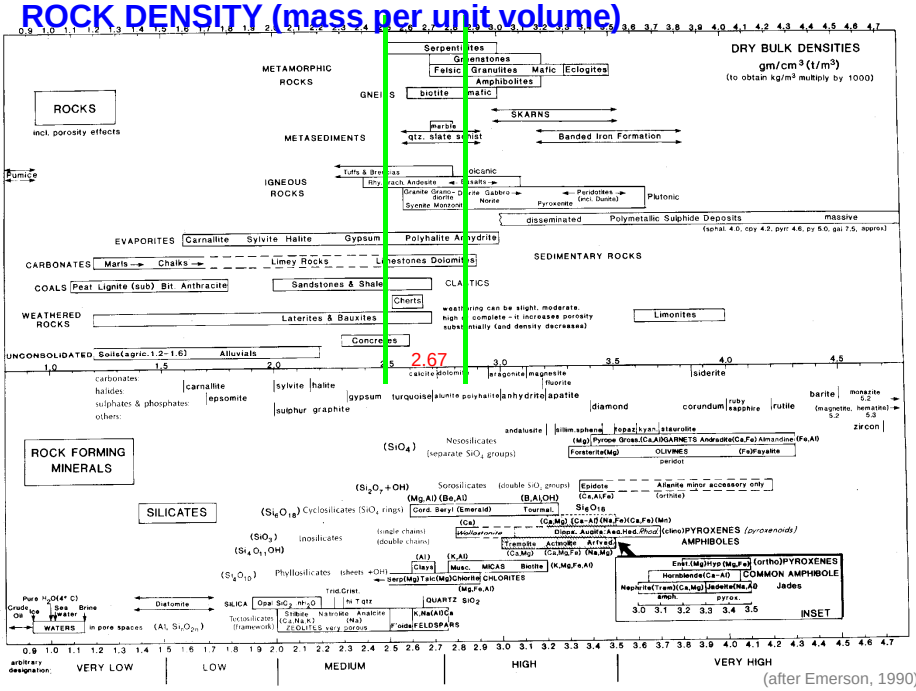
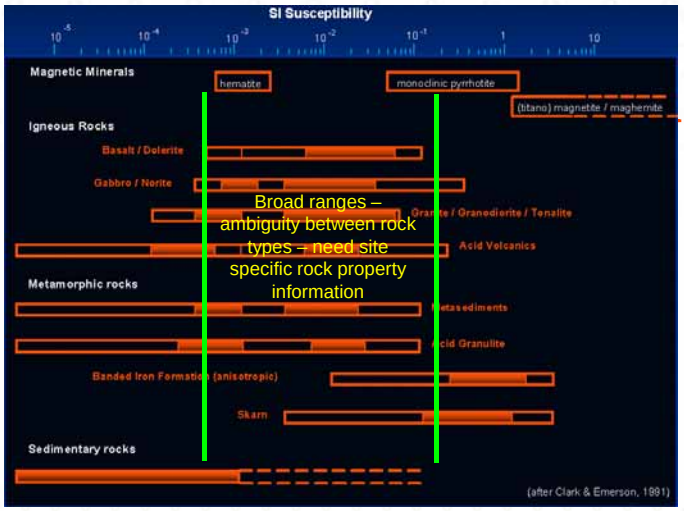
In a geological context, porphyry density varies depending on its composition and the gravity response of the porphyry can be +ve or –ve depending on its contrast with the host rock

ROCK DENSITY (mass per unit volume)



(after Emerson, 1990)

Susceptibilities of common rocks



Vol. Percent Magnetite approx. 0.1% 0.5% 1% 5% 20%

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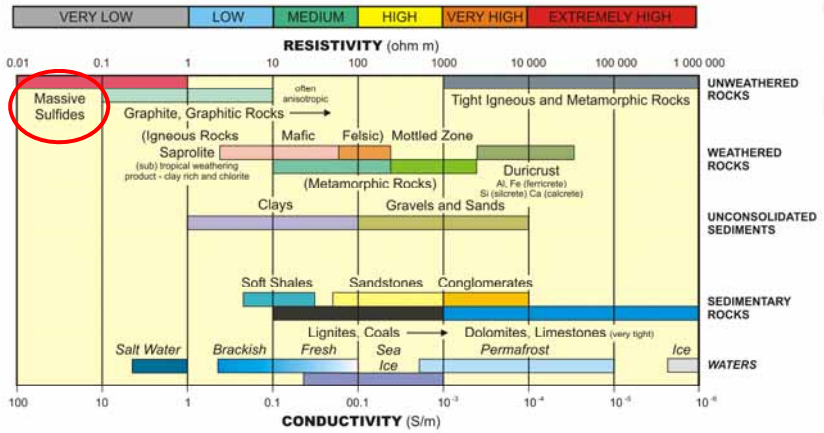
Magnetic Susceptibility = ease to which a rock becomes magnetised by an inducing field.

Resistivity/Conductivity ranges for common rocks



After Emerson, 1989

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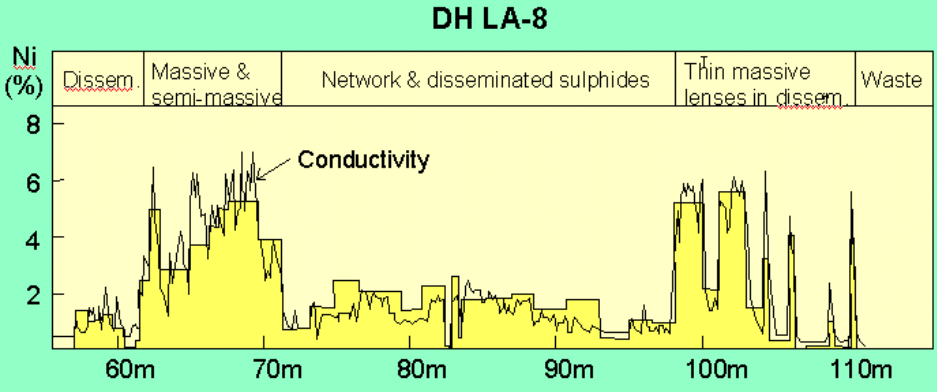
Resistivity = resistance to current flow through material

Correlation between nickel grade and conductivity
(Enonkoski Mine, Finland)

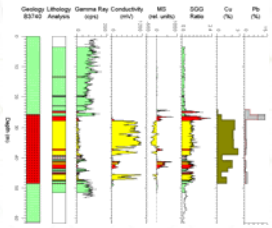


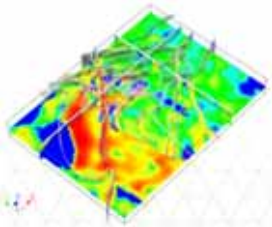
(after Hattula, 1992)

Reasons for measuring rock properties

- **Geophysical Inversion Constraints**

- Evaluation of geological & geophysical models
- Make decisions regarding remote geophysical surveys
- Lithological interpretation
- Calibration of borehole logs
- Resource estimation
- Hydrogeology
- Paleomagnetism





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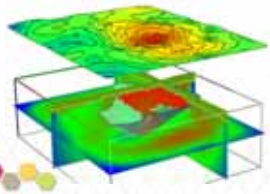
How do we get physical rock properties

- Existing literature
- Rock samples measurements
- Drill core sample measurements
- Down hole logging
- Remote sensing (→ inversion of geophysical surveys)



field data
↓
inversion
↓
rock property model

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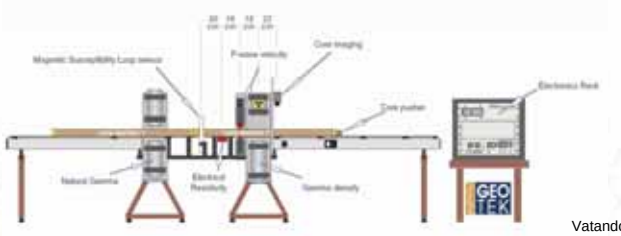
Lab measurements – rock samples and drill core

Geotek multi-sensor core logger



Vatandoost et al. (2008)

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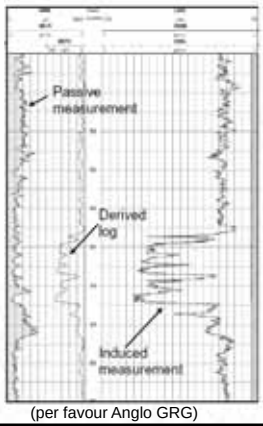
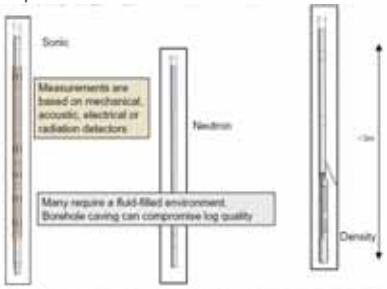
Down hole logging basics

- "Continuous" (ie. closely spaced) measurements of physical properties down hole
- Tools are lowered under their own weight and logged upwards.
- Data are transmitted to the surface computers via wireline
- ~1cm intervals, ~1-6m/s (*may be outdated ?*)
- Tools are calibrated and can be compensated for by borehole effects.
- Digital or paper plots down hole.

A typical log comprising gamma ray, porosity, density and caliper.



(per favour Anglo GRG)



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Borehole logging

- density
- resistivity
- conductivity
- polarisation
- susceptibility
- natural gamma
- others(?)
- sonic (+FW+TV)
- dipmeter
- porosity
- self-potential
- dip/deviation
- caliper
- spectral

Multi-dimensional data!

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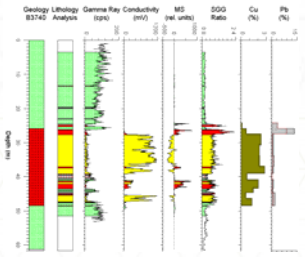
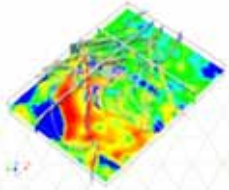
Interpretation - maximising rock property data

- Rock property data management and query tools (RPDS).
- Plots and histograms
- Statistical modelling - automated multi-dimensional analysis
- Sinepick (Televiewer data)
- Modelling - geologically constrained inversion.





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Rock Property Data Management

Multiple data sources throughout the industry, government, academia, and publications.

Large amount of data and metadata, especially with wireline data.

Archived at numerous locations around the world with significant risk of loss.

Stored in various hardcopy and digital formats.

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Rock Property Database Vision

- general organization of petrophysical measurements: sample and wireline
- global "normalization" of geological description and rock property data
- quality control and classification
- global access with extensive search
- public and private data
- connection to modelling software

Types of queries:

- *Retrieve boreholes from BC which have been logged between 1980 and 1990 that have density measurements and that come from Xstrata-owned holes.*
- *What is the correlation between velocity and fracture frequency for rhyolites in VMS-type deposits?*
- *What is the mean density of granite in central west QLD?*

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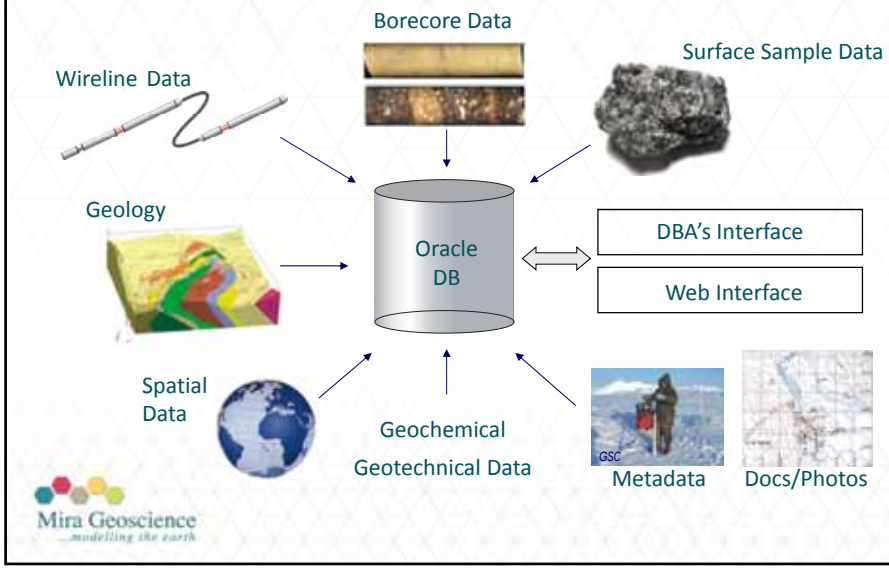
RPDS Input



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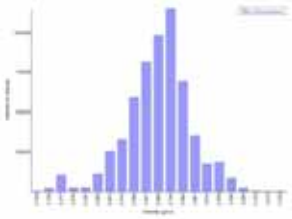
RPDS Output

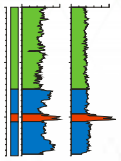
Tabular output

Borehole ID	Depth	DEN	RES
GSC-BC-HO-ES-86246	45.1	3.07341	481.629
GSC-BC-HO-ES-86246	45.2	3.13952	507.121
GSC-BC-HO-ES-86246	45.3	3.09074	535.831
GSC-BC-HO-ES-86246	45.4	3.12643	544.258
GSC-BC-HO-ES-86246	45.5	3.17196	526.859
GSC-BC-HO-ES-86246	45.6	3.1208	514.0065
GSC-BC-HO-ES-86246	45.7	3.15418	509.117
GSC-BC-HO-ES-86246	45.8	3.19541	500.733
GSC-BC-HO-ES-86246	45.9	3.07266	479.5395
GSC-BC-HO-ES-86246	46	3.08519	449.814
GSC-BC-HO-ES-86246	46.1	3.11718	420.4125

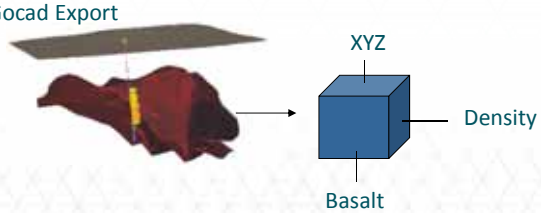
Graphical output



LogView Export



Gocad Export



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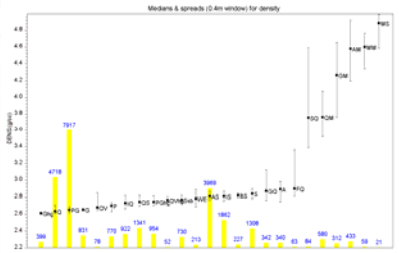
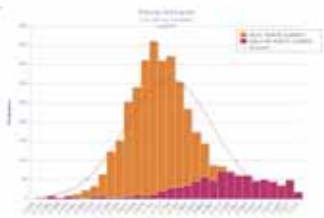
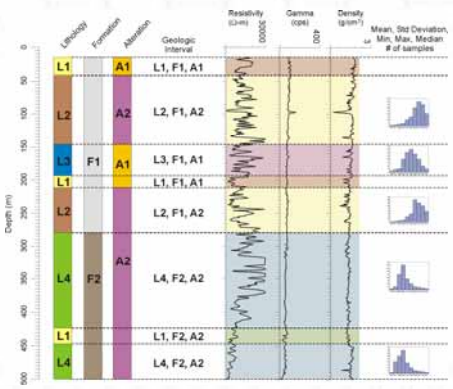
Understanding Rock Property Distributions





bimodal distributions



Multi-dimensional data

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LogTrans

Fullagar Geophysics Pty Ltd

- Automatic interpretation tool for geophysical borehole logs

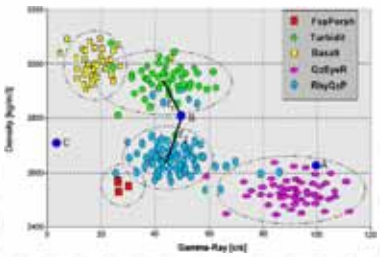
  "Convert squiggly lines to useful form."

  - Multi-log parameter analysis.
  - Adaptable for geological, geotechnical or geochemical interpretation
  - Discriminate lithology, alteration, grade, ore/waste, strength
  - Batch processing
  - Provision of a measure of confidence
  - Optional stratigraphic constraints
  - Extended application to 3D block models

- Two stage operation

  - Conditioning based on control data
  - Application to non-control data

Multi-dimensional statistical grouping of measurements to define domains



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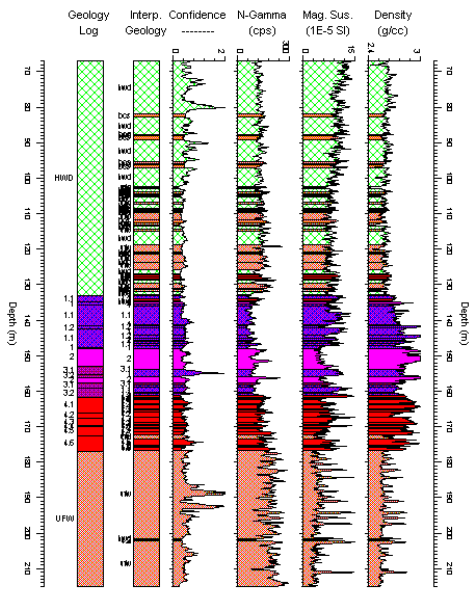
LH502 LogTrans Geological Interpretation



Control hole

HWD hangingwall dolomite

Unit 1 sideritic siltstone

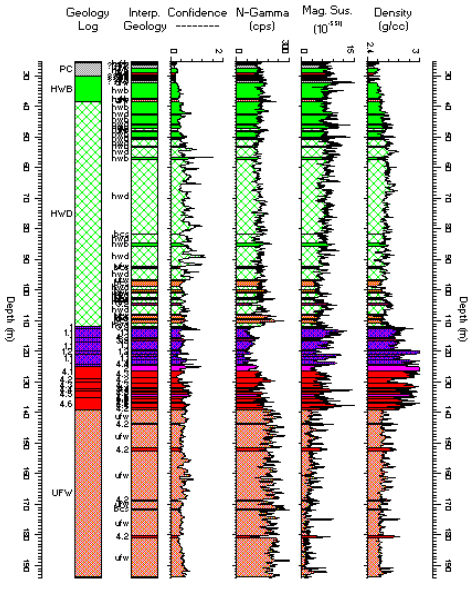
Unit 2 sphalerite in shale + Pb

Unit 3 sideritic siltstone

Unit 4 sphalerite in shale

UFW upper footwall siltstone

LH643 LogTrans Geological Interpretation



Independent hole

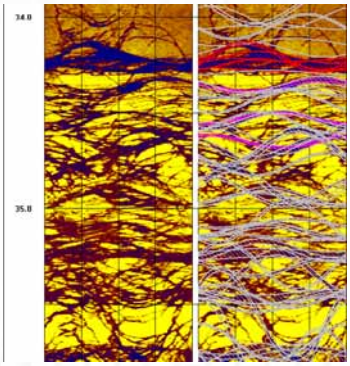
Unit 1 sideritic siltstone

Unit 4 sphalerite in shale

Fullagar Geophysics

Sinepick

- Automatic interpretation ('picking') of sinusoids and breakouts in televiewer data

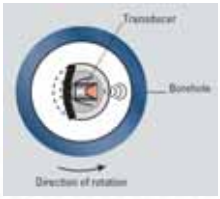


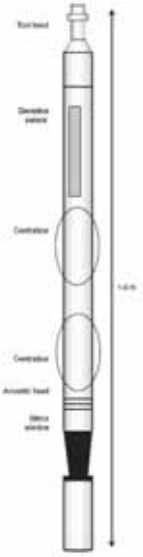
Auto picking of fractures from sinusoids

Acoustic televiewer (ATV)

Measures both reflection amplitude and travel time of acoustic pulse as a function of both depth and azimuth

Orientation of televiewer also recorded: on-board accelerometers & magnetometers





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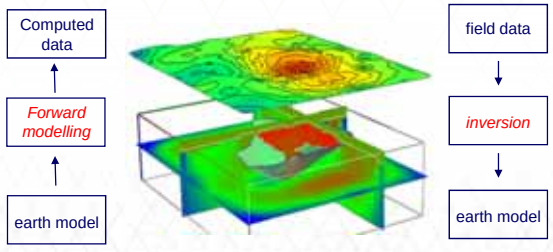
Quantitative geophysical modelling of rock properties

"Forward modelling" computes the response of a geological model attributed with rock property data (density, susceptibility, conductivity etc).

"Inversion" algorithms produce a rock property model consistent with measured survey data (subject to imposed geological and petro physical constraints).



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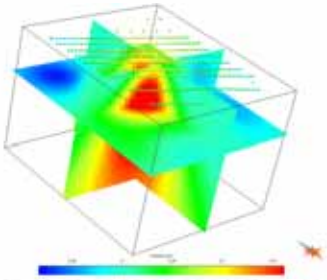
“Unconstrained” inversion

- Recover a rock property model from geophysical (remote) survey data.
- Starting model homogeneous background - no geological knowledge
- Well accepted for first pass potential field inversion, relatively easy to use, but limited, highly non-unique (more than one model can explain the geophysical response)

- Model constraints such as depth weights and smoothness are typically used in a geologically unconstrained inversion.

Unconstrained inversion



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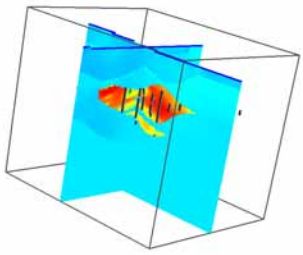
Geophysical inversion in a geological context

- a.k.a. geologically constrained inversion

- Less models can explain geophysical data and maintain consistency with down hole geology and petrophysics
  → a more robust model.
- Inversion explicitly operates on a geological model (constrained by drill hole geology) attributed with physical rock properties

- Geologically constrained inversions produce additional value-add information from the contributing data sets.



Geologically constrained inversion. Constrained by drill holes, interpreted sections and down hole density.

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Rock property constraints

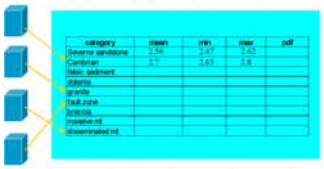
- Geophysical inversion can incorporate rock property constraints…

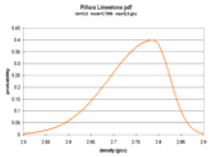
…By assigning meaningful rock property contrasts to geological boundaries.

…Imposing upper and lower bound constraints on rock property variations (assigned per lithology).

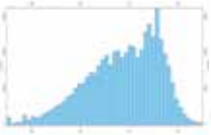
…Imposing probably distribution constraints on rock property variations (assigned per lithology).

…Explicitly constrained down hole rock property constraints on the model.

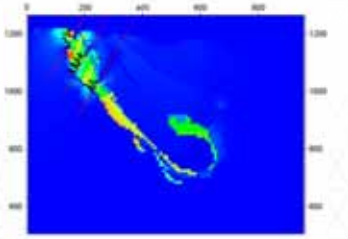




Target distribution



Inverted cell properties



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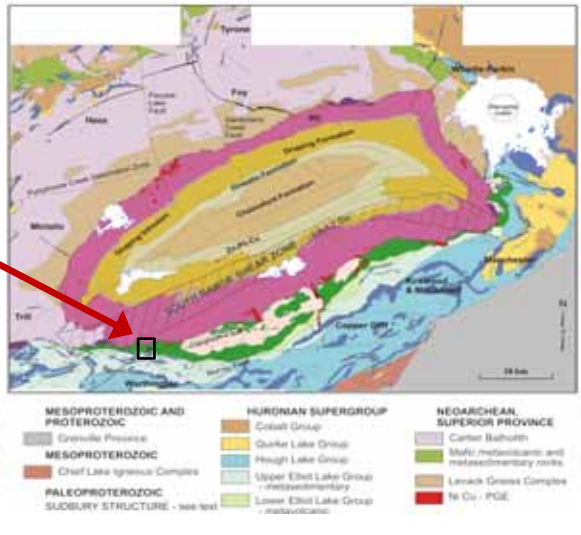
Victoria case study: deposit-scale geology

Victoria property location



courtesy KGMH International (ex QuadraFNX)

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Methodology

Key elements:

- wireline logging (or core measurements) for selected drill holes
- geological model construction
- geologically constrained inversion of gravity and magnetics
- pseudo-lithology prediction

Name	Color	
01_INMS		Inclusion massive sulphide
02_MTBS		Meta-basalt
03_MTBSm		Magnetic meta-basalt
04_MTBSmd		Dense magnetic meta-basalt
05_MTGB		Meta-gabbro
06_MTSD		Meta-sediment
07_MTSDm		Magnetic meta-sediment
08_OLDI		Olivine diabase
09_QD		Quartz diorite
10_SLNR		Sub-layer norite

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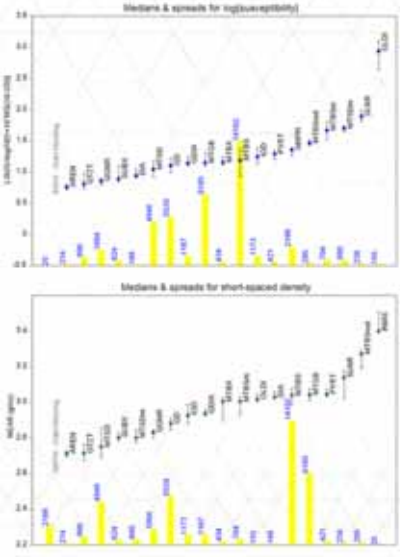
Physical rock property data

- 9 holes logged with multi-parameter probe
- fairly low density and magnetic susceptibility contrasts except for a few rock types
- New rock types derived from original bimodal distributions (MTBSmd, MTSDm, MTBSm)



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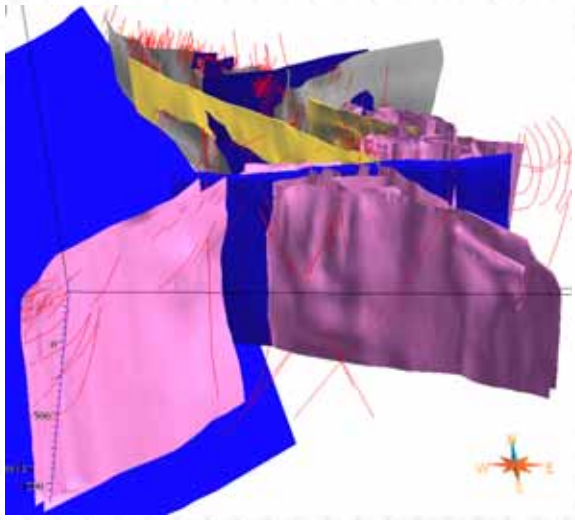
Geological modelling



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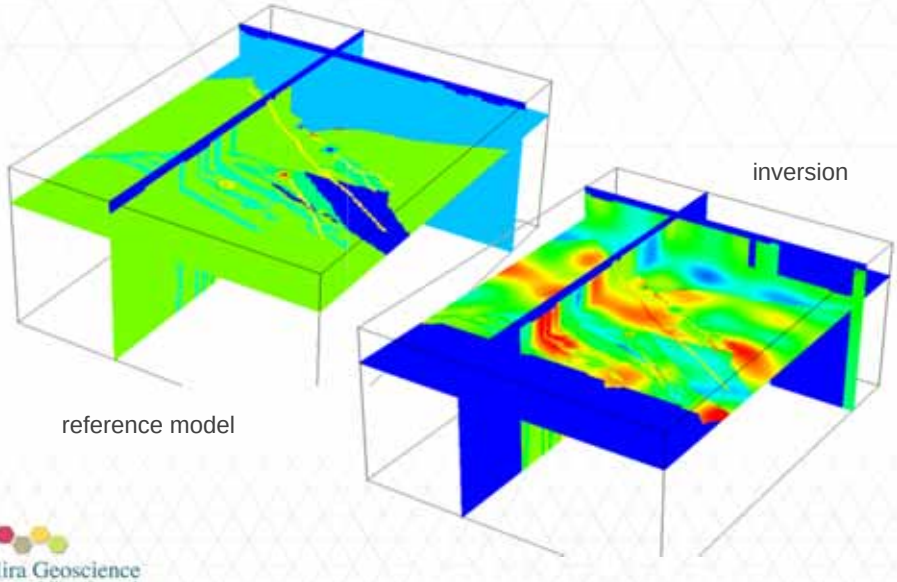
Constrained gravity inversion results



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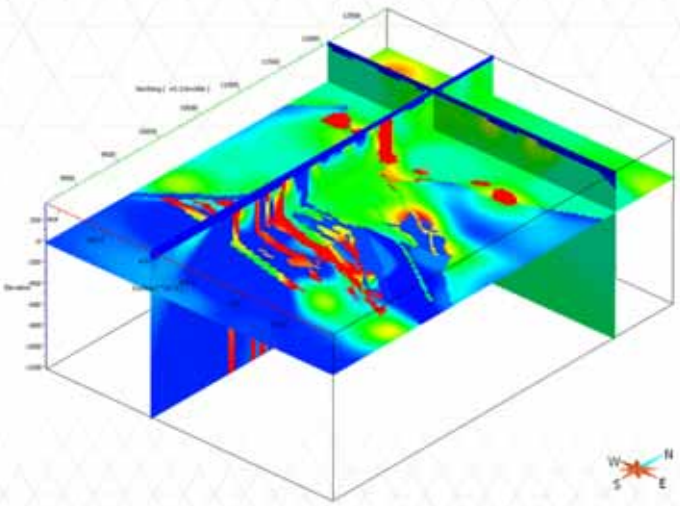
Constrained magnetics inversion results



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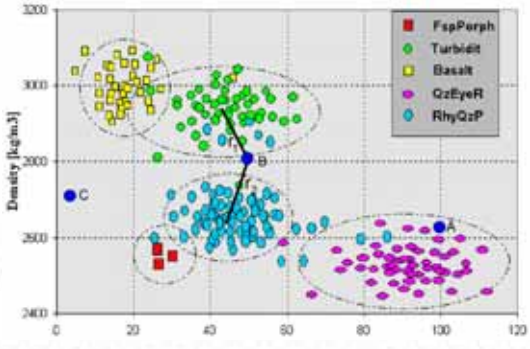
The more rock property data to constrain the interpretation, the more robust the final 3D model.

Pseudo-lithology prediction (Logtrans)

- assign a rock type to each model cell (with confidence value), based on the physical properties of the cell after inversion, to estimate a “revised geology”, consistent with geophysics and petrophysics.

- Can highlight:
  - errors/omissions in the original geological model
  - internal lithological variability and/or alteration

LogTrans algorithm schematic



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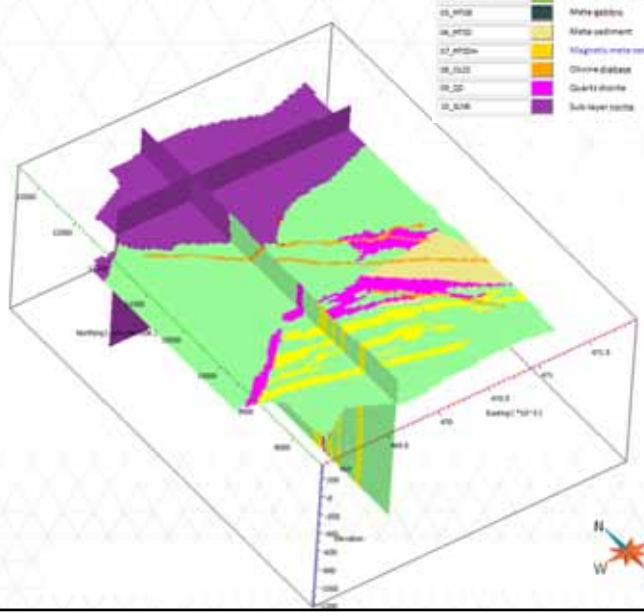
LogTrans Results

Easting = 470000
Northing = 5142000
Elev = 0



initial model

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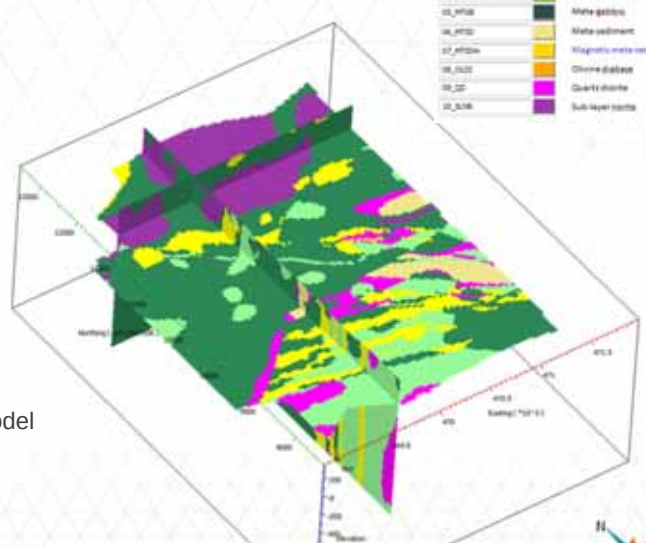
LogTrans Results

Easting = 470000
Northing = 5142000
Elev = 0



predicted model

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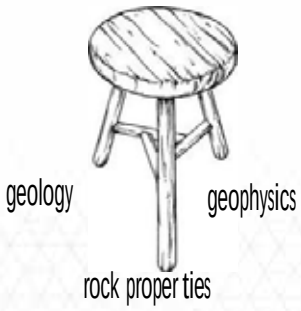
Conclusions

- Understanding physical rock properties is paramount to interpreting geology from geophysical surveys.
- Collect down hole rock property data → understand site specific rock property variations
- Management, access and the ability to query rock property data is important.
- Aside from geophysical modelling, other applications of rock properties include lithology prediction, calibration of borehole logs, resource estimation, hydrogeology.
- A variety of methods and tools exist for interpreting and maximising the information from rock property data.



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