Testing Joint Inversion Code with Geologically Realistic Models

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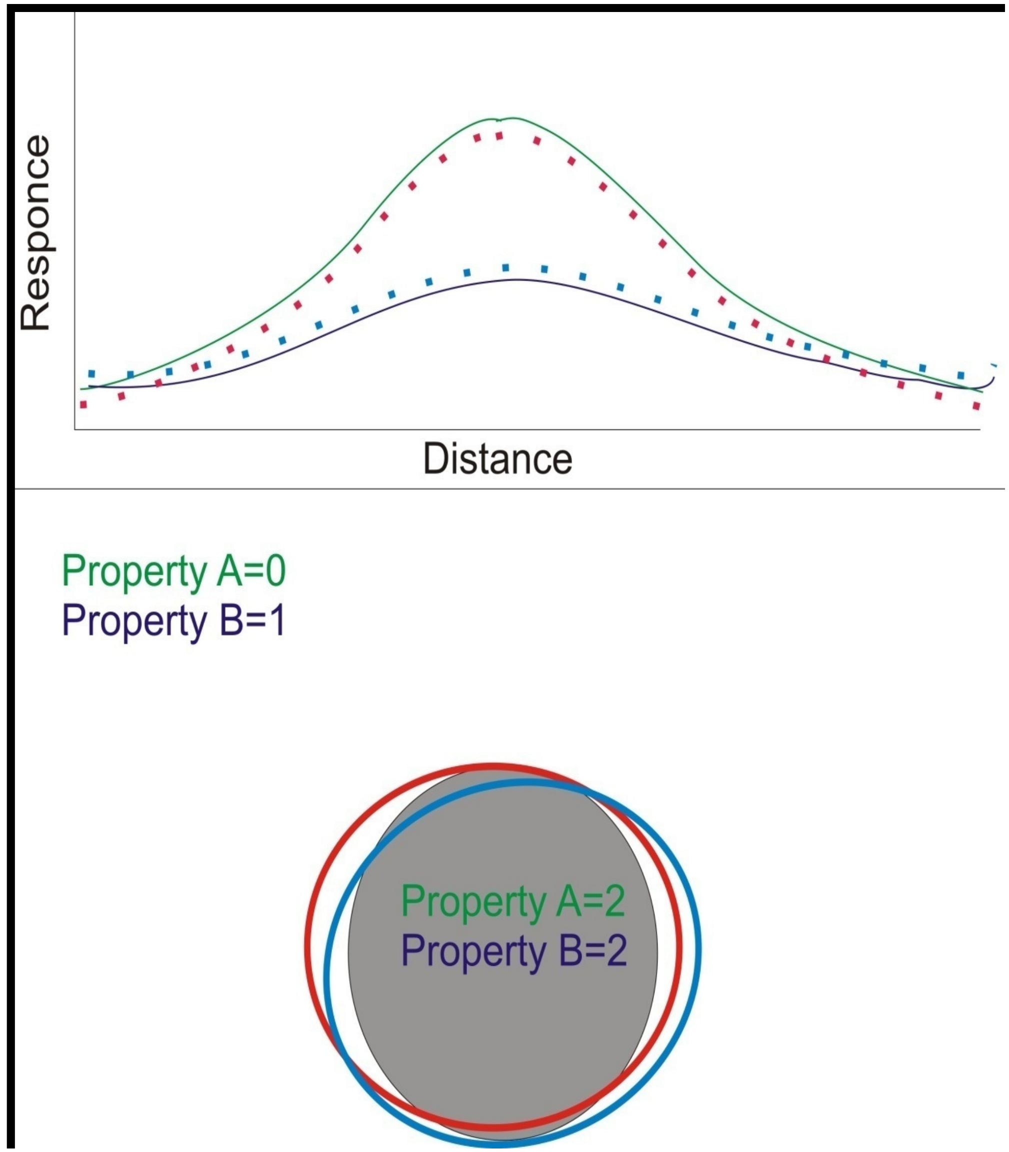
Outline

- Background
  - Joint Inversion
  - Unstructured Meshes
  - Voisey’s Bay Deposit
- 2D Testing
  - Models
  - Forward Modelling
  - Inversion Modelling
- 3D Testing
  - Models
  - Challenges
- Conclusions

Joint Inversion

- Increase confidence in modelling results

- An alternative to constrained inversion



Joint Inversion

$$\phi_j = \sum_i \rho_i \psi_i(m_1, m_2)$$

- Measure of misfit

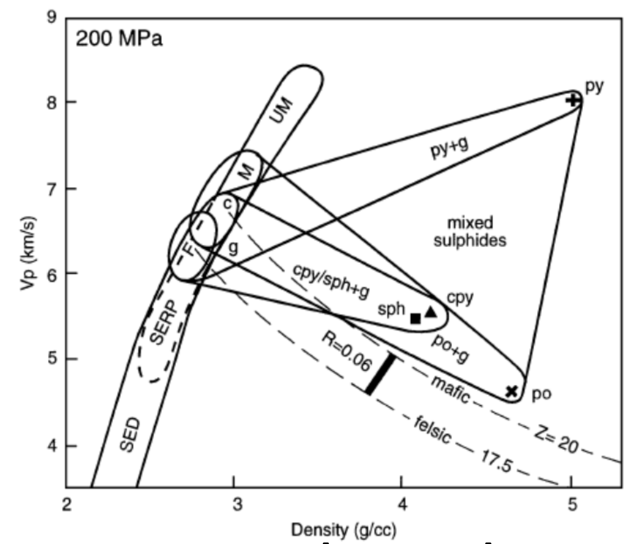
$$\lambda = \sum_{i=1}^{N} \left(\frac{d_i^{pred} - d_i^{obs}}{\sigma_i} \right)^2$$

- Measure of physical property structure

$$\gamma = \sum_{j=1}^{M} (m_j - m_{j+1})^2$$

RHOE

- Lithological Relationships

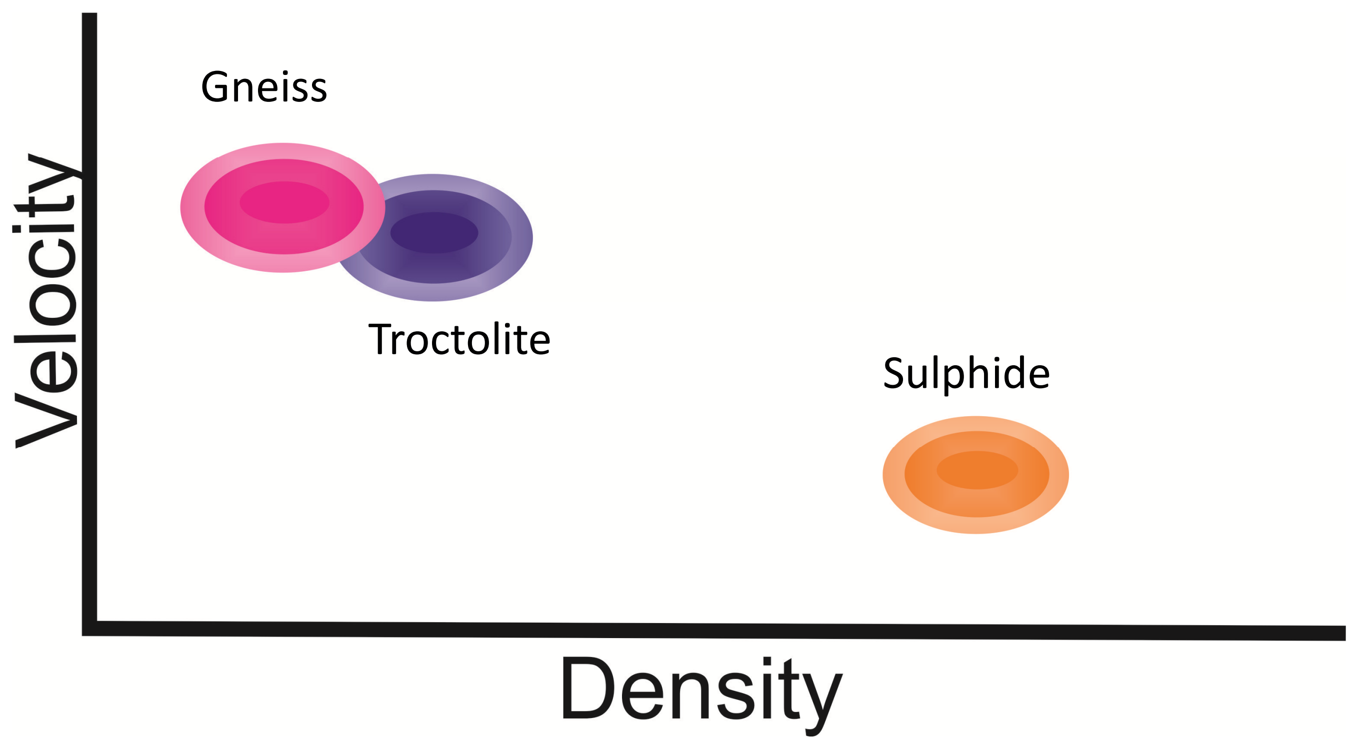


- Structural Similarity

$$\vec{T}(x, y, z) = \nabla m_i(x, y, z) \times \nabla m_j(x, y, z)$$

Joint Inversion

Lithological relationships through fuzzy C-mean clustering



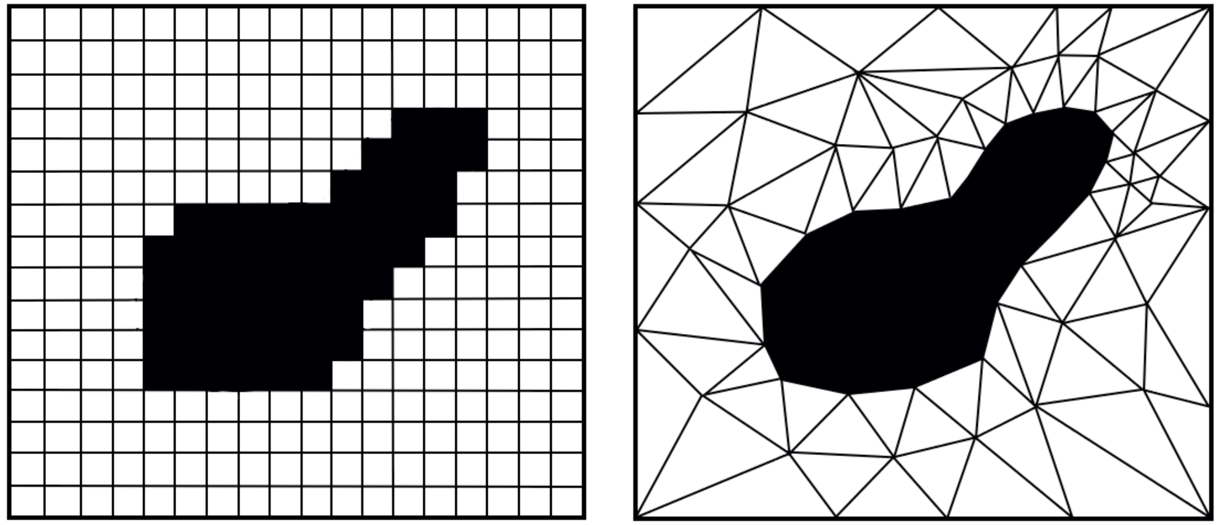
Unstructured Meshes

Benefits

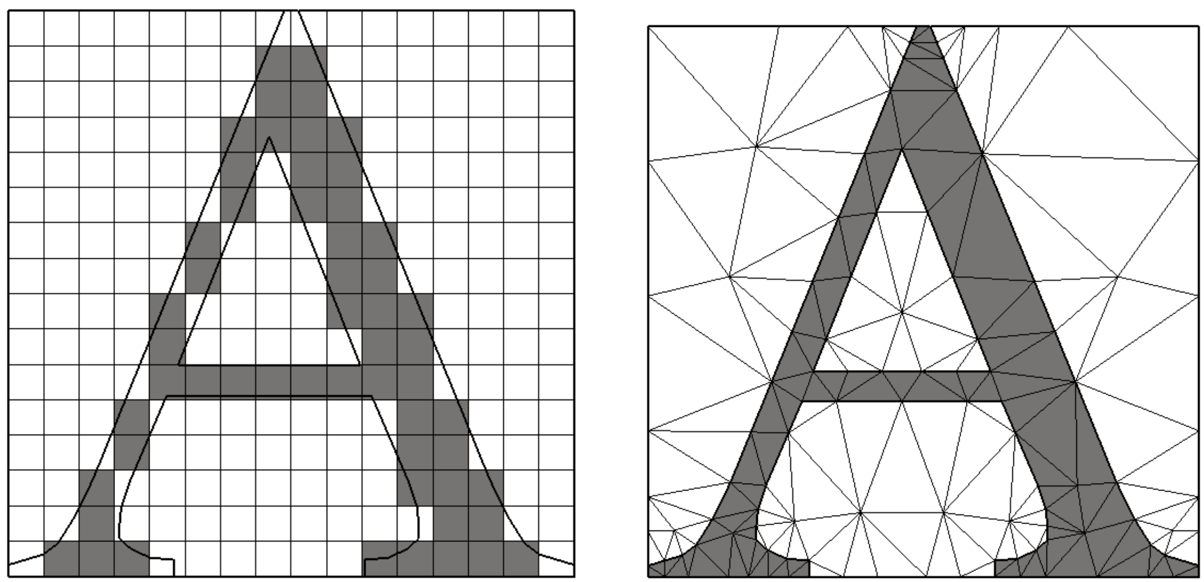
- Accurately depict complex geological structures
- Require less cells to depicted same degree of complexity than rectilinear grids

Disadvantages

- Limited availability of compression codes leads to increased computing demands
- Process for producing meshes is more complex and time consuming

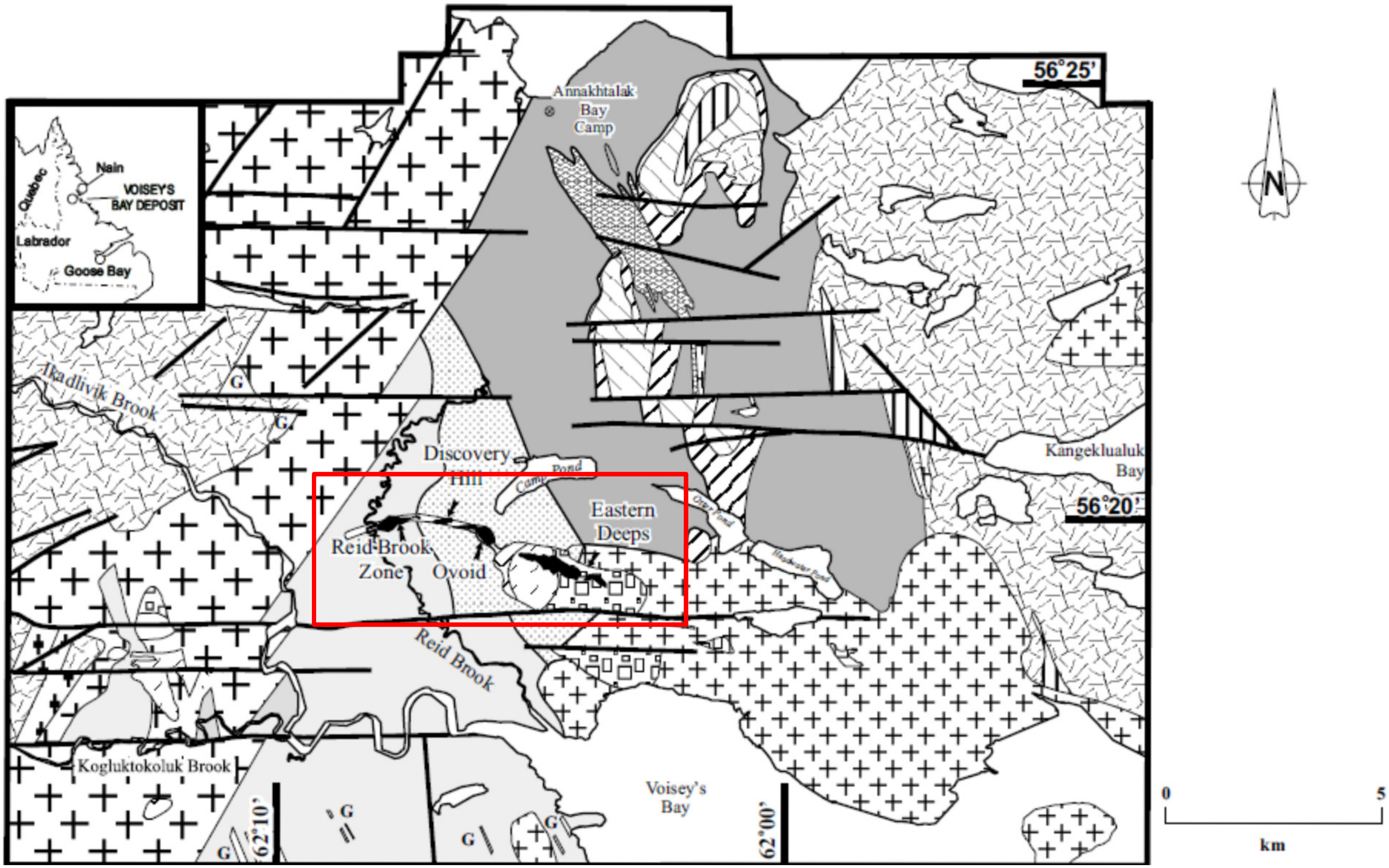


Figures courtesy of Hormoz Jahandari



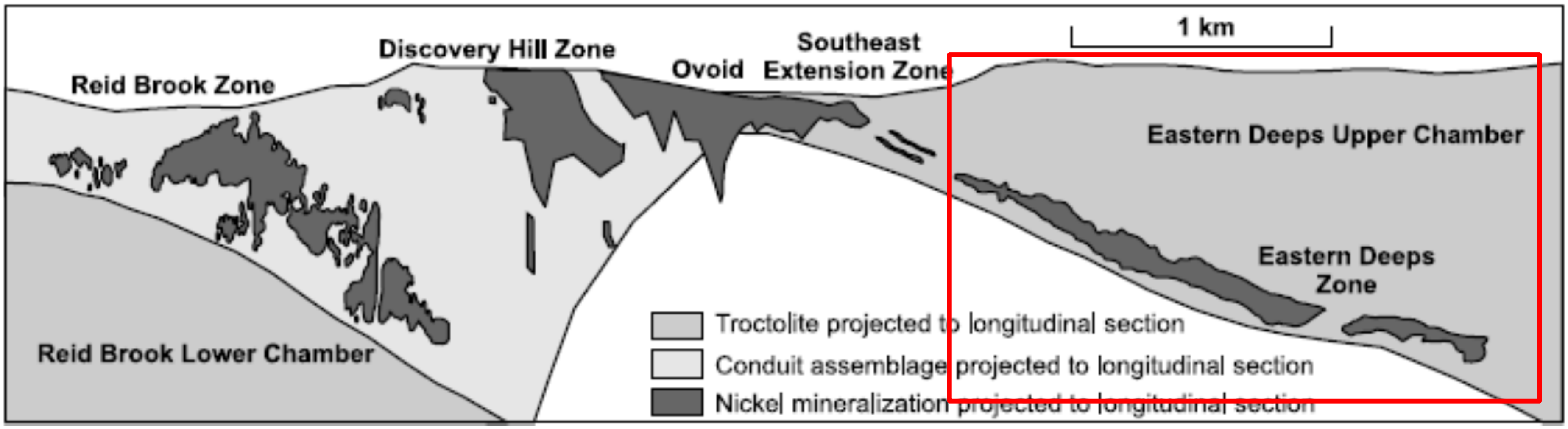
Lelièvre, P. et al., 2012

Geologically Realistic Models: Voisey's Bay Deposit



After Evans-Lamswood et al., 2000

Geologically Realistic Models:
Eastern Deeps Zone

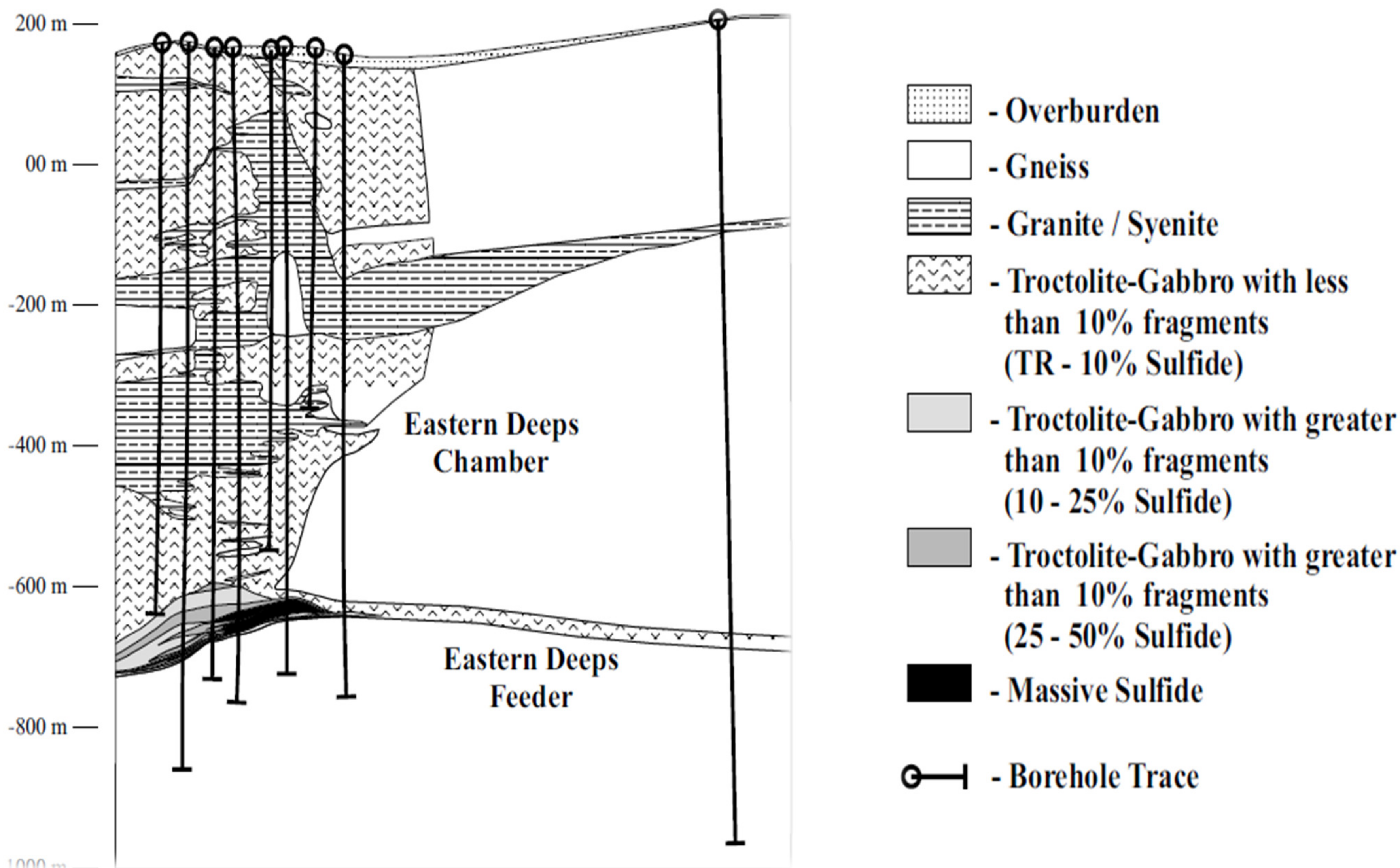


(after Li et al., 2000)

Premise of Project: 2D testing

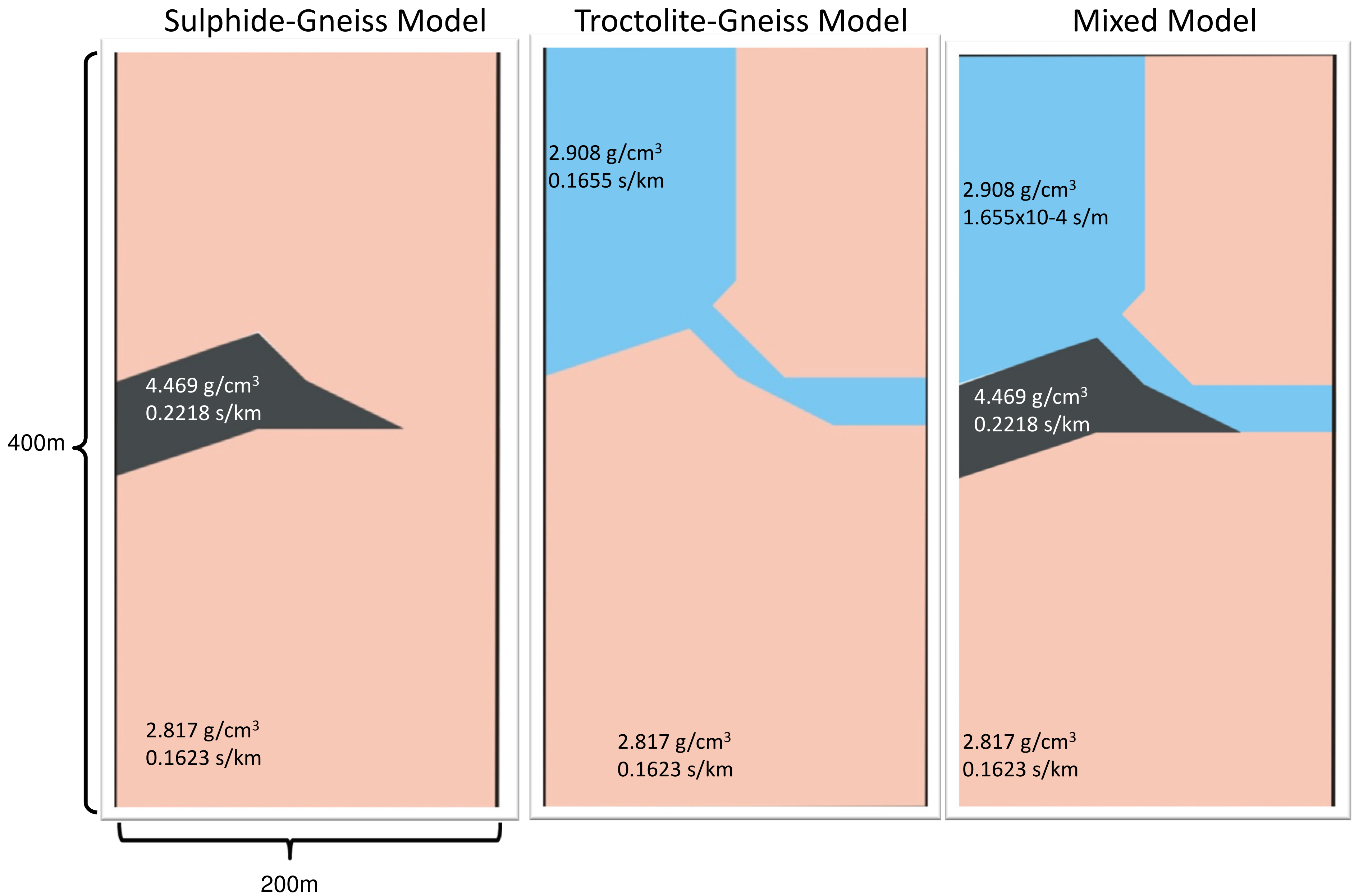
- To develop an understanding of the affects of different inversion parameters in a battery of tests with relatively low computational requirements
- Test different characteristics that one might expect to encounter in a real geological setting

Eastern Deeps Zone



After Evans-Lamswood et al., 2000

2D Models



Sulphide-Gneiss Model
Troctolite-Gneiss Model
Mixed Model
4.469 g/cm³
0.2218 s/km
2.817 g/cm³
0.1623 s/km
400m
200m
2.908 g/cm³
0.1655 s/km
2.817 g/cm³
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1.655x10-4 s/m
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0.2218 s/km
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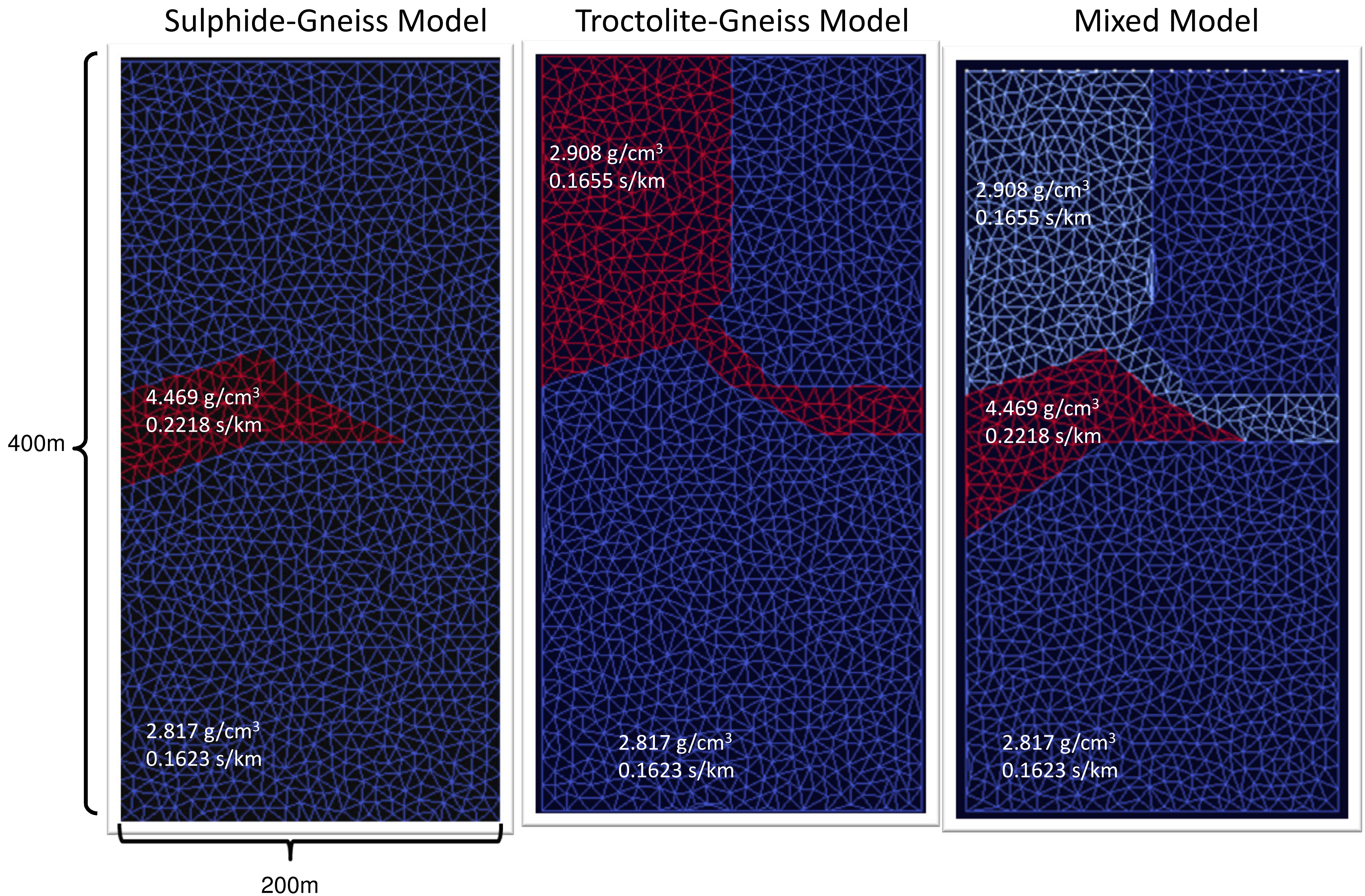
2D Models



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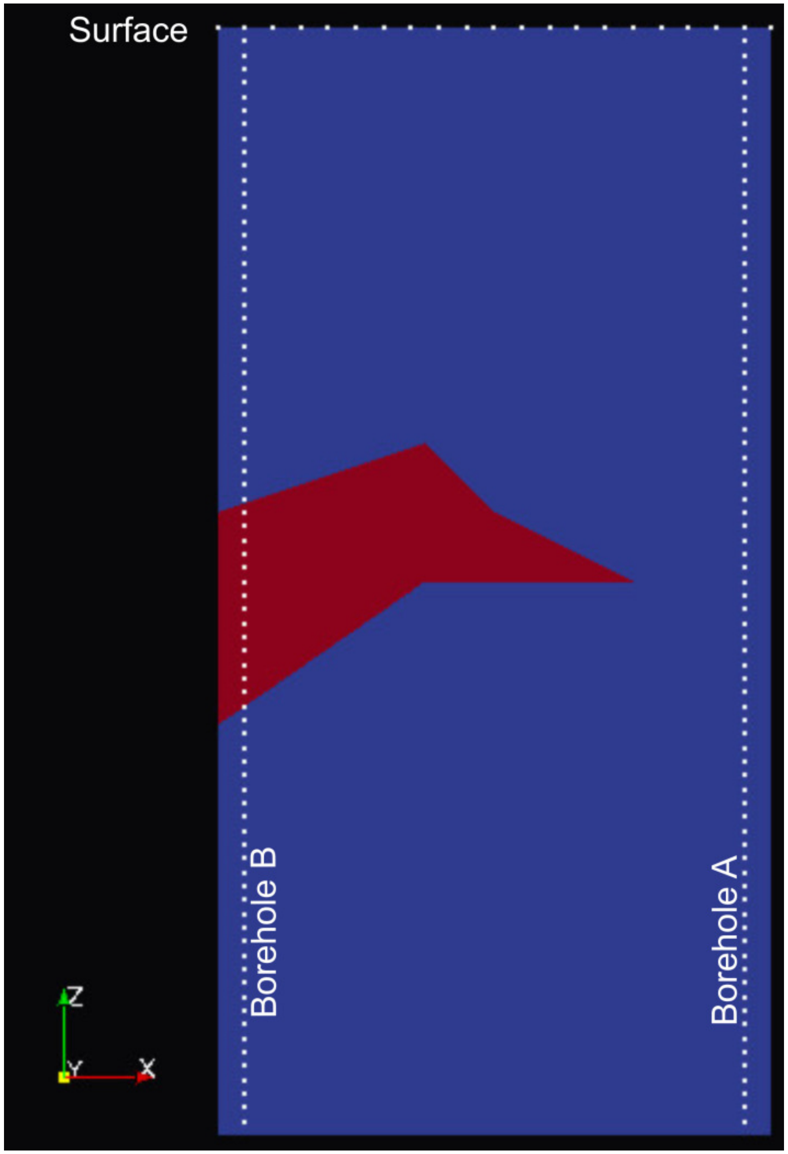
Gravity Stations and Seismic Source/Receiver Locations



Gravity

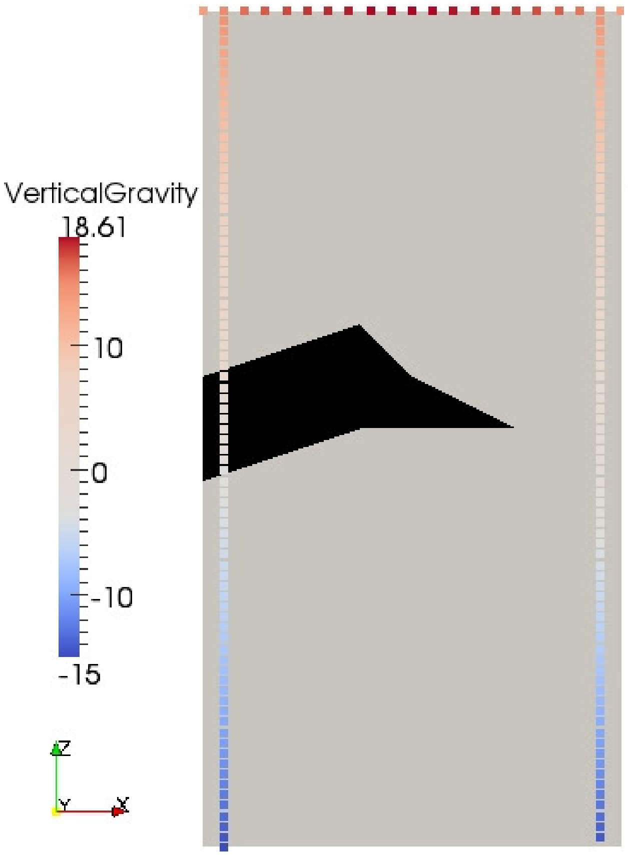
- stations located at surface and in boreholes
- Tests run with:
    - Surface stations only
    - Borehole A stations only
    - Borehole B stations only
    - Borehole A and B stations
    - All stations

Seismic tomography:

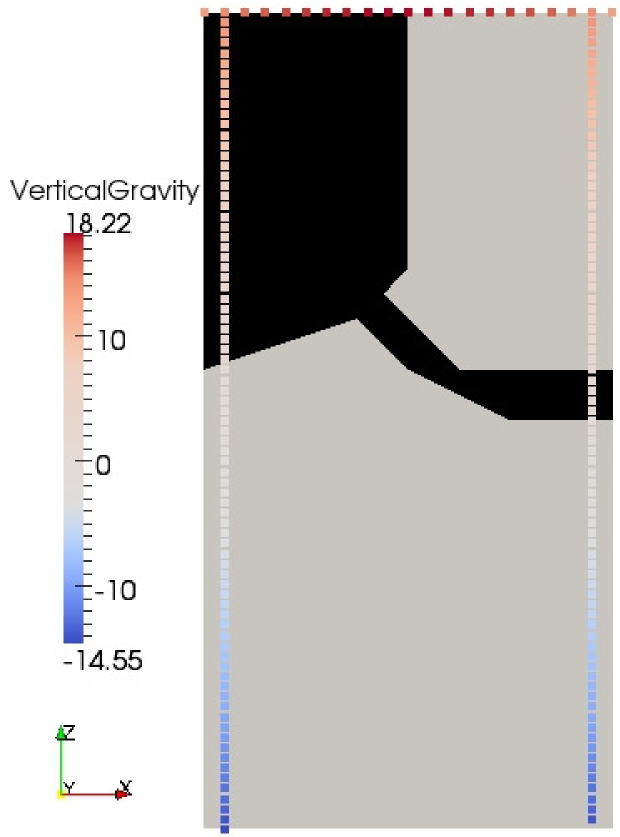
- Sources in borehole A
- Receivers in borehole B

Results from Gravity Forward Modelling

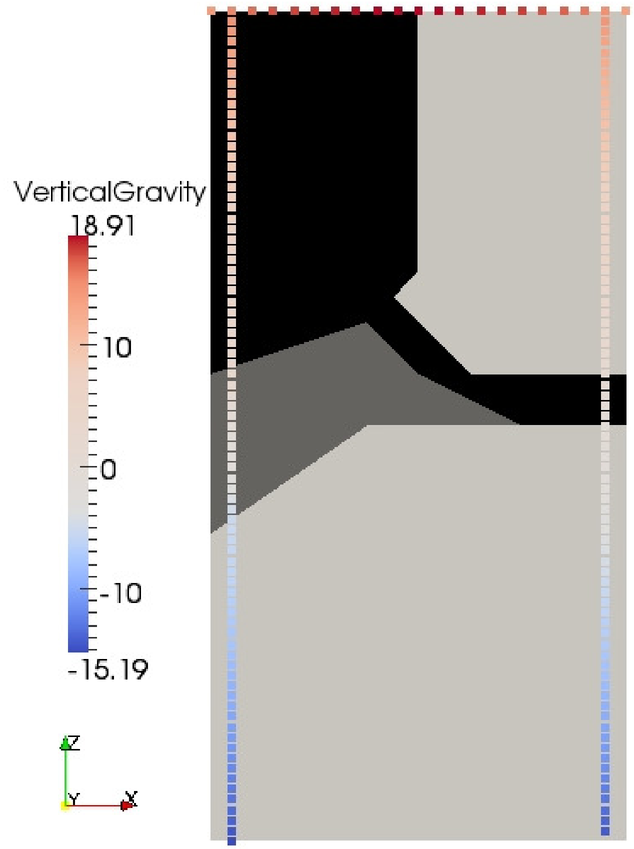
Sulphide-Gneiss Model



Troctolite-Gneiss Model

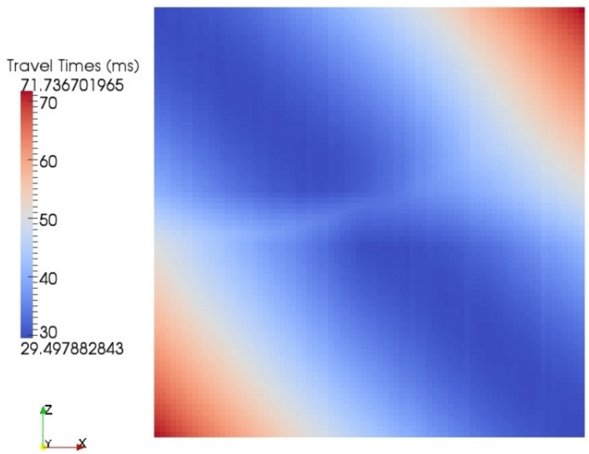


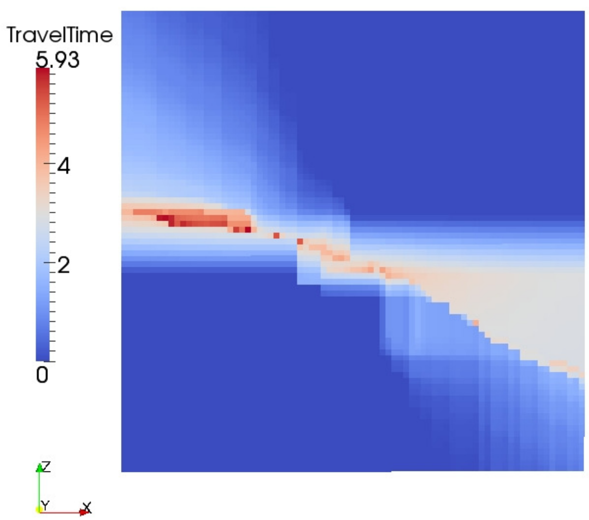
Mixed Model



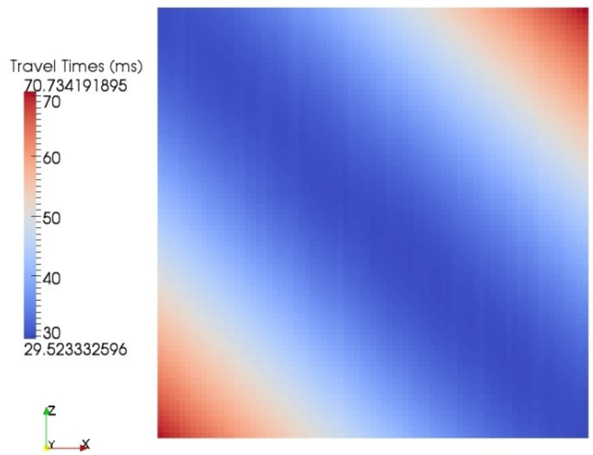
Results of Seismic Forward Modelling

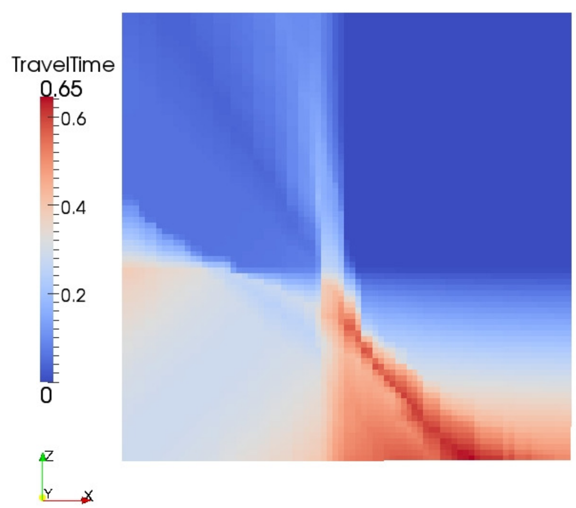
Sulphide-Gneiss Model





Troctolite-Gneiss Model





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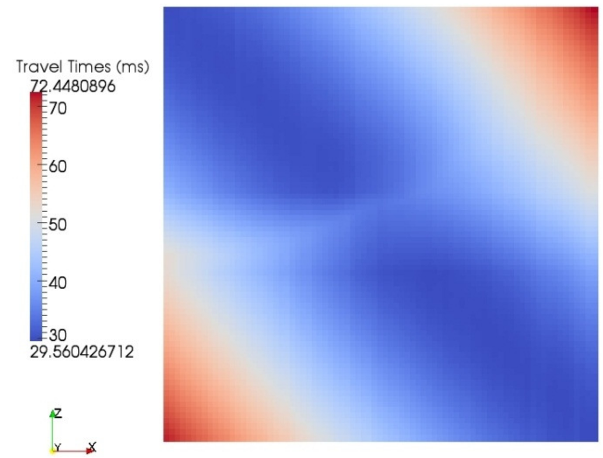
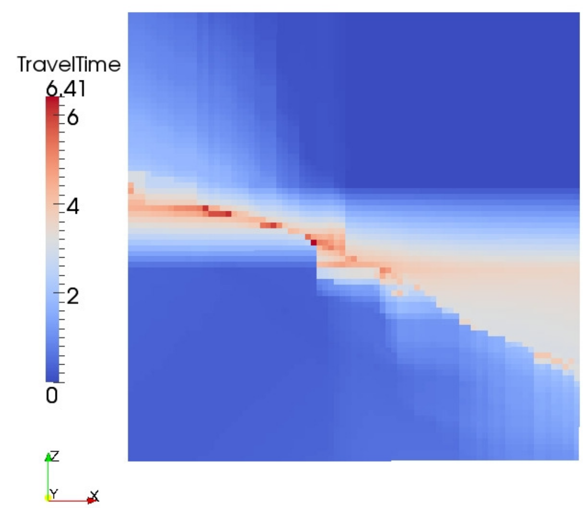




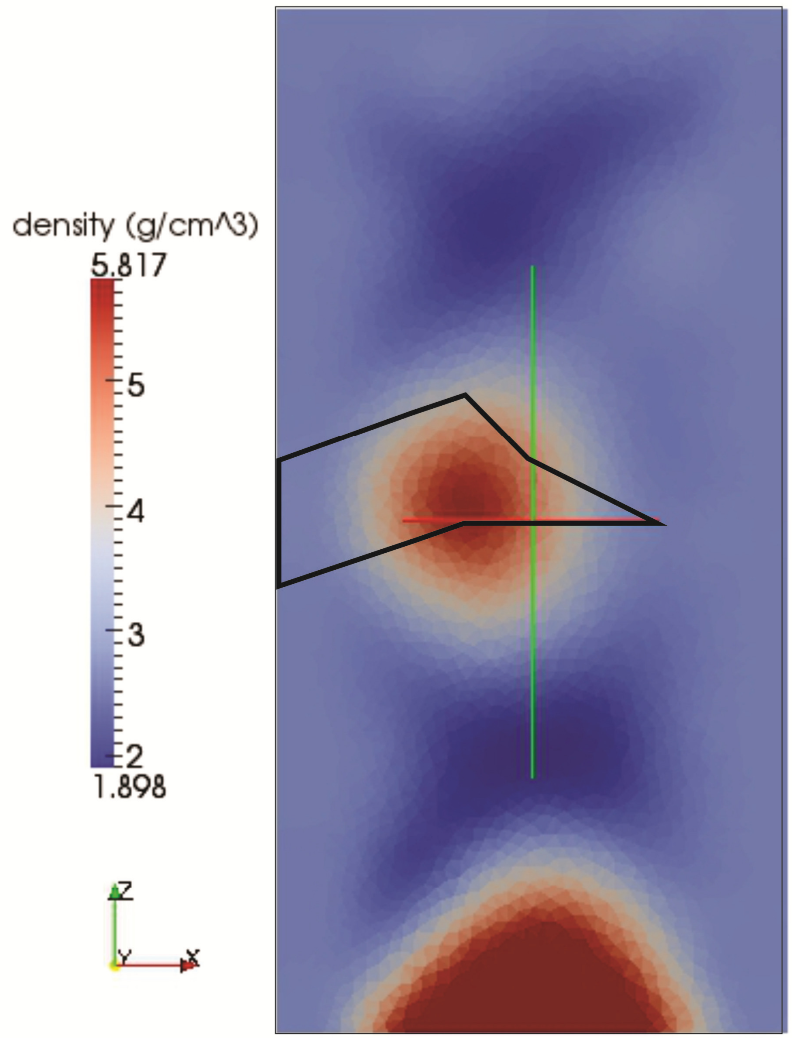
Inversions in 2D

- Inversions run for synthetic data produced from all three models
- Tests run with varying parameters and different amounts of noise added to data
- Noise levels:
  - Low Noise = 0.1% noise
  - Moderate Noise = 1% noise
  - High Noise = 10%

Examples of 2D Inversion Results

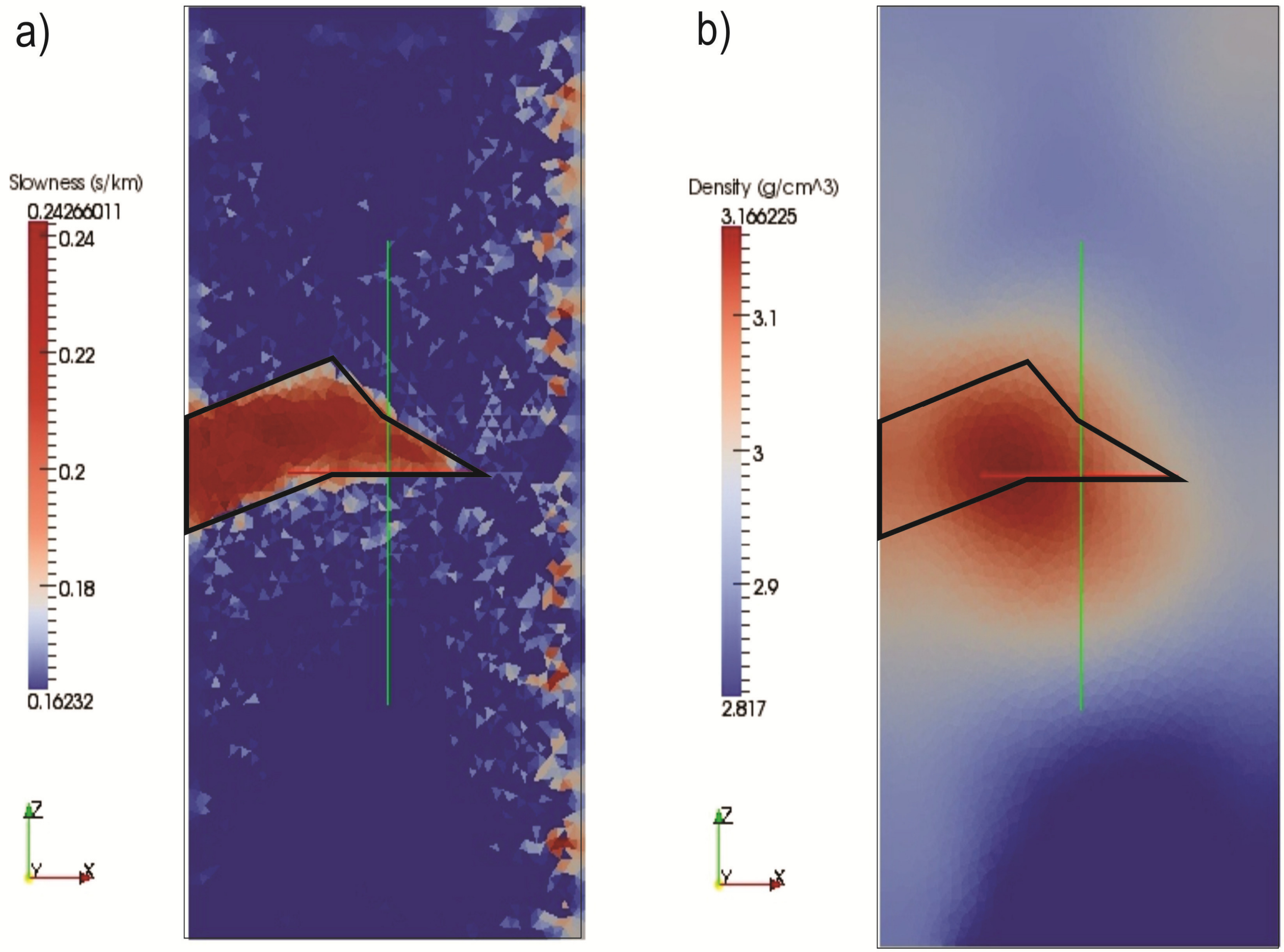
1) Improving the density distribution through joint inversion
2) Modelling from borehole gravity
3) Effect of the similar parameter on joint inversion results
4) Ability to model small physical property contrasts

Example 1:
Improvement due to Joint Inversion:



Gravity-only inversion of moderate noise data from borehole A and B stations

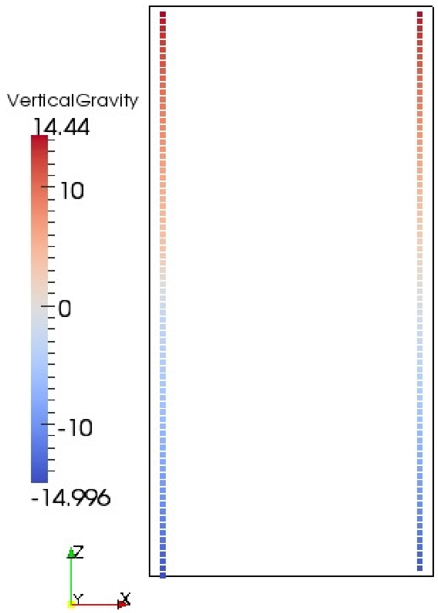
Example 1:
Improvement due to Joint Inversion:

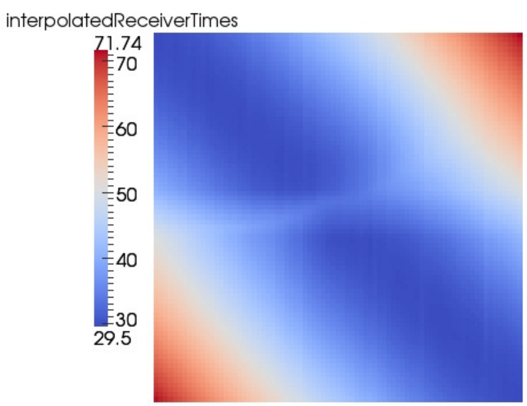


Joint inversion of moderate noise data from borehole A and B stations

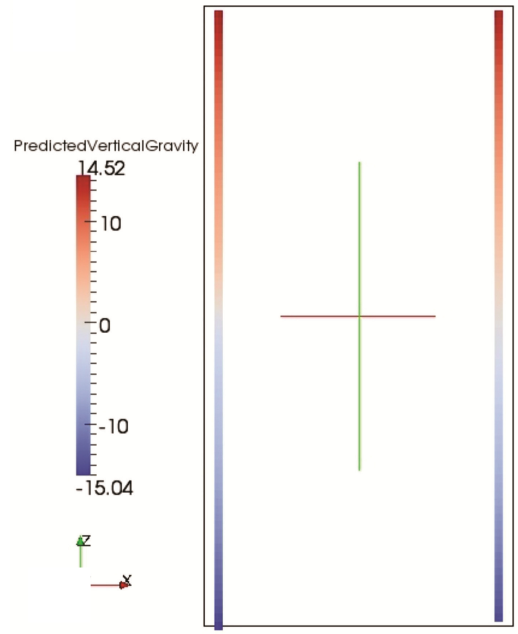
Example 1:
Improvement due to Joint Inversion:

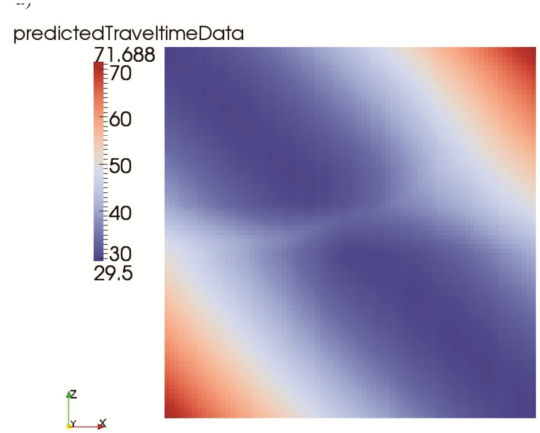
Clean Synthetic Data:



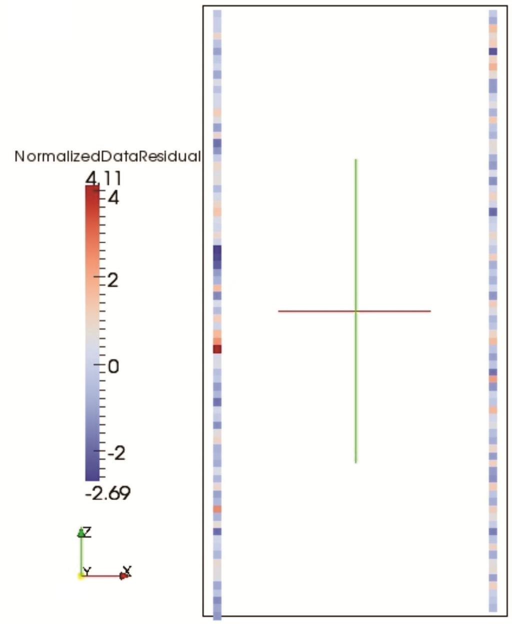


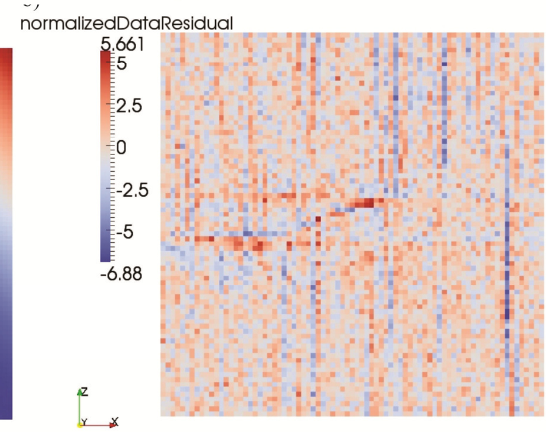
Predicted Data:





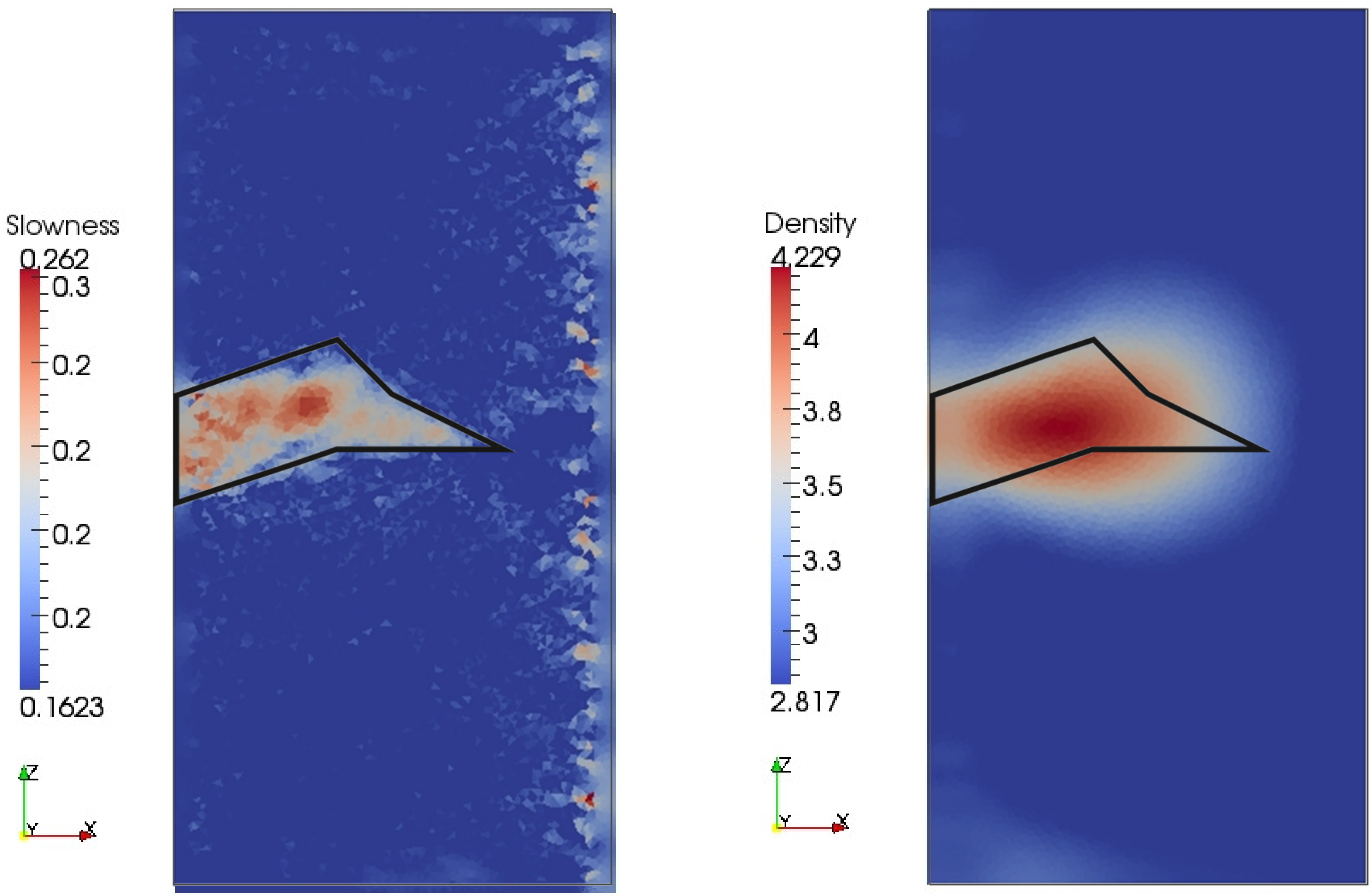
Normalized Data Residuals:





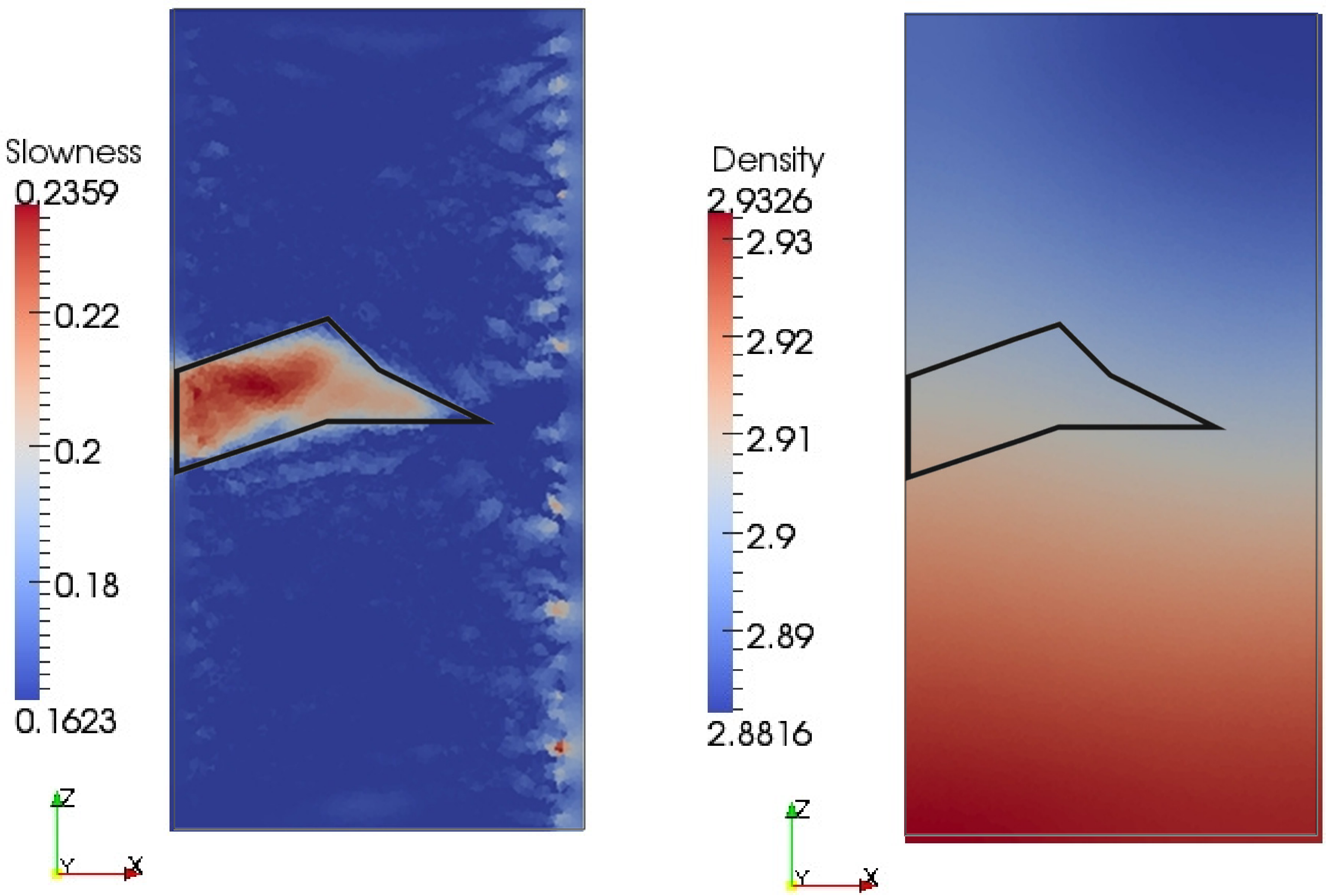
Data from the joint inversion of moderate noise data from borehole A and B stations

Example 2:
Modelling from Single Borehole Data



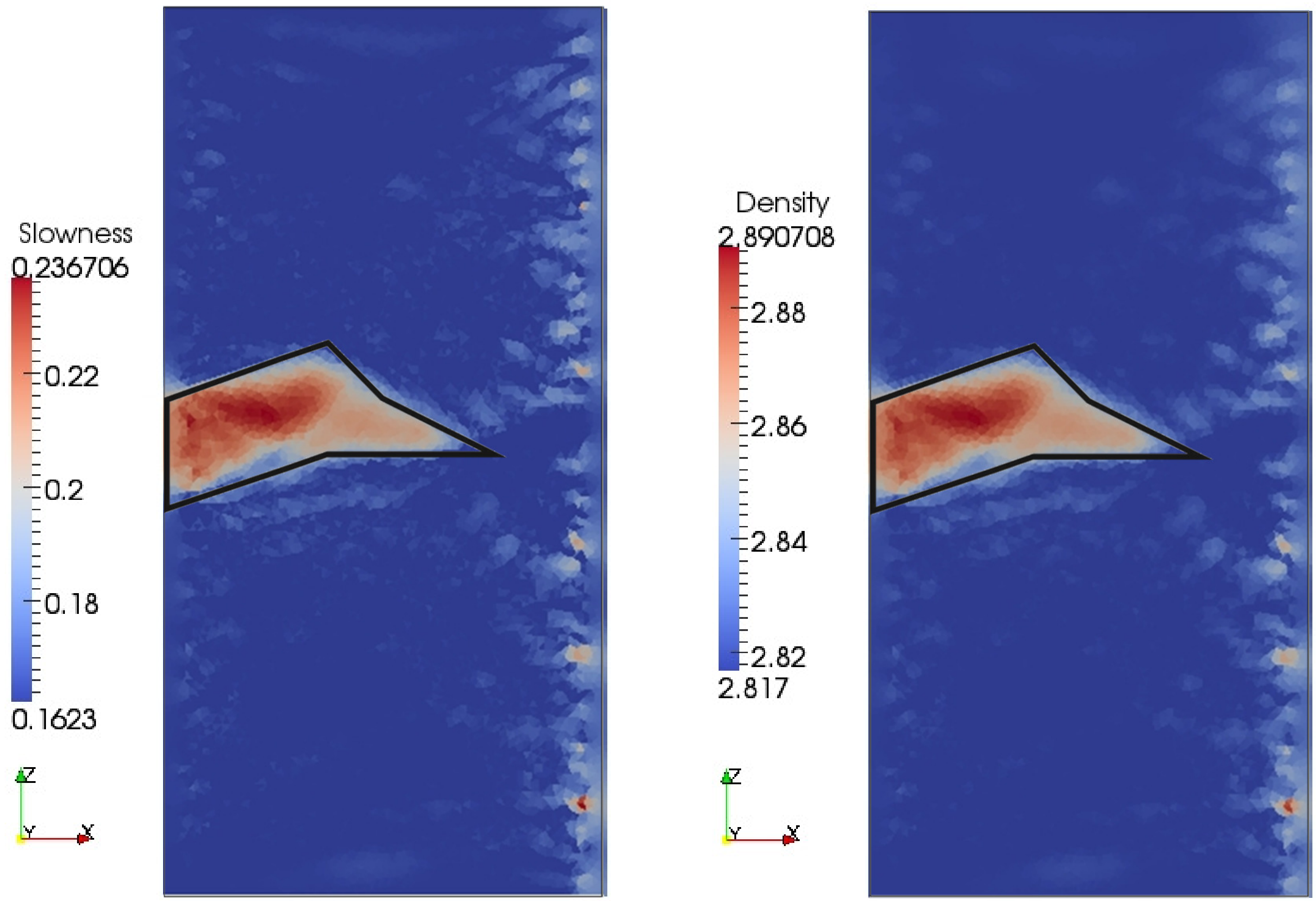
Joint inversion of moderate noise data, gravity data from borehole B data

Example 3:
Effect of the Similarity Parameter



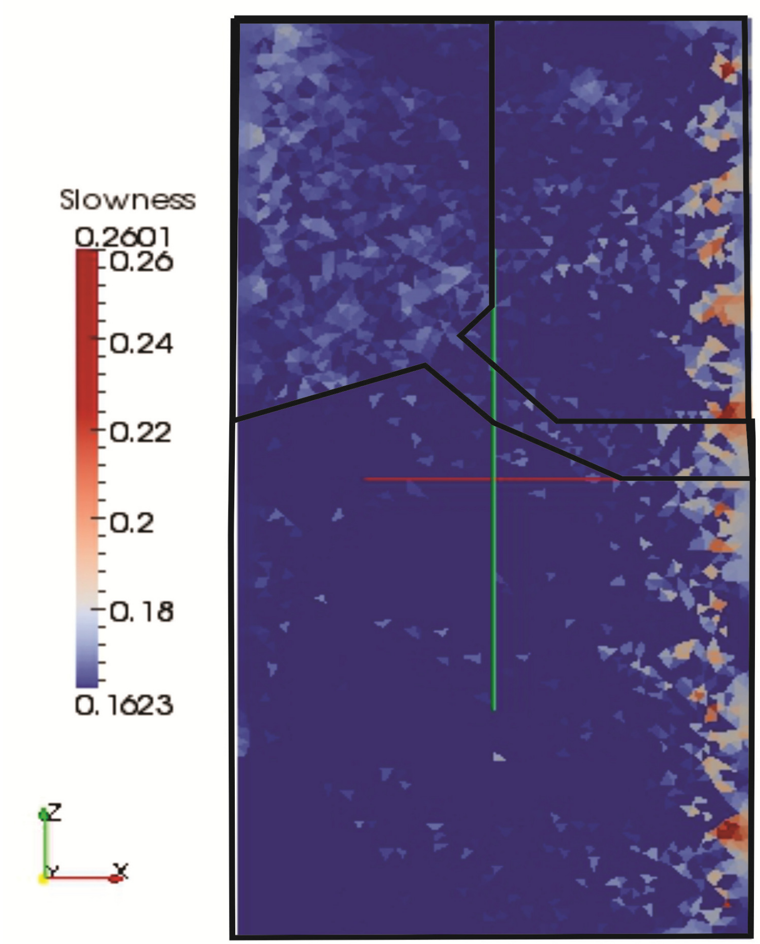
Joint Inversion of high noise data using a low similarity parameter, gravity data from surface stations only

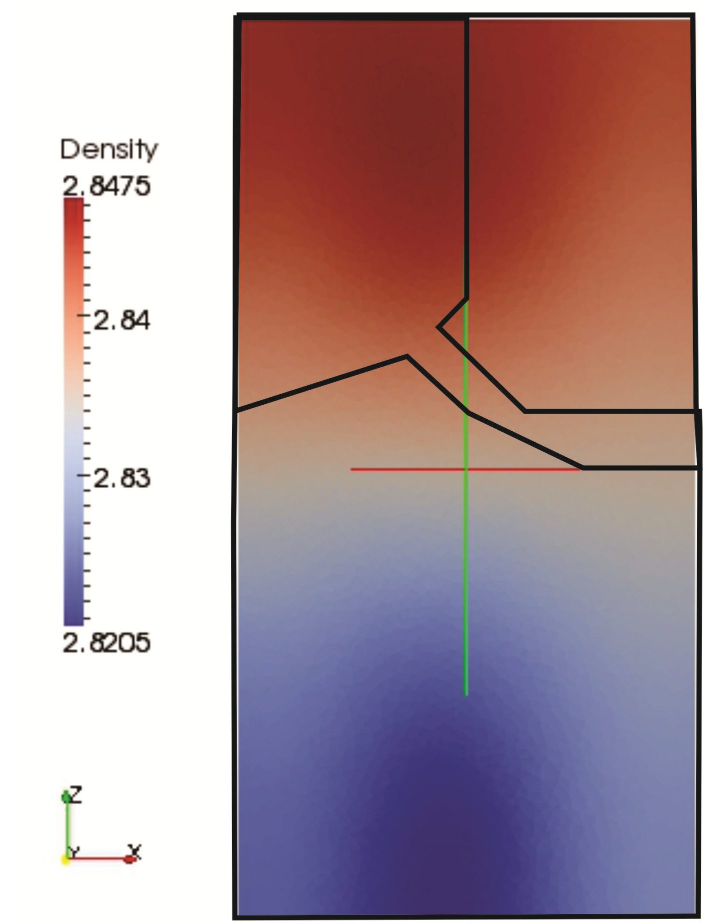
Example 3:
Effect of the Similarity Parameter



Joint Inversion of high noise data using a low similarity parameter, gravity data from surface stations only

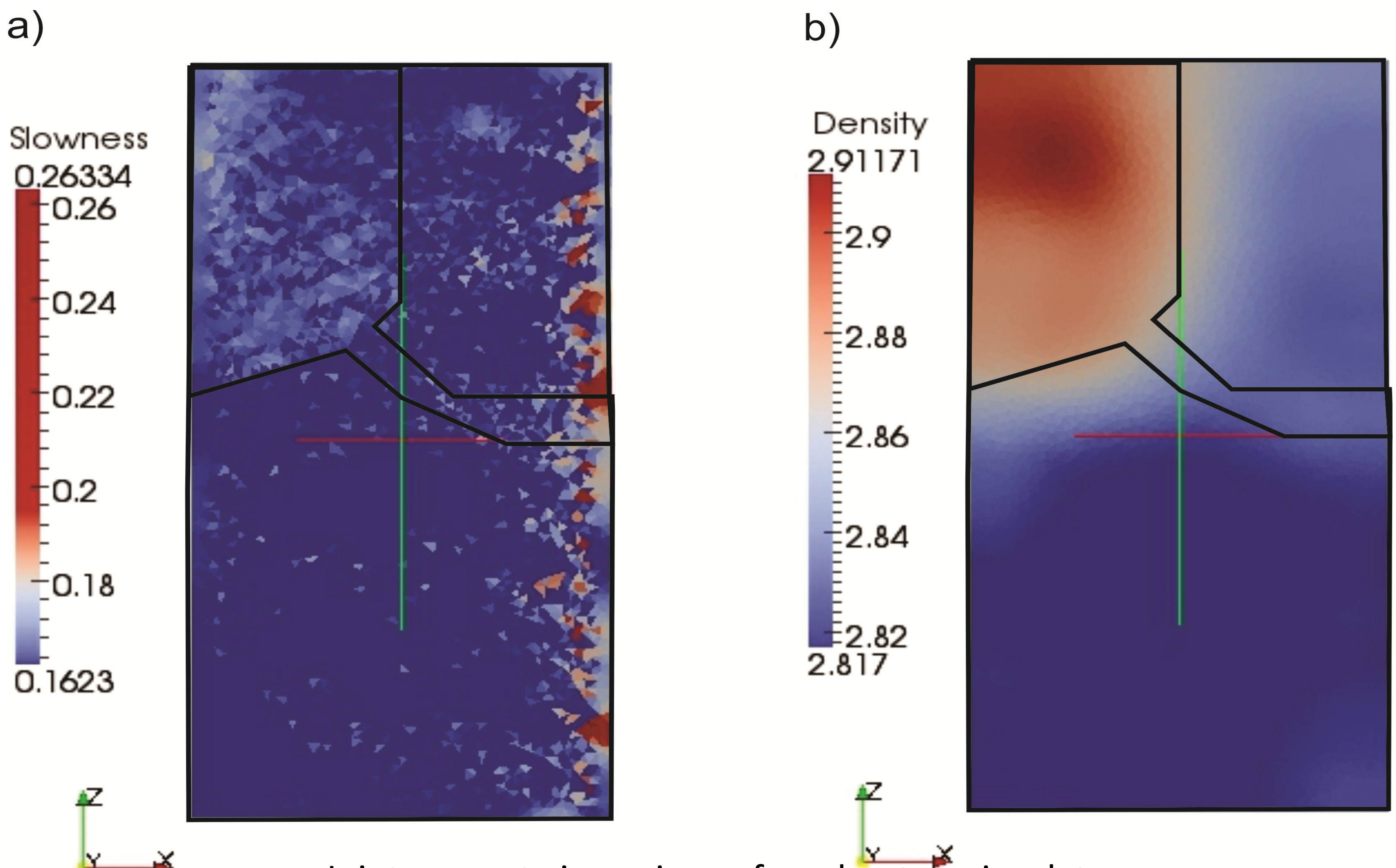
Example 4:
Modelling Small Physical Property Contrasts:





Single property inversions of moderate noise data

Example 4:
Modelling Small Physical Property Contrasts:

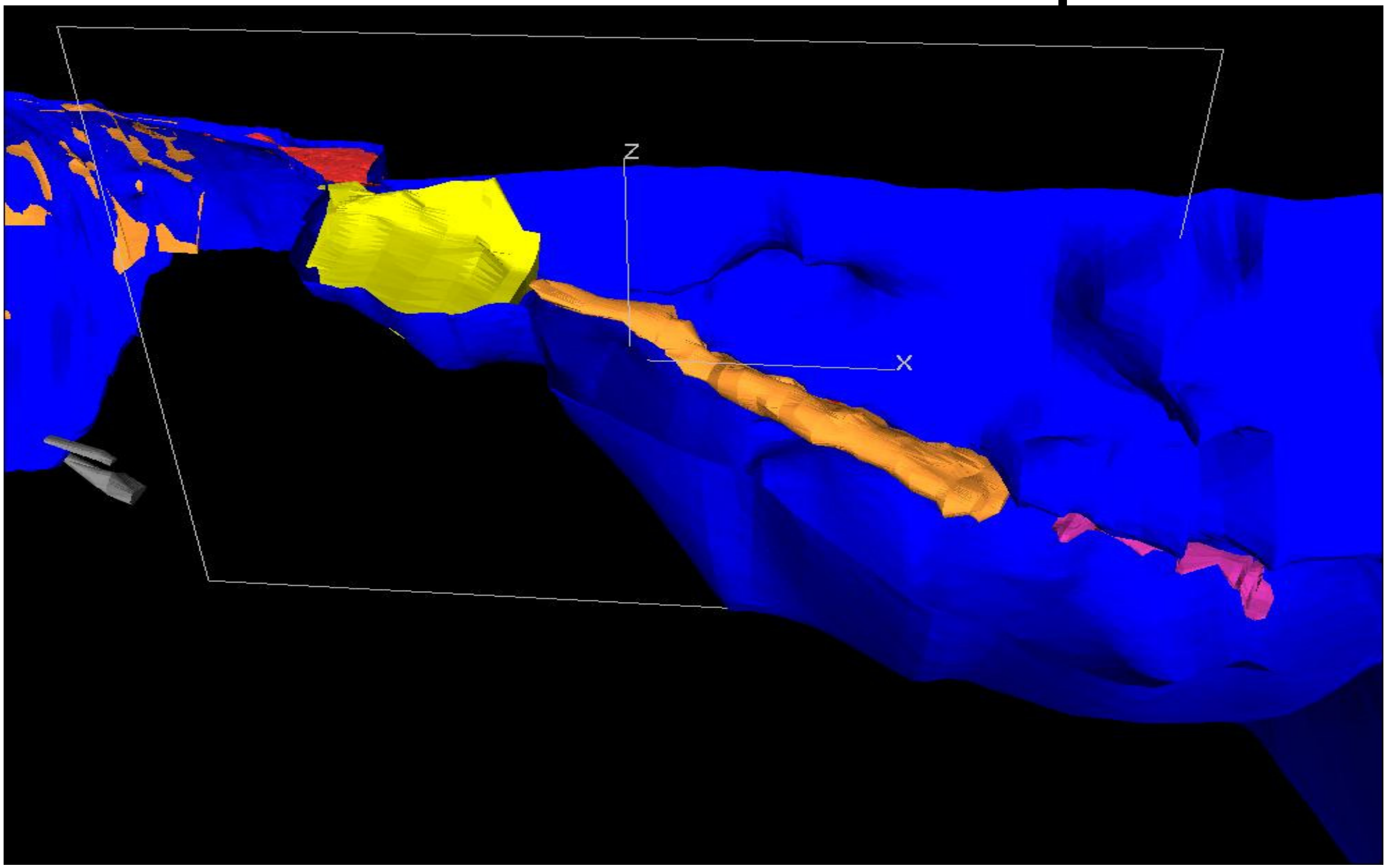


Joint property inversions of moderate noise data

Premise of Project: 3D Testing

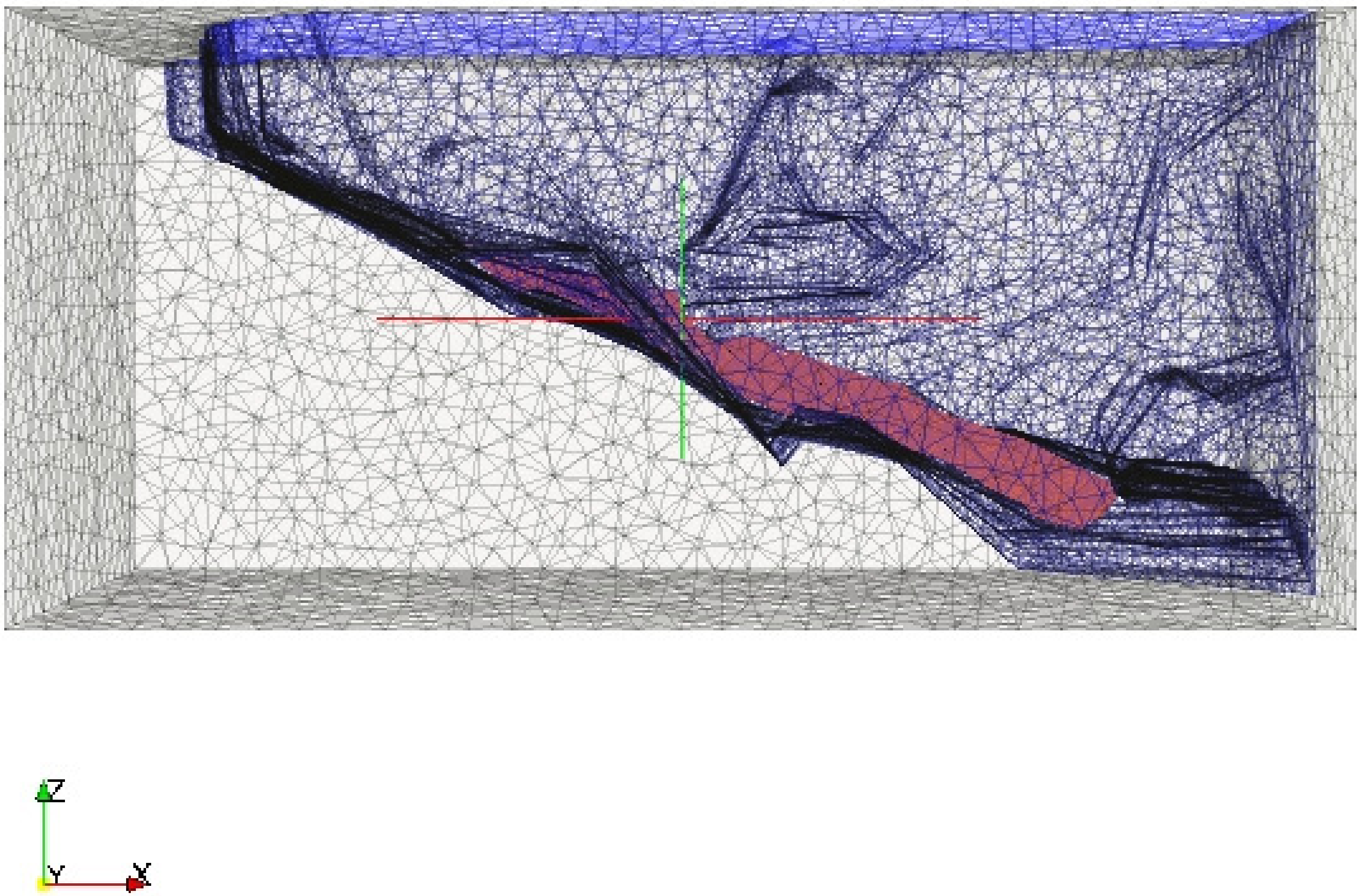
- To test the of the inversion code to model geology at the scale of a mine
- Determine the limitations on the size of inversions   due to CPU time and memory restrictions

3D Models: Eastern Deeps Model

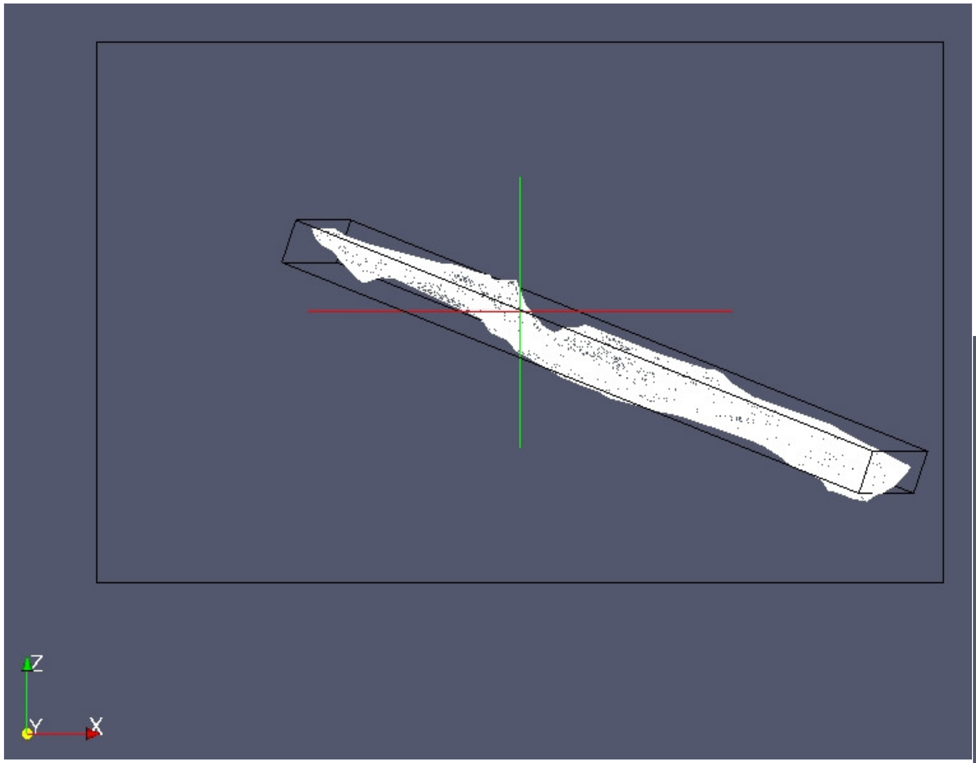


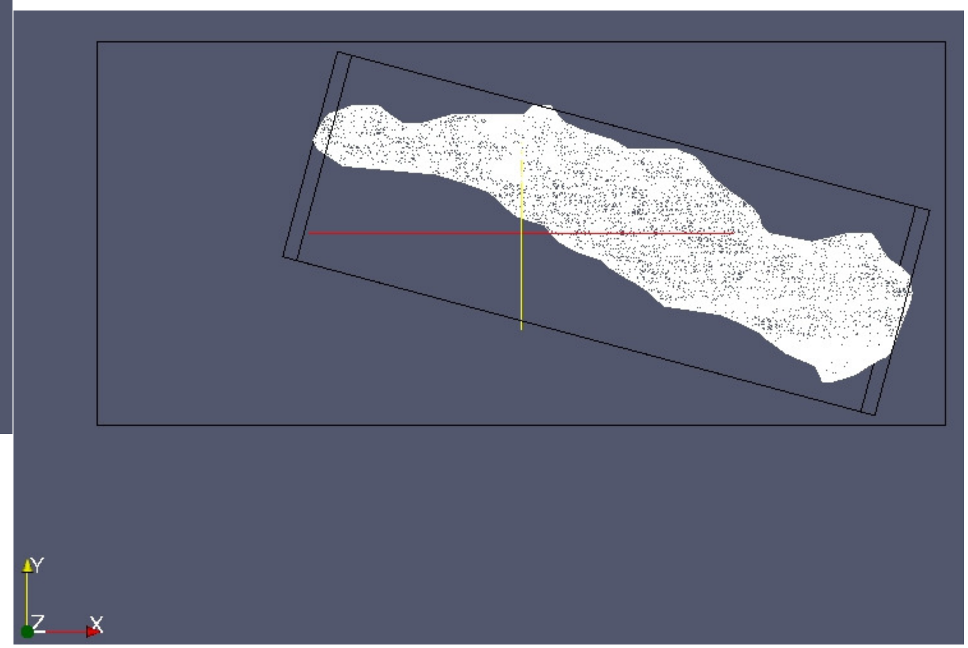
Tetrahedral model based on the Datamine model of the Eastern Deeps zone at Voisey's Bay

3D Models: Eastern Deeps Model



3D Models: Simplifying the Model



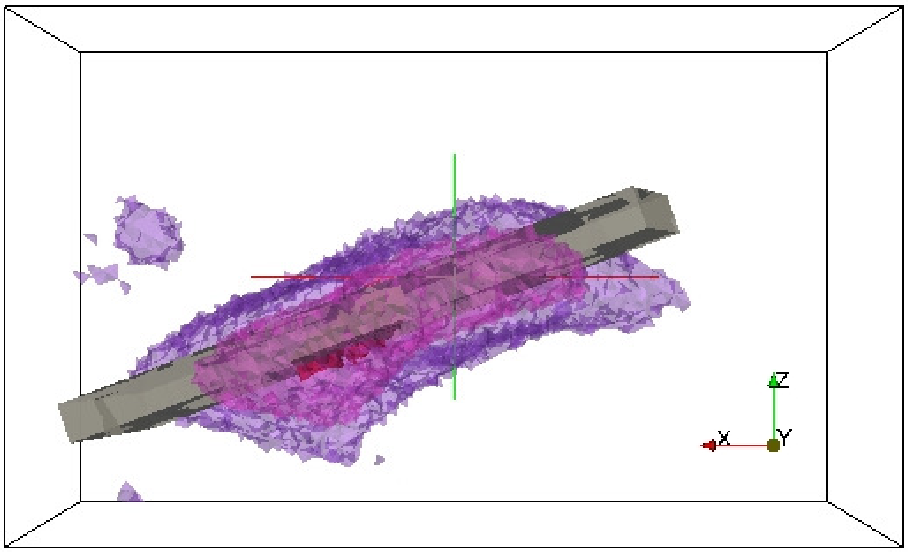


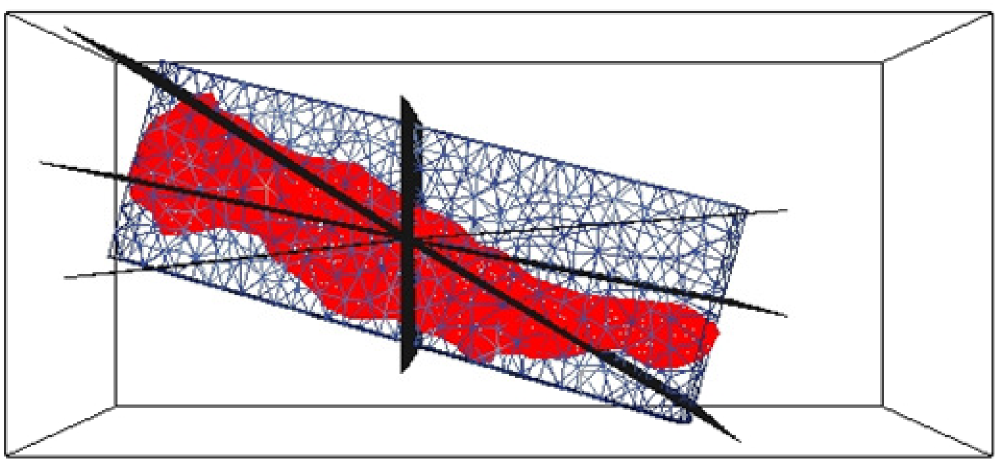
Block model based on Eastern Deeps model.
Used to run many of the 3D test inversions.

Challenges of 3D Joint Inversion

- Computationally expensive
- Matrix = num. cells x num. data
  - Refining a mesh increases number of cells
  - Amount of data restricts number of cells
- Coarse meshes
  - decreases the accuracy of forward modelling
  - affects ability to attain good inversion results
- Small Data Sets
  - Limits ability to resolve models well

Challenges of 3D Joint Inversion





Data Array

- Average Borehole Spacing: 680m
- Source/Receiver Spacing: 100m
- 12 Sources (1 borehole)
- 76 Receivers (8 boreholes)
- 1152 source-receiver pairs

Inversion Mesh

- Max. Cell Size: 10 000m^3
- Num. Cells: 411 300

Computational Requirements:

- Memory Usage: 3Gb Virtual Memory
- Cpu Time: 5 days 9hr 38min

Looking Forward

- 3D joint inversion
  - Gravity surface array (50m spacing) and borehole gravity from a single borehole
  - Simple ‘starburst’ seismic tomography source/receiver configuration
  - Mesh of no more than 500 000 cells

Conclusions

- 2D inversion is a viable means of testing the abilities of a joint inversion code
- This joint inversion was successfully able to:
  - model a buried body
  - model a body with a small physical property contrast
  - model a body well with only borehole gravity stations
- 3D joint inversion at mine presents challenges in terms of computational requirements
  - compromises can be made to allow for good results to be attained

Acknowledgements

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- Vale
- Atlantic Canada Opportunities Association
- School of Graduate Studies