Constrained inversion of gravity and magnetic data: a real time exploration tool?

Hugh Miller
Michael R. Ash
Michael Wheeler
Colin G. Farquharson

Department of Earth Sciences
Memorial University of Newfoundland, and
Inco Innovation Centre

MEMORIAL UNIVERSITY

Objectives

- To invert potential field data from the Voisey's Bay project to produce three-dimensional density and susceptibility models of the region containing the ore bodies located at Voisey's Bay

- Gravity
  - Role data collection
  - Examine basic parameters commonly used in Grav3D (UBC-GIF)
  - Test methods of constraining gravity inversion

- Magnetics
  - Examine preliminary inversions using UBC inversion codes

Outline

- Physical Property Data
- Density Model Construction
- Gravity Data
- Forward Models
- Unconstrained Gravity Inversion
- Constrained Gravity Inversion
  - Regional models
  - Kriging models
- Magnetic Data and Magnetic Inversions

MEMORIAL UNIVERSITY

Physical Property Data

Name	Density (g/cc)						Susceptibility (SI) x 10 $^{-3}$		
	Count	Mean	Std. Dev.	Var	Min	Max	Mean	Min	Max
Enderbitic gneiss (ENGN)	2340	2.81	0.07	0.01	2.60	3.02	1.43	1.14	1.98
Massive Sulphide (MASU)	5222	4.61	0.11	0.01	4.00	5.13	12.1	12.1	14.2
Troctolite (TR)	4317	3.18	0.026	0.07	2.61	4.15	9.16	0.07	15.5

- Density data
  - Derived from the regression of geochemical data (provided by VBNC)
  - Drill separation ~50m and sample spacing ~2m

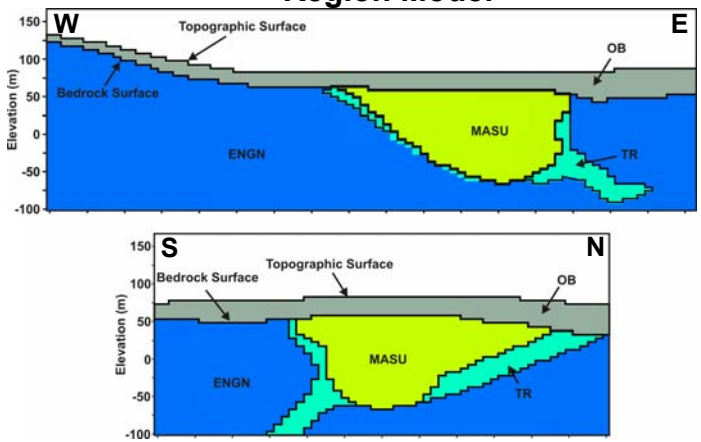
- Magnetic susceptibility data
  - Over 500 core samples collected (14 sample the Ovoid)
  - Susceptibilities were measured using a standard AC bridge susceptibility meter and a DC process to remove the effect of induced magnetic fields

MEMORIAL UNIVERSITY

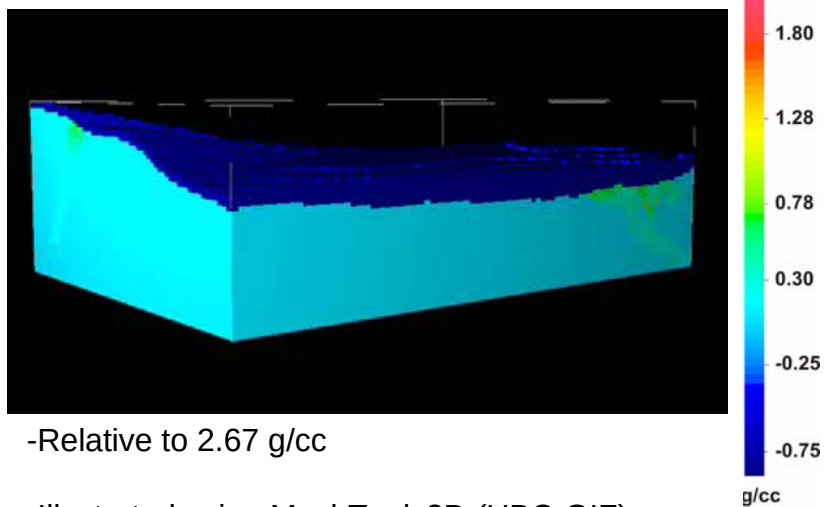
Density Model Construction

- Regions were generated in Gocad using the surfaces and wireframes provided by VBNC
  - Model 1: Regional Model
    - OB → 1.92 g/cc
    - ENGN → 2.81 g/cc
  - Model 2: Kriged Model
    - MASU and TR → Kriging
  - Model 3: Decimated Model
    - ENGN, MASU and TR → Kriging (25%)

Region Model



Kriged Model



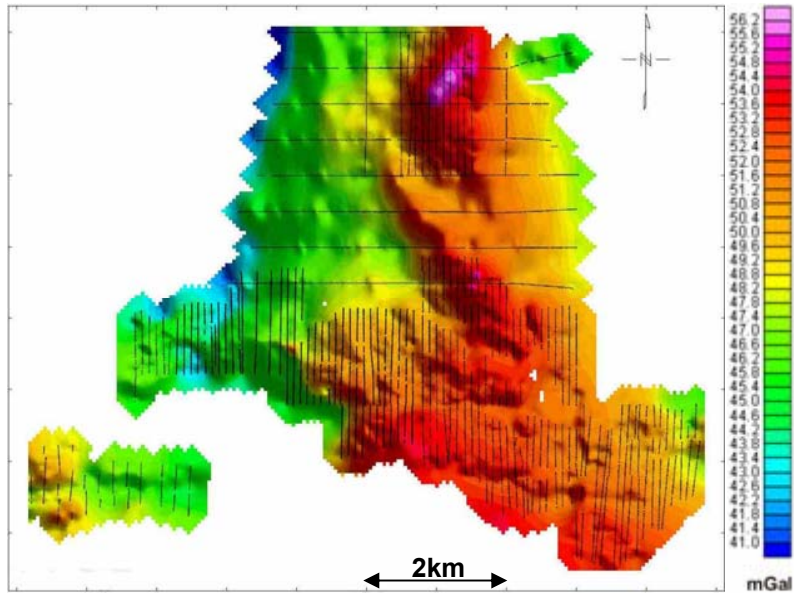
-Relative to 2.67 g/cc

-Illustrated using MeshTools3D (UBC-GIF)

MEMORIAL UNIVERSITY

Gravity Data

- The gravity data were collected along 105 lines
  - Line spacing ranges from 200m to 1000m
  - Station spacing ranges from 25m to 50m



- Only 3 lines were collected over the Ovoid
  - Station Spacing ~25m
  - Line Spacing ~200m

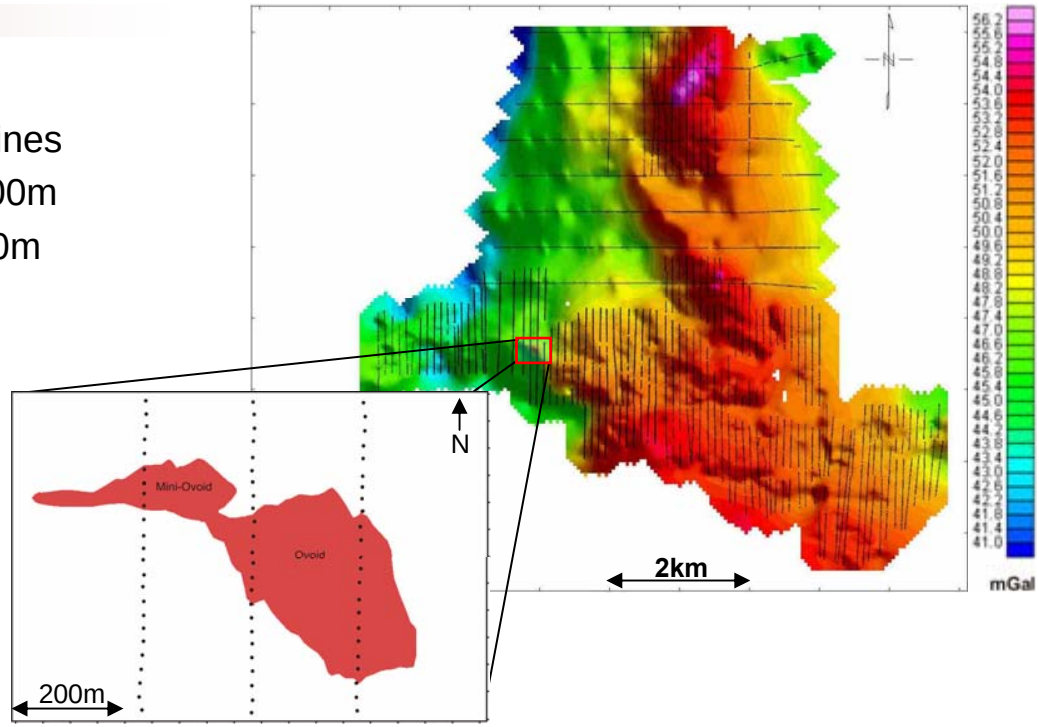
- Regional field was calculated using standard upward continuation methods
  - The residual field was calculated by vertically projecting (Gocad) the regional field to the observation locations

MEMORIAL UNIVERSITY

Gravity Data

- The gravity data were collected along 105 lines
  - Line spacing ranges from 200m to 1000m
  - Station spacing ranges from 25m to 50m

- Only 3 lines were collected over the Ovoid
  - Station Spacing ~25m
  - Line Spacing ~200m



- Regional field was calculated using standard upward continuation methods
  - The residual field was calculated by vertically projecting (Gocad) the regional field to the observation locations

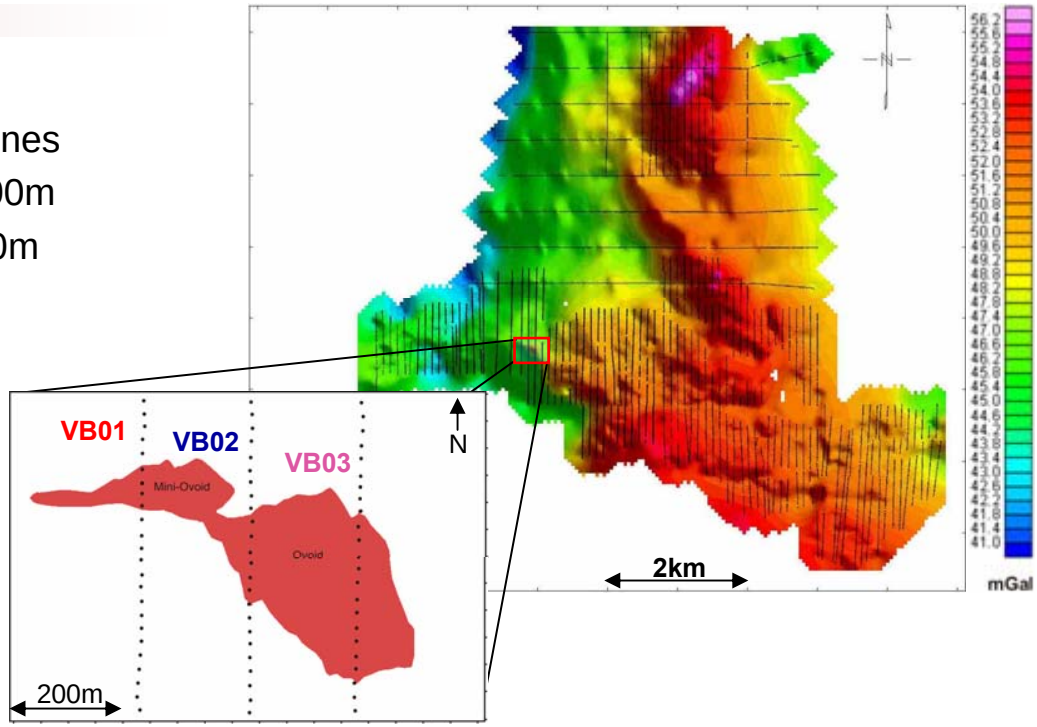
MEMORIAL UNIVERSITY

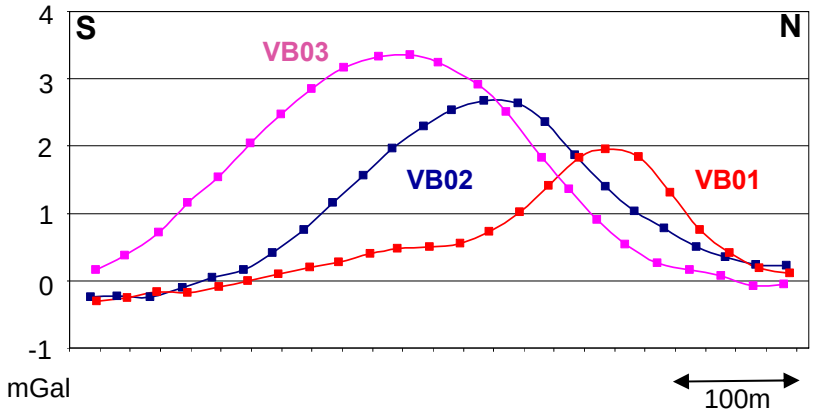
Gravity Data

- The gravity data were collected along 105 lines
  - Line spacing ranges from 200m to 1000m
  - Station spacing ranges from 25m to 50m

- Only 3 lines were collected over the Ovoid
  - Station Spacing ~25m
  - Line Spacing ~200m

- Regional field was calculated using standard upward continuation methods
  - The residual field was calculated by vertically projecting (Gocad) the regional field to the observation locations



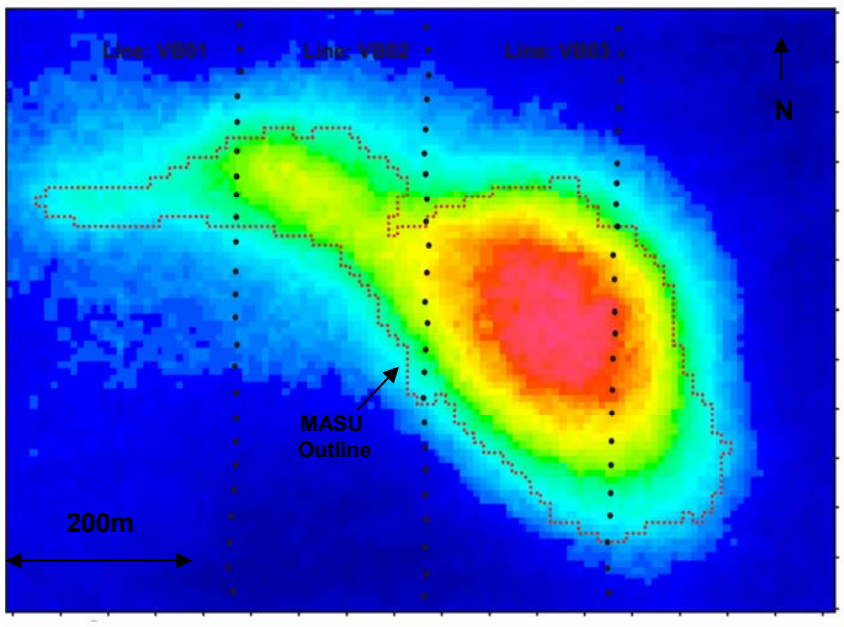


MEMORIAL UNIVERSITY

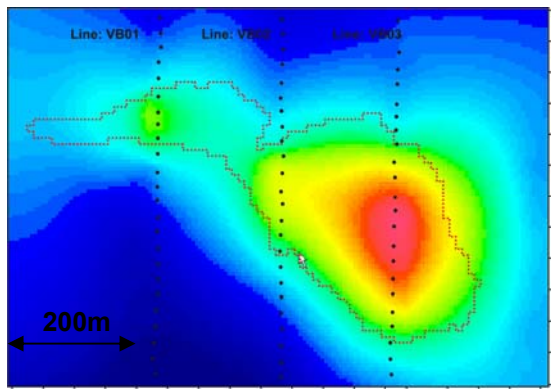
Forward Model

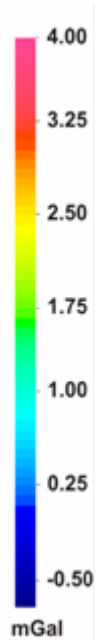
- A forward model (FM) was calculated from the kriged density model using gzfor3d (UBC-GIF)
- A visible offset is observed between the maximum amplitude and position of the survey lines
  - Offset is ~70m west

Calculated Gravity Field



Residual Data (50m x 50m Grid)



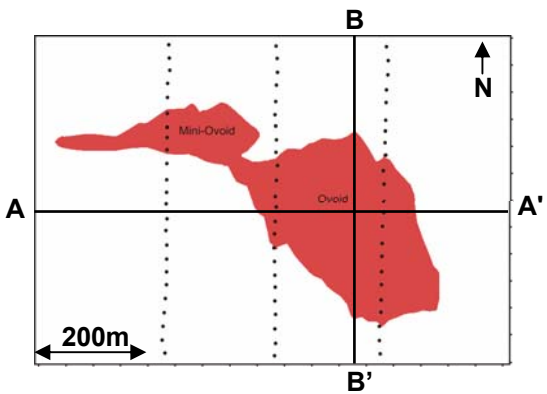


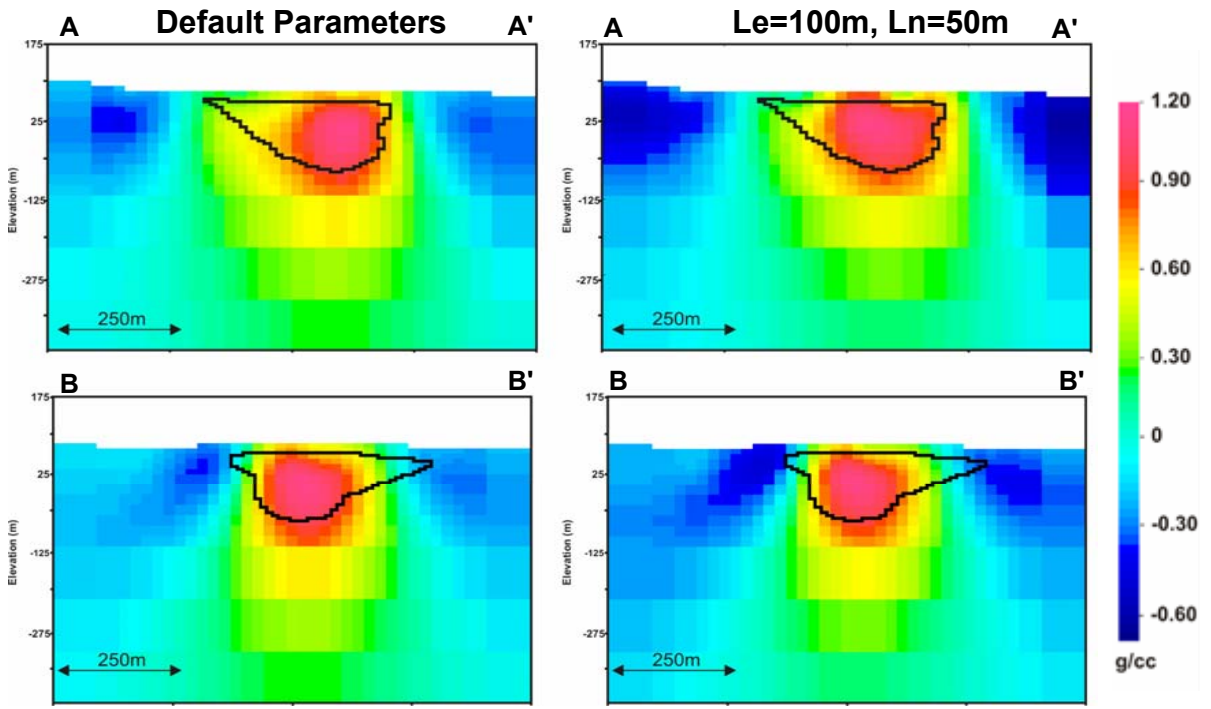
-Gridding is a constraint!

MEMORIAL UNIVERSITY

Unconstrained Inversion

- The UBC-GIF codes were used to invert the residual dataset



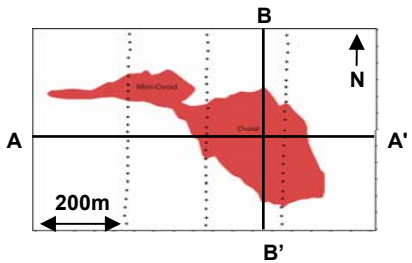


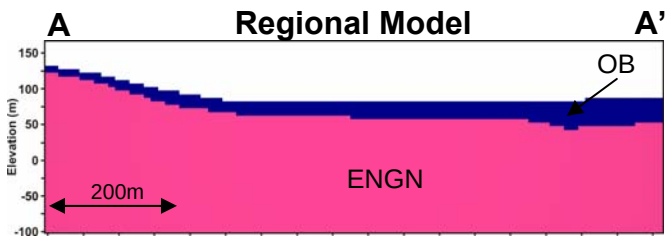
MEMORIAL UNIVERSITY

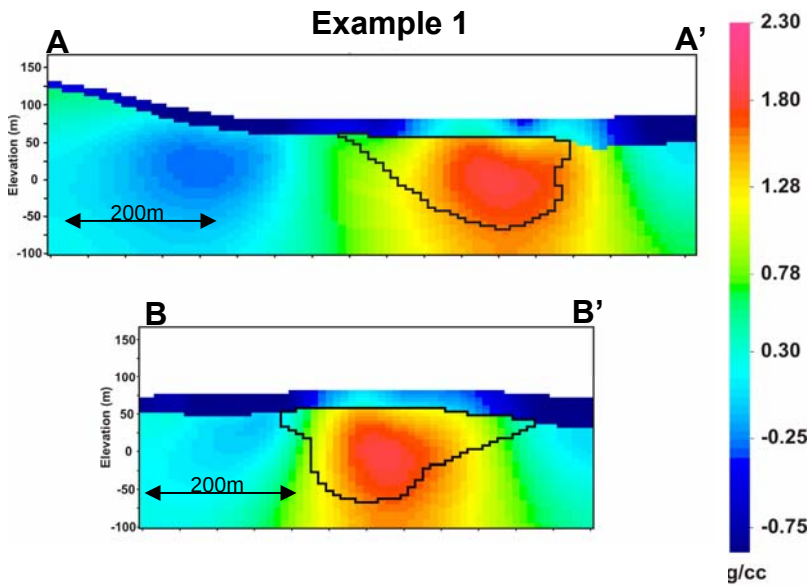
Constrained Inversion: Two Layer Regional Model

•A two layer regional model was incorporated into the inversion process

- •Example 1:Reference Model \ Initial Model
- •Example 2: Weighting Model





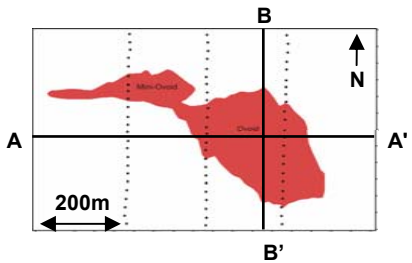


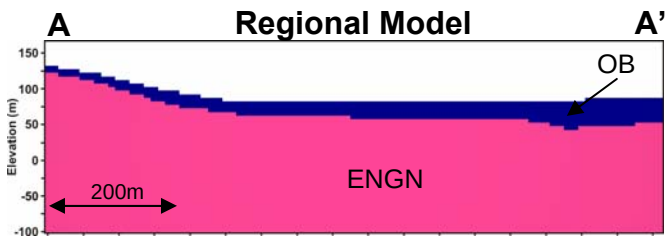
MEMORIAL UNIVERSITY

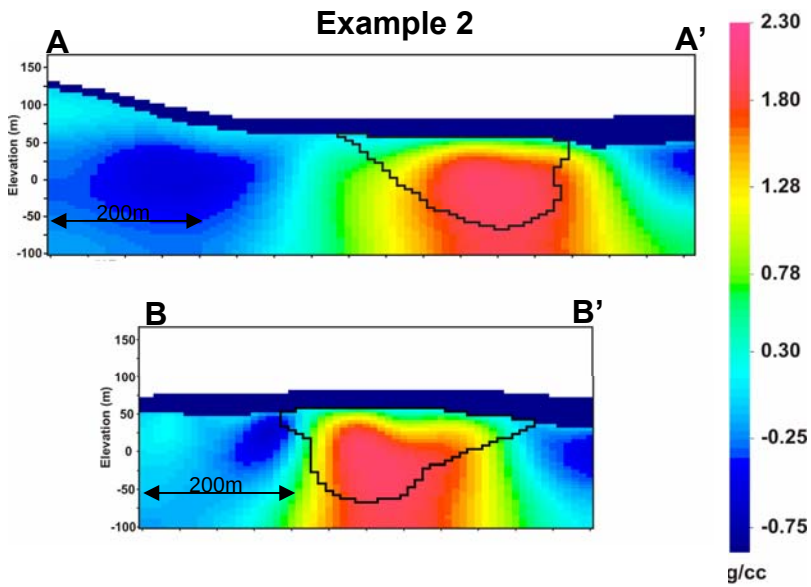
Constrained Inversion: Two Layer Regional Model

•A two layer regional model was incorporated into the inversion process

- •Example 1: Reference Model \ Initial Model
- •Example 2: Weighting Model







MEMORIAL UNIVERSITY

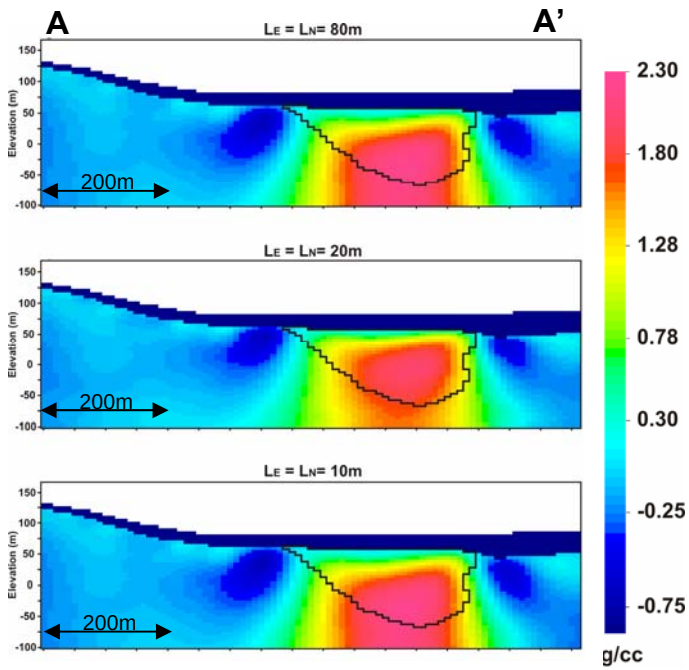
Constrained Inversion: Two Layer Regional Model

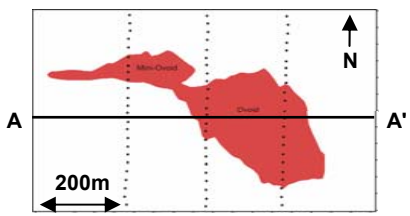
•The UBC-GIF codes were used to invert the FM dataset

•Le and Ln → Smoothing in the horizontal direction

•Lv length scale → Smoothing in the vertical direction

•Beta → Anomaly depth





MEMORIAL UNIVERSITY

Constrained Inversion: Two Layer Regional Model

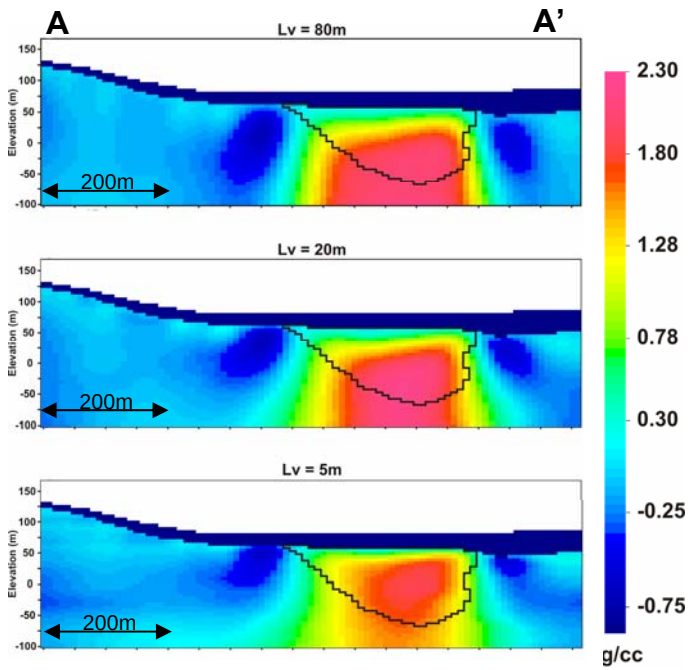
•The UBC-GIF codes were used to invert the FM dataset

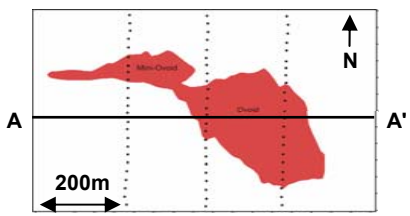
•The length scales (Le, Ln and Lv) and depth weighing parameters (beta) have a major influence on the recovered models

•Le and Ln → Smoothing in the horizontal direction

•Lv length scale → Smoothing in the vertical direction

•Beta → Anomaly depth





MEMORIAL UNIVERSITY

Constrained Inversion: Two Layer Regional Model

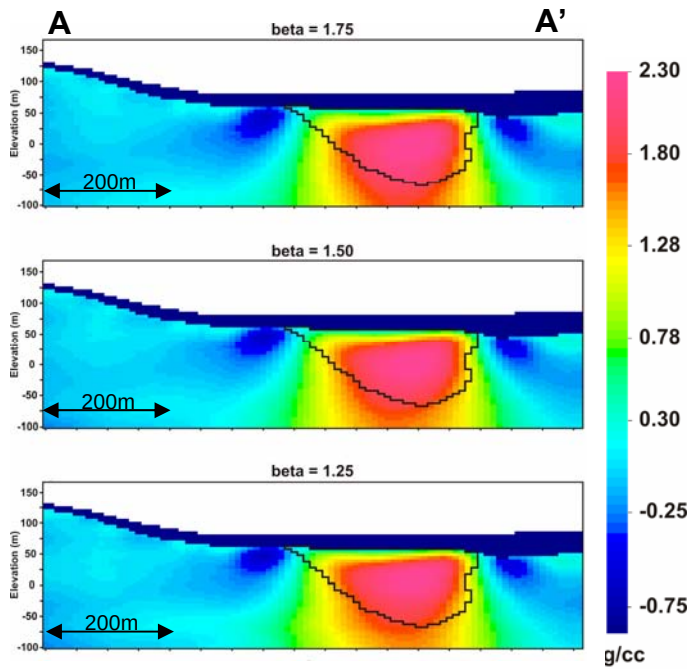
•The UBC-GIF codes were used to invert the FM dataset

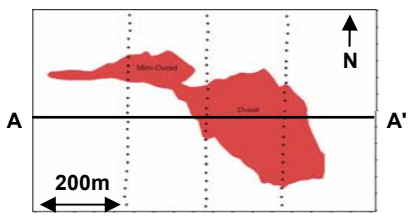
•The length scales (Le, Ln and Lv) and depth weighing parameters (beta) have a major influence on the recovered models

•Le and Ln → Smoothing in the horizontal direction

•Lv length scale → Smoothing in the vertical direction

•Beta → Anomaly depth

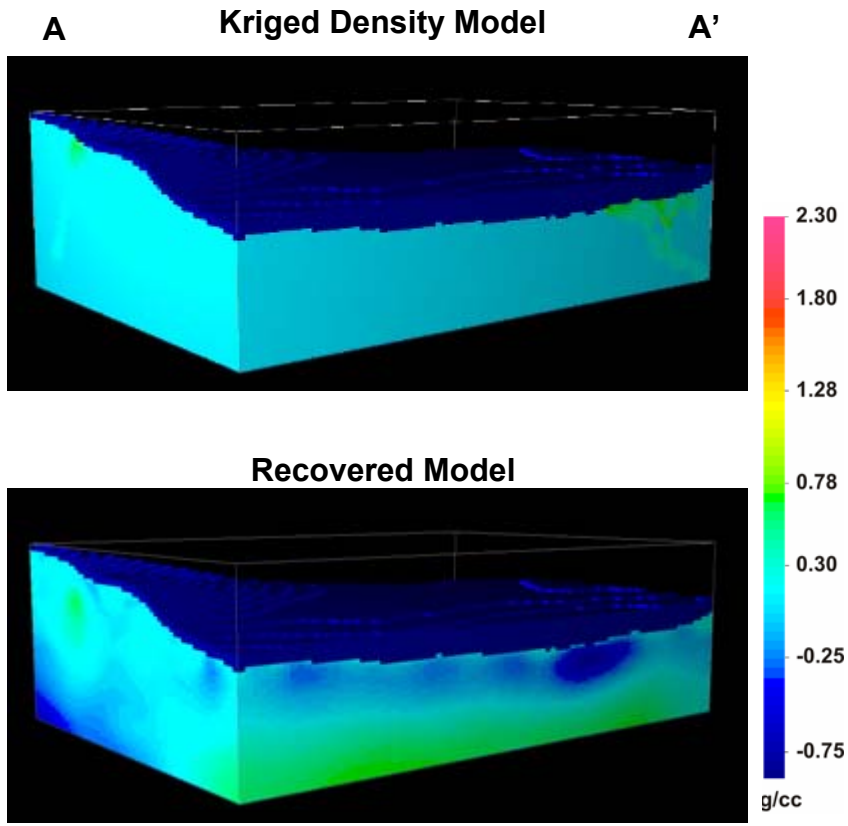


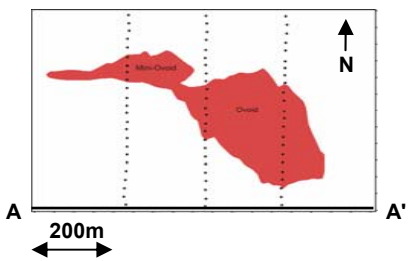


MEMORIAL UNIVERSITY

Constrained Inversion: Two Layer Regional Model

- The FM data was inverted using
  - Le, Ln, Lv → 20m, 20m, 5m
  - Beta → 1.50
- Constrained
  - Regional model
  - Weighted model
- Result: The recovered density anomaly has a amplitude and a density distribution which compares favorably with the kriged model

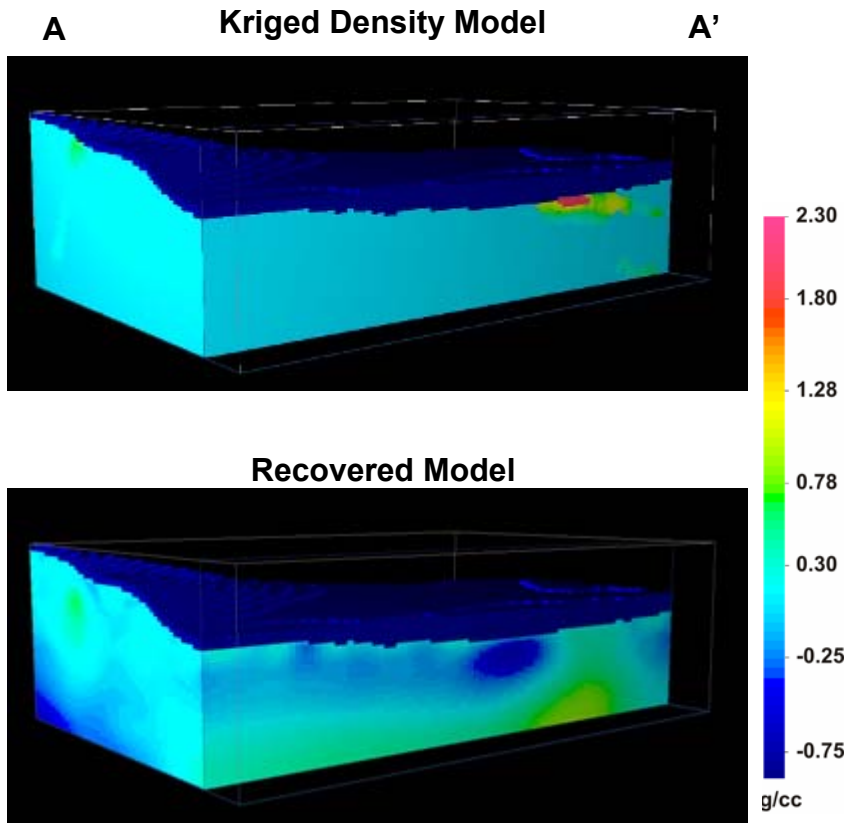


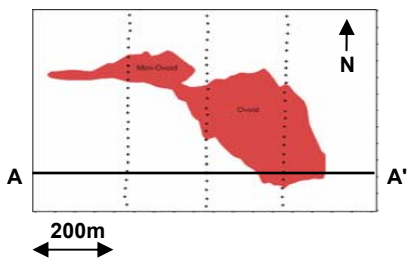


MEMORIAL UNIVERSITY

Constrained Inversion: Two Layer Regional Model

- The FM data was inverted using
  - Le, Ln, Lv → 20m, 20m, 5m
  - Beta → 1.50
- Constrained
  - Regional model
  - Weighted model
- Result: The recovered density anomaly has a amplitude and a density distribution which compares favorably with the kriged model

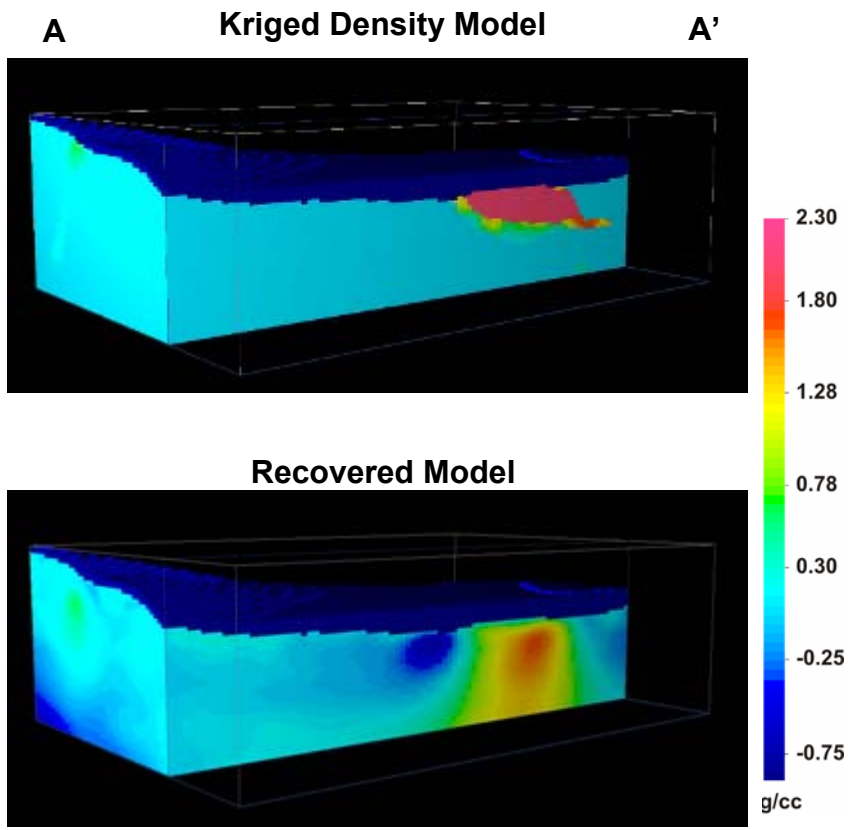


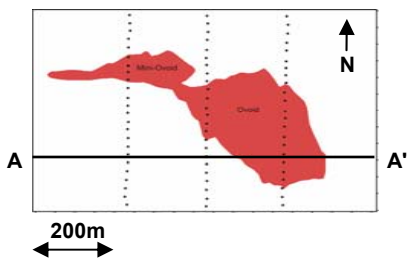


MEMORIAL UNIVERSITY

Constrained Inversion: Two Layer Regional Model

- The FM data was inverted using
  - Le, Ln, Lv → 20m, 20m, 5m
  - Beta → 1.50
- Constrained
  - Regional model
  - Weighted model
- Result: The recovered density anomaly has a amplitude and a density distribution which compares favorably with the kriged model

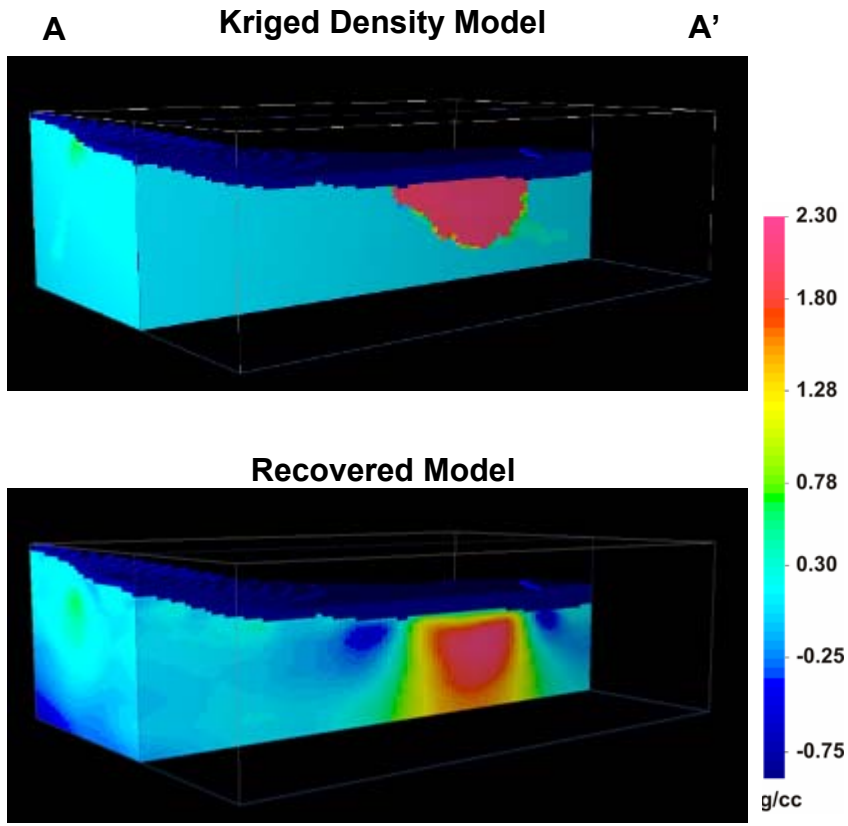


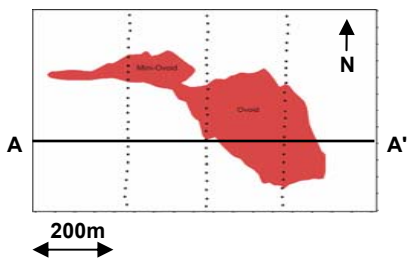


MEMORIAL UNIVERSITY

Constrained Inversion: Two Layer Regional Model

- The FM data was inverted using
  - Le, Ln, Lv → 20m, 20m, 5m
  - Beta → 1.50
- Constrained
  - Regional model
  - Weighted model
- Result: The recovered density anomaly has a amplitude and a density distribution which compares favorably with the kriged model

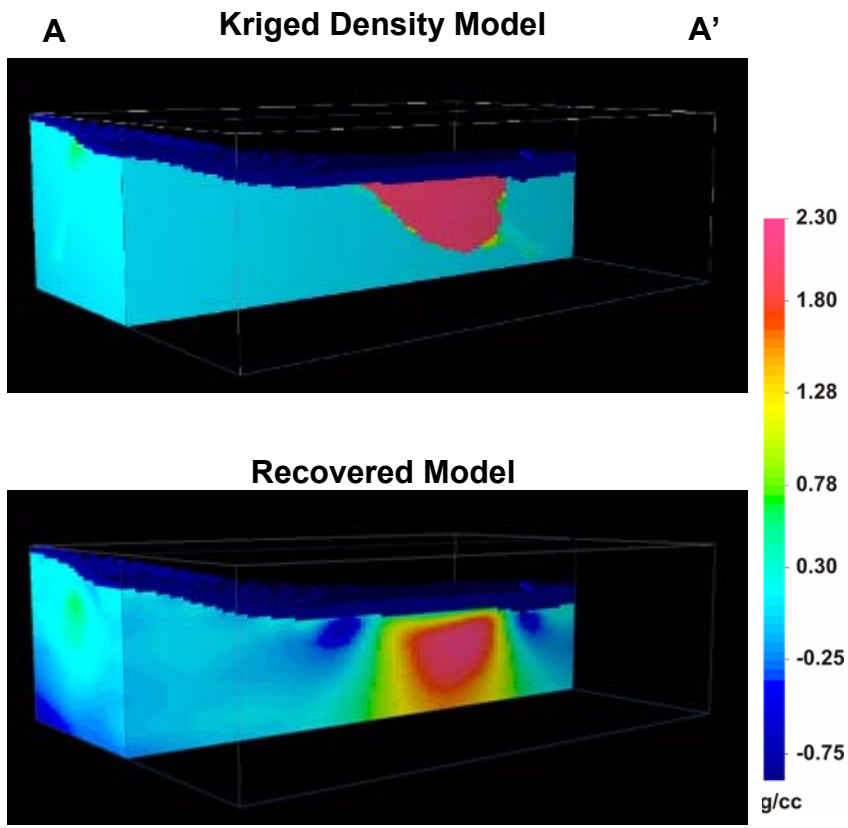


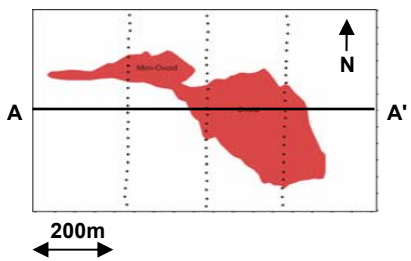


MEMORIAL UNIVERSITY

Constrained Inversion: Two Layer Regional Model

- The FM data was inverted using
  - Le, Ln, Lv → 20m, 20m, 5m
  - Beta → 1.50
- Constrained
  - Regional model
  - Weighted model
- Result: The recovered density anomaly has a amplitude and a density distribution which compares favorably with the kriged model

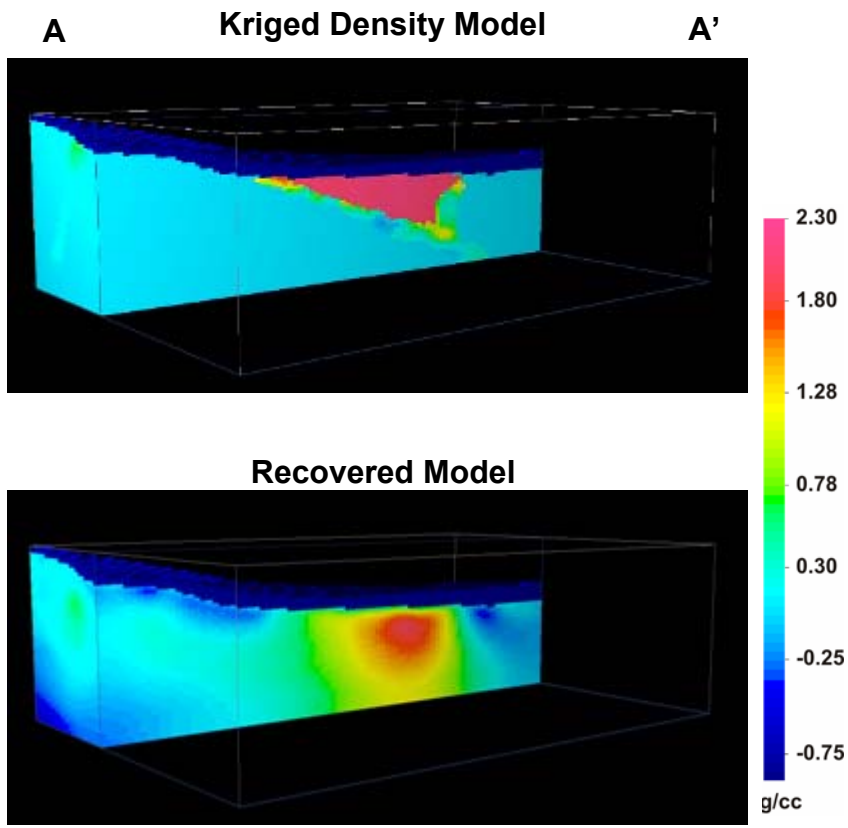


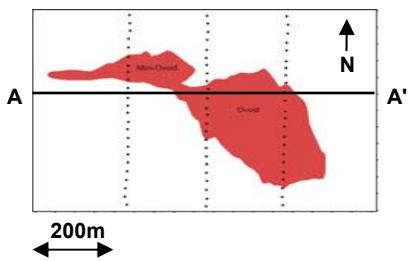


MEMORIAL UNIVERSITY

Constrained Inversion: Two Layer Regional Model

- The FM data was inverted using
  - Le, Ln, Lv → 20m, 20m, 5m
  - Beta → 1.50
- Constrained
  - Regional model
  - Weighted model
- Result: The recovered density anomaly has a amplitude and a density distribution which compares favorably with the kriged model

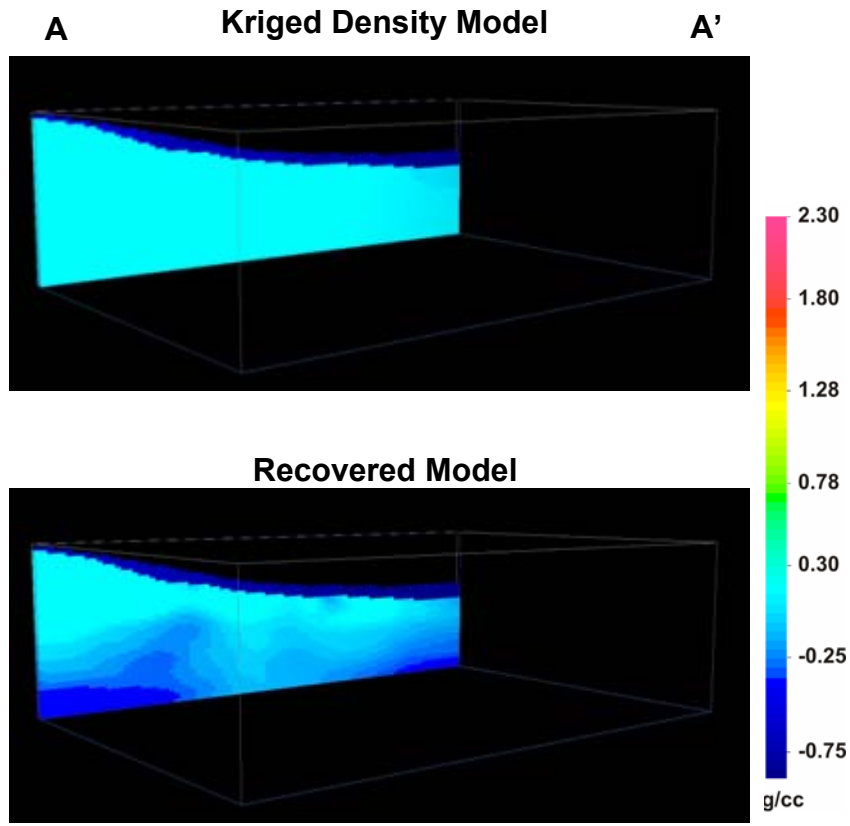


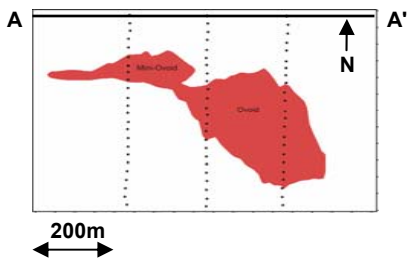


MEMORIAL UNIVERSITY

Constrained Inversion: Two Layer Regional Model

- The FM data was inverted using
  - Le, Ln, Lv → 20m, 20m, 5m
  - Beta → 1.50
- Constrained
  - Regional model
  - Weighted model
- Result: The recovered density anomaly has a amplitude and a density distribution which compares favorably with the kriged model

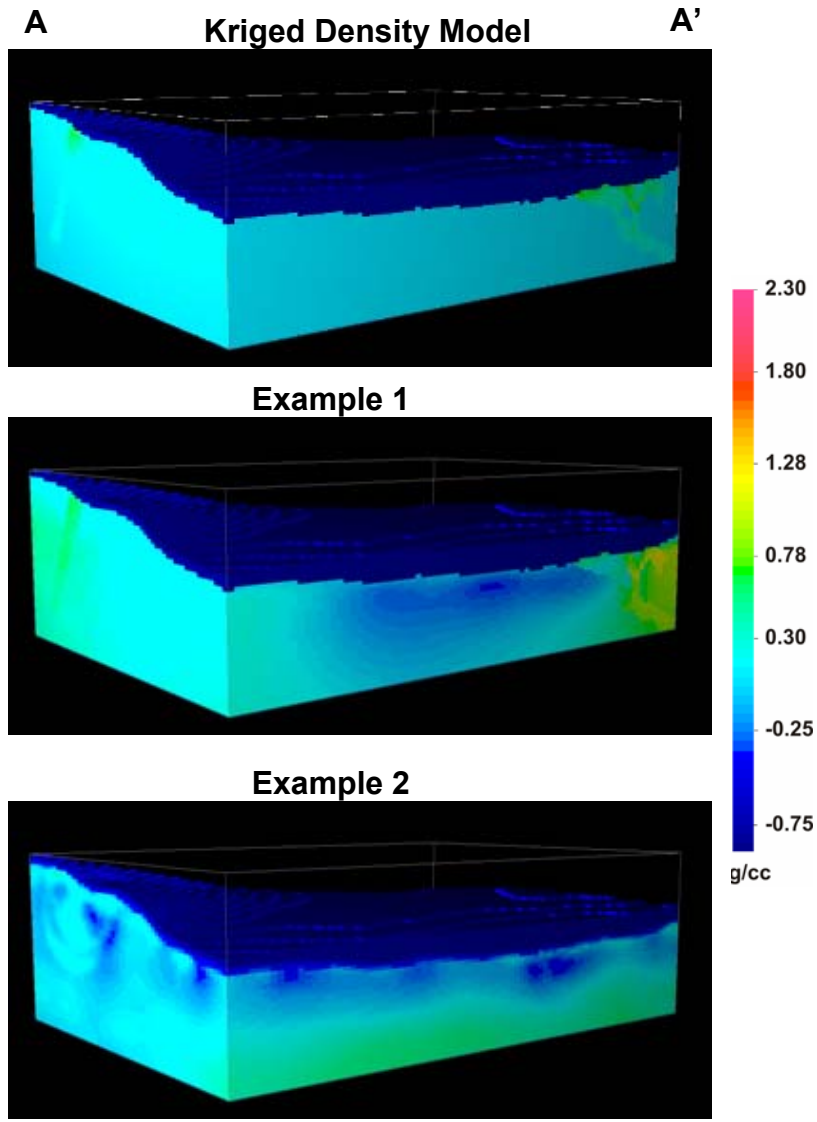


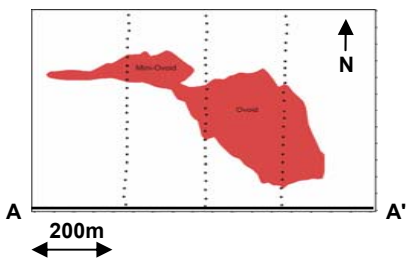


MEMORIAL UNIVERSITY

Constrained Inversion: Kriged Density Model

- Example 1:
  - Residual data
  - The kriged density model was used as the reference model
- Example 2:
  - FM data
  - A reference model was created using 25% of the drill logs



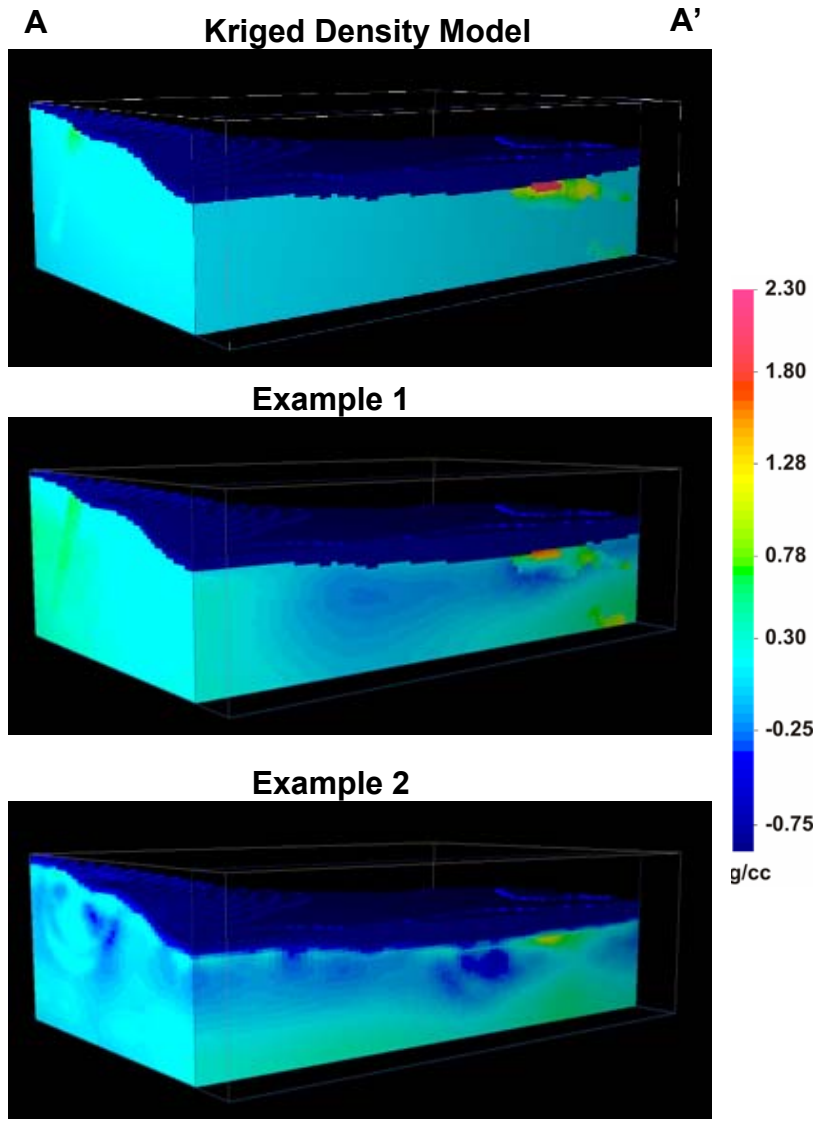


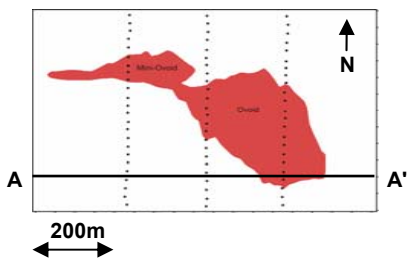
MEMORIAL UNIVERSITY

Constrained Inversion: Kriged Density Model

- Example 1:
  - Residual data
  - The kriged density model was used as the reference model

- Example 2:
  - FM data
  - A reference model was created using 25% of the drill logs



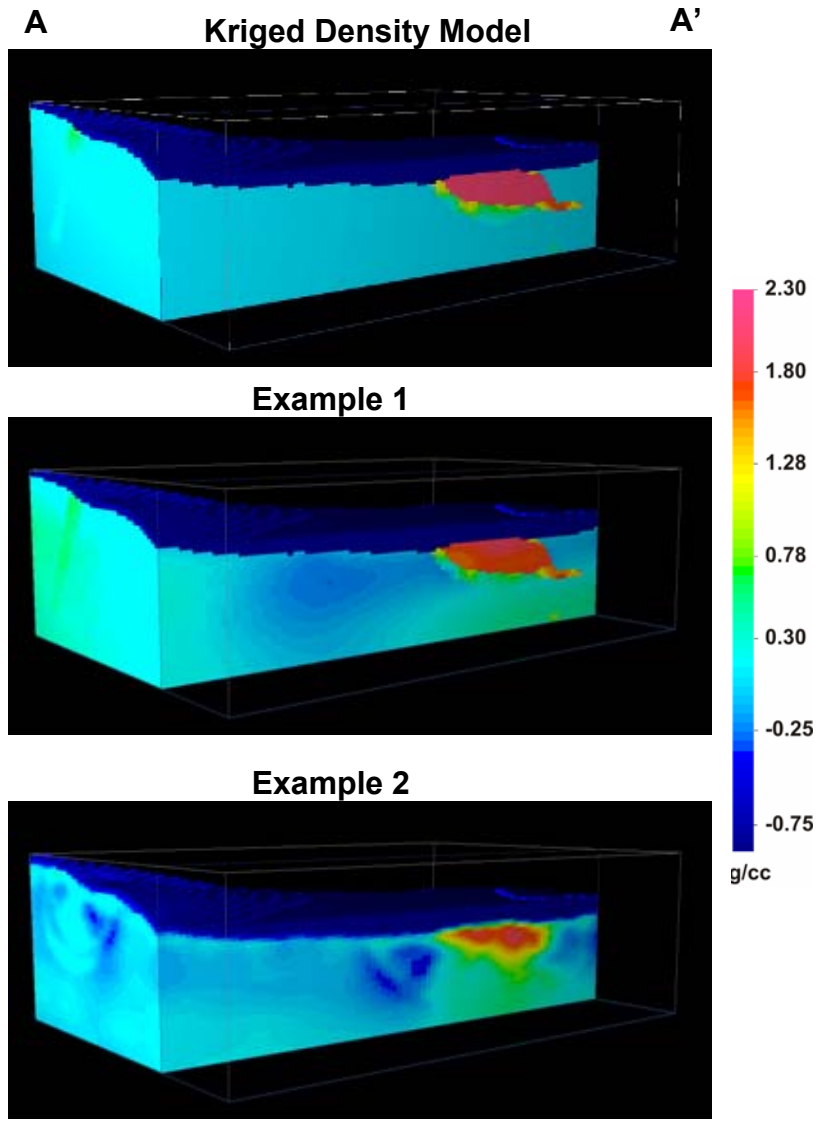


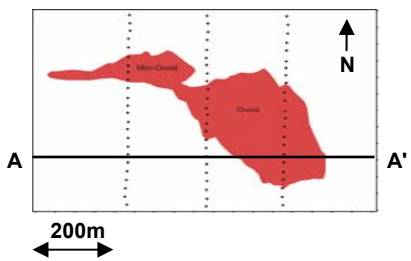
MEMORIAL UNIVERSITY

Constrained Inversion: Kriged Density Model

- Example 1:
  - Residual data
  - The kriged density model was used as the reference model

- Example 2:
  - FM data
  - A reference model was created using 25% of the drill logs

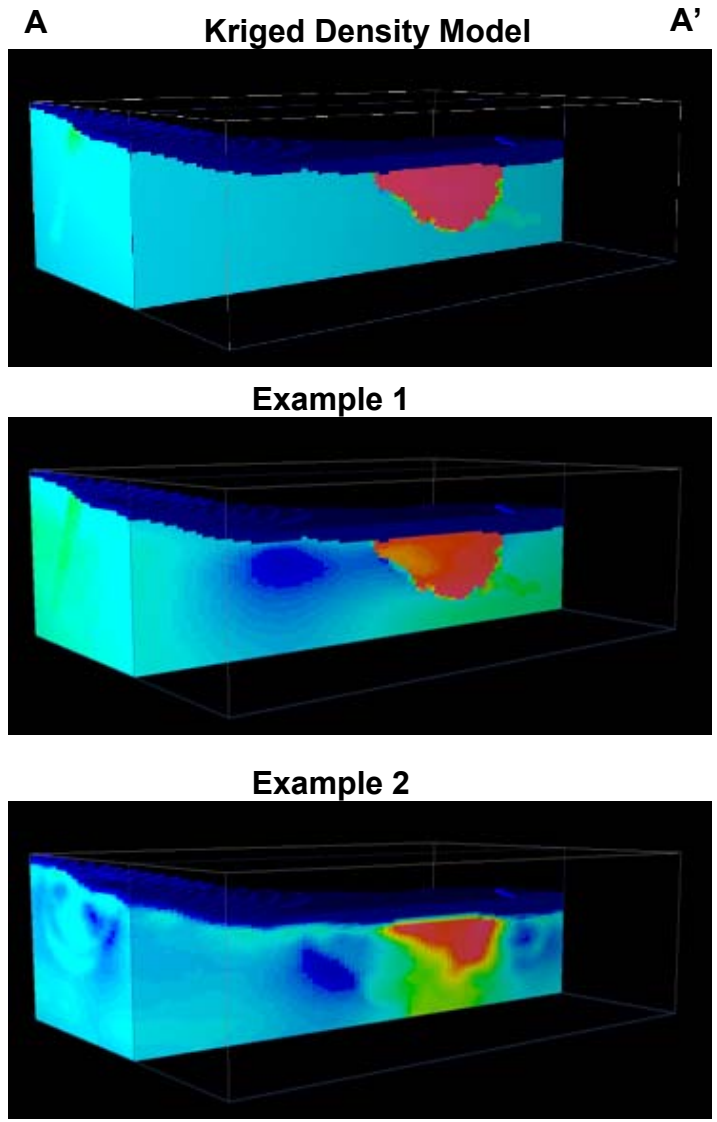


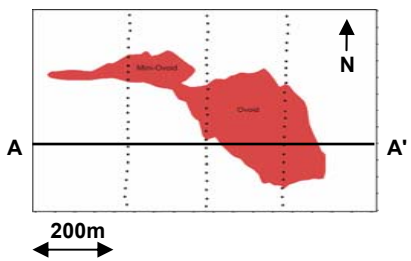


MEMORIAL UNIVERSITY

Constrained Inversion: Kriged Density Model

- Example 1:
  - Residual data
  - The kriged density model was used as the reference model
- Example 2:
  - FM data
  - A reference model was created using 25% of the drill logs

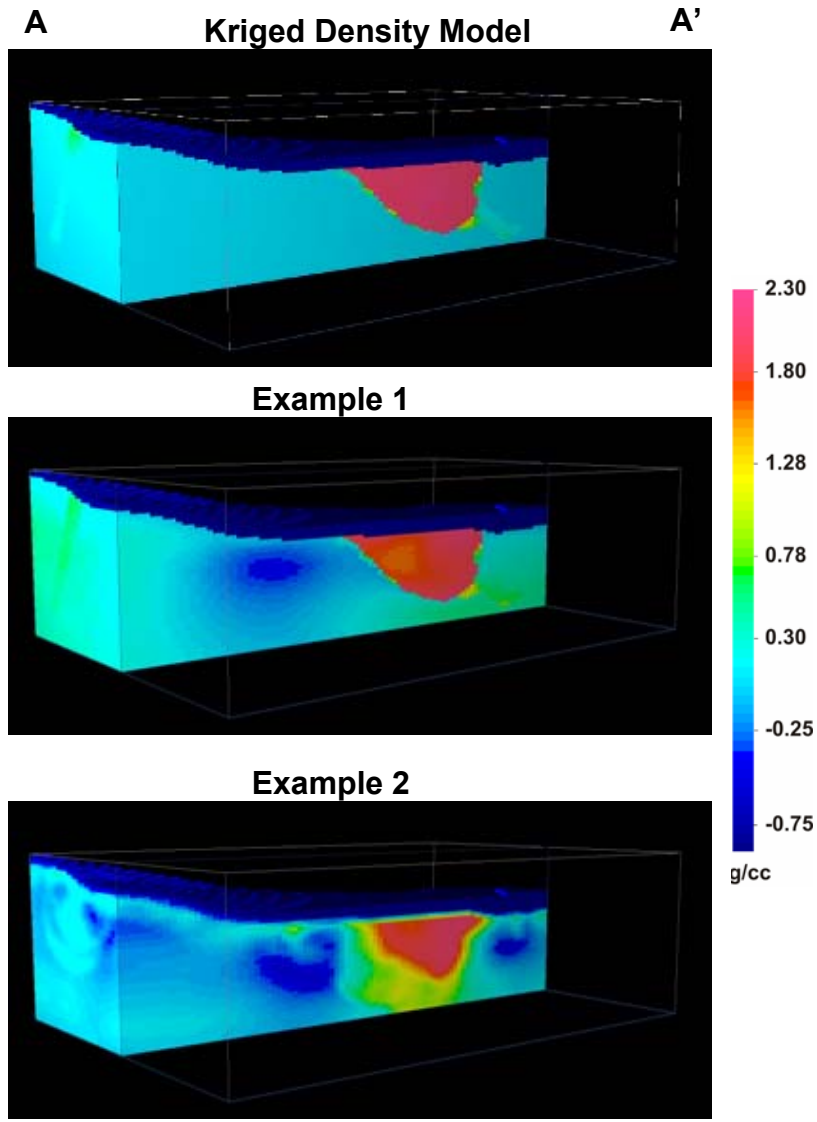


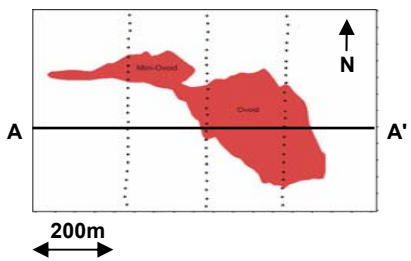


MEMORIAL UNIVERSITY

Constrained Inversion: Kriged Density Model

- Example 1:
  - Residual data
  - The kriged density model was used as the reference model
- Example 2:
  - FM data
  - A reference model was created using 25% of the drill logs



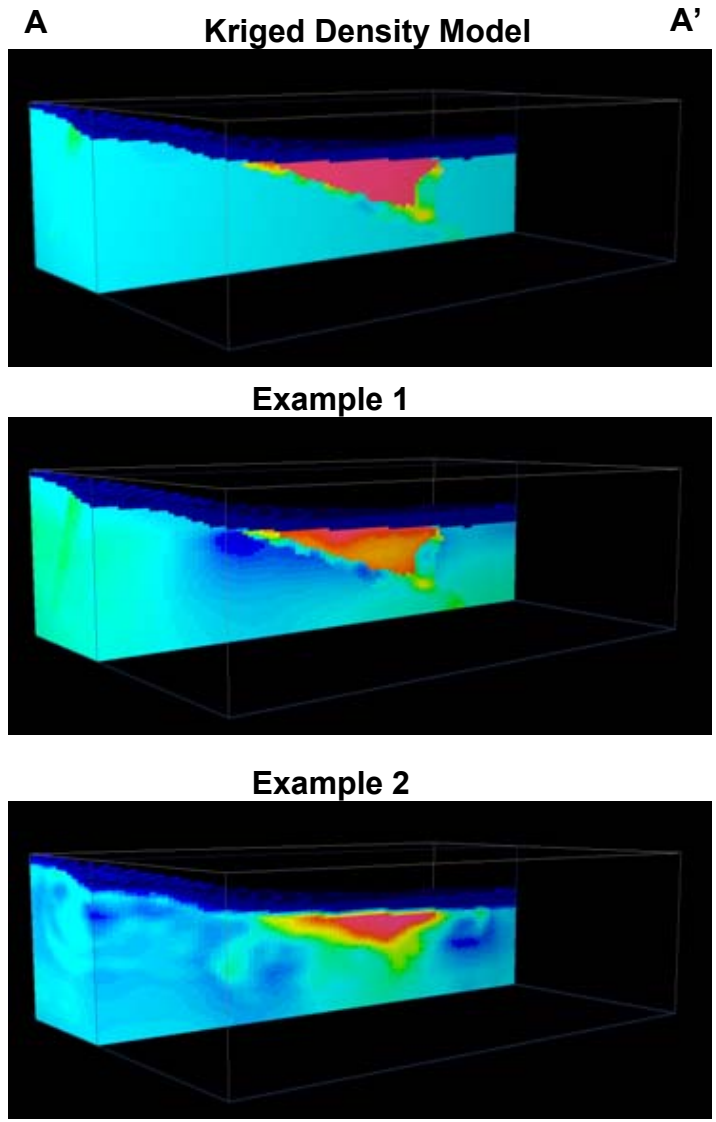


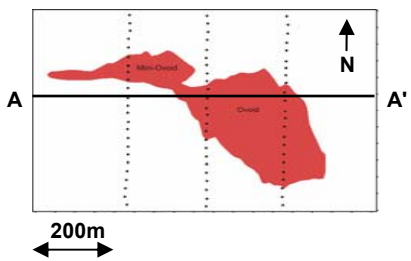
MEMORIAL UNIVERSITY

Constrained Inversion: Kriged Density Model

- Example 1:
  - Residual data
  - The kriged density model was used as the reference model

- Example 2:
  - FM data
  - A reference model was created using 25% of the drill logs

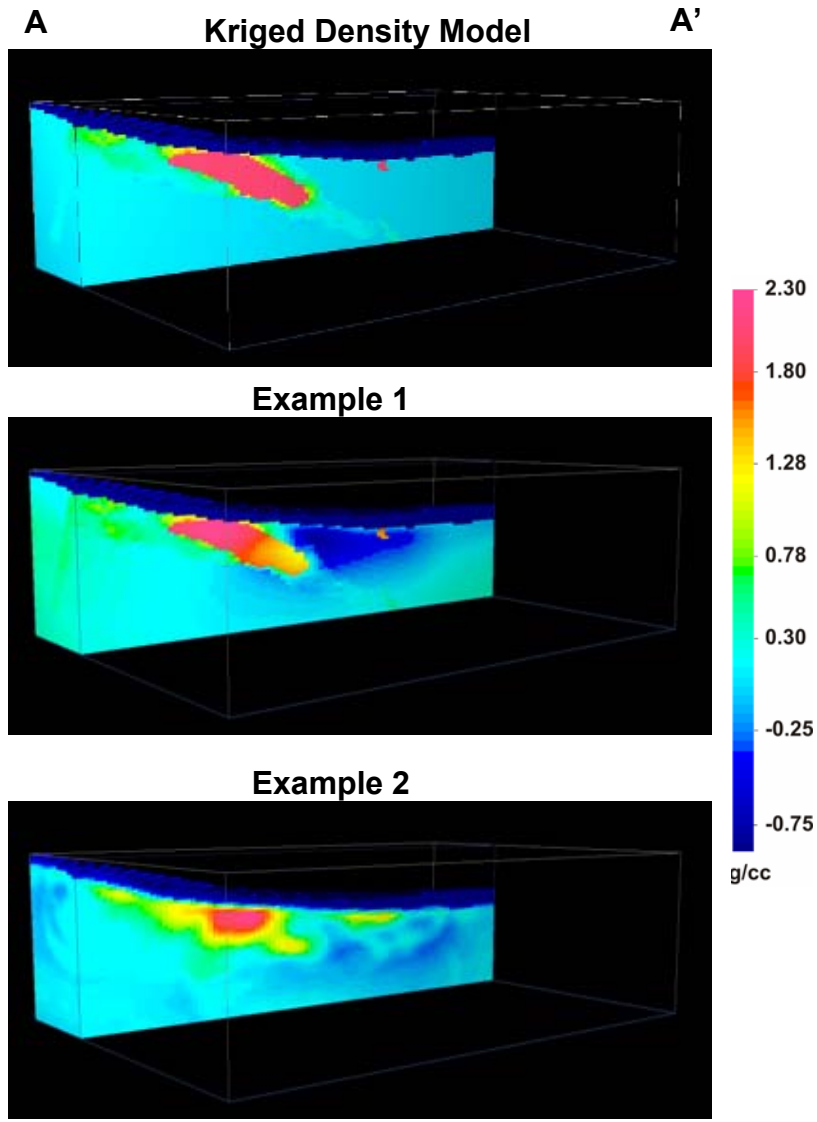


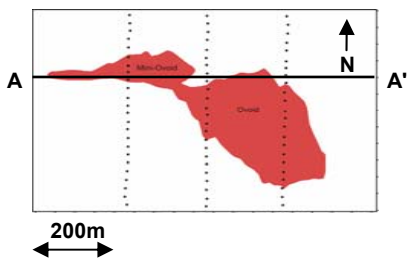


MEMORIAL UNIVERSITY

Constrained Inversion: Kriged Density Model

- Example 1:
  - Residual data
  - The kriged density model was used as the reference model
- Example 2:
  - FM data
  - A reference model was created using 25% of the drill logs



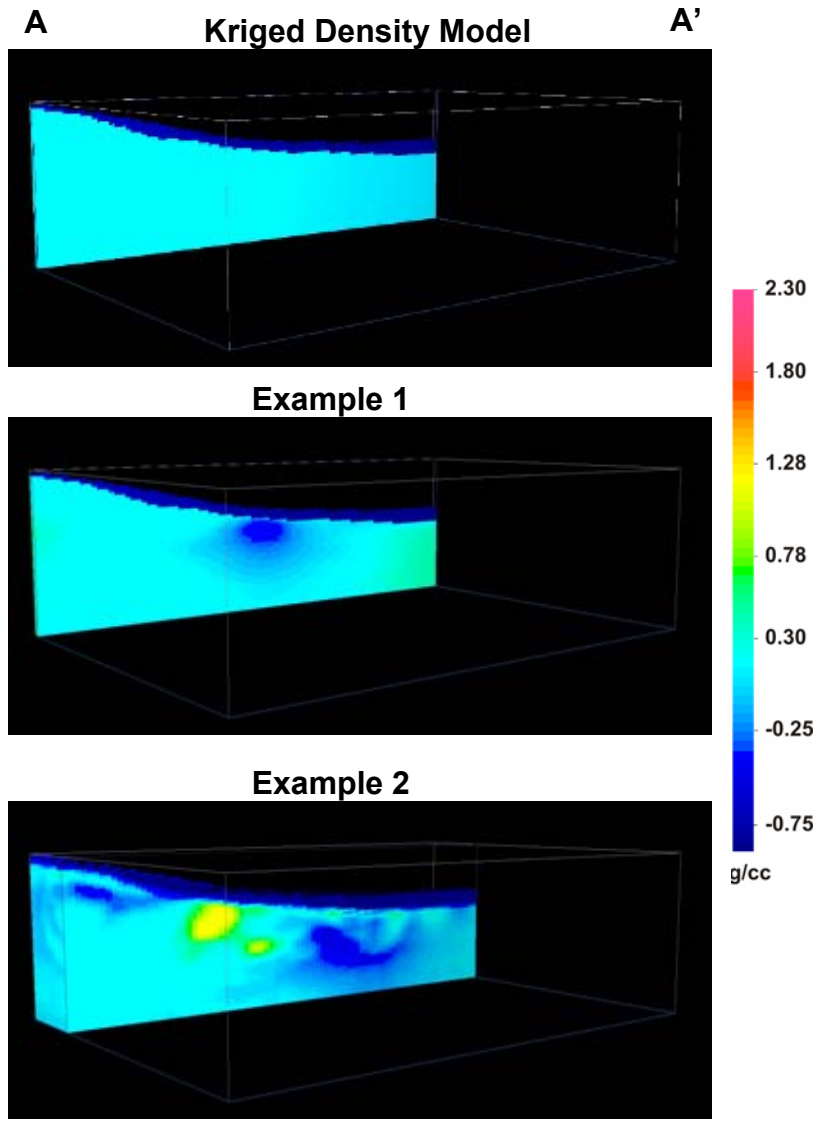


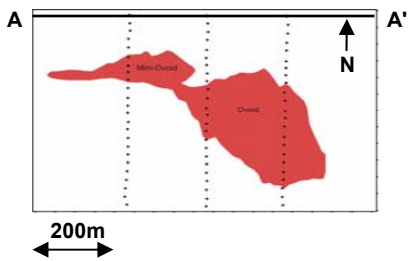
MEMORIAL UNIVERSITY

Constrained Inversion: Kriged Density Model

- Example 1:
  - Residual data
  - The kriged density model was used as the reference model

- Example 2:
  - FM data
  - A reference model was created using 25% of the drill logs





MEMORIAL UNIVERSITY

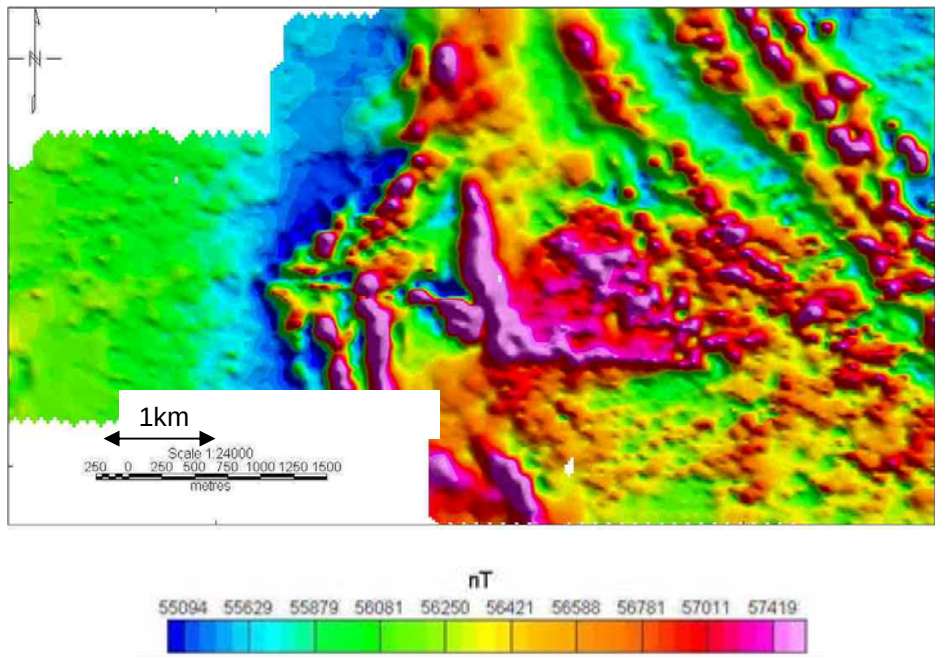
Magnetic Data \ Inversions

•Ground magnetic data was used for inversions

•A Koenigsberger ratio (remanent/induced magnetic intensity) of ~1.5 indicates that remanence cannot be ignored

•The NRM direction is ~30°

•The pyrrhotite present in the Ovoid is hexagonal and non-magnetic so the magnetization is associated with magnetite



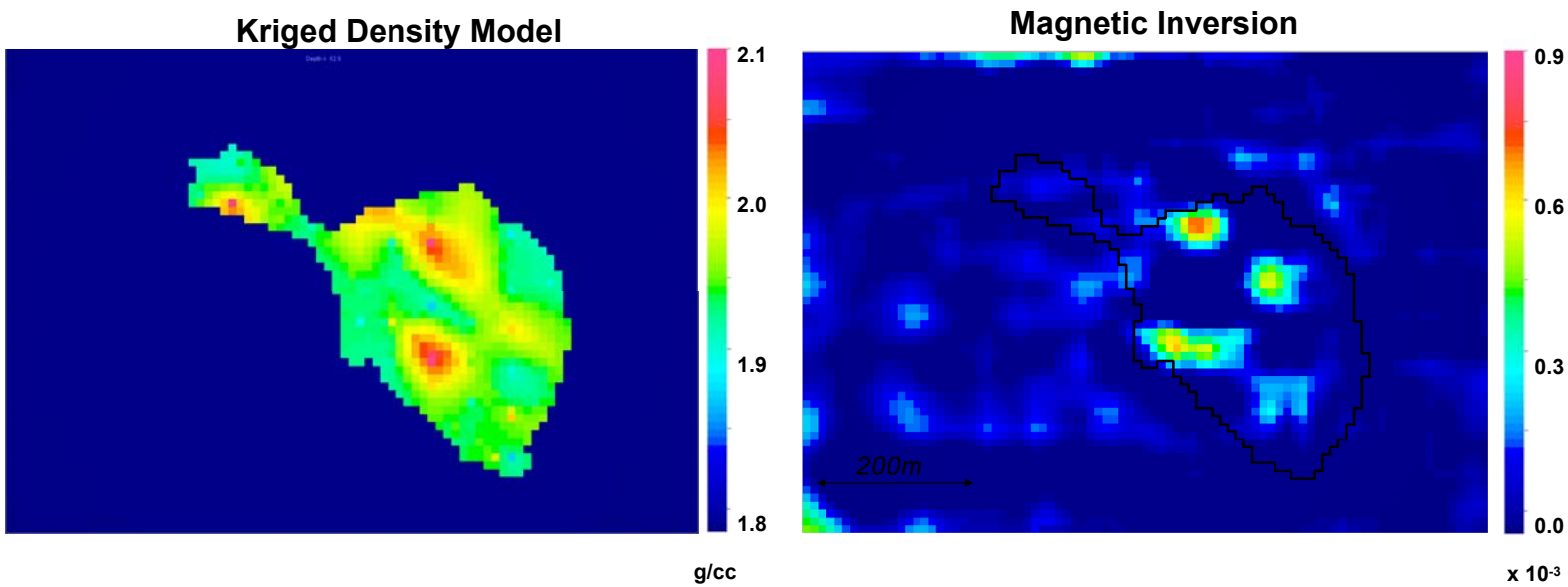
MEMORIAL UNIVERSITY

Magnetic Inversion - UBC

•Regional field was removed using a method developed by Li and Oldenburg (1998)

•The susceptibility anomalies are comparable to the location of high density regions observed within the Ovoid

•High density regions → concentrations of magnetite?



MEMORIAL UNIVERSITY

Conclusions

- Gravity
  - Length scales and depth weighting parameters have a major influence on recovered models
  - A reasonable model of the Ovoid can be obtained when overburden is included in the inversion
  - Incorporating drill log information into the inversion guides the inversion towards a acceptable solution
- Magnetics
  - Examples shown are preliminary and further work is needed to constrain magnetic inversions
  - Further integration is necessary to understand the relationship between the gravity, magnetics and geochemistry

MEMORIAL UNIVERSITY

Acknowledgements

Inco Innovation Centre

Voisey's Bay Nickel Corporation

(Brian Bengert and Robert Wheeler)

University of British Columbia – Geophysical Inversion Facility

MEMORIAL UNIVERSITY