3D Hybrid Gravity Inversion for Base of Salt Modelling

A base of salt test with gravity gradients

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Non-Seismic Geophysics, Finding Petroleum Event
The Geological Society, Burlington House, London, February 2015

Outline

Update on Geosoft's inversion technologies

Introduction
- Inversion philosophy
- SEAM I data

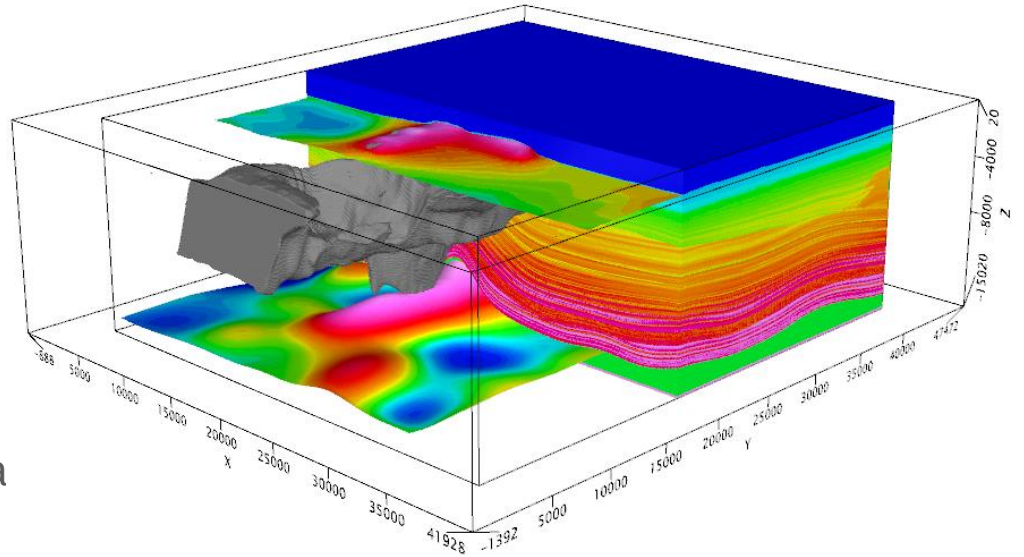
Previous work - Hatch, et. al. paper

Hybrid models

VALEM/VOXI

Base of salt example using SEAM data

Summary



Inversion Philosophy

"*Essentially, all models are wrong, but some are useful*."

George E. P. Box http://en.wikiquote.org/wiki/George_E._P._Box

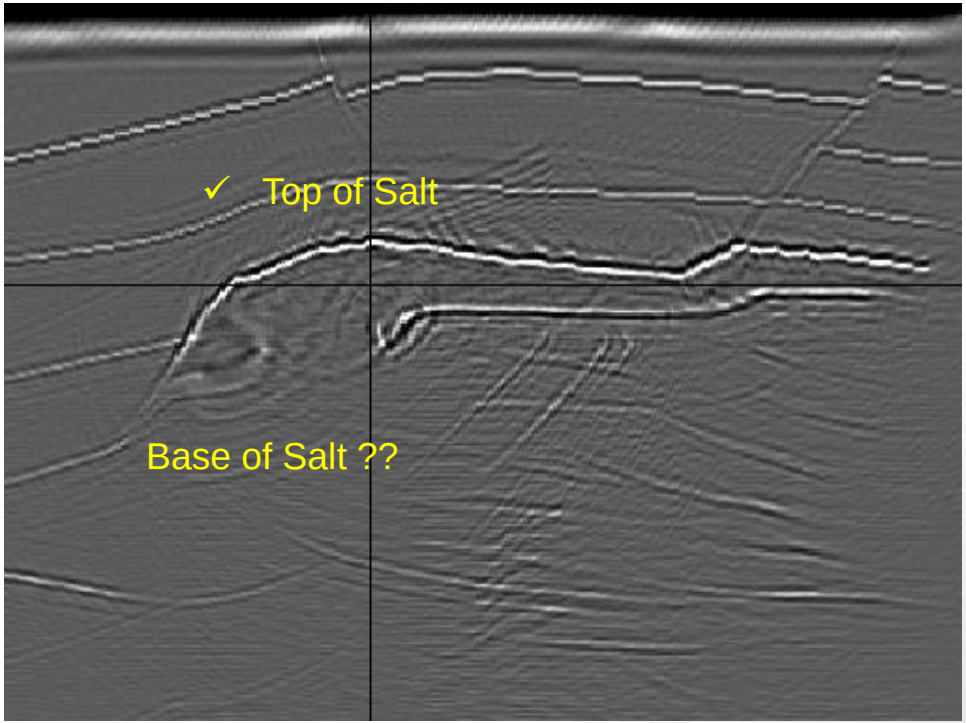
Box argues that the ***simplest*** model that satisfies the information is the most useful model.

Occam's Razor (~1300): *"If you have two equally likely solutions to a problem, choose the simplest."*

To paraphrase*: Inversion should aim for the simplest model that honors the constraints and fits the observed data within the uncertainty of that data.*

Reducing Exploration Risk using Potential Field Data
The Base of Salt Problem

- Seismic exploration is the primary geophysical method used in O&G Exploration.
- Interpretation can be improved by using - **high resolution** - potential field data in conjunction with seismic data.
- The Base of Salt problem is a case where gravity data are used to assist the picking of base of salt horizons.

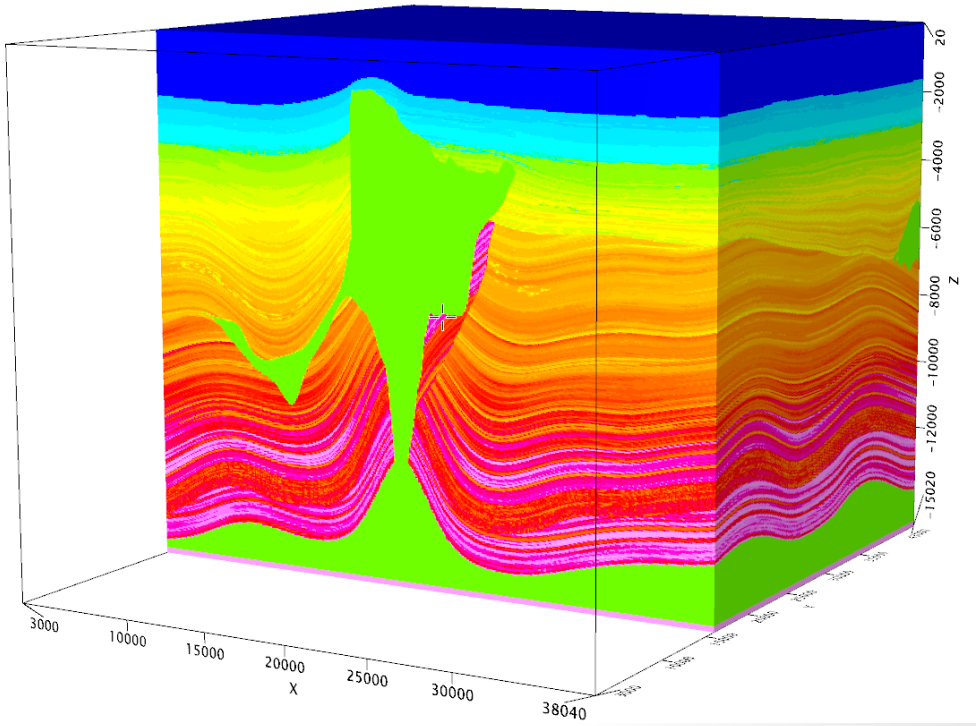


SEAM I Density Model

- Designed by industry consortium to test major challenges of subsalt imaging in Tertiary basins in deepwater Gulf of Mexico.

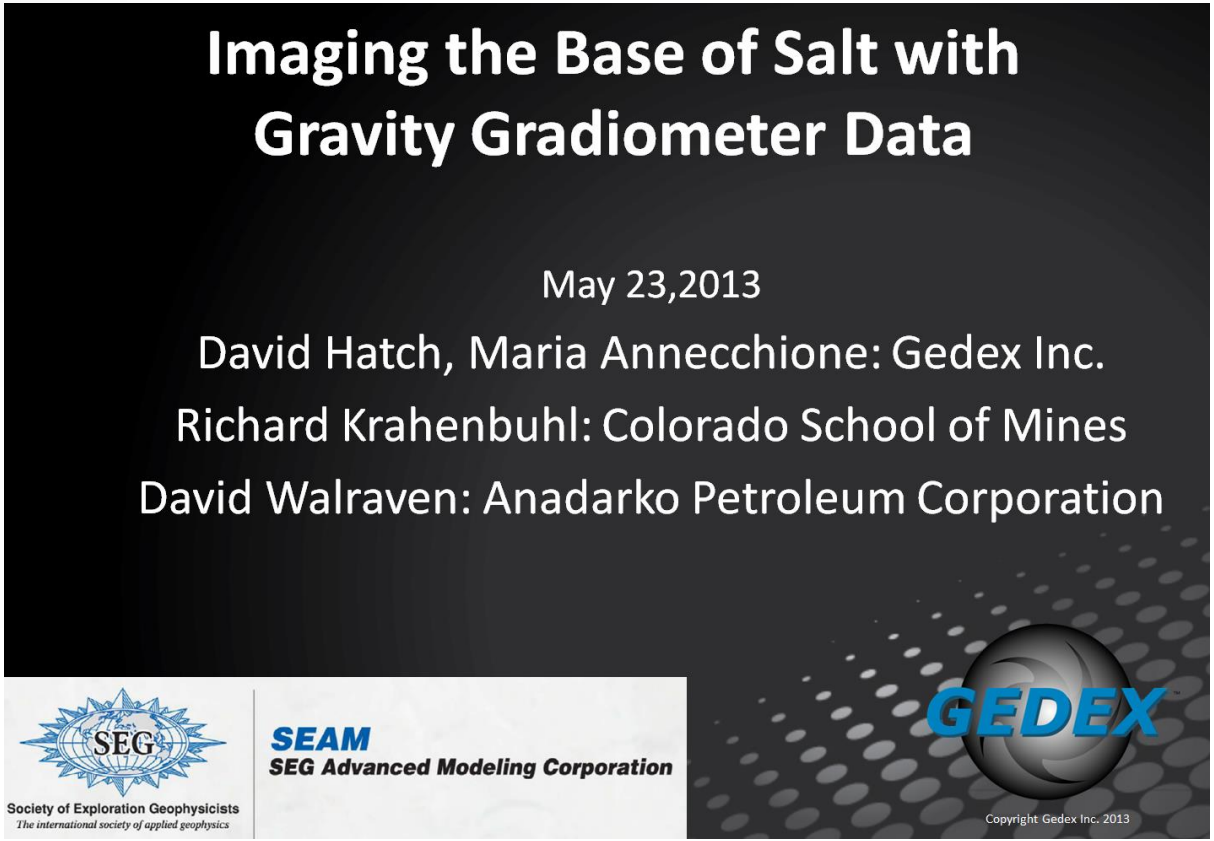
- Includes rugosity, overhangs, grottos, mini-basins, 11 km deep salt feeder, mother salt, and more.

See Pangman, 2007 Leading Edge



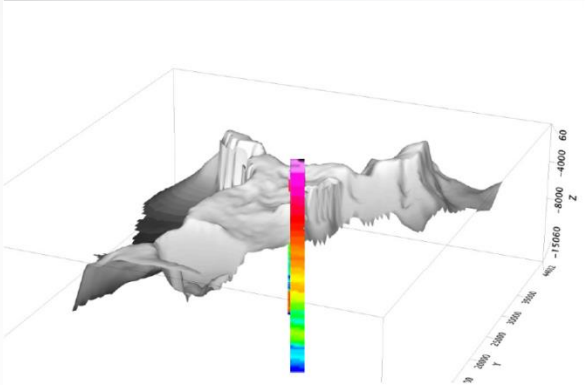
SEAM
SEG Advanced Modeling Corporation

Earlier Inversion Results



2013 SEAM Workshop, Geoscience Advancements With SEAM Data

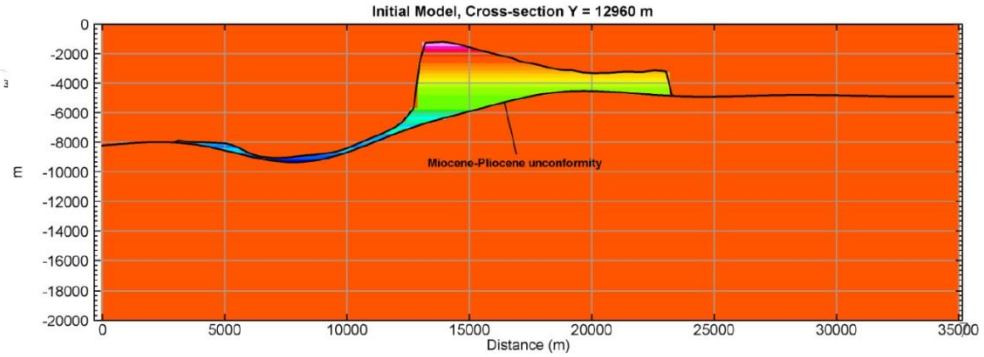
GM-SYS 3D Inversion: Model Setup



Constraints:

- Top of salt
- Vertical density contrast function
- Active area within salt boundaries

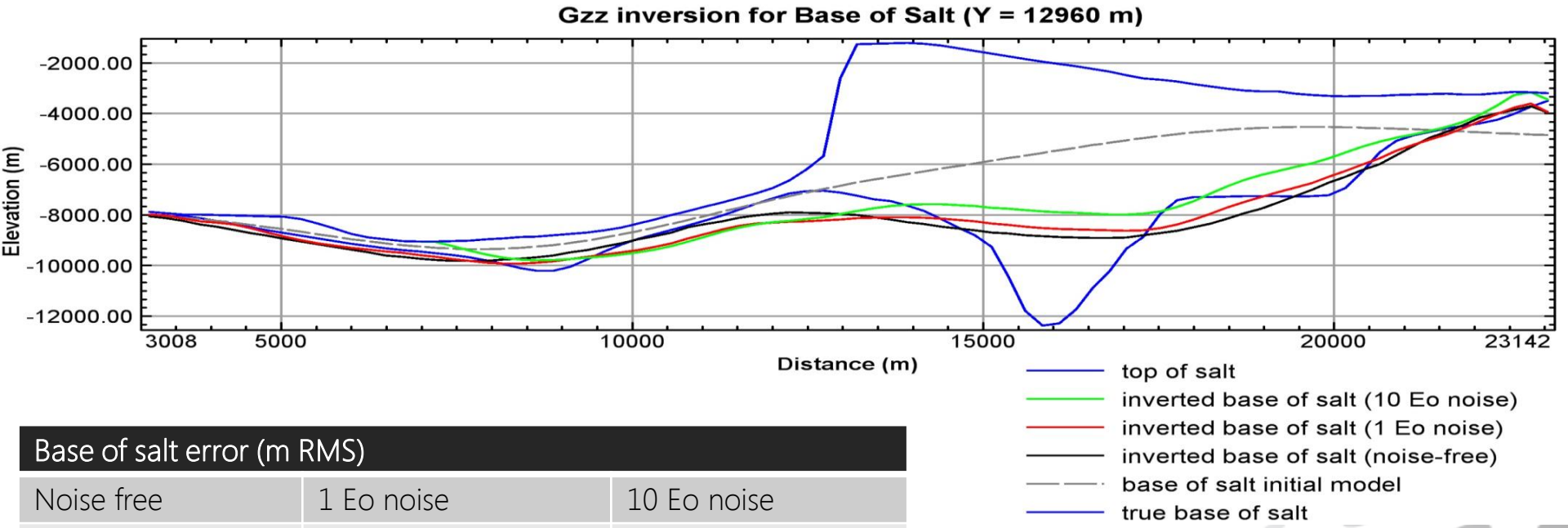
Starting model: Miocene-Pliocene unconformity surface



GM-SYS 3D inversion using Pearson approach

(From Hatch et. al., 2013 with permission)

Interface Inversion: Line 12960

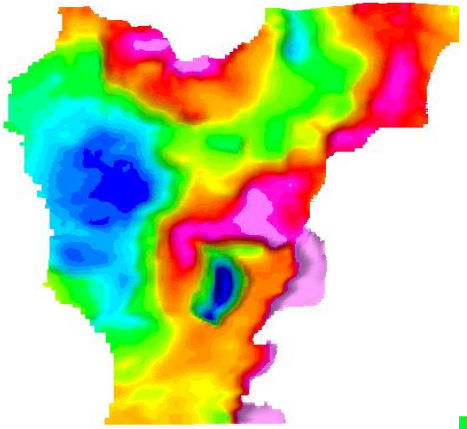


Base of salt error (m RMS)		
Noise free	1 Eo noise	10 Eo noise
424	510	662

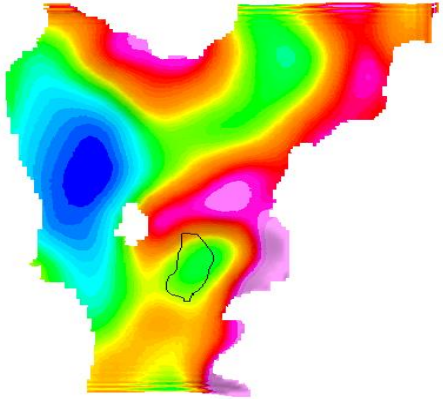
Gzz data misfit (Eo RMS)		
Noise-free	1 Eo noise	10 Eo noise
0.035	0.28	1.32

Interface Inversion: Base of Salt

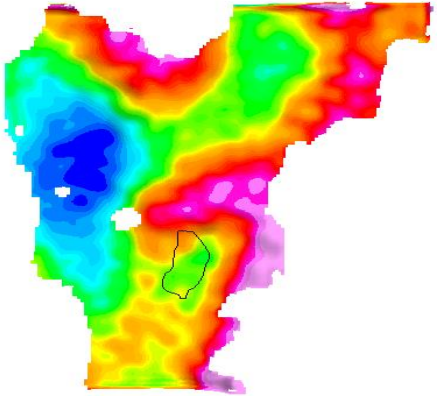
True base of salt



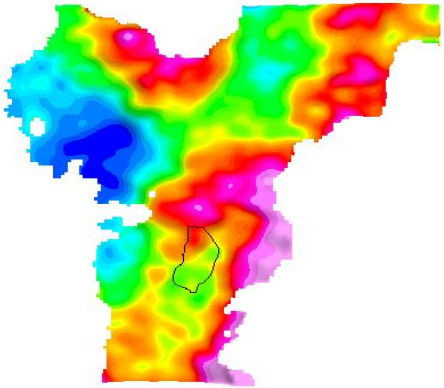
Inverted base of salt (0 Eo noise)



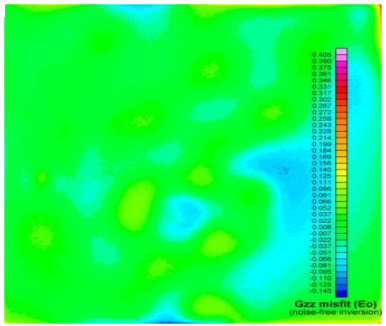
Inverted base of salt (1 Eo noise)

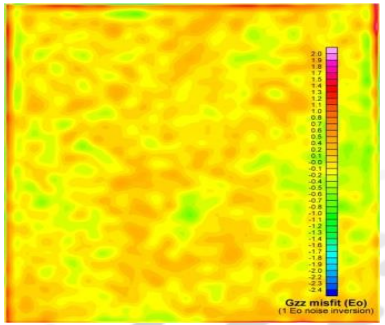


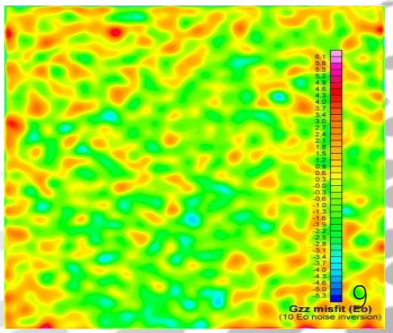
Inverted base of salt (10 Eo noise)



Gzz Misfit







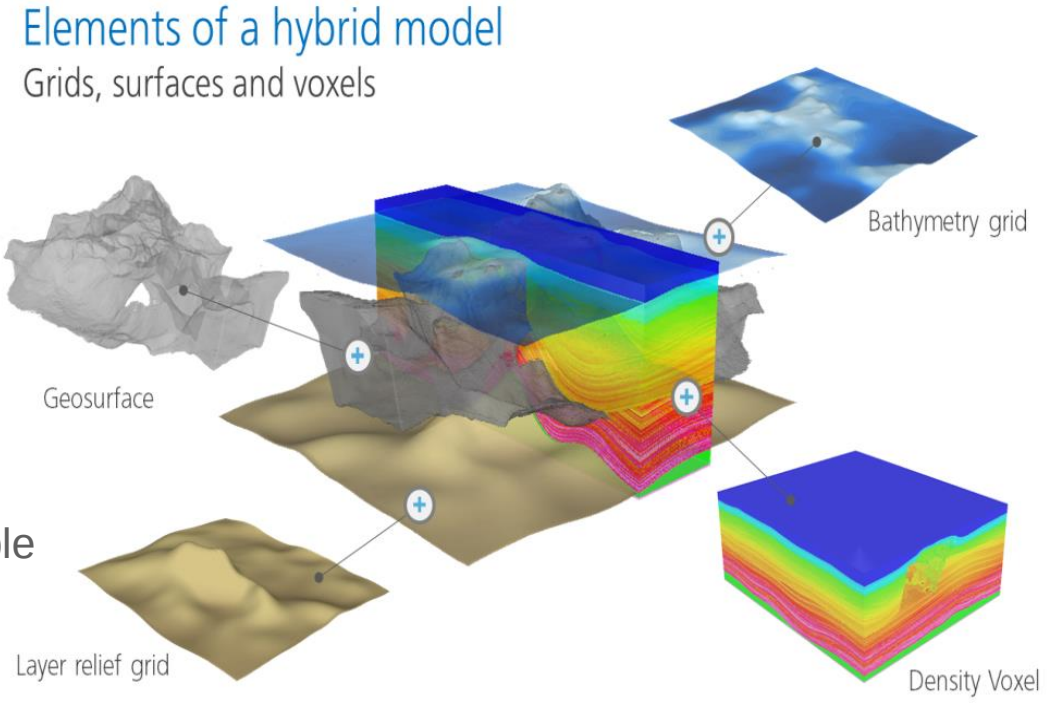
New Hybrid models

Hybrid data structures

- Grids – bathymetry
- Voxels – seismic volume
- Geosurfaces – complicated salt body

Hybrid calculations

- Frequency domain – very fast but inflexible
- Space domain – slower but very flexible



Voxel **A**ssisted **L**ayer **E**nhanced **M**odeling.

- New inversion option in GM-SYS 3D – **One single platform**
- Sends inversion volume to VOXI (**Vox**el **I**nversion)
- VOXI space-domain uses High Performance Computing
- Assimilates results back into GM-SYS 3D

VOXI interface accessible to VALEM

Additional constraints available in VOXI interface:

- Constant or voxel constraints
- Upper & lower density bounds
- Parameter weighting
- Gradient weighting: EW, NS, & vertical
- Allows inclusion of faults, boreholes, varying uncertainty in starting model, etc.

Can invert on:

- Gravity
- Magnetics
- All FTG components
- All Falcon™ AGG components

Inversion model setup

Bathy, autochthonous salt, & basement represented by grids

Slightly simplified SEAM density cube

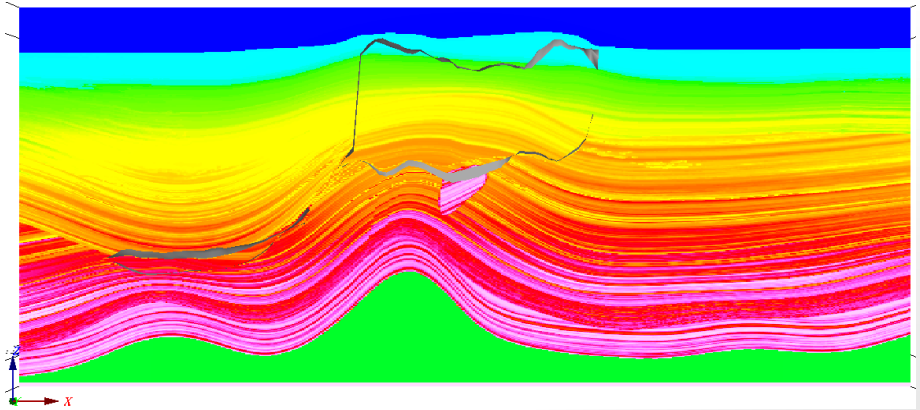
Replaced allochthonous salt with interpolated fill

Constraints:

- Top of salt
- Active area with salt boundaries
- Top of autochthonous salt is base of active volume

Demonstrate the maximum that can be achieved with perfect data

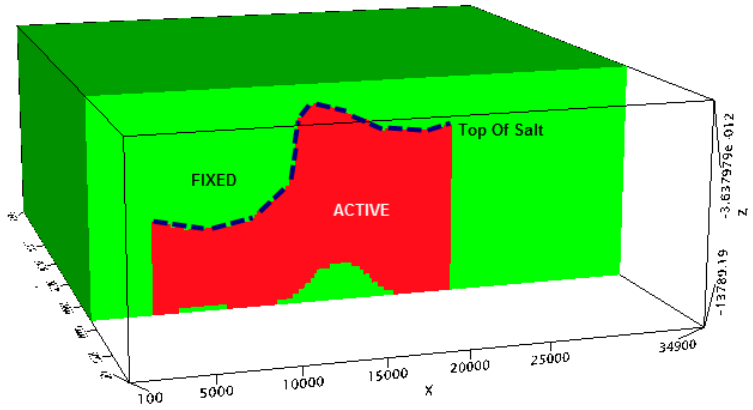
Interpolated fill



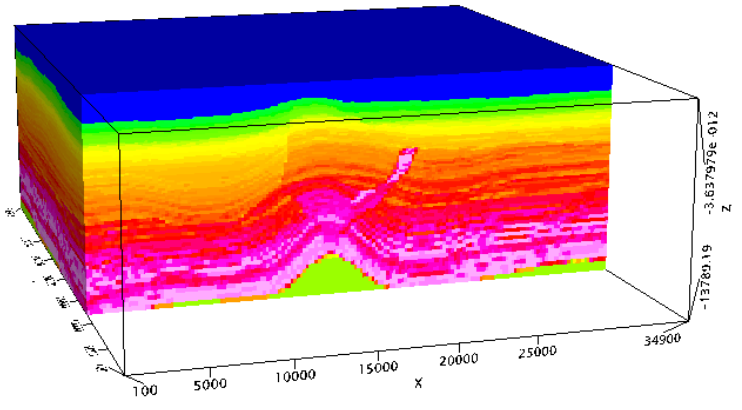
Inversion Methodology 1

1. Define *Active Inversion Domain* below top of salt.
2. Define the *Sediment Reference Model*

1. Active Domain

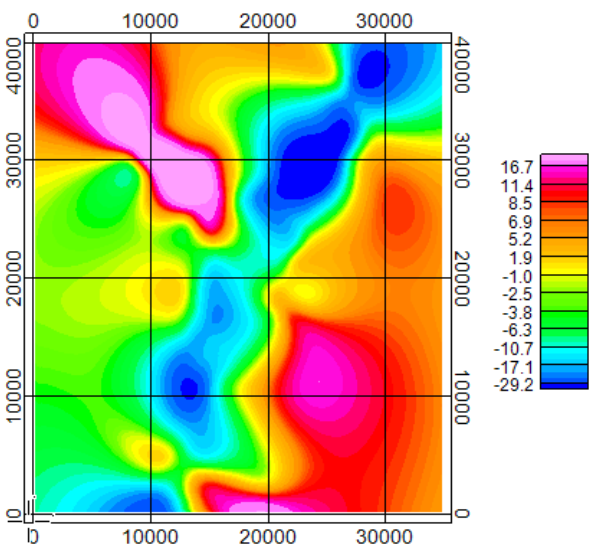


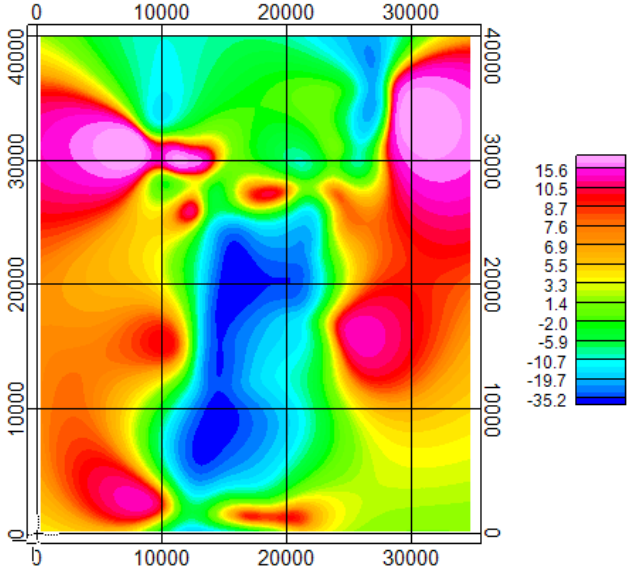
2. Sediment Model



Inversion Methodology 1

3. Form the *Residual Data: ΔG_{NE} and ΔG_{UV}*
   (Observed data – Sediment response)



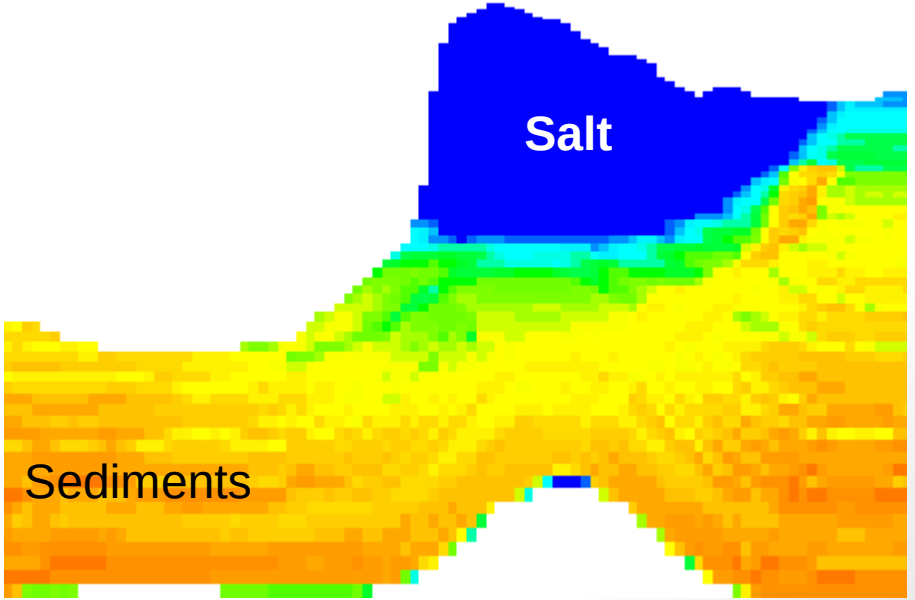


Residual Data: Falcon™ AGG G_{NE} and G_{UV}

Inversion Methodology 1

4. Invert the Residual Data
5. Iteratively enforce Salt Density or Sediment Density

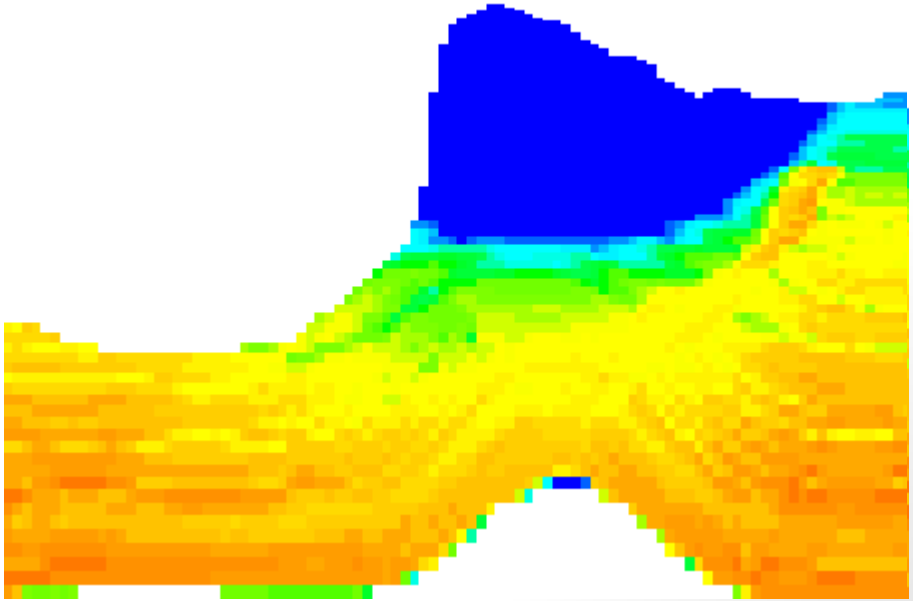
Smooth Inversion



Inversion Methodology 1

IRI Salt Focusing

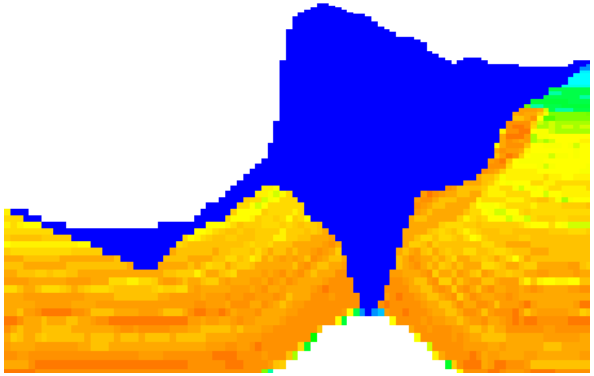
Iterative **R**eweighting **I**nversion (**IRI**) focusing takes an initial inversion result and uses it as an iterative reweighting constraint in a subsequent inversion. This process is repeated several times in order to produce a refined or "focused" final inversion result.



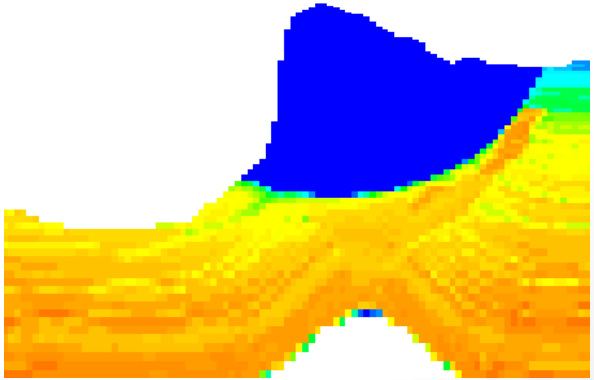
Inversion Results 1

The IRI Salt Focusing model:

1. Response fits gravity gradient data to 0.5 Eo.
2. Does not show salt feeder or thin salt extrusion.
3. Reflects a realistic measure of the ability of gravity gradient data to map the Base of Salt with only top of salt constraint.



SEAM Model

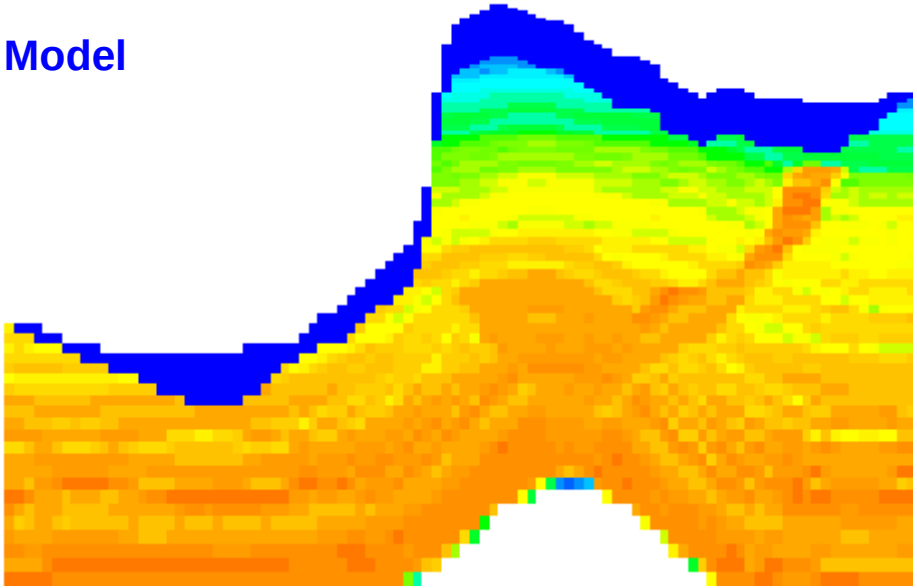


IRI Salt Focusing

Inversion Methodology 2

Define salt to a depth of 1km below top of salt.

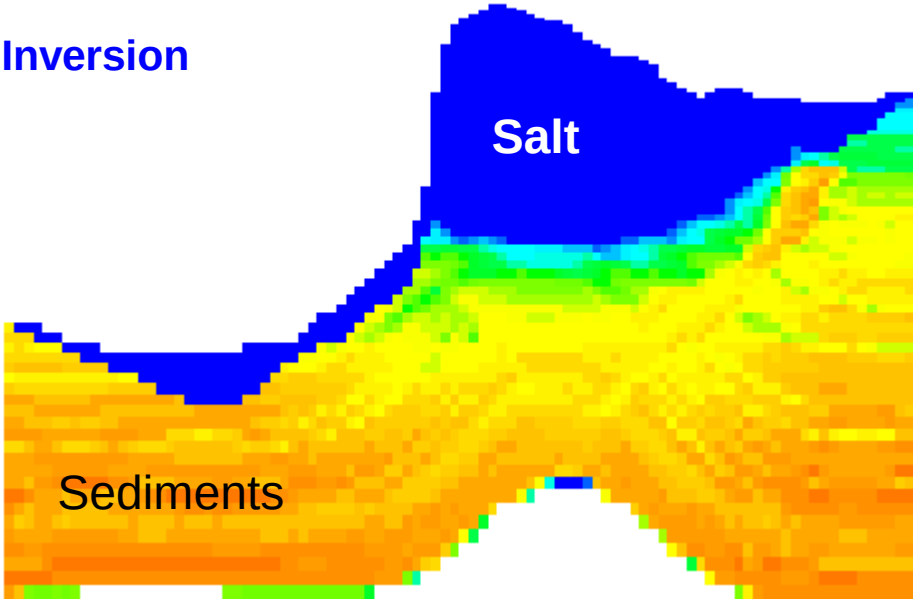
Starting Model



Inversion Methodology 2

4. Invert the Residual Data
5. Iteratively enforce Salt Density or Sediment Density

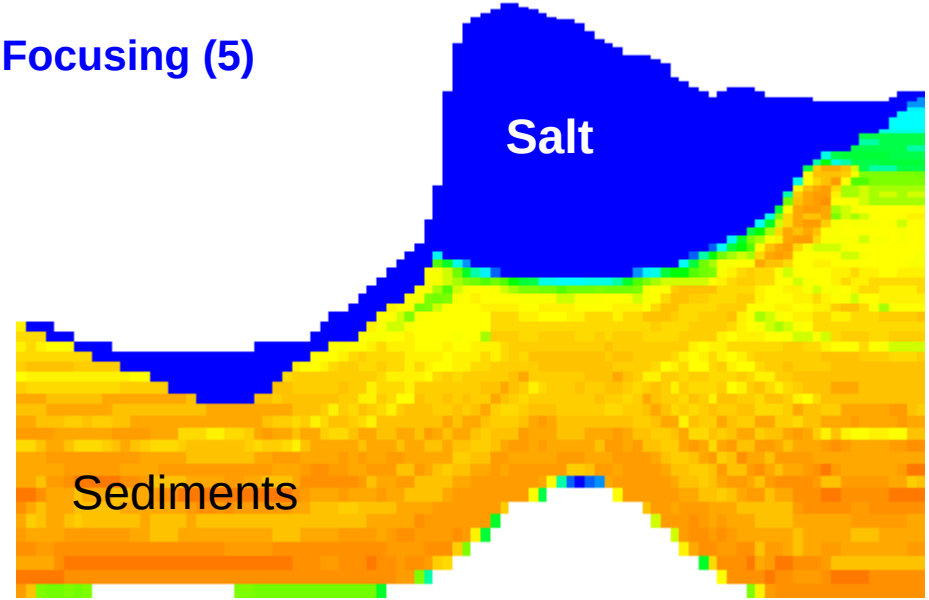
Smooth Inversion



Inversion Methodology 2

4. Invert the Residual Data
5. Iteratively enforce Salt Density or Sediment Density

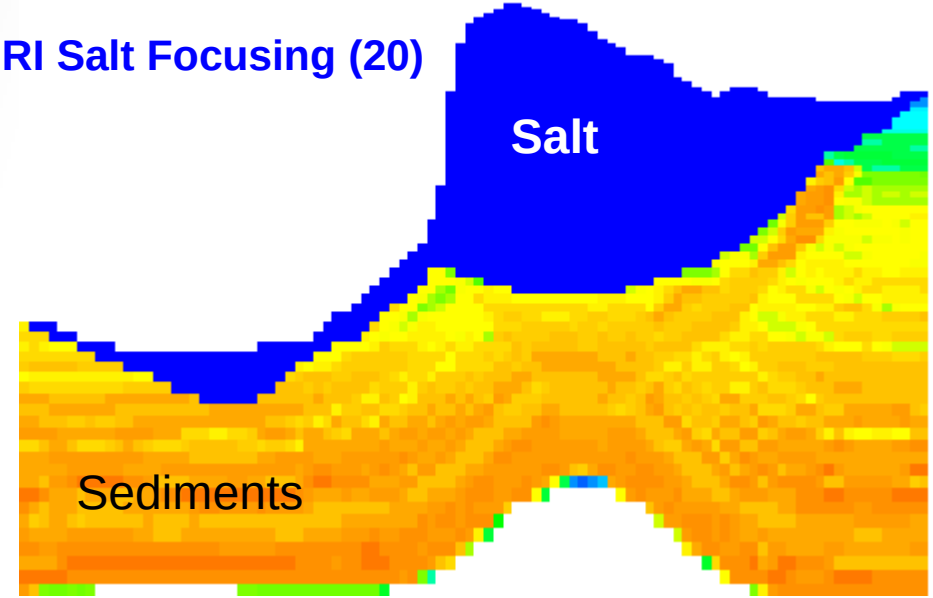
IRI Salt Focusing (5)



Inversion Methodology 2

4. Invert the Residual Data
5. Iteratively enforce Salt Density or Sediment Density

IRI Salt Focusing (20)

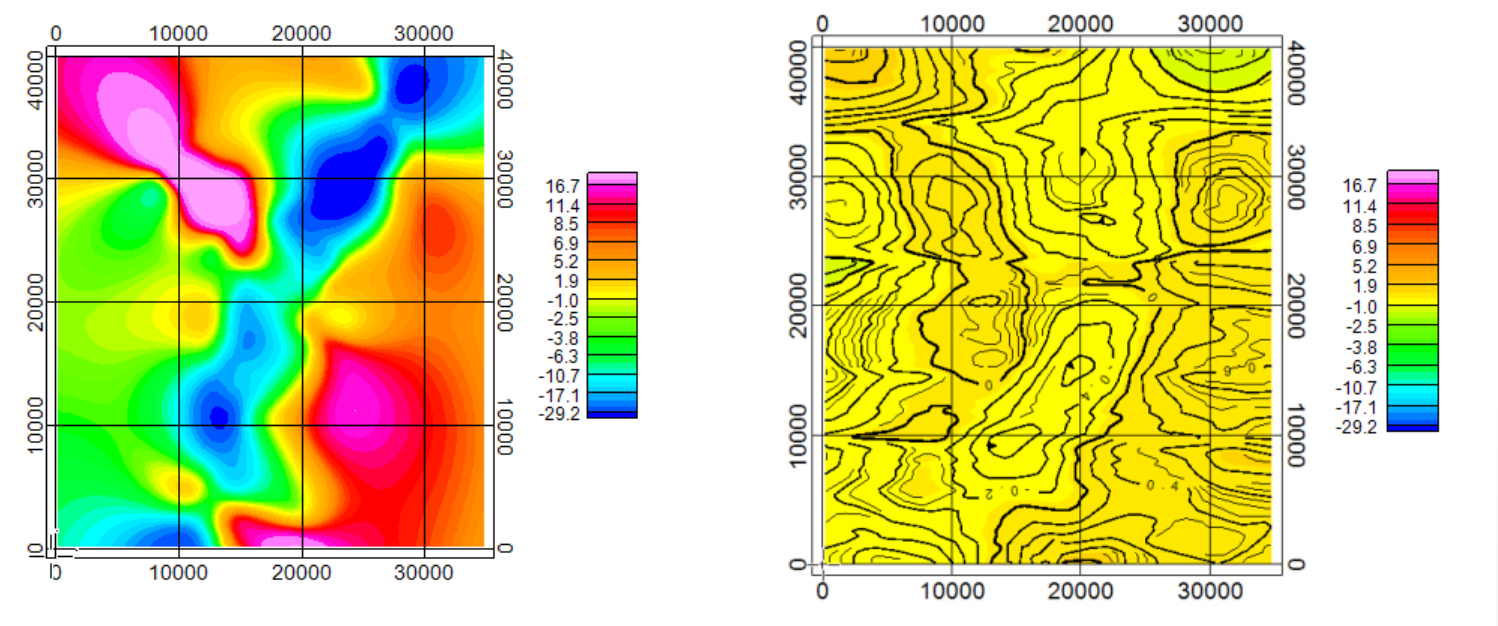


Honoring Occam's Razor

With just these constraints, **we are at the limit of what gravity gradient inversion can achieve!**

Inversion Results 2

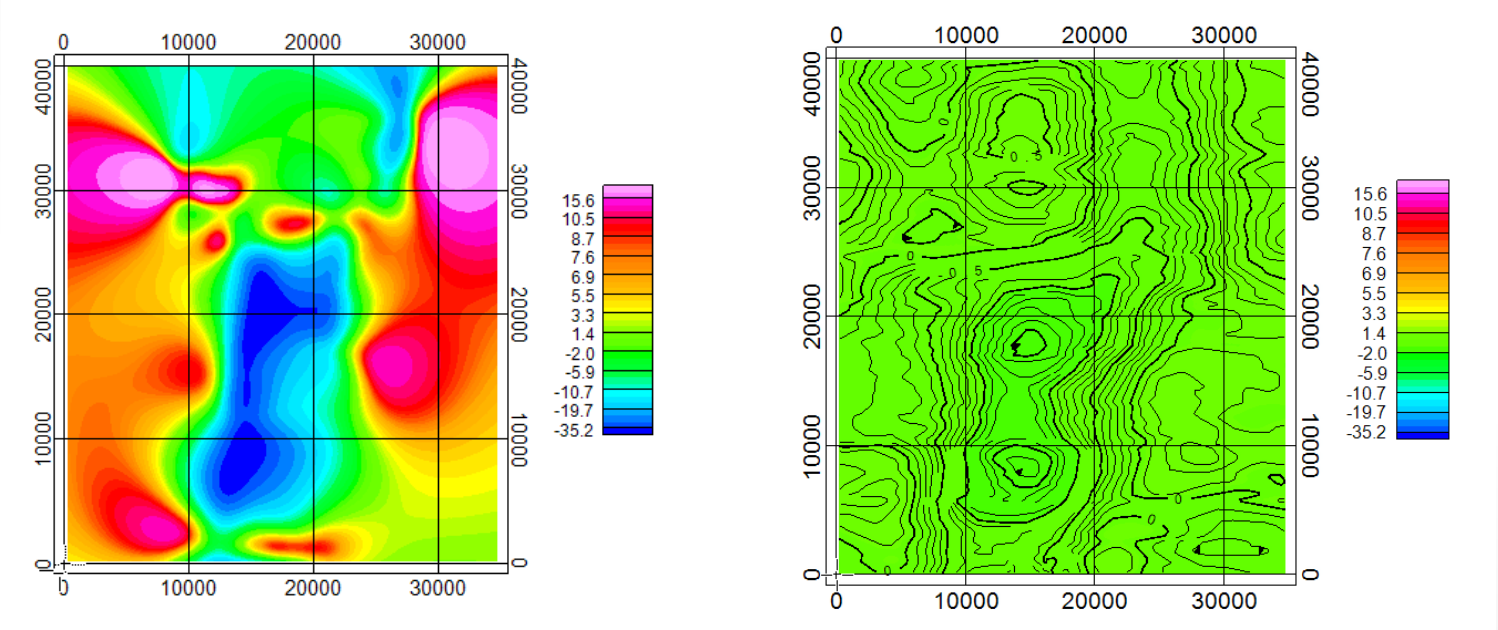
Observed Data and Misfit: G_{NE}



(same colour scale)

Inversion Results 2

Observed Data and Misfit: G_{UV}

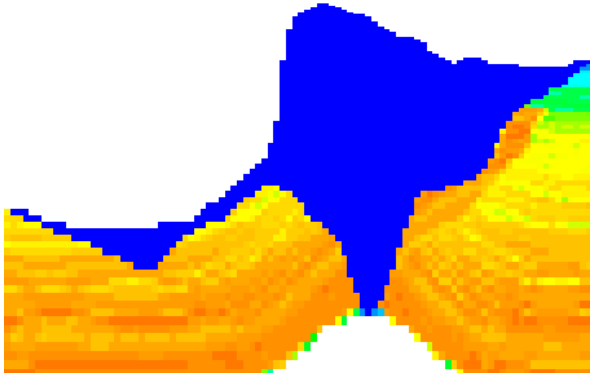


(same colour scale)

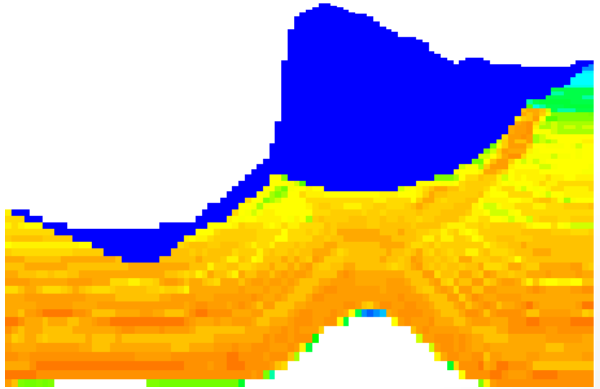
Inversion Results 2

The IRI Salt Focusing model:

1. Response fits gravity gradient data to 0.5 Eo.
2. Does not show salt feeder.
3. Reflects a realistic measure of the ability of gravity gradient data to map the Base of Salt with top of salt constraint and 1km of salt.



SEAM Model

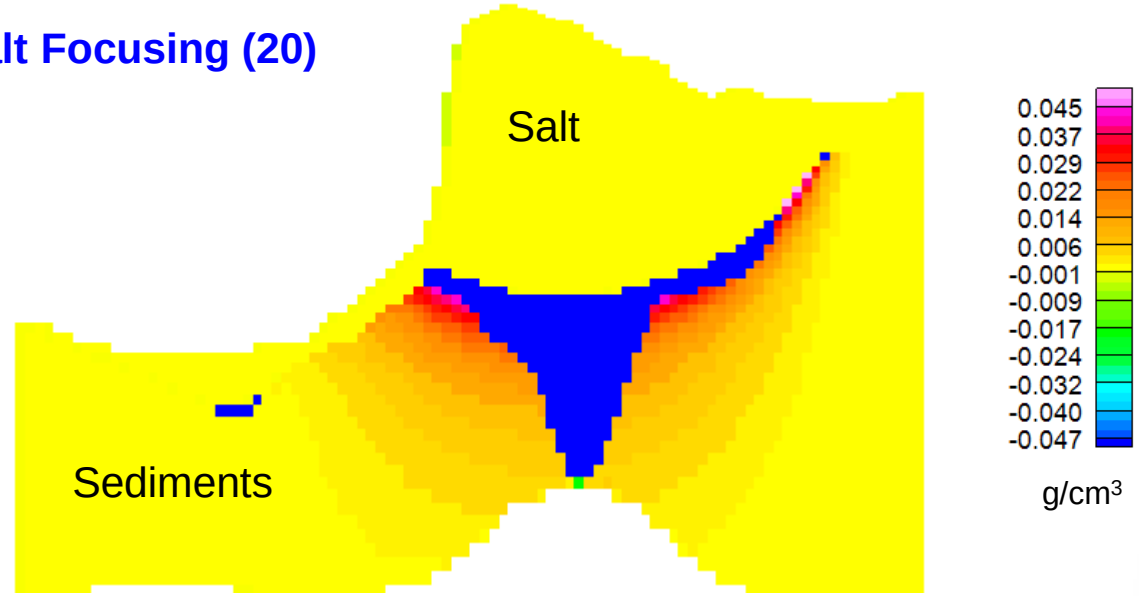


IRI Salt Focusing

Inversion Results 2

The difference between the SEAM model and the model recovered by inversion. Note that the sediment density is correctly determined to an accuracy of ~0.026 g/cm^3 and the salt density is exact. This indicates that for all practical purposes, gravity gradient data will not resolve the salt feeder.

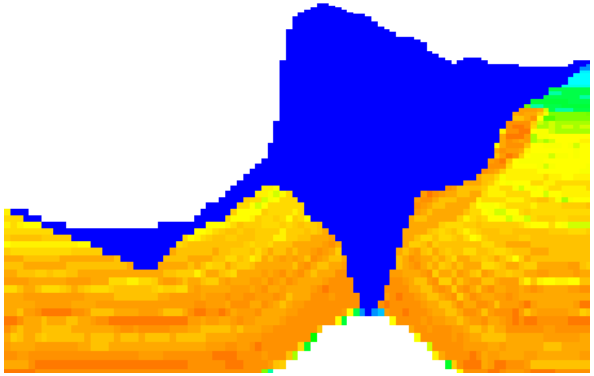
Δ IRI Salt Focusing (20)



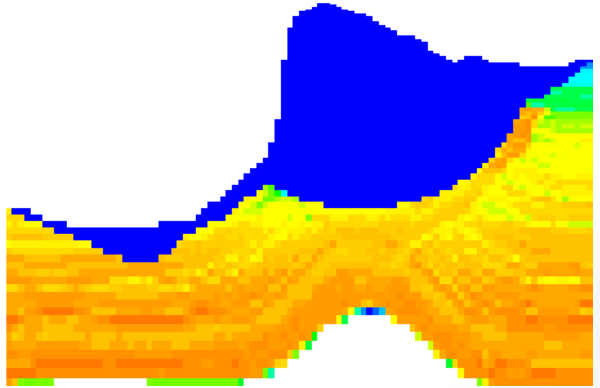
Inversion Results 3

The IRI Salt Focusing model:

1. Response fits gravity gradient data to 0.1 Eo.
2. Does not show salt feeder.
3. Reflects a realistic measure of the ability of gravity gradient data to map the Base of Salt with top of salt constraint and 1km of salt.



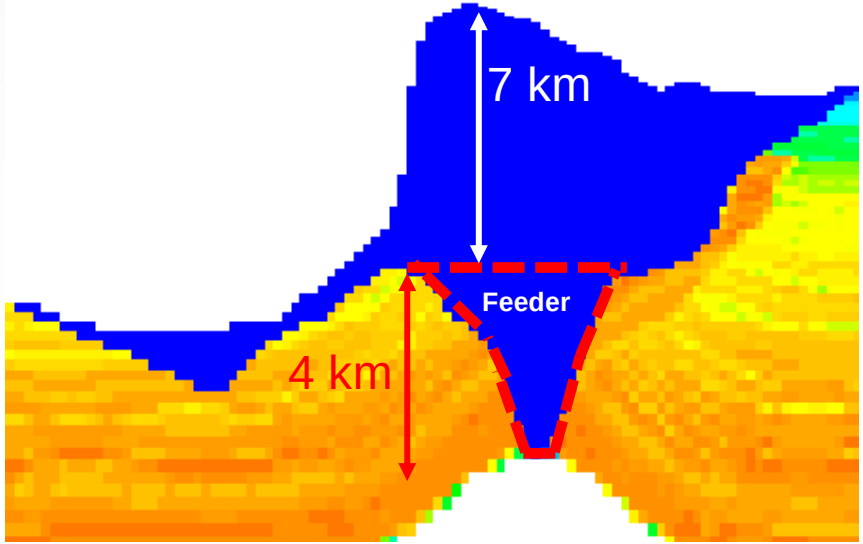
SEAM Model



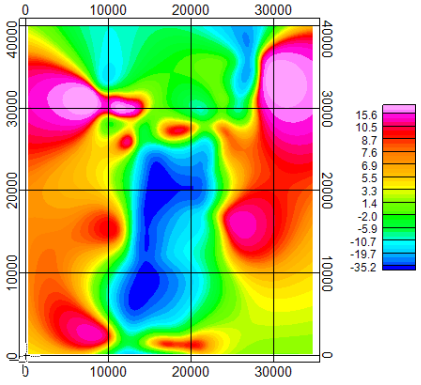
IRI Salt Focusing

Feeder Response

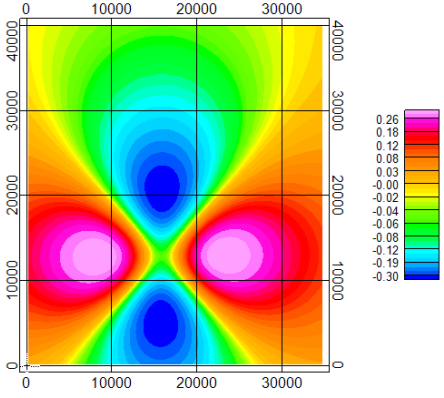
Feeder Model: Computing the response from the feeder.



Observed Data and Feeder Response: G_{UV}



Range: 50.0 Eo



Range: 0.7 Eo

Summary

Hybrid inversion (layer earth + sharp boundary voxel inversion) of gravity data can improve seismic imaging

Inversion should aim for the simplest model that honors the constraints and fits the observed data within the uncertainty of that data.

Current gravity data has limited ability to detect deep, short-wavelength salt features.

Thank you

We love to hear from our customers, so if you have any questions, e-mail us at explore@geosoft.com or visit www.geosoft.com.