Geophysical imaging in the Nordkapp Basin

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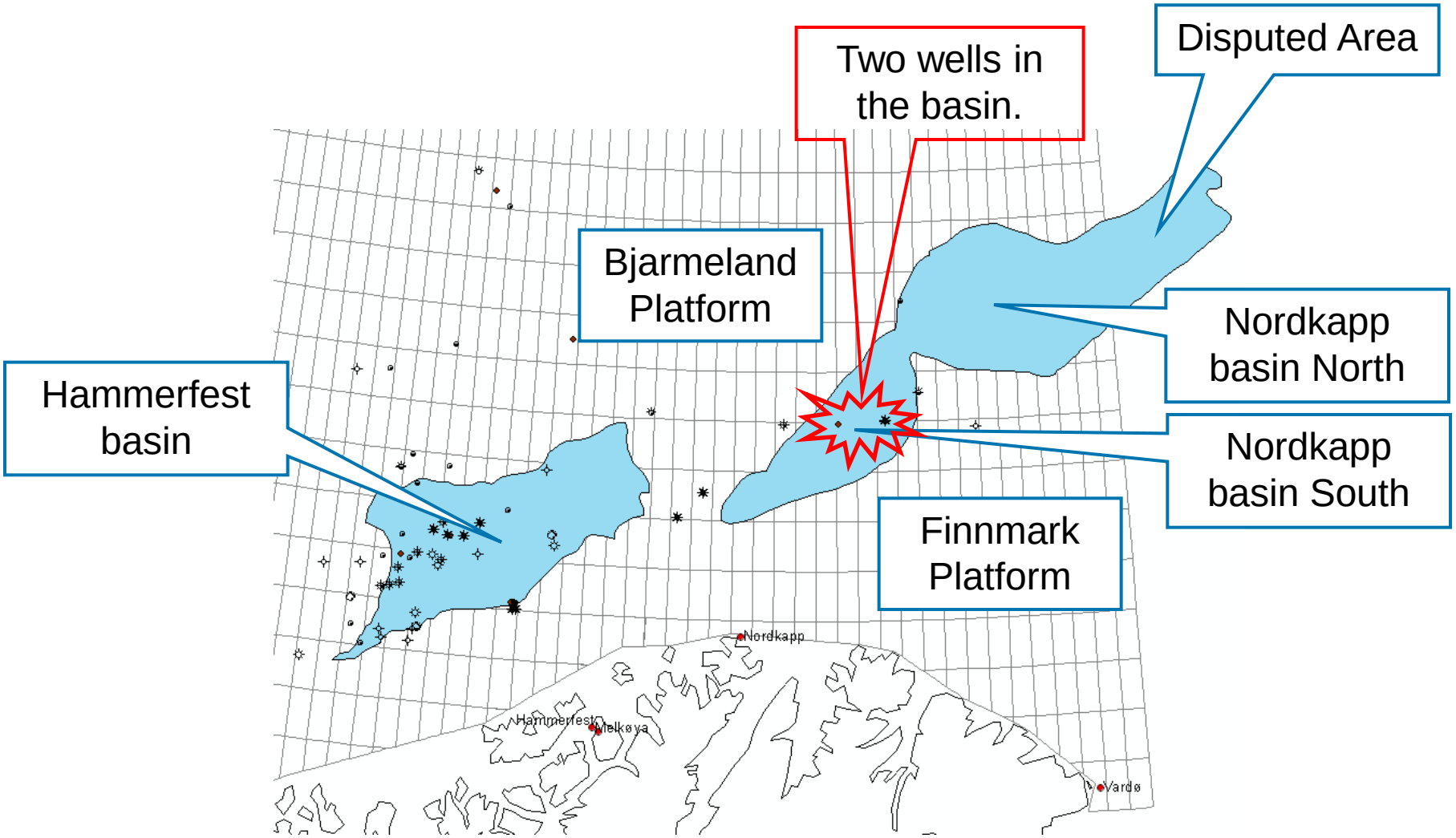
Meeting with NPD

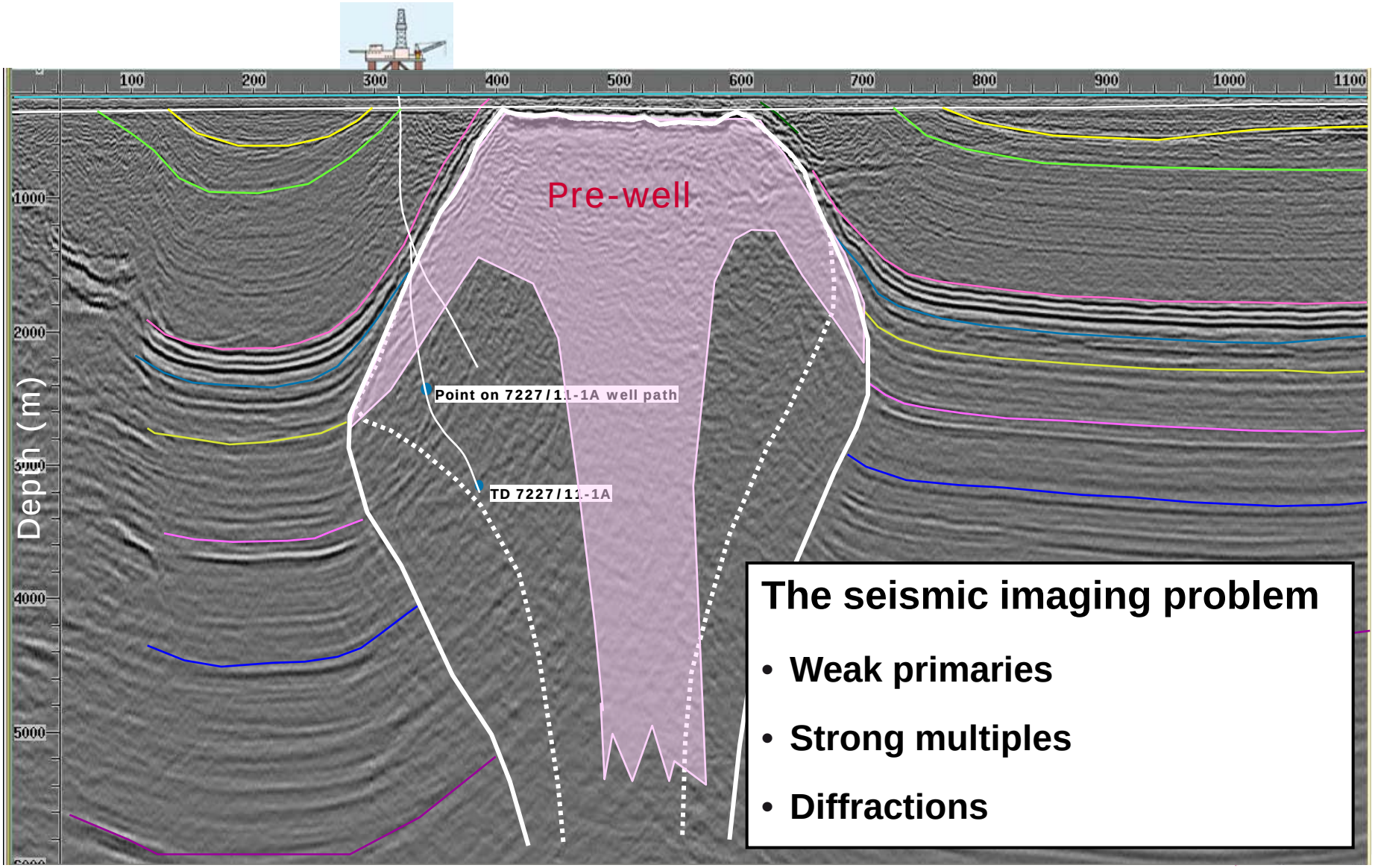
Stavanger 18 March 2010

The Nordkapp Basin - Location

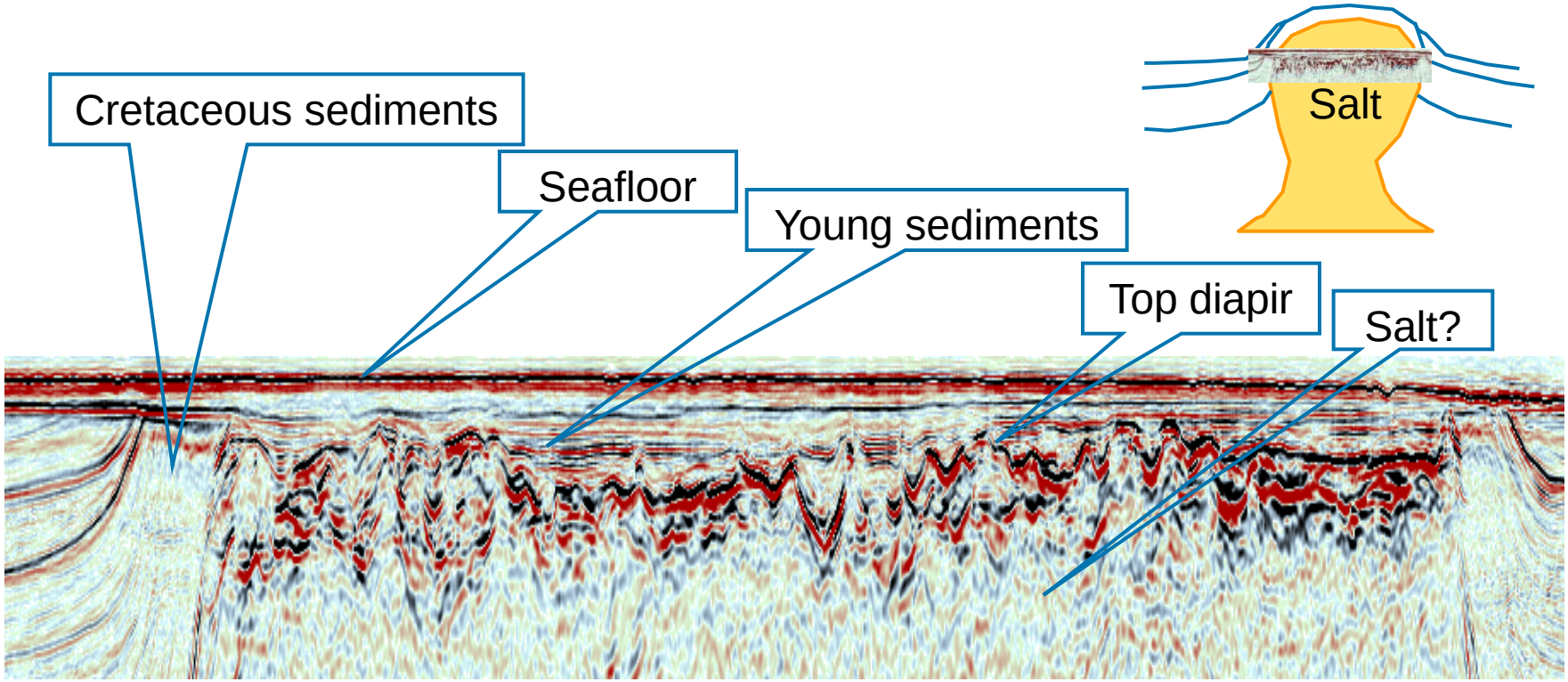


Statoil

Uranus pre and post-well interpretations



The seismic shadow zone- where is top salt?



The top of salt often represents a very strong and undulating reflector resulting in focusing/defocusing energy effects and generating diffractions.

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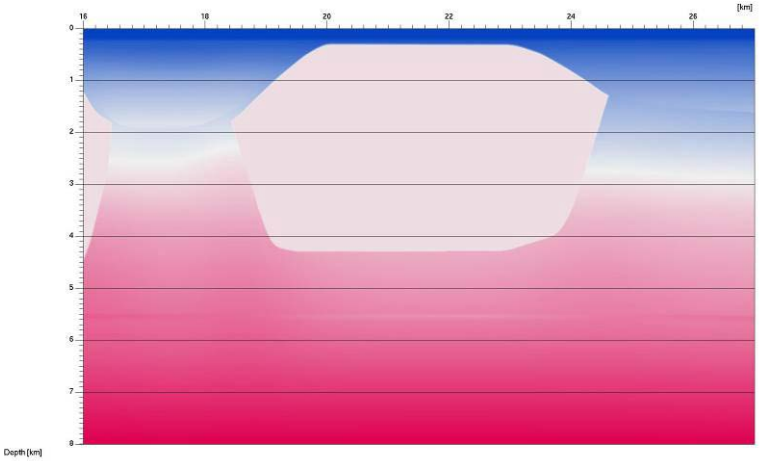
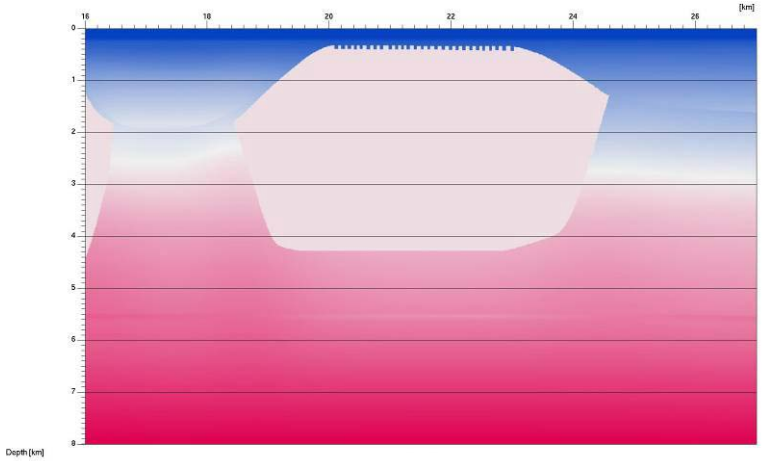
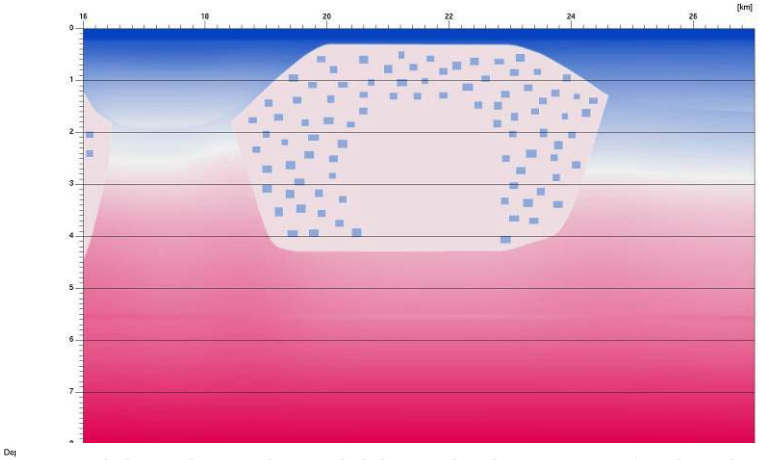
Velocity models “Dirty salt”



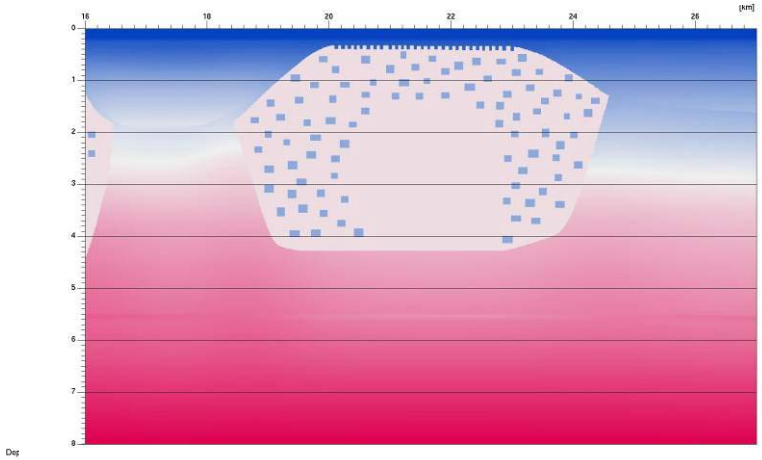
Model 1: Clean salt model



Model 2: Clean salt model with top diffractors



Model 3: Dirty salt model (pertubations 70% of salt velocity)



Model 4: Dirty salt model with top diffractors(pertubations 70% of salt velocity)

Haugen, Arntsen and Mispel, SEG 2008

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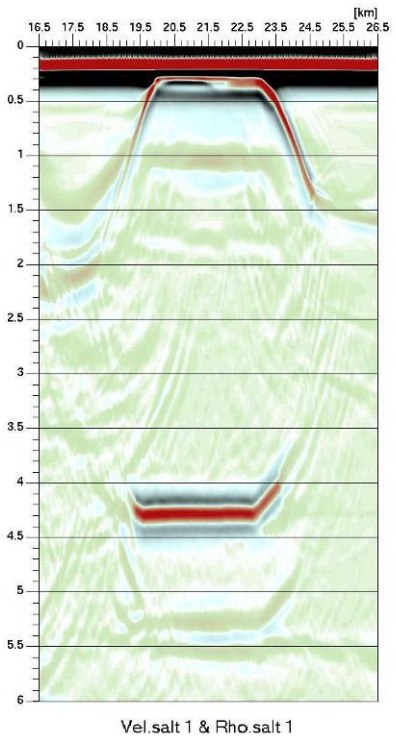
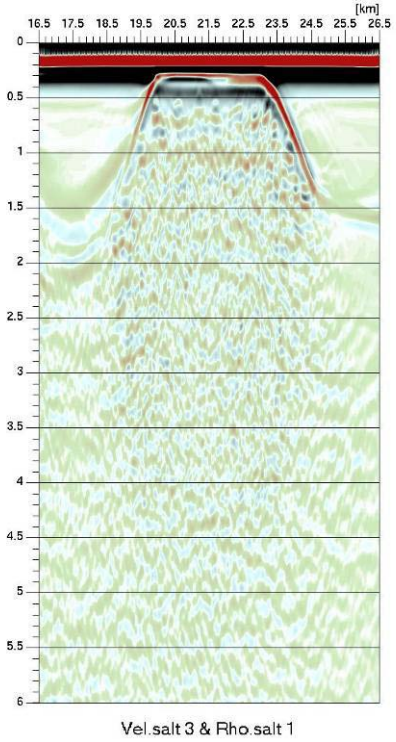
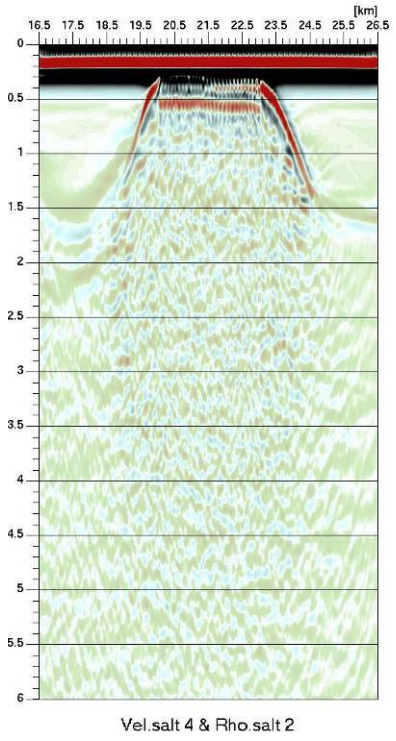
PSDM with clean-salt velocity model



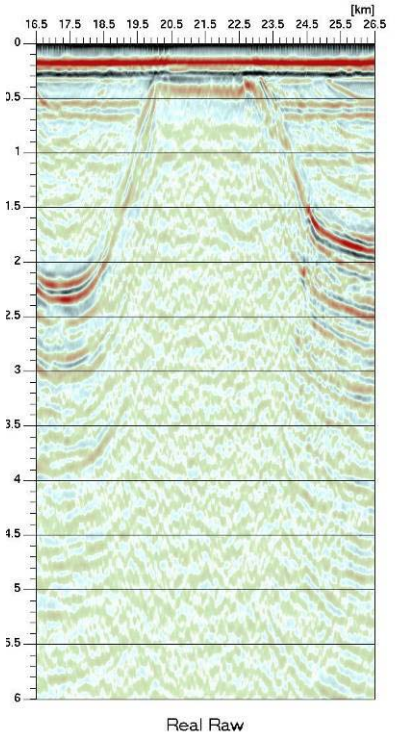
Clean salt



Diffractors



Diffractors and rugous top salt



Real data

Haugen, Arntsen and Mispel, SEG 2008

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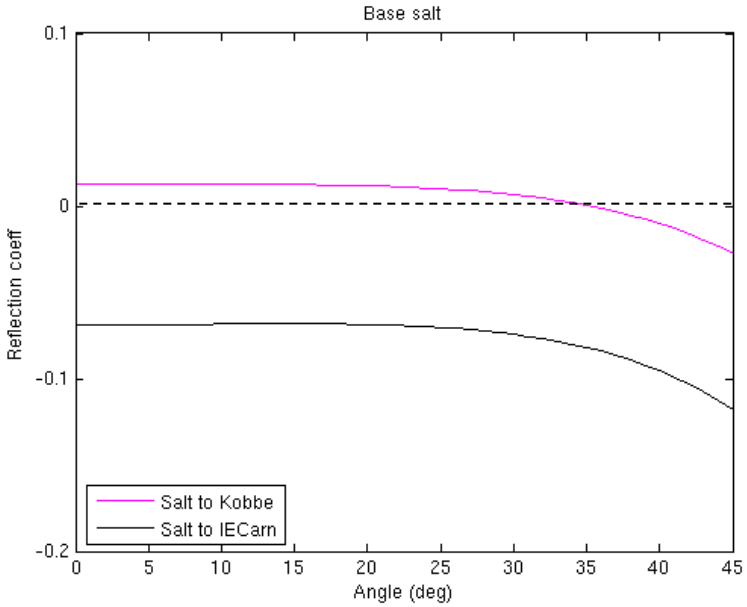
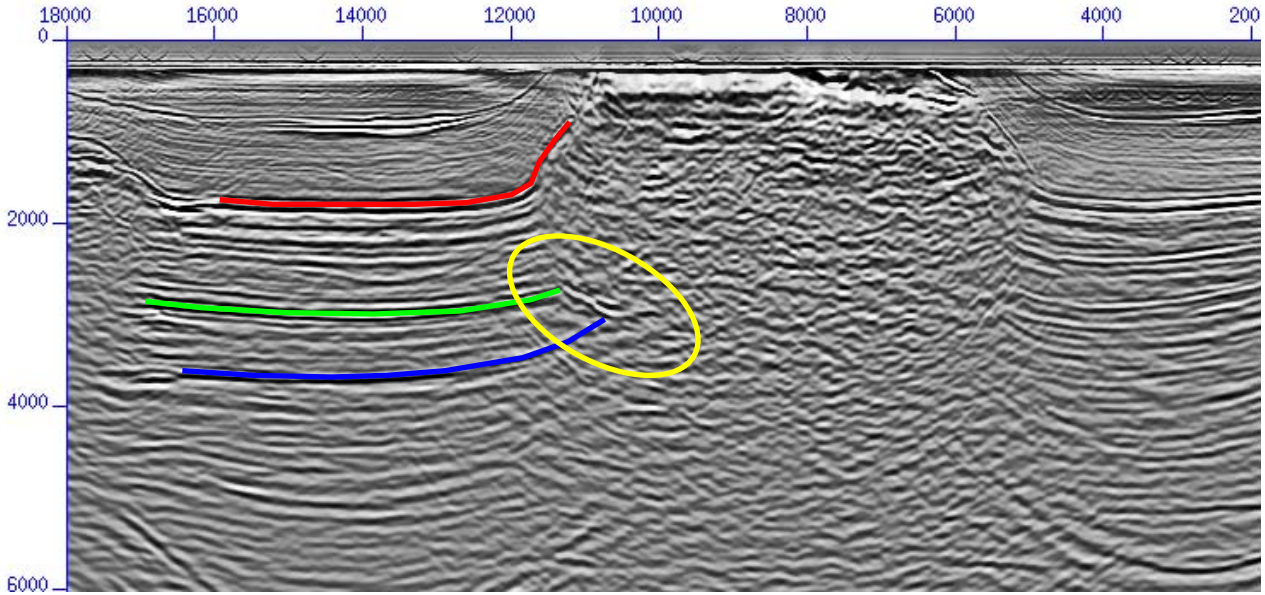
Week primaries

- BoS to Kobbe shale: “Invisible”; weak reflection at normal incidence and dimming
- BoS to TIE Carn: Similar to Carn Brine response; bright
- Hence, we should see a salt-trap if it is there





TTI anisotropic wave equation PSDM by Statoil R&D

BCU

Top IE Carn

Kobbe Fm

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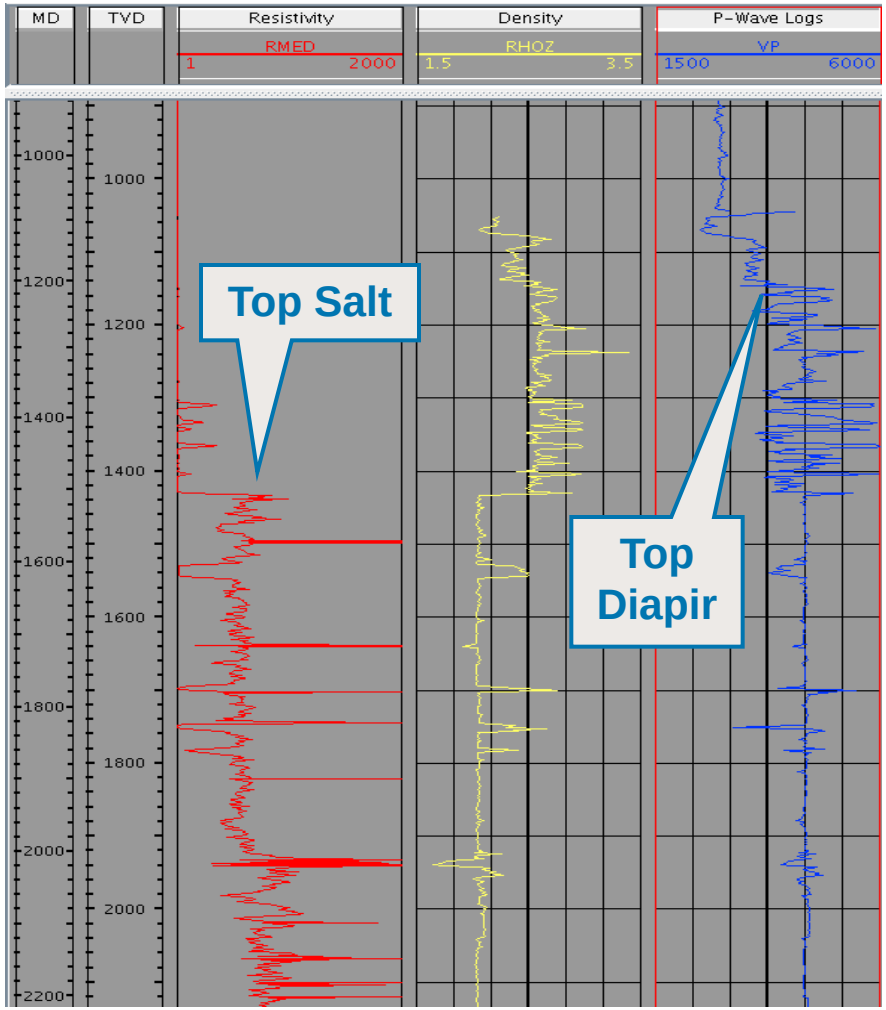
Can we image the salt-sediment interface with alternative geophysical methods?



Characteristic properties of rock salt:

- Low mass density
  - Gravimetry
- High electric resitivity
  - Magnetotellurics
  - Controlled-Source EM
- Imaging the salt-sediment interface with gravity and EM
- Seismic is needed to get the details

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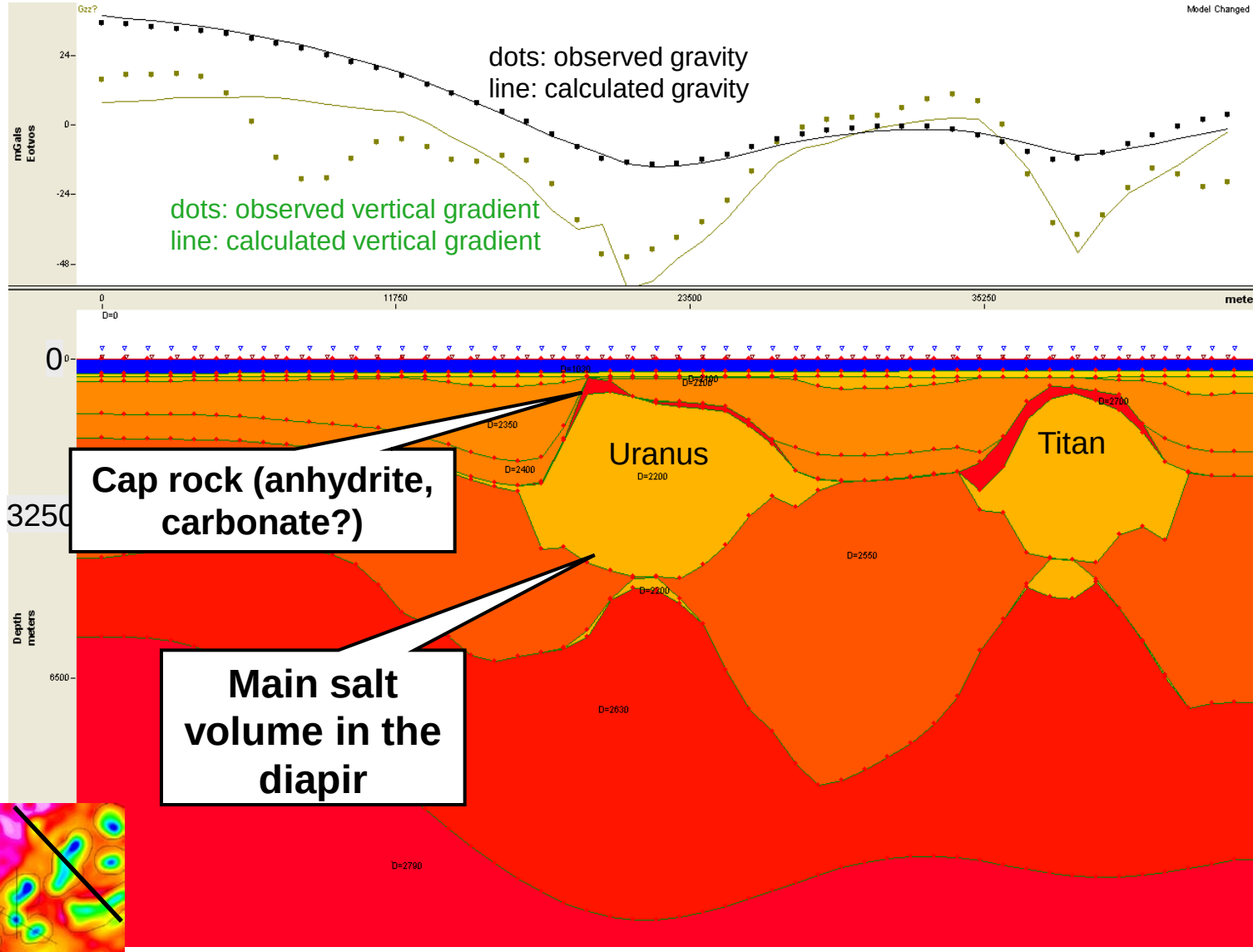

Gravity modeling by Christopher Stadtler

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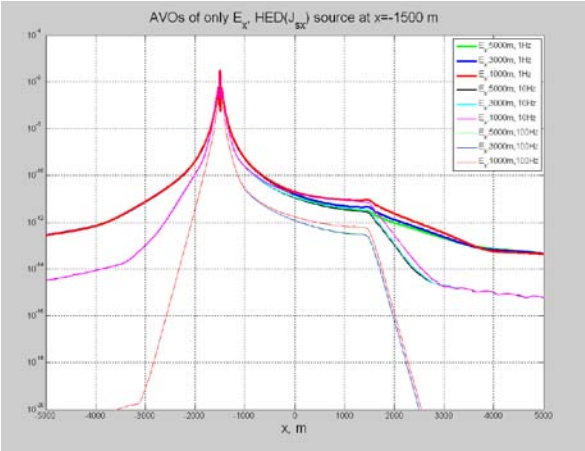
Salt imaging with CSEM
Phase 1: Proving the concept

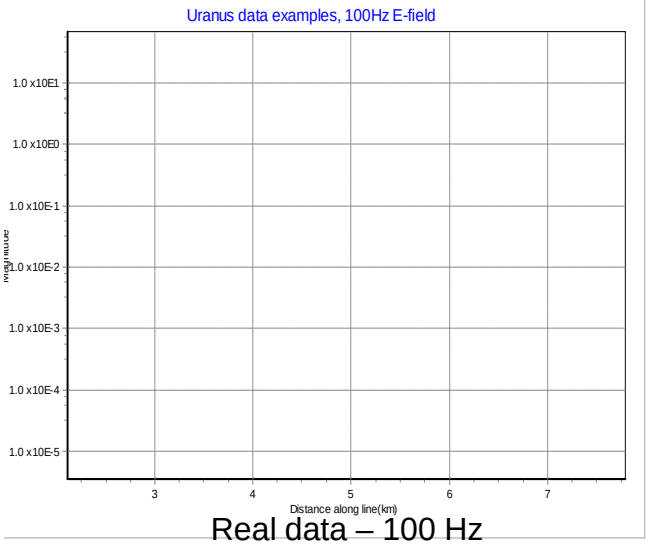
Novel idea proposed by Harald Westerdahl, formerly NGI:

- **Salt has high resistivity (we logged 1000 Ohm-m in Uranus well)**
- **Salt imaging using CSEM should be feasible**
- **Receiver development and field test with NGI in 2006**



Pre-survey modeling

Receiver sled landing on Uranus seabed, 15. August 2006



Real data – 100 Hz

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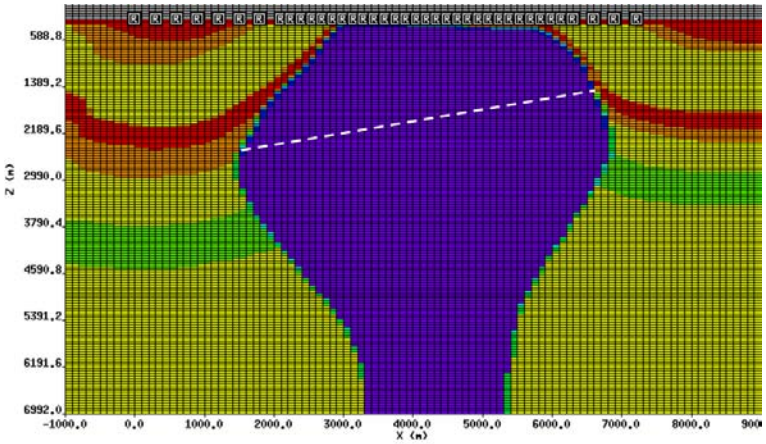
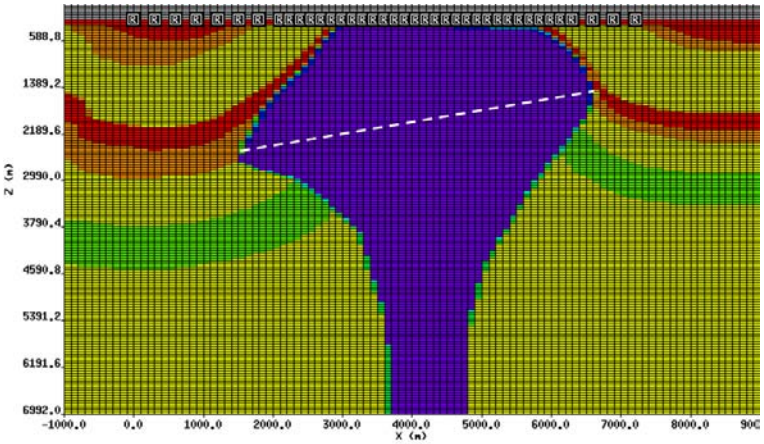
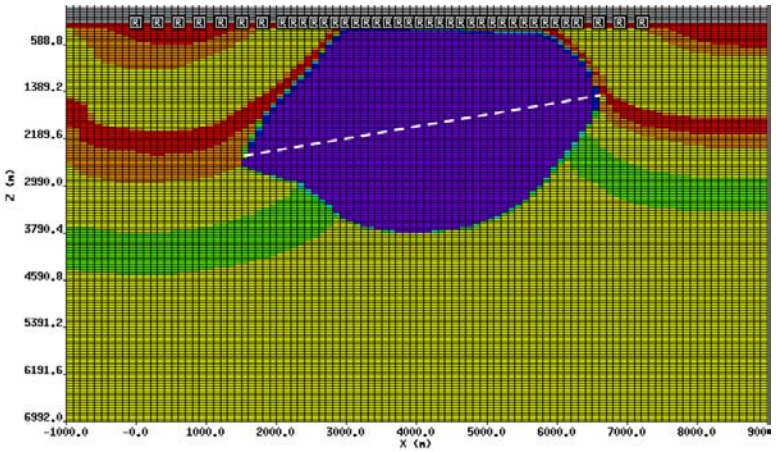
Feasibility - CSEM





- **Max and min salt models**
- **Salt resistivity: 1000 Ohmm**
- **Can CSEM discriminate between max and min salt cases?**
- **Can CSEM see the salt stem?**



Statoil in-house

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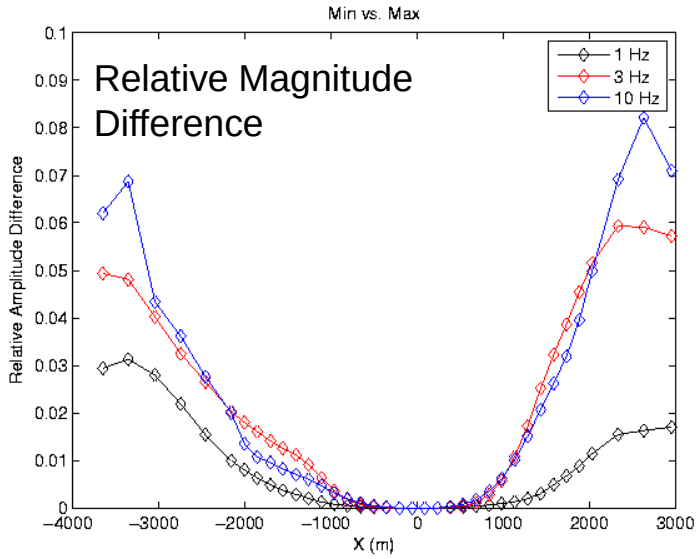
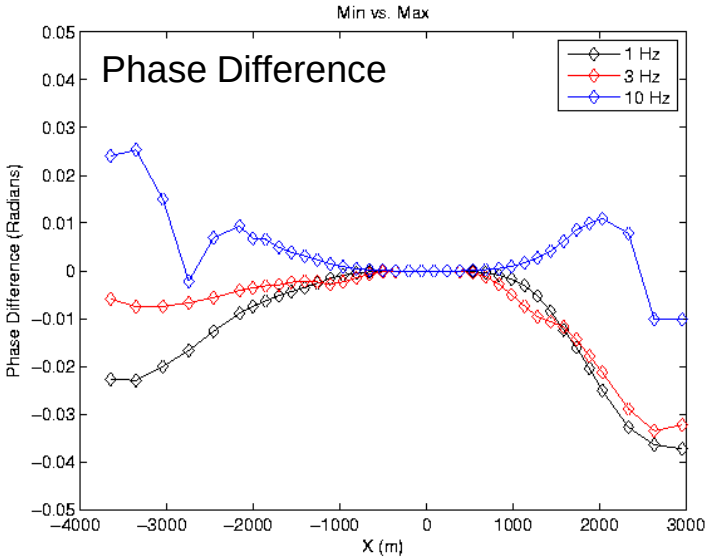
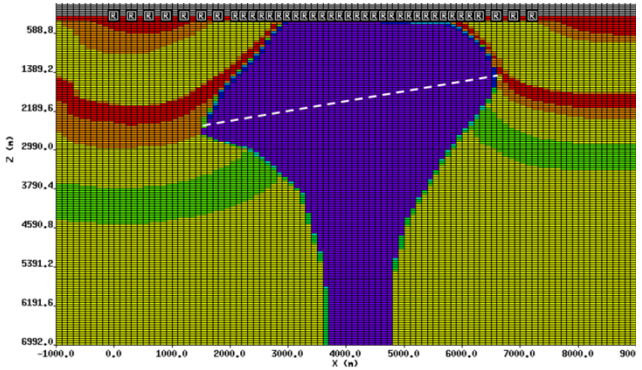
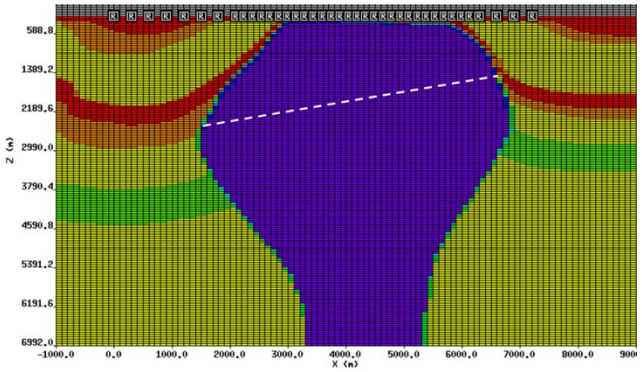
Min vs max salt interpretation









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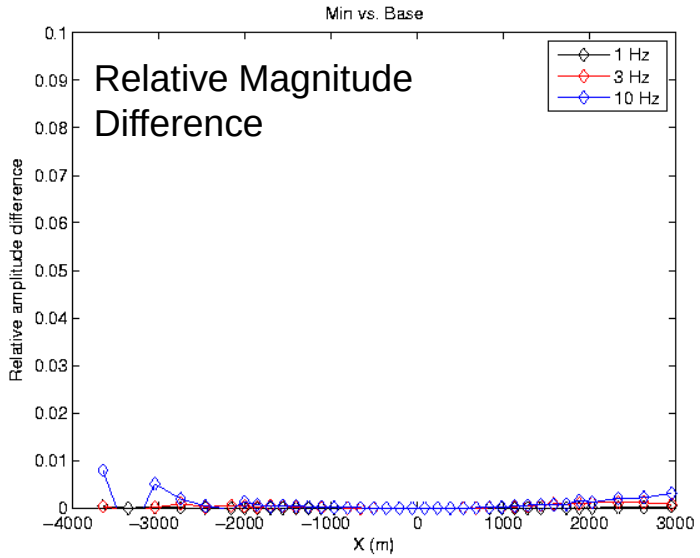
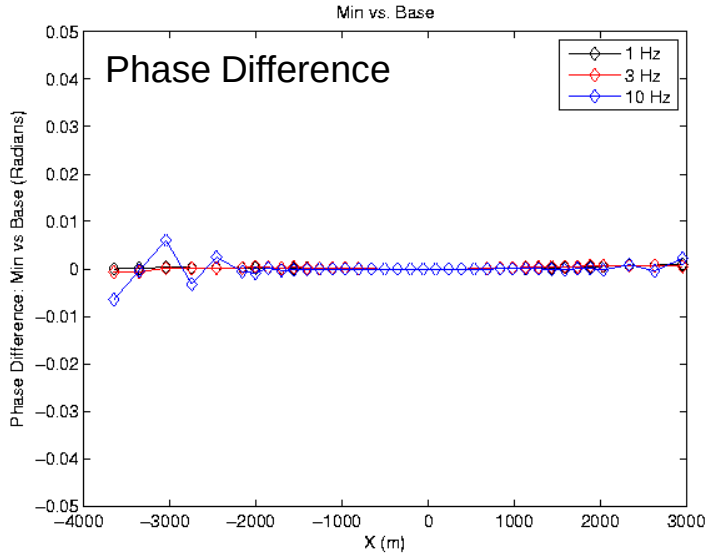
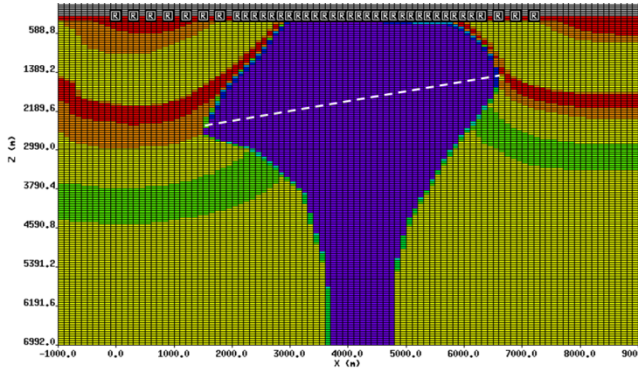
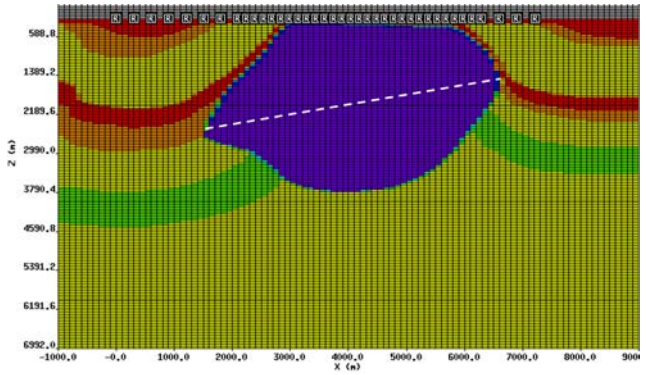
Min salt with and without stem









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Salt imaging with CSEM and MMT
Phase 2: Acquisition with EMGS April 2007

EM acquisition with emgs,
Nordkapp Basin April-May 2007

- **Same receivers for both CSEM and MT**
- **CSEM: Purpose designed high-frequency source signal**
- **MT: 48 hours nominal listening time**

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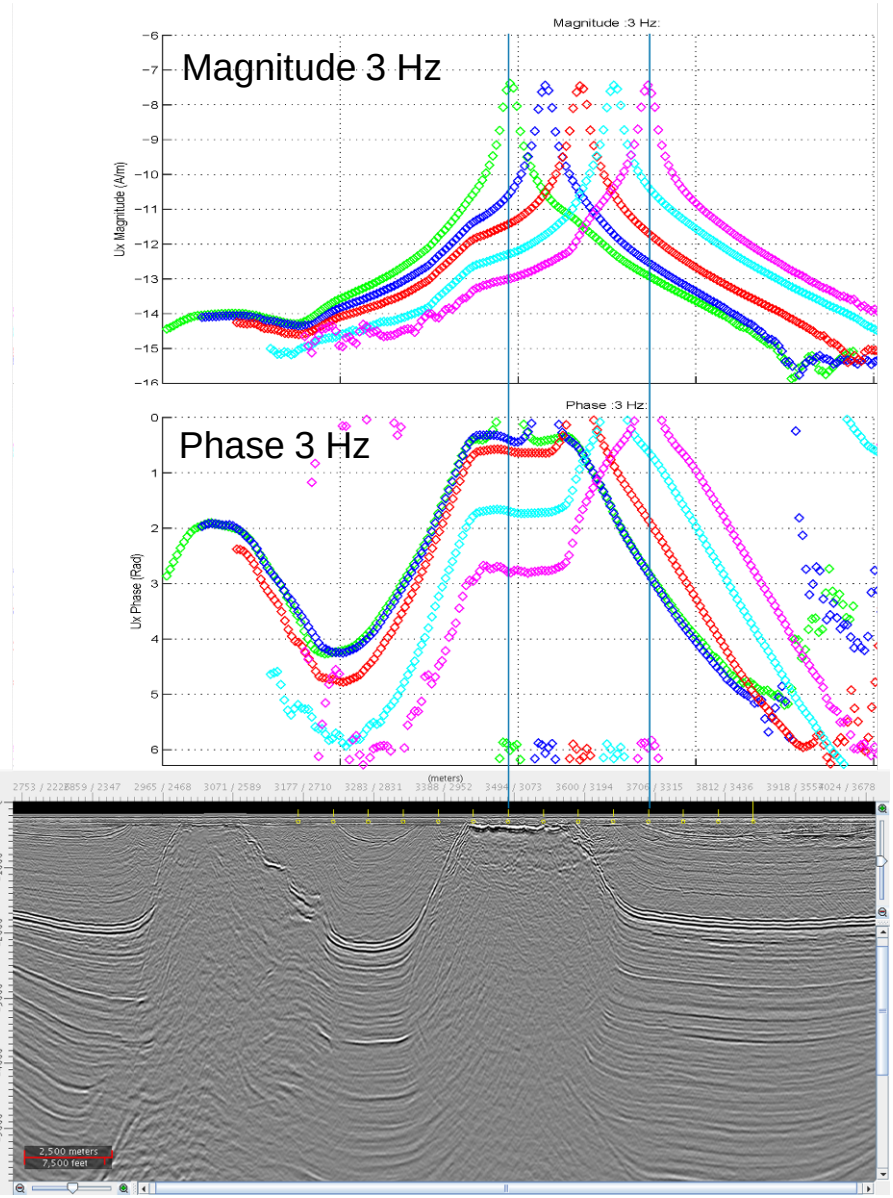
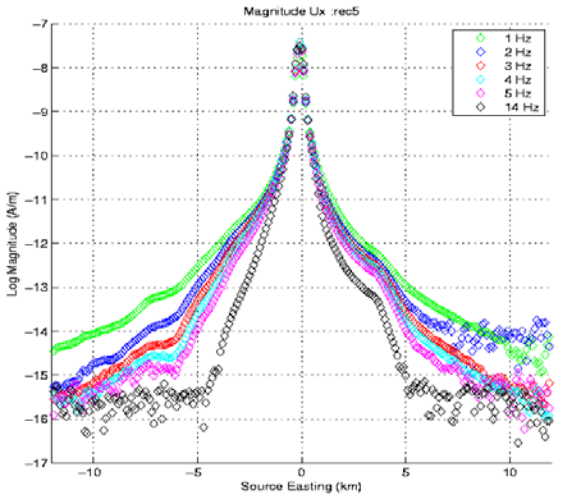
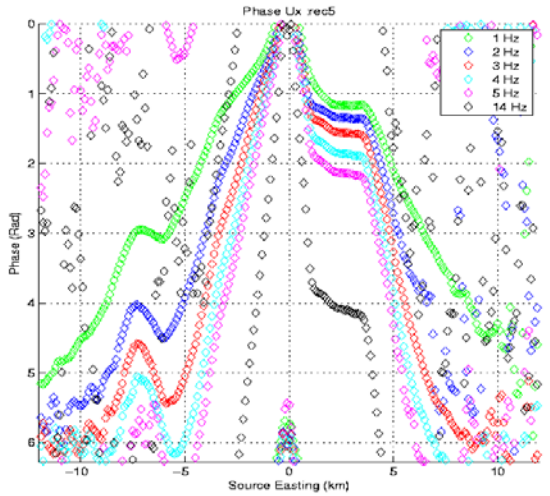
CSEM magnitude and phase - Up-going Ex







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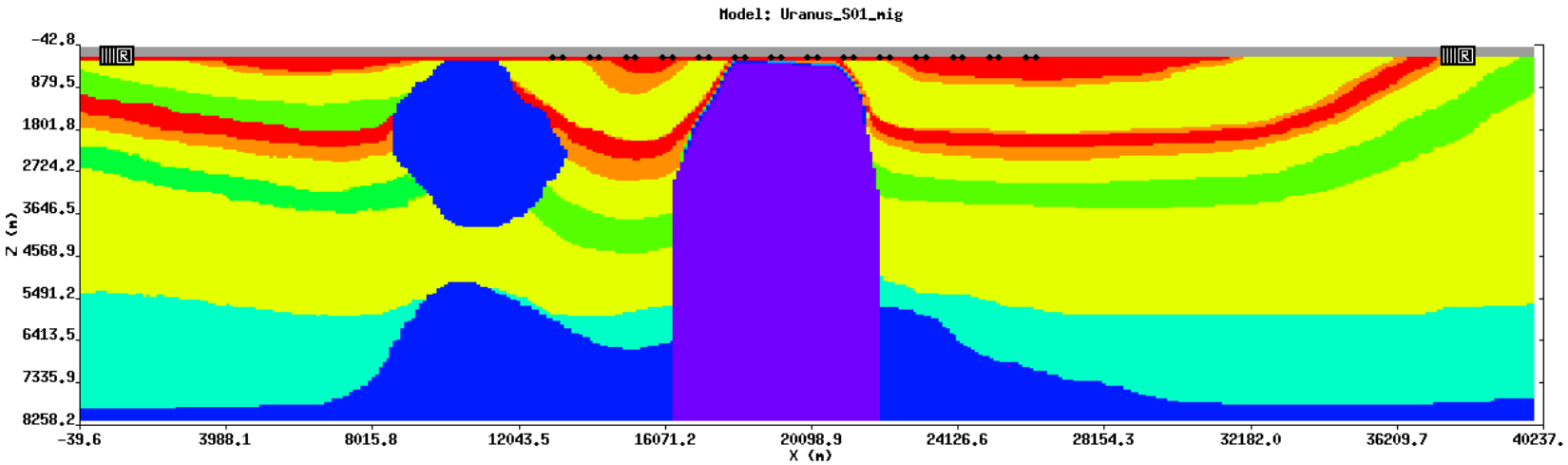
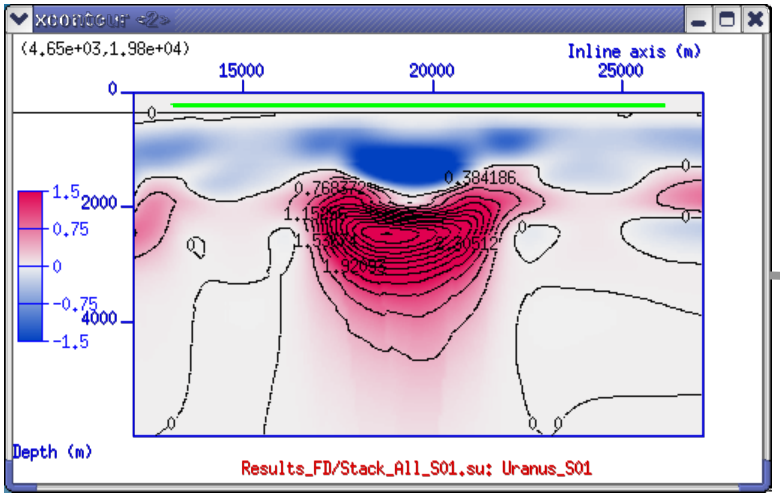
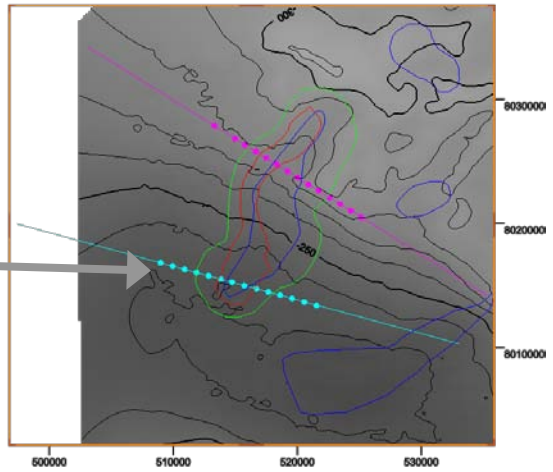
CSEM salt-flood model and depth migration







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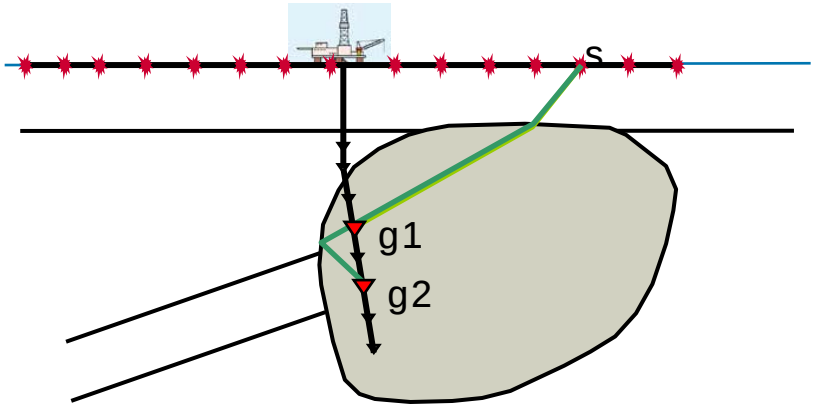
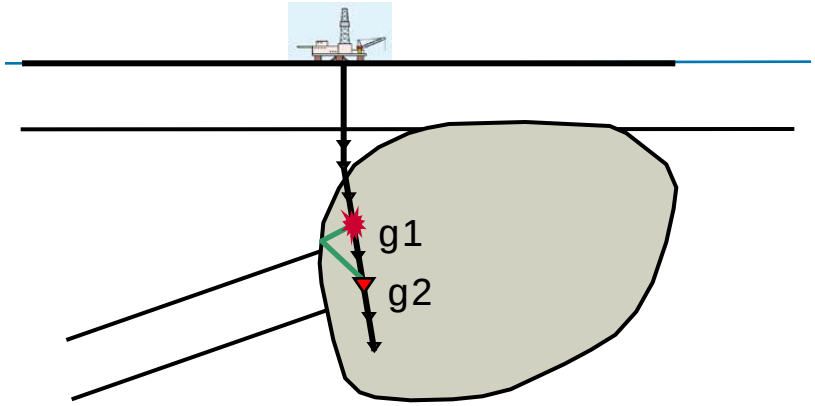
From walkaway to virtual sources



Real walkaway VSP acquisition geometry



Virtual source geometry

The Virtual Source method was first used by Bakhulin and Calvert (SEG, 2004) and is claimed a patent by Shell

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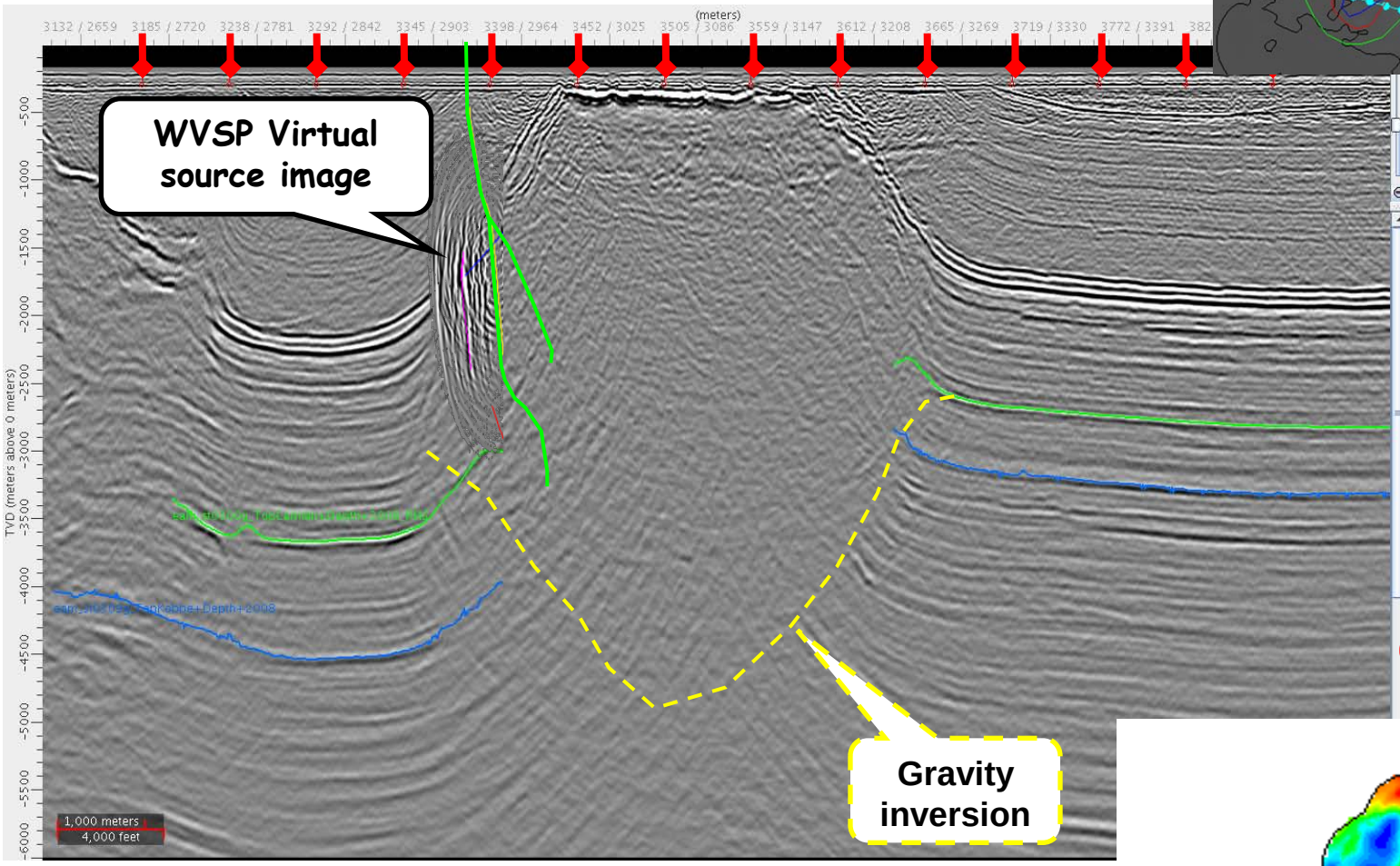
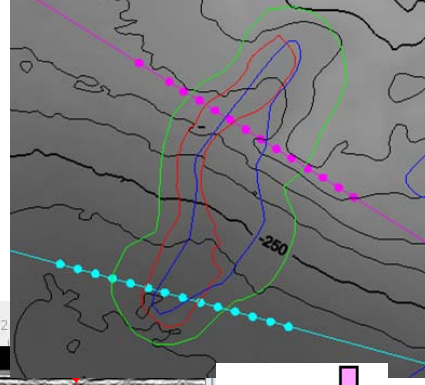
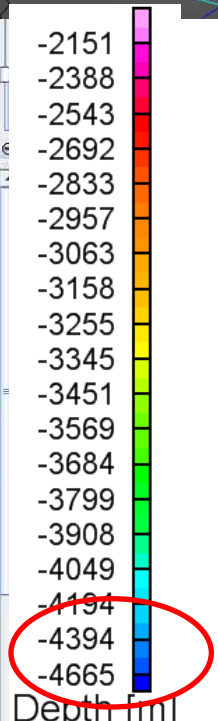
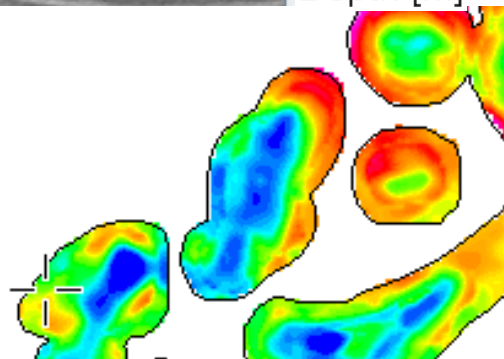
Uranus S01 (well line) – 3D PSDM

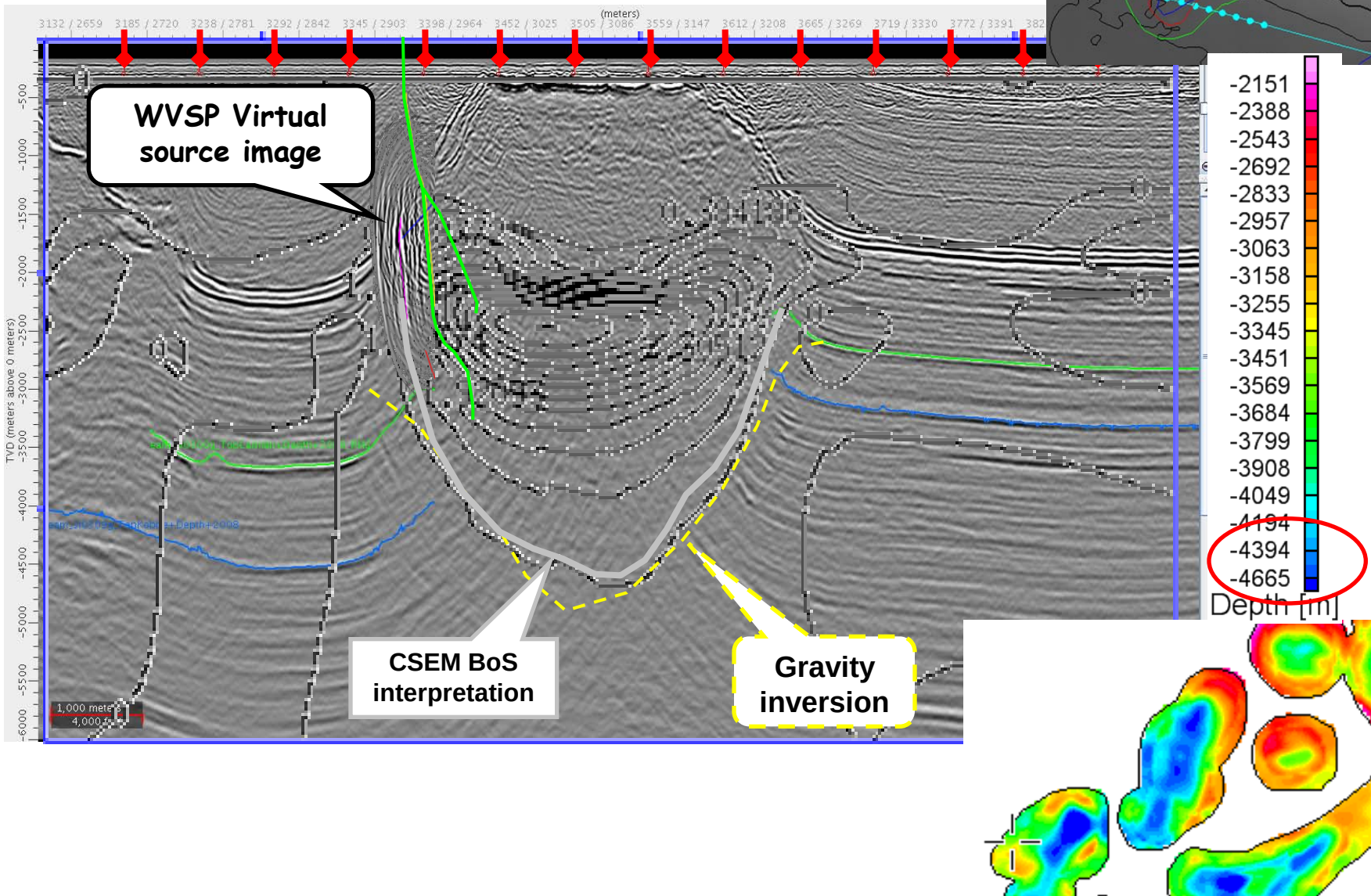




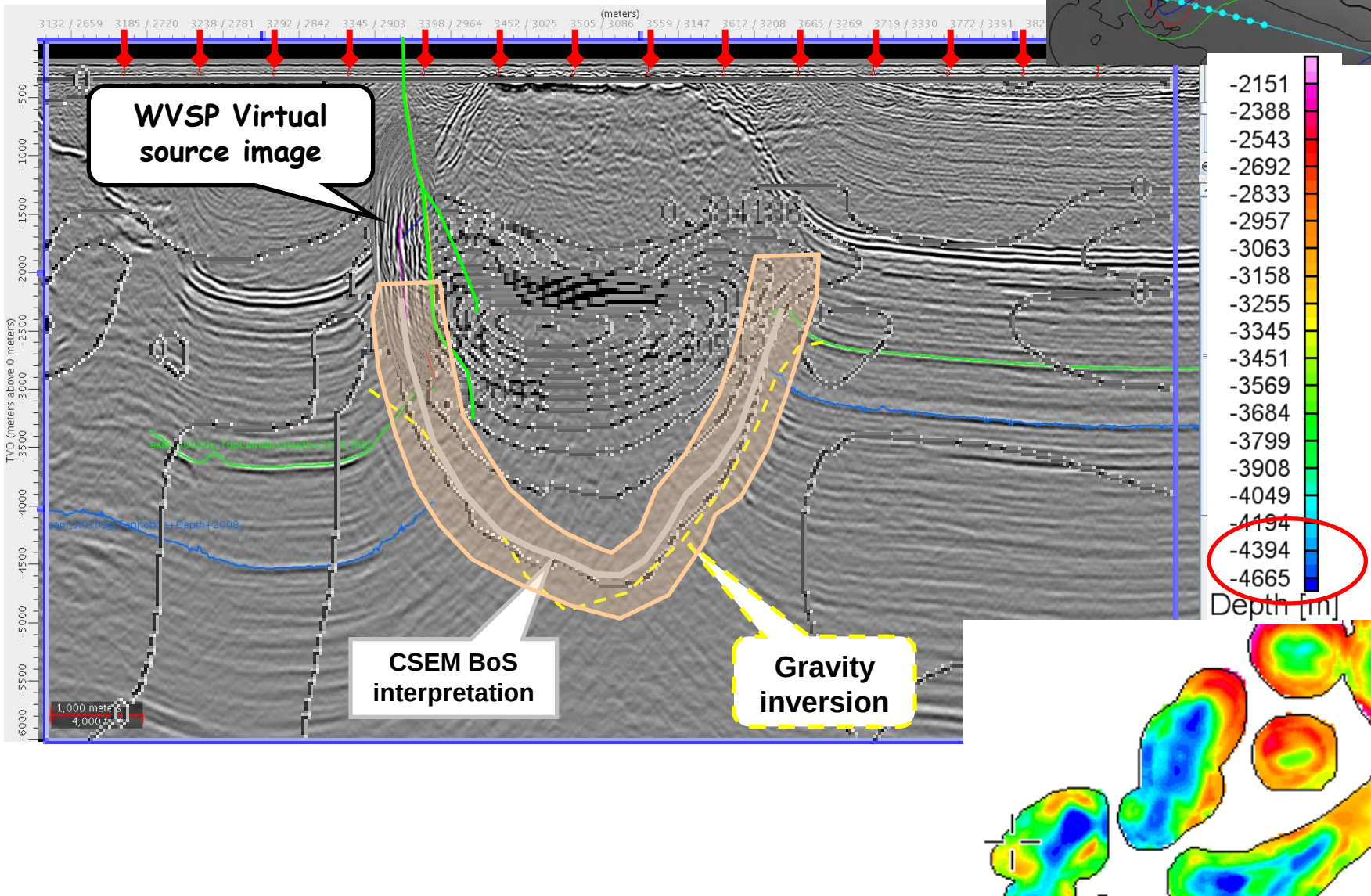




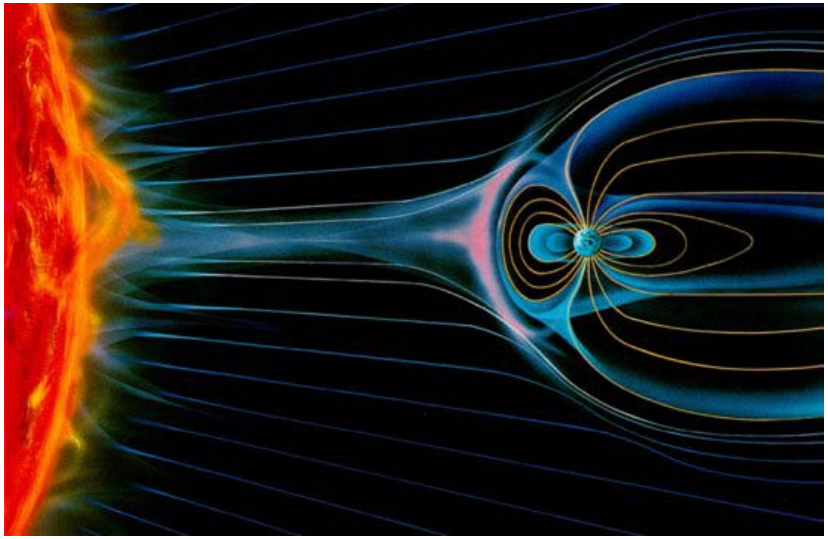
Uranus S01 (well line) – CSEM migration

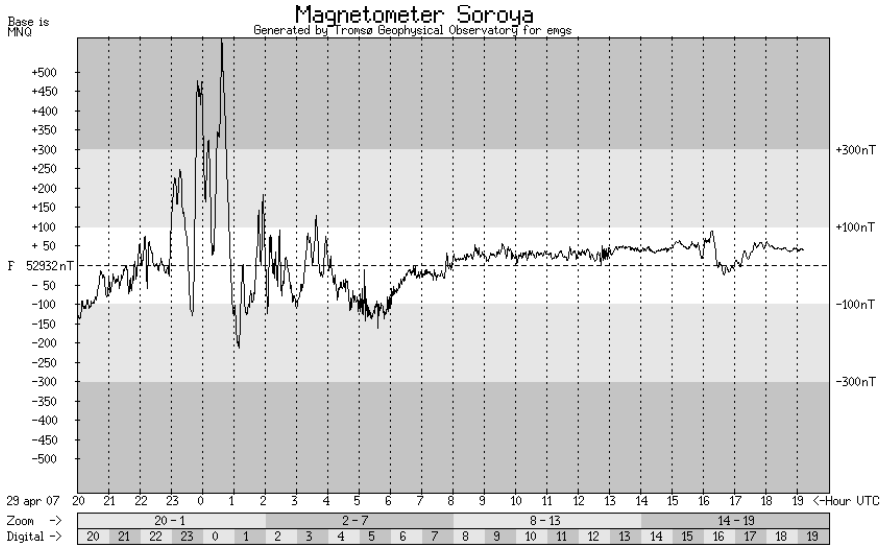


Uranus S01 (well line) – CSEM migration



Magnetotellurics (MT)





- Passive exploration method
- Naturally occuring geomagnetic variations is the power source

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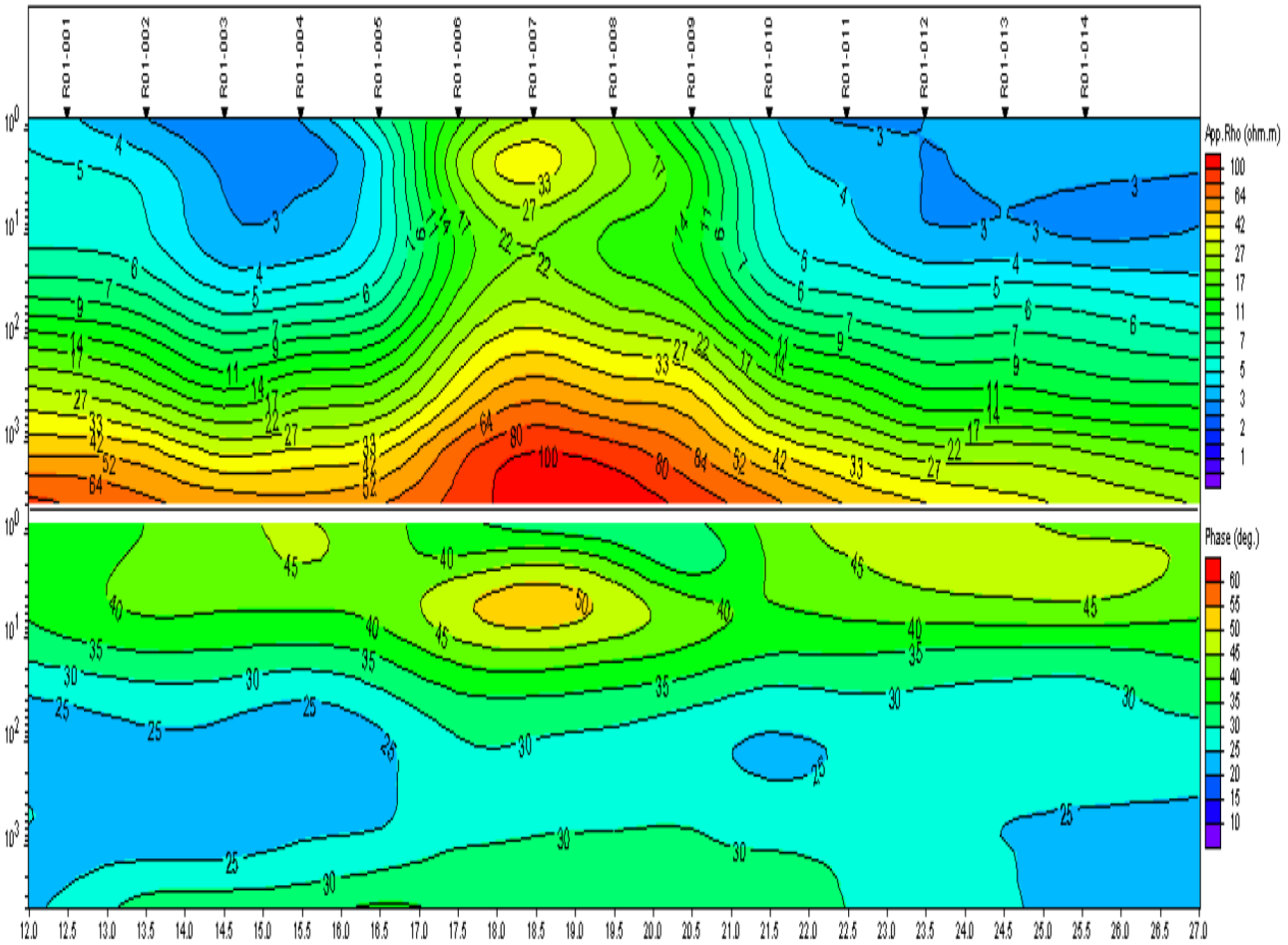
Uranus S01 (well line) – MT apparent resistivity

TM mode



MT processing by Geosystem – Luca Masnaghetti

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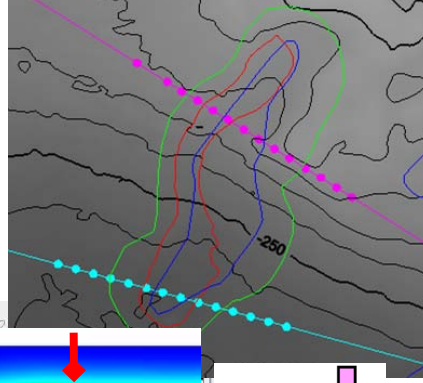
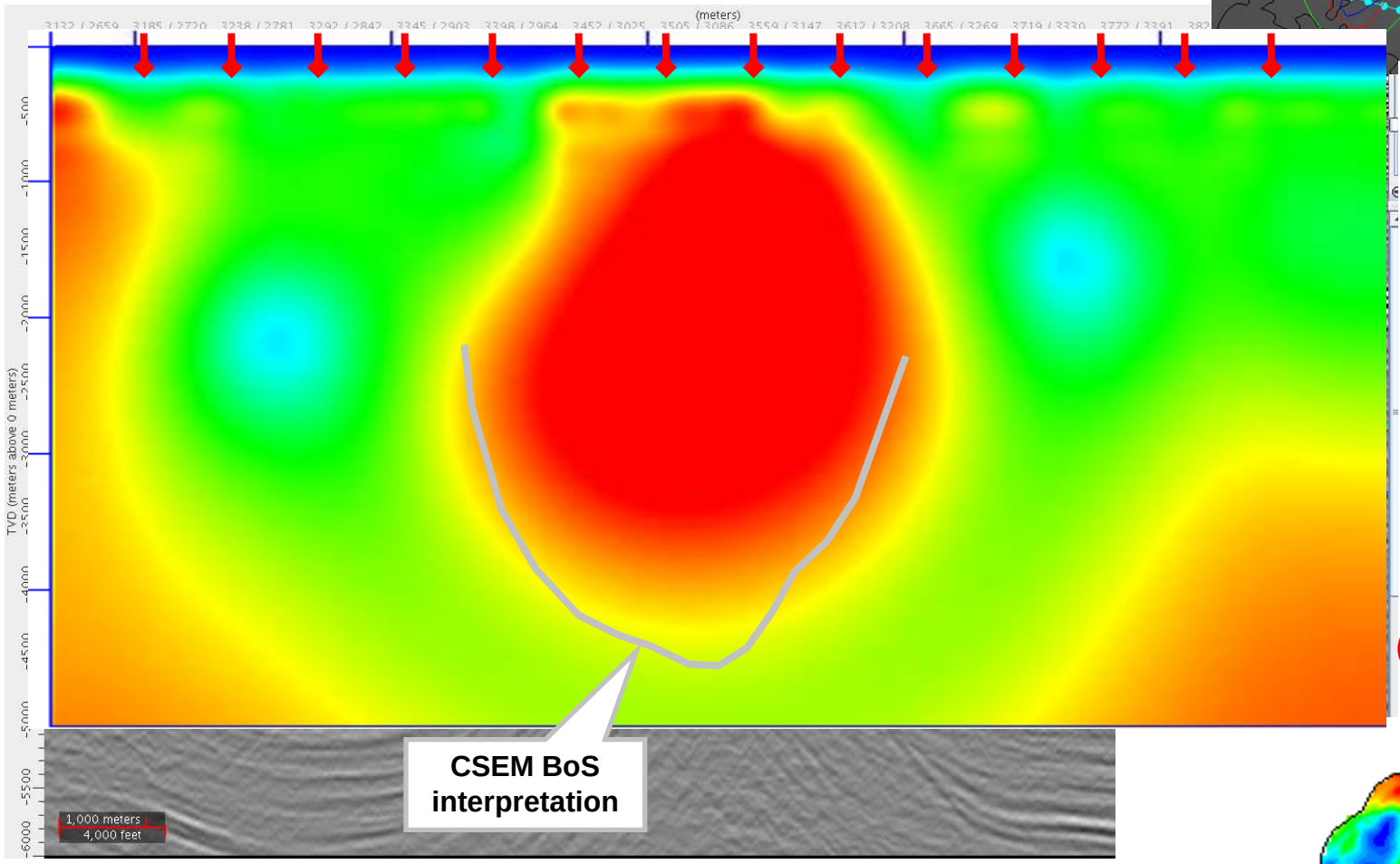
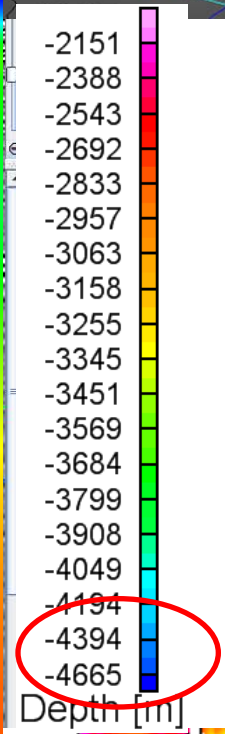
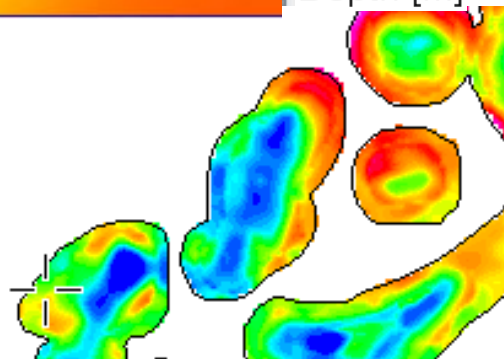
Uranus S01 (well line) – MT inversion

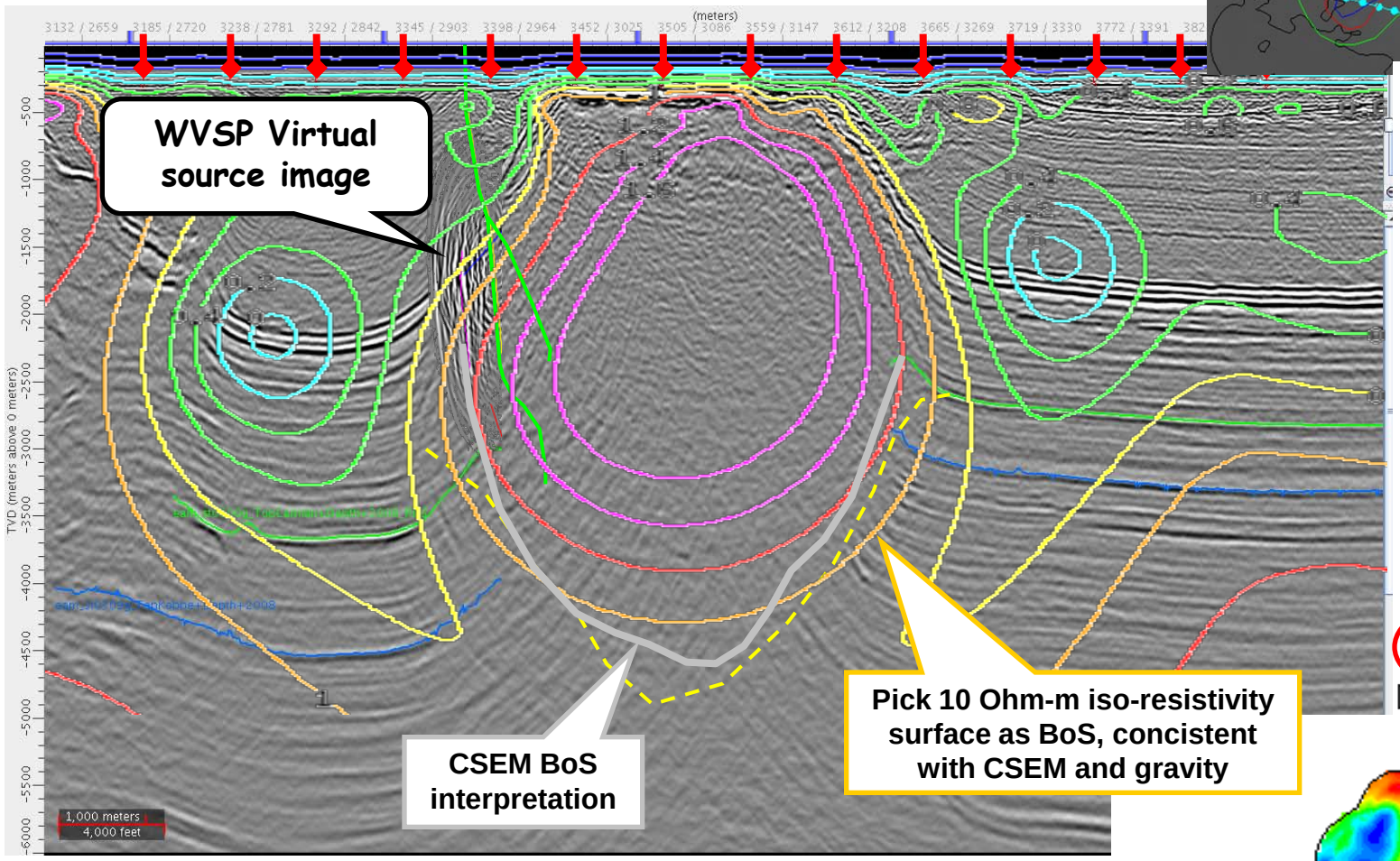


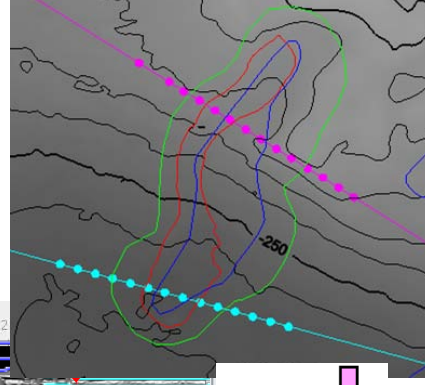


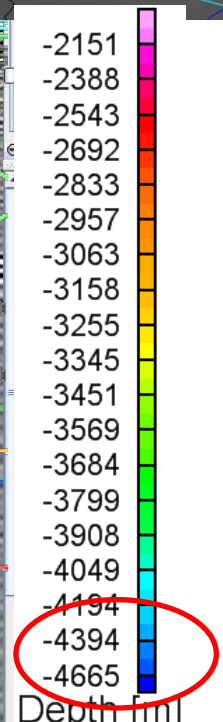


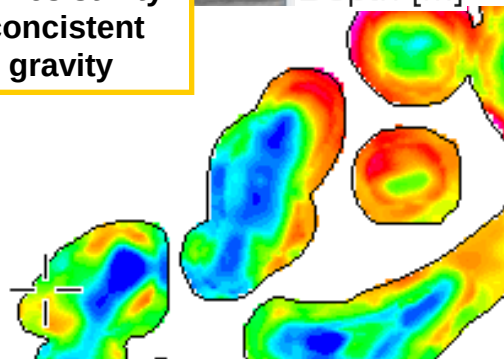


Uranus S01 (well line) – MT and CSEM



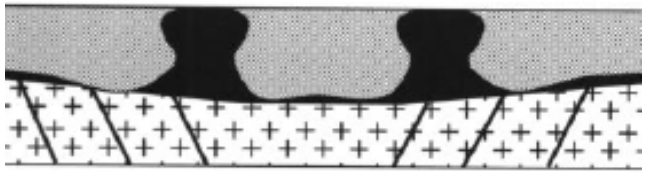






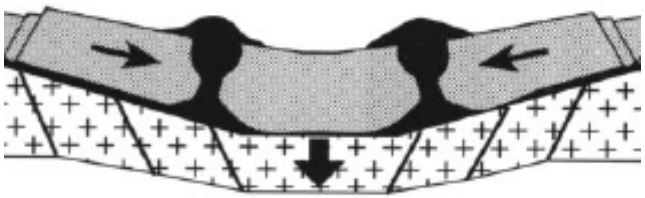
Nordkapp Basin - Brief geological history

Early Triassic: Reactive diapirism



Middle Triassic: Differential loading

?



Middle Triassic: Rapid diapir rise and salt extrusion

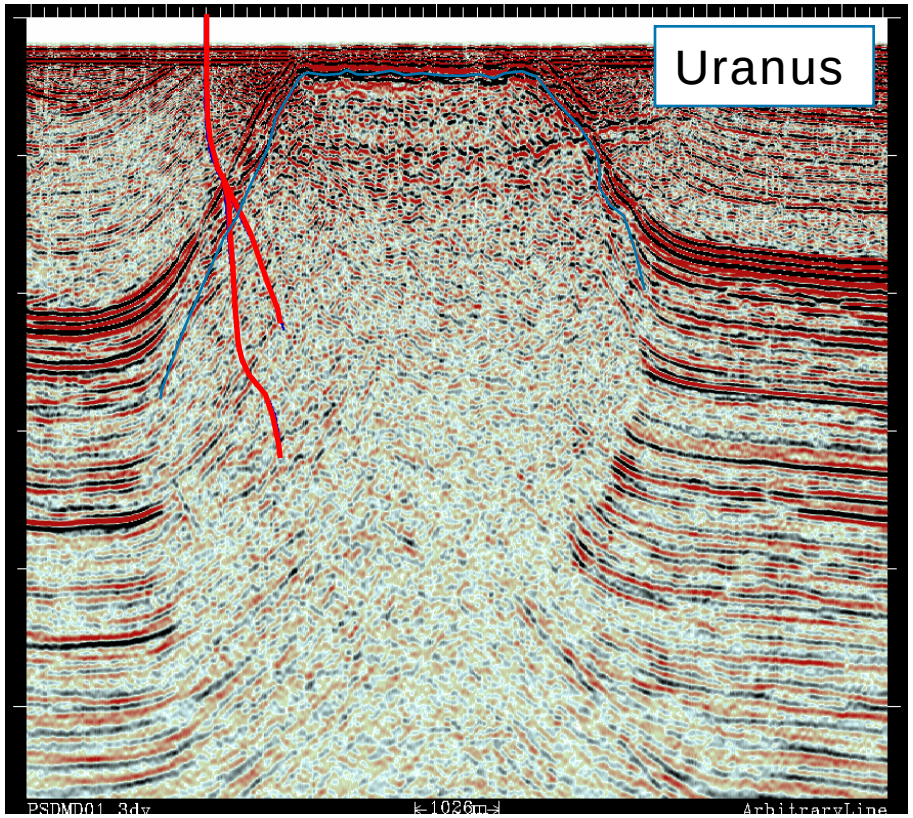
Tertiary: Diapir shortening and uplift

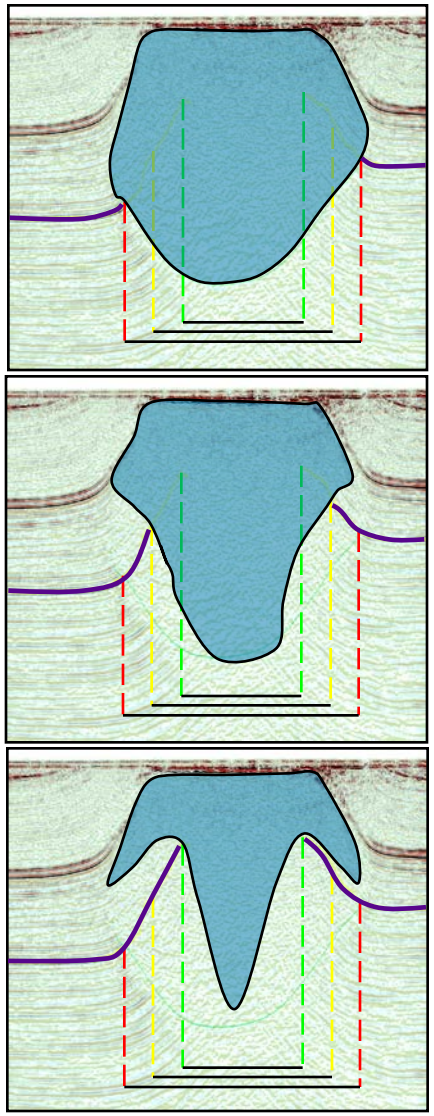
Tertiary: Erosion

Nilsen, Vendeville and Johansen (1995)

Statoil

Economic implications of salt body size and shape

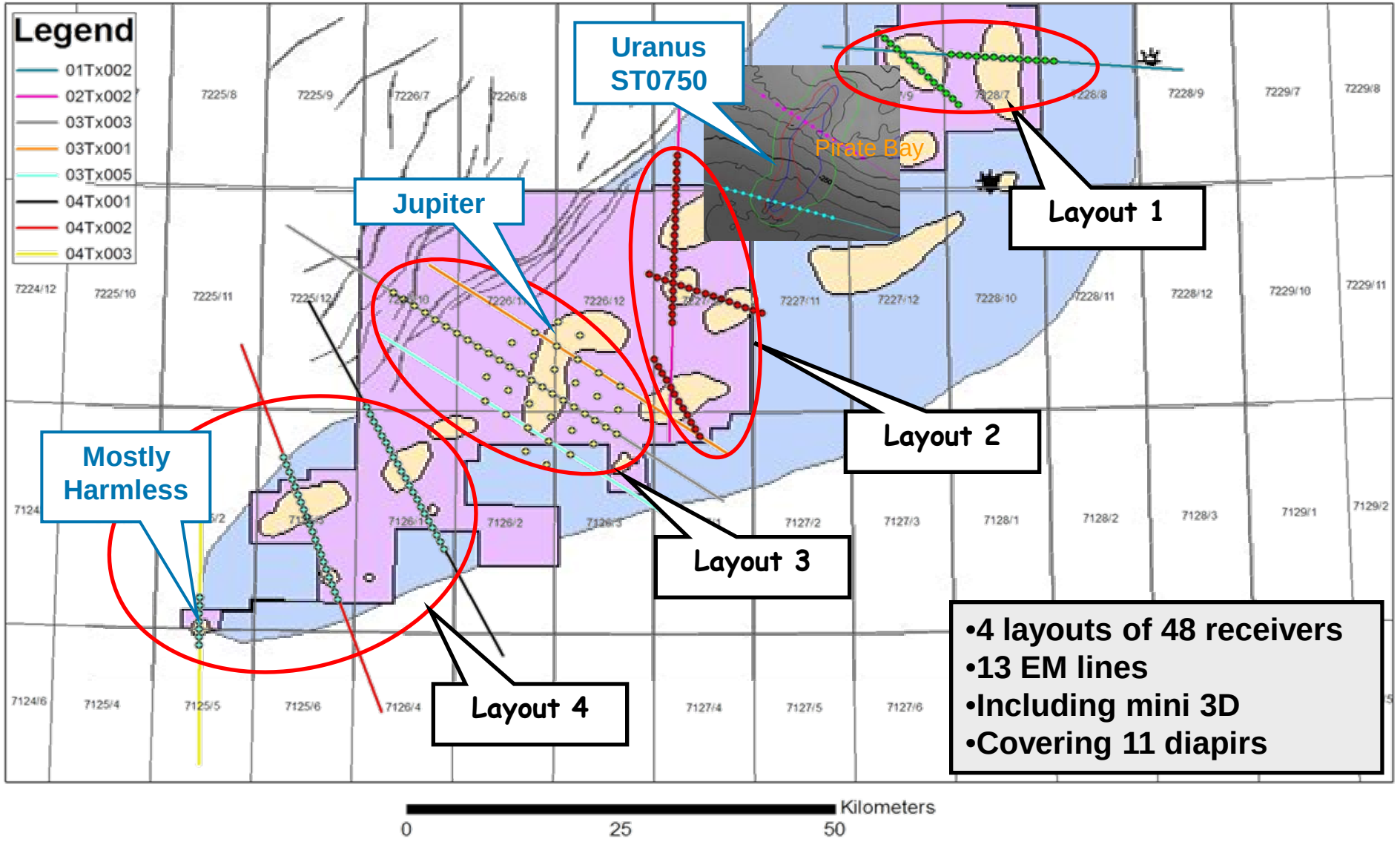




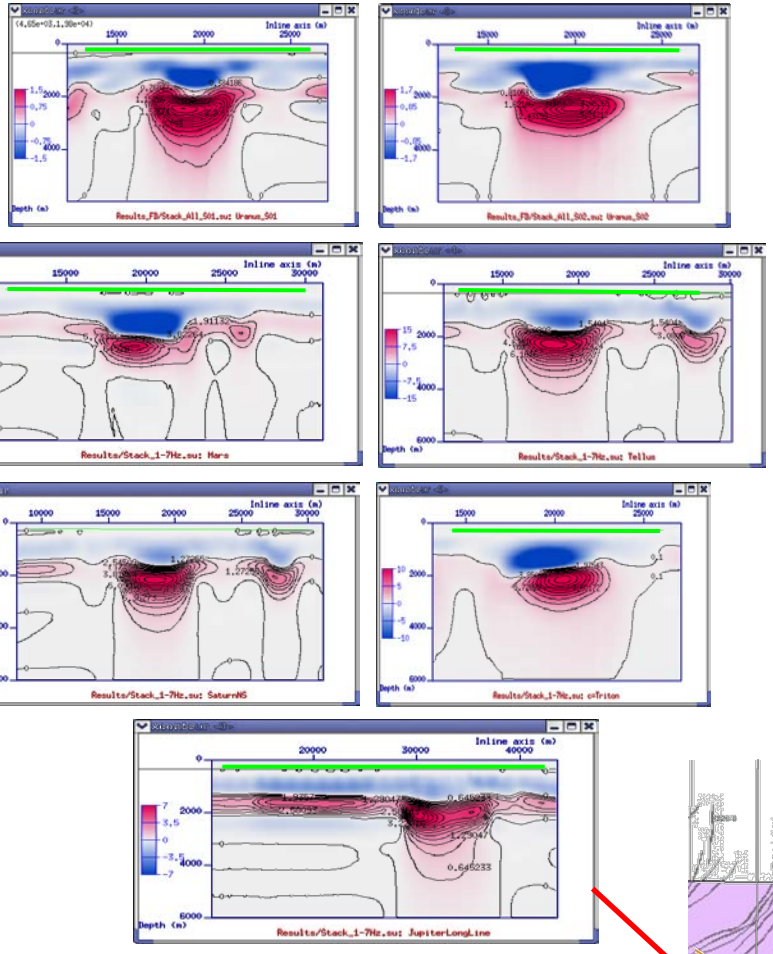
- **Large salt – small volumes**
- **Small salt and overhang – large volumes**

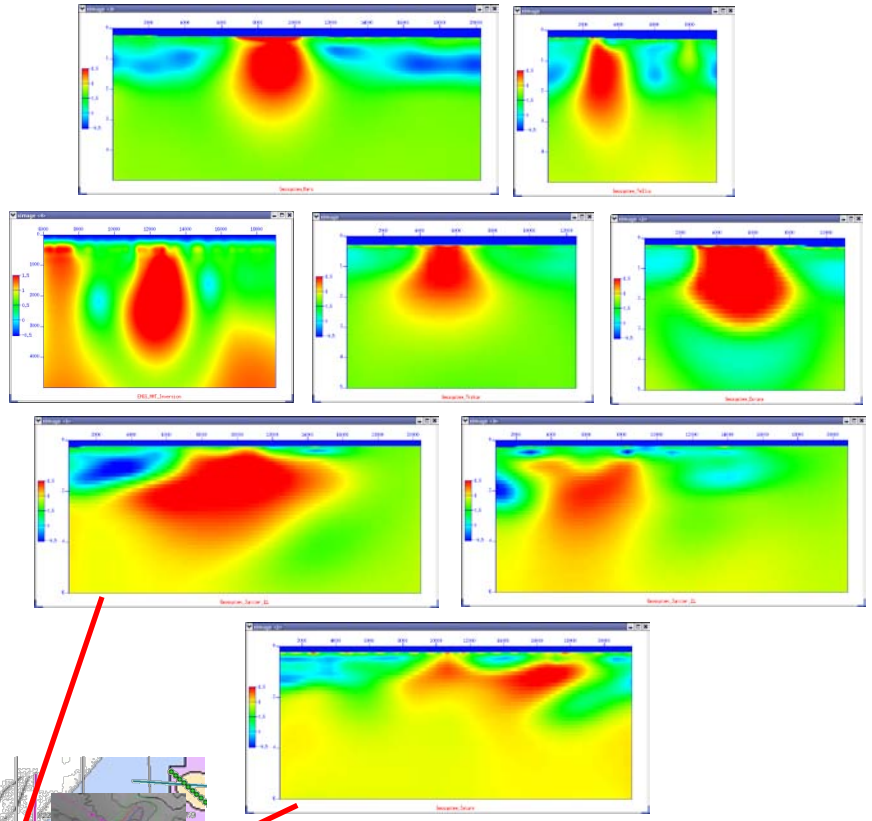
Statoil

Salt imaging with CSEM and MMT
Phase 3: EM campaign in Seismic Area F (PL230)



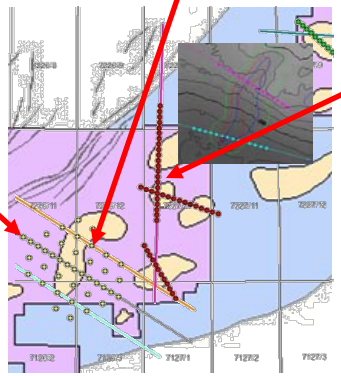
EM campaign – Results





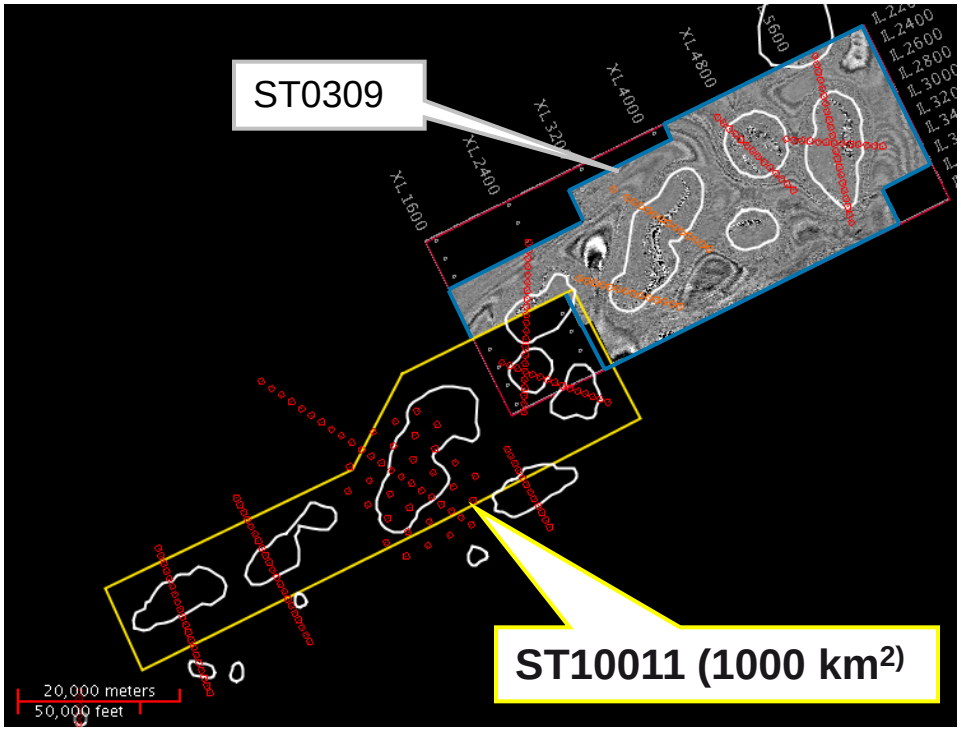
CSEM depth migration

MT inversion



Statoil

PL230 3D seismic acquisition and processing 2010-2011



- Deep receiver tow: 15m
- Short near offsets: 100m

Fast track 3D depth imaging

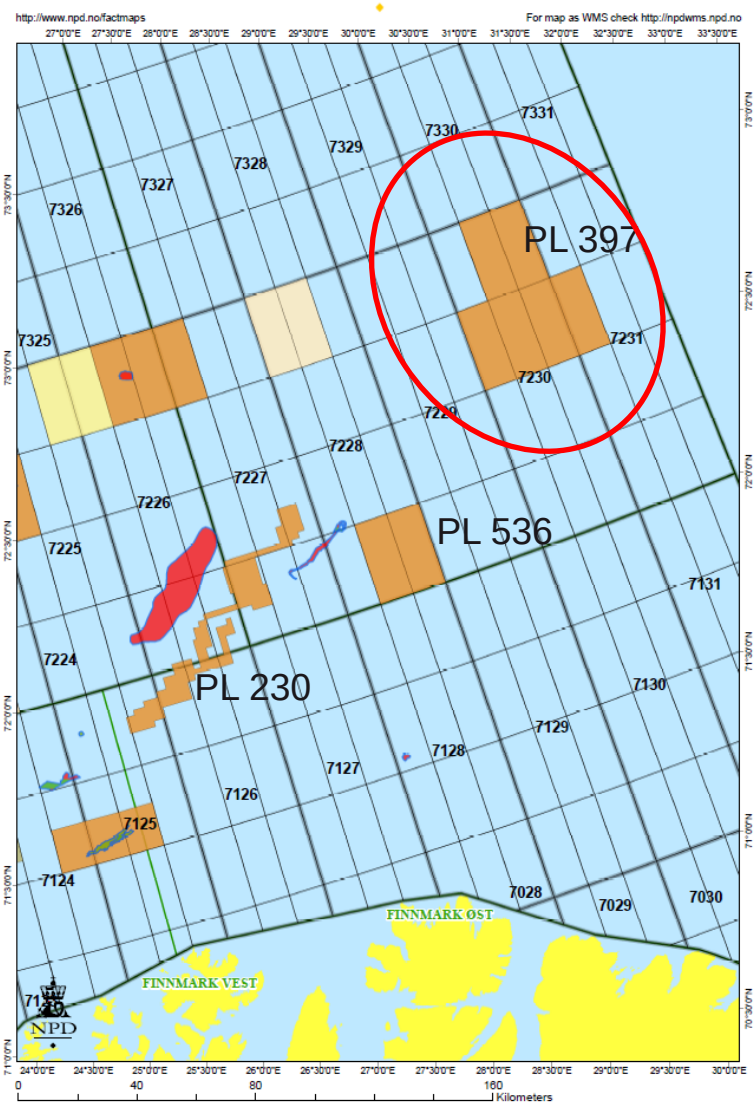
- Onboard time processing
- 3D poststack depth migration

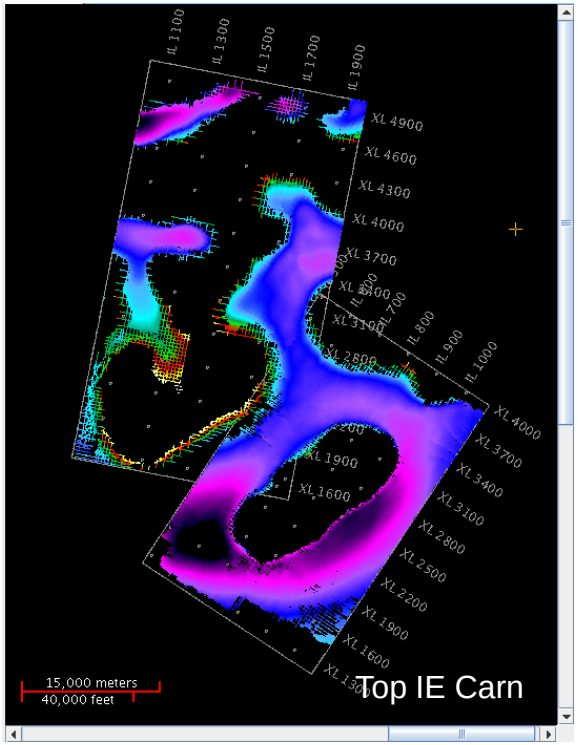
3D joint imaging:

- Sediment flood
- Anisotropic tomography update
- Top salt interpretation
- Joint EM and gravity inversion
- Salt flood
- Base salt joint interpretation
- Sub salt scans

Statoil

Northern Nordkapp Basin - PL379

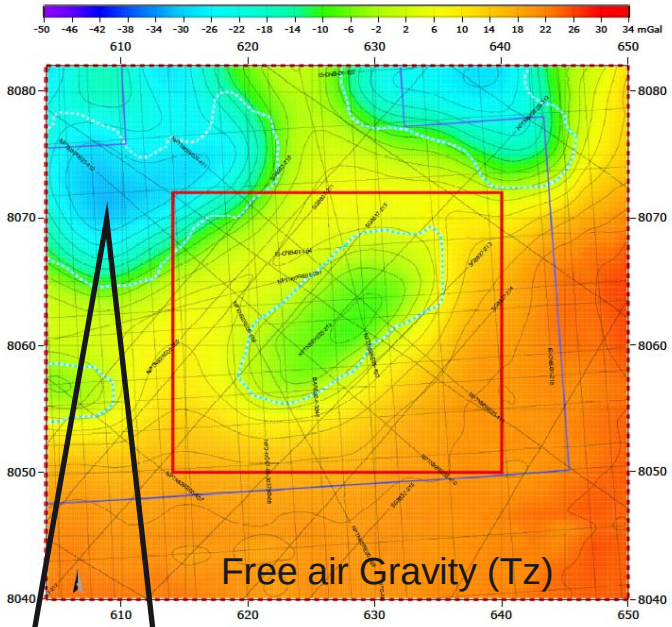




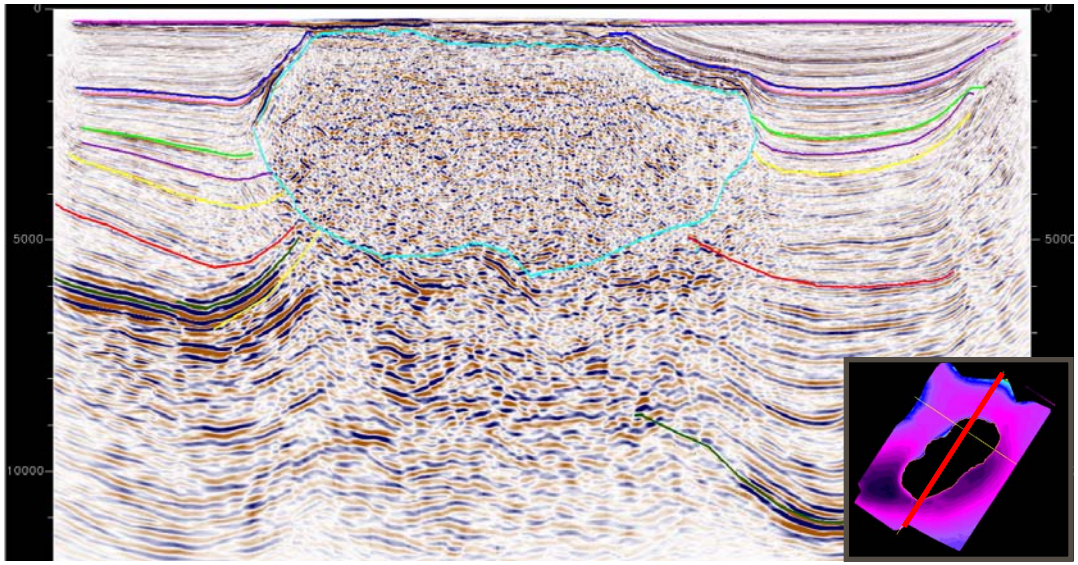
- 3D seismic surveys: ST0624 and ST0811
- Gravity and FTG data
- CSEM and EM lines

Statoil

ST0624 - Horizons interpreted



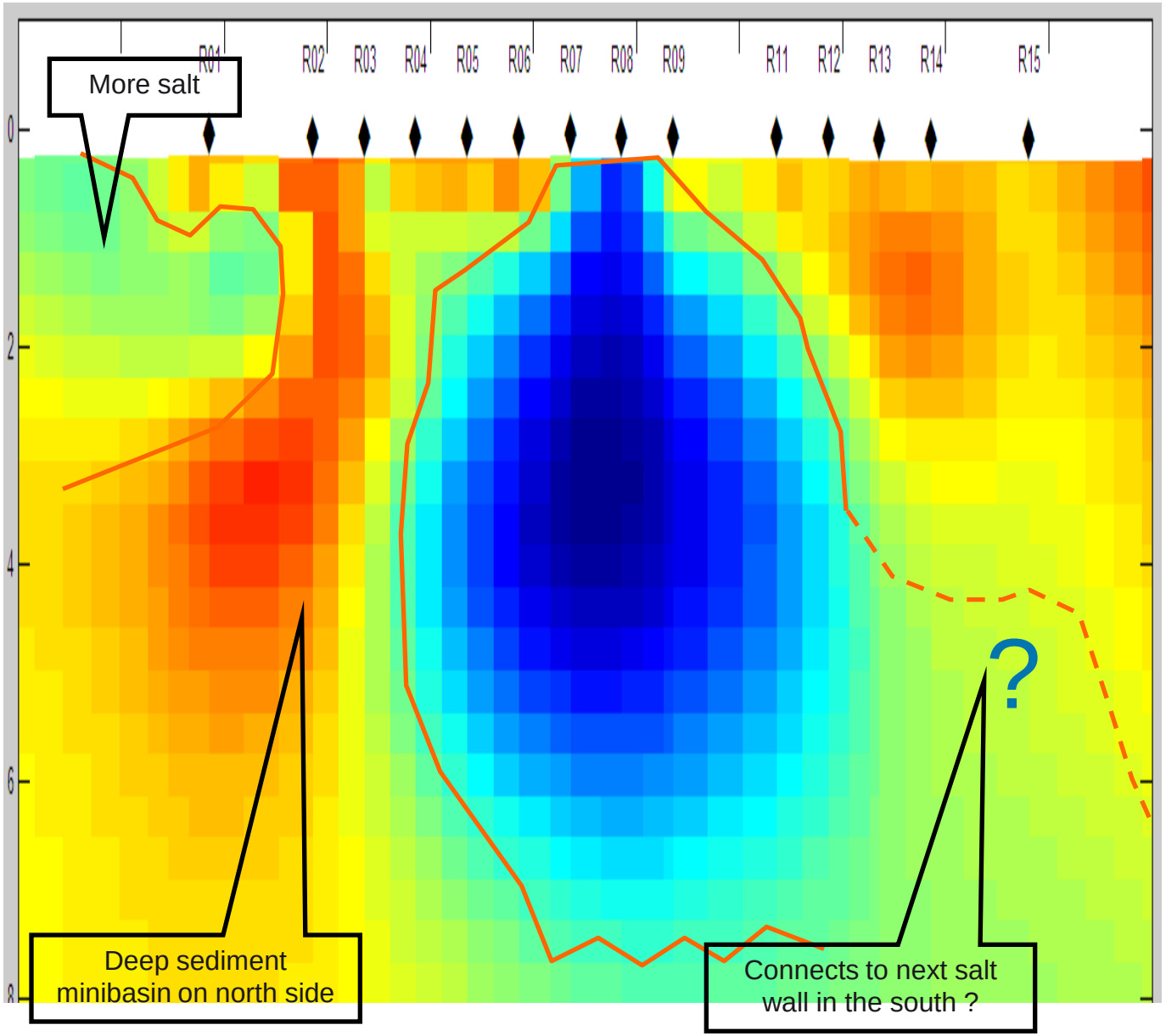
Even more salt than Aramis

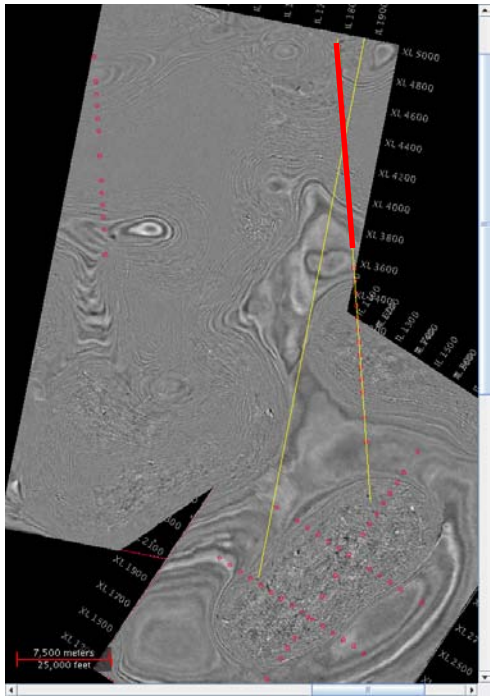


- Deep base salt; 5-6 km
- No prospective salt overhangs
- Small Carnian onlap closure

Statoil

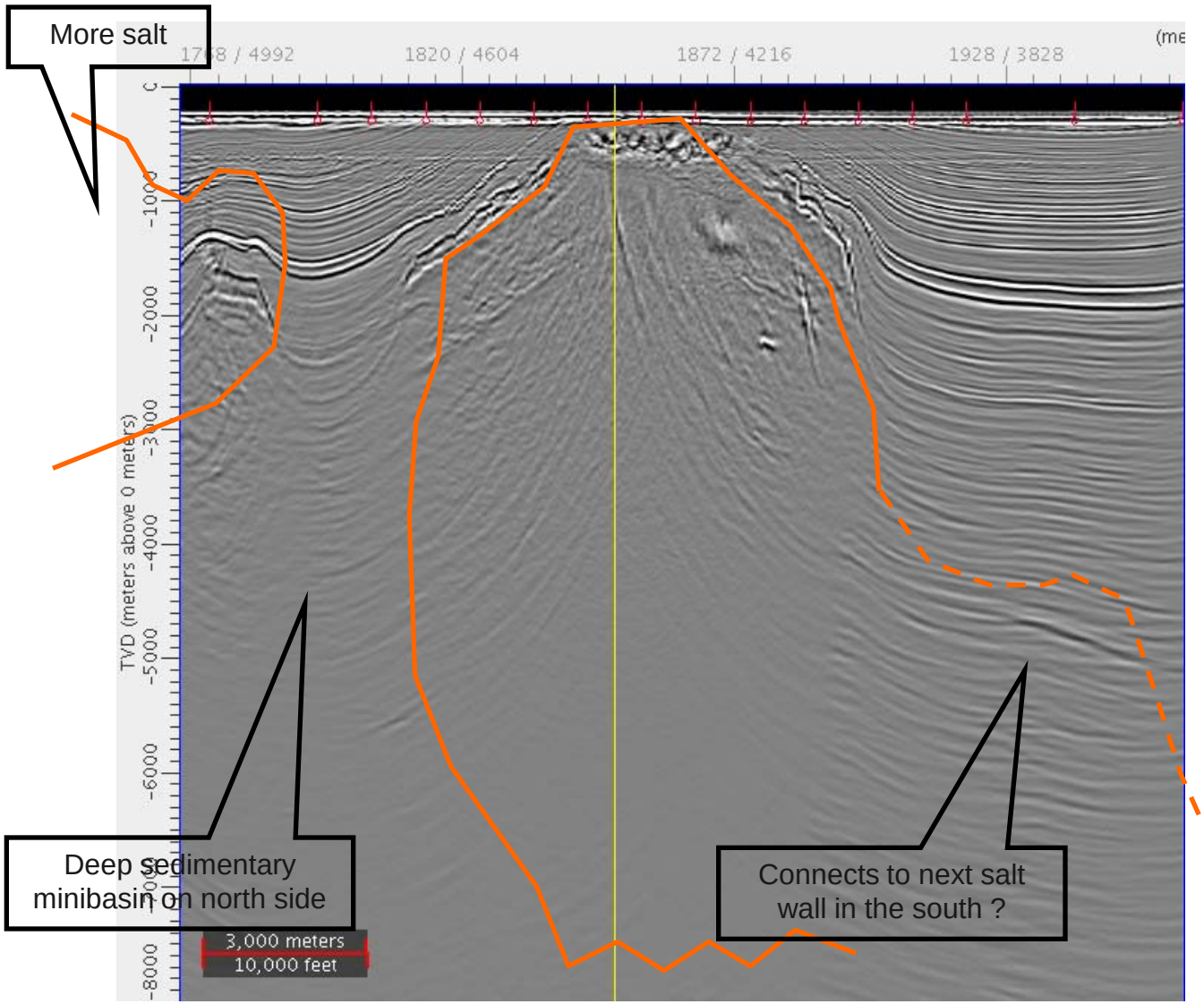
PSDM random line and MT inversion

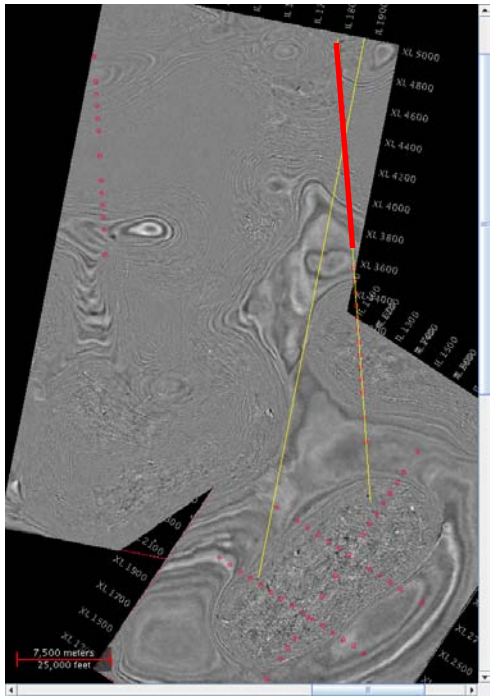




Statoil

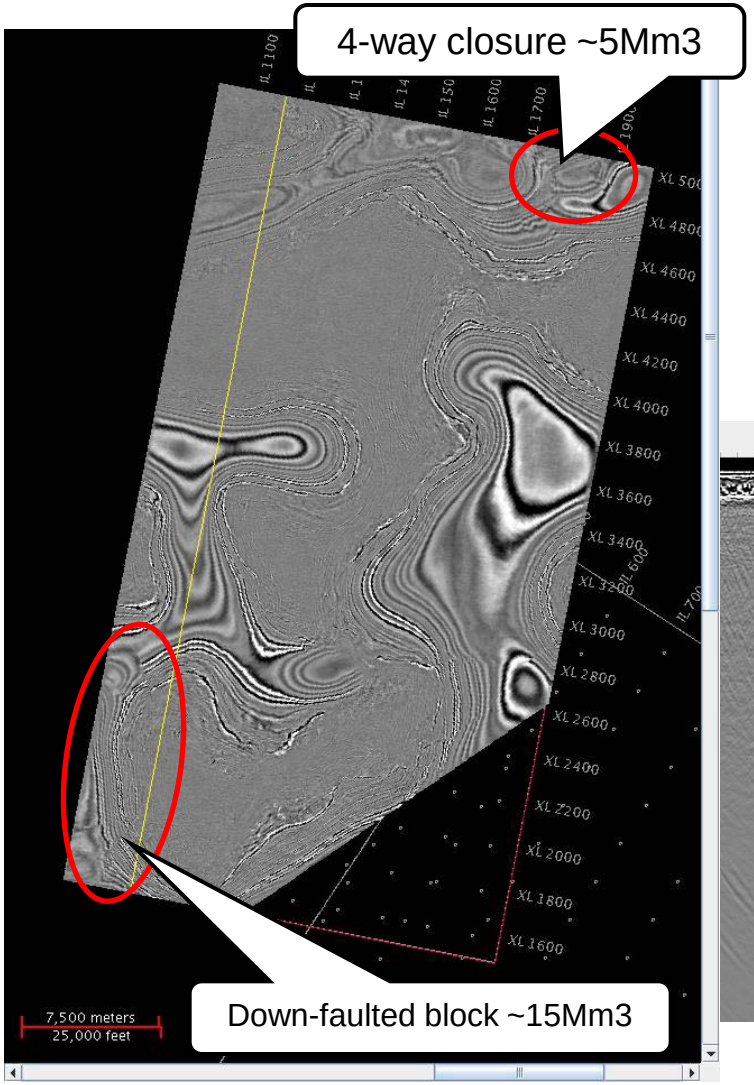
PSDM random line and MT inversion



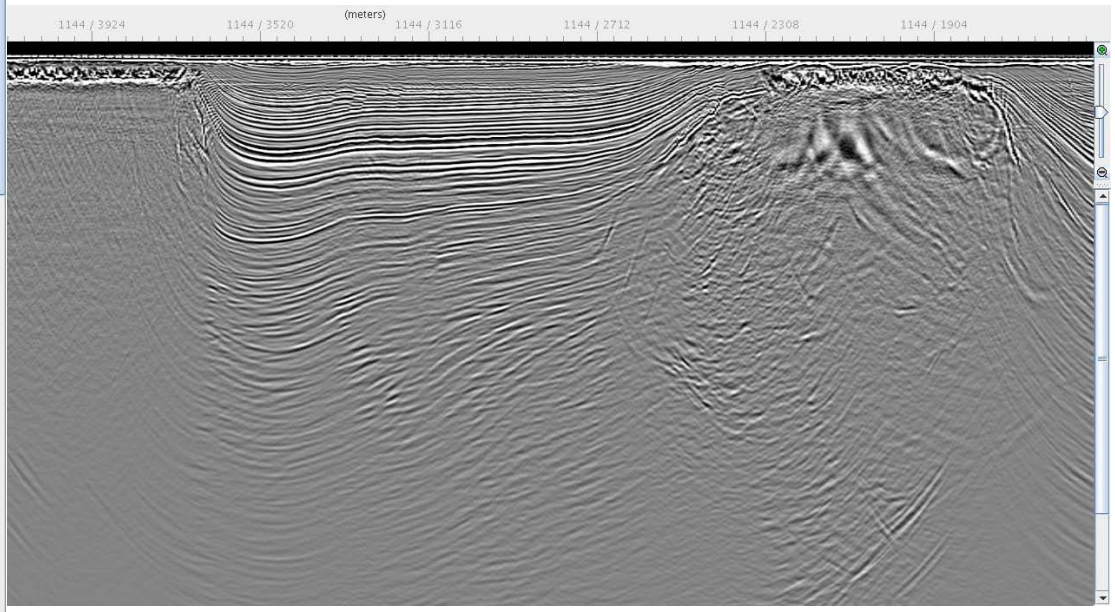


Statoil

ST0811 prospectivity

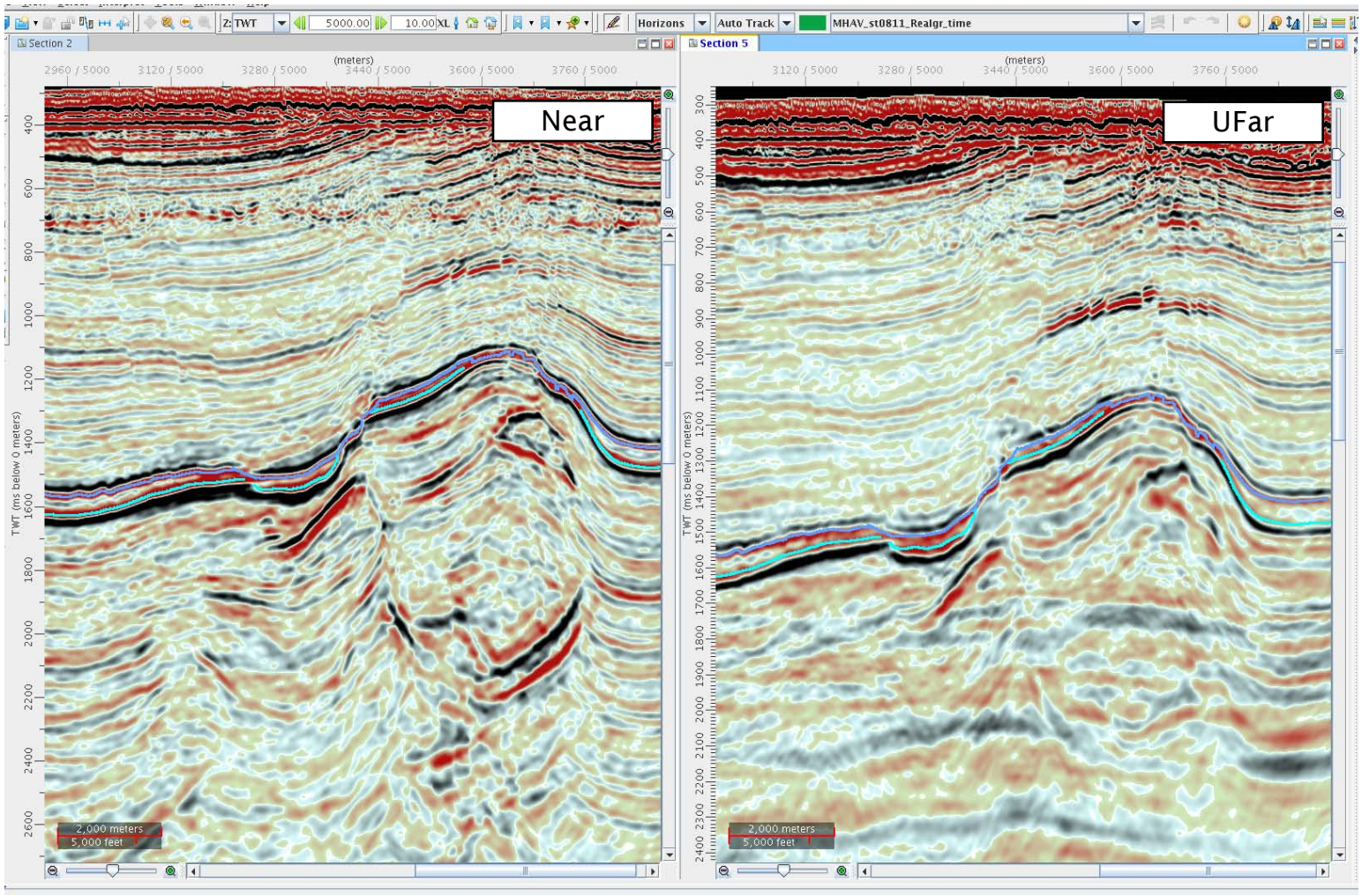


- Huge salt walls
- No subsalt traps
- 2-4 Realgrunnen prospects
- Many small Carnian closures



Statoil

4-way closure with AVO anomaly



Statoil

Conclusions

- Most likely there are no diapirs like the Uranus pre-well model in the Nordkapp Basin
- Data integration is important to complete the NKB imaging puzzle (EM, grav, seismic)
- Diapirs in southern sub-basin
- Salt walls in northern sub-basin
- Many small prospects
- Interesting prospects in southern basin to be imaged by new 3D ST10011

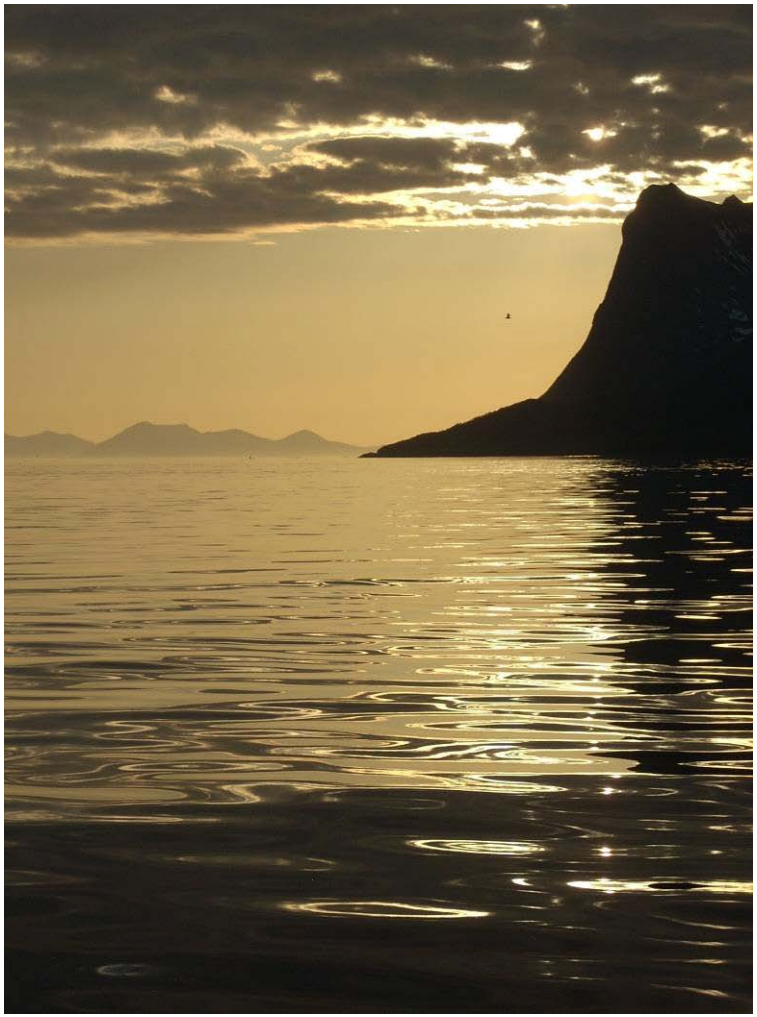


Photo: Eva Andrea Myrlund

Statoil