Recent Advances

in marine acquisition and processing technology applicable to The Netherlands offshore

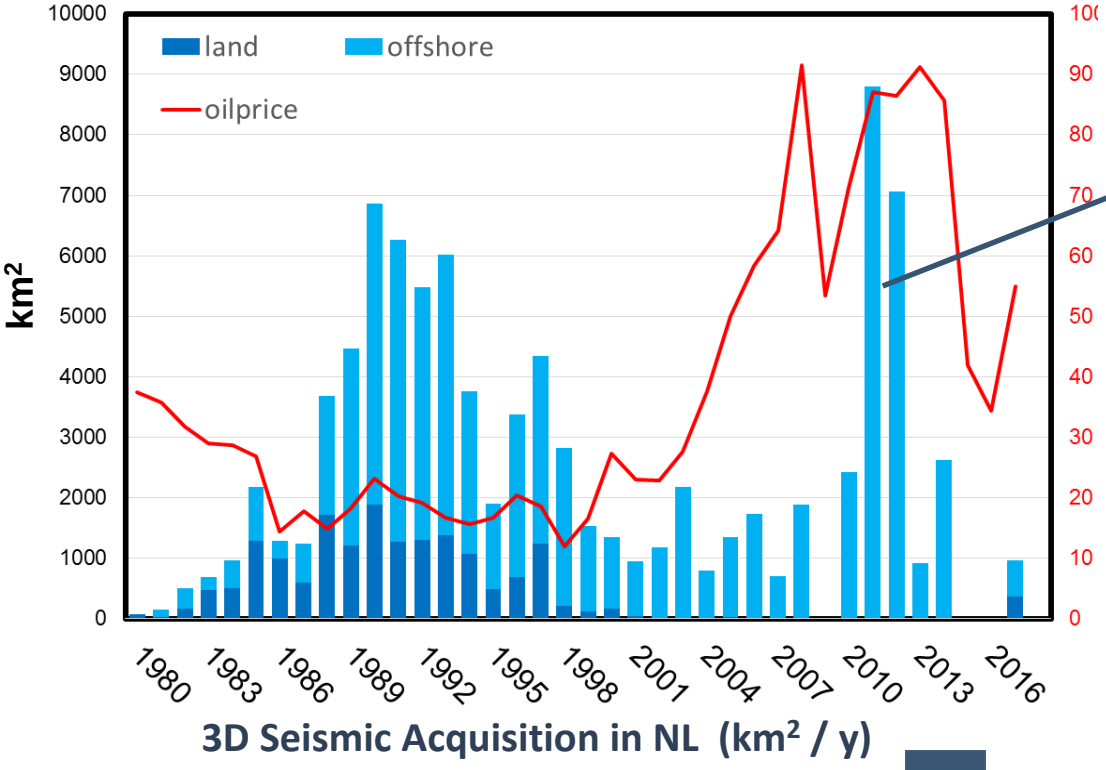
Martin Ecclestone

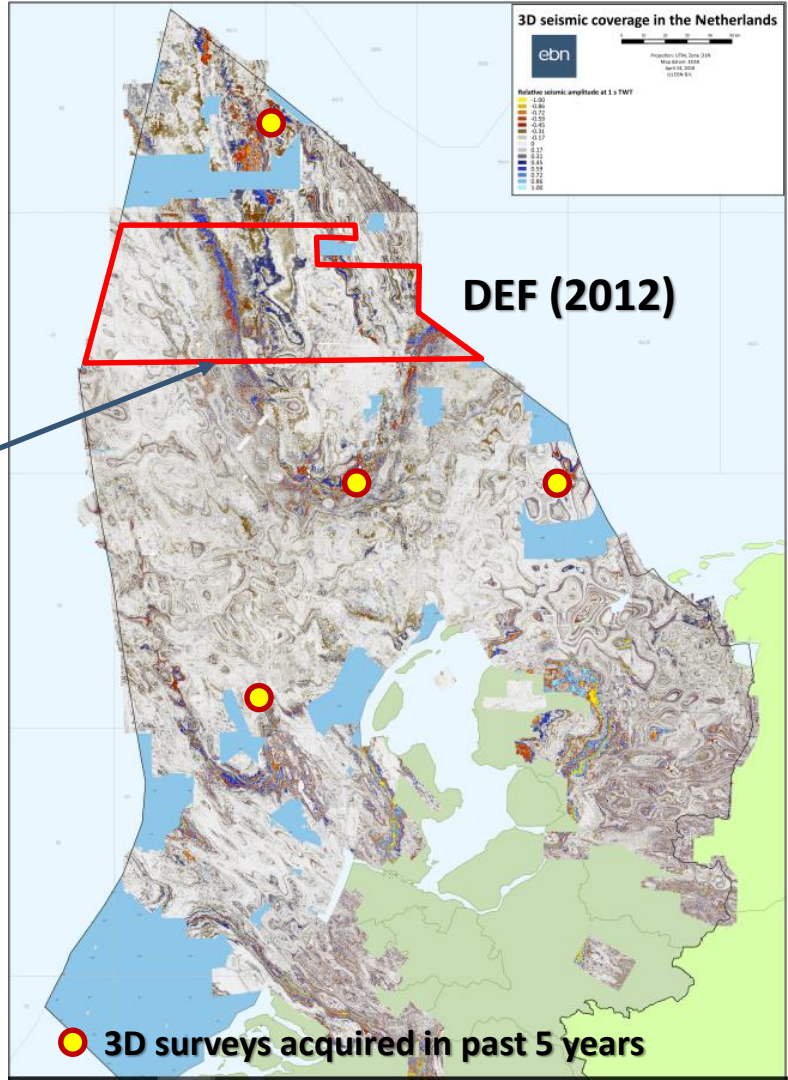
November 21st 2018

Agenda

- Introduction
- Geophysical technology evolution
  - **B**road**b**and (BB)
  - **F**ull **W**aveform **I**nversion (FWI)
  - **R**everse **T**ime **M**igration (RTM)
- Legacy 3D data
- Broadband reprocessing or reshoot?
- Summary

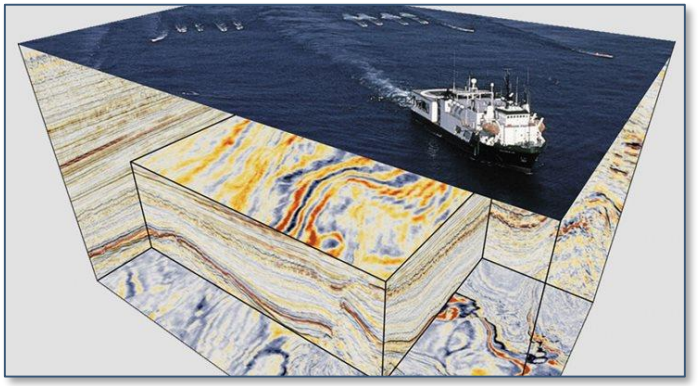
Introduction





Introduction

- Seismic data represents a unique **snap-shot** in time:
  - Subsurface (Static and 4D)
  - Acquisition and processing technology
- 3D acquisition, processing and computing technology has made tremendous advances in the past decade – **Broadband** is now the standard
- In areas without serious imaging challenges :
  - Consider **Broadband** reprocessing of existing 3D data if processing is older than **5 years**
- In areas with serious imaging challenges:
  - **Broadband** reprocessing first and then evaluate value/feasibility of **Broadband** 3D re-shoot



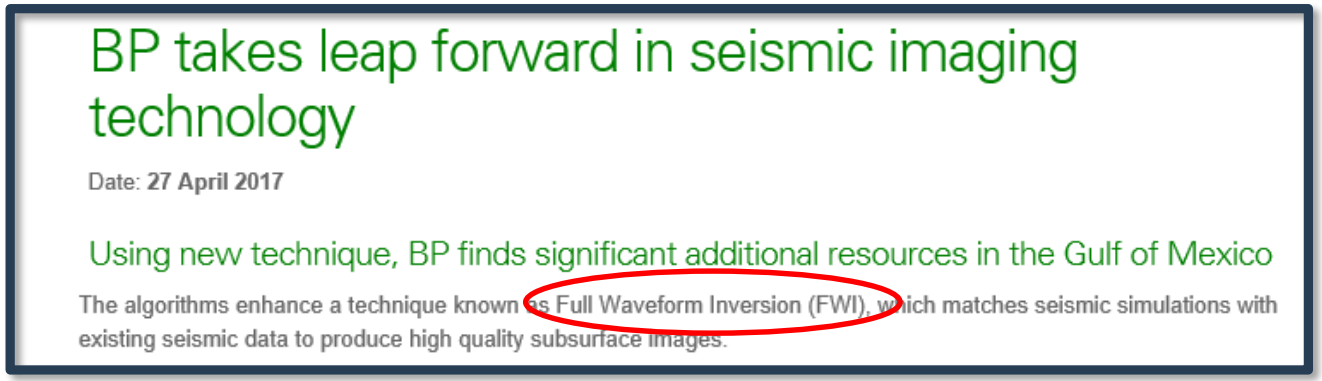
Introduction

FINANCIAL TIMES

FRIDAY 23 SEPTEMBER 2016 WORLD BUSINESS NEWSPAPER USA $2.50 Canada C$3.00

Brunei's energy production prospects were "very good" because the latest seismic techniques were revealing both new reserves and extra deposits in existing fields, the minister said. Pipeline network improvements would also make production from some known fields commercially viable for the first time, he added.

7th August, 2017



BP takes leap forward in seismic imaging technology

Date: **27 April 2017**

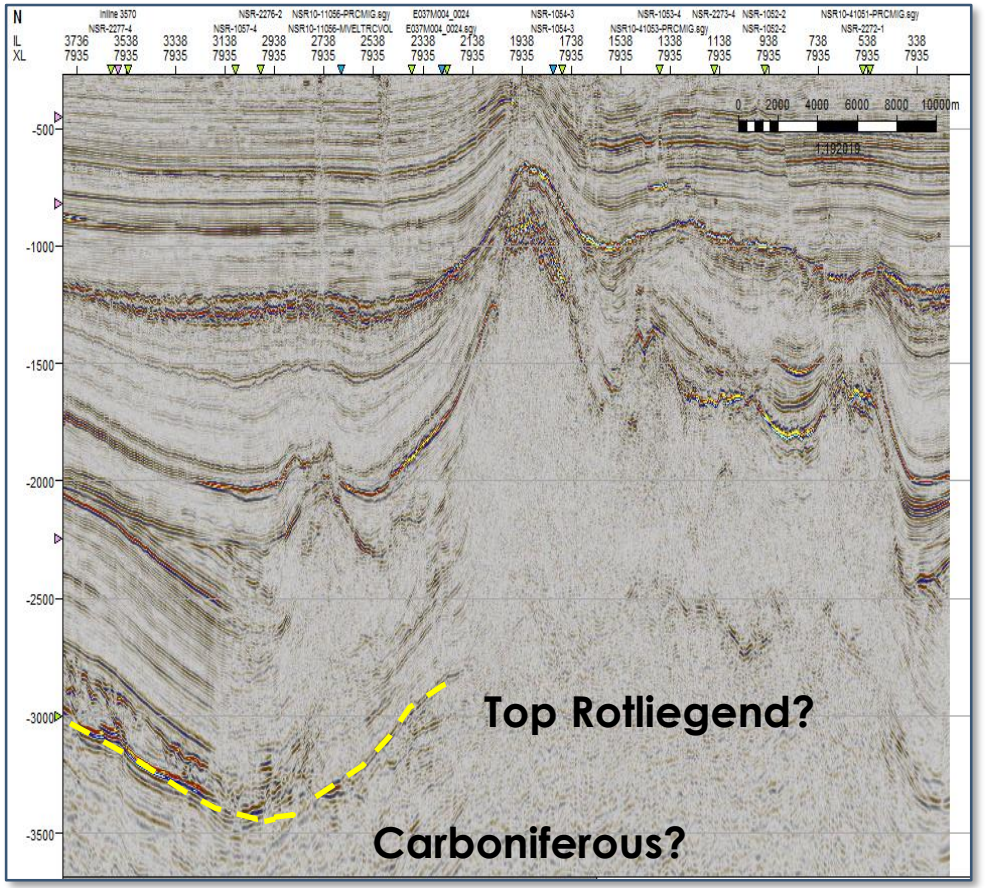
Using new technique, BP finds significant additional resources in the Gulf of Mexico

The algorithms enhance a technique known as Full Waveform Inversion (FWI), which matches seismic simulations with existing seismic data to produce high quality subsurface images.

Introduction

- Zechstein salt structures:
  - Complex morphologies with high & variable AI contrasts
  - Surrounded by deformed anisotropic sediments
  - Propagate distorted wavefields
  - Typically flanks and underlying stratigraphy poorly illuminated/imaged
  - Accurate salt extent and hence velocity model derivation often challenging
- Carboniferous
  - Seismic imaging hampered by signal penetration through complex overburden and high AI contrasts (Top and base ZE)

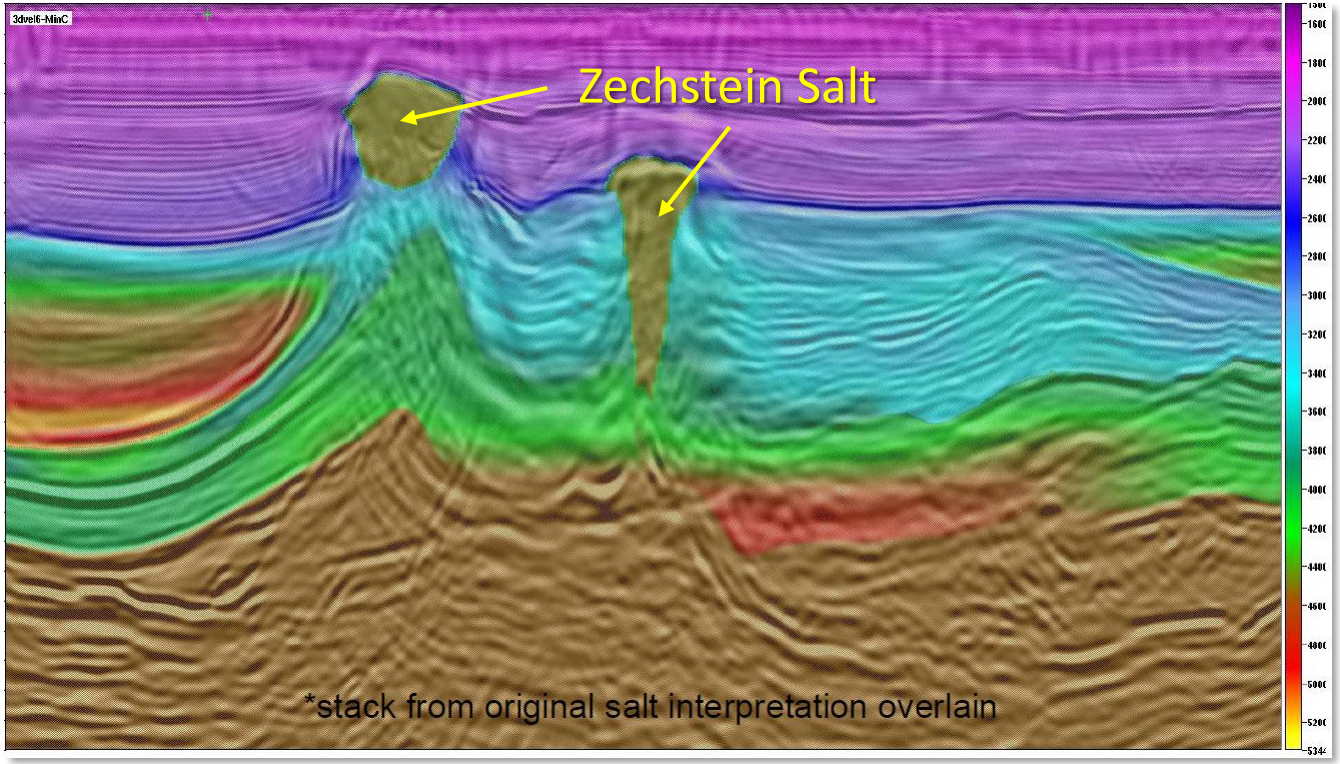
Seismic Reflectivity Time



Challenging imaging & depth conversion

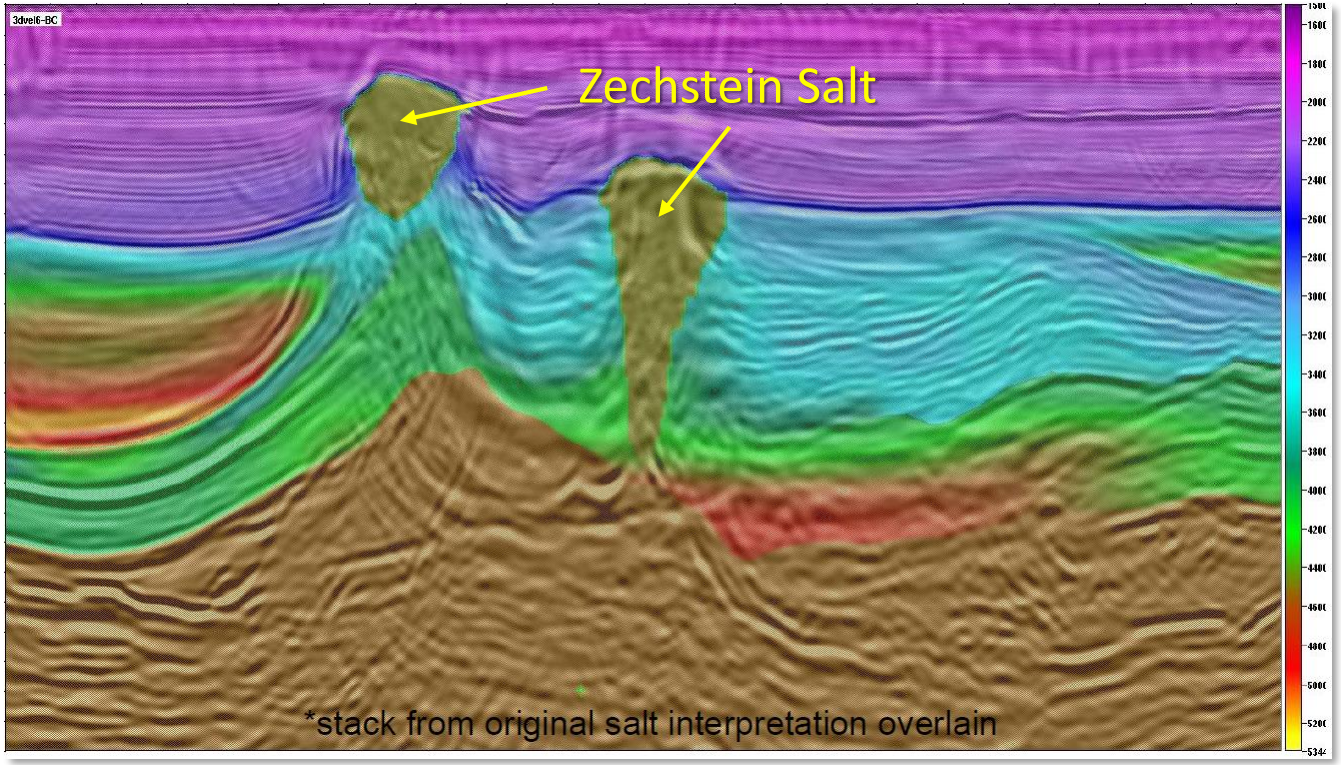
Introduction

Minimum Salt Scenario



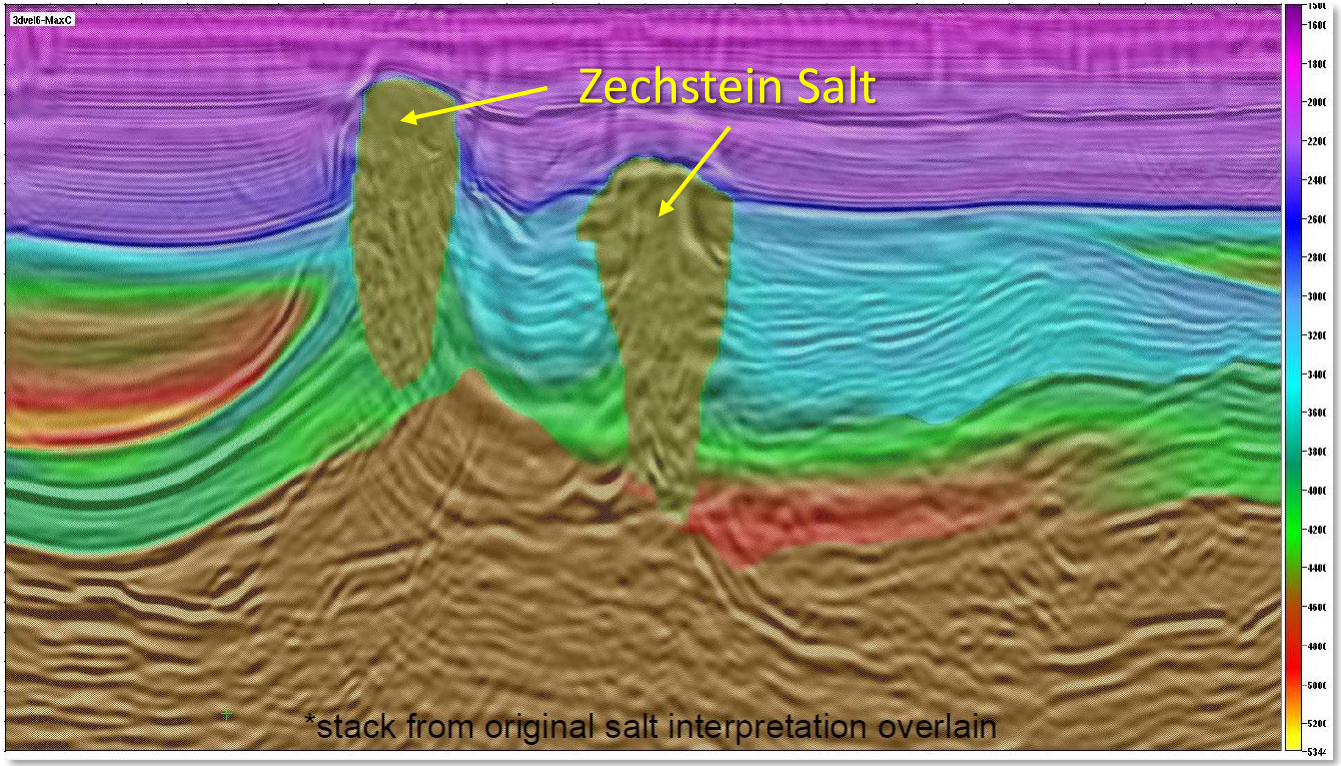
Introduction

Base Case Scenario



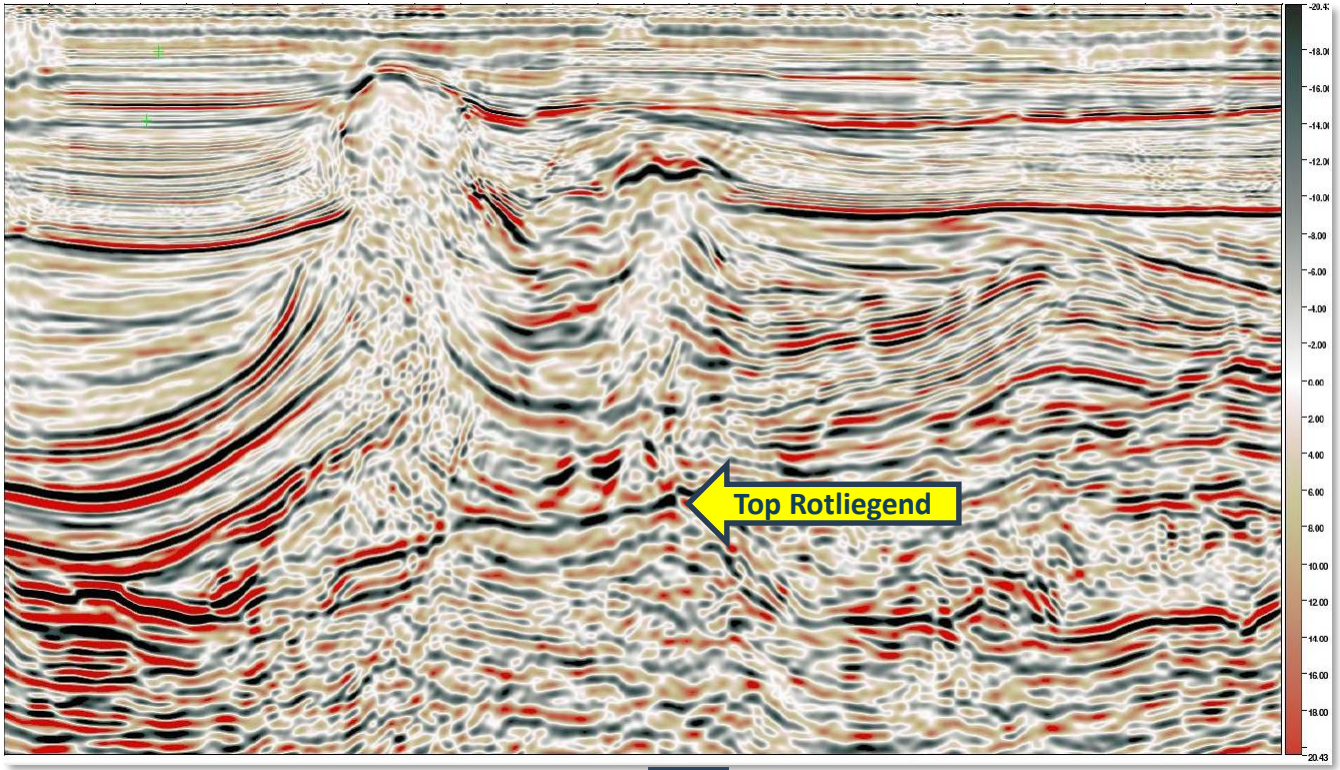
Introduction

Maximum Salt Scenario



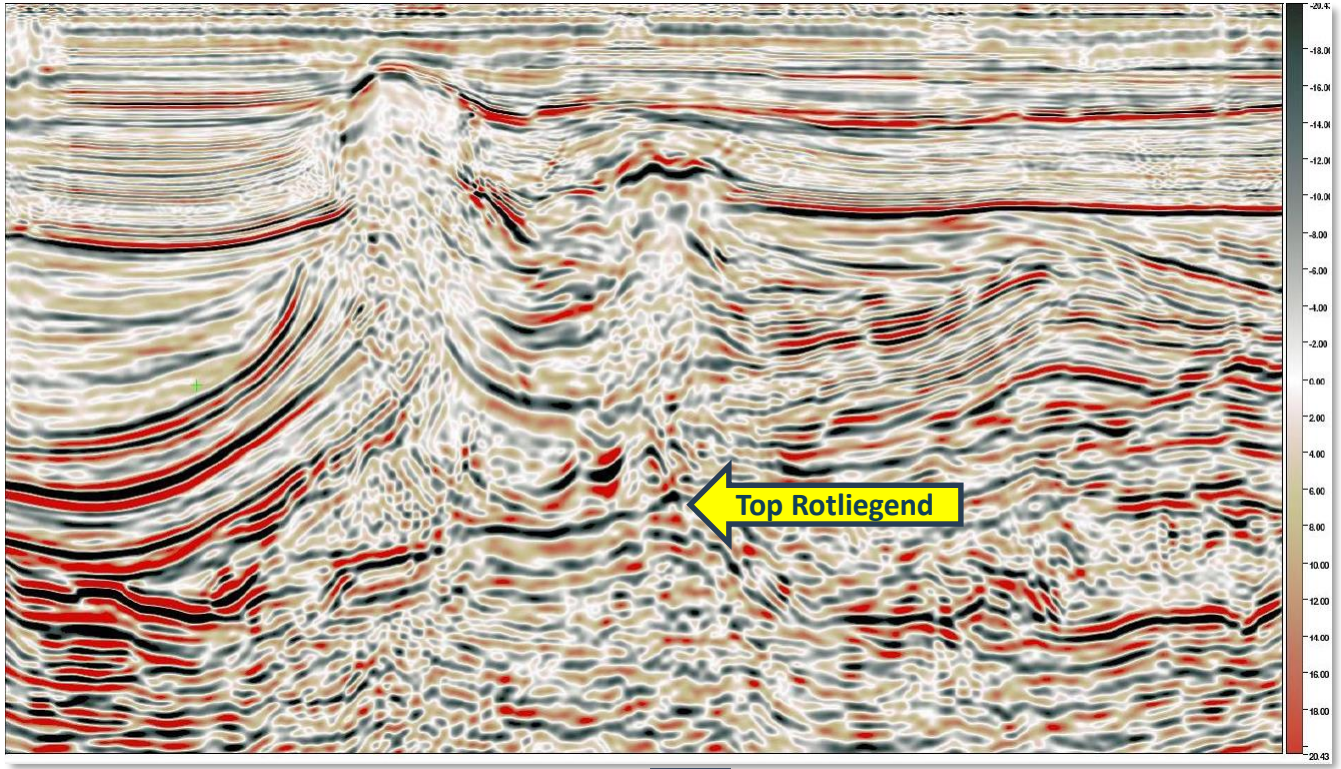
Introduction

Minimum Salt Scenario



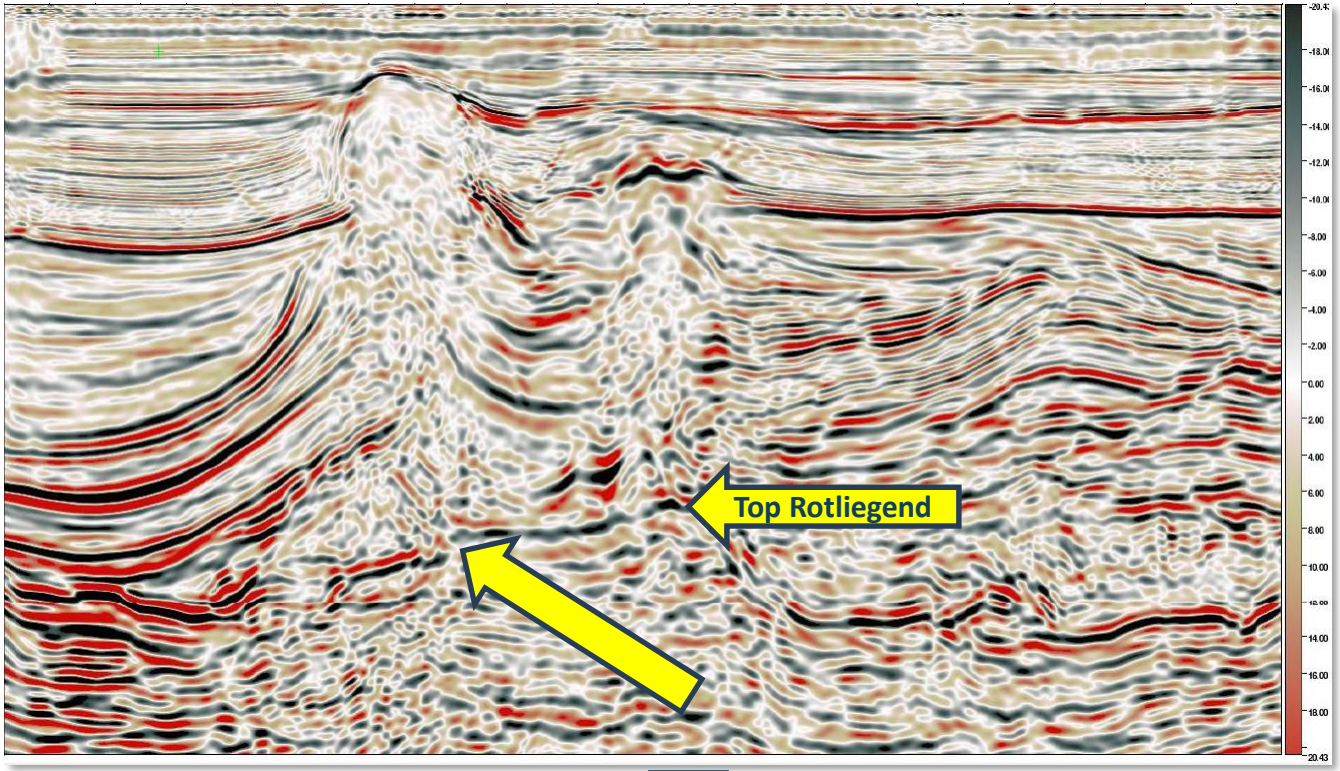
Introduction

Base Case Scenario



Introduction

Maximum Salt Scenario



Agenda

- Introduction
- Geophysical technology evolution
  - **B**road**b**and (BB)
  - **F**ull **W**aveform **I**nversion (FWI)
  - **R**everse **T**ime **M**igration (RTM)
- Legacy 3D data
- Broadband reprocessing or reshoot?
- Summary

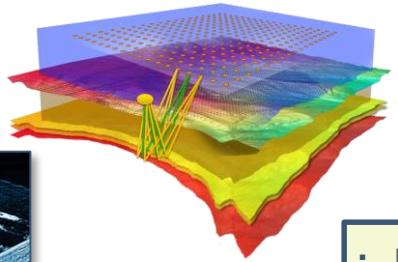
Geophysical Technology Evolution

1960 -1970

- Analogue recording
- 2D seismic land, dynamite source & geophones
- Paper displays & hand contouring
- First computers IBM 1130, Univac

1970 -1980

- Digital recording
- 2D seismic land vibroseis
- 2D marine seismic, airgun, hydrophone
- 3D land acquisition & processing
- Multi-channel processing
- 2D post-stack wave equation migration
- Bright spot technology



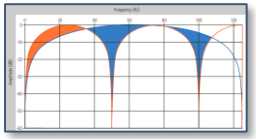
1980 -1990

- Large scale 3D marine seismic acquisition
- 3D dip-moveout, time migration and **FWI**
- 2D pre-stack Kirchhoff depth migration
- 2D surface related multiple elimination
- Seismic stratigraphic interpretation using seismic amplitudes, dip and azimuth attributes
- 3D workstations
- CRAY, Convex, UNIX
- First SNS 3D's acquired
- Parabolic radon filtering
- KF filtering

Carpeting of North Sea and Gulf Coast with 3D seismic

1990 -2000

- Probabilistic inversion
- 3D interpretation
- Time-lapse seismic
- 3D pre-stack Kirchhoff depth migration
- 3D surface related multiple elimination
- 3D volume interpretation
- Introduction of parallel computers – IBM SP2



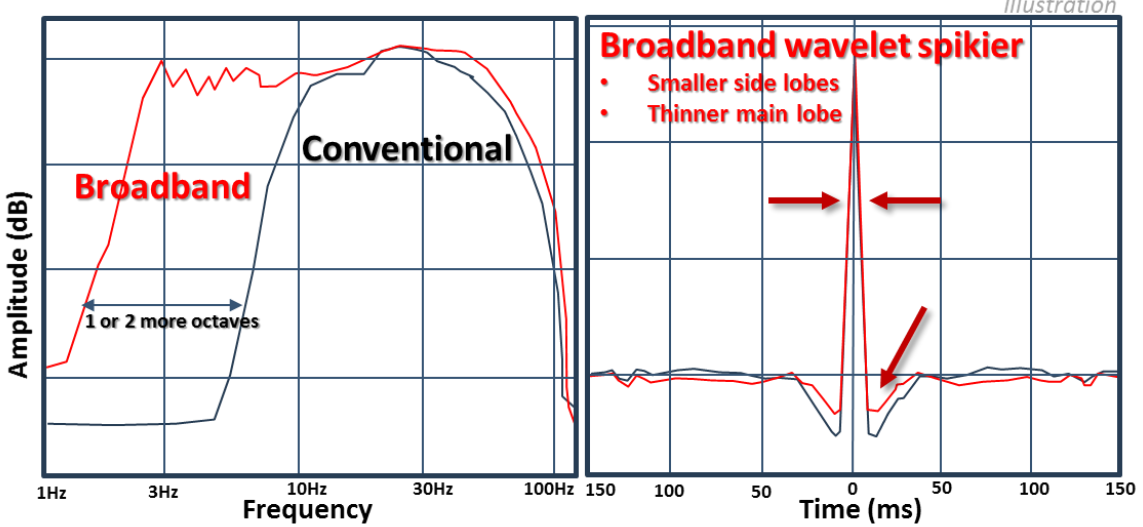
2000 -2010

- Reservoir geophysics
- Multi-azimuth marine acquisition – MAZ, WAZ, RAZ and OBS
- Anisotropic model building
- 3D pre-stack wave equation migration – Reverse Time Migration
- Pre-stack & multi azimuth interpretation
- Computing clusters
- CSEM surveys deep water
- Large scale implementation time-lapse seismic
- **Broadband acquisition and processing**

2010 -2020

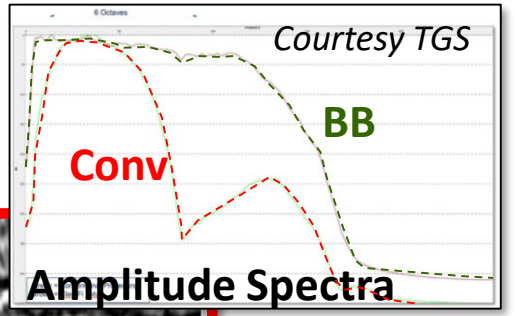
- Wireless seismic
- WAZ on land
- **Broadband processing conventional 3D**
- **Full Waveform Inversion (FWI) implemented**
- **Reverse Time Migration (RTM) implemented**
- Least Squares Migration (LSM)
- **Least Squares Reverse Time Migration (LSRTM) implemented**
- Towards Elastic Full Waveform Inversion
- Multi-core processors
- Widespread OBN deployment & cost reduction initiatives
- Flying OB nodes ?
- AI ?

Broadband



- Broadband = Seismic with increased signal bandwidth
  - Increased **high** frequencies: usually only shallow
  - Increased **low** frequencies: main benefit of Broadband at target levels
- Typical low frequency limits in seismic:
  - Legacy data : starts at **~8 Hz**
  - Broadband reprocessed legacy data : can start at **~5 Hz**
  - 'Real' Broadband (dedicated acquisition and processing) : starts at **~2-3 Hz**
- **Note** : Each step from 2 to 4 to 8 Hz each time adds 1 Octave to the spectrum – **Very Significant!**

Broadband Reprocessing



conventional

broadband

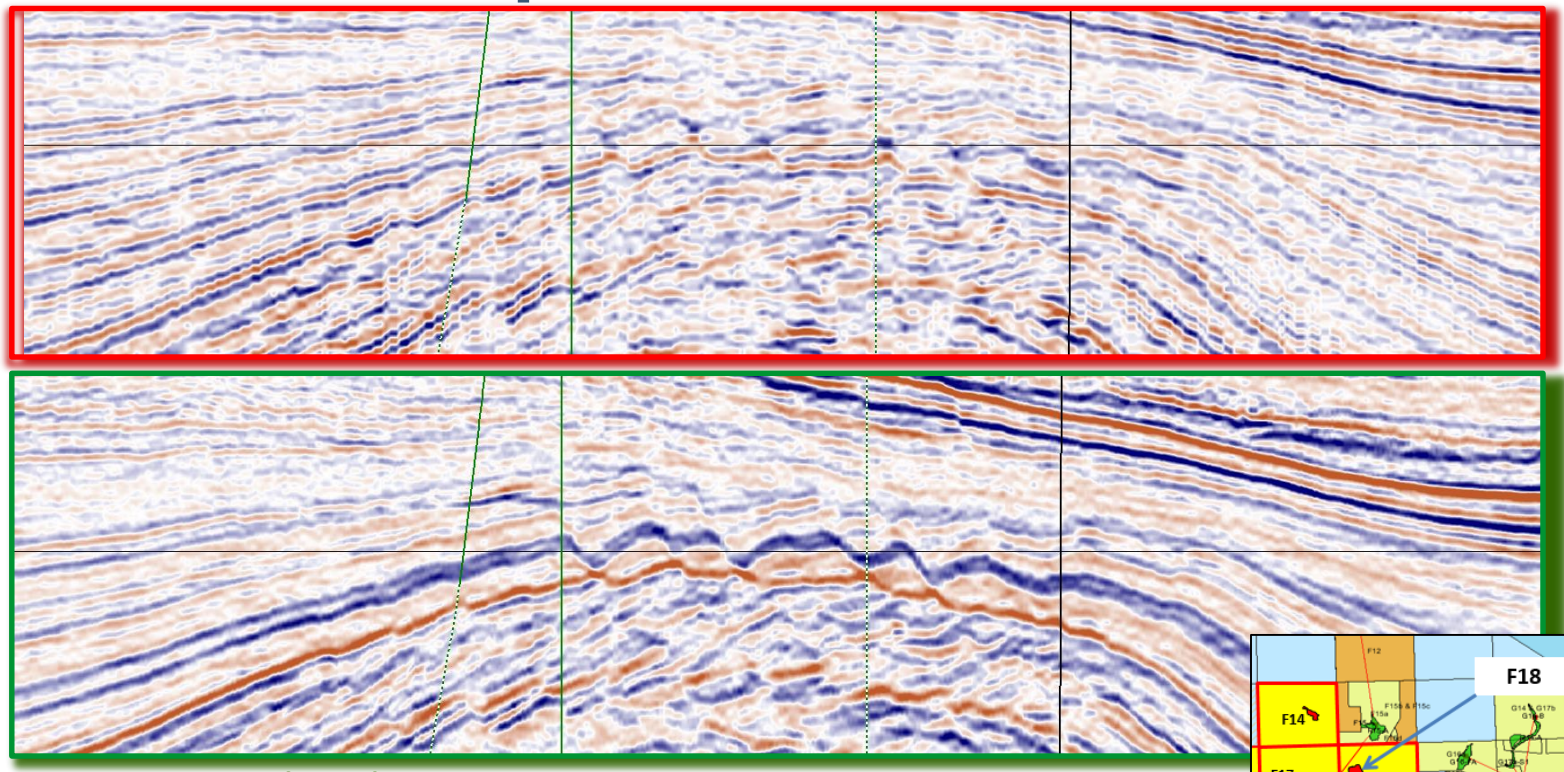
Dedicated BB Processing : Source de-signature, (3D) de-ghosting, LF boost

Courtesy Stirling

Broadband Acquistion

conventional

broadband



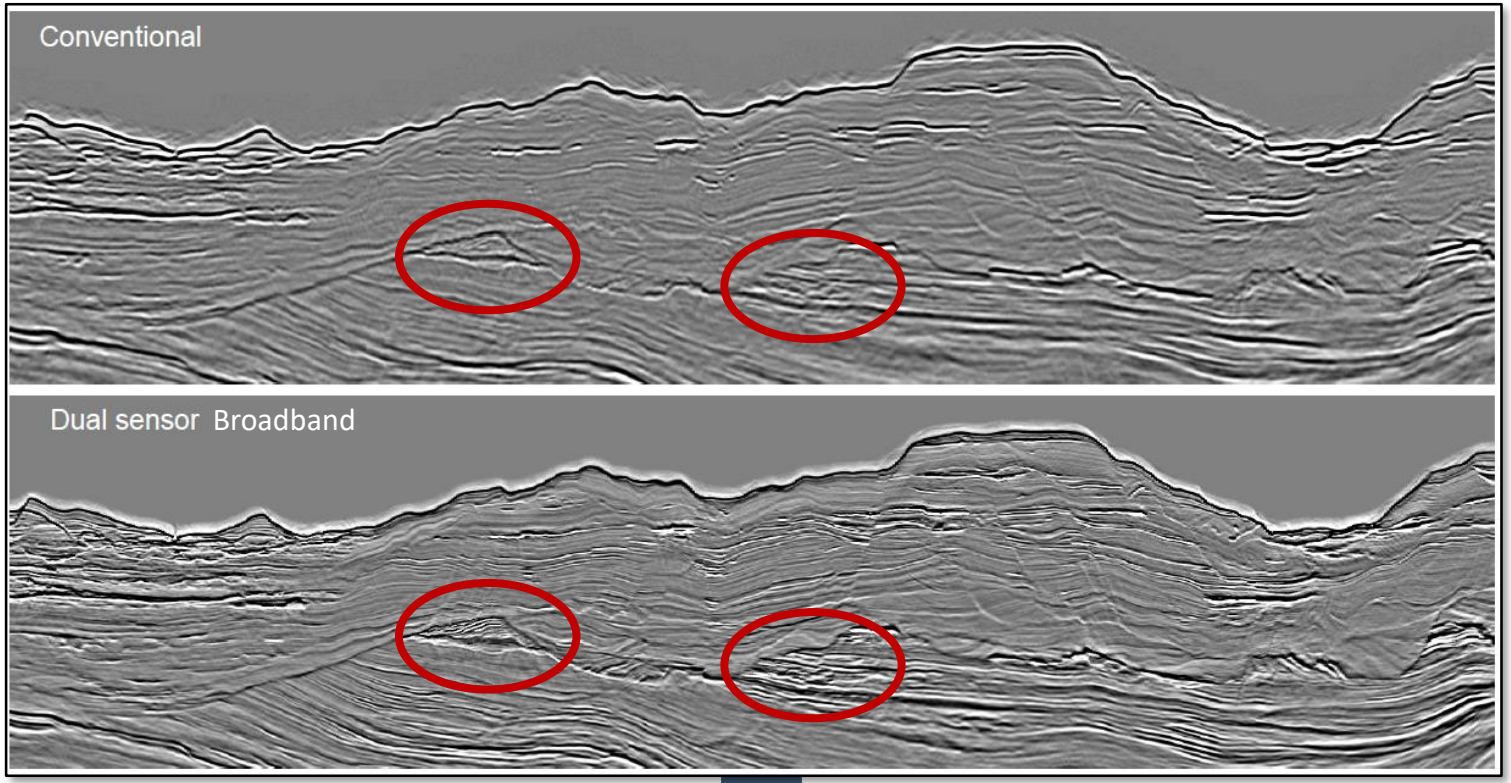
CGG Broadseis (2015)

Fregat (F18)

Courtesy PGS

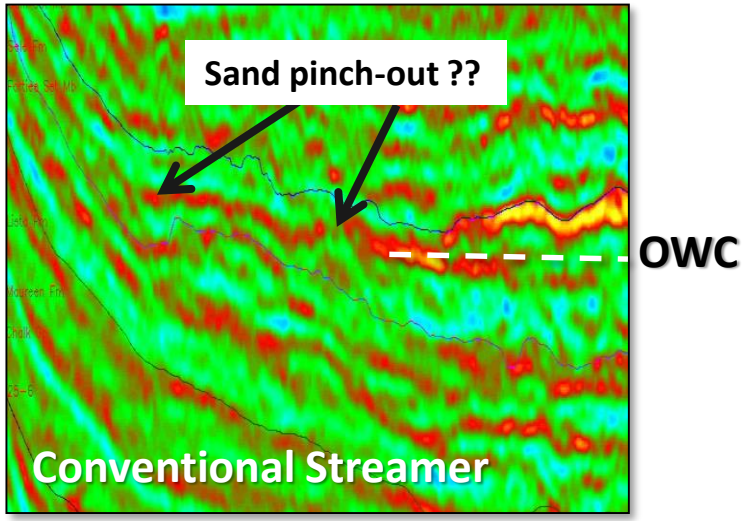
Broadband Acquistion

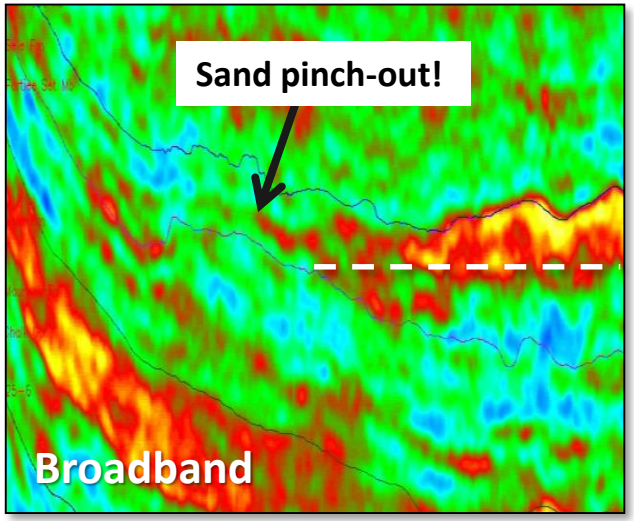
Camamu Area -Brazil

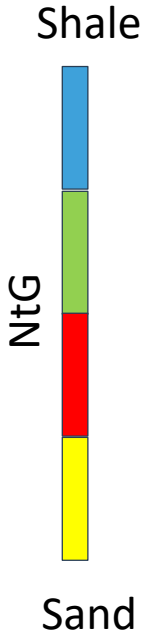


Broadband Inversion

North Sea Reservoir







Impedance inversion (without well information)

OWC observed below structural spill-point

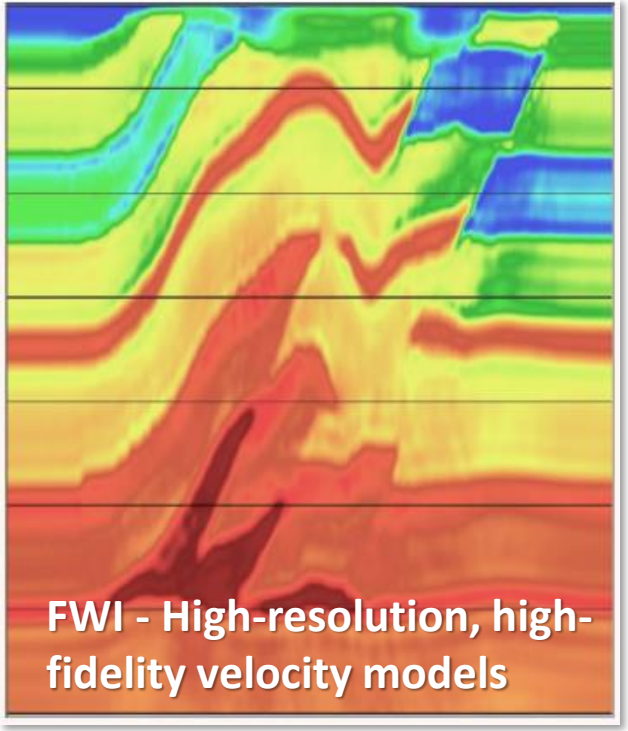
Thick sands are now visible on the Broadband data

Broadband – General Benefits

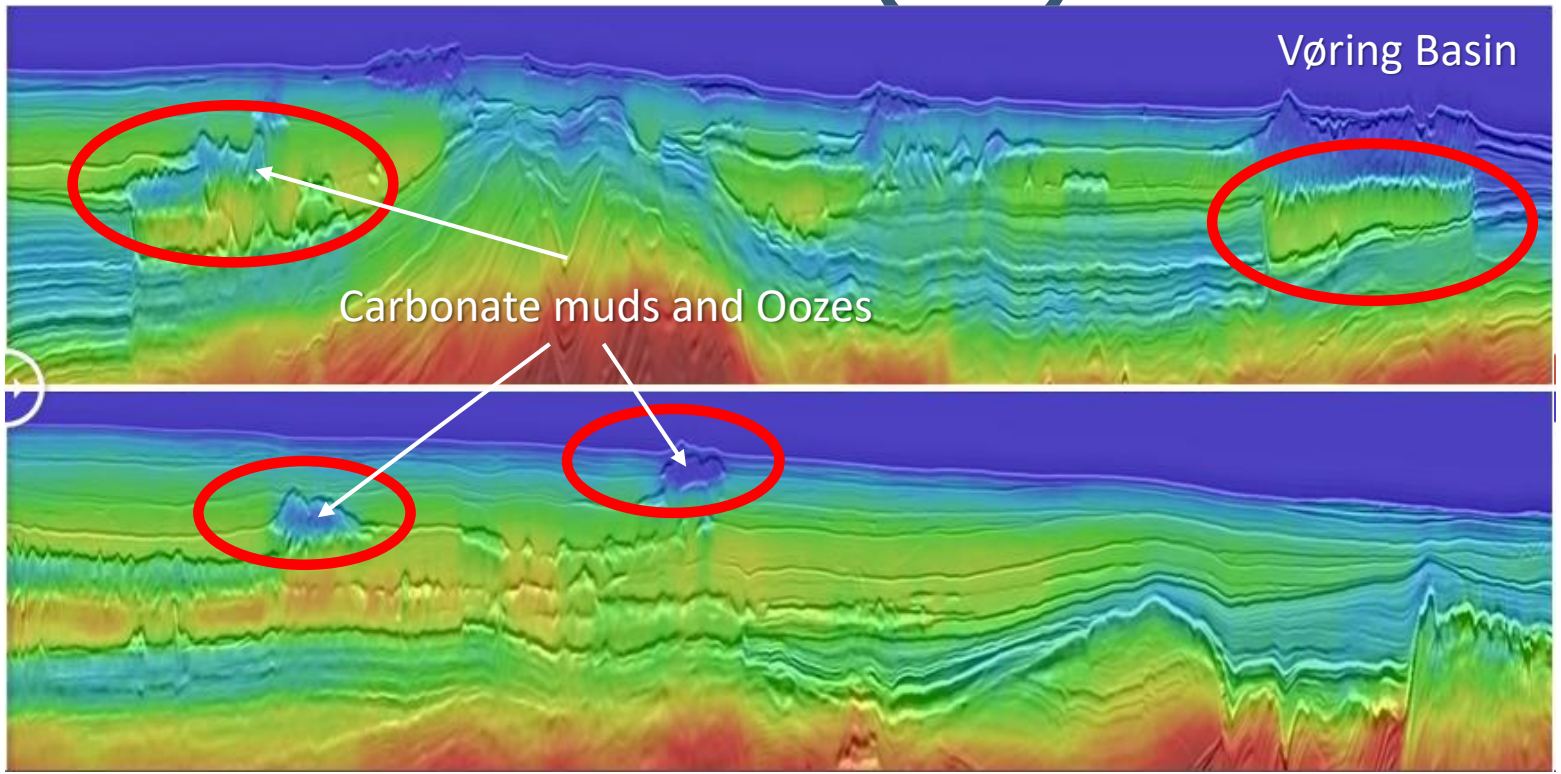
- Higher frequencies in shallow section (may avoid need for geohazard site survey)
- Supports improved velocity model derivation and imaging :
  - **FWI** and **RTM** requirements better supported
- **Lower frequency** content allows for more stable and faster interpretation
- Deeper signal penetration (low frequencies scatter less)
- Higher vertical resolution (sharper wavelet with lower sidelobes)
- Helps resolve thin/thicker layers (interpretation and rock properties)
- Improved acoustic impedance inversion
- Improved quantitative interpretation (RTM improves amplitude stability)

Full Waveform Inversion (FWI)

- Invented in the 1980's
- Computing advances - implemented 'recently'
- Refines the velocity model by iterative matching of modelled data with recorded data
- Requires **LOW** frequency data (Broadband)
- Enables improved velocity model derivation to depth of approximately **1/3 of maximum** offset

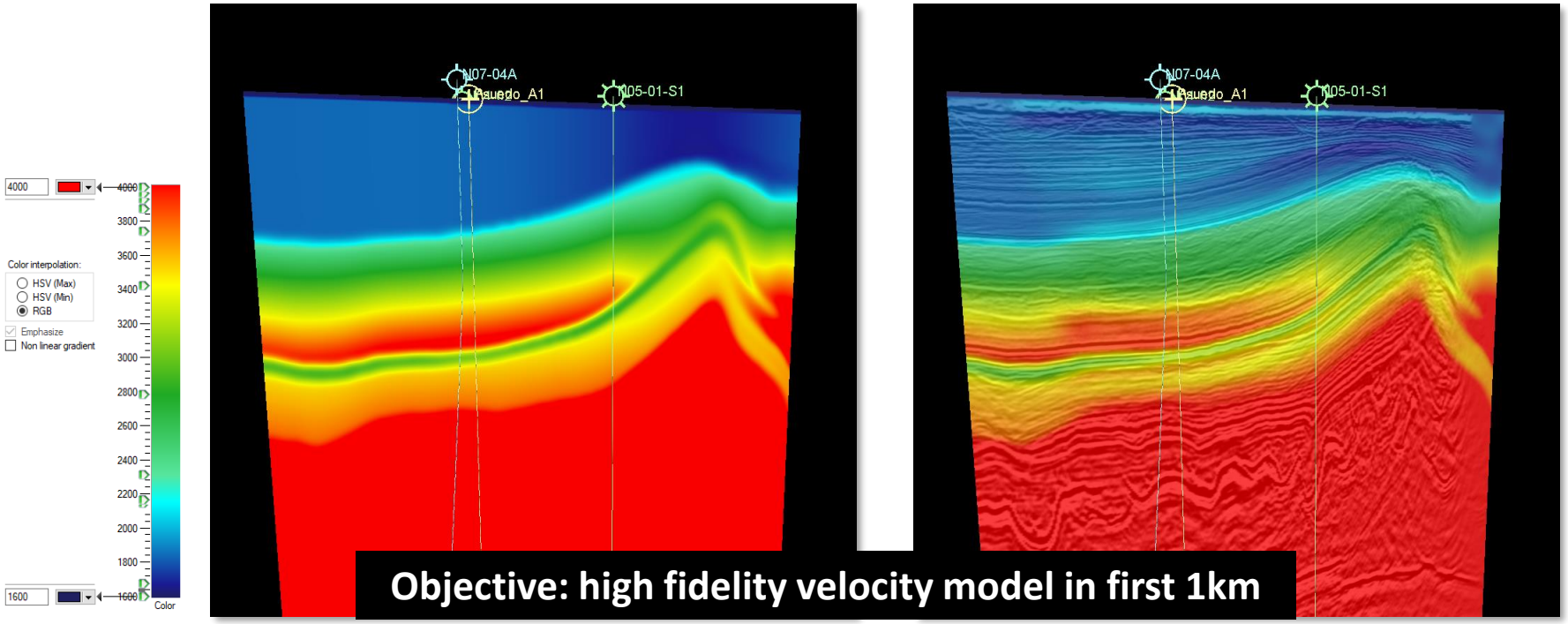


Full Waveform Inversion (FWI)



Courtesy of ORANJE-NASSAU ENERGIE

Full Waveform Inversion (FWI)

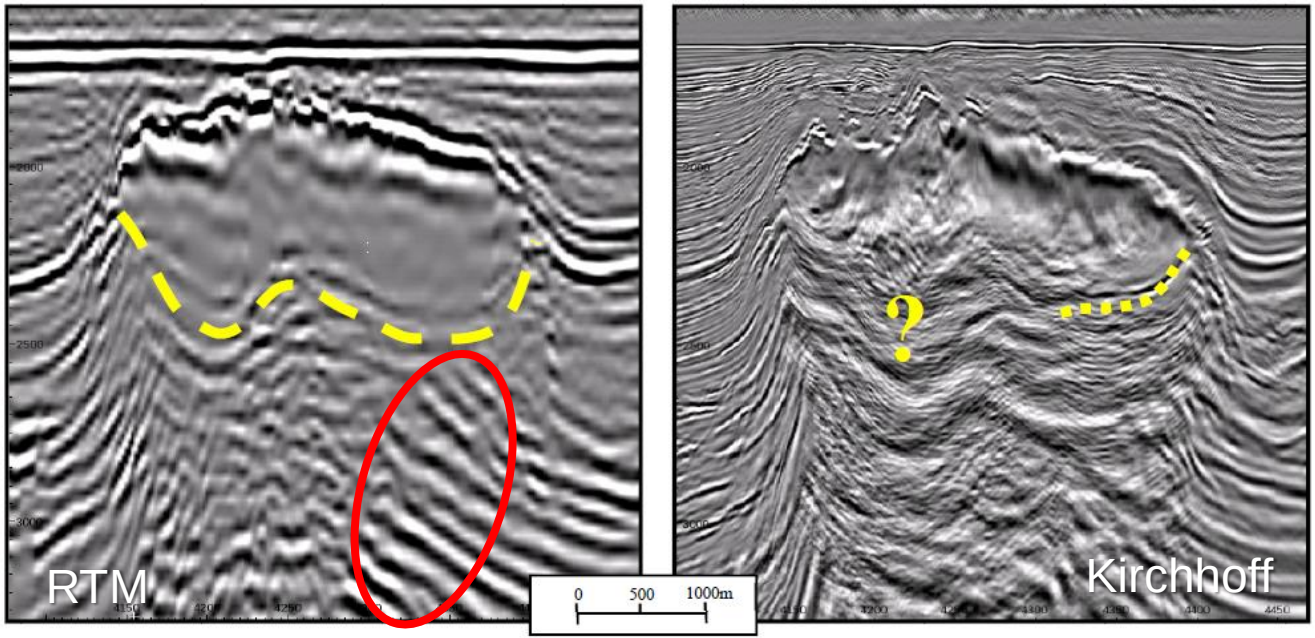


Initial Model

Second Iteration

Imaging - RTM vs. Kirchhoff

Offshore West Africa

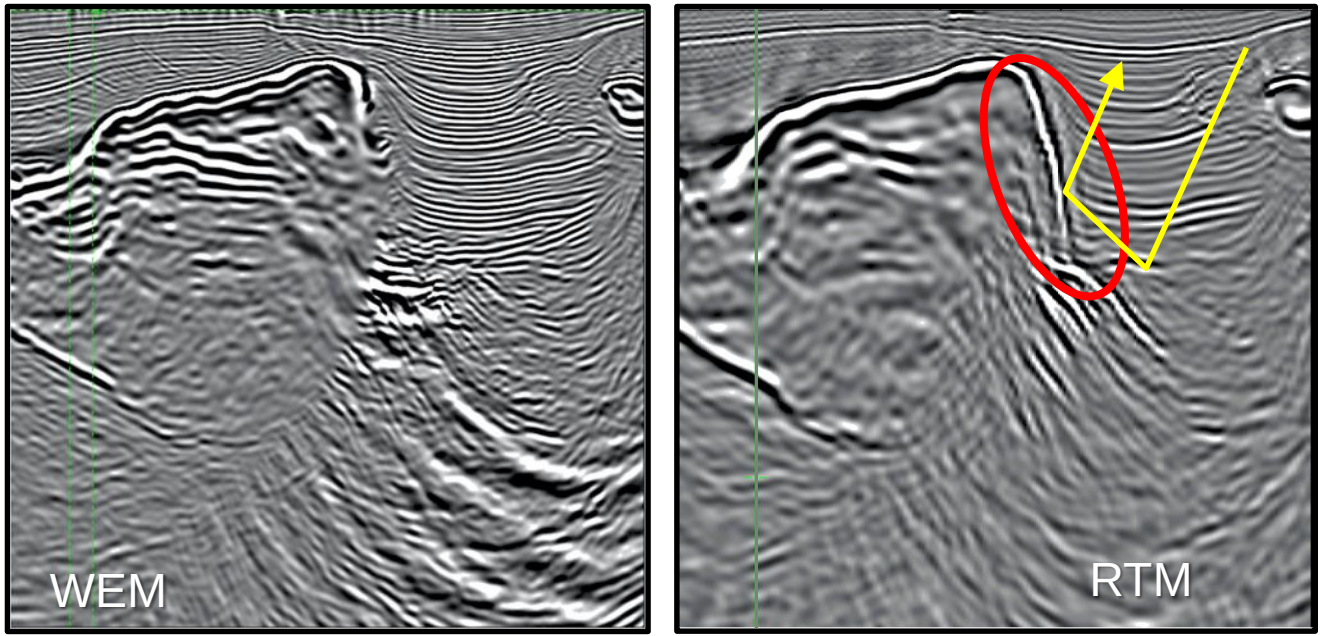


*Comparison between ENI proprietary **RTM 30Hz** (left) and **Kirchhoff** (Right)*

Need both?

Imaging – WEM* vs. RTM

Offshore West Africa

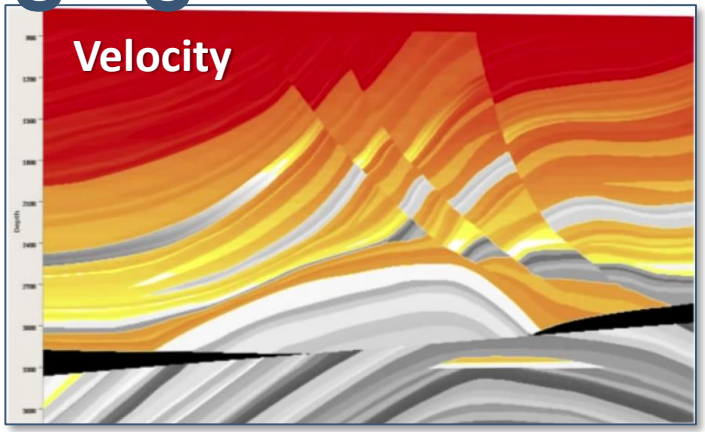


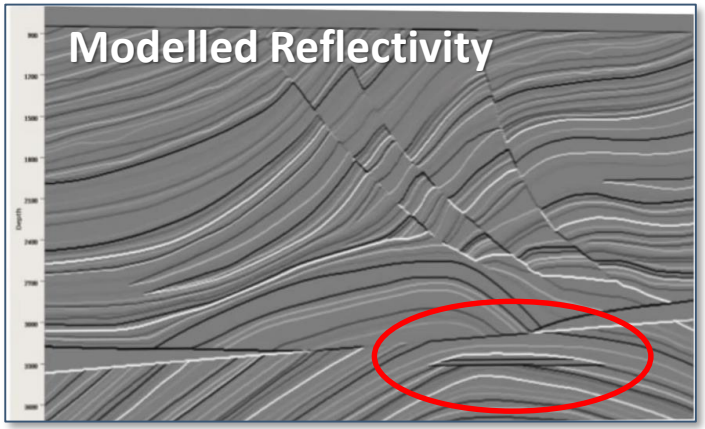
Comparison between WEM (left) and RTM (Right)

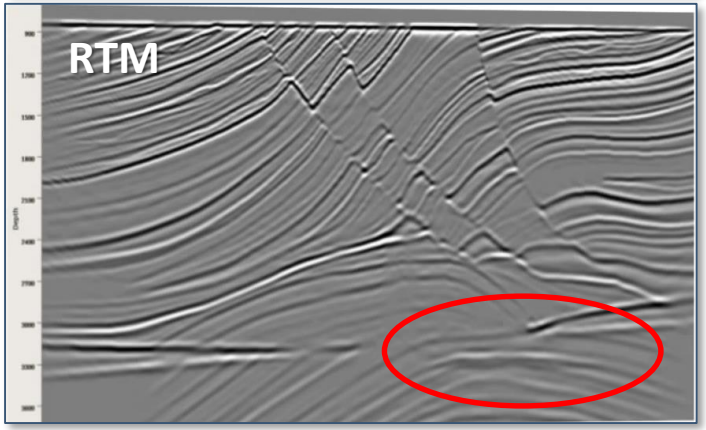
*WEM = Wavefield Extrapolation Migration

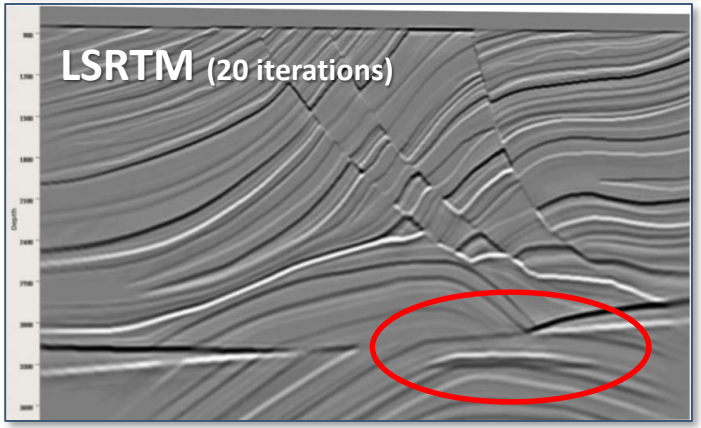
http://sepwww.stanford.edu/data/media/public/sep//biondo/3DSI_frame.html

Imaging - RTM vs. LSRTM

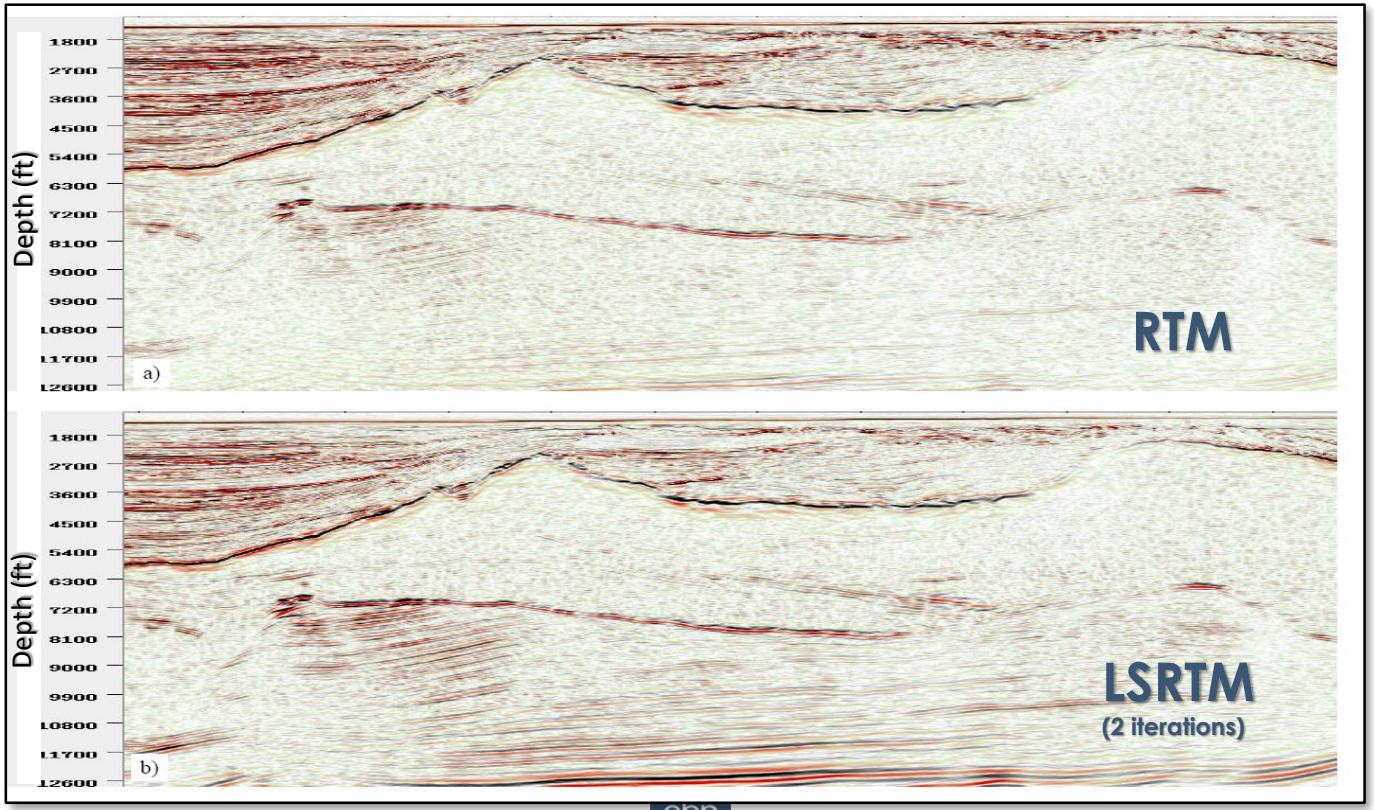








Imaging - RTM vs. LSRTM



Freedom WAZ data GOM

Imaging Comparison

- **(LS)RTM**
  - Best migration tool commercially available today to tackle imaging in structurally complex geological settings
  - Expensive

	(LS)RTM	WEM	Kirchhoff
Stable in complex models	✓	✓	✗
Has no dip limitations	✓	✗	✓
Handles turning waves	✓	✗	✓
Handles prism waves	✓	✗	✗
Addresses multi-pathing	✓	✓	✗

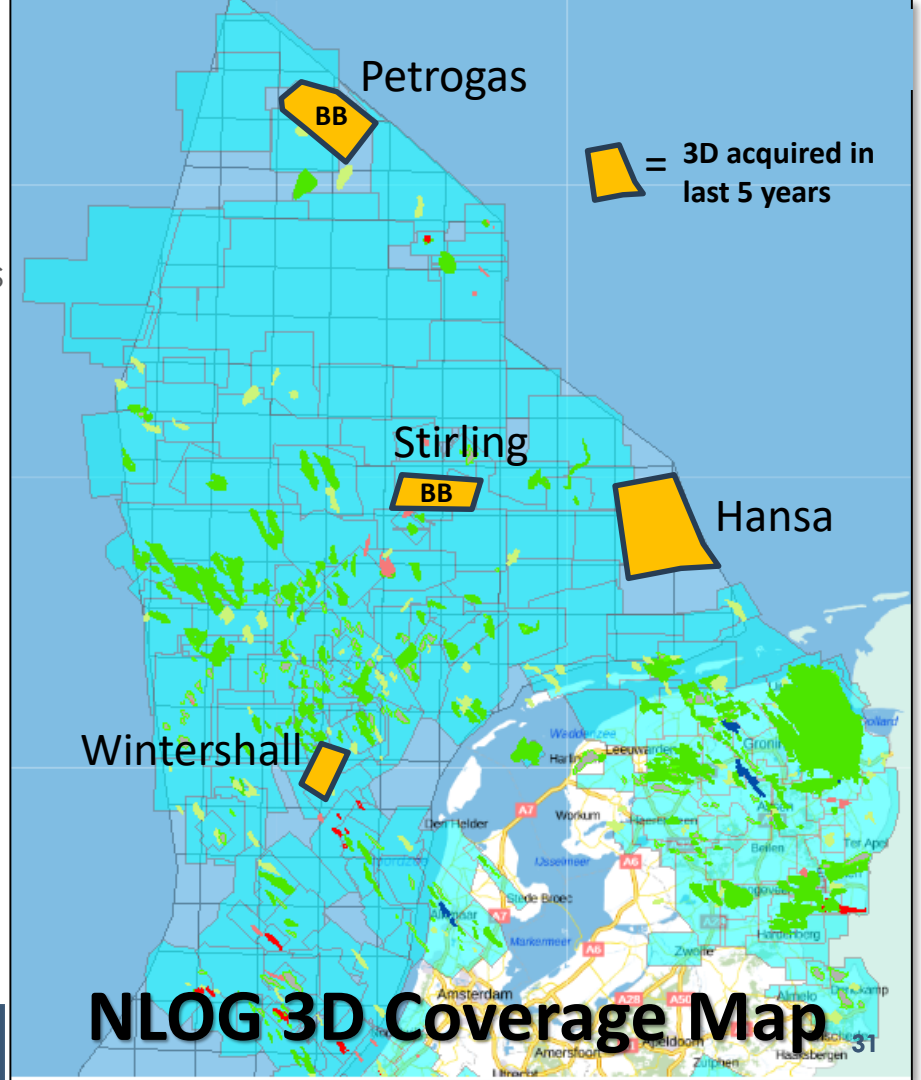
https://www.youtube.com/watch?v=ywdML8ndYeQ

Agenda

- Introduction
- Geophysical technology evolution
  - **B**road**b**and (BB)
  - **F**ull **W**aveform **I**nversion (FWI)
  - **R**everse **T**ime **M**igration (RTM)
- Legacy 3D data
- Broadband reprocessing or reshoot?
- Summary

Legacy 3D Data

- **Majority** of offshore 3D data acquired in 80's & 90's
- **Importance** of low frequencies not recognised.
- Legacy data generally characterised by:
  - Low fold (e.g. 20)
  - Short max-offsets (e.g. 3000m)
  - Single-sensor streamers towed shallow (e.g. 6m)
  - In-field low-cut filtering
  - Narrow azimuth range
- BB reprocessing of legacy 3D still advisable
- Legacy 3D data acquistion parameters **not optimal** for most effective use of **FWI** and **RTM** in areas exhibiting severe imaging challenges

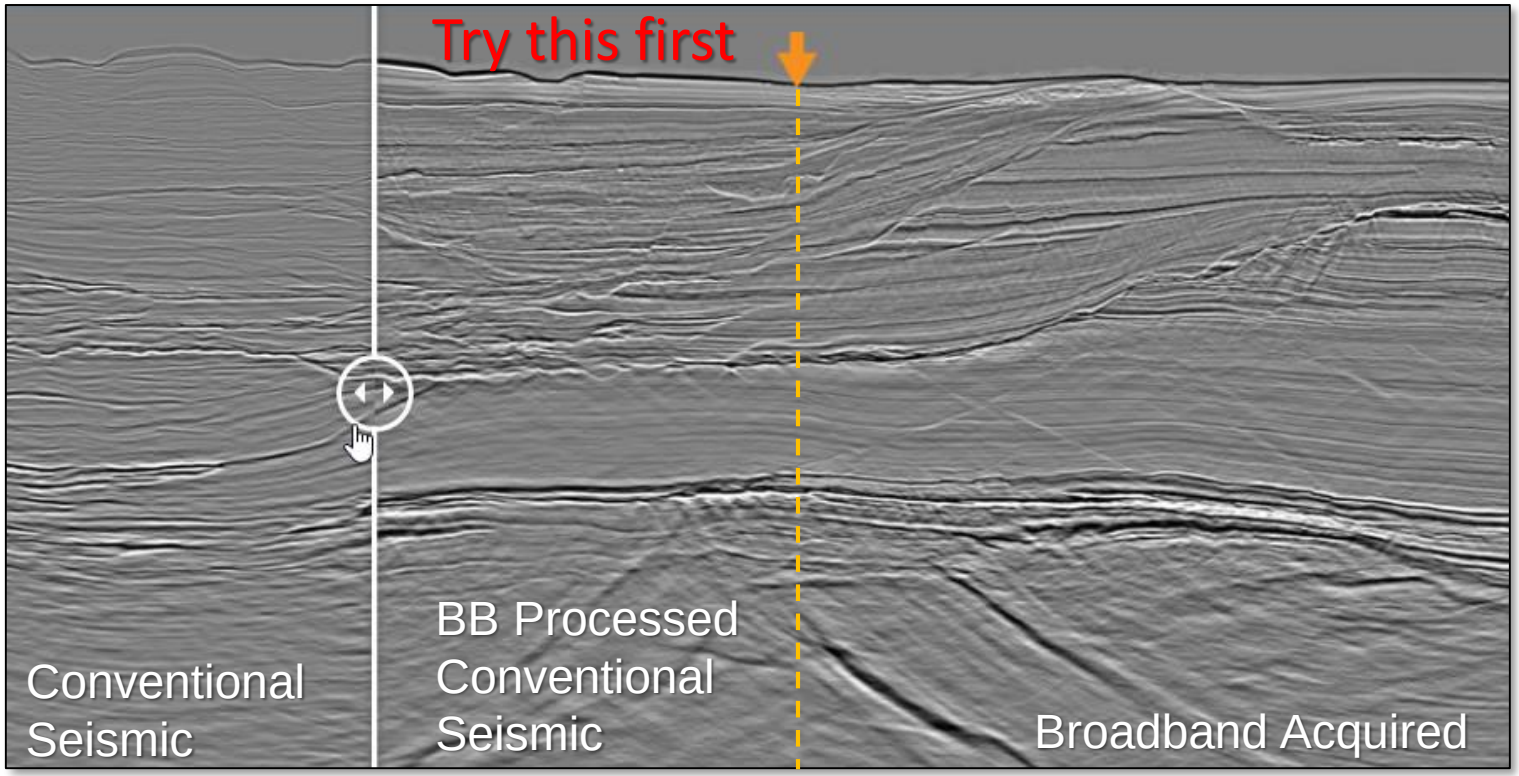


Agenda

- Introduction
- Geophysical technology evolution
  - **B**road**b**and (BB)
  - **F**ull **W**aveform **I**nversion (FWI)
  - **R**everse **T**ime **M**igration (RTM)
- Legacy 3D data
- Broadband reprocessing or reshoot?
- Summary

Courtesy PGS

Broadband Reprocessing or Reshoot?

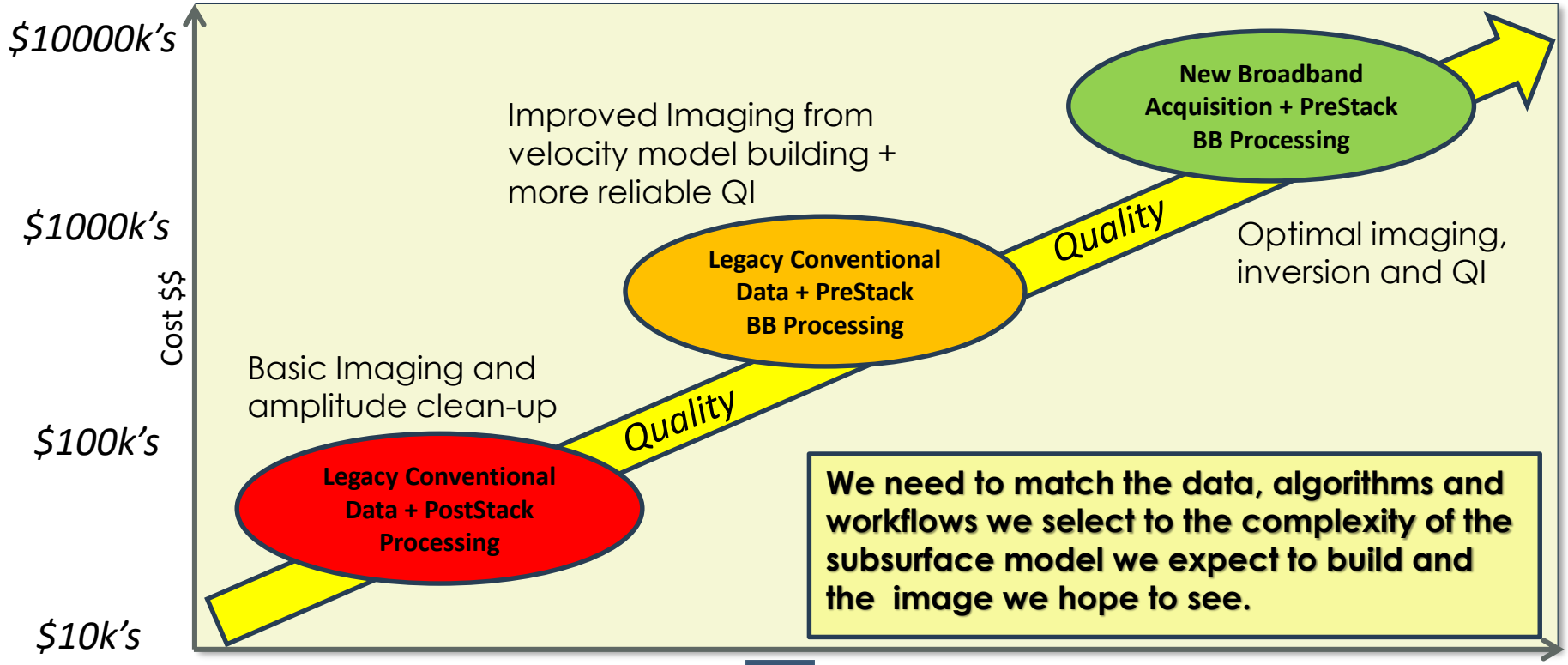


Broadband Reprocessing or Reshoot?

Broadband	Reprocessing (NL 3D Legacy Data)	Reshoot (idealized)
Broadband Spectrum	Sub-optimal	✓
Offset range	Sub-optimal	✓
De-signature	Sub-optimal	✓
De-ghost	Sub-optimal	✓
De-multiple	Sub-optimal	✓
Illumination	Sub-optimal	✓
Azimuth Richness	Sub-optimal	✓
Velocity Model Derivation (FWI)	Sub-optimal	✓
Imaging (RTM, LSRTM)	Sub-optimal	✓

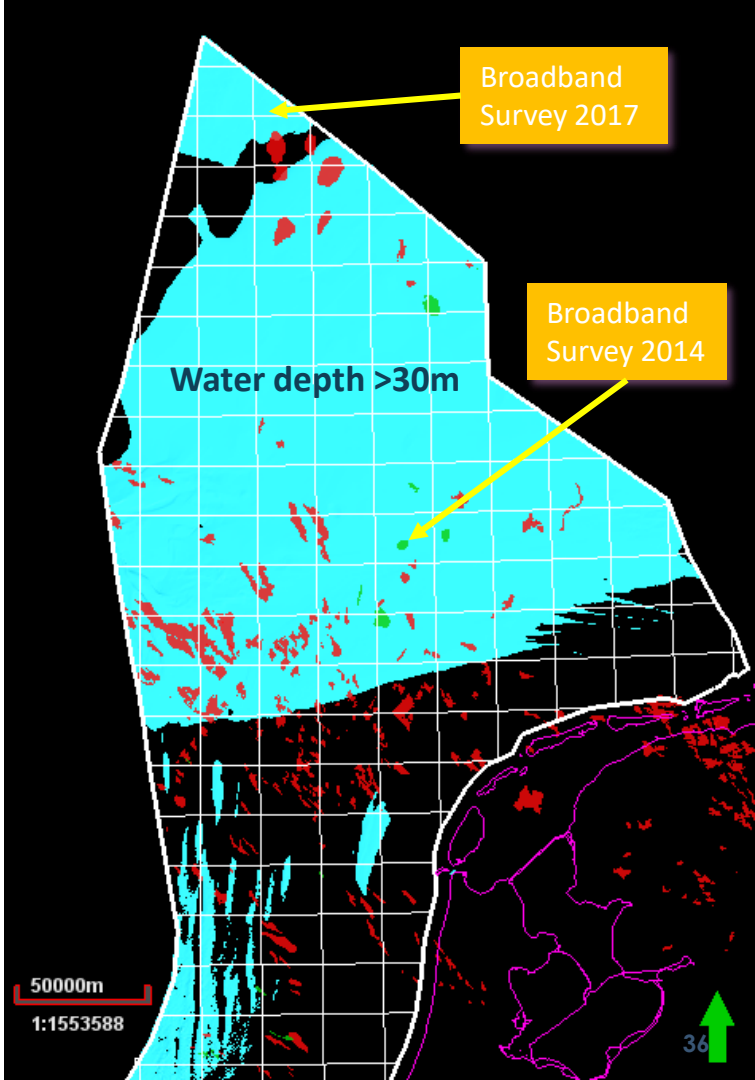
For severe imaging challenge

Broadband Reprocessing or Reshoot?



3D Broadband Reshoot

- Broadband acquistion requires deep streamer tow e.g. >15m*
- Broadband acquistion requires minimum water depth >30m
- OBN for shallower water depth and areas with restrictions

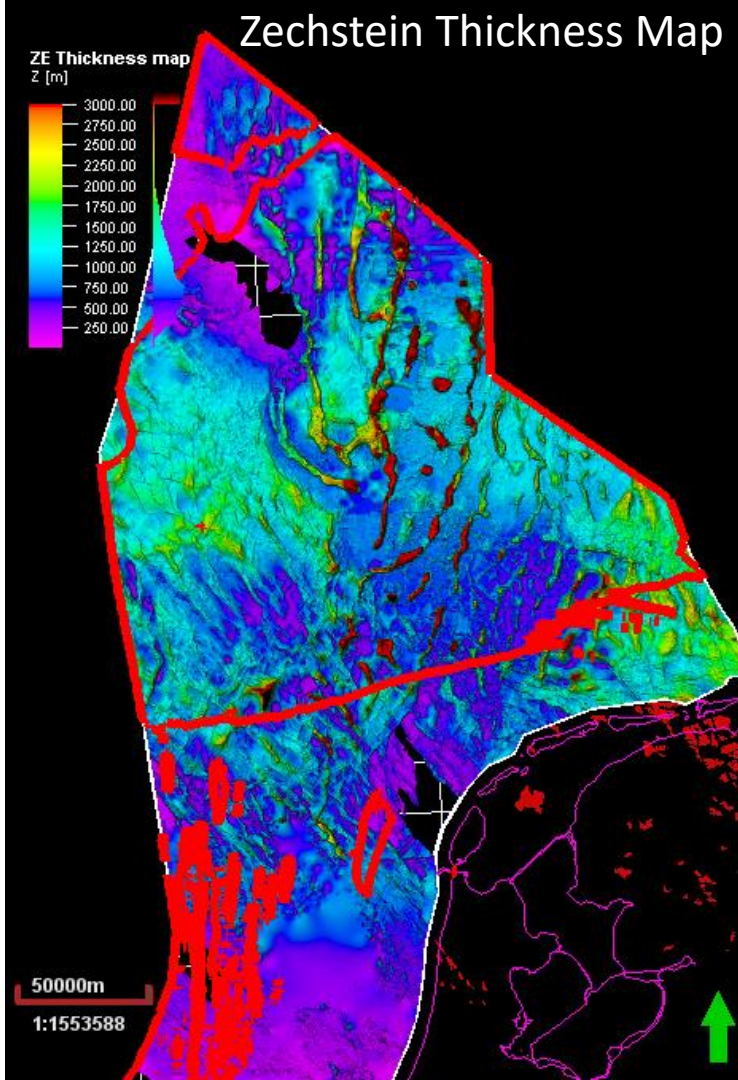


** Ideally >20m*

ebn

3D Broadband Reshoot

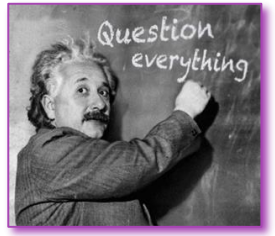
- Many areas with complex salt diapirism in NL SNS remain undrilled
- These undrilled areas typically have severe **imaging** and **depth conversion** challenges
- **Is there an opportunity to identify new economic gas fields by BB reshoot?**



Agenda

- Introduction
- Geophysical technology evolution
  - **B**road**b**and (BB)
  - **F**ull **W**aveform **I**nversion (FWI)
  - **R**everse **T**ime **M**igration (RTM)
- Legacy 3D data
- Broadband reprocessing or reshoot?
- Summary

Summary



- Significant improvements in seismic data quality/interpretability can be achieved with **Broadband reprocessing**
- Consider reprocessing again if existing 3D was processed **>5 years**
- **Broadband 3D reshoot** is likely required to tackle severe imaging challenges by allowing optimal application of **FWI** and **(LS)RTM**
- Undrilled areas in the NL SNS exist with severe imaging challenges and where **water depths >30m** enabling **3D Broadband reshoot**


ebn