Successful 3-D Seismic Imaging: From Industry Selective Targeting to Academic Systematic Research

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Memorial University of Newfoundland

PPSC

EnCana

Oil and Gas Development Program

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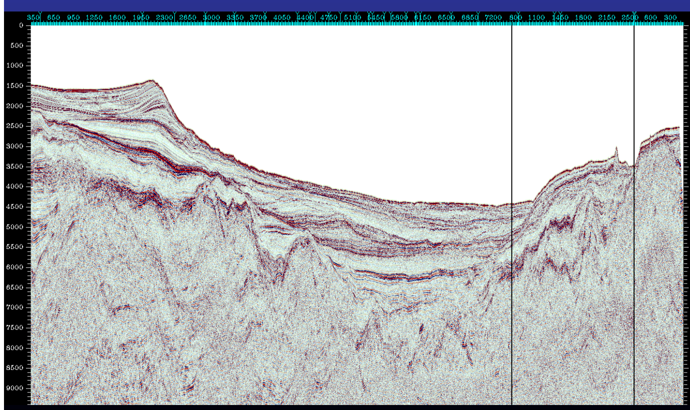
1. 3D Industry targeting
Marine Petroleum Exploration =
A systematic search for petroleum using geoscience methods (mostly seismic reflection) and drilling under the ocean bottom;
A complex business venture under the forces of the market (demand and supply) set to discover oil and gas

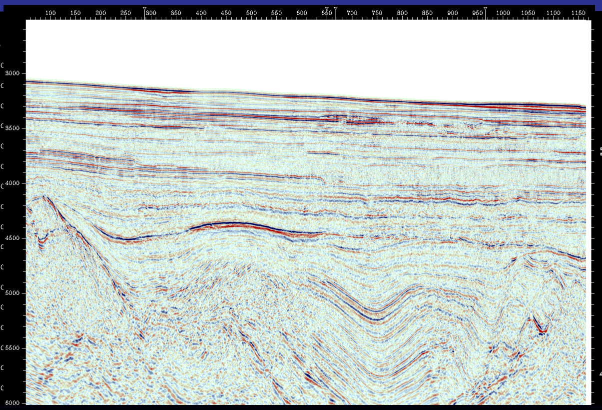
3D Seismic Reflection Method

- Is the most important method in the tool kit of a petroleum explorationist
- The main purpose of geophysics exploration is to most accurately render through graphic representations specific portions of the Earth's subsurface geologic structure
- 3D is by far the most adequate and most celebrated geophysical method

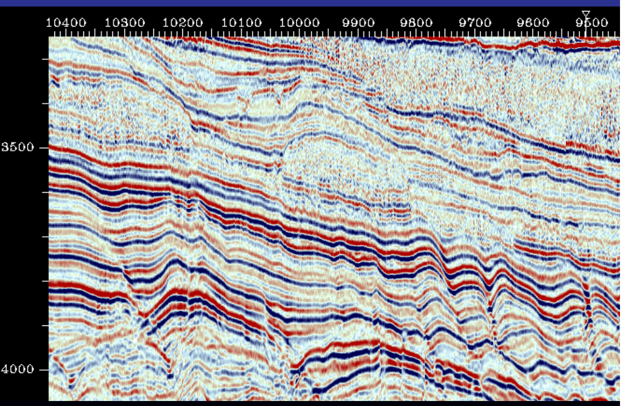
1. Regional scale



2. Prospect scale



3. Detail scale



How we arrived to 3D seismic?

- **A. Seismic Technology: The First Revolution 1950s**
  1. GSI build transistors that ultimately resulted in the birth of **Texas Instruments**;
  2. Mid -1950s broght the recording of seismic signals on **magnetic tape.**
  3. Harry Mayne's invented **common-depth-point (CDP) data stacking**.

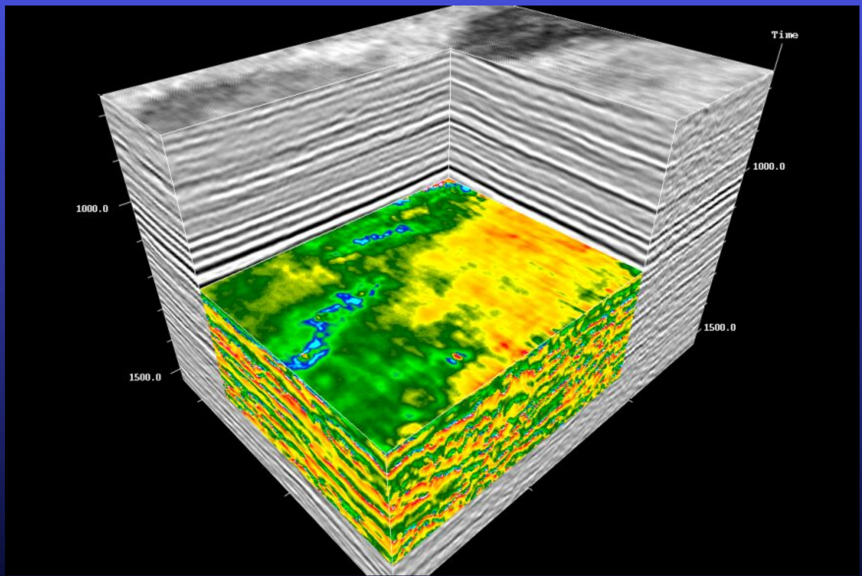
- **B. Digital Technology: The Second Revolution**
  1. In 1961, **GSI** introduced the **digital field system and computer for seismic-data processing.**
  2. In 1964, IBM introduced its **360 series of digital computers**; Geoscientists began moving data into **computers**, and processors started generating **processing algorithms**.
  3. Seismic technology evolves in parallel to **information technology (IT).**
  4. Complete digital gathering and processing systems were developed

- **C. Three-Dimensional Seismic: The Third Revolution**
  1. The concept of 3D-seismic surveying has existed since the earliest days of geophysics. Implementation hindered by the efficiency and accuracy of data acquisition, high cost and computing power necessary to condense, process, display, and help interpret data.
  2. Early 1970s, the industry had developed a **data-processing arsenal** including programs for single and multichannel processing, deconvolution, velocity filtering, automated statics, velocity analysis, migration, inversion, and noise reduction.
  3. First 3D seismic survey was shot by Exxon over the Friendswood field near Houston in 1967.
  4. In 1972, GSI enlisted support of Chevron, Amoco, Texaco, Mobil, Phillips, and Unocal for a major research project to evaluate 3D seismic **at Bell Lake field in southeastern New Mexico**, a structural play with 9 producers and several dry holes and had sufficient borehole data to ensure that 3D seismic could be correlated to subsurface geology. After only 1 month acquisition, processing required another 2 years, and producing migrated time maps and interpretation on paper (without workstations!) was also a lengthy process. The project was a **defining event** in seismic history because the resulting maps confirmed the field's nine producers, condemned its three dry holes, and revealed several new drilling locations in a mature field.

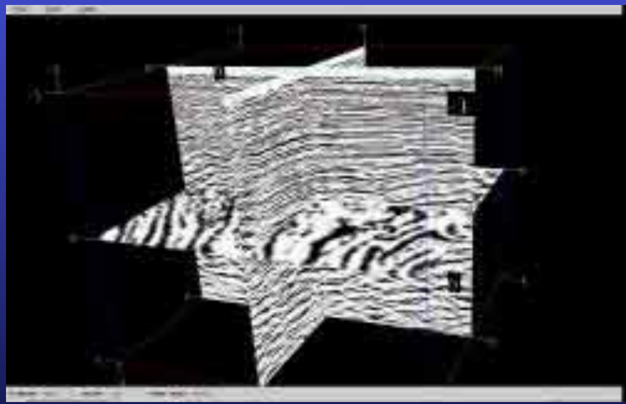
Modified After Graebner and http://www.spe.org/spe/jsp/basic/0,,1104_1714_1004089,00.html

Marine 3-D Seismic Survey

- **The first marine 3D datasets were created from closely spaced 2D lines acquired with a single streamer (late seventies). The early 1980s saw the first attempts to tow dual streamers-presently up to 20 streamers are used**
- **3D seismic data** are displayed as a **three-dimensional cube** that may be sliced into numerous **planes or cross-sections**.
- More expensive than 2D data, 3D produces **spatially continuous** imaging which reduce uncertainty in areas of **expensive exploration**, **structurally complex geology** and/or **small or subtle reservoir targets**



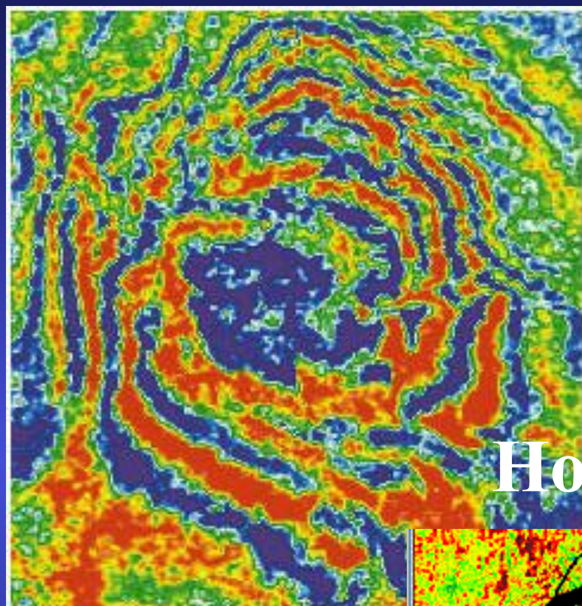
3-D Data Cube in Western Canada Basin



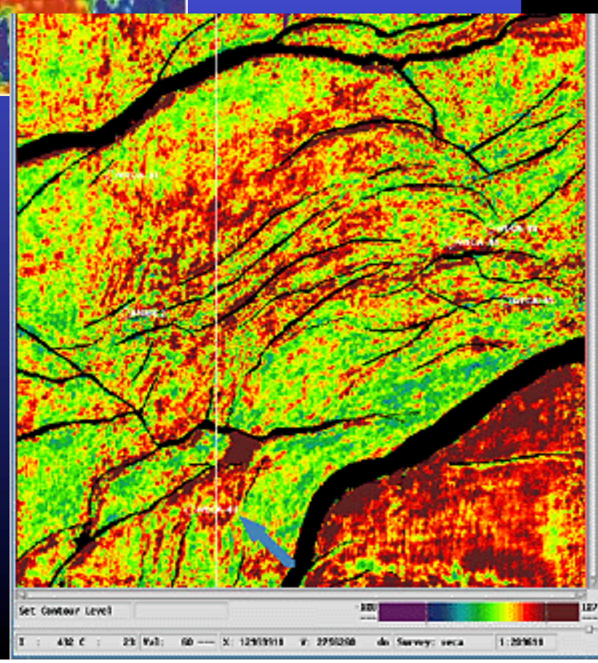
3-D Seismic Cross Section and Time Slice from a 3-D Cube

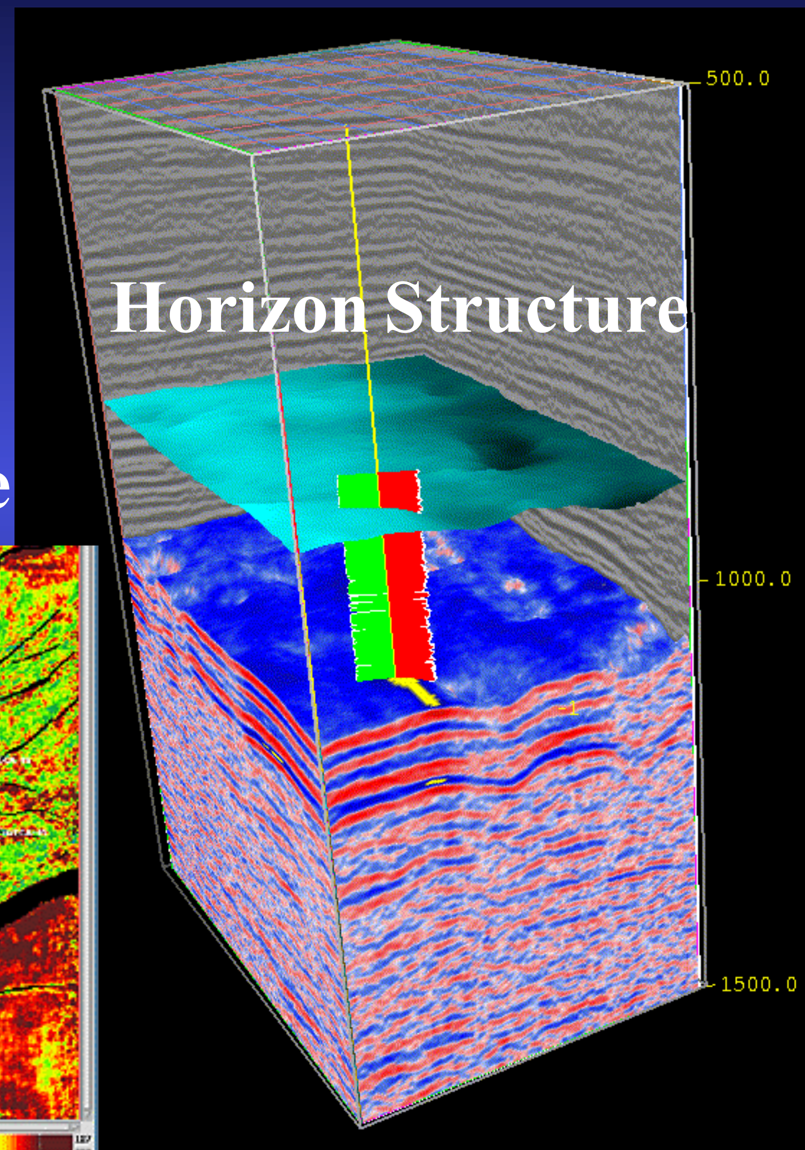
3-D Interpretation

Time Slice

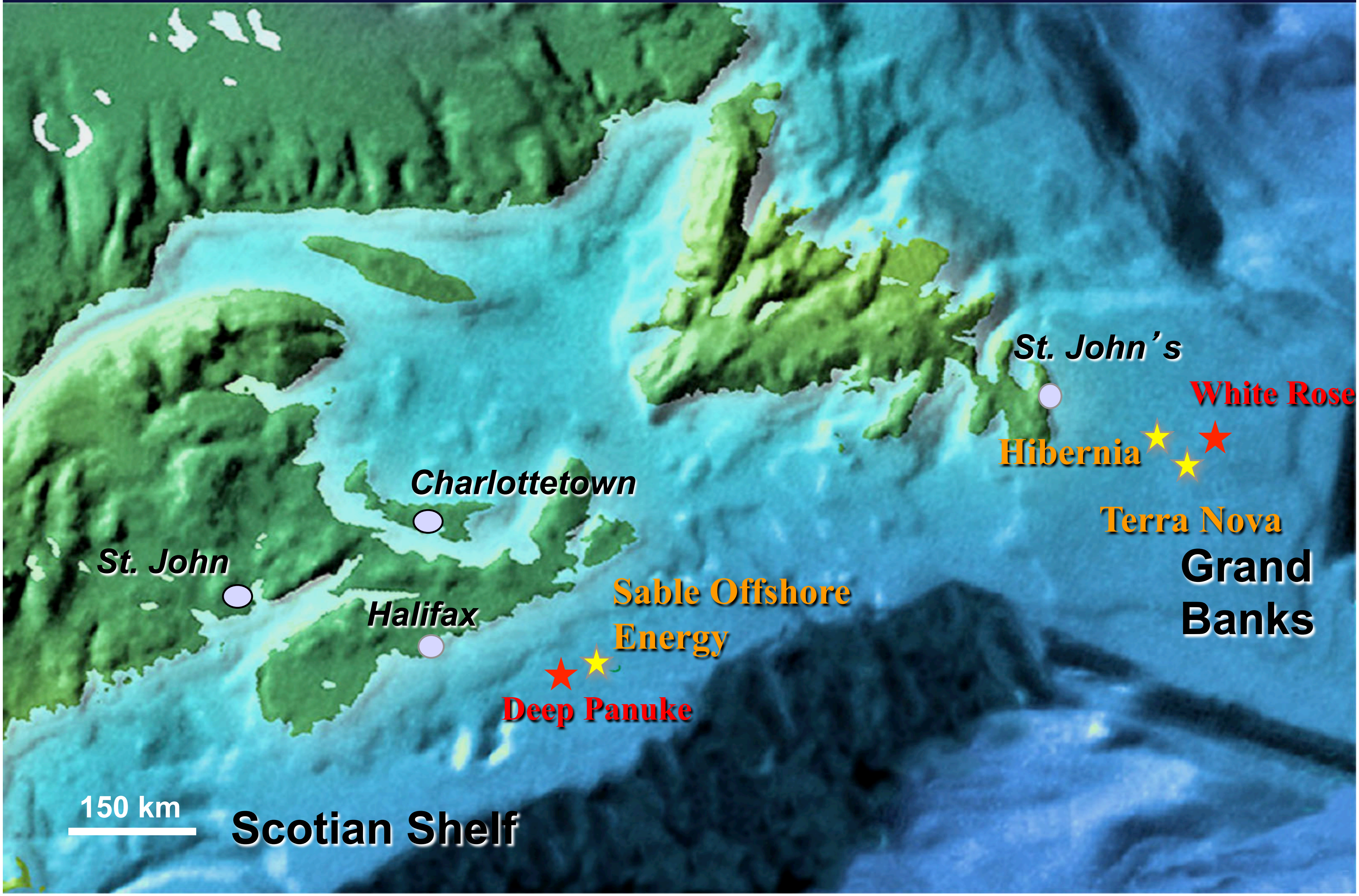


Horizon Slice

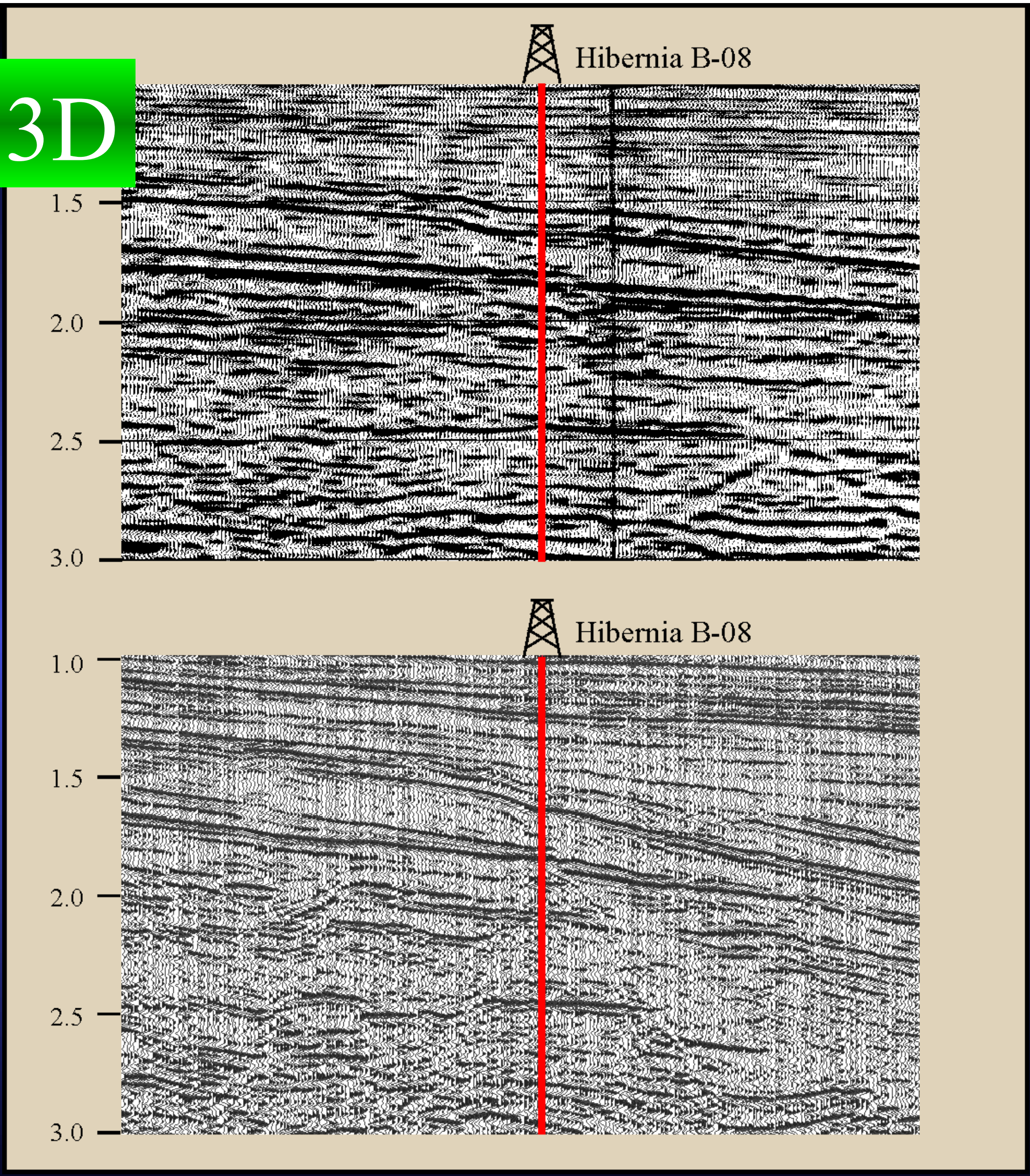




Atlantic and Northern Canada 3D Examples



Hibernia 3D

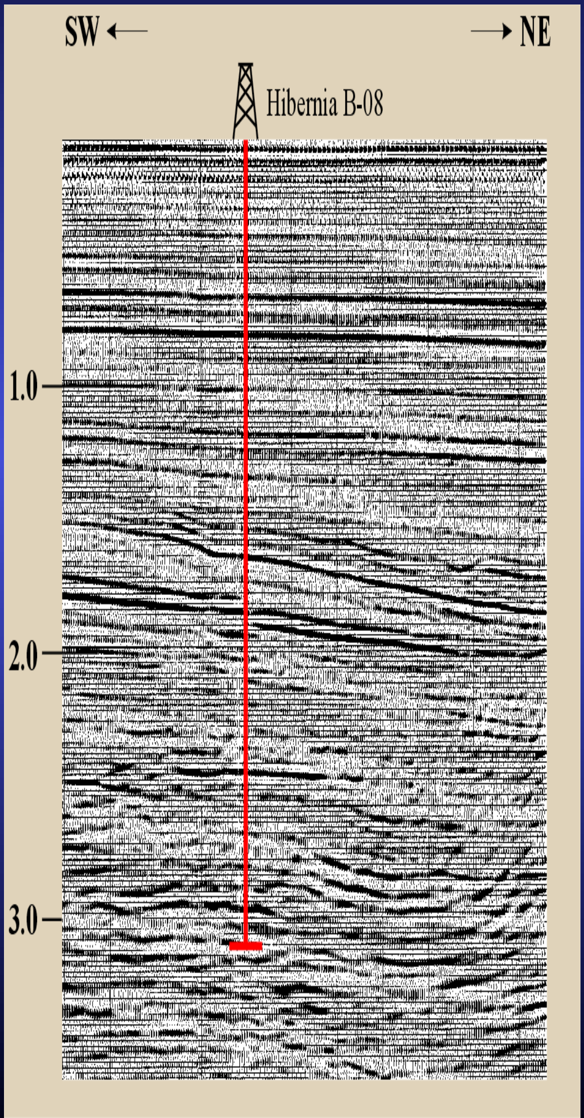


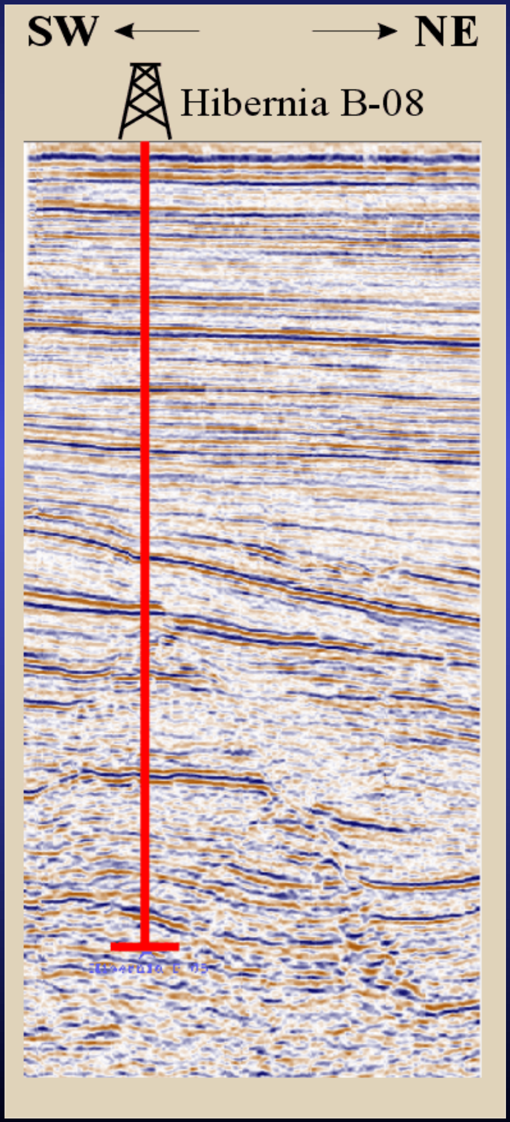
1980/81

1991

Modified after McIntyre et al., 2004

Hibernia L-504





Survey Statistics Hibernia Seismic

1964	**1980**	**1991**	**2001**
• 1,500 m	• 2,300 m	• 3,000 m	• 4,050 m
• 9,195 km	• 4,099 km	• 21,247 km	• 43,938 km
• 283 days	• 118 days	• 127 days	• 63 days
• 32 km/day	• 35 km/day	• 167 km/day	• 697 km/day
Dense 2D	**3D**	**3D**	**undersh.3D**

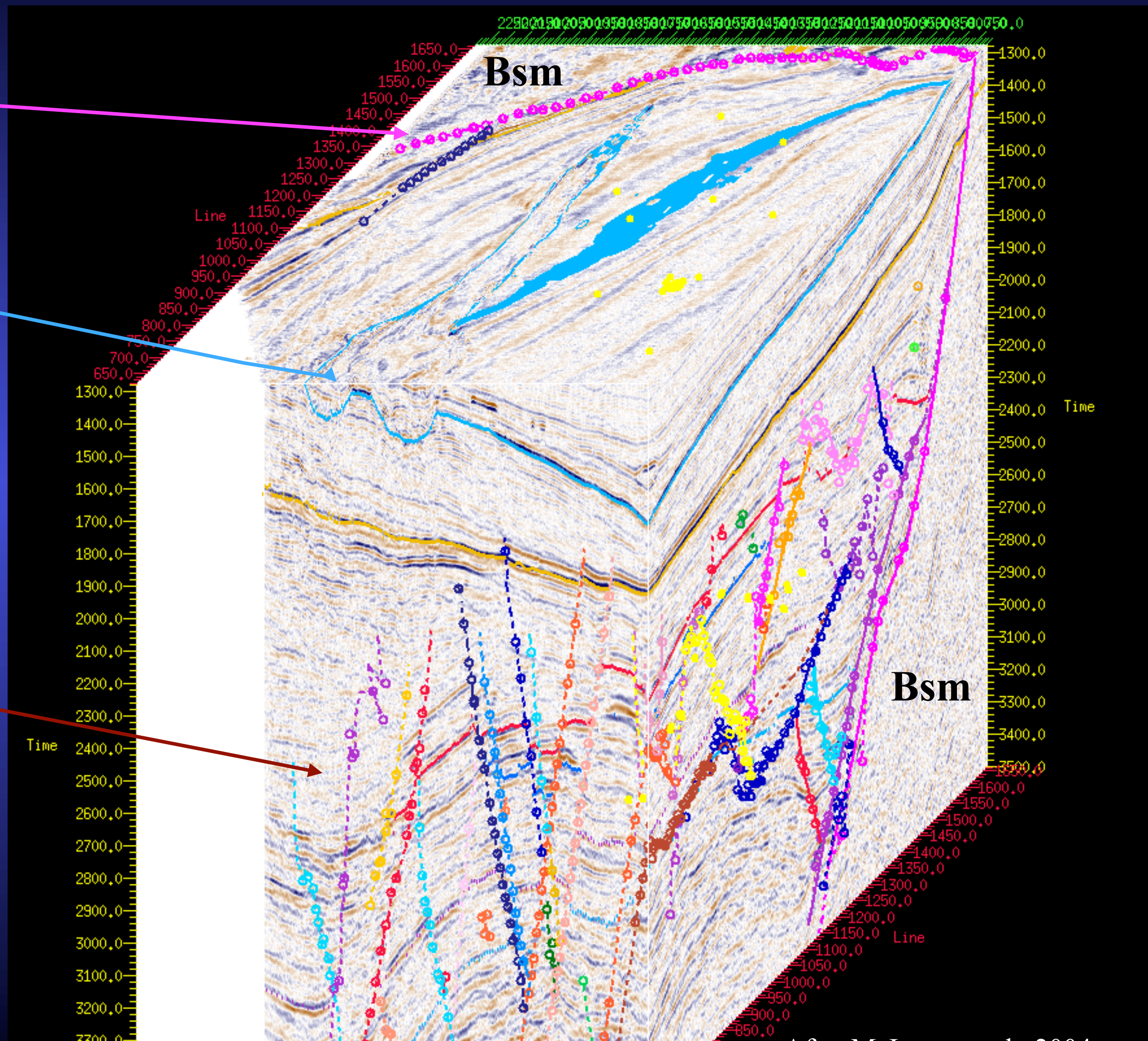
Modified after McIntyre et al., 2004

1991 Hibernia 3D cube

Murre Fault

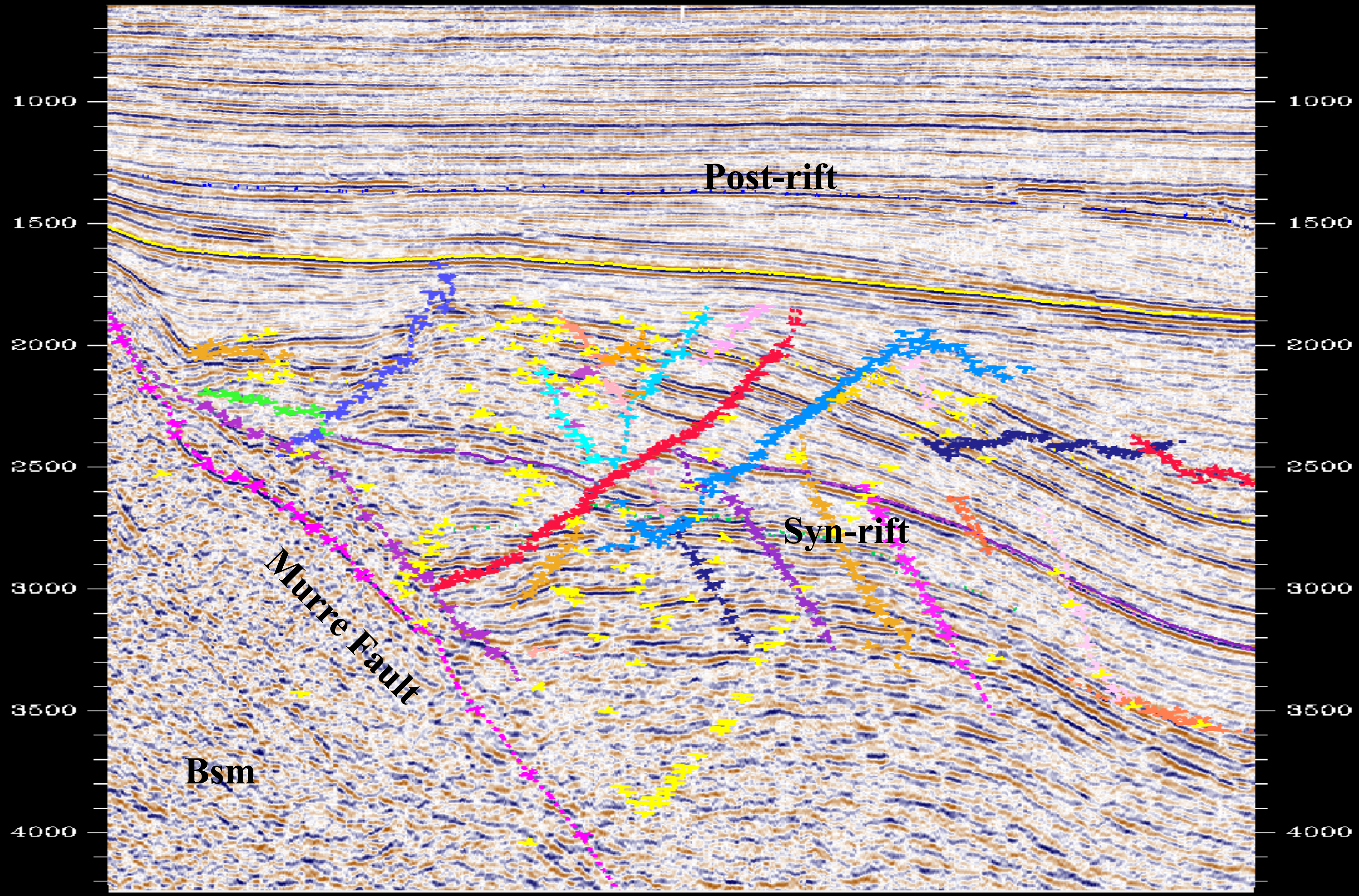
Tertiary canyon

Faulted
Extensional
Anticline



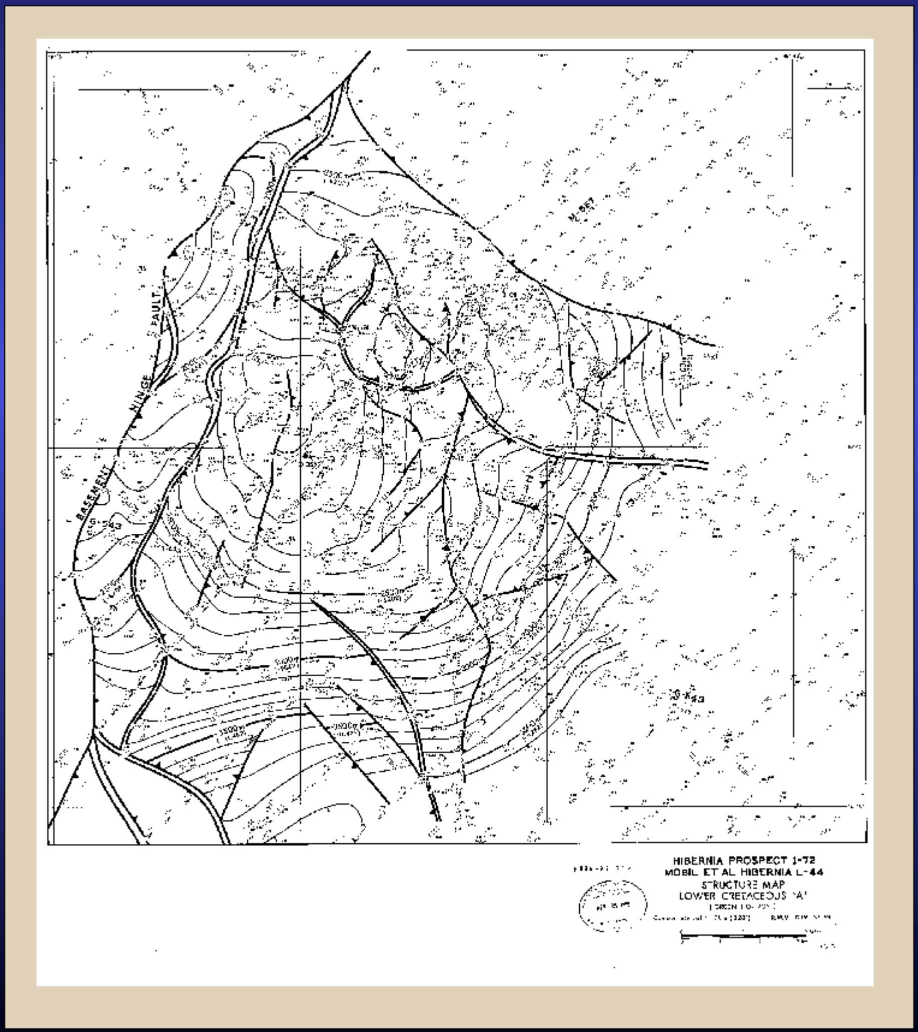
After McIntyre et al., 2004

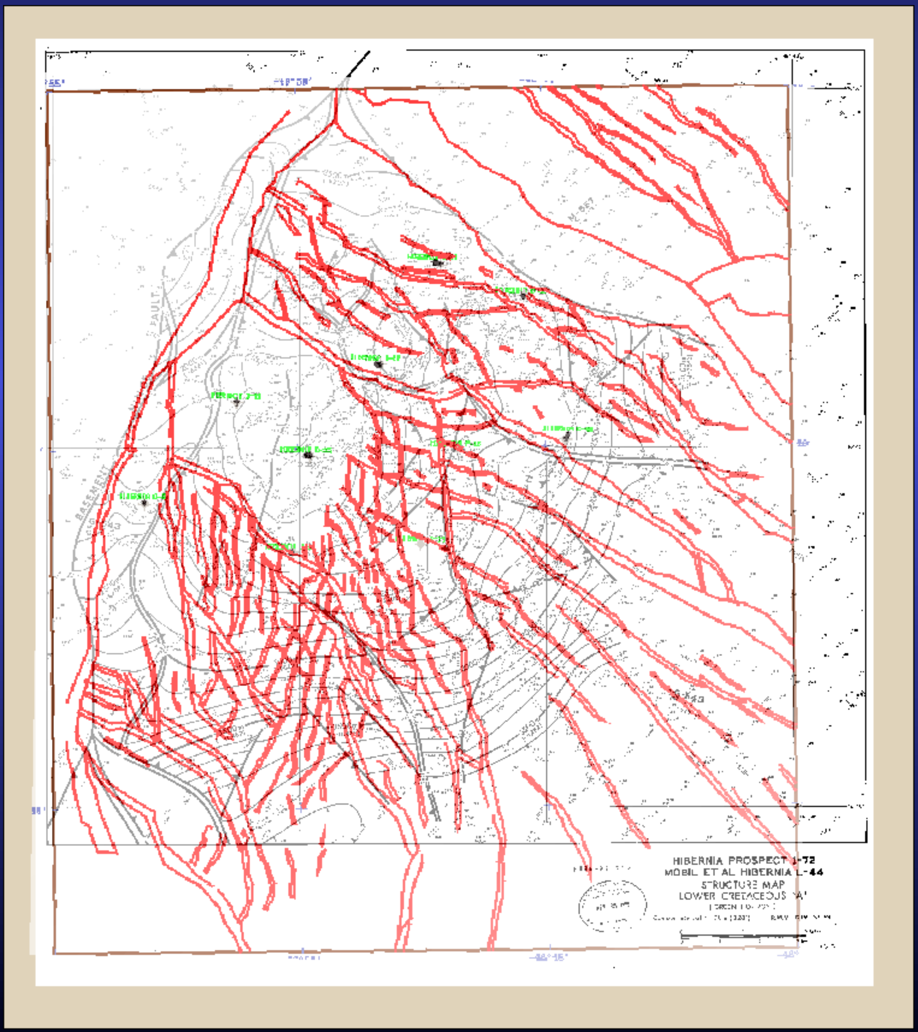
1991 Hibernia 3D Arbitrary Line



Modified After McIntyre et al., 2004

Comparison between 2D and 3D interpretation of the field structure





After McIntyre et al., 2004

Modern 3D Seismic

- **By late seventies-early eighties, 3D becomes a "must" during delineation** of large fields by multinational oil companies. The subsurface could be depicted on a rectangular grid that provided interpreter with detailed **information about full 3D subsurface volume**.

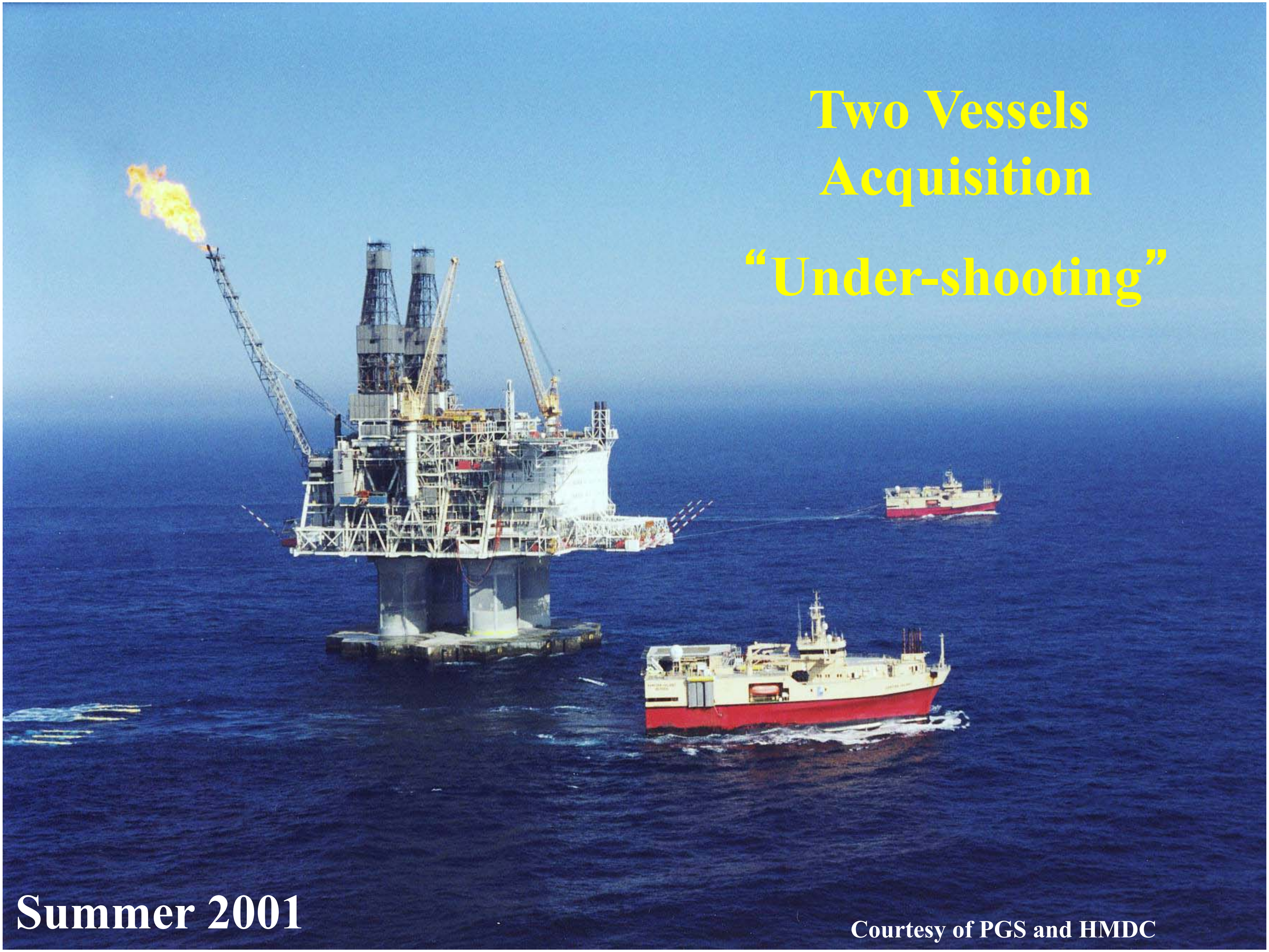
Advantages:

3D data provides **clearer and more accurate information** than those from 2D data. Any desired cross section can be extracted from the volume for display and analysis, including vertical sections along any desired zigzag path-well ties. Lateral detail also was enhanced by the dense spatial coverage in 3D surveys. Slicing the data volume horizontally at fixed reflection times yield comprehensive overviews of subsurface structural features, particularly faulting. Attributes can be mapped and displayed along curved reflector surfaces such as faults, channels. The accurate positioning of events made possible through 3D migration also improved subsurface imaging of flatter-lying stratigraphic targets. The result was **improved value of seismic data for exploration and production functions.**

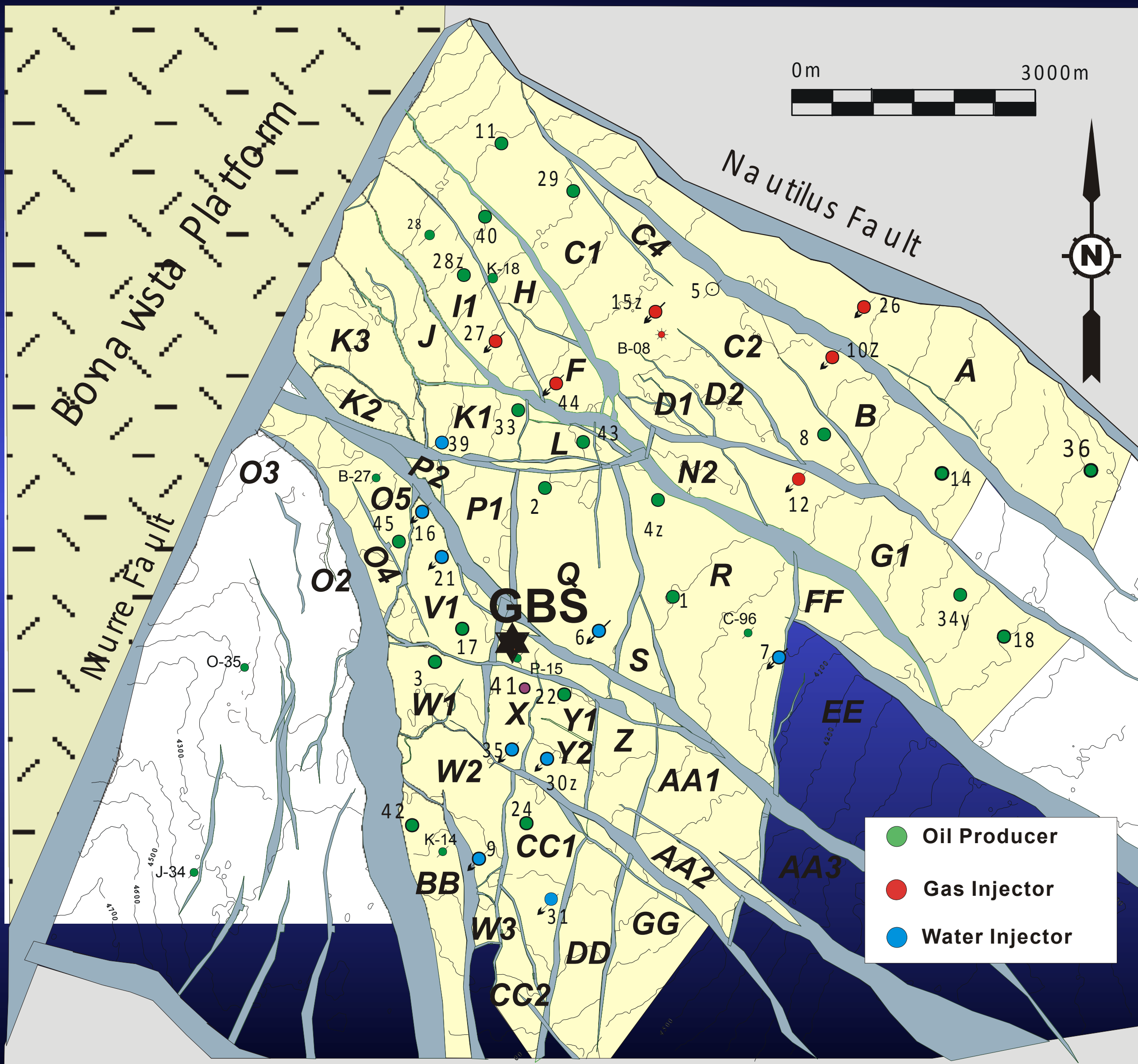
Modern 3D Seismic Technology

3D-seismic technology is widely applied to solve problems and reduce uncertainties across the entire range of **exploration, development, and production** operations. Surveys are used to characterize and model reservoirs, to plan and execute enhanced-oil-recovery strategies, and to monitor fluid movement in reservoirs as they are developed and produced. These capabilities have been made possible by **advancements in data acquisition, processing, and interpretation** that have both improved accuracy and reduced turnaround time.

Modified after http://www.spe.org/spe/jsp/basic/0,,1104_1714_1004089,00.html


Two Vessels
Acquisition
“Under-shooting”
Summer 2001
Courtesy of PGS and HMDC

Fault Compartmentalization in Hibernia Reservoir

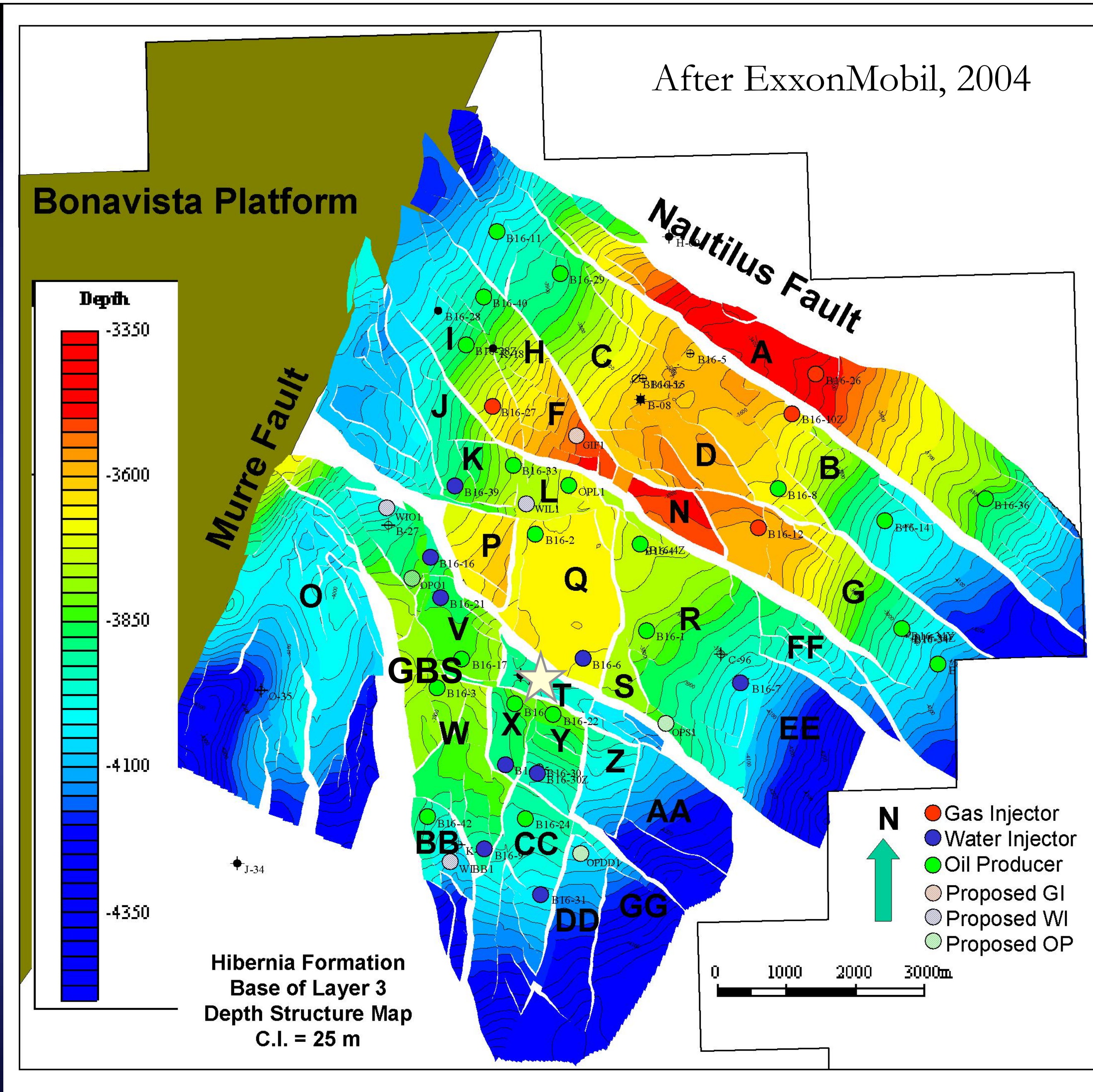


- About 30 major faults and many more minor faults segment the reservoir
- sands are isolated laterally
- set up different OWC
- producer-injector pairs required for each major block

GAS Injection for support in the north, WATER injection in the south

> 400m oil column, TVDs -3600 to -4000m

After Hynes et al., 2004

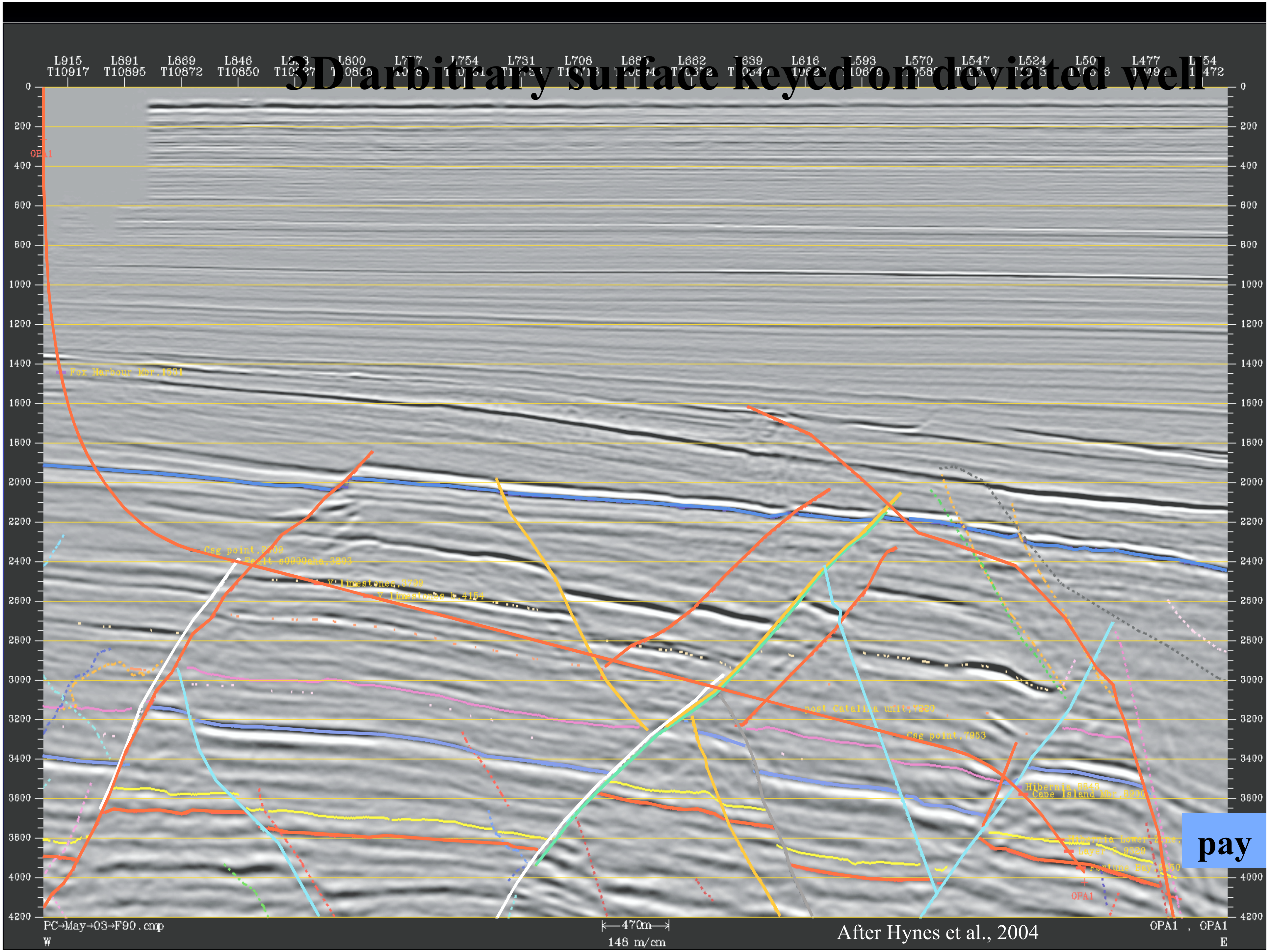


Hibernia Reservoir

- 49 wells
- 220,000 bopd
- Best chance to find reserves is in a known field - optimizing and drilling using 3D seismic based model
- Seismic faults = barriers and baffles
- More than 600 faults
- Non-seismic faults
- **Reservoir development is like playing chess based on a 3D board!**

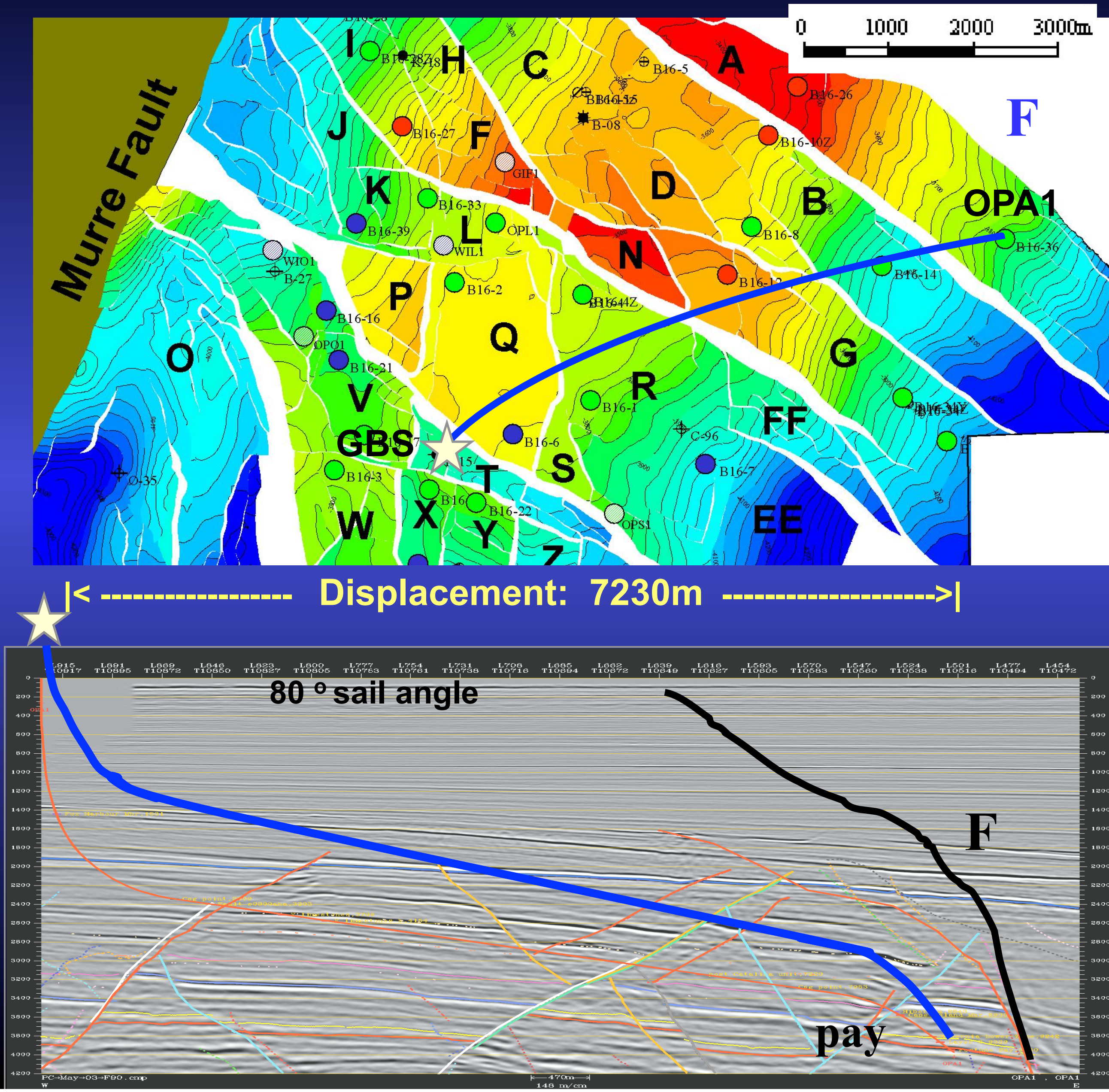
After Hynes et al., 2004

3D arbitrary surface keyed on deviated well



After Hynes et al., 2004

Seismic Line along well trajectory



3D guides field development

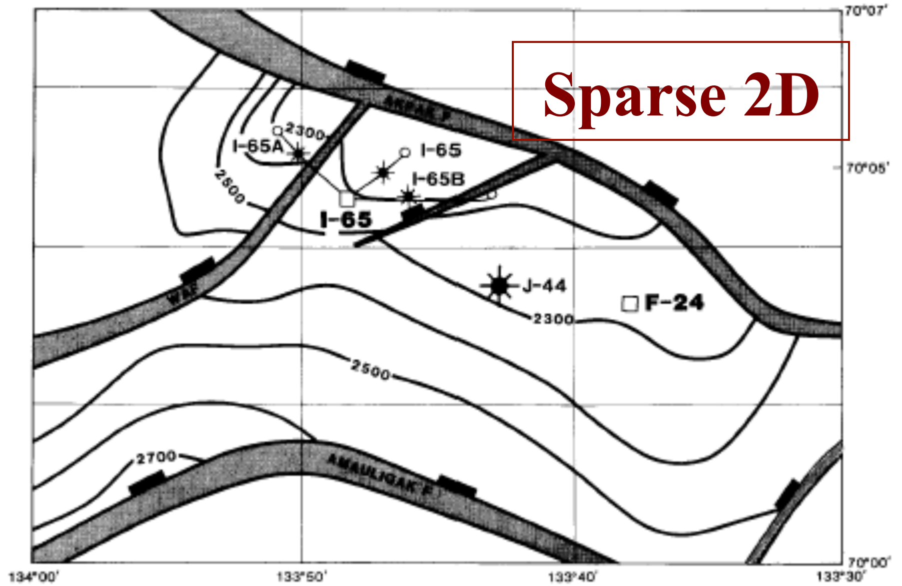
B-16 36 (OPA1):
latched at 8.5 km,
pressures to 9.3 km,
(30,530 feet MD)

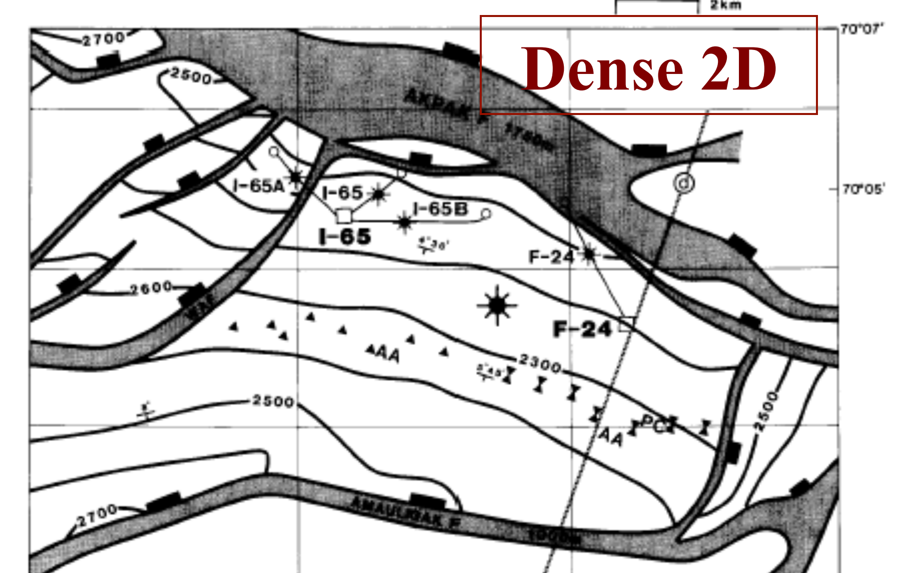
communication to injector (3.5 km NW and 300 m updip) established

–

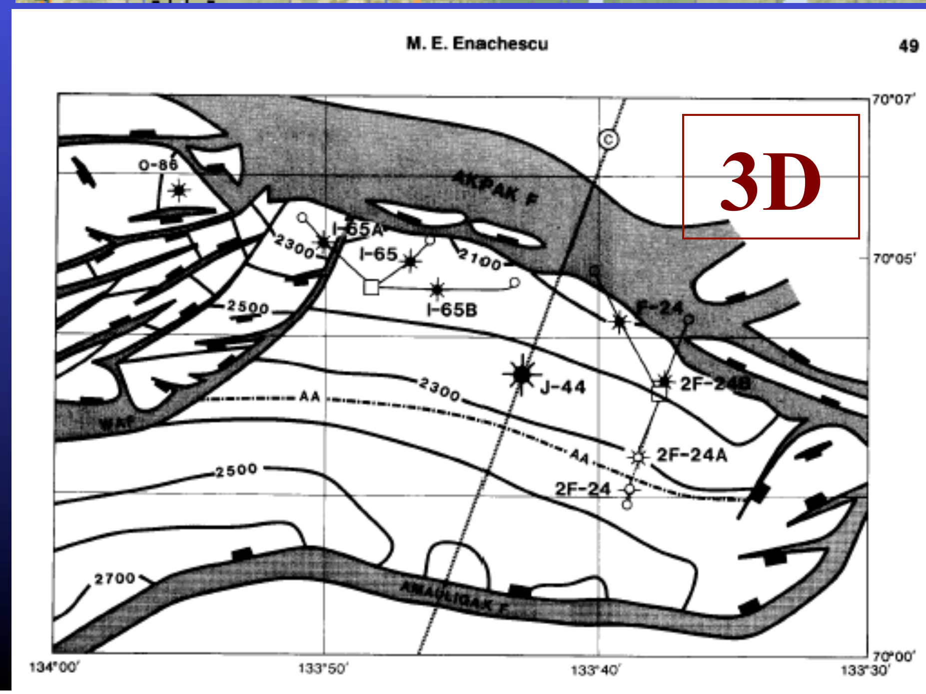
After Hynes et al., 2004

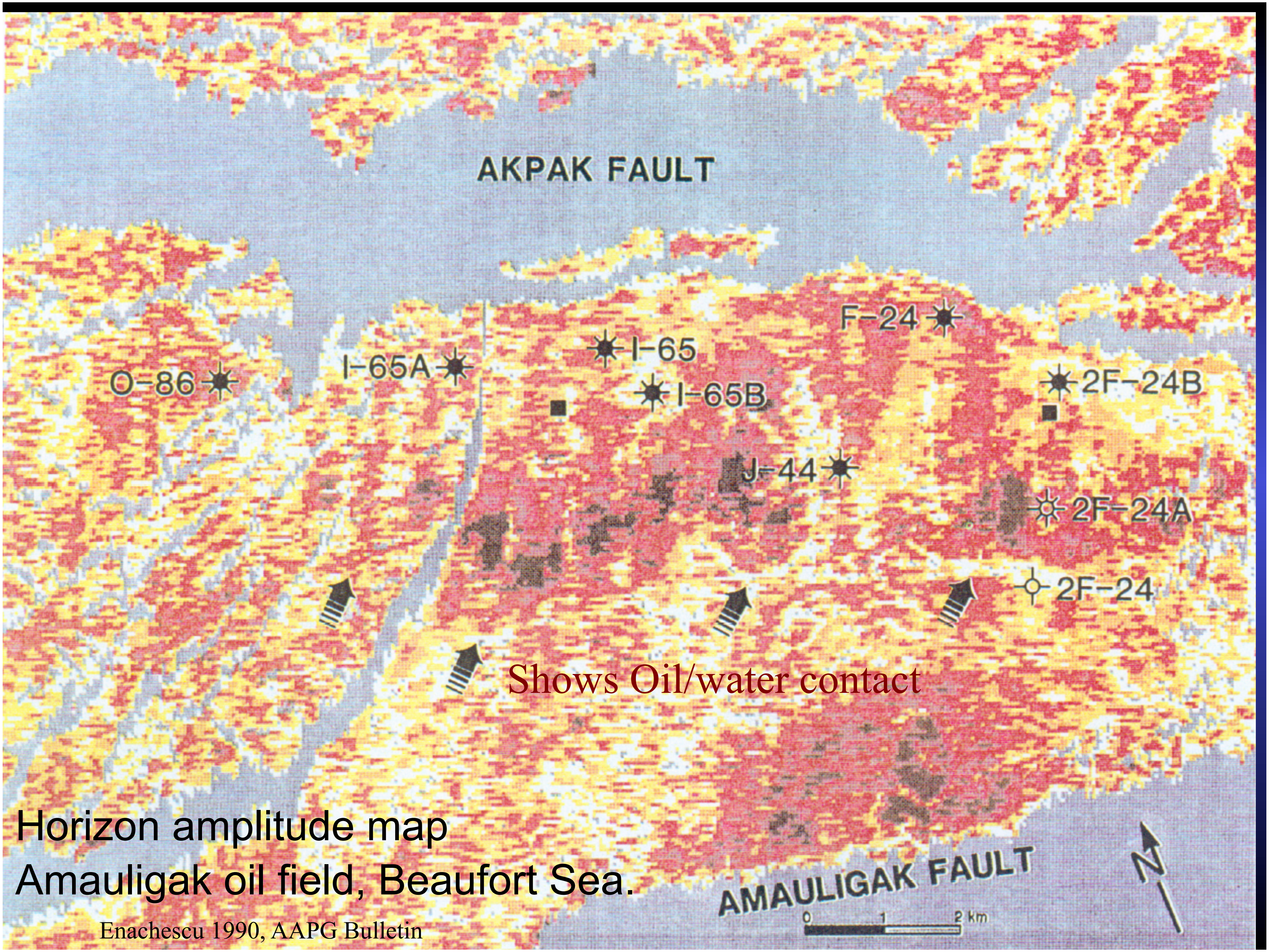
Ones more Back in Time-1980's





Enachescu 1990, AAPG Bulletin

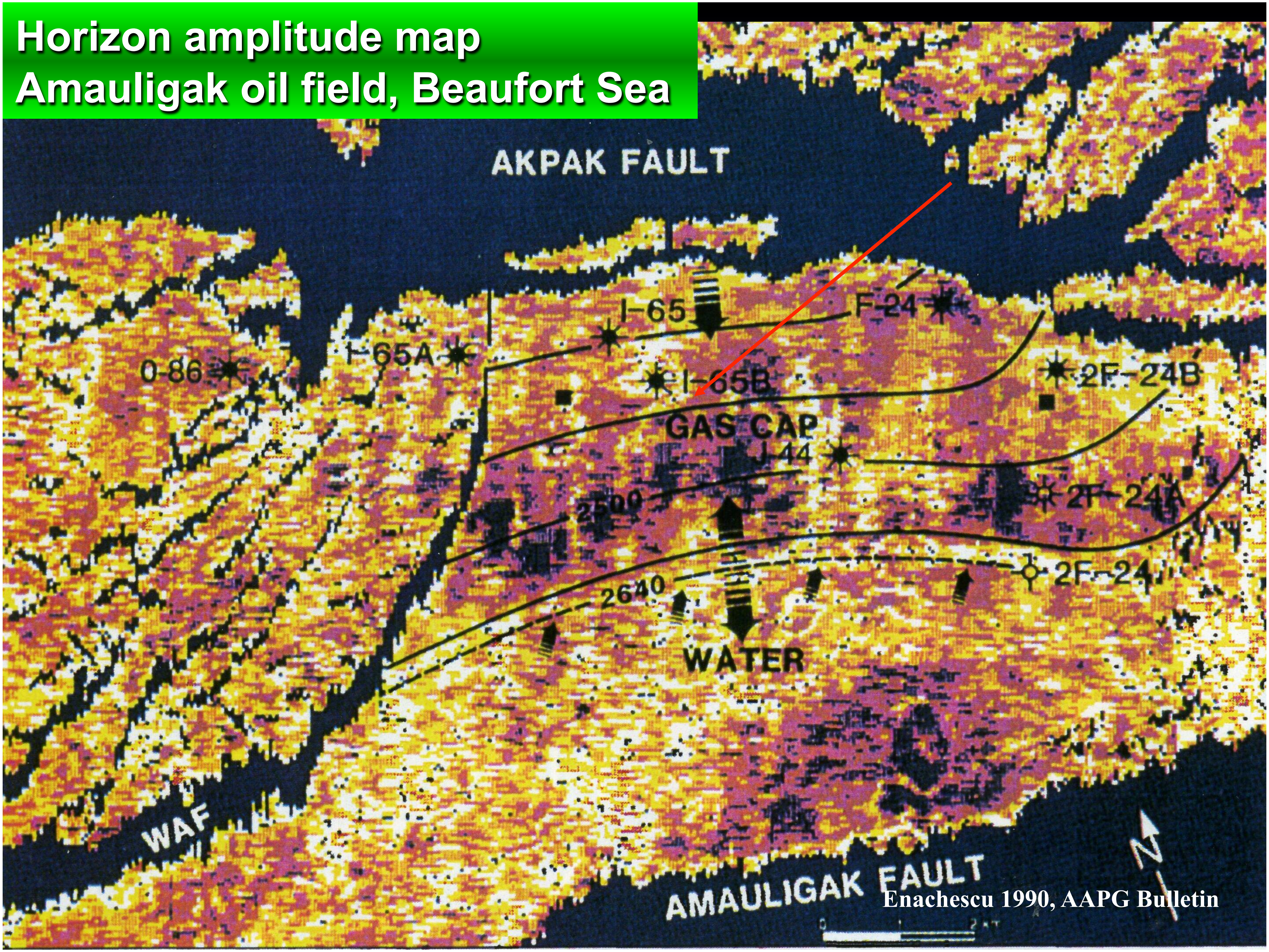




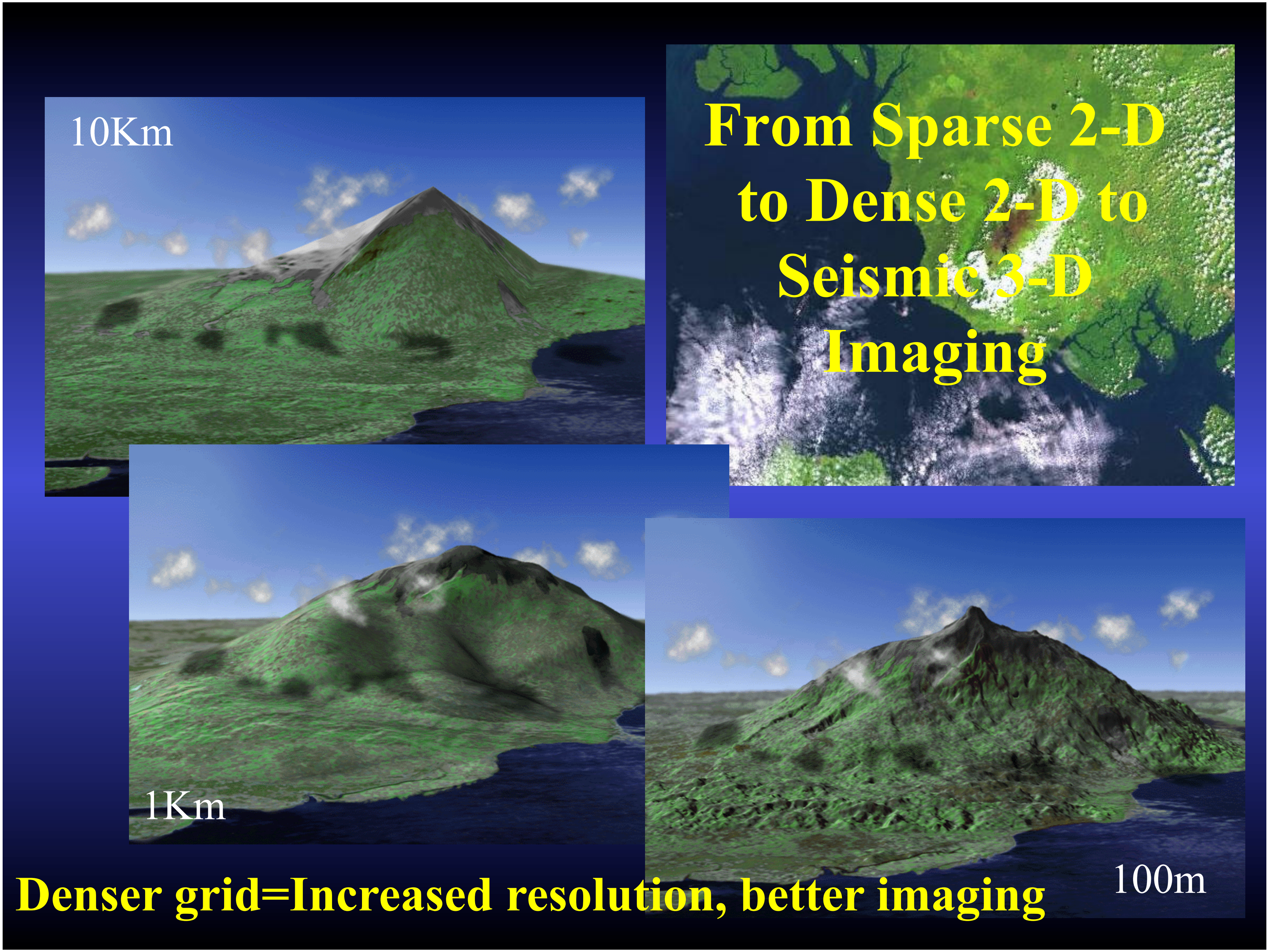
Horizon amplitude map
Amauligak oil field, Beaufort Sea.

Enachescu 1990, AAPG Bulletin

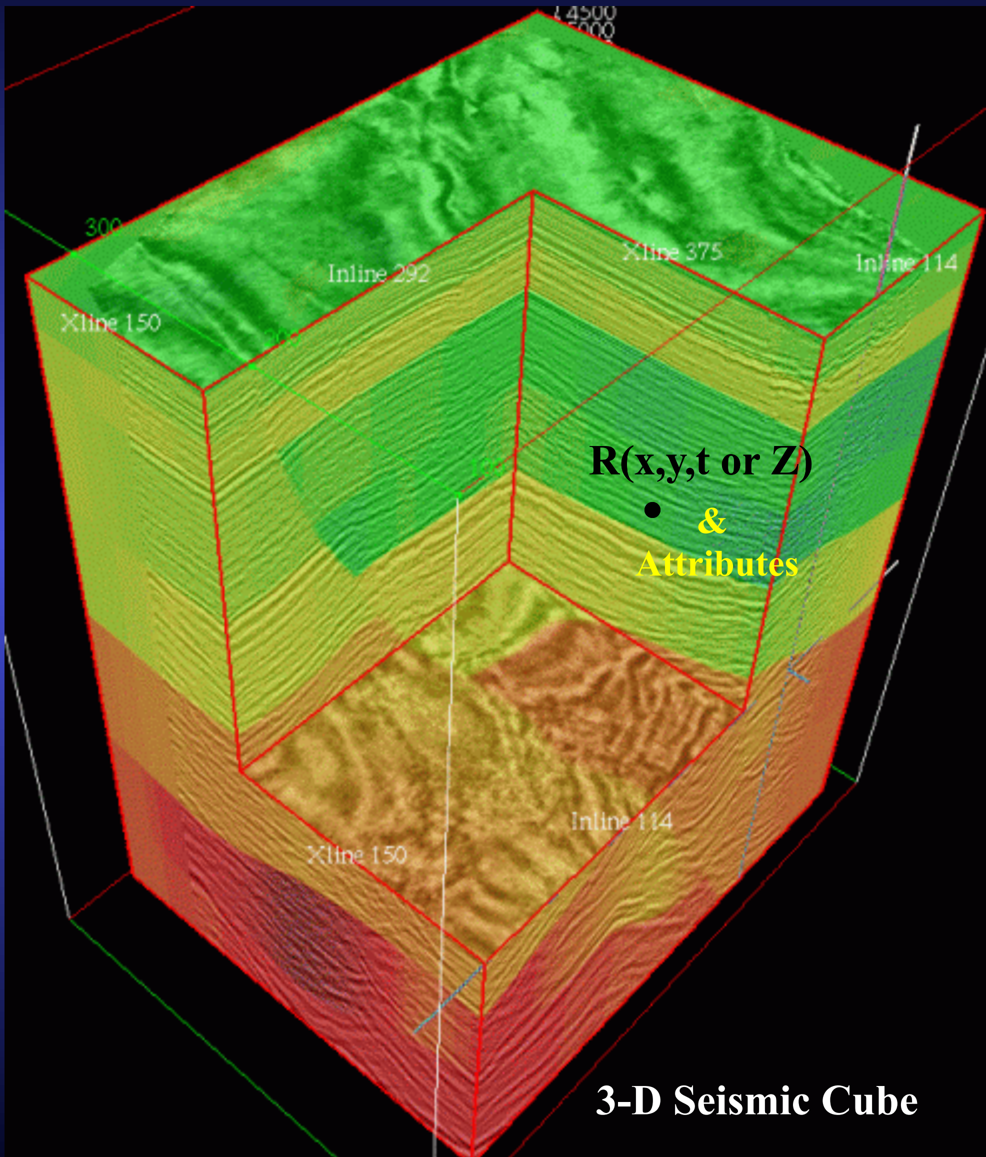
Horizon amplitude map
Amauligak oil field, Beaufort Sea



Enachescu 1990, AAPG Bulletin

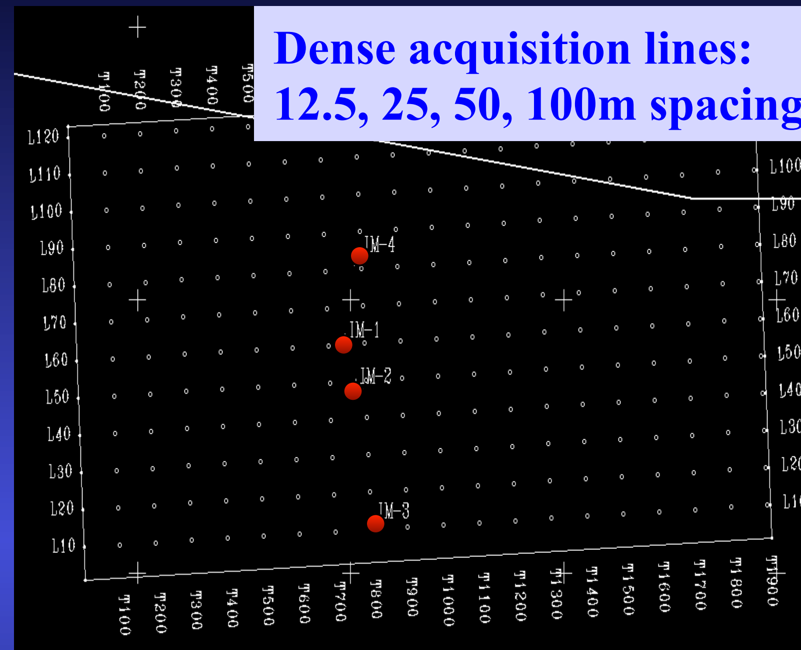

From Sparse 2-D to Dense 2-D to Seismic 3-D Imaging
10Km
1Km
100m
Denser grid=Increased resolution, better imaging

Three-Dimensional (3-D) Seismic Survey

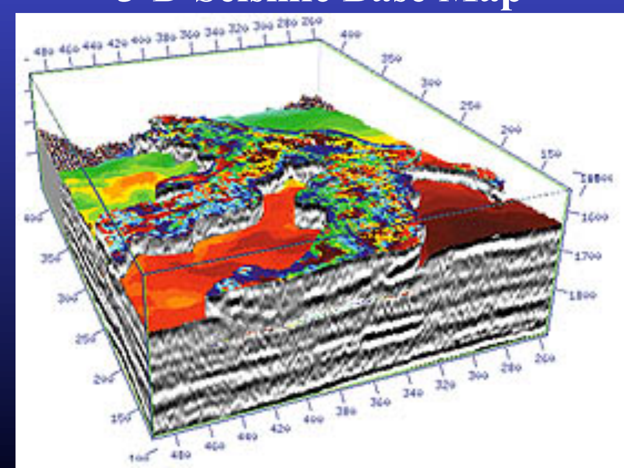


3-D Seismic Cube

Dense acquisition lines: 12.5, 25, 50, 100m spacing



3-D Seismic Base Map



3-D Seismic Display

Seismic Attributes

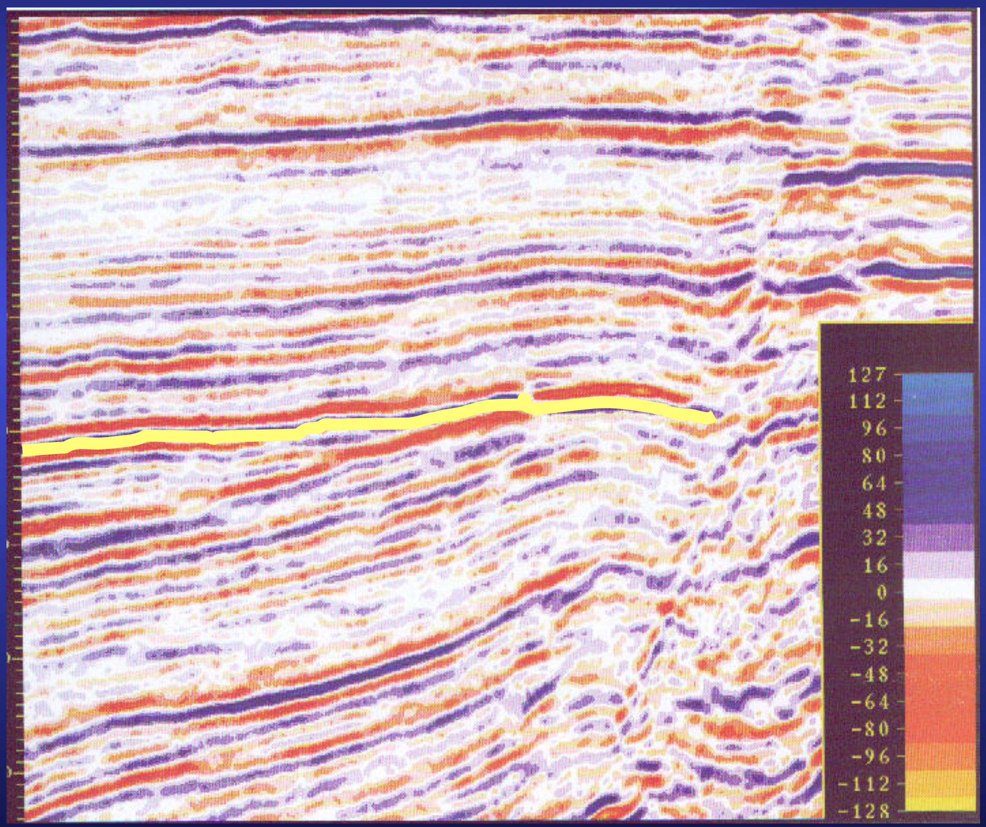
- Seismic attributes are derived from seismic data (3D data is best; some attribute information can be derived from 2D).
- These attributes can be thought of as different ways of viewing and studying the data.

In general terms:

1. Time-derived attributes provide structural information
2. Amplitude-derived attributes provide stratigraphic and reservoir information
3. Frequency and attenuation-derived attributes have growing applications for stratigraphic, reservoir and permeability information.

after Alistair Brown, AAPG Mem 42

Horizon Attributes



Time

Time slice, Isochron, Trend, Residual, Dip, Azimuth, Difference, Edge, Illumination, Phase, Curvature, Roughness

Amplitude

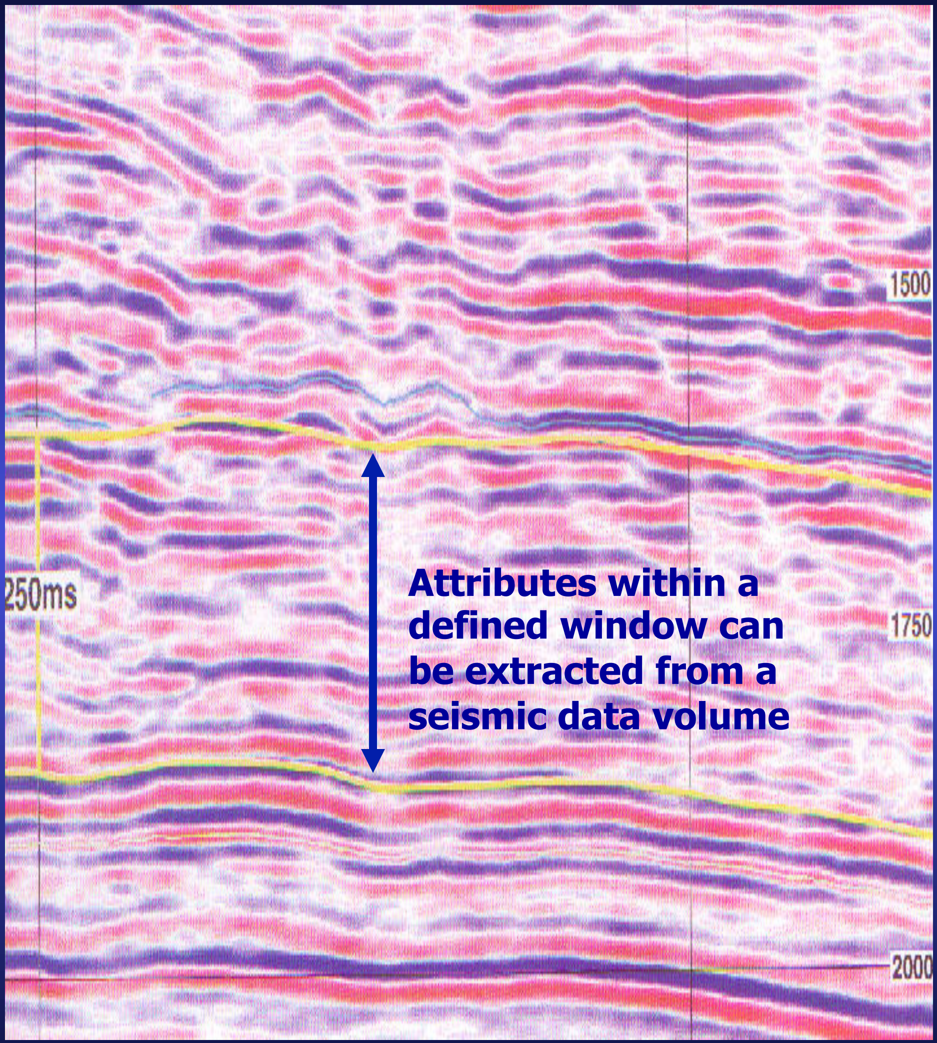
Reflection Amplitude, Composite amplitude, Relative impedance, Reflection strength, Amplitude ratio, Amplitude over background

Frequency

Instantaneous frequency, Response frequency, Envelope-weighted Inst. frequency, Time-derivative frequency

Modified from Fergusson and after Alistair Brown, AAPG Mem 42

"Window" Attributes



Time

Coherence, Continuity, Semblance, Covariance, Peak-Trough diff., Dip max. correlation, Azimuth Max. Corr., Signal to noise, Parallel bed indicator, Chaotic bed indicator, Trace difference.

Amplitude

Total absolute amp., RMS amplitude, Average peak amplitude, Percent greater than, Maximum amplitude, Maximum absolute amplitude.

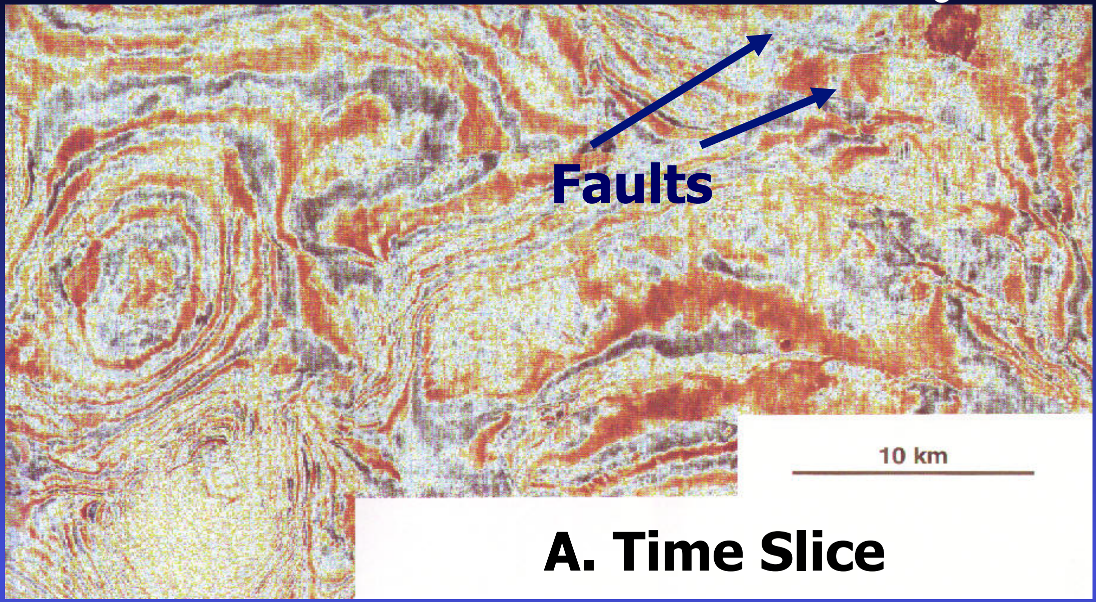
Frequency

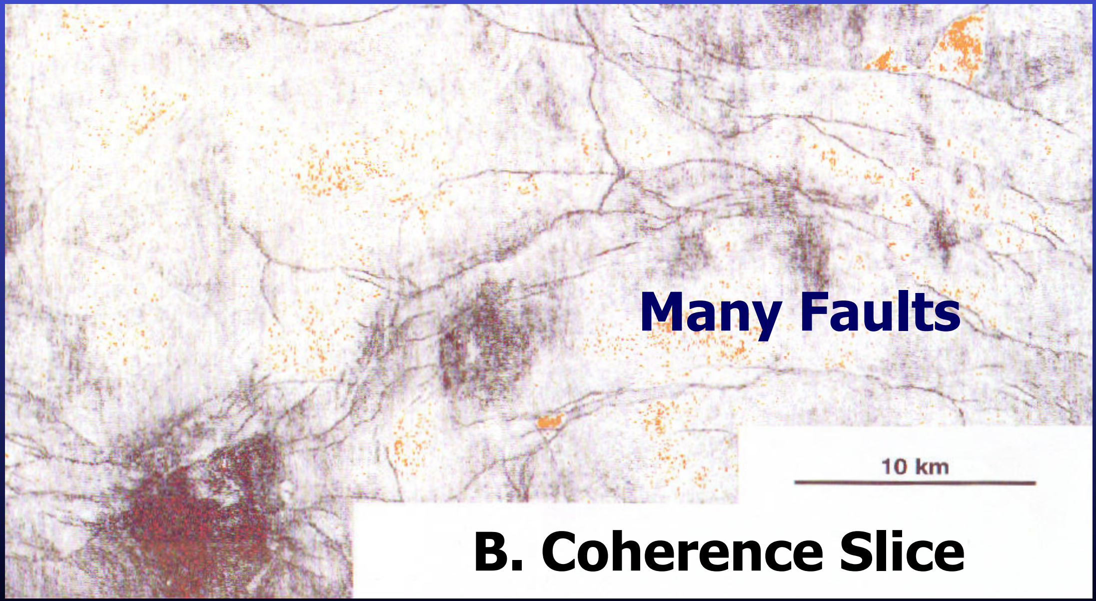
Average inst. freq., RMS inst. freq., Zero crossings, Spectral bandwidth, Hybrids and others.

Typical window types include: i) constant time interval, ii) constant interval hung from a horizon and iii) interval between two horizons.

after Alistair Brown, AAPG Mem 42

"Similarity" Attributes





Coherence, continuity, covariance and semblance attributes are derived using math; volume transforms

Differences are detected, and displayed on the slices.

These attributes are useful for "anomalies" mapping.

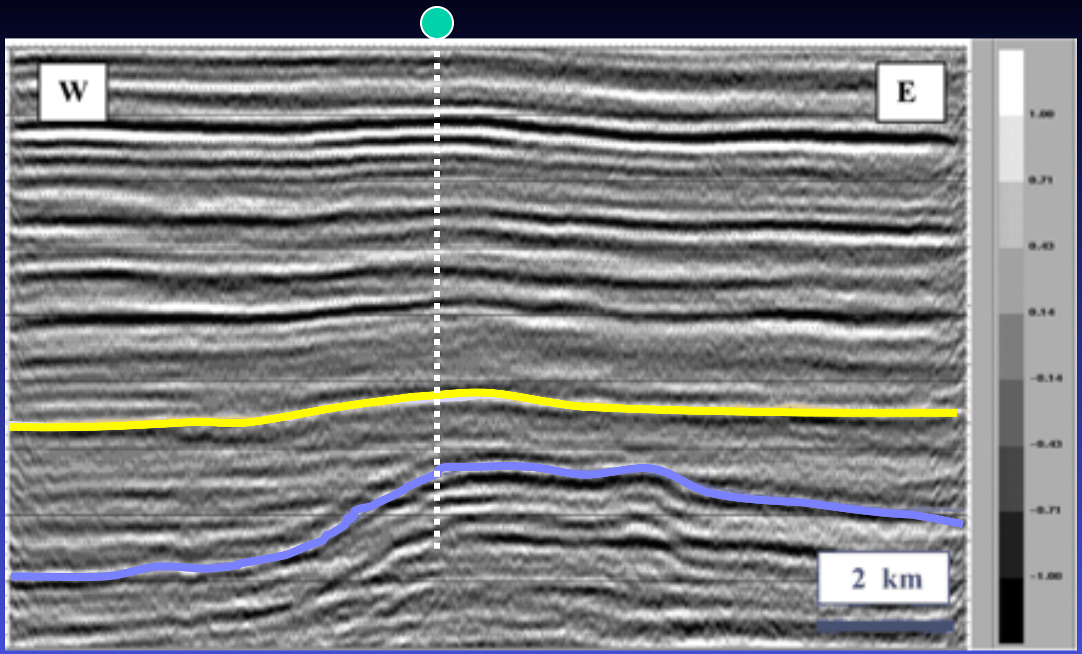
Fault visibility on time slices is dependant on orientation (A).

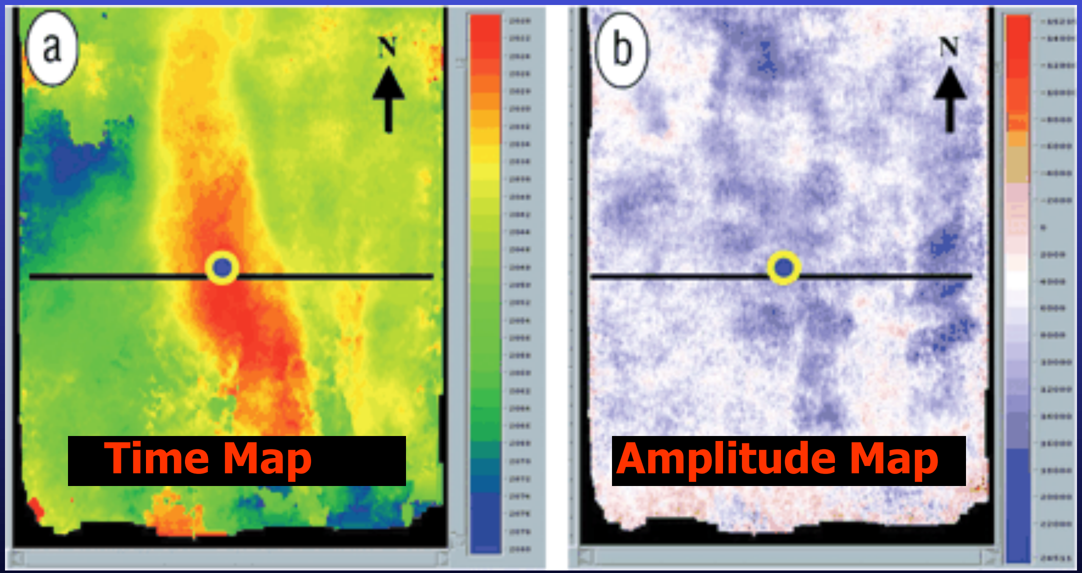
Fault visibility is improved on coherence slices (b) because they are not dependant on orientation).

'Similarity' attributes are free of interpretive bias.

Modified from Fergusson and after Alistair Brown, AAPG Mem 42

Case Study





Seismic profile showing top reservoir (Yellow) and base of source (Blue).

The time structure and amplitude attribute maps are for top reservoir.

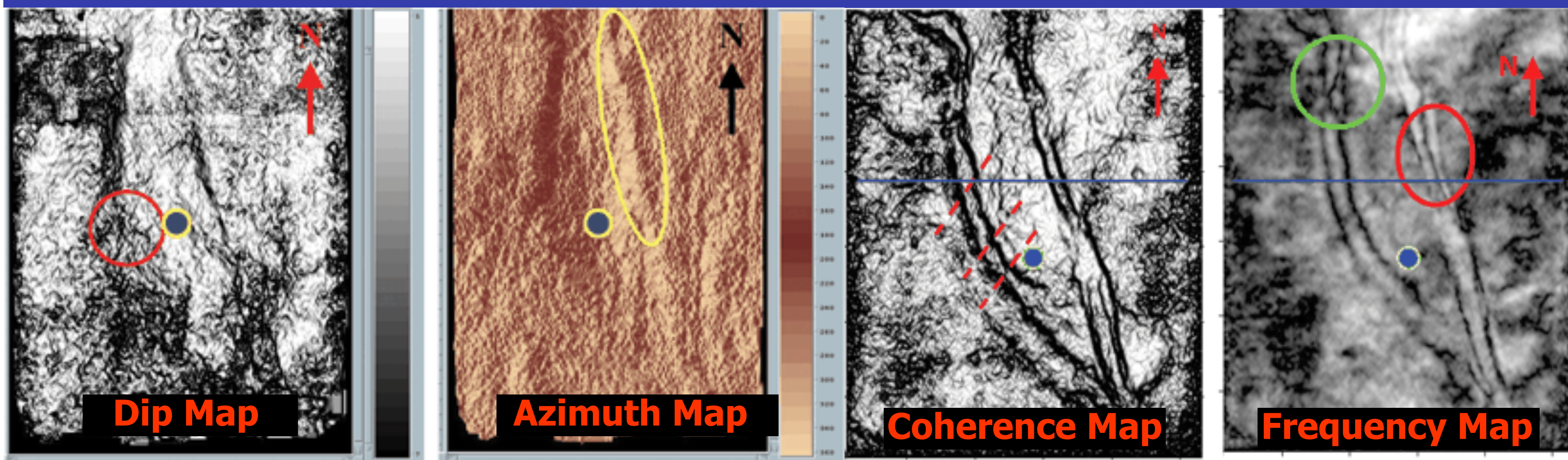
The area of interest lies west of the well (blue dot).

No clear indication of fracturing can be extracted confidently from the Time Structure or Amplitude maps.

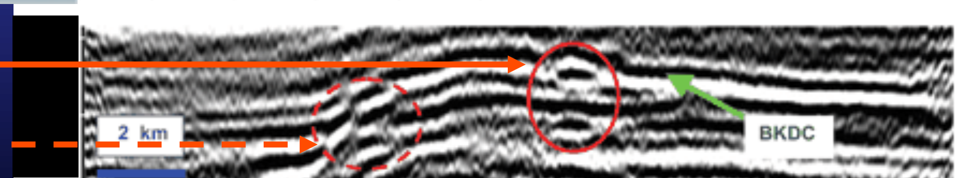
Compiled by Fergusson, *Case study taken from* "Detection of potential fractures and small faults using seismic attributes" *The Leading Edge*; September 2004; v. 23; no. 9; p. 903-906; DOI: 10.1190/1.1803500

Dip and azimuth maps generated from top reservoir time interval. The Dip map shows a possible fractured zone west of the well. The Azimuth map better delineates the east flank of the fault block.

The Coherence and frequency maps show better detail. Red dash => enechelon faults. Red / green circles show where the frequency map shows clearer image than the coherence map.

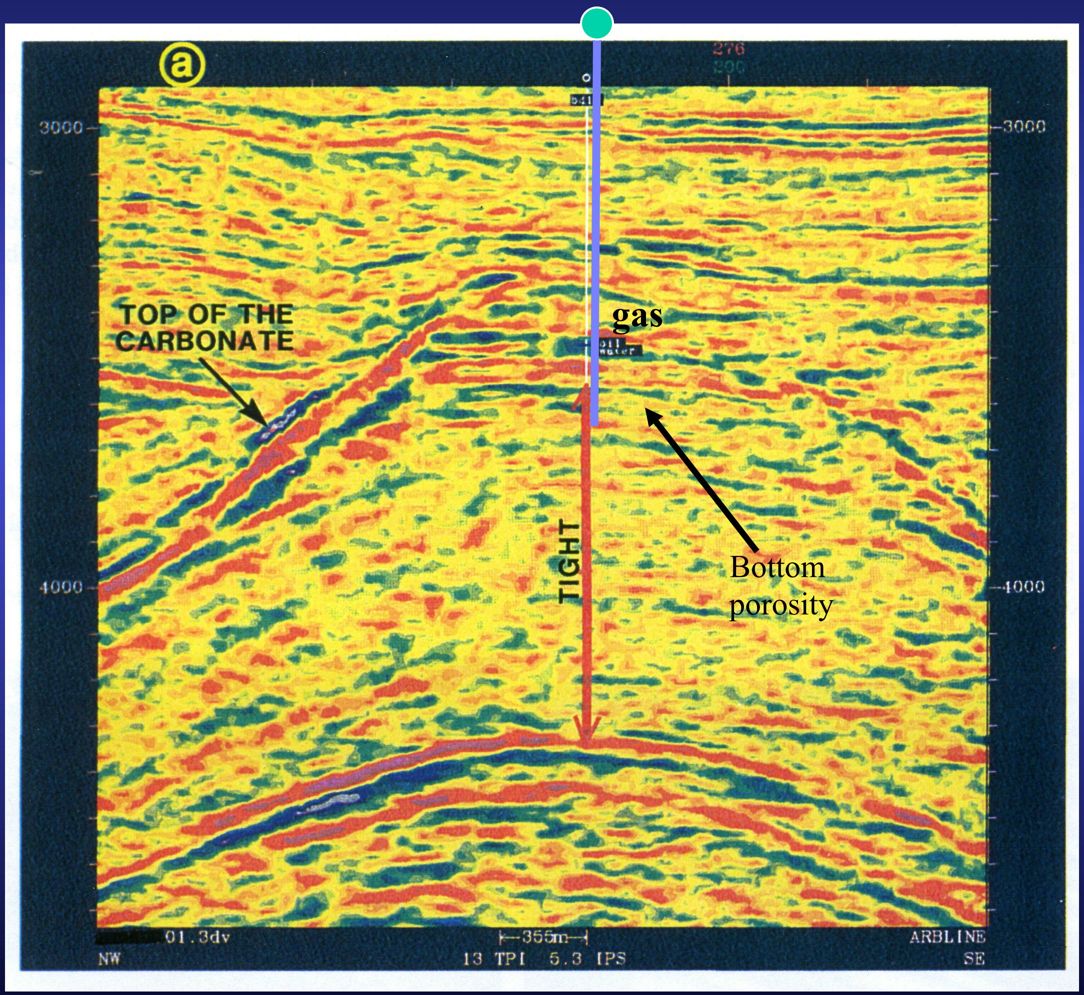


Frequency mapped faults
Coherence mapped faults



USE MULTI-ATTRIBUTE ANALYSIS!

Madura Strait-Indonesia



Enachescu 1993, Leading Edge

3D Vertical section through carbonate porous mound. Horizontal reflectors indicated stratified reservoir fluids

Use to map reefal build-ups; paleo-karst from Silurian to Present

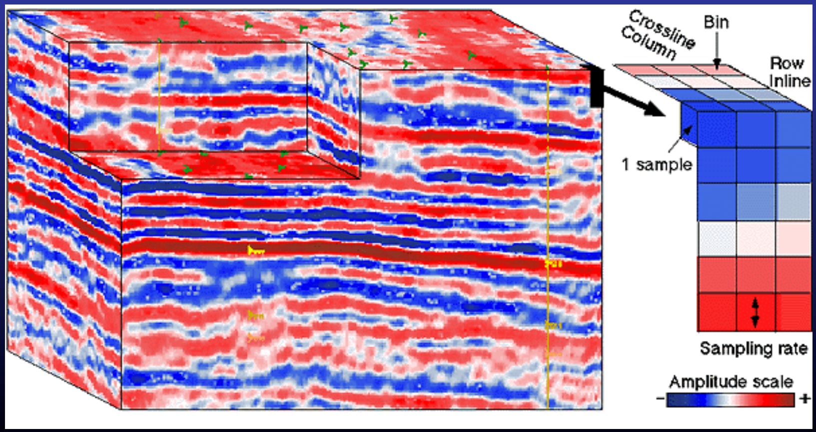
Advantage to have a deep well (4km +)

- Logs
- Startigraphic column
- Synthetic seismogram
- Direct correlation of seismic to the well geology
- Correlation as identification of events, lithology, fluid effects-not always perfect
- Good velocities for conversion

Seismic 3D Data Processing Volume

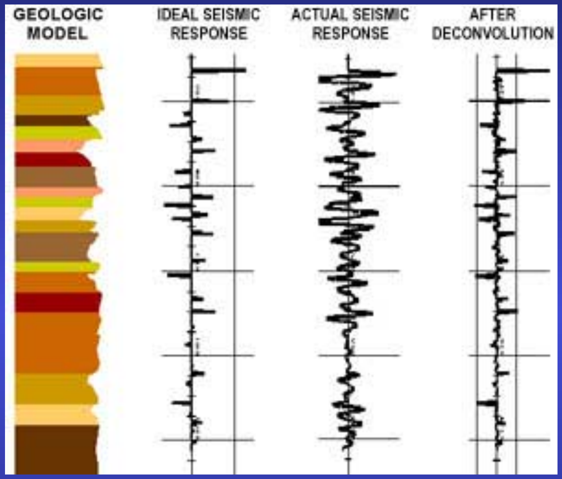
- 480 channels per streamer
- 8 streamers = 3840 channels total
- 9 seconds of data at a 2 ms sample rate = 4500 samples
- bytes per shot = 480 * 8 * 4500*4 bytes/sample = 69 MB
- Boat speed 8 km/hour - shot interval 25 m - shot every 11 seconds.
- For a 50*70 sq km survey you need about 250 000 shots
- This is 17 250 000MB =16846GB=16.8TB
- Data rate is 25 Megabaud or 10 times high speed cable internet
- More space needed for positioning and other parameters!

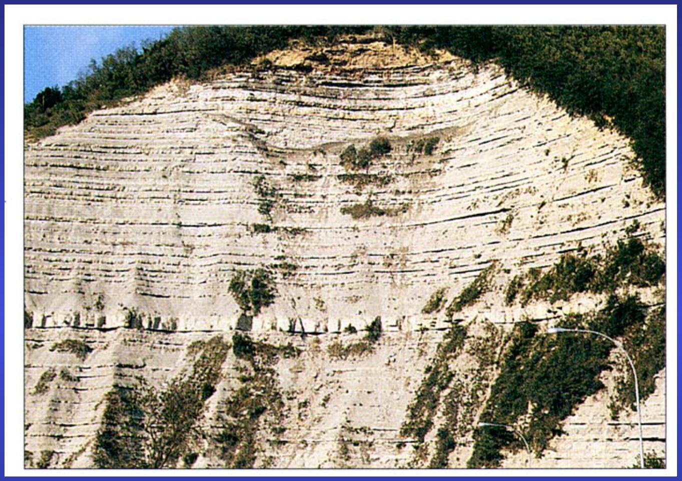
Mewhart, 2003, pers comm

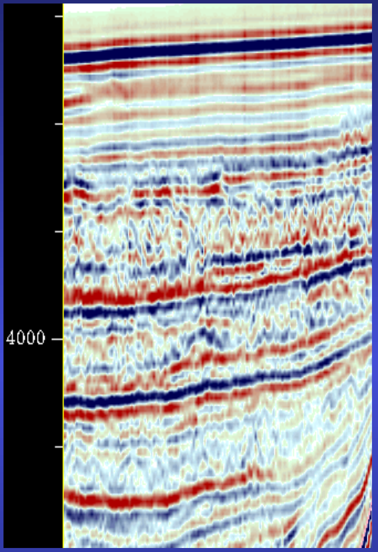


Vertical Resolution in 3D surveys

Deconvolution simplifies or 'deconvolves' our output pulse from the seismic response and converts it into a cleaner, sharper, pulse







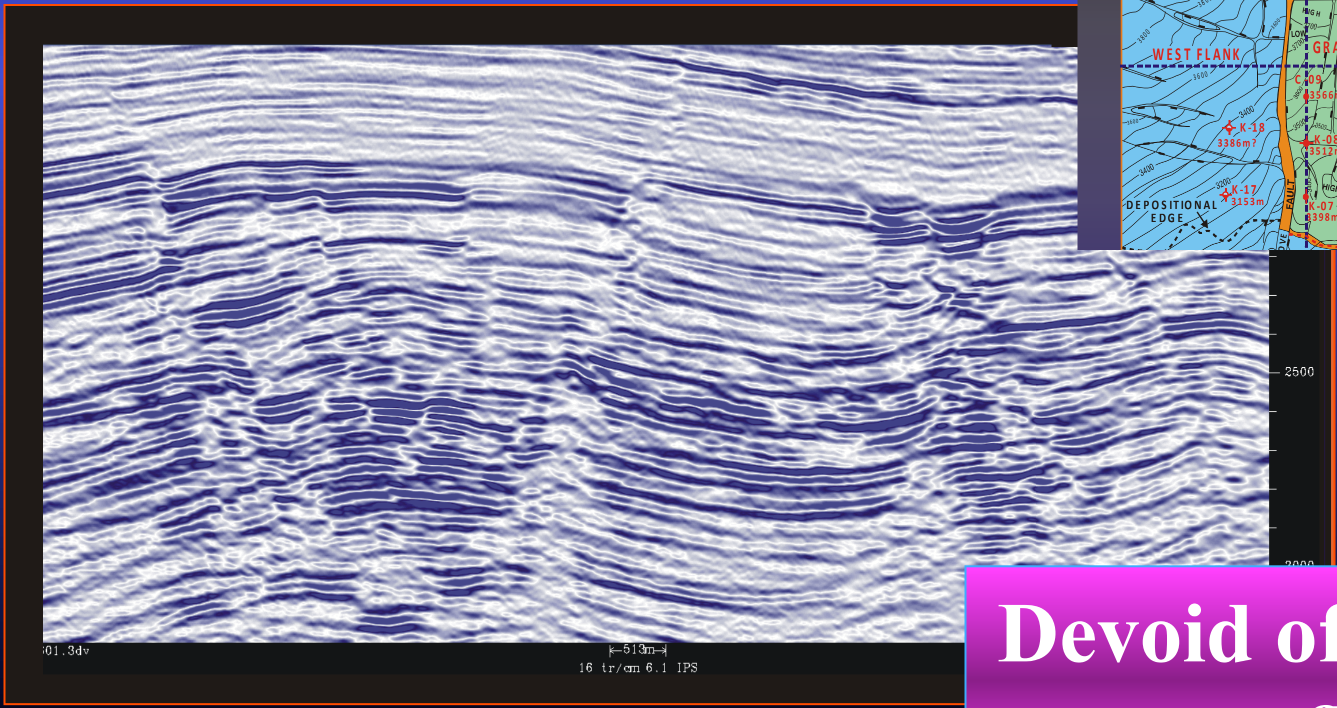
The questions we have as **seismic interpreters are: How many layers? How thick they are?**

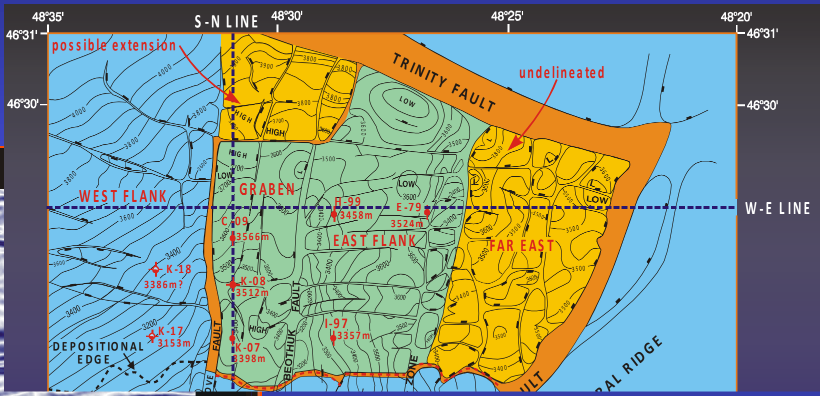
Seismic reflection method can identify geological layers only when:
a.) there is a seismic impedance (velocity×density) contrast between them
b.) layers are thick enough to allow imaging of their boundaries at the 10 - to 100 Hz propagating signal resolution

Can radar spot a plane, a bird, a flying ant?

3D Seismic Interpretation

- **3-D extracted section** over the Terra Nova oil field, offshore Newfoundland, which contains 400 MMBBLS recoverable. Faults and layering are visible over the Central Graben and Eastern Horst blocks. The pay zone is in the middle.

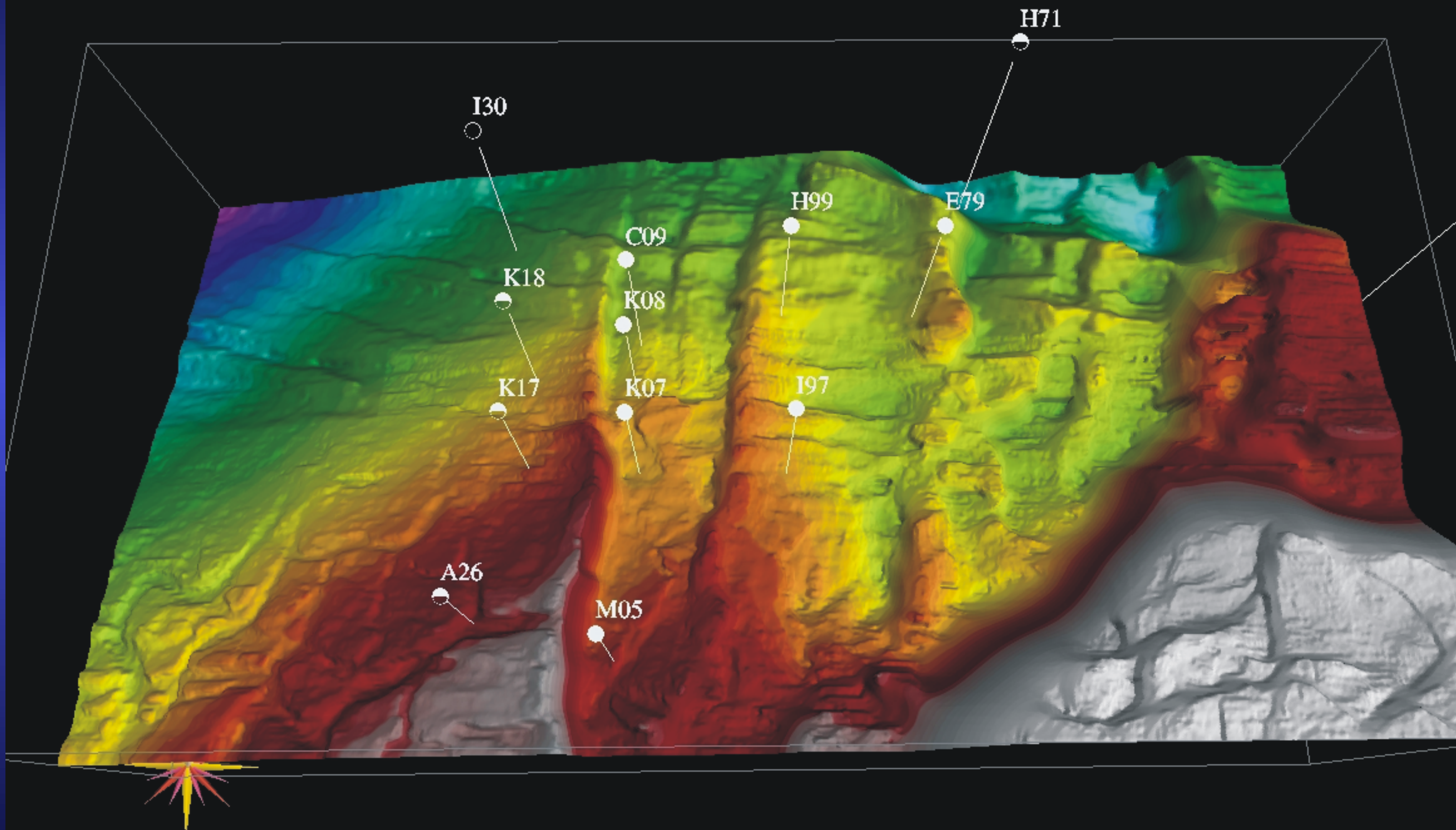




Time Structure map Bottom of Reservoir

Devoid of out-off-plane reflections!

Interpreted 3D Diagram of the Terra Nova Field

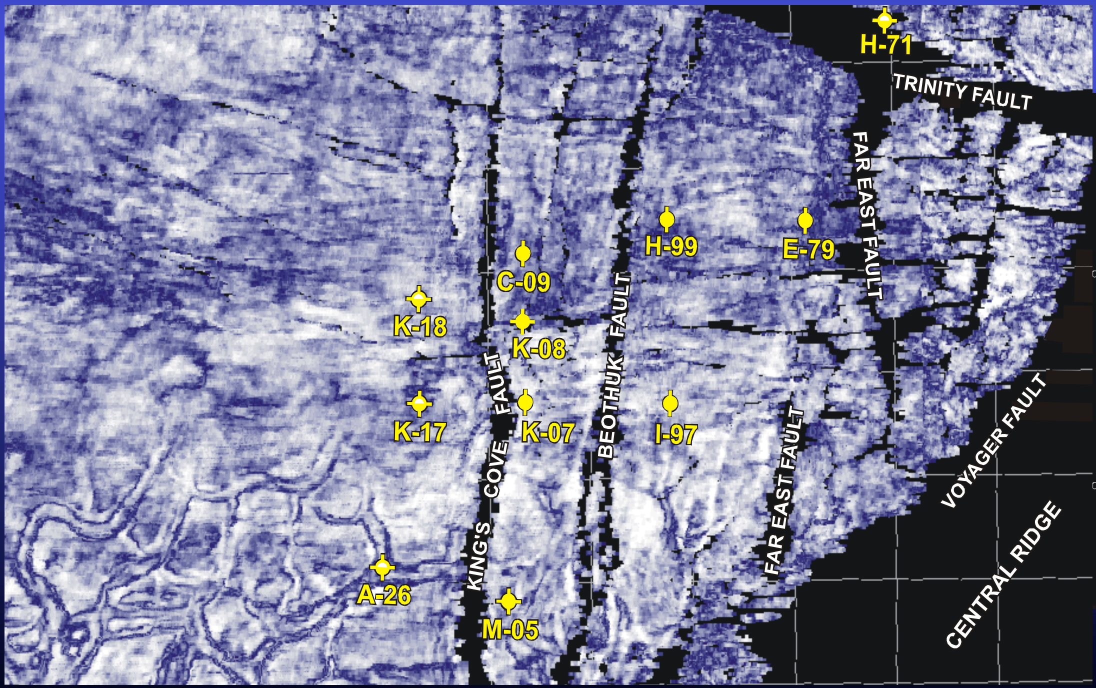


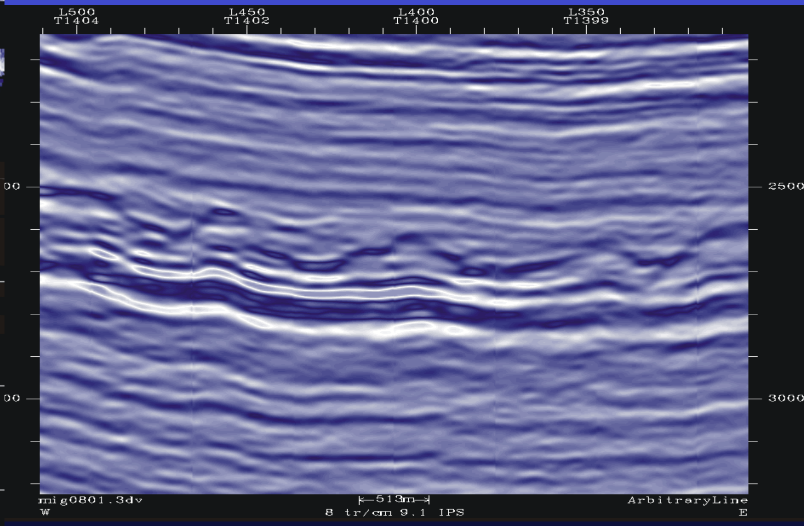
Structural nose- forced fold

After Enachescu et al., 1996

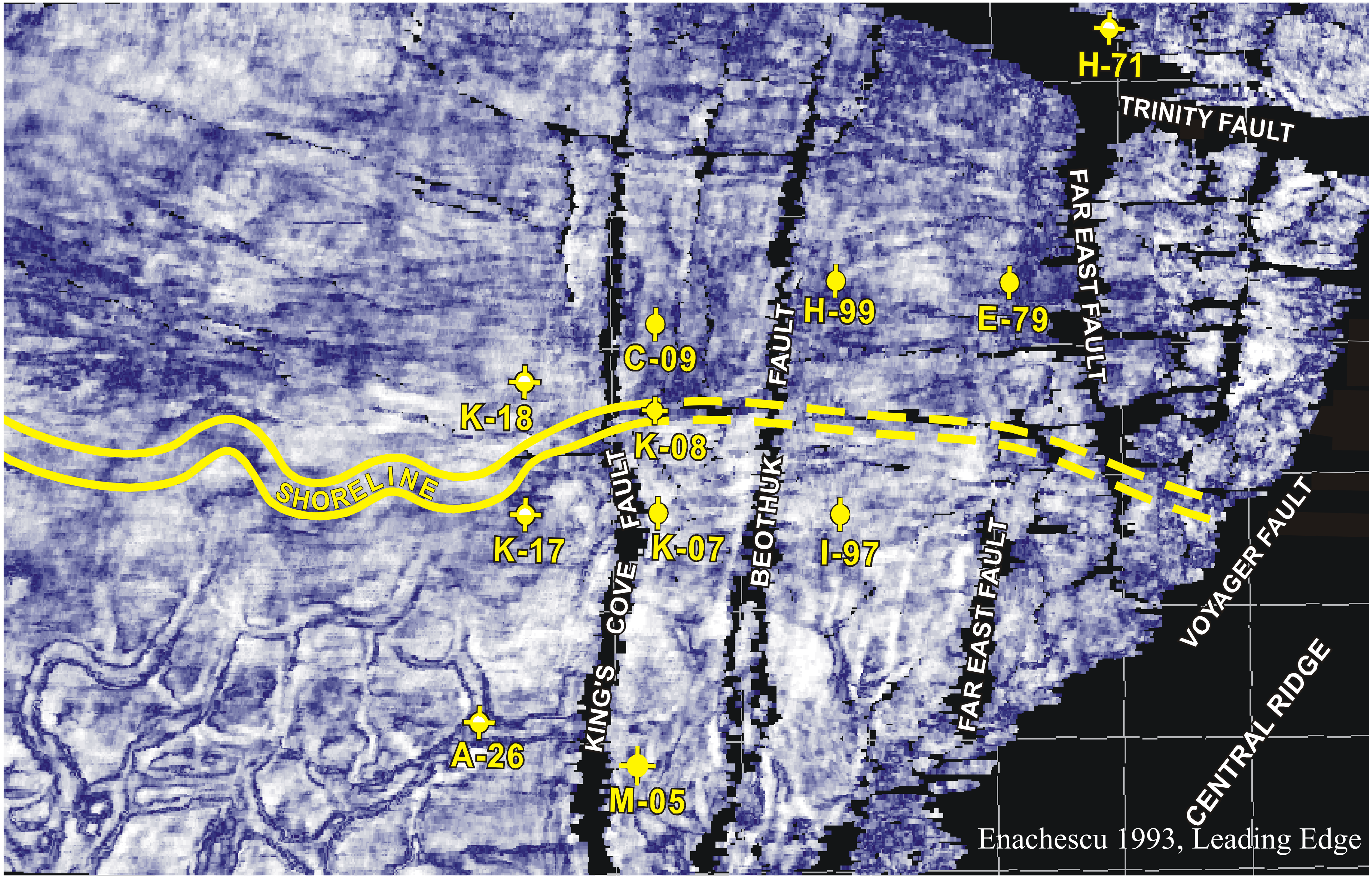
3D Seismic Interpretation

Horizon Amplitude Map of the Late Jurassic Unconformity (153 Million years old) interpreted from a **3D seismic volume** over the Terra Nova oil field. The horizon mapped situated at 2-3 km bellow the water bottom, shows an intricate valley system that brought reservoir sandstones into the field area. A highstand shore line separating the land and sea areas is also interpreted.

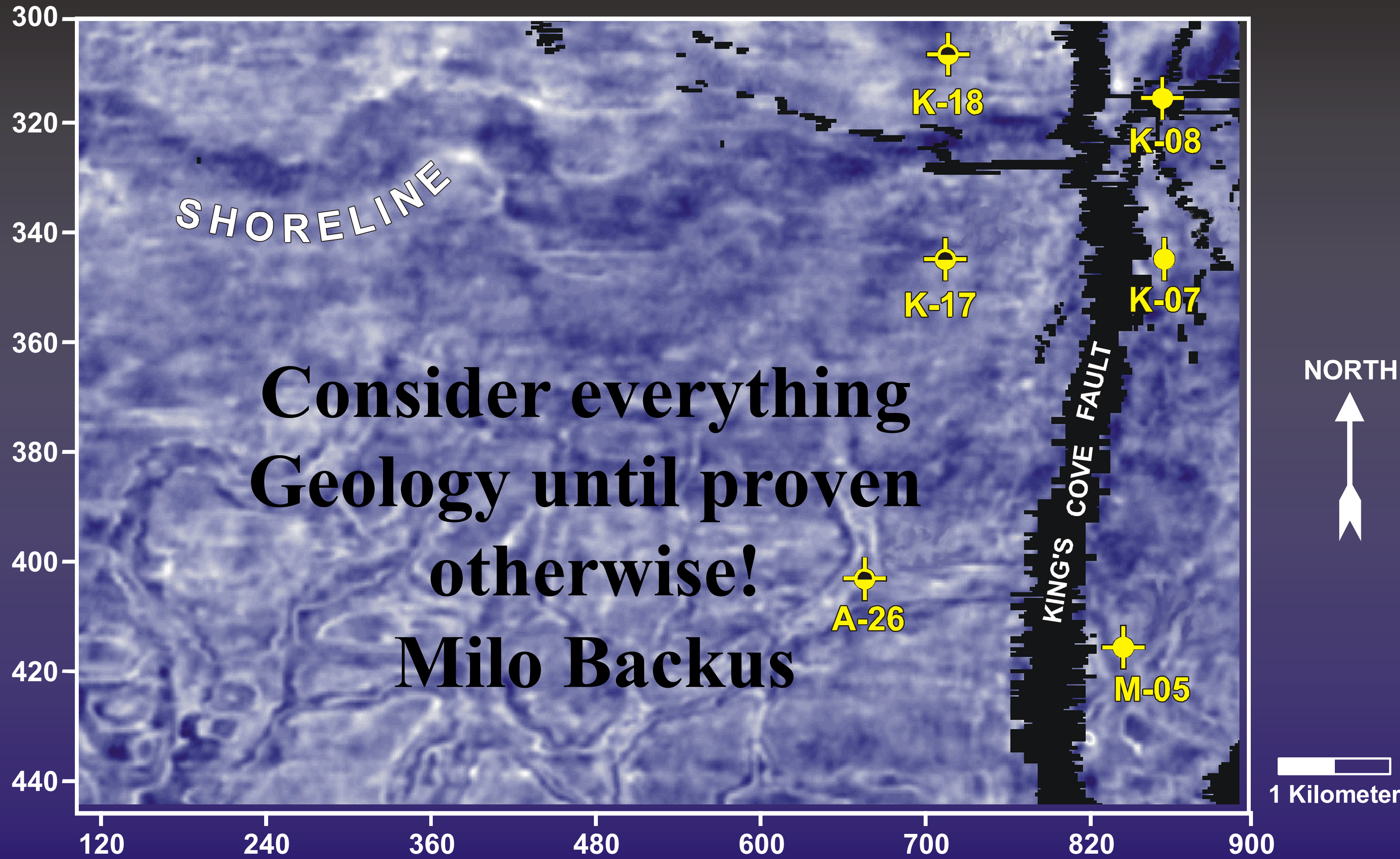




3D Horizon Amplitude Map

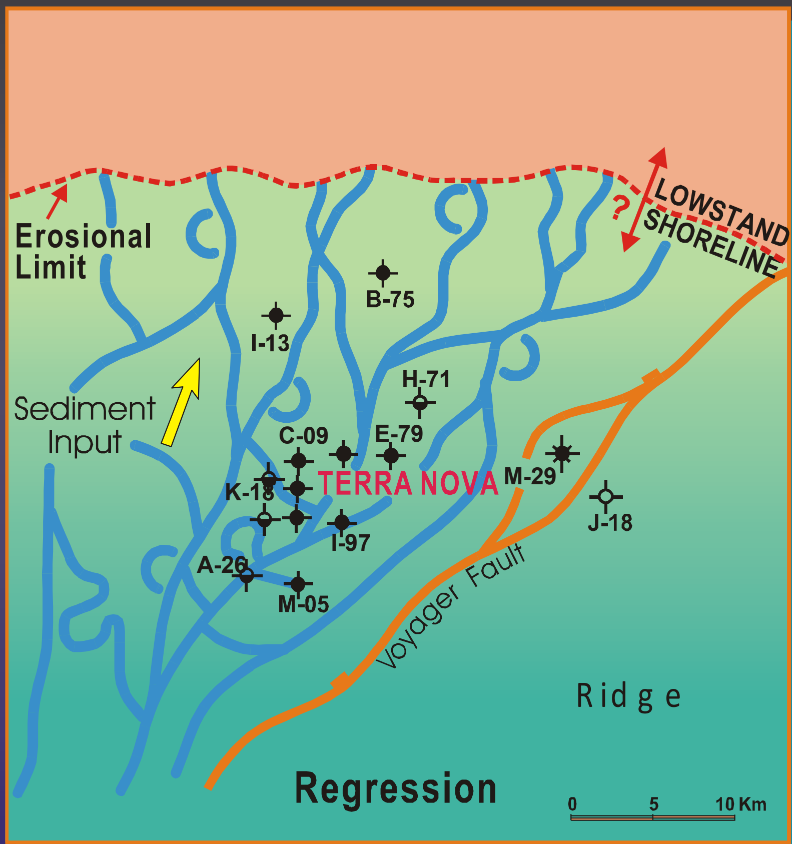


SOUTH TERRA NOVA
Peneplanum Slice



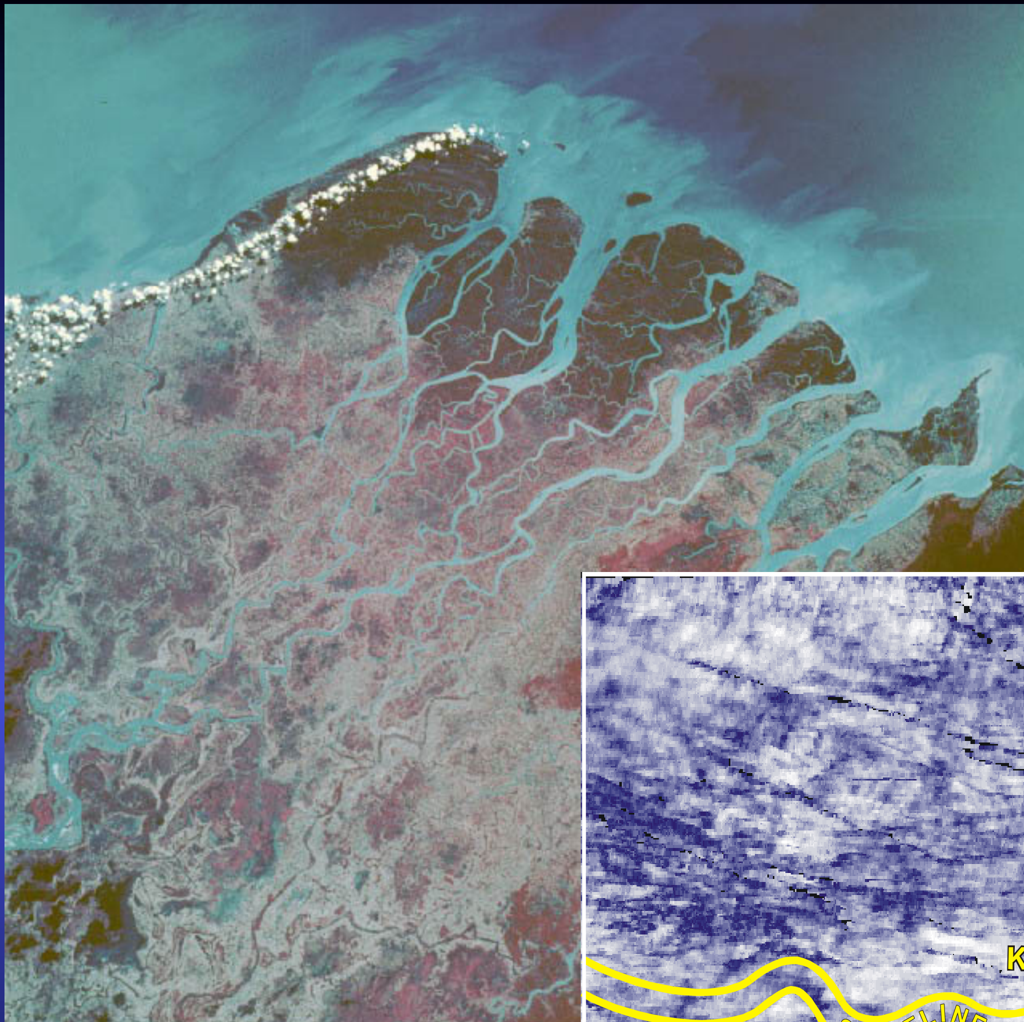
Consider everything Geology until proven otherwise!
Milo Backus

LOWSTAND
Erosion & Channelization

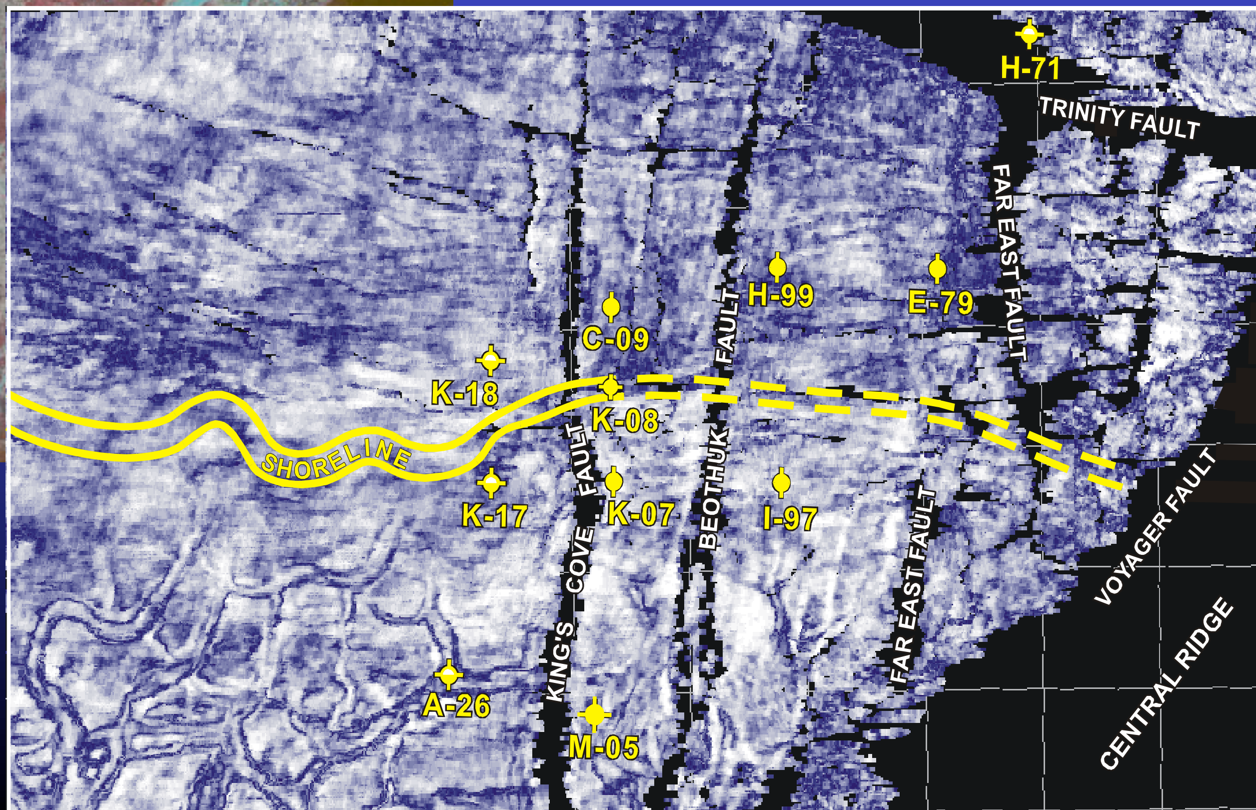


HIGHSTAND
Reworking & Deposition

Deltas: Present and Past



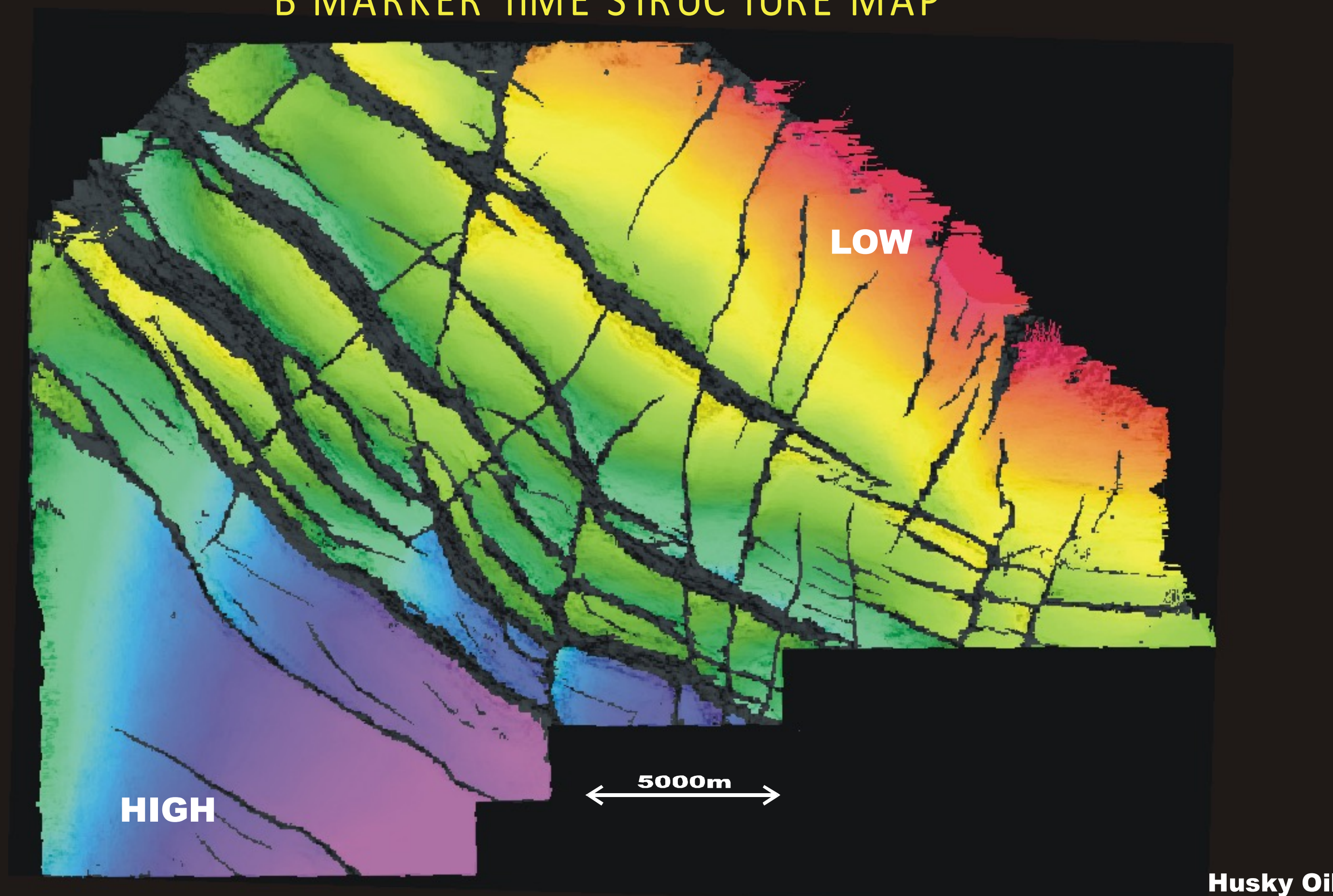
Irawadi



Terra Nova


It is unlikely many currently planned or future exploration wells in Atlantic Canada will be drilled without 3D control
Ivan Sereda, Manager Atlantic Exploration Chevron
The deeper the water, the riskier the geology, the harsher the exploration area, the more is the need for 3D

B MARKER TIME STRUCTURE MAP

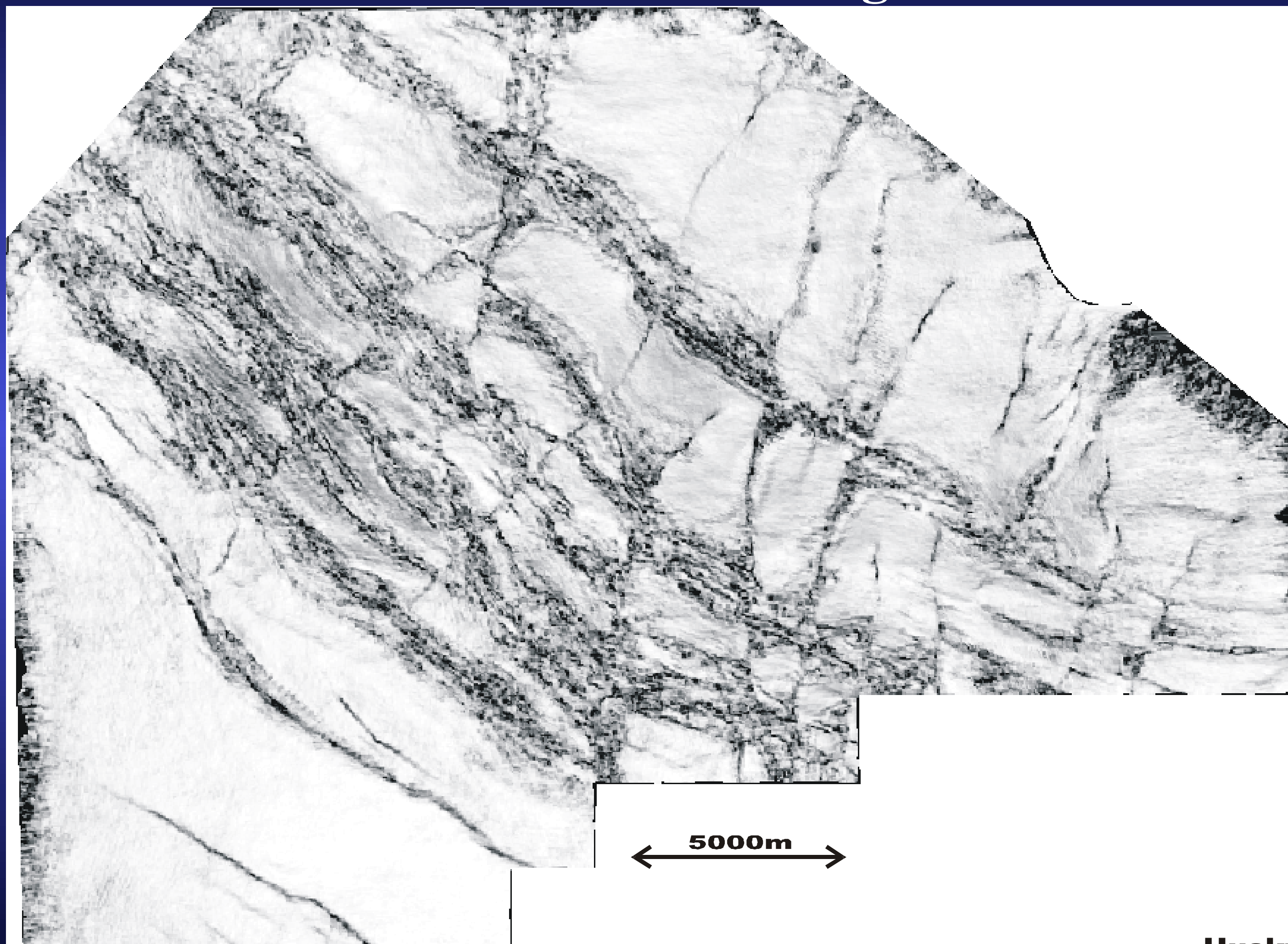


Jdb98-15b.cdr

Enachescu et al,1998

SEMBLANCE TREND SLICING

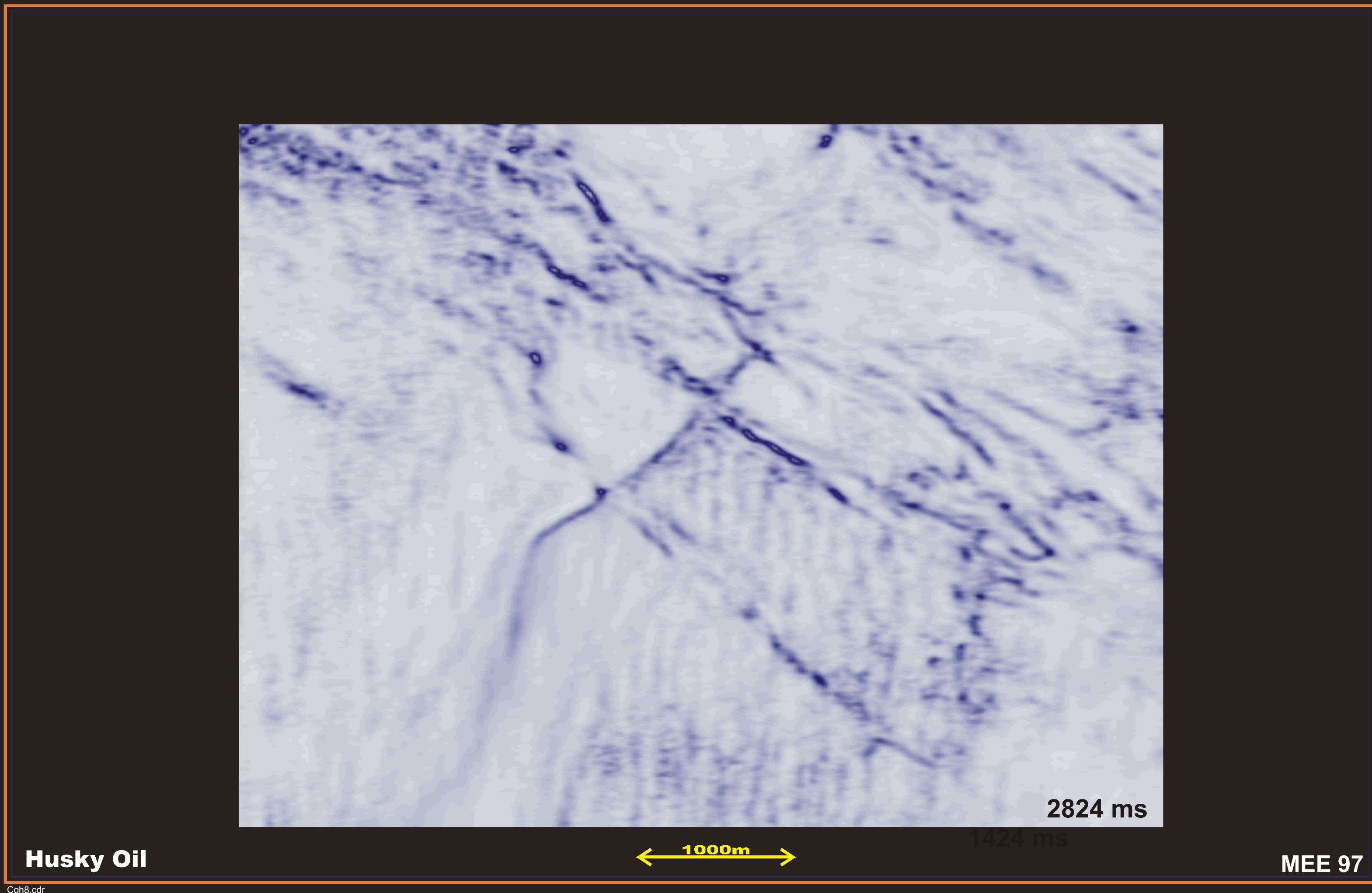
Fault Pattern Rendering B Marker



Husky Oil

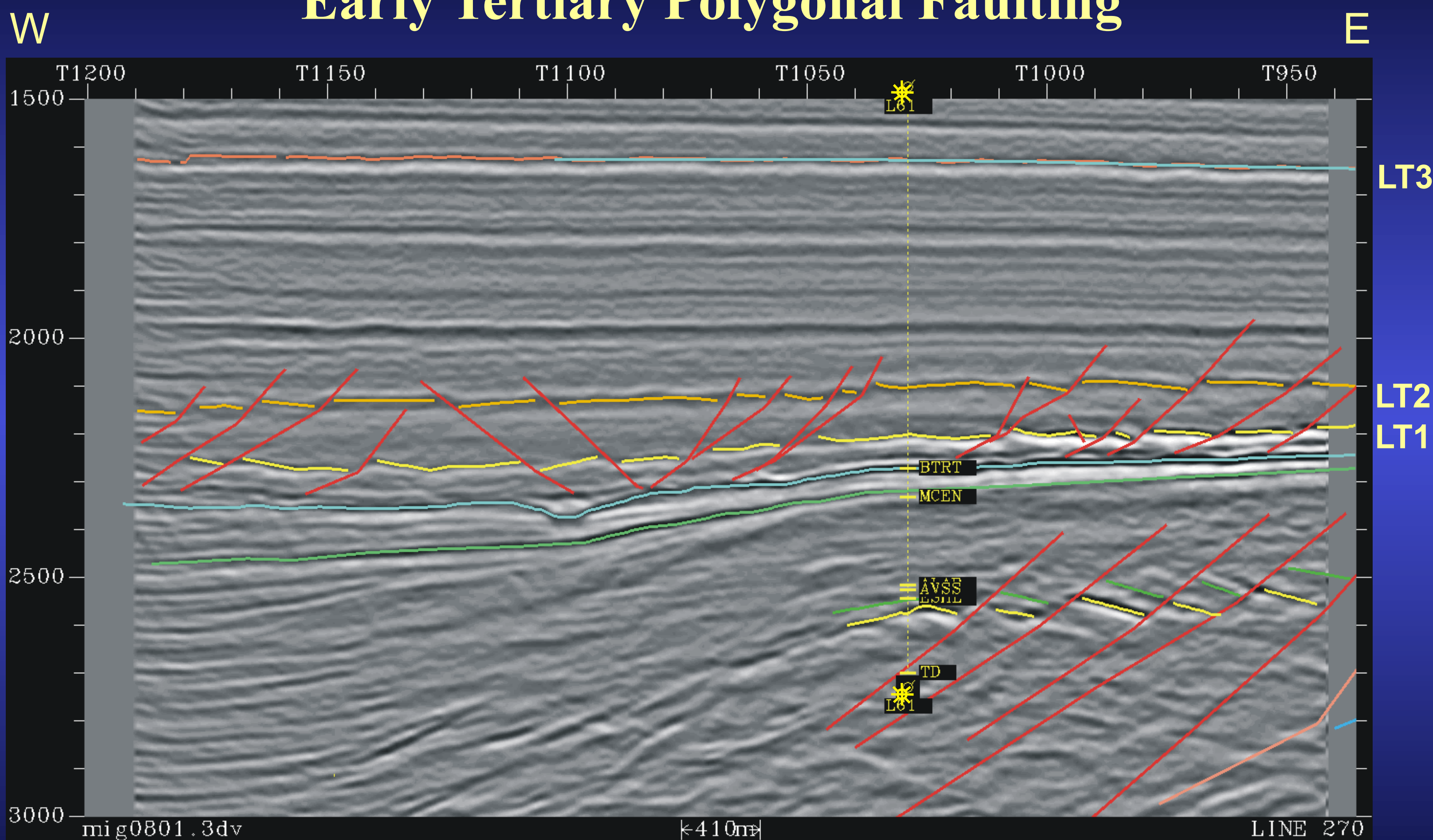
Enachescu et al,1998

CONTINUITY CUBE TIME SLICE INTERSECTING FAULTS



Enachescu et al,1988

White Rose Field 3D Seismic Section
Early Tertiary Polygonal Faulting



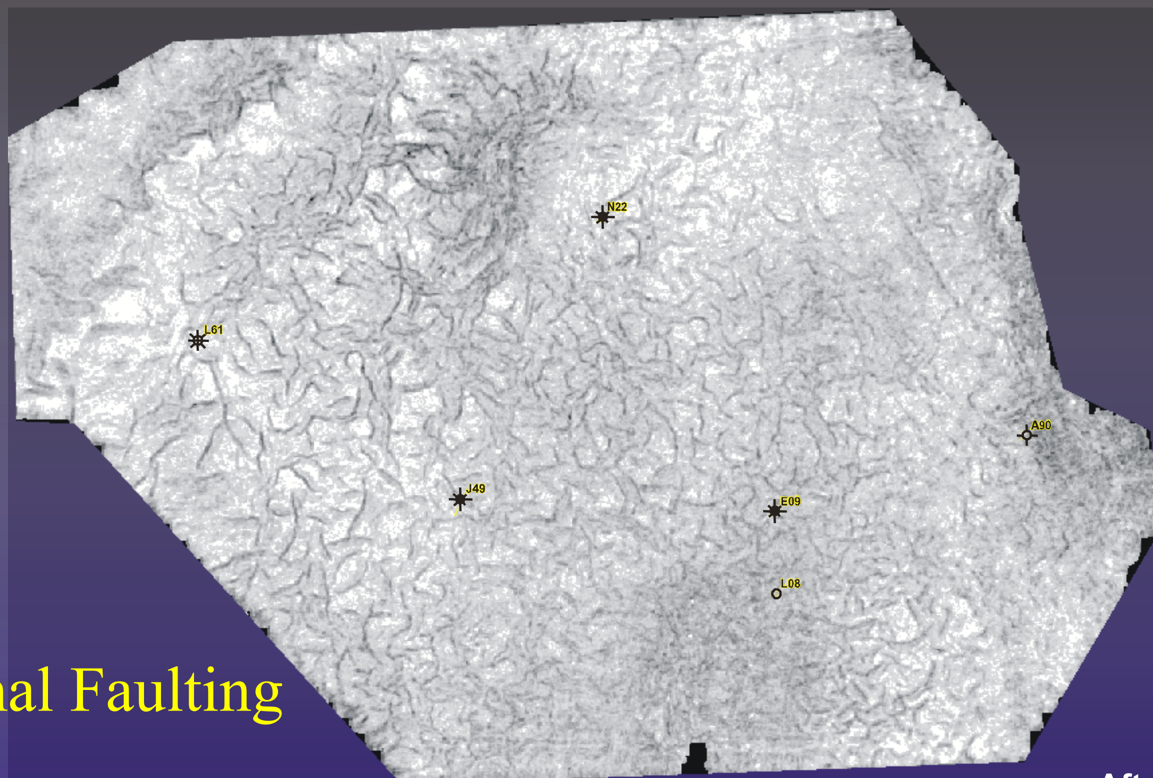
Husky Oil

After SKUCE 98

Enachescu et al,1998

WHITE ROSE 1997 3-D CONTINUITY HORIZON SLICE

EARLY TERTIARY LT2 FAULT PATTERN



Polygonal Faulting

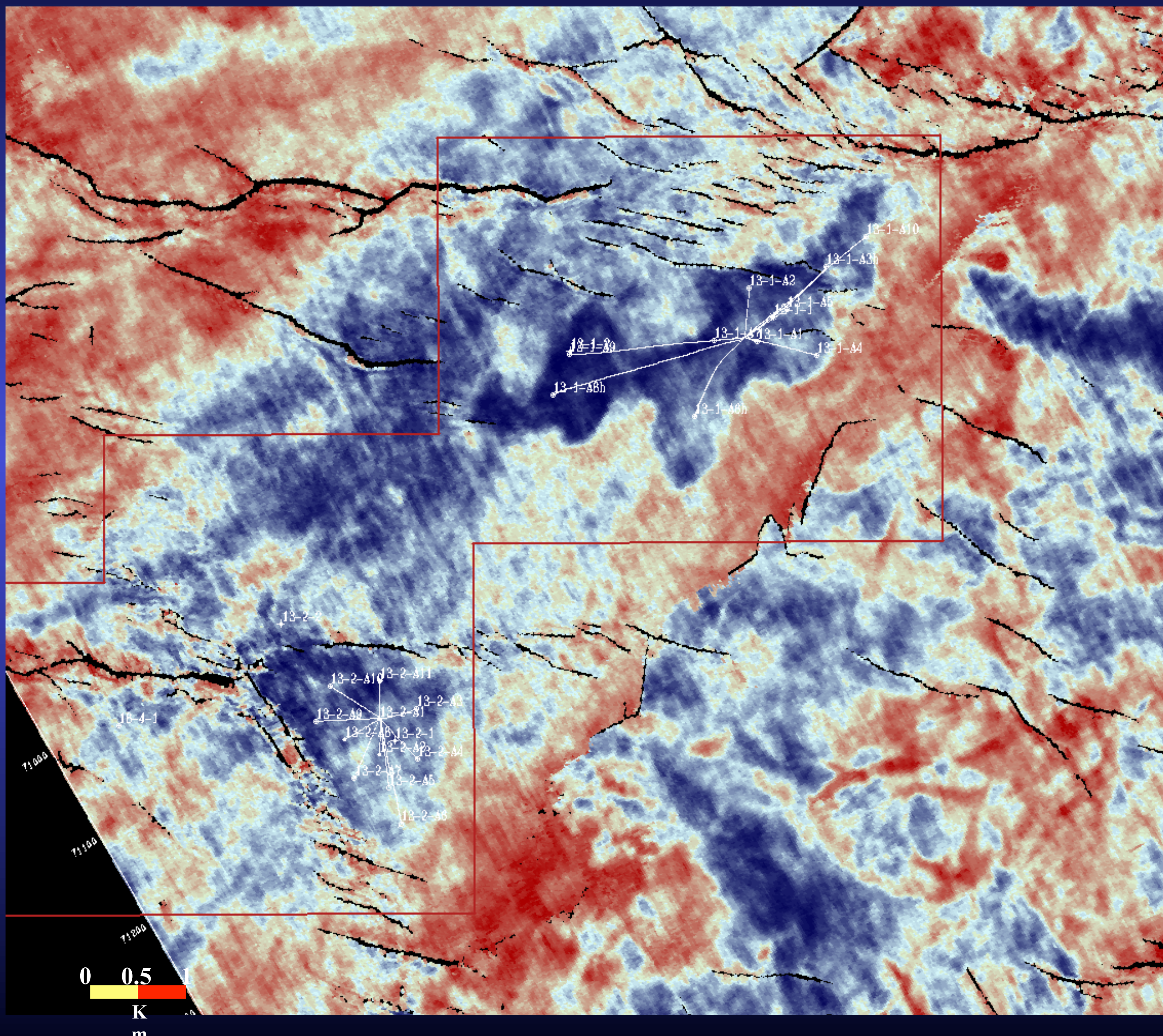
Husky Oil

After SKUCE 98

JDB98-35s.cdr

From Enachescu et al.,1998

3D Seismic Interpretation



After Enachescu et al. 2002

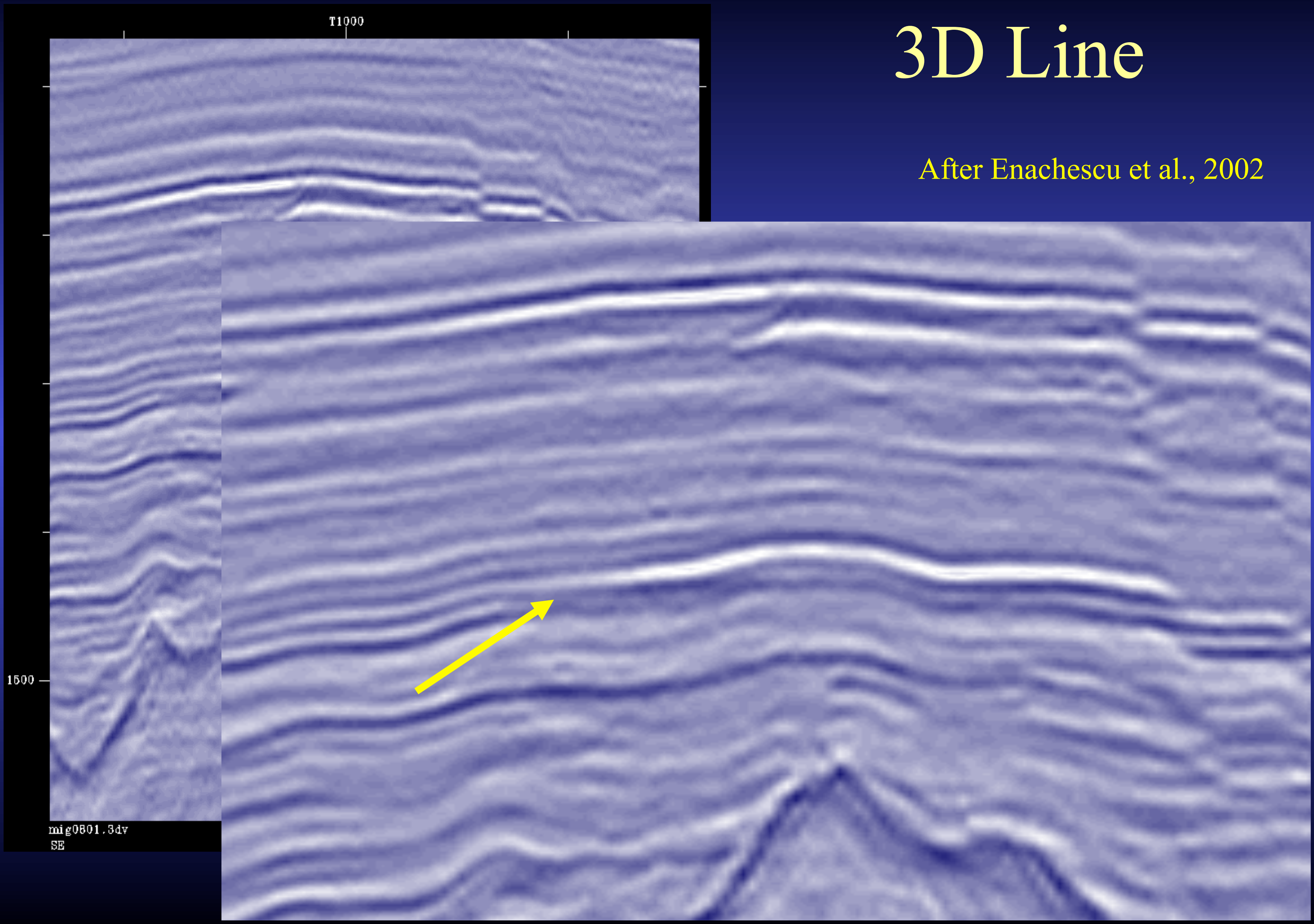
- **Horizon Amplitude Map** of top of the oil reservoir over a field in South China Sea shows in dark blue the shape of the anticline trap and the oil/water contact.
- This is an exceptional situation when seismic method can directly map an oil reservoir.
- Usually this **is not possible** because oil and water have similar

seismic impedances:
product between Velocity and Density

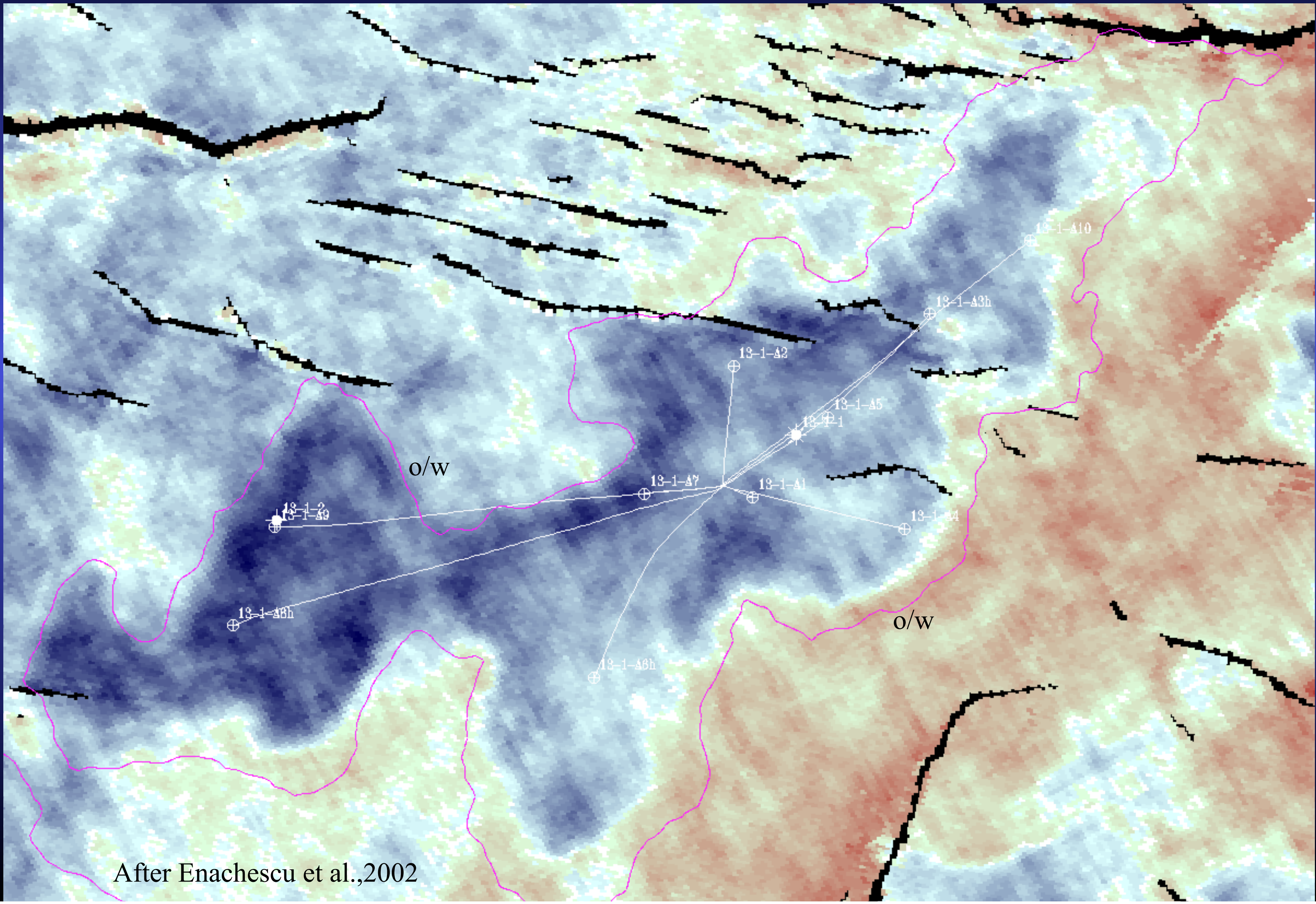
$$Z = V \times d$$

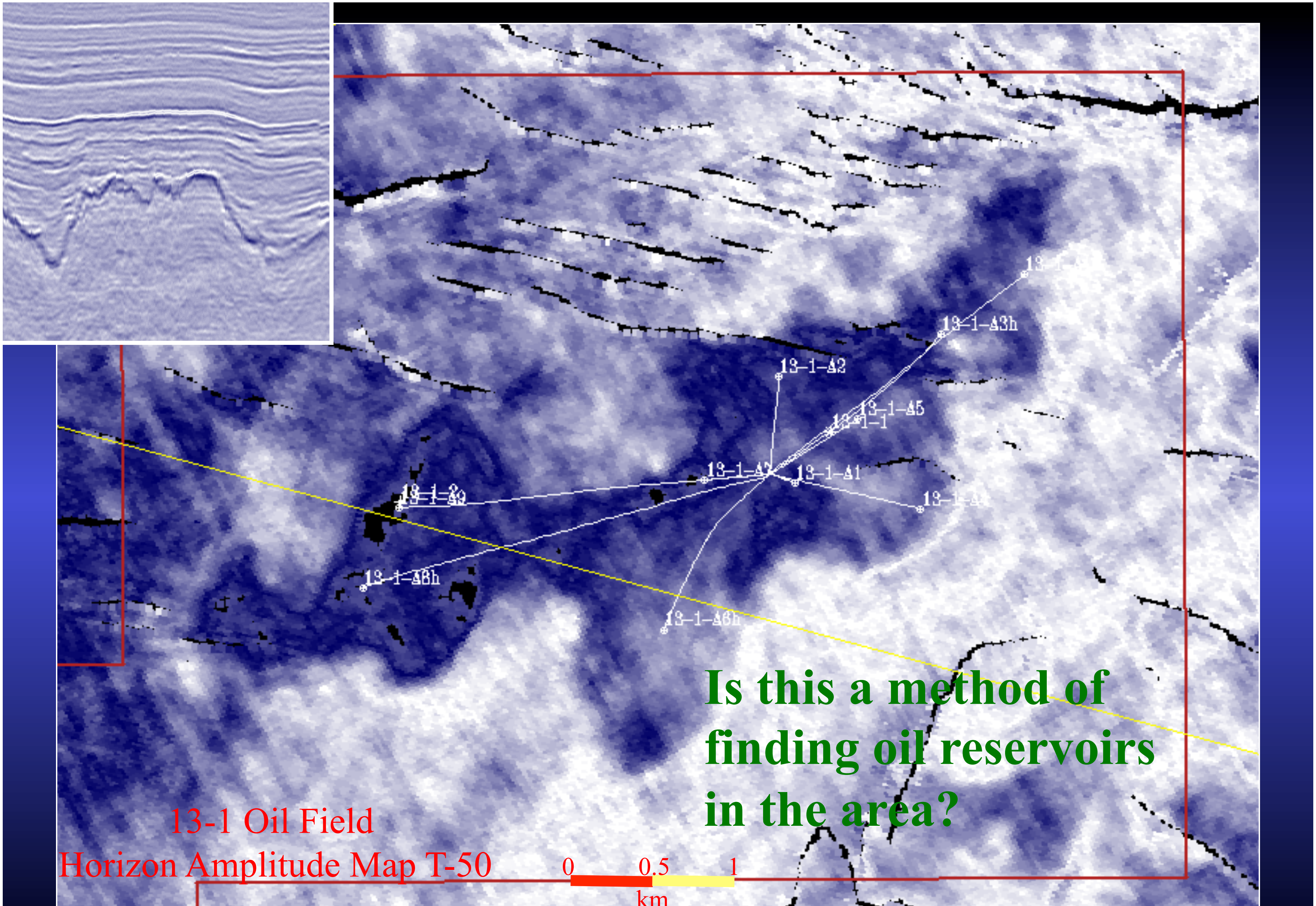
3D Line

After Enachescu et al., 2002



Wenchang 13-1 Amplitude Map with OW contact

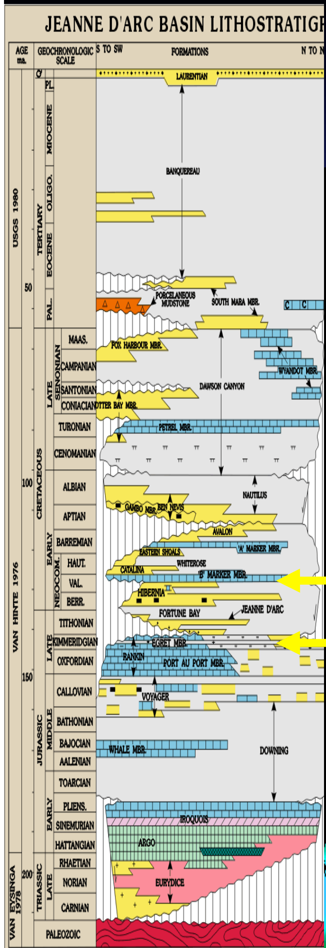


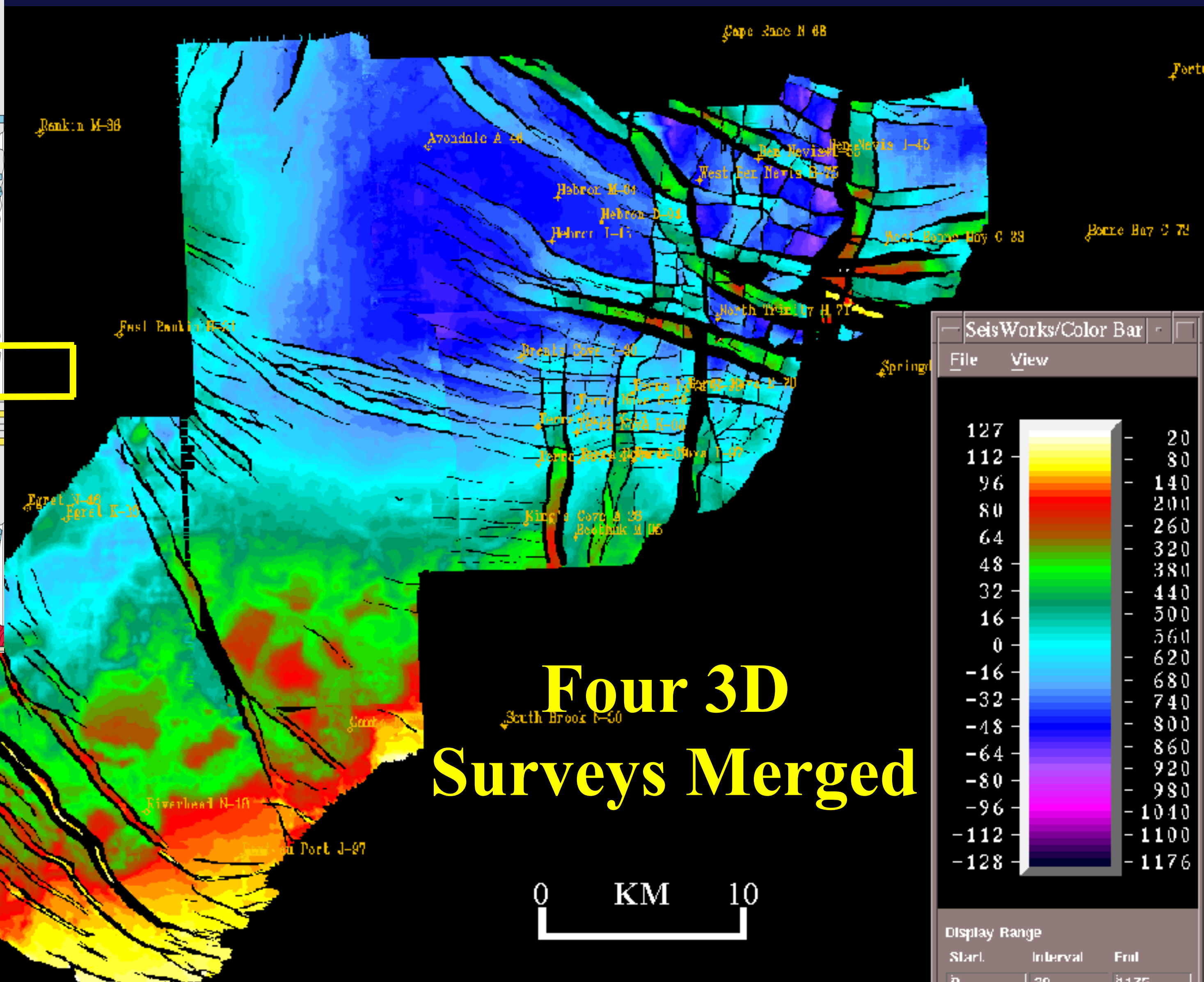


Unique case of mapping an oil field using amplitude!

After Enachescu et al., 2002

Isochron B Marker to Kimmeridgian Unconformity

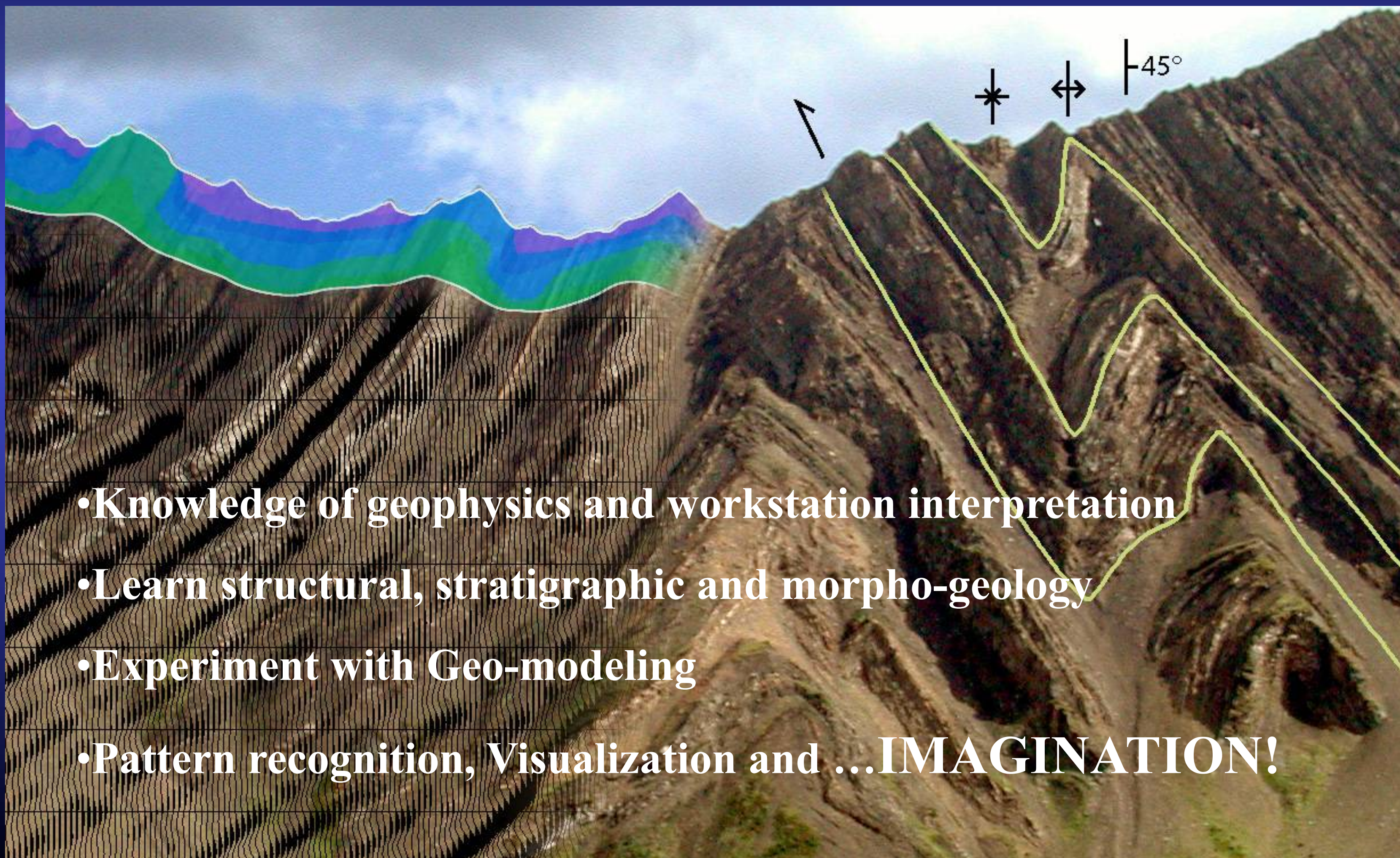




After McIntyre et al., 2004

Seismic Data to Subsurface Image

How to resolve the Inverse Problem of Exploration Geophysics (interpret data) ?

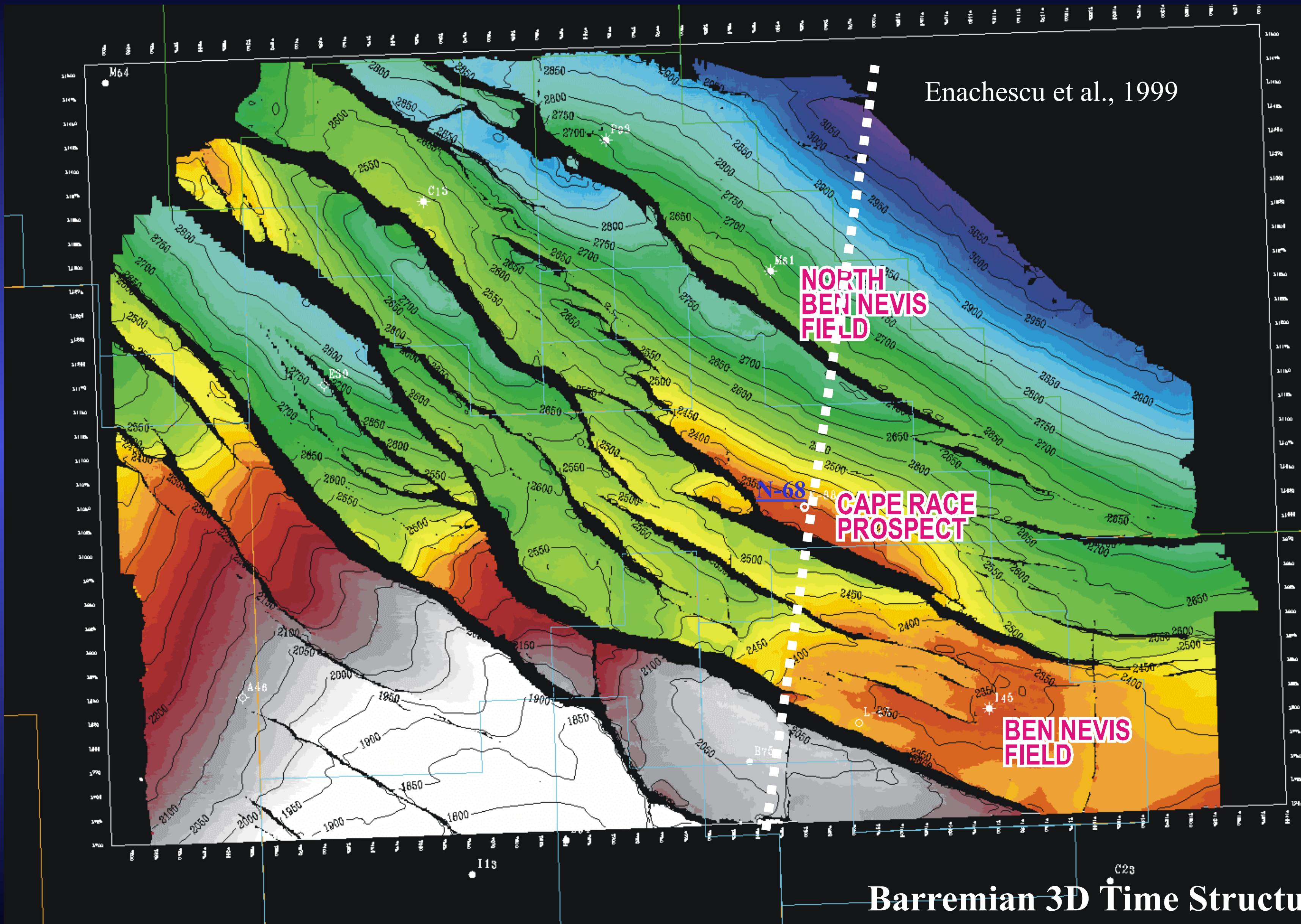


- Knowledge of geophysics and workstation interpretation
- Learn structural, stratigraphic and morpho-geology
- Experiment with Geo-modeling
- Pattern recognition, Visualization and …IMAGINATION!

Selective Targeting

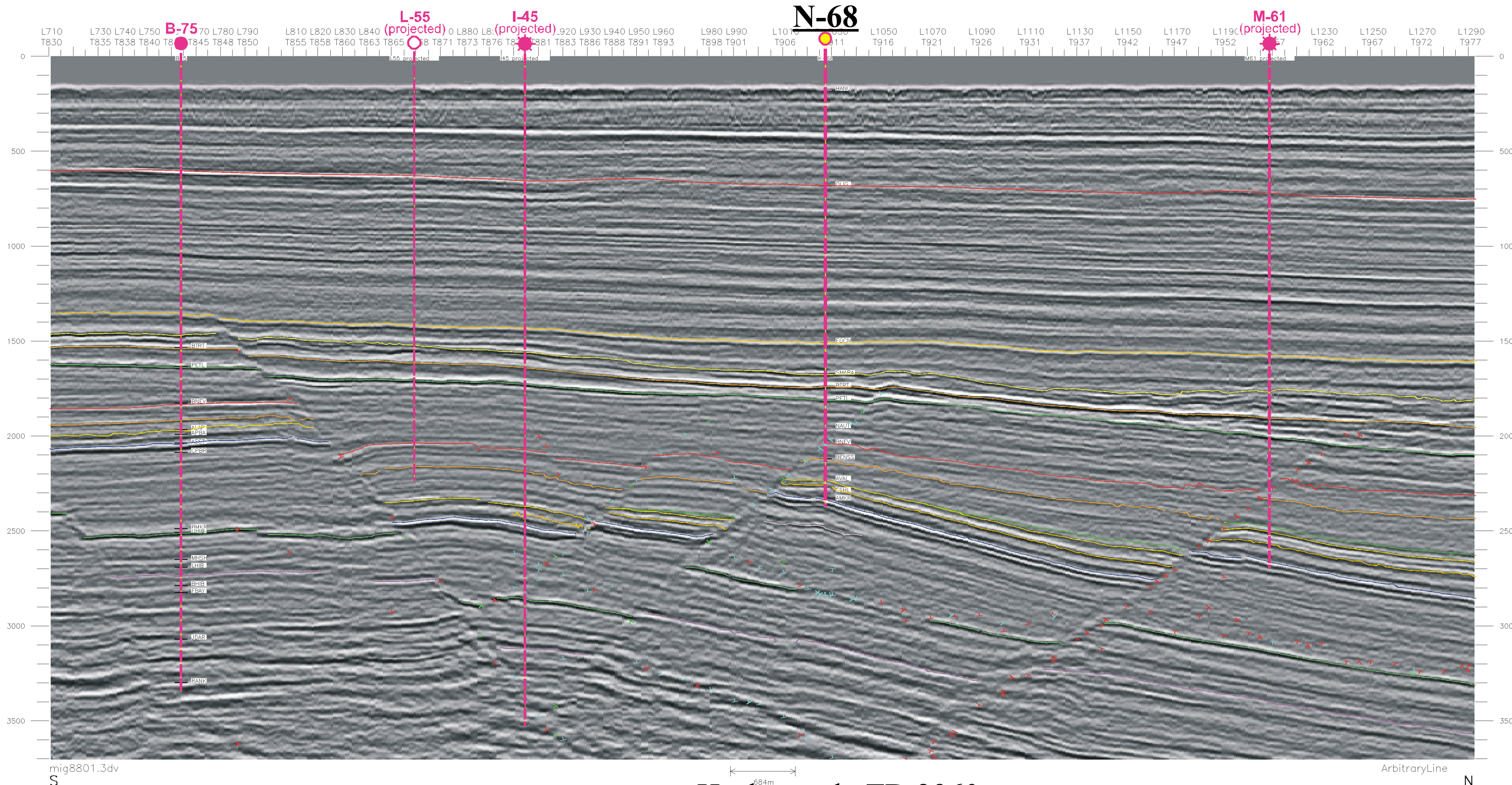
- No doubt introduction of 3D surveys in petroleum exploration has revolutionized the exploration practice and considerably improved our success ratio in discovering hydrocarbons.
- Three-dimensional reflection seismic gives the clearest representation of subsurface geobodies of all known geophysical methods.
- From the timid and costly beginnings of the early eighties, when method was only used to delineate known fields and only affordable to multinationals, to the present day when even small companies can use it on a routine basis in exploration and production, the technique is now de rigueur to the upstream petroleum sector.
- Improvements in field techniques (Positioning, Tuned source arrays, etc..) and data processing, which have been facilitated by advances in computer technology have advanced the 3D seismic method to a point that allows the imaging of subsurface geological complexity that has astonished geoscience professionals.

Not A Slam Dunk!



Barremian 3D Time Structure M

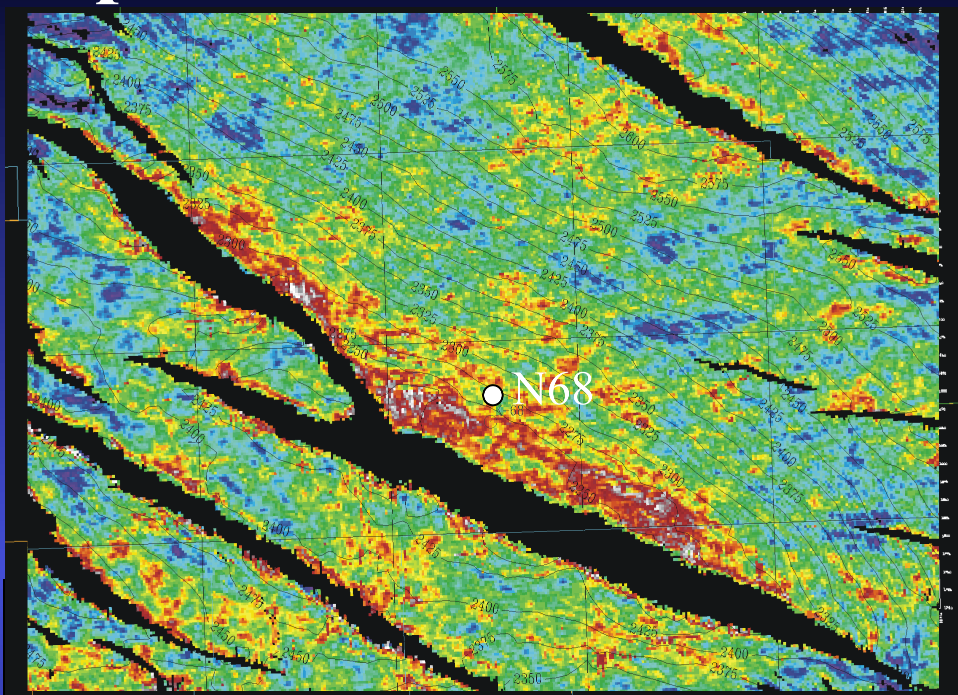
3-D Regional Seismic Section Over West Ben Nevis, Ben Nevis, Cape Race and North Ben Nevis Structures

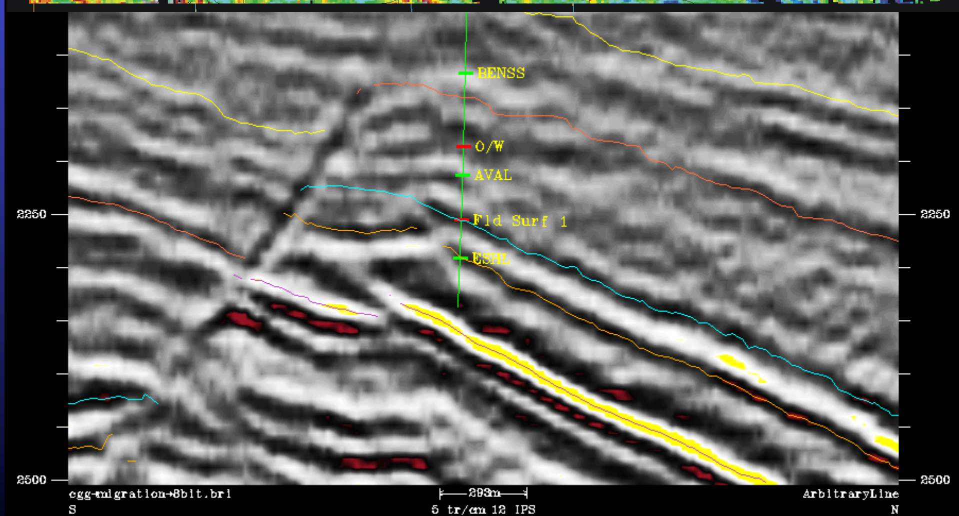


Husky et al., TD 2960m

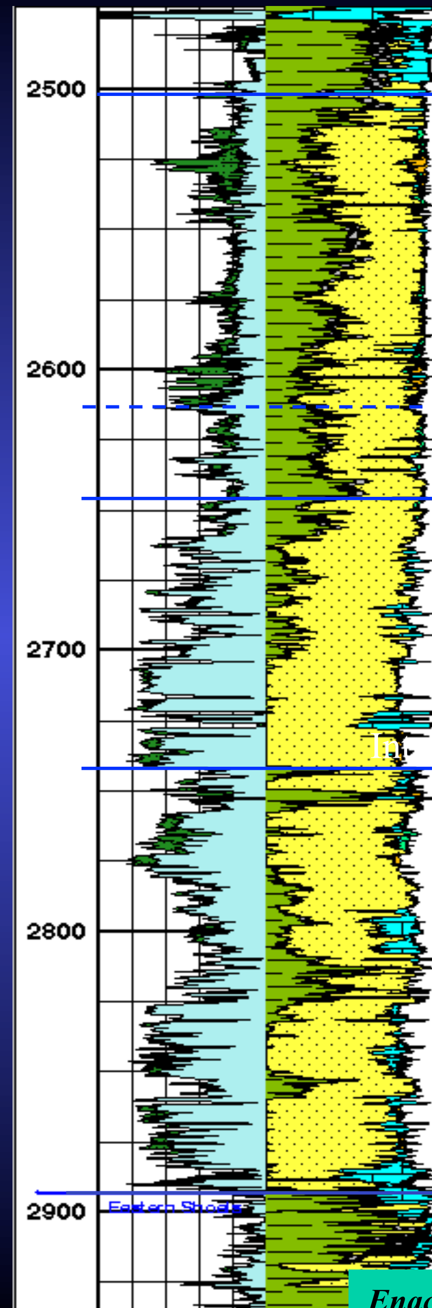
Enachescu et al., 1999

Cape Race N-68 3D





Enachescu et al., 1999



Ben Nevis

BEN NEVIS
Avg Por 15%
Avg Perm 55mD
Thickness 143m
net/gross 0.25

Oil-water contact

Avalon

No Perms in the Ben Nevis; No seal in Avalon

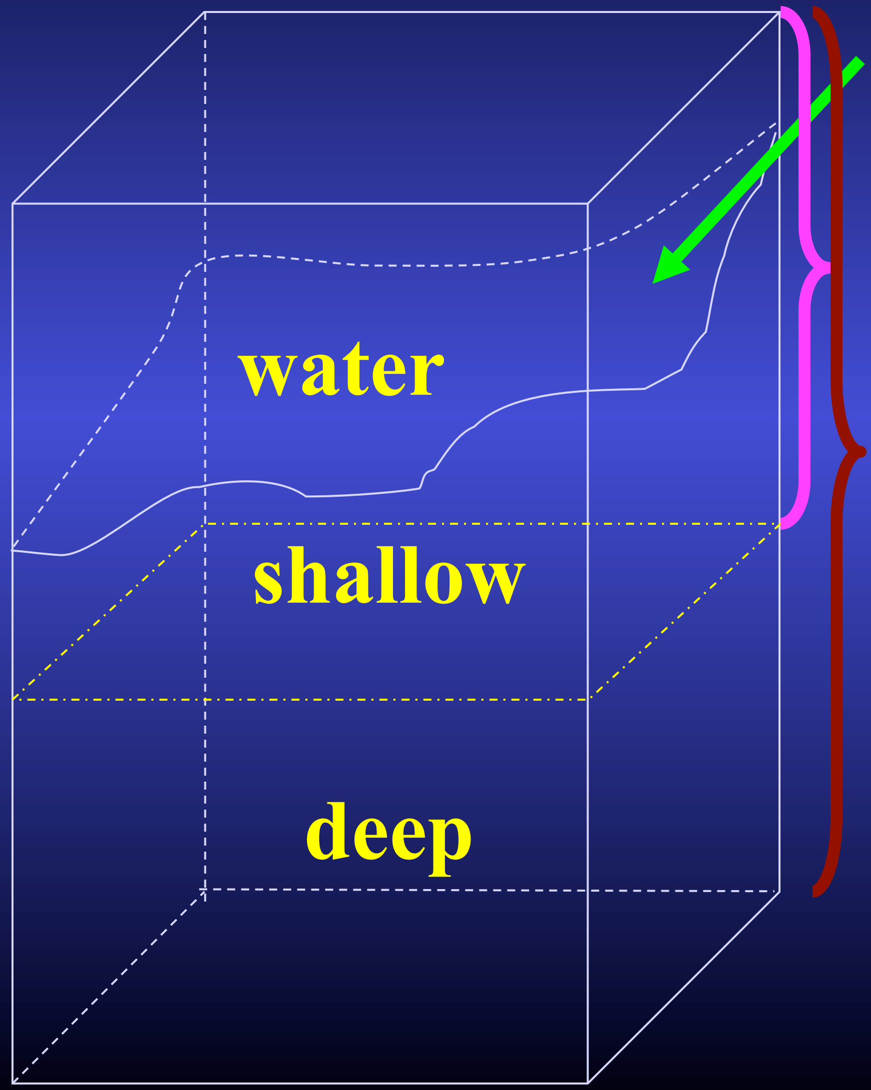
Intra-Avalon Mkr

AVALON
Avg Por 16%
Avg Perm 220mD
Thickness 245m
net/gross 0.7

Eastern Shoals

Enachescu et al, 1999

Surveys for Drilling at Sea



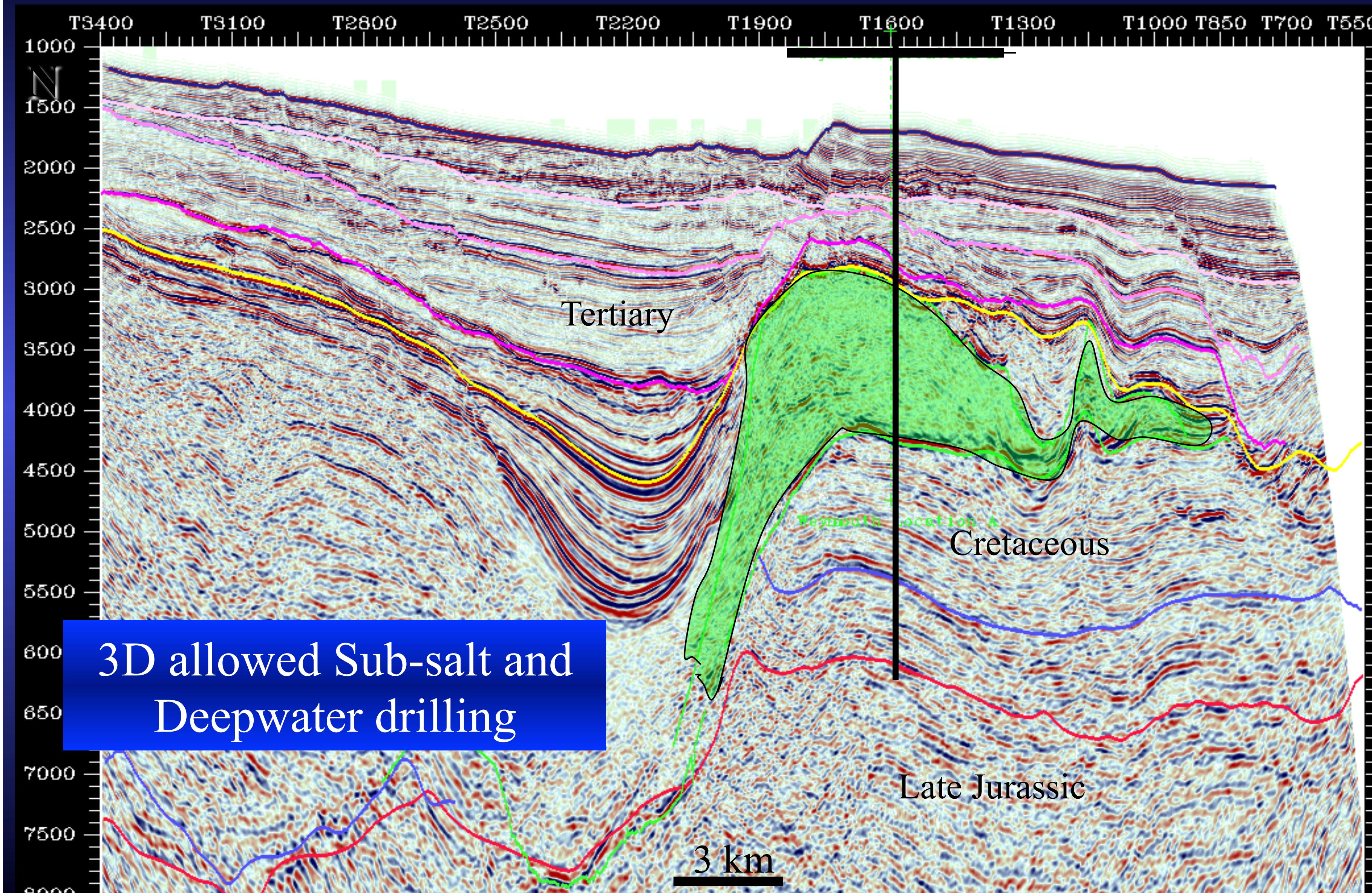
1. Multi-bean bath

2. 3D Site survey

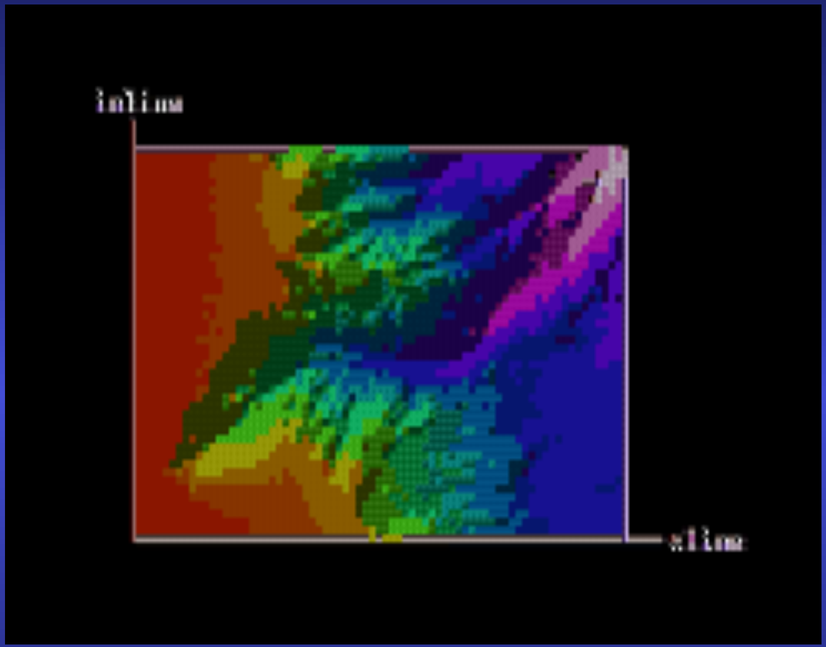
3. Prospect 3D

All three are compulsory!

Weymouth A-45 Subsalt 3D pre-stack time line



Hogg and Enachescu, 2005

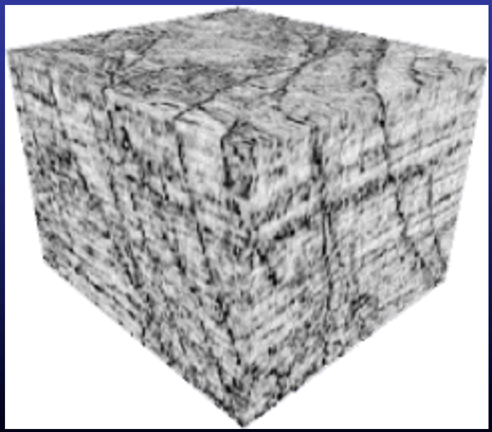


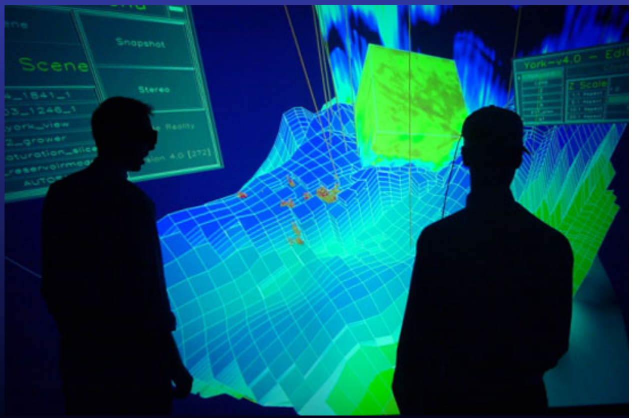
Hogg and Enachescu, 2004

Sea Bottom canyon image derived from deepwater exploration 3D cube

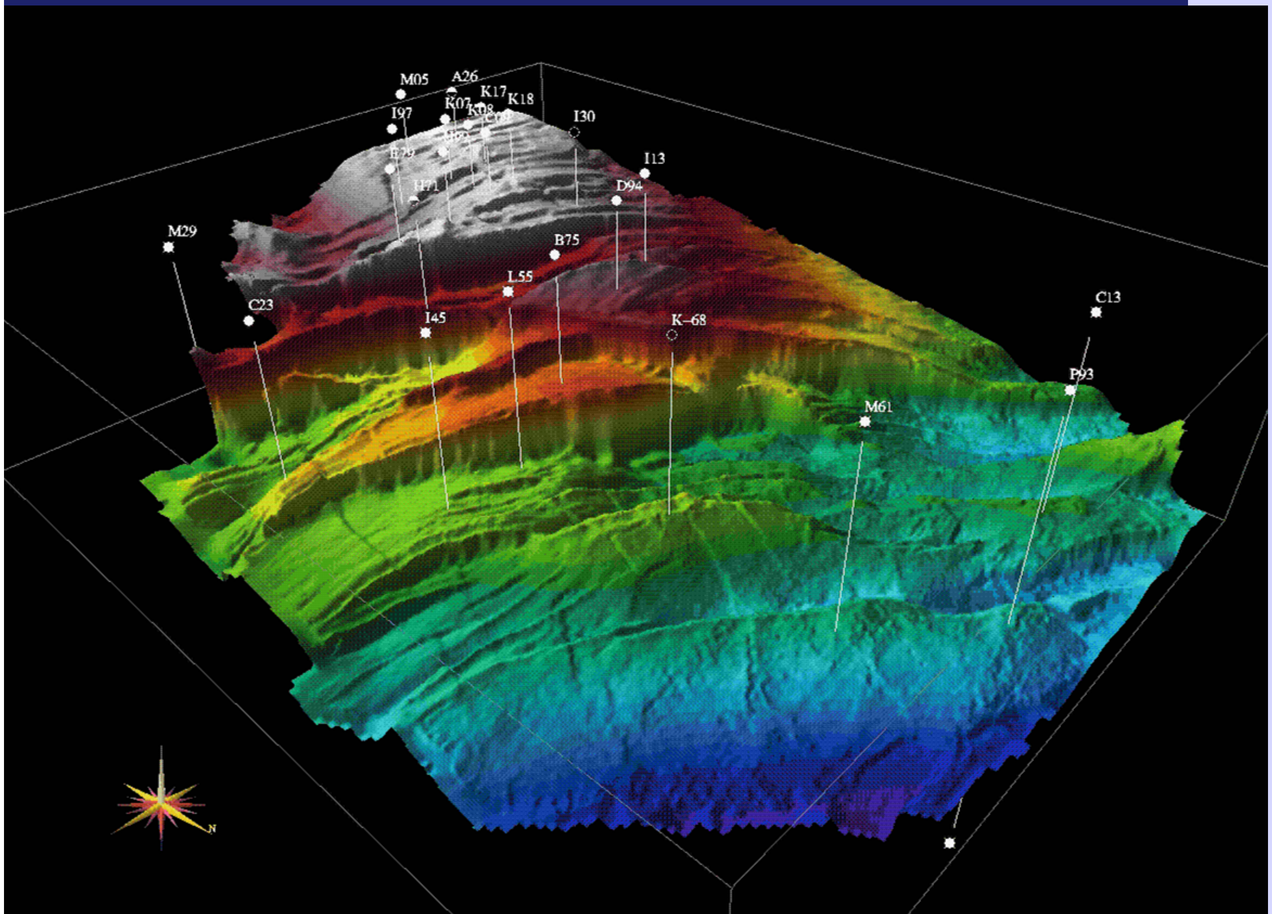
Data Visualization

- Powered by advanced supercomputer power, rapid data loading, high-speed networking and high-resolution graphics, **Visualization Centers** provide the ability to display and manipulate complex volumes of 3D data in a collaborative, team environment
- The result is: a) **better interpretation** of b) **more data** c) **in less time**. The final images geophysicists show to their managers, investors, economists and engineer colleagues must be **simple, depth scaled, have tree-dimensionality and most closely resembles the true sub-surface geology**.





Data Visualization



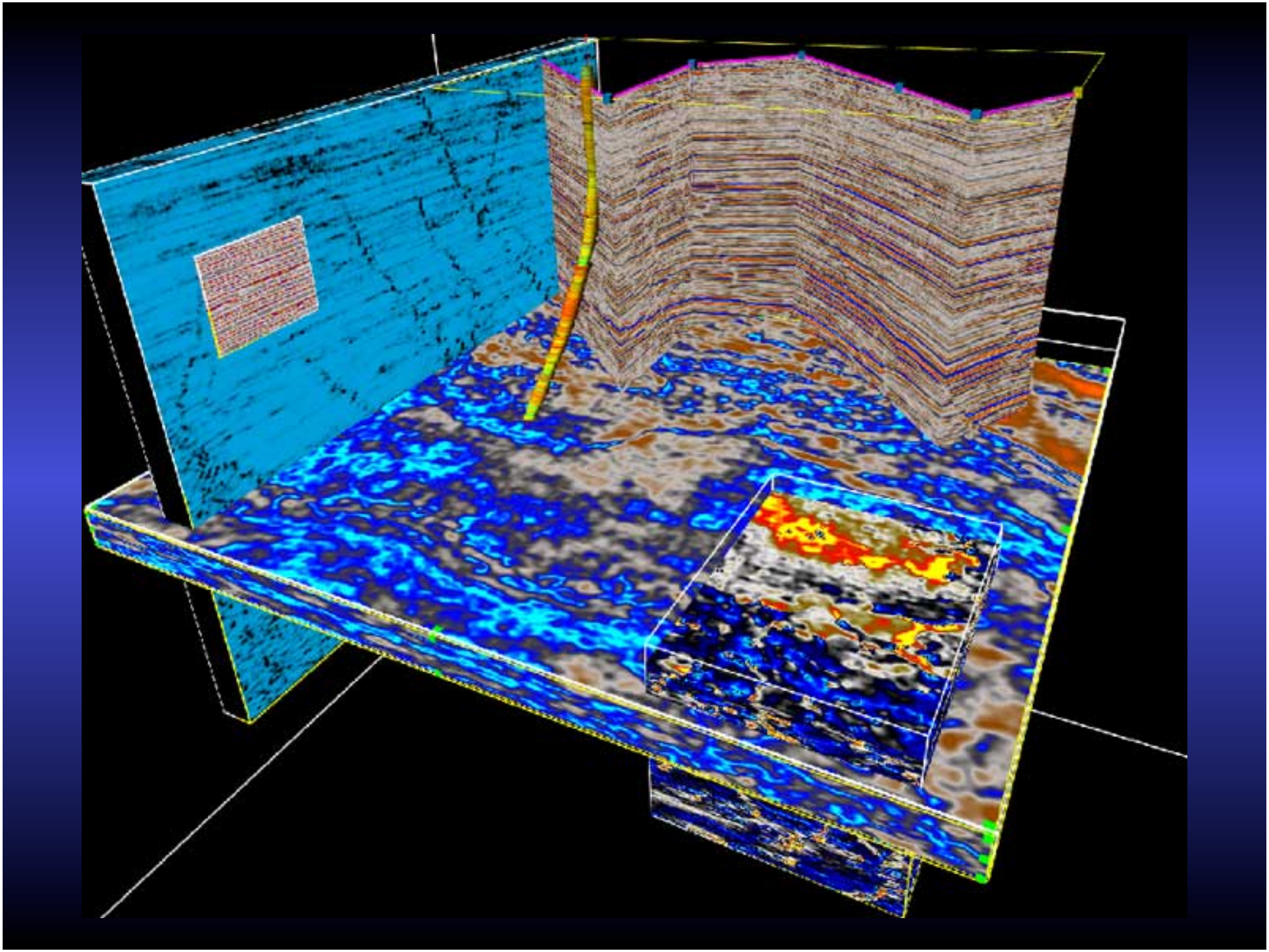
Enachescu et al., 2001

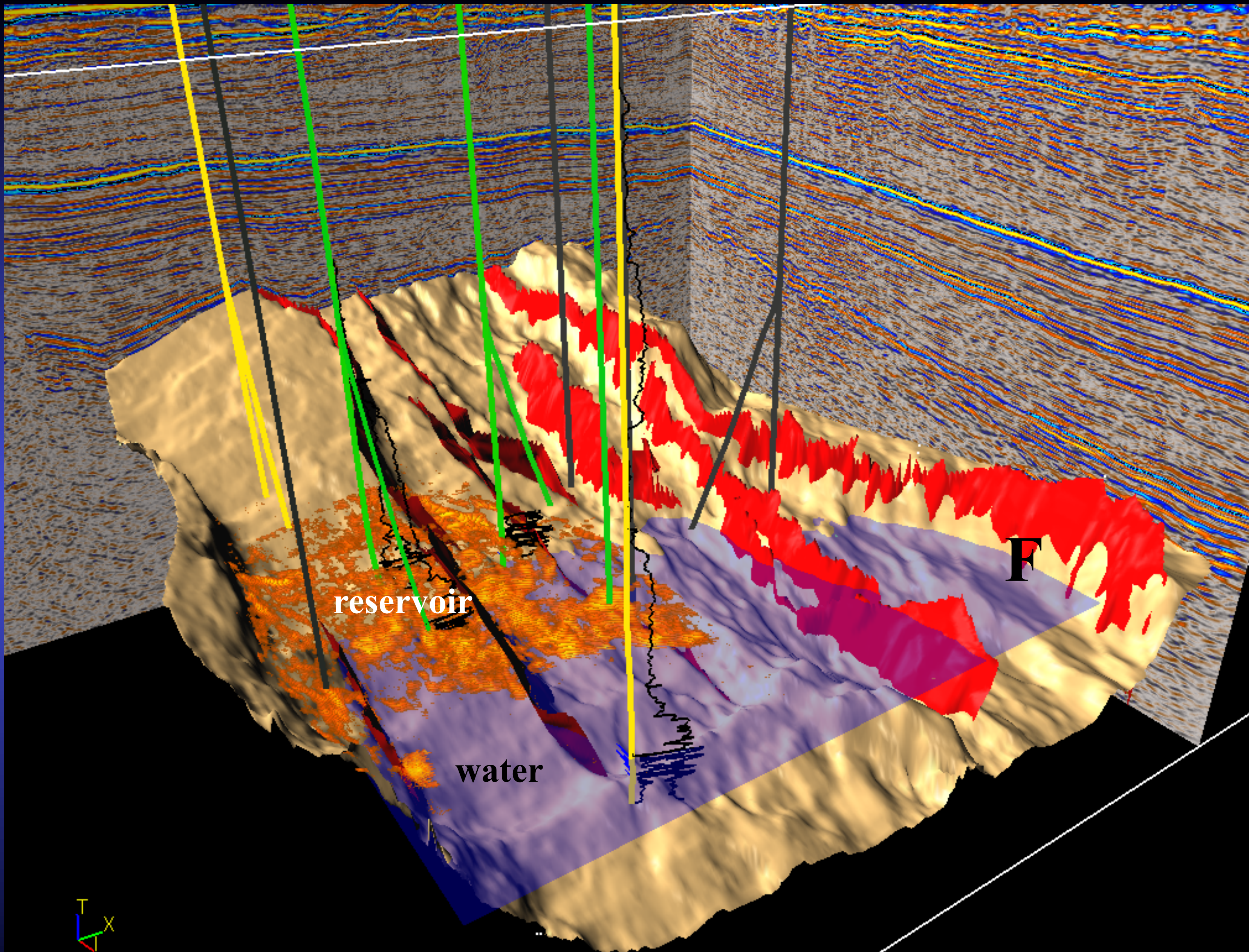
The image above is a 3D surface of a seismic horizon showing the central part of the Jeanne d' Arc Basin, offshore Newfoundland.

The area includes the 150,000 bod producing field Terra Nova and the potential development at Hebron-Ben Nevis oil field area, that might contains half Billion Barrels recoverable.

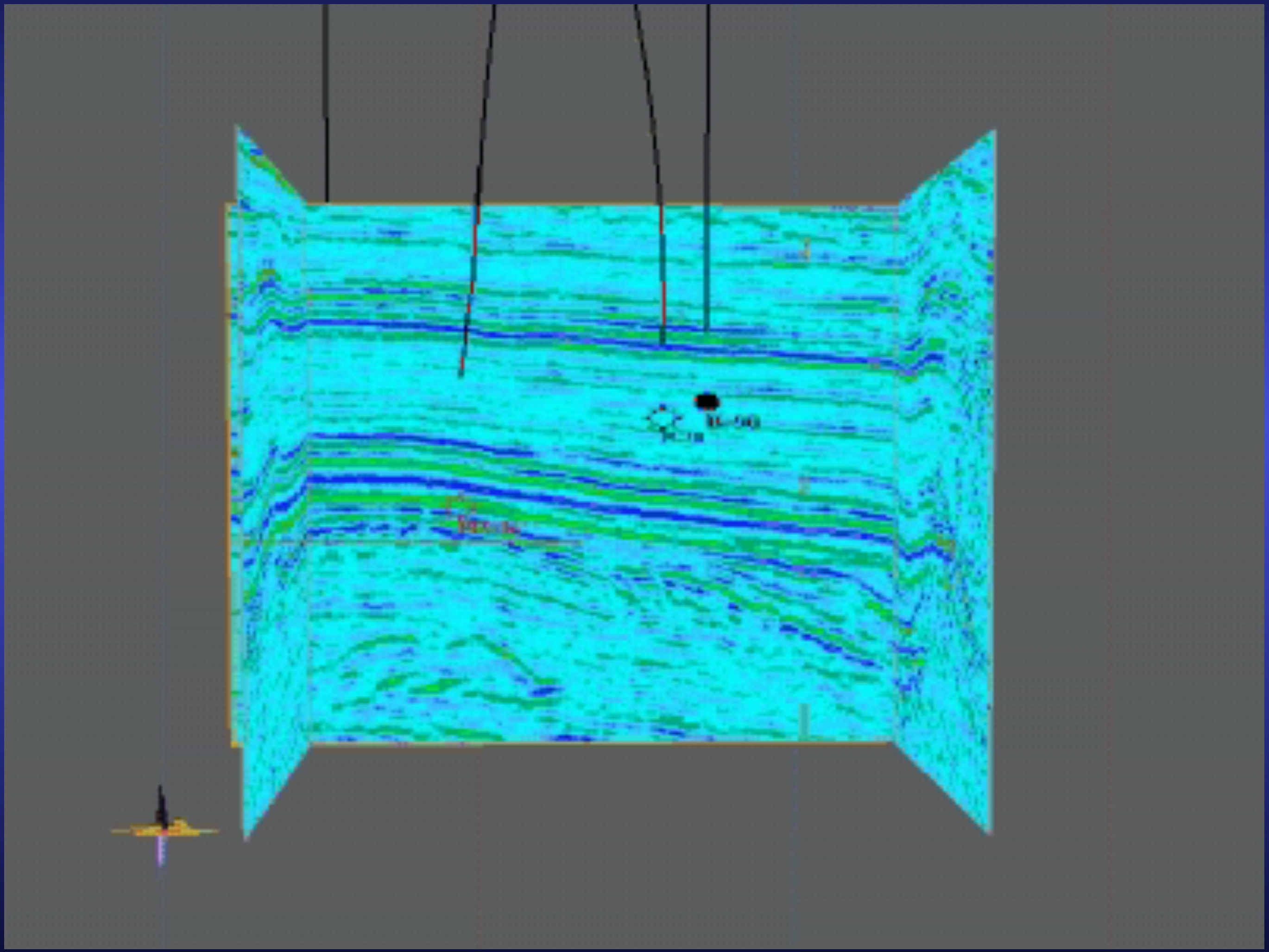
The diagram is constructed by using a 2000 sq km 3D seismic survey and interpreting a 25 by 25 m grid of seismic traces.

Over 1 Billion barrel of recoverable oil is contained in the structural-stratigraphic traps contained in this diagram.



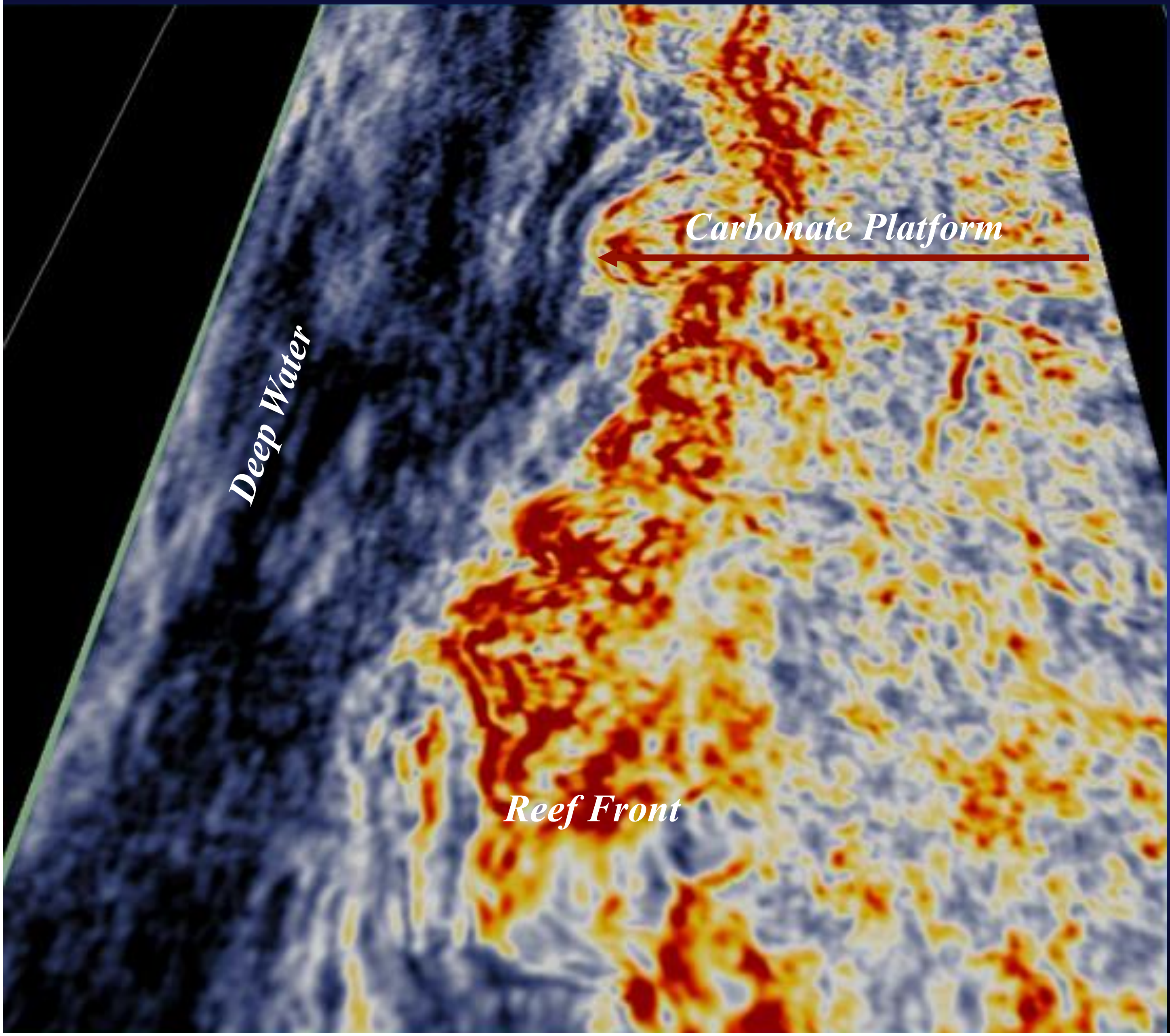


Stratigraphic pool in turbidites



Imaging the Jurassic Platform Margin (Abenaki)

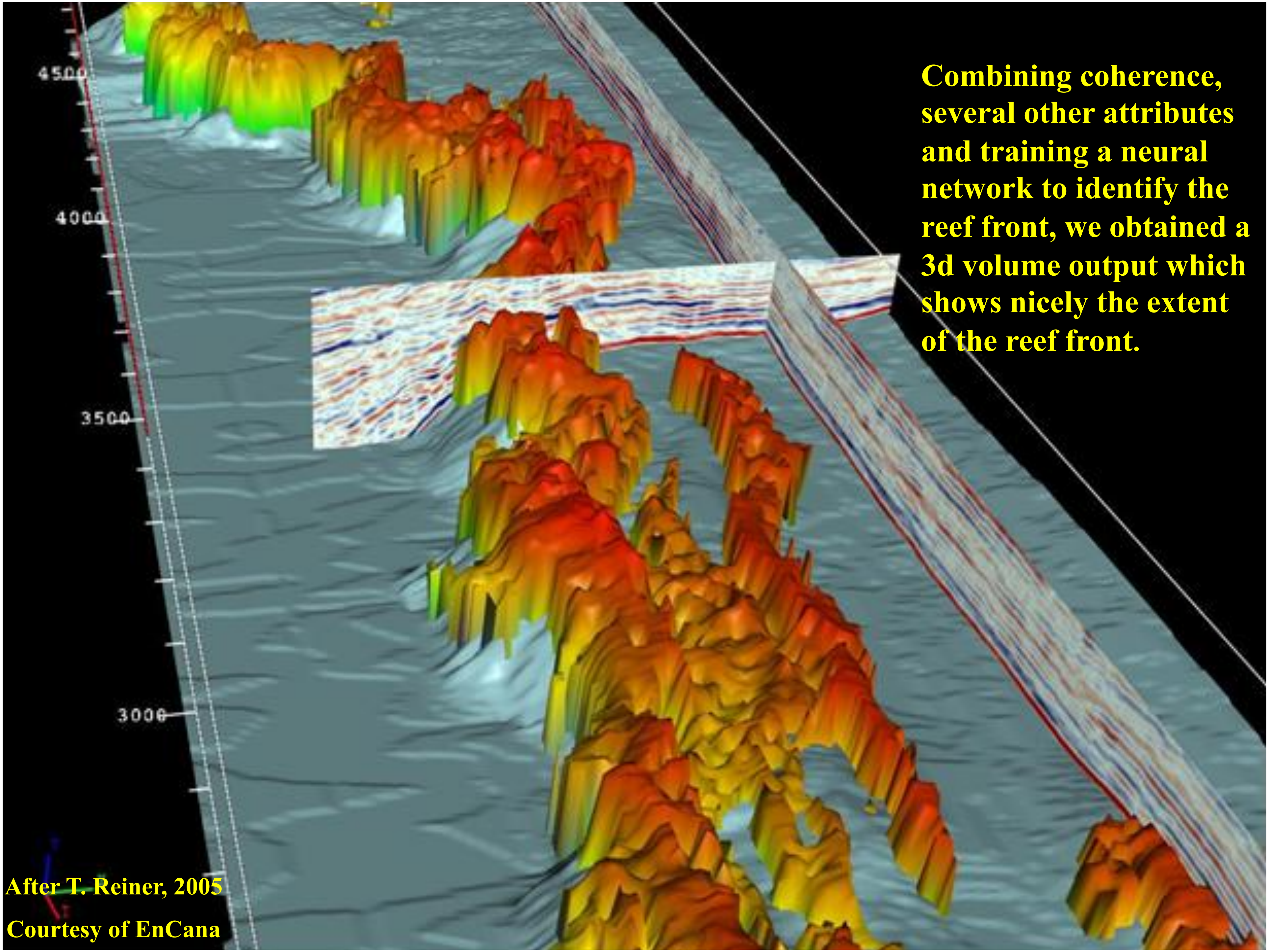
Deep Panuke Gas Field



Time Slice through a 3D Coherency Cube

After T. Reiner, 2005

Courtesy of EnCana


4500
4000
3500
3000
Combining coherence, several other attributes and training a neural network to identify the reef front, we obtained a 3d volume output which shows nicely the extent of the reef front.
After T. Reiner, 2005
Courtesy of EnCana

Modern History of 3D

Phase 1. **End seventies-early eighties**: try out on giant field delineation; *Structural surveys on discovered large fields*

Manager said: "It's a luxury, who needs it?"

Phase 2. **Late eighties-early nineties**: used on all significant discoveries, a must for major developments; *Structural survey with some stratigraphic application*

Manager said: "It's a good tool, but too expensive"

Phase 3. **Late nineties**: Routine for offshore exploration; most work done in spec by contractors; *Structural-stratigraphic; mapping deepwater fans; 4D, 4C*

Manager said: "Negotiate price cuts with contractors and used flashy displays during farm-outs" (almost bankrupts contractors, see mergers etc.)

Phase 4. **Post-2000:**: Routine in offshore exploration from first year of concession; *Stratigraphic-Structural plays, special surveys and re-acquisition*

Manager said: "It makes money and helps me make my stock options!"

Phase 5. The best is yet to come; Widespread use, Academic Research, cross-trained geoscientists, *time-lapse, 4C, "Q", multi-azimuth surveys; planetary science, small fracture and porosity detection, climate change, used in conjunction to IODP*

Testing the Discovery

Industry

Play

Lead

Prospect

Discovery

Petroleum Field

You might get rich!

Academia

Observation

Study

Project

Scientific Disc

Theory

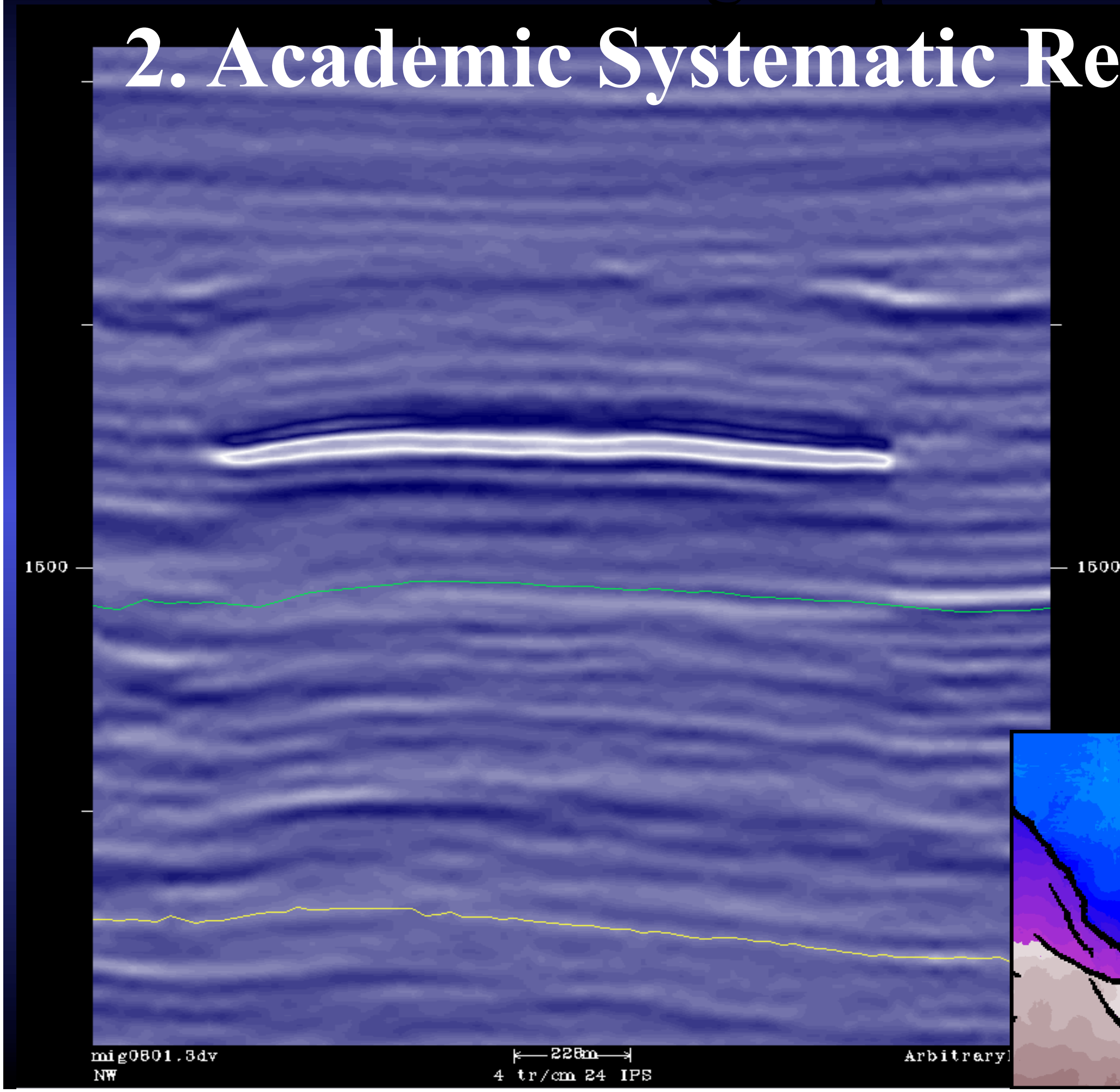
You might get famous!

Selective Targeting

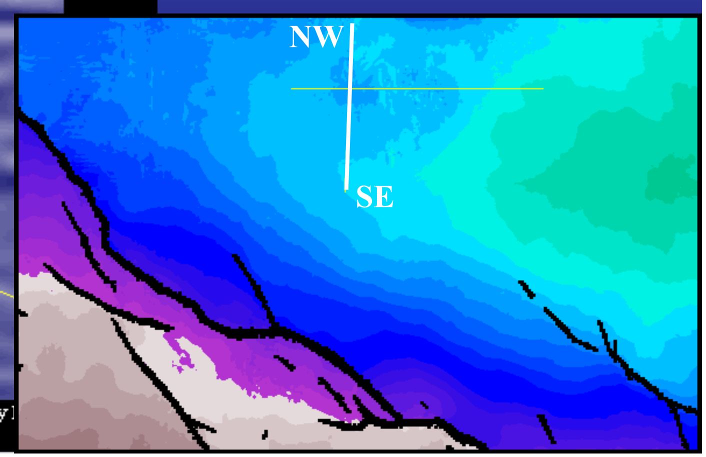
- Industry is practicing selective targeting by 3D of previously identified structural and stratigraphic leads: subsurface closures that may become drilling prospects if proven by 3D interpretation
- Spectacular examples of marine seismic mapping of ancient paleodrainage systems, buried erosional surfaces, marginal, slope and basin fans, carbonate platforms, reef barriers, paleo-karst features, intersecting fault systems, stacked thrust sheets, lithology changes, etc., have been mapped during 3D interpretation, are broadly discussed in the literature and some will be illustrated in this presentation.
- Advances in marine acquisition capabilities include multi-streamer recording, ocean bottom 2C 3-D, 4C detectors, 3-D time lapse seismic monitoring of producing reservoirs (or "4D"), and most recently Schlumberger's "Q" technology - all of which can be utilized to lower the geologic risk and open new frontiers to exploration.
- Only the 3D seismic method can provide a complete depiction of subsurface structure and in some cases directly map accumulations of petroleum and allow geoscientists to guide highly deviated or horizontal wells into "sweet spots" only a few metres wide and located several km beneath the surface!

Bright Spot

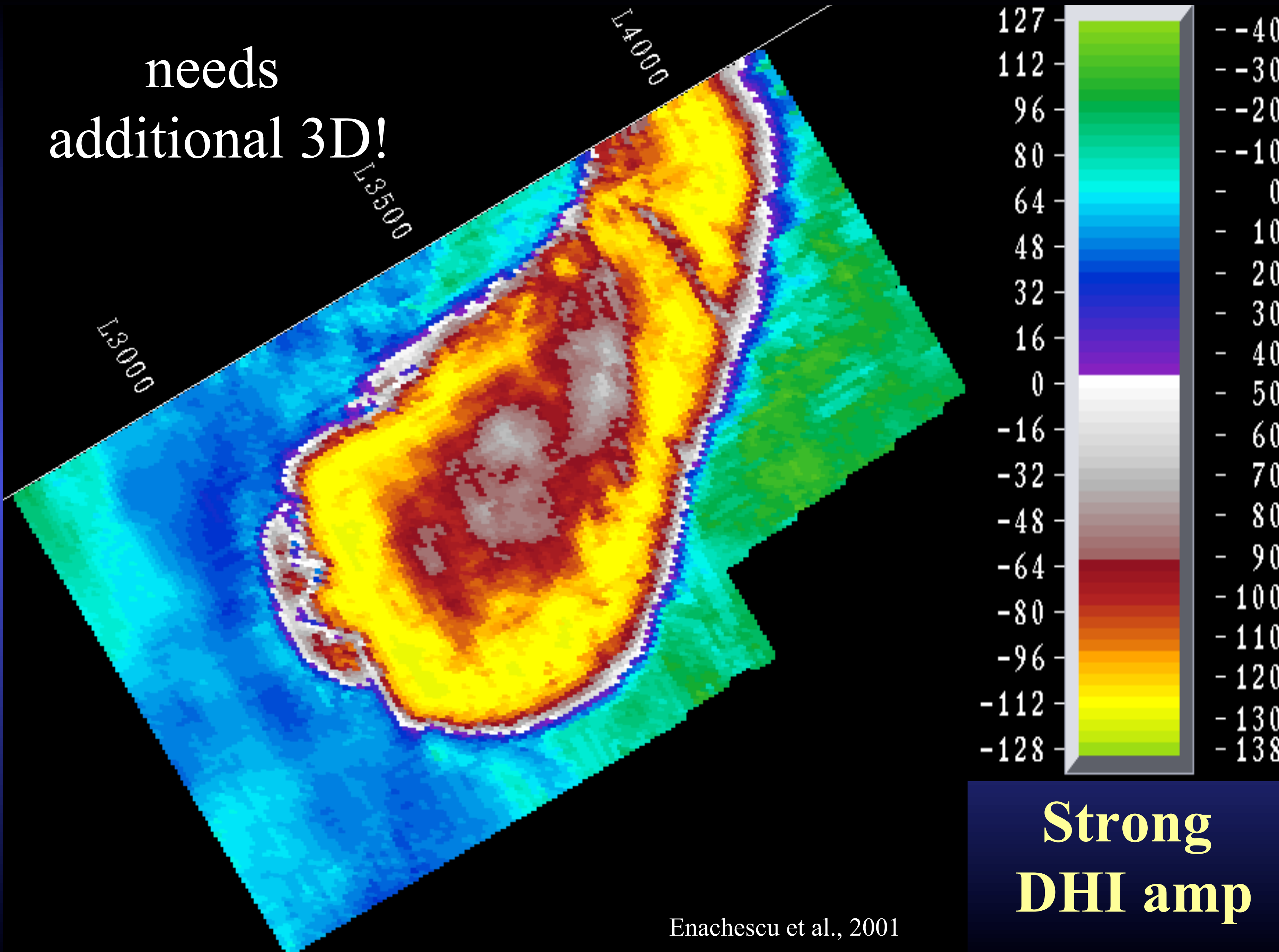
2. Academic Systematic Research



Enachescu et al., 2001



needs
additional 3D!

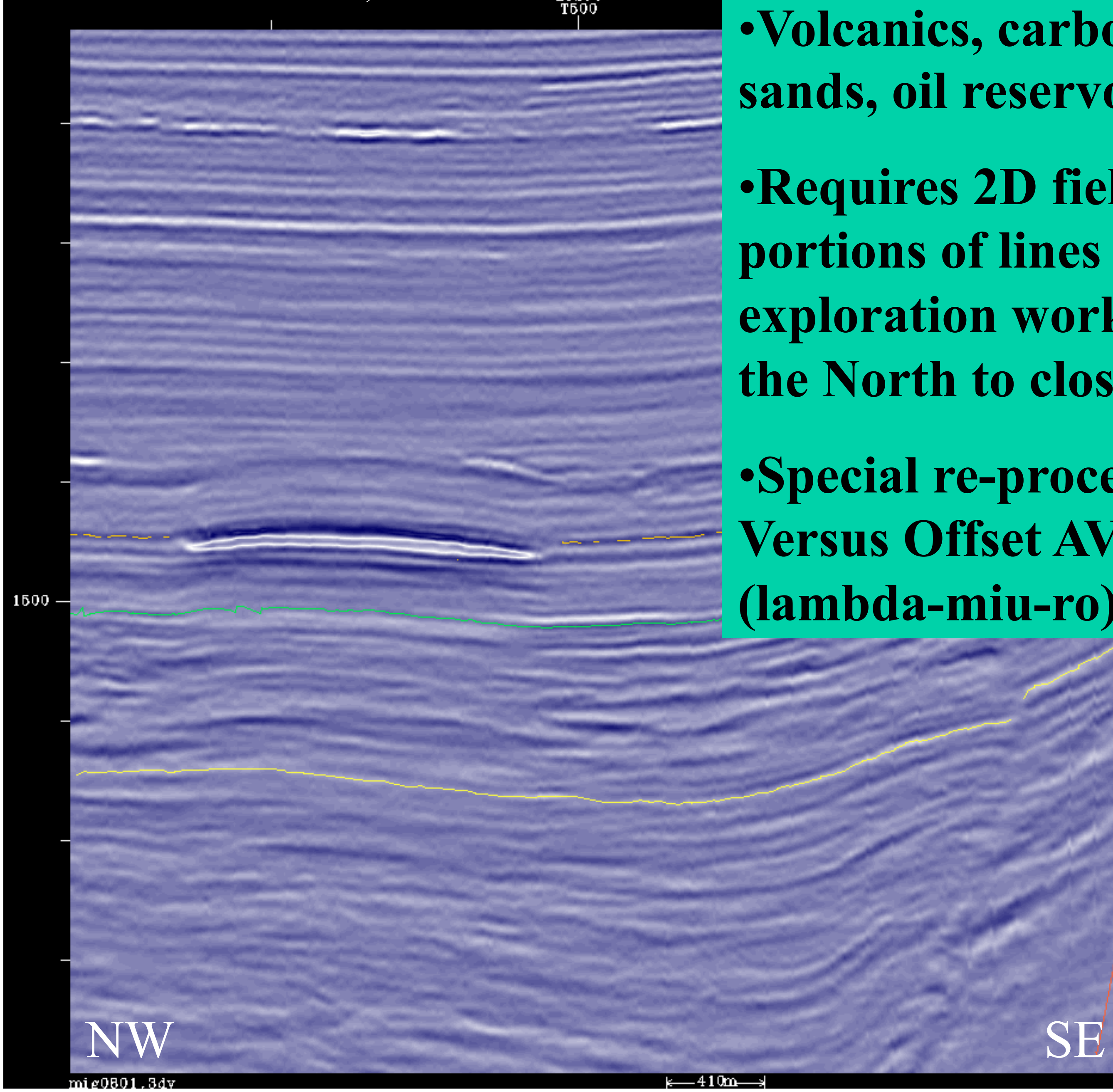


Enachescu et al., 2001

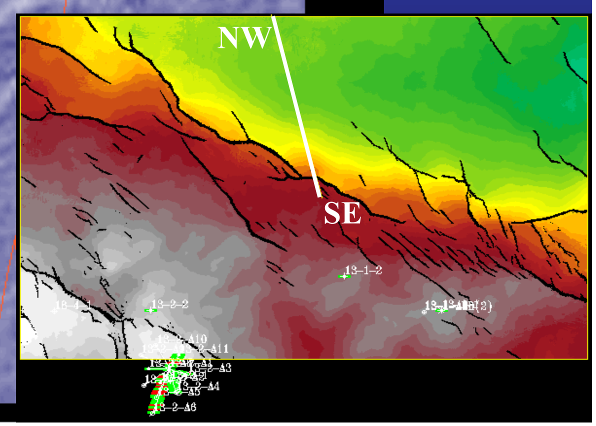
Strong DHI amp

Nature of Bright Spot

Enachescu et al., 2001



- Volcanics, carbonate, coal, gas sands, oil reservoir?
- Requires 2D field data on selected portions of lines to do further exploration work and 3D coverage in the North to close the anomaly!
- Special re-processing, Amplitude Versus Offset AVO, Inversion, LMR (lambda-miu-ro), modeling, etc.



Industry Limitations

- Exploration ignores sometimes the regional context; there is not enough cross-training
- Few public datasets
- Geophysicists get addicted and go on binges
  Example: seismic stratigraphy (e.g. Sable); abuse of attributes; abuse of automatic routines, abuse of visualization!
- Exploration works on a 5 years cycle, frequent changes in an exploration team
- Development of discoveries with all 3D data passed to a different team
- Most of the exploration papers remain unwritten….

Systematic Research

- Despite recent advancements in marine seismic acquisition methods and the use of multi-streamer vessels (up to 20 streamers were deployed) only a very small portion of the ocean and sea surface has been surveyed by 3D.

Industry covered 1% from world oceans
Academic Research left with 99%

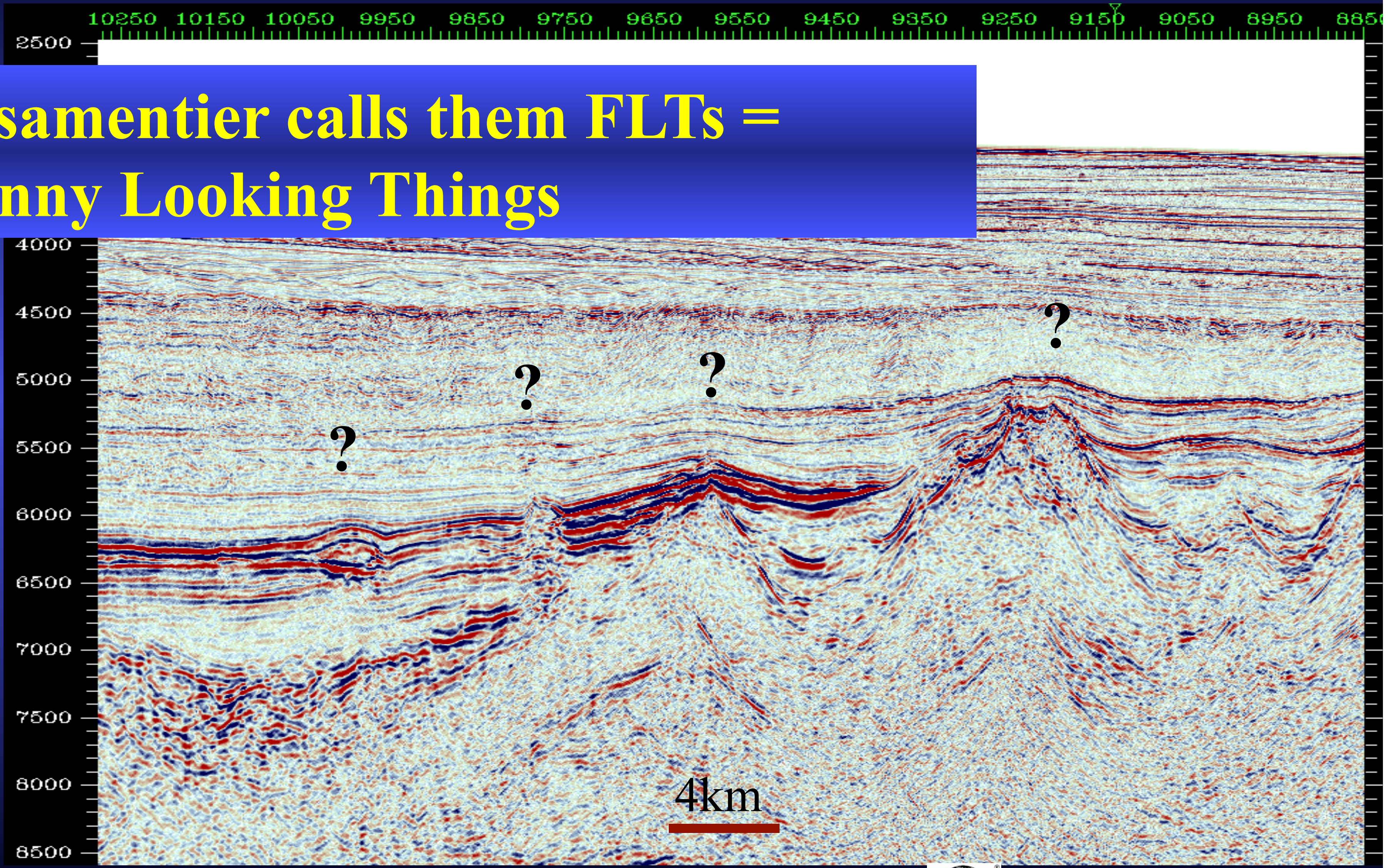
- Most of the industry generated 3D seismic cubes have yet to be fully mined for geoscience information, as petroleum geoscientists are primarily focused on those particular zones that are recognized to contain petroleum.
- Moreover, the petroleum industry is active only in sedimentary basins with recognized petroleum potential and 3D seismic is selectively targeted to structures and stratigraphic features that have been pre-selected from dense MCS 2D surveys or to areas near existing oil and gas discoveries.

Systematic Research

- **Academic 3D can provide fundamental data to researchers from areas and environments that are unlikely to be surveyed by the petroleum industry.**
- **Certain depositional environments, suture zones and subduction zones that are non-conducive to deposition of petroleum reservoir and source rocks have been ignored by the 3D seismic industry.**
- **Many geological provinces under the world's seas and oceans including those with thinner sedimentary cover, volcanic terranes, or located on distal parts of the continental slope, within transitional zones, serpentinized peridotite ridges, oceanic crust domain, large igneous provinces, transform zones or mid-oceanic ridges, to mention only a few, remain to be investigated by 3D seismic in order to reveal their in depth constitution and spatial architecture.**
- **Thick sedimentary accumulations located on plate margins including non-disturbed passive margin sequences or the distal part of the fans of major fluvial systems (e.g. Bengal, Indus) also remain to be studied by this method. Other lines of research that can benefit from systematic study by 3D seismic include process geoscience studies such as investigating source to sink depositional processes, modern rift systems, earthquake generation by known and blind fracture zones, climate change, etc.**

Orphan Basin 2D Line

Posamentier calls them FLTs = Funny Looking Things

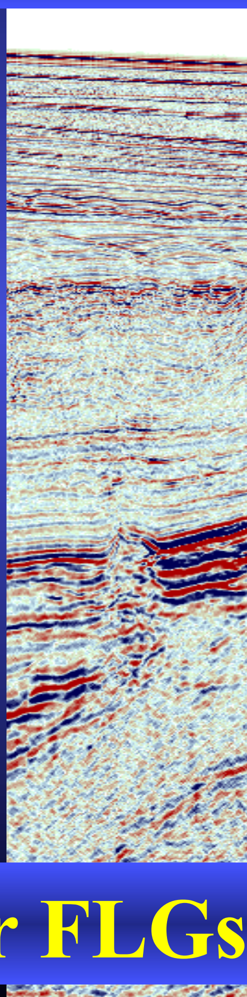


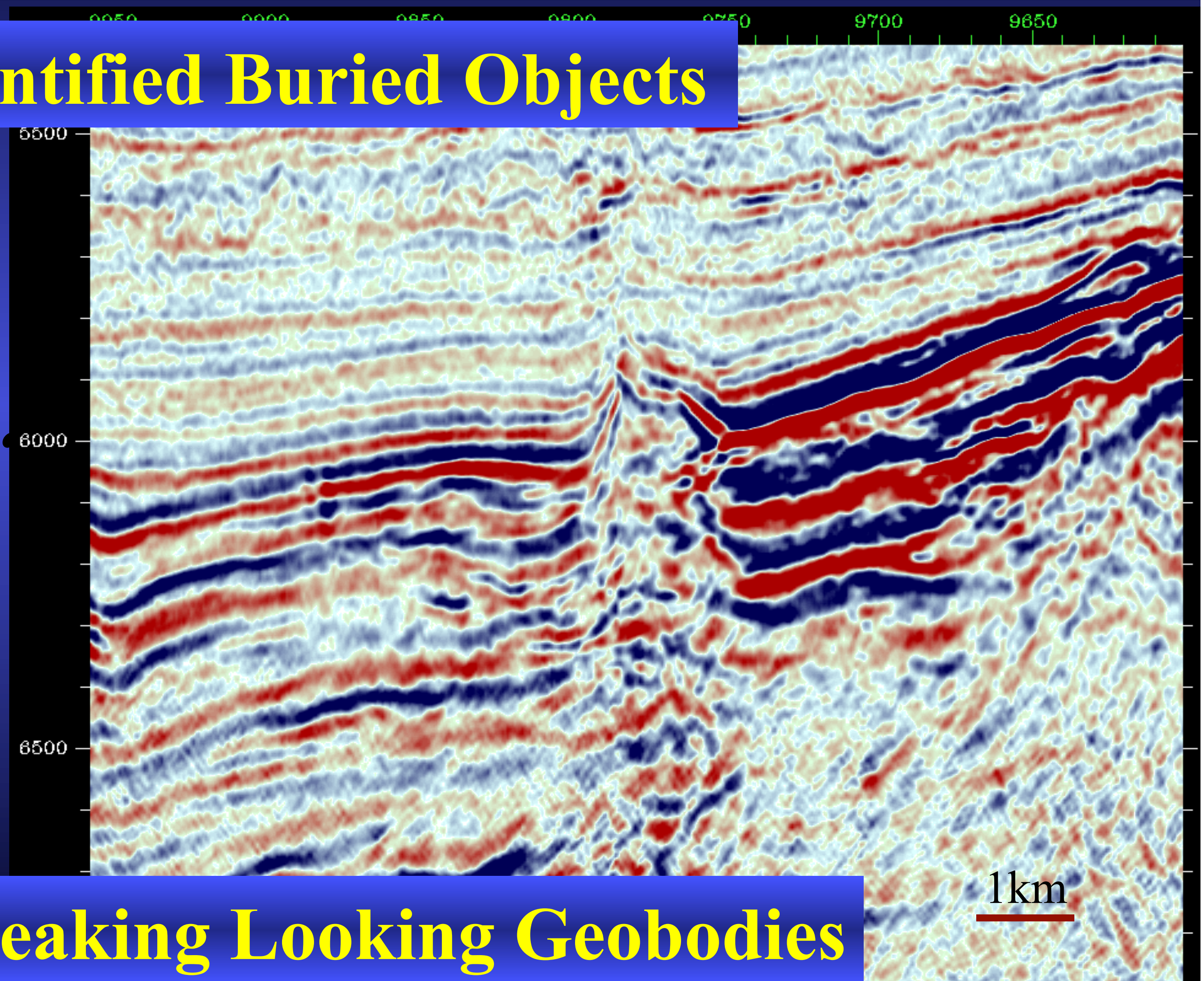
data Courtesy of GSI

Orphan Basin 2D Line

I call them:

UBOs = Unidentified Buried Objects

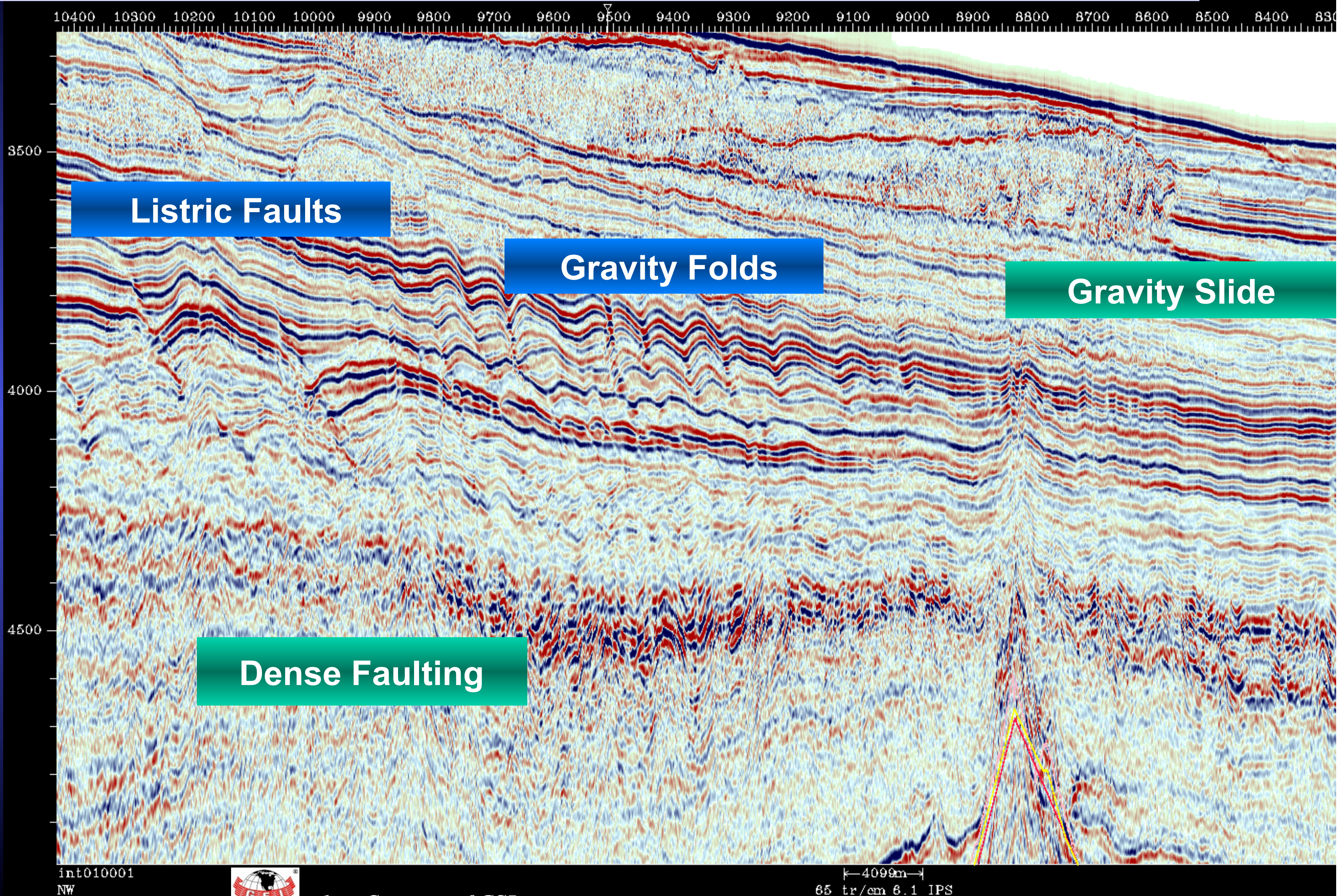




Or FLGs = Freaking Looking Geobodies

data Courtesy of GSI

Shallow marine geology needs to be described in 3D

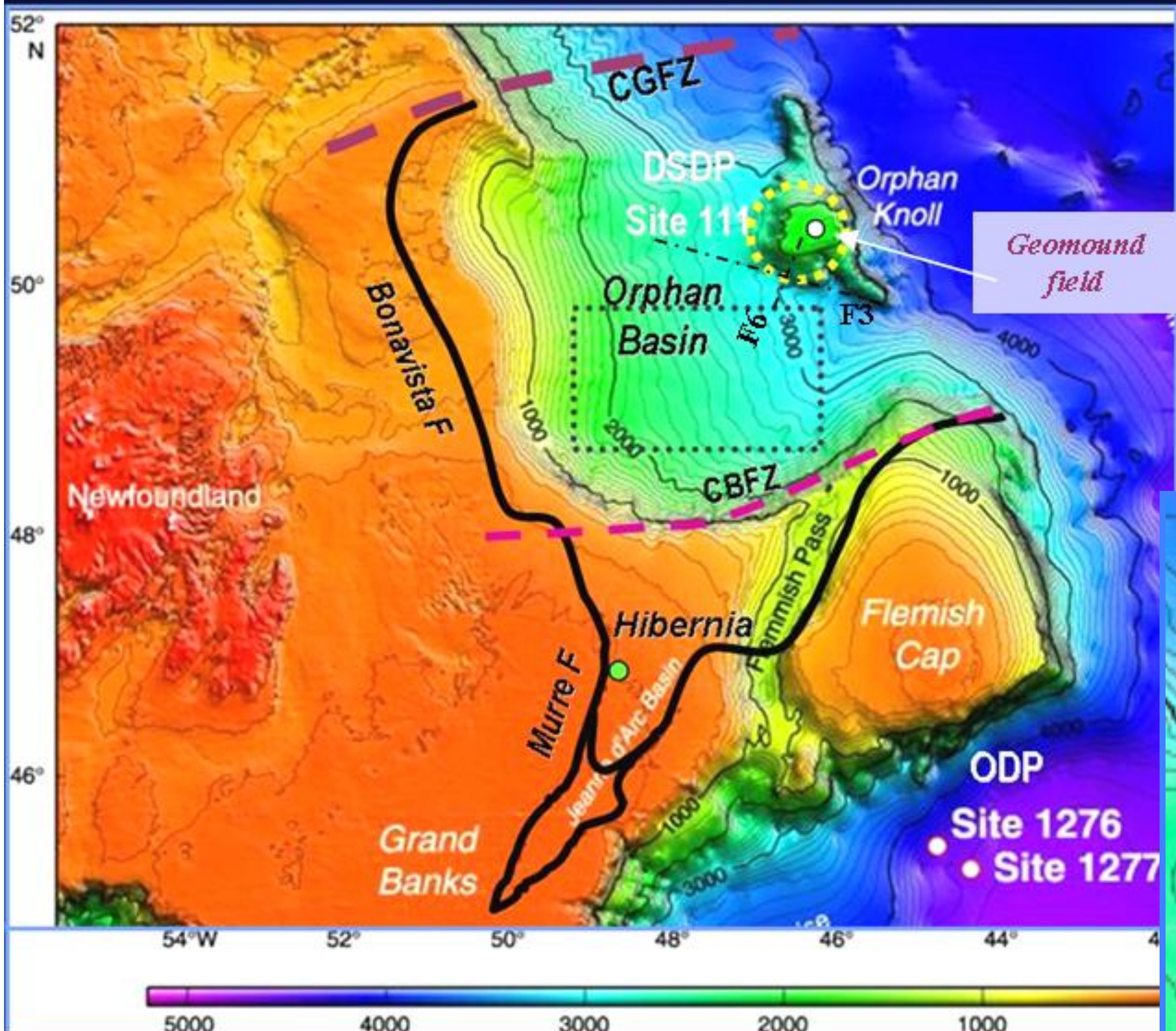


data Courtesy of GSI

Research subjects already in 3D studies

- Sand injection; polygonal faulting (Cardiff U. group)
- Gas hydrates; hydrocarbon/hydrothermal vents
- Chemosynthetic communities and the subsurface
- Fault plane shapes/fault nucleation
- Geomorphology on passive and active margins
- Diagenesis of siliciclastics
- Fracture detection
- More meteorite craters
- Earthquake prediction time lapse
- Multi-azimuth surveys

Bathymetry after Tucholke, Sibuet and ODP leg 210 party

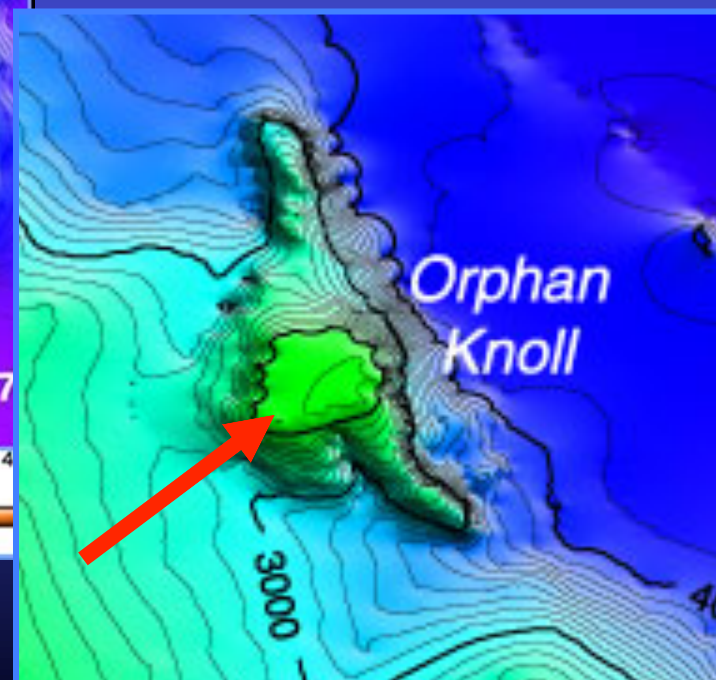


Enachescu, 2004

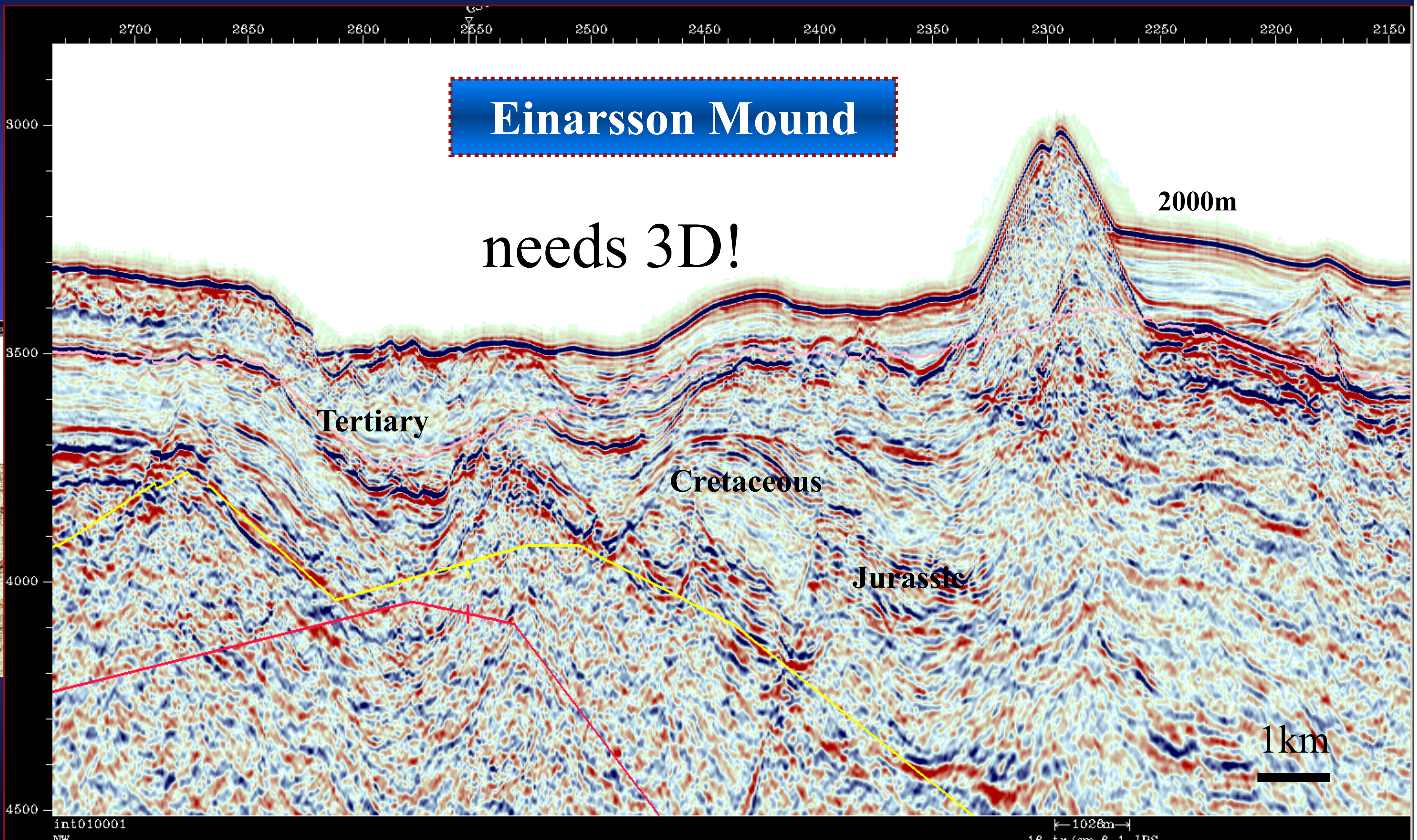
The Leading Edge of Geophysics, December 2004

- **Industry exploration**
- **Free of mounds**
- **Mounds only on the Orphan Knoll**

Final Goal Natural Protected Area?

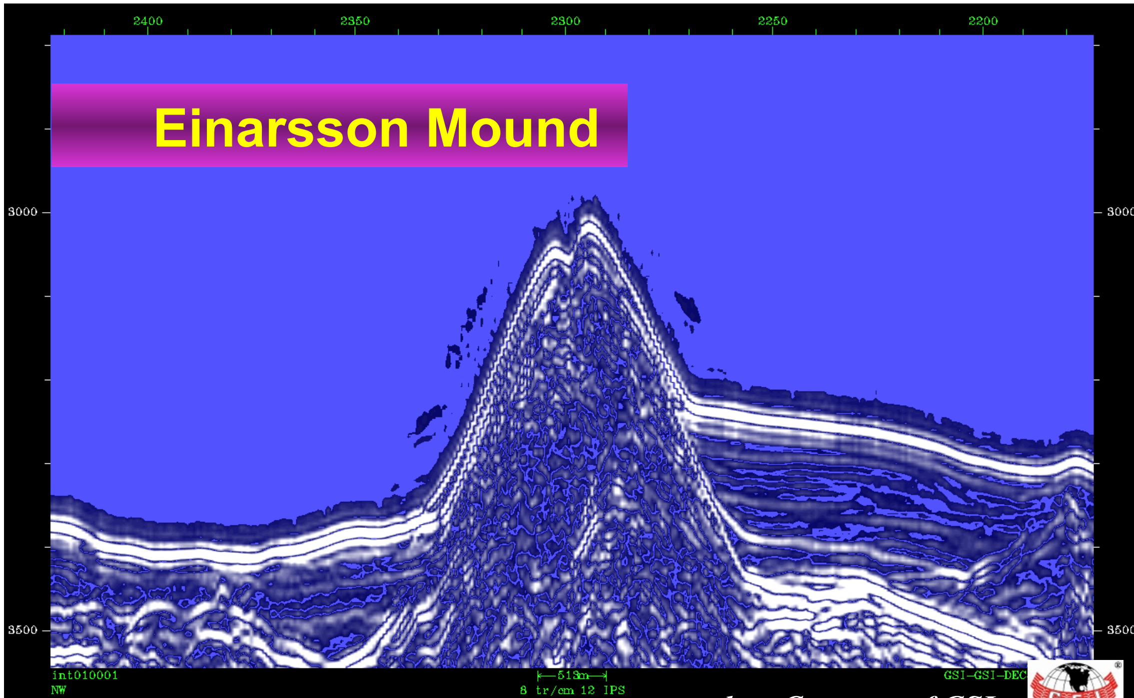


Line GSI-OR0-102



data Courtesy of GSI

Enachescu, 2004



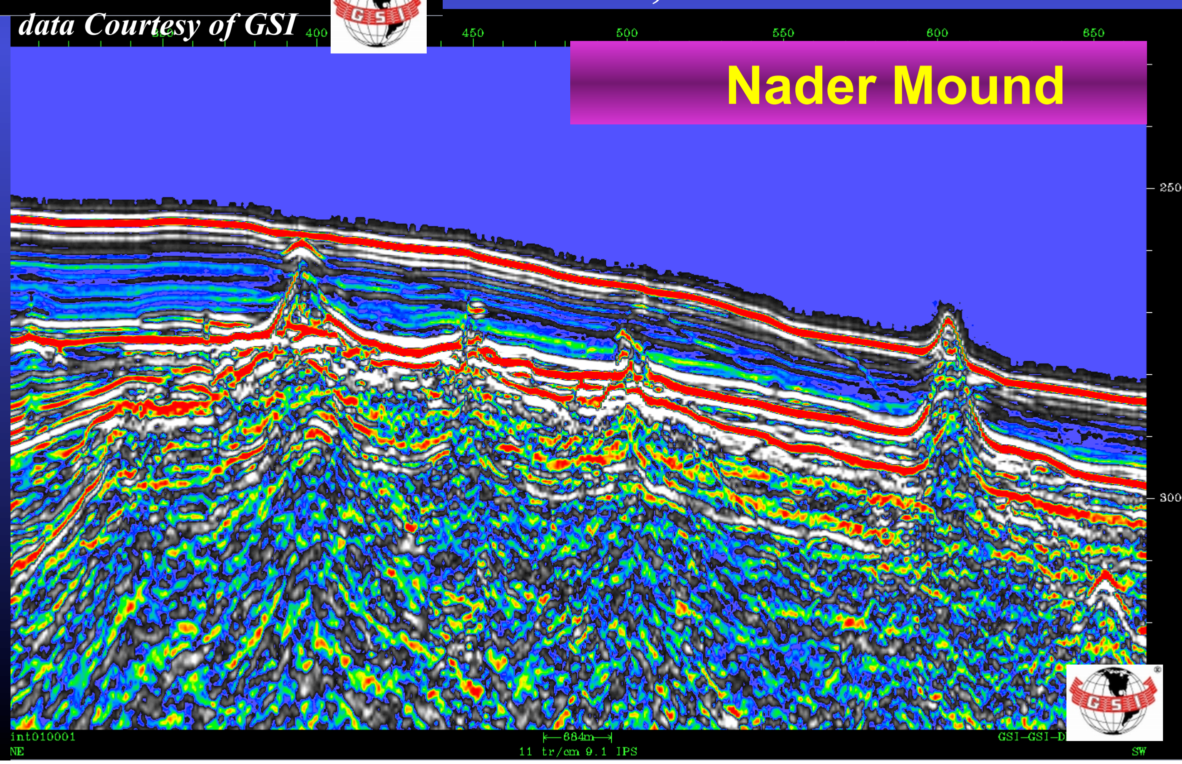
Geomounds

1800-2300m subsea!

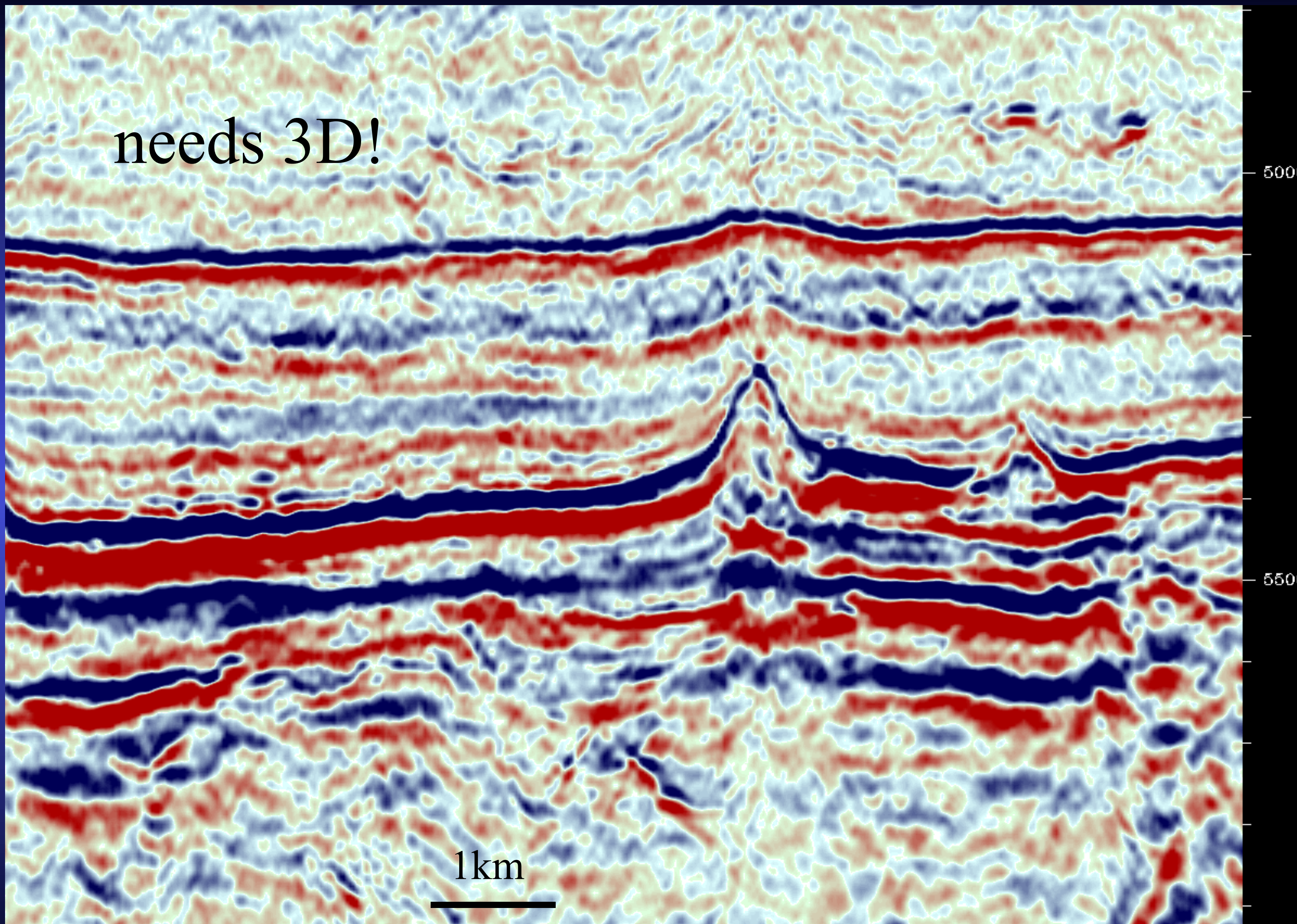
Bioherms?
Bacterial?
Vents?

Enachescu, 2004

data Courtesy of GSI



- **Deepwater corals sampled from the Orphan Knoll and Nova Scotia slope but not at this water depth and not reef building type**



Enachescu, pers com

data Courtesy of GSI

Academic Limitations and Recommendations

- Research 3D is limited only by money, personnel and time: You will be the unique acquisition outlet
- There are many interpretation labs: Rice, Cardiff, Memorial, CSM, Imperial College, U of Texas: use them
- Work in teams of geoscientists
- Make data sets public /do not hoard!

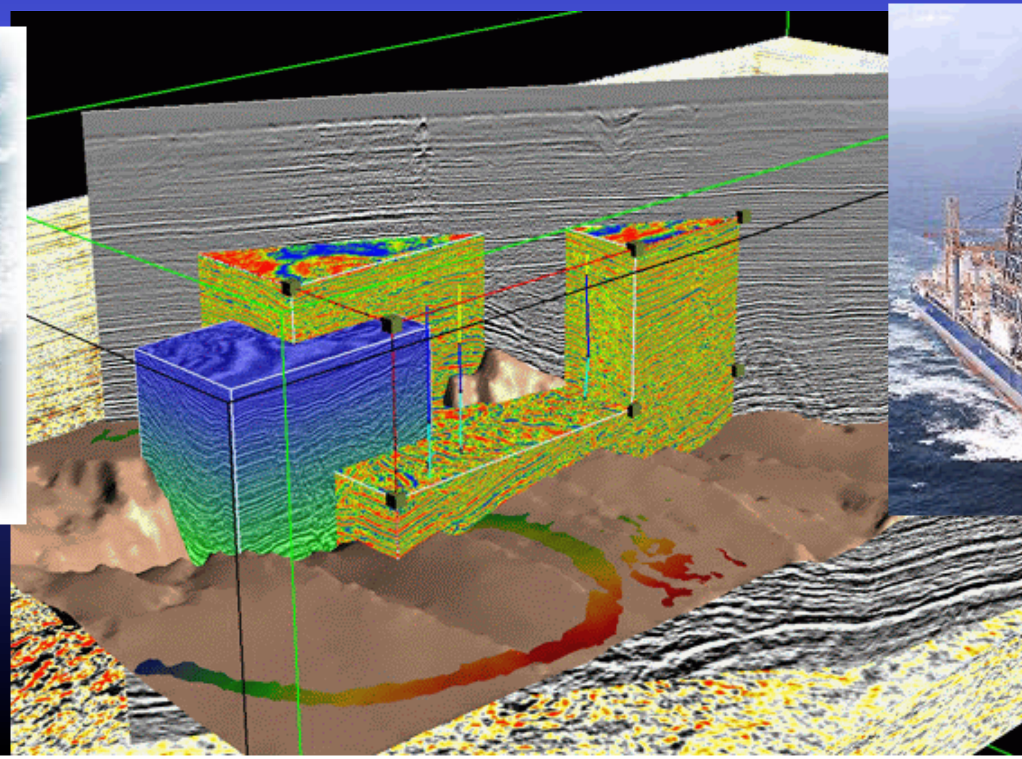
A Look Ahead

- I proposed but a few potential applications; the range of possible investigative projects is immense and new research is almost certain to bring surprises and more than a few breakthroughs.
- However, benefits will be limited without integration with other geophysical methods and broad access to data by geoscientists with different interests and specializations.
- The International Ocean Drilling Program, which provides essential ground truthing for the modern geological paradigm, is in great need of a year-round, reliable and cheaper alternative to contracting industry 3D seismic programs for project definition and drillhole guiding.
- The oil industry can be counted on to provide some access to proprietary data in areas of lesser exploration interest, but 21st century geoscience will benefit greatly from permanent access to a US publicly funded 3D seismic vessel.
- With dedicated operators and committed research community, the academic use of the 3D seismic method will considerably improve our knowledge of the earth's crust and advance understanding of our evolving planet.

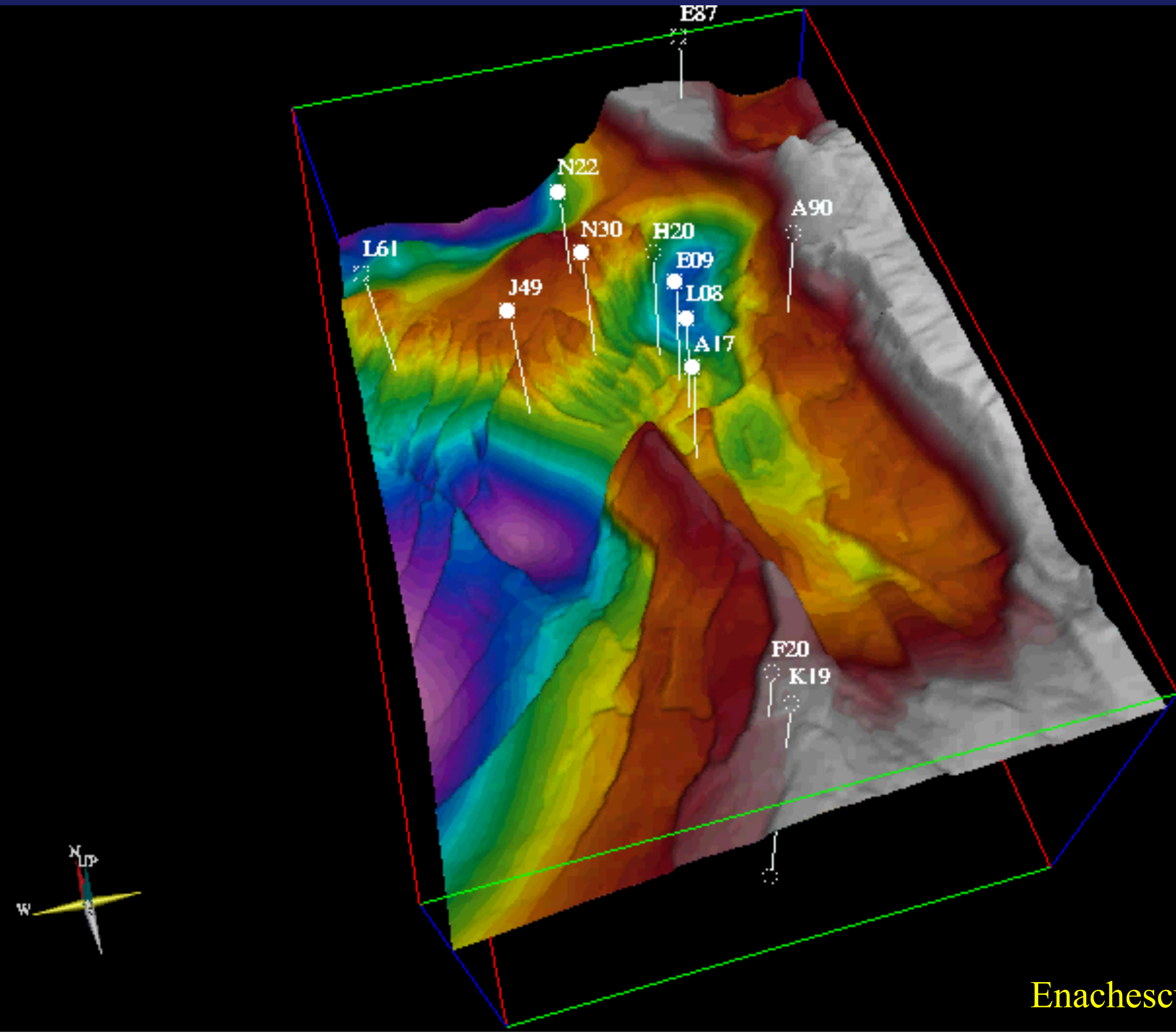
Summary

3D Seismic Reflection is the favorite method for oil and gas prospecting as it gives us a clear image of the subsurface prior to drilling and it helps reduce the inherent risk of exploration

It should open a new era in marine academic research!



White Rose oil and gas field (Atlantic Canada) 3D diagram 40 ×20Km²



Enachescu et al., 2002

During seismic data recording:

- No harm was done to large marine mammals, birds, fish stock or crustaceans
- No damage to environment or people
- No cultural impact on remote communities, aboriginal traditions or minorities

Memorial University of Newfoundland

EnCana

Thank you for attention!

PPSC