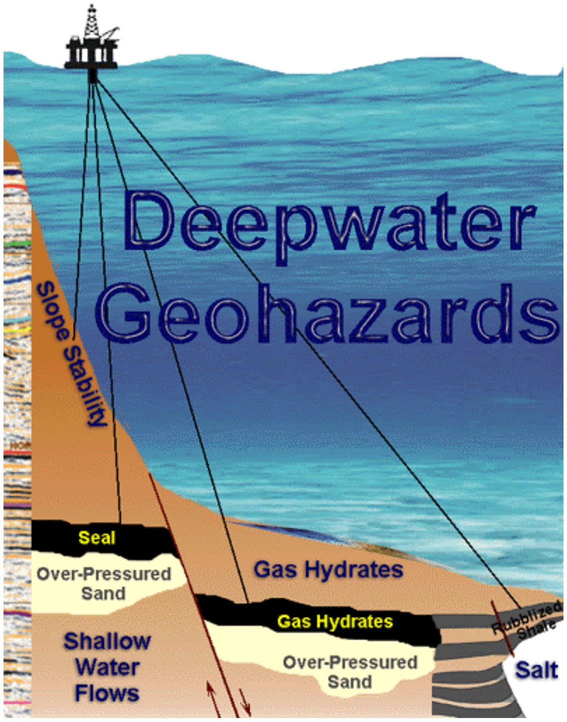


ERCH
Energy Research Clearing House

Drilling Engineering Association (DEA)

&

Minerals Management Service

Presents

Deepwater Geohazards Workshop

"Reviewing Technology Advancements
And Identifying Future Challenges"

April 3-4, 2001

Del Lago Conference Center
600 Del Lago Blvd.
Montgomery, Texas 77356

INTRODUCTION

Deepwater activity in the Gulf of Mexico and other areas around the world has increased dramatically as a result of improved 3D seismic data, key deepwater discoveries, recognition of high deepwater production rates, evolution of deepwater exploration and development technology, and the OCS Deep Water Royalty Relief Act (DWRR). The increase in activity is accompanied by corresponding increase in geohazard occurrences.

The **Energy Research Clearing House (ERCH)**, the **Drilling Engineering Association (DEA)**, and the **Minerals Management Service (MMS)** hosted this Deepwater Geohazard Workshop to describe the state of geohazard technology today and to identify future challenges that should be addressed by industry. The workshop focused on issues related to the identification, mitigation and prevention of **Shallow Water Flows**, **Gas Hydrates**, and **Sub-salt Formations**.

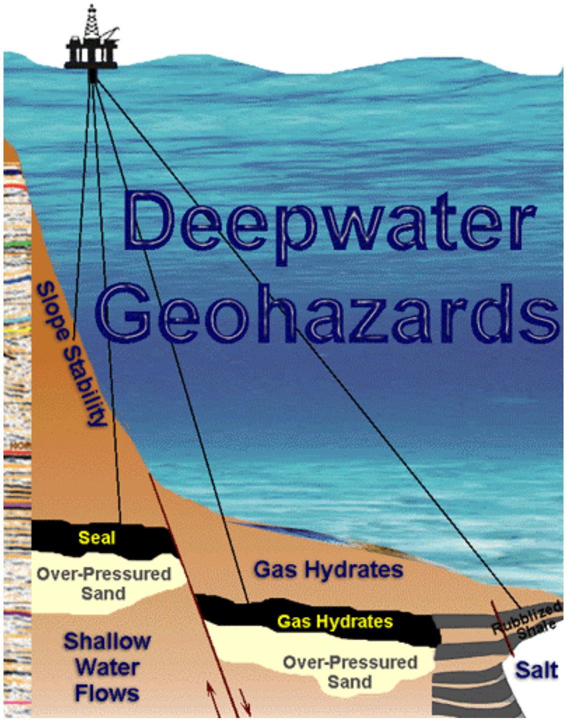
The Deepwater Geohazards Workshop set these **goals**:

- Present how industry currently addresses deepwater geohazard occurrences
- Describe new technology developments related to these hazards
- Identify and prioritize areas not being addressed currently
- Formulate joint industry projects

CD Contents and Navigation

All presentations and Q&A session summaries are available on this CD. Use the interactive Table of Contents at the left of the screen to click your way to a particular document.

NOTE: "Hazard Avoidance in Gas Hydrate Bearing Sediments" (Ruppel) opens as an independent file.



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BLUE TEXT IS LINKED TO PRESENTATION

AGENDA

Monday, April 2, 2001		
TIME	**TOPIC**	
6:00 - 9:00 PM	Speakers/Organizers Dinner (Christy's restaurant located in conference center)	All speakers and organizers
Tuesday, April 3, 2001		
TIME	**TOPIC**	**SPEAKERS**
7:00 AM	Registration & Breakfast	
7:20 AM	Welcome and Introduction	Mike Utt - Unocal & Roger Entralgo - ERCH
7:40 AM	*Keynote Address*	Andrew W. Hill - BP
	SWF SESSION	
8:00 AM	Introductory Remarks	Jim Niemann - Chevron
8:15 AM	*Update on Shallow Water Flow Database*	Roger Entralgo - ERCH
8:30 AM	*ODP Proposal on Overpressure and Fluid Flow Processes in the Deepwater Gulf of Mexico: Slope Stability, Seeps, and Shallow Water Flow*	Peter Flemings - Penn State University
9:00 AM	*Experimentally Derived Diagnostics for Detecting Anomalous Pore Pressure*	Joel Walls - Rock Solid Images & Jack Dvorkin - Stanford Rock Physics Laboratory
9:30 AM	*Quantification of Shallow Water Flow Zones Using Pre-stack Inversion of Seismic Data*	Nader Dutta - WesternGeco

10:00 AM	**BREAK**	
10:30 AM	*Evaluation and Successful Drilling of a Shallow Water Flow Sand, Mississippi Canyon Block 727 #1, Poseidon Prospect*	Jim Niemann - Chevron
11:00 AM	*Modeling of Casing Collapse Due to Shallow Water Flow Wells*	Michael McLean - BP
11:30 AM	*Shallow Water Flow Evaluation of the Holstein Field*	Kathleen Horkowitz - BP
12:00 PM	*Discussion Period*	Session Chairmen & Audience
12:30 PM	**LUNCH**	
HYDRATES SESSION		
1:30 PM	Introductory Remarks	Carole Fleming - Chevron
1:40 PM	*Natural Gas Hydrates R&D in the Gulf of Mexico*	Craig Lewis - Chevron
2:00 PM	*Gas Hydrate Research at the DOE National Laboratories*	Lorie Langley - Oak Ridge National Laboratory
2:30 PM	*Hazard Avoidance in Gas Hydrate-Bearing Sediments:* Calibrating Field Observations and Applying Predictive Numerical Models	Carolyn Ruppel - Georgia Institute of Technology
3:00 PM	*Gas Hydrate: Resource or Hazard?*	Roger Sassen - Texas A&M University
3:30 PM	**BREAK**	
4:00 PM	*Seafloor Stability, Hydrates and Sediments*	Dendy Sloan - Colorado School of Mines
4:30 PM	*The Application of High -Resolution, Deep -Tow Seismology to Deepwater Geohazard Studies*	Joe Gettrust - Naval Research Laboratory
5:00 PM	*Seismic Facies Analysis Applied to Sea Floor Gas Hydrates - A Case Study Offshore Gulf of Mexico*	Jesse Hunt & Bill Shedd - Minerals Management Service (MMS)
5:30 PM	*Discussion Period*	Session Chairmen & Audience
6:00 PM	**MEETING ADJOURN**	
6:30 – 8:30 PM	**EXHIBITION / FOOD & BEVERAGES**	

Wednesday, April 4, 2001		
TIME	**TOPIC**	**SPEAKERS**
7:15 AM	Registration & Breakfast	
7:45 AM	Welcome & Introduction	Mike Utt - Unocal & Roger Entralgo - ERCH
	SUB-SALT SESSION	
8:00 AM	*Sub-salt Well Geo-Hazards*	Ron Sweatman - Halliburton
8:30 AM	*Sub-salt Drilling Challenges and Solutions*	Tom Bowles - BP
9:00 AM	*Potential Problems Associated with Drilling Salt and Sub-salt*	John Karpa - Chevron
9:30 AM	*VSP Inversion Techniques for Sub-Salt Pore Pressure Prediction - Atlas Prospect (MC714)*	Matthew Czerniak - Texaco
10:00 AM	**BREAK**	
10:30 AM	*Salt/Rubble Zone Drilling Fluid Challenges/Solutions*	Mike Johnson - INTEQ
11:00 AM	*Analysis of Salt Creep in a Deepwater GOM Well and Preventing Salt-induced Casing Damage*	Colby Ballew - Halliburton
11:30 AM	*Discussion Period*	Session Chairmen & Audience
12:00 PM	**LUNCH**	
	MMS SESSION	
1:00 PM	*MMS Perspectives on Deepwater Geohazards and Recent Industry Drilling Results*	Mike Smith - Minerals Management Service (MMS)
1:30 PM	Discussion period to identify topic areas not currently being addressed in all three topic sessions	Session Chairmen, MMS, & Audience
3:00 PM	**MEETING ADJOURN**	
Thursday, April 5, 2001		
TIME	**TOPIC**	
8:00 AM	Golf - Tee Times for Del Lago Golf Course	Slots still available

The Impact of Deepwater Geohazards on Business Delivery

Andrew W. Hill
Global Geophysical Site Investigation
Network Leader
BP Exploration, Houston

LINK TO PRESENTATION

In 1989 John Browne set BP Exploration out to find and develop giant oil and gas resources in the 300 unexplored basins of the world.

From this moment BP's new exploration business focus moved heavily towards the unexplored deepwater areas of the world. Central to this was the company's early success in the Gulf of Mexico.

This process almost immediately brought a change in the importance of Geohazards to business delivery.

The new BP, a vastly different company to that of 1989, is now faced with Geohazards complexity in almost every deep water arena that we operate in, and at a level that we could have hardly begun to consider back in 1989. However one thing remains true: the learning we derive from the Deepwater Gulf of Mexico remains central to our success elsewhere.

For a company that has changed so much, in such a short time, and with such strong organic growth aspirations, the full integration of the various strands of Geohazards work, and the effective transfer of learnings from one operational arena to another is an essential pre-requisite for safety, operational integrity, and production growth.

At BP, the potential adverse impact of Geohazards on our business goals is being mitigated through close teamwork between different disciplines, aggressive use of new technologies, and proactive use of internal and external networks to ensure transfer of best practices across the organization.

Andrew W. Hill
Geohazards Team Leader,
BP Exploration, Houston

Andy Hill's first degree was a B.Sc. (Hons) in Maritime Studies from the University of Wales. After a brief period working for a marine exploration seismic company, he went on to take a M.Sc. in Marine Geology and Geophysics at University College London.

In 1982, he joined Geoteam UK Ltd., now part of the Fugro group, as a Geophysicist working on acquisition, processing and interpretation of, primarily, multi-channel data from North Sea Projects.

In 1984, he transferred to A/S Geoteam in Oslo, Norway, where he worked as Senior Processor in the seismic processing group.

In 1988, he was recruited by the then British Petroleum and worked on European and International projects out of London, Glasgow and Aberdeen, until 1996 when he transferred to Houston.

Since then, he has been first hand witness to the transformation of BP's business in the Gulf of Mexico and globally with the integration of the interests of Amoco, Arco and Vastar.

He is now Geohazards Team Leader for BP's operations in the GoM, and Global Geophysical Site Investigation Network Leader.

In 2000, he was awarded a BP Technology Innovation Award for the leading the effort to introduce AUV survey systems to the industry.

The Impact of Deepwater Geohazards on Business Delivery

Andrew W. Hill
Geohazards Team Leader
BP Exploration, Houston

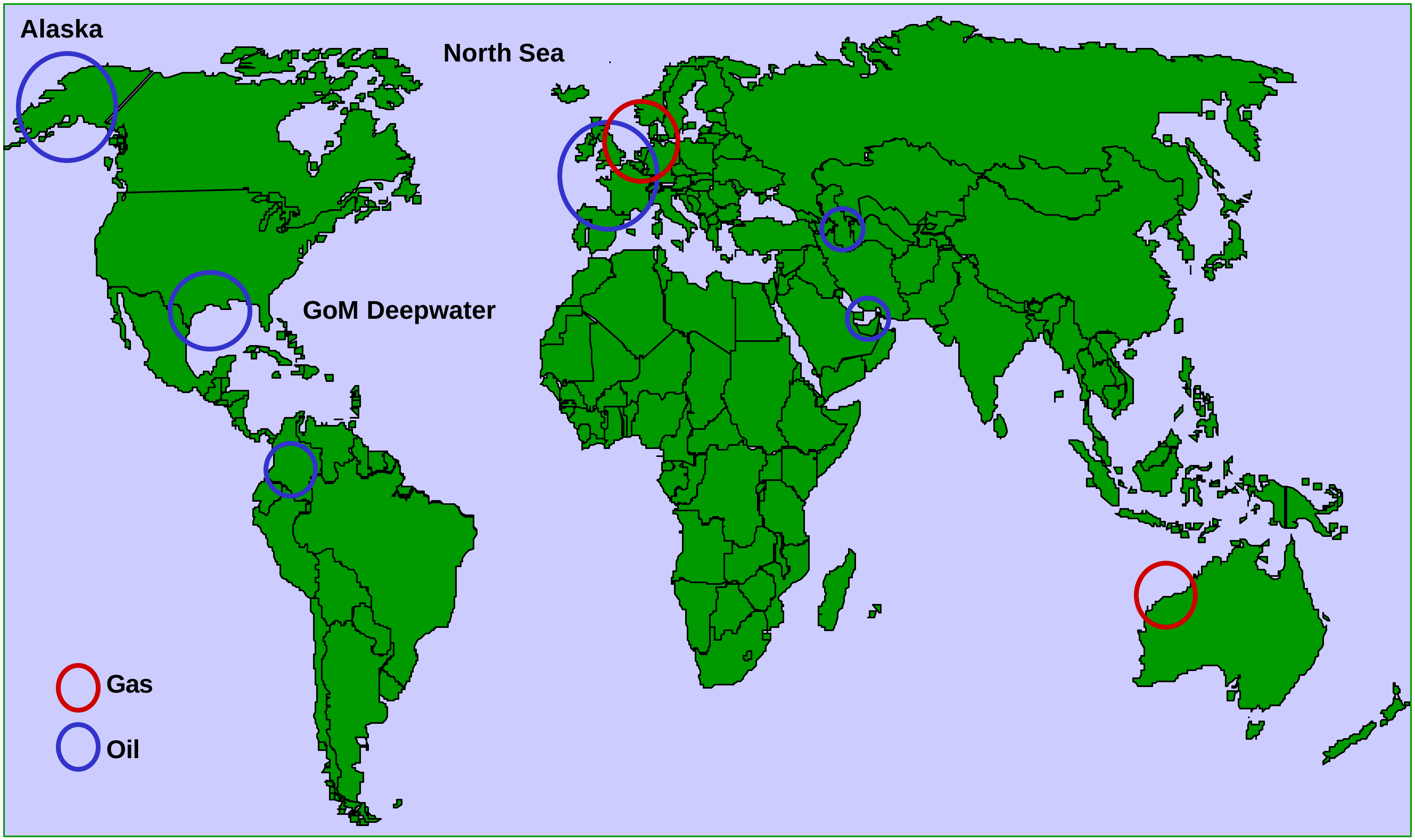
ERCH, DEA and MMS:
Deepwater Geohazards Workshop
Del Lago, April 2001

Introduction

- The Ever Increasing Deep Water Profile
  - 1989 - The Way Ahead

Deepwater Geohazards Workshop

1998: BP Major Centers



Introduction

- The Increasing Deep Water Profile
  - 1989 - The Way Ahead
  - 1998 – Start of the Mergers
  - 2001 – A New Company
  - Resulting Deepwater Profile

Deepwater Geohazards Workshop

BP 2001

Deepwater Geohazards Workshop

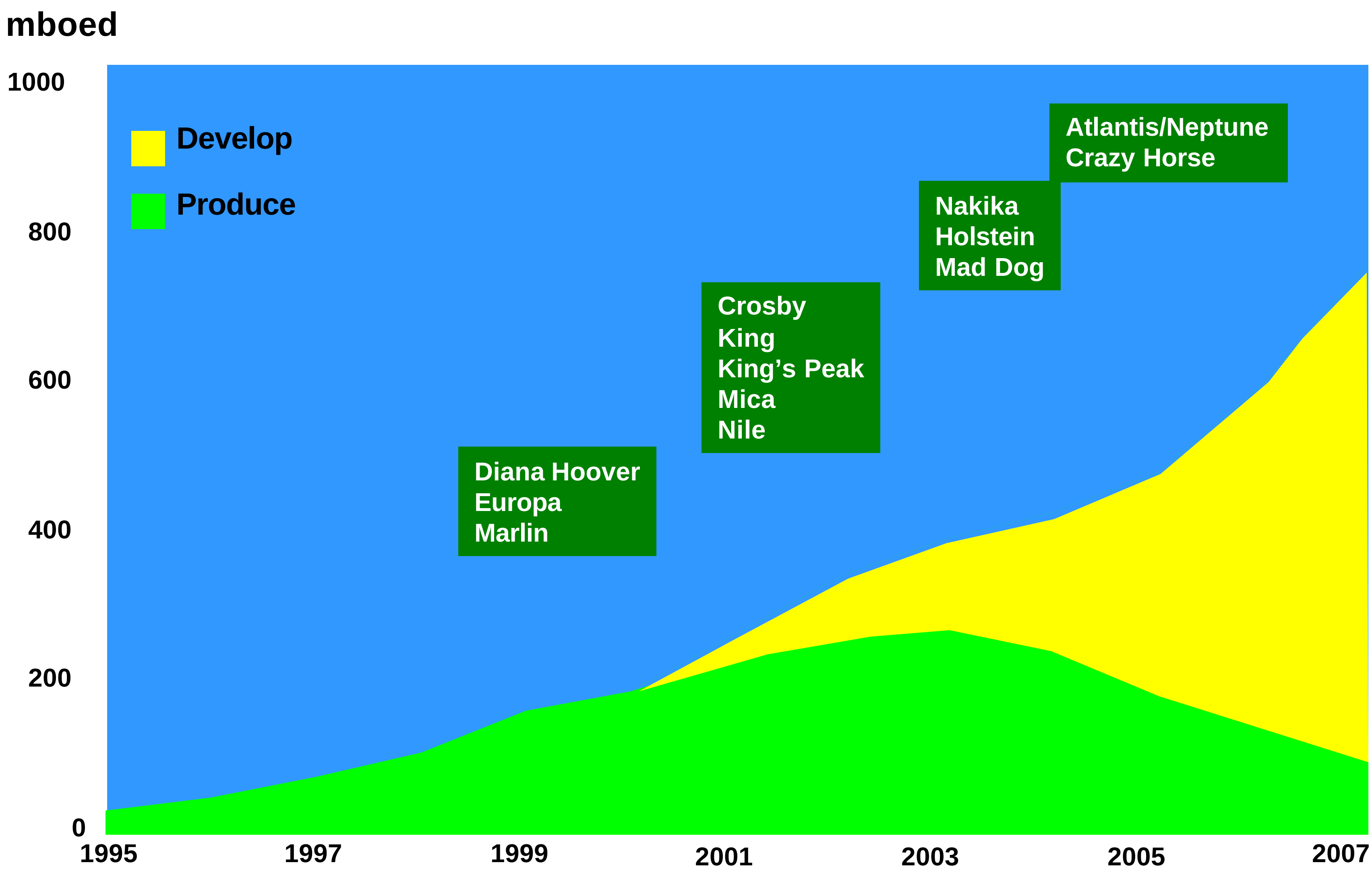
BP: Deep Water

BP: Gulf of Mexico Status

- Discovered 3.5 bn barrels
- 9 fields on stream
- 11 projects underway
- Production of 350,000 b/d by 2003

Deepwater Geohazards Workshop

BP: Gulf of Mexico Deep Water Production

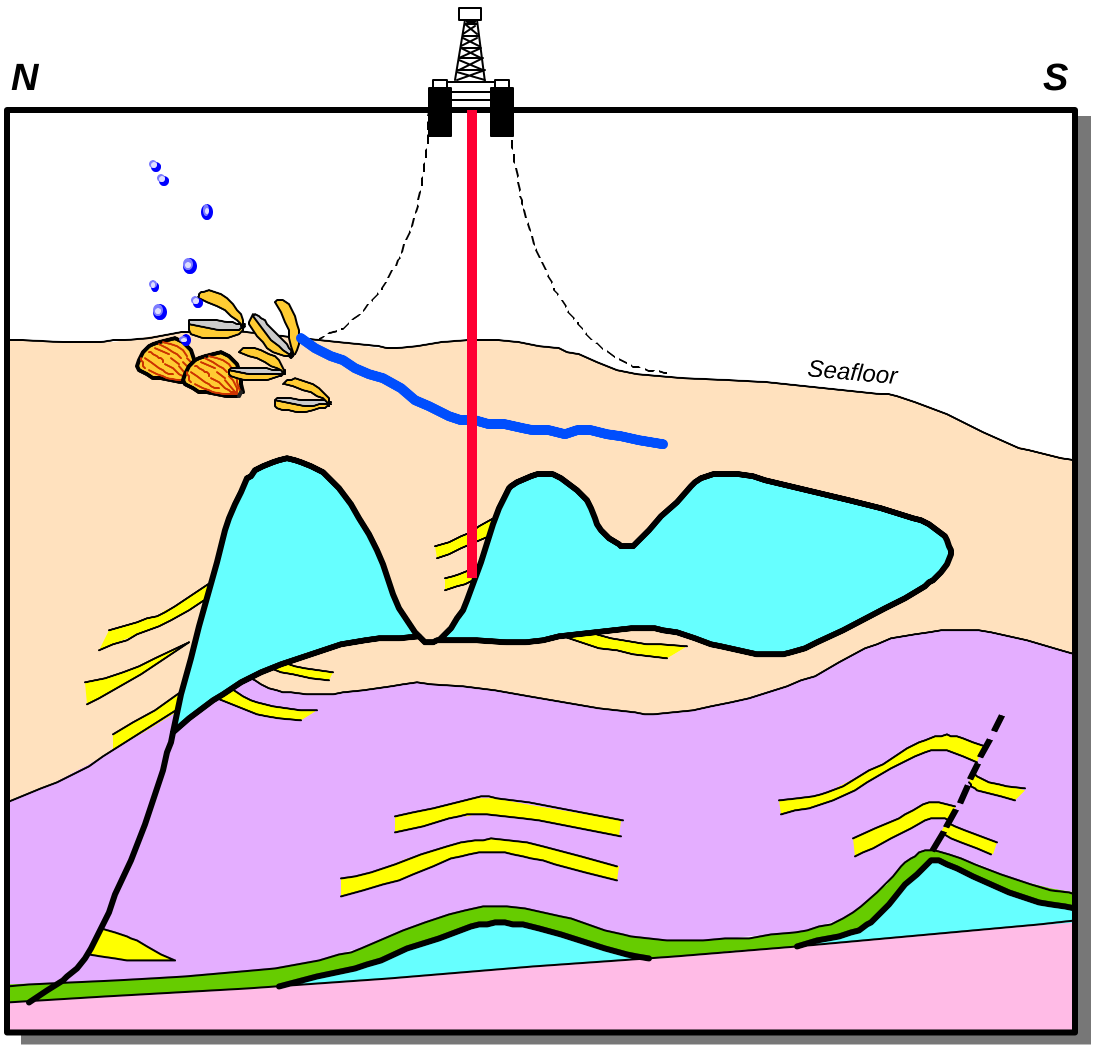


Challenging Times in Deepwater GoM

- ***Total Activity High***
- ***Geohazards***
  - » ***Widespread***
  - » ***Diverse***
  - » ***Complex***

Deepwater Geohazards Workshop

Deepwater GoM Concerns



- Hurricanes
- Loop Currents
- 6000 ft + water depth

- Unstable Seabed
- Chemosynthetics
- Shallow Flows

- Pore Pressure

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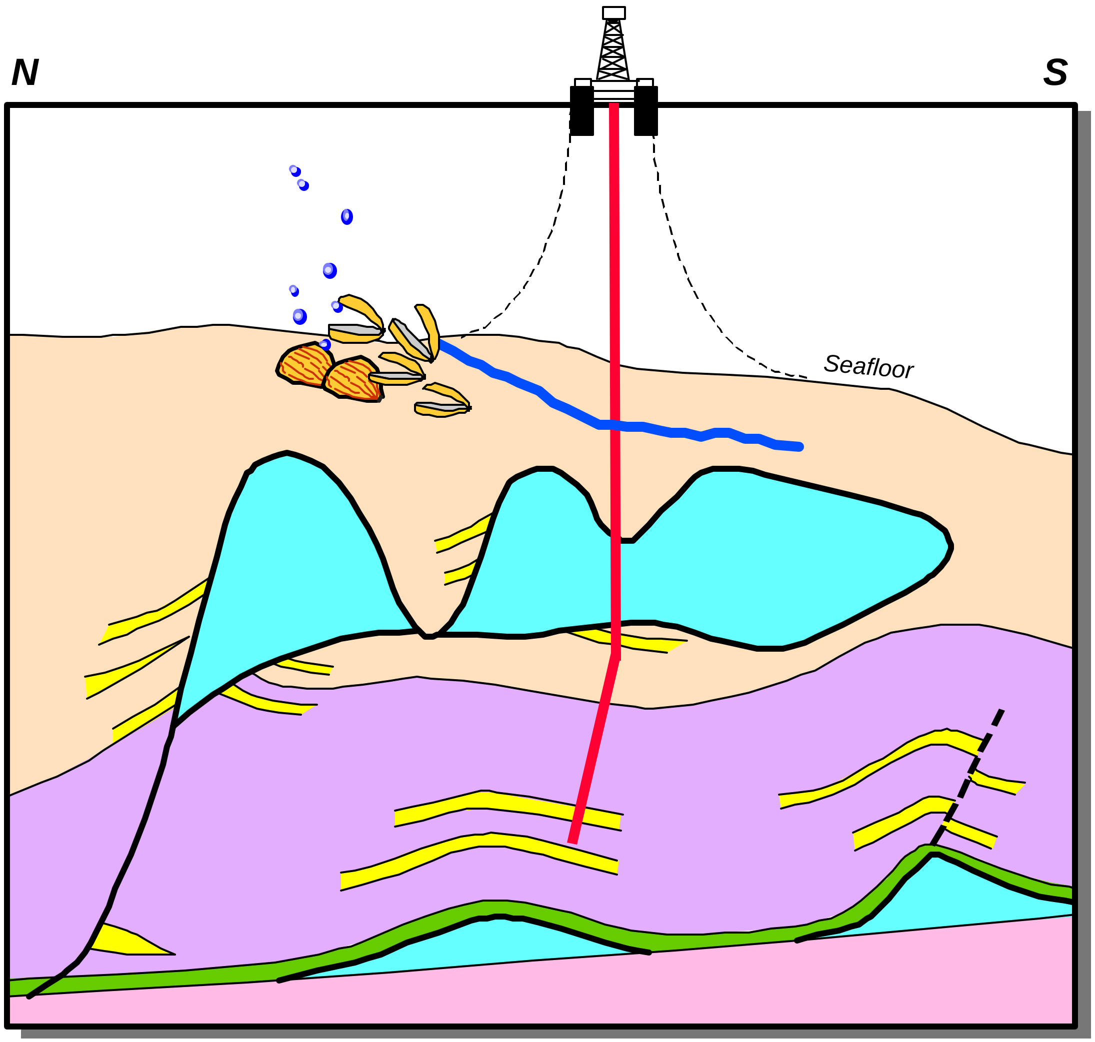
Deepwater GoM Concerns: Now



- Hurricanes
- Loop Currents
- 6000 ft + water depth

- Unstable Seabed
- Chemosynthetics
- Shallow Flows

- Salt
- Pressured Rafts
- Subsalt

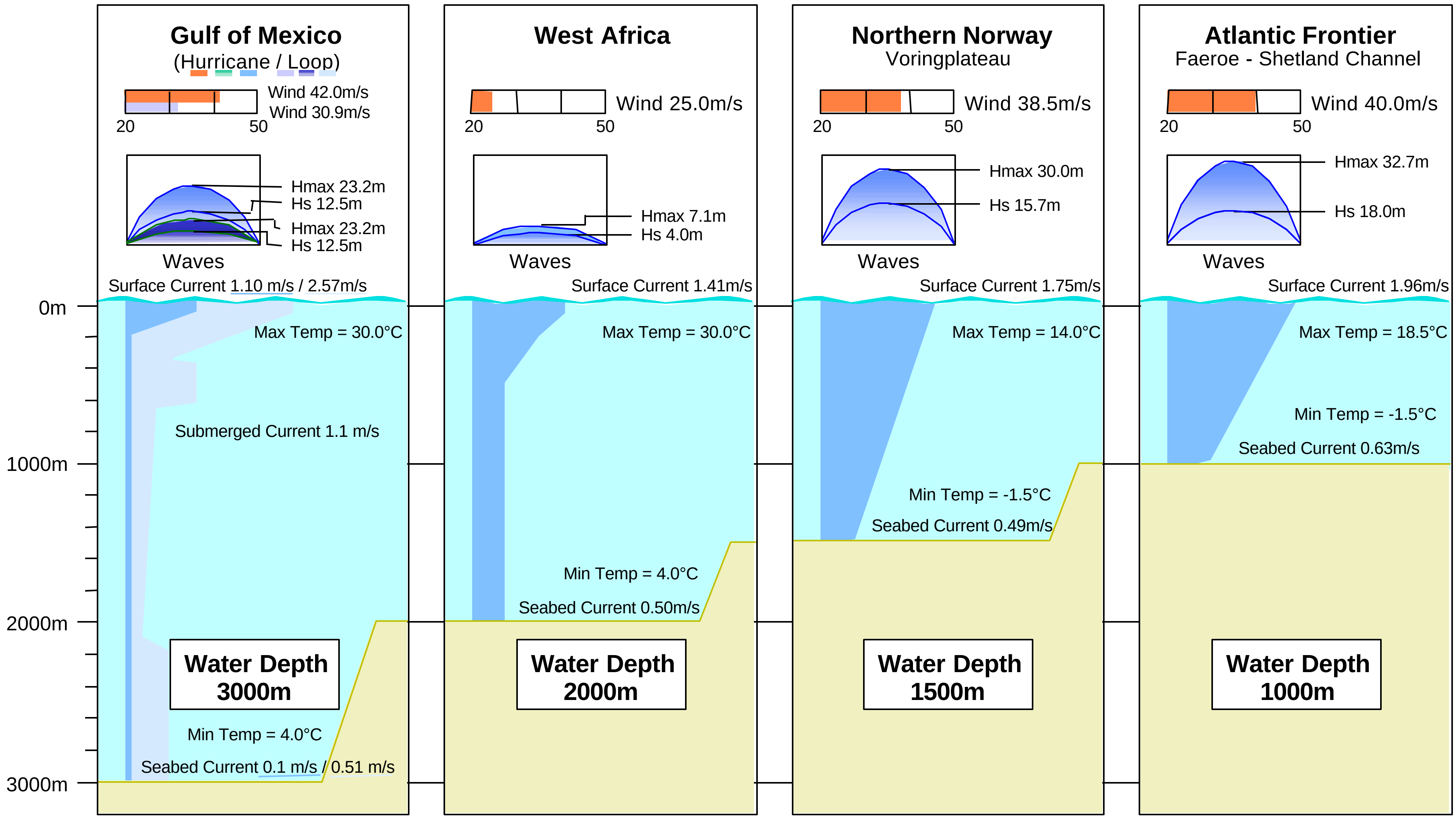
- Pore Pressure
- Deep, New Stratigraphy
- And much more besides…

Challenging Times

- ***Deepwater Total Activity is High***
- ***Business Delivery Requires:***
  - ***HSE Assurance***
  - ***Production Growth and Flow Assurance***
  - ***F, D, and L Cost Control***
- ***Geohazards faced ?***
  - **Widespread, Diverse, and Complex**
  - **Requires an Integrated Answer**

Deepwater Geohazards Workshop

Deepwater Design Parameters



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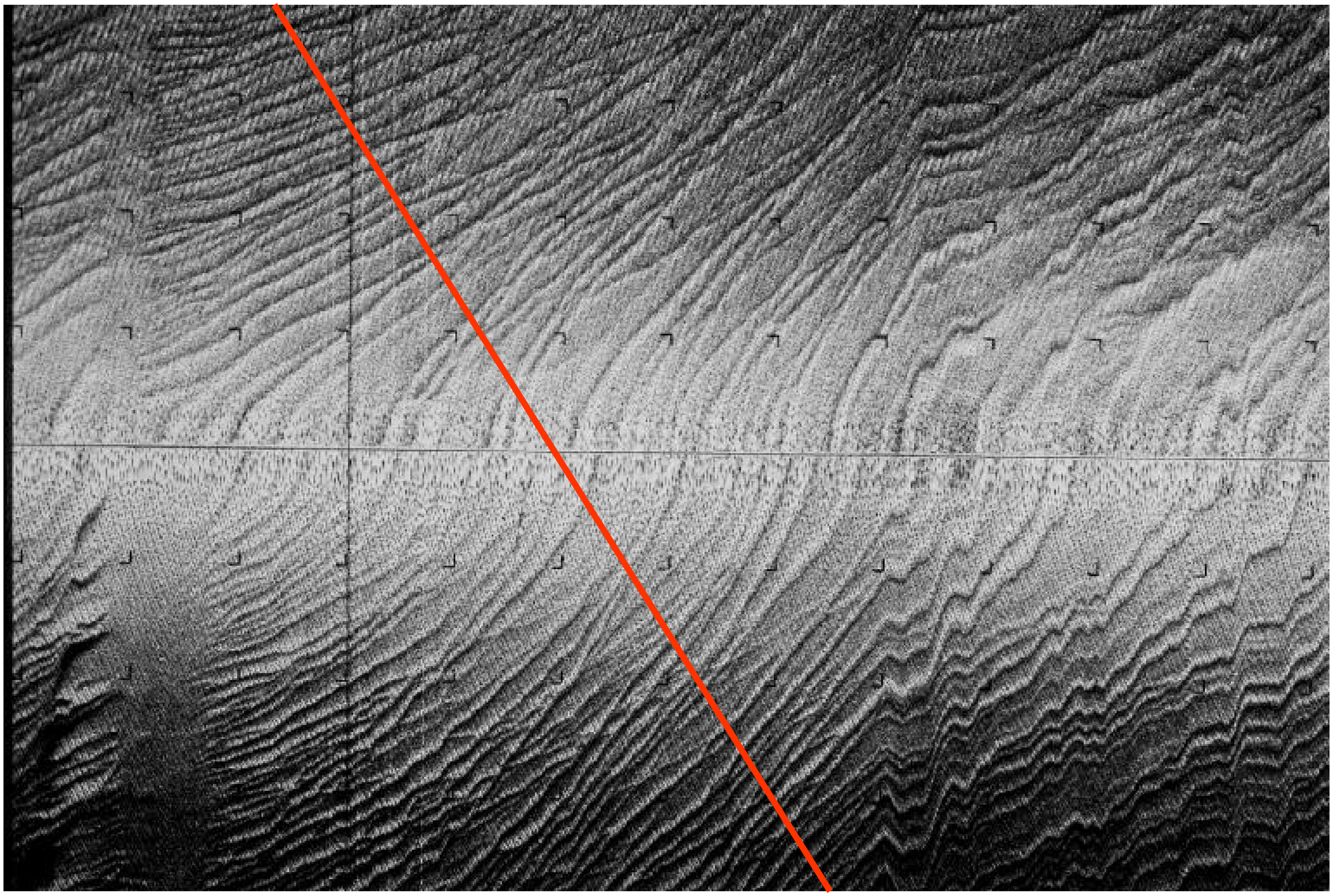
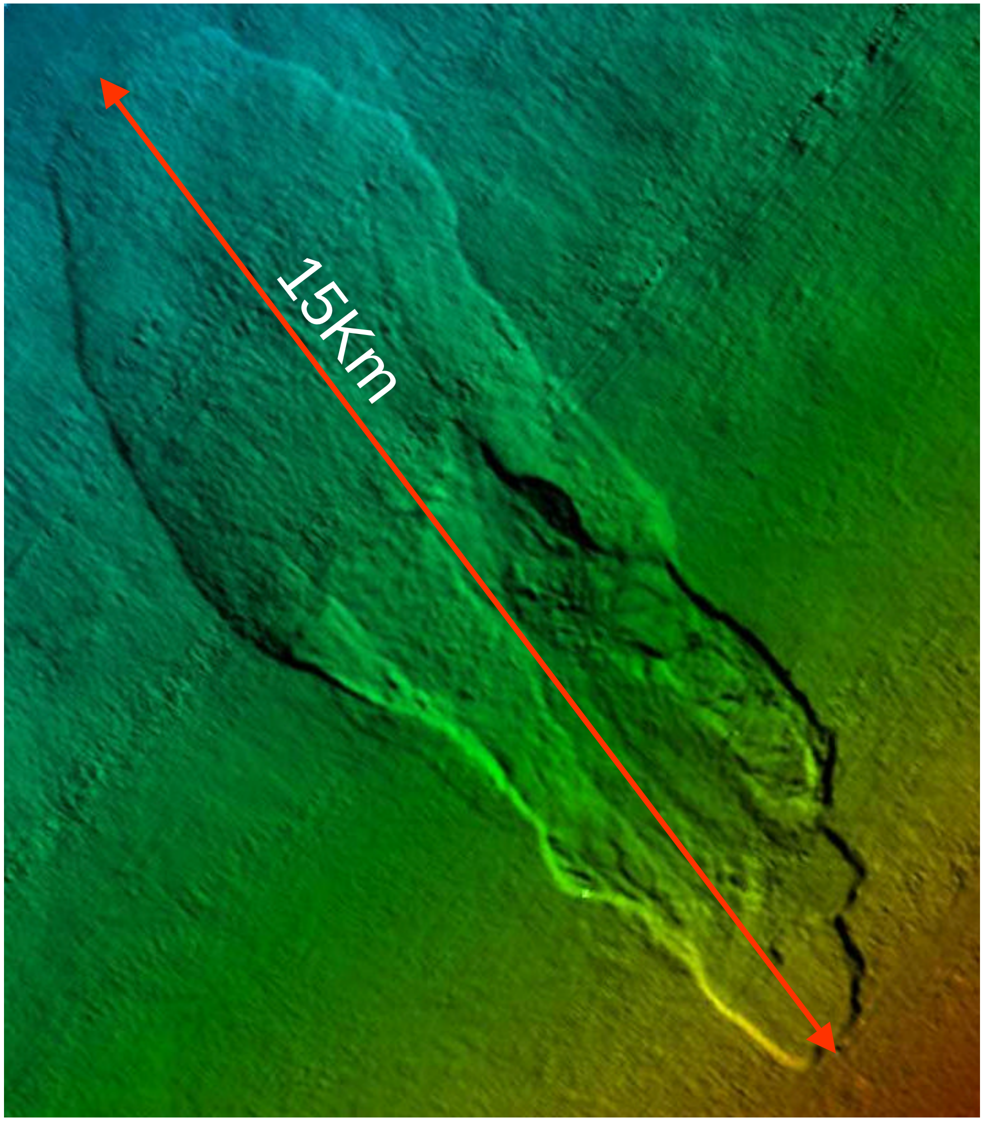
Gulf of Mexico - Furrows



Courtesy Texas A&M

Slope Instability



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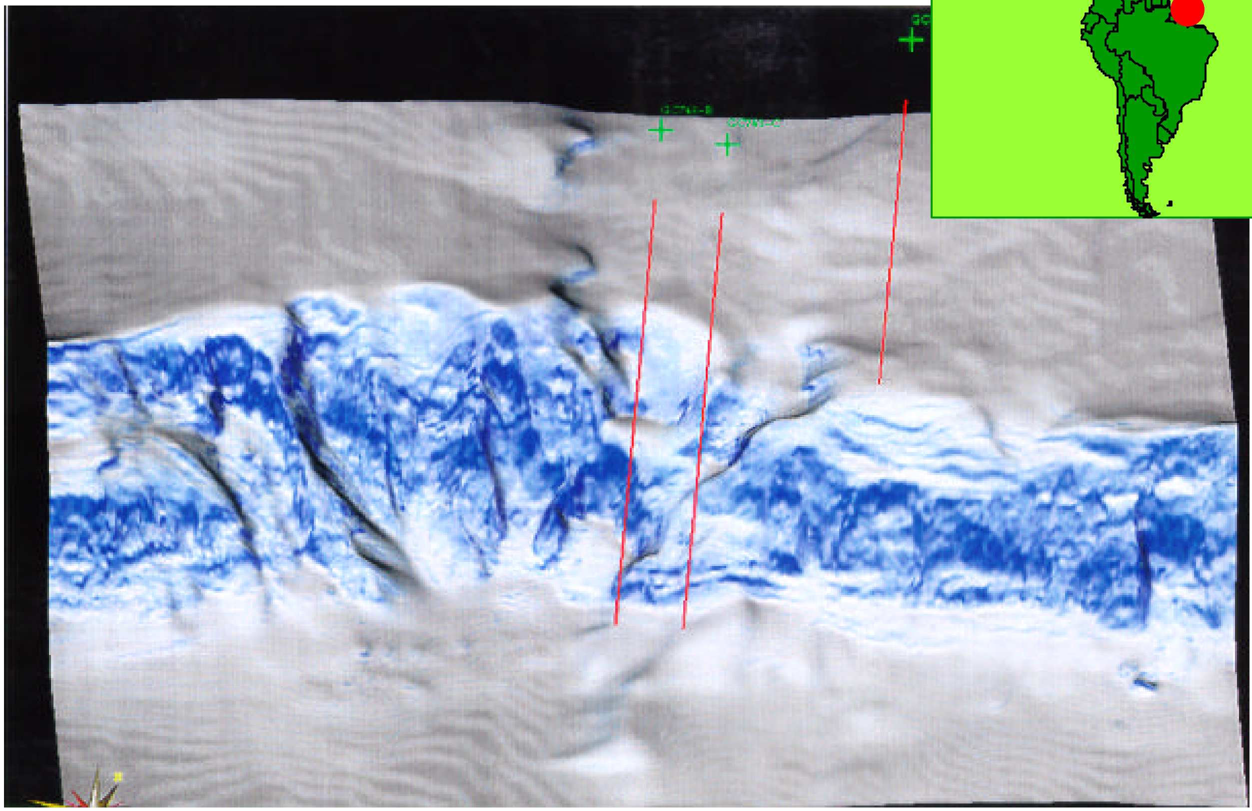
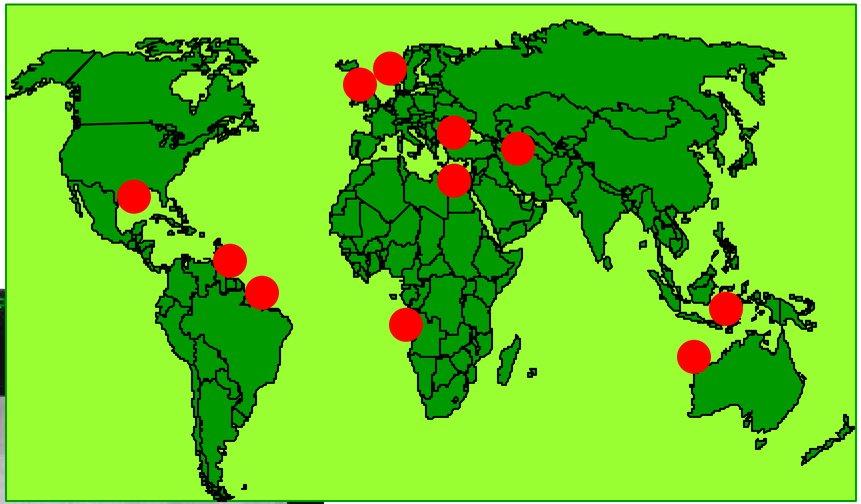
Slope Instability

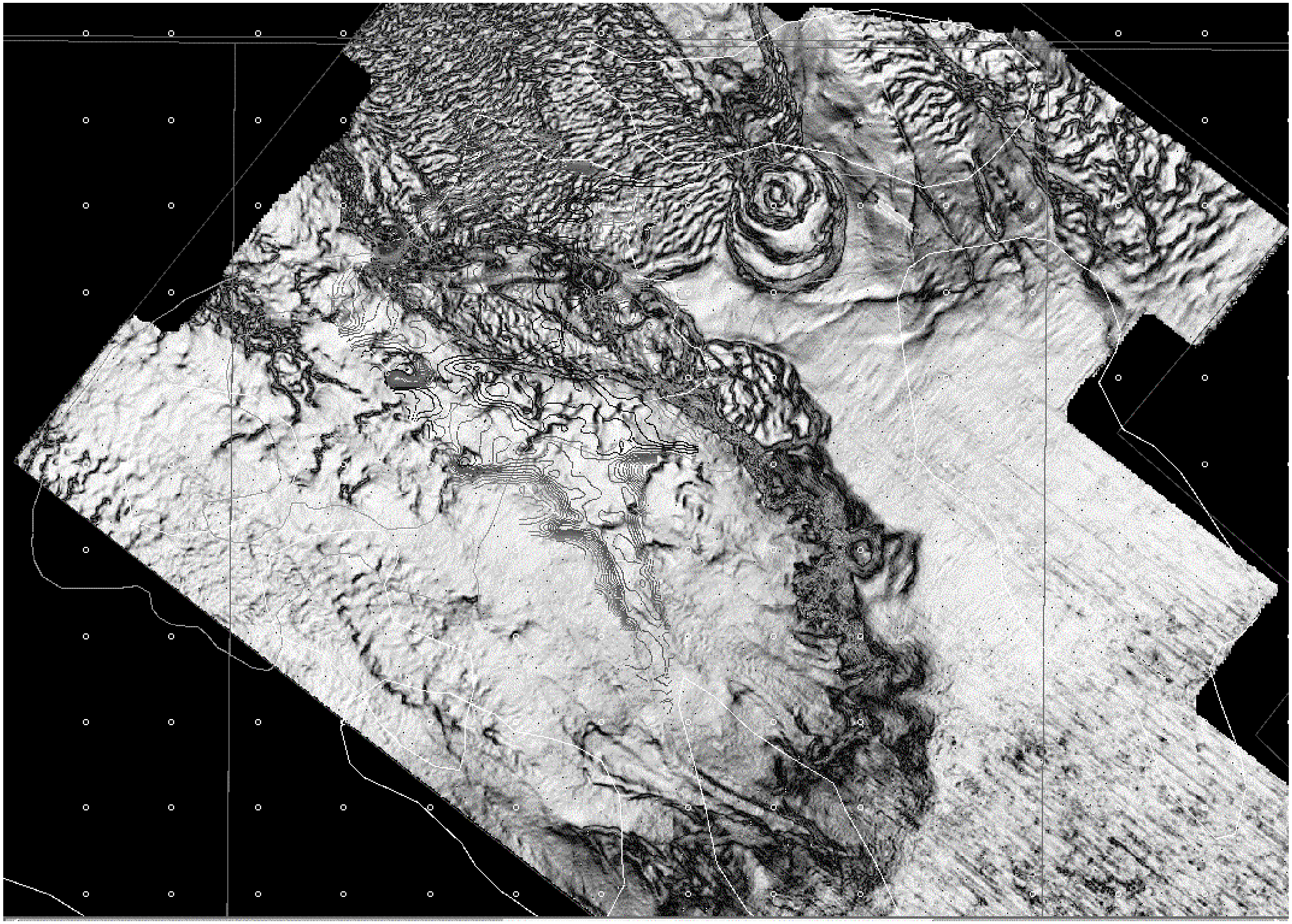




GoM Sigsbee Escarpment

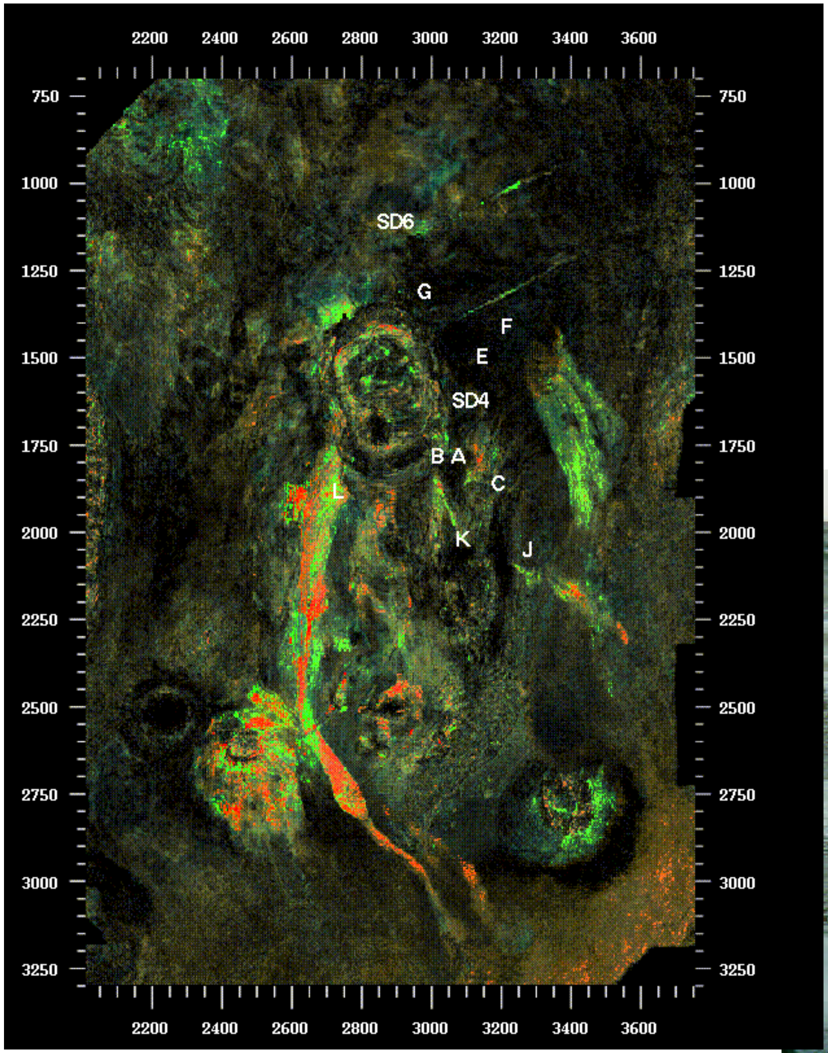
Deepwater Geohazards Workshop

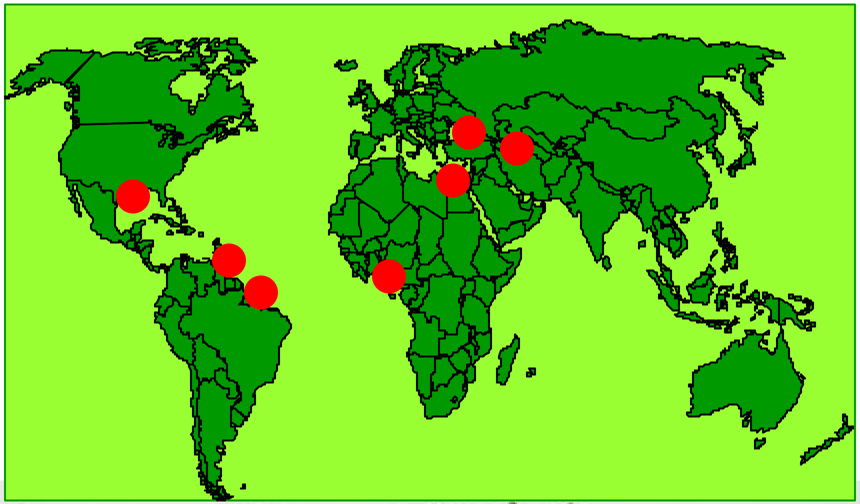
Slope Instability: Nile Delta



Deepwater Geohazards Workshop

Mud Volcanoes and GeoPressure





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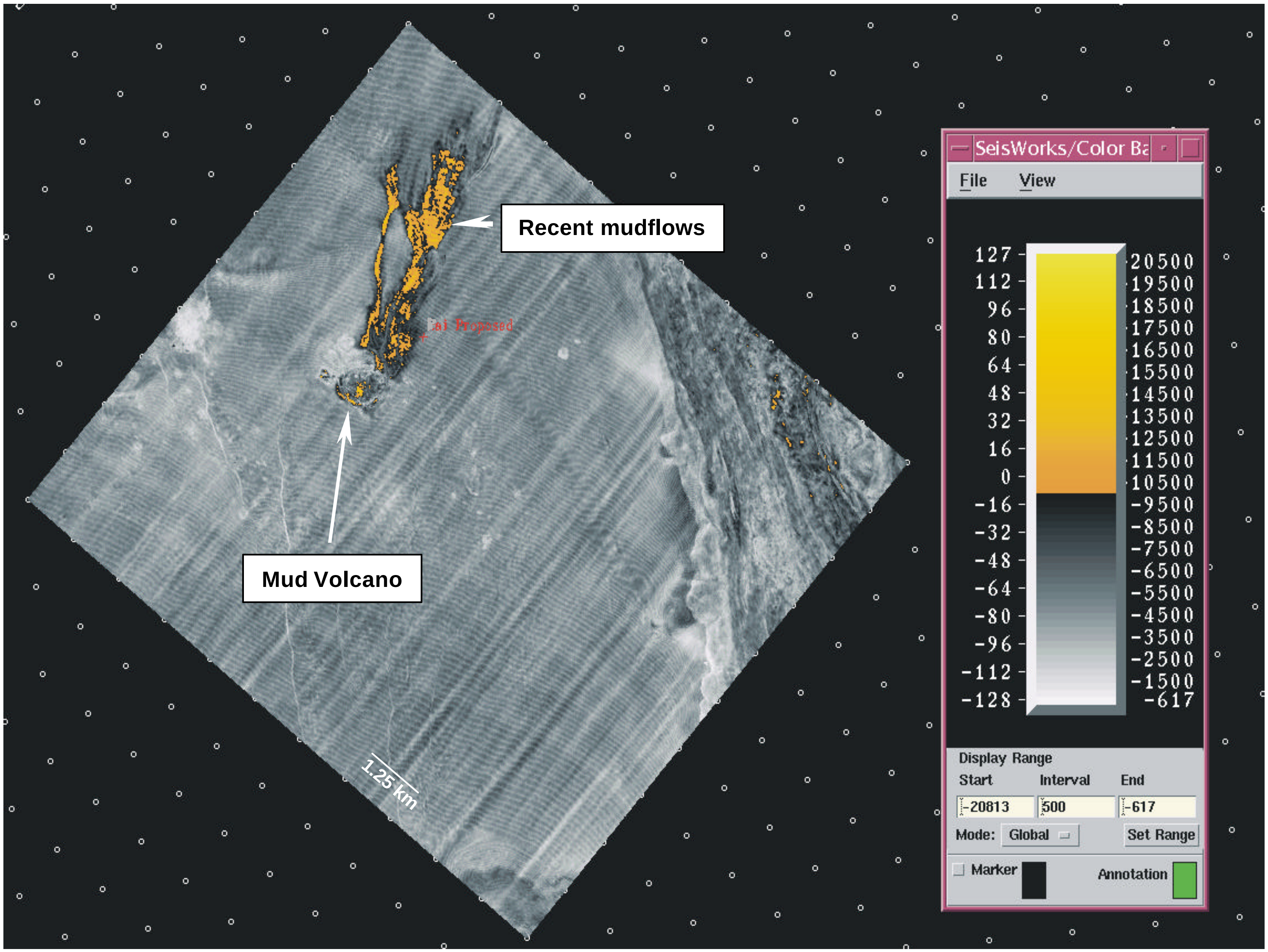
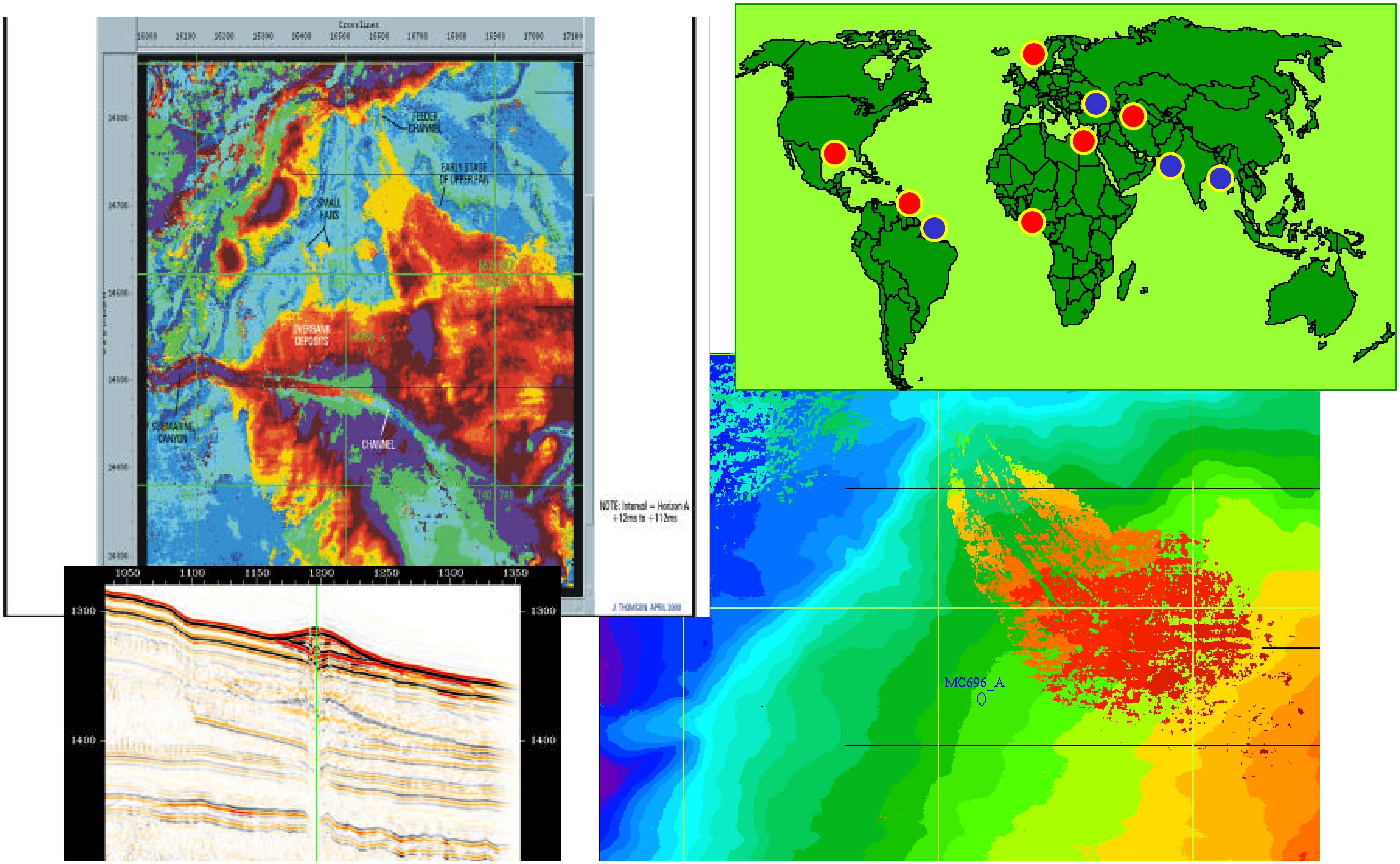
Deepwater Brazil



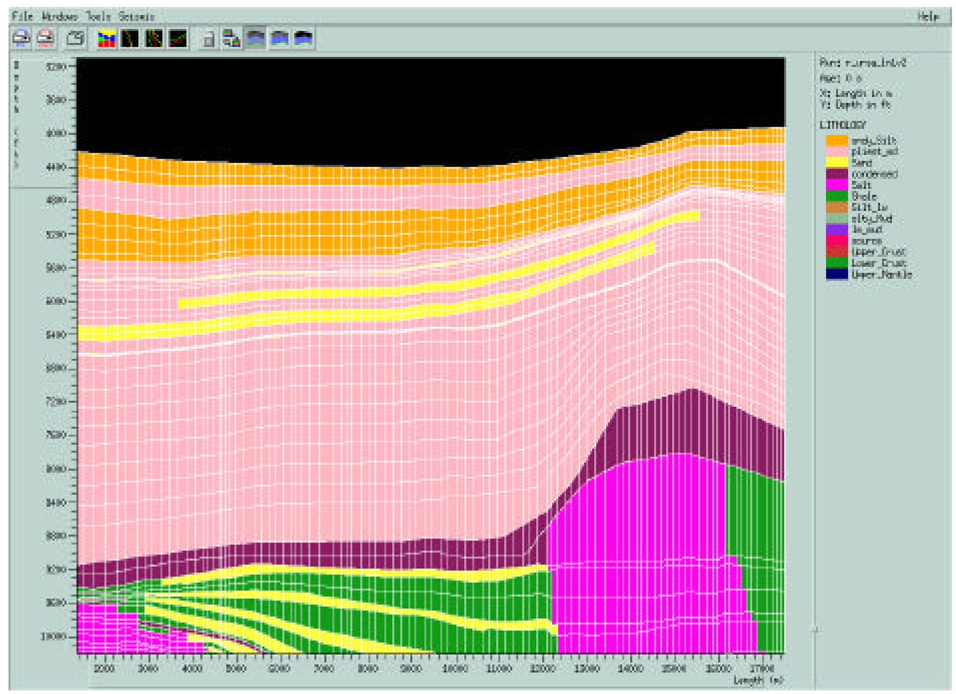
Deepwater Geohazards Workshop

Shallow Water Flow



SWF: Providing the Answer

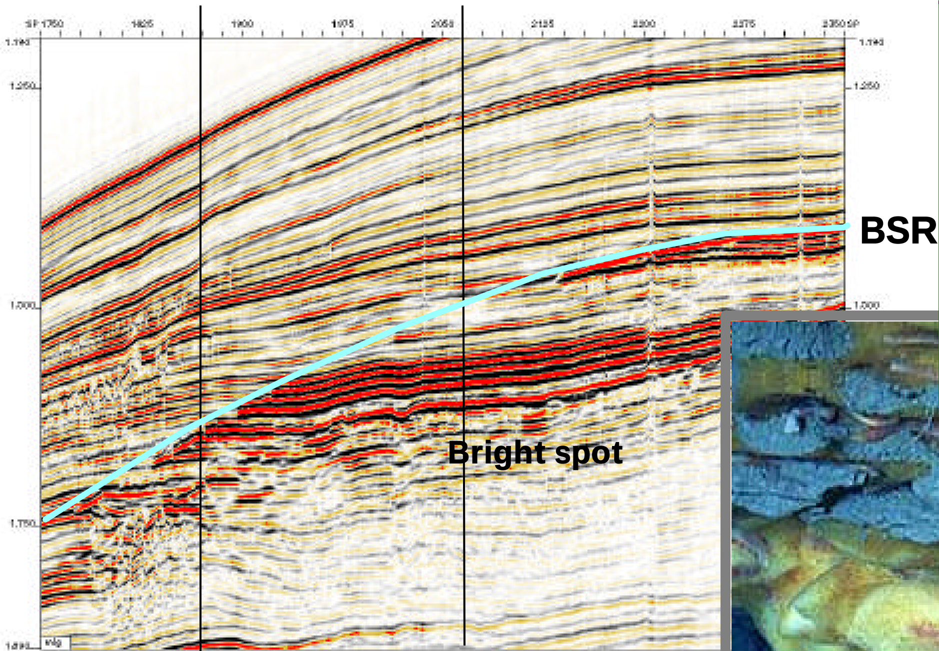
- **Internal:**
  - A Broad Integrated Approach
  - Multi-Disciplinary Teams
  - Life of Field
  - Shared Learning
- **External:**
  - Sponsoring
  - Encouraging
  - Sharing



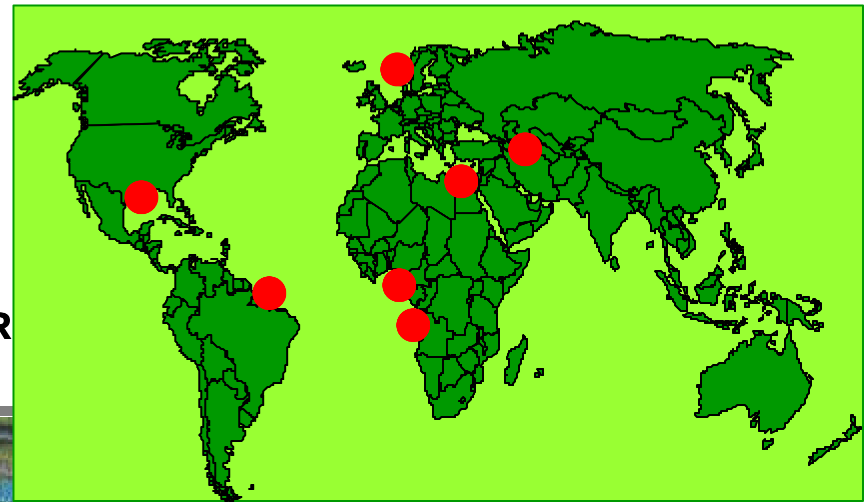
Basin Modeling of Shallow Flow Conditions

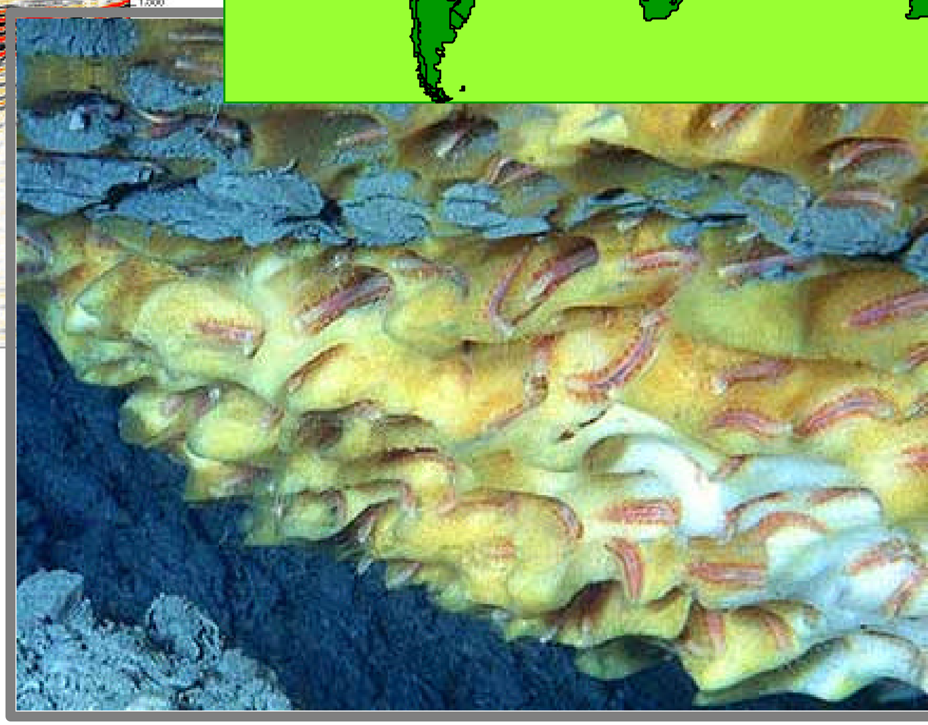
Deepwater Geohazards Workshop

Hydrates, Seabed Communities and….



Suspected BSR Mid Norway





Ice Worms
Deep Water Gulf of Mexico

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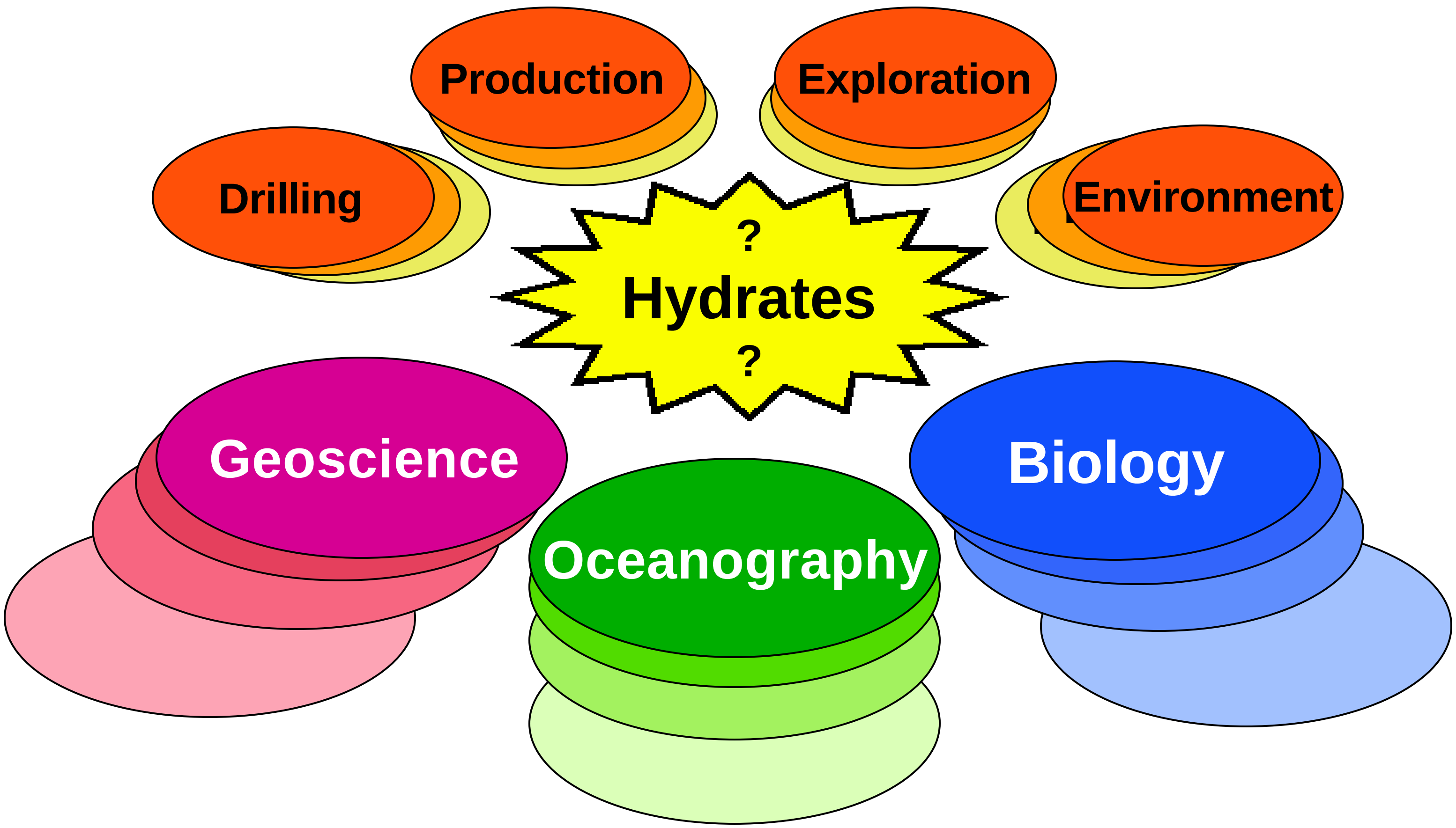
Linkages, Interplay of Impact



Geohazards: A Time of Challenge

- Given:
  - Operational Integrity is essential
  - The size of the Business Prize
  - The Complexity of the Challenge
- An Integrated Approach is a Necessity
- The Best Data are required…..

Delivering the Data:

- April Activity for BP in one GoM field:
  - Drilling Rig
  - Ocean Bottom Seismic Spread
  - 4C Seismic Spread
  - Geotechnical Deep Coring Spread
  - Geotechnical Shallow Coring Spread
  - HR3D Spread

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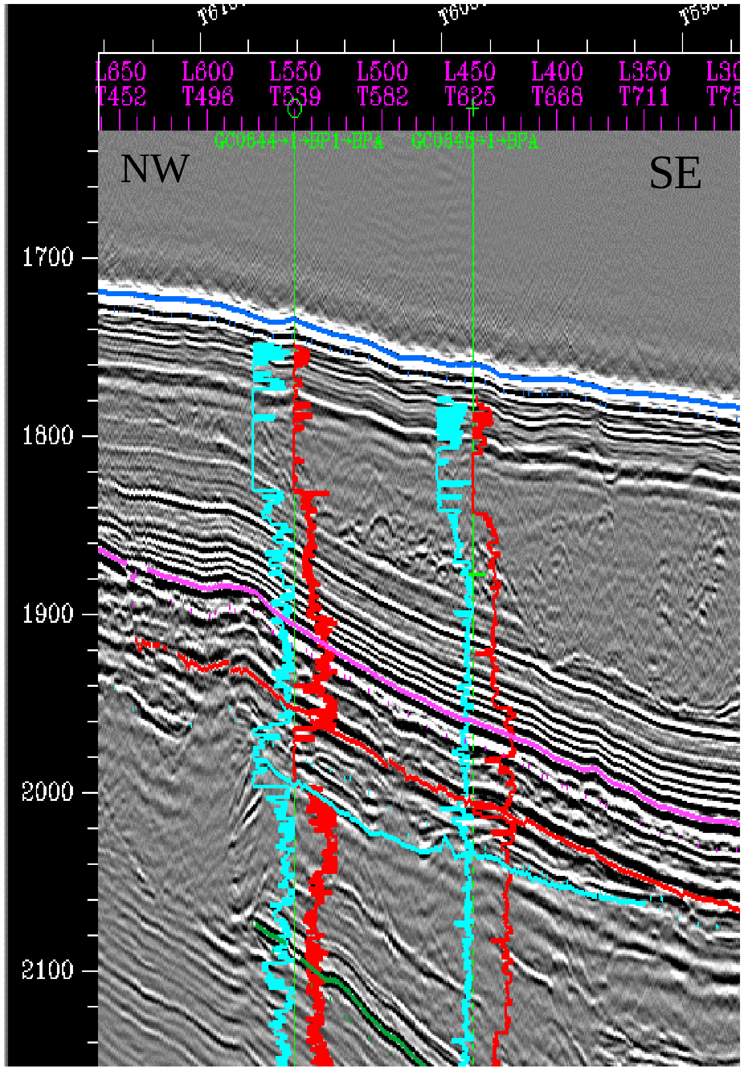
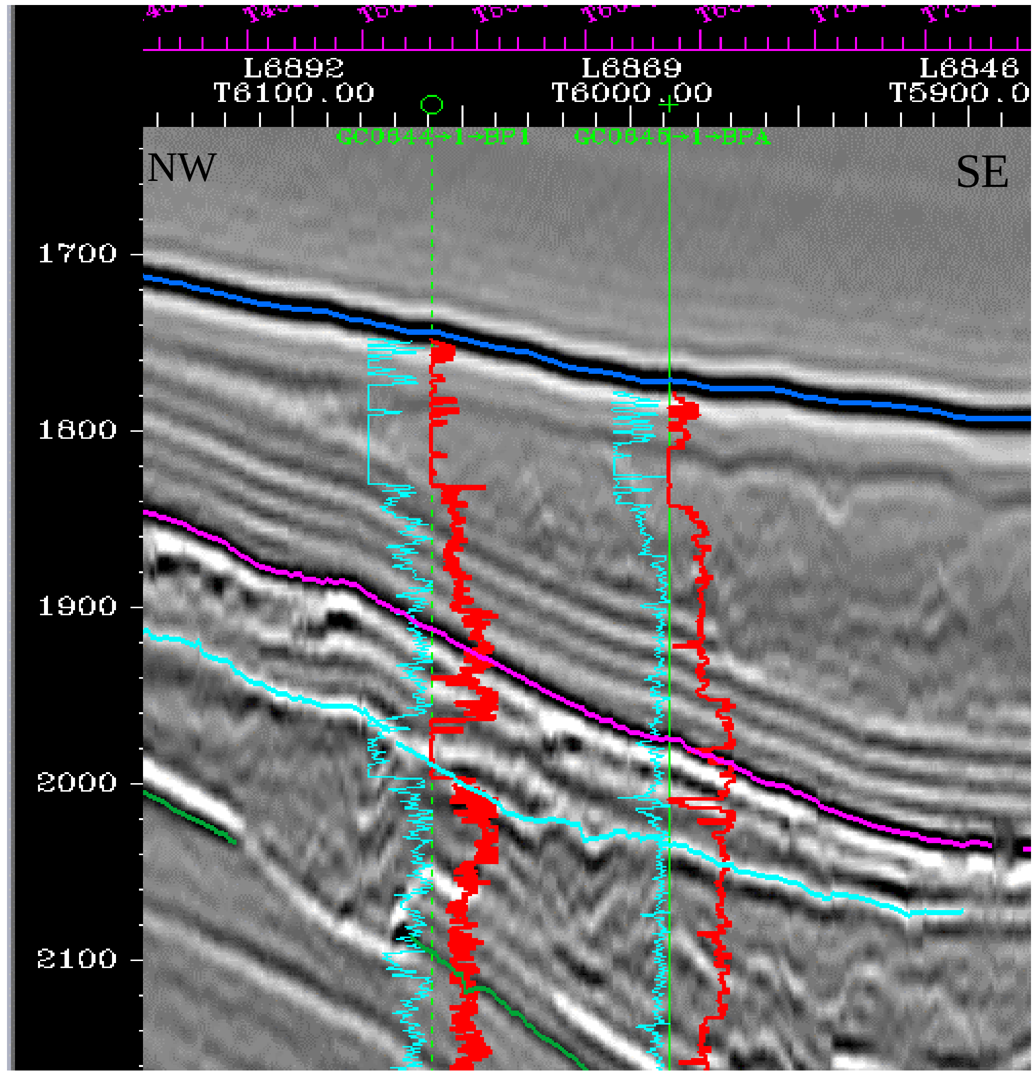
HR3D vs. Exploration 3D





Data Acquisition

- April Activity for BP in one GoM field:
  - Drilling Rig
  - Ocean Bottom Seismic Spread
  - 4C Seismic Spread
  - Geotechnical Deep Coring Spread
  - Geotechnical Shallow Coring Spread
  - HR3D Spread
  - Seabed Survey AUV Spread

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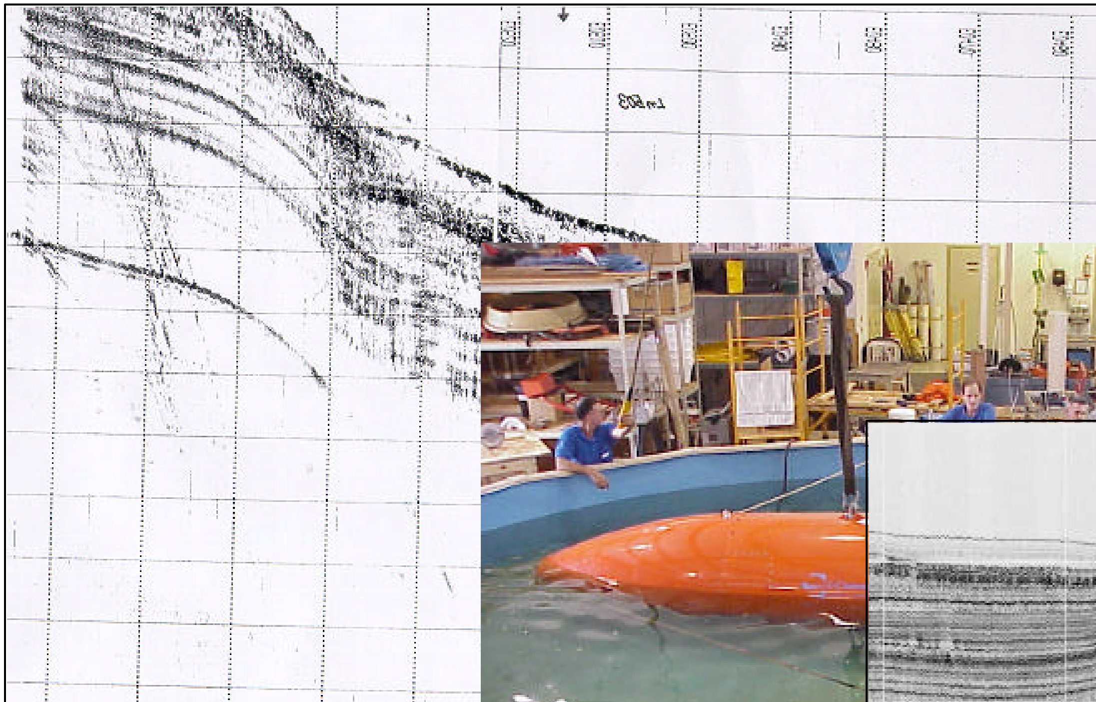
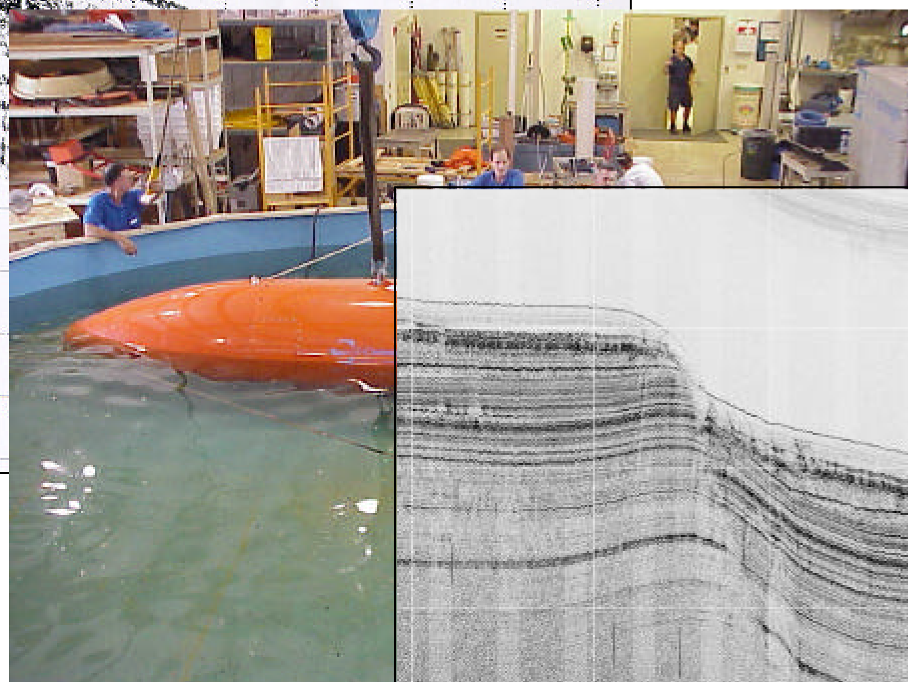
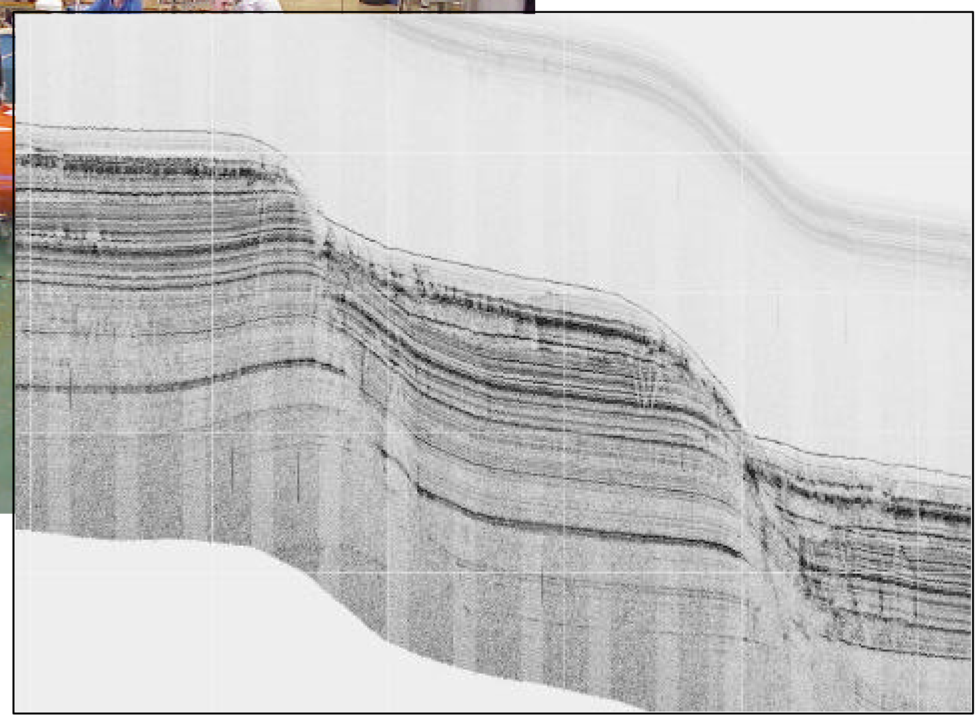
AUV: New Strides in DW Acquisition



Surface Towed Pinger

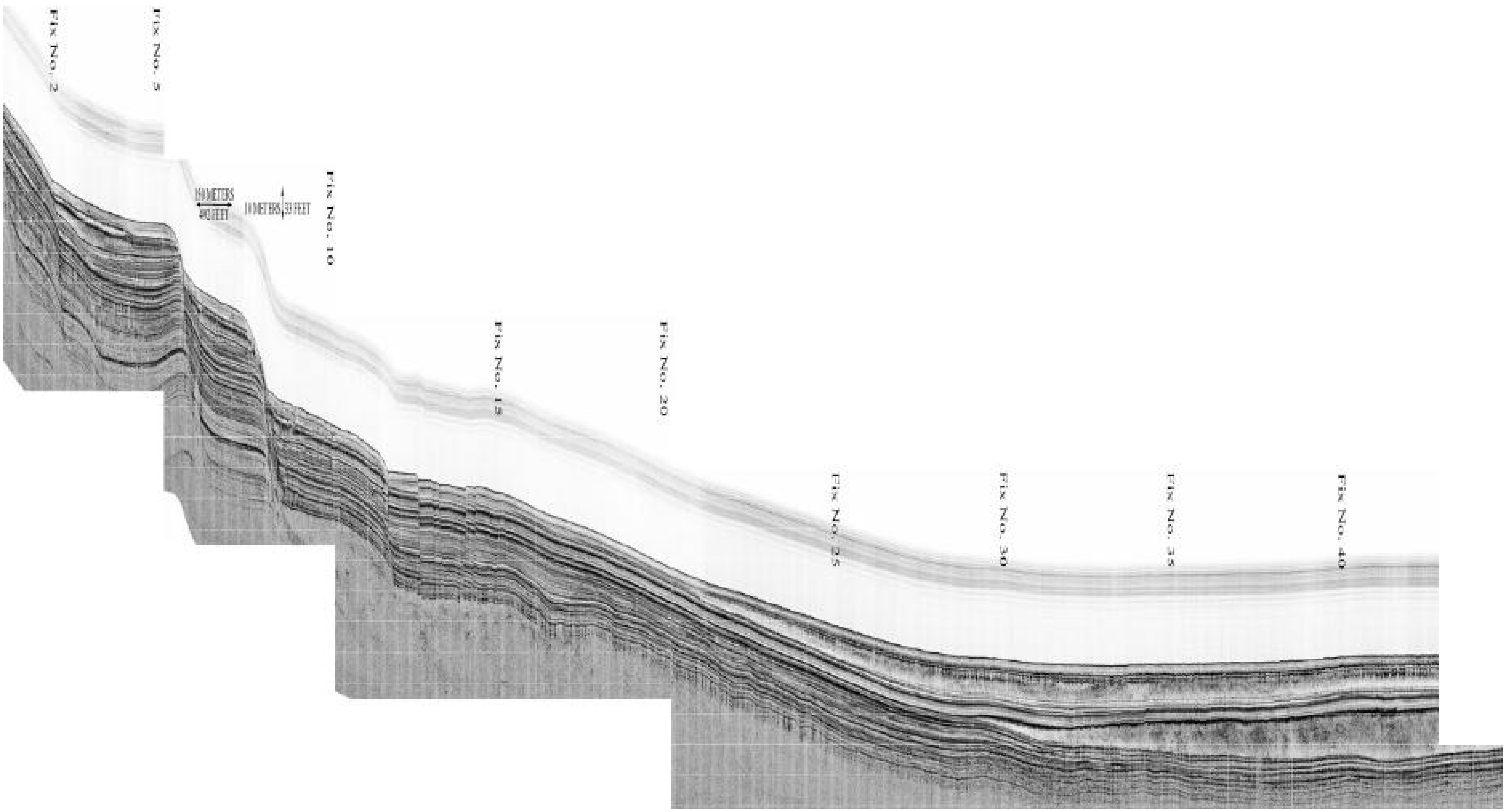




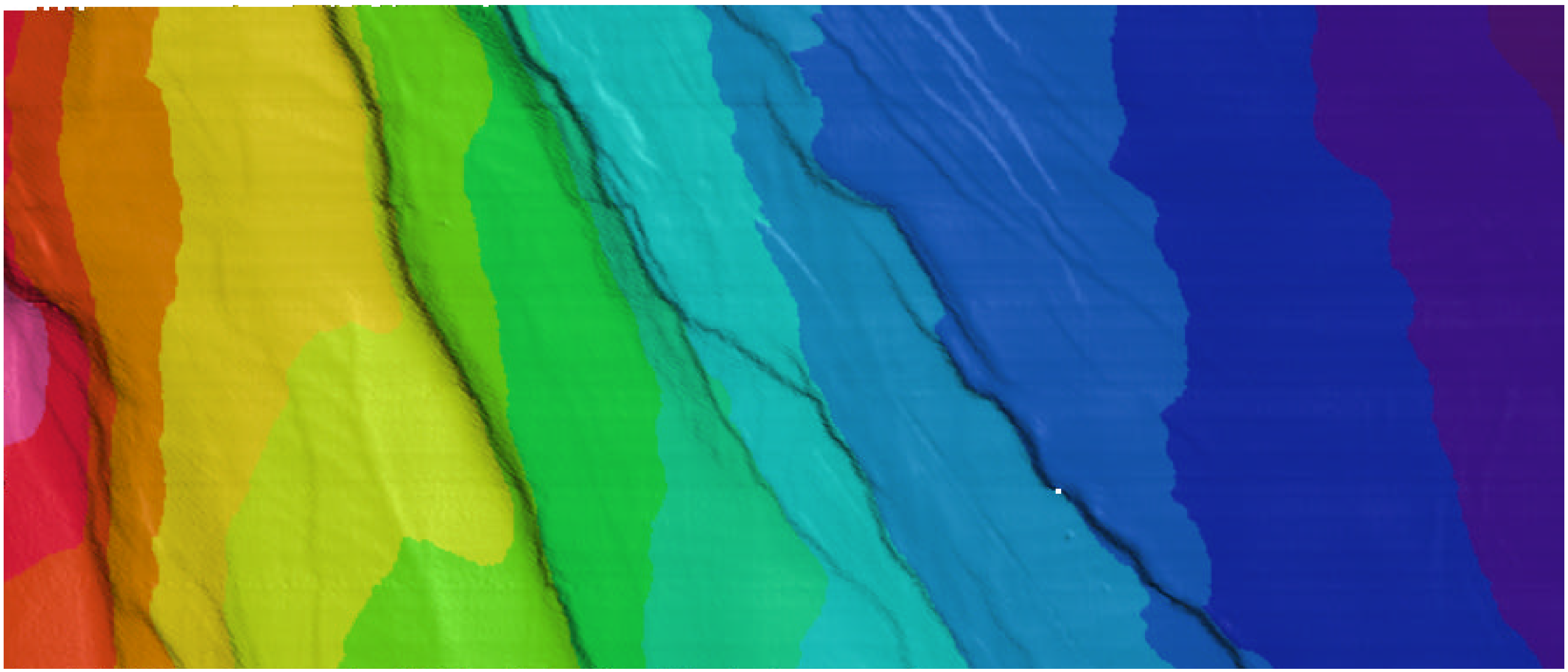
AUV Chirp Profiler

Deepwater Geohazards Workshop

AUV: Profiler Data



AUV: Bathymetry Data (3x3m Cell)



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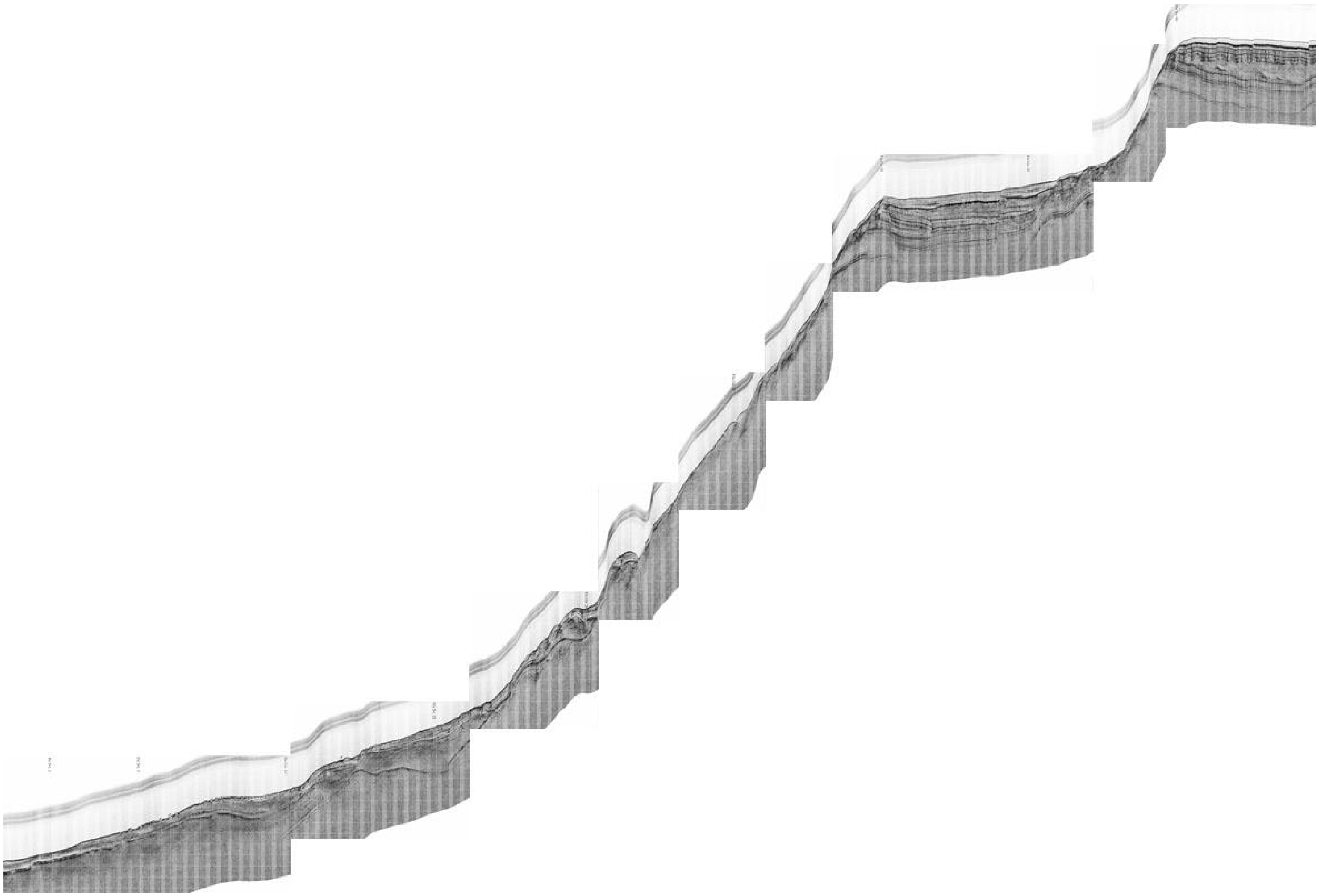
Sigsbee Escarpment: Profiler



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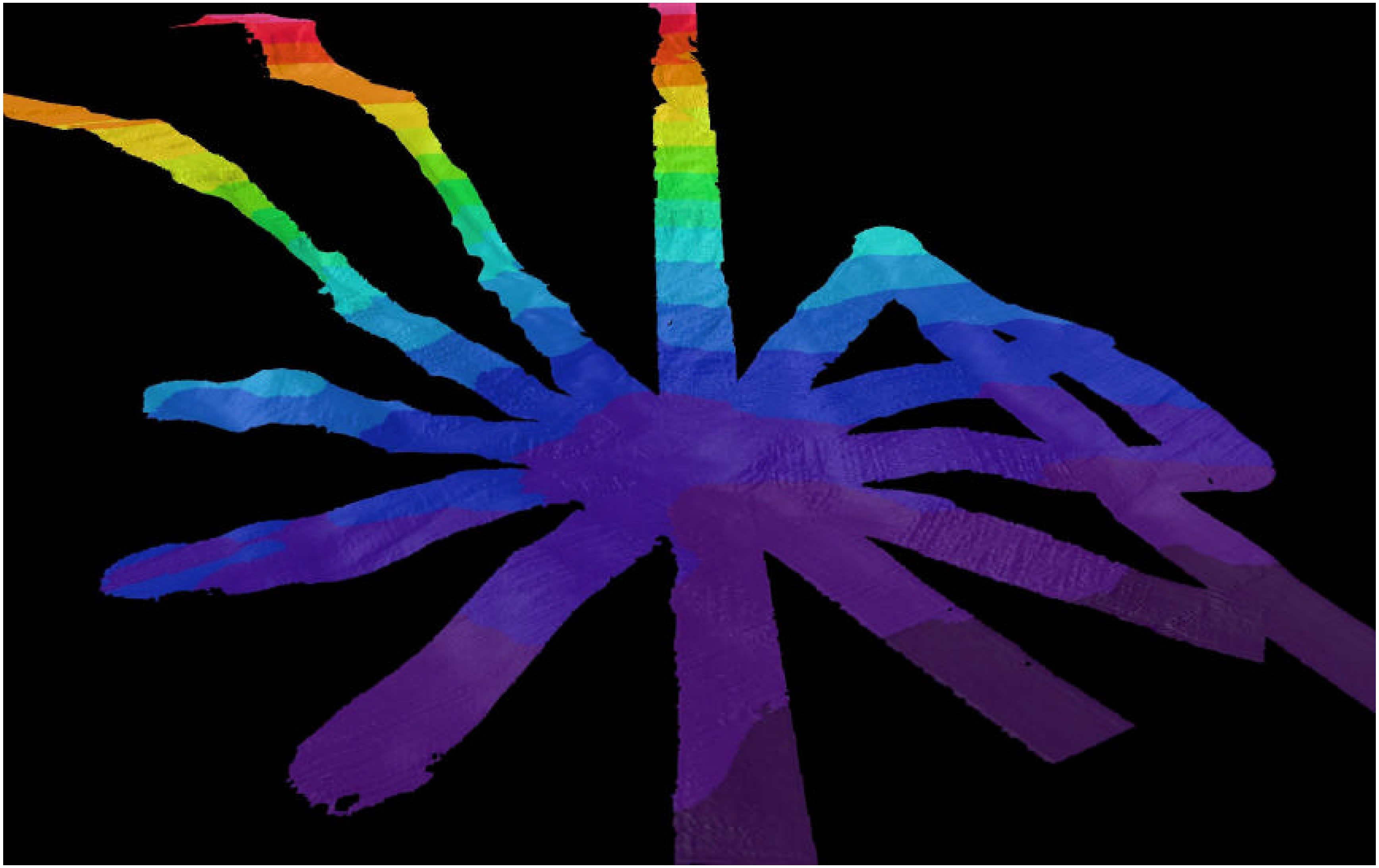
AUV: Sigsbee Escarpment Tests



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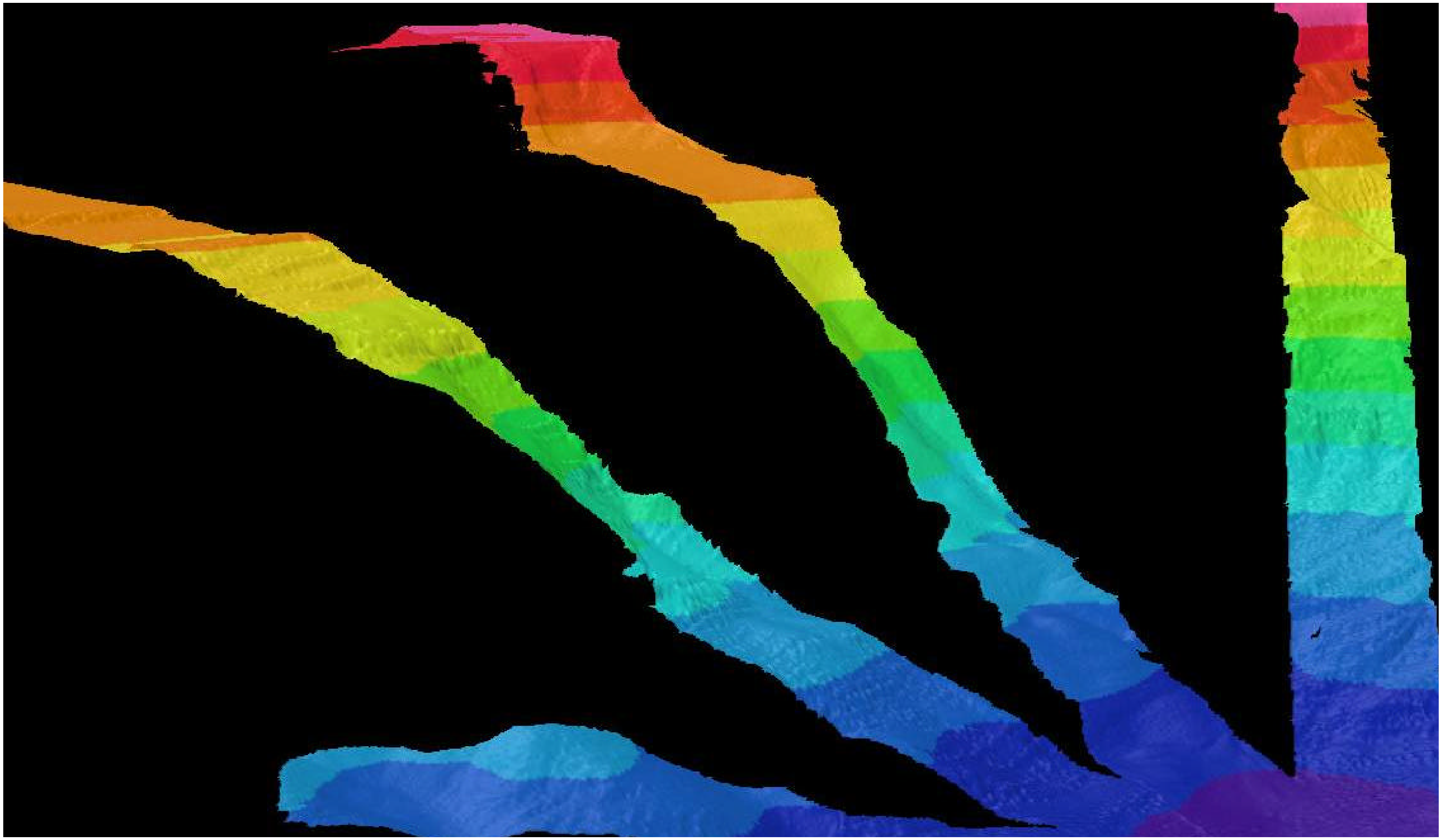
Sigsbee Escarpment Detail



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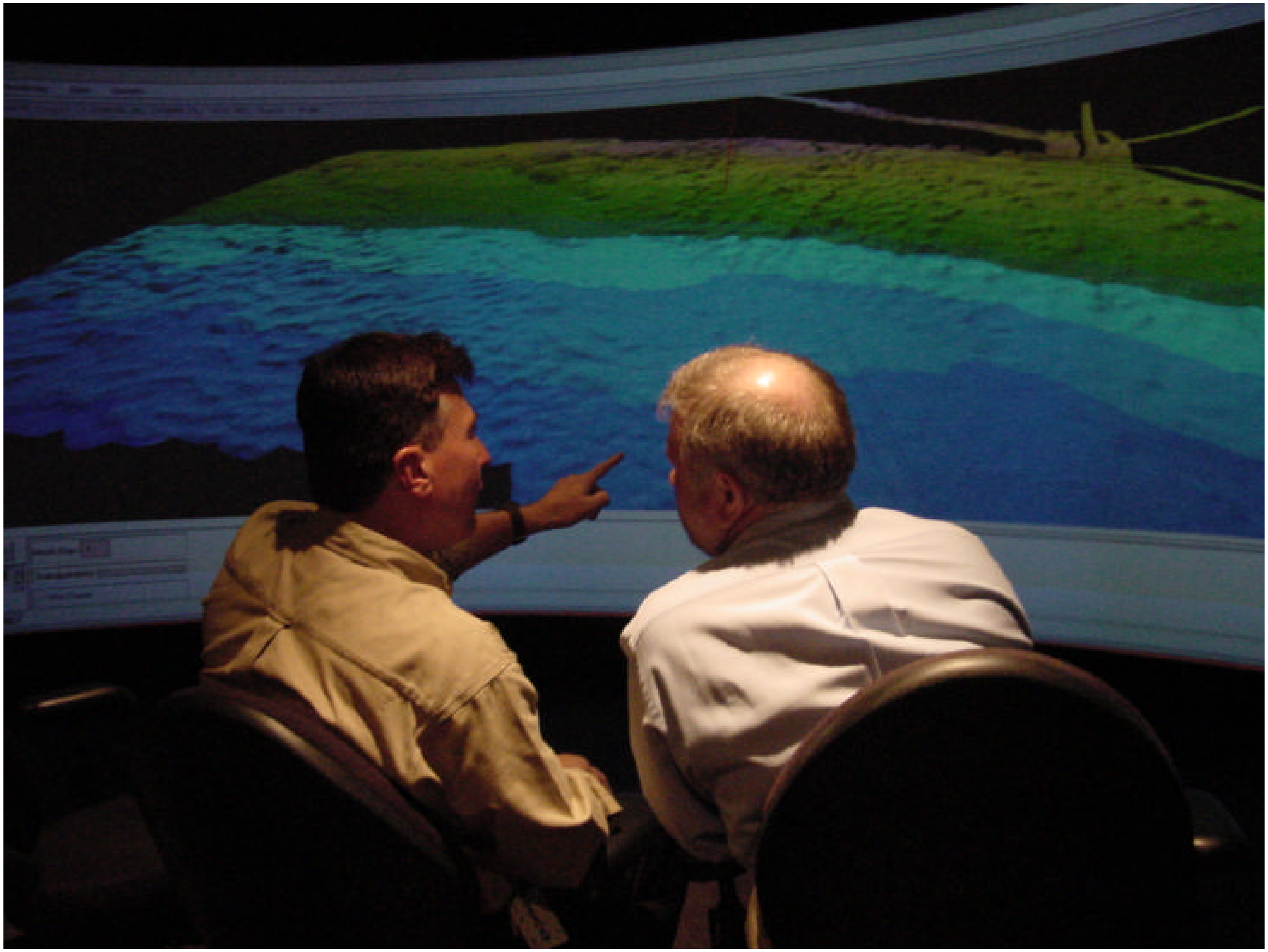
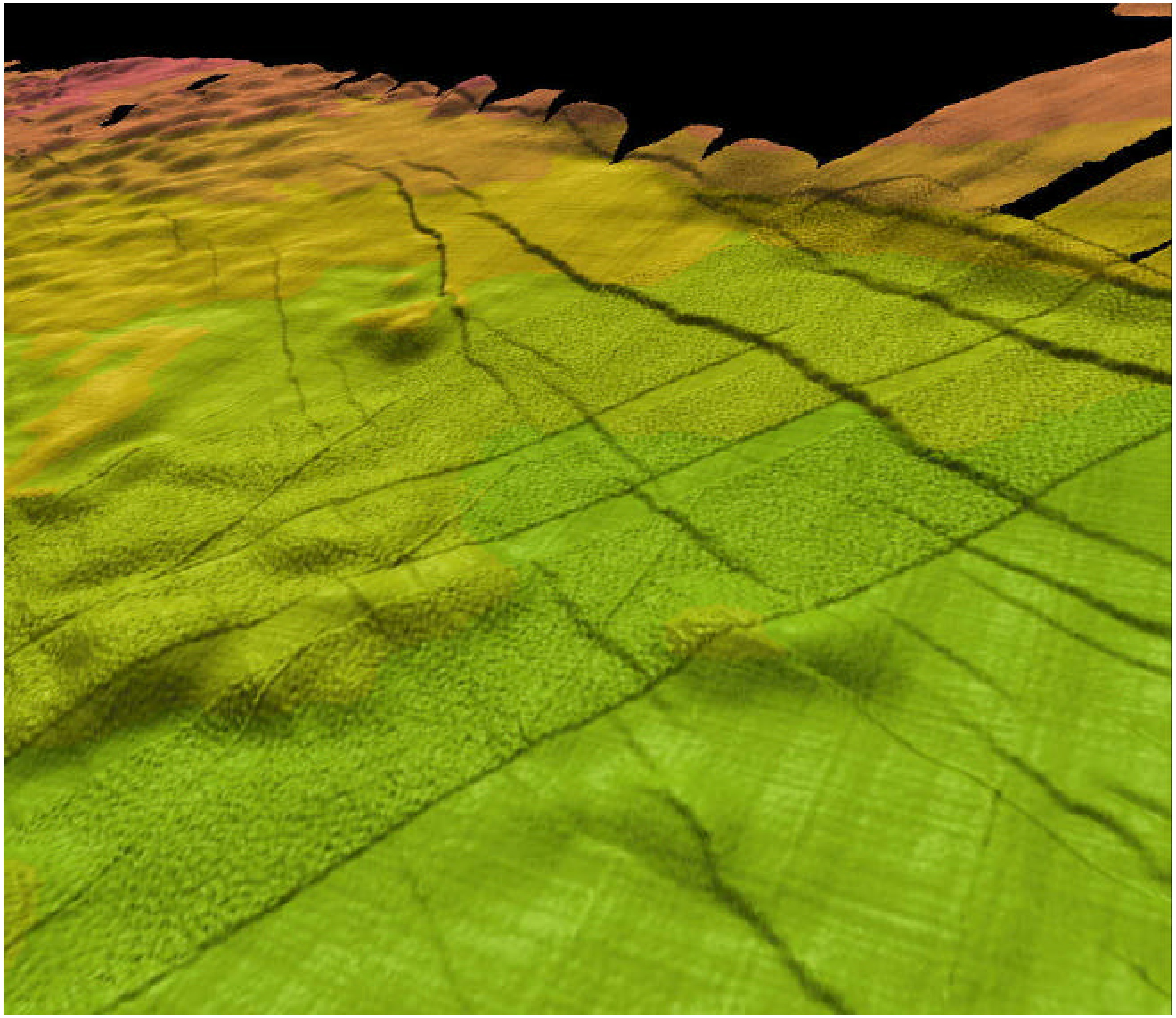
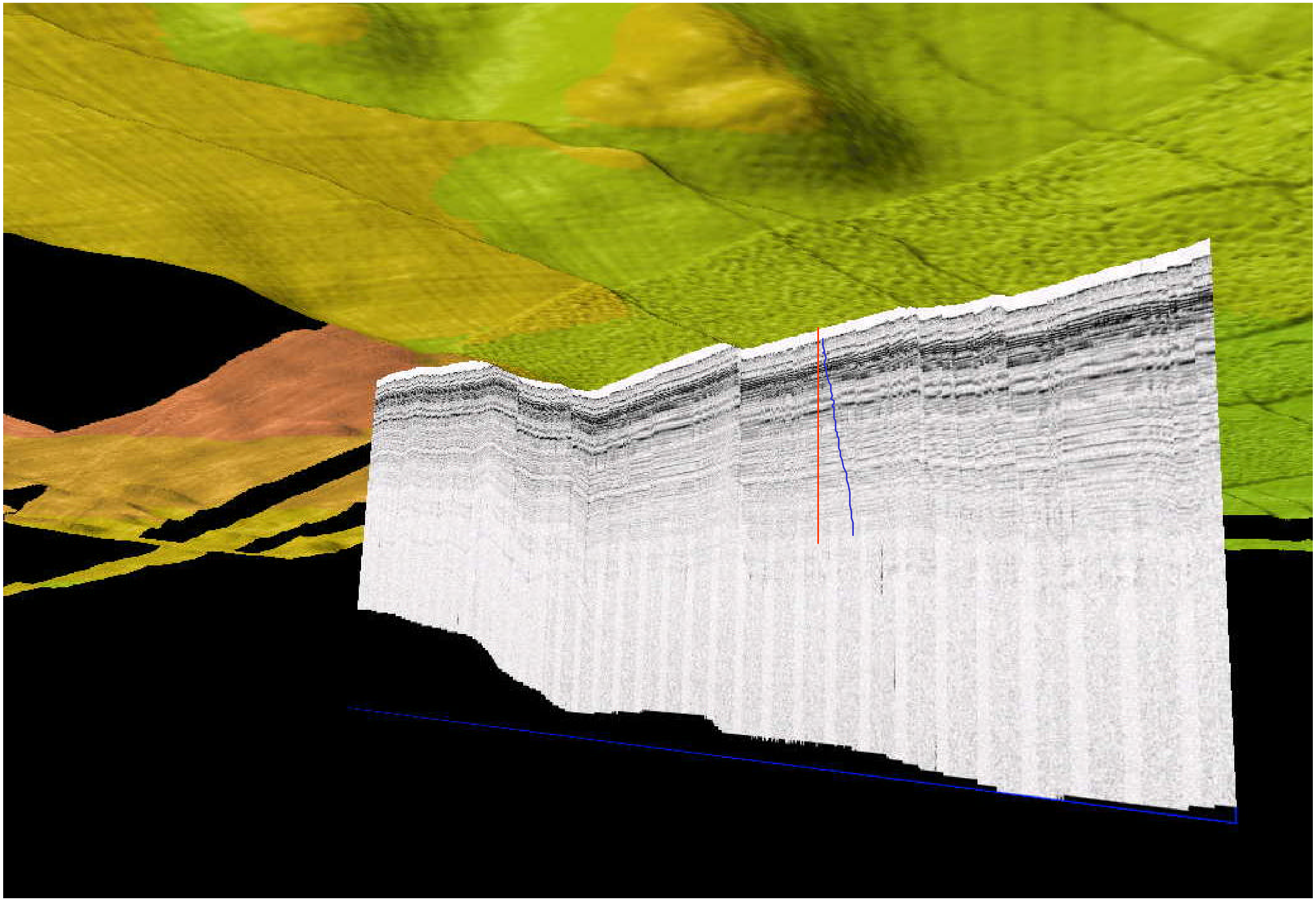
Immersive Interpretation



Seabed Visualization…



Combined with Sub-seabed Imagery

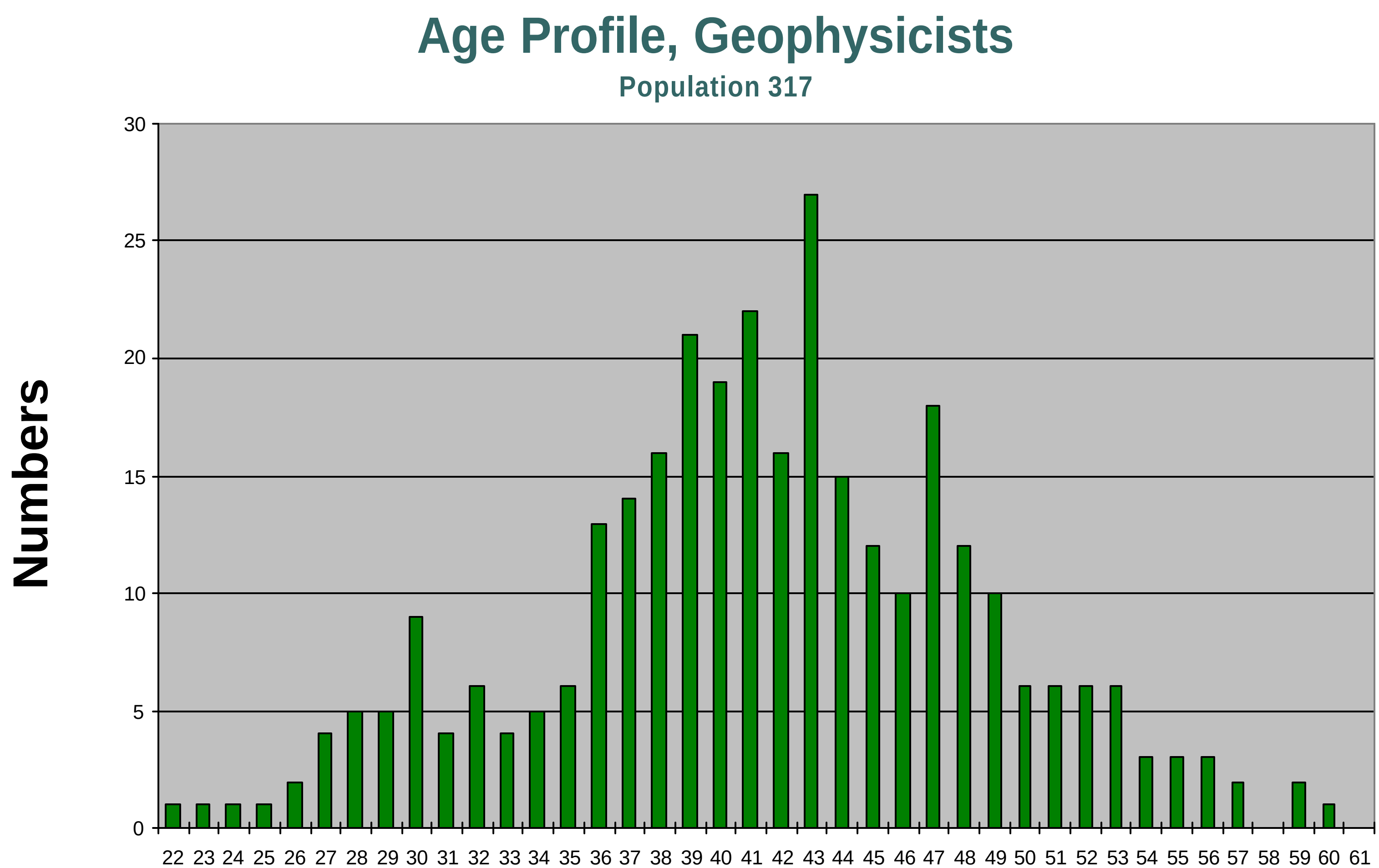


Technology, Tools, and People ??

- The Prize is Great
- The Complexity is Challenging
- Integrated Teams and Technology can deliver the Understanding
- People ?

Deepwater Geohazards Workshop

Never a Better Time ??



BP Geophysicists Age Distribution

Never a Better Time ??

- The Prize is Great
- The Complexity is Challenging
- The Integrated Teams and Technology can deliver…..
- People ?

Summary

- Geohazards Challenge
  - ***Complexity***
  - ***Volume***
  - ***Interaction***

- Geohazards Solution
  - ***Technology***
  - ***Data***
  - ***Skills Integration***
  - ***Communication***

- ***Delivery of Safe and Environmentally Neutral Operations is Achievable.***

Deepwater Geohazards Workshop

Shallow Water Flow Abstracts

Update on Shallow Water Flow Database

Roger Entralgo
Energy Research Clearing House (ERCH)

LINK TO PRESENTATION

The Drilling Engineering Association (DEA), Minerals Management Service (MMS), American Association of Drilling Engineers (AADE) and Energy Research Clearing House (ERCH) held the Shallow Water Forum in June 1998. This meeting was to identify major gaps in shallow water identification technology. A report at this meeting described an analysis of 123 Gulf of Mexico wells having shallow water flows since the phenomenon first occurred in 1985. The analysis reported that $30,600,000 had been spent preventing SWF's and $137,000,000 had been spent remediating SWF's. A major identified gap was an up-to-date database of shallow water flow occurrences. There are approximately 150 wells in the Gulf of Mexico that represent SWF occurrences. Individual companies have been maintaining updates by incorporating their own wells. However, it is important that a collaborative widely accessible and user-friendly database be maintained to facilitate proper planning for future wells.

The objectives of the database is to:

- Collect, Organize, Combine, Update & Enhance all existing SWF Databases in the GOM
- Continually maintain database by adding new wells and the latest software
- Make database widely accessible through the Internet
- Determine what constitutes a shallow water flow and categorize the different types of flows
- Expand to a worldwide database in future phases

The database is driven by interactive map based software with links to defined categories. The information will have interactive links to reference pre-defined categories. Full search capabilities of all categories will allow for easy retrieval of desired charts and information. The data added to the database is compiled into the following categories in up-dated web-based database management software:

- Map Layers
- Protraction
- Lease
- Block
- Well
- Platform
- Operator
- Cement Records
- Data Sheets
- Daily Drill Reports
- Leak-Off Tests
- Mud Records
- Check shots
- Digital Logs
- 3D Seismic Surveys
- Drilling Summary
- Hazard Surveys
- Video Clips

Key features include:

- Web Based Software
- Layered Base-Map Interface (Toggle on & off capabilities)
- Integrated Document Management (Insertion, Linking, & Cataloging)
- Flexible Indexing & Powerful Searching (Including Full Text Searching)
- Variety of Data Management Types:
  - Digital Logs & Seismic Data
  - Office Documents
  - Scanned Images
  - Video
  - Web Pages … And More
- Centralized Document Management

The database is designed to improve the quality of data access and reduce access costs, consolidate industry data into a centralized location, capture industry knowledge and lessons learned, review key information from different sources, stage needed information for further processing, preserve original data formats, to help reduce the risks in the planning and development of drilling future wells. The first phase of the SWF database project commenced on June 1, 2001 for a one-year interval. This project is a direct outcrop of the 1998 SWF Forum and is support by the DeepStar 5500 committee. Participation is open to all operators, service companies, governmental agencies, academic institutions, and research facilities that have data to share.

Scientific Drilling and Shallow Water Flow: A Cooperative Industry-Academic Ocean Drilling Proposal

Peter B. Flemings, The Pennsylvania State University

LINK TO PRESENTATION

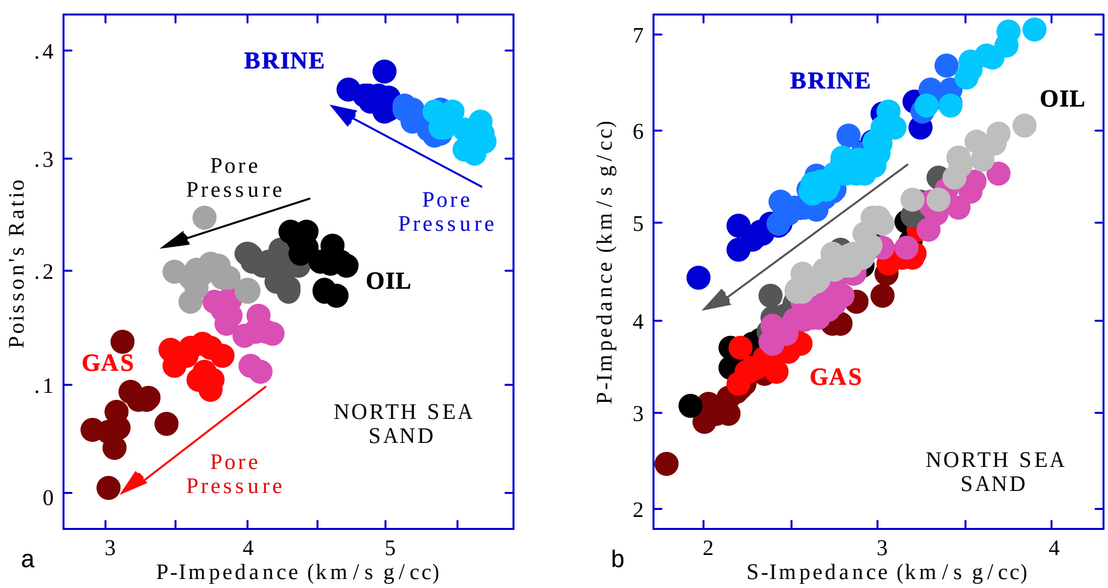
Members from industry and academia have proposed to study shallow water flow in the deepwater Gulf of Mexico through a comprehensive geotechnical drilling program using the *Joides Resolution*, the riserless vessel of the Ocean Drilling Program. A core component of the drilling proposal is that it has direct application to shallow water flow problems and has broader implications for understanding fluid flow at all depths in sedimentary basins. Two sites have been targeted. First, a normally pressured depositional basin will be drilled (Brazos-Trinity Basin 2) in order to characterize rock and fluid properties and in-situ conditions at a range of known effective stress conditions. Second, an overpressured location (Ursa Basin) will be examined to characterize rock and fluid properties in shallow overpressure and to test a flow-focusing model. This model predicts that where sand bodies are rapidly buried by overburden of varying thickness, characteristic pressure, stress, and compaction states will result. At each location, in-situ measurements will include Logging While Drilling, piezoprobe experiments to determine in-situ pressure and temperature in low permeability mudrocks, and wireline packer stress measurements to determine in-situ stress conditions. Whole round cores will be taken for geotechnical analysis (consolidation tests) to compare lab-derived pre-consolidation stresses with in-situ observations. Pore water sampling will be used to further constrain hydrodynamic fluxes. One hole will be sealed with a packer for long term monitoring. This will accurately determine the pressure within the permeable overpressured sand and establish the framework for long-term observation of fluid flow behavior. A better understanding of pressure evolution and flow focusing has the potential to: 1) illuminate the controls on slope stability; 2) illustrate the processes driving seeps and associated biological communities; 3) allow industry and ODP to use a predictive approach to drilling stable boreholes; and 4) show how pressure, stress and geology couple to control fluid migration on passive margins. Details about the proposed drilling program can be found at http://hydro.geosc.psu.edu/Odp/odp.html.

Experimentally Derived Diagnostics for Detecting Anomalous Pore Pressure

JACK DVORKIN
Stanford Rock Physics Laboratory
JOEL WALLS
Rock Solid Images

LINK TO PRESENTATION

By analyzing experimental data we show that in many gas-filled rocks, the Poisson's ratio (PR) decreases with decreasing differential pressure (confining minus pore pressure). In many liquid-saturated rocks the opposite is true: PR increases with decreasing differential pressure. This means that in gas-saturated rocks, PR decreases with increasing pore pressure and in liquid-saturated rocks it increases with increasing effective pressure. We confirm the generality of the observed effect by theoretically reproducing it via effective medium modeling. This effect can be used as a new tool for seismic pore pressure and pore fluid monitoring during production as well as for overpressure detection from surface seismic, cross-well, sonic logs and measurements ahead of the drill bit. An example of a diagnostic chart for pore pressure detection is given in the figure below, based on laboratory measurements of the elastic-wave velocity in unconsolidated North Sea sands (Blangy, 1992). Different regions in the crossplots correspond to different pore pressure and pore fluid. One can identify both pore pressure and pore fluid from seismic (and separate the pore pressure effect from the pore fluid effect) by superimposing seismic elastic rock properties on a diagnostic chart. Note that diagnostic charts have to be site- and rock-type-specific.



Quantification of Shallow Water Flow Zones Using Prestack Inversion of Seismic Data

NADER DUTTA
Western Geophysical

LINK TO PRESENTATION

Highly porous sands, prone to flowing when drilled (shallow waterflow sands), pose a serious risk and have cost the oil industry hundreds of millions of dollars to date. Detection of these shallow waterflow prone sands is important for reducing environmental risks and commercial losses. The use of standard seismic data for detection has been explored and found successful at the Ursa site in the Mississippi Canyon area of the Gulf of Mexico. Although the data quality of the selected set is at or below average, reprocessing at 2 ms yielded sufficient quality to invert the seismic data successfully using a pre-stack genetic algorithm. The attributes inverted from seismic are density, p-wave and shear wave velocity. The shear wave velocity data obtained through AVO characteristics were combined with the other data to create a reliable discriminator. Using synthetic data it was found that the straight ratio of compressional velocity and shear wave velocity was the most sensitive combination. This quantity was subsequently successfully tried on real data from a 3D survey in the Gulf of Mexico. It is recommended that the detection method described be tried prior to drilling in deepwater areas with shallow waterflow occurrences. Conventional data may be used provided they honor large reflection angles and are processed carefully to preserve amplitudes and high frequencies.

Evaluation and Successful Drilling of a Shallow Water Flow Sand, Mississippi Canyon Block 727 #1, Poseidon Prospect

CHERYL CASWELL, RON DUPRE, JEFF DIEFFENBAUGHER, RICK GRAFF, BOBBY LUNSFORD, SCOTT MCLEOD, JAMES NIEMANN, BILL RAU, TODD ROBICHAUX, ANDREW WOMACK
Chevron North American Exploration and Production Co.

LINK TO PRESENTATION

A shallow sand sequence producing severe shallow water flow was successfully drilled riserless and controlled with drilling mud in a well in Mississippi Canyon Block 727 (Poseidon prospect) in the central, deepwater Gulf of Mexico. Integrating a detailed stratigraphic/hazards interpretation and pore pressure model with the well design and procedure planning plus rig-site evaluation while drilling keyed this successful drilling outcome. Regional seismic mapping, offset wells, and seismic attribute analysis indicated the proposed OCS-G-13145 #1 well in Mississippi Canyon Block 727 would penetrate a thick sequence of stacked, turbidite sands from 1352' to 2254' BML. Pore pressure gradients were anticipated to exceed the seawater hydrostatic gradient within this interval based on calculated curves from offset wells and the anticipated mudweight based on regional trends. Based on the MMS Guidepoints checklist, this section was determined to be a high risk for shallow water flow. A detailed stratigraphic prognosis in seismic 2-way travel time was prepared for the well site location and converted to depth using an average velocity function from an offset well hung at the projected mudline depth. The well was designed to jet 36" conductor pipe from an anticipated water depth of 4880' to 300' below mudline. The hole was to be drilled riserless hole to ~6000 MD (1000' BML) to set and cement 28" casing ~ 300'above the anticipated shallow water flow sand sequence. The larger 28" casing was selected to rapidly drill 26" hole riserless without underreaming to ~7500' MD (2500' BML) and land and cement 22" casing before rigging up the BOP and installing marine riser. In anticipation of shallow water flow, a detailed plan of action was prepared to kill any shallow flow encountered by circulating heavy drilling mud down the drillstring and taking mud returns at the seafloor. To enable this plan, 26,000 barrels of 16.0 PPG liquid mud were brought out to the rig in five workboats.

The well spudded in 4886' WD on August 19, 2000, and the 36" (297' BML) and 28" casing (992' BML) were set without incident. An earth scientist arrived at the rigsite to correlate the seismic interpretation, the offset well logs and the logging while drilling data from downhole to apprise the drilling personnel of potential shallow water flow zones predicted by the pre-spud evaluation. Drilling personnel were alerted at ~50' above the first potential SWF zone. At 6542' MD (1571' BML) the ROV camera recorded a severe shallow water flow up through the wellhead. 541 barrels of 14 PPG drilling mud was immediately pumped down the drillstring to kill the well followed by 11.9 PPG drilling mud for an effective downhole static mudweight of 9.28 PPG (referenced to KB). The well continued to be drilled to a TD of 7550' MD (2582' BML) gradually increasing mudweight to 12.2 PPG for an effective downhole static mudweight of 9.73 PPG at TD (referenced to KB). 22" Casing was run and landed to 7498' MD (2527' BML) and cemented without incident. A LOT of 10.9 PPG was recorded which was within the anticipated range of 10.5 to 11.0 PPG. Well operations continued for an additional 123 days with no reported incidents of abnormal casing wear or deformation in the interval that flowed while drilling riserless. The close integration of earth science interpretation with drilling engineering on this Poseidon well serves as a working model for the successful drilling of shallow water flow hazards in the deepwater Gulf of Mexico.

Modeling of Casing Collapse Due to Shallow Water Flows

MICHAEL MCLEAN AND MARK ALBERTY
BP UTG Sunbury
ANDY RAWICKI
Chevron North American Exploration and Production Co.

LINK TO PRESENTATION

The drilling of geopressured sands before running the riser and blow out preventer (BOP) are the most common cause of shallow waterflows (SWF) and also one of the most damaging mechanisms. When geopressured sands are encountered before running the 20" conductor and the high-pressure wellhead, conventional well control practices are not possible. There is no closed system in which to circulate mud and the BOP have not yet been run to close and contain the pressure. The common practice is to drill with seawater and gel sweeps. This fluid column provides insufficient gradient to suppress geopressure. The resulting flow from geopressured sand can result in erosion by the flowing sand causing significant hole enlargement.

Problems associated with SWF-induced erosion have been experienced on both the Ursa and Genesis fields in the Gulf of Mexico. Following batch drilling operations, casing integrity was compromised in both these fields, most notably in Ursa, where the first template was completely abandoned.

A model has been developed integrating the hydraulics, geomechanics and tubular technology aspects of the SWF induced problem. The purposes of the model are to help interpret the primary causes of past problems and to help take mitigating steps where future problems are predicted, for example increasing the well spacing. Many simplifying assumptions have been used to make the model manageable to operate in an Excel environment. Nevertheless, good matches have been achieved with the Ursa and Genesis experiences.

This presentation sets out the mechanisms and basic assumptions utilized in the model. The experiences encountered on both Ursa and Genesis are given and compared with the model predictions. Finally, insights into the SWF induced problem gained from running the model are given which should help to reduce trouble costs associated with encountering SWF in future drilling operations.

Shallow Water Flow Risk Assessment For Field Development Planning Using HR3D Seismic And Wellbore Stability Modeling

Kathleen O. Horkowitz*, Alex Calvert**, Jim Thomson*, Tom Byrd**, Eric Ekstrand**, Donald Bruce** - BP Geohazards Team* and BP Holstein Development Team**

LINK TO PRESENTATION

SWF risk assessment for exploration and appraisal drilling focuses on predicting the risk of occurrence of overpressured sands, the depth of occurrence and the potential overpressure with respect to the impact of the SWF on the single well in question. SWF risk assessment for field development, however, has the added need to assess the impact of SWF on borehole stability in multi-well development programs. It becomes increasingly more important therefore, to characterize the areal distribution and lateral continuity of shallow sands in addition to providing estimates of sand layer thickness, depth of occurrence and potential overpressure. This case study documents SWF risk assessment and wellbore stability modeling for development planning for Holstein Field, a Gulf of Mexico deepwater field in southern Green Canyon.

SWF risk assessment for the GC644-1 exploration well predicted low risk of flow from 480 – 915 ft. BML. The GC644-1 was drilled in 4276 feet of water with seawater and experienced a slight SWF at 714 ft. BML. Correlation of MWD gamma ray and resistivity logs with pressure while drilling (PWD) measurements indicated the flow was coming from a 90 ft. thick sand package at 4990 ft. MD (714 ft. BML).

Results from the exploration well were used to assess risk at the appraisal well location, GC645-1, drilled in 4344 ft water depth. Seismic interpretation from exploration 3D seismic and high-resolution 2D seismic indicated the 90 ft. sand package thinned toward the GC645-1 location and would likely be represented by a thin sand and silty-shale in the GC645-1 interval. Risk of SWF was rated as a high risk of slight intensity flow. The GC645-1 appraisal well penetrated a 15 ft. thick sand at 710 ft. BML with no flow observed through setting the 20” casing at 6547 ft. MD (2117 ft. BML.).

The occurrence of the SWF in the exploration well and no flow in the appraisal well posed important questions about determining the optimum location for the development facility to minimize risk of SWF and impact of potential SWF on the multi-well program. The decision was made to acquire high-resolution 3D seismic to minimize the risk of SWF by providing high-resolution data for defining sand distribution, sand thickness and lateral sand continuity. The high-resolution 3D seismic survey was acquired over a nine square mile area with 330 foot (100m) cable length and 0.5ms sample rate. Final migrated data is 4-fold with inline spacing of 24 ft. (7.5m) and dominant frequency through the interval of interest of 130 Hz. Vertical resolution is estimated to be approximately 10 feet using an interval velocity for the zone of interest of 6000 ft/sec from offset seismic-to-well tie correlations. The high-resolution data clearly show the eastward thinning and pinch out of the thick, B2 sand package encountered in GC644-1. Instantaneous phase displays and interval coherence and amplitude mapping define the lateral extent and continuity of the B1 sand around the GC645-1 location.

The optimal location for the Holstein facility was determined by a) isopach mapping and instantaneous phase displays which clearly identified the pinch out of the thick SWF B2 sand and b) coherence and amplitude mapping which defined the lateral continuity of the B1 sand and a zone around the GC645-1 location where the interval in question would not differ significantly from the GC645-1 penetration. While general thickness trends of the SWF interval were mappable from the exploration 3D, the high-resolution 3D provided detail of a channel associated with the B2 sand and the resolution to map the B1 sand and its lateral continuity. These advantages allowed the development team to define the optimal location for the Holstein facility to minimize risk of SWF.

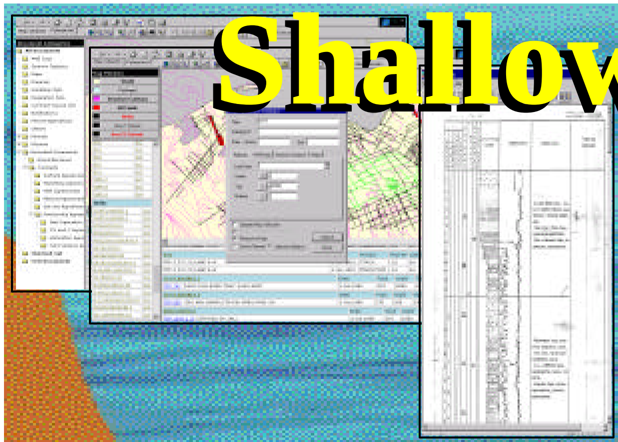
SWF well stability modeling was conducted using the McLean et al. program with parameter inputs from the drilling and subsurface reservoir teams. Results indicate that relatively minor changes to basic drilling procedures (ROP, pump rate) are required for successful drilling of the base case Holstein well pattern. Alternative well patterns required by different facility designs have also been evaluated. Tighter well spacing requires further modifications to drilling procedures beyond simply increasing ROP and decreasing pump rate to mitigate potential instability in the wellbores. Further work is being conducted to optimize well pattern and sequencing.

The high-resolution 3D seismic survey added value to field development planning by providing the ability to map the extent of the thick SWF sand in GC644-1 and the distribution and continuity of the thinner B1 sand in the area around the proposed development facility. Wellbore stability modeling proved to be a valuable tool in an area initially considered to have low risk of SWF with low potential impact on the wellbore from any slight flow that might occur. The ability to evaluate wellbore sensitivity to different well spacing patterns, overpressure and drilling procedures provided the development and drilling team with critical information for final development planning.

Deepwater Geohazards Workshop

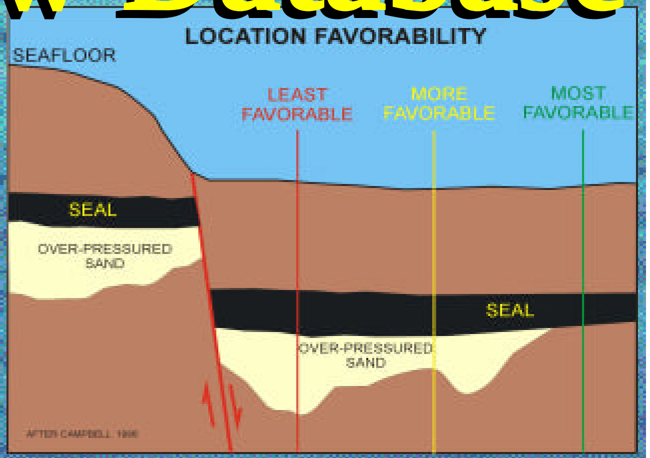
Shallow Water Flow Presentations

Shallow Water Flow Database



DEA-133

CTR 5502



- ✦ Direct outcrop of the 1998 SWF Forum
- ✦ Reduce risk in deep water well planning
- ✦ Capture industry knowledge & lessons learned
- ✦ Develop & categorize an industry standard
- ✦ Consolidate data in a centralized location
- ✦ Improve quality of data & reduce access time

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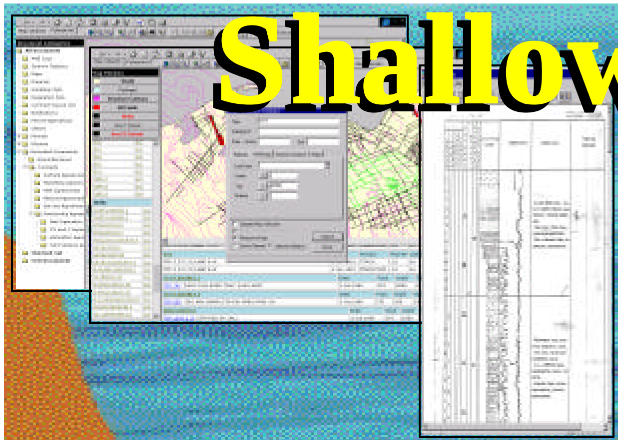
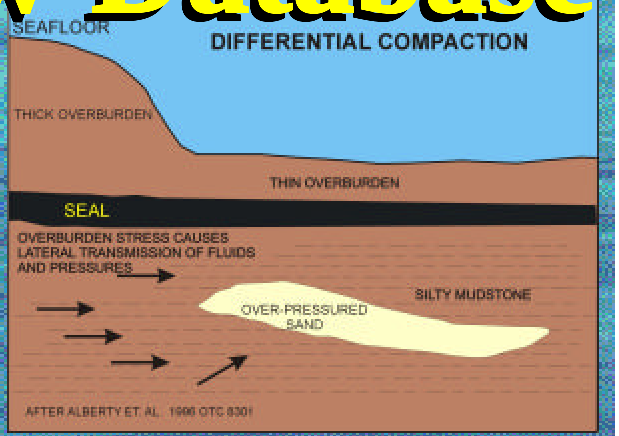
Energy Research Clearing House

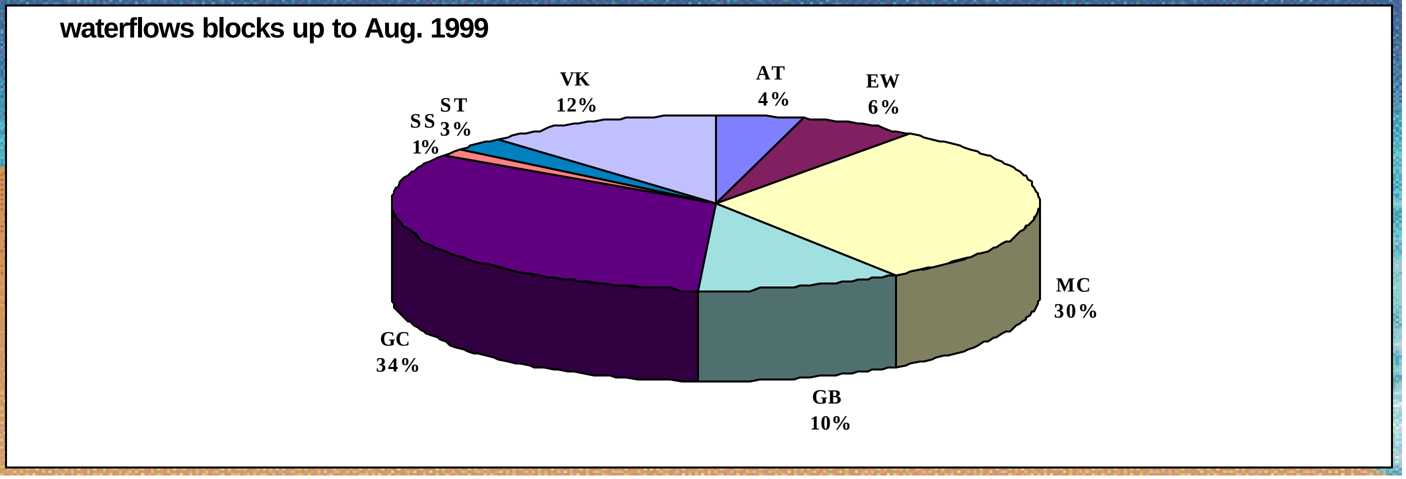
Shallow Water Flow Database





GOM Occurrences

- ✦ March 2001, ~ 230 active leases in deepwater GOM
- ✦ August 1999, ~ 70 documented shallow water flows
- ✦ Occurring in water depths greater than 500 feet
- ✦ Occurring 450 – 3500 feet below the mudline



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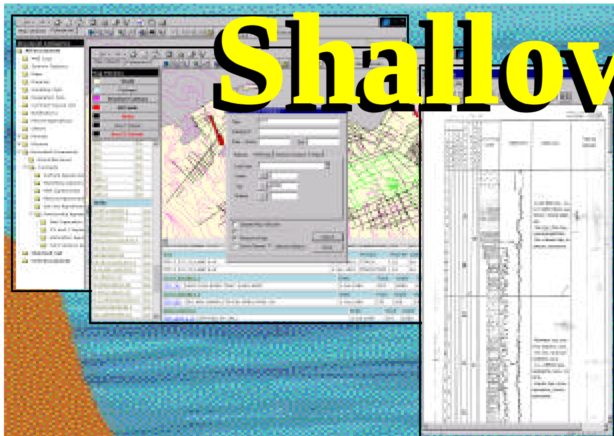
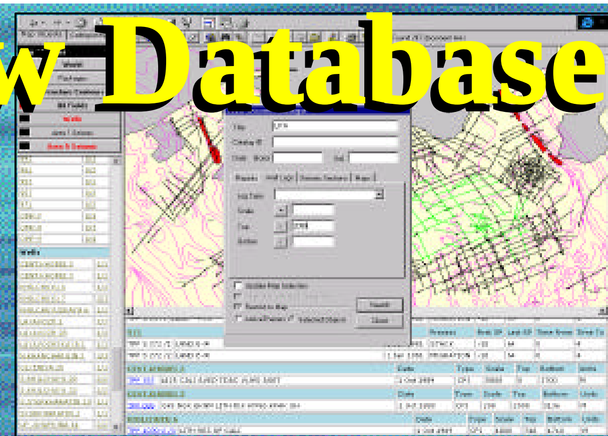
Shallow Water Flow Database



Technical Objectives



- ✦ Update 1995 DeepStar GOM CD-ROM database
- ✦ Include wells from other GOM SWF databases
- ✦ Add new GOM shallow water flow wells
- ✦ Web based for worldwide access
- ✦ Accommodate all variety of data types
- ✦ Tie well data to layer-based map
- ✦ Include full-text searching

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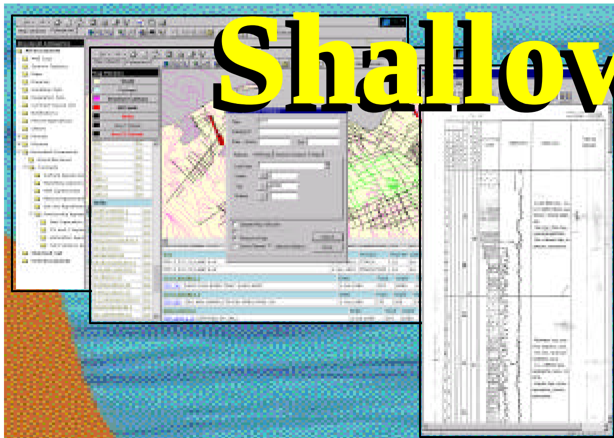
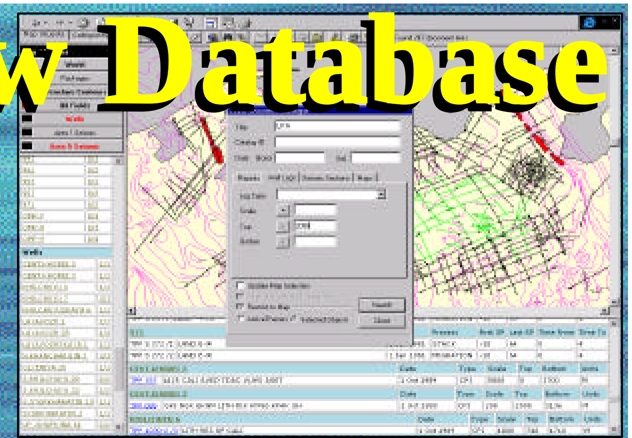
Shallow Water Flow Database





Participating Companies

- **DeepStar**

  Amerada Hess, BpAmoco, Chevron, Conoco, Elf, Eni, ExxonMobil, Kerr McGee, Marathon, Oxy, Petrobras, Phillips, Shell, Texaco, Unocal, Vastar

- **Others**

  BHP, Halliburton, MMS

- **Participation is open to all companies willing to share data**

Exploring the Origin and Behavior of Shallow Water Flow Systems Through Ocean Drilling.

P. B. Flemings, A. Huffman, J. A. Thomson, M. O. Maler, R. E. Swarbrick, C. Winker

Overview

- Hydrodynamics of Overpressure
- Model For Shallow Water Flow (SWF)
- Testing SWF Models with Ocean Drilling
- Drilling Proposal
- Industry/Academic/Govt. Interaction

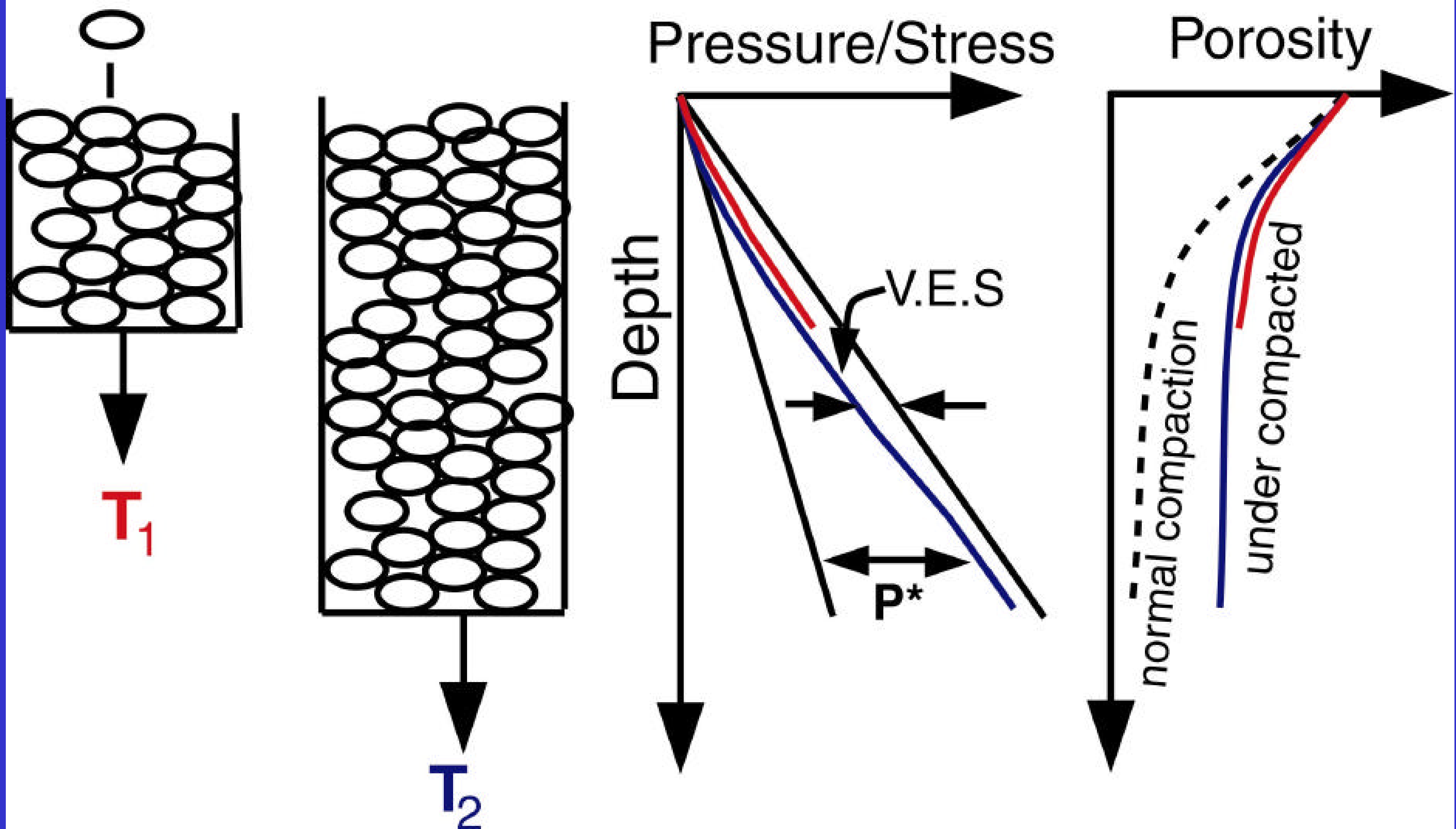
Key Points

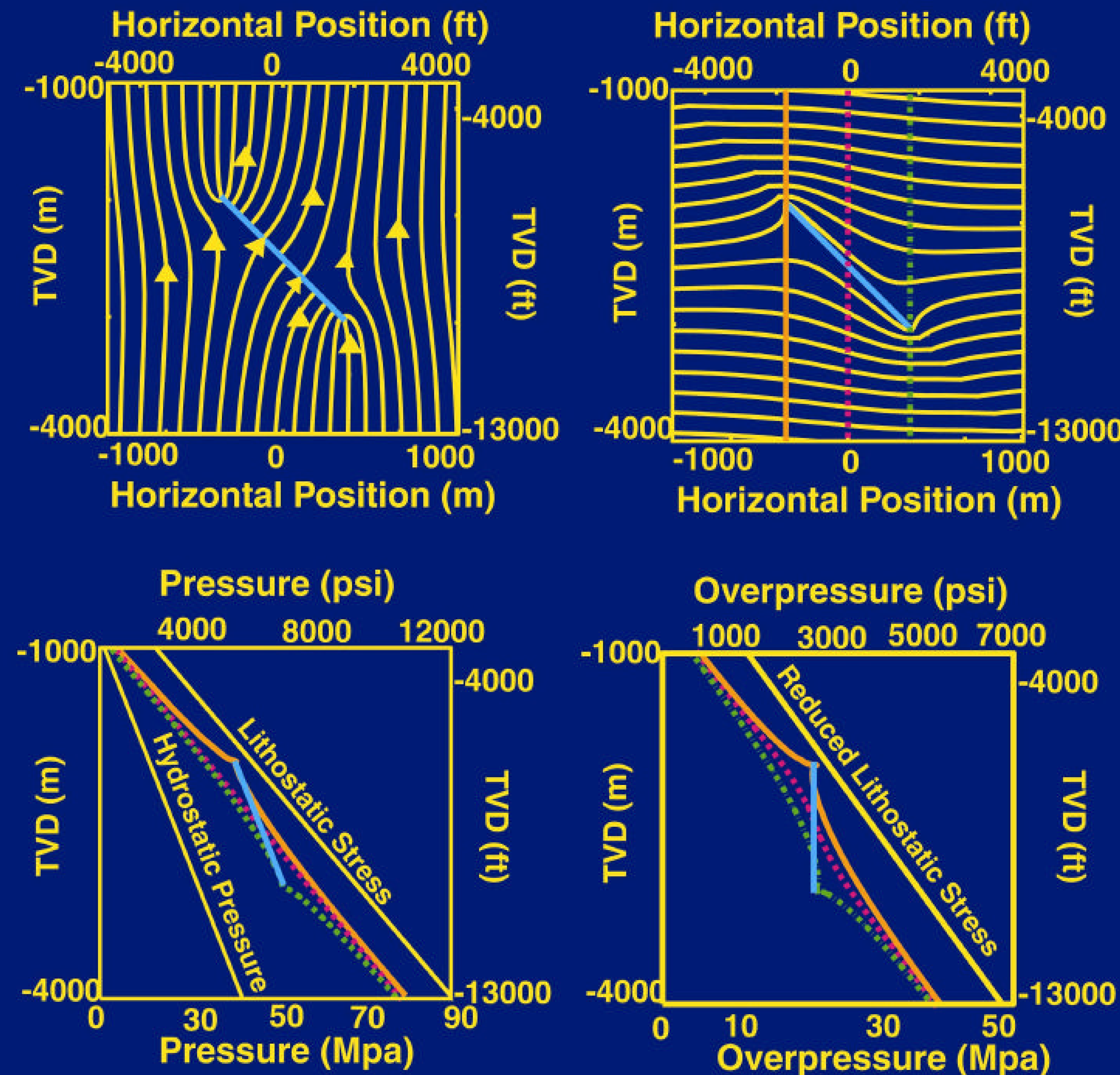
- Simple Model for Pressure/Stress State

- Exciting Opportunity for Fundamental Measurements of Importance to Industry

- Opportunity for Industry Interaction and Add-On Science

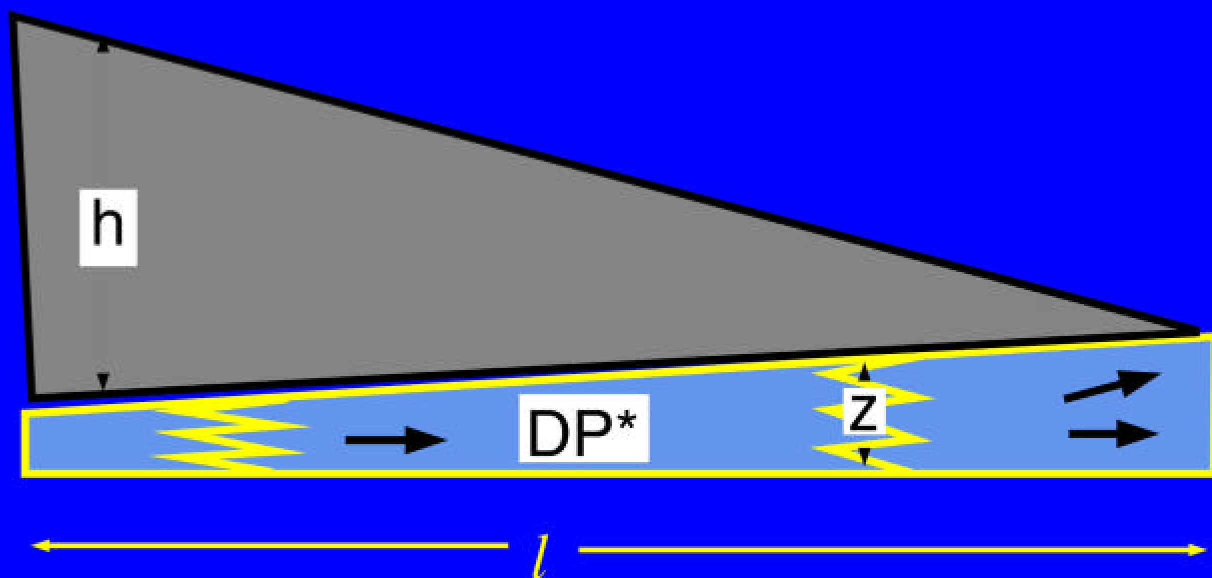
Sedimentation and Overpressure



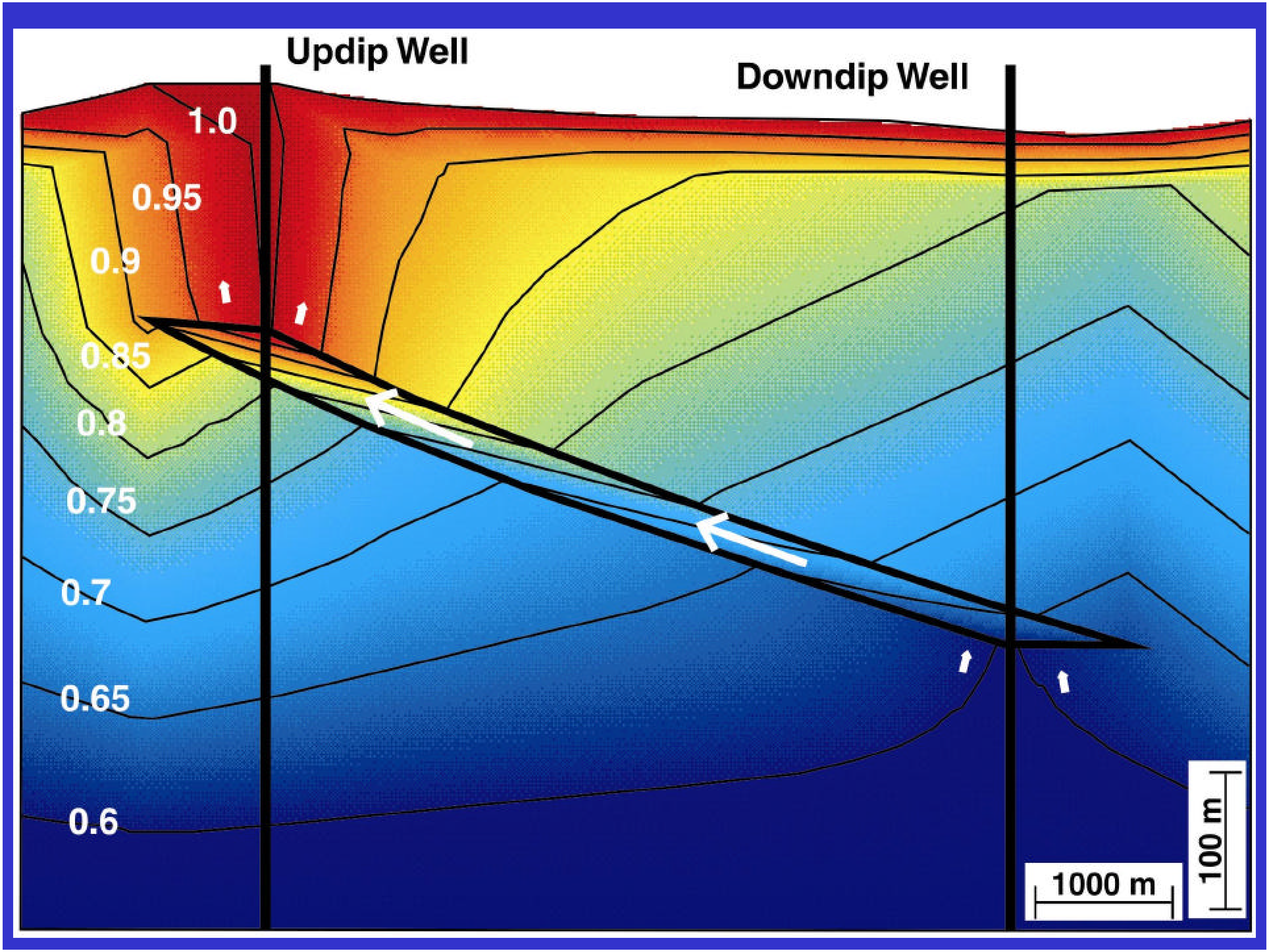


Horizontal Position (ft)
-4000
0
4000
-1000
-4000
TVD (m)
TVD (ft)
-4000
-13000
-1000
0
1000
Horizontal Position (m)
Horizontal Position (ft)
-4000
0
4000
-1000
-4000
TVD (m)
TVD (ft)
-4000
-13000
-1000
0
1000
Horizontal Position (m)
Pressure (psi)
4000
8000
12000
-1000
-4000
TVD (m)
TVD (ft)
Lithostatic Stress
Hydrostatic Pressure
-4000
-13000
0
30
50
70
90
Pressure (Mpa)
Overpressure (psi)
1000
3000
5000
7000
-1000
-4000
TVD (m)
TVD (ft)
Reduced Lithostatic Stress
-4000
-13000
0
10
30
50
Overpressure (Mpa)

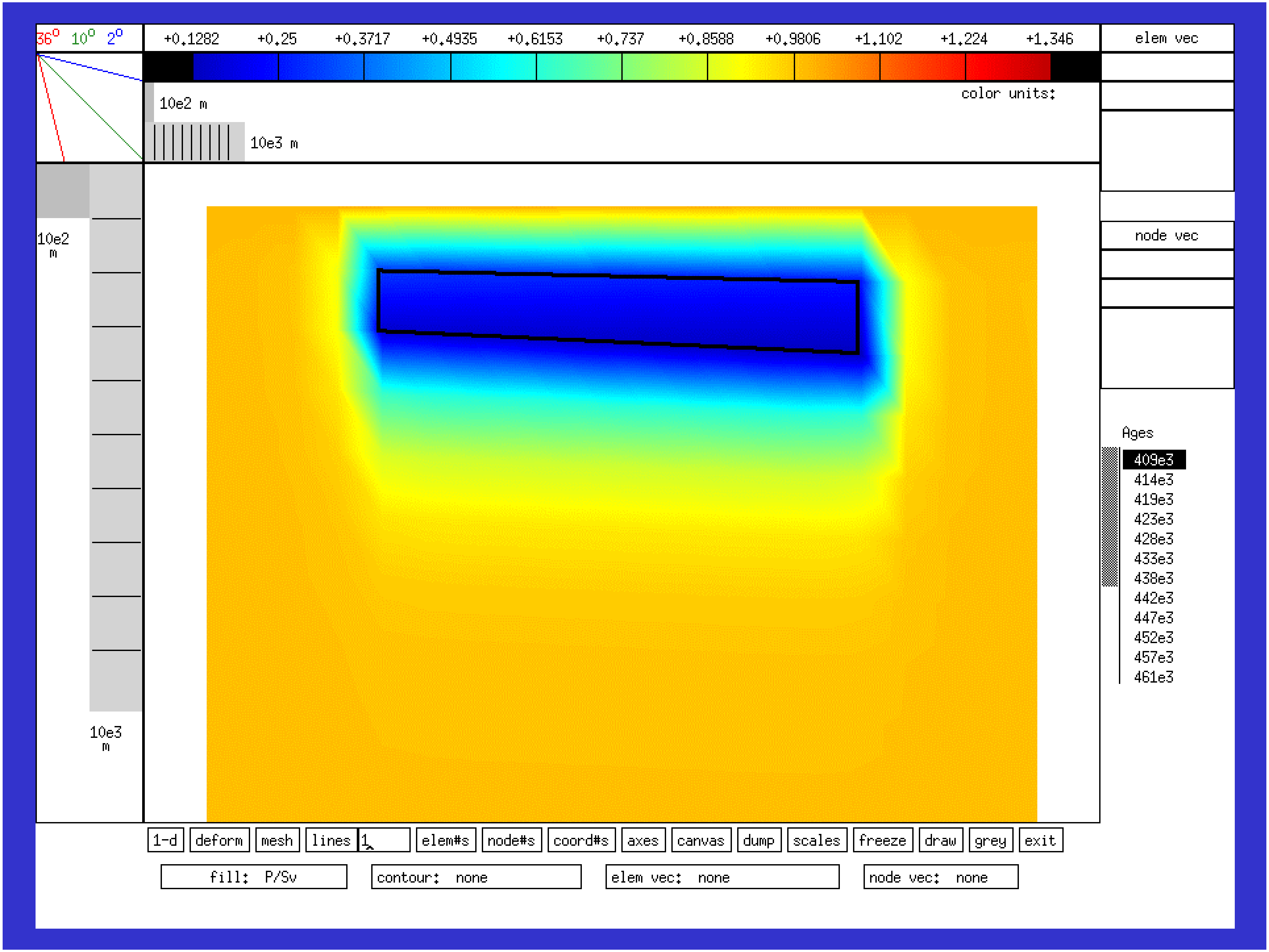
Flow Focussing By Sediment Loading

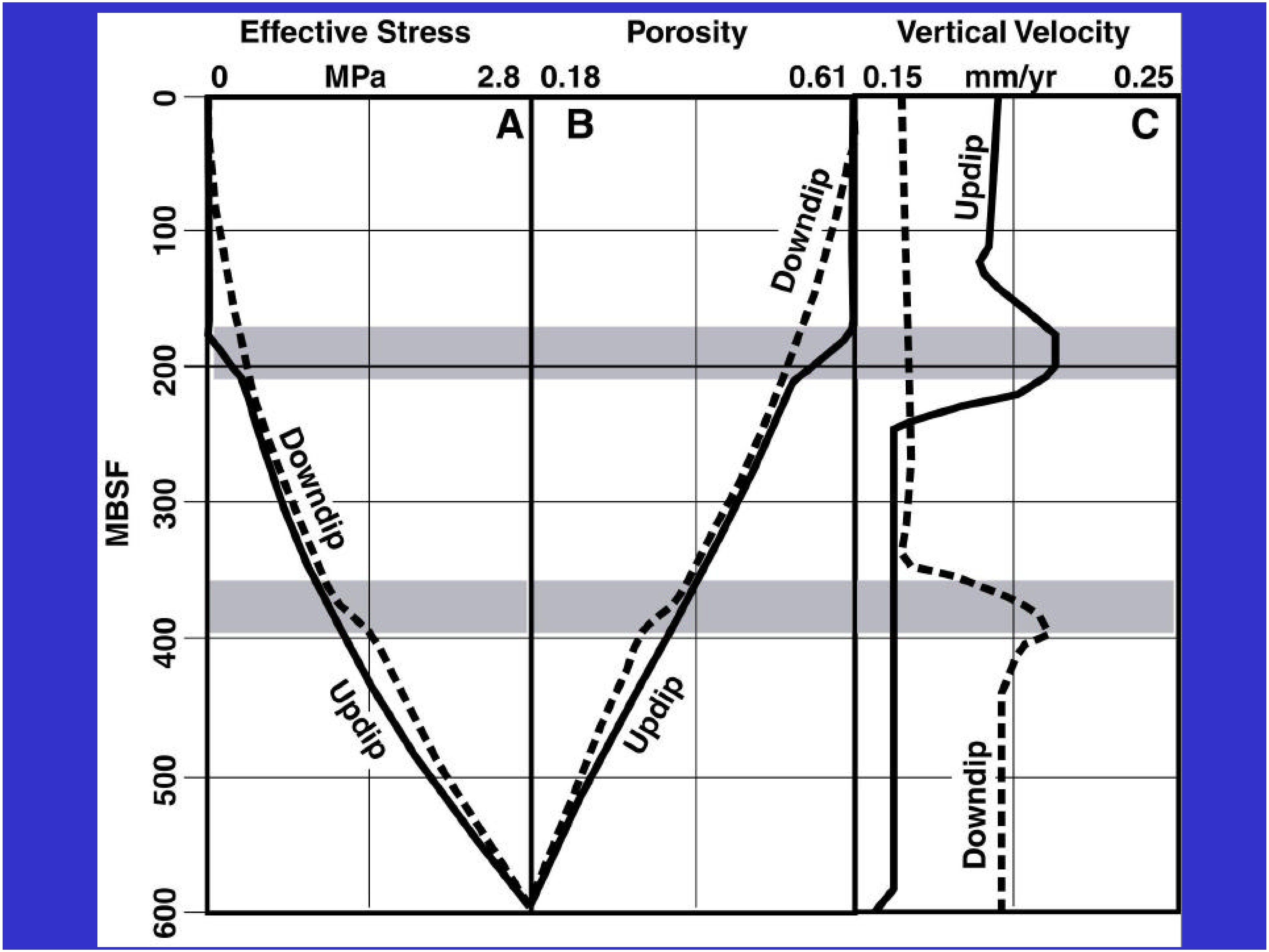


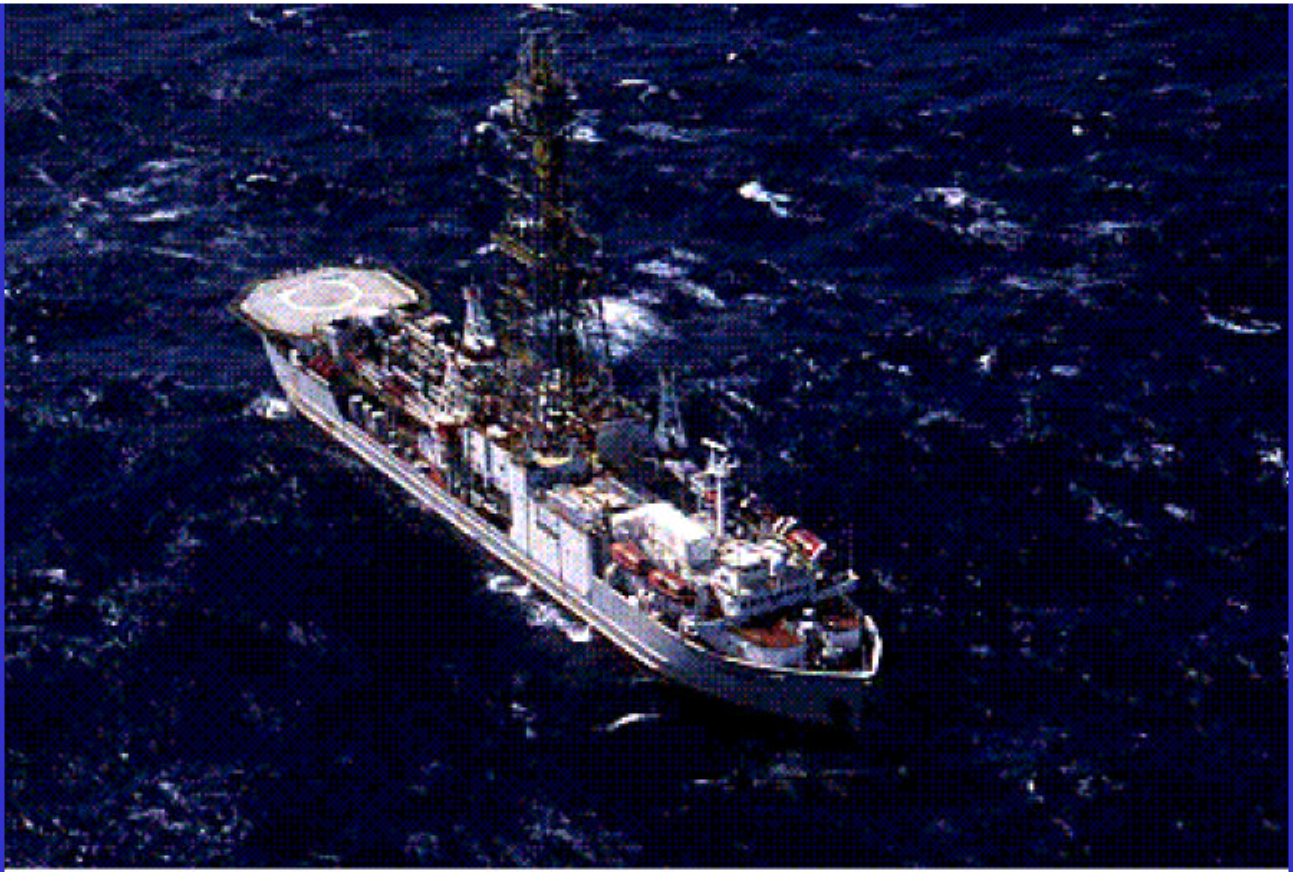
$$DP^* = (B\rho_b - \rho_f)g\frac{\int_l h(x)(z(x))dl}{l}$$



Updip Well
Downdip Well
1.0
0.95
0.9
0.85
0.8
0.75
0.7
0.65
0.6
100 m
1000 m


36° 10° 2°
+0.1282 +0.25 +0.3717 +0.4935 +0.6153 +0.737 +0.8588 +0.9806 +1.102 +1.224 +1.346
elem vec
color units:
10e2 m
10e3 m
10e2 m
10e3 m
node vec
Ages
409e3
414e3
419e3
423e3
428e3
433e3
438e3
442e3
447e3
452e3
457e3
461e3
1-d
deform
mesh
lines
1
elem#s
node#s
coord#s
axes
canvas
dump
scales
freeze
draw
grey
exit
fill: P/Sv
contour: none
elem vec: none
node vec: none


Effective Stress
0
MPa
2.8
Porosity
0.18
0.61
Vertical Velocity
0.15
mm/yr
0.25
A
B
C
MBSF
0
100
200
300
400
500
600
Downdip
Updip
Downdip
Updip
Updip
Downdip



JOIDES Resolution

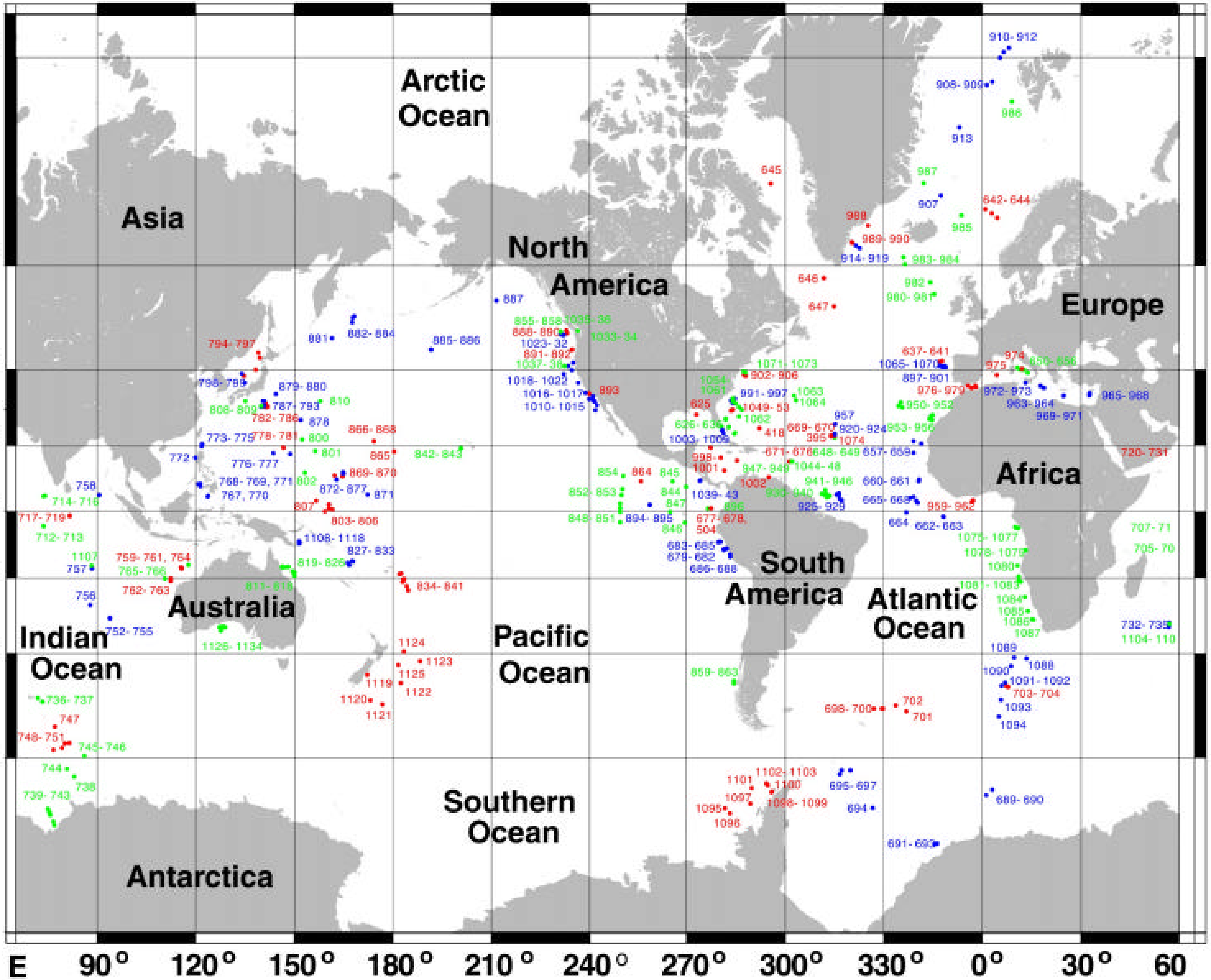
Riserless drillship

Continuous coring

Shipboard analysis

Water depth: 123 - 19620 ft

http://www-odp.tamu.edu



ODP Legs 100-182, Sites 625-1134

(from http://www-odp.tamu.edu)

New Technology for ODP

1) Piezoprobe

2) Wireline Packer

Present Technology

1) Whole Core, Wireline logs

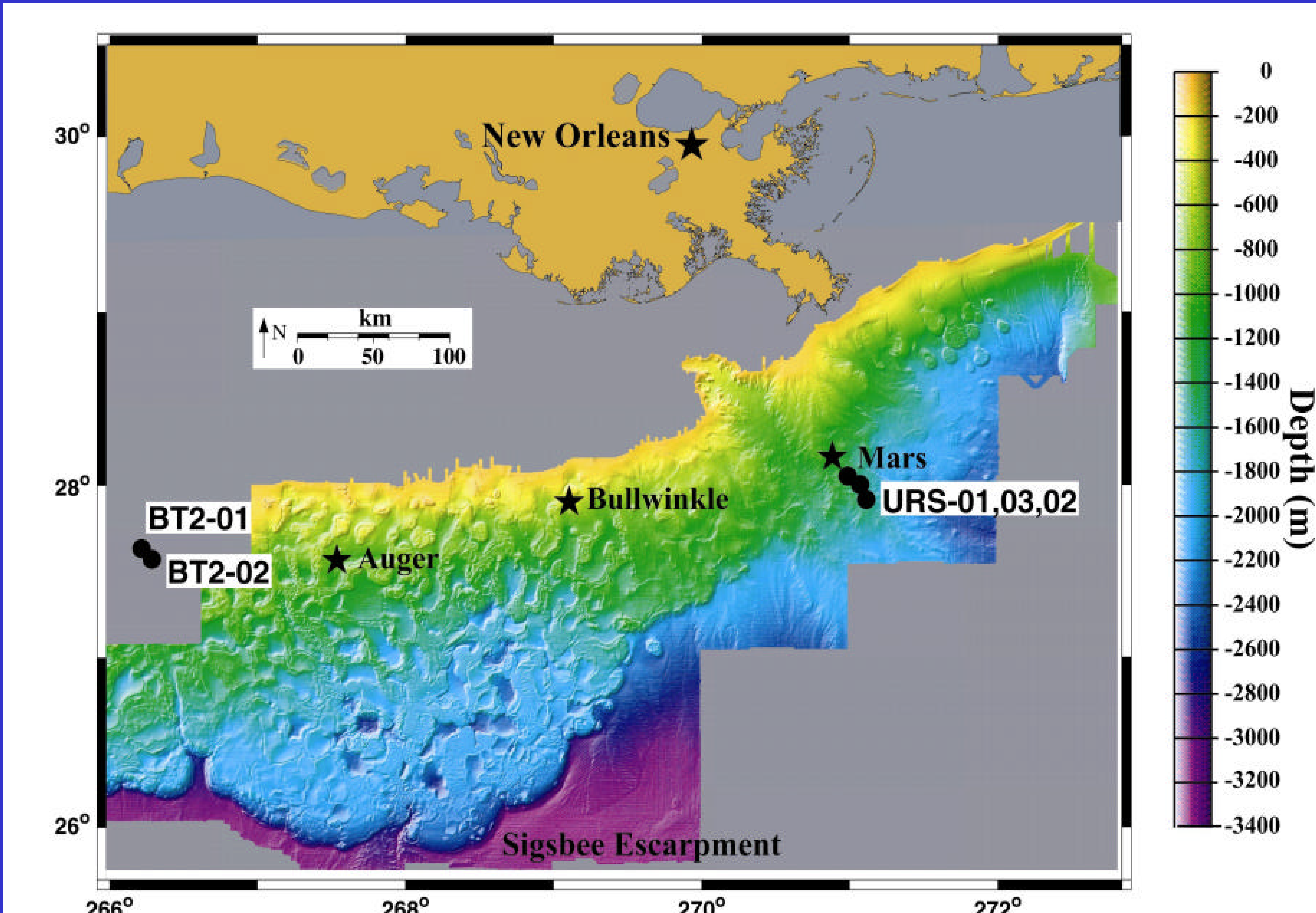
2) Temperature, Pore Fluid

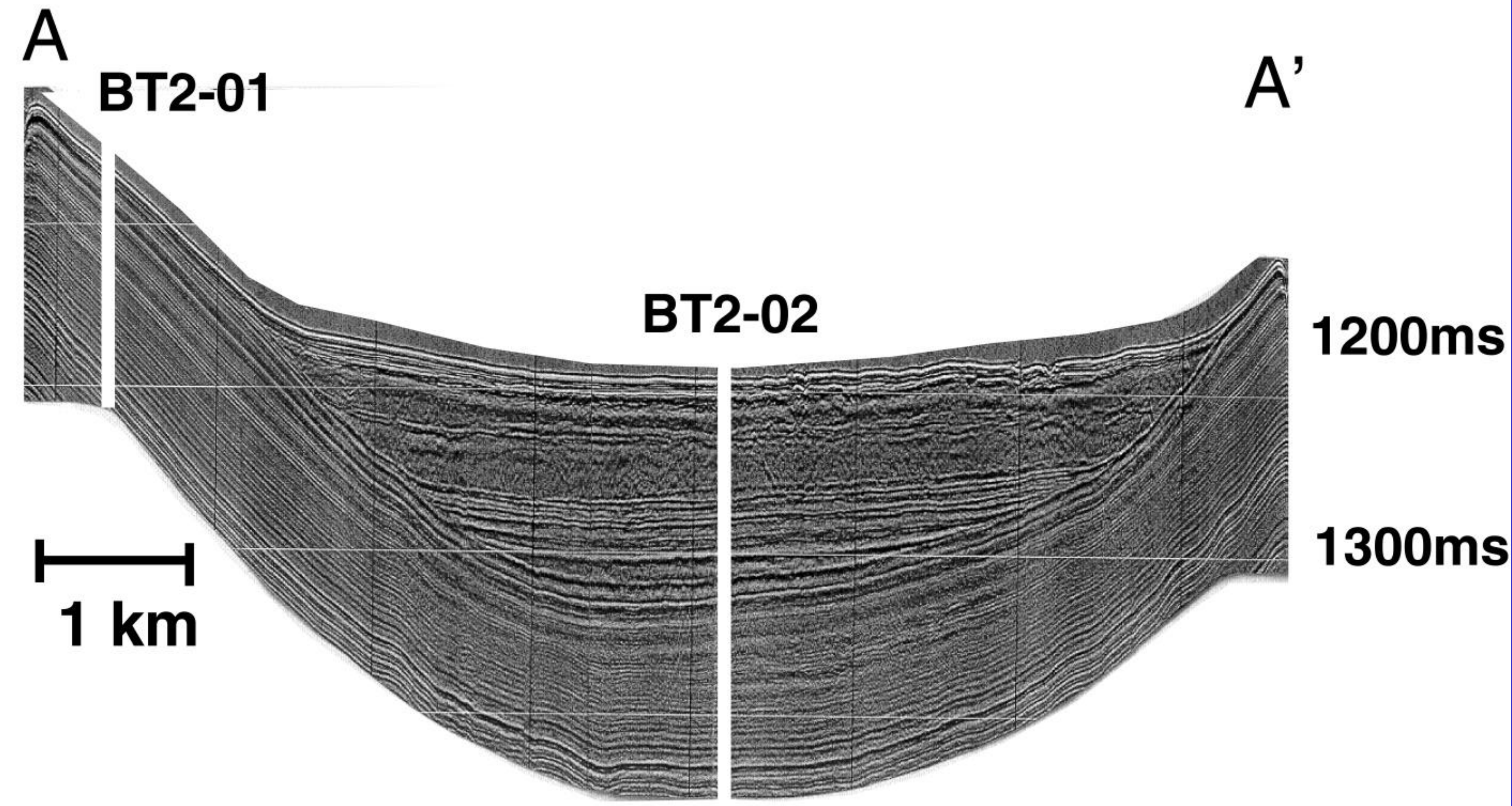
3) CORK-Long Term Monitoring

Proposal

Drill 2 End Members:

- **Normally Pressured (BT2)**
- **Overpressured (Ursa)**


New Orleans
Mars
URS-01,03,02
Bullwinkle
BT2-01
BT2-02
Auger
Sigsbee Escarpment
N
km
0
50
100
30°
28°
26°
266°
268°
270°
272°
Depth (m)
0
-200
-400
-600
-800
-1000
-1200
-1400
-1600
-1800
-2000
-2200
-2400
-2600
-2800
-3000
-3200
-3400



A
BT2-01
A'
BT2-02
1200ms
1300ms
1 km

Brazos Trinity Basin #2

1) Whole core

2) Pressure measurements with piezoprobe

3) Least Principal Stress

4) Full log suite

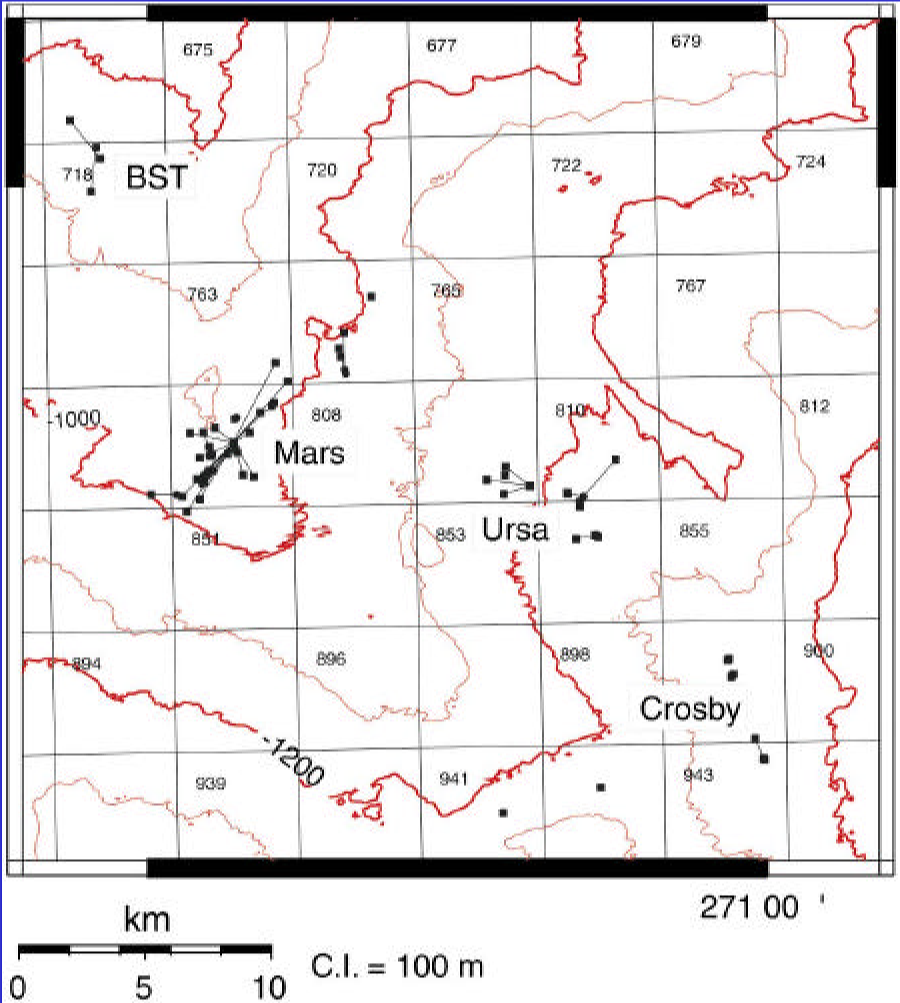
5) Temperature, Pore Fluid

Brazos Trinity Basin #2

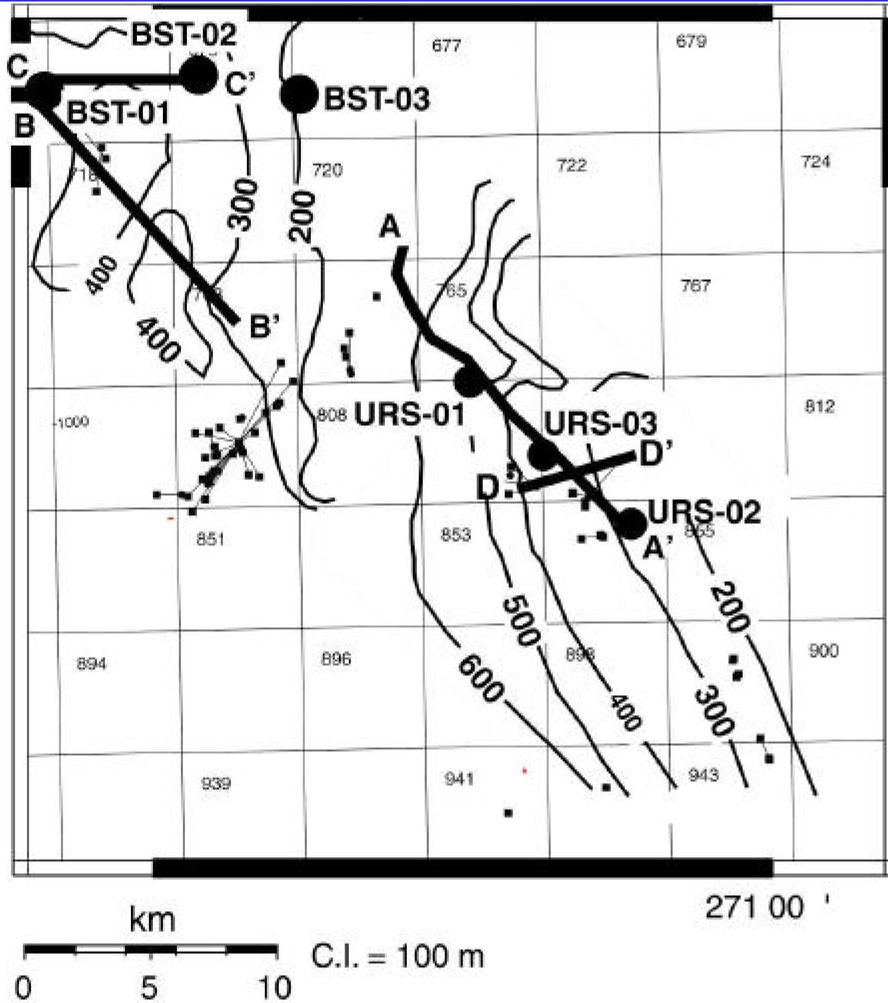
How do sediments behave between 100-1000 mbsf (The "Data Gap")?

What is the petrophysical response?

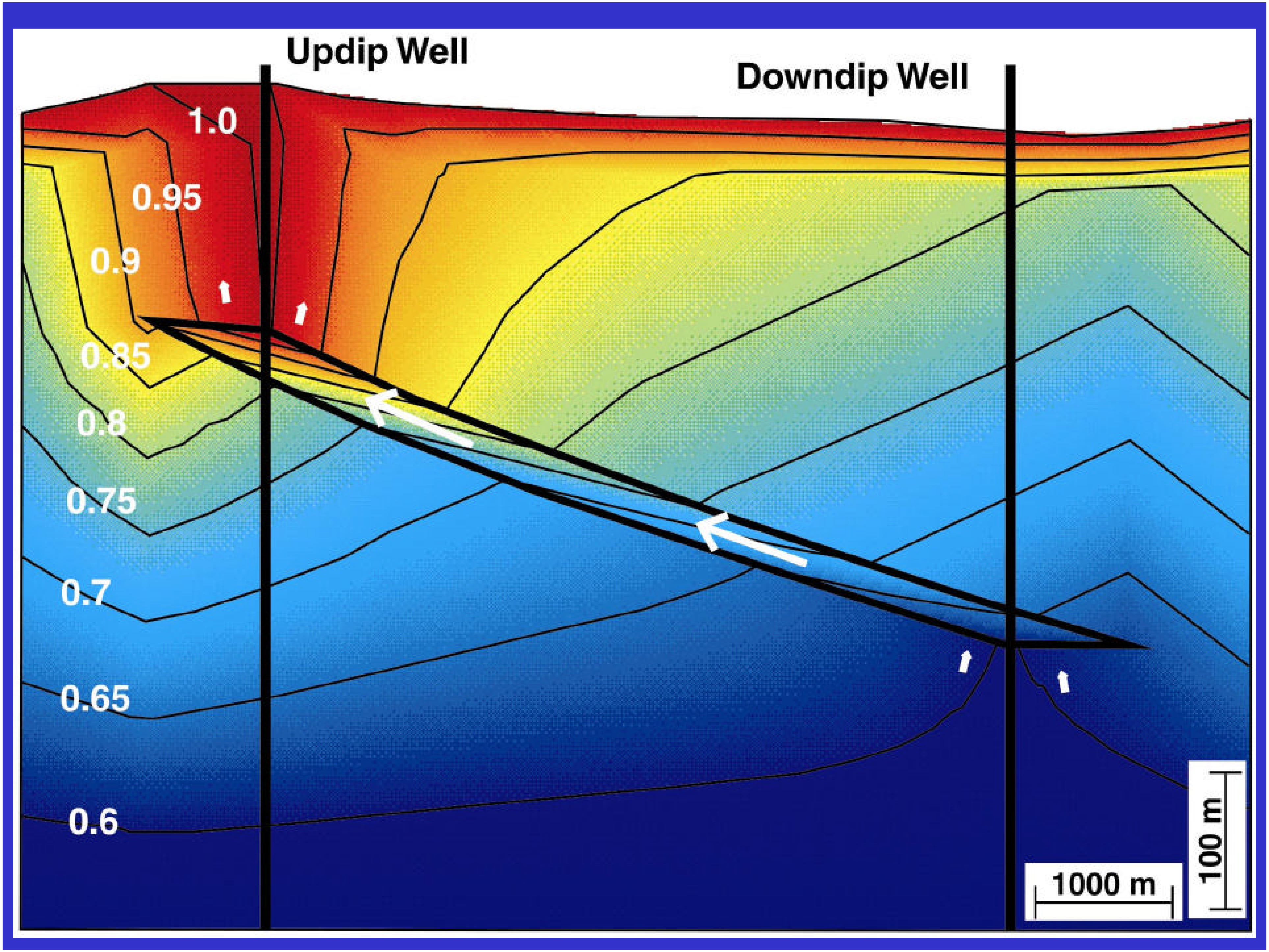
Linkage between compaction – permeability- rheology – hydrodynamic to1000 meters below mudline

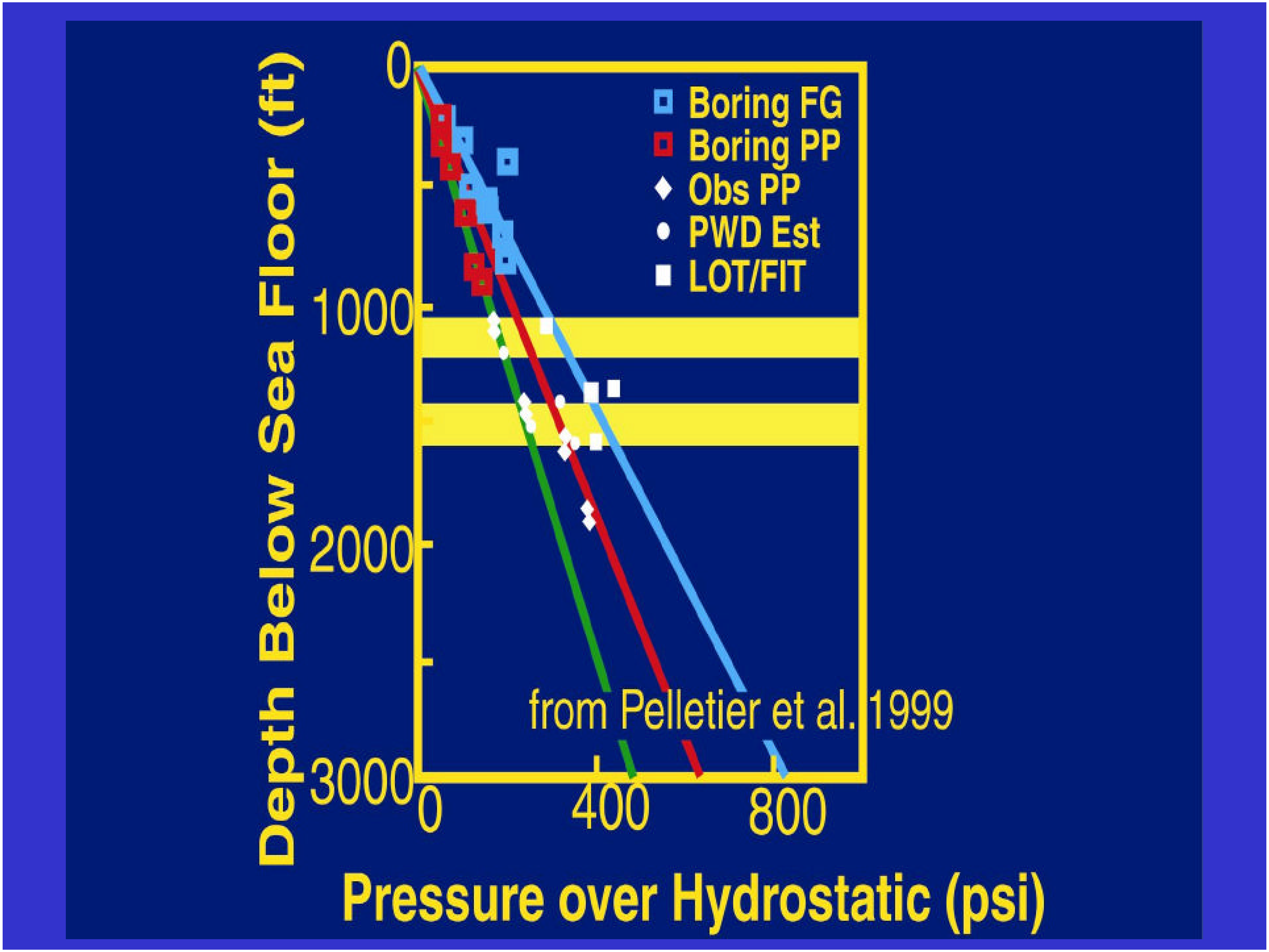


675
677
679
718
BST
720
722
724
763
765
767
-1000
Mars
808
810
812
851
853
Ursa
855
894
896
898
900
-1200
Crosby
939
941
943
271 00 '
km
0 5 10
C.I. = 100 m



BST-02
C
C'
BST-03
BST-01
B
677
679
718
720
722
724
300
200
400
400
B'
A
765
767
-1000
808
URS-01
URS-03
812
D'
D
URS-02
A'
851
853
855
500
200
894
896
898
900
600
400
300
939
941
943
271 00 '
km
0 5 10
C.I. = 100 m


Updip Well
Downdip Well
1.0
0.95
0.9
0.85
0.8
0.75
0.7
0.65
0.6
1000 m
100 m



Depth Below Sea Floor (ft)
0
1000
2000
3000
0
400
800
Boring FG
Boring PP
Obs PP
PWD Est
LOT/FIT
from Pelletier et al. 1999
Pressure over Hydrostatic (psi)

Ursa

Test Flow-Focussing

1) Do pressure and stress follow flow-focussing?

2) Does porosity map pressure? (Unloading?)

3) How does least principal stress vary?

Schedule

April 6: Response to reviews due to ODP (5 pages).

May 17, 2001: SSEPS Meeting
[Scientific Steering and Evaluation Panels]

July 2001: Site Survey Evaluation

August 2001: SciCom ranking
OPCOM scheduling

IF SUCCESSFUL – BETWEEN Nov.2002 and Sept. 2003 [6 unscheduled Legs]

Industry/Academic/ODP Interaction

Conoco OBC proposed for 2001.

Discussions under-way for add-on science

Fugro-ODP working for application of tools on *J.R.*

Data Release in progress (3D Hi-Res, Lo-Res, Logs, geotechnical)

Solutions for Seismic Reservoir Characterization

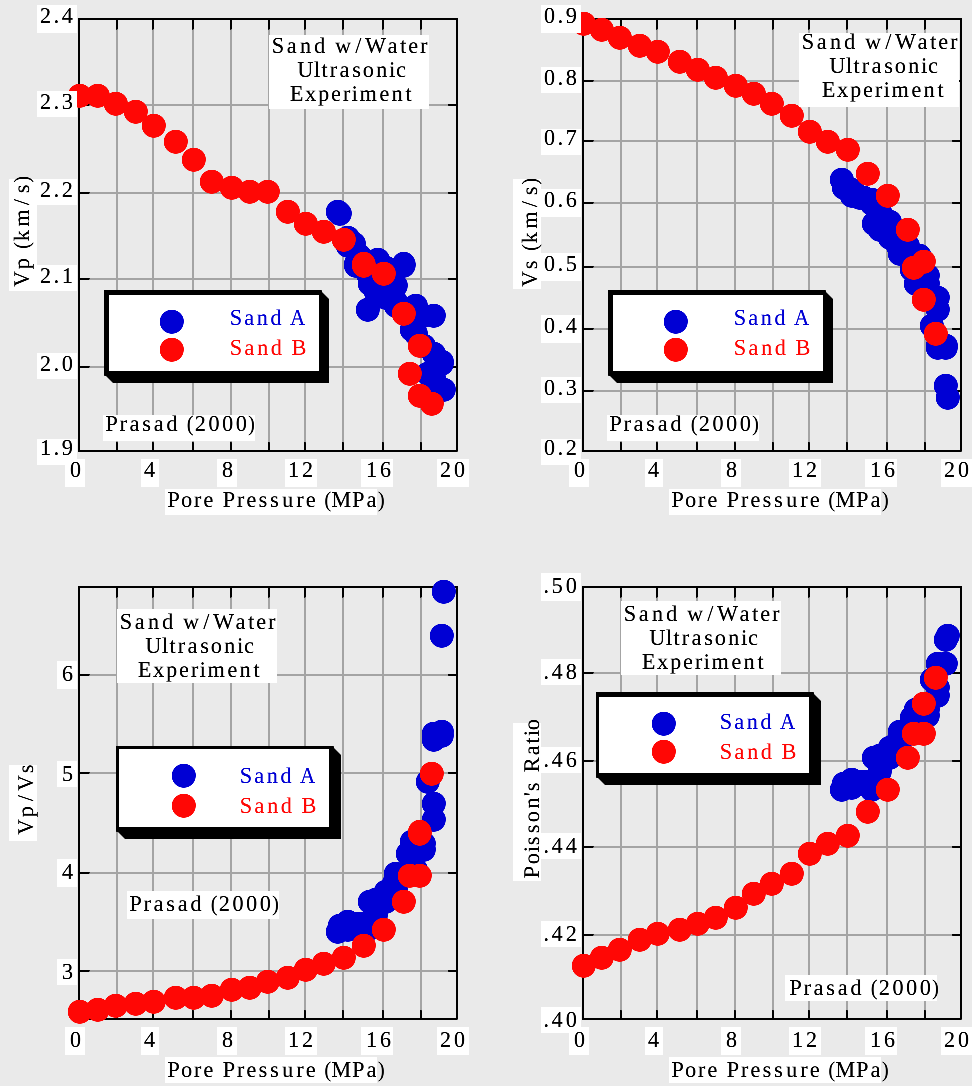
Rock Physics of High Pore Pressure

Jack Dvorkin
and
Joel Walls

ROCK SOLID IMAGES

1. SANDS WITH WATER

Pore pressure in sands w/water acts to reduce the velocity and elevate Vp/Vs and Poisson's ratio

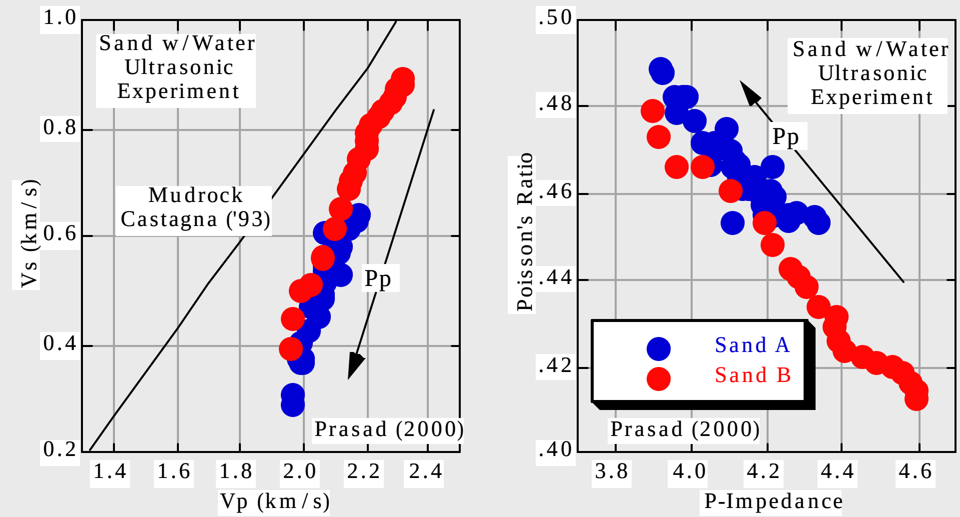


$$n \equiv PR = \frac{1}{2}\frac{(Vp/Vs)^2 - 2}{(Vp/Vs)^2 - 1}$$

ROCK SOLID images

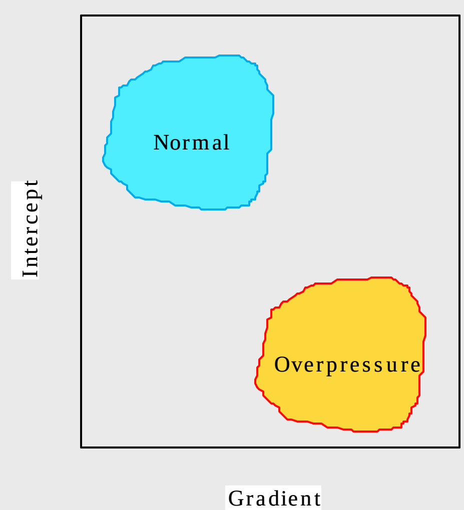
Solutions for Seismic Reservoir Characterization

Vp/Vs relations in overpressured water sand deviate from existing models

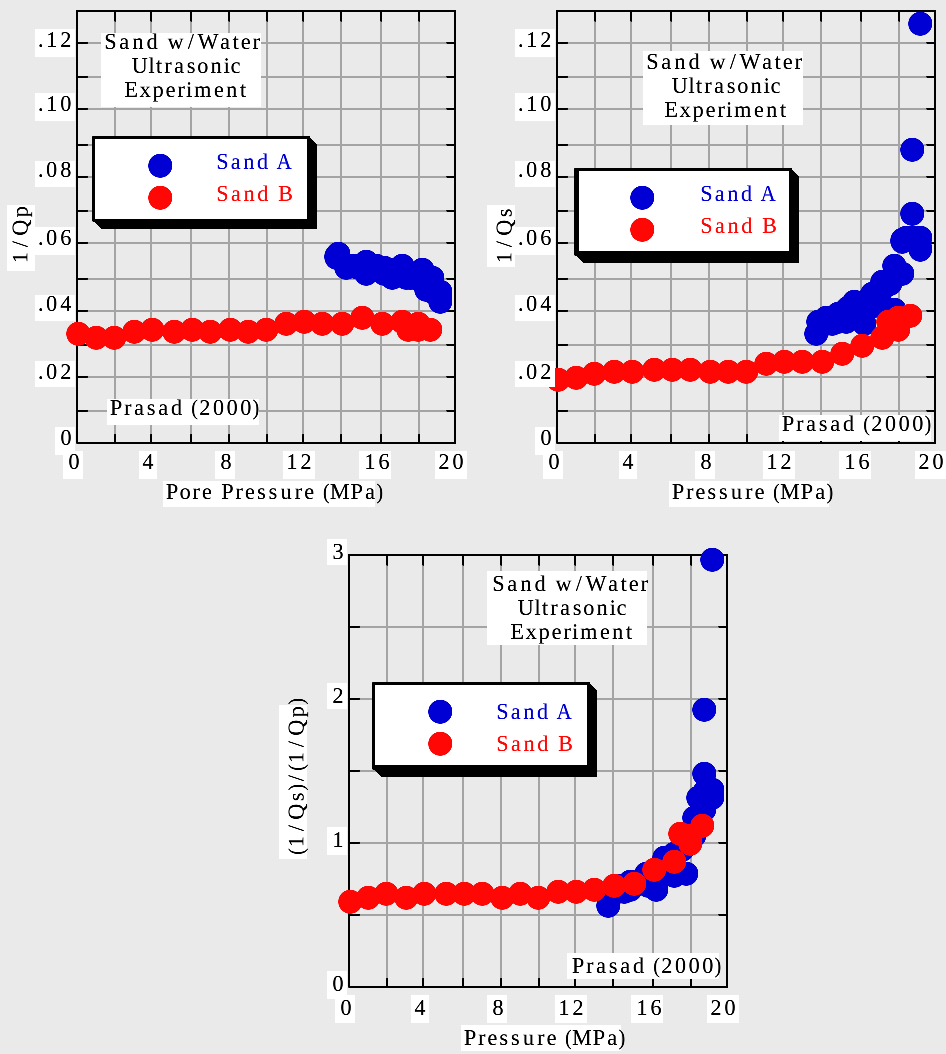


This effect is basis for overpressured sand detection

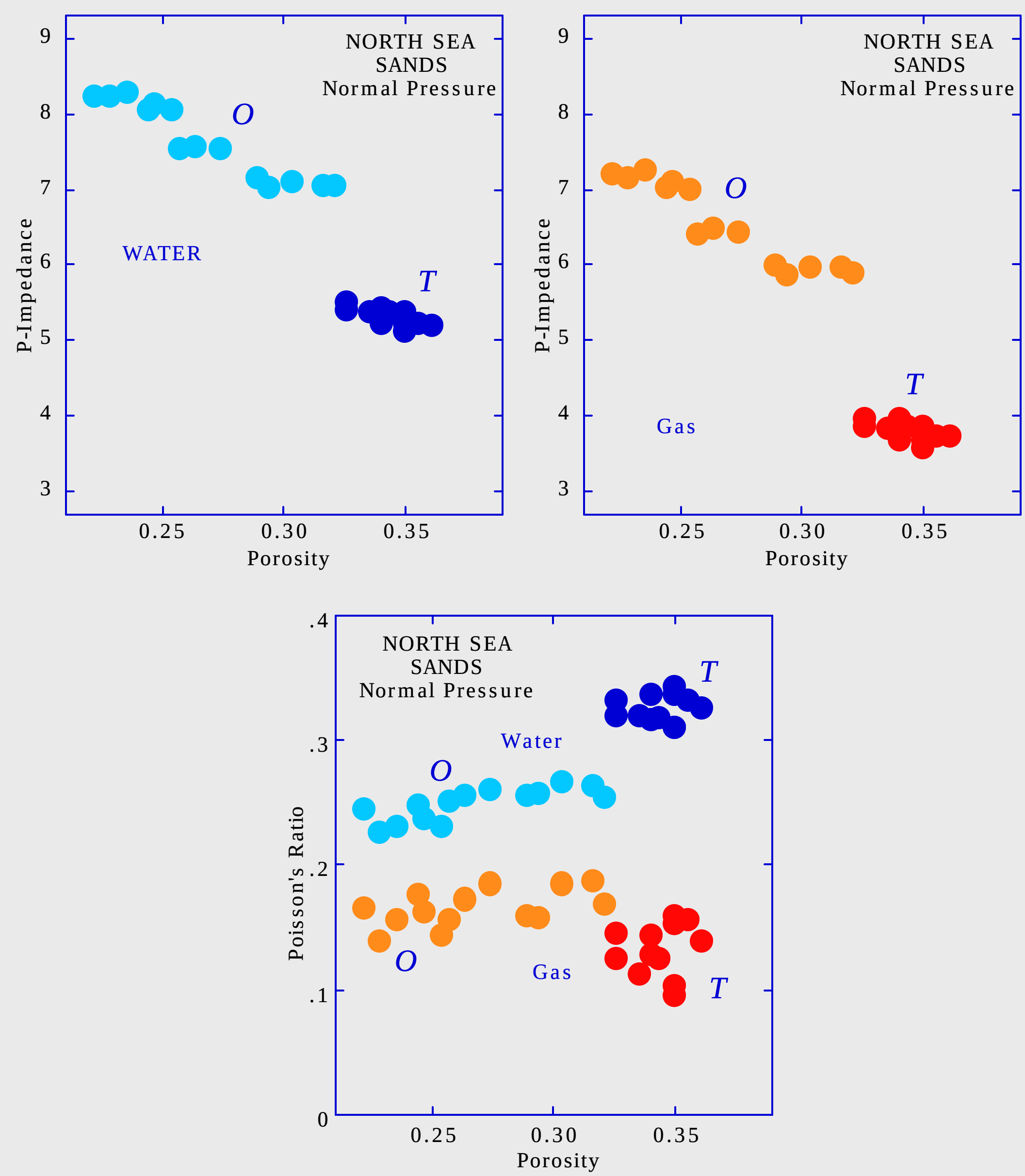
$$R(q) \approx \underbrace{d\left(\frac{\ln I_p}{2}\right)}_{\textbf{Intercept}} + \underbrace{d\left(\frac{1}{1-n} - \frac{\ln I_p}{2}\right)}_{\textbf{Gradient}} \sin^2 q$$



Attenuation is another factor that helps in overpressured water sand detection



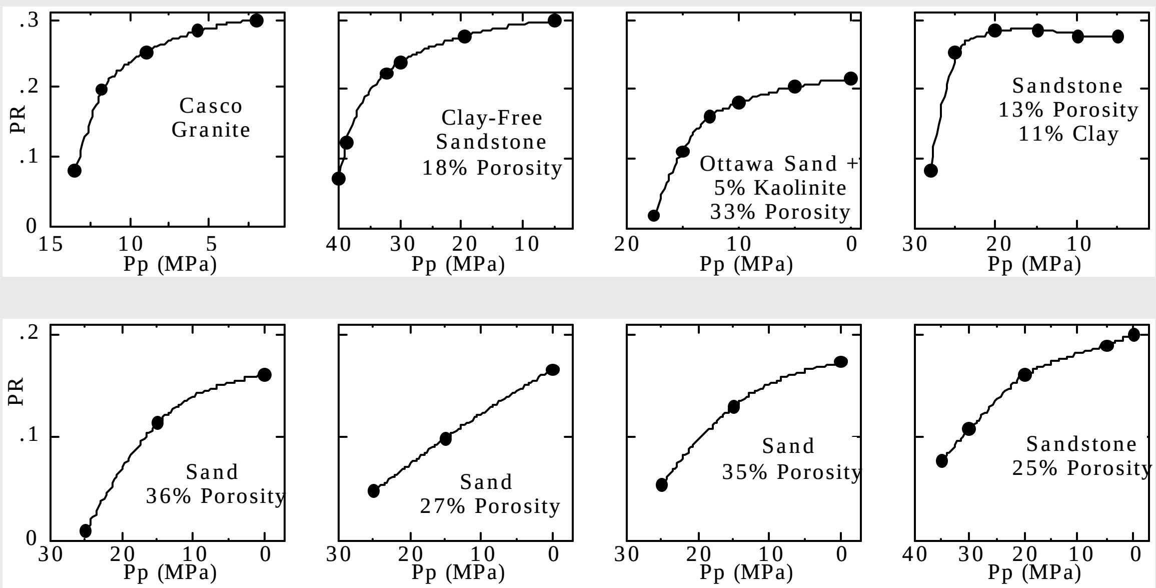
Physics: Pore pressure makes sand softer



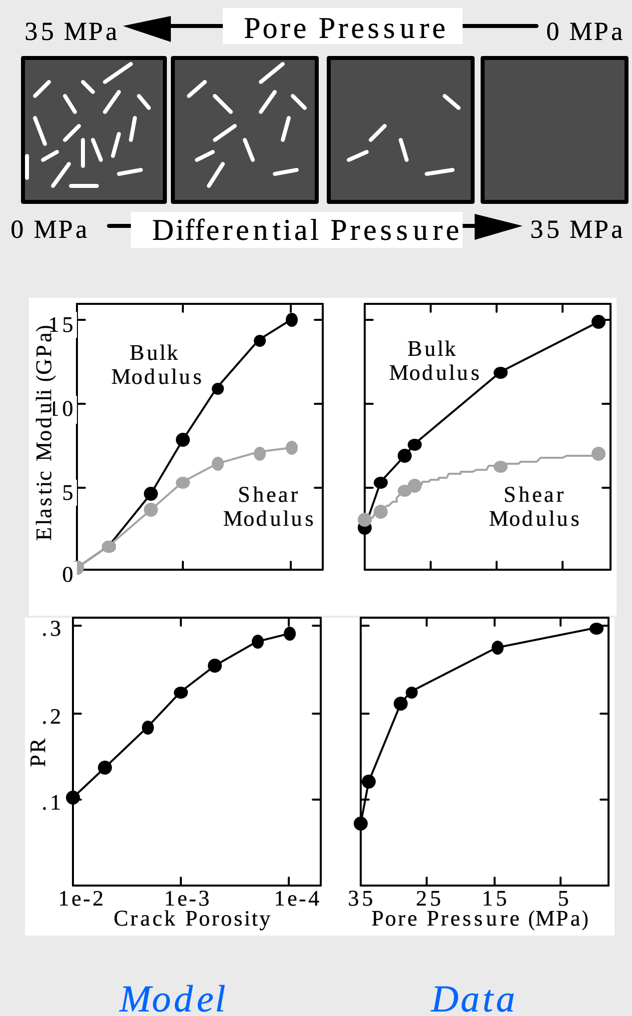
2. SANDS WITH GAS

Rocks with gas often behave opposite to rocks with water:

Poisson's (and Vp/Vs) ratio decrease with increasing pore pressure

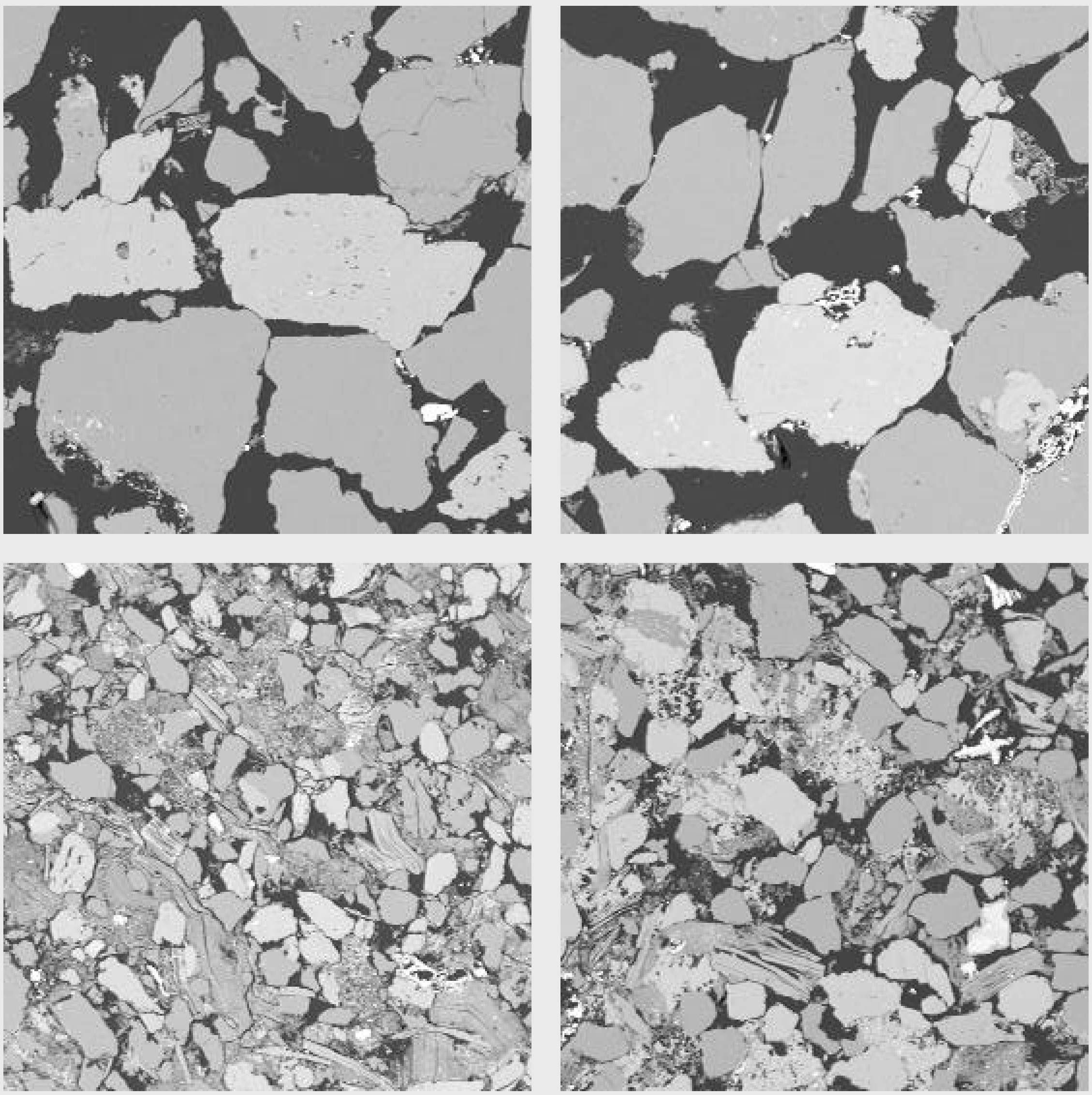


Physics: Pressure opens compliant cracks

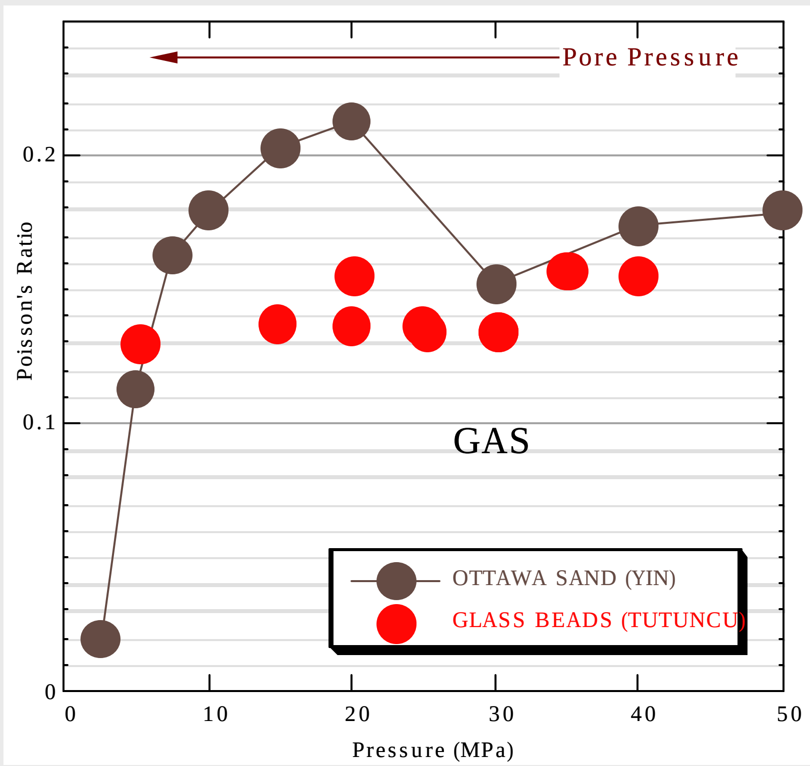


Solutions for Seismic Reservoir Characterization

Compliant cracks do exist in granular sands as grain contacts

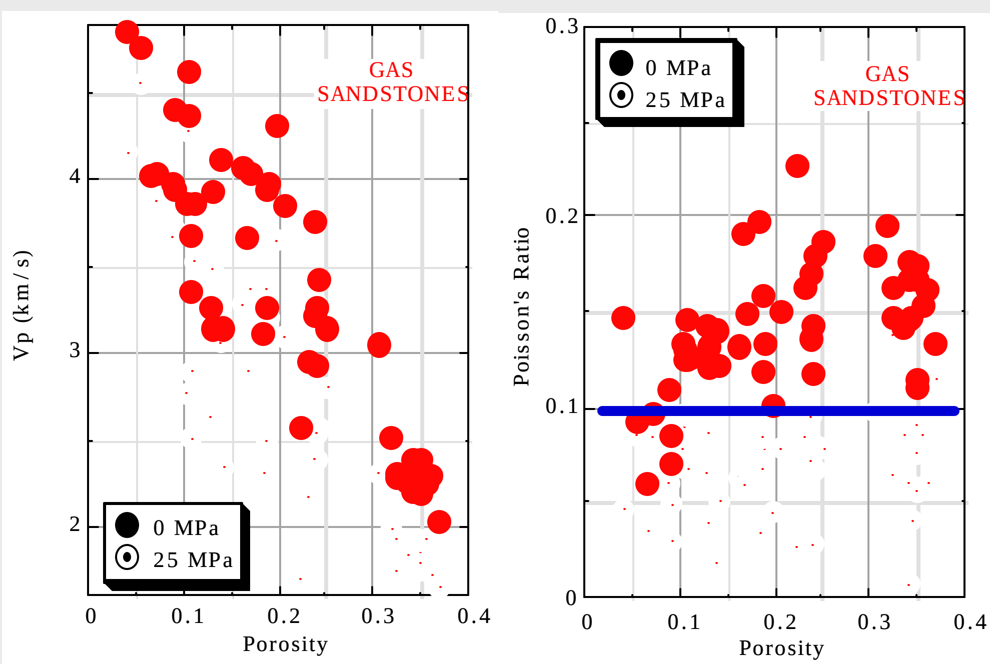


Compliant cracks do exist in granular sands as grain contacts



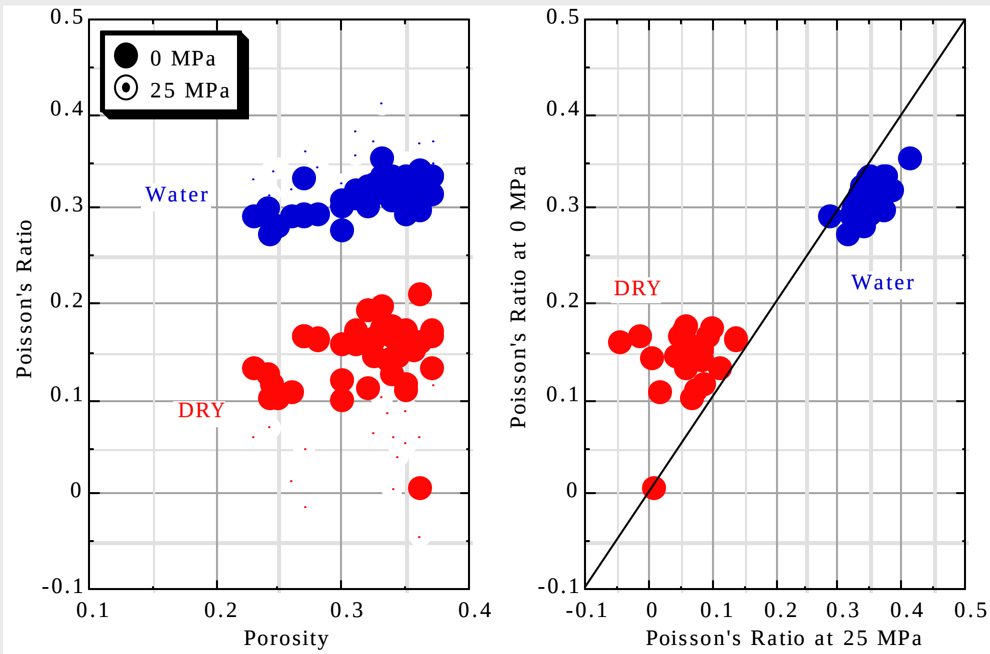
Importance for pore pressure prediction:

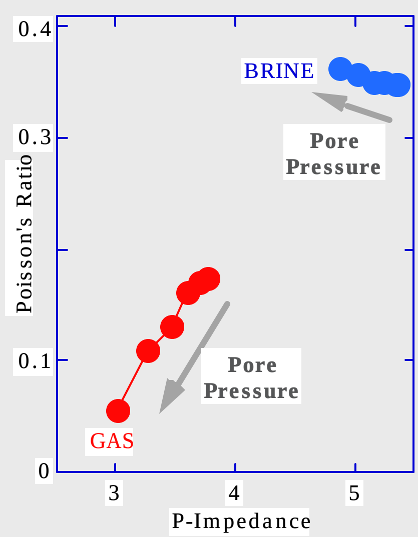
Velocity depends on many factors while Poisson's ratio is universal in sands



3. JOINT PRESSURE AND FLUID IDENTIFICATION

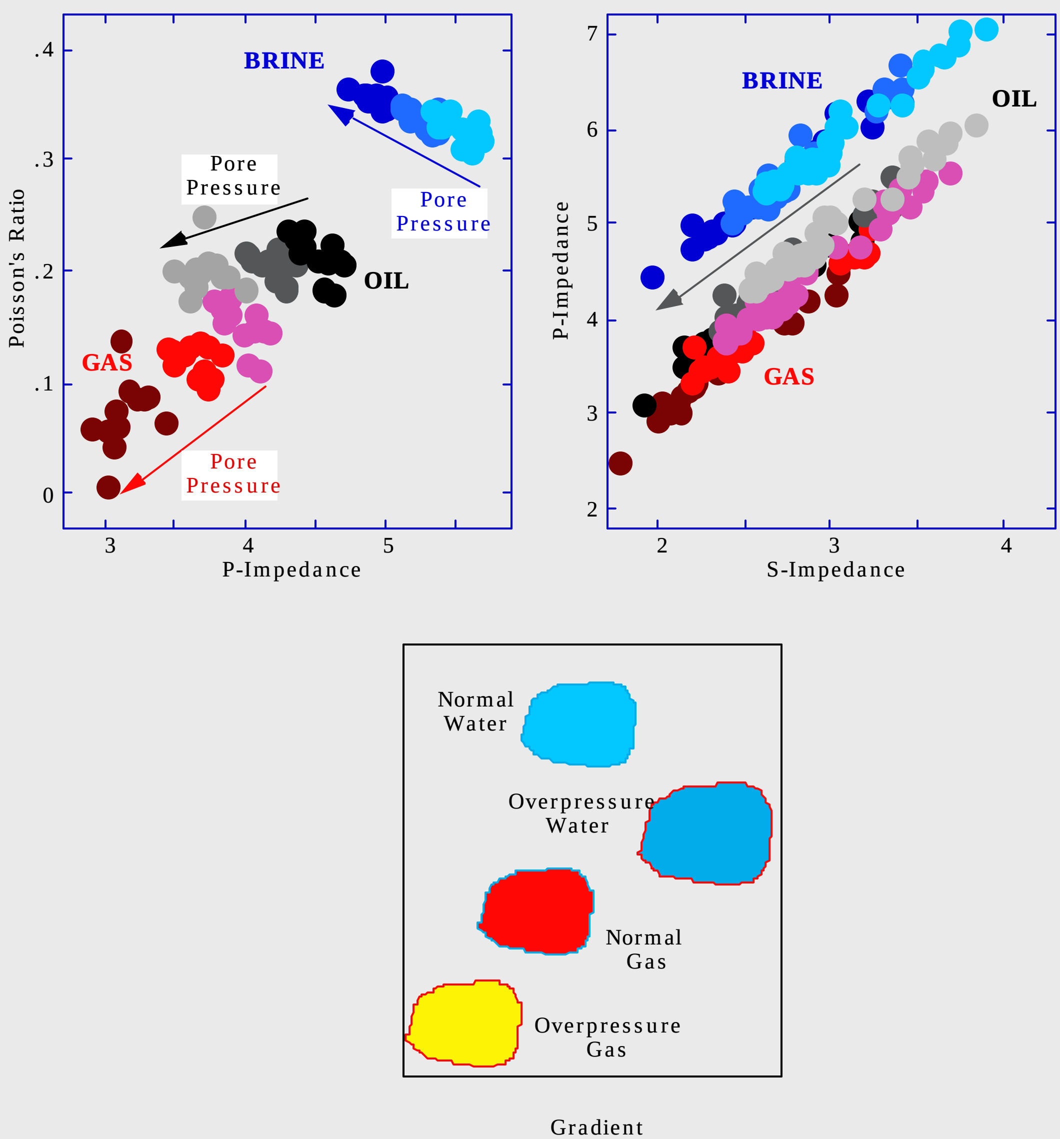
Combined P- and S-wave data can help predict Fluid and Pressure





Solutions for Seismic Reservoir Characterization

Diagrams for fluid and pressure prediction



Quantification of Shallow Water Flow Zones Using Prestack Inversion of Seismic Data

Nader C. Dutta and Rob de Kok

WesternGeco, Houston

Geohazard Workshop, Del Lago

April 3, 2001

Outline

- Introduction
- SWF Identification: Proposed methodology
  - Four-step process
  - Use of conventional p-wave seismic data
  - GA Pre-stack seismic inversion (key step)
- Example application (Ursa site)
- Conclusion

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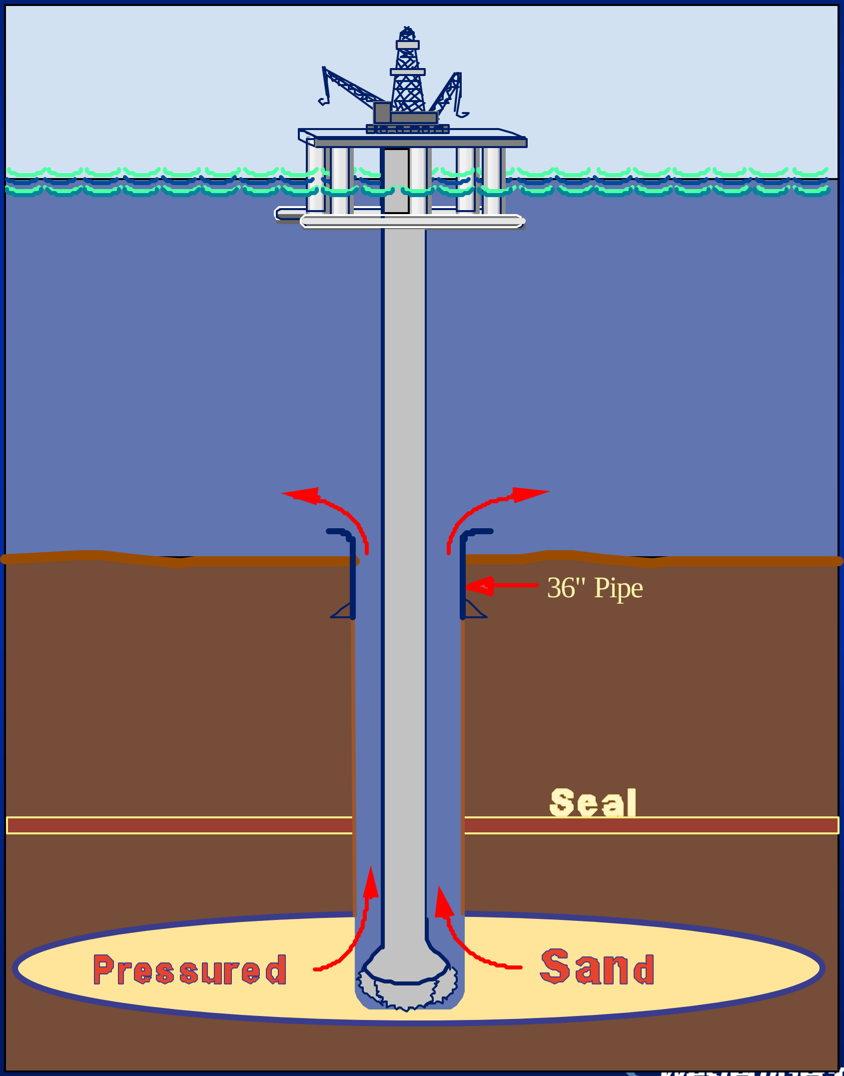
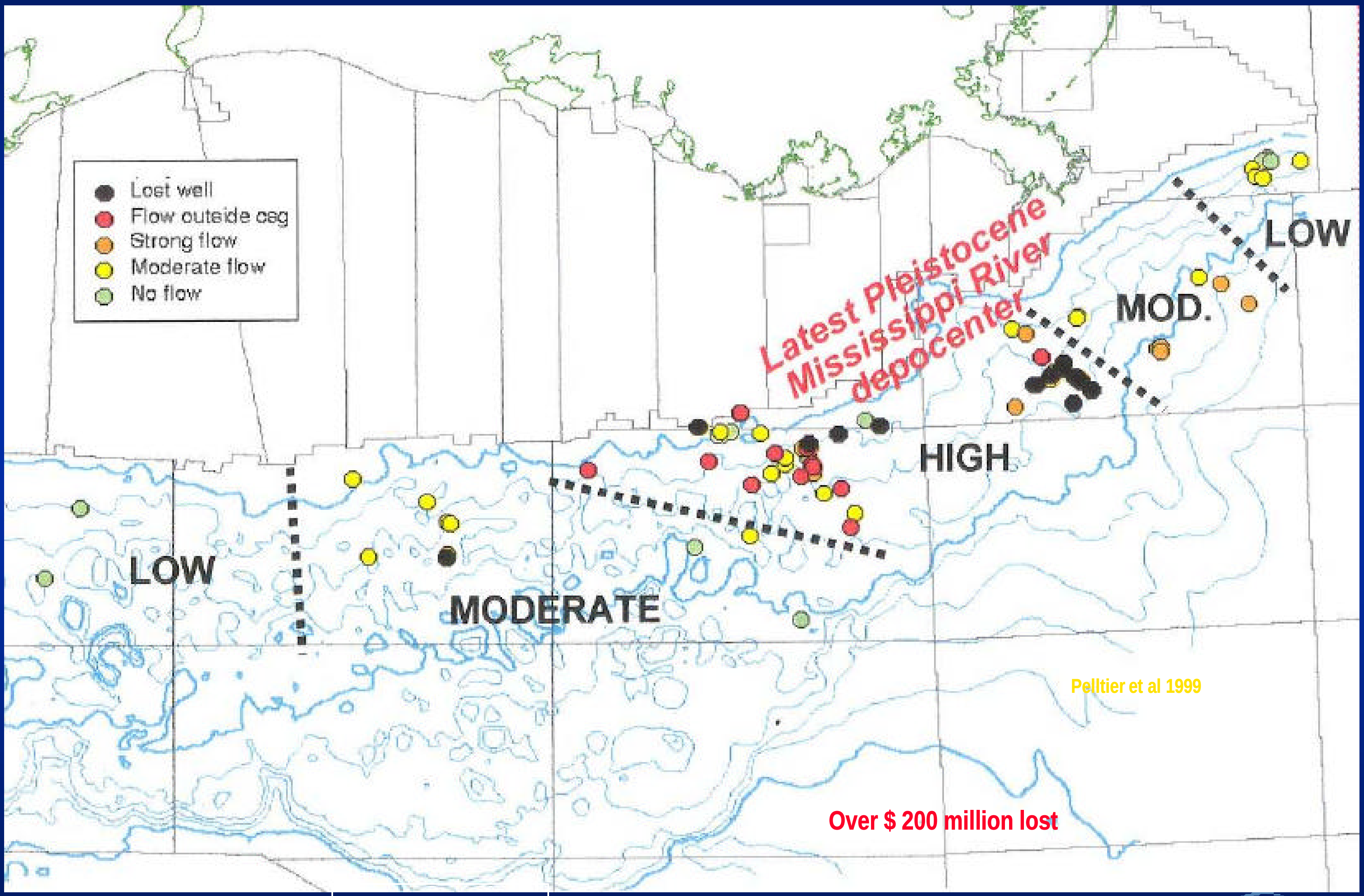
Shallow Water Flow (SWF): Geopressured Sands

- It is a Deepwater Problem
- Seal must be present (Typically between 1200'- 2000' bml)
- Flow typically increases with time
- Significant Sediment pile up at well head
- Usually the result of:
  - Compaction disequilibrium, or
  - Differential compaction



Shallow Waterflow Hazard in the Gulf of Mexico



After J.P. Pelletier, et. al.

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SWF Evaluation Process: Four-step Process

1. Stratigraphic Evaluation
- Where are SWF Sands?
- Can it Flow?

4. Pore Pressure /FG Analysis
- Is there energy to flow?
- Can it be held back?

Well Plan

2 ms processing
Interpretation

Use rock model to compute PP / FG
Using high frequency velocities (P and S from GA inversion

2. Seismic Attribute Analysis
- Visualize 'risky' areas
- How likely is the flow?

3. GA-Inversion For Rock Properties
- What are SWF characteristics?
- Water-Sand Vs Gas-Sand?

Reconnaissance AVO Analysis

Obtain Vp / Vs ratios from GA Inversion

1) Stratigraphic interpretation

- Interpretation of
  - anomalous amplitudes
  - sea bottom features
  - faults
- Products
  - 2D sections showing SWF boundaries
  - Maps showing SWF outlines

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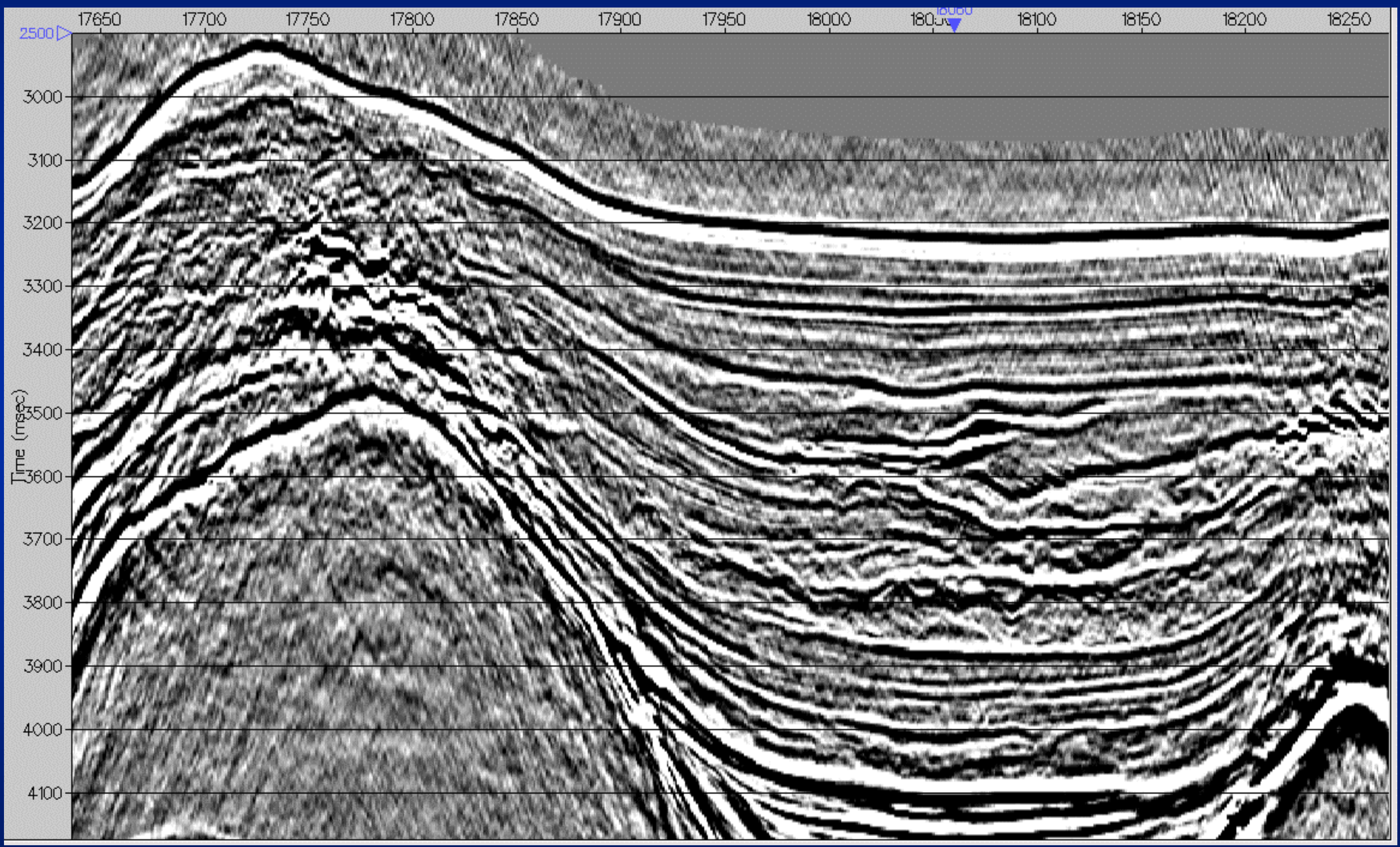
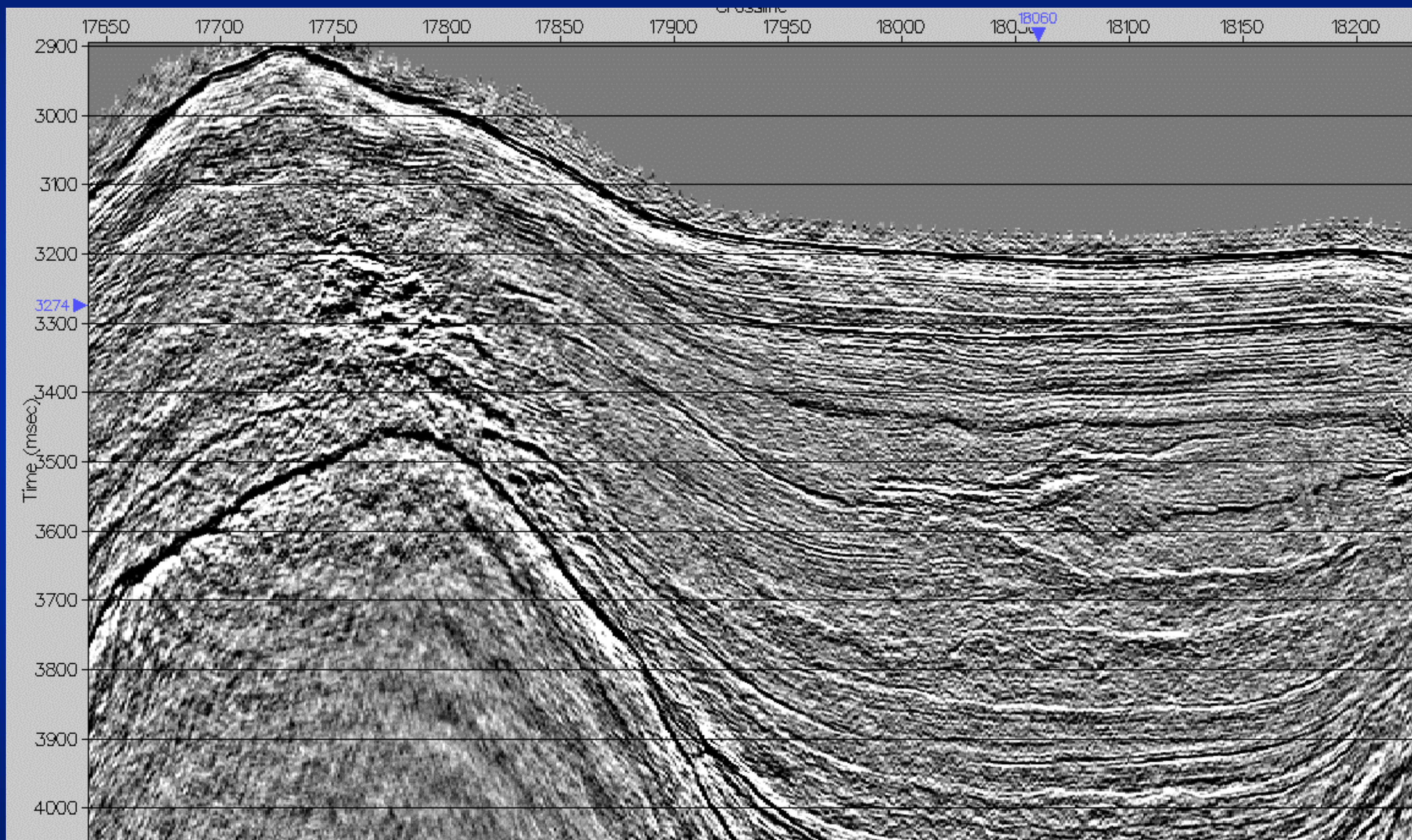
Line C: 4 ms processing



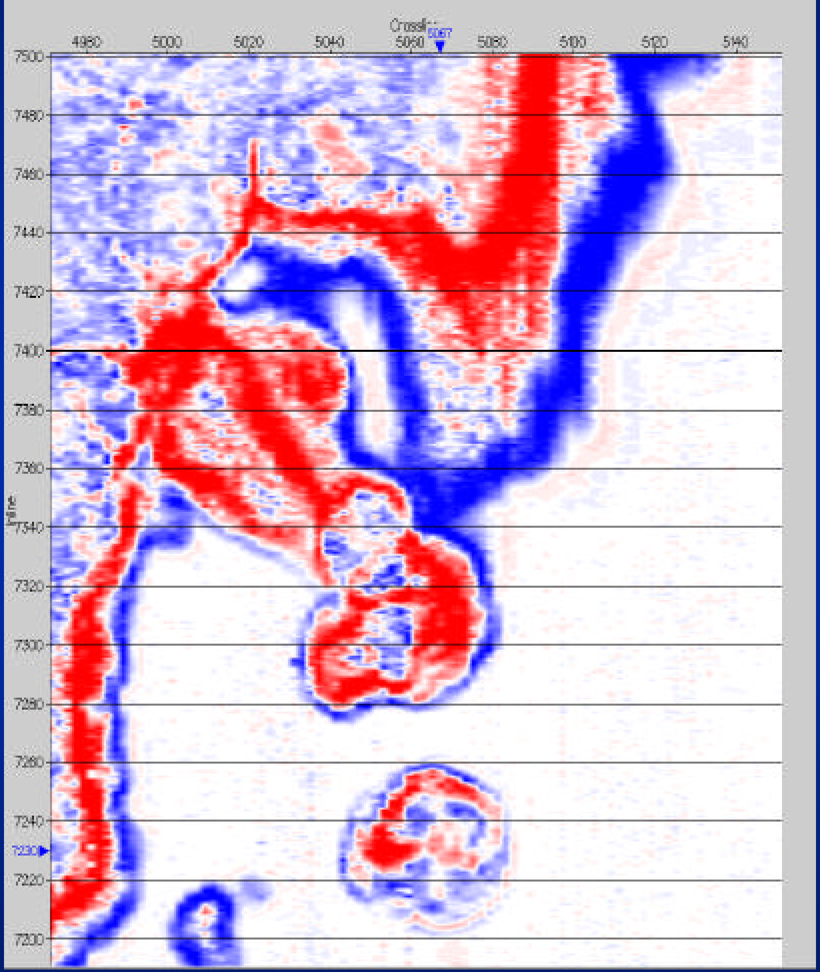
© 2000
Initials Date 7 of NN

Line C: 2 ms processing (high_Resolution)

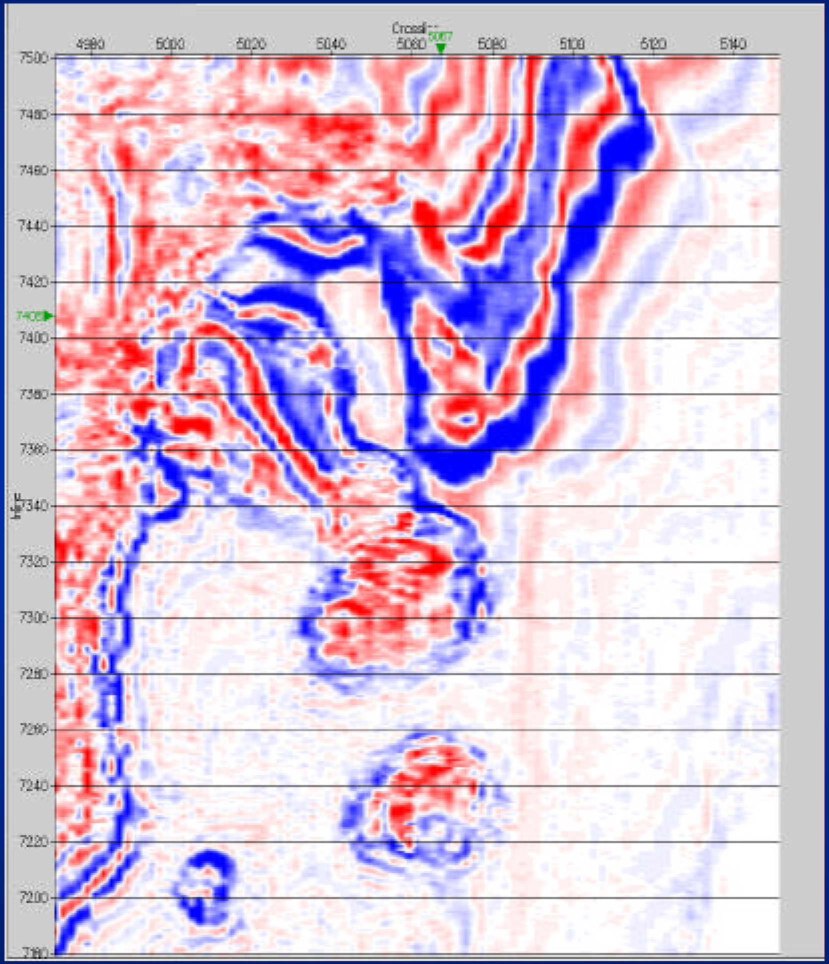


Timeslice

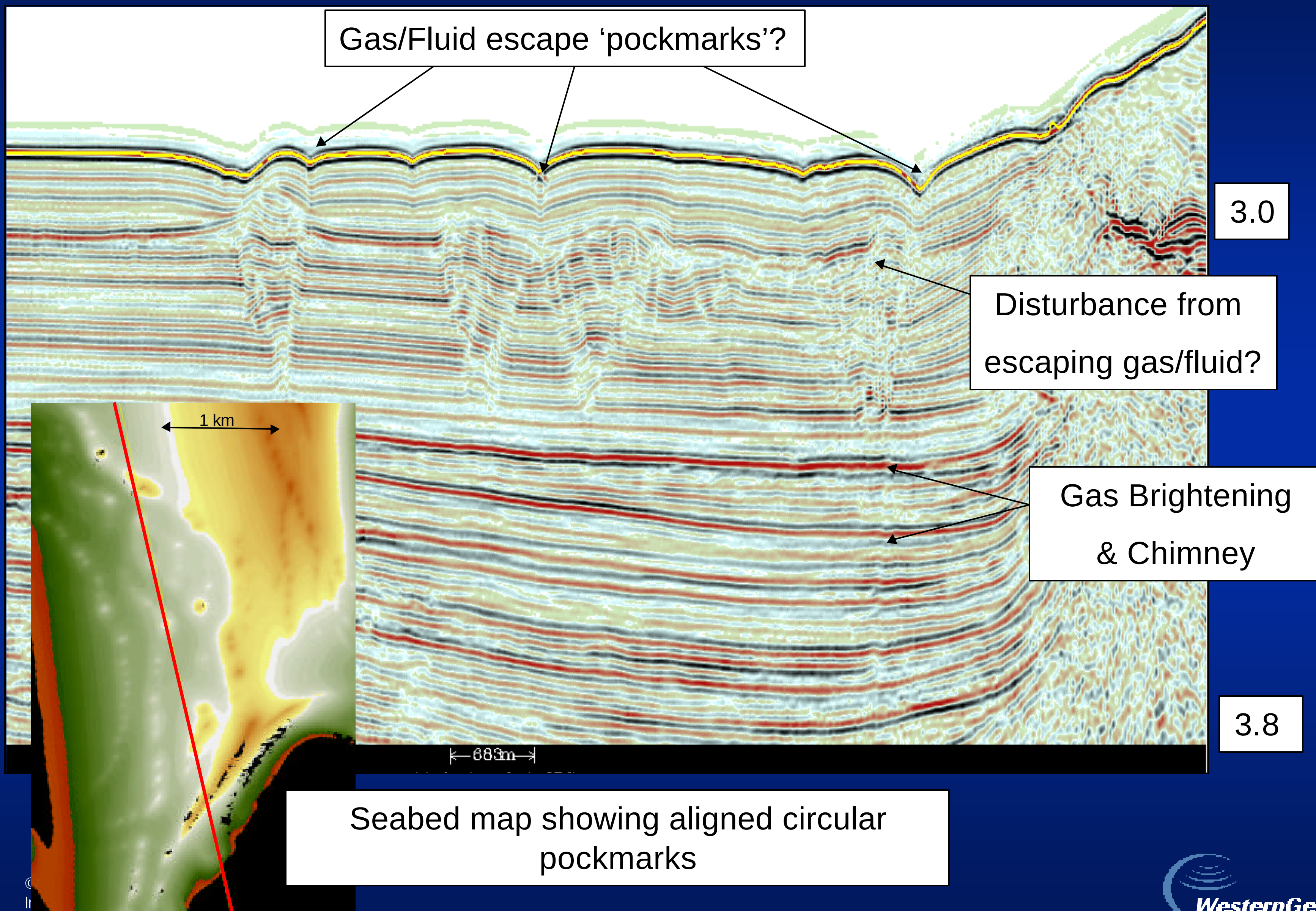
4ms cube with production signal processing



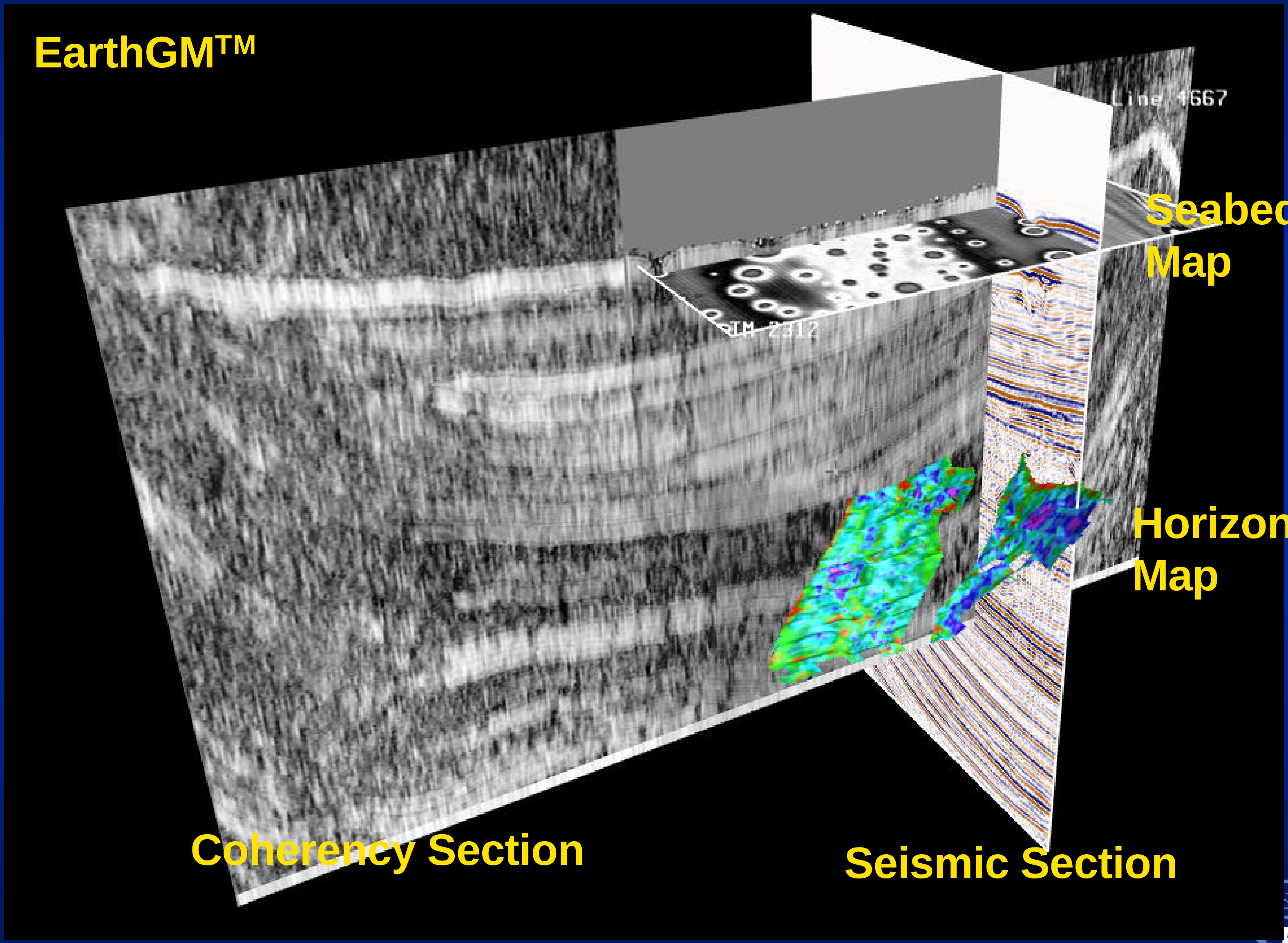
2ms cube with high resolution signal processing



Gas Escape Features



Composite 3D View of Pockmarks



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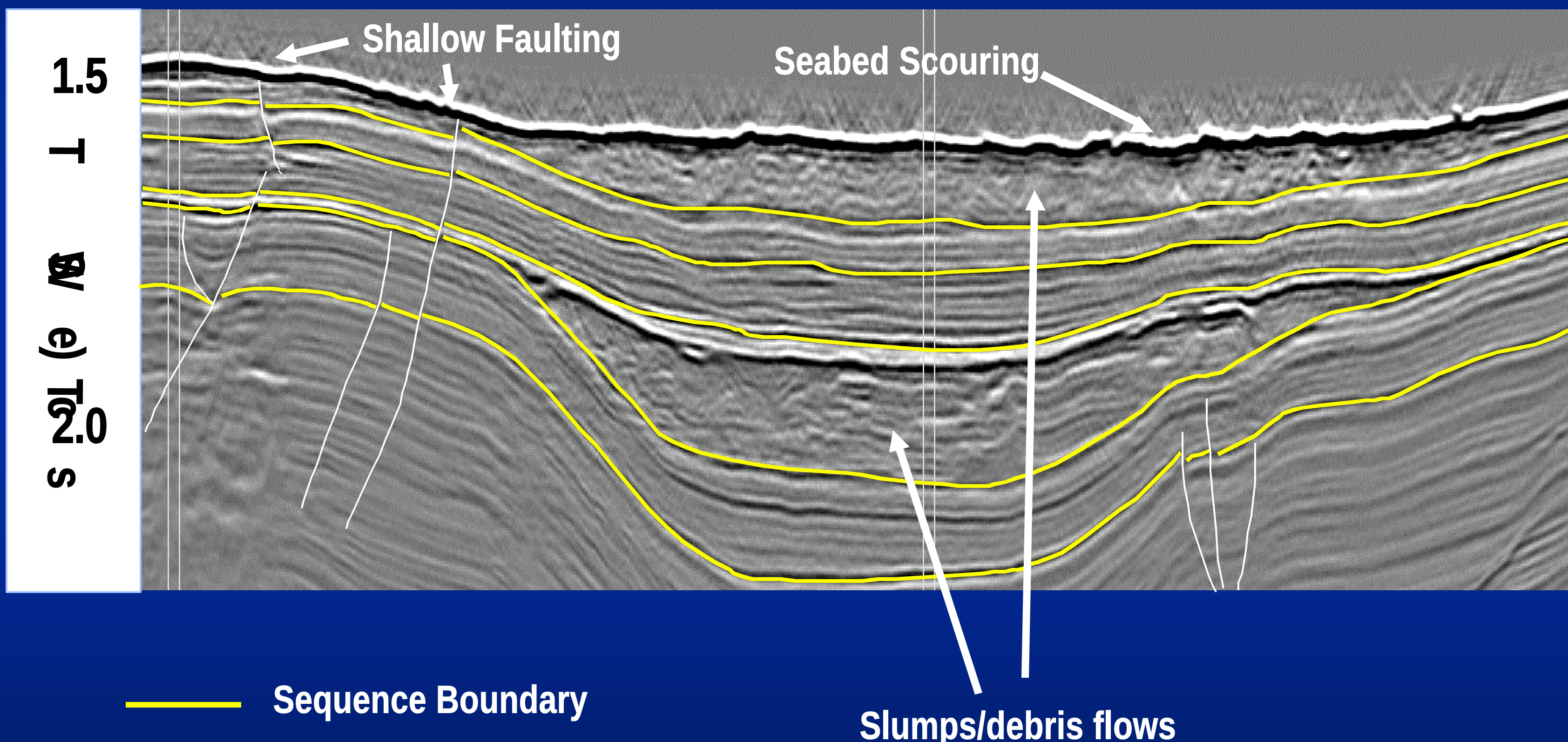
Near Sea-bottom Geology – East Breaks



2) AVO analysis

- Steps
  - Reprocessing at 2 ms sampling interval
  - AVO analysis
  - Selection of CMP gathers
- Products
  - Sections showing indication high risk areas
  - Maps showing high risk area

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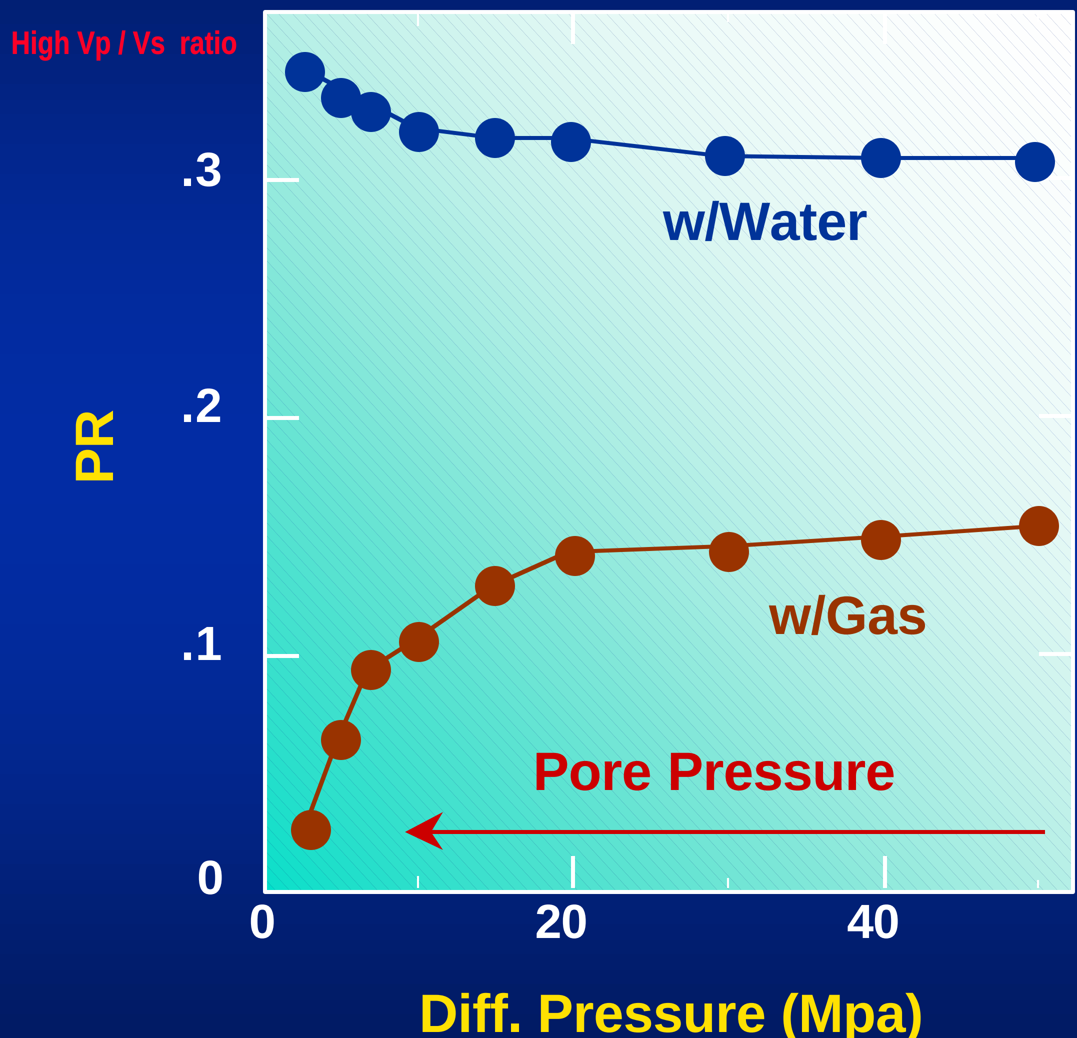
Poisson's Ratios of SWF Sediments



Diff. PR = OVB-PP

Poisson's ratio is a better indicator of pore pressure & SWF Sands

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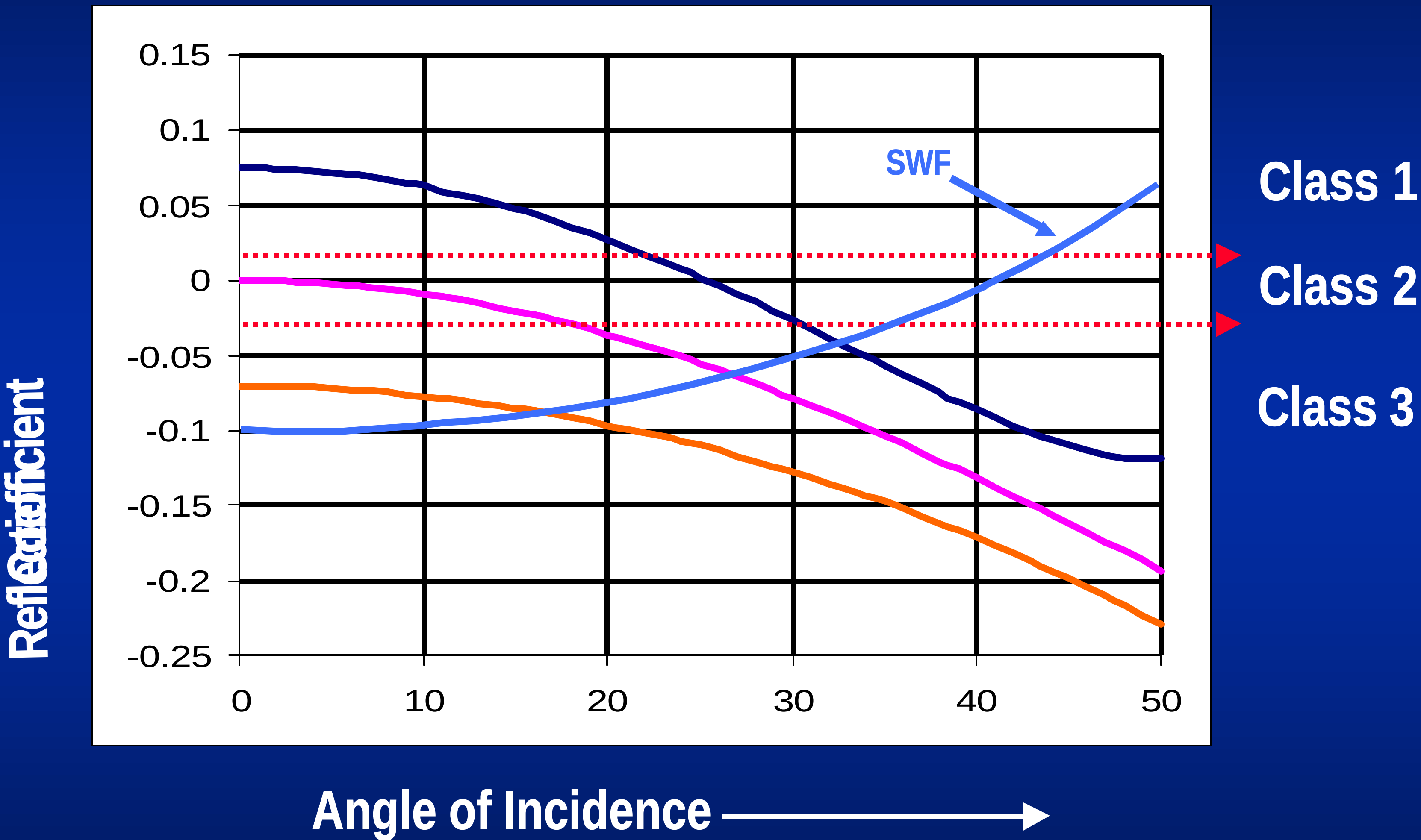
AVO Classes



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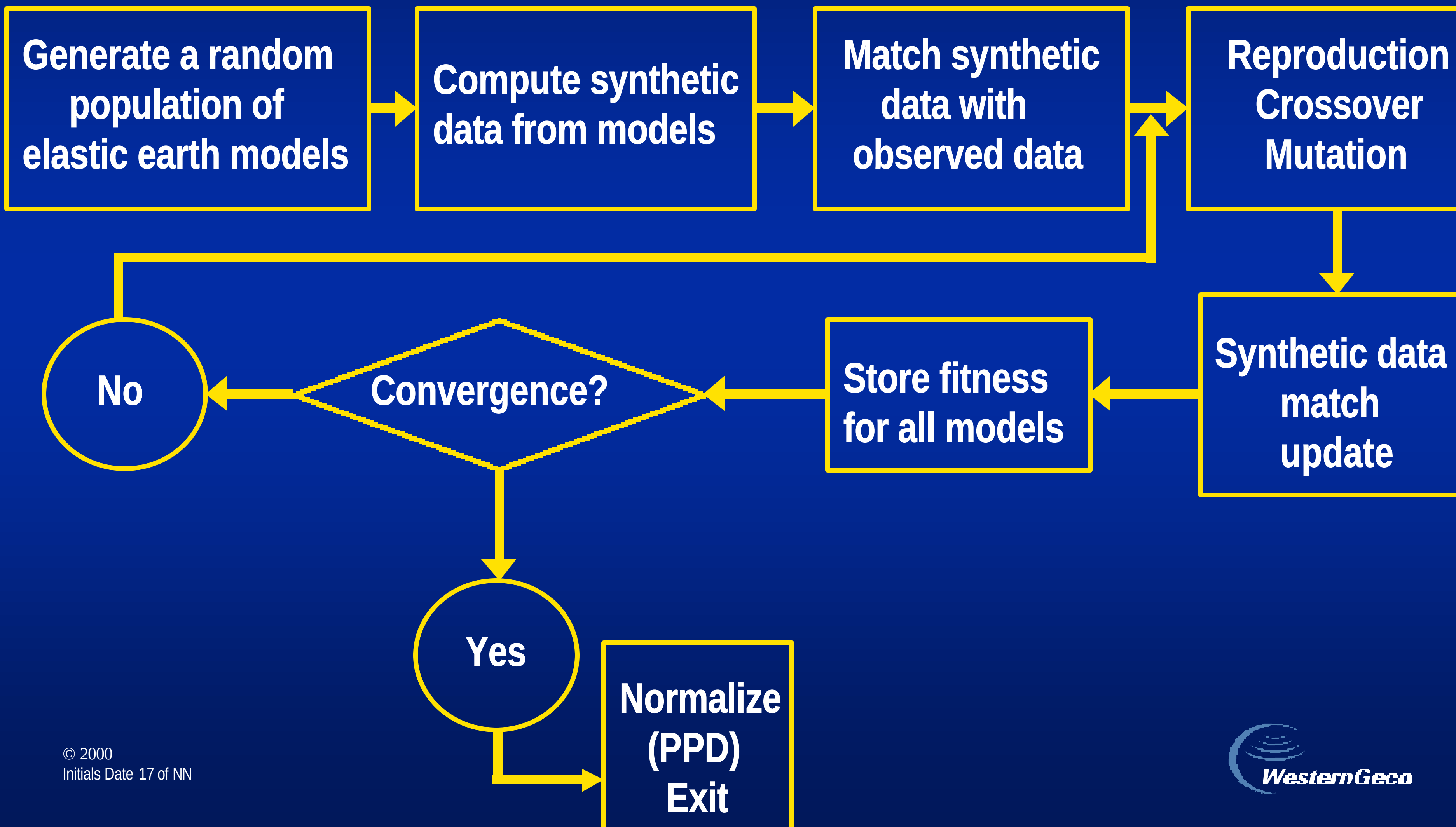
3. GA prestack inversion

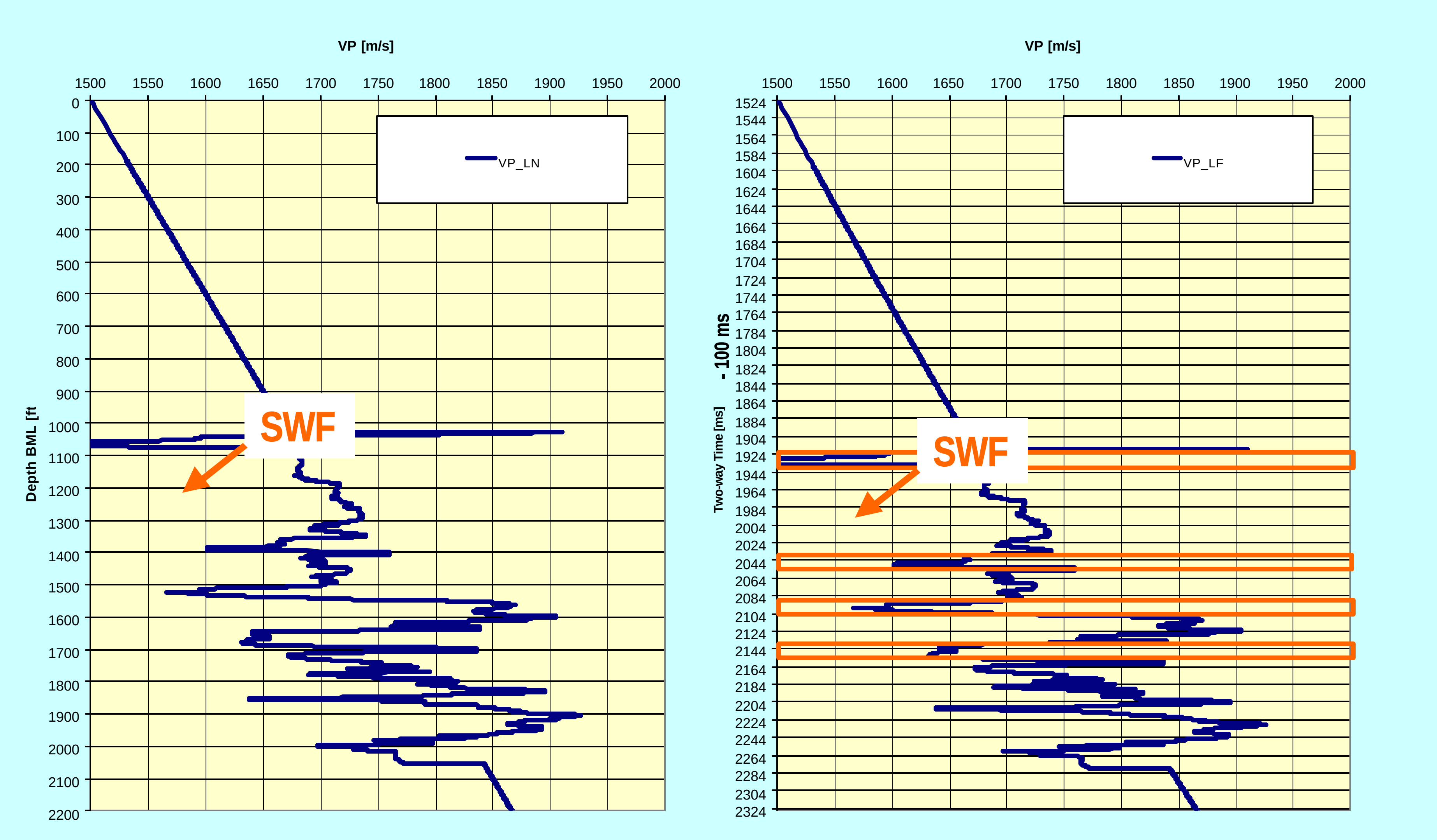
- Create start model
- Input prestack panels
- Run GA algorithm
- Compare real with model data
- Perturb model and iterate until agreement

Prestack GA Inversion

GA Flow Diagram



SWF Deepwater GoM Example, MC 809 #1



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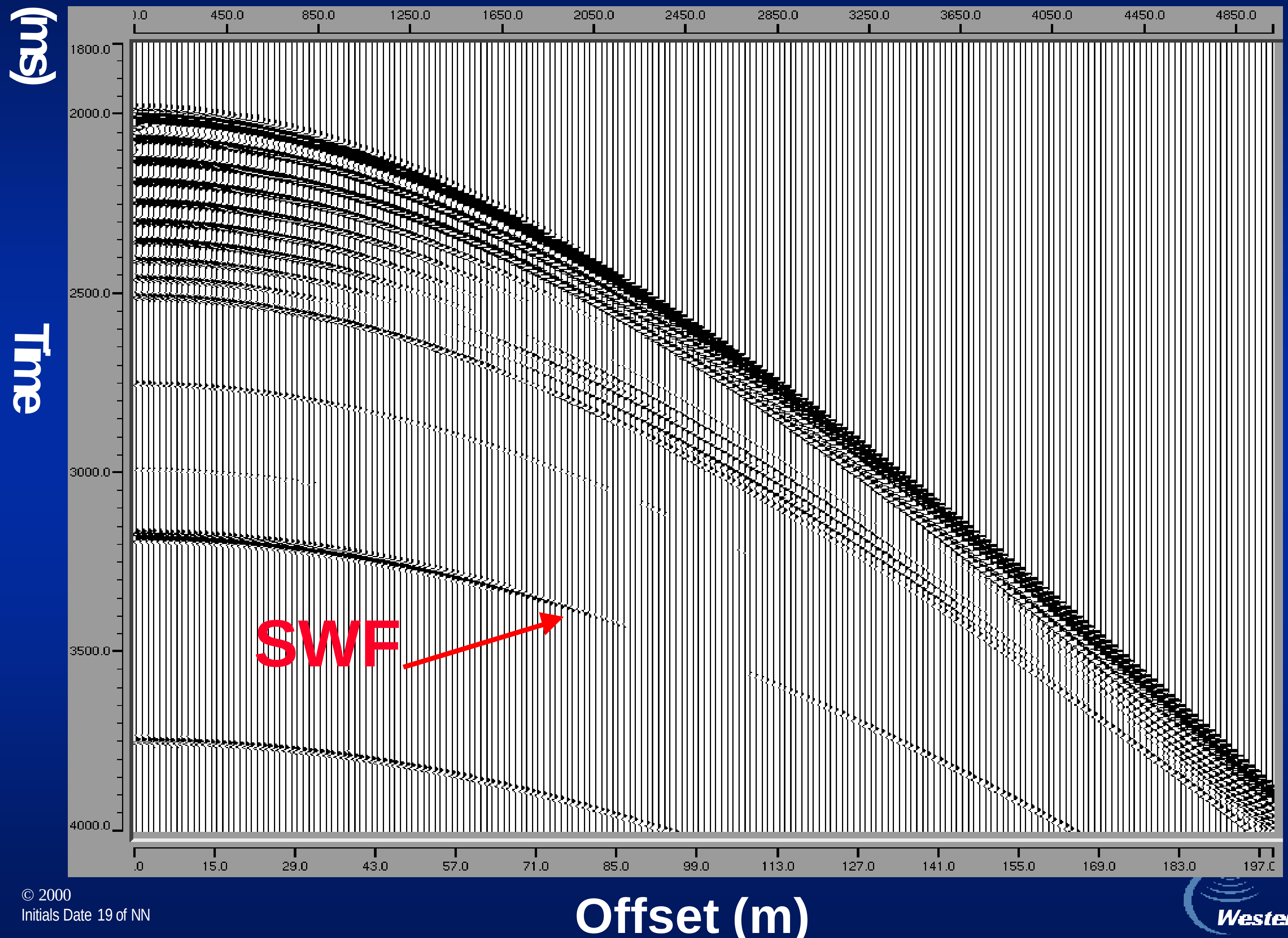
Full Waveform Synthetic Seismogram



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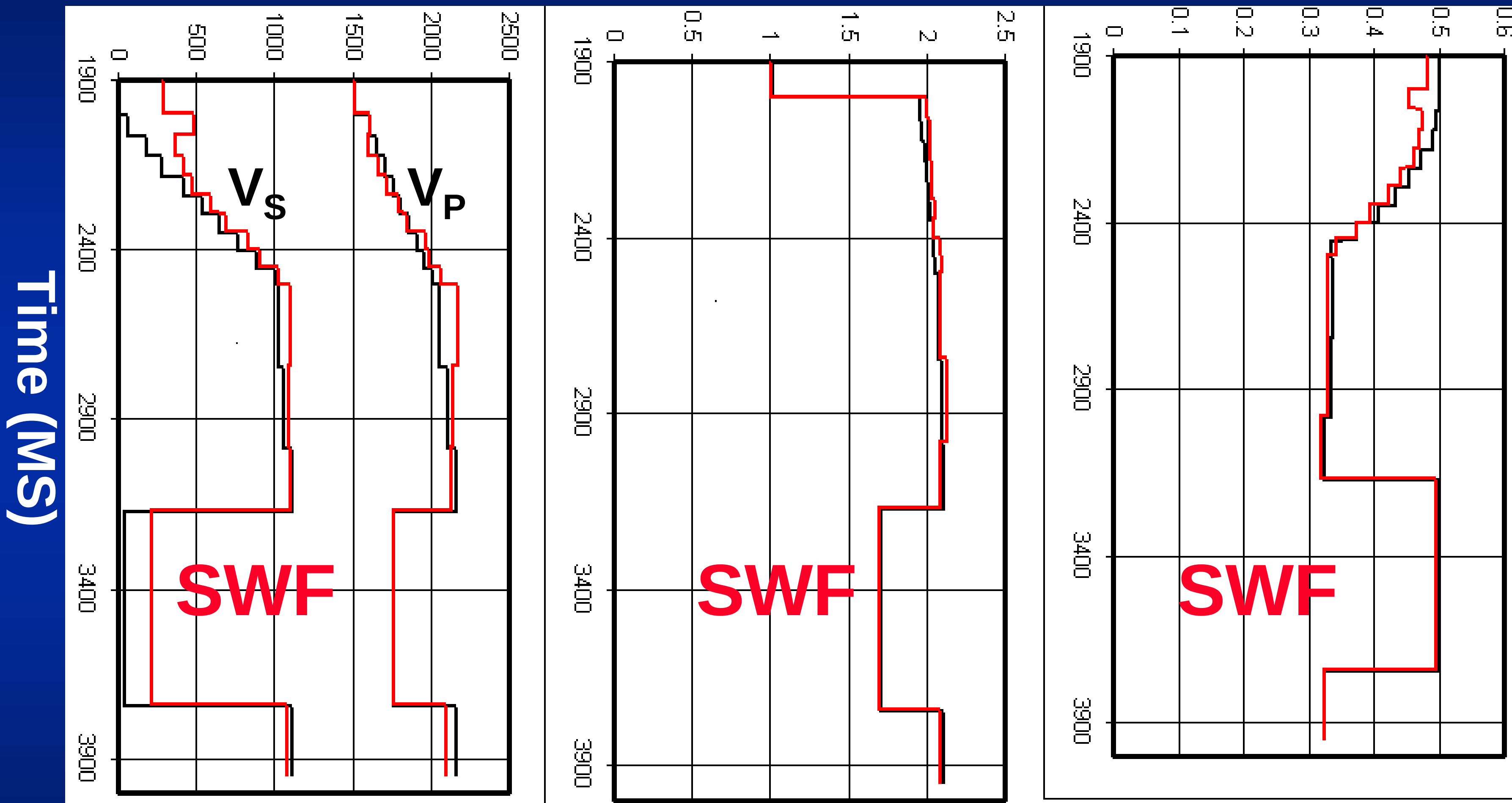
Prestack Inversion on Synthetic Model



Velocity (m/s) **Density (g/cm^3)** **Poisson's Ratio**

True Model: **Inverted Model:**

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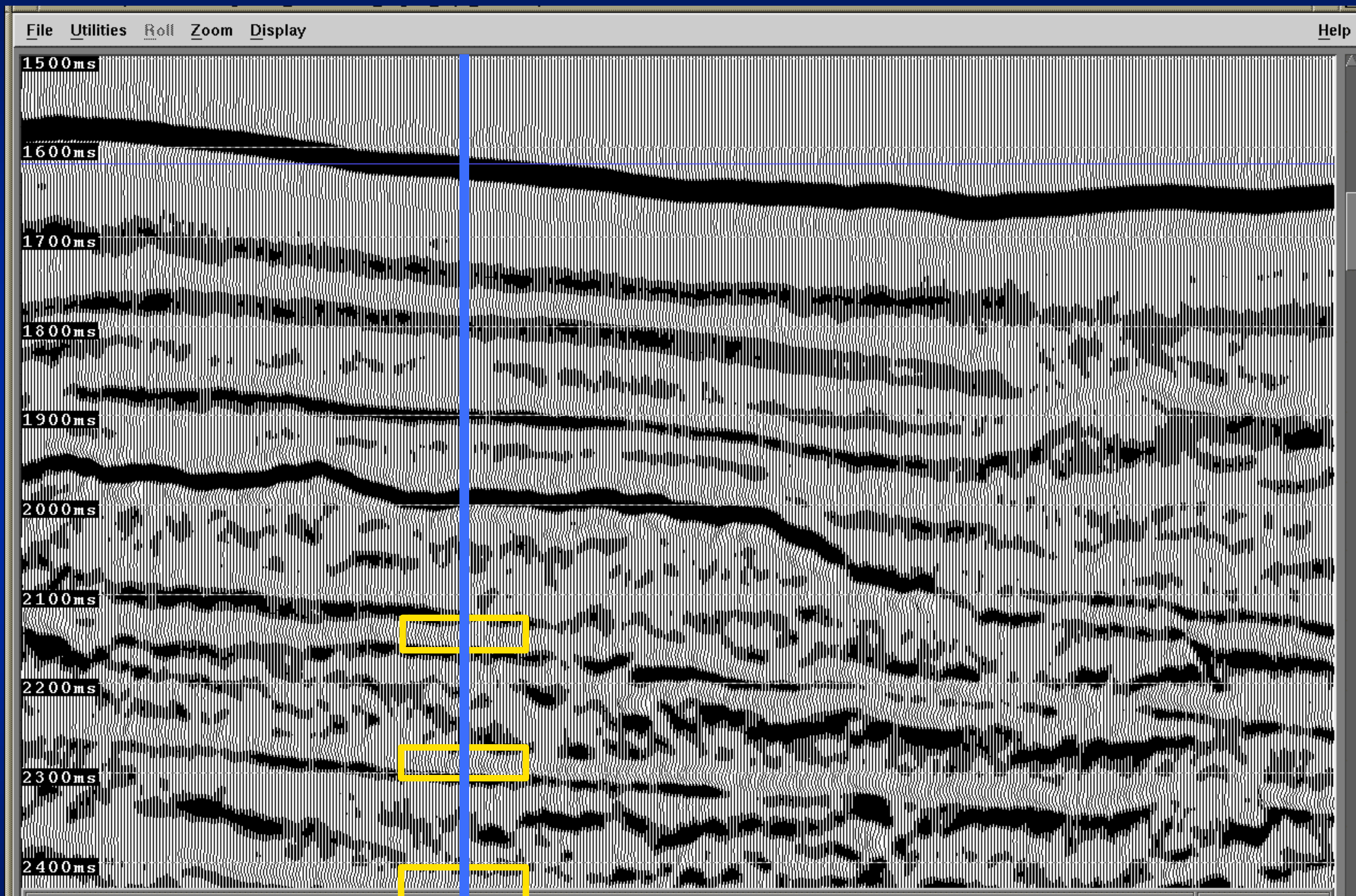
SWF Zones, Seismic Example, MC 854 #2



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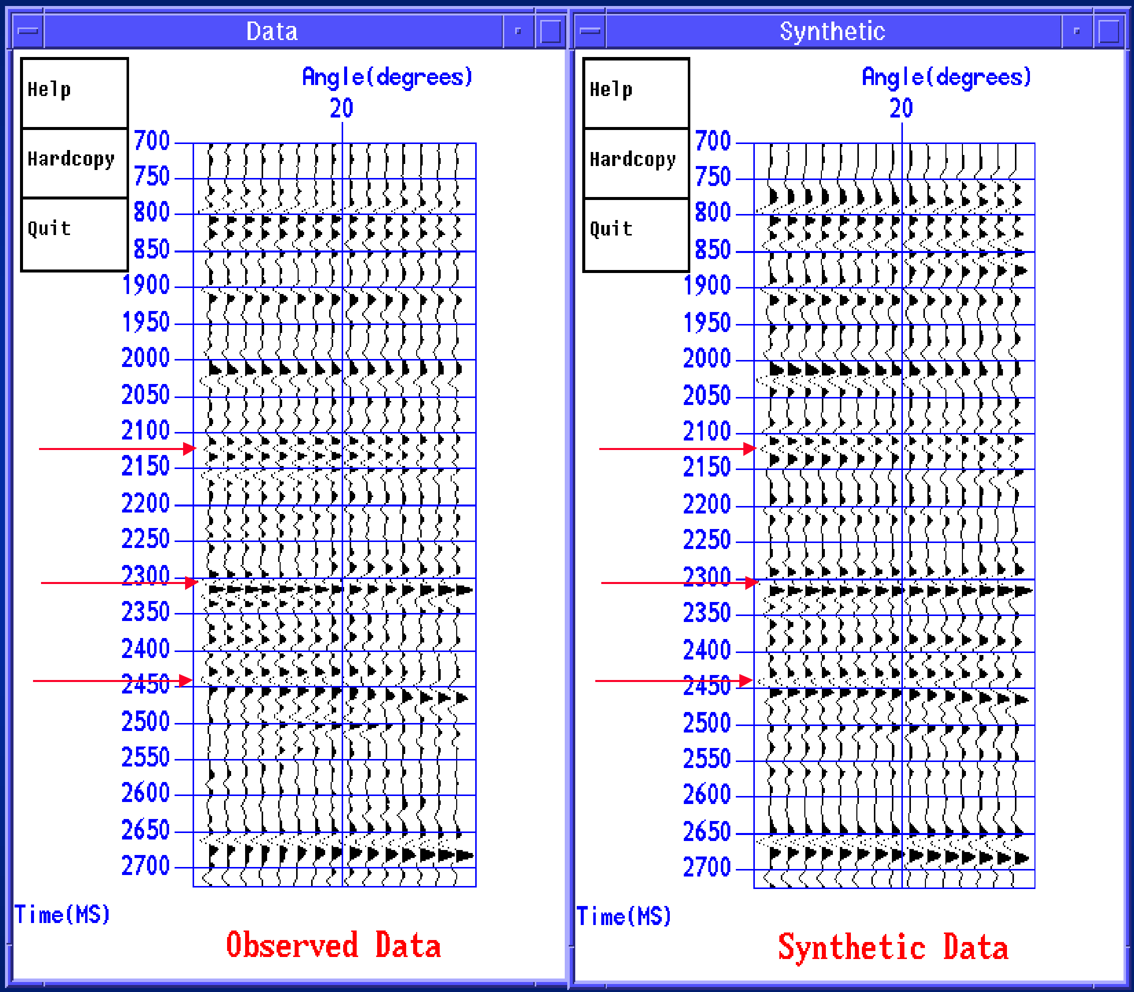
Real and Synthetic Angle Traces, MC 854 #2 GA Results



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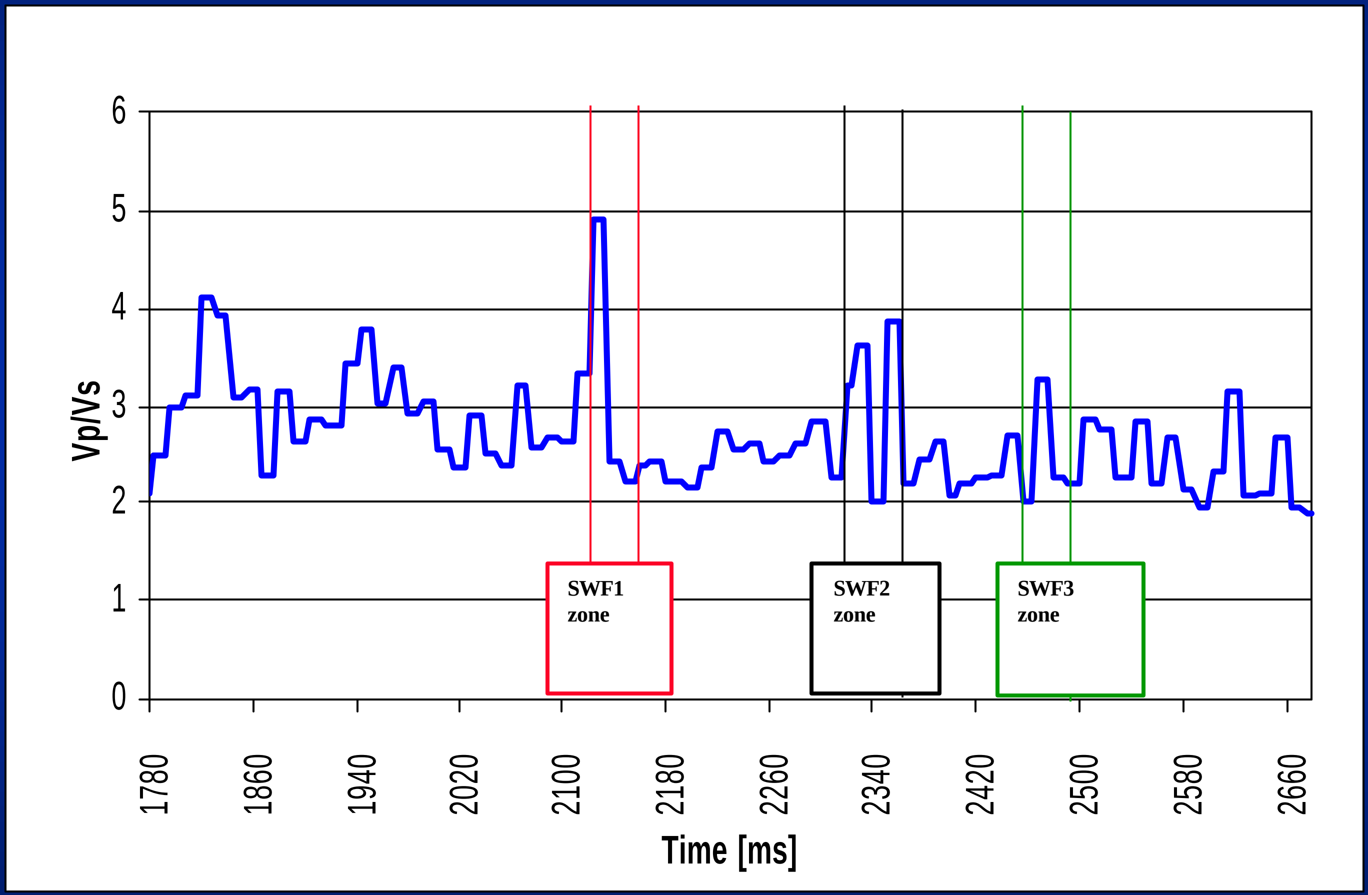
V_p/V_s log Obtained from Pre-stack Inversion at well MC 854 #2 (GA Results)



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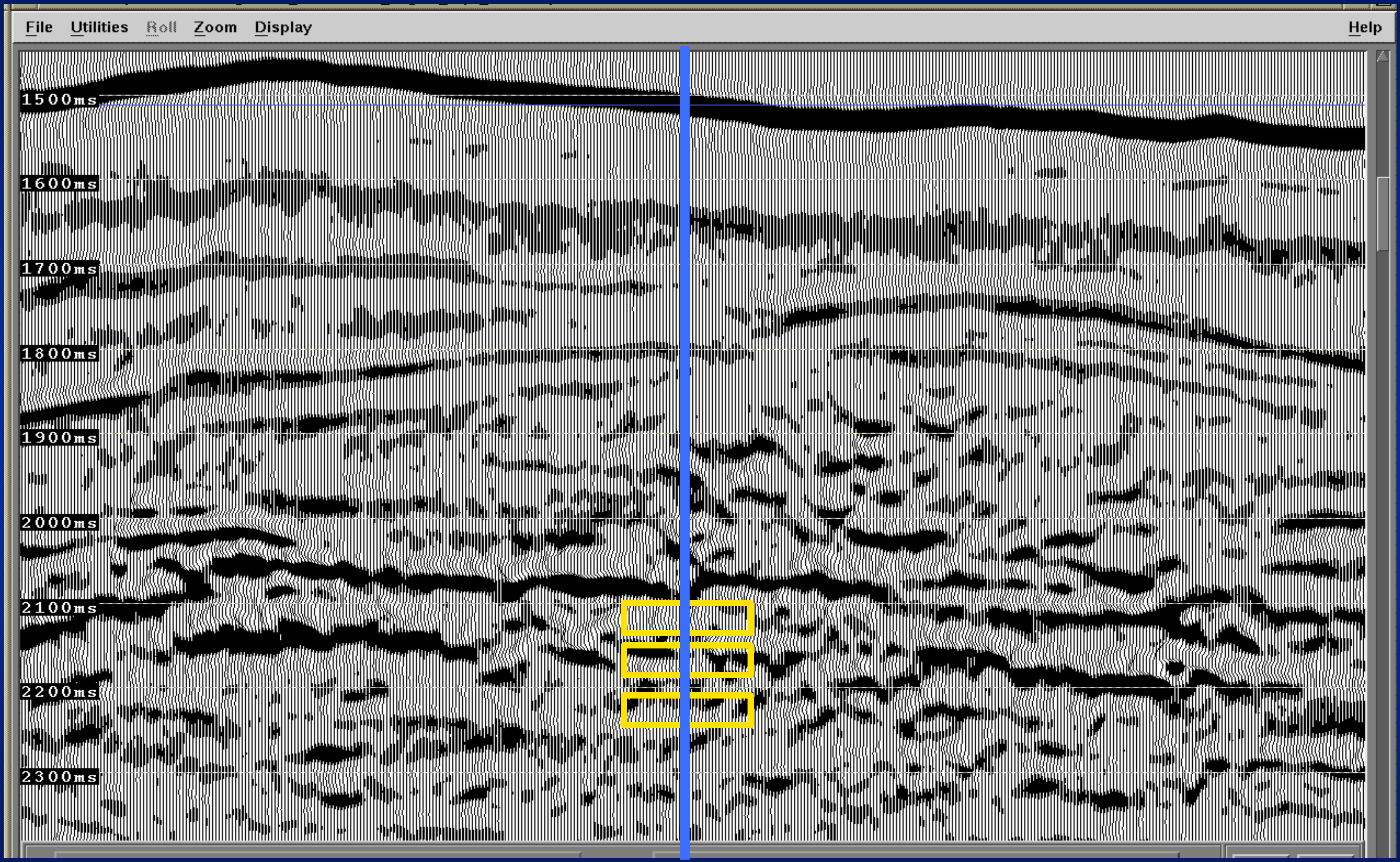
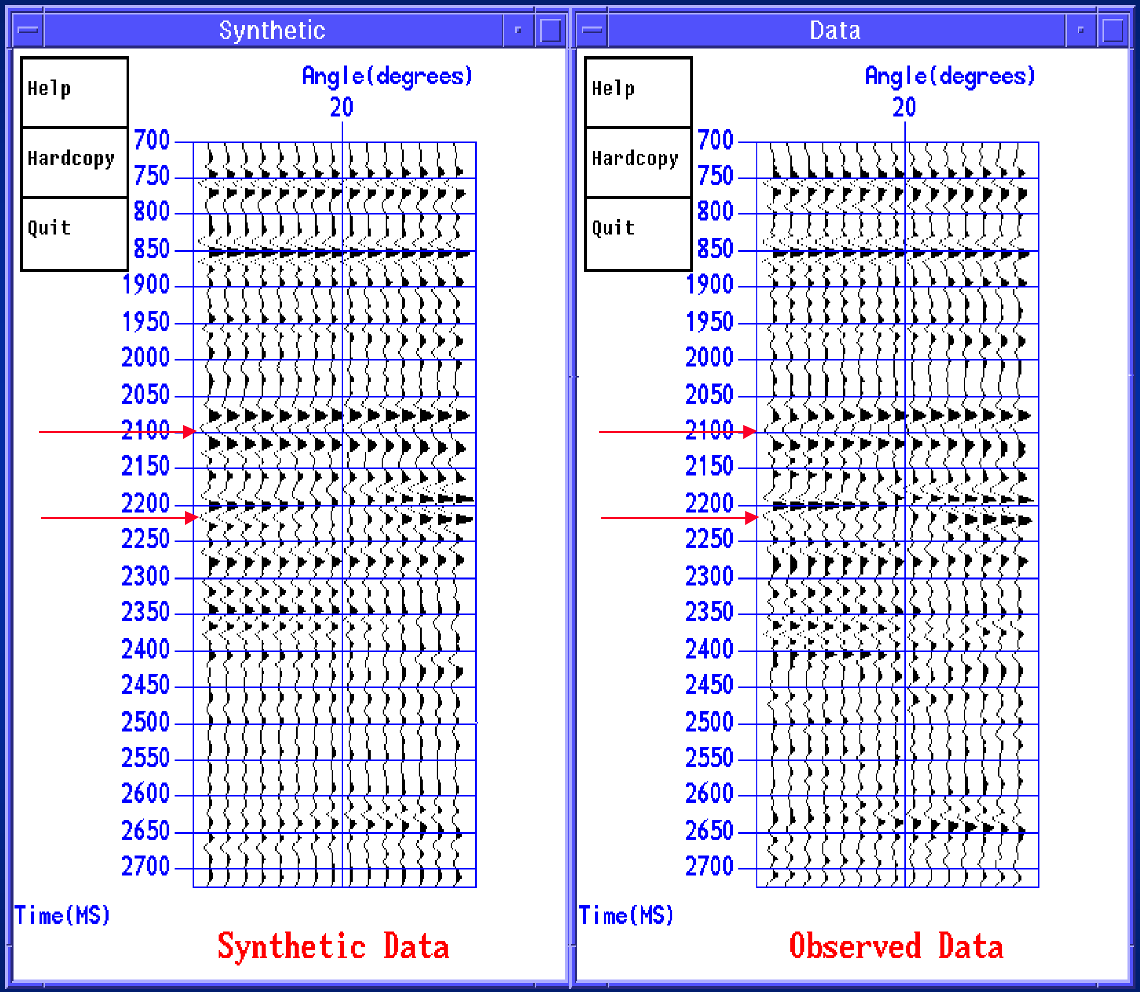
Location SWF Zones, Seismic Example, 809#1



Real and Synthetic Angle Traces, MC 809 #1
GA Results

Polarity reversal
SWF zone



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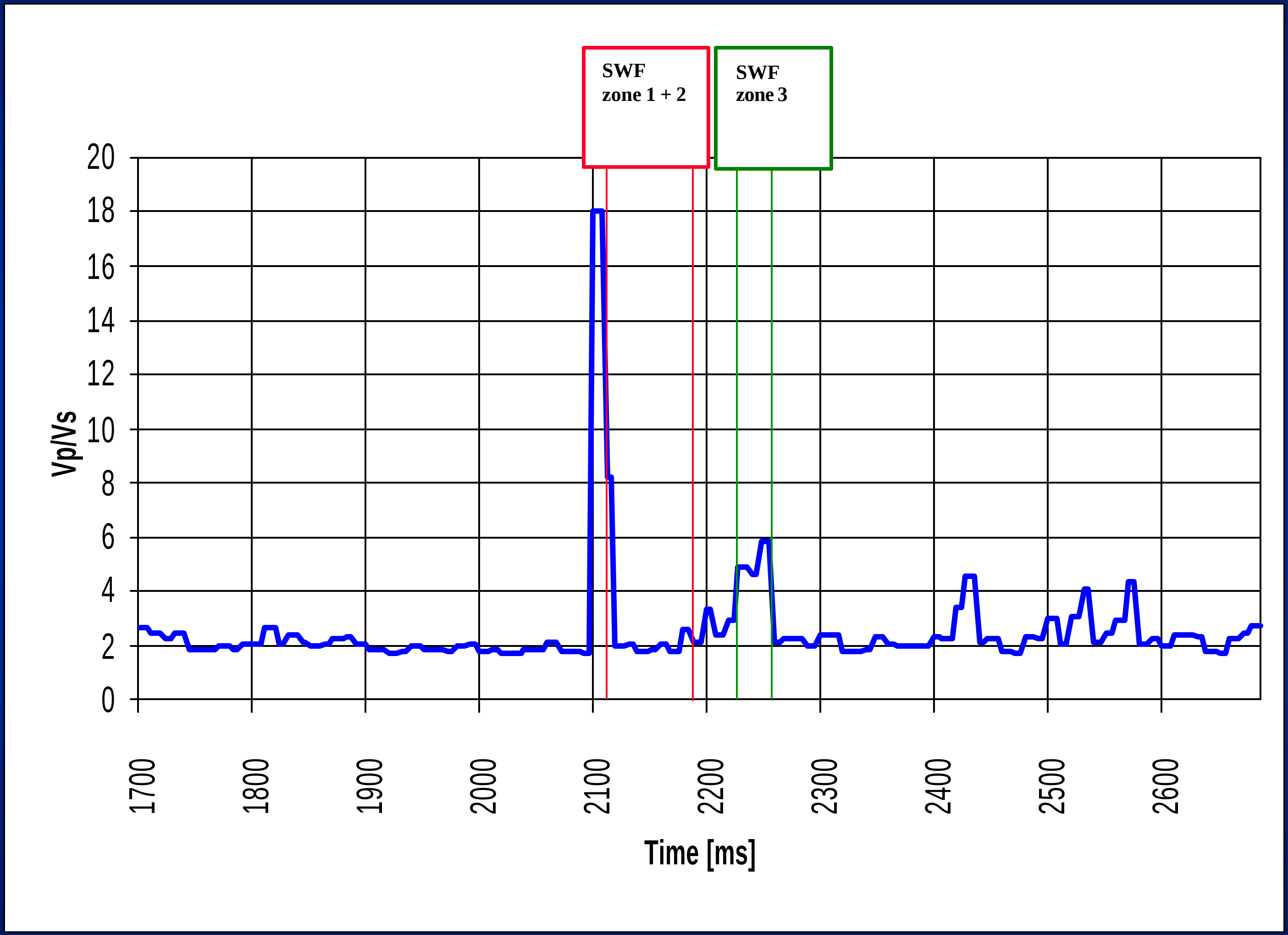
V_p/V_s log Obtained from Pre-stack Inversion at well MC 809 #1(GA Results)



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4. Effective Stress & Pressure Prediction: A Methodology

Input

Velocity
Gross Lithology
Temperature

Transforms (SEM)

Velocity
Lithology
Temperature

Effective Stress, Poisson's Ratio

Bulk Density

Overburden

Output

Effective Stress (s)
Overburden Stress (S)
Pore Pressure (P=S- s)

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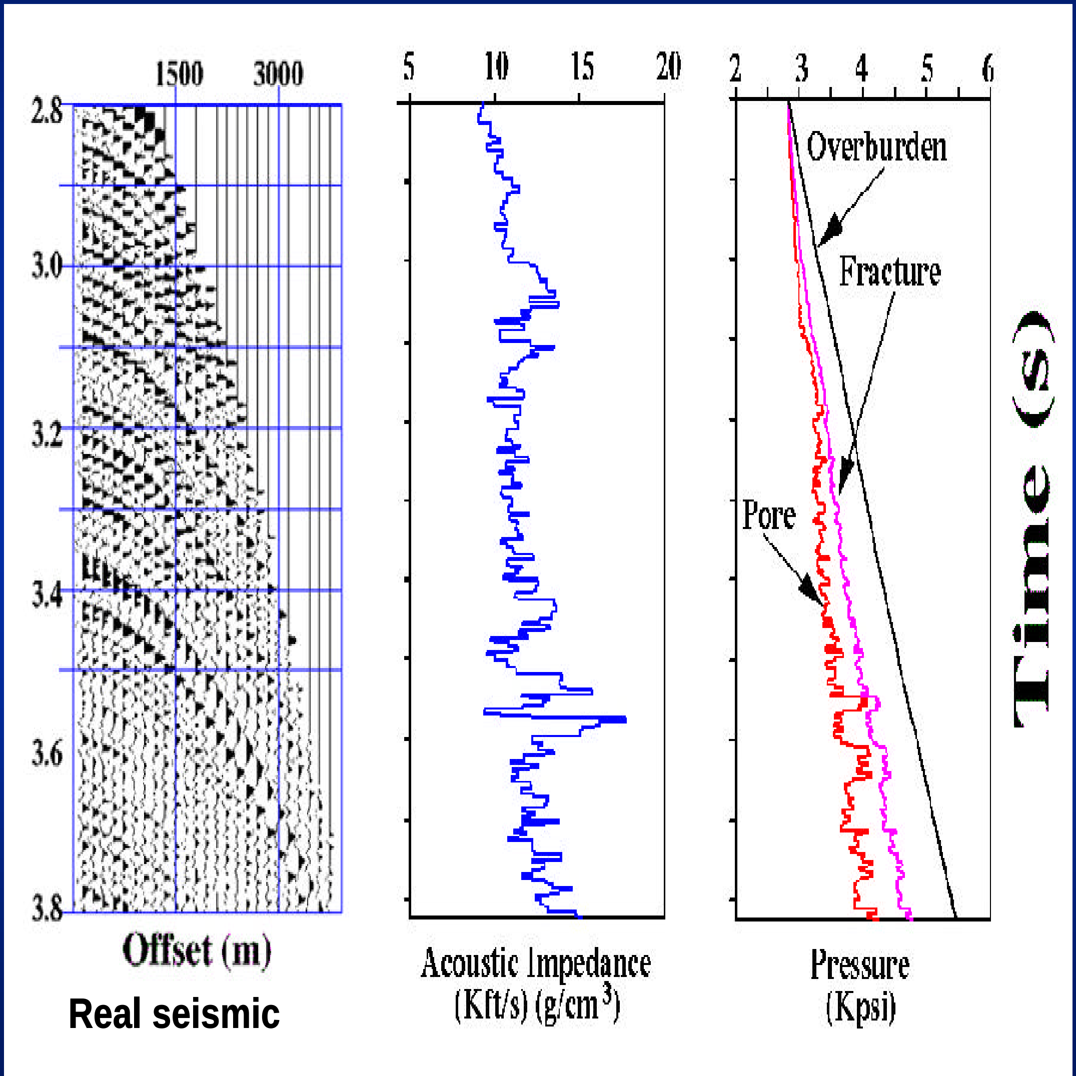
(Dutta 1997)

Pressure Prediction - Prestack Inversion

- Condition, calibrate prestack seismic data
- Compute Vp, Vs, r, from seismic inversion
- Verify with log data, build density model
- Compute overburden
- Use GOM model for Vp « effective stress (Dutta, '97)
- Compute predicted pore pressure, fracture gradient



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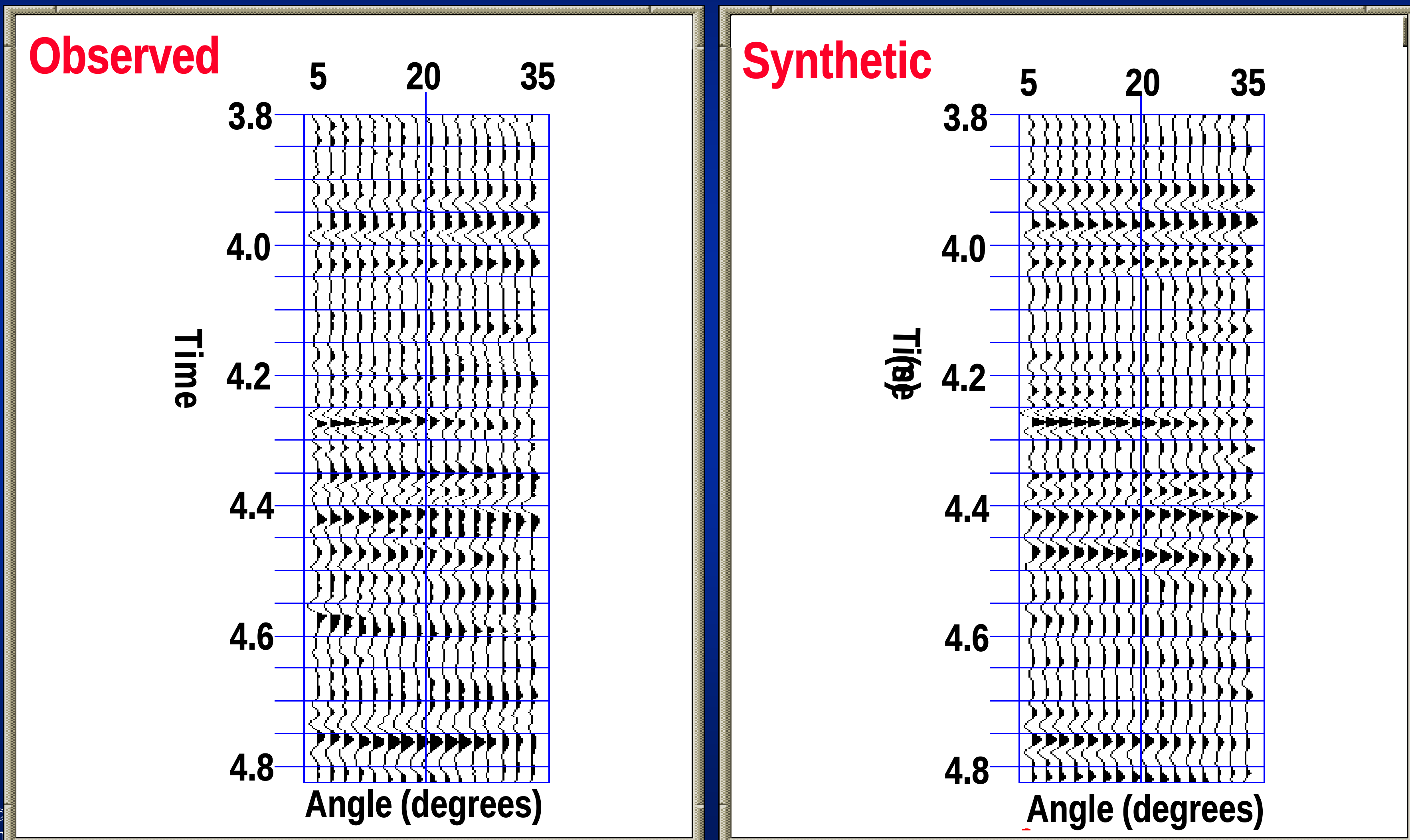
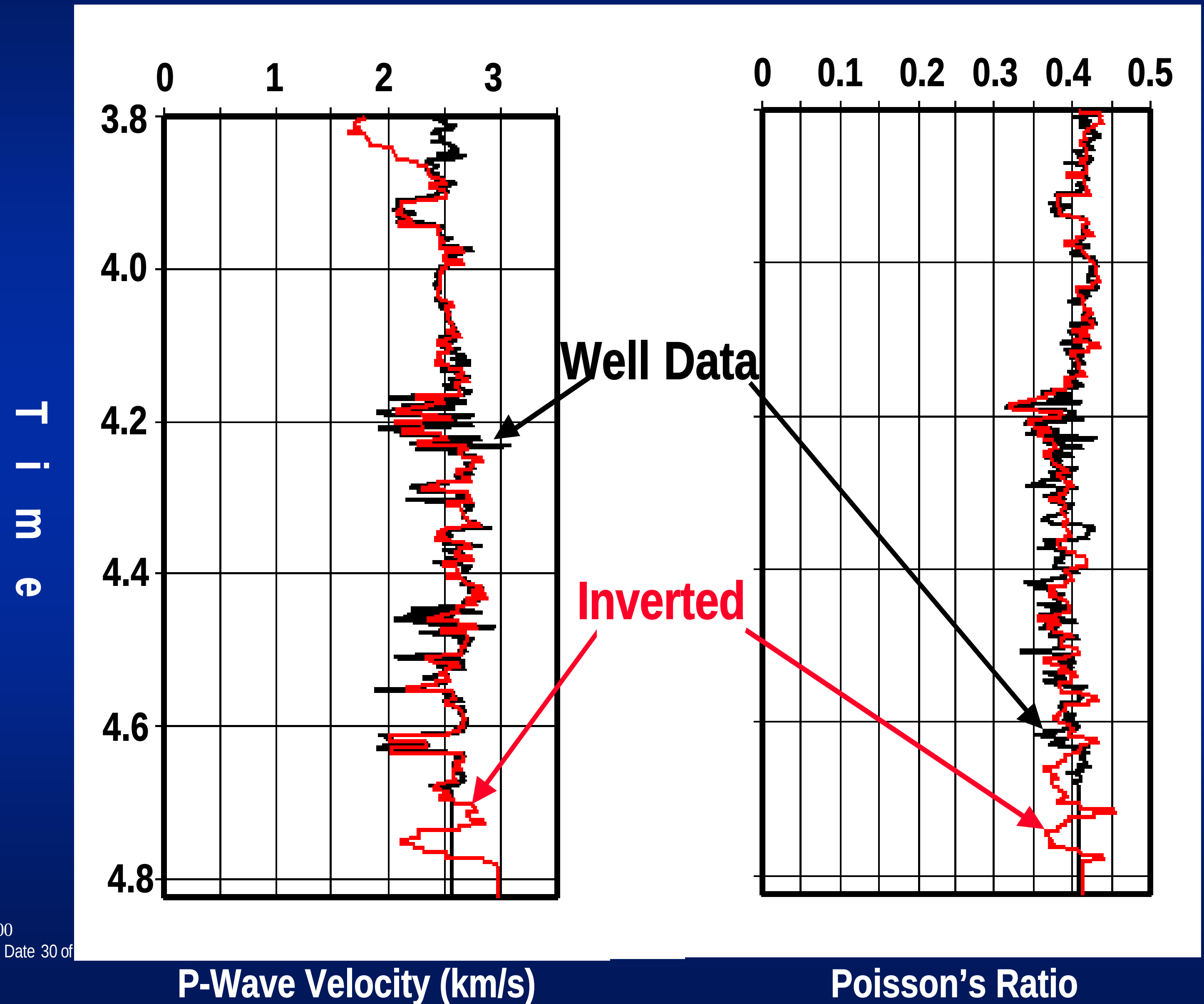
Prestack Inversion- Pressure Prediction

Comparison between observed and synthetic data



Prestack Inversion- Pressure Prediction



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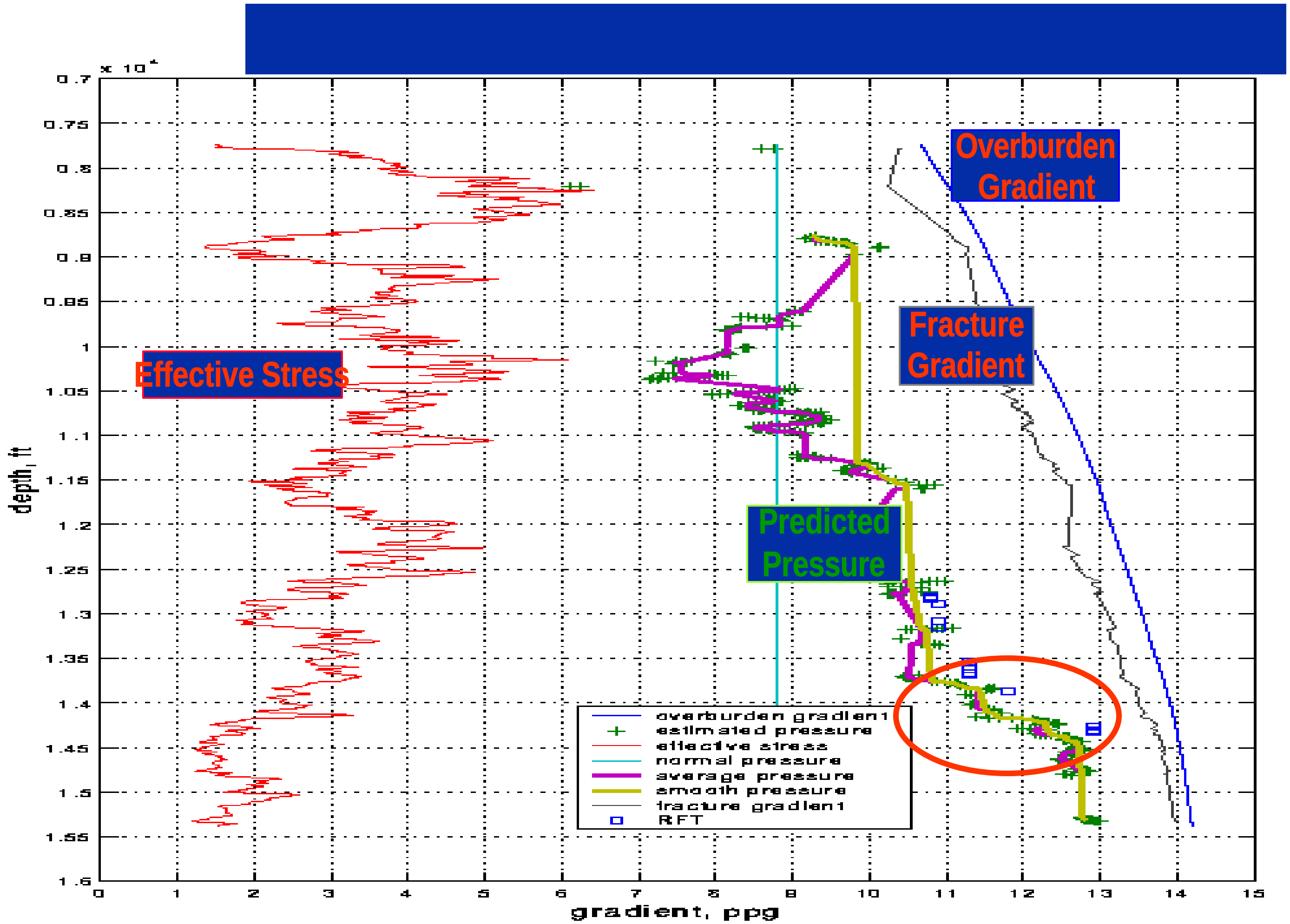
GA Run 3 - Prediction 12-20-99 Deepwater GOM MC



Dutta and Khan, EAEG Amsterdam, 2001

SWF Evaluation Process: Four-step Process

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- Water-Sand Vs Gas-Sand?

Reconnaissance AVO Analysis

Obtain Vp / Vs ratios from GA Inversion

Thanks to my WesternGeco Colleagues

- Mashuir Khan
- Jeff Lauve
- Riaz Ahmad
- Randy Utech
- Subhashis Mallick
- Bob Vauthrin
- Bruce Bird
- Jesse Bell

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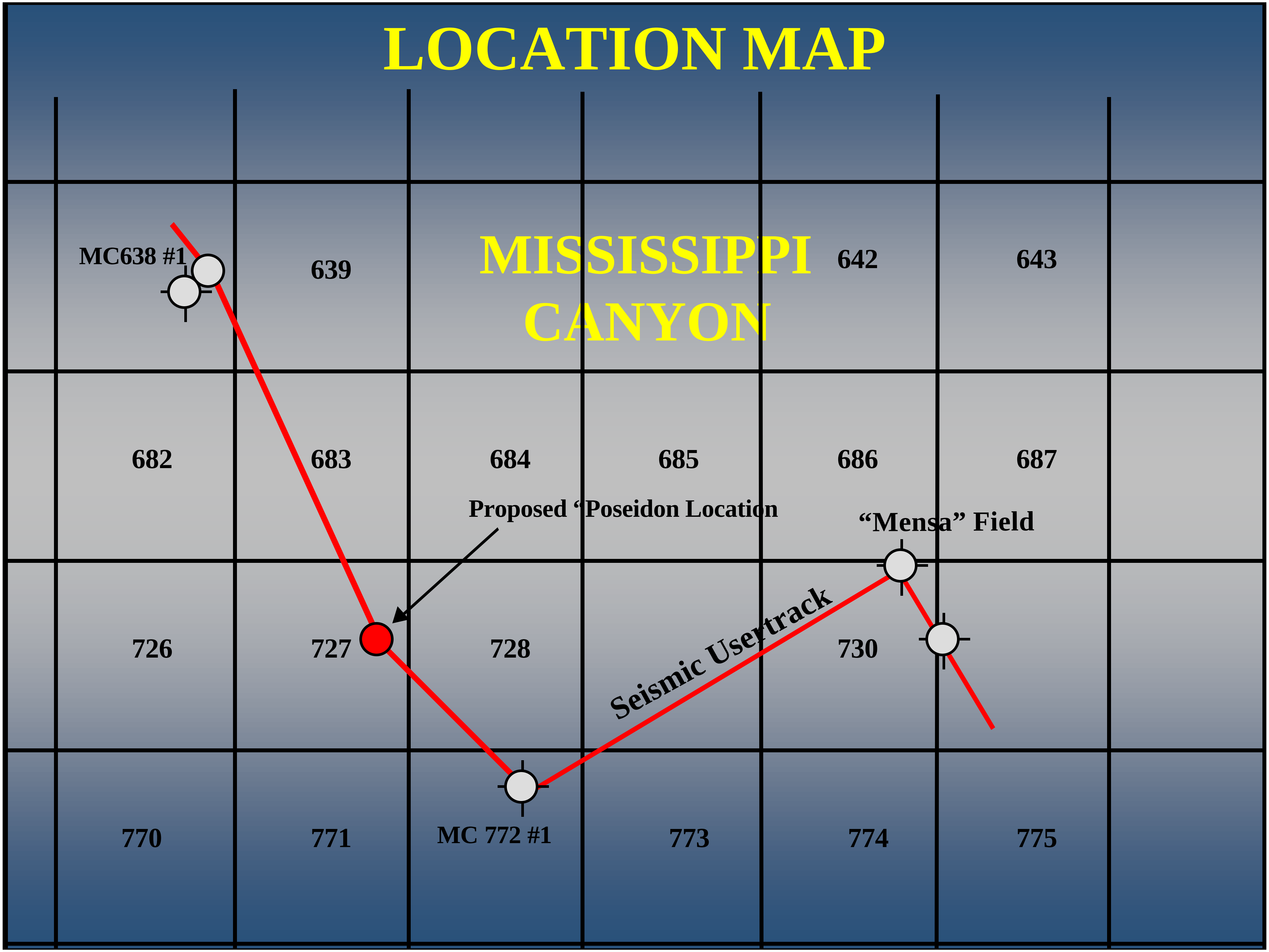
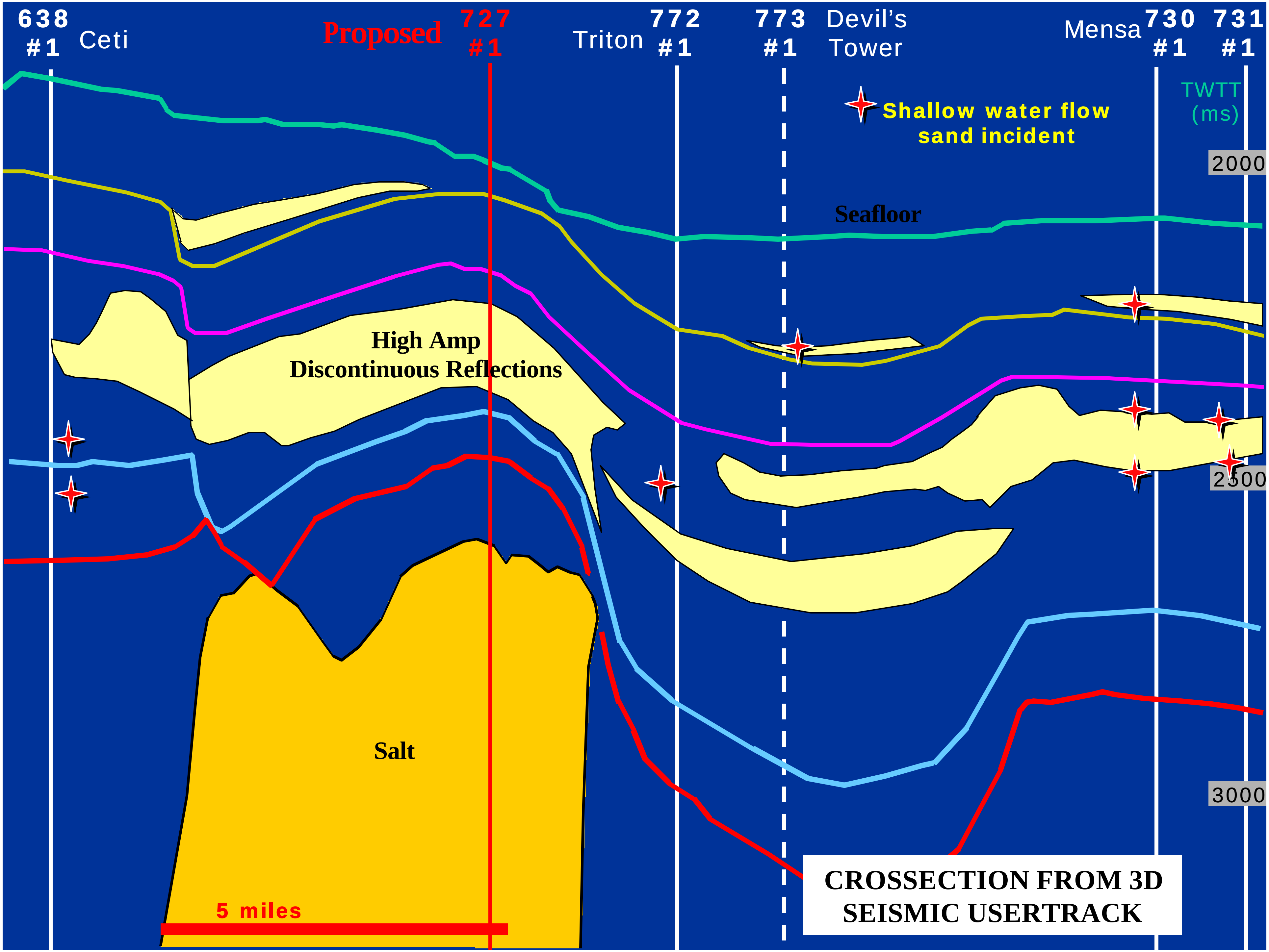
EVALUATION AND SUCCESSFUL DRILLING OF A SHALLOW WATER FLOW SAND MISSISSIPPI CYN BLOCK 727 #1 POSEIDON PROSPECT

Cheryl Caswell, Ron Dupre, Jeff Dieffenbaugher, Rick Graff, Bobby Lunsford, Scott McLeod, James Niemann, Bill Rau, Todd Robichaux, Andrew Womack

INTRODUCTION

- Shallow stratigraphic, drilling hazards and pore pressure/fracture gradient evaluation indicated high risk for shallow water flow.
- Detailed mud program and shallow water flow plan developed to mitigate potentially severe shallow water flow.
- A large shallow water flow was identified where expected, successfully killed while drilling and isolated behind casing with cement.


LOCATION MAP
MISSISSIPPI
CANYON
MC638 #1
639
642
643
682
683
684
685
686
687
Proposed "Poseidon Location
"Mensa" Field
726
727
728
Seismic Usertrack
730
770
771
MC 772 #1
773
774
775



638
#1
Ceti
Proposed
727
#1
Triton
772
#1
773
#1
Devil's
Tower
Mensa
730
#1
731
#1
TWTT
(ms)
Shallow water flow
sand incident
2000
Seafloor
High Amp
Discontinuous Reflections
2500
Salt
3000
5 miles
CROSSECTION FROM 3D
SEISMIC USERTRACK

Drilling Prognosis:

- Mudline (4908’) to 333’ BML: Sands, silts, and clays expected.
- 333’ to 1052’ BML: Low energy, silts and clay expected.
- 1052’ to 1975’ BML: Thick, possibly overpressured sand 450’ intervals expected from 1352-1696’ and 1816’-1969’ BML.
- 1975’ to 2485’ BML: Interbedded sandy turbidites, silts and clay. Sands between 2017’ and 2254’ BML could be over-pressured
- 2485’ to 2952’ BML: Primarily shale with interbedded silt and sand.
- 2952’ to 3958’ BML: Primarily shale to top of salt, possibly unstable gumbo formation w/anomalous old paleo fauna.

Time To Depth Interpretation

- There is sparse velocity data in the shallow section and project earth scientists generally are not concerned with shallow velocities.
- Water depth and geologic variability create large uncertainties in depth ~ **+/- 100’-200’.**
- Using appropriate checkshot velocities, accounting for geologic variability and calibrating to actual water depth can reduce uncertainty to ~ **+/- 50’**.

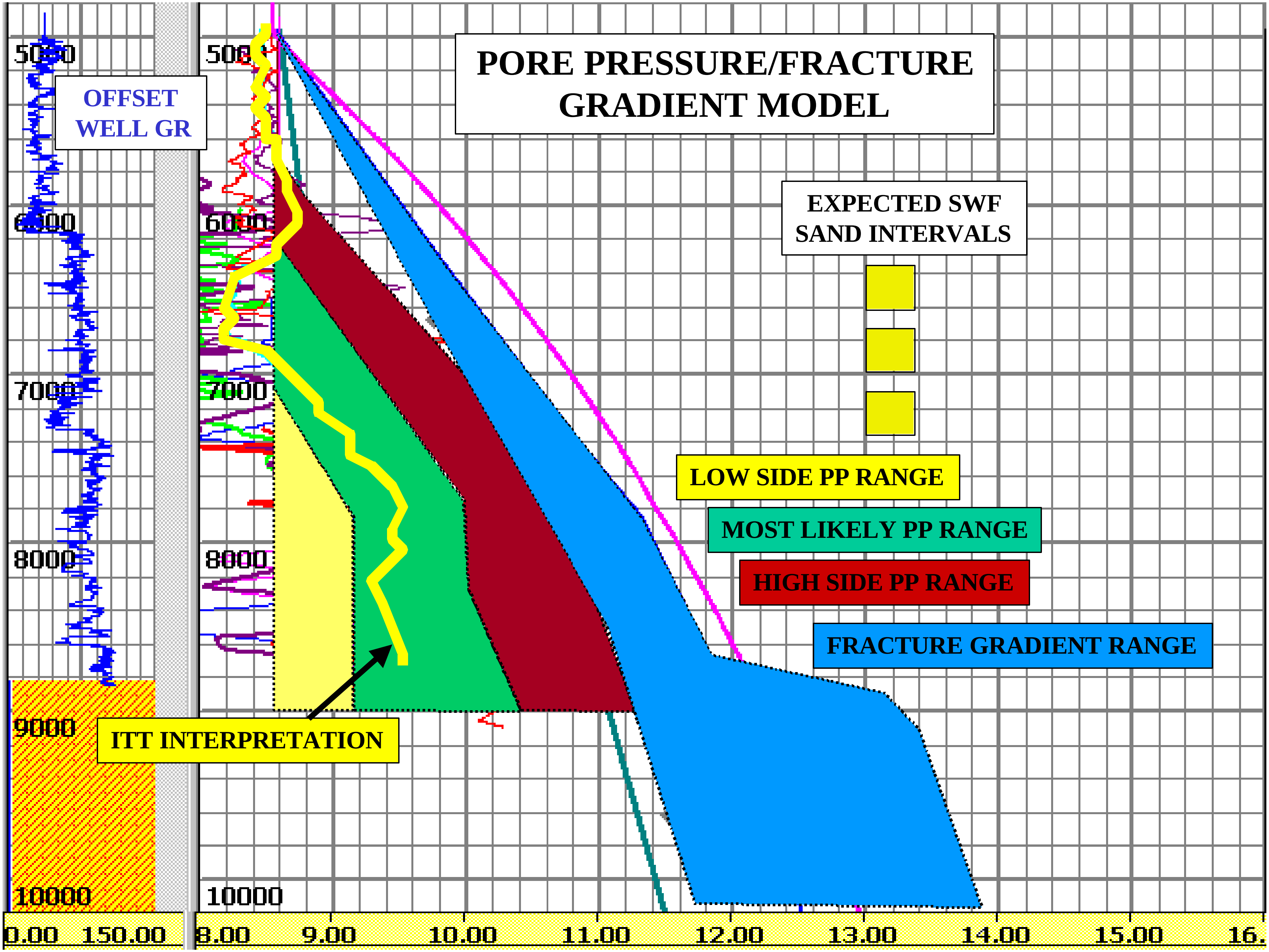
EVALUATION OF SWF RISK USING MMS GUIDEPOINTS
CHEVRON OCS-G-13145 #1, MISSISSIPPI CANYON BLOCK 727

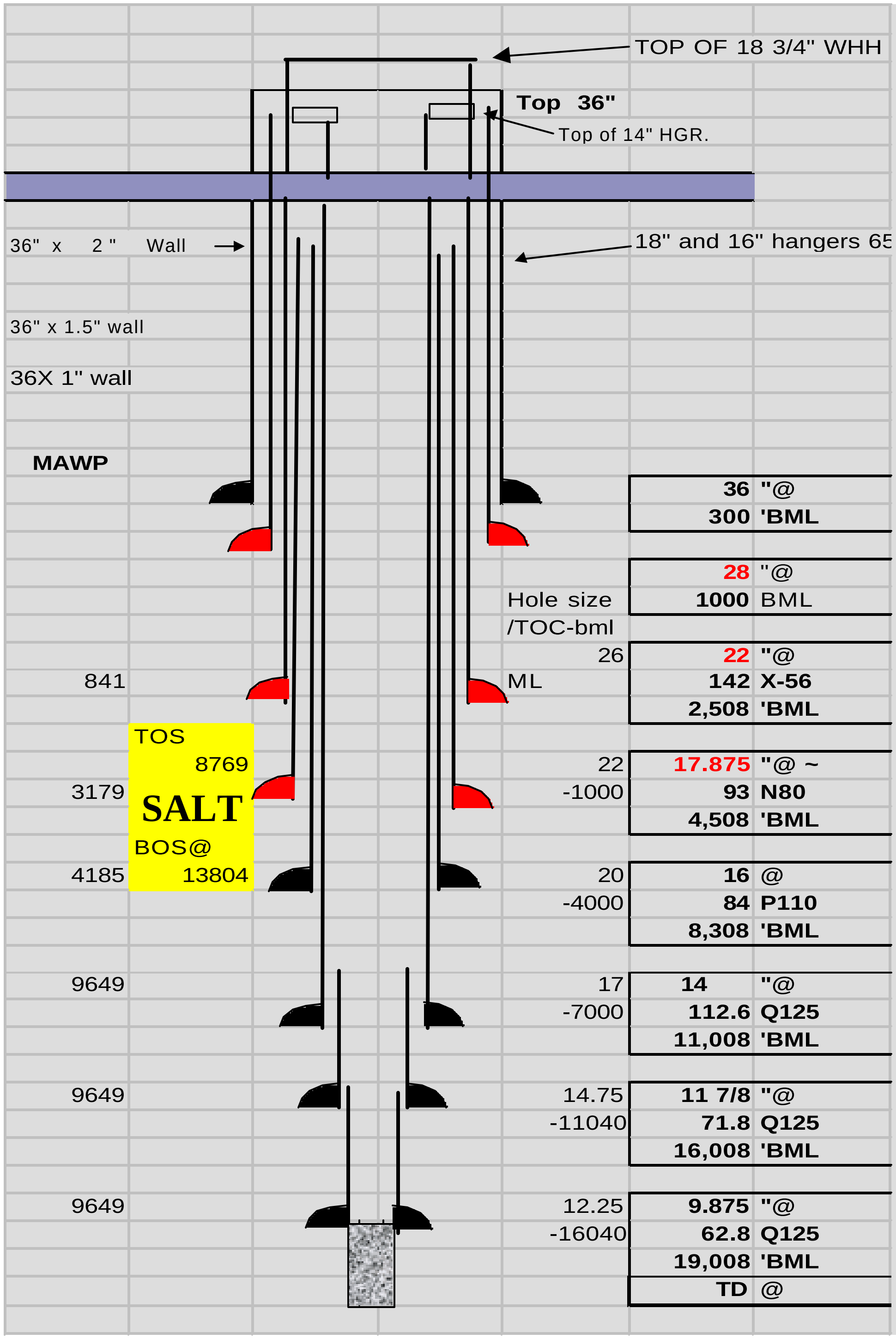
NTL No. 00 -*** Shallow Hazards Requirements for Exploration and Appraisal Drilling Operations

Shallow Water Flow Interpretation Guide Points

MMS U. S. Department of the Interior
Minerals Management Service
Gulf of Mexico OCS Region

1. Does the interval contain an aquifer? **NO**
2. Is there a competent regional or sub-regional seal above the potential flow zone? **YES**
3. Is there a sand-prone layer contained within a structural trap? **YES**
4. Is there a stratigraphic trap formed by dipping sand-prone layer(s) truncated by faulting, erosional downcutting or depositional pinch-out? **NO**
5. Is there evidence of high sedimentation rates (>1500 ft/my) and rapid burial leading to pressure disequilibrium? **YES**
6. Is there a localized amplitude event consisting of an anomalously bright reflection? If so, can tuning effects be ruled out as the cause **YES**
7. Is there evidence for the presence of a geopressured zone, i.e. stratigraphic layer(s) containing pore pressure greater than hydrostatic pressure? **YES**
8. Can a known shallow water flow zone from a nearby well be correlated to the interval? **YES** If so, is there consistency of seismic character? **YES**
9. Has a nearby well proven that SWF can be ruled out? If so, is there consistency of seismic character? [A negative indicator which significantly reduces SWF risk.] **NO, YES**
10. Has seismic sequence analysis identified sedimentary deposits likely to contain a SWF interval? **YES**
11. Does the seafloor amplitude map indicate areas of anomalously strong reflection indicating authigenic carbonate hardgrounds associated w/ seafloor flow? **NO**
12. Are mud volcanoes or other expulsion features present on the seafloor? **NO**
13. Are buried expulsion features recognized on subsurface data? **NO**
14. Does bathymetric mapping indicate the presence of seafloor scarps possibly associated with faults or other pressure conduits? **YES**
15. Is there an isolated sand body capable of absorbing excess pressures caused by compaction disequilibrium? **YES**
16. Is there evidence of differential compaction resulting in excess pressures transferred from thick overburden areas? **YES**
17. Is the zone buried deeply enough (>500 ft) for development of a sufficiently strong seal? **YES**
18. Are there high-amplitude, discontinuous reflectors within expanded stratigraphic sequences? **YES**
19. Is the water depth great enough (>500 ft) to be associated with SWF? **YES**


PORE PRESSURE/FRACTURE GRADIENT MODEL
OFFSET WELL GR
EXPECTED SWF SAND INTERVALS
LOW SIDE PP RANGE
MOST LIKELY PP RANGE
HIGH SIDE PP RANGE
FRACTURE GRADIENT RANGE
ITT INTERPRETATION
5000
6000
7000
8000
9000
10000
0.00
150.00
8.00
9.00
10.00
11.00
12.00
13.00
14.00
15.00
16.



CASING PROGRAM

- “Big Bore” wellhead selected to add 18” liner.
- 28” pipe to protect uphole section in case of SWF.
- 26” hole to be drilled in one pass with no under-reaming to minimize hole exposure, riserless mud volumes and avoid pack off and lost circulation.
- In case of SWF, drill riserless with heavy mud taking returns at mudline.

SHALLOW WATER FLOW MUD PROGRAM

2000 bbls. <-------- The stated volume is minimum required to dynamically build 10.0 ppg pad mud

500 bbls.

36"

SWS

*** No riserless drilling contengency this interval ***

28"

3000 bbls.

500 bbls.

SWS

Depth	PP	Drill MW PP+.5	Kill MW PP+1.5
5300			
5400			
5600			
5800			
5900			
6000			
6100			
6200	(MOST LIKELY)		
6300	8.6	11.2	12.7
6400	8.6	11.0	12.6
6500	8.6	11	12.5
6600	8.65	11	12.5
6700	8.8	11.5	13
6800	8.85	11.6	13.1
6900	8.9	11.6	13.1
7000	9.0	11.9	13.4
7100	9.1	12.1	13.6
7200	9.2	12.3	13.8
7300	9.3	12.5	14
7400	9.4	12.7	14.0
7500	9.5	12.8	14.0

Potential SWF sands

Pits # 1 & 2 have 11.9 ppg DMW to follow kill mud

Potential SWF sands

14.0 ppg lead (500 bbls) kill MW followed by drill MW per depth from blending manifold

Adjust MW in pits # 1 & 2 to 12.8 ppg

Potential SWF sands

22"

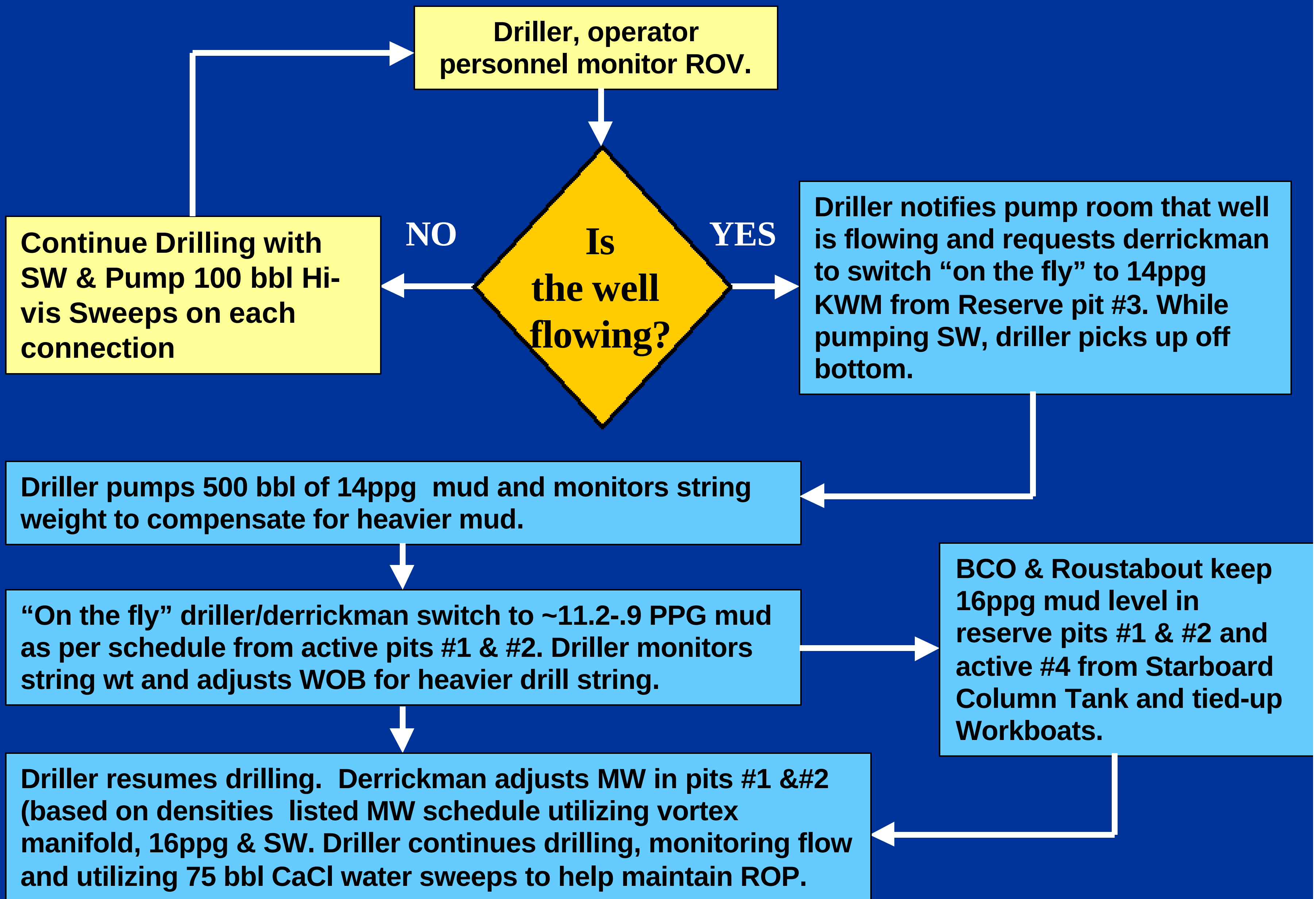
- **Drill MW required to give an EMW = "Most Likely PP + 0.5 PPG.**
- **Kill MW figured to give EMW = 1.5 PPG + "Most Likely" PP (14.0 Max.).**
- **22,500 bbls made available at rig using 5 work boats w/ limited variable deckload capacity of rig.**
- **Mud mixing manifold was a "critical enabler" to the plan.**

Vortex Mud Mixing Manifold

- Variably adjust mudweight "on the fly"

- Reduced volumes (1 barrel of 16 PPG base mud = 3 barrels of 11 PPG finished mud).

SWF ACTION PLAN



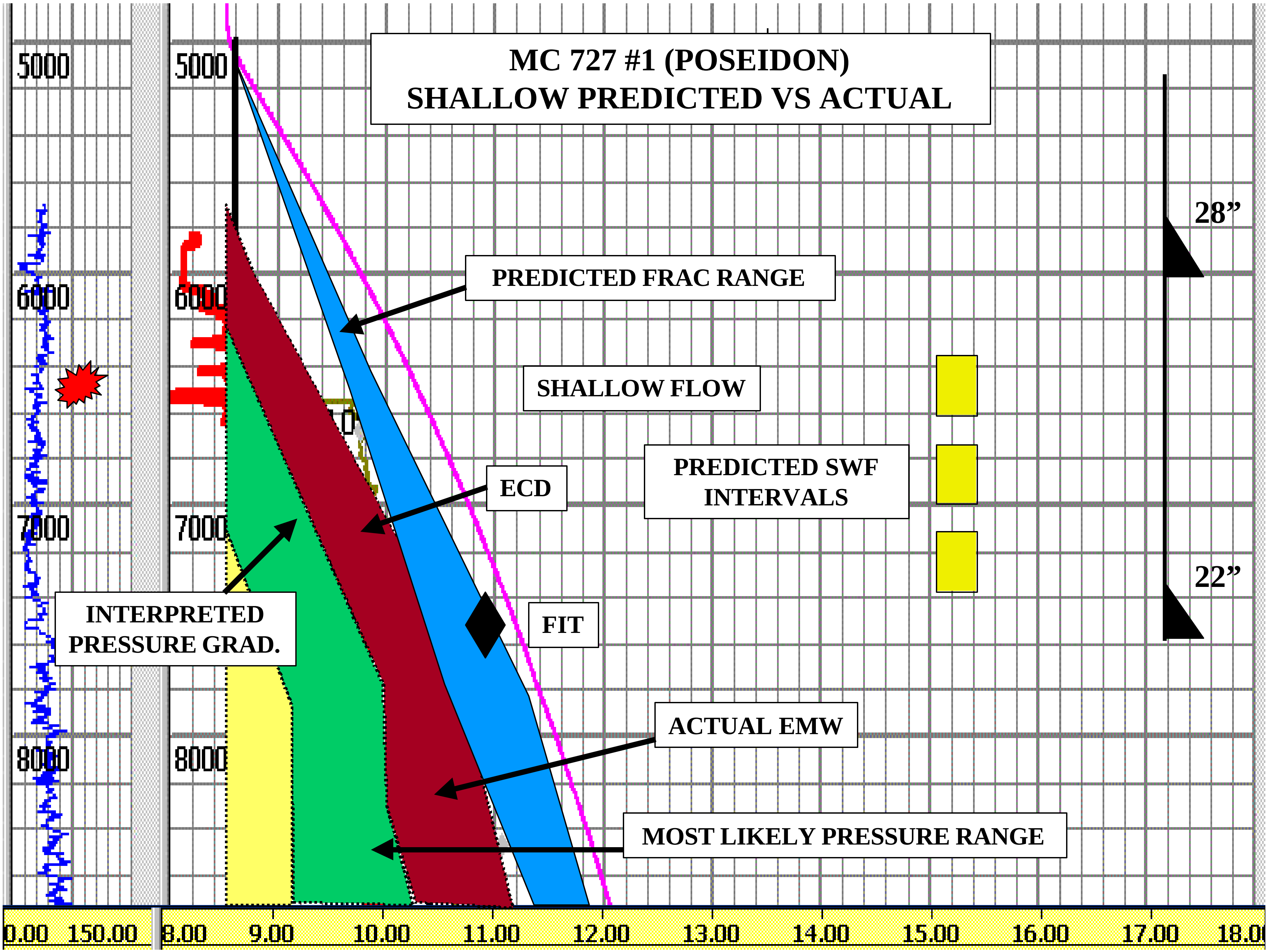
Well Status

- Well spudded in 4886' WD
- Conductor and 28" Pipe sections drilled riserless without incident using seawater.
- Geologist at rigsite to correlate MWD log and drilling indicators w/offset logs and seismic.
- At ~6530' MD, drilling personnel alerted that possible SWF sands might be encountered within next 50 feet.
- At 6542' MD (1571' BML) while drilling with seawater, well began to flow.

SHALLOW WATER FLOW VIDEO

OUTCOME

- SWF successfully killed without interruption in drilling.
- 26" hole section drilled successfully to 7550' MD (2664' BML).
- Due to high ROPs, ~15,500 barrels of mud were used - 6500 barrels less than anticipated.



MC 727 #1 (POSEIDON)
SHALLOW PREDICTED VS ACTUAL
PREDICTED FRAC RANGE
SHALLOW FLOW
PREDICTED SWF INTERVALS
ECD
FIT
INTERPRETED PRESSURE GRAD.
ACTUAL EMW
MOST LIKELY PRESSURE RANGE
28"
22"
5000
6000
7000
8000
0.00
150.00
8.00
9.00
10.00
11.00
12.00
13.00
14.00
15.00
16.00
17.00
18.00

Shallow Section Summary

- 22 “ Casing landed to 7498’ MD
- Casing cemented with a nitrogen foamed cement lead and unfoamed tail with returns taken at the wellhead.
- Better than expected FIT of 10.9 PPG.
- No water or gas flow at wellhead.
- Over 2,000,000 lbs. of casing and BOP weight placed on wellhead with no subsidence or casing deformation problems observed.

SWF Avoidance/Mitigation Model

- Drilling hazards/stratigraphic interpretation and PP/FG evaluation closely integrated with drilling engineering design and planning.
- Careful consideration given to the risk of SWF relative to costs of mitigation and the cost/benefit of avoidance versus mitigation.
- Detailed process planning, innovative engineering and rigsite geologic correlation while drilling contribute to success.

Modelling of Casing Collapse as a result of Shallow Water Flow (SWF)

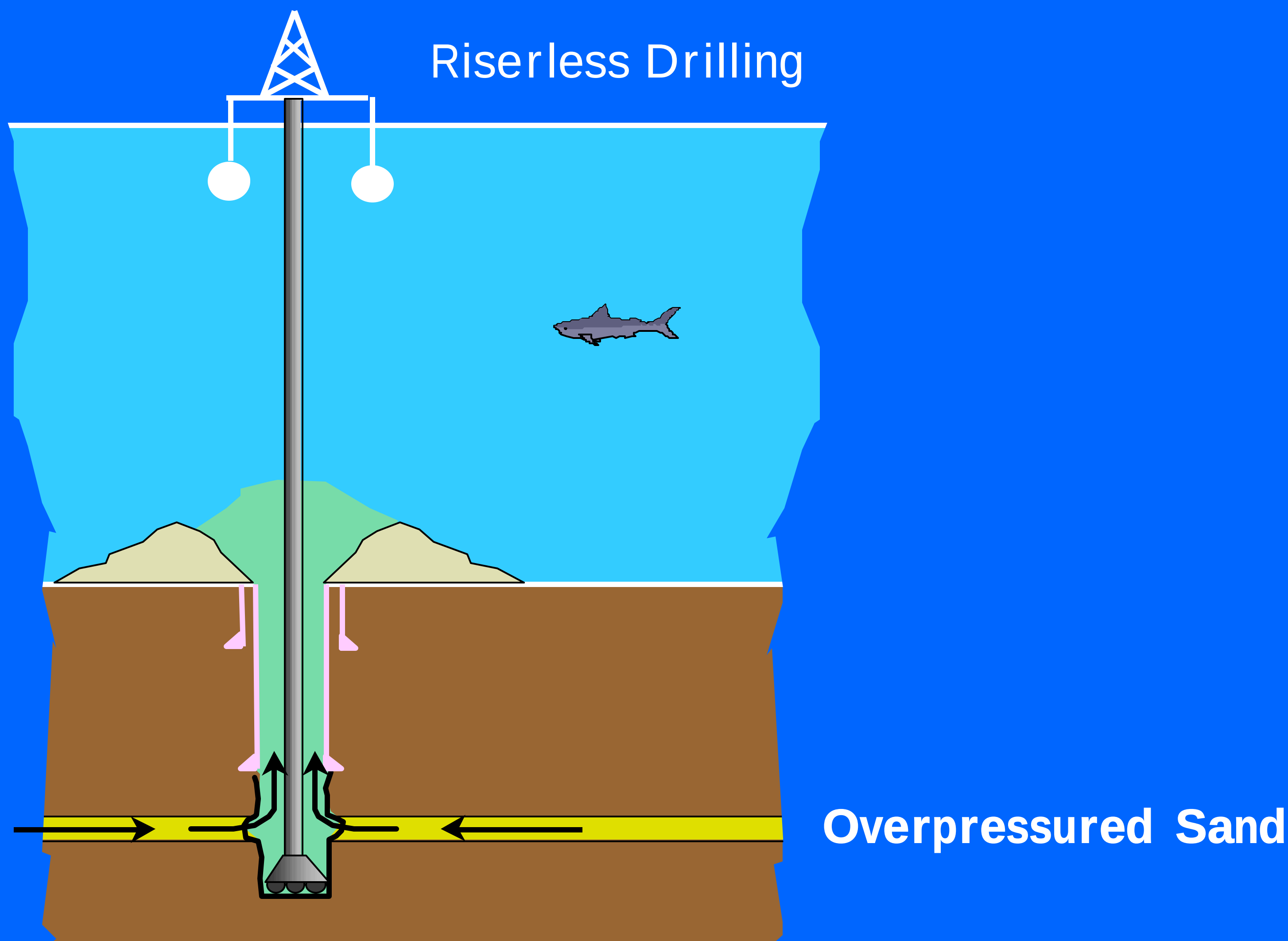
Mike McLean (bp), Mark Alberty (bp)

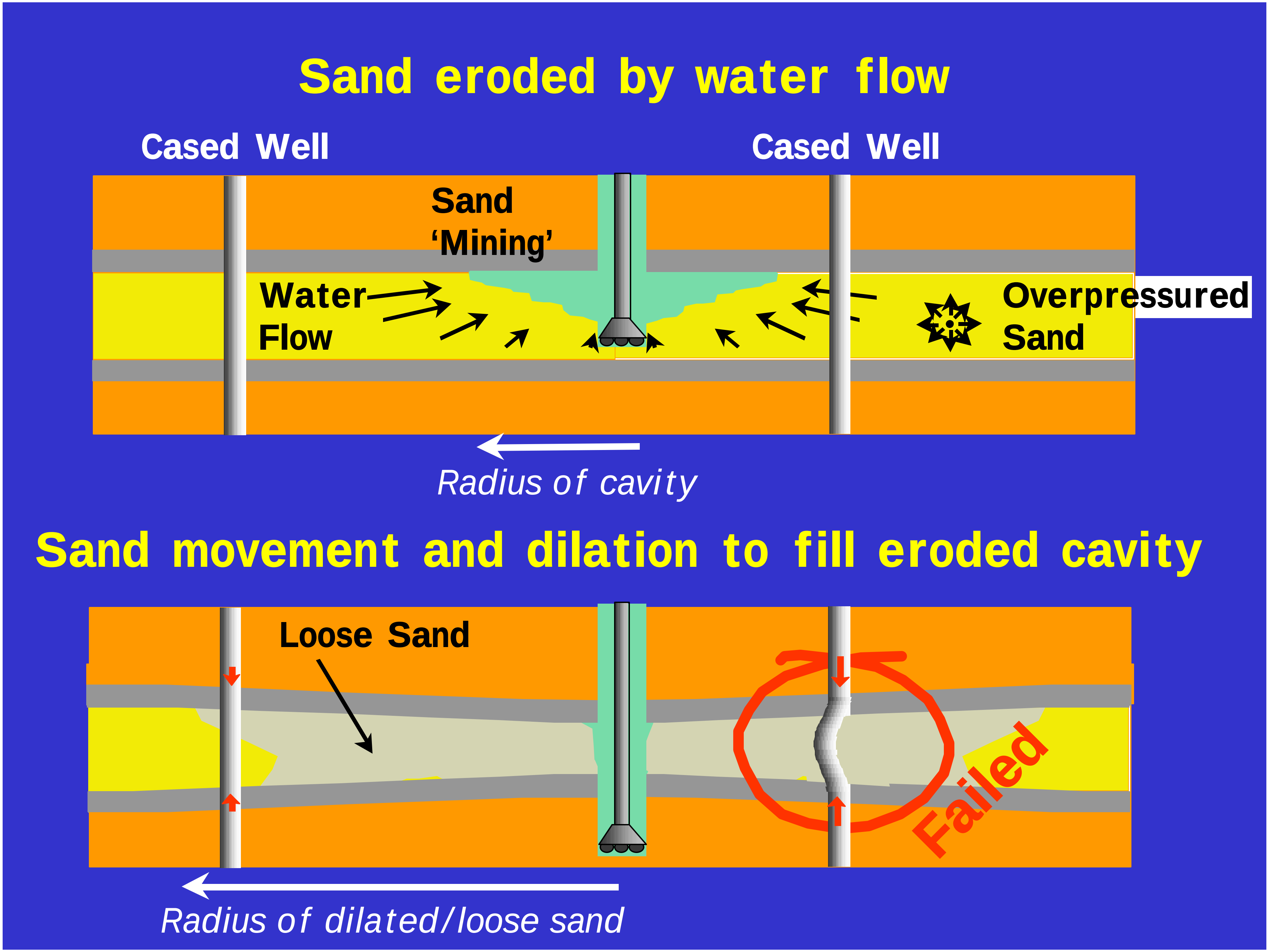
and Andy Rawicki (Chevron)

Presentation Outline

- Definition of the problem and assumed processes.
- Technical disciplines involved.
- Why model the SWF problem?
- URSA field case
- Genesis field case
- Conclusions/Lessons Learnt

The Problem




Sand eroded by water flow
Cased Well
Cased Well
Sand
'Mining'
Water
Flow
Overpressured
Sand
Radius of cavity
Sand movement and dilation to fill eroded cavity
Loose Sand
Failed
Radius of dilated/loose sand

Technical Disciplines Involved

- How much sand is eroded? Hydraulics

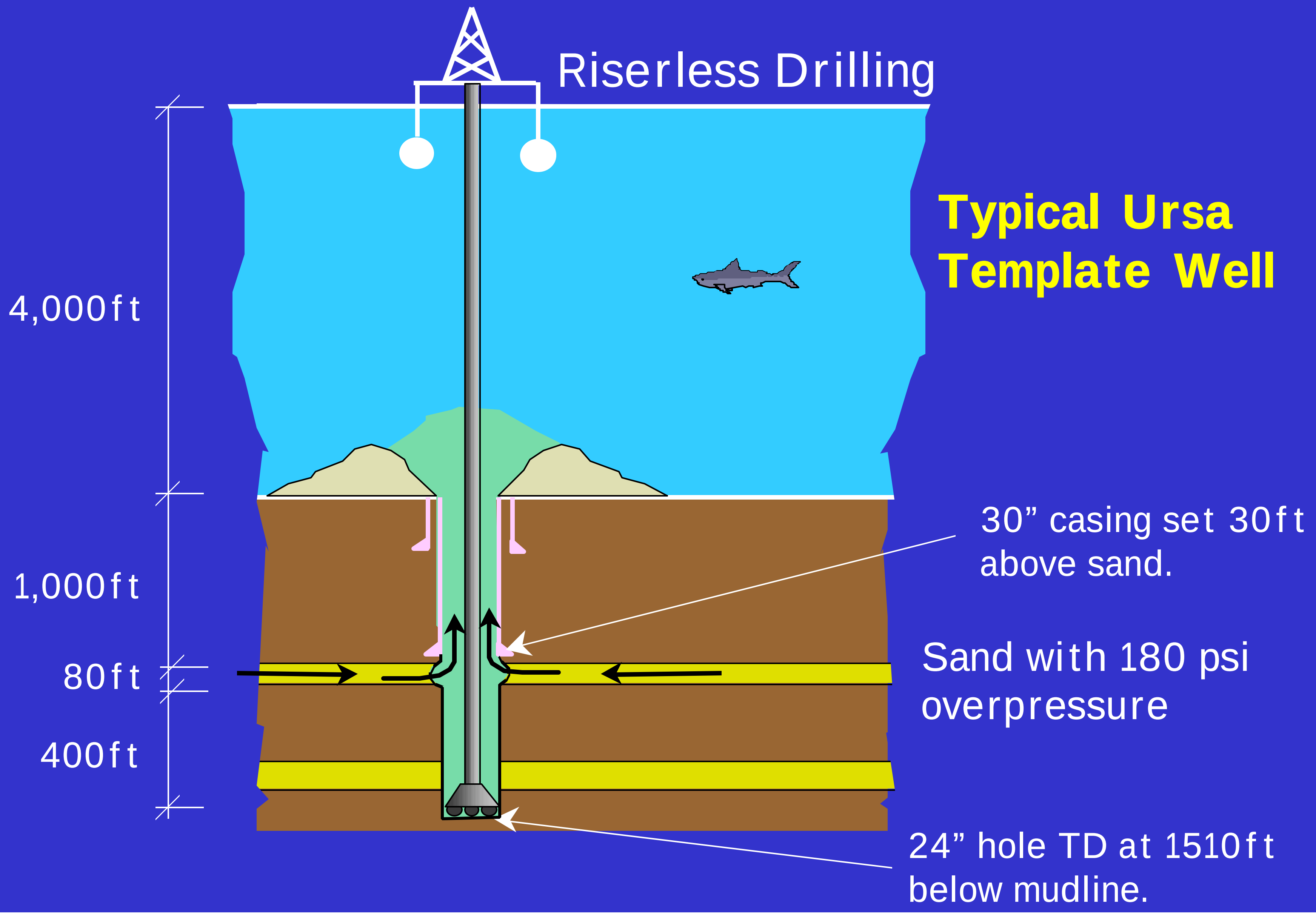
- How does the surrounding rock react to the cavity caused by sand erosion? Geomechanics

- How does movement in the overburden resulting from Item 2 above effect the integrity of existing casings within the "zone of influence"? Tubular Technology

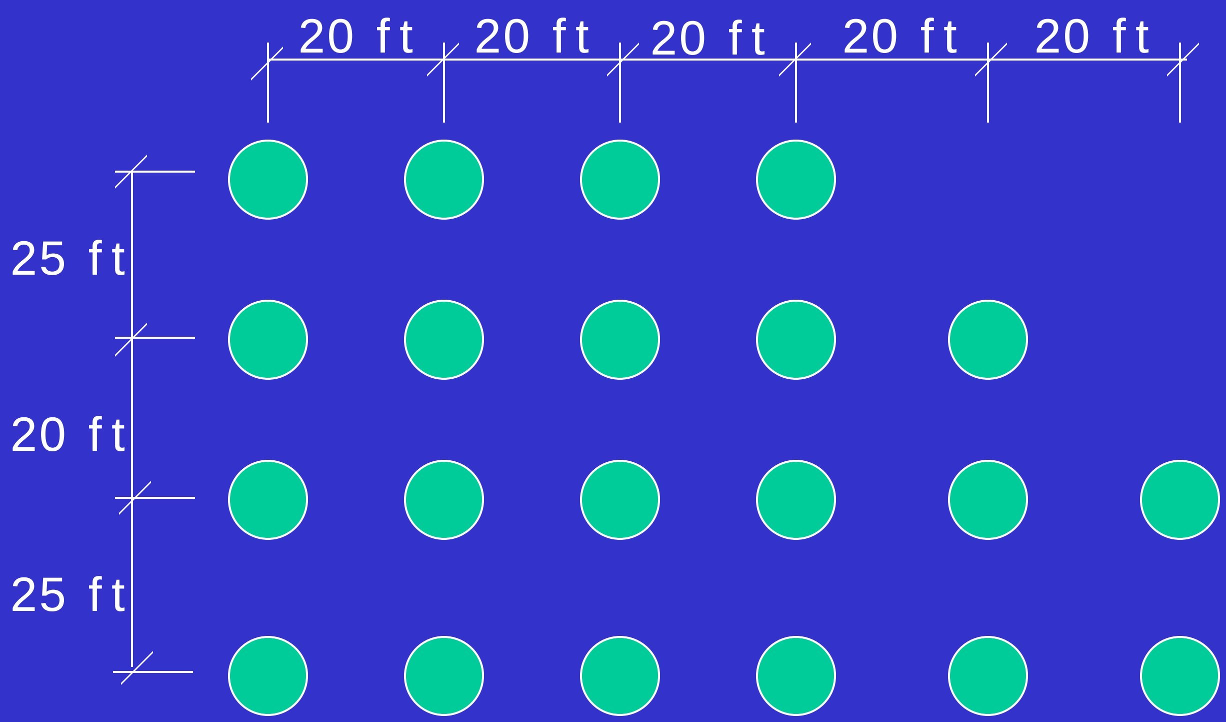
Purpose of SWF Model

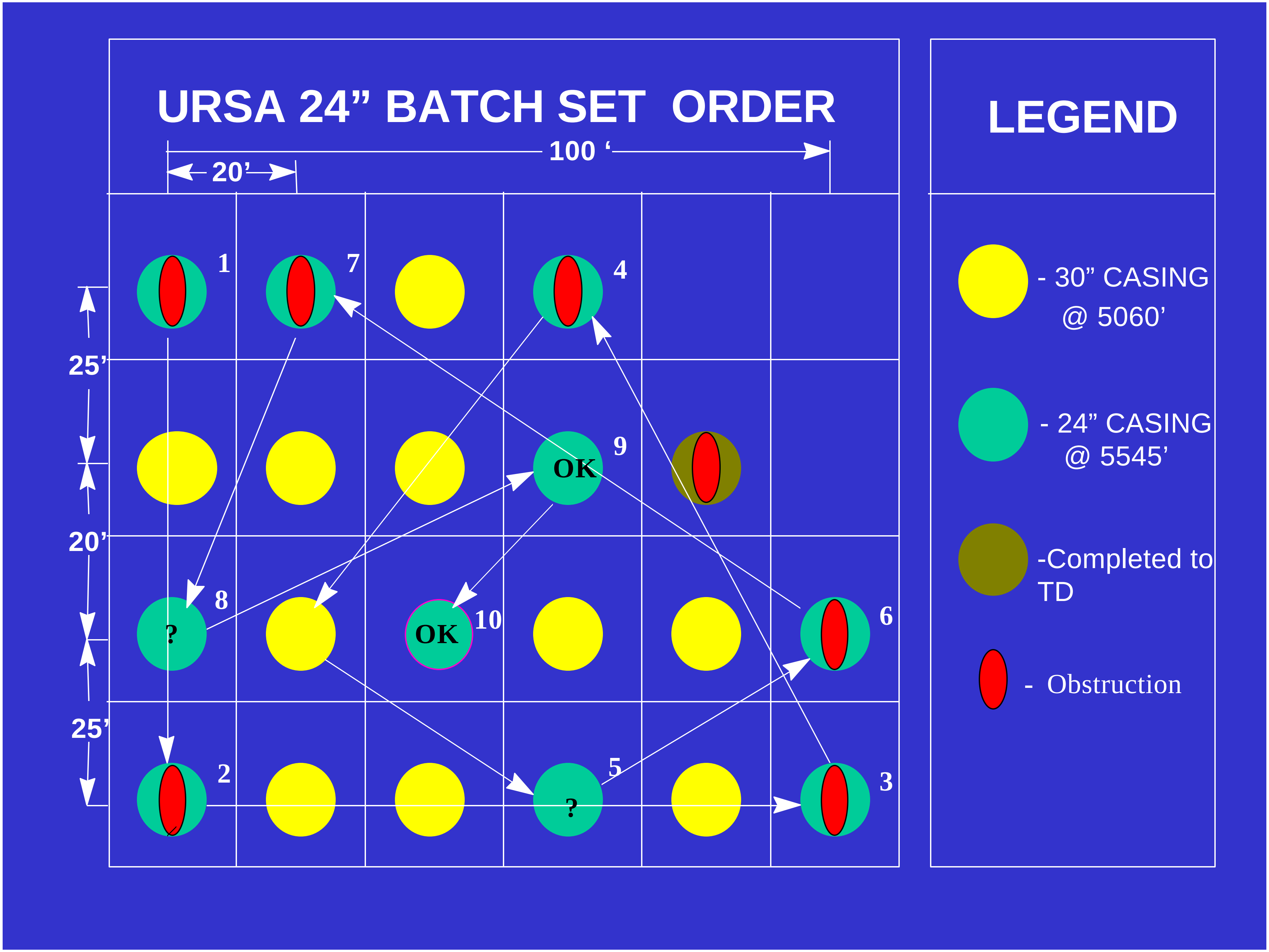
- Analyze Past Problems
- Influence Design of New Installations
  - *Facilities*
  - *Drilling program*
- Monitor Stress Accumulation
- Avoid another URSA

URSA Case Study



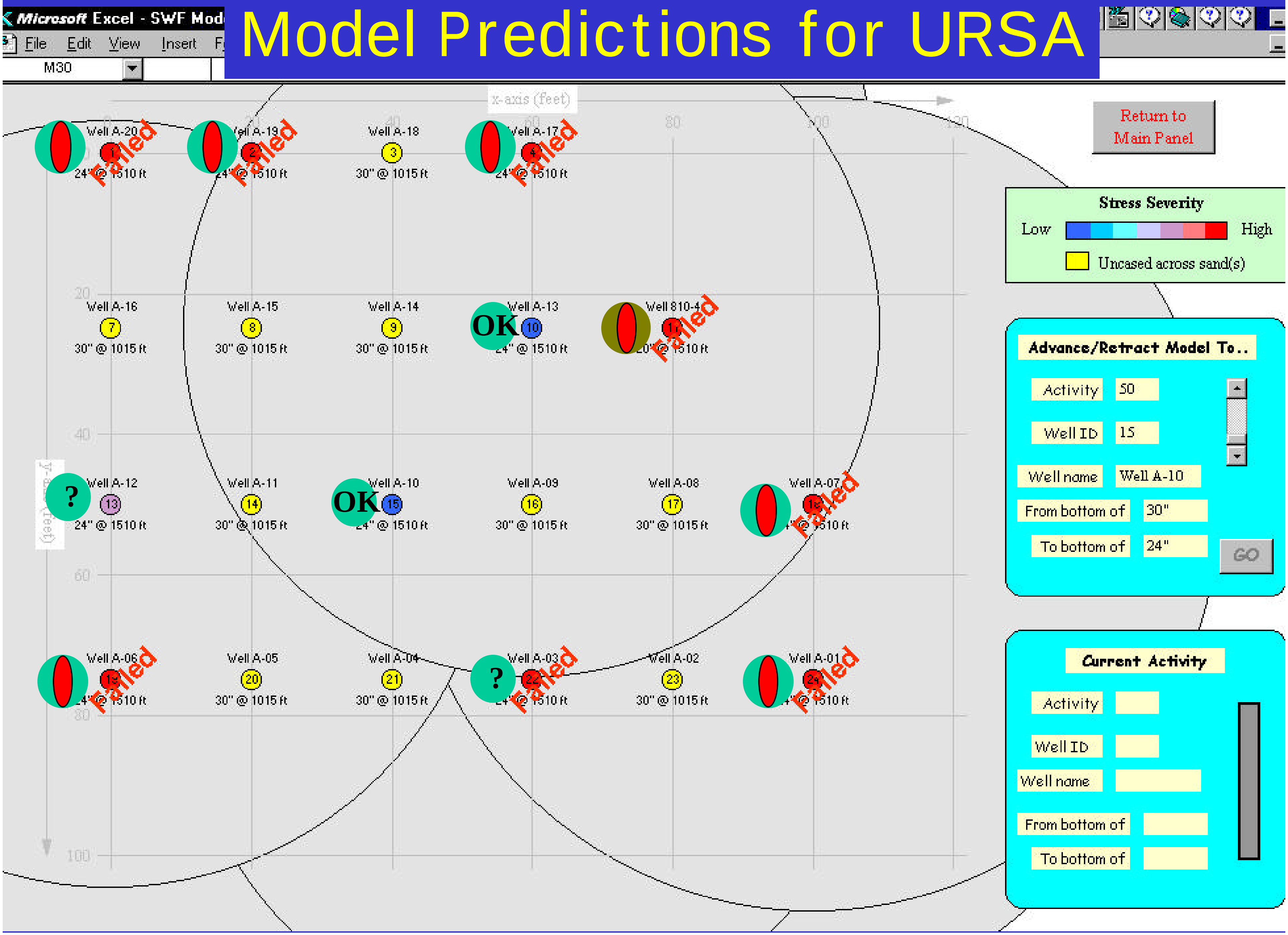
Well Spacing at Ursa Template





URSA 24" BATCH SET ORDER
100 '
20'
25'
20'
25'
1
7
4
9
OK
8
?
OK
10
6
2
5
?
3
LEGEND
- 30" CASING @ 5060'
- 24" CASING @ 5545'
-Completed to TD
- Obstruction

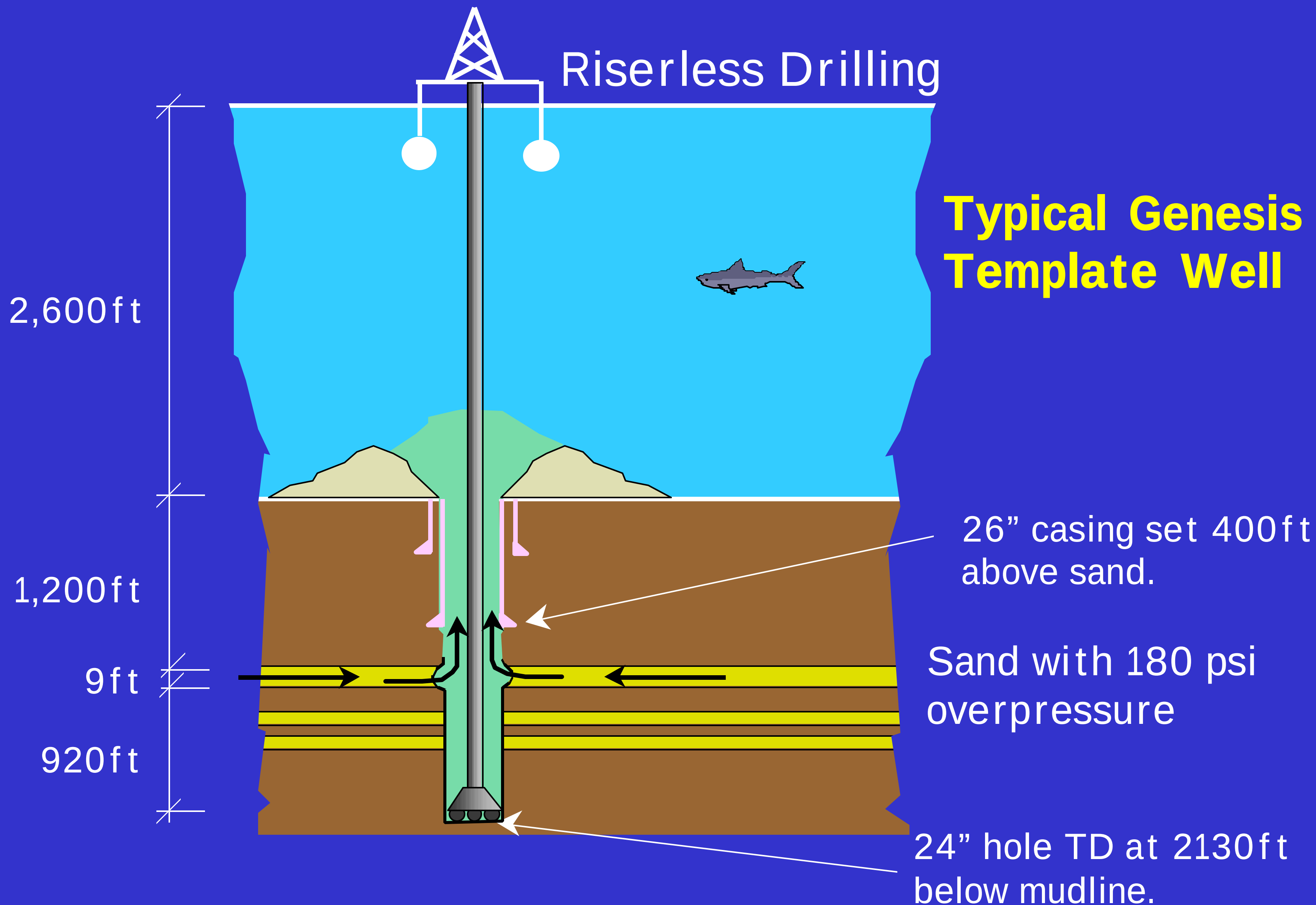
Model Predictions for URSA



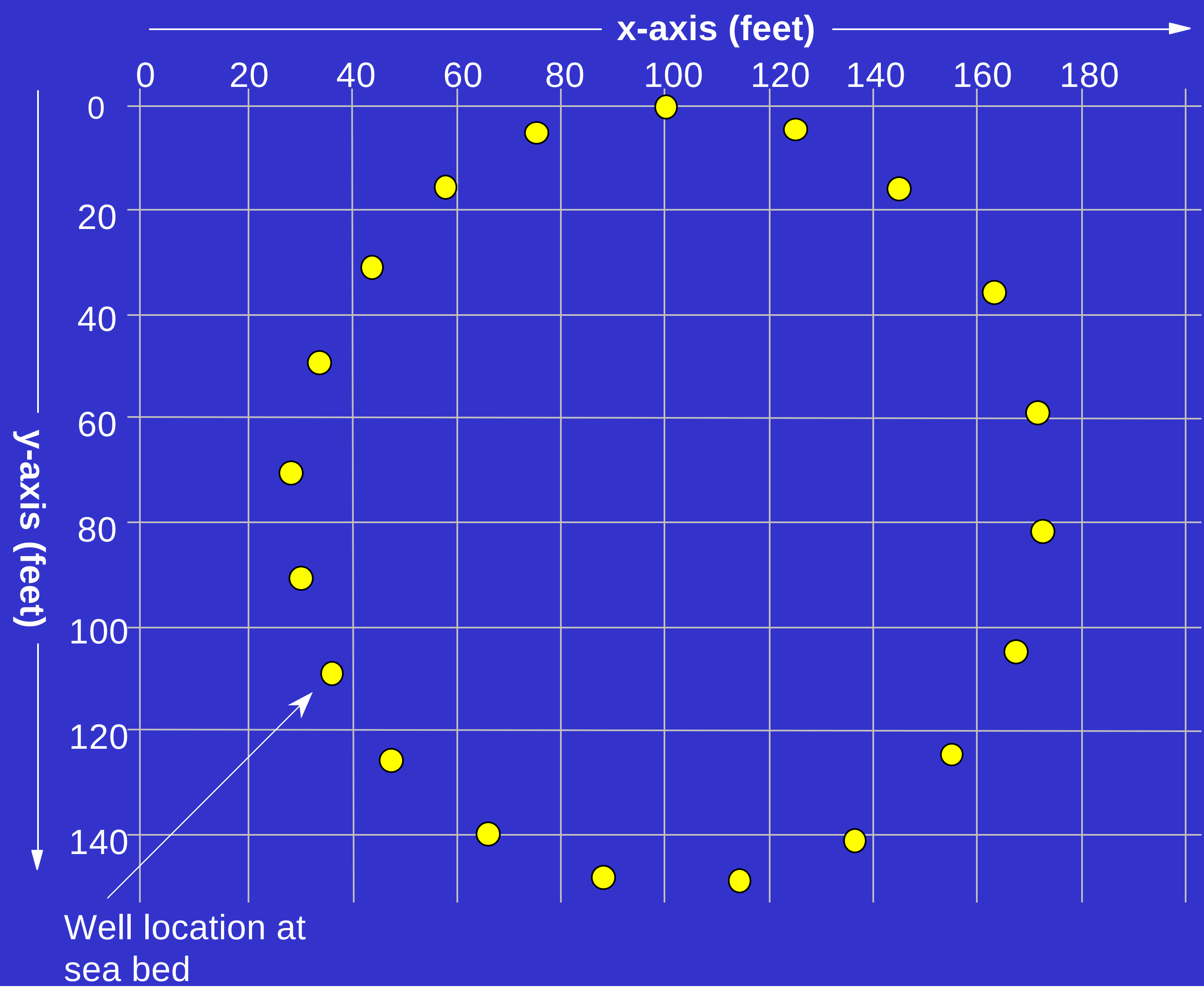
Summary of Ursa Data

- Water depth of 4,000 ft.
- 80 foot thick sand at 1,000 ft below mudline.
- 180 psi overpressure in sand.
- Drilled riserless.
- Rectangular well grid at 20-25 ft spacing.
- Drilling sequence optimized for minimizing SWF problems.
- Typically sands flowing for approximately 20 hours.
- Flow rate from sands 20,000 bbl/day (model estimate).
- Sand eroded 30,000-50,000 cu.ft/well (model estimate).
- Radius of disturbed zone 50-70 ft (model estimate).
- Lost 7-9 wells due to buckling/distortion of 24” casing.
- Template abandoned – moved to new location.

Genesis Case Study



Well Spacing at Genesis Template

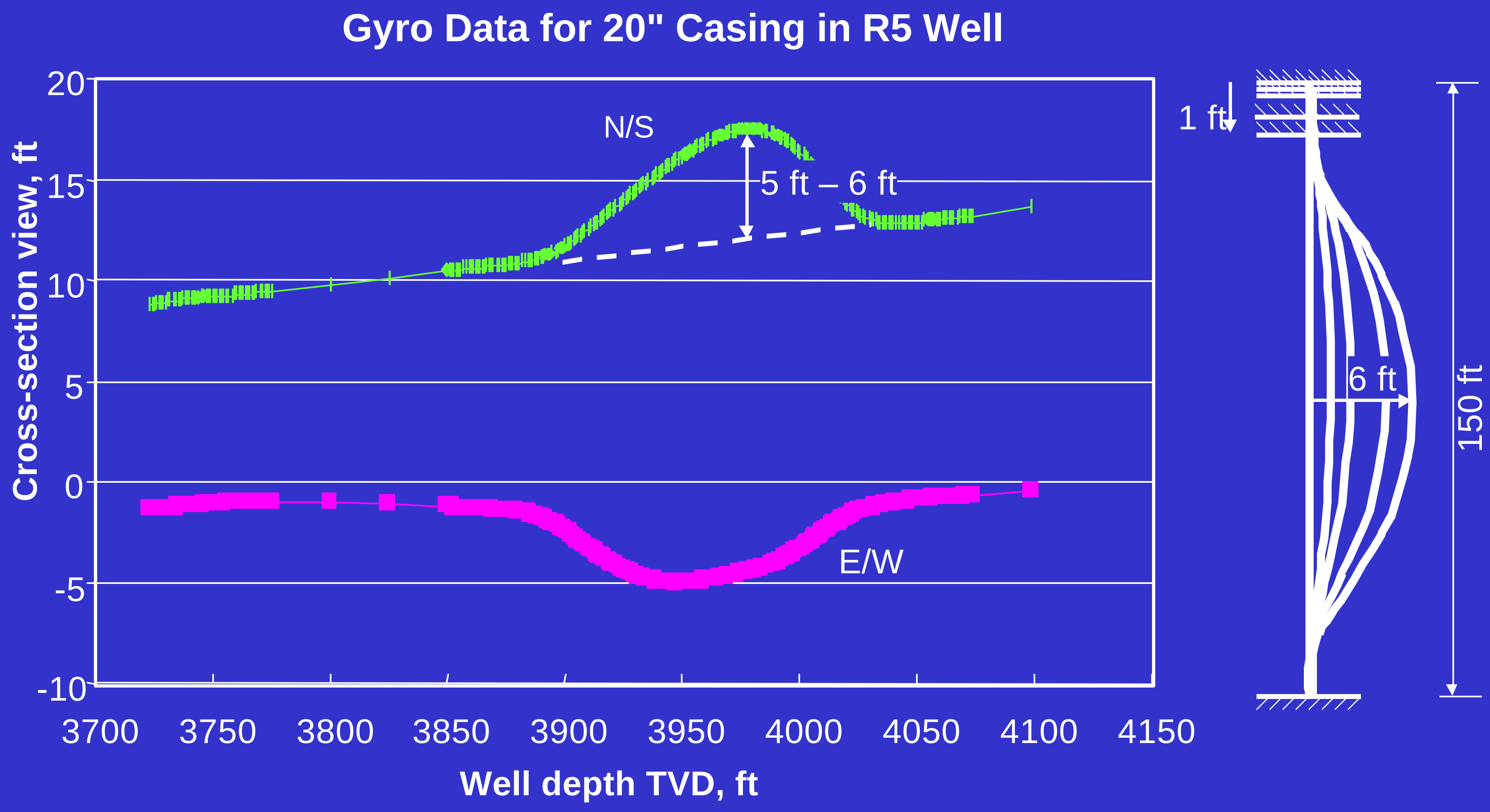


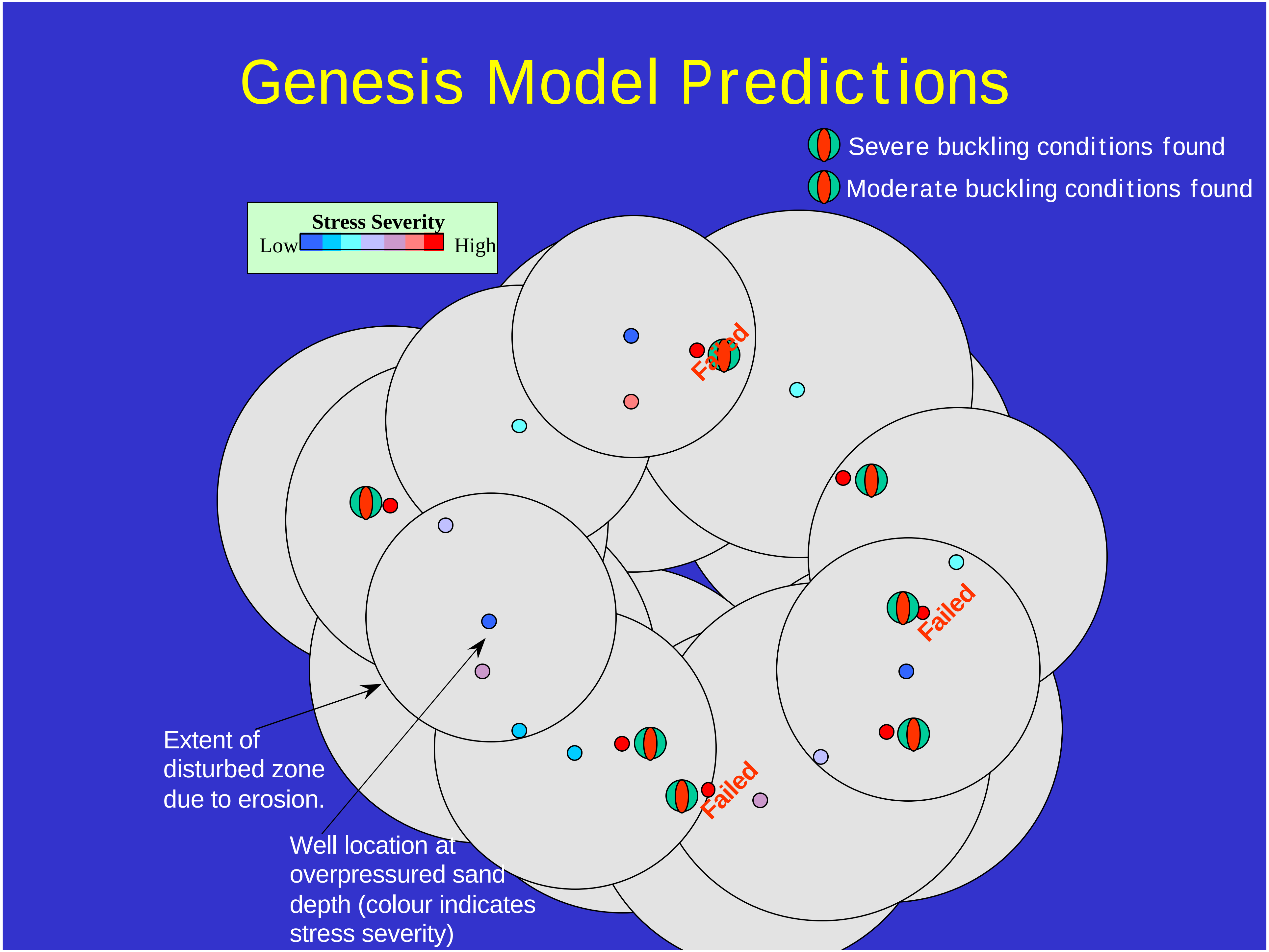
Genesis Gyro and Caliper Results

ORDER	SLOT	Max DLS	Depth	Minimum ID
1	U-3			
2	S-1	**58.51**	**3997**	**15.64**
3	S-5	5.13	3990	normal
4	Q-2	**56.36**	**3996**	**17.69**
5	U-2	**2.92**	**3740**	**18.01**
6	R-5	**51.03**	**4026**	**16.66**
7	R-2	11.11	3734	normal
8	U-5	19.84	3997	normal
9	T-5			
10	U-4			
11	T-4	**3.56**	**4000**	**normal**
12	Q-4			
13	T-2	**1.97**	**4275**	**normal**
14	Q-3	6.55	4035	normal
15	R-4	5.58	4005	normal
16	Q-1			
17	R-3	**1.09**	**3900**	**normal**
18	R-1	**3.06**	**4100**	**normal**
19	T-3	**1.28**	**4075**	**normal**

"Normal" denotes that no restrictions less than 18.2" were seen in the 20" casing (nominal ID was 18.73"). Red font indicates doglegs greater than 5 degrees/ 100' **OR a casing ID < 18.2".**

Genesis Example of Lateral Displacement from Gyro Data




Genesis Model Predictions
Severe buckling conditions found
Moderate buckling conditions found
Stress Severity
Low
High
Failed
Failed
Failed
Extent of disturbed zone due to erosion.
Well location at overpressured sand depth (colour indicates stress severity)

Summary of Genesis Data

- Water depth of 2,600 ft.
- 9 foot thick sand at 1,200 ft below mudline.
- 170 psi overpressure in sand.
- Drilled riserless.
- Circular well grid at 25 ft spacing.
- Drilling sequence optimized for minimizing SWF problems.
- Typically sands flowing for approximately 25 hours.
- Flow rate from sands 2,000 bbl/day (model estimate).
- Sand eroded 5,000 cu.ft/well (model estimate).
- Radius of disturbed zone 30-50 ft (model estimate).
- Lost 1 well, 3 wells could not run 16 inch casing.

Lessons Learnt / Conclusions

- Sand volumes eroded can be very large (50,000 cu.ft /well or more).
- Resultant cavities can be 25 ft radius or more.
- Dilation zone radius can be 75 ft radius of more.
- “Mining Induced” compaction can be as much as 1 ft even for erosion from a thin (10 ft) sand interval.
- Thin sands can still cause a problem. In fact, in some instances thin sands may be worse that thick sands.
- Effective casing compression/buckling length may be much longer than the thickness of the eroded sand interval.
- Drilling practices can be important in reducing severity of problem. For example
  - *high ROP,*
  - *low pump rates,*
  - *reduce hole length below overpressured sand body.*
- Grid pattern is important (circular better than rectangular).

Shallow Water Flow Risk Assessment For Field Development Planning Using High-Resolution 3D Seismic and Wellbore Stability Modeling

Kathleen Horkowitz, Alex Calvert, Jim Thomson,
Tom Byrd, Eric Ekstrand, and Donald Bruce

with thanks to Mike McLean and Mark Alberty

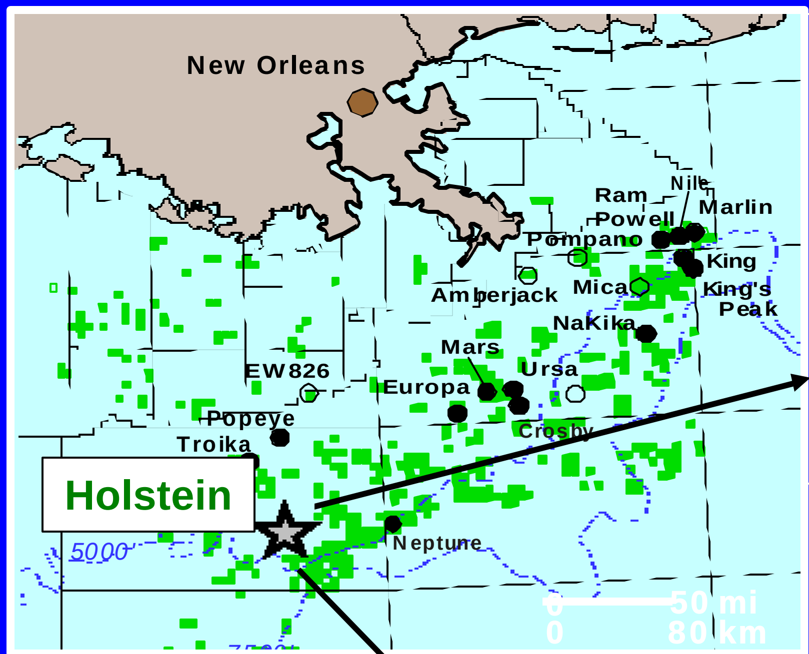
BP

Presentation Outline

- Introduction
  - SWF risk assessment for development vs. exploration drilling
- Project Objectives
- SWF Mapping Results

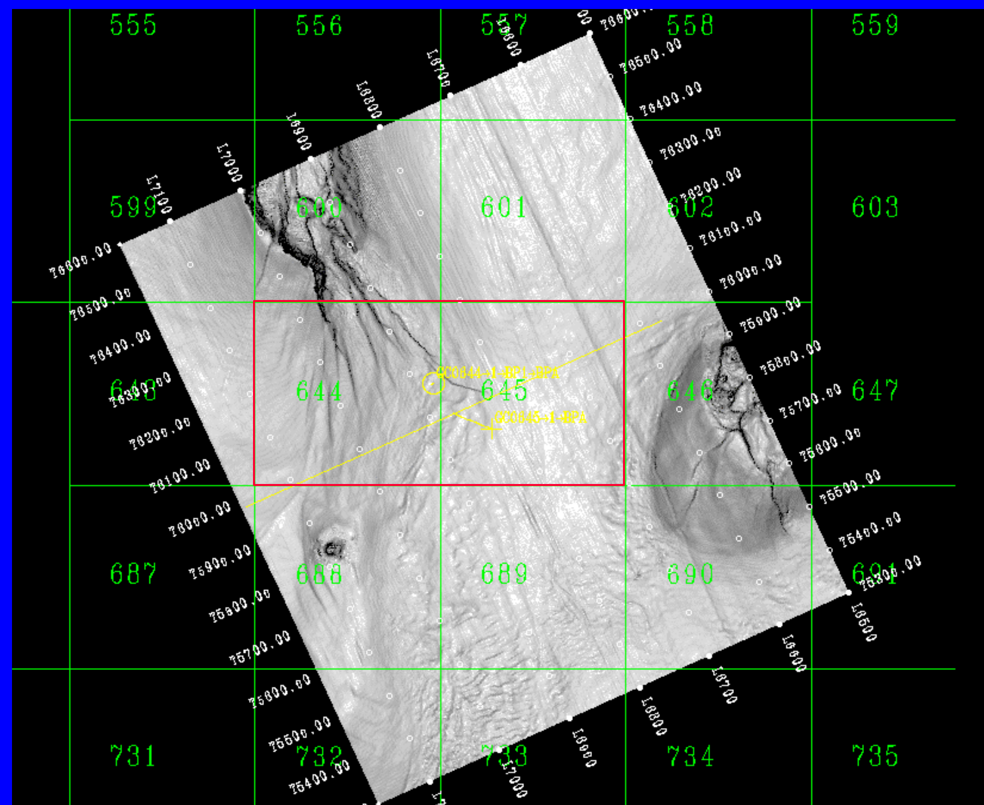
- Pressure While Drilling Observations (PWD)
- Shallow Water Flow Modeling
- Conclusions

Holstein Field
Southern Green Canyon, GOM



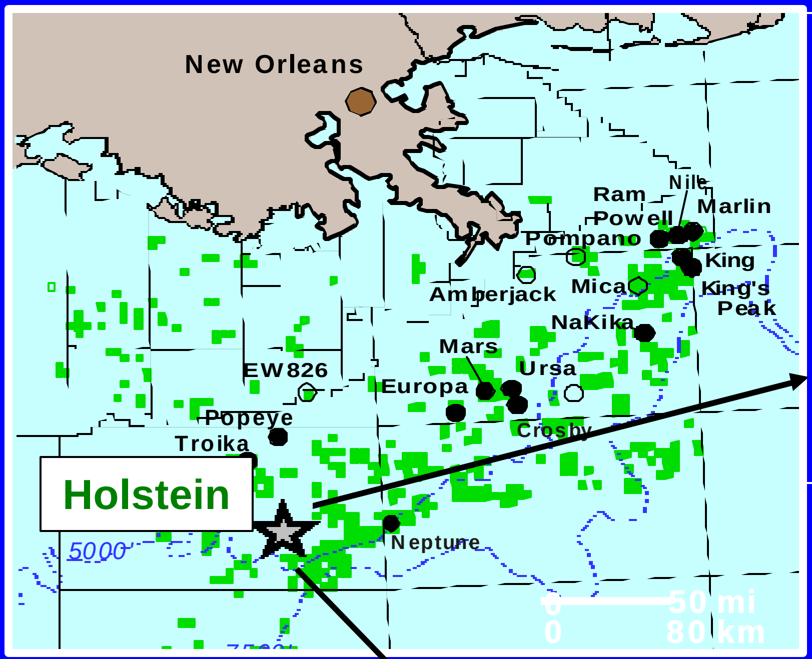
4300 ft water depth

Seafloor Dip Map with
exploration and appraisal well locations



- **GC-644**
  - **Flow observed**
  - **90’ sand**
- **GC-645**
  - **No flow observed**
  - **15’ sand**

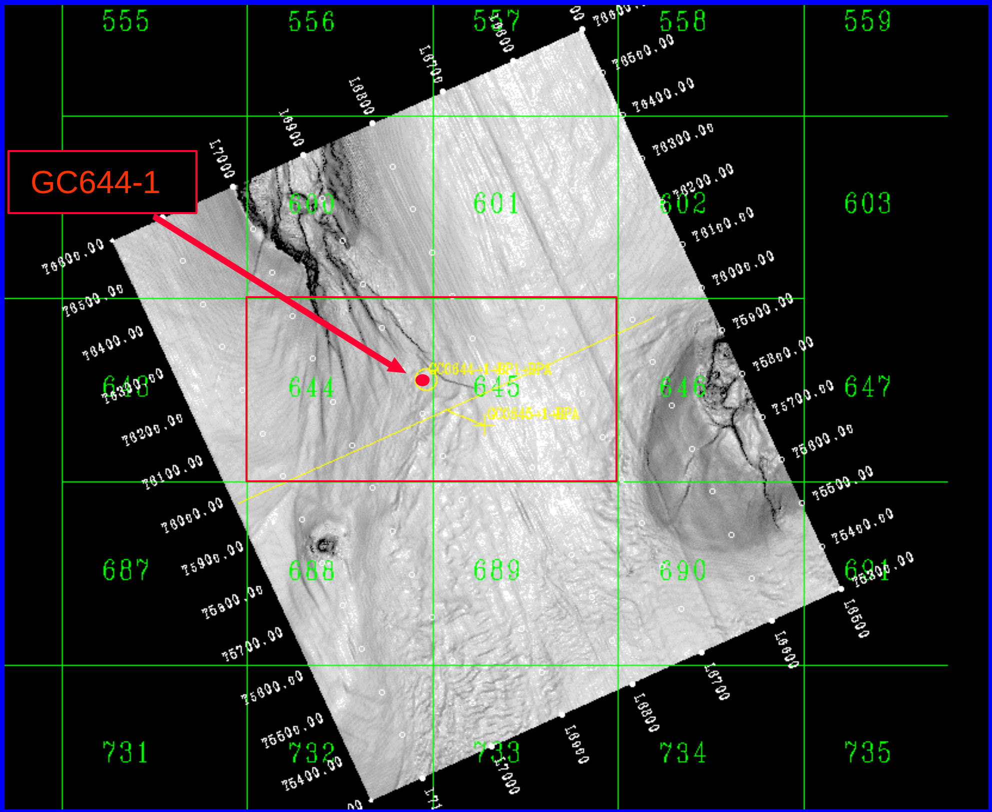
Holstein Field
Southern Green Canyon, GOM



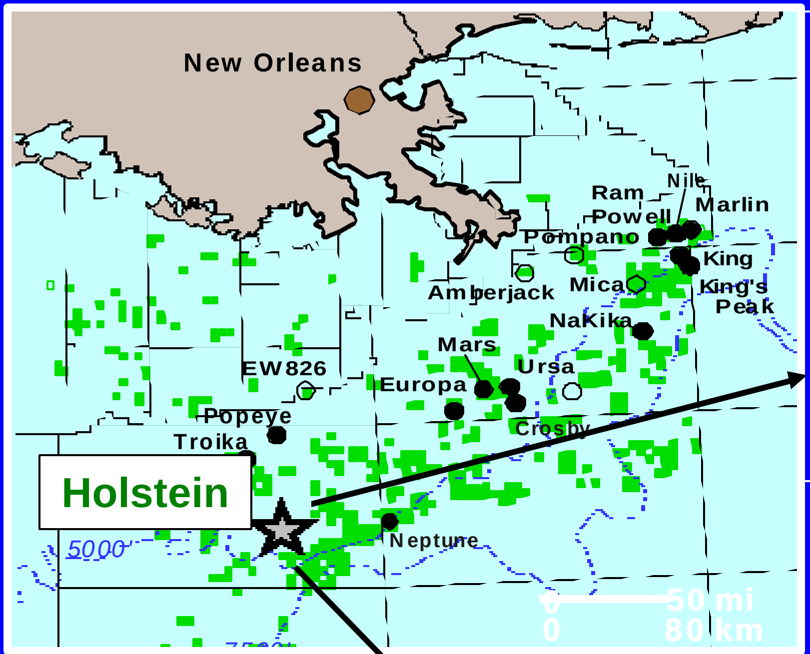
- **GC-644**
  - **Flow observed**
  - **90' sand**
- **GC-645**
  - **No flow observed**
  - **15' sand**

4300 ft water depth

Seafloor Dip Map with exploration and appraisal well locations

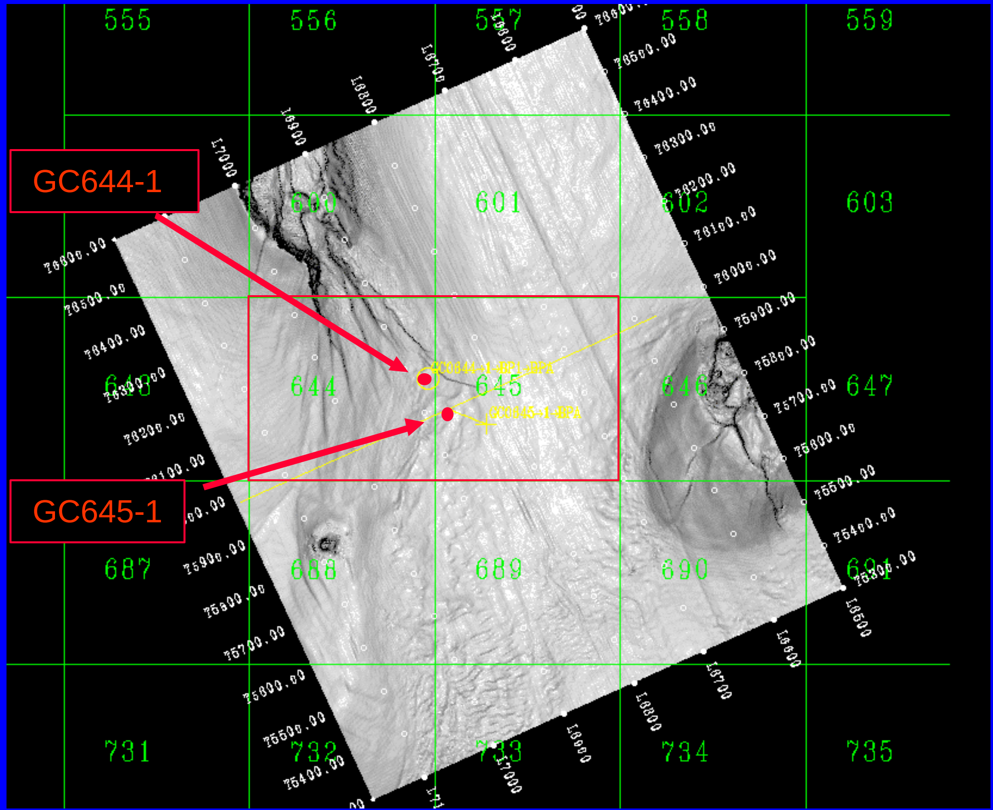


Holstein Field
Southern Green Canyon, GOM



4300 ft water depth

Seafloor Dip Map with
exploration and appraisal well locations



- **GC-644**
  - **Flow observed**
  - **90’ sand**
- **GC-645**
  - **No flow observed**
  - **15’ sand**

Project Objectives

- Delineate area that minimizes risk of shallow water flow
  - Map distribution of SWF sand using HR3D
  - Define optimum location for development facility

- Determine development plan that minimizes risk of SWF-induced casing failure
  - Evaluate well data and model proposed development plans
  - Examine sensitivity to geological and drilling parameters

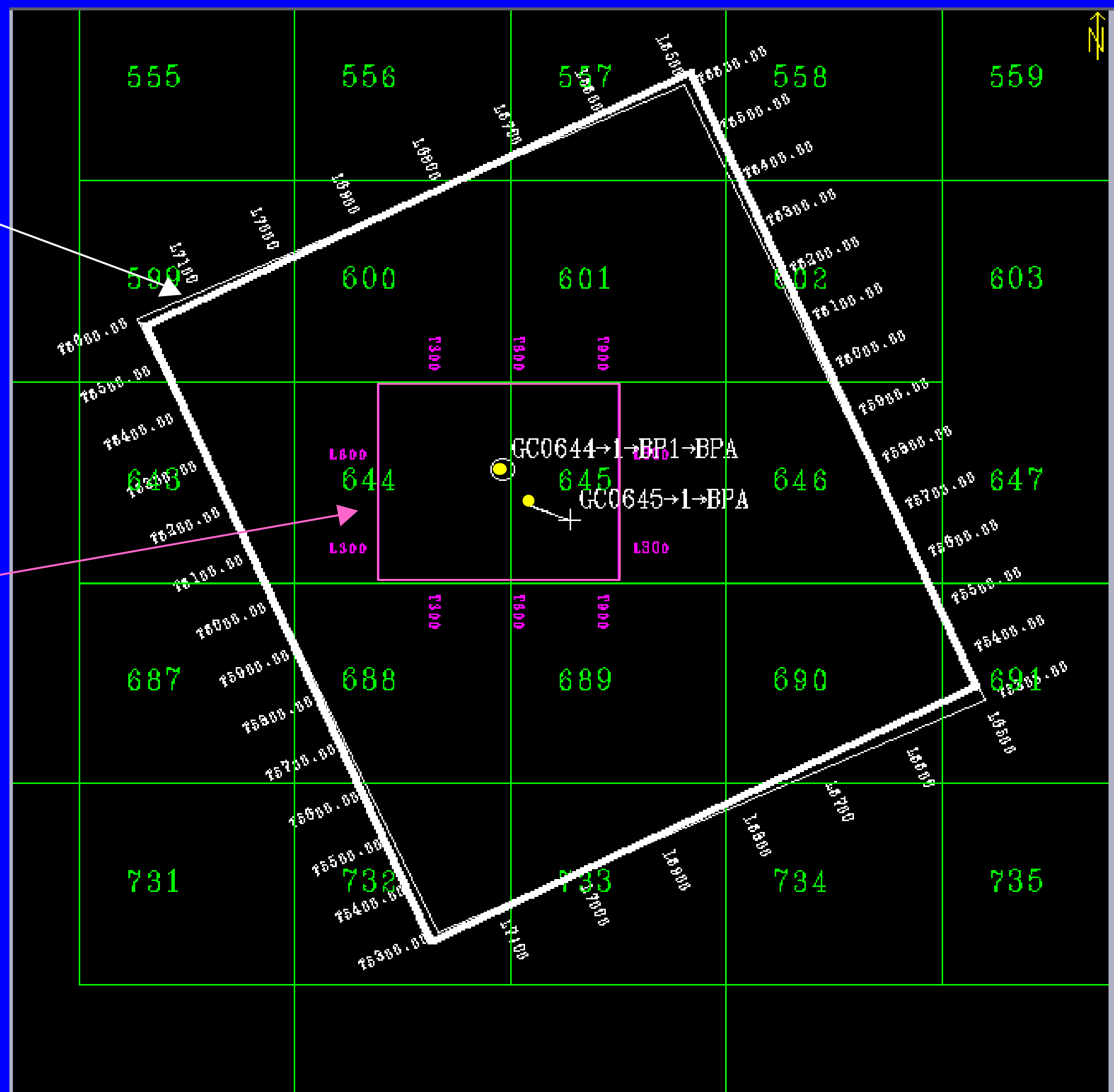
Conventional and High Resolution 3D Seismic Data Volumes

Exploration 3D

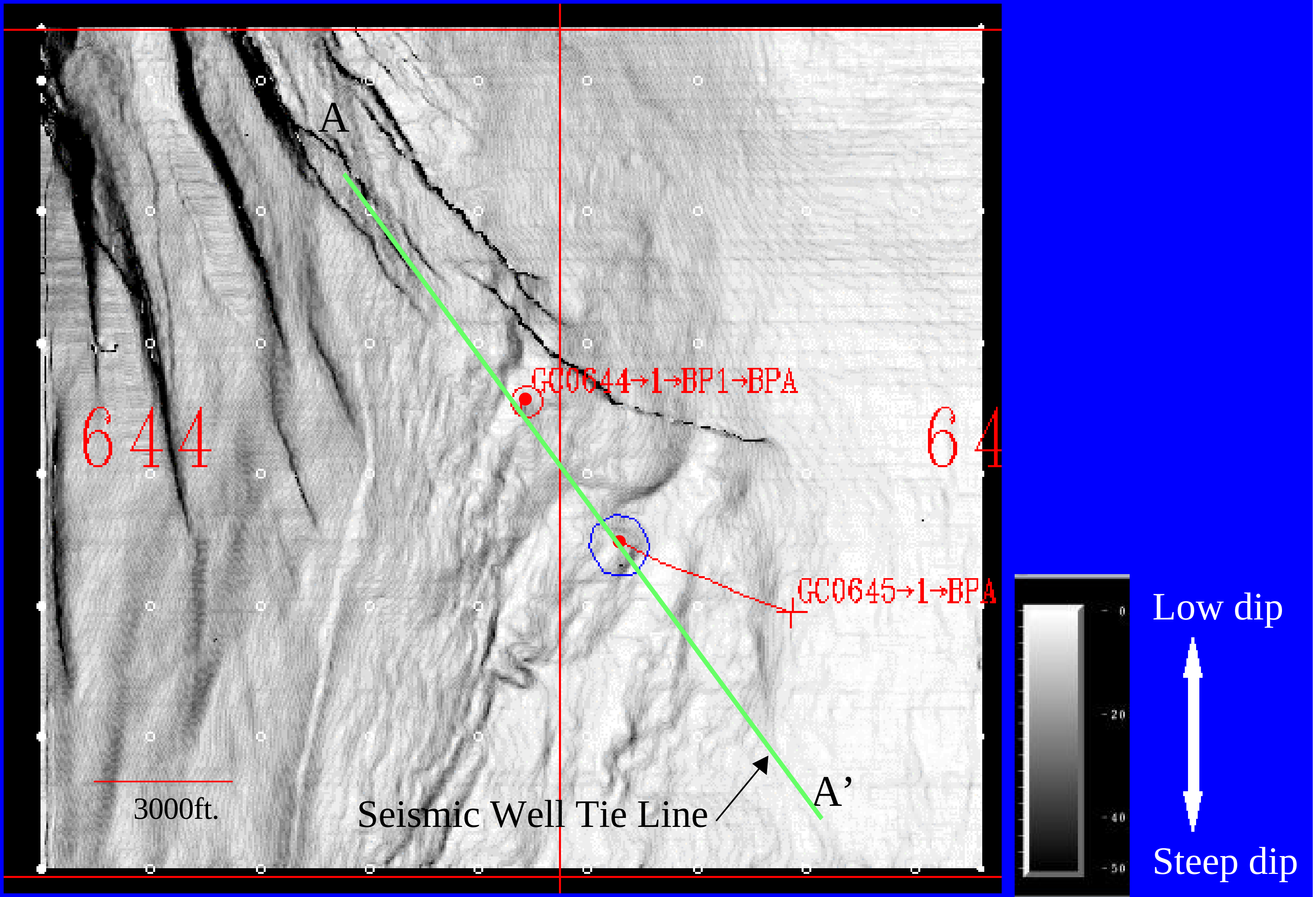
- Freq$_d$: 50-60 Hz
- Line spacing: 65 ft.
- Sample rate: 4 ms
- Tuning thickness = ~30ft.

High Resolution 3D Seismic

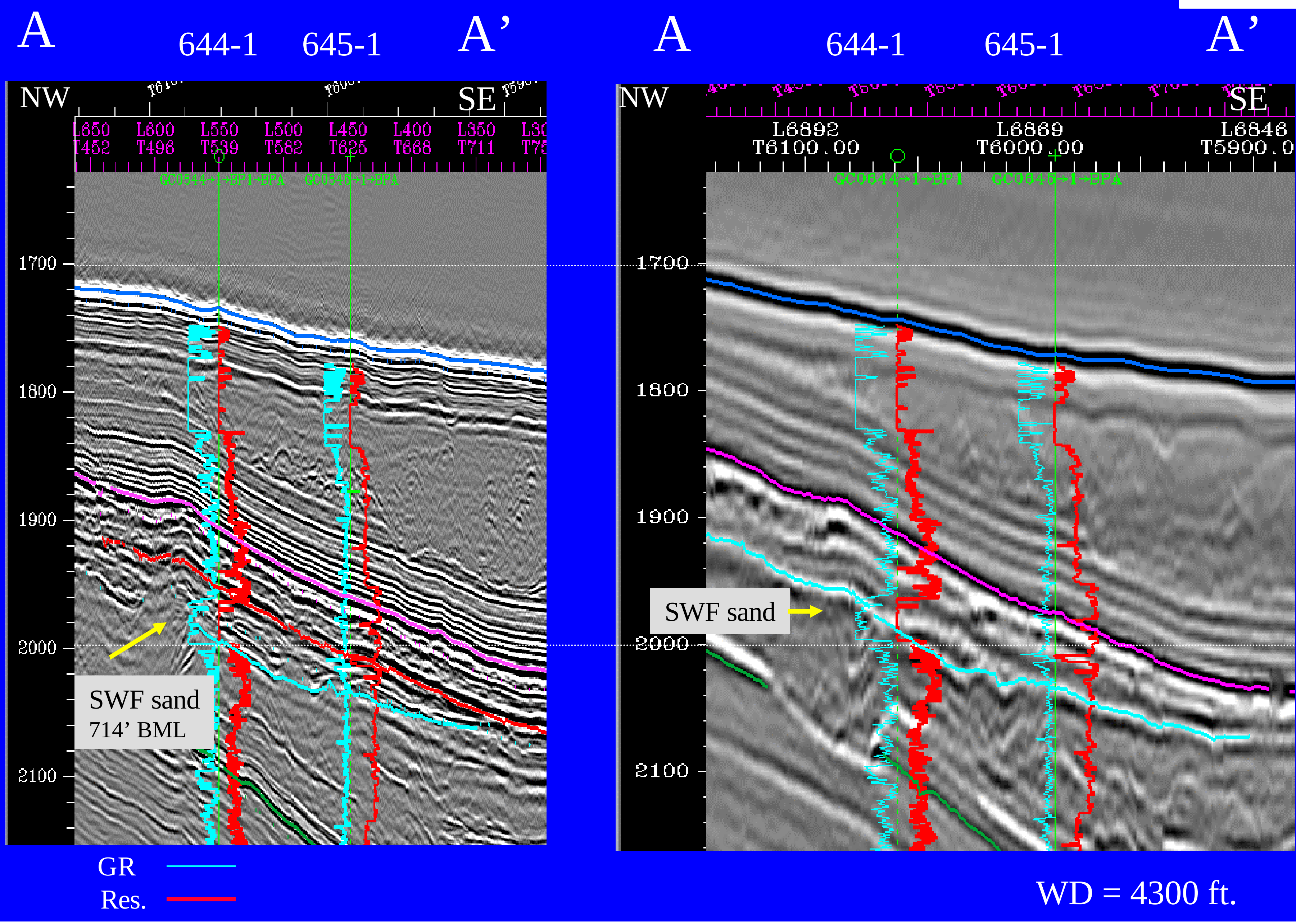
- Freq$_d$: 130-150 Hz
- Line spacing: 24 ft.
- Sample rate: 1 ms
- Tuning thickness = ~10 - 12 ft.



Seafloor Dip Map
(High-Resolution 3D)

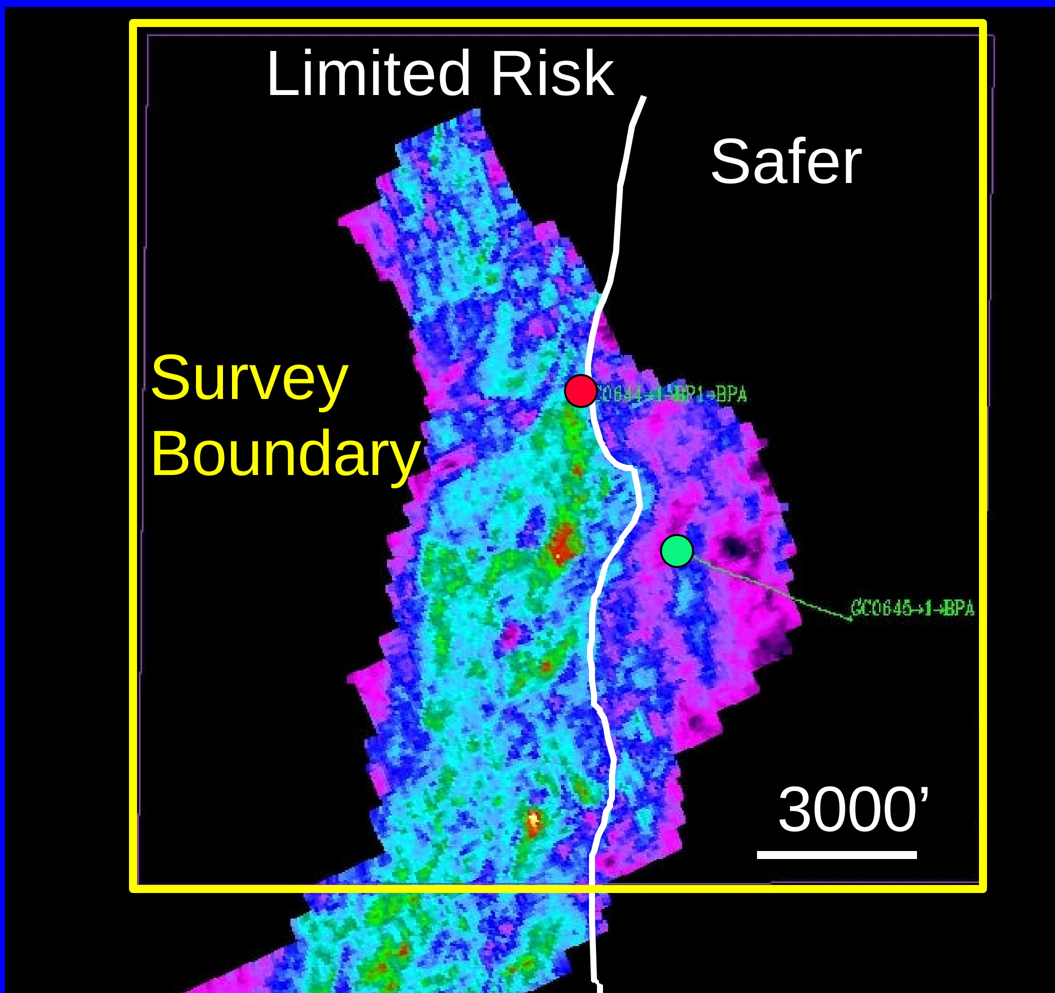


HR3D   Exploration 3D



WD = 4300 ft.

Project Status
Post-Appraisal Well



Limited risk of significant SWF

GC-645 appears to be located in relatively sand poor region

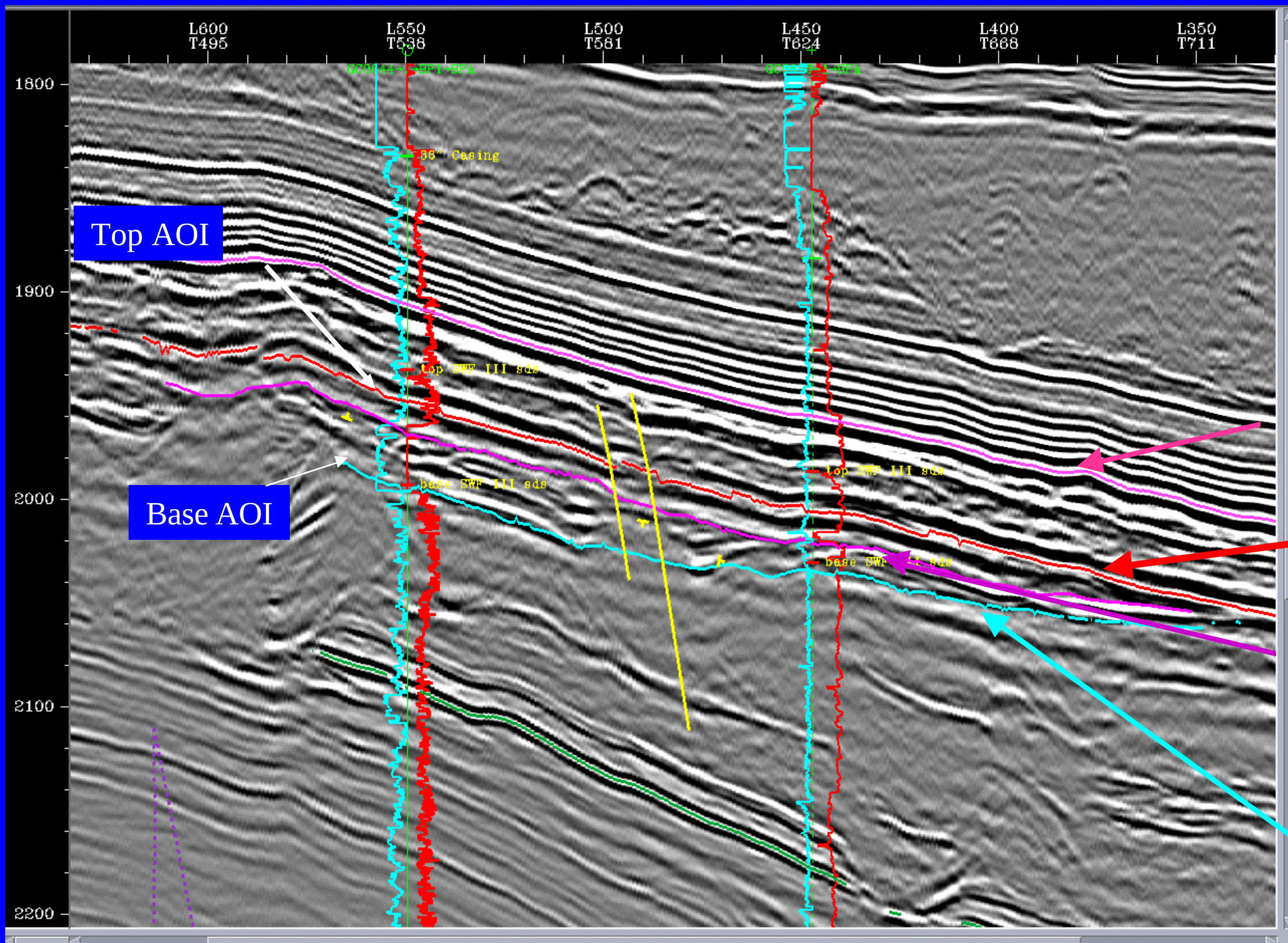
Recommend location near GC-645

New high-res 3D should allow more detailed mapping

HR3D Well Tie Line A – A”

GC 644-1 GC 645-1

NW



SE

Horizon A

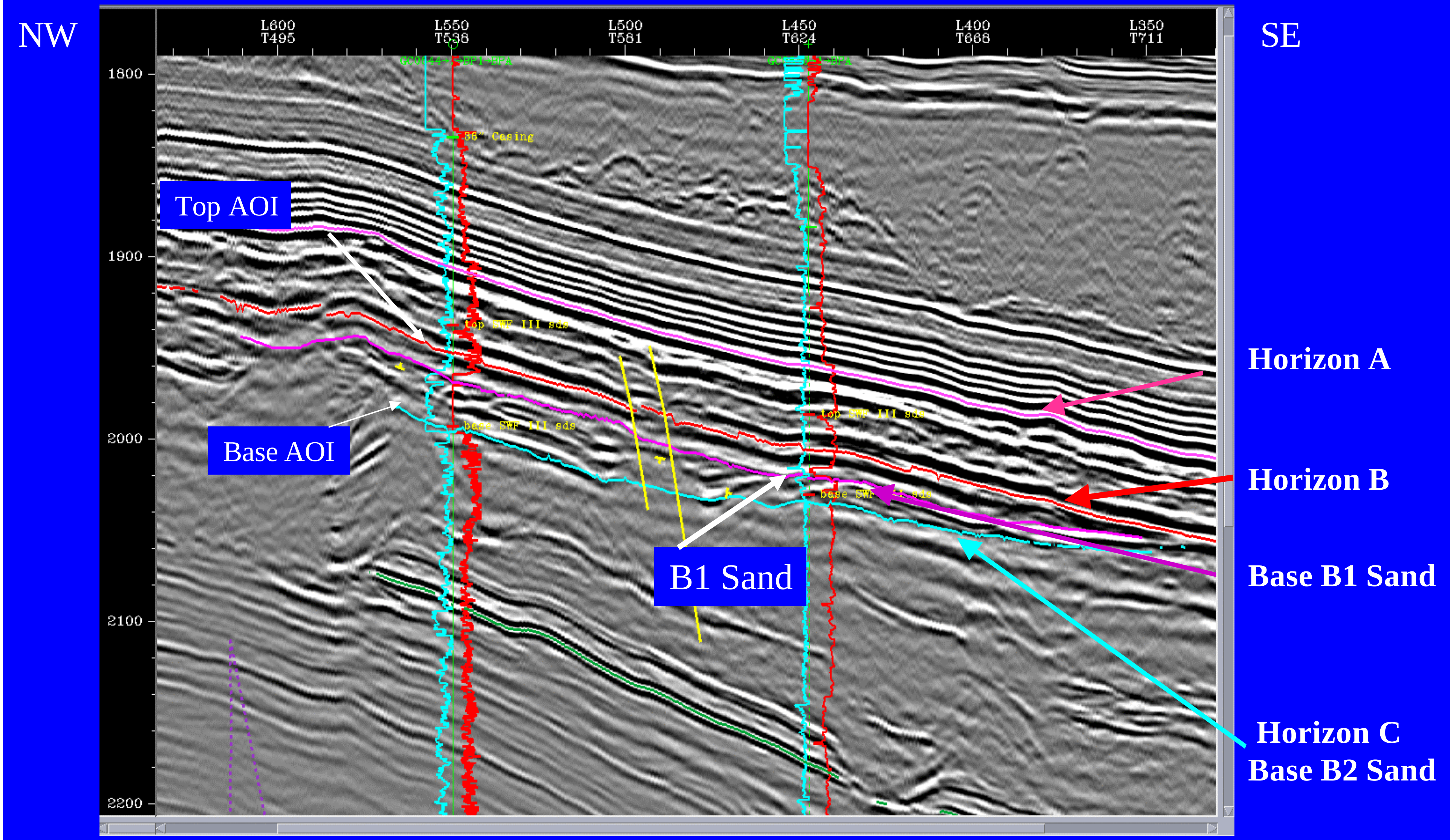
Horizon B

Base B1 Sand

Horizon C
Base B2 Sand

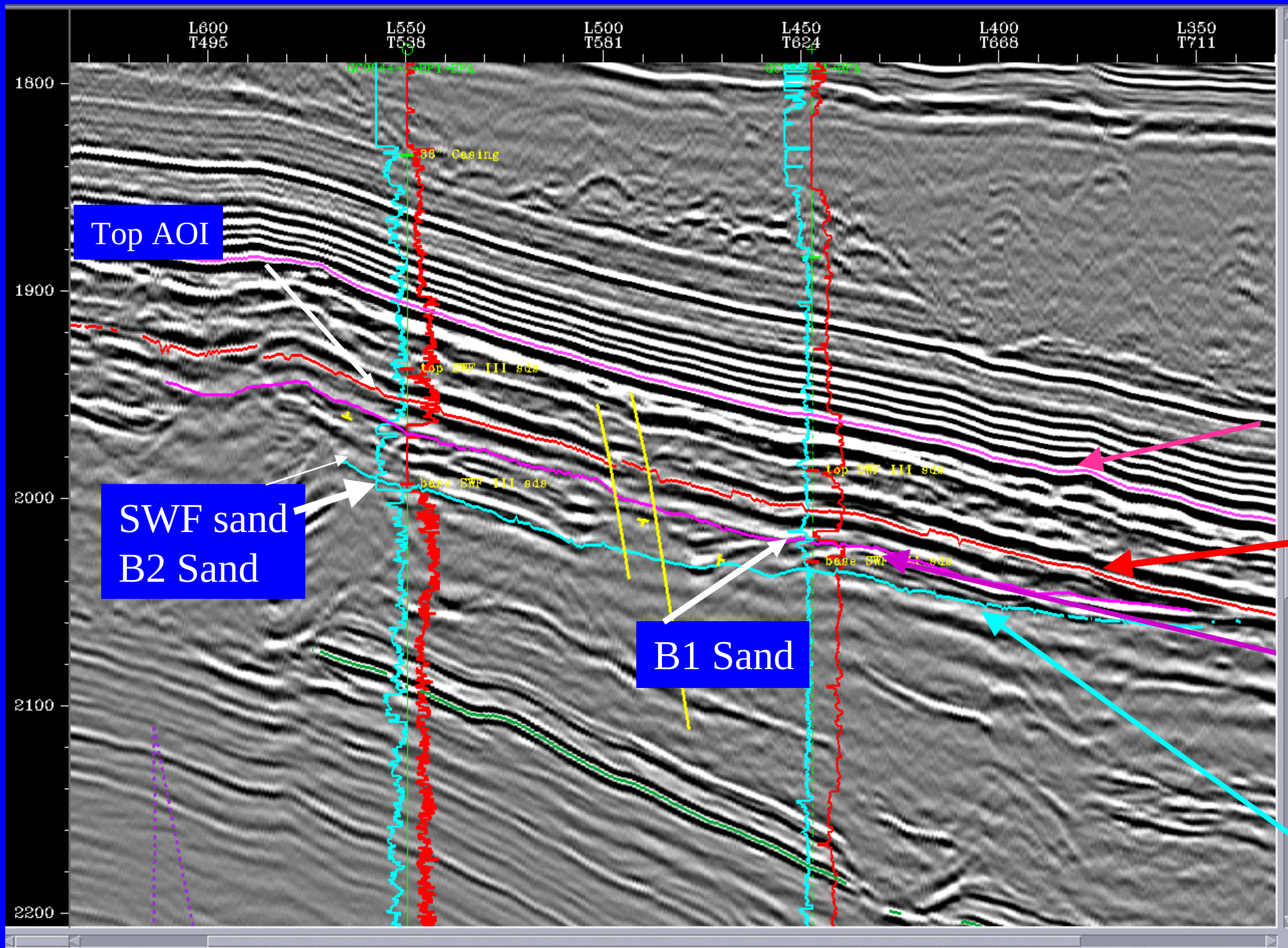
HR3D Well Tie Line A – A”

GC 644-1 GC 645-1



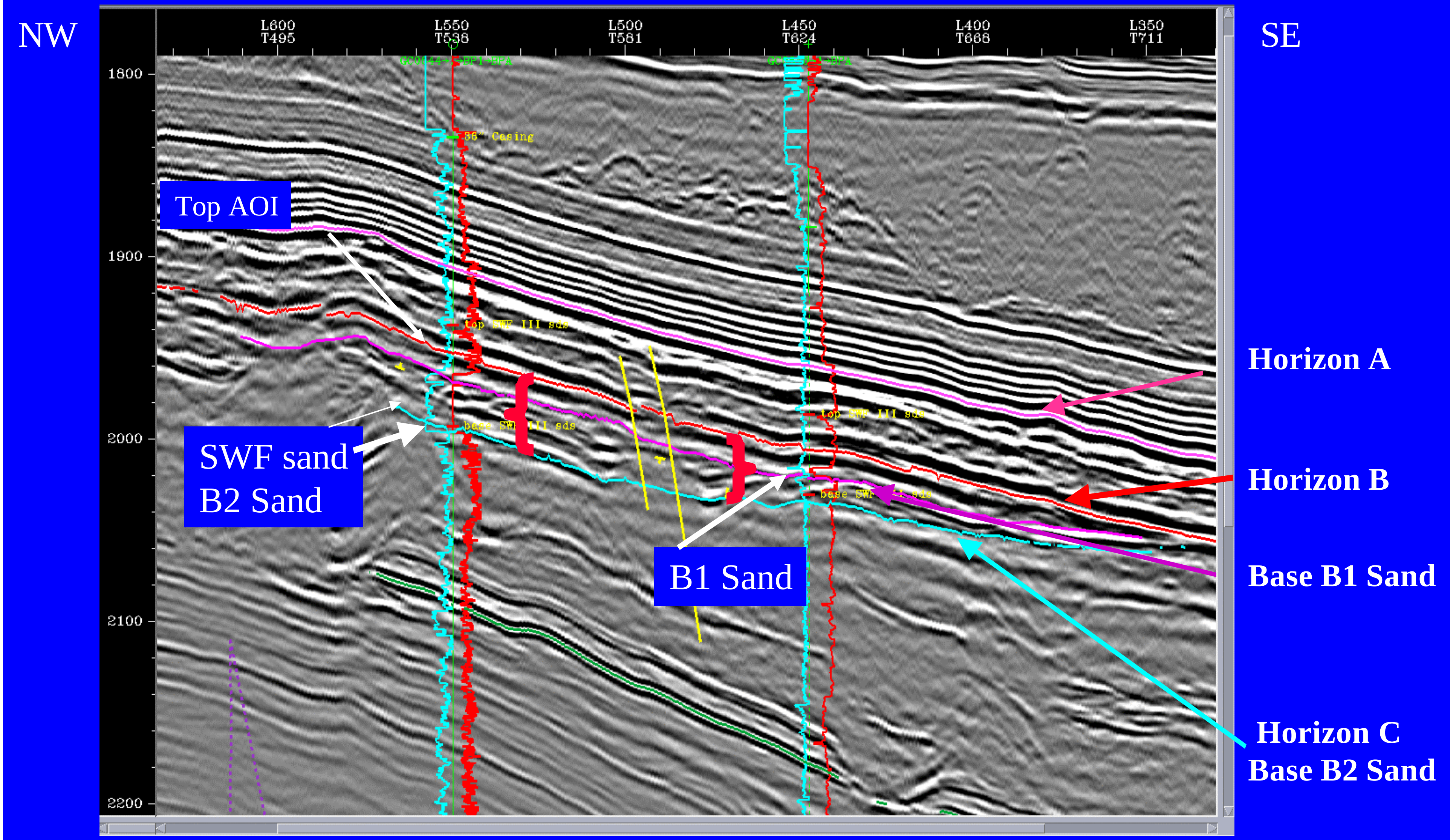
HR3D Well Tie Line A – A”

GC 644-1 GC 645-1

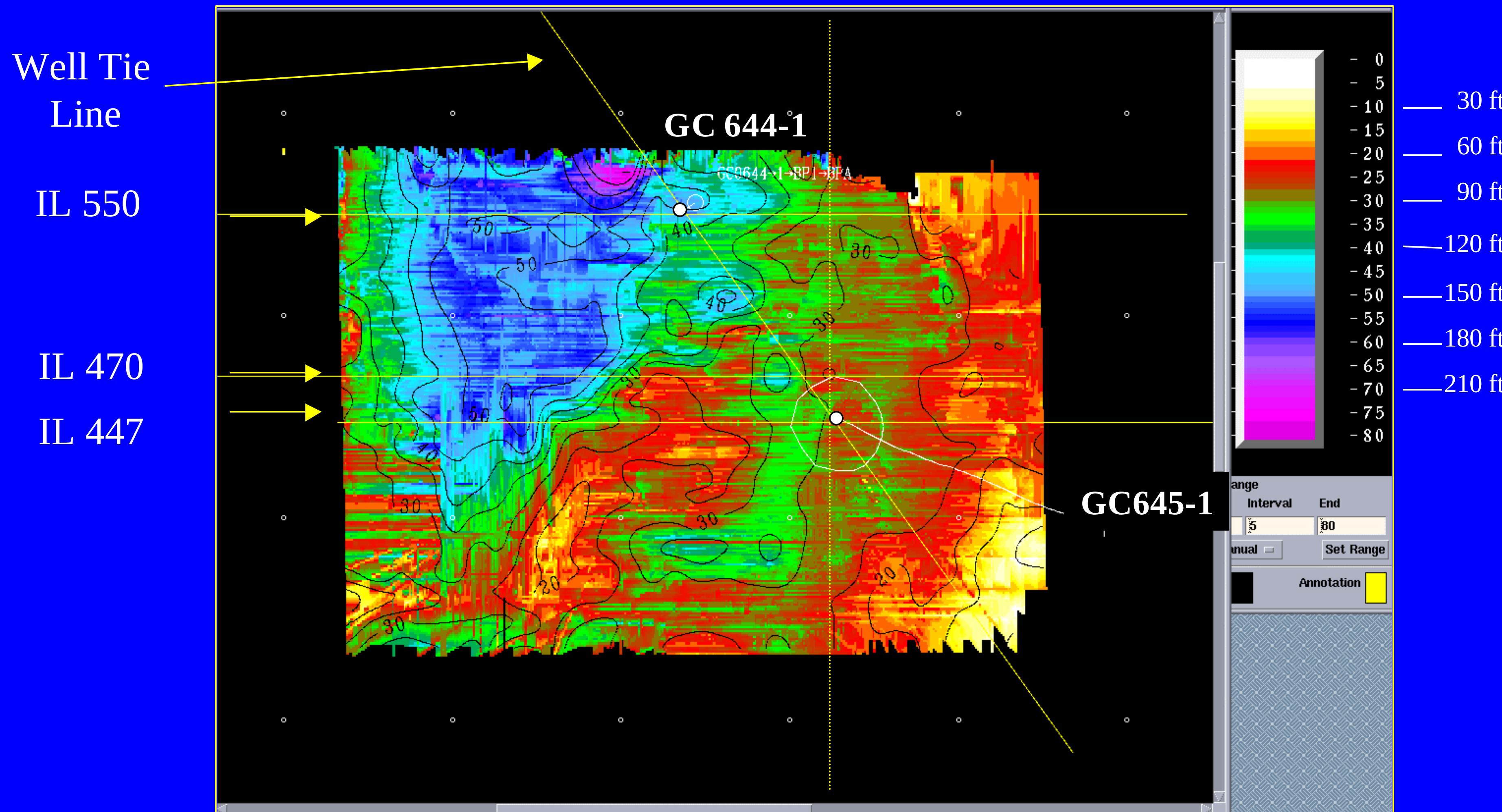


HR3D Well Tie Line A – A"

GC 644-1 GC 645-1

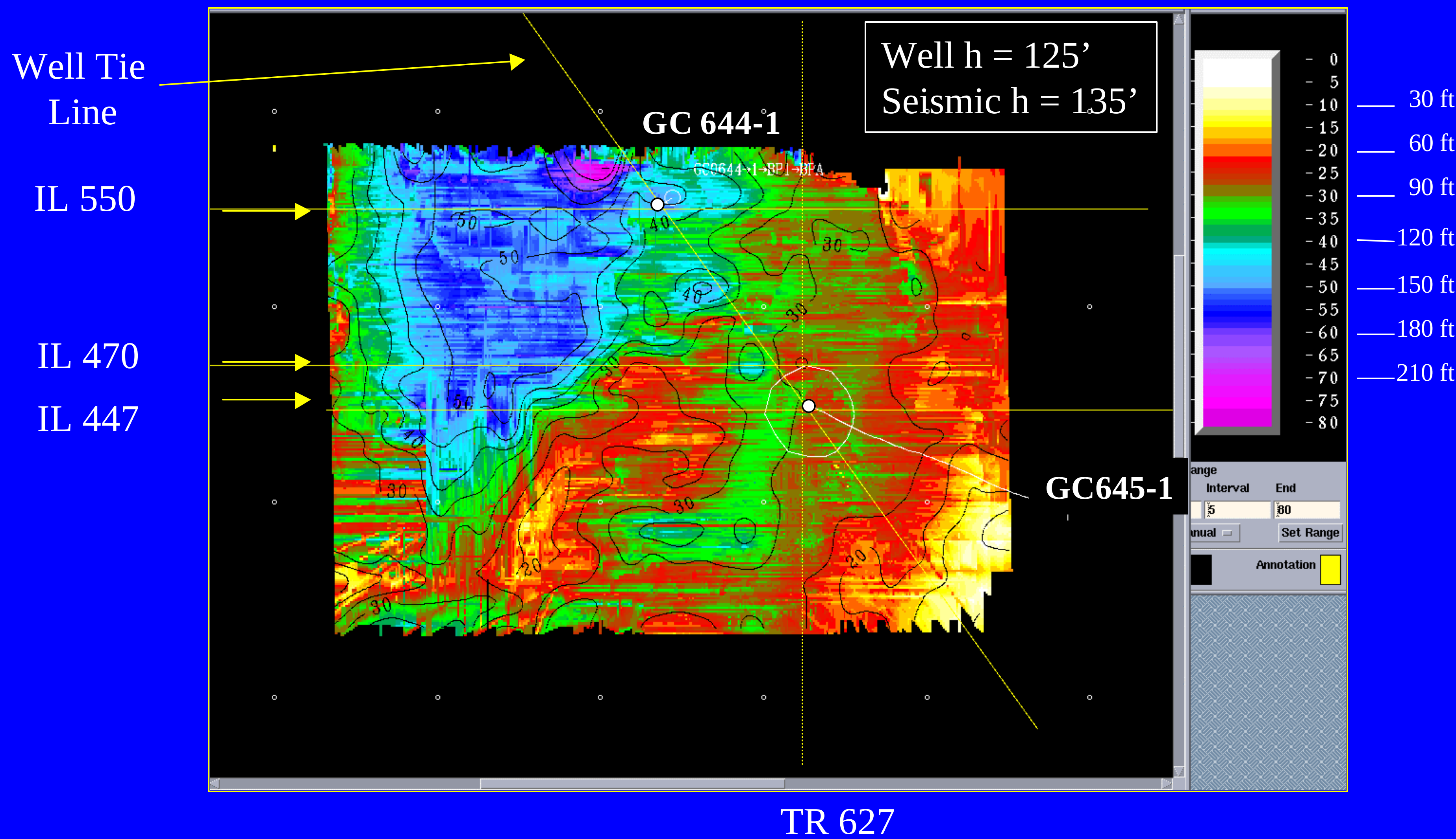


HR3D Isochron: SWF Sand Interval
(Horizon B-C)



TR 627

HR3D Isochron: SWF Sand Interval
(Horizon B-C)



HR3D Isochron: SWF Sand Interval

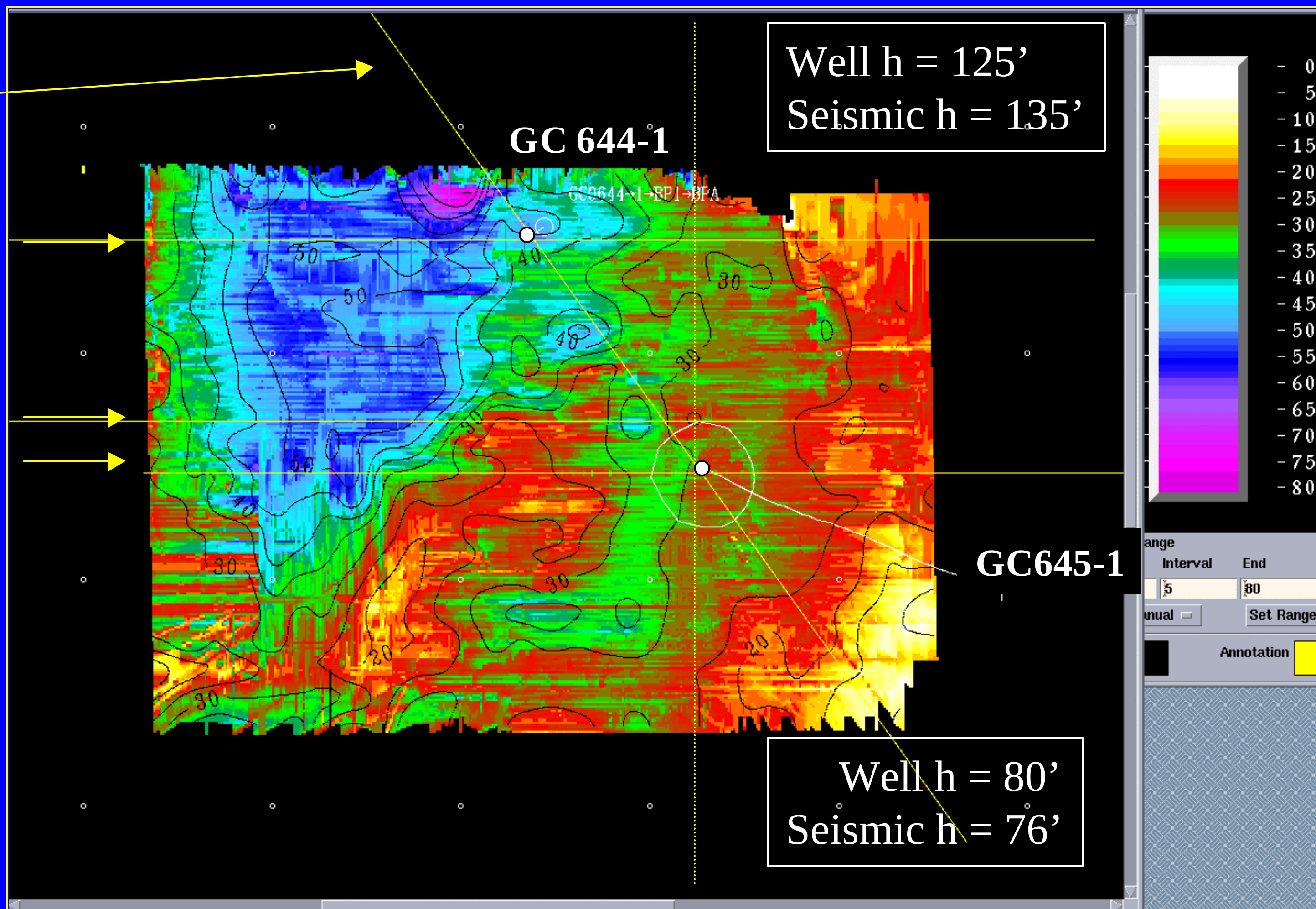
(Horizon B-C)

Well Tie Line

IL 550

IL 470

IL 447



30 ft

60 ft

90 ft

120 ft

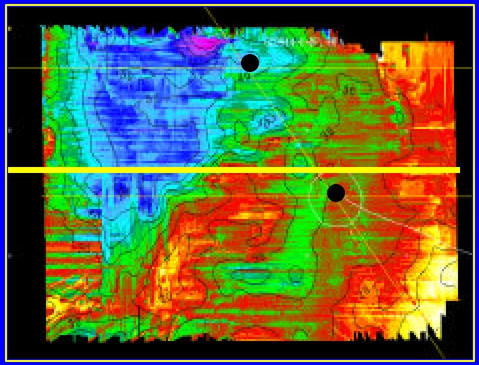
150 ft

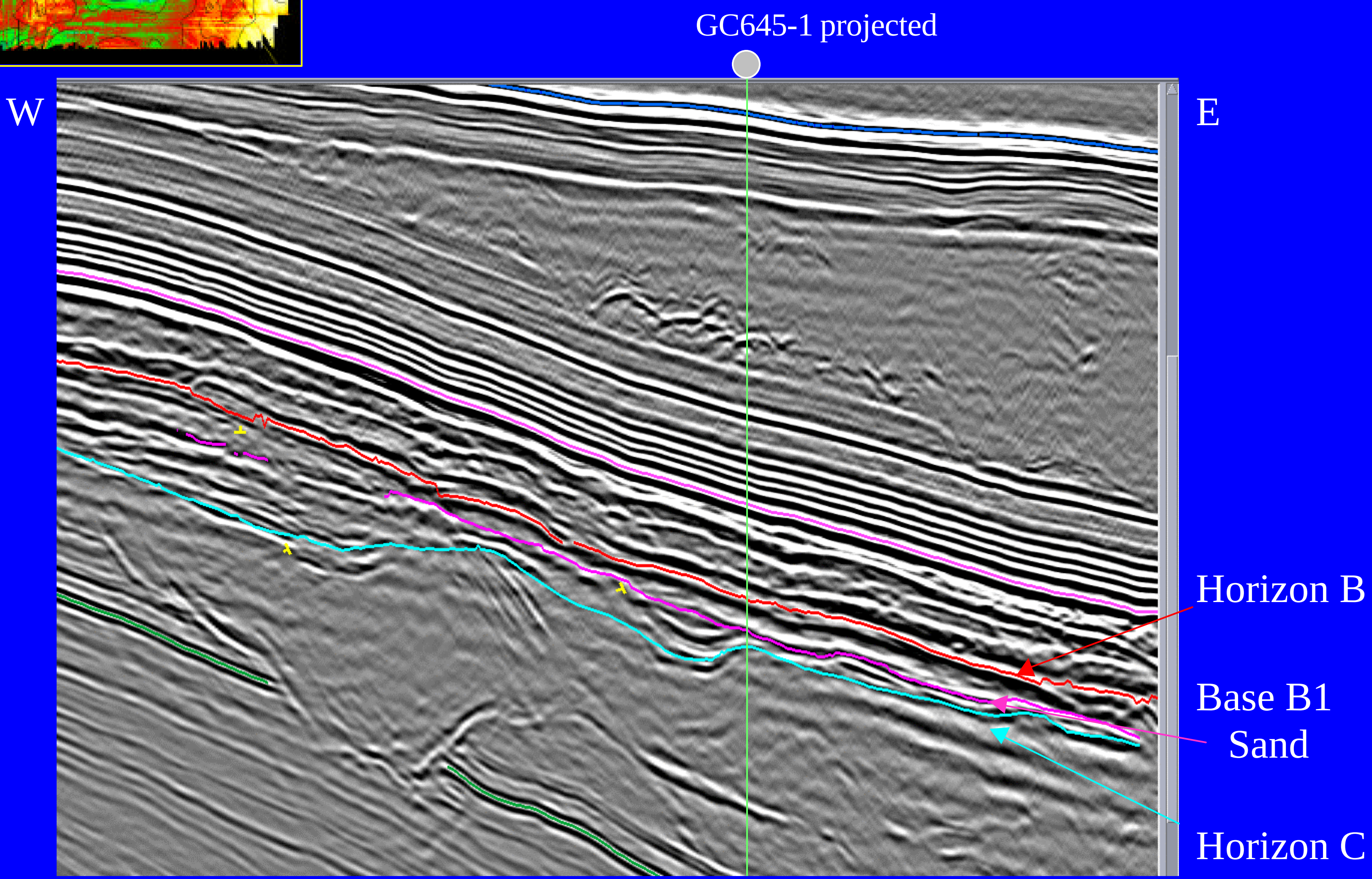
180 ft

210 ft

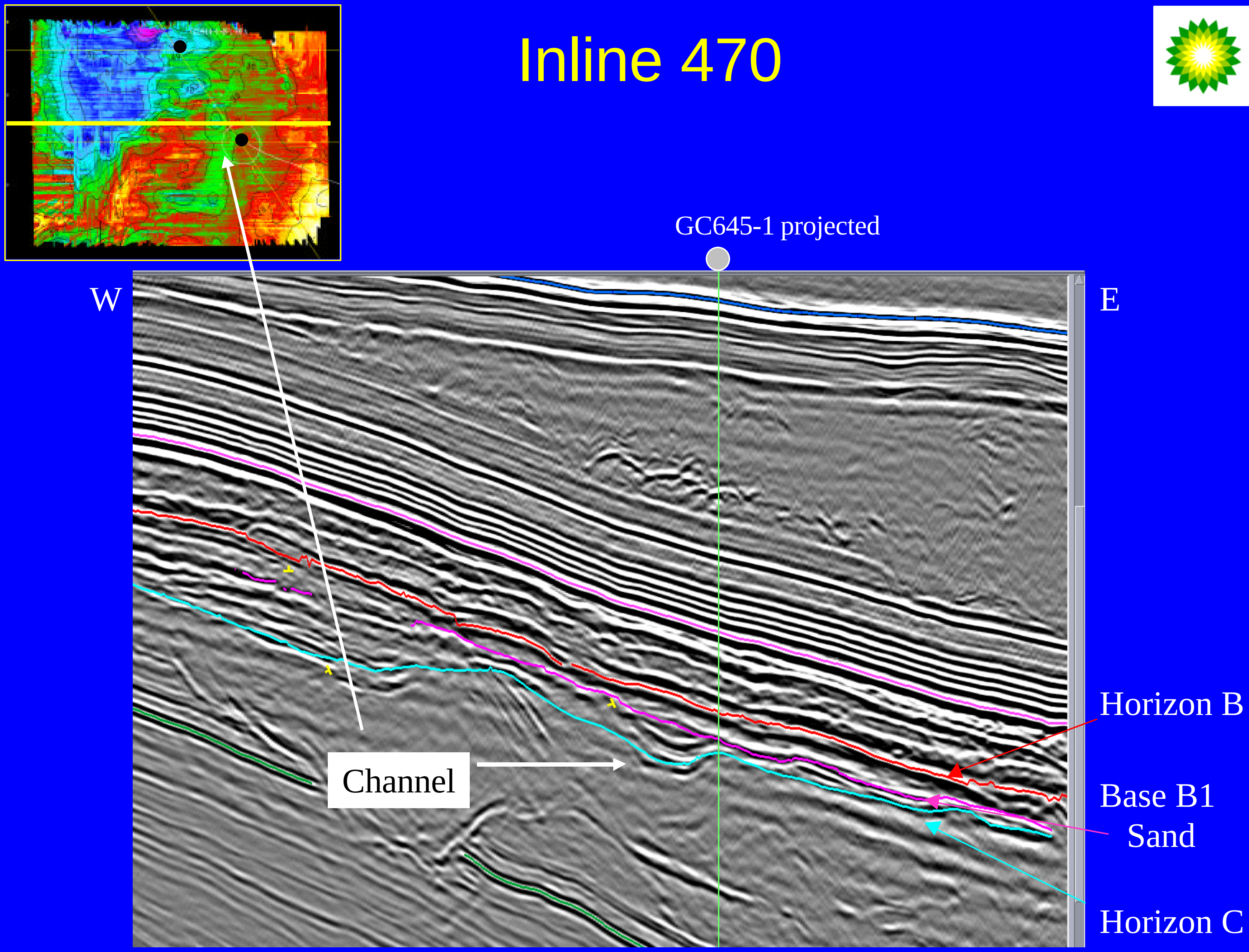
TR 627

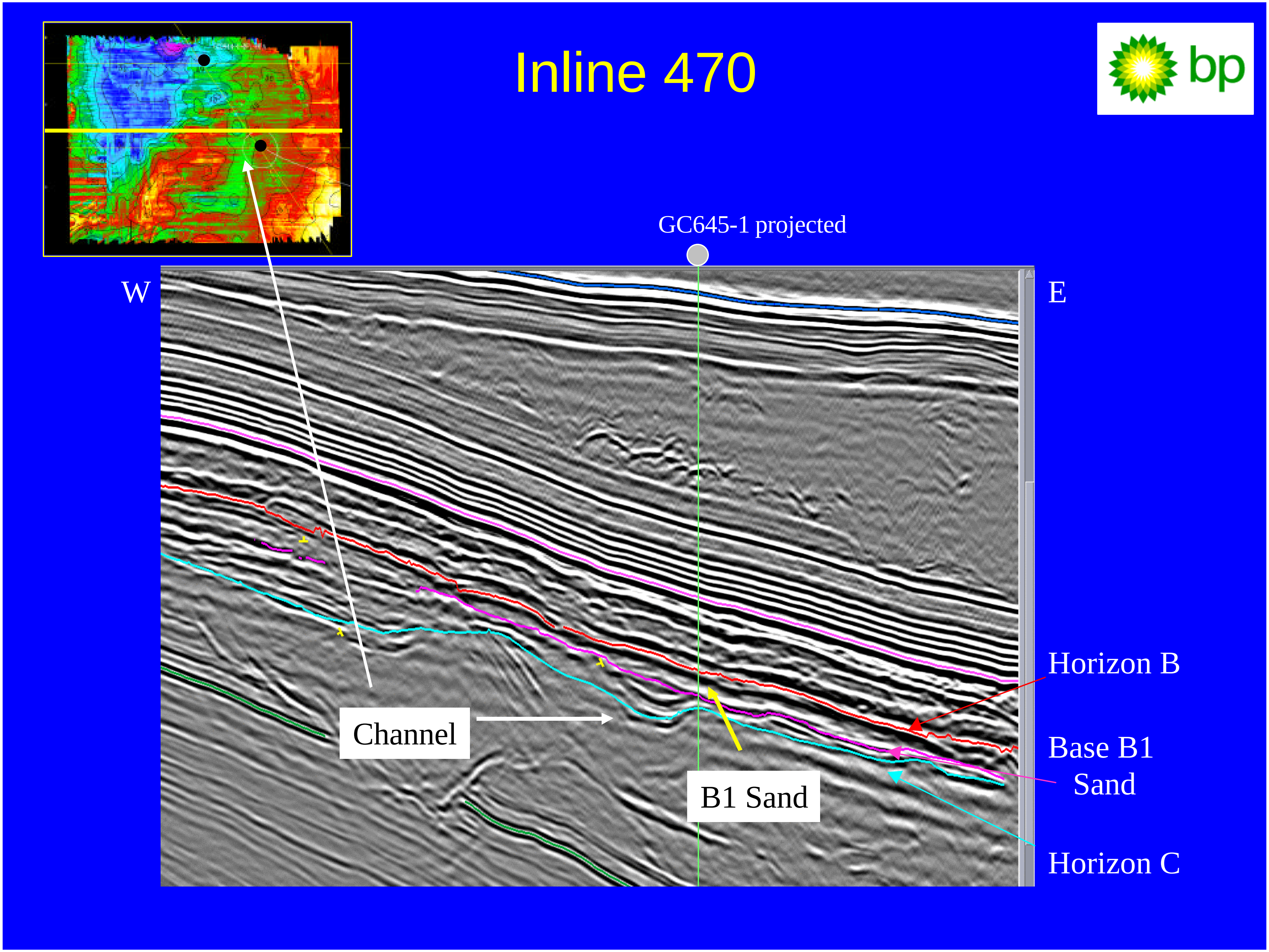
Inline 470



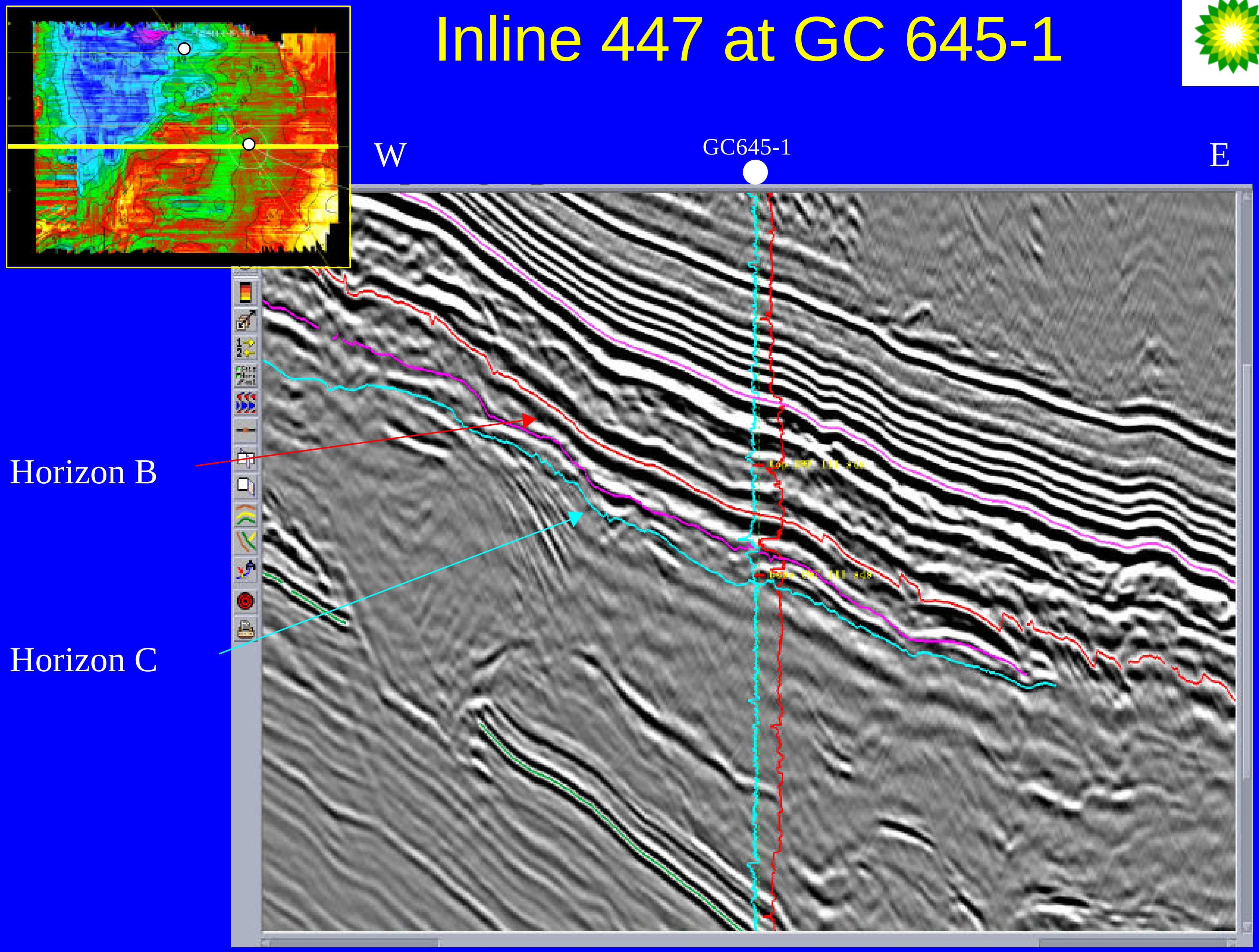


Inline 470

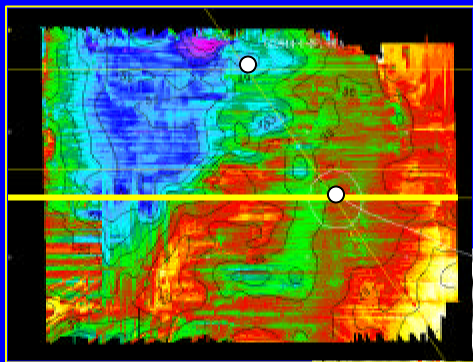

GC645-1 projected
W
E
Channel
Horizon B
Base B1
Sand
Horizon C

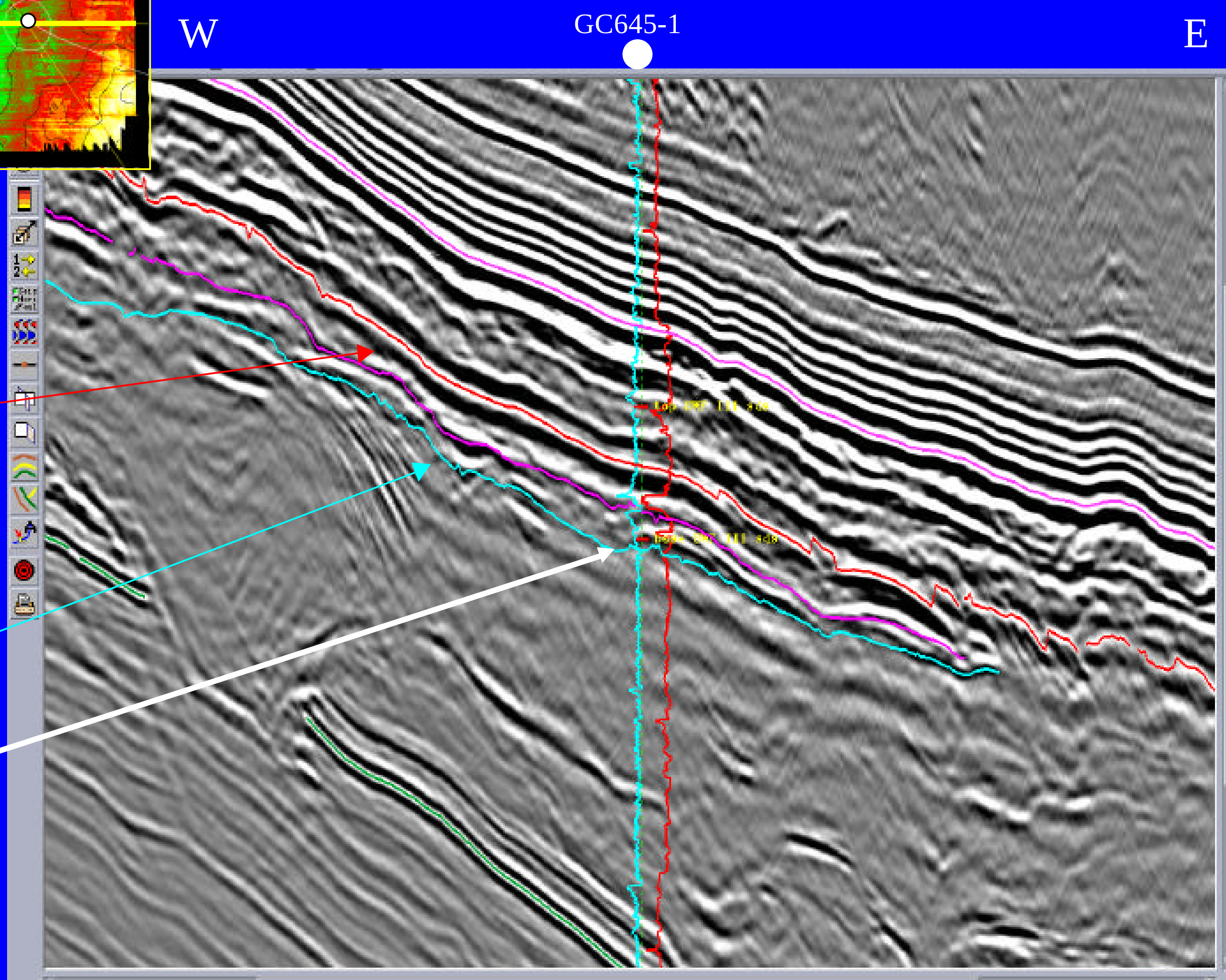

Inline 470
GC645-1 projected
W
E
Horizon B
Base B1
Sand
Horizon C
Channel
B1 Sand

Inline 447 at GC 645-1



Inline 447 at GC 645-1



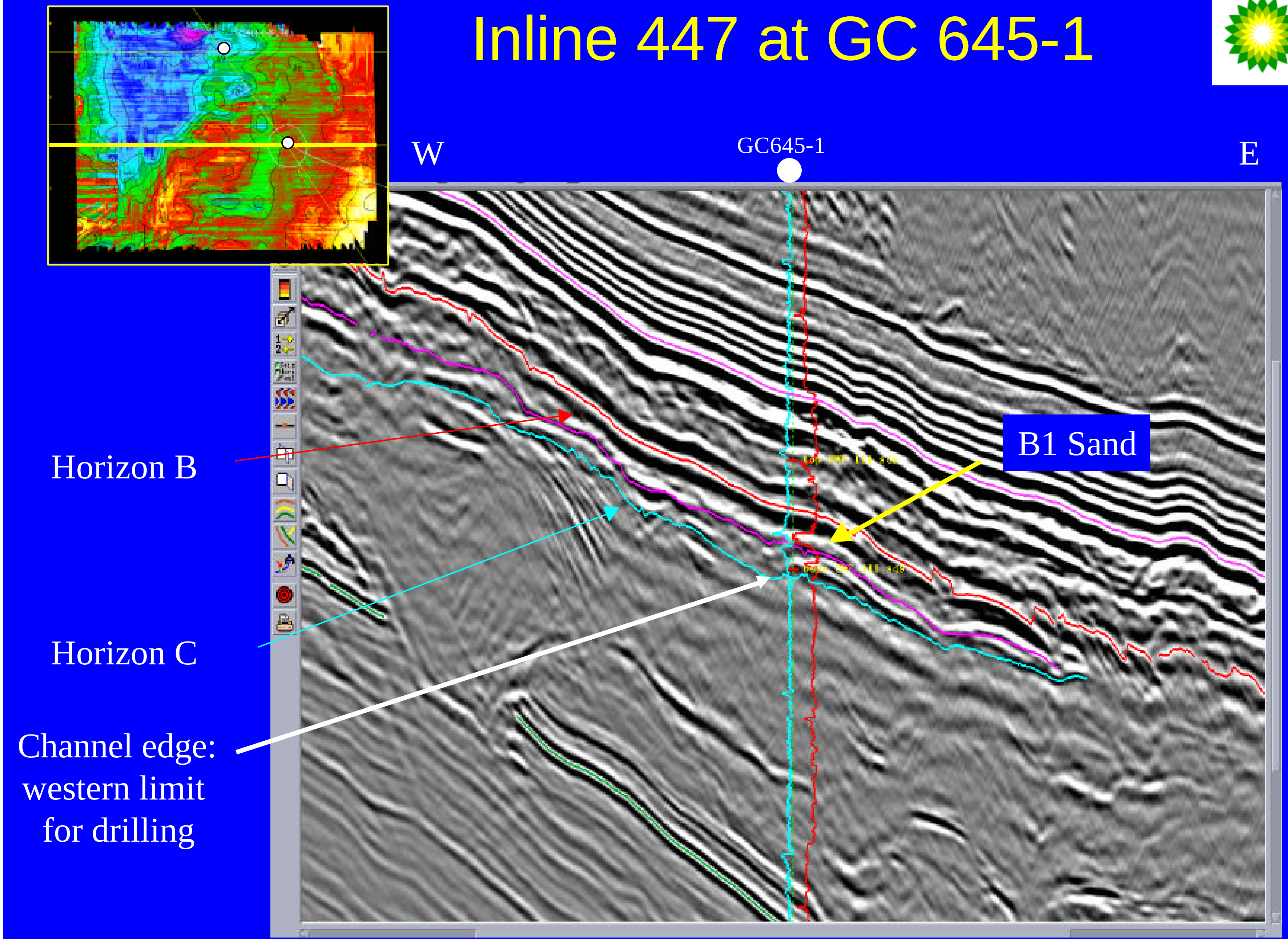


Horizon B

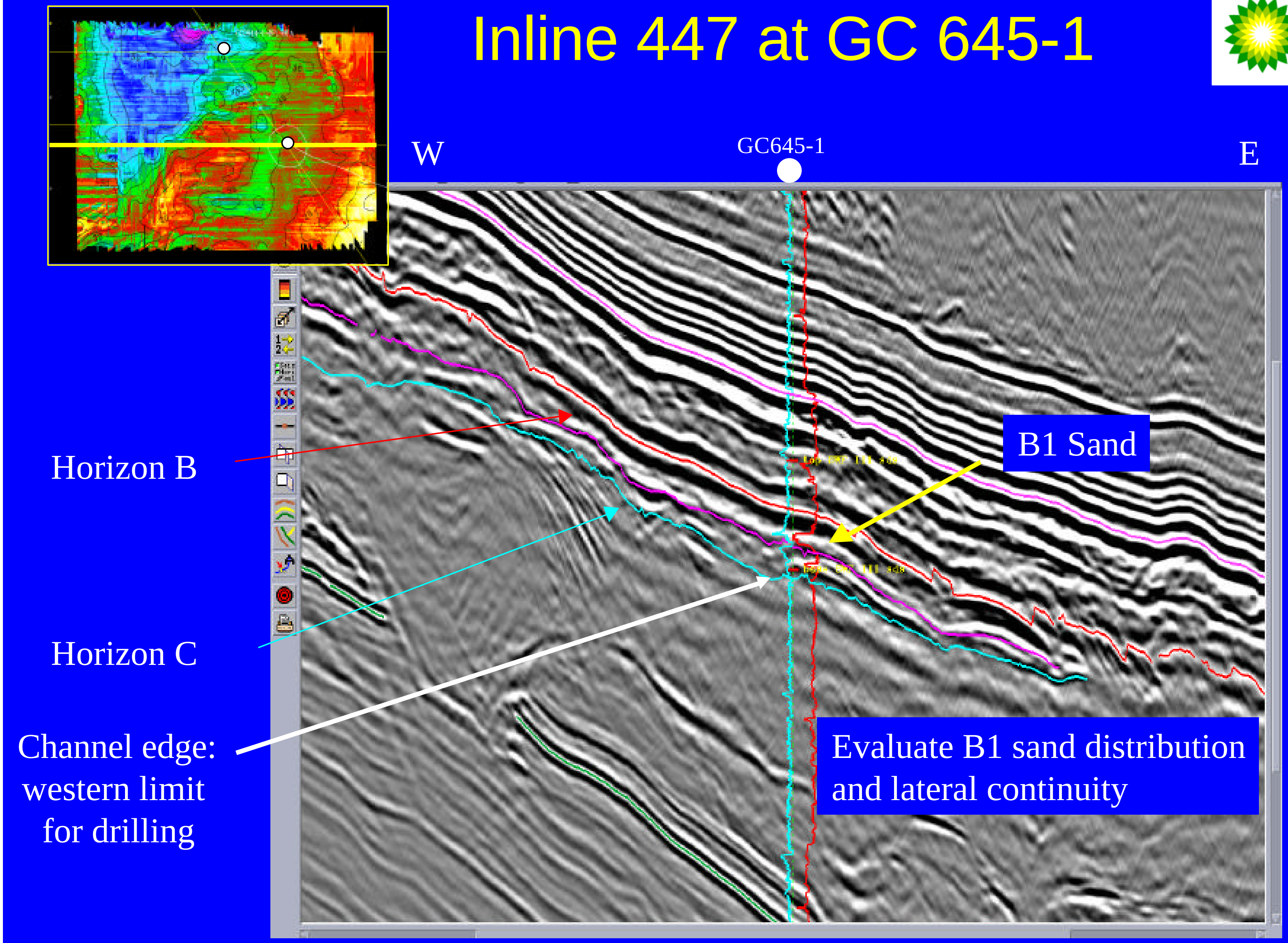
Horizon C

Channel edge:
western limit
for drilling

Inline 447 at GC 645-1

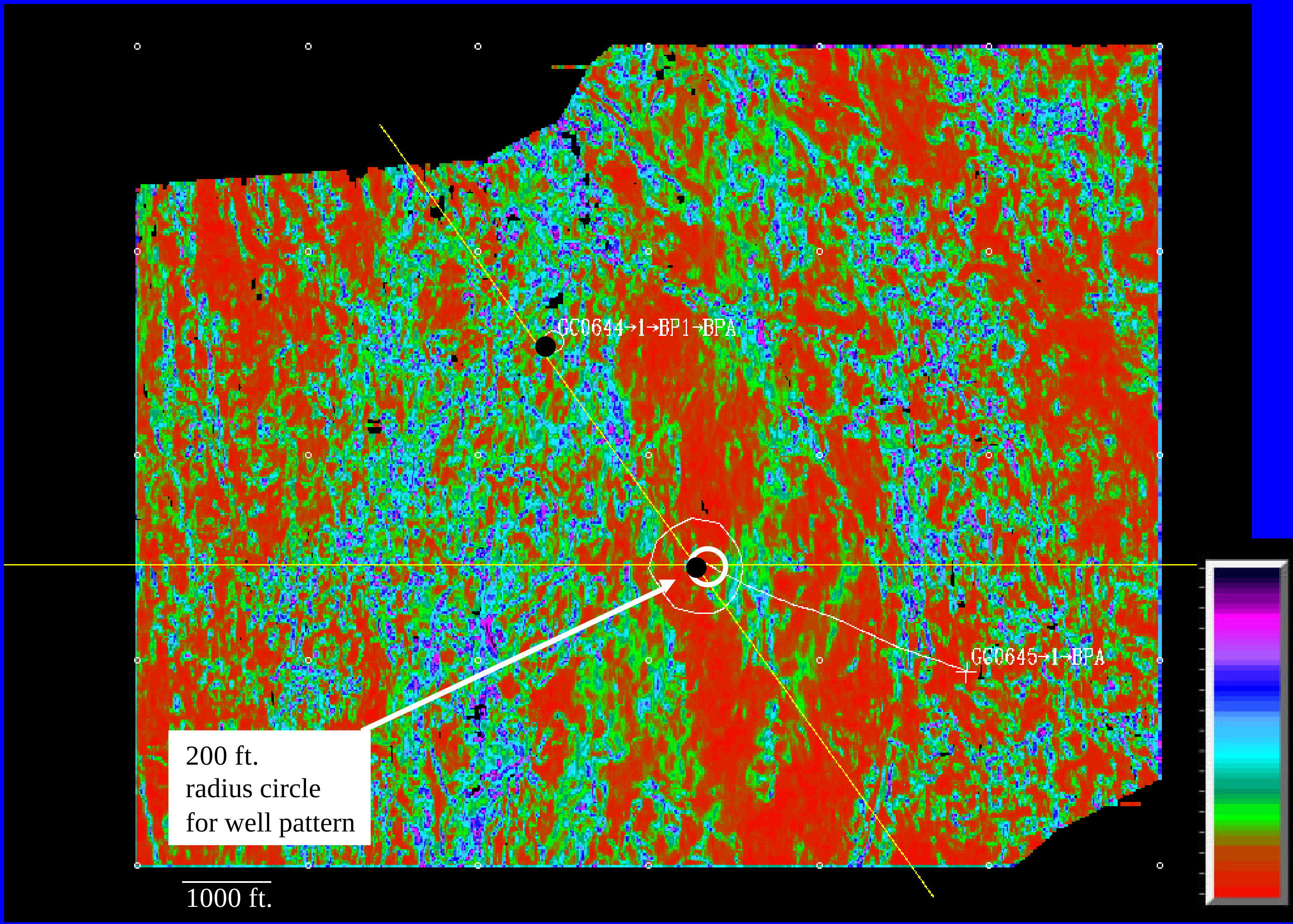


Inline 447 at GC 645-1



B1 Sand: Lateral Continuity
Coherence Extraction

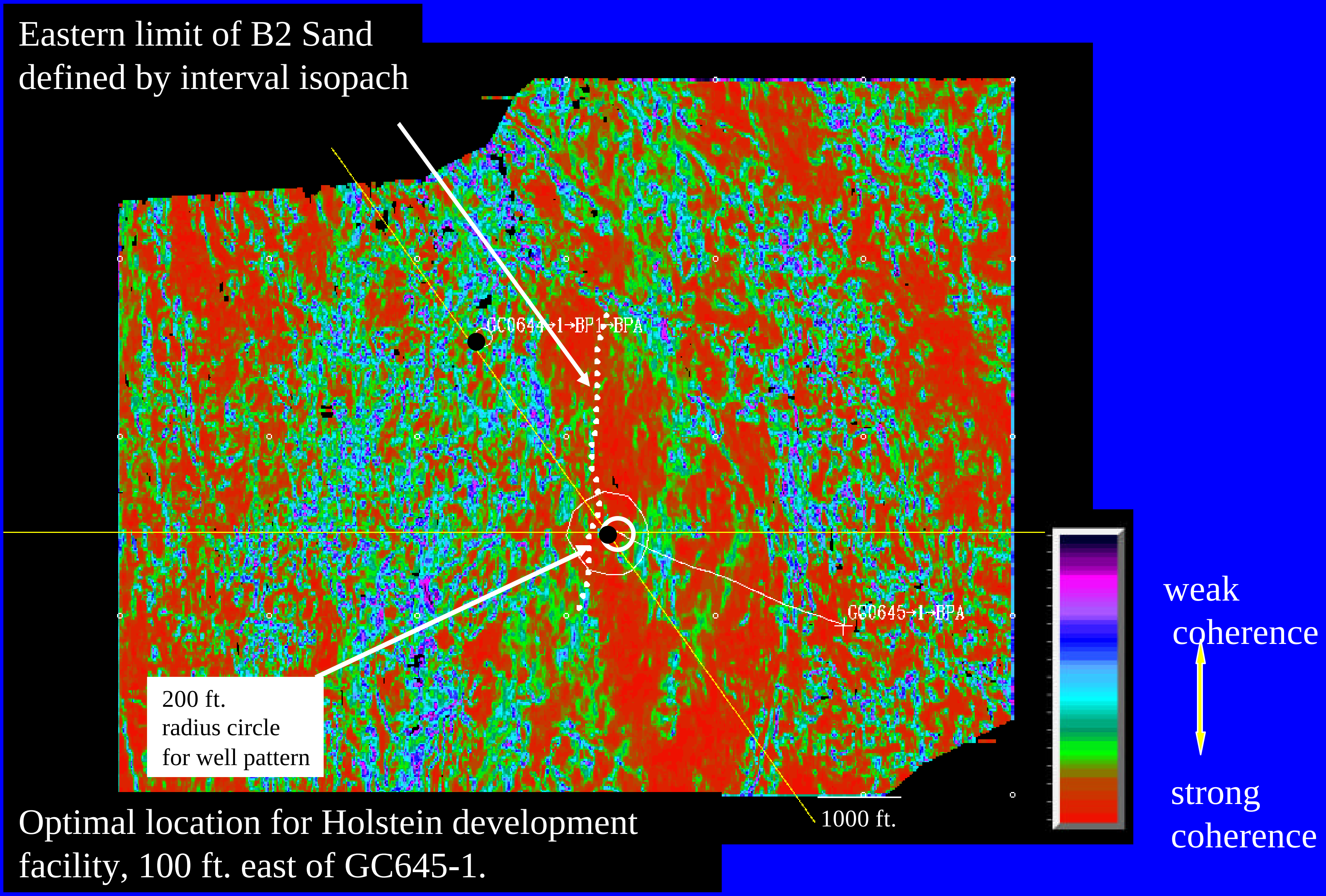
4ms window



weak
coherence

strong
coherence

Optimal Development Location



SWF Interpretation Results

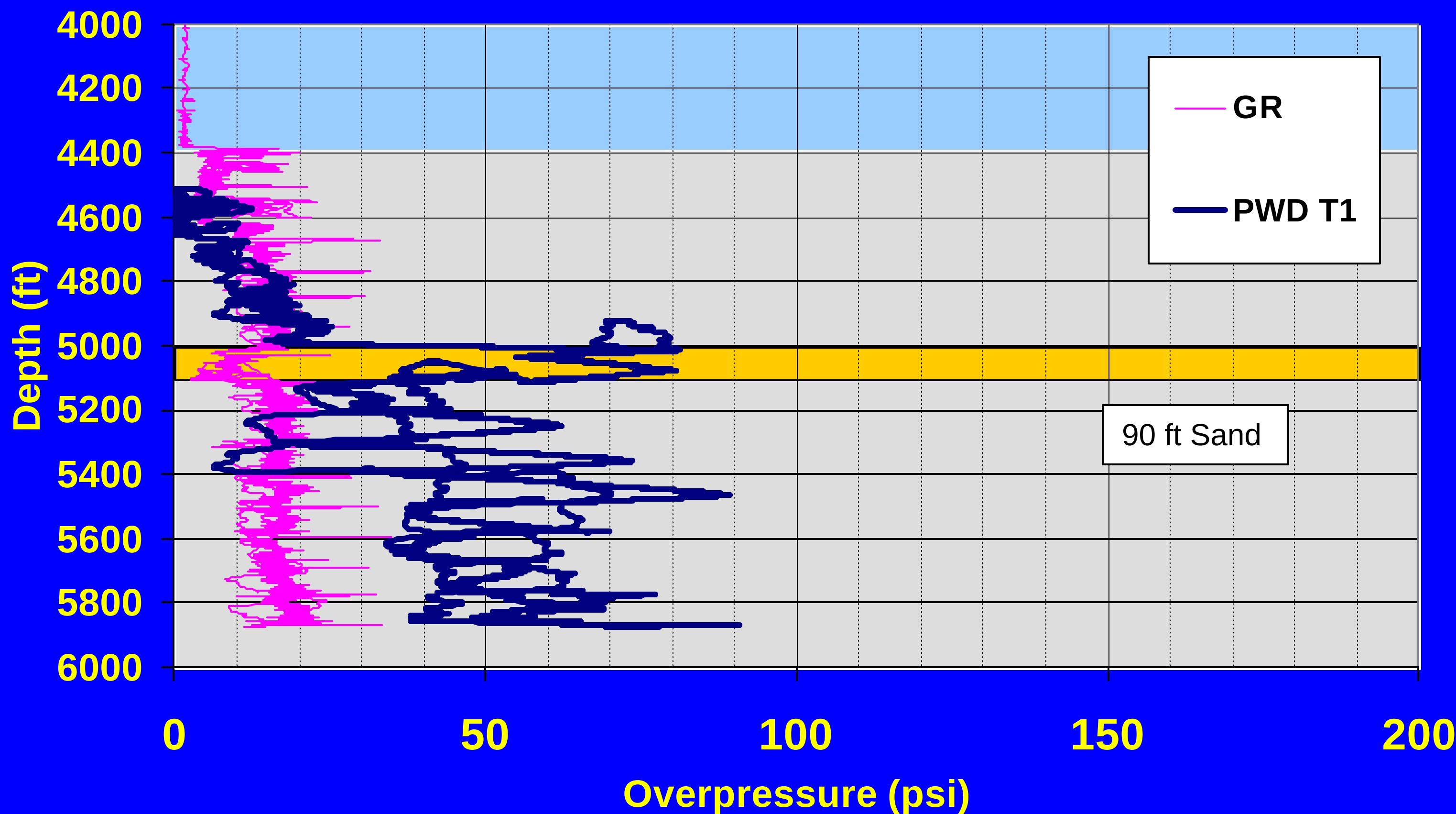
- High-Resolution 3D -- Value Added
  - accurate maps of thickness variation in the SWF B2 sand
  - lateral continuity and distribution of thinner B1 sand
- Defined Optimum Area for Development Facility
  - B2 Sand isopach cutoff (GC 644-1 SWF sand)
  - B1 Sand lateral continuity

Presentation Outline

- Introduction
- Project Objectives
- SWF Mapping Results

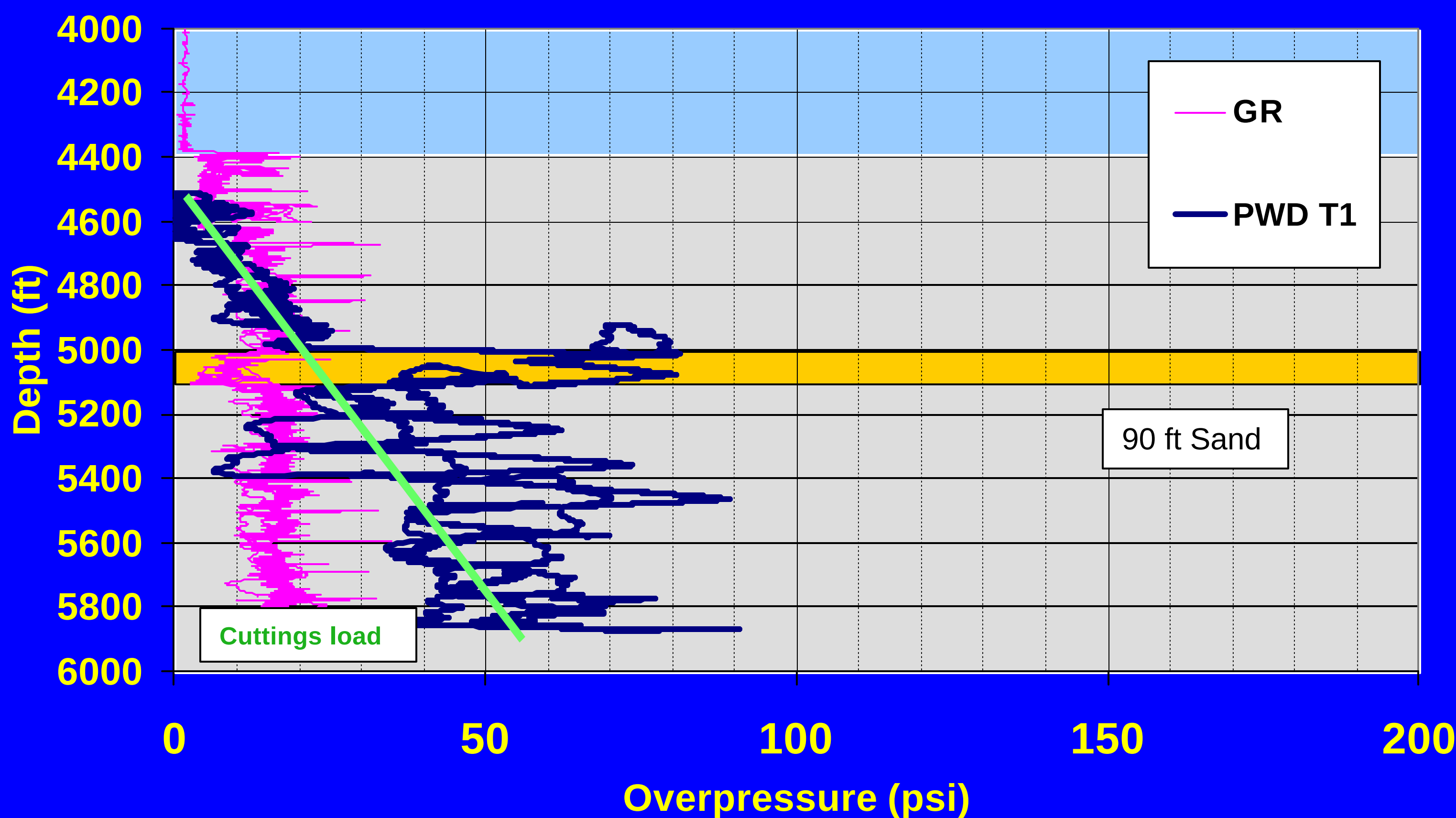
- Pressure While Drilling Observations (PWD)
- Shallow Water Flow Modeling
- Conclusions

PWD Observations – GC644



- 90’ sand appears to flow and produce sand
- Overpressure at least 50-60 PSI possibly 80-90 PSI

PWD Observations – GC644



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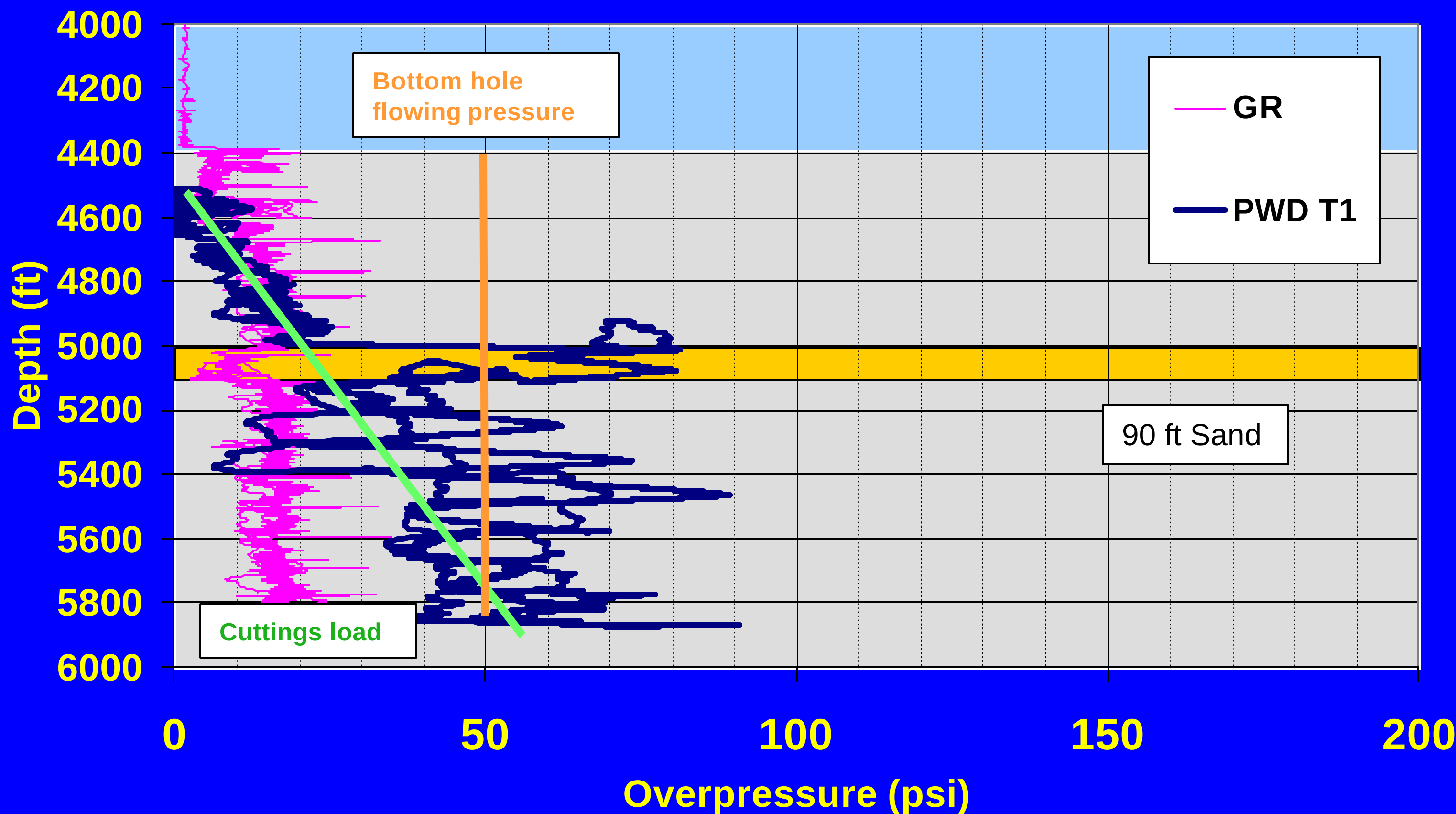
PWD Observations – GC644



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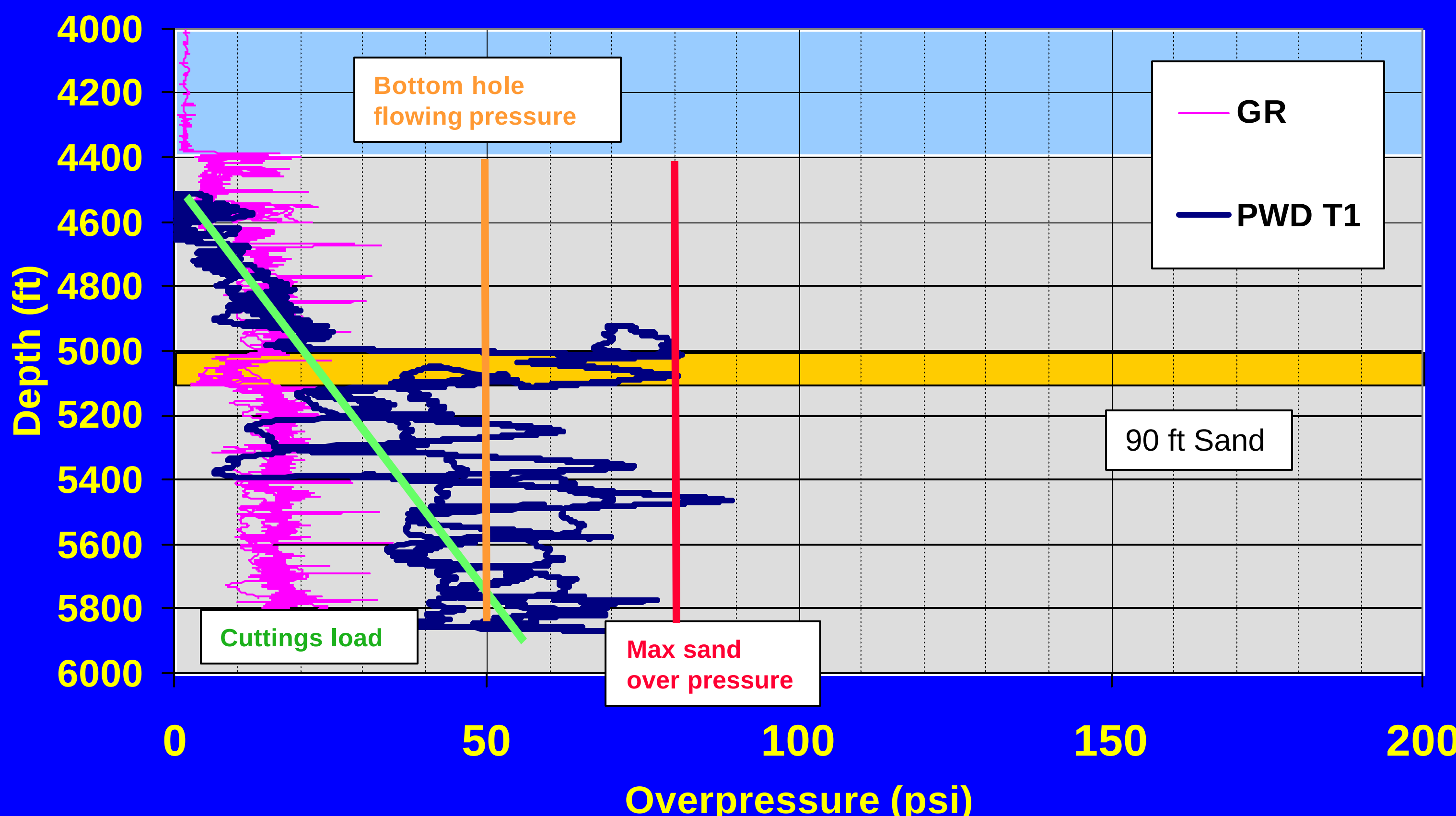
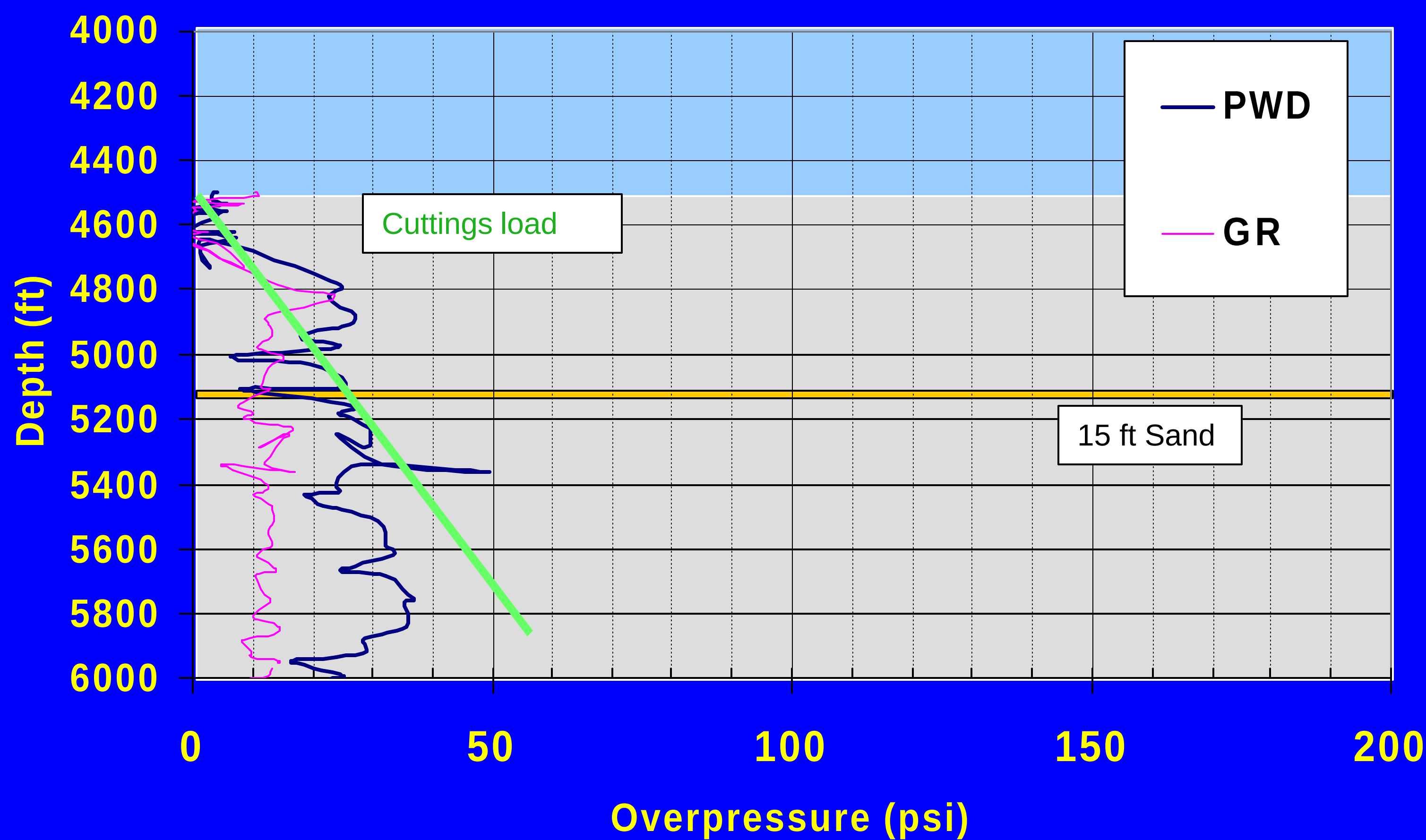
PWD Observations – GC644



- **90’ sand appears to flow and produce sand**
- **Overpressure at least 50-60 PSI possibly 80-90 PSI**

PWD Observations – GC645



- **No sand production observed from 15’ sand**
- **Overpressures of 20-30 PSI undetectable**
- **Some data problems (being investigated)**

Development Cases Tested

- Circular Pattern (Base case)
  - 15’ sand, 700’ BML with 30 PSI over pressure
  - GC-645 + 19 wells batch set 20” casing (2200’ BML)
  - Well spacing 40’, 14 outer circle, 6 inner circle
  - Rate of Penetration (ROP) 50 ft/hr
  - Pump rate (PR) 1500 gallons/min
  - No pressure depletion of sands

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  - 18 wells with ~20’ grid spacing

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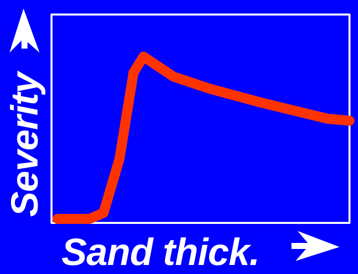
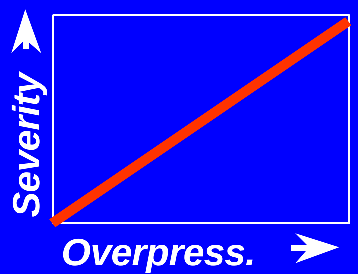
- Spar Supported Vertical Riser (SSVR) pattern
  - 18 wells with ~20' grid spacing
- Pattern Variations
  - 30ft spacing circular
  - SSVR+15,35, and 75%

Parameters vs. Problem Severity

Uncontrollable



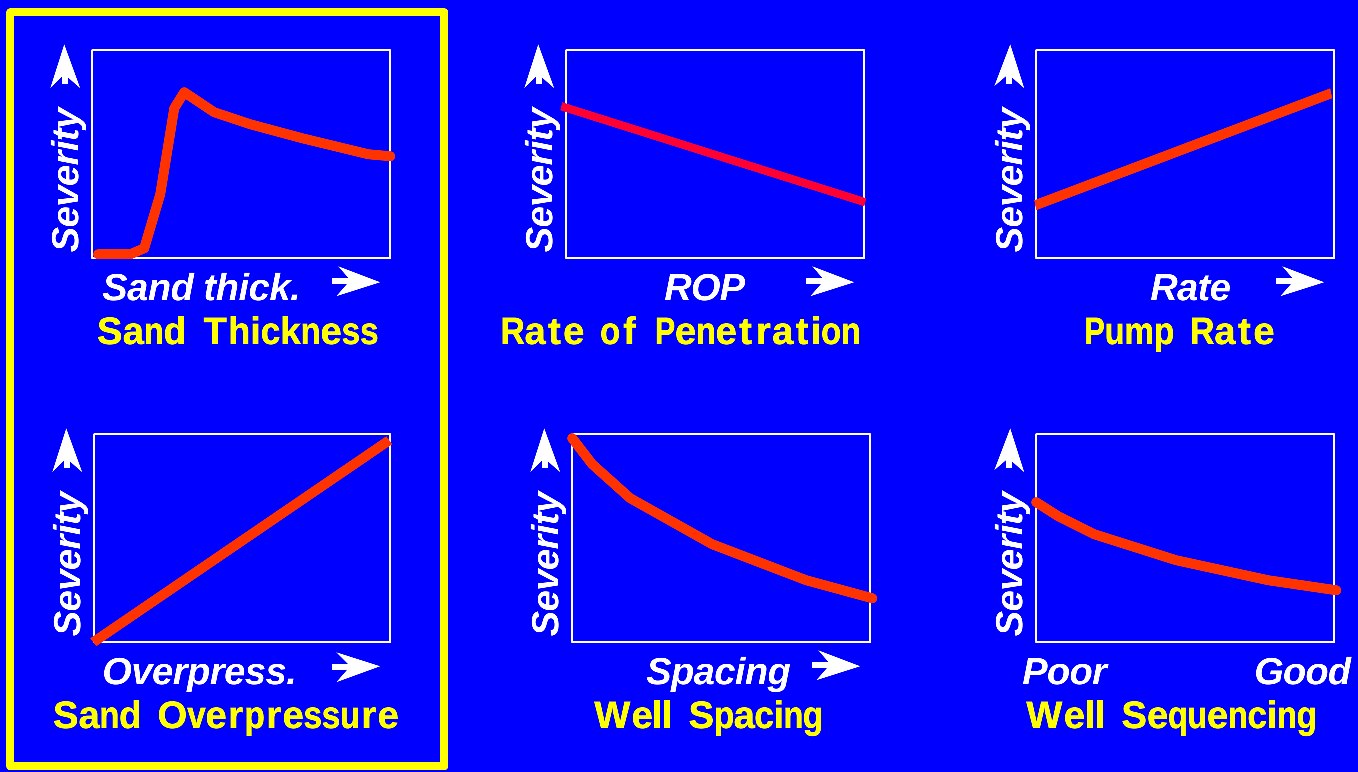
Sand Thickness



Sand Overpressure

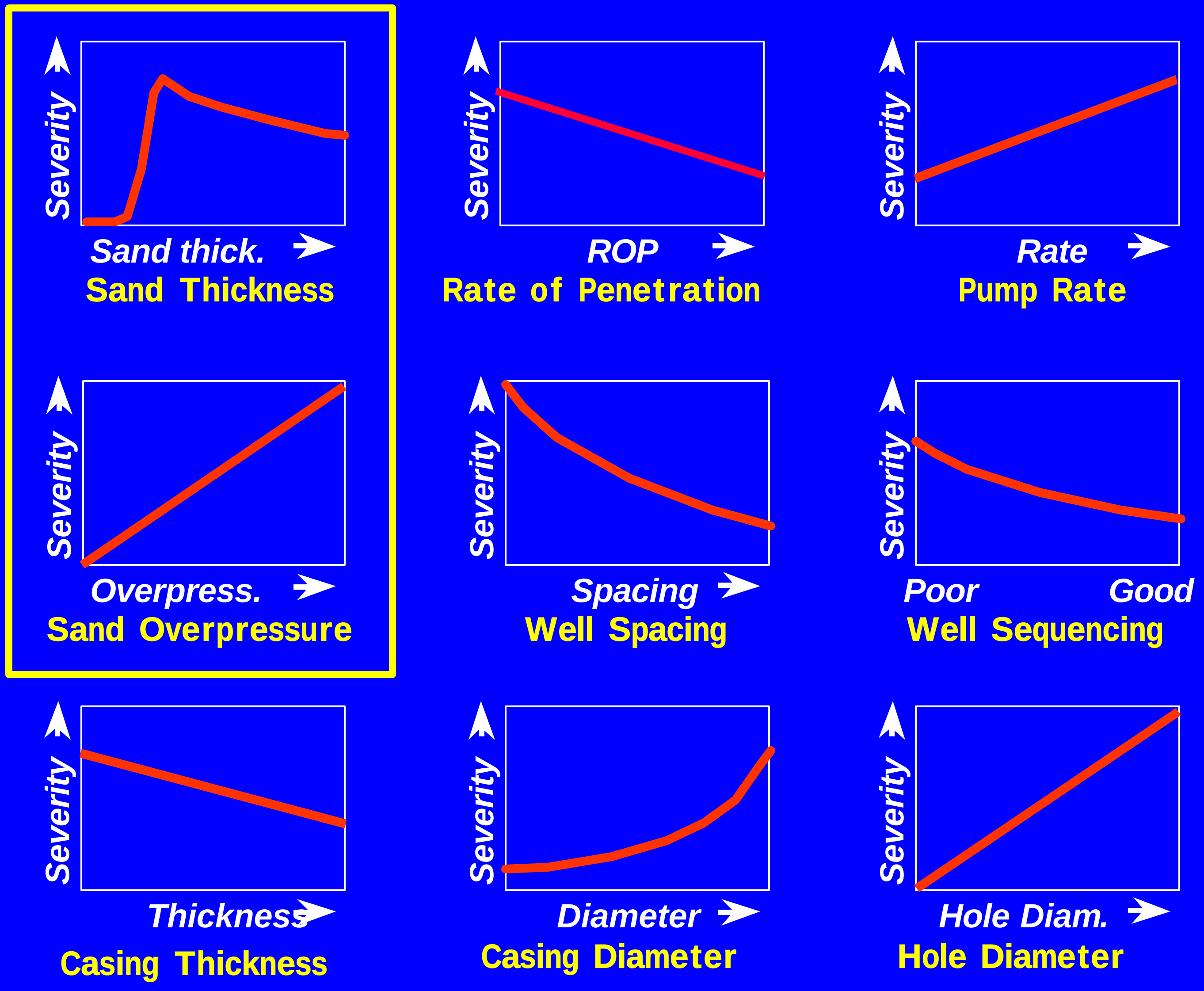
Parameters vs. Problem Severity

Uncontrollable

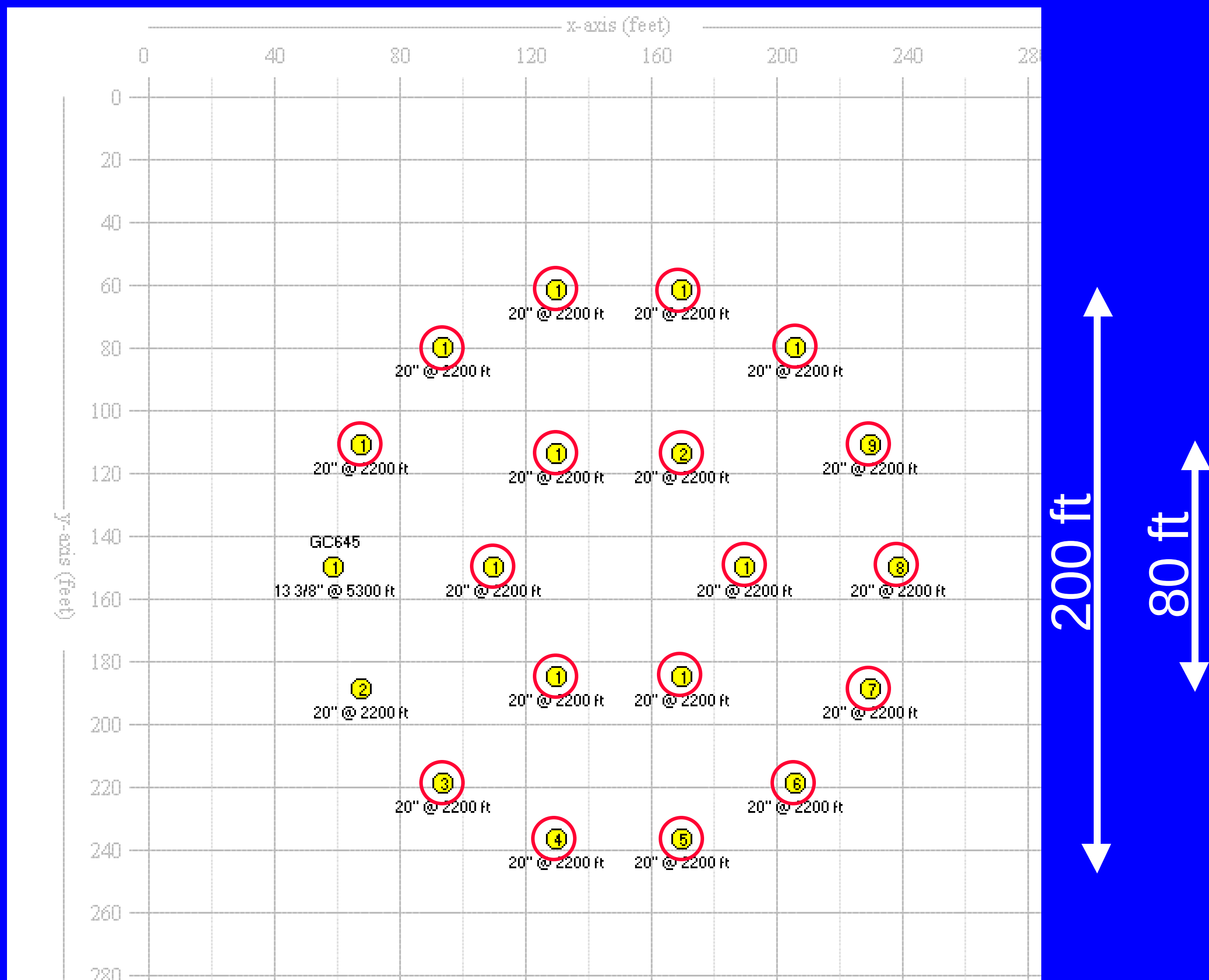


Parameters vs. Problem Severity

Uncontrollable



Base Case Pattern: Circular 40ft spacing



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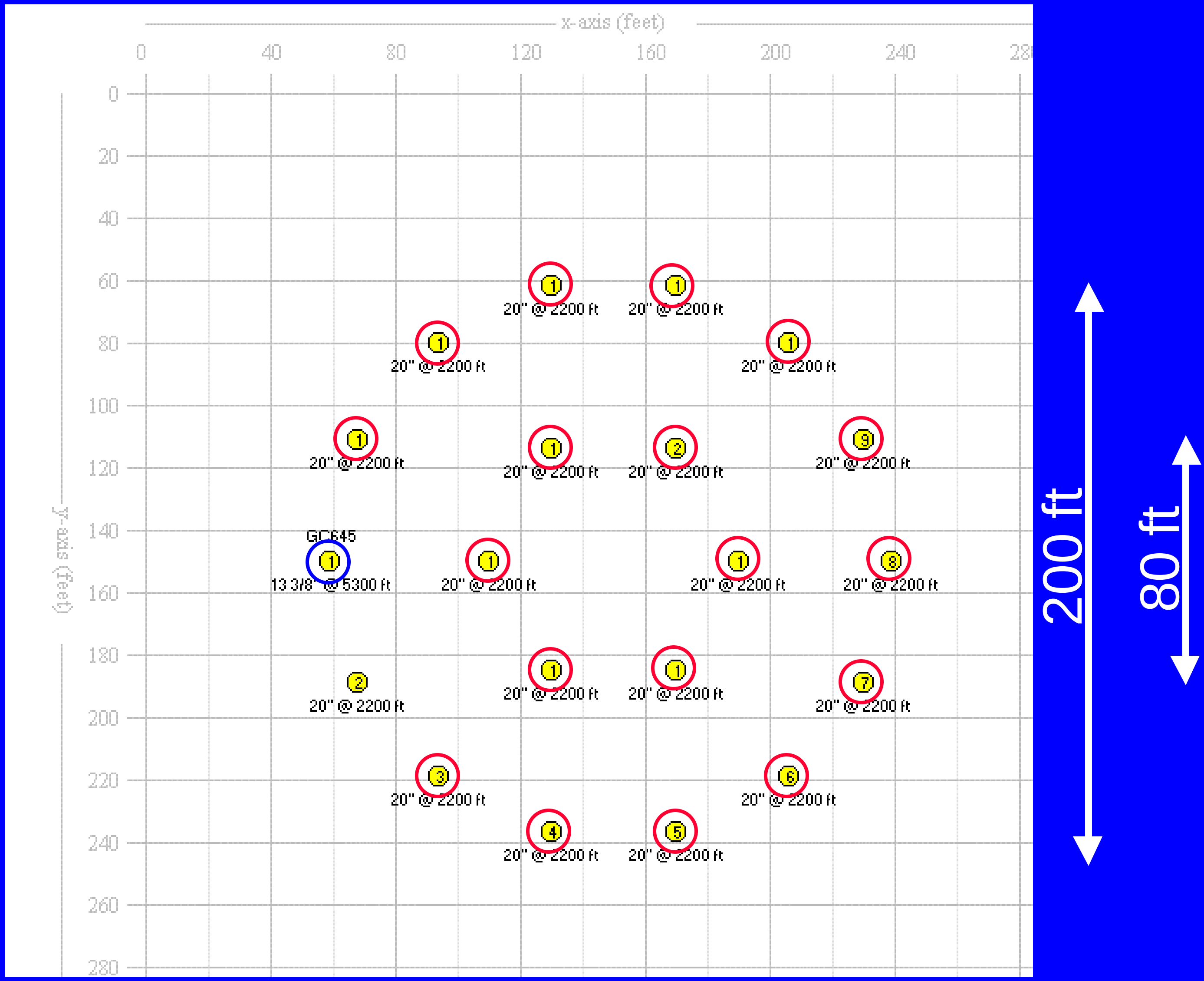
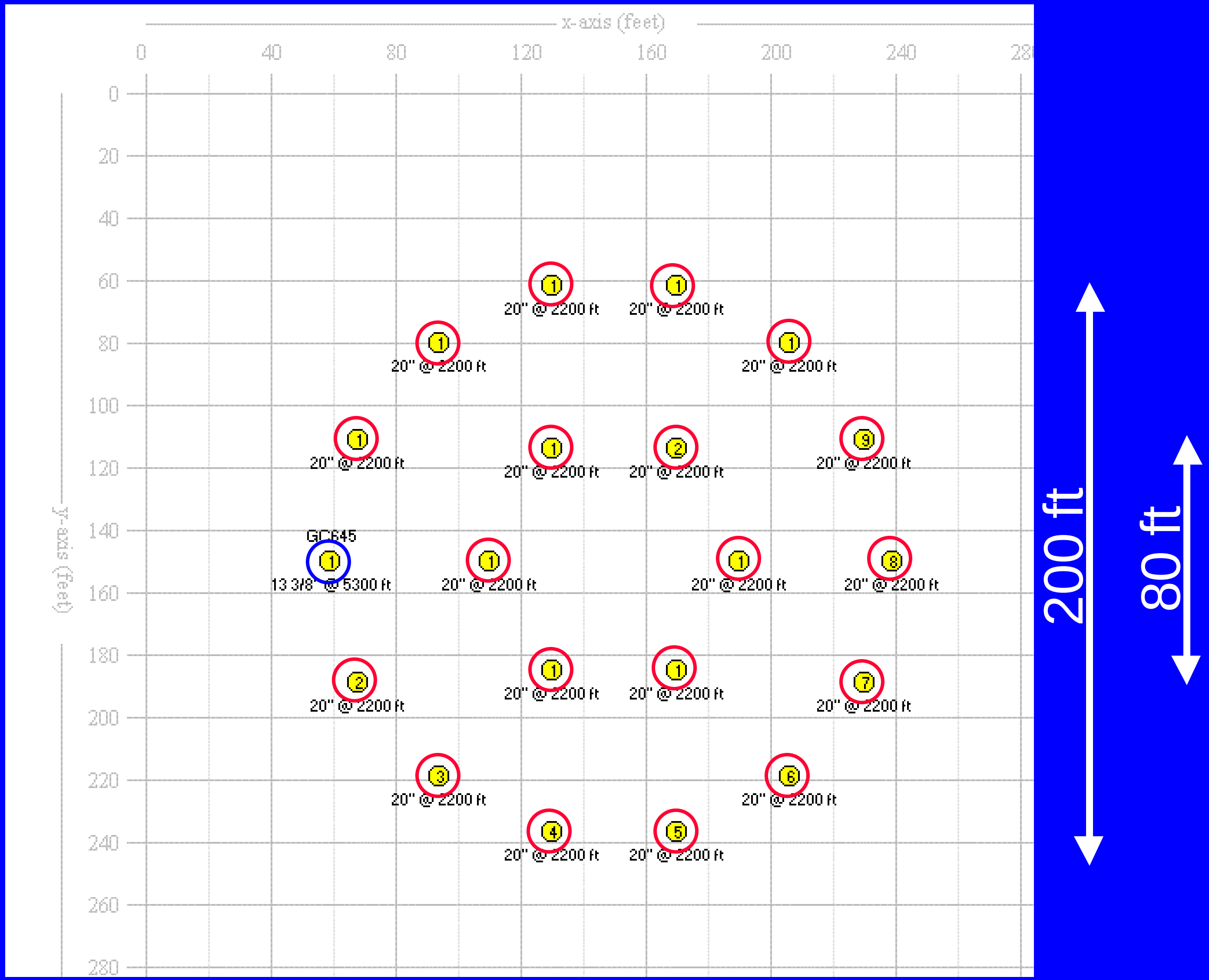
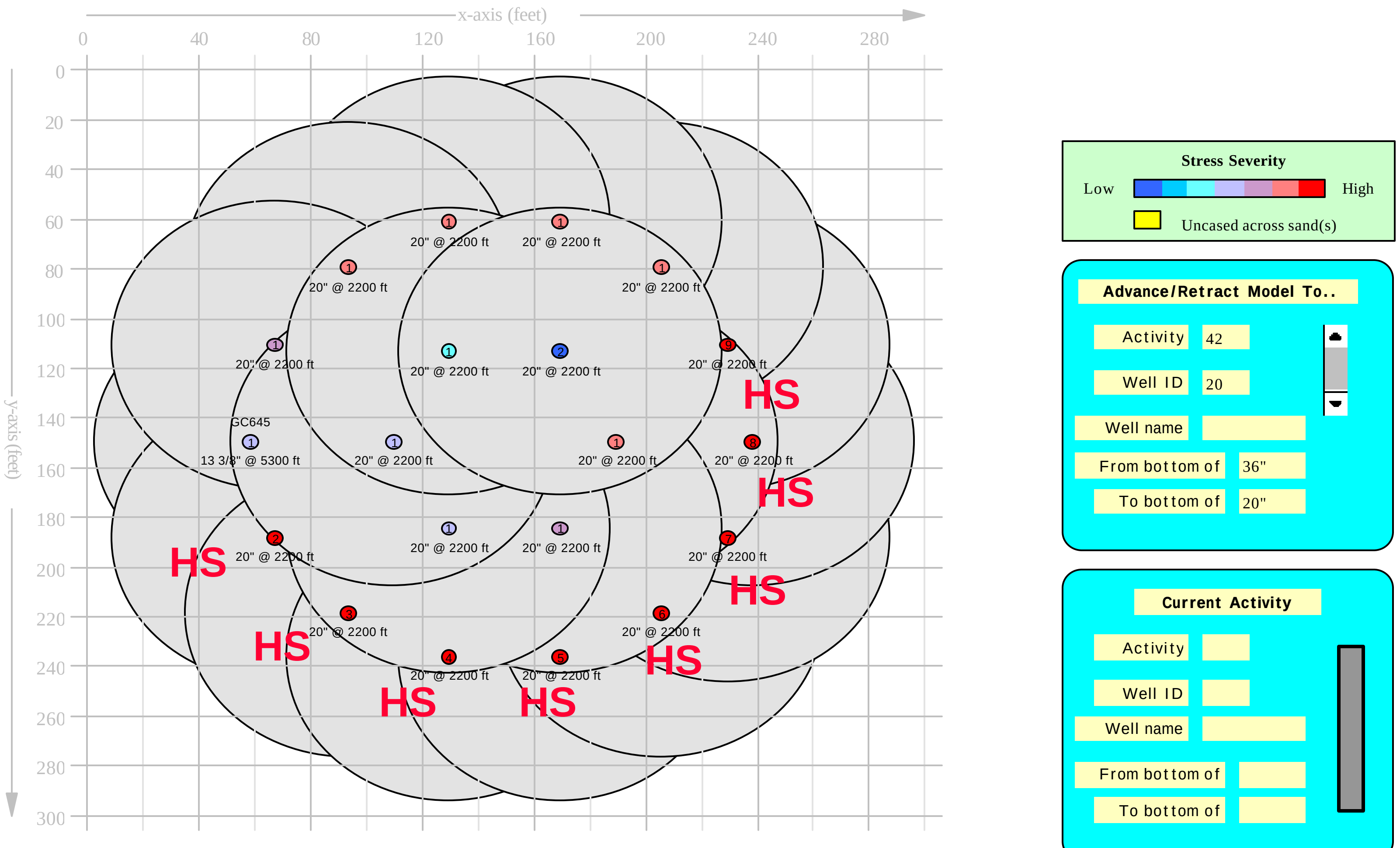


Base Case Pattern: Circular 40ft spacing



Circular 40ft –Result



HS = High Stress

Results: Circular 40 ft spacing (20 wells)

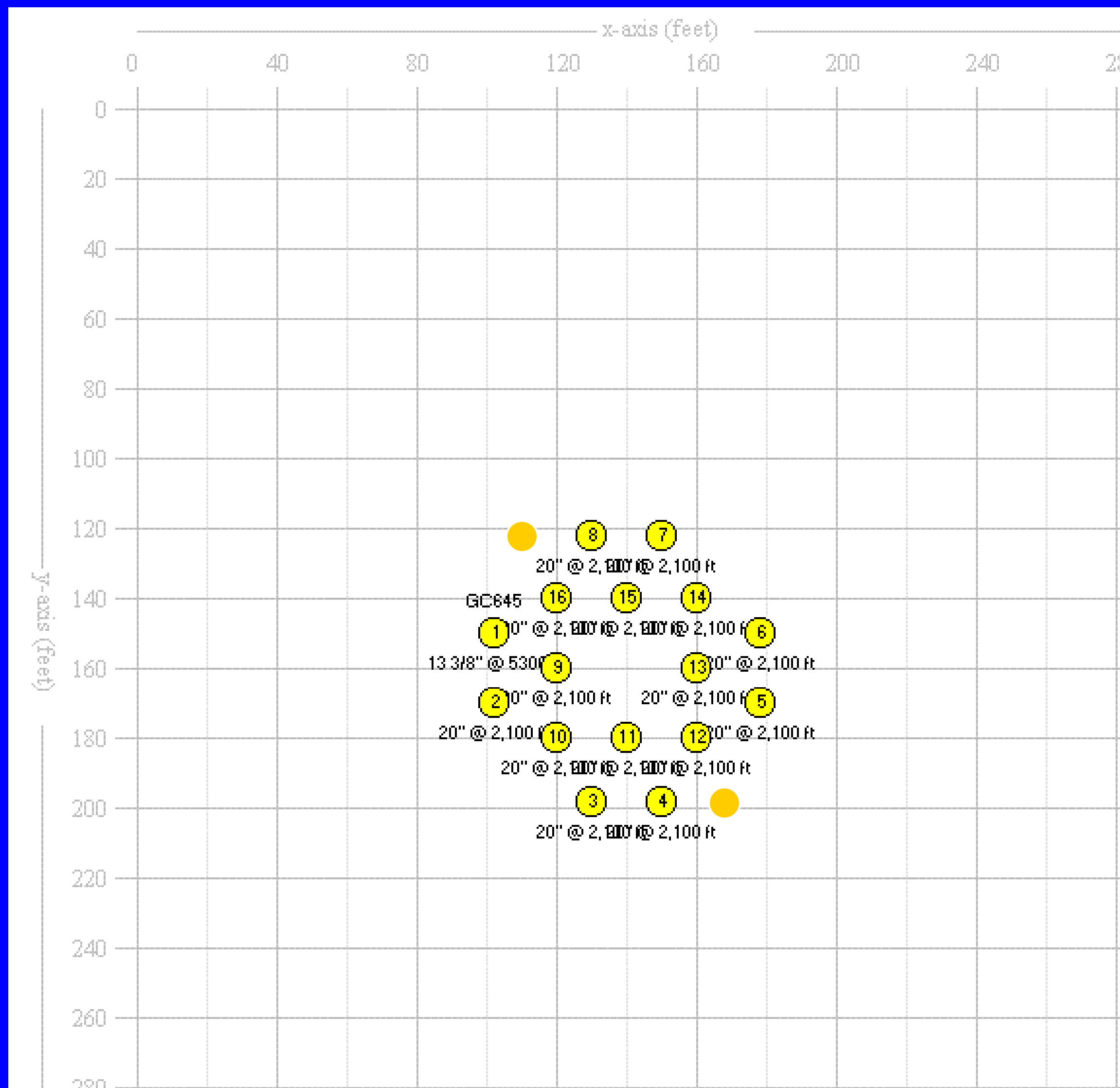
Base

PSI	ROP	PR	Press. Depletion	Perm	High Stress	Failures
30	50	1500	0%	6 Darcy	8	0
20					0	0
30				3 Darcy	0	0
30			1%		1	0
30	70				0	0
30		1200			0	0

Differences from base case parameters are listed

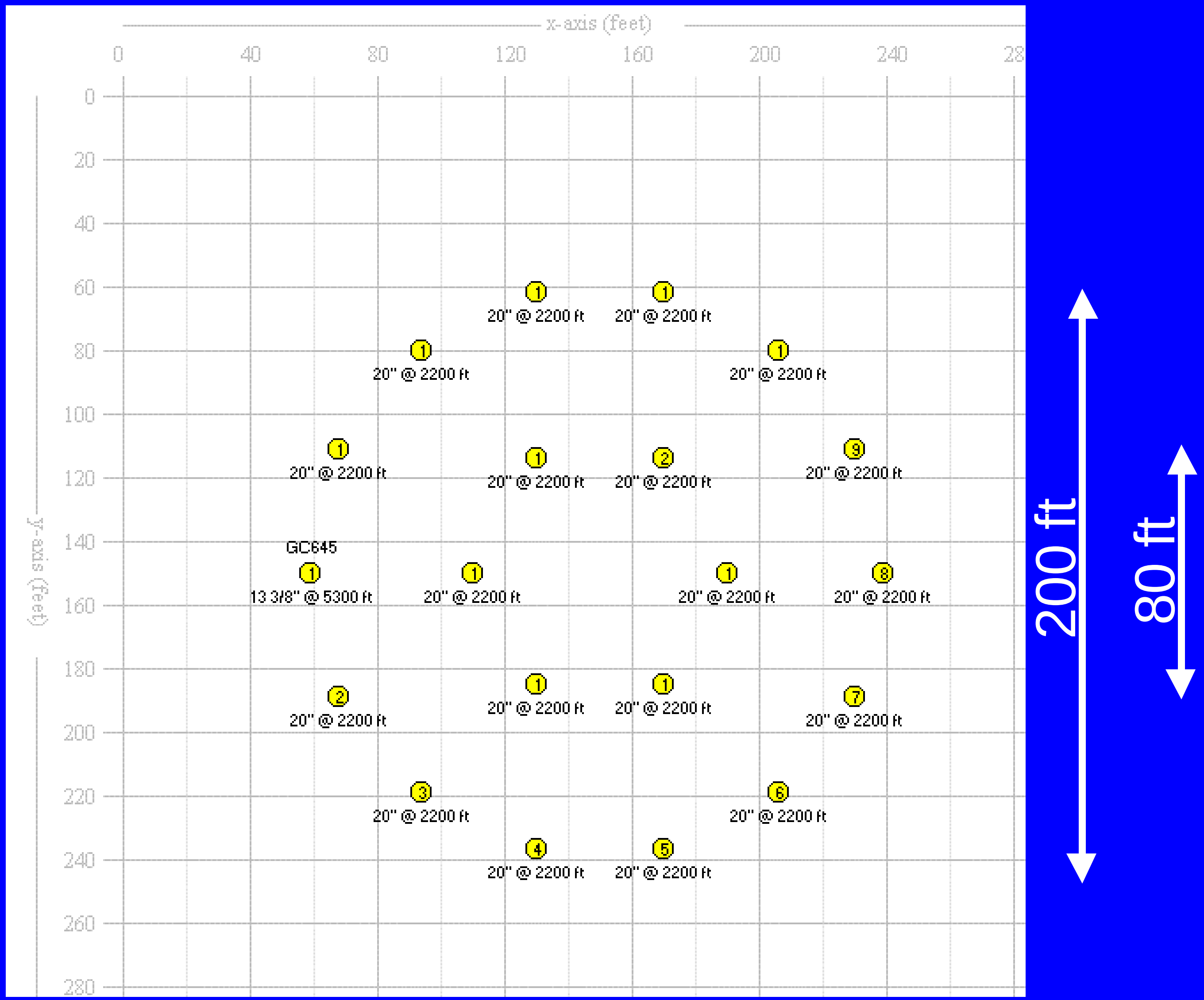
- SWF in only one well does not cause failure of adjacent wells
- Base case not OK with 30 PSI over pressure
  - Note: 0 High Stress or Failures for only 18 wells
- Base case fine with 20 PSI over pressure
- Simple drilling practices have significant impact
  - Drill with high ROP and low pump rate to increase cuttings load
- No need to weight up with mud unless concerned about sticking

Pattern: SSVR-18 wells

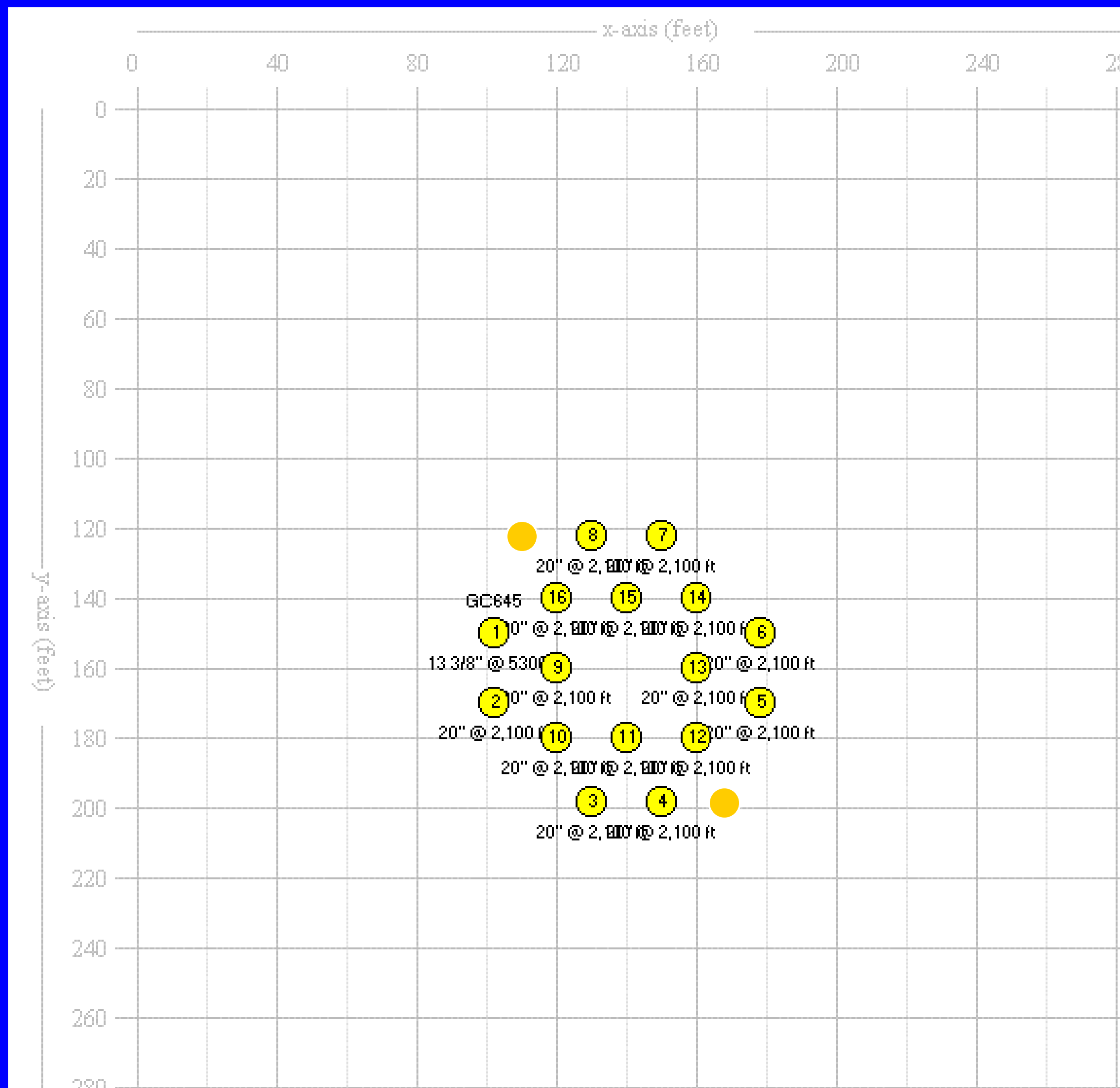


80 ft

Pattern: Circular 40ft spacing

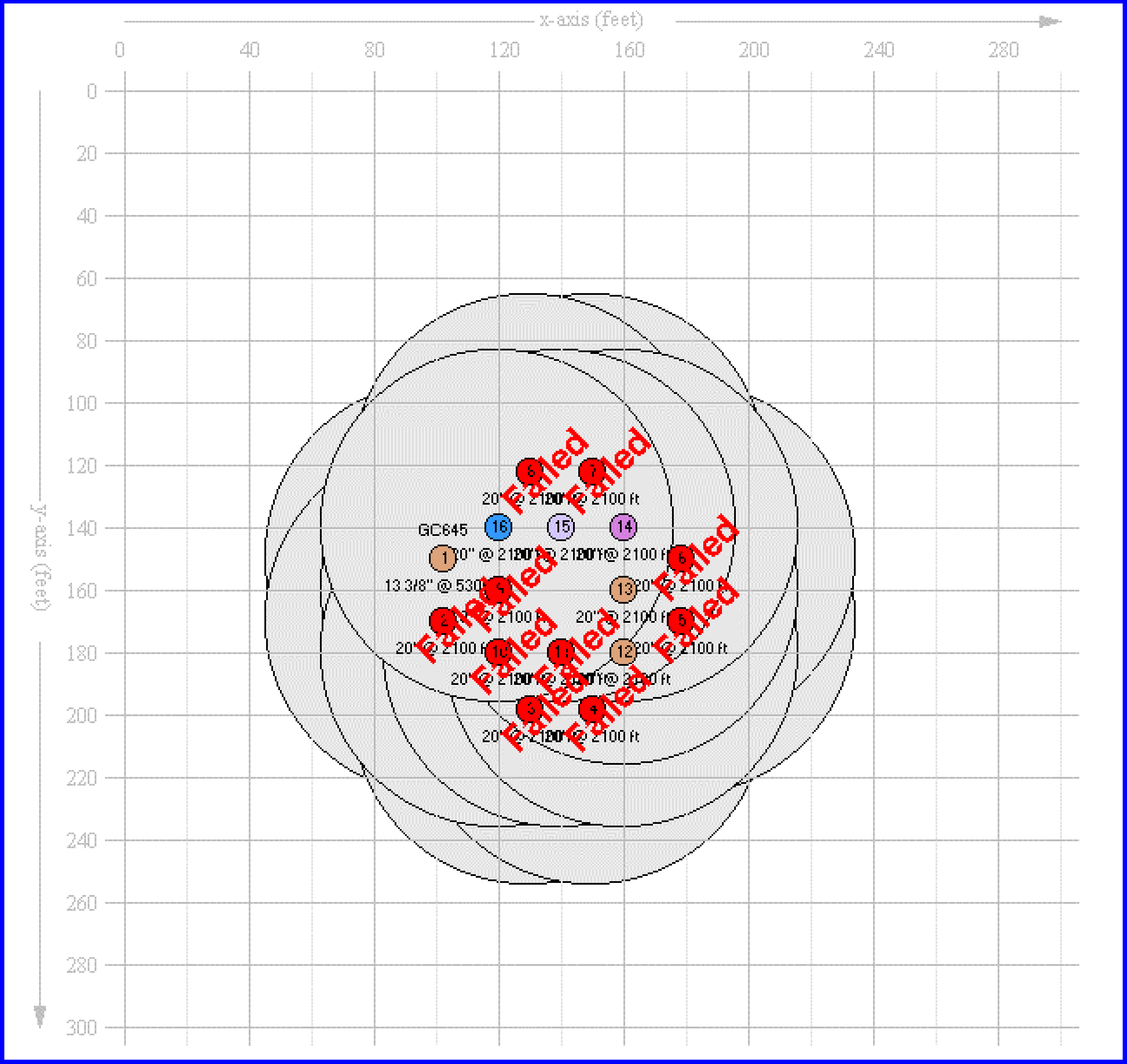


Pattern: SSVR-18 wells



80 ft

SSVR-Base Results



Results: SSVR (18 wells)

	PSI	ROP	PR	Press. Depletion	Perm	High Stress	Failures
Base	30	50	1500	0%	6 Darcy	1	12
	20					0	9
	10					0	0
	30				3 Darcy	1	8
	30			1%		2	10
	30	70				9	2
	30	110				0	3
	30	70	1200			3	6

Differences from base case parameters are listed

- Base case not OK with 30 or even 20 PSI over pressure
- Base case fine with 10 PSI over pressure
- Simple drilling practices have limited impact
- Thicker casing or setting 13 3/8” immediately not sufficient
- Must weight up with mud to drill this pattern

Results: Variations (18 wells)

Pattern	PSI	ROP	PR	High Stress	Failures
Circular 40ft	30	50	1500	0	0
Circular 30ft	30	50	1500	6	6
Circular 30ft	30	70	1200	0	0
SSVR*	30	70	1200	3	6
SSVR+15%*	30	70	1200	4	4
SSVR+35%*	30	70	1200	5	0
SSVR+75%	30	70	1200	0	0

*Feasible

- Circular 30 ft pattern requires minor modification of drilling proc.
- Minor increases in SSVR spacing have limited impact
- SSVR+75% drillable with minor modification of drilling proc.
- SSVR pattern may have room for further expansion…

Conclusions I

- A significant SWF occurred at GC-644
- No evidence of SWF observed at GC-645
- A significant SWF at GC-645 may have been undetectable
- Optimum facility location ~100ft east of GC-645
- Risk of SWF is not negligible but manageable

Conclusions II

- Circular pattern with 40 ft spacing least risky for SWF
  - Should be fine with increased ROP and/or decreased pump rate
- Reducing well spacing increases risk without mitigation
- Original SSVR pattern requires use of drilling mud
- Expanded SSVR pattern may be viable without mud
- Software allows closer ties with facilities and drilling teams for optimization of seabed pattern and drilling procedures

Tuesday
April 3, 2001

SHALLOW WATER FLOW

1. SWF database
Roger Entralgo, ERCH

How do you access the database?

Access through web browser – must be user affiliated with project
Can be accessed worldwide
Linked from ERCH website

Why are there so few entries in the database?

70 incidents but only 3 wells in database
Environmental problem – need collaboration
At least 7 companies are evaluating incidents for inclusion in database

Are there links to papers on SWF?

In phase 2, the database will include news items, published materials, lessons learned

2. Exploring the origin and behavior of SWF systems through ocean drilling
Peter Flemings, Penn State University

Regarding the slide with LOT and other pressures, please discuss the reservoir seal capacity (if flow leaks to surface).

In a sand, a LOT provides estimate of reservoir seal capacity (LOT normally done in shale) – recommend LOTs in sand

What is salinity of water coming from the flow in the video (is brine more dense that seawater)?

Gravity effects may be due to suspended sediment rather than density of brine – sediment usually creates cloud

What height plume is expected above seabed during SWF?

To get a high plume, gas must be part of flow or significant difference in density of fluids

3. Experimentally derived diagnostics for detecting anomalous pore pressure
Jack Dvorkin, Stanford Rock Physics Laboratory

How blurred will the results be with real formation analysis, compared to lab slides? What about clay content?

Clay content does change the data, but based on limited data existing, the data will still fall into the expected corners of the multicolored plot

How will velocity measurements vary at actual seismic frequencies as opposed to ultrasonic frequencies tested in lab?

The main reason for differences are the compliant cracks – results may be same in gas sands
200 khz frequency in lab – relatively low – predict that separation will still occur but will require adjustment

Is the poisson's ratio calculated from velocity only or is it measured?

It is dynamic poisson's ratio

4. Quantification of SWF zones using prestack seismic data
Nader Dutta, WesternGeco

What kind of attributes exist for narrowing down SWF prospects? Does it include facies analysis? Do you use high res 3D?

Surface features, amplitude, poisson ratios. Yes, facies analysis. Yes, high res 3D.

5. Evaluation and successful drilling of a SWF sand, Mississippi Canyon Block 727 #31, Poseidon Project
Jim Niemann, Chevron

Why drill with seawater at the outset?

Didn't want to vent mud to the seafloor until necessary

What was the ROP?

Controlled drilling – specific rate unknown

When you hit the SWF, did you have a hydrocarbon gas anomaly on the mudlog? Some things in the video moved up very quickly – hydrate snow?

No mudlogging at the time – all vented to seafloor.

What indicators showed the SWF was coming up within 50 ft? Resistivity data?

MWD logs, offset logs, seismic data.

What was your PP prediction method?

Resistivity after well was drilled. Before drilling, we used PP plots from offsets (sonic and resistivity data).

What log suite did you use in the riserless section of the hole?

Gamma ray, resistivity, directional, PWD.

Did you use a special subsea wellhead hanger? Specially developed for this well?

Big bore wellhead with 28" protection pipe, hung off 22" casing. Available from Vetco.

Was there hydrate accumulation?

No significant build up.

6. Modeling of casing collapse resulting from SWF
Mike McClean, BP

Did you allow the wells to flow while drilling or kill them?

Killed prior to running casing – drilled riserless with SW

7. SWF risk assessment for field development planning using HR3D seismic and wellbore stability modeling
Kathleen Horkowitz & Alex Calvert, BP

A 15 ft or less sand is no problem?

No flow observed from the 15 ft sand

Why is a circular development well pattern better than rectangular?

Avg distance between wells is about 50% greater

Did you use a drilling spar? Did you avoid using mud for environmental reasons?

Yes, and it increased the risk. We used batch setting.

On the Blk 644 well: How long did well flow? Why would flow occur and then cease?

Debated at BP. Could be periodic pressure changes.

PWD versus depth never showed pressure going back to –0-. Did you circulate the hole clean?

No.

Why did you do the high-res 3D?

Decided after exploration and appraisal wells to map the distribution of the 90 ft SWF sand. Felt it would help find the optimum location.

Did you do a detailed comparison between the original data and the high res?

Post appraisal part of the project – amplitude extraction from the SWF showed potential thinning to the east toward the Blk 645 location. We determined that using exploration 3D, but needed high-res 3D to map the 15 ft sand in the Blk 645 location. This supports the differences between planning an exploration well and planning field development. Acquiring high-res 3D costs same as one day of total rig costs – good insurance.

SWF POST SESSION QUESTIONS:

There was a scale 3.5 earthquake off Texas coast last year – is this a geohazard?

It might reactivate a slope but does not seem to at this time.

Has the SWF database established a standard for measuring SWF severity? When it's done, will it be given to API committee preparing standards for preventing annular flows?

No standard yet. And we have no linkages to the API at this time. We are working with the MMS on NTLs.

What is the effect of PP induced cracks on borehole stability?

Would decrease the stability but to what extent is uncertain.

What is the effect of PP cracks on LOT/FIT pressure data? What effect does SWF PP have on frac gradient calculations?

Cracks increase the chance of failure. Calling it a crack may be misleading.

How can you drill SWF zones without allowing the flow to initiate?

BP is putting much effort into dual gradient drilling (DGD) as a means to avoid SWF. First we are attempting simpler remedies, like higher ROP and lower pump rates. Also considering installing drainage wells. Drilling a large diameter hole with high ROP helps hold back the flow even while drilling with seawater. Another option is CaCl brines.

How can we encourage companies to submit data to the database?

Finding time to gather and compile suitable data is difficult. However, performing this task is an excellent preparation for working with SWF problems.

Could you drill stress relief wells (drainage wells) around the template area?

URSA analysis shows that placing a drainage well at each corner of the grid, TD below SWF zone with gravel pack or screen to prevent sand mining might have reduced mining from 50K cu ft to about 2K cu ft. Letting the water flow is fine; preventing erosion is the key.

Most of theses rocks will compact and it's not reversible. What are the elastic limits?

If you have a compaction change, different mechanisms are required.

More than one mechanism is always involved.

The primary focus is on shallow depth, but there are also rapid flowing gas vents, seeps, etc. We need to look deeper in the profile – lots of fluid movement down below.

Are you suggesting that SWF is charged from below?

Yes, that's why it's important to look at deeper features.

There is much debate about how the deep features affect SWF.

We can't ignore the biology. There is gas, multiphase problems. There are viable microorganisms at 10,000 ft.

It is interesting to note there is little, if any, shallow gas in deepwater GOM – does that argue against biological activity?

It was demonstrated at the League City workshop that SWF pressures result from depth, trapped by impermeable layers. We believe that shallow gas exists – we're just not drilling it.

Residual gas saturation can cause an impermeable seal to form. Can be in a shale.

Do we know enough to manage SWF on exploration wells?

There is plenty of qualitative evidence, but we need quantitative data, shallow core data – well logs don't exist for top hole. We need acoustic measurement. The Ocean Drilling Program (ODP) provides data as open resource all companies can access.

Do we know enough to manage SWF on development wells?

Not answered at this time.

Shallow cores are available – can we use them?

No, they are frozen and don't provide valid data.

How do you determine whether to use water base or oil base mud?

Oil based mud is not used as it cannot be vented to the seafloor (not environmentally acceptable).

Deepwater Geohazards Workshop

Gas Hydrates
Abstracts

Natural Gas Hydrates R&D in the Gulf-of-Mexico

Craig A. Lewis, Chevron Petroleum Technology Company

LINK TO PRESENTATION

There is evidence that accumulations of gas hydrates exceed the volumes of coal, oil and natural gas combined. If the technology can be improved to produce this vast resource, gas hydrates could have profound impact on the fossil fuels energy business. Some research and development (R&D) has occurred on the North Slope and the Far East, but little work has been done in the Gulf-of-Mexico, at least not deep below the mudline.

The presentation will begin with hydrates at the seafloor, which are being studied by a number of organizations. Quite a bit of work has been completed and is ongoing, so the focus of this talk will not be on seafloor hydrates.

The focus of this presentation will be on hydrates well beneath the seafloor, the technical questions and challenges facing deepwater operators, and their potential implications on deepwater GOM safety issues, if any. This will be followed with some potential industry R&D responses to better understand the occurrence of hydrates.

The Department of Energy (DOE) is now soliciting proposals from the National Labs, Academia, industry and others to address four key areas for DOE:

1. R&D related to hydrates located in the Gulf of Mexico
2. R&D related to hydrates located in Alaskan permafrost
3. Use as an effective medium for transporting gas
4. Development of a modeling consortium/partnership

For Key Area No. 1 above, the DOE is soliciting four sub-areas as follows:

- Drilling and producing conventional hydrocarbons through hydrates
- Sea floor stability
- Hydrate characterization
- Hydrate production feasibility studies

The presentation will conclude with one such industry-led response to challenges of hydrates in the Gulf of Mexico. Although still in the formation stage, it is hoped that this effort will be an integrated industry / National Lab / Academia approach over a period of several years. It is hoped that this effort will leverage the core technical competencies of numerous organizations.

Gas Hydrate Research at the DOE National Laboratories

Lorie Langley, Chair/ORNL,
DOE Methane Hydrates Inter-Laboratory Working Group Committee

LINK TO PRESENTATION

The Department of Energy has developed an aggressive program plan that addresses research and development of gas hydrates as a future energy resource. In May 2000, the Methane Hydrate Research and Development Act of 2000 was signed into law identifying DOE to establish a research program to review, develop, and produce gas from hydrates with the potential for a major payoff--energy security for the foreseeable future.

This briefing will provide an overview of the current research being performed at the DOE National Laboratories for gas hydrates, proposed areas of research for gas hydrates and associated research that apply to deepwater hazards, and the expertise associated with the specific labs for future hydrate research. Areas for partnerships will be identified as well as point of contacts for the laboratories.

Hazard Avoidance in Gas Hydrate-Bearing Sediments: Calibrating Field Observations and Applying Predictive Numerical Models

C. Ruppel
Associate Professor of Geophysics
School of Earth and Atmospheric Sciences,
Georgia Tech, Atlanta, GA 30332-0340
(404) 894-0231; cdr@piedmont.eas.gatech.edu

LINK TO PRESENTATION

Deep-sea drilling (e.g., Ocean Drilling Program), acquisition of high-resolution seismic lines and other geophysical data, and measurement of geochemical and hydrologic parameters at and near the seafloor have all contributed to a more complete understanding of the amount and distribution of gas hydrate in marine sediments. Such targeted data sets may assist in avoiding gas hydrate-related deepwater drilling hazards at some specific, very well studied locations. However, at the larger scale of lease blocks or thermogenic basins, a two-pronged effort will be required to ensure safety and seafloor stability during drilling of sediments that have the potential to contain gas hydrates: First, hazard avoidance is fundamentally dependent on the ability to interpret remotely-sensed data (e.g., any data obtained at or above the seafloor) in terms of in-site amounts and distributions of gas hydrate in the deeper sediments. Thus, a critical step in advancing the science of hazard avoidance is calibration of remotely sensed data using direct, drilling-based observations that provide access to deeper sediments. Only through such calibrations will routinely collected remotely sensed data achieve their full potential in characterizing gas hydrate-bearing sediments quickly, reliably, and relatively inexpensively. Second, predictive numerical modeling of the formation, distribution, and concentration of gas hydrate in marine sediments is in its infancy. When based on solid field data, such predictive, transport-based numerical modeling holds significant promise for guiding safe drilling practices in gas hydrate-bearing sediments. This presentation assesses the current state of knowledge for both the field-based and numerical modeling-based parts of the hazard avoidance effort. In addition, specific, field-based examples are used to describe the observational data and modeling studies that will be required to ensure safety and seafloor stability during future deepwater drilling for extraction of conventional resources.

Gas Hydrates in the Gulf of Mexico Slope as a Potential Drilling Hazard

Roger Sassen, Geochemical and Environmental Research Group
Texas A&M University - College Station, Texas 77845 USA

LINK TO PRESENTATION

Gas hydrates are ice-like crystalline minerals in which hydrocarbon gases and non-hydrocarbon gases are held within rigid cages of water molecules. All three gas hydrate crystal structures known to occur naturally have been found near the sea floor on the Gulf of Mexico slope. Structure I gas hydrate, which occurs in the Gulf and many other basins, is usually pure bacterial methane (Kvenvolden, 1995, 1999). Structure I gas hydrate has a body-centered cubic lattice, structure II gas hydrate has a diamond lattice. Other gas hydrates are thermogenic in origin (i.e. related to gas associated with oil). Structure H gas hydrate has a hexagonal lattice (Sloan, 1998). Both structure II and structure H gas hydrate are believed to co-exist in the Gulf at water depths as shallow as ~540 m (Sassen and MacDonald, 1997). Structure II gas hydrate generally includes C_1-C_4 hydrocarbons (methane through isobutane) whereas structure H gas hydrate generally includes C_1-C_5 hydrocarbons (methane through isopentane) as significant components (Sloan, 1998).

Gas hydrate sites extend along the Gulf slope offshore Texas and Louisiana over a distance >500 km, and the maximum width of the belt is >100 km. Solid gas hydrate has been recovered from shallow sediments (< 6 m) by piston coring and by research submersibles from > 50 localities on the Gulf slope (Fig. 1). The distribution of mapped gas hydrate sites corresponds to a late Pleistocene depocenter (Galloway et al., 2000, Fig. 18). The minimum observed water depth of occurrence of gas hydrate in the Gulf of Mexico is ~ 440 m and the maximum depth is > 2,400 m (Sassen et al., 1999). The thickness of the gas hydrate stability zone (GHSZ) increases with water depth. Calculations of stability, based on free gas with 90.4% methane, suggest that thickness of the GHSZ may be as much as ~ 450 m at 540 m water depth, and > 1 km at 1930 m water depth in the Gulf (Milkov and Sassen, 2000). There is an obvious subregional association between gas hydrate, seeps with chemosynthetic communities, and oil and gas discoveries and fields because all are derived by rapid fluid flow from the same subsurface hydrocarbon system (Fig. 1). The figure also highlights specific gas hydrate study sites of GERG's Applied Gas Hydrate Research Program (Green Canyon 184 and 234, Mississippi Canyon 853, and Atwater Valley 425) and nearby gas and oil fields. Thus exploration, exploitation, and pipeline transportation in the Gulf slope automatically involves proximity to gas hydrate accumulations and concomitant sediment deformation.

Although substantial progress is being made by Joeseph Gettrust of NRL and others at the MMS, geophysics has not been successfully utilized in the Gulf slope as a reliable tool to directly detect gas hydrate, which has implications to pre-drill hazard surveys and to pipeline routes. Geophysics can detect the chaotic wipe-out zones associated with sea floor gas vents and seeps, but piston coring shows that only a few such sites will be found to contain gas hydrate. Free gas often exists at vent and seep sites because natural inhibitors, such as brines, appear to retard gas hydrate crystallization. In addition, although important elsewhere on continental margins, there is no evidence of widespread Bottom Simulating Reflectors (BSR) in the Gulf slope, and no evidence has been presented linking any BSR to gas hydrate in the Gulf slope. Some gas hydrate in salt withdrawal basins, where most wells are drilled, may not show any obvious geophysical evidence of the occurrence of massive gas hydrate in the shallow subsurface of the Gulf (William Bryant, personal communication).

Thus, hazard surveys have a weakness because geophysics lacks a direct detection capability as yet because many vents and seeps share similar characteristics, and may not detect any hydrate-associated anomaly in sediment where hydrate is present. Therefore, one important avenue of research is to develop better geophysical tools for identification of gas hydrate. The most practical approach available at present involves using piston cores to directly sample geophysical anomalies detected that might or might not contain gas hydrate, and to subject them to basic geochemical analysis including C_1-C_5 hydrocarbon gases. Piston cores often recover intact gas hydrate, if present in massive or nodular morphology, and thermogenic gas hydrate even if present in small concentration at the time of sampling can be inferred by means of distinctive molecular ratios from sediment including anomalous ratios of ethane, propane, and butanes to methane.

Gas hydrate stability has been studied in the Gulf under natural conditions, revealing important new insight. Temperature, pressure, and the availability of hydrate-forming gas molecules are fundamental factors, among others, that control the stability of gas hydrate (Sloan, 1998). Thermogenic gas hydrate (structure II and H) are stable at higher temperatures and lower pressures than structure I gas hydrate (Sloan, 1998). Only a thin skin of gas hydrate appears to be unstable from natural driving forces in the Gulf slope, whereas deeply buried gas hydrate appears to be for all intents and purposes geologically stable (Sassen et al., 2001). Roberts et al. (1999) suggest that outcropping structure II gas hydrate at Green Canyon (GC) Block C 185 (~540 m water depth) are episodically unstable because of natural fluctuations in temperature from warm core eddies and other factors. Variable or decreasing rates of free gas flux also impact gas hydrate stability, especially of gas hydrate that outcrops on the sea floor (Egorov et al., 1999). The main zone of gas hydrate disturbance is mapped along the upper Gulf slope (Milkov et al., 2000) where sediment deformation is most commonly observed in the upper few meters of sediment. In contrast, thermogenic gas hydrate is stable at depths > 1 kilometer in sediment of the Gulf in deep water such as near Atwater Valley Block 425 (Milkov and Sassen, 2000), so the bulk of gas hydrate in the Gulf remains stable unless perturbed by drilling or other sea floor activity.

Sediment deformation related to gas hydrates appears to constitute a potential hazard (Milkov et al., 2000), and sediment deformations appears to be ubiquitous near massive gas hydrate (Ginsburg and Soloviev, 1998). Crystallization of gas hydrate rather than gas hydrate decomposition appears to be the main agent of sediment deformation in the Gulf slope at this point in geologic time and basin evolution. For example, geochemical analysis of gas venting from structure II hydrate-bearing sediments at the GC 185 gas and oil seep site shows no molecular evidence of gas hydrate decomposition. If gas hydrate is decomposing, gas venting from hydrate-bearing sediments would be expected to show molecular evidence in the form of abundant ethane, propane, and butanes, the hydrocarbons that comprise structure II gas hydrate (Sassen et al., 2001). These molecular properties are not observed in vent gas. Instead, the gas venting from hydrate-bearing sediment at GC 185 shows stripping of hydrate-forming molecules (Sassen et al., 2001, in press). This suggests that at GC 185 and other sites where copious thermogenic gas is venting under appropriate conditions, gas hydrate is not only stable but appears to be increasing in volume over time, forming thick vertically stacked deposits. These thick accumulations of gas hydrate are structurally focused by salt and fault conduits for upward fluid flow, and usually occur on or near the rims of salt withdrawal basins. Gas hydrate is less commonly found within the relatively undeformed sediment of salt withdrawal basins (Sassen et al., 1999).

New insight into how gas hydrate deforms sediment is available from study of hydrate sites on the sea floor using research submersibles and piston cores, often at chemosynthetic communities such as GC 184 and GC 234 (Sassen et al., 1998). The chaotic sediment fabric at the GC 185 site is distinctive because of the outcropping gas hydrate mounds (MacDonald et al., 1994; Sassen et al., 1999), and because of massive vein filling by gas hydrate in sediment. Veins of gas hydrate are sometimes >40 cm in thickness, and thus occupy a considerable volume of total sediment. Sassen et al. (1999) suggests a mechanism of vein filling. Gas pressure appears to open tension fractures along sub-horizontal planes of weakness in the mud. These tension fractures fill rapidly with gas hydrate, which props them open, and veins probably continue to expand by pressure of crystallization. Sediment is highly deformed in areas of vein filling and angular clasts of gas hydrate are observed suspended in mud matrix. Sea floor experiments are consistent with the suggested mechanism of vein formation in that gas hydrate crystallization can be induced to occur within seconds or minutes of mixing natural gas and water at the GC 185 site (Sassen and MacDonald, 1997).

Gas hydrate is unexpectedly abundant along the rims of salt withdrawal basins, where is it thought to comprise thick vertically-stacked accumulations such as at the archetypal Mississippi Canyon Block 853 site near Mars and Ursa (Fig. 1), and is less abundant in the salt withdrawal basins themselves. All three known types of gas hydrate occur in the Gulf, often in proximity to drill sites, discoveries, producing fields, and along pipeline routes. Only a thin skin of gas hydrate appears to be unstable from natural driving forces in the Gulf slope, whereas deeply buried gas hydrate appears to be geologically stable. The greatest hazard in the deep Gulf is not natural, but related to exploration, production, and transportation of conventional gas and oil in ultra-deep water. One of the more significant problems to be addressed is that drilling, production, and transportation may increase sediment temperature, destabilizing gas hydrate and causing large pressure excursions, rapid sediment deformation, and possibly localized shallow water flows. Whenever massive gas hydrate is disturbed by a temperature increase, a hazard should be considered to exist. Improved knowledge of the geology, geophysics, and geochemistry of gas hydrate is necessary to continue the safe activities that have so far prevailed in the Gulf slope as activities move into deeper and deeper water of the Gulf slope. The easiest action is to avoid massive gas hydrate, and combined geophysics and piston coring during hazard surveys provide a means to decrease risk.

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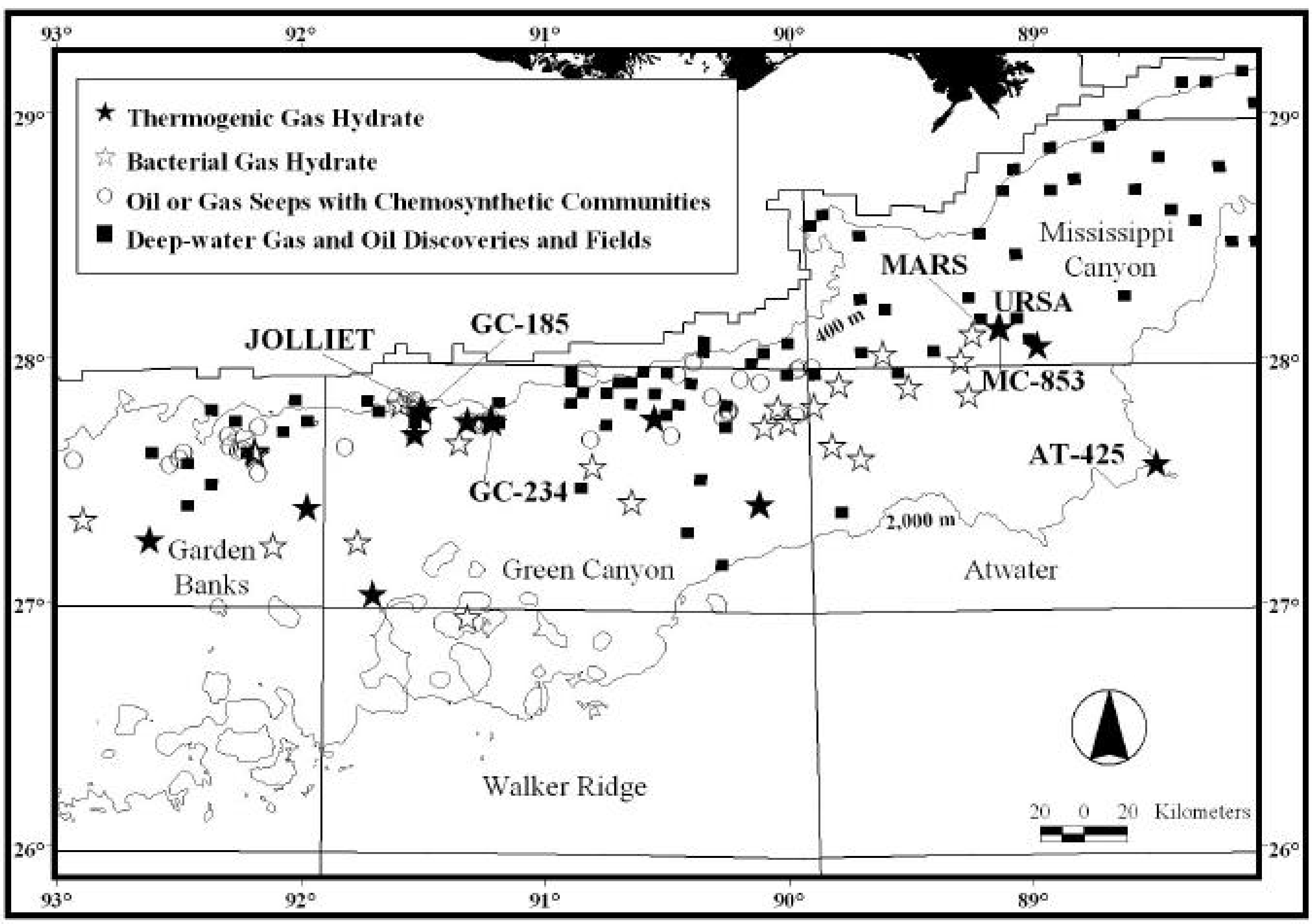
Figure 1. Sketch map showing sites where intact gas hydrate has been recovered, major oil seeps with chemosynthetic communities, and locations of gas and oil fields and discoveries. The map highlights four major study gas hydrate areas (Green Canyon 184 and 234, Mississippi Canyon 853, and Atwater Valley 425) which are described in the list of useful references.



Seafloor Stability, Hydrates and Sediments

E. Dendy Sloan, Jr., Director
Center for Hydrate Research
Colorado School of Mines

LINK TO PRESENTATION

This work will consider the determination of the pressure and temperature at which hydrates form and dissociate in sediments. There are several instances regarding the impact of sediments on hydrate formation. There is a question about whether sediment properties could cause the 50 m discrepancy between the Blake Bahama Ridge (ODP Leg 164) BSR and hydrate recovery. There is a similar discrepancy in the BSR record and hydrate recovery from Leg 146 in the Cascadia Margin. Pictures with be given of seafloor sediments which have been disrupted by hydrates.

Sediment/surface phenomena directly determine whether properties (density, thermal conductivity, heat capacity) of sediment and hydrates mixtures can be obtained through linearly weighted combinations of both constituents. For example, if one wishes to decompose hydrates in sediments, he/she is constrained to use linear averages of heat capacity, density, and thermal conductivity of hydrates and sediments, but the departure from such linearity may effect the energy economy of hydrate recovery.

Our laboratory has performed hydrate phase-equilibrium experiments in sediments. In addition to almost 25 years of hydrate phase equilibrium measurements, we have recently performed hydrate dissociation/formation experiments for AGIP S.p.A. in evaluating hydrate formation in consolidated Adriatic cores. This paper will provide experimental results and a model to indicate the stability of hydrates in sediments, with implications for seafloor stability.

BIOGRAPHICAL SKETCH

E. Dendy Sloan, Jr. is the Weaver Distinguished Professor of Chemical Engineering and Director of the Center for Hydrate Research at the Colorado School of Mines, where he heads a group of 10 researchers. Dr. Sloan has three degrees from Clemson University, did post-doctoral work at Rice University, and has five years industrial experience with DuPont. His research has concentrated on natural gas hydrates, with over 125 publications in the area. The second edition of his monograph Clathrate Hydrates of Natural Gases, (705 pages and software) was published by Marcel-Dekker, Inc. in 1998. A second book, Hydrate Engineering, was published by SPE in April 2000. In 1993 he organized and chaired the First International Gas Hydrate Conference, sponsored by the New York Academy of Sciences. The hydrate research in his laboratory is sponsored by a consortium of 12 companies, the Department of Energy, the National Science Foundation, and various industries. He is a Fellow of the American Institute of Chemical Engineers, was SPE Distinguished Lecturer on Hydrates in 1994, and was given the Donald L. Katz Award for Gas Research in 2000.

High-Resolution, Deep-Tow Seismologic Studies of Deepwater Geohazards

J. F. Gettrust, Naval Research Laboratory, Code7432

LINK TO PRESENTATION

Technology developed by the Naval Research Laboratory (NRL) to study the acoustic properties of marine sediments has proven to be very useful for studies of the geotechnical properties of sediments in deep water. This technology, based on a Helmholtz Resonator source and multichannel hydrophone array, has successfully operated (usually ~300 m above the seafloor) in water depths up to ~5000 meters. This deep tow capability, combined with the relatively high-frequency (250Hz – 1kHz) source provides resolution on the order of ~2 meters within the upper 1 km of sediments. This depth range includes the stability field of natural gas hydrates, which investigators have been studying for the past decade. As the dissociation of gas hydrates has been shown to be related to seafloor stability, the ability to resolve potential geohazards in deep water has become increasingly important for both the Navy and commercial ventures, including drilling in deep water. Data taken with this system reveal ubiquitous faulting through the entire hydrate stability zone even in relatively benign geologic environments. These data also show evidence of significant, localized dissociation of gas hydrates, some of which is ongoing.

We plan to extend this technology by placing controlled sources on the seafloor to directly generate shear waves. This would allow us to obtain compressional velocity (Vp) and shear velocity (Vs) measurements to define regions in which an abnormally high Vp/Vs ratio can be used to infer, for example, over-pressured sands. Simulations of the advantage of bottom source-receiver geometry with 250Hz-1kHz source signals demonstrate the potential of this technique when coupled with either OBCs or bottom-mounted vertical hydrophone arrays.

Seismic Facies Analysis Applied to Sea Floor Gas Hydrates A Case Study Offshore Gulf of Mexico

Jesse L. Hunt, Jr.
Minerals Management Service

LINK TO PRESENTATION

The Gulf of Mexico Region of Minerals Management Service (MMS) undertook a mammoth project during the past two years to map the seafloor reflector on all available deepwater 3-D seismic surveys. To date, seafloor maps have been prepared for 128 3-D seismic surveys covering approximately 80% of the Central Gulf slope and about 70% of the Western Gulf Slope. It is noted on the data that most deep faults that cut the seafloor have high amplitude anomalies associated with them. Comparison with known core locations and visual observations reveals that the anomalies are often caused by carbonate hardgrounds, chemosynthetic communities or seafloor hydrates associated with hydrocarbon seeps. In order to determine if these features can be differentiated by using 3-D seismic data, ground-truthing efforts have been undertaken. These efforts include using core data and direct observations using a submersible.

Another method for differentiating these features is seismic facies analysis using seismic waveform analysis. A seafloor feature adjacent to Cooper Field in Garden Banks was selected for a case study. This area has a detailed pre-drilling site survey complete with core data and direct submersible observations. A gas hydrate mound and mud volcano were observed at the site.

A structural interpretation of the seafloor from 3-D seismic data provided conventional horizon attributes such as amplitude, two-way travel time, dip, and azimuth maps. An interval of 24 milliseconds from above the seafloor reflector to below the seafloor reflector was selected for wave-trace analysis using *Stratimagic* ™ software. The various trace shapes were analyzed and classified into a set of 20 model traces that represents the diversity of various trace shapes present in the interval. Using core data and observations, model traces were established at the site of the hydrate mound, mud volcano and oil/gas saturated mud. Following analysis, when core locations for 17 other cores in the area were plotted on the facies map, there was 100% correlation between the facies prediction using *Stratimagic* ™ and the findings in the cores.

Further analysis is being done on 8 sites where submersible observations were conducted in the summer of 2000. Hopefully, this type of analysis will enhance MMS's ability to identify and differentiate carbonate hardgrounds, chemosynthetic communities, and seafloor hydrates by using extensive 3-D seismic data, and better help MMS meet its legal mandate to identify geohazards and protect chemosynthetic communities.

Deepwater Geohazards Workshop

Gas Hydrates
Presentations

Deepwater Geohazards Workshop

Industry Hydrate R&D in GOM

Craig Lewis, April 3, 2001
Chevron Petroleum Technology Company

Potential Safety Issues for Industry

- Hydrates at the Seafloor
  - Associated with vents
  - Variable through time
  - Potential hazard for pipelines and structures
- Hydrates beneath the seafloor
  - Hard to detect/quantify remotely
  - Potential hazard for structures and wells?
    - Impact of long-term production through hydrate-bearing zones?
  - Association with shallow water flow?

Recommended Industry Approach

- Hydrates at the Seafloor
  - Support ongoing work at Texas A&M, LSU & MMS
  - Recognize that surficial hydrate occurrences are not static
    - Continuous monitoring may add value
  - Share lessons learned freely between companies, government agencies, labs, academia, etc.

Recommended Industry Approach

- Hydrates beneath the Seafloor
  - Recognize that there is much we do not know
  - Recognize that potential safety issues warrant a better understanding of subsurface hydrate occurrence
  - Share lessons learned freely
  - Form Industry-led JIP to address potential safety issues

Key Technical Issues

- What are the physical and chemical properties of sediments containing gas hydrates?
- What acoustic, resistivity or other measurements provide the most information?
- Can we use seismic modeling to better shoot, process and interpret the gas hydrate properties?
- What geochemistry studies would be helpful?
- How can we better preserve & transport gas hydrate cores to laboratories?
- How can we cut and test cores to calibrate both the seismic and open hole logging data?

Objectives of the R&D

- Develop a research plan
  - Learn how to characterize the gas hydrates in the deep water GOM
  - Address potential safety issues relating to
    - Drilling wells
    - Producing deeper, hotter wells up through hydrates
    - Installing & operating pipelines
- Develop a database of existing seismic, core and log data
  - Assess the current known sites where gas hydrates occur in the GOM
- Use existing knowledge to choose 1-3 sites where field tests can be conducted to develop better data sets

Objectives of the R&D

- Plan and execute a field program to obtain better data sets to characterize the gas hydrate sediments in the GOM, and shallow free gas underneath hydrates
- Assess <u>potential</u> safety problems associated with long-term production through hydrate-bearing zones
- Provide the information others may need to assess the size and potential of the gas hydrate deposits in the GOM, and shallow gas underneath hydrates

Timeframe

- Phase 0 (Planning) — Apr 2000 - Apr 2001
  - DOE/Chevron Workshop — 8/00
  - Form a JIP — 8/00-3/01
  - Seek DOE Co-Funding — 4/01
  - DOE awards — ?
- Phase I — Mid 2001 - 2002
  - Build Database, Models, etc.
  - Site Selection
- Phase II — 2003-2004
  - Field Data Collection
  - Data Analyses
- Phase III — 2005+
  - Additional Field Data Collection

Phase I 2001-2002
Scope & Deliverables

- Develop database by collecting existing seismic, core and log data that cover the gas hydrate areas in the GOM
- Develop recommended seismic, logging, & coring evaluation program
  - Need industry standard when drilling through potential hydrate zones
  - Need set of cost effective protocols for drilling and collecting data in the hydrate zones

Phase I 2001-2002
Scope & Deliverables

- Develop set of criteria for determining where to drill narrow-bore tests for collecting new data
- Select sites for field data collection program
- Develop new technologies required to go to the field, collect, and analyze the new data on gas hydrates

Phase II & III (2003-2004) Scope & Deliverables

- Plan drilling and testing programs
  - Develop detailed plans for obtaining new seismic, log and core data
  - Integrate plans with existing programs, such as the ODP at Texas A&M University
- Shoot seismic, drill, core and log
  - Conduct multiple field tests in 2003
  - Evaluate new data
  - Conduct multiple field tests in 2004

Estimated Costs

	2001	2002	2003
JIP Design Phase	$900K	$1820K	-0-
GOM Testing	-0-	-0-	Under Review
Totals	$900	$1820K	Under Review
Industry Funding	$180K	$360K	Under Review
DOE Co-Funding	$720K	$1460K	Under Review
DOE Cost Share	80%	80%	80%

Economic Justification

- Are there potential safety issues?
  - Drilling issues?
    - Do hydrates contribute to SWFs, or not?
  - Long-term production issues through hydrates?
  - Pipeline issues?
- If there are no safety issues, R&D can stop…
- If there are potential safety issues…
  - How can industry
    - Risk Assessment Evaluation Methodology
    - Mitigate Risk
    - Remediate Risk

Summary

- Hydrates at the Seafloor
  - Currently being addressed by MMS, Academia, etc.
- Hydrates beneath the Seafloor
  - Hard to detect & quantify remotely
  - <u>Might</u> be a potential hazard for structures and wells
  - <u>Might</u> contribute to shallow water flows
  - <u>Might</u> not be a problem at all

Summary - Industry R&D Plan

- Hydrates beneath the Seafloor
  - Recognize that there is much we do not know
  - Recognize potential safety issues warrant better understanding of subsurface hydrate occurrence
  - Should share lessons learned freely
  - Should form Industry-led JIP to address R&D issues
    - Seek DOE co-funding to make this R&D possible
    - Should leverage integrate Work Plans with National Labs, USGS, Academia, NRL, ODP, etc.
    - Plan & Execute the R&D

More JIP Information

- Additional Participants Welcome
  - Can provide cash, or combination of cash and in-kind services
- For More Information, Contact Either
  - Craig Lewis
    - 281.596.2350, “cral@chevron.com”
  - Emrys Jones
    - 281.596.2269, “emry@chevron.com”

Methane Hydrates Research at DOE National Laboratories

Presented at

Deepwater Geohazards Workshop

Lorie Langley
Committee Chairwoman
DOE Methane Hydrates Inter-Laboratory Working Group Committee

DOE Methane Hydrates Program Overview

DOE-FE • (NETL) National Energy Technology Laboratory • (SCNG) Strategic Center for Natural Gas

Gas Exploration, Production & Storage – Brad Tomer
www.netl.doe.gov/scng

Partnerships
Academia
National Laboratories
Industry
Consortia

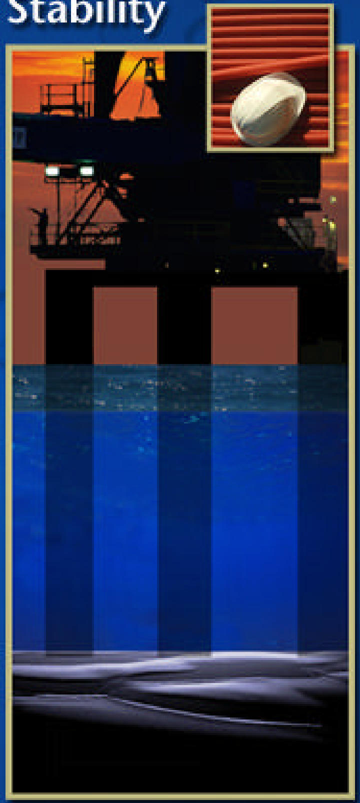
Inter-agencies
DOI: USGS, MMS
DOD: NRL, CRREL
DOC: NOAA
NSF: ODP

Production

Global
Carbon Cycle

Resource
Characterization

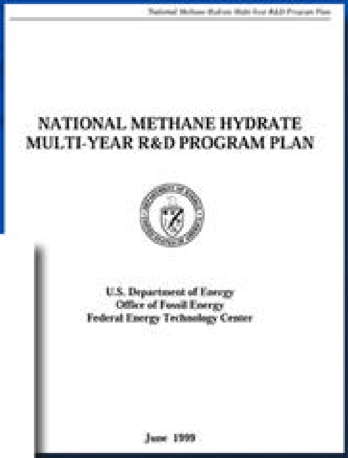
Safety & Seafloor
Stability



Program Goal: Produce the knowledge and technology necessary for commercial production of methane from hydrates and address the associated environmental & safety issues

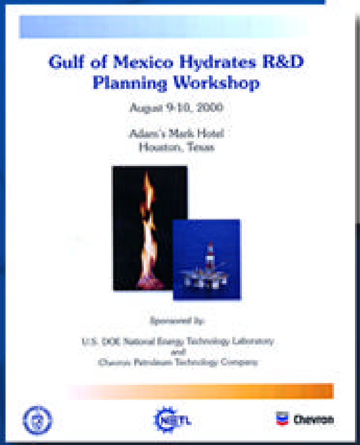
Methane Hydrates - *History*

1982-1992	DOE funded research for evaluation of methane hydrates as an energy resource
November '97	Federal Energy Research and Development for Challenges of the 21st Century
January '98	Workshop between DOE-HQ, National Laboratories, USGS, & NRL produced a research agenda. The DOE Working Group Committee was formed.
June '99	National Methane Hydrates Multi-Year R&D Program Plan www.fe.doe.gov/oil_gas/methanehydrates/99hydrate.pdf
May '00	Methane Hydrates Research and Development Act of 2000
August '00	GOM Hydrates R&D Planning Workshop www.netl.doe.gov/scng/index-b.html
Feb '01	Program Solicitation "Methane Hydrates" www.netl.doe.gov/business
March/April '01	National Laboratory Solicitation


NATIONAL METHANE HYDRATE
MULTI-YEAR R&D PROGRAM PLAN

U.S. Department of Energy
Office of Fossil Energy
Federal Energy Technology Center

June 1999


Gulf of Mexico Hydrates R&D
Planning Workshop

August 9-10, 2000

Adam's Mark Hotel
Houston, Texas

Sponsored by:
U.S. DOE National Energy Technology Laboratory
and
Chevron Petroleum Technology Company


DOE National Laboratories Involved in Gas Hydrate Research
Pacific Northwest National Laboratory
Idaho National Engineering & Environmental Laboratory
Brookhaven National Laboratory
Lawrence Berkeley National Laboratory
Argonne National Laboratory
National Energy Technology Laboratory
Lawrence Livermore National Laboratory
Oak Ridge National Laboratory
ORNL 2000-05377a/djr
U. S. Department of Energy

Ongoing Hydrate Research

- Physical, thermodynamic, and kinetic properties evaluation
- Determination of crystalline structure & hydrogen bonding for water/gas interactions
- Evaluation of hydrate phase transitions under various temperature and pressures

Proposed Hydrate Research

- Obtain Gulf of Mexico hydrate samples (with Naval Research Laboratory)
- Analyze samples at Advanced Photon Source (x-ray)
- Begin three phase studies of synthetic materials using NMR
- Compare LLNL - USGS and ANL synthetic samples

ANL Capabilities for Hydrate Research

- Neutron diffraction using the Intense Pulsed Neutron Source
- Apply Raman Spectroscopy to structure and phase changes
- X-ray diffraction using the Advanced Photon Source (APS)
- NMR using the high pressure toroidal NMR Chamber

POC Dave Schmalzer (schmalzer@anl.gov)

bnl

Ongoing Hydrate Research

Understand factors governing hydrate thermodynamic stability:

- Techniques have been developed to grow large crystals at -5°c for neutron studies
- X-ray study of field samples

Proposed Hydrate Research

- Kinetic study with PFTs to track methane production
- Study localized hydrate decomposition stimulated by sonolysis mimicking direct subsurface conditions
- Kinetic modeling using molecular simulation methods including the Methods of Moments (MOM)

BNL Capabilities for Hydrate Research

- A dedicated bench-scale unit (P: to 12 MPa; T: -20 to +150ºC; V ~ 1.5 L) operable in both static and dynamic modes
- Crystal growth and neutron studies of clathrate hydrates
- Kinetics & kinetic modeling
- Perfluorocarbon Tracer (PFT) technology, methane transport

POC: Devinder Mahajan (dmahajan@bnl.gov)

Ongoing Hydrate Research

- Measure microbial location and activity on samples from Canada and Japan
- Model advective transport of methane in compacting sediments and hydrate deposits
- Measure sonic properties of hydrate-filled sediments

Proposed Hydrate Research

- Hydrate stability under natural and anthropogenic disturbances, including capillary effects and the formation of highly branched dissociation patterns
- Development of pressure seals under hydrate deposits
- Instrumentation for laboratory, field, and pipeline monitoring of hydrates

INEEL Capabilities for Hydrate Research

- Microbiological studies
- Geophysical studies
- Reservoir seismic interpretation
- Transport model development
- Feasibility evaluation for a large-scale hydrates test center

POC: Bob Cherry (CHY@inel.gov)

Ongoing Hydrate Research

- Development of multiphase, multicomponent, thermal reservoir simulator incorporating equilibrium thermodynamics and kinetics
- Application of simulator to assess recoverability of hydrates in various geological environments

Proposed Hydrate Research

- Application of VSP, single well and crosswell seismic techniques for high resolution characterization
- Forward simulation of seismic wavefields
- Low frequency laboratory measurement of seismic velocities
- Geomechanical modeling of stability
- X-ray and NMR imaging of dissociation

LBNL Capabilities for Hydrate Research

- Reservoir simulation
- Seismic and electrical geophysics
- Isotope geochemistry
- Microbial studies

POC: Larry Myer (lrmyer@lbl.gov)

Ongoing Hydrate Research

- Dissolution/dissociation of pure methane and CO_2 hydrates inside/outside the stability field for T&P
- Physical and kinetic properties of gas hydrates
- Deformation testing, thermal properties, elastic properties
- Kinetic behavior
- Gas exchange of CO_2 - CH_4 hydrates

Proposed Hydrate Research

Fundamental physical properties and chemical stability of gas hydrates in nature and during recovery

- Mechanical disturbance to hydrate bearing sediments
  - Factors affecting hydrate content & composition during core drilling
  - Stability of hydrate formation during production
  - Resource assessment tools for the Gulf of Mexico
- Hydrate formation as a diagenetic process in marine sediments

LLNL Capabilities for Hydrate Research

- Geophysics and Geochemistry Studies
- Predictive Models
- Economic Validation
- Basic Research of seafloor safety and stability

POC: William Durham (durhaml@llnl.gov)

Ongoing Hydrate Research

- Crystallography evaluations by neutron and x-ray diffraction on CO_2, CH_4, C_2H_6, THF hydrates
- Hydrate/sediment slurry experiments completed at SPS for hydrate stability and formation
- Completed data modeling for using measured velocity to estimate gas hydrates concentrations
- Developing task for support to Chevron for characterization during GOM hydrate research activities

Proposed Hydrate Research

- High-resolution, three-dimensional seismic reflection modeling
- Information fusion for hydrate resource assessment and shallow water flow analysis
- Crystallographic studies of polycrystalline and single crystal structures
- Insitu sensor development
- Collaborations for enhanced methane hydrate systems analysis using the SPS
- Environmental benefits and impacts of methane hydrate production

ORNL Capabilities for Hydrate Research

- Seafloor Process Simulator Facility for scale-up experiments
- High Flux Isotope Reactor (HFIR) for neutron diffraction activity
- Computational resources for hydrate assessment and understanding geophysical properties

POC: Lorie Langley (langleyla@ornl.gov)

pnnl

Ongoing Hydrate Research

- **In situ characterization of hydrate formation/dissolution in consolidated sediments**
- **Multiphase reactive transport modeling of hydrate reservoirs**
- **CO2 Sequestration**
- **Organic separation/immobilization and isotope separations**

Proposed Hydrate Research

- **Methane Recovery from methane hydrates**
  - Advanced method that manipulate PT-thermodynamics without energy imput
  - Applied engineering methods to enhance heat transfer to reservoir
  - Improved mining strategies
- **CO_2 Sequestration**
  - Develop molecular-level models to understand hydrate-sediment/soil interactions
  - Enhancing ocean sequestration using inorganic supports

PNNL Capabilities for Hydrate Research

- **Mid to large-scale testing capabilities**
- **Field data from deep sea ecology (marine lab in Sequim, WA)**
- **Field Testing of CO_2 sequestration concepts with NRL**

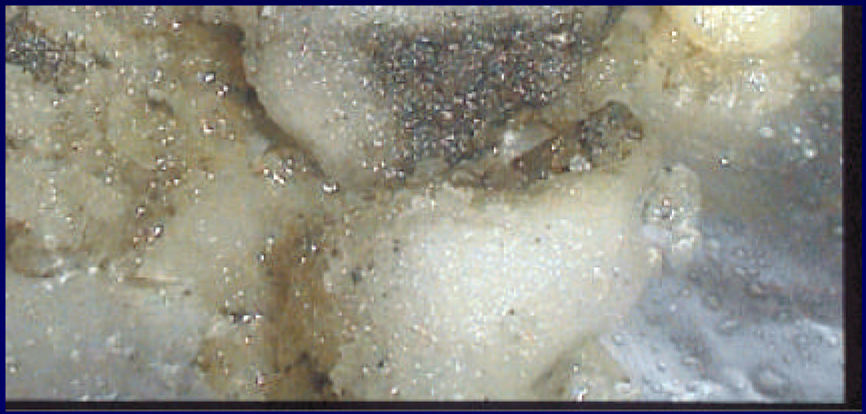
POC: Jagann Bontha (j.r.bontha@pnl.gov)

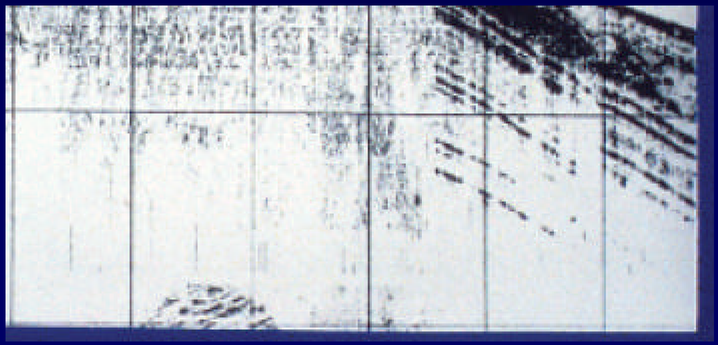
Gas Hydrate:
Resource or Hazard?

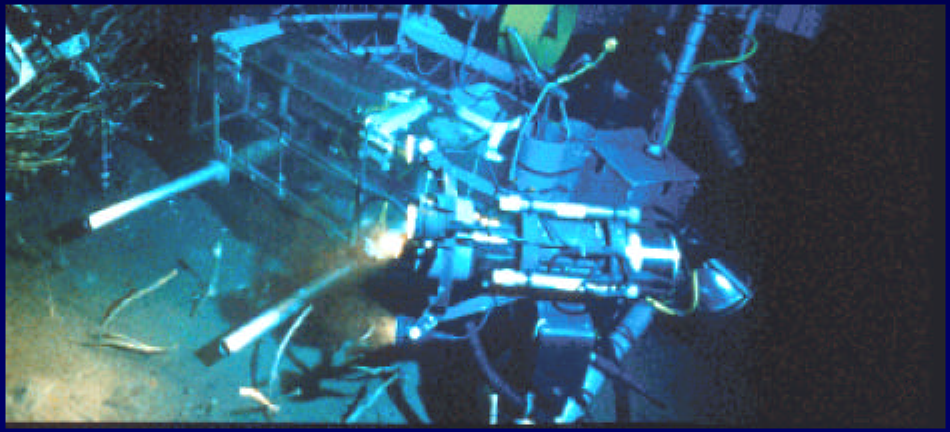
The Deep-Water Gulf Case History

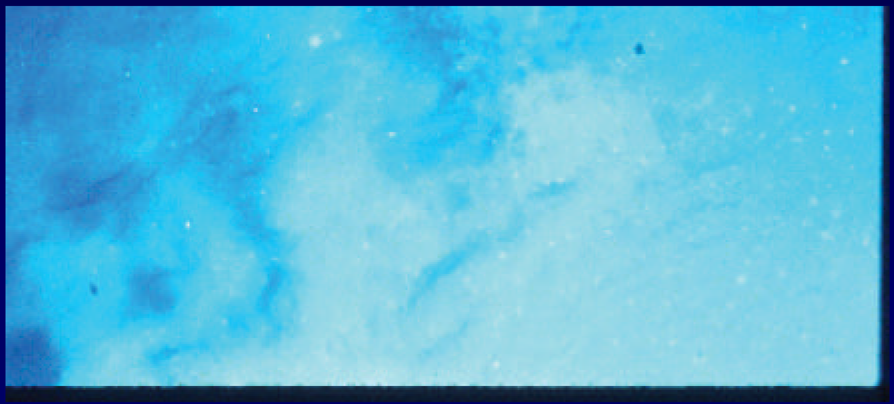
Geologically Recent and Ongoing Oil and Gas Seepage

5^{12}
$5^{12}6^4$
5^{12}
$4^35^66^3$
$5^{12}6^8$
Ratcliffe (1990)

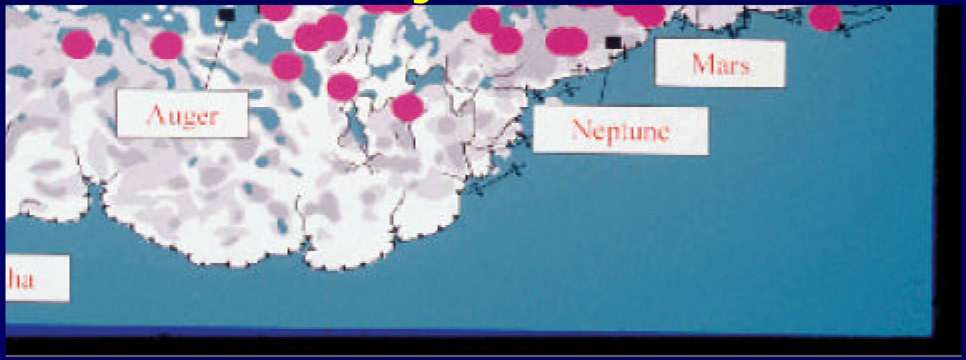








Gas Hydrates, Gulf of Mexico



Structural Focusing of Thermogenic Gas Hydrates

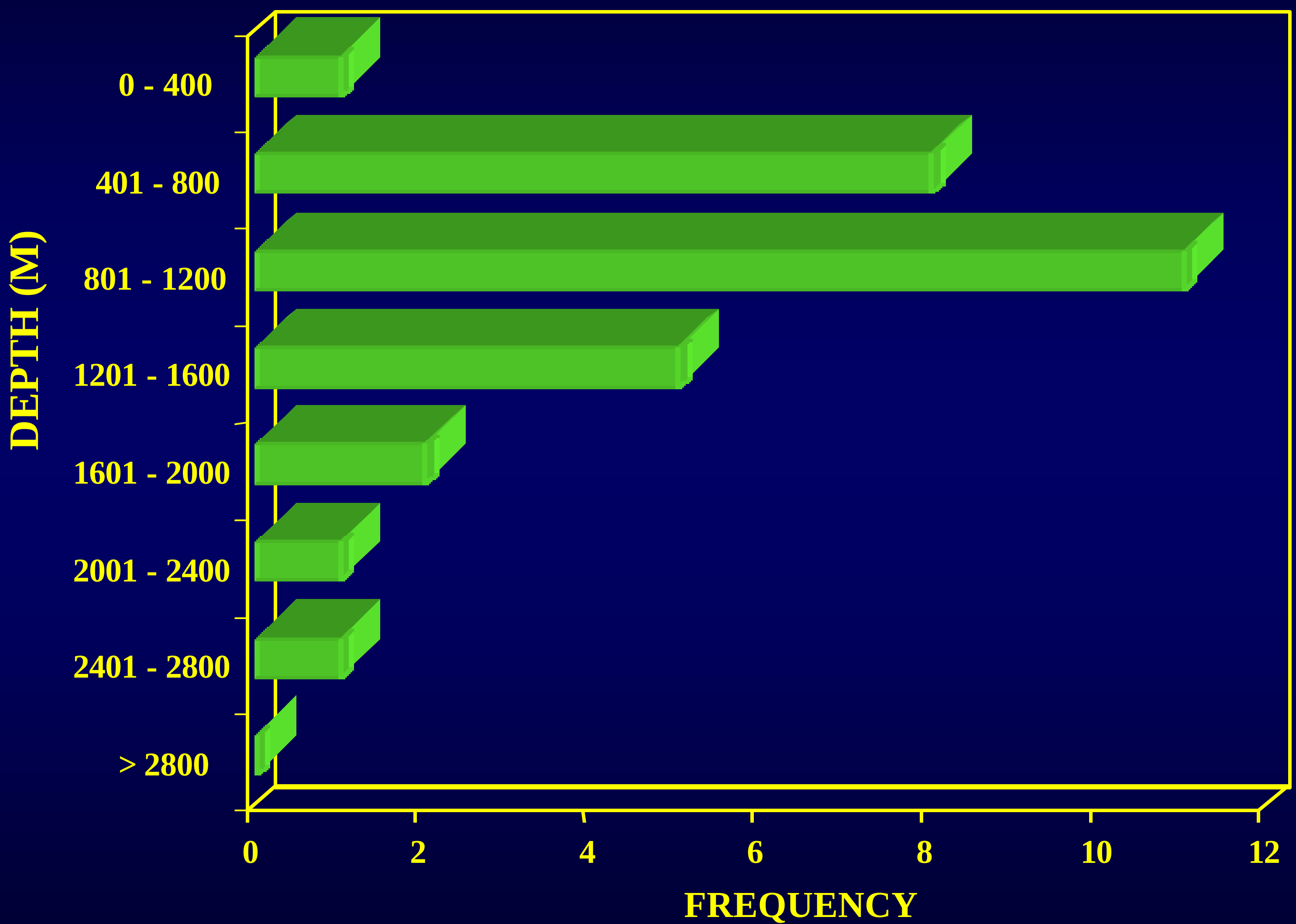
Rims of Intrasalt Basins

Salt Ridges

Deep Active Faults

Sigsbee Escarpment

Gas Hydrate Depth Distribution From Piston Cores

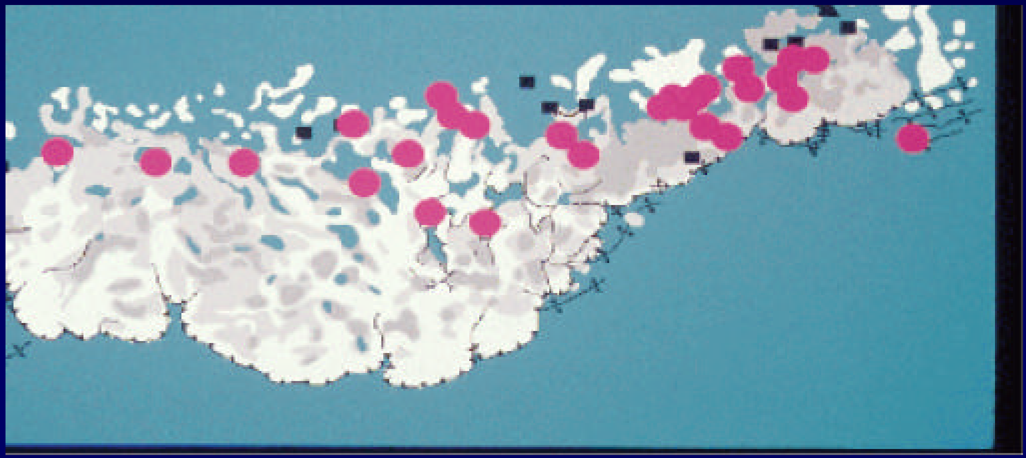


Thermogenic Gas Hydrates

Thermogenic Gas Hydrates

Bacterial Methane
Gas Hydrates

Bacterial Gas Hydrates



Green Canyon Block 185 Gas Hydrate Site (Bush Hill)

Fault Migration Conduit

Exposed Vein-Filling S.II Gas Hydrate

Oil Staining, Hydrogen Sulfide

Complex Chemosynthetic Community

Water Depth = 541 Meters

Green Canyon Block 185 Gas Hydrate Site (Bush Hill)

MAXIMUM PRESERVATION DEPTHS BELOW SEAFLOOR AT 540 METERS WATER DEPTH

Structure I: Not Stable
Structure II: 310-490 Meters

Gas Hydrate Mounds


MOUND
FLANK

Gas Hydrates in Chemosynthetic Communities

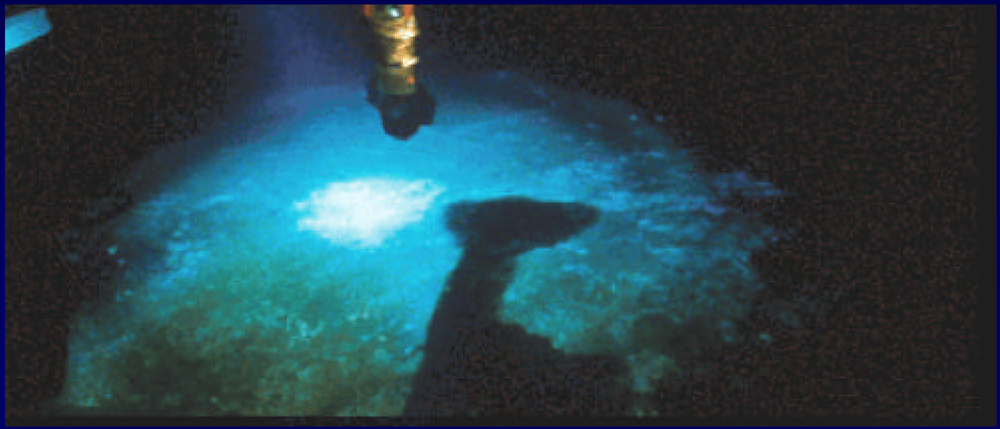
Research Submarine Gas Hydrate Experiments

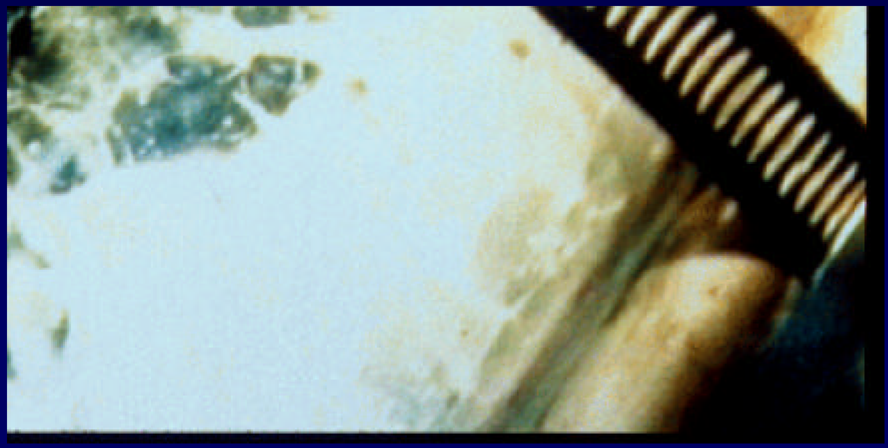
Green Canyon 185

Starting Material: Vent Gas

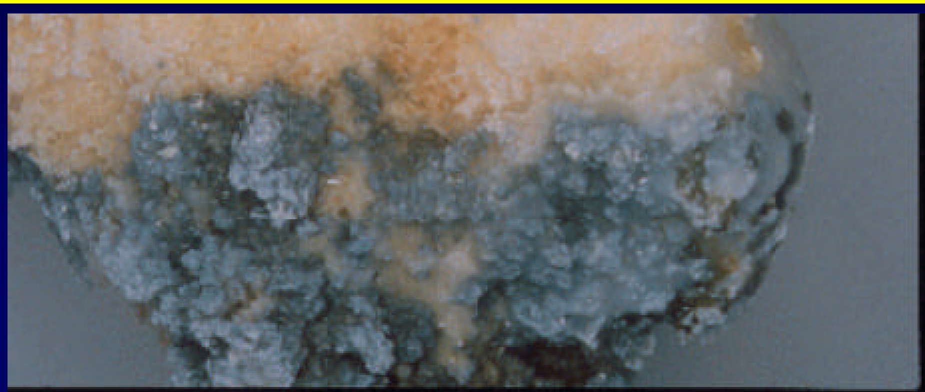
Temperature = 9.2^{o}C

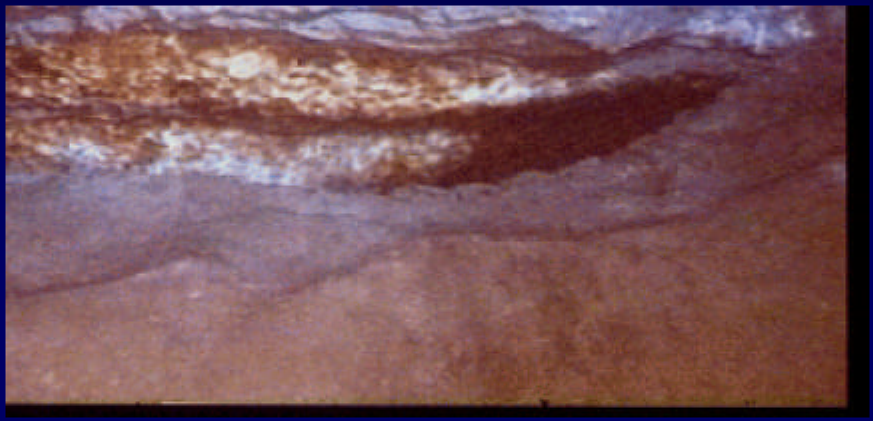
Water Depth = 540 Meters





Vein-Filling by Gas Hydrates in Hemipelagic Mud "Fracture Porosity"





Soft Sediment Deformation During Hydrate Crystallization and Decomposition

Mississippi Canyon Block 852 and 853 Gas Hydrate Sites

Major fluid flow release point from Ursa salt basin

Salt-related sea floor salt features > 1km

High amplitudes

Water depth = ~ 1060 meters

Mississippi Canyon Block 852 and 853 Gas Hydrate Sites

MAXIMUM PRESERVATION DEPTHS BELOW SEAFLOOR AT 1060 METERS WATER DEPTH

Structure I: 310 Meters
Structure II: 610-750 Meters

Atwater Valley Block 425 Gas Hydrate Site

Major fluid flow release point in Mississippi Fan Fold Belt

Fault-related sea floor feature

High Amplitudes

Water Depth = ~1935 Meters

Atwater Valley Block 425
Gas Hydrate Site

MAXIMUM PRESERVATION DEPTHS BELOW SEAFLOOR AT 1930 METERS WATER DEPTH

Structure I: 650 meters
Structure II: 740-890 meters

PISTON CORE SAMPLING

Water Depth Distribution of Gas Hydrates from Piston Core Data

Research Submarine Sampling

Sediment Effect on Hydrate Equilibria

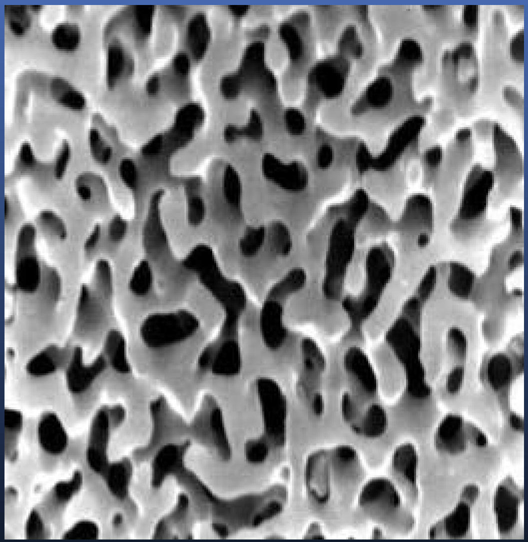
Deepwater Geohazards Workshop

del Lago, Texas April 3 & 4, 2001

Center for Hydrate Research

Colorado School of Mines

Douglas Turner & E. Dendy Sloan



Agenda

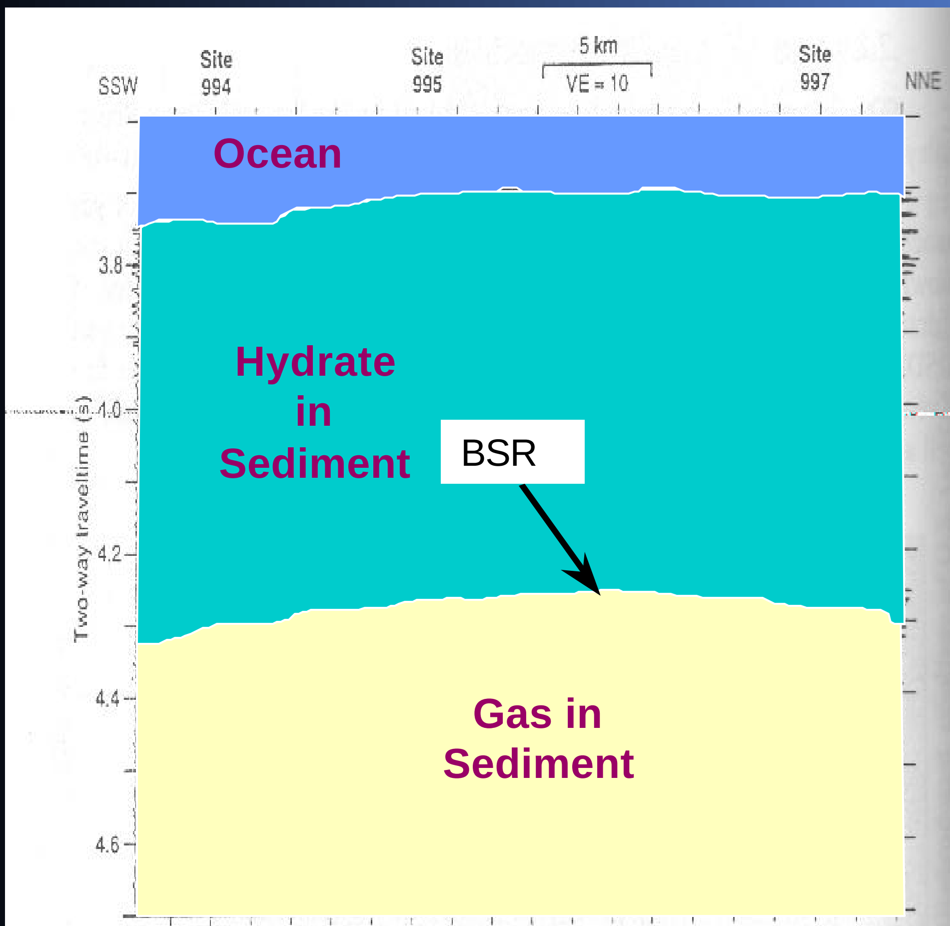
- Conclusions
- Incentives & Background
- Experiment & Model
- Future Work
- Conclusions

Conclusion

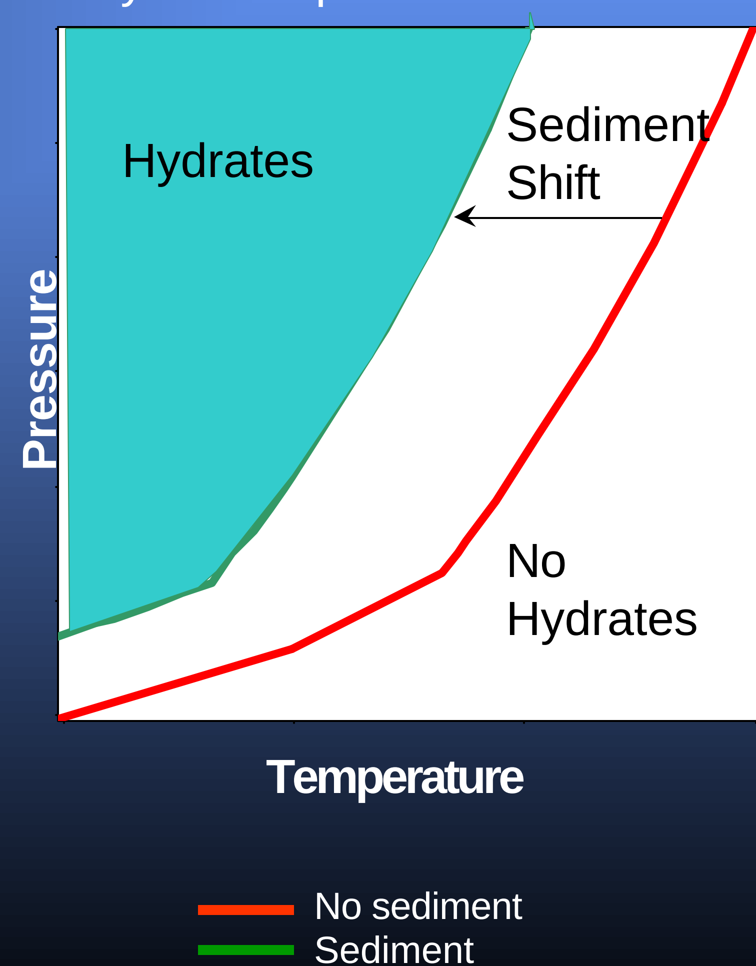
- Consolidated data with model THF show ΔT
- Consolidated large pore CH_4 data show no ΔT
- Consolidated small pore CH_4 data needed
- Building un-consolidated sediment apparatus

Incentives & Background

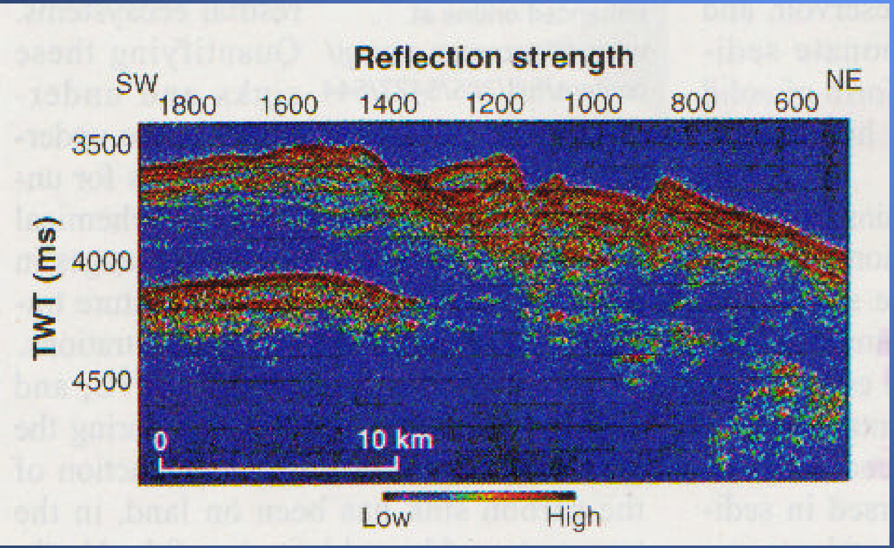
Capillary Effects Explain BSR Shift

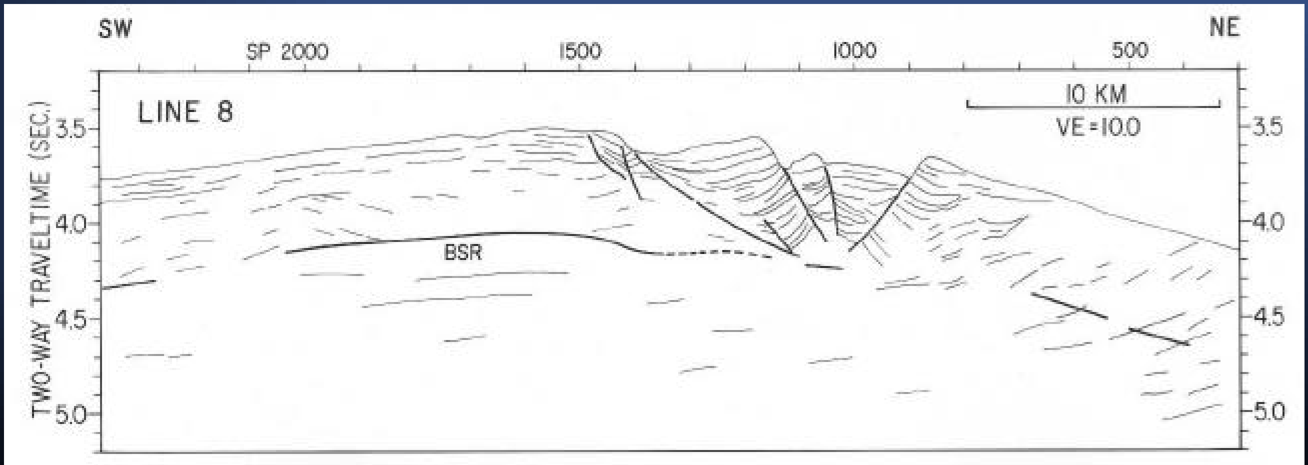


Hydrate Equilibria in Sediments



Slumping Can Damage Pipelines & Offshore Foundations





Pore Hydrates Knowledge Base

- Silica gel data (70 Å)
  - 1990 Handa and Stupin
- Single pore model
  - 1992 Bishnoi's Lab (Clarke, et al.)
  - 1998 Clennell, et al.
- Single pore glass data
  - 1999 Uchida, et al.
- Labs now doing pore distribution
  - Sandler, et al., University of Delaware
  - Smith, et al., NETL

Experiment & Model

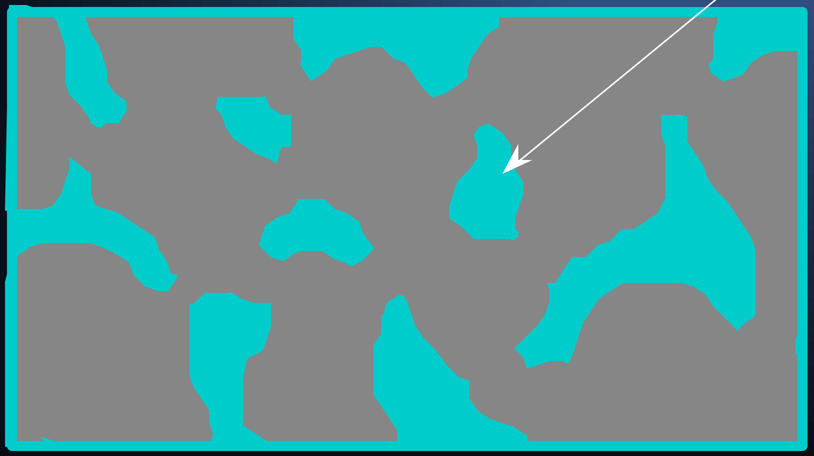
Data & Model Objectives

Data & Model Objectives

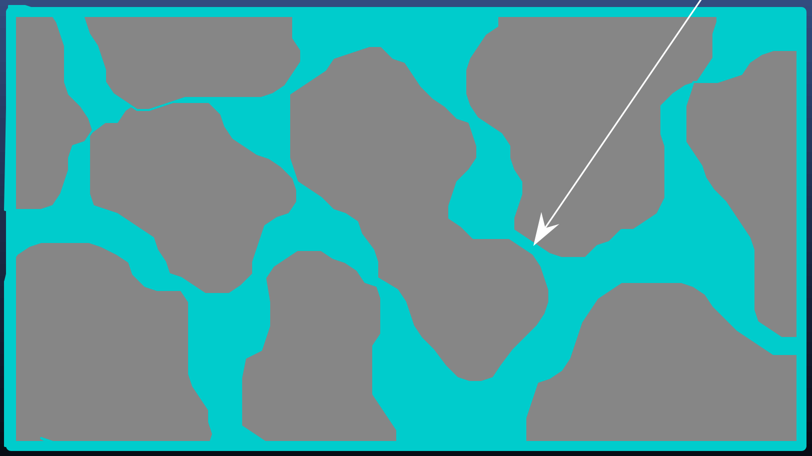
- Pore distribution effect on hydrate equilibria
- Consolidated & un-consolidated sediments

Contrasting Sediments

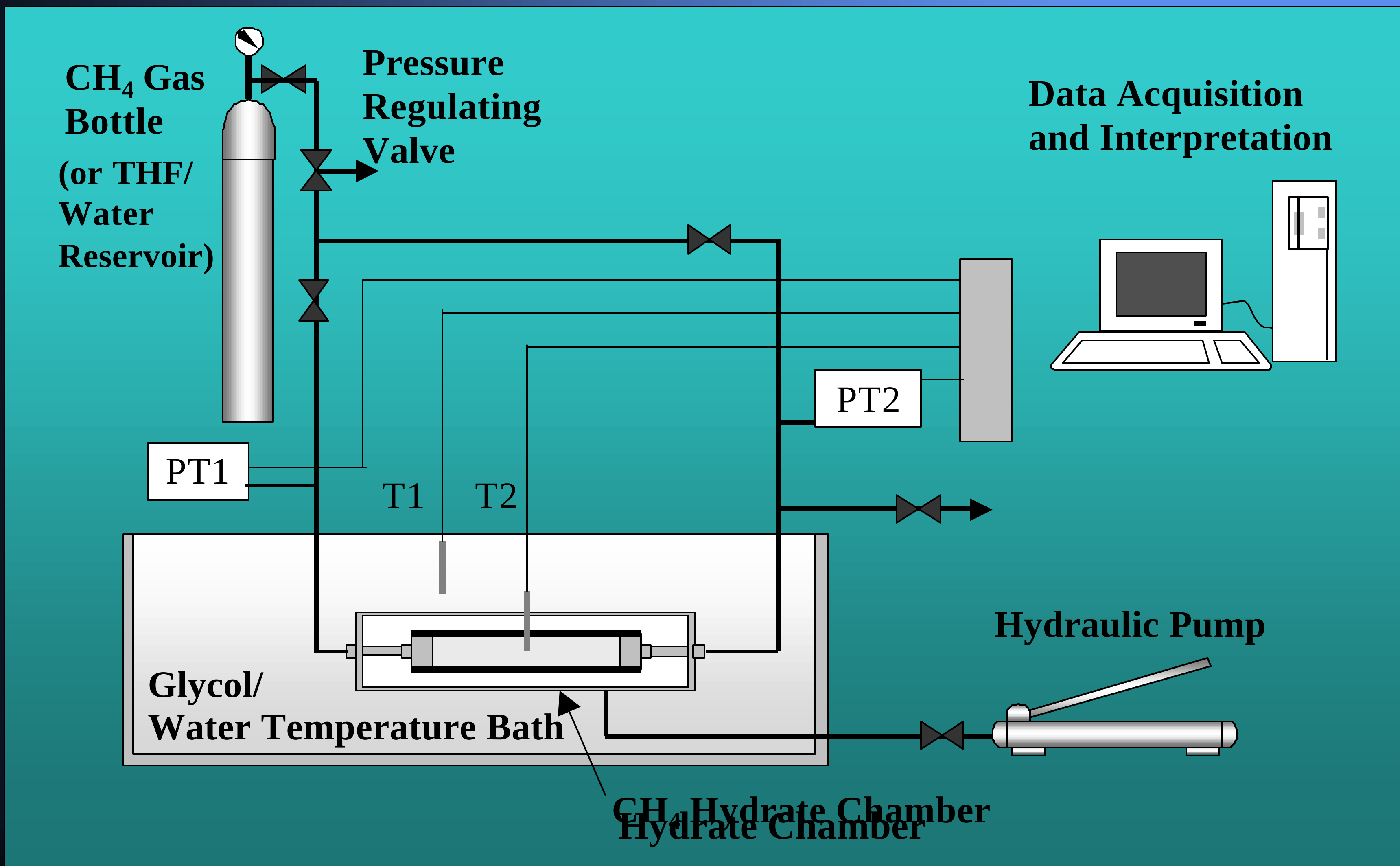
- **Consolidated**
  - permafrost
    - Mallik 2L-38
  - constrained expansion
  - capillaries: pores



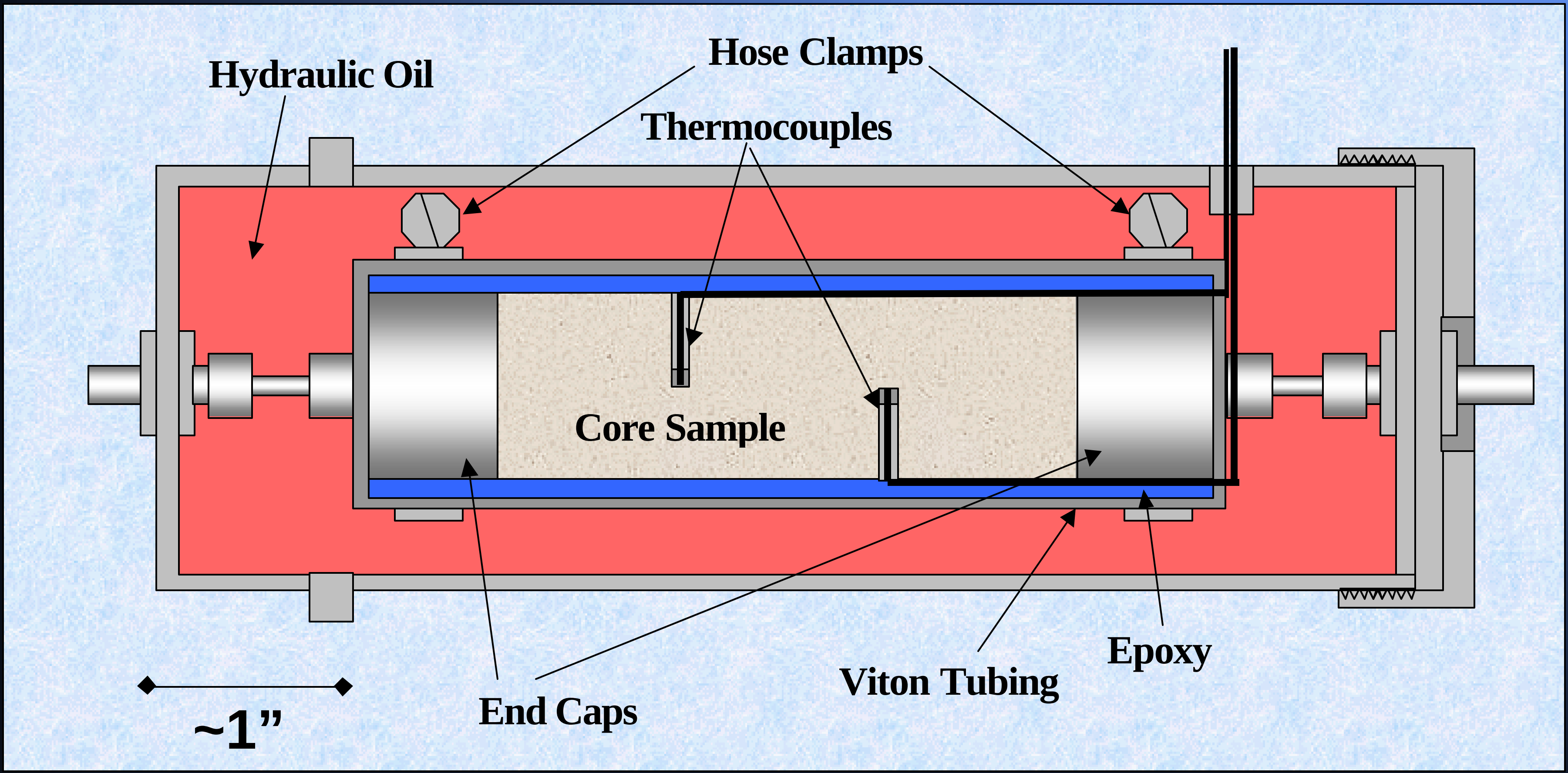
- **Un-Consolidated**
  - ocean basin
    - Blake Bahama Ridge
    - Gulf of Mexico
  - free expansion
  - capillaries: grain spaces



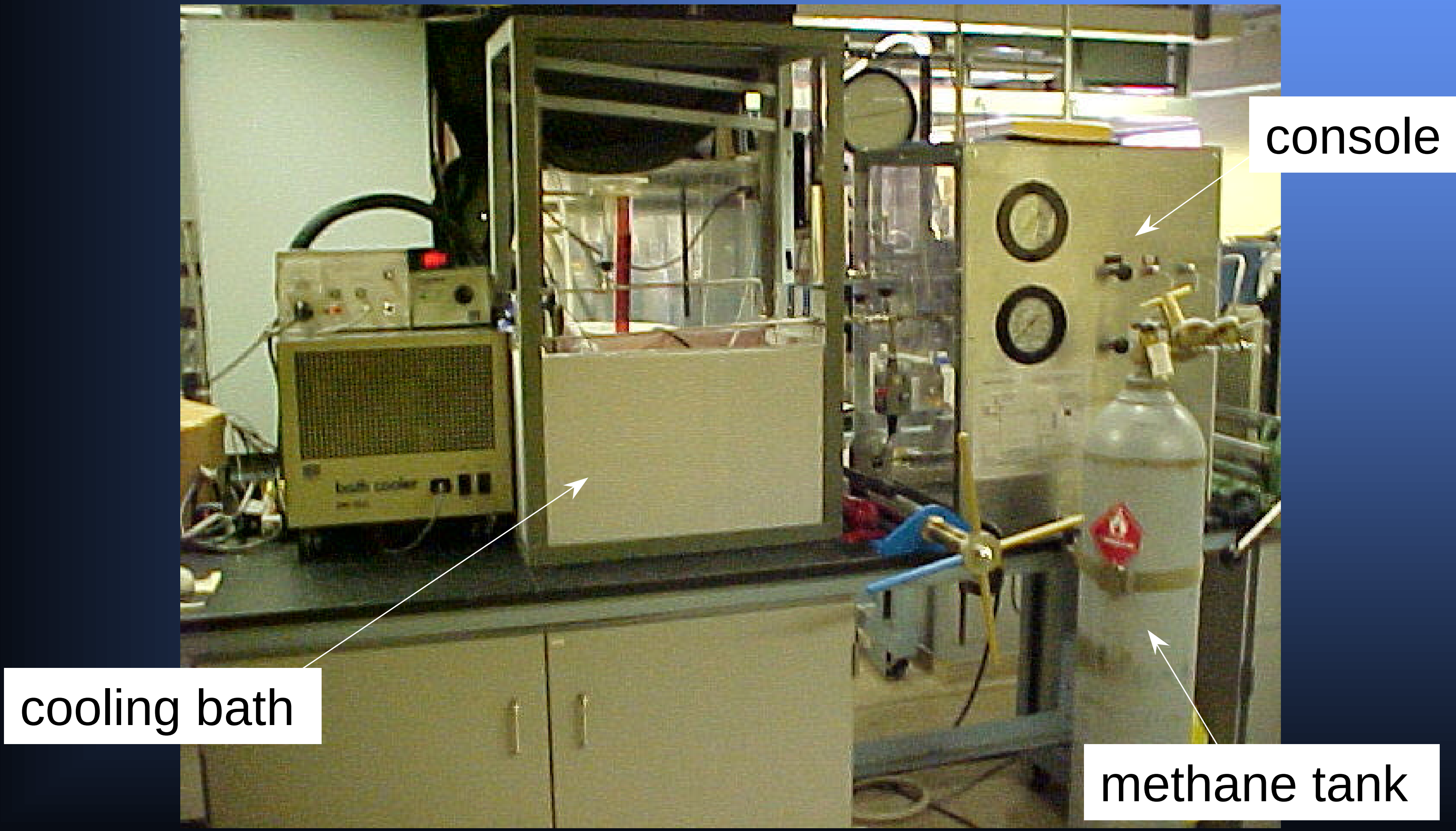
Consolidated Sediment Apparatus



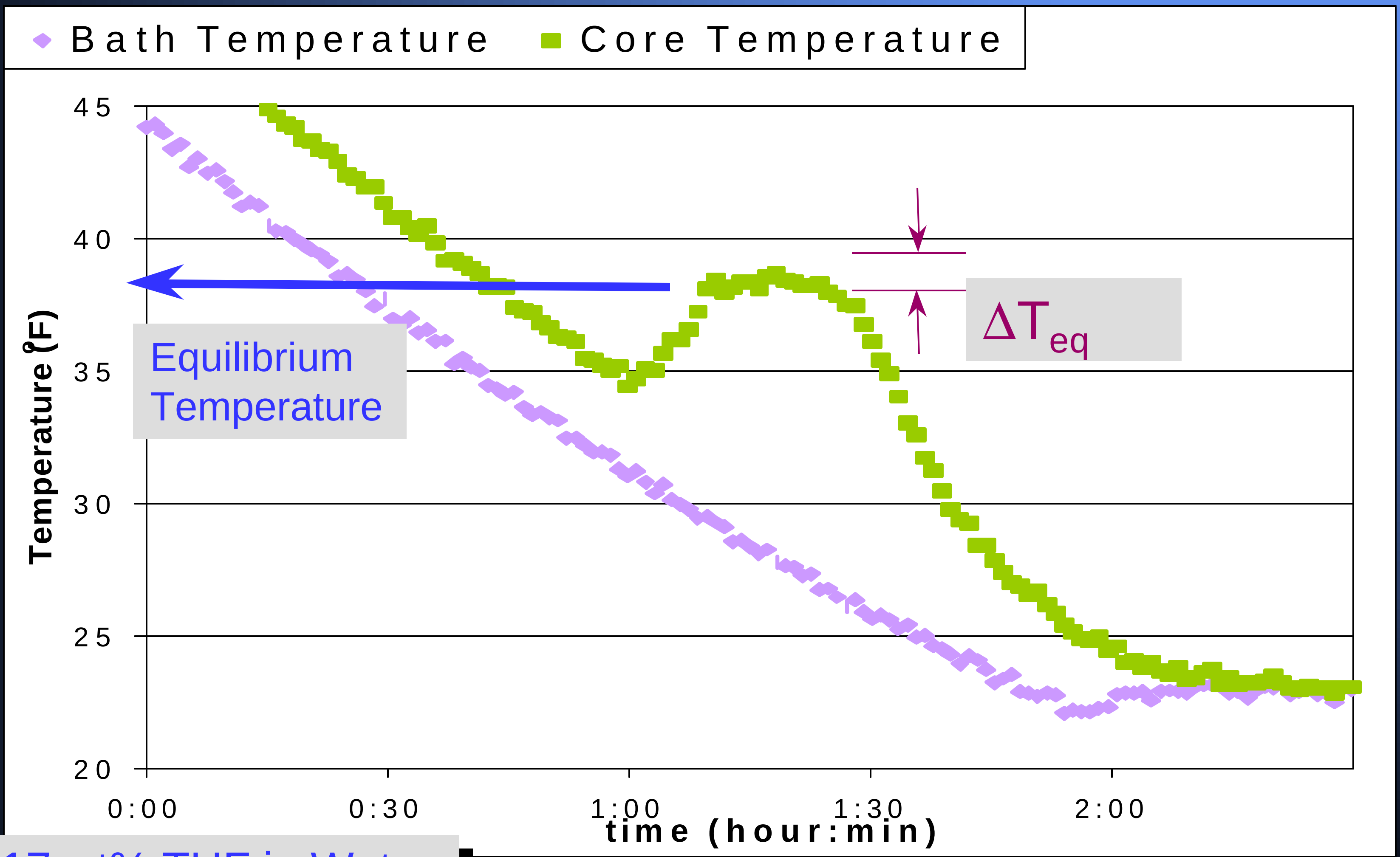
Hydrate Chamber Details



Consolidated Sediment Apparatus



Plateaus Indicate Phase Changes



17 wt% THF in Water

Ceramic Core (1) THF Data

	ΔT_{form} (°F)	Pore Size (A)
Run1	-1.5	681
Run2	-1.7	603
Run3	-1.0	1061
Run4	-1.6	664
Run5	-1.2	908
Run6	-1.3	798
Average	-1.4	786
Standard Deviation		173

Predicted Sediment Pore Radius

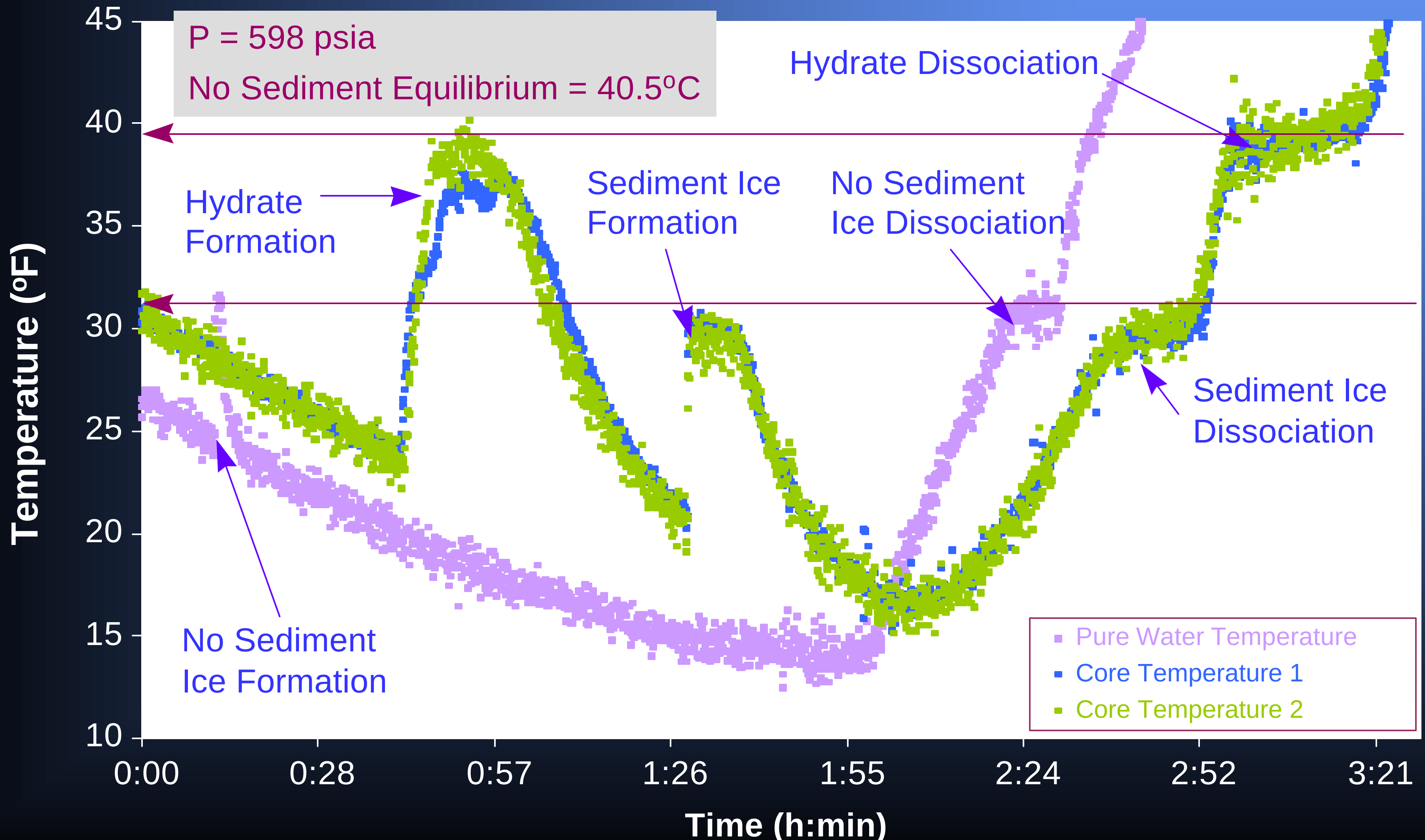
<u>THF Hydrate</u>

- No sediment: $T_{eq} = 39.9^{o}F$

	Adriatic Sandstone	Ceramic (1)
Ave T_{eq} =	$38.1^{o}F$	$38.5^{o}F$
ΔT_{eq}=	$-1.8^{o}F$	$-1.4^{o}F$
$r_e \simeq$	600 Å	786 Å

(typical sandstone r_e ∅ 10^3 to 10^5 Å)

CH_4 Hydrate Equilibrium Shifts

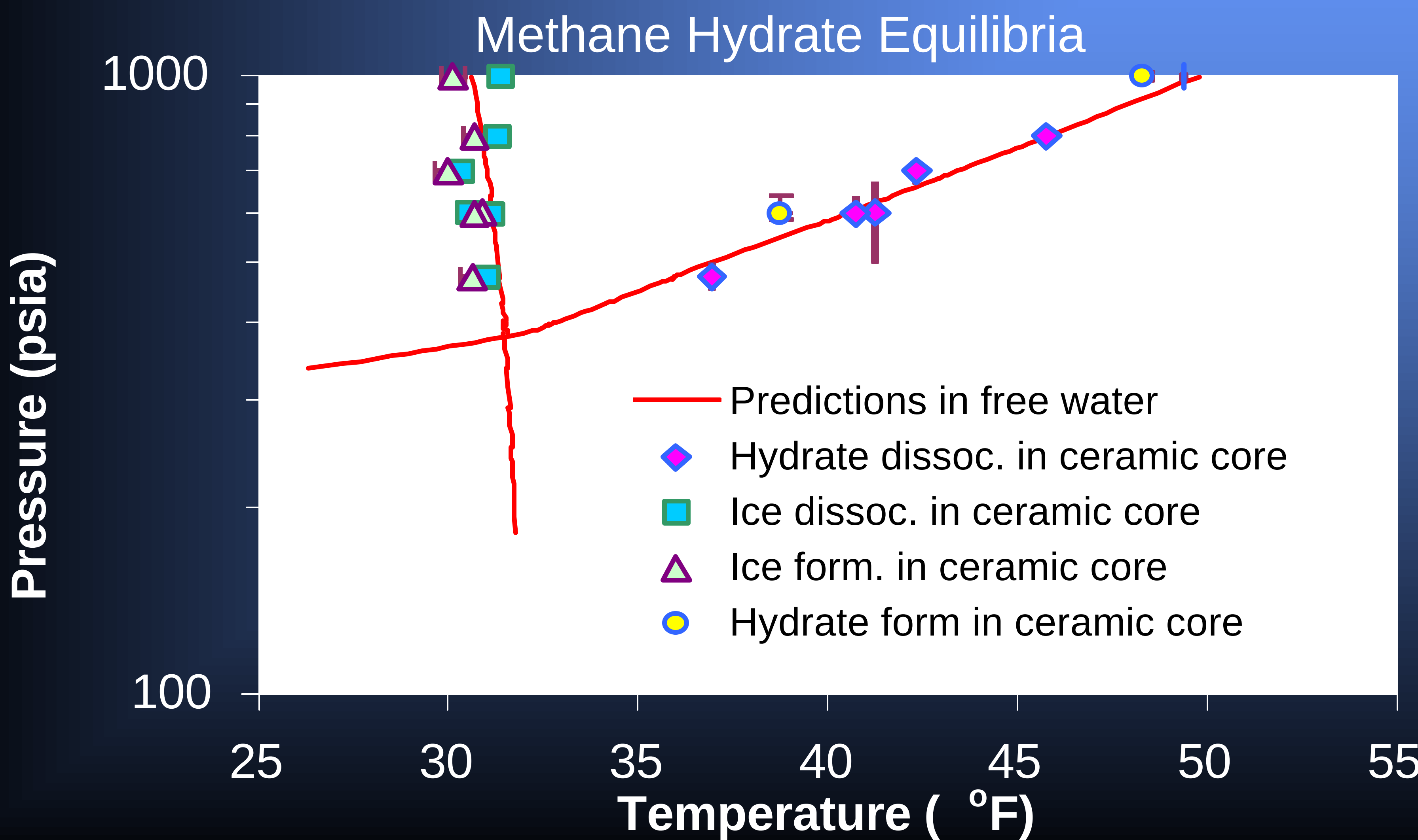


Ceramic Core (2) CH_4 Data

		Outside Core	Inside Core		
	P (psia)	T_{eq} (^oF)	T_{eq} (^oF)	ΔT_{eq} (^oF)	Pore Size (A)
Run1	475	36.1	37.0	0.9	infinite
Run2	597	40.6	40.7	0.2	infinite
Run3	600	40.6	41.3	0.7	infinite
Run4	700	43.4	42.4	-1.1	936
Run5	798	45.8	45.8	0.0	infinite
Run6	996	50.3	49.4	-0.9	2170

Average Pore Size	infinite

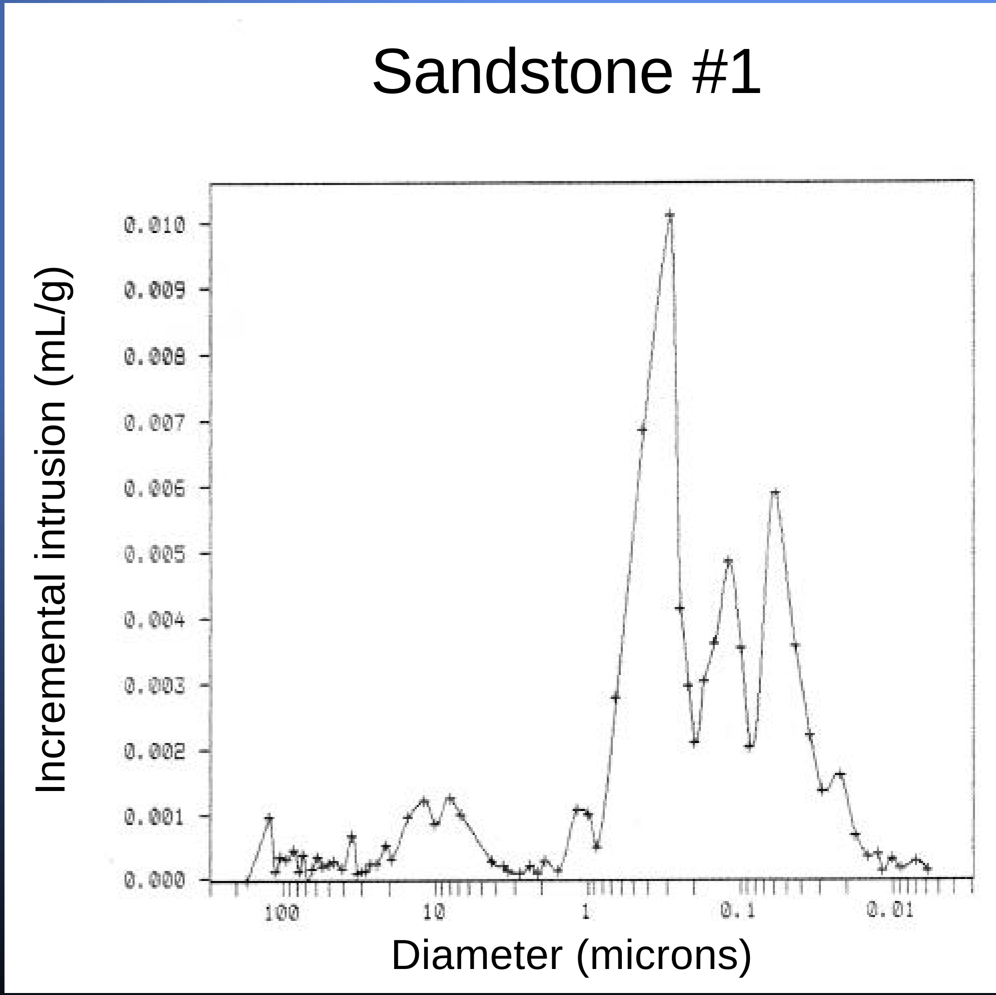
Ceramic (2) Pore Equilibria Data



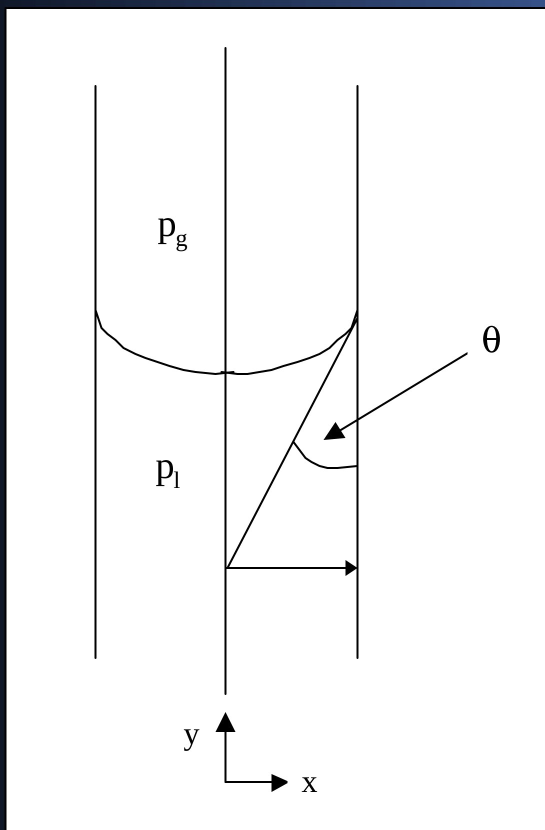
Mercury Porosimetry Pore Size

- Hg has low viscosity
- Pressurized into pores
- ΔV recorded

Sample	Ave Pore Diam. (A)
Ceramic Core (2)	922616
Adriatic Sandstones	
1	1246
2	6074
3	12062
4	21470
5	23887
6	40292
7	46416
8	52532
9	74550
10	103182
11	168916



Surface Effects: Capillary DP



Young Laplace Equation

$$\Delta p = p_g - p_l = \frac{2s}{r}\cos q$$

σ = surface tension

θ = wetting angle

r = pore radius

Hydrate Equilibria Sediment Effects

reference chemical potential

P and T corrections to chemical potential from reference conditions

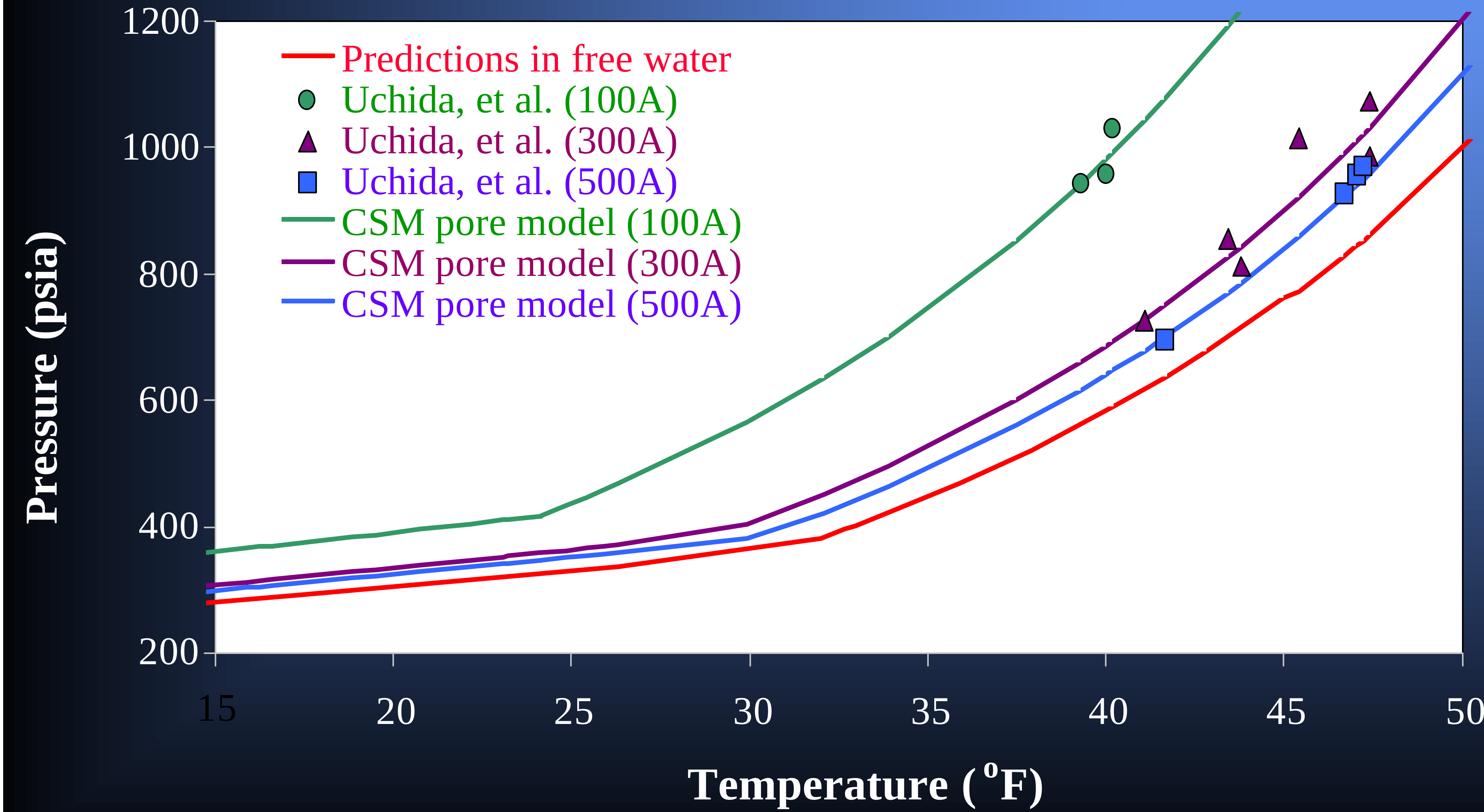
$$\frac{\Delta m_w^o}{RT_0} + \int_{p_o}^{p_l} \frac{\Delta V_w^{MT-L_o}}{RT_f} dp - \int_{T_o}^{T_f} \frac{\Delta h_w^{MT-L_o}}{RT^2} dT$$

$$- \sum_m v_m \ln\left(1 - \sum_j \frac{C_{mj} f_m}{1 + C_{mj} f_m}\right) = \frac{-2 s V_l}{r R T_f} \cos q$$

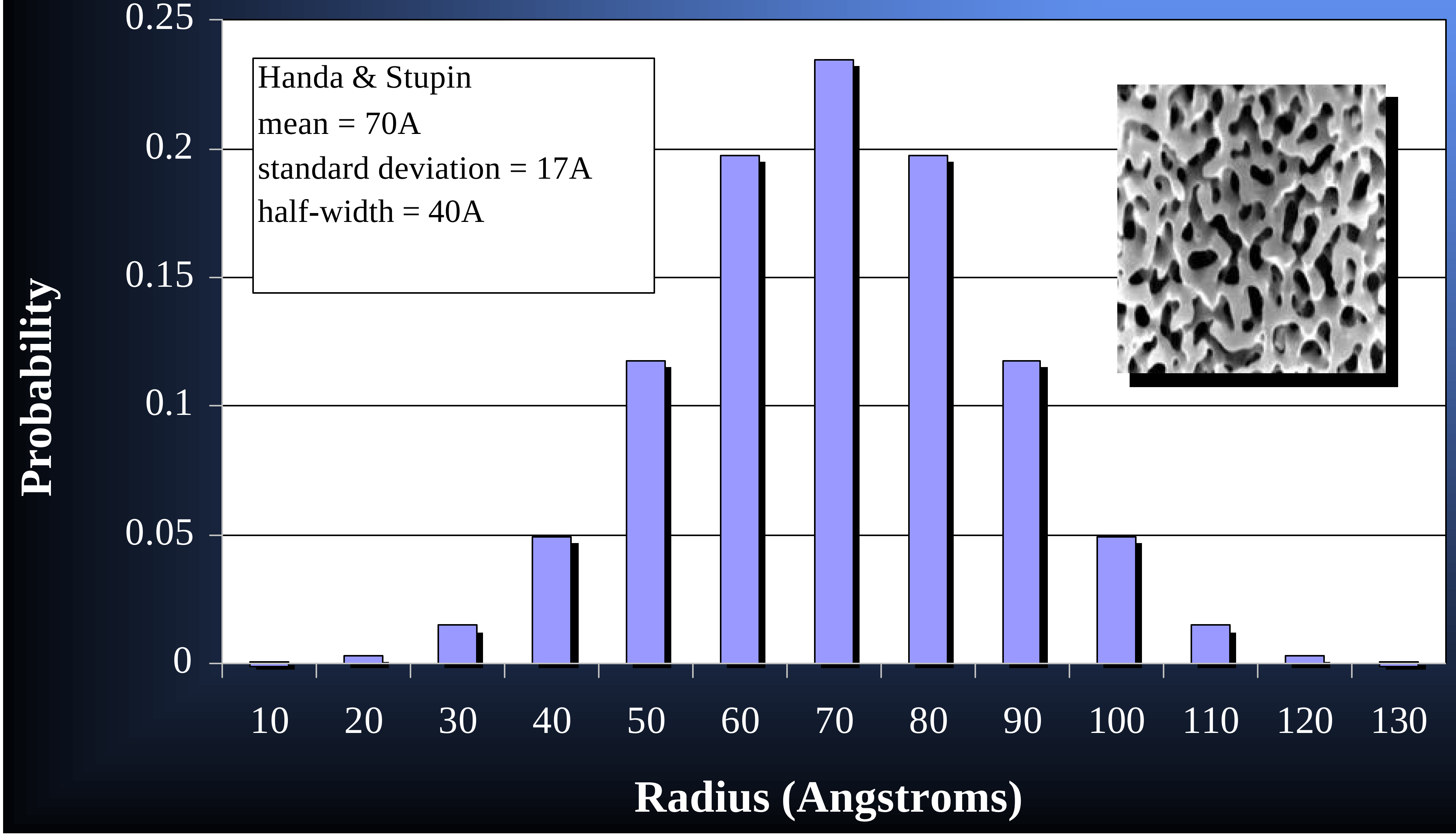
statistical component

Young-Laplace activity

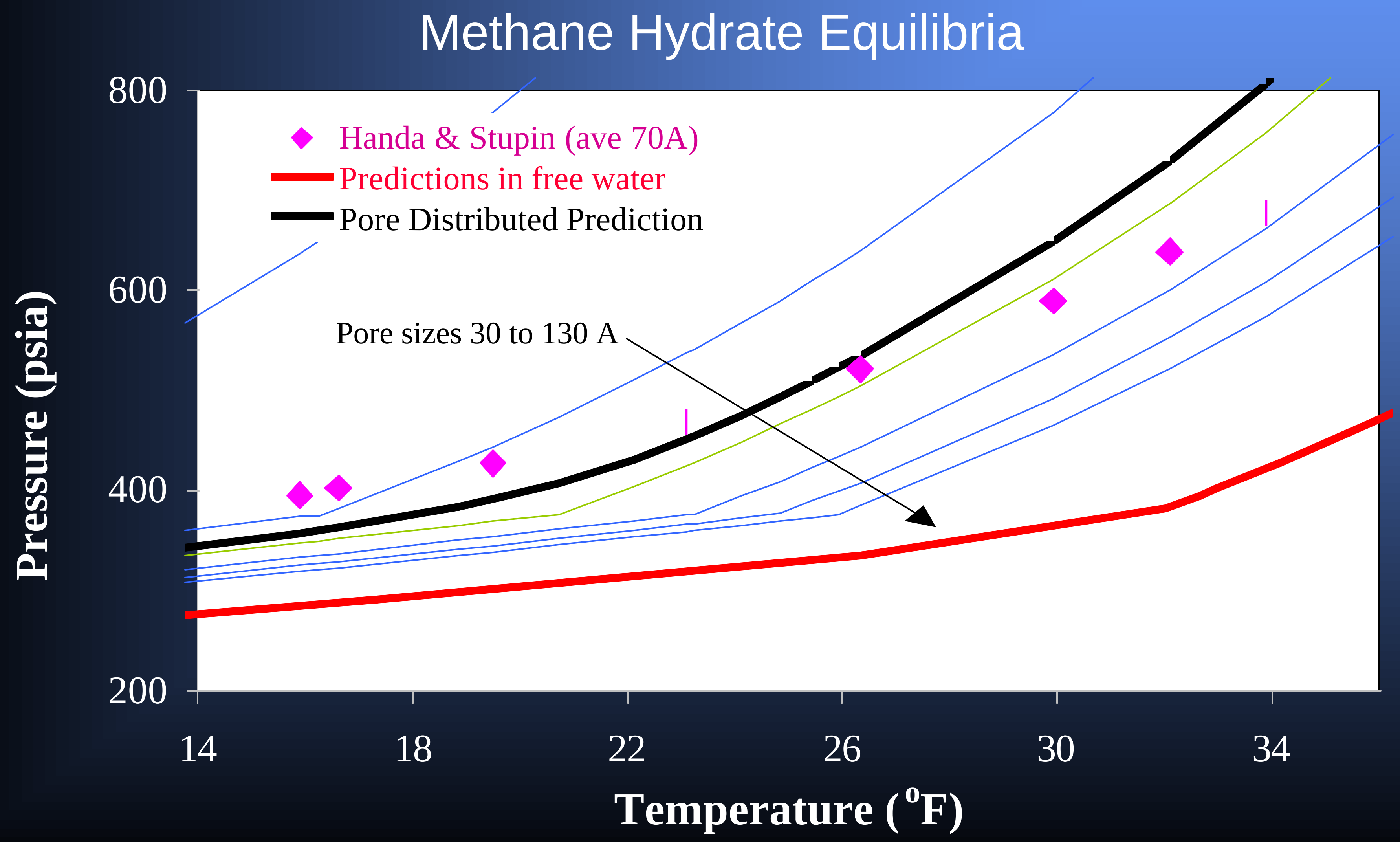
Model Fits Single Pore Data



Normal SG75 Distribution



A Pore Distribution Enhances Model

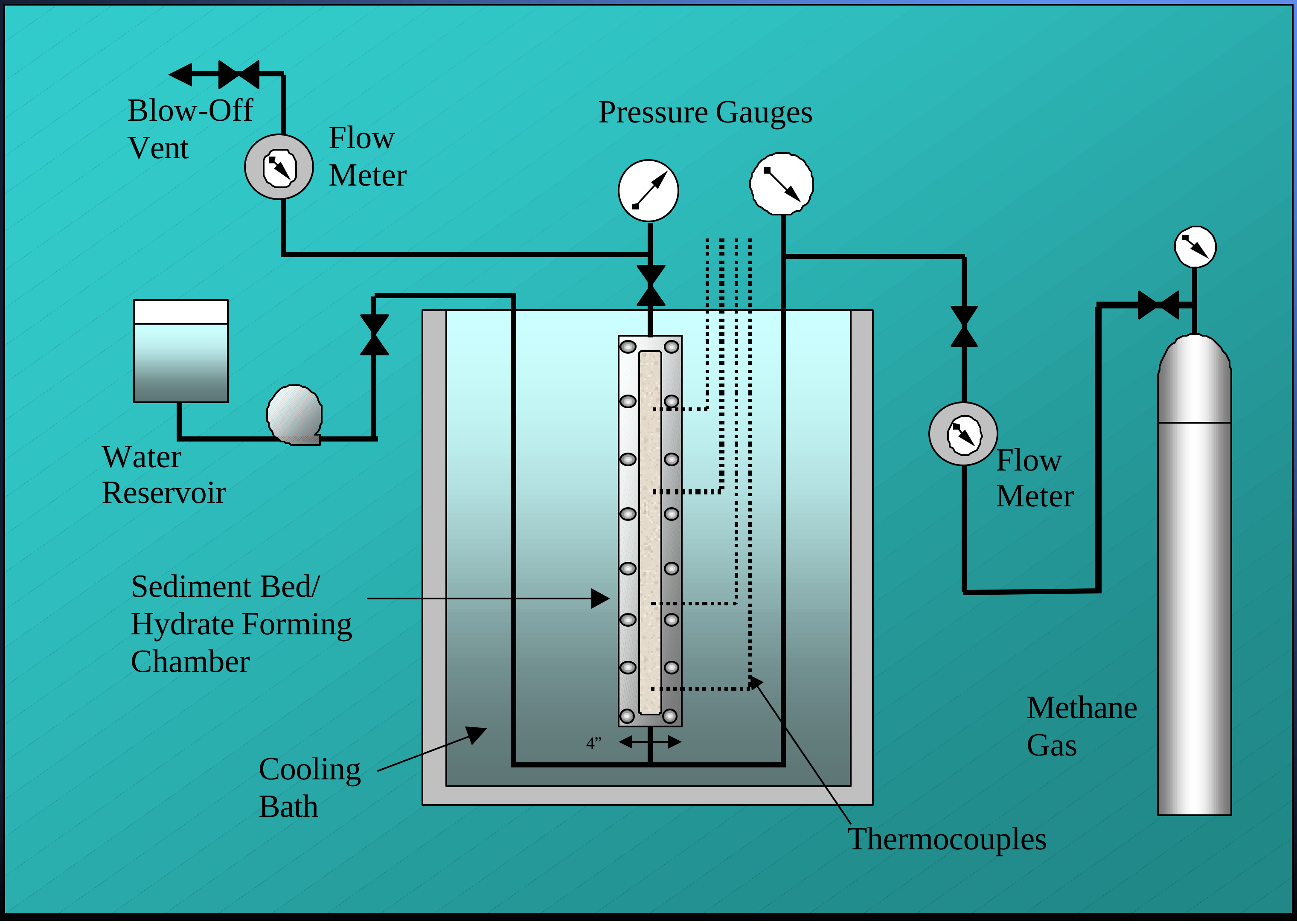


Future Work

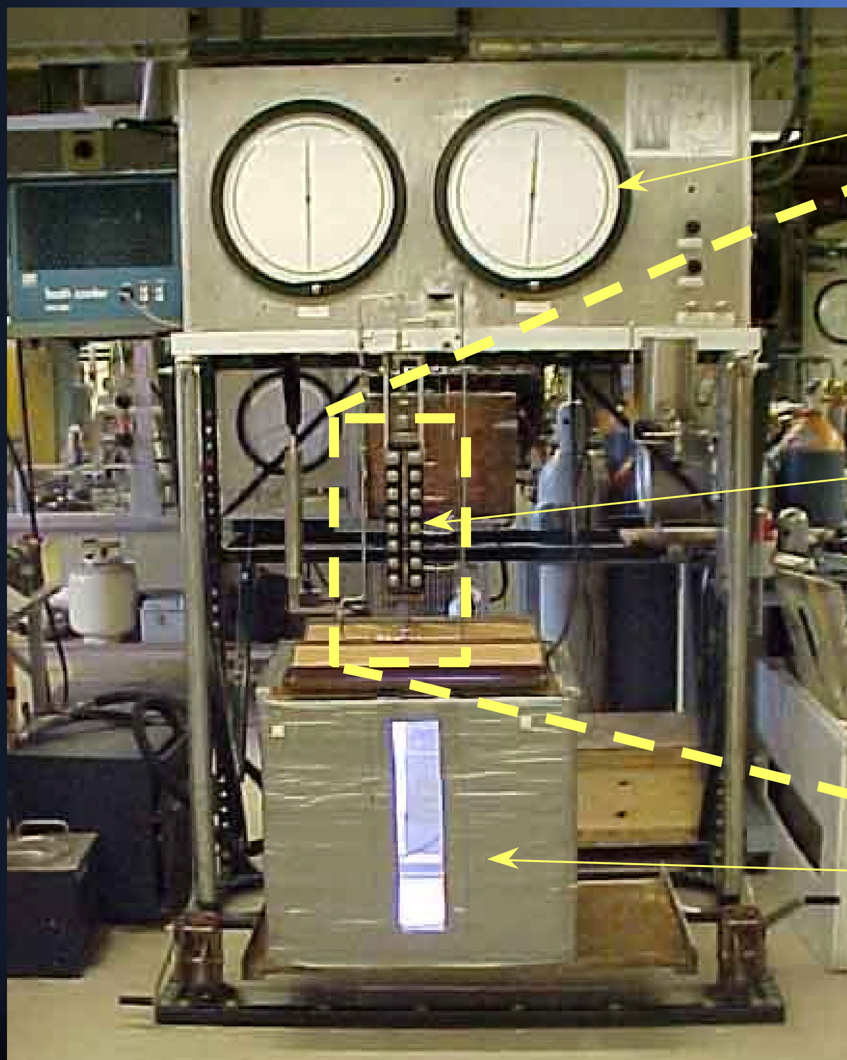
More Consolidated CH_4 Data Needed

- Significant equilibrium shifts require smaller pore sizes
  - Rules of Thumb:
    - for $r > 10^4$ Å , negligible capillary effect
    - for $r < 200$ Å , large capillary effect
  - Adriatic Sandstone with $r_{ave} = 1246$ Å

Un-Consolidated Sediment Apparatus



Un-Consolidated Sediment Apparatus

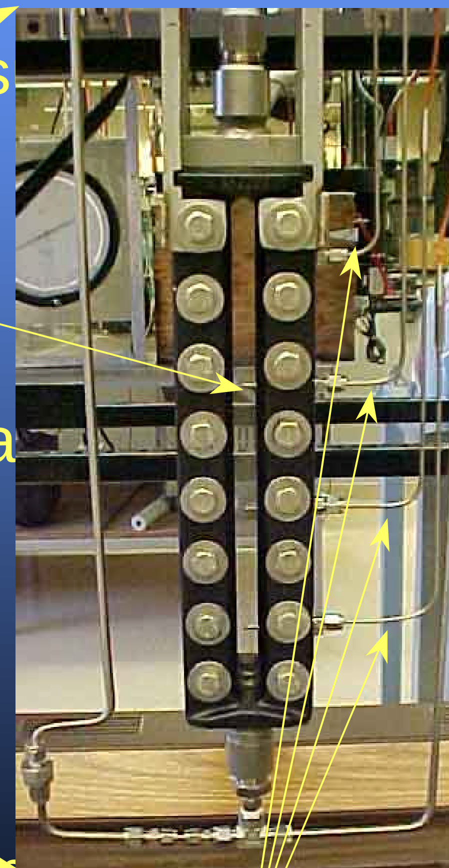


Press

Site
Glass

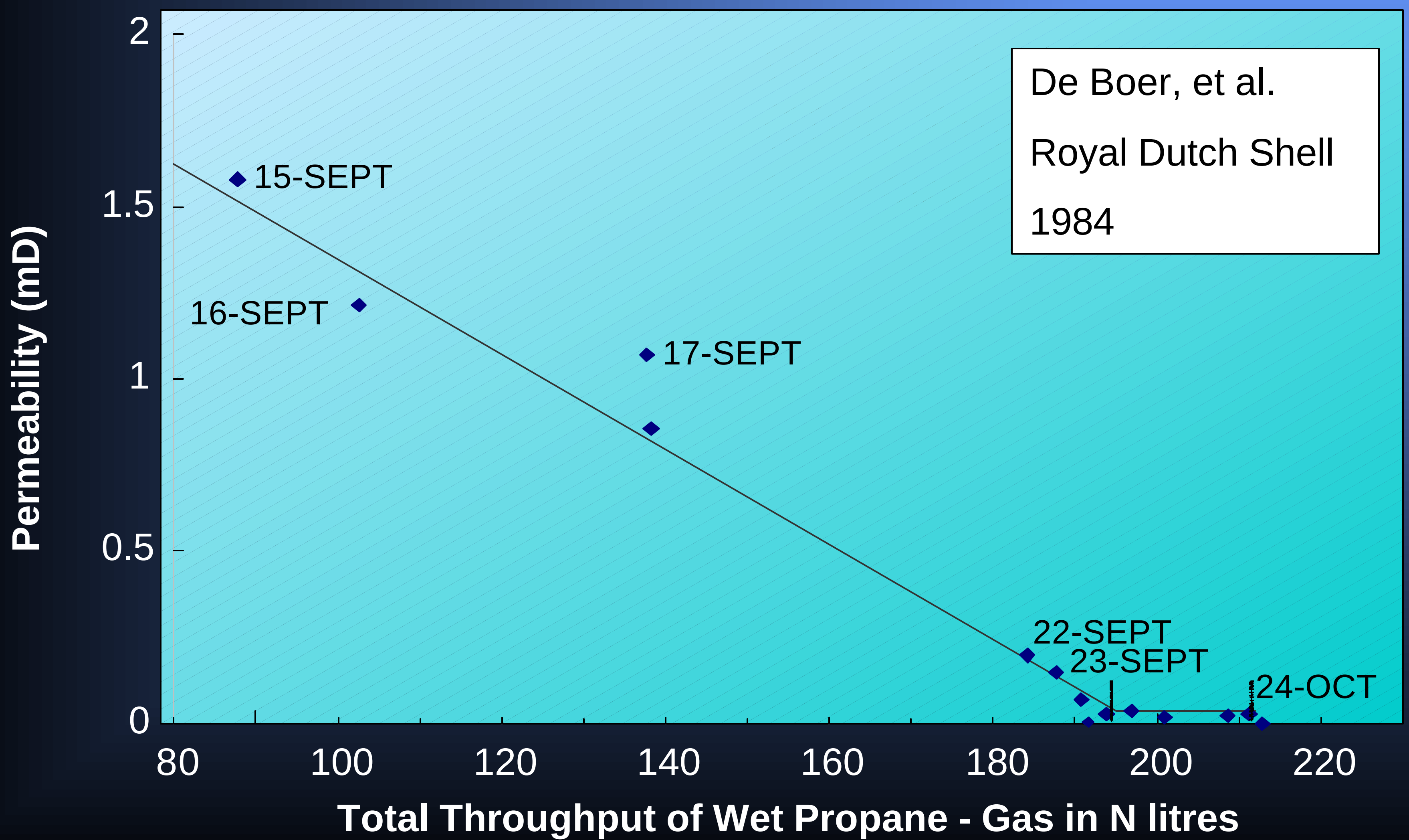
Forma

Cooling Bath



Thermocouples

Permeability Decreases with Hydrate Growth



Conclusion

- Consolidated data with model THF show ΔT
- Consolidated large pore CH_4 data show no ΔT
- Consolidated small pore CH_4 data needed
- Building un-consolidated sediment apparatus

Thanks To

COORSTEK
Amazing Solutions.

Robert S. Cherry

&

INEEL
Idaho National Engineering & Environmental Laboratory

Idaho National Engineering
and Environmental Laboratory

High-Resolution, Deep-Tow Seismologic Studies of Deepwater Geohazards

J. F. Gettrust
Code 7432
Naval Research Laboratory

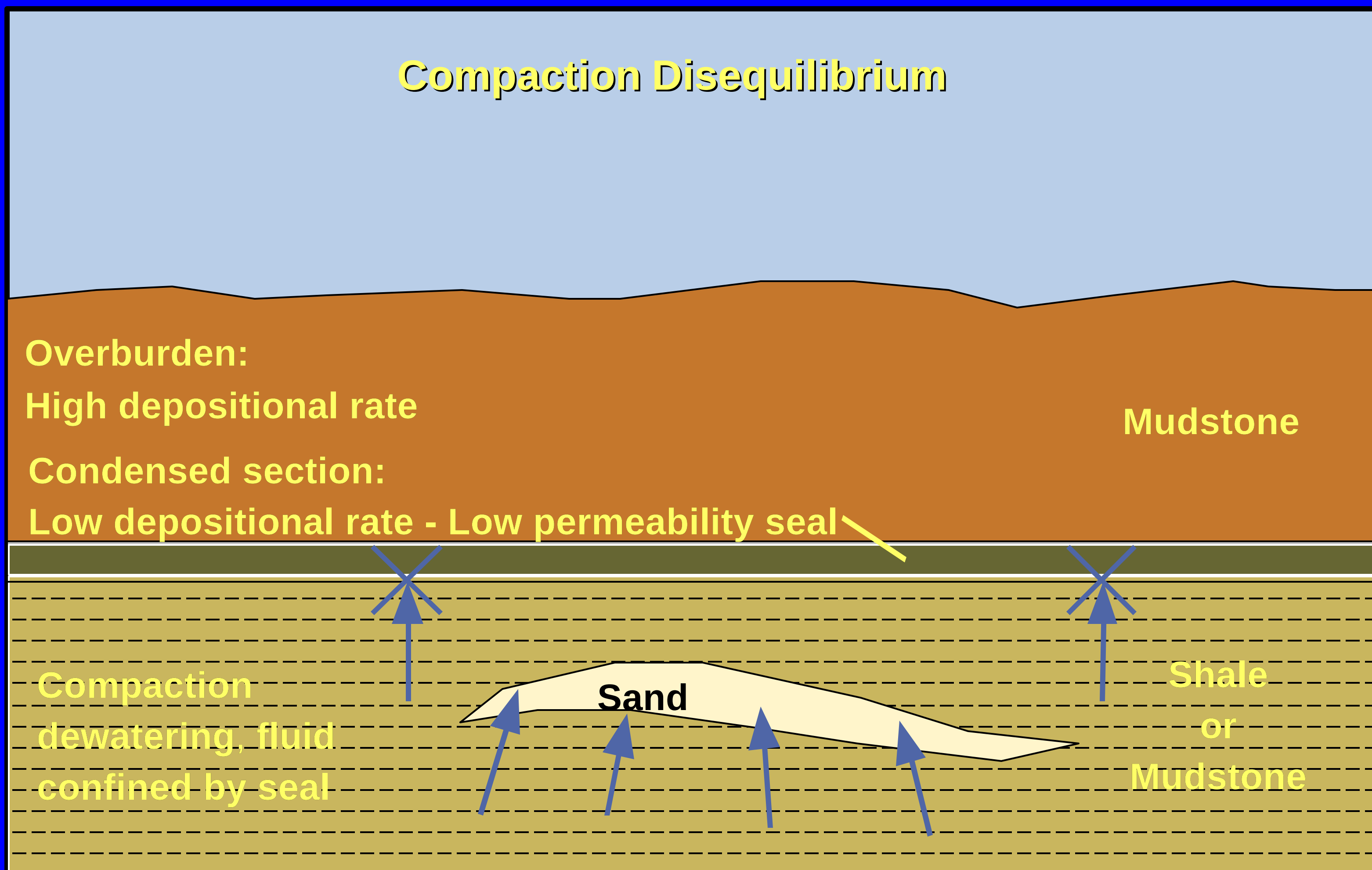
The Application of High-Resolution, Deep tow MCS to Studies of Geohazards in the Gulf of Mexico

- Deep-Tow MCS system towed close to the seafloor samples upper 1-km of sediments with resolutions ~2 m.
- Navy developed Helmholtz-resonator source (250Hz-1000Hz) easily adapted for bottom-mounted operations.
- Long-term objective is to resolve anomalous regions using imagery and Vp/Vs ratios.

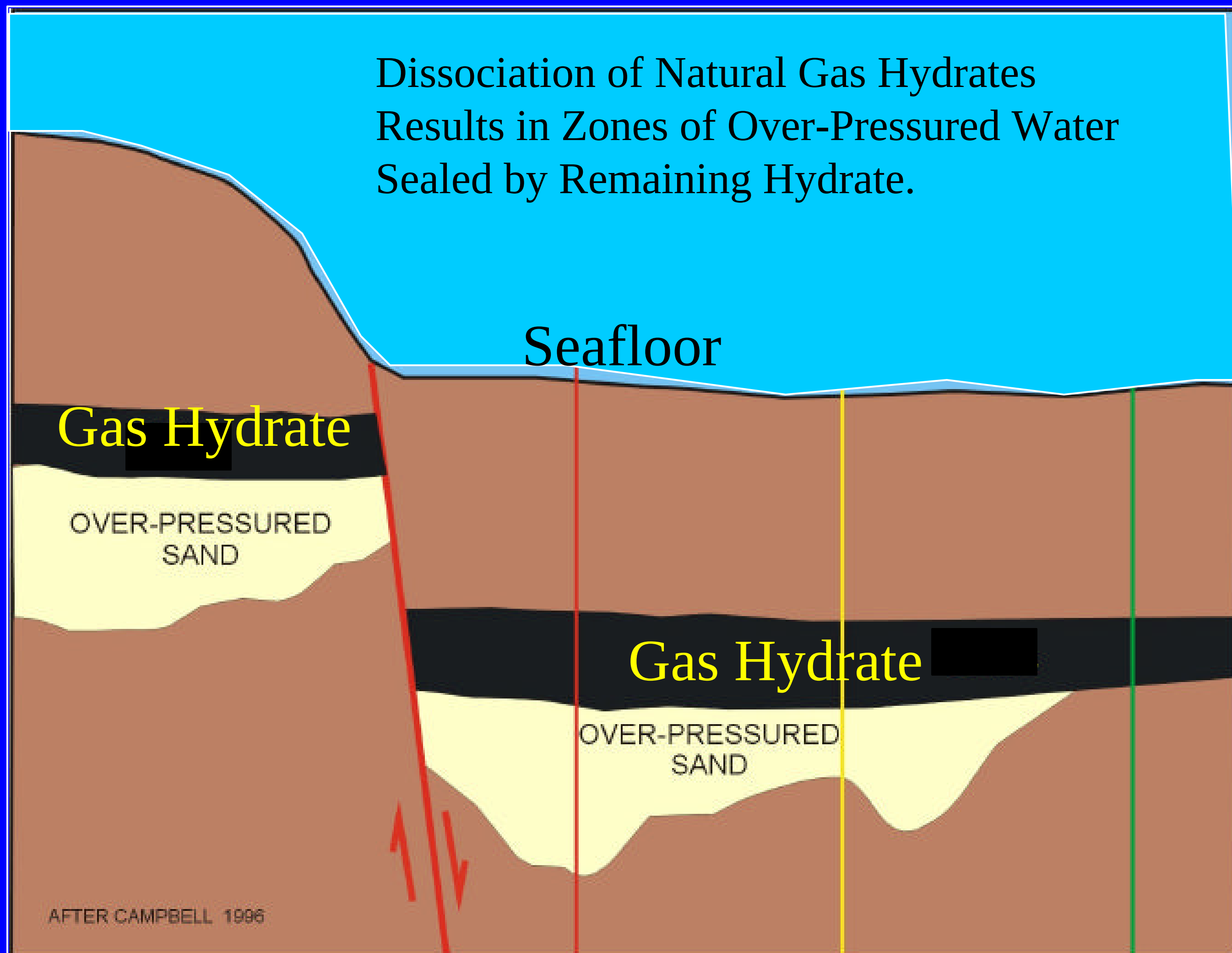
An Example: Geologic Models for Shallow Flow

- Conventional model, sands capped by low permeability seal with rapid deposition.
- Alternative model, dissociation of natural gas hydrates with hydrate “cap” serving as seal.
- Either model will result in anomalous seismic signature and/or Vp/Vs ratios.

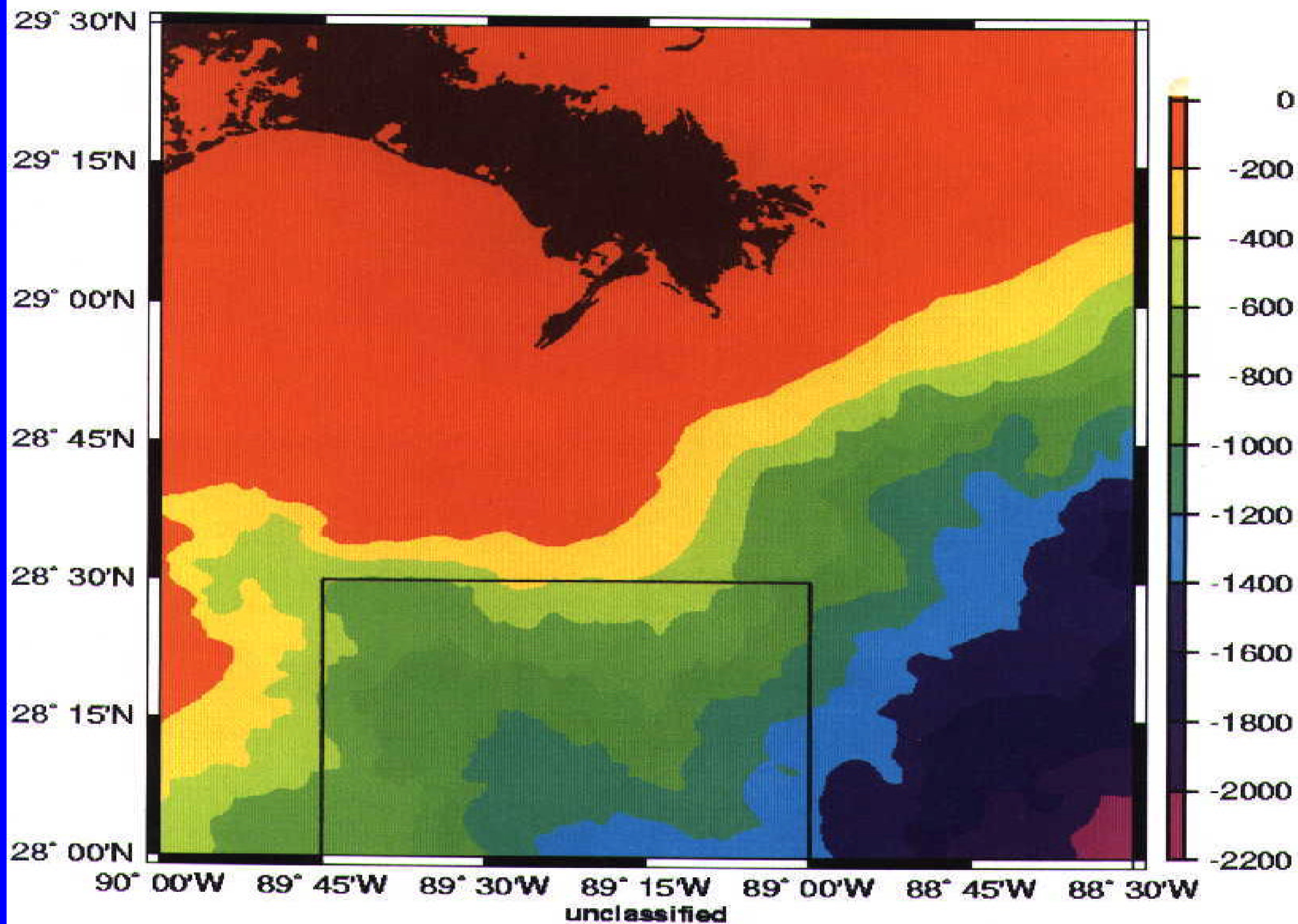
Proposed Mechanism for High-Pressure Sands
(after M. Alberty, BP)



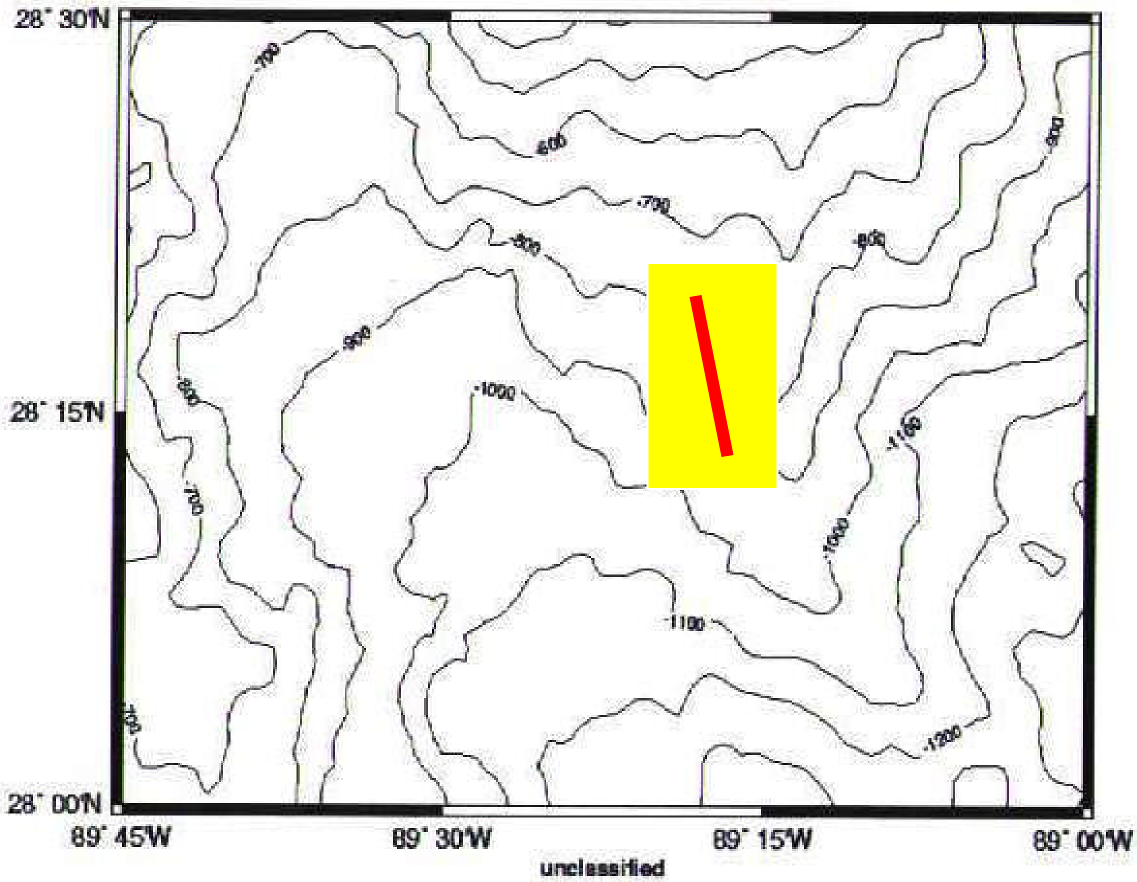
Alternative Model for Shallow Water Flow

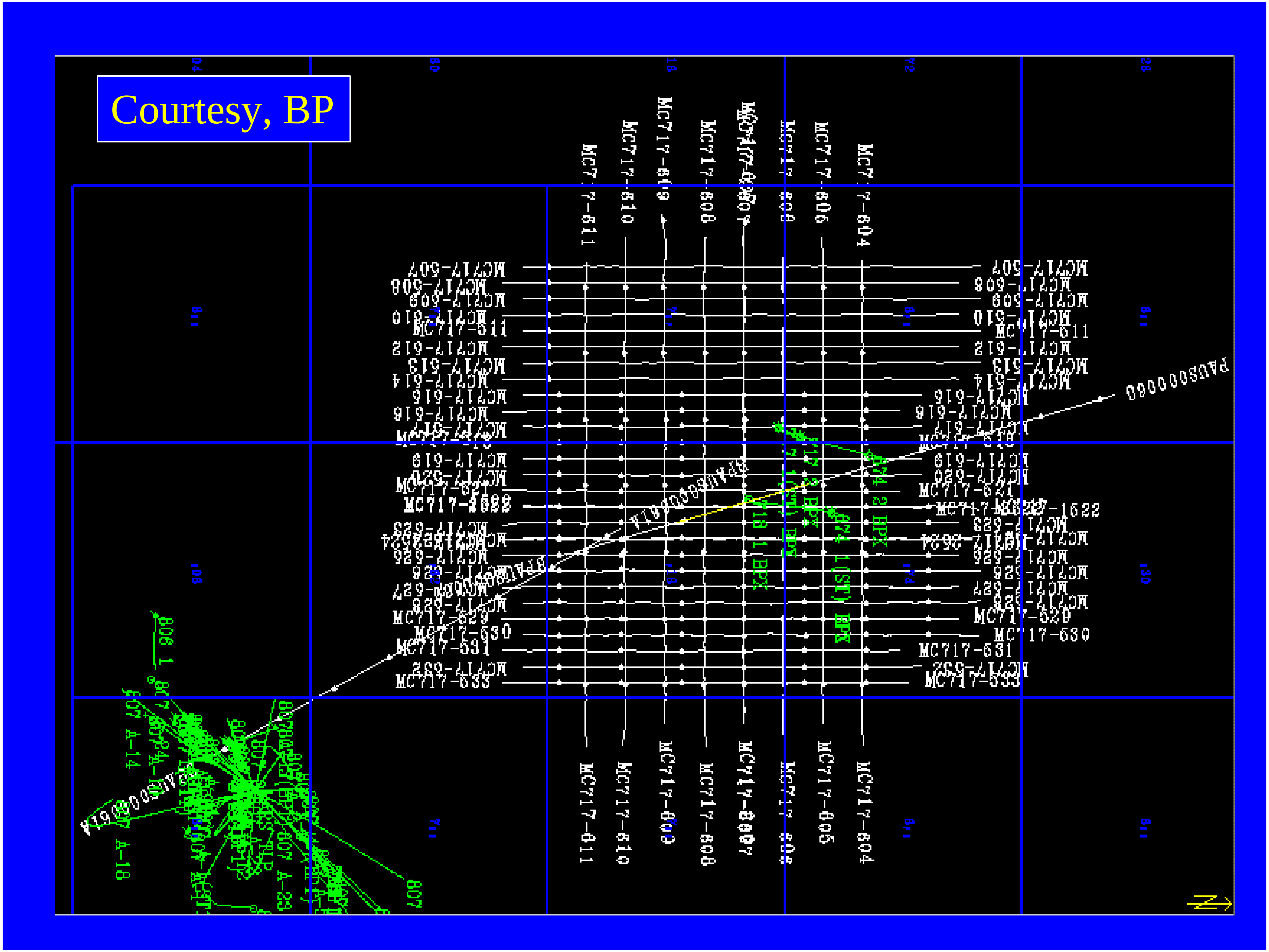


NGDC 0.5' Prototype Bathymetry

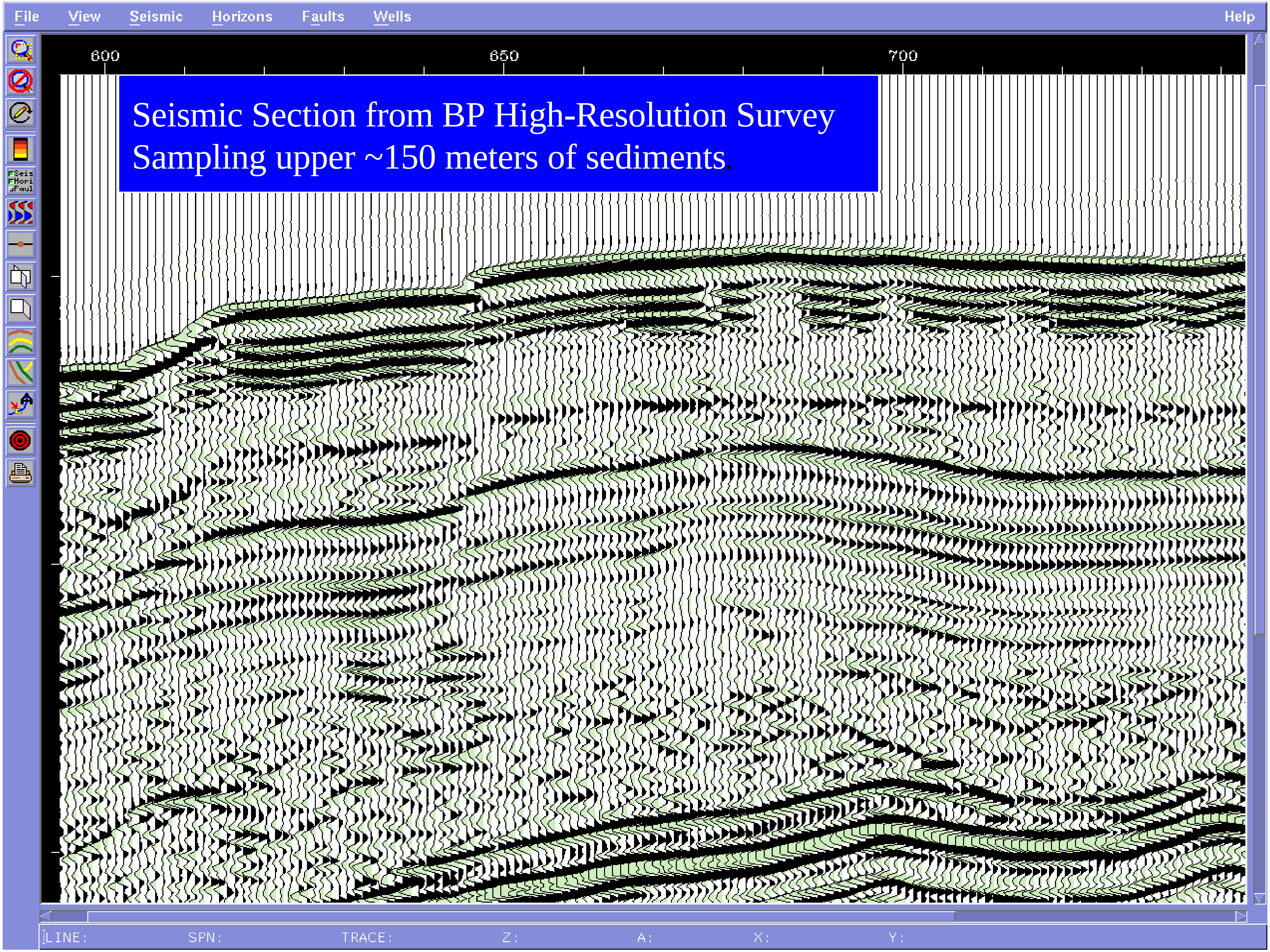


NGDC 0.5' Prototype Bathymetry

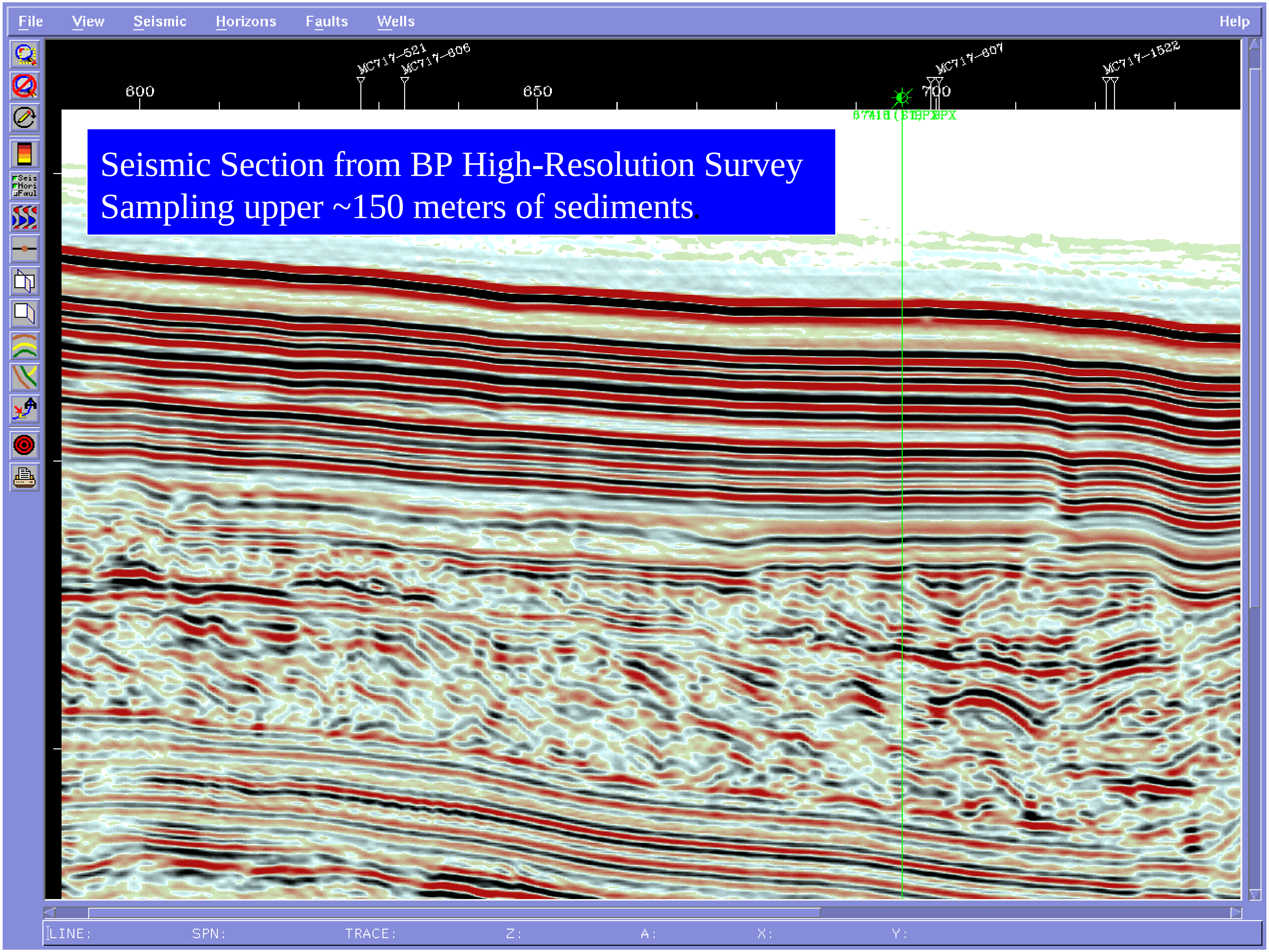




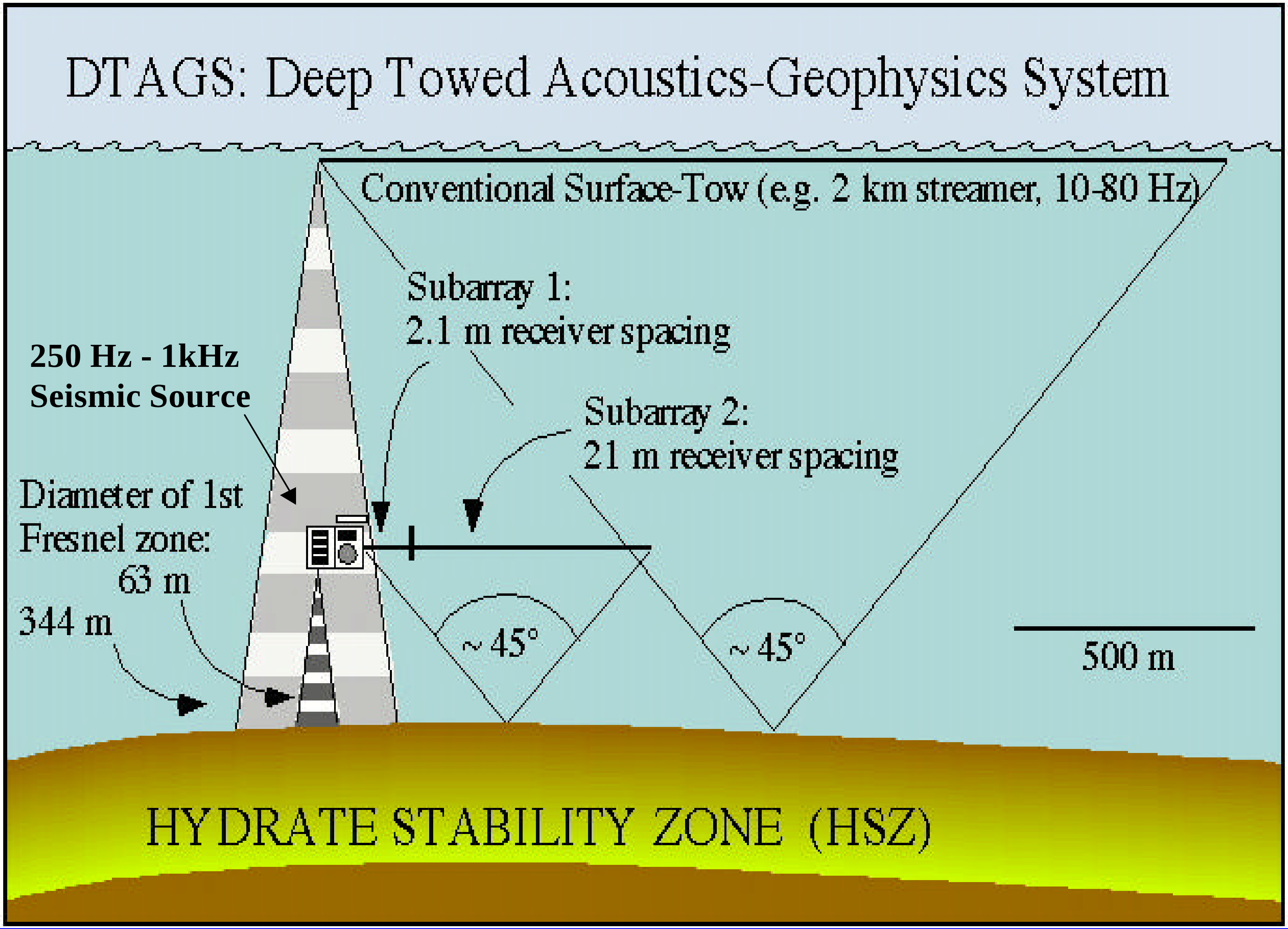
Courtesy, BP


File
View
Seismic
Horizons
Faults
Wells
Help
600
650
700
Seismic Section from BP High-Resolution Survey
Sampling upper ~150 meters of sediments.
LINE:
SPN:
TRACE:
Z:
A:
X:
Y:

Seismic Section from BP High-Resolution Survey
Sampling upper ~150 meters of sediments.



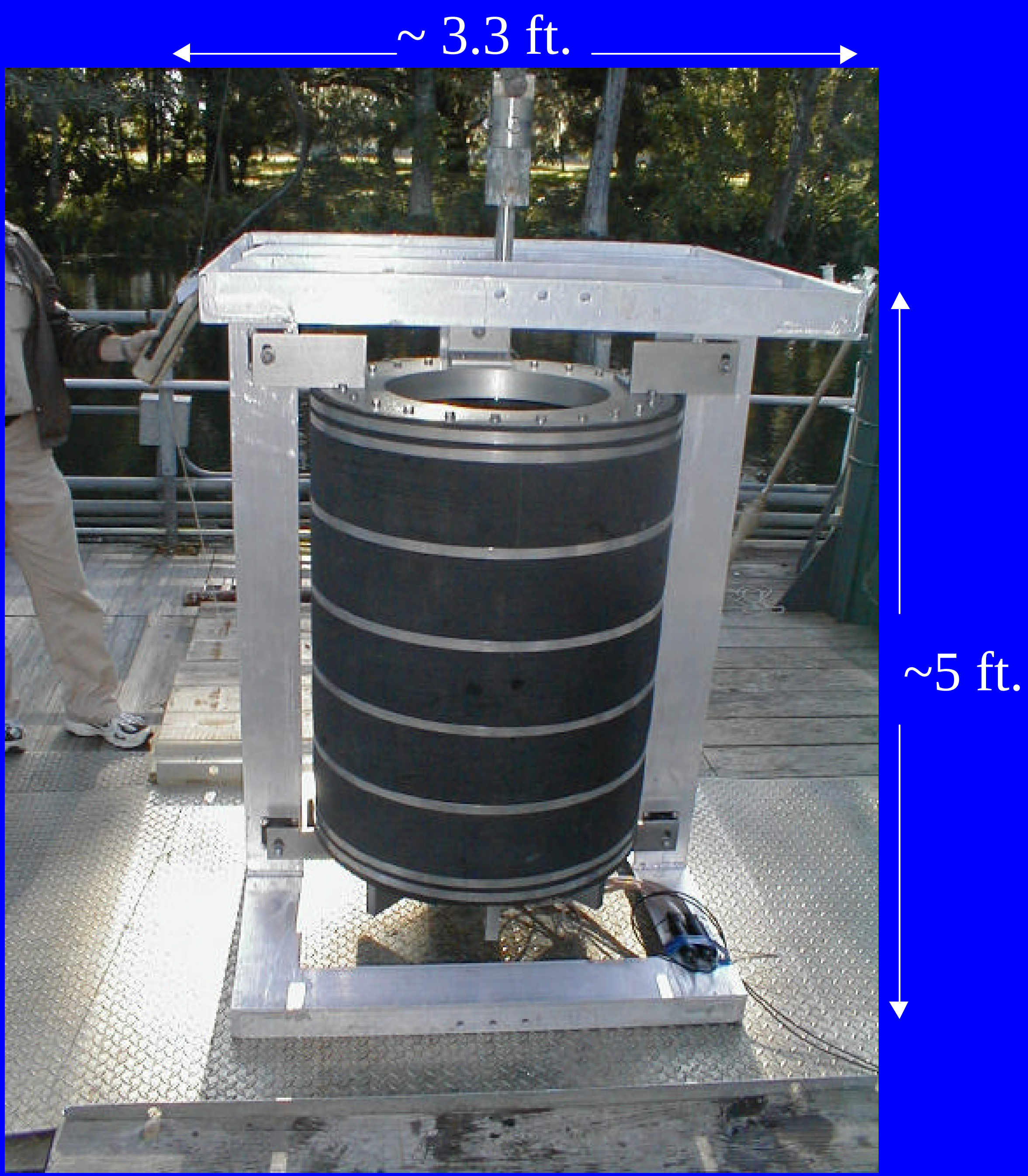
DTAGS vs. Conventional acquisition



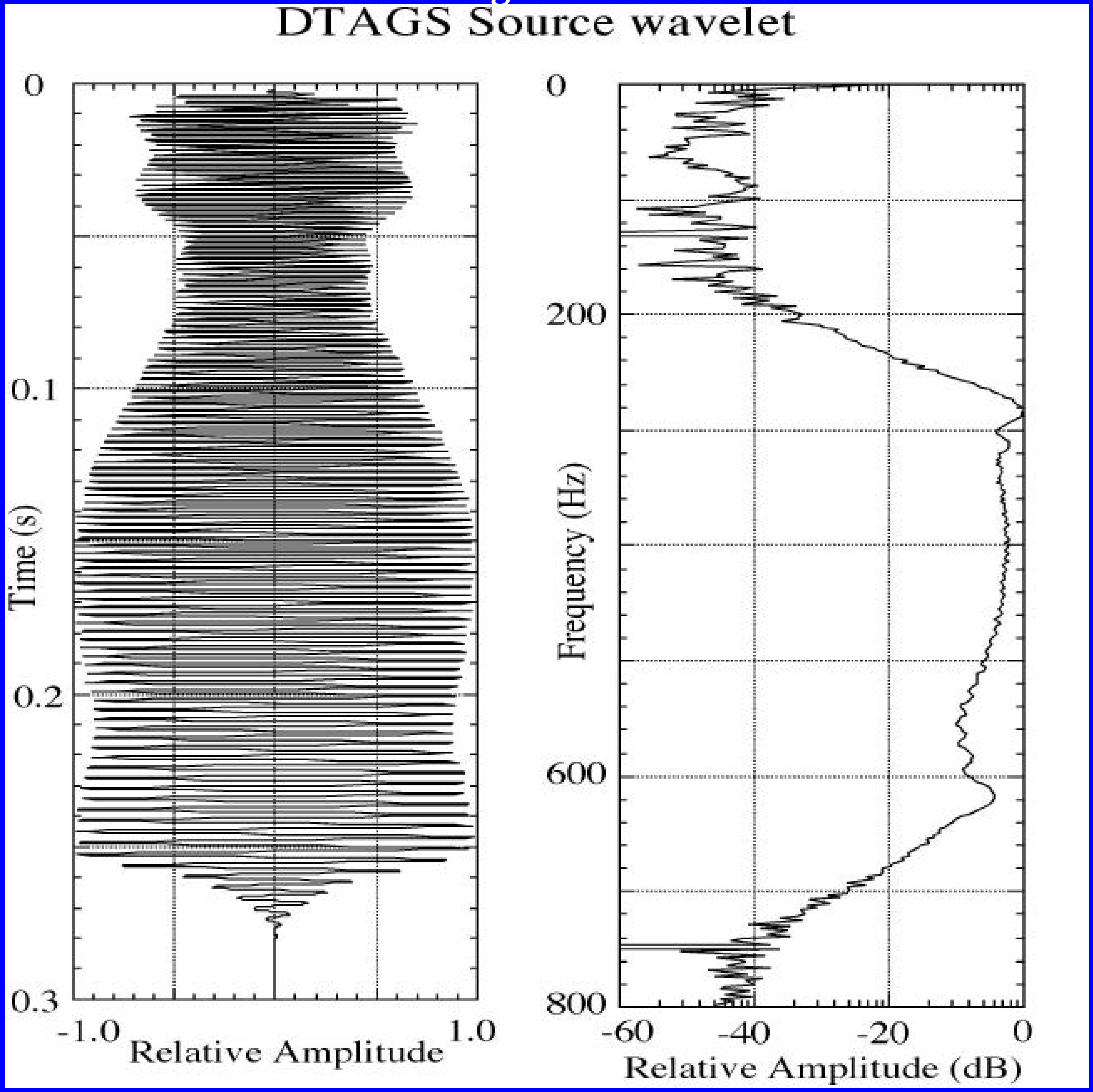
Weight:

1790 lbs in air

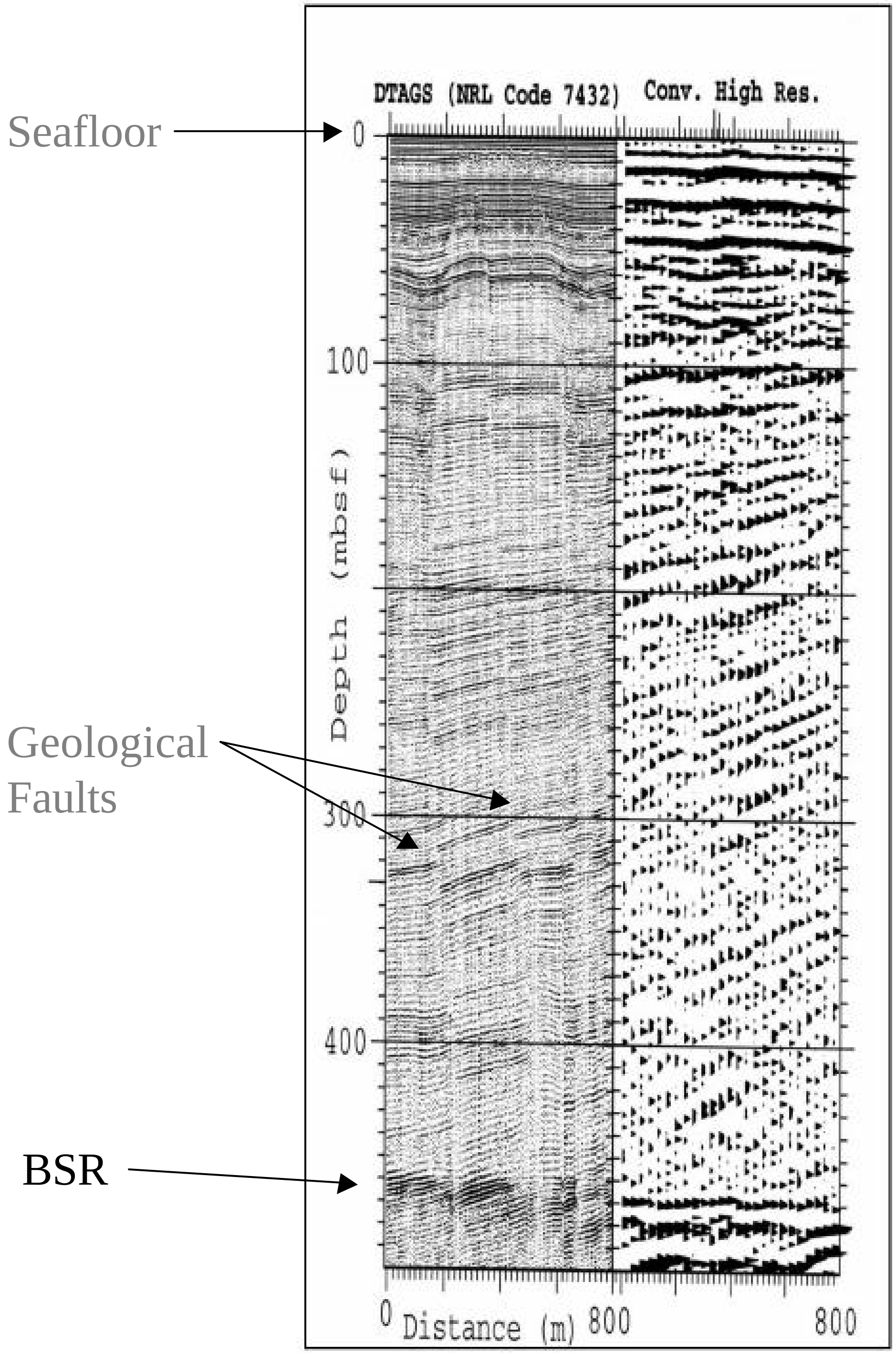
1349 lbs in water



Original



DTAGS Source wavelet
0
0.1
0.2
0.3
Time (s)
-1.0
1.0
Relative Amplitude
0
200
600
800
Frequency (Hz)
-60
-40
-20
0
Relative Amplitude (dB)

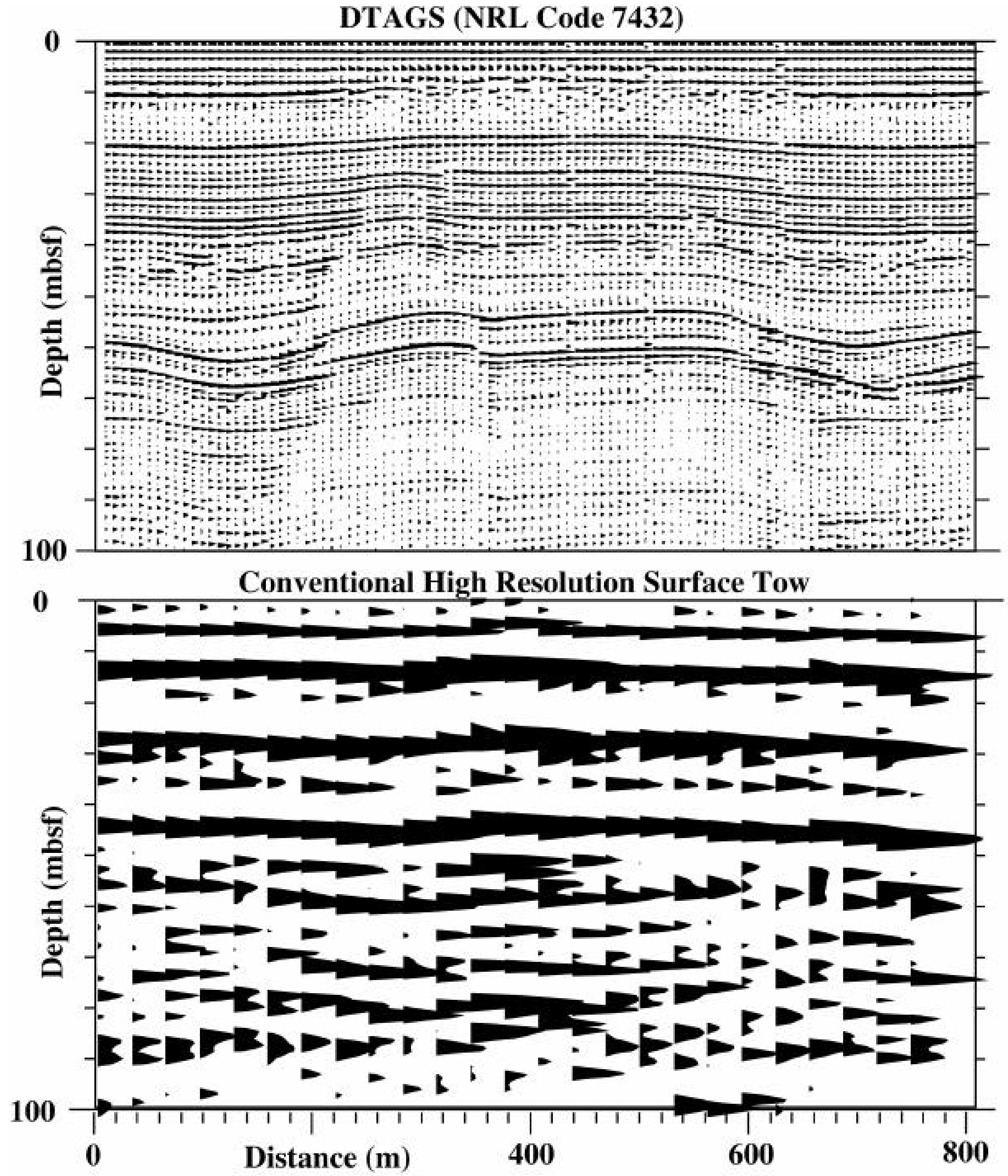


The order of magnitude improvement in both vertical and lateral resolution of DTAGS data (250-650 Hz) over conventional high-resolution single-channel air gun data data (10-220 Hz), Line 31 from Katzman et al., 1994 is clearly shown in this figure.

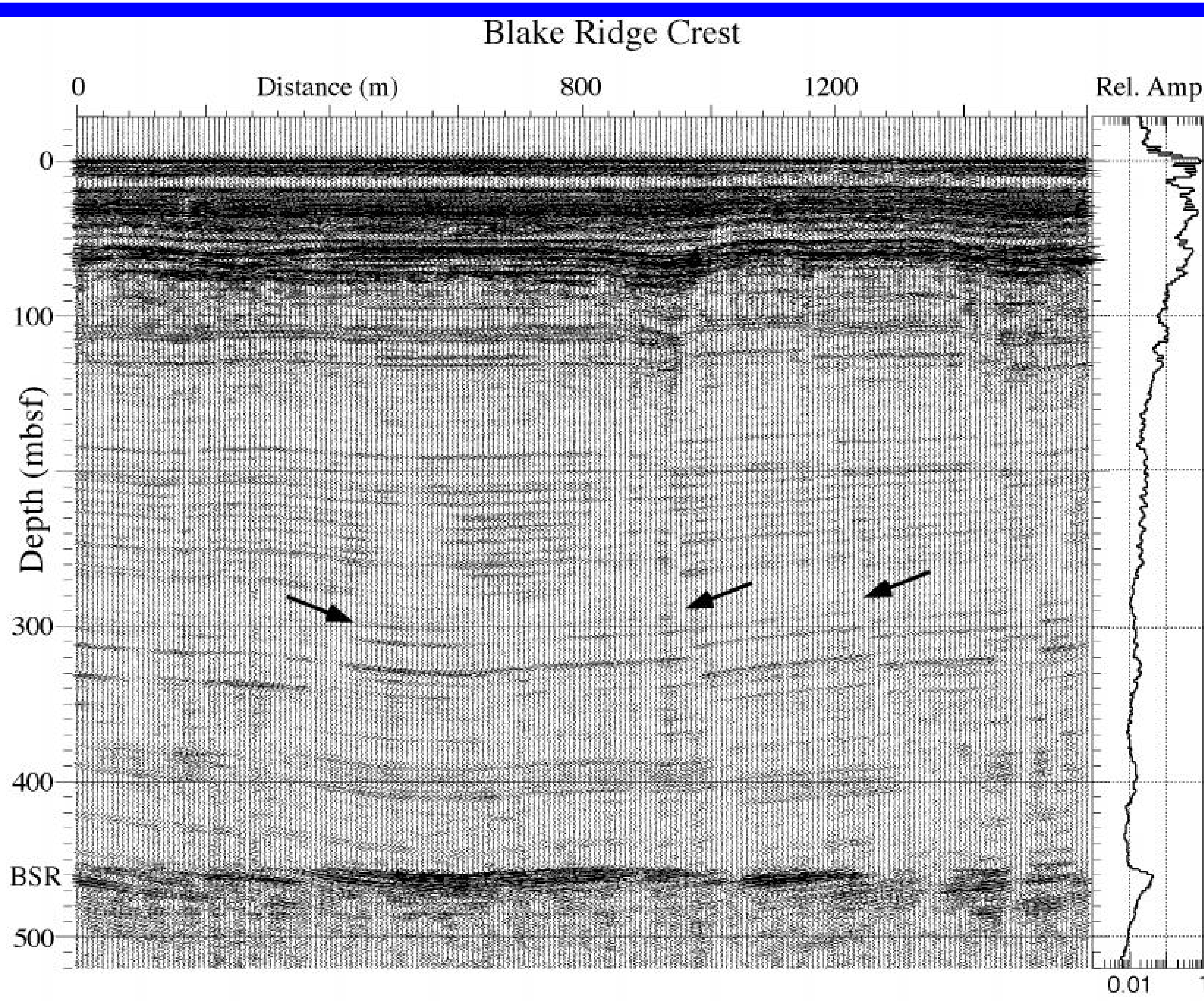
The very sharp images of the growth faults ubiquitous on the Blake Ridge (Rowe and Gettrust, 1994) are confirm that these faults extend through the hydrate stability zone.

The DTAGS data shown here were recorded ~1km south of the site where the Katzman et al. data were taken (near ODP Site 997).

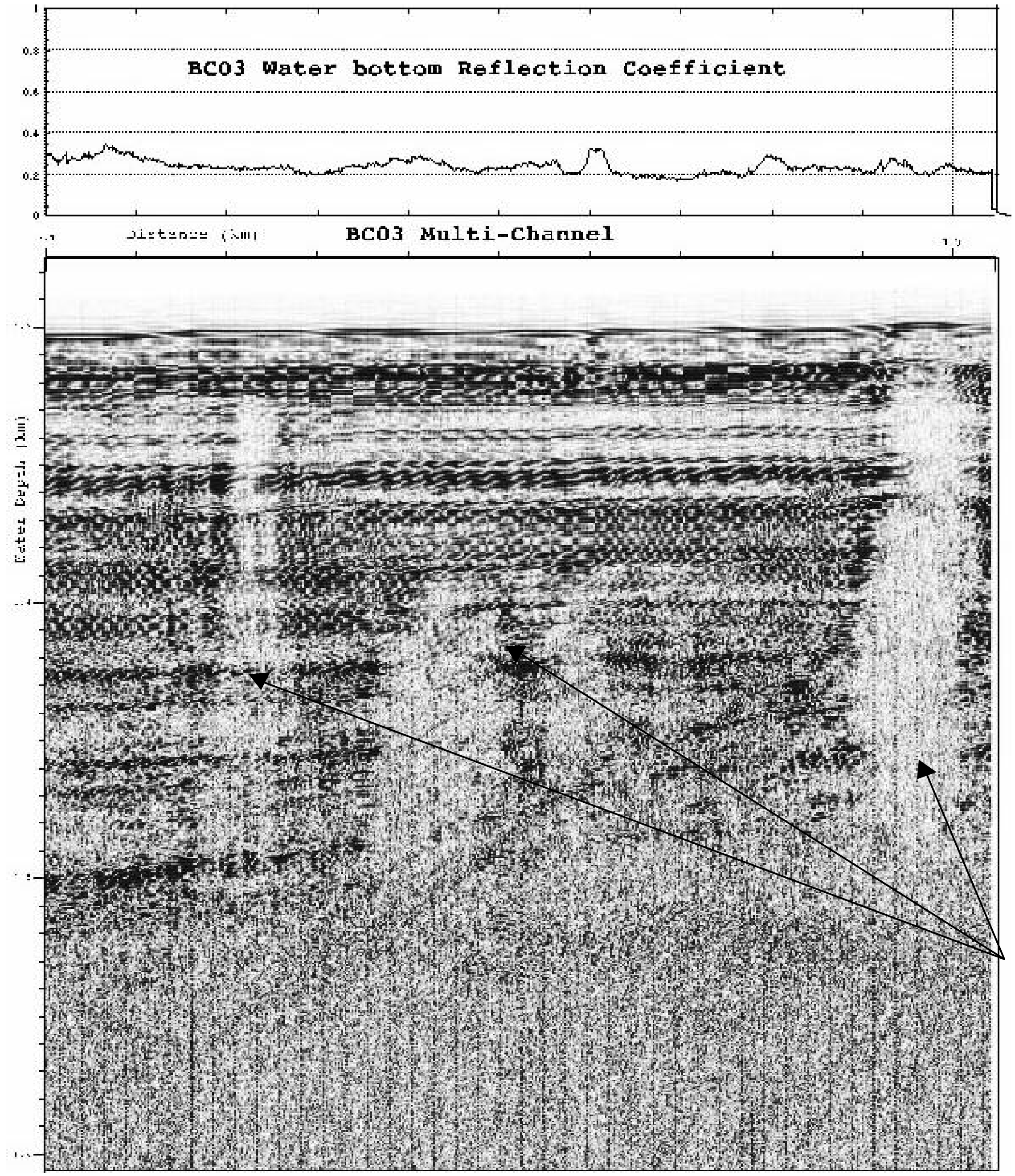
Both of the data sets presented are converted to depth using the interval velocities from Holbrook et al., 1996 for Site 997.



DTAGS (NRL Code 7432)
0
100
Depth (mbsf)
Conventional High Resolution Surface Tow
0
100
Depth (mbsf)
0
Distance (m)
400
600
800

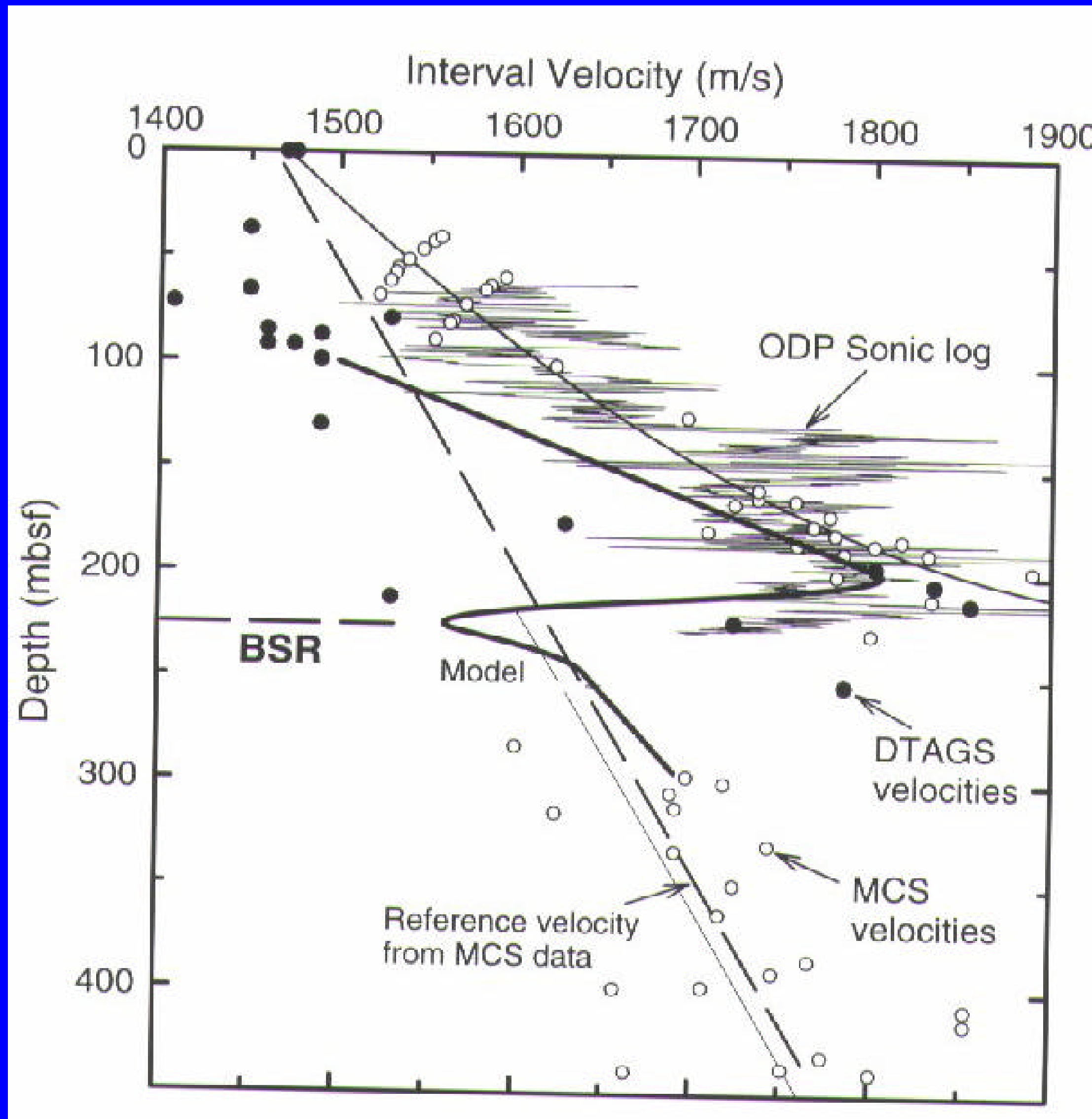

Blake Ridge Crest
0
Distance (m)
800
1200
Rel. Amp.
Depth (mbsf)
0
100
300
400
BSR
500
0.01
1
FIGURE 4

Cascadia Margin
DTAGS Data



“Wipe Out” zones related to dissociation of hydrates

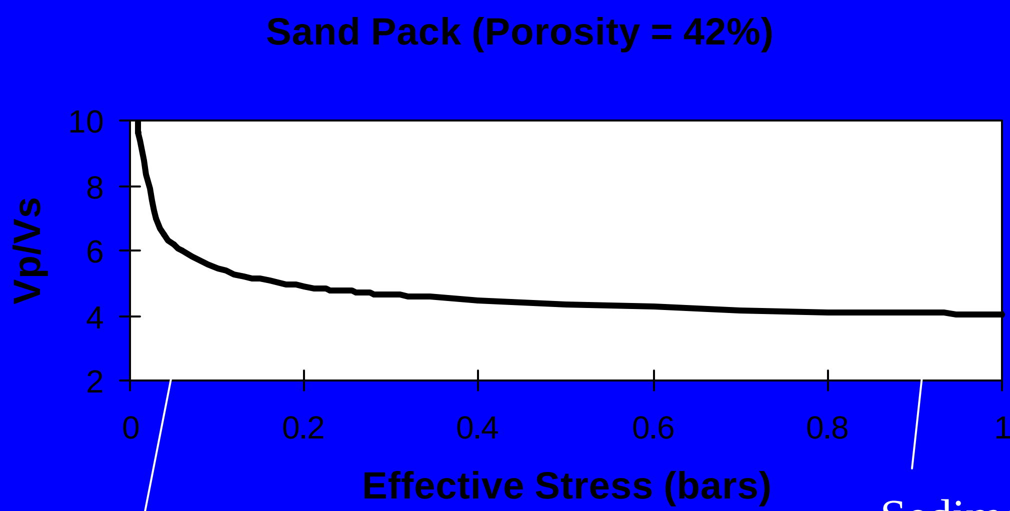
Interval Velocity Comparison



Future Developments

- Initially, we use “conventional” deep-tow seismic to search for structural and/or Vp anomalies.
- We plan a second phase during which we will use bottom source and bottom receivers to identify Vp/Vs anomalies.

Impact of Effective Stress on Vp/Vs Ratios



Sediments act more like solid

Sediments act more like fluid

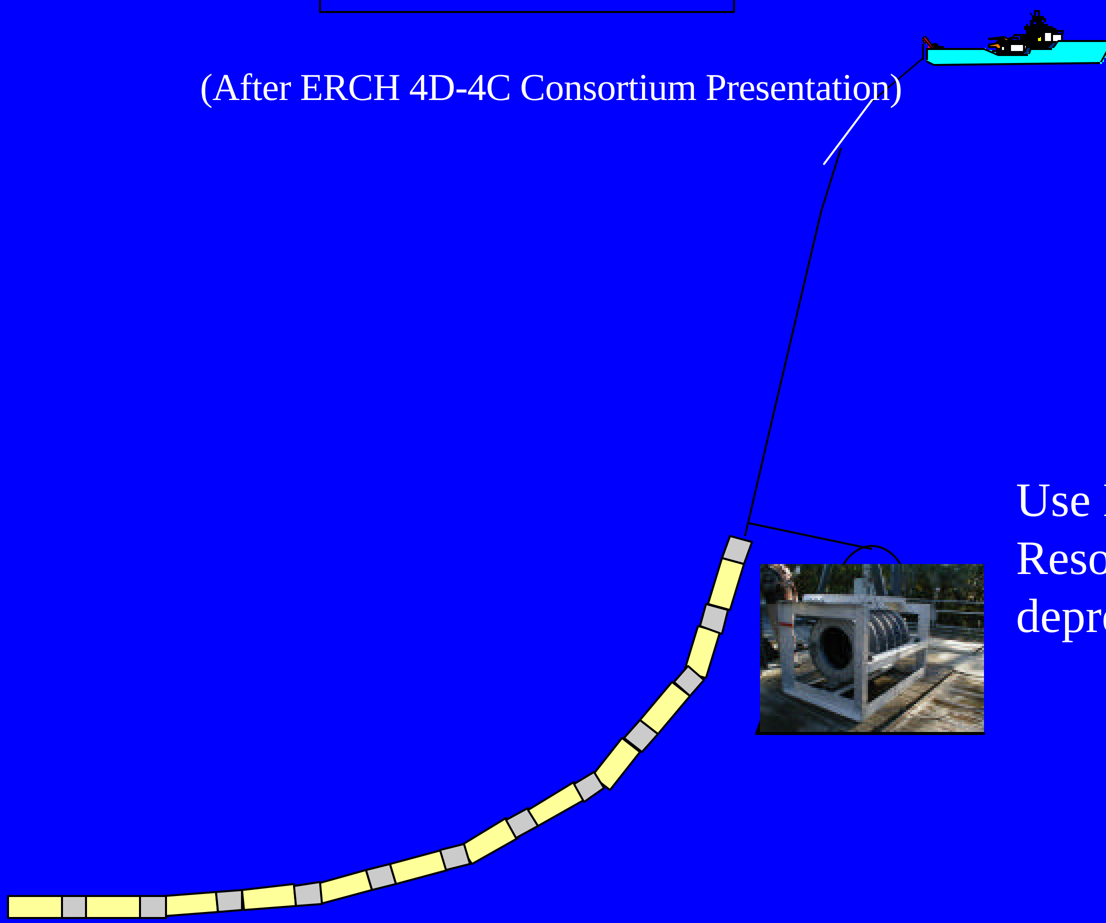
Relationship between Vp/Vs and effective stress for a 42% porosity sand pack predicted from empirical equations given by Castagna et al. (1993).

Issues Concerning Data to Resolve Vp/Vs Accurately

- With conventional MCS velocity uncertainty may be 20-40% (Dutta, 1998).
- Two Techniques Proposed that can Significantly Improve Estimates of Critical Parameters:
  - Deep-Tow MCS with Higher Source Frequency
  - Bottom-Source, OBC System

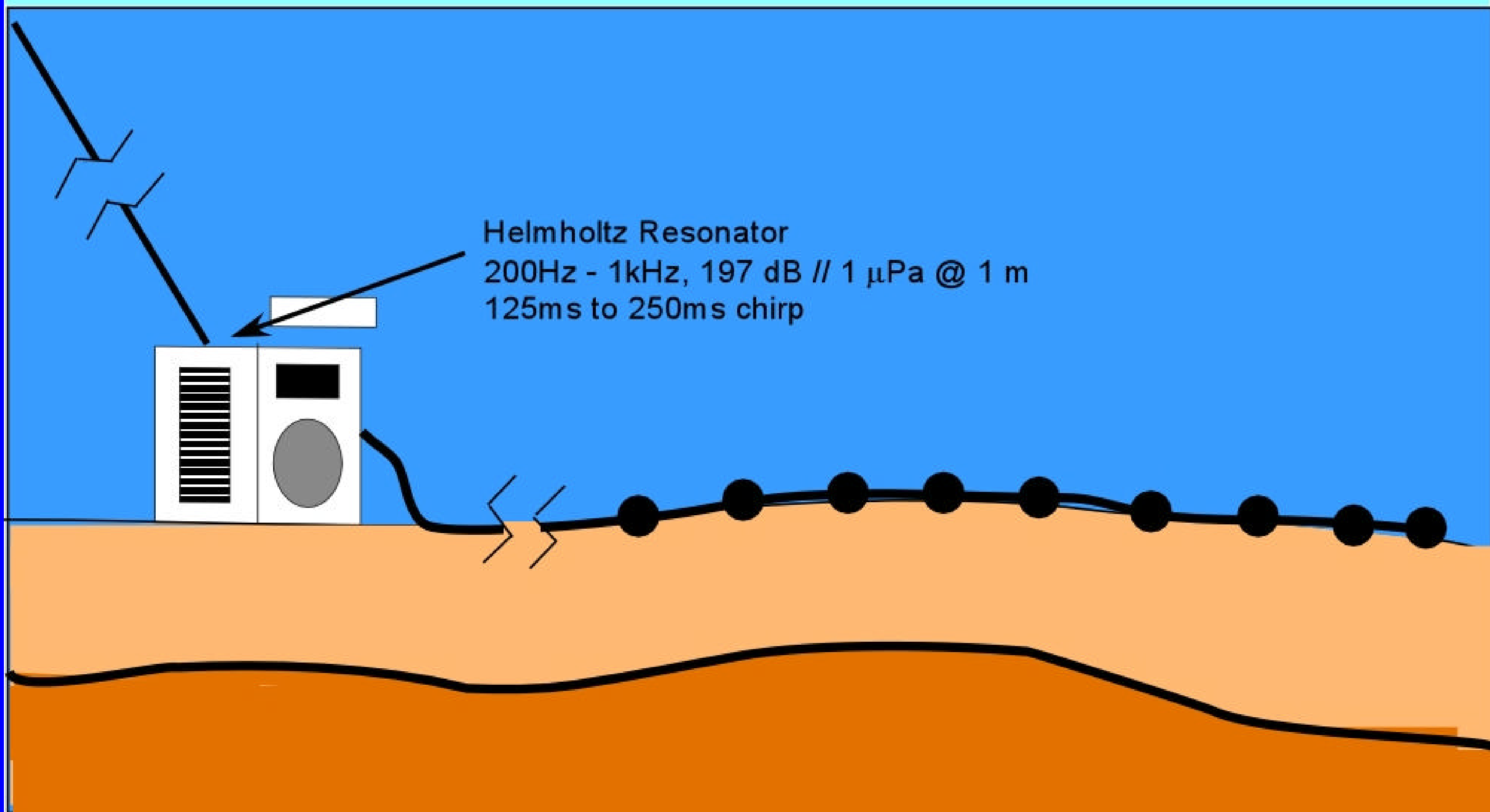
Draping Under Tension

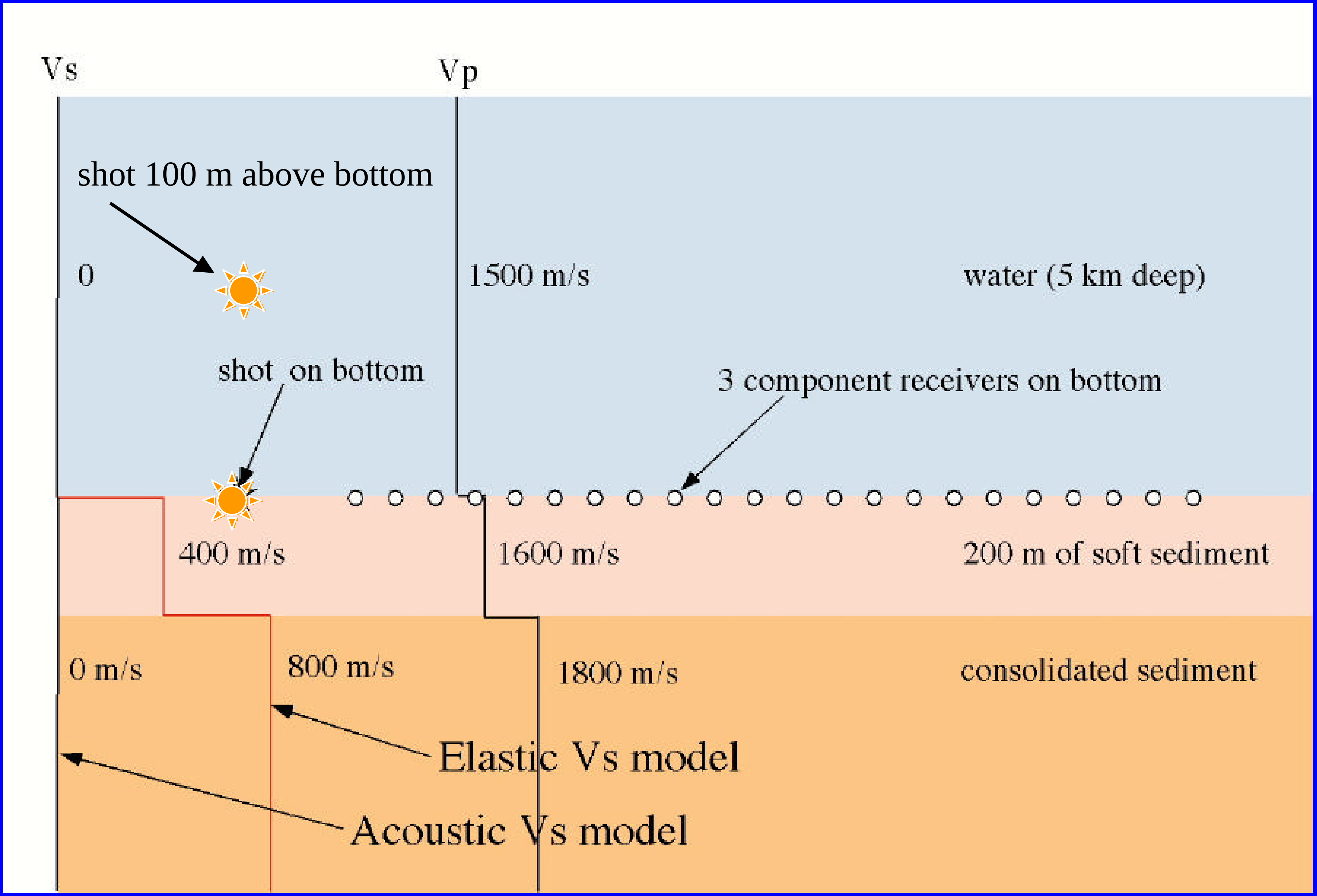
(After ERCH 4D-4C Consortium Presentation)



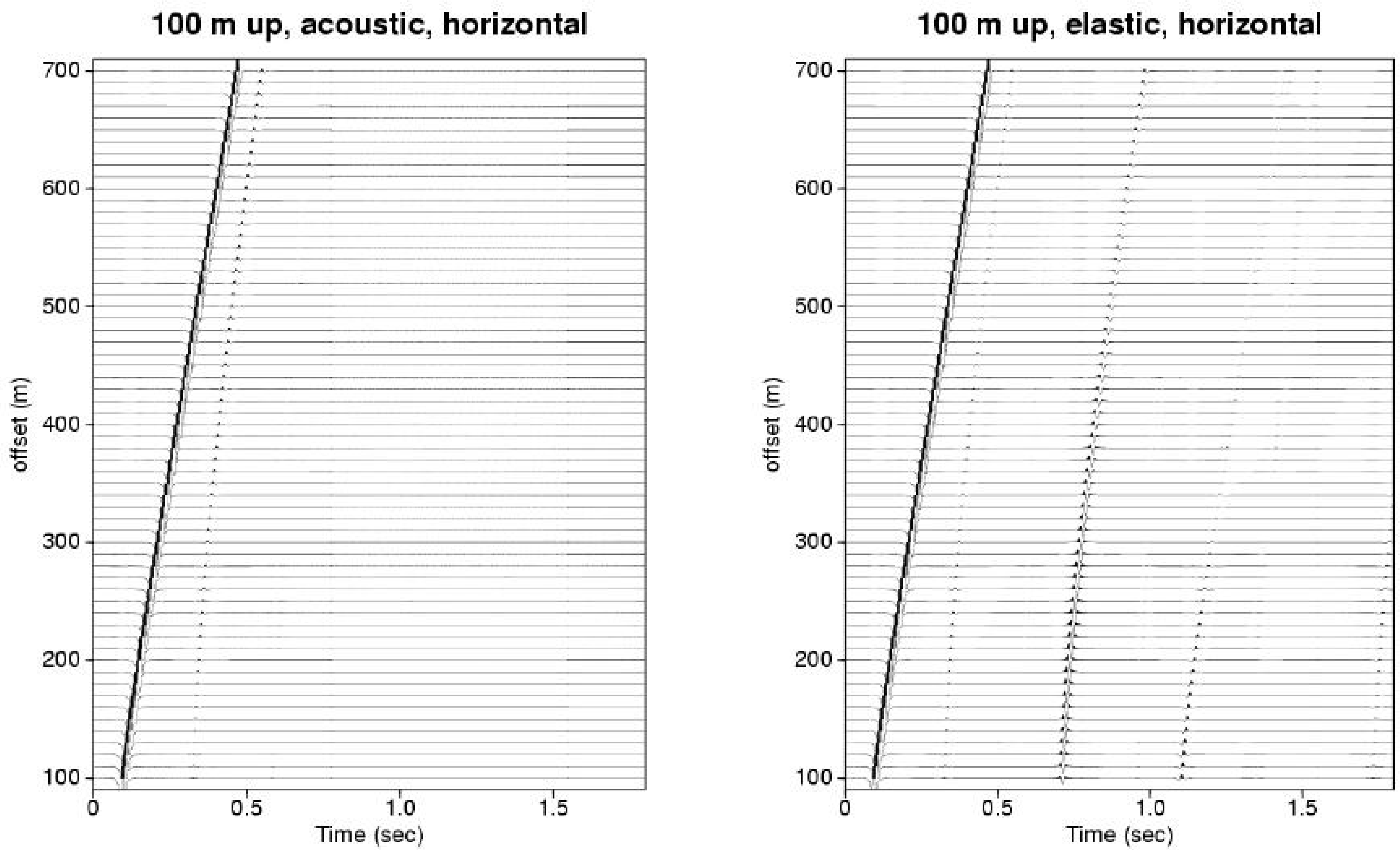
Use Helmholtz Resonator as depressor/source

Bottom Source-Receivers Geotechnical System

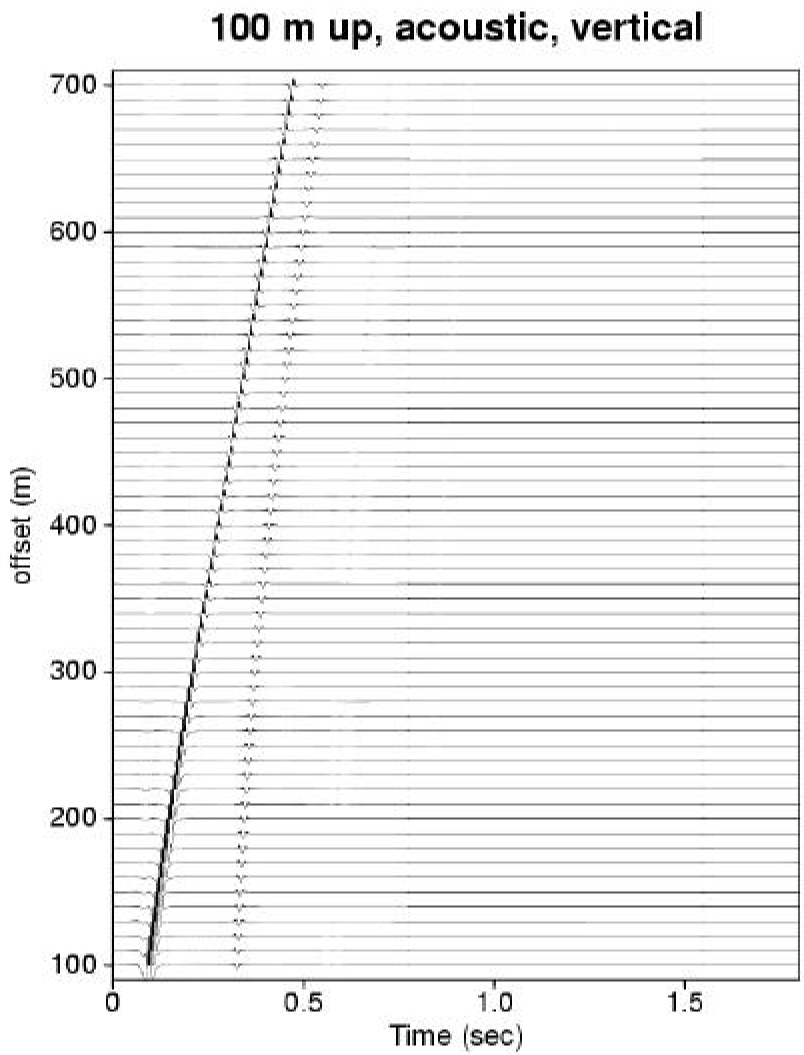




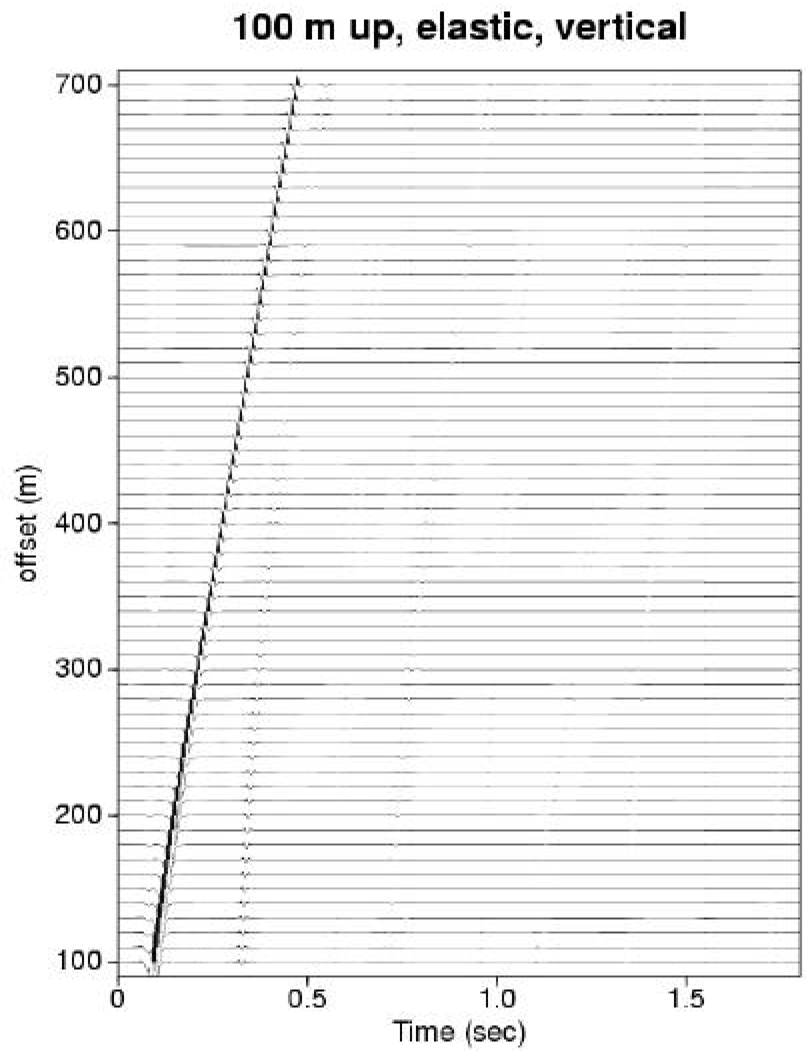
Vs
Vp
shot 100 m above bottom
0
1500 m/s
water (5 km deep)
shot on bottom
3 component receivers on bottom
400 m/s
1600 m/s
200 m of soft sediment
0 m/s
800 m/s
1800 m/s
consolidated sediment
Elastic Vs model
Acoustic Vs model



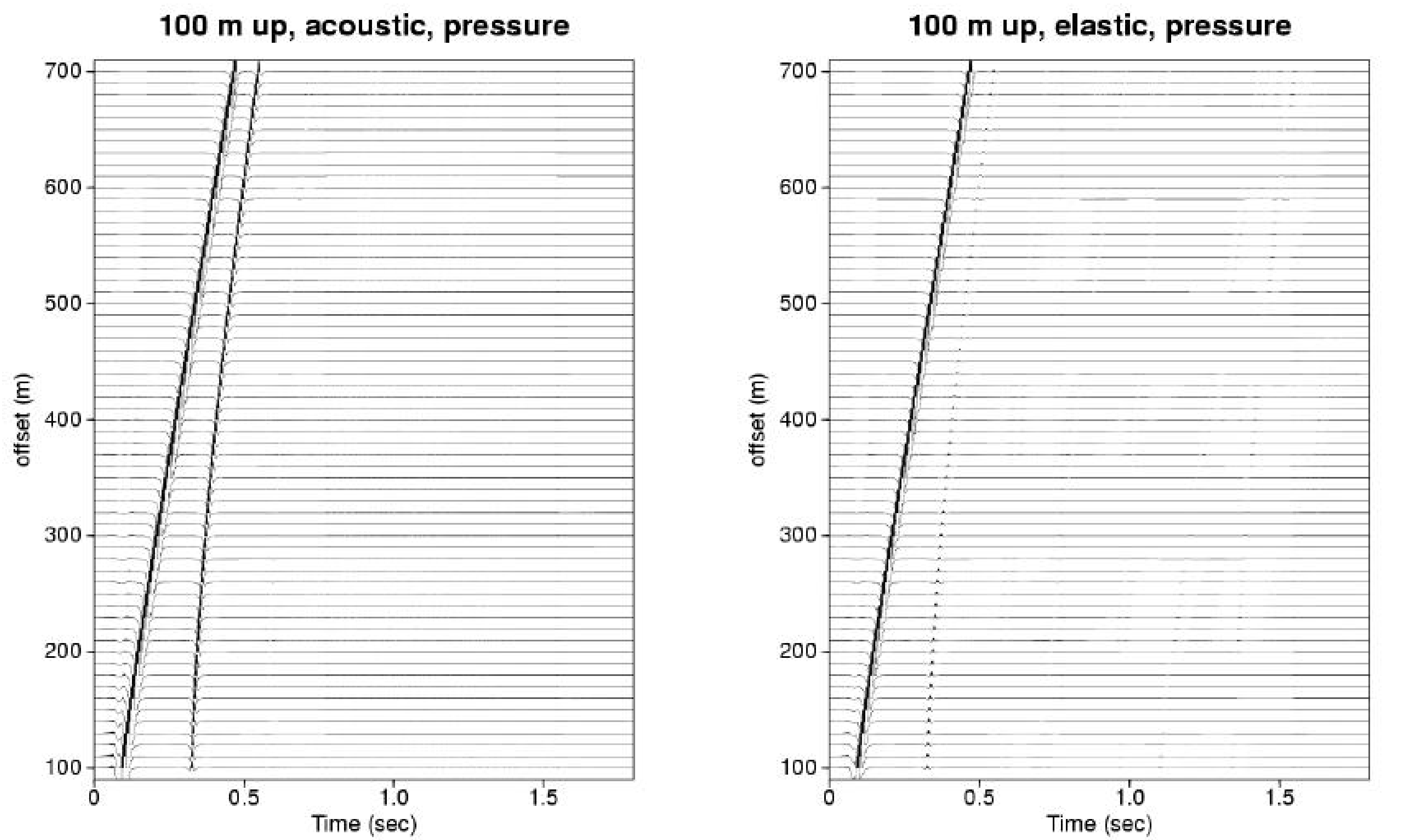
100 m up, acoustic, horizontal
offset (m)
700
600
500
400
300
200
100
0
0.5
1.0
1.5
Time (sec)
100 m up, elastic, horizontal
offset (m)
700
600
500
400
300
200
100
0
0.5
1.0
1.5
Time (sec)

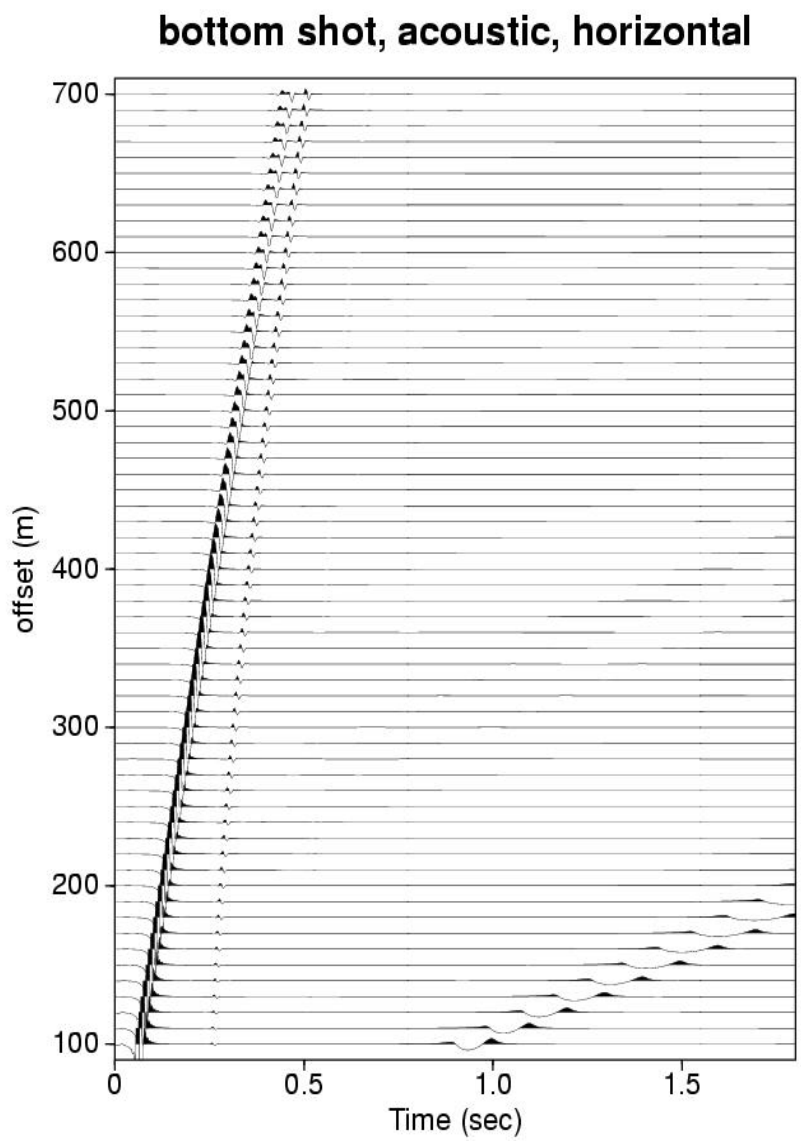


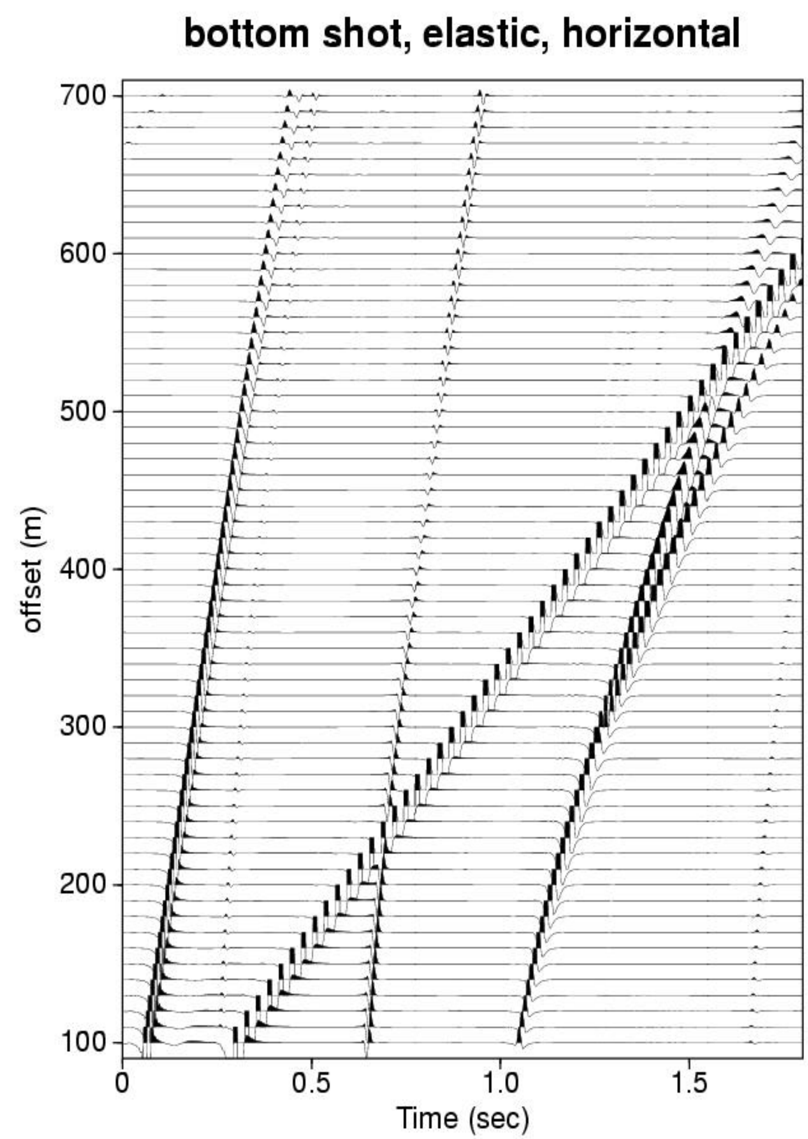
100 m up, acoustic, vertical
offset (m)
700
600
500
400
300
200
100
0
0.5
1.0
1.5
Time (sec)

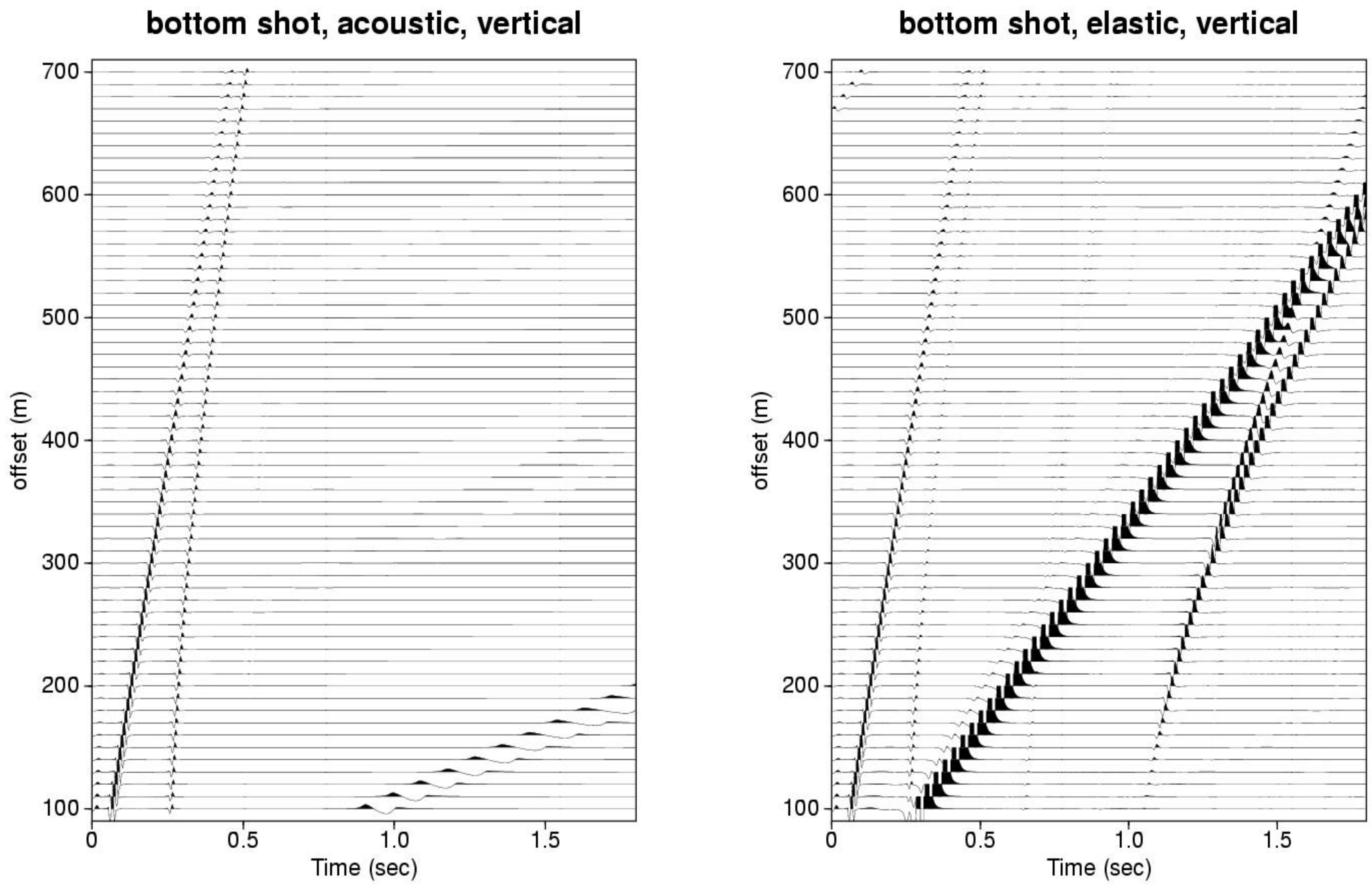


100 m up, elastic, vertical
offset (m)
700
600
500
400
300
200
100
0
0.5
1.0
1.5
Time (sec)

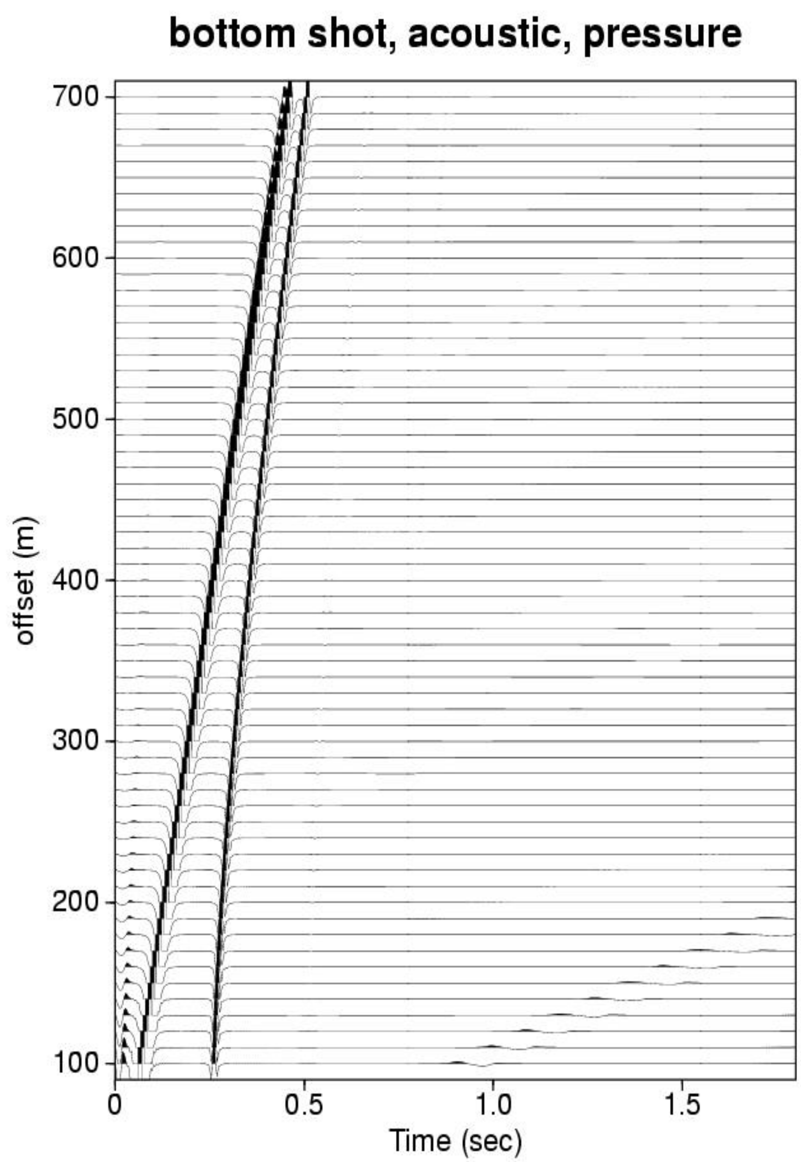

100 m up, acoustic, pressure
100 m up, elastic, pressure
offset (m)
Time (sec)
700
600
500
400
300
200
100
0
0.5
1.0
1.5

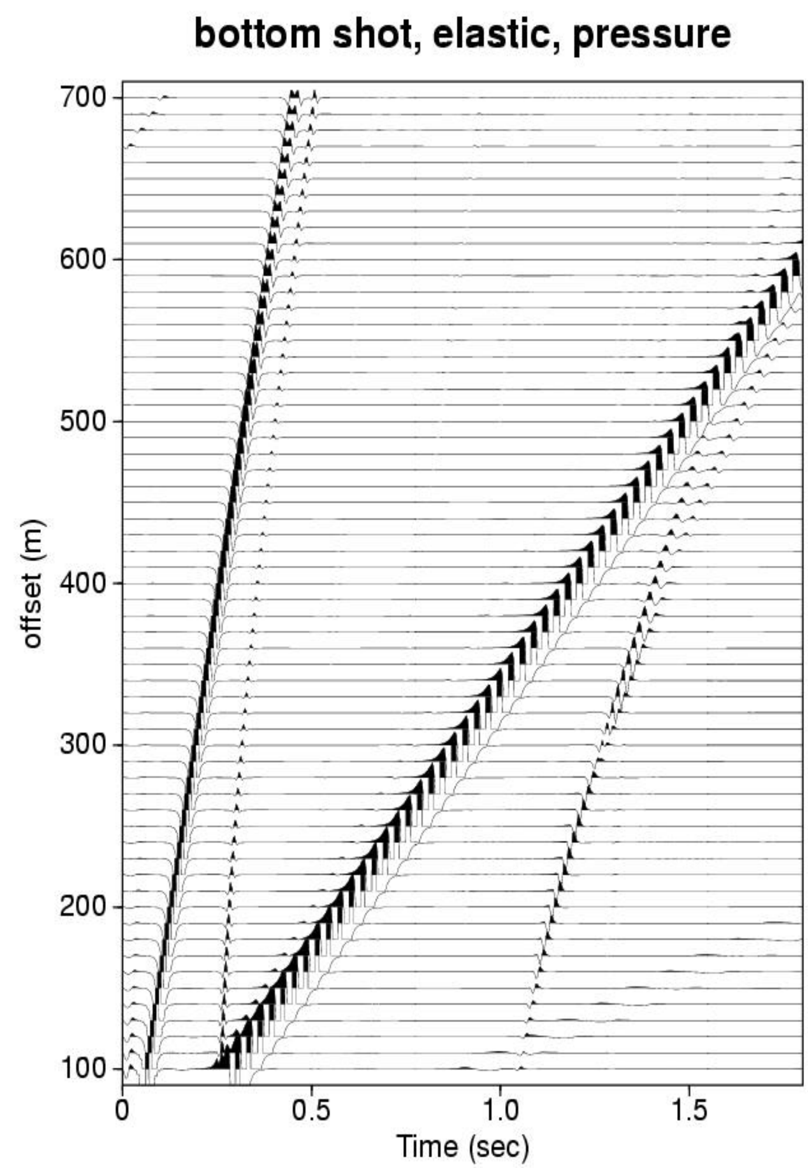

bottom shot, acoustic, horizontal
offset (m)
700
600
500
400
300
200
100
0
0.5
1.0
1.5
Time (sec)


bottom shot, elastic, horizontal
offset (m)
700
600
500
400
300
200
100
0
0.5
1.0
1.5
Time (sec)



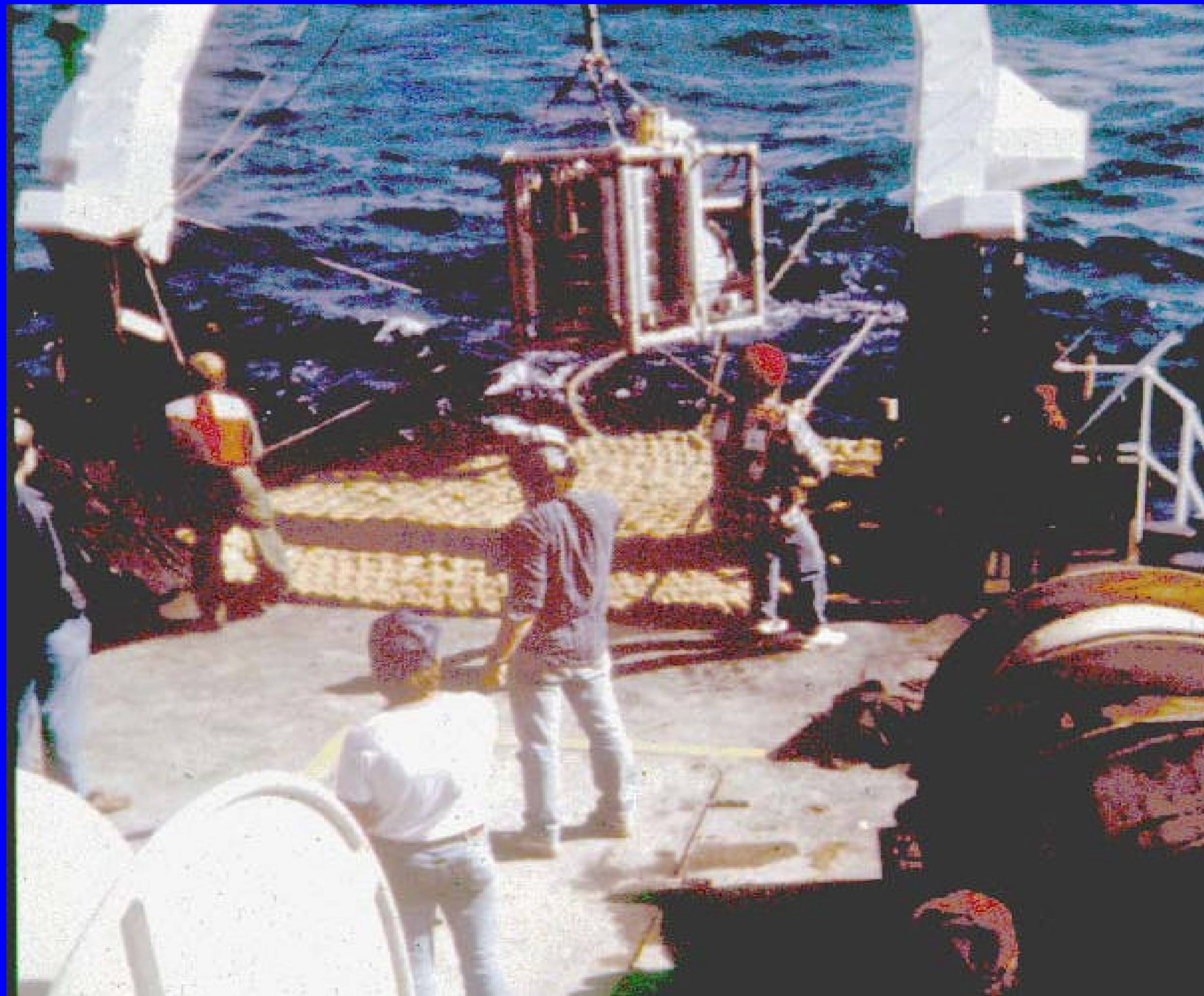
bottom shot, acoustic, vertical
bottom shot, elastic, vertical
offset (m)
700
600
500
400
300
200
100
0
0.5
1.0
1.5
Time (sec)


bottom shot, acoustic, pressure
offset (m)
700
600
500
400
300
200
100
0
0.5
1.0
1.5
Time (sec)


bottom shot, elastic, pressure
offset (m)
700
600
500
400
300
200
100
0
0.5
1.0
1.5
Time (sec)

Summary

- Either Deep-Tow MCS or Bottom-Source OBC technique can resolve parameters that are diagnostic of areas with the potential for Shallow Water Flow.
- OBC Bottom-Source Technique:
  - Directly generates & senses shear waves (does not rely on P-S or S-P conversion).
  - Need an OBC with frequency response compatible with Bottom Source.
  - Geophone coupling issues (however, hydrophone data may be sufficient).
- Deep-Tow MCS:
  - Faster surveys than OBS Bottom-Source.
  - Requires generation of converted shear waves.
  - Indirect techniques for interpretation of shear wave properties (e.g., AVO).



Seismic Facies Analysis Applied to Sea Floor Gas Hydrates

A Case Study Offshore Gulf of Mexico

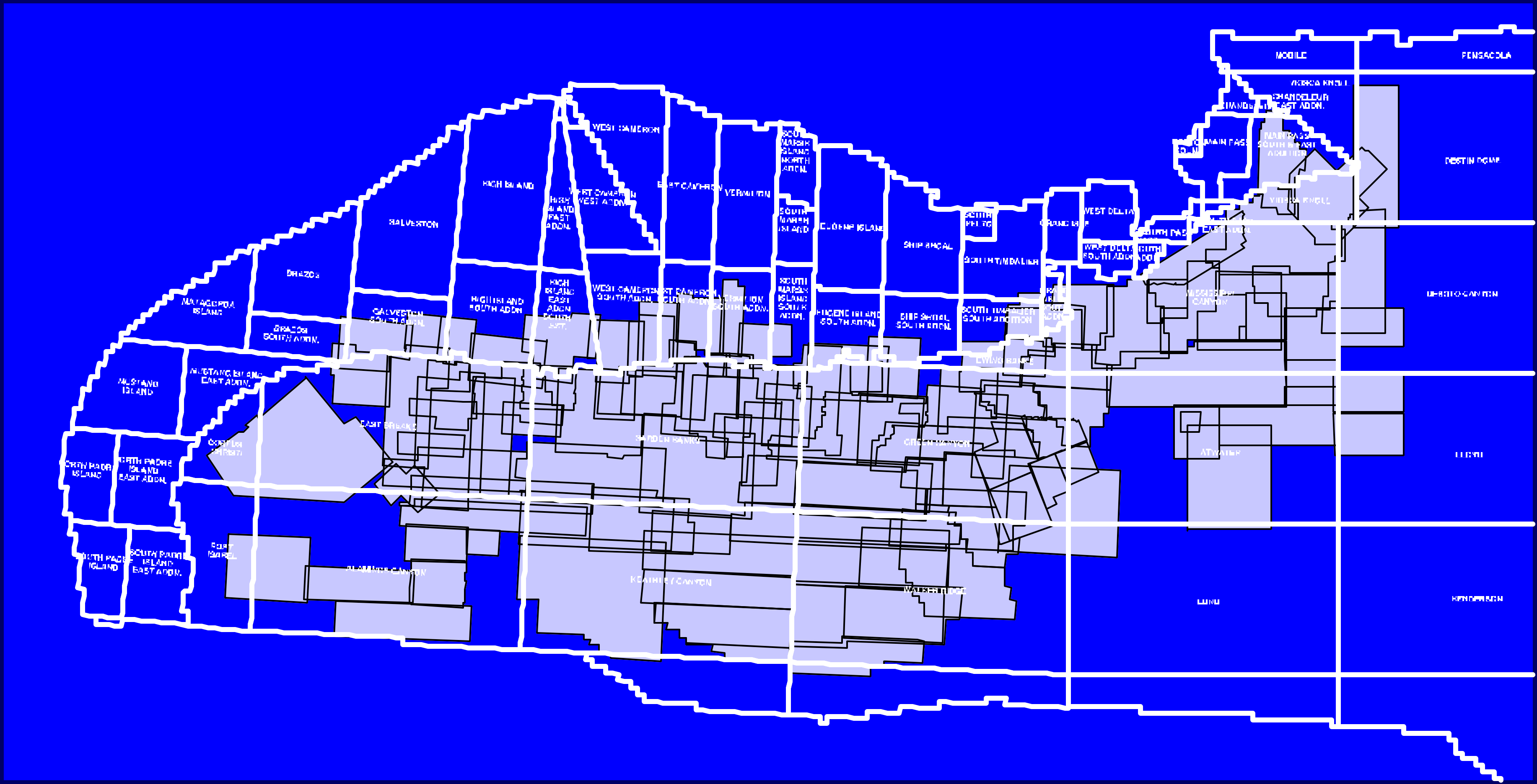
Jesse L. Hunt, Jr.

Minerals Management Service - New Orleans

U.S. Department of the Interior

Interpreted Seafloor Maps

128 3-D Seismic Surveys Completed



Seismic Facies Analysis Applied to Sea Floor Gas Hydrates

Methodology

Data: Deep Water Offshore GOM 3D

Sea Floor Gas Hydrates

Structural Interpretation

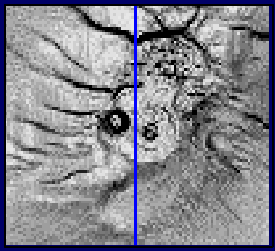
- Conventional Horizon Attributes

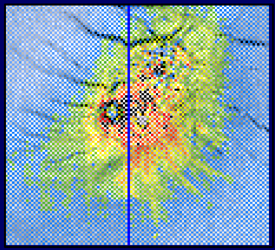
Stratigraphic Interpretation

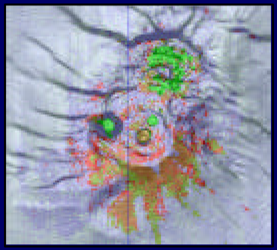
- Seismic Facies Analysis

Summary

Conclusions







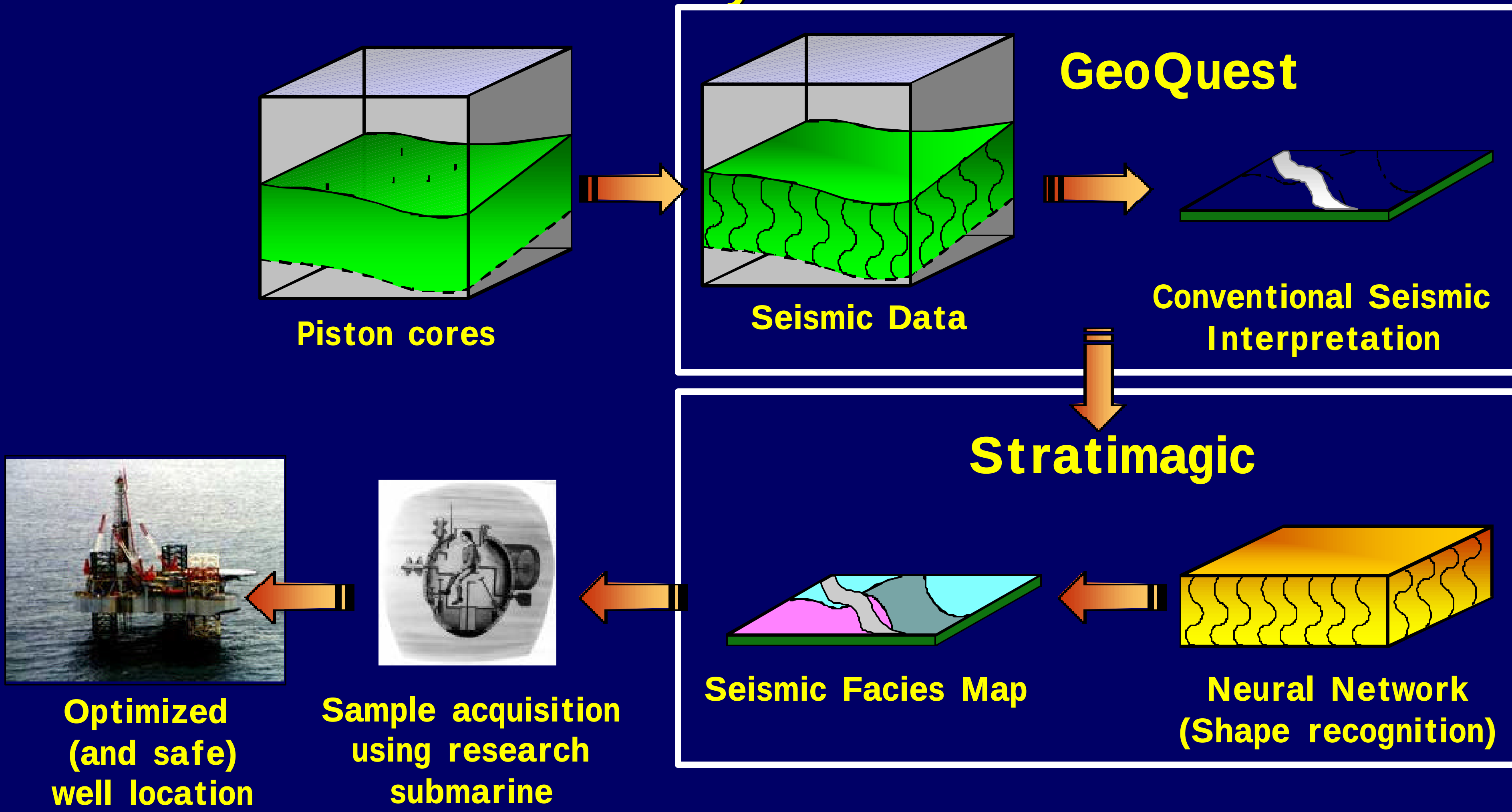
Sea Floor Geophysics

"Conventional amplitude-based seismic attributes correlate well to sea floor carbonate hardgrounds, chemosynthetic communities, and gas hydrates?"

"Can seismic trace shapes be used to differentiate between mud volcanoes, gas/oil-saturated muds, hardgrounds, chemos and gas/hydrate mounds?"

Methodology:

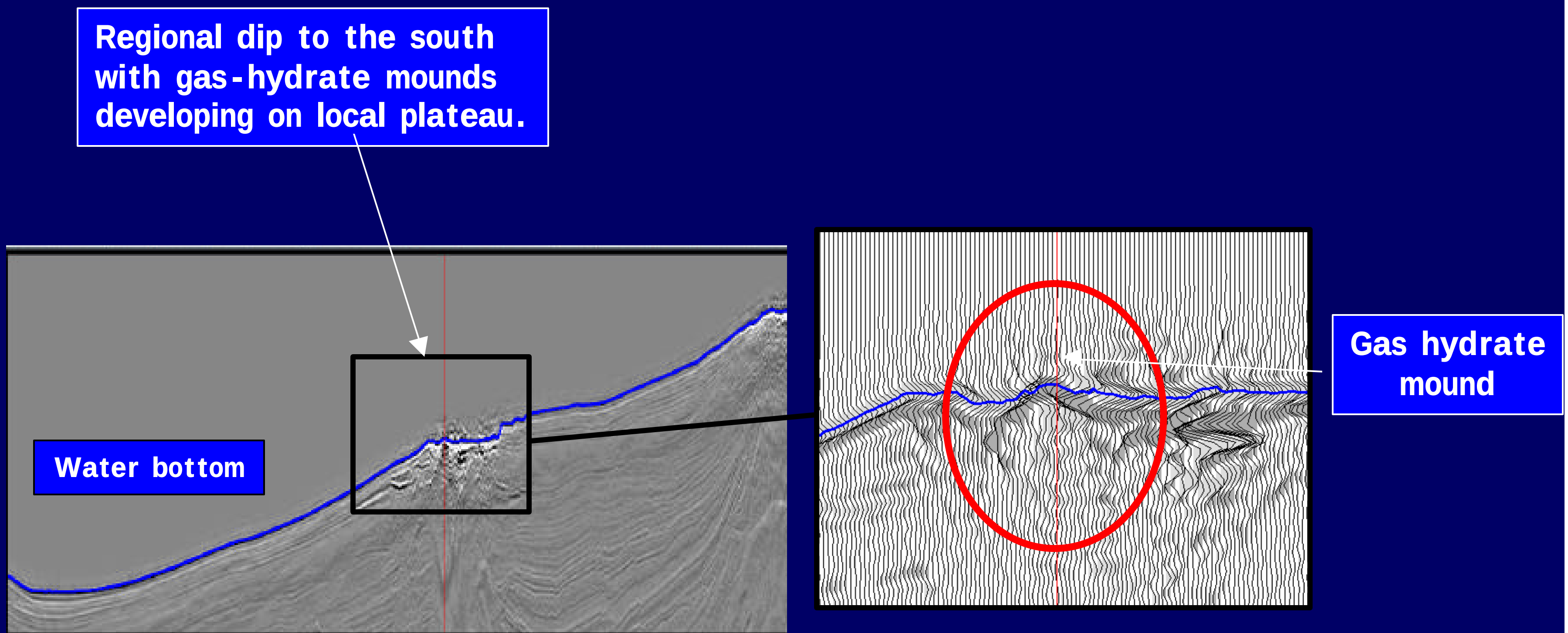
Cores, 3D Seismic Data, Seismic Interpretation and Seismic Facies Analysis



Sea Floor Gas Hydrates

- **Sea Floor Geohazards**

Gas hydrates developed on the water bottom are drilling geohazards affecting sea floor stability.



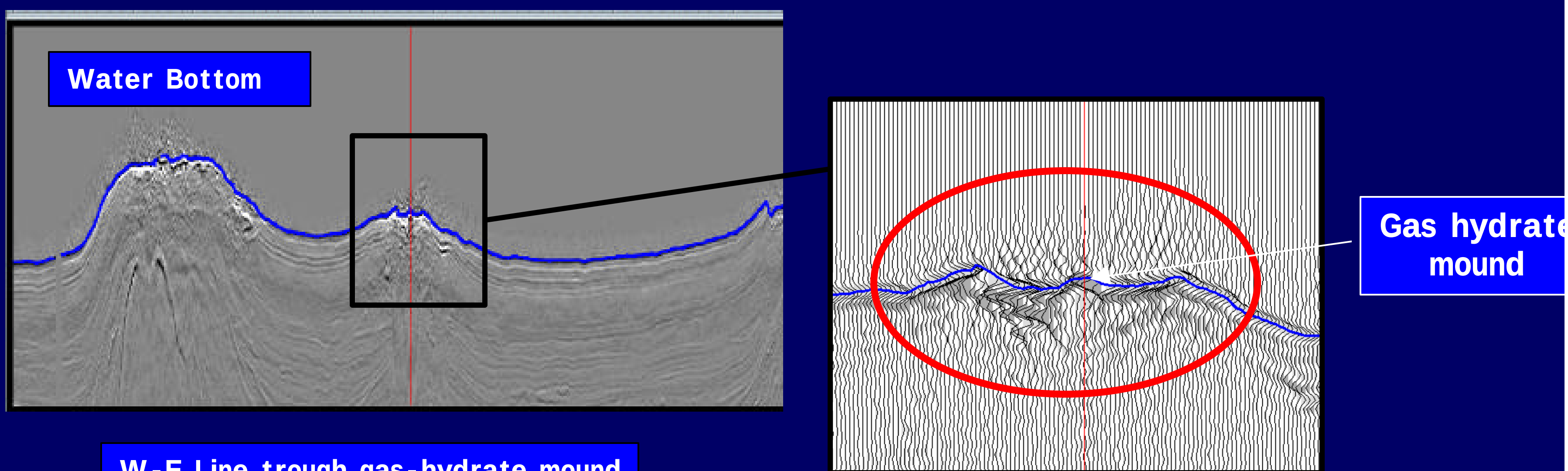
N-S Line trough gas-hydrate mound

Sea Floor Gas Hydrates

- Sea Floor Geohazards

Chemosynthetic ecosystems (methane-eating bacteria, tube worms, clams…) are associated with gas vents.

Gas-hydrates are characterized by high seismic velocities (due to methane trapped in ice crystals).

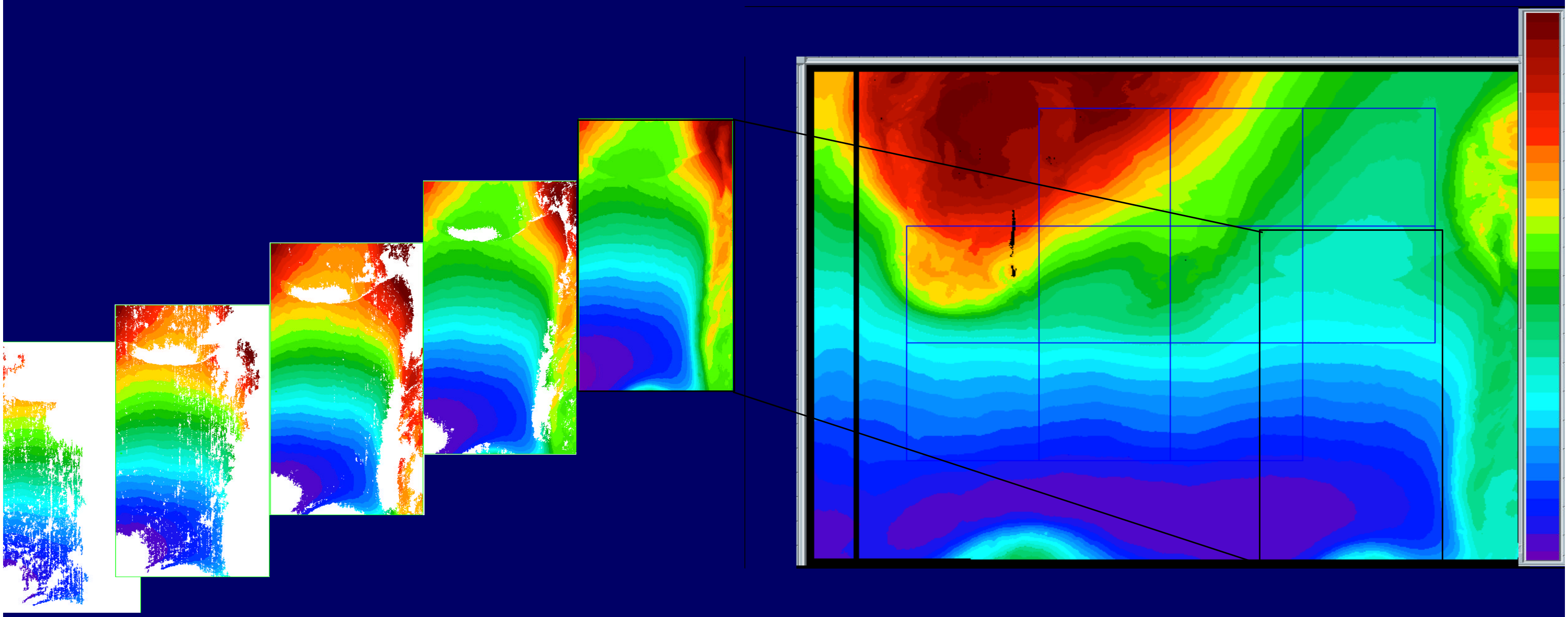


W-E Line trough gas-hydrate mound

Structural Interpretation

- **Water bottom Time Horizon**

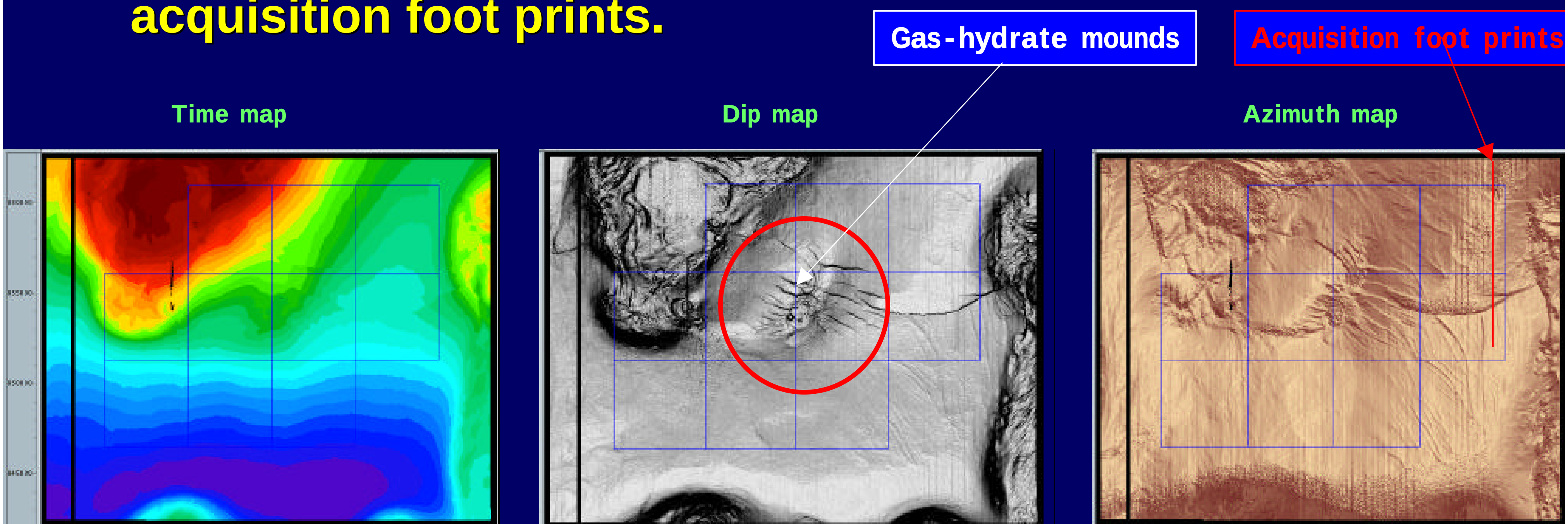
3D-Seismic data accessed from GeoQuest™ project.
Water bottom **interpreted by Stratimagic™ model-based 3D-propagator.**



Structural Interpretation

- Conventional Horizon Attributes

Dip and azimuth maps highlight water bottom topography and tectonics. These were used as QC tools for picking and seismic data quality. Note the WNW-ESE fault system associated with the gas hydrate mound and the N-S acquisition foot prints.

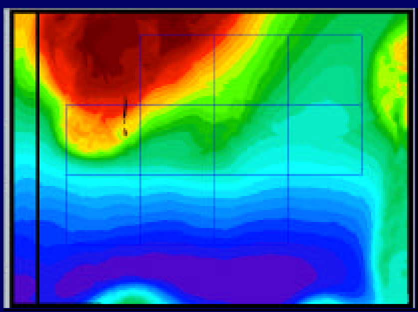


Structural Interpretation

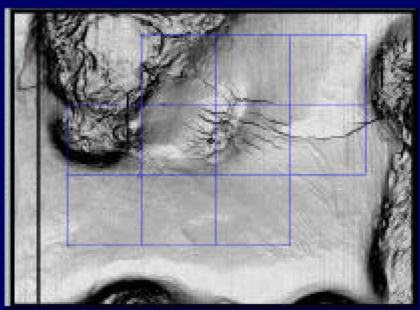
- **Mixed Maps**

  By combining several attributes, water bottom topography is enhanced, highlighting crater-like features outlining gas-hydrate mounds.

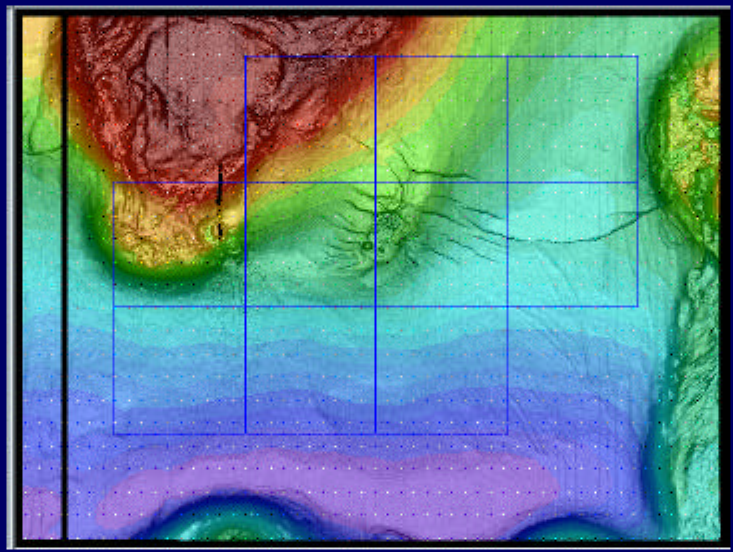
Time map



Dip map



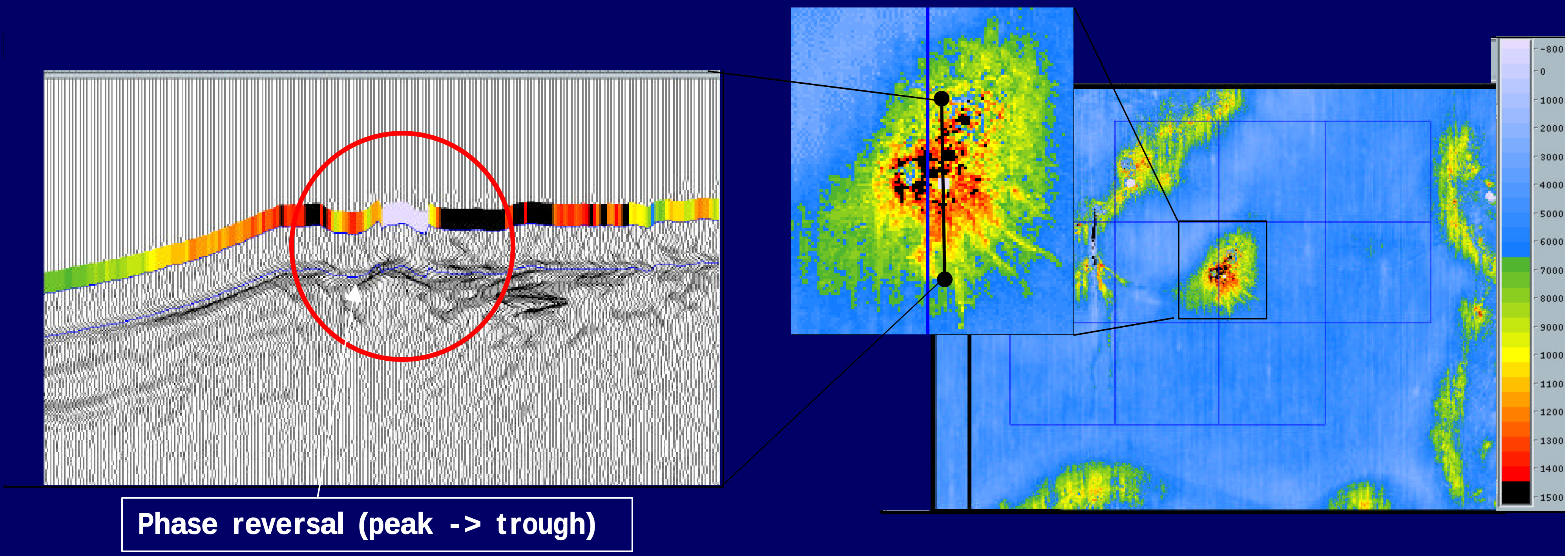
Mixed map



Structural Interpretation

- Conventional Horizon Attributes

Amplitude map of the water bottom shows high amplitudes related to gas-hydrate systems with phase reversals at gas-saturated mud volcanoes.



Stratigraphic Interpretation

Seismic Facies Analysis using NNT: What Is It ?

Seismic Facies: The description and geologic interpretation of seismic reflection patterns including waveshapes (continuous, sigmoidal, etc.), frequency, amplitude, and continuity.

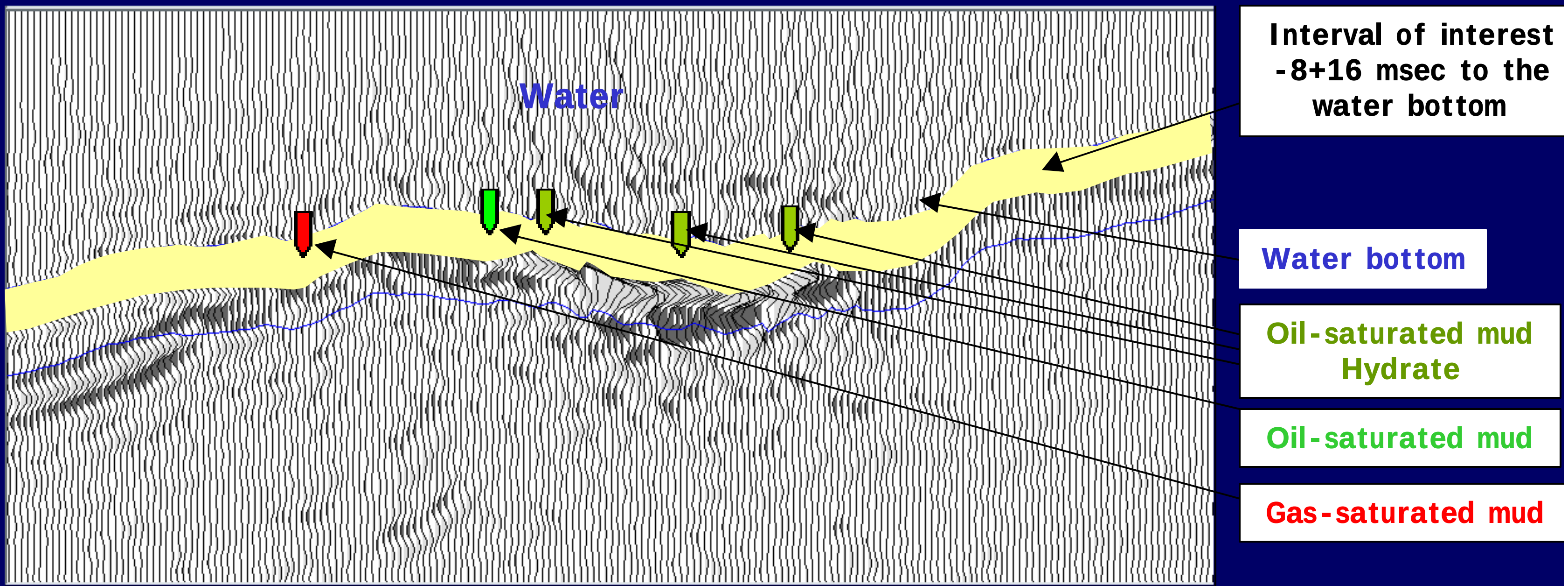
Neural Network Technology (NNT): The ability to analyze and classify trace shapes using a discriminating process.

Seismic Facies Map: This is a similarity map of actual traces to a set of model traces that represents the diversity of various trace shapes present in an interval.

Stratigraphic Interpretation

- **Interval of interest**

Using core samples and horizon slices, an interval of interest was defined to investigate trace shape variations related to water bottom gas-hydrates.

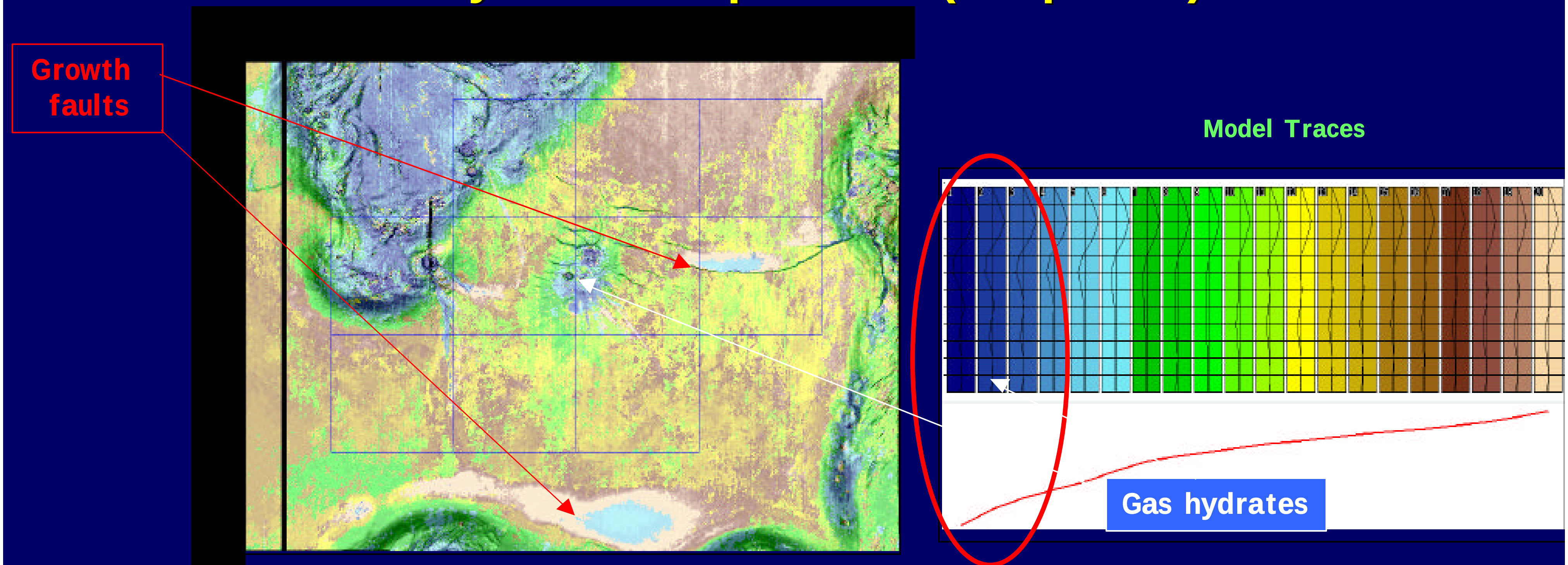


S-N Line trough gas-hydrate samples

Stratigraphic Interpretation

- Unpiloted Regional Seismic Facies Analysis

A seismic facies map was created using 20 model traces (generated by Neural Network) over the 24-msec interval referenced to the water bottom reflector. Gas Hydrates are characterized by trace shapes #1-3 (deep blue).

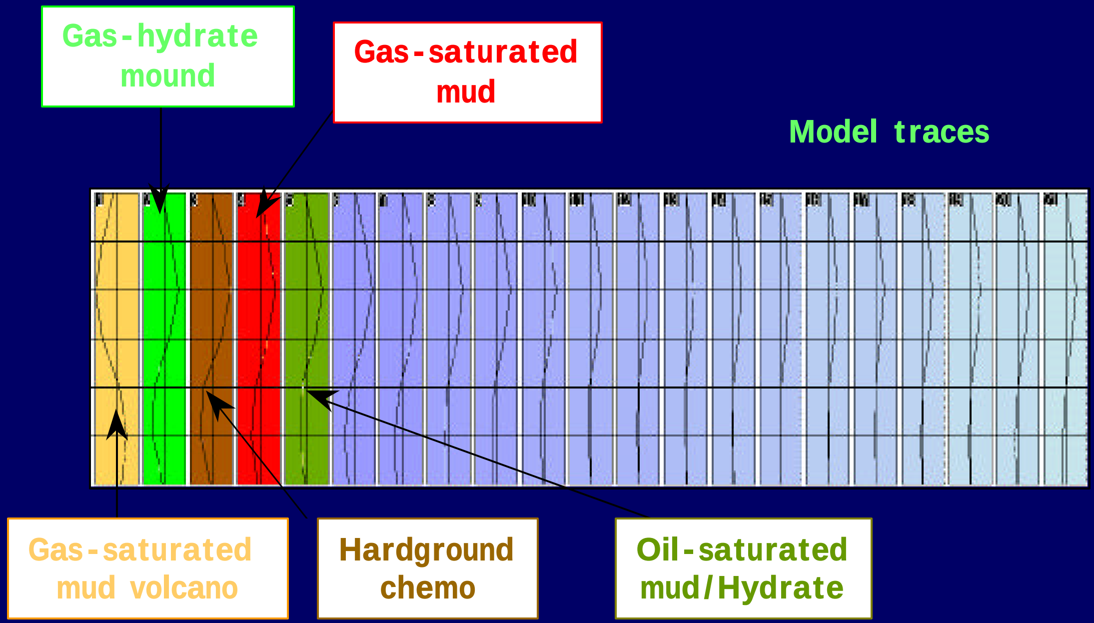


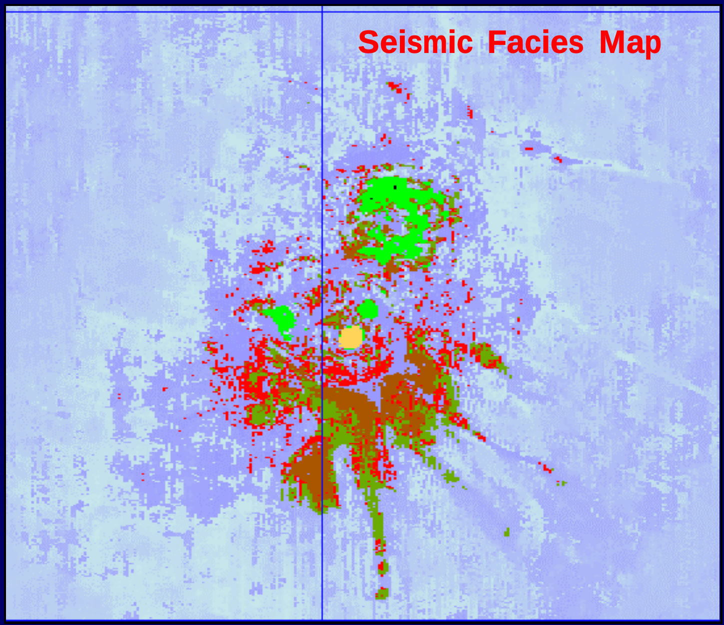
Seismic Facies Map

Stratigraphic Interpretation

- **Piloted Seismic Facies Analysis**

  Using seismic traces at core locations as indicators of gas-saturated mud volcanoes, gas/hydrate mounds, gas-saturated mud, hard-ground chemo and oil-saturated mud/hydrate, piloted seismic facies map was generated over the 24-msec referenced to the water bottom.

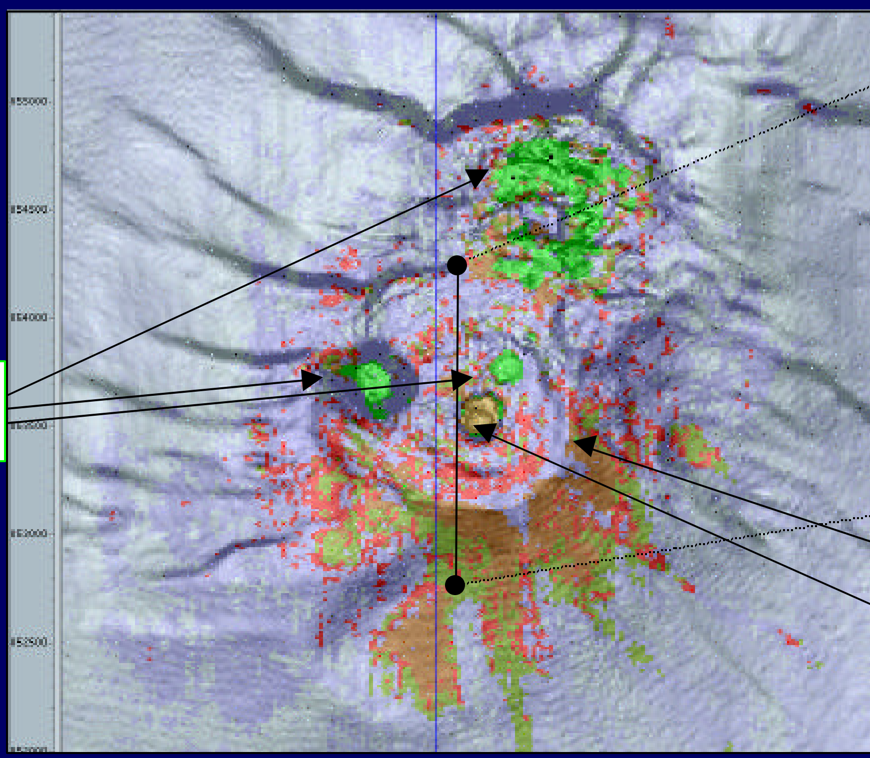




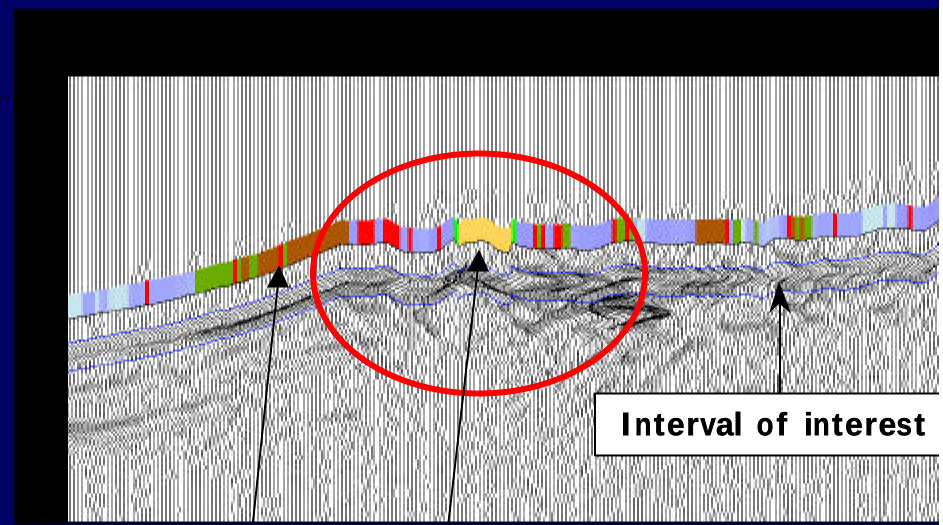
Stratigraphic Interpretation

- Piloted Seismic Facies Analysis

Combining the piloted seismic facies map with the water bottom dip map, several gas-hydrate structures have been identified.



Mixed Seismic Facies/Dip Map

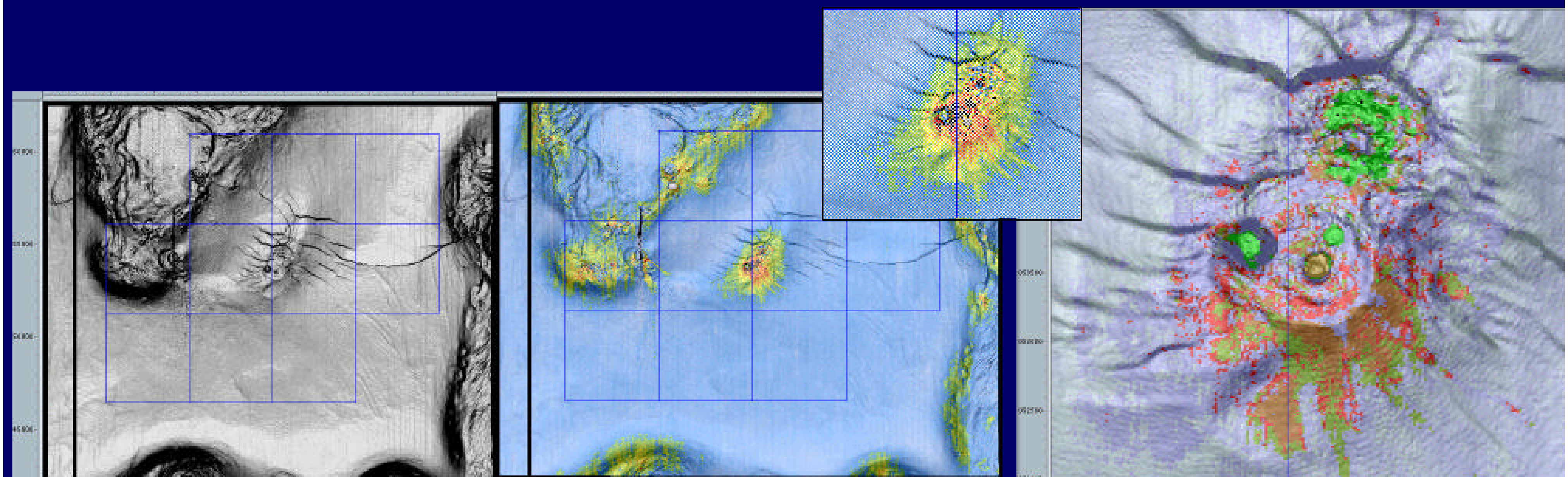


S-N line

Summary

- **Optimized and Safe Drilling location**

Rig/Pipeline location can be optimized to minimize risk of sea floor instability by using a combination of structure, amplitude and seismic facies maps.

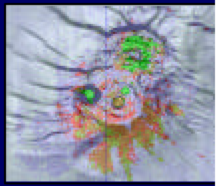


Structure-based approach

Amplitude-based approach

Seismic Facies approach

Conclusions



The knowledge of Sea Floor Geophysics can be greatly enhanced using a combination of conventional seismic analysis, (structure and amplitude) and seismic facies analysis calibrated to gas hydrate and sediment samples.

Stratimagic plays a key role in this new methodology by revealing subtle geological features <u>only</u> expressed in the shape of the seismic trace. The Stratimagic Neural-net based shape recognition can be applied to any seismic attribute (Amplitude, AVO, Frequency, …) in time or depth and does not require high-resolution 3D survey.

This new technology aids in minimizing drilling geohazards such as those related to gas-hydrate and shallow water flows within deep offshore prospects.

Manuel Poupon of Paradigm Geophysical is gratefully acknowledged for his assistance in the interpretation and the preparation of this presentation.

Tuesday
April 3, 2001

HYDRATES

1. Natural gas hydrates R&D in the GOM
Craig Lewis, Chevron

Not all hydrates have BSRs, not all BSRs have hydrates. Can you drill through them without recognizing them?

Yes. LWD may not see them. They are not necessarily "massive" deposits and may not cause any problem.

What is the possibility of shallow gas underneath hydrates?

There are occurrences of free gas under hydrates. Produceable.

Are there BSRs in GOM?

A few in the western Gulf. Scarcity of hydrates could be related to deposition weights, mixed sands and shales in GOM as compared to other areas.

2. Methane hydrates research at DOE National Laboratories
Lorie Langley, DOE Methane Hydrates Inter-Laboratory (Oak Ridge National Laboratory)

What is the National Lab budget and human resource allocation?

1997 -- $500K
1998 -- $1 million
2000 -- $2 million
2001 -- $10 million, but may be reduced

3. Hazard avoidance in gas hydrate bearing sediments: calibrating field observations and applying predictive numerical models
Carolyn Ruppel, Georgia Institute of Technology

Is the implication that both hydrates and free gas are needed for BSRs?

No.

Are you aware of a BSR with no hydrate above it?

Those who model across BSRs say you only need gas below to produce the BSR. But you can have hydrates and no BSRs.

4. Gas hydrates in GOM slope as a potential drilling hazard
Roger Sassen, TAMU

Notes on presentation (35mm slides):

- Structure II and Structure H – oil related hydrates found in Green Canyon GOM
- GOM rapid gas flux from depth – reservoir gas, not hydrate decomposition
- Cannot prove BSRs exist in GOM
- Possibly trillion cu ft of gas in Green Canyon
- 6000 piston cores in GOM
- Bacterial or thermogenic hydrate generation

- Gas hydrate at surface almost always associated with life – edible to organisms – and intense sediment deformation
- Emplacements on seafloor – hard to determine where they exist and to what extent – could be featureless – watch for sediment deformation
- Hydrates less pure the methane – the more heavies included, the more stable the hydrate (shallower, warmer)
- Vein filling by gas hydrates in hemipelagic mud – thickest vein about 40 cm

No questions

5. Sediment effect on hydrate equilibria (seafloor stability, hydrates and sediment)
E. Dendy Sloan, Jr., Colorado School of Mines

Regarding the granular material in experiments – have you included clays?

Started off with simplest material but hope to obtain clays for future tests.

Comment

Showing delta T in unconsolidated sediments too. Also experimenting with acoustic assessment.

6. High resolution, deep-tow multi-channel system studies of deepwater geohazards
J. F. Gettrust, Naval Research Laboratory

What radiation pattern does the helmholtz have?

Looks like a point source. Can be modified – will be testing a scale model soon.

Can you couple the resonator with an AUV to reduce navigation problems?

Would be nice but need funding. Takes a lot of current for light, power.

7. Seismic facies analysis applied to seafloor gas hydrates
Jesse Hunt, MMS

Without ground truth or core data, how confident is this method in virgin areas?

Not as confident. It's hard to say if it's hydrates or carbonates at this point.

Is there a fault under the mud volcano?

It's a wipe out. Would need deeper seismic.

How did you pick the 20 classes? Where did you start the interval?

Did a horizon slice on the seafloor. Studied the wavelets. We developed the best looking maps from using 8 classes.

HYDRATES POST-SESSION QUESTIONS:

Is there a chance that hydrates differ if made by man or nature?

Yes – many activities prove that thermogenic and biological (plus sediment) differ.

Is there a way to get seafloor samples onshore that remain representative of seafloor conditions?

If you freeze the core in liquid nitrogen, it will be preserved very accurately.

Why don't we capture free gas escaping from the GOM?

Don't know why. Could do it with a plastic bucket over Jolliet Field.

What role do sealevel fluctuations play?

If we had a 100m drop in sealevel, **5%** of the GOM hydrate would decompose. A change in temperature of 4 degrees centigrade at seabed would decompose **40%** of the hydrate – over a period of time.

Has there been an attempt to estimate the volume of gas being lost from the ocean?

Yes, they average Pacific and Atlantic emissions, but not GOM or South American areas. The best estimates show that it is insignificant compared to automobile emissions.

Other questions not answered at this time:

If hydrates are not a safety issue, is there any reason industry should be interested in them? (for C. Lewis)

Are there drilling/production safety issues with hydrates below the seafloor? Other than those discussed in the Barker / Gomez and Jamarkin / Davalath papers, have there been many drilling problems? Production problems? (for C. Lewis)

How long before we can predict hydrate formation rates within 10%? How do we scale from pore to labs to field data? (for C. Ruppel)

Deepwater Geohazards Workshop

Sub-Salt Formations
Abstracts

Sub-Salt Drilling Challenges and Solutions

Tom Bowles
Drilling Operations Deepwater Exploration – GoM
BP Amoco Corporation

LINK TO PRESENTATION

Wellbore design and operational drilling plans required for successful penetration of Gulf of Mexico deepwater salt and sub-salt sediment sections required consideration of the varying rock stresses and induced pore pressures created by these intrusive salt bodies. Several techniques have been used by BP to successfully drill and case these sediment-to-salt intervals. A discussion of wellbore designs and drilling practices used to maintain wellbore stability will be addressed based upon experience gained during recent drilling operations conducted in the Green Canyon lease block areas.

Drilling bit mechanics and BHA selections used to penetrate and control wellbore deviation required to mitigate damaging doglegs will be reviewed. Techniques used to measure pore pressure while drilling operations for real-time relative pore pressure change indications, well control considerations, and potential drilling fluid loss control will also be discussed.

Potential Problems Associated with drilling Salt and Sub-salt

LINK TO PRESENTATION

The Atlas Prospect is a four-way structural closure covered by an allochthonous salt sheet of Late Miocene to Early Pliocene age. The objectives are Upper to Middle Miocene lowstand turbidite fans deposited in a salt withdrawal basin centered in Mississippi Canyon Blocks 713-714. Fair to poor seismic definition increases the trap uncertainty.

The first well, MC 713 #1, encountered high-pressure sediments above salt associated with a converging Pliocene Shale wedge. These unexpected pressures required an extra casing string to reach salt. Another unplanned casing string was required in salt, when high pressure was encountered 1200 ft. from the base. This high pressure was due to fractures in the salt associated with a sub-salt fault. Below salt, high pressure, water-wet sands flowed water up and into the base-salt/sediment interface, forcing the well to be P&A'd. A sidetrack in salt was attempted, however, the higher pressured sub-salt section was now in communication with the salt fractures. The sidetrack was P&A'd. Two subsequent wells, MC 714 #1 & 2, were J&A'd with mechanical problems.

Lessons learned from the 713 #1 well, and extensive planning mitigated most of the problems above and in salt in the MC 714 #3 well. The #3 well was positioned near the edge of the Pliocene Shale wedge, and where the base of salt was free of structural complications. The well did not experience the same problems that caused abandonment of the 713 #1 well. However, fracturing of the salt, while drilling near its base, forced the setting of casing 33 ft. below salt rather than the planned 1000 ft. Fracturing within salt occured 1400 ft. from the top of salt. The salt failed because the high mud weight, necessary to drill out of salt, exceeded the fracture gradient of the salt. The well continued to drill 1000 ft. below salt where converging pore pressure and fracture gradient made it impossible to drill ahead. The second well was also P&A'd. Total well cost for the project was $65.4 MM.

VSP INVERSION TECHNIQUES FOR SUBSALT PORE PRESSURE PREDICTION – ATLAS PROSPECT (MC714)

Matthew Czerniak, Texaco

LINK TO PRESENTATION

A study was initiated to assess the confidence and accuracy of pore pressure prediction techniques utilizing "Look Ahead" VSP Inversion Technologies for subsalt applications. Post-drill analysis using partially Constrained Sparse-Spike Inversion (CSSI) of conventionally processed vertical seismic profile (VSP) corridor stacks were used to estimate earth (interval) velocities "Ahead of the Bit" for use in pore pressure prediction: 1.) Below the base of salt (MC714 #1), and 2.) Beyond the final TD of the MC714 #3 well at approximately 16,000 ft. TVDkb for the Chevron-Texaco Atlas Prospect, Mississippi Canyon Block 714.

The Atlas Prospect (MC714), located in 3250 ft. of water in the Eastern Gulf of Mexico, was an ideal case study because a conventionally processed VSP was acquired both in the MC714 #1 well (corridor stack #1 - shot wholly within salt), and in the MC714 #3 well (corridor stack #2) acquired 1000 ft. below base of salt. Although the intention was to assess pore pressure prediction techniques, the conclusions suggest that any renewed interest in the prospectivity and drillability of this area should be re-evaluated and viewed, in the context of this study, as unfavorable.

The daily drilling history for the well reported that the base of salt was exited with a surface equivalent mudweight of 14.6 PPG (15.2 EMW ECD) at a depth of approx. 15,000 ft. TVDkb and immediately experience well control problems, kicks, and lost returns. The mudweight was increased several times over the next 1000 feet to in excess of 15.5 PPG (16+ EMW ECD). The well was abandoned after running 9 5/8 inch casing to that point without validating a Leak-Off test (LOT) that would have allow a sufficient drilling margin to continue the well.

The following comments are compulsory with the conclusions of this assessment:

- The acoustic impedance profile (in time), which resulted from the inverted corridor stack waveform from the MC714 #3 well (*cstk2*), agreed favorably with the "Look Ahead" VSP profile generated by inversion of the MC714 #1 well (*cstk1*) acquired wholly within salt, confirming the look-ahead capability within salt.

- The acoustic impedance profile from the inverted corridor stack waveform from the MC714 #3 well (*cstk2*) was compared against the pseudo acoustic impedance profile generated from the cross product of the checkshot interval velocity with an empirically-based velocity*density transform (Gardner-type transform), and against the actual velocity-depth function. The comparisons below the base of salt were in close agreement with the recorded data.

- The "Look-Ahead" inverted velocity-depth function from the MC714 #3 well from final TD (16,000 ft. TVDkb) onward was transformed to pore pressure and projected along with the previously plotted checkshot and mudweight data. The results suggest that the pore pressures at the Atlas Prospect MC714 #3 location remain at-or-near hard overpressures for projections down to approximately 23,000 feet TVD. An assessment of the drillability of this prospect, even optimized with expandable casing sections, suggests that this prospect will resist being drilled. This also reflects poorly on the seal integrity of any shales being viewed as a cap-rock.

Key Fluid Attributes for Successful Sub-Salt Drilling

Mike Johnson, INTEQ

LINK TO PRESENTATION

The advent of more advanced seismic imaging has made identification of sub-salt structures more readily identifiable and has led to increased sub-salt activity. Sub-salt exploration can be challenging due to a plethora of issues associated with salt and salt migration.

Early in the well construction process, shallow geo-pressure may exist as a result of salt movement. The result can be a costly exhaustion of casing inventory in the early phases of the well.

Within the salt structure, the rates of penetration (ROP) for water and Psuedo-oil mud have historically been very low. Additionally, attempts to increase the ROP by increasing the weight on bit (WOB) have led to unacceptable inclination problems. These areas have seen improvement utilizing straight hole drilling devices, in association with bit type and weight-on-bit maximization.

The “rubble” or the “gouge” below the salt, can be characterized by fractured, highly reactive and poorly cemented rock. In-situ pressure within the “rubble” or “gouge” may exist if an adequate trapping structure is present at the point the salt is exited. This abnormal pressure, coupled with pre-existing fractures and poor rock cementation, can create a very low window of operation. Pore pressure and fracture pressure proximity can lead to loss of circulation problems. The tendency for loss of circulation can be exacerbated if hole cleaning, bit or bottom hole assembly balling lead to annular pressure increases in this highly reactive clay environment.

In some cases, sub-salt prospects are drilled with minimal Non-Productive Time (NPT). The reasons for this divergence, can in many cases, be explained by examining the pre-planning, execution and end-of-well processes. It is beyond the scope of this presentation to describe an integrated approach to wellbore stability, but fundamental parts of this approach will be discussed.

This presentation will focus on many of the problematic areas previously mentioned, key fluid attributes to address these areas and explain why these attributes contribute to a vital component of sub-salt drilling, hole stability. This presentation will also attempt to parallel several potentially successful sub-salt fluids.

Analysis of Salt Creep in a Deepwater GOM Well And Preventing Salt-induced Casing Damage

H.C. Ballew, Halliburton Energy Services

LINK TO PRESENTATION

When asked to identify a geo-hazard associated with deepwater operations in the Gulf of Mexico, the majority of operators would probably identify shallow water flows. A tremendous amount of industry attention and resources have been applied to developing means of preventing and remediating problems that arise from the occurrence of a flow. Operators drilling through salt formations, would probably identify the long term risk associated with salt creep as a greater hazard than shallow water flows.

While drilling operations are in progress it is possible to control the onset of salt creep. A straight line function response to in-situ stress changes is all that is required to prevent salt creep from occurring. To illustrate this point for every one pound per gallon increase in the in-situ stresses the mud weight must be increased by one pound per gallon to prevent an acceleration of the salts closure rate. The rate of salt creep in the Gulf of Mexico is on the order of 2.5 – 3.0 inches per year.

During cementing operations it is possible that the rate of salt creep may be accelerated while the cement is transitioning from a liquid to solid state. As cement begins to develop gel strength it looses its ability to transmit hydrostatic pressure throughout the length of the cement column. Since salt creep is a function of the differential pressure placed across the formation, it is possible that salt may deform the bore-hole and point-load the casing during this critical period. Preventing point-load damage depends on a synergistic approach in well planning that combines several design parameters. It is important to drill a smooth, uniform hole size in salt with adequate annular clearance to enhance mud displacement by primary cement slurries. The slurry must resist salt creep during curing by maintaining a positive differential pressure until it rapidly hardens The hardening period must be reduced to minutes instead of hours to quickly distribute salt loads with structural properties such as ductility and tensile/compressive strength. Along with complimentary casing designs, these measures will help prevent casing damage by point loading. Experience has shown that casing failures will occur much sooner if well designs don't prevent point loading.

Numerical Analysis, can be performed to determine the effect of salt creep on cement sheath and casing during various stages of the wells life. When the mechanical properties of cement such as Young's Modulus, and Poisons Ratio of the cement are known, its ability to withstand the salt movement may be determined. The analysis, may also be used to determine the cement that could delay casing collapse. If it is not possible to achieve a uniform placement of cement within the annulus, it may be better to tack the shoe and leave the salts uncemented. When primary cement placement fails due to hole conditions such as lost circulation, the model may predict the onset of point loading, the potential for damage, and if remedial cementing must be used to prevent loss of the well.

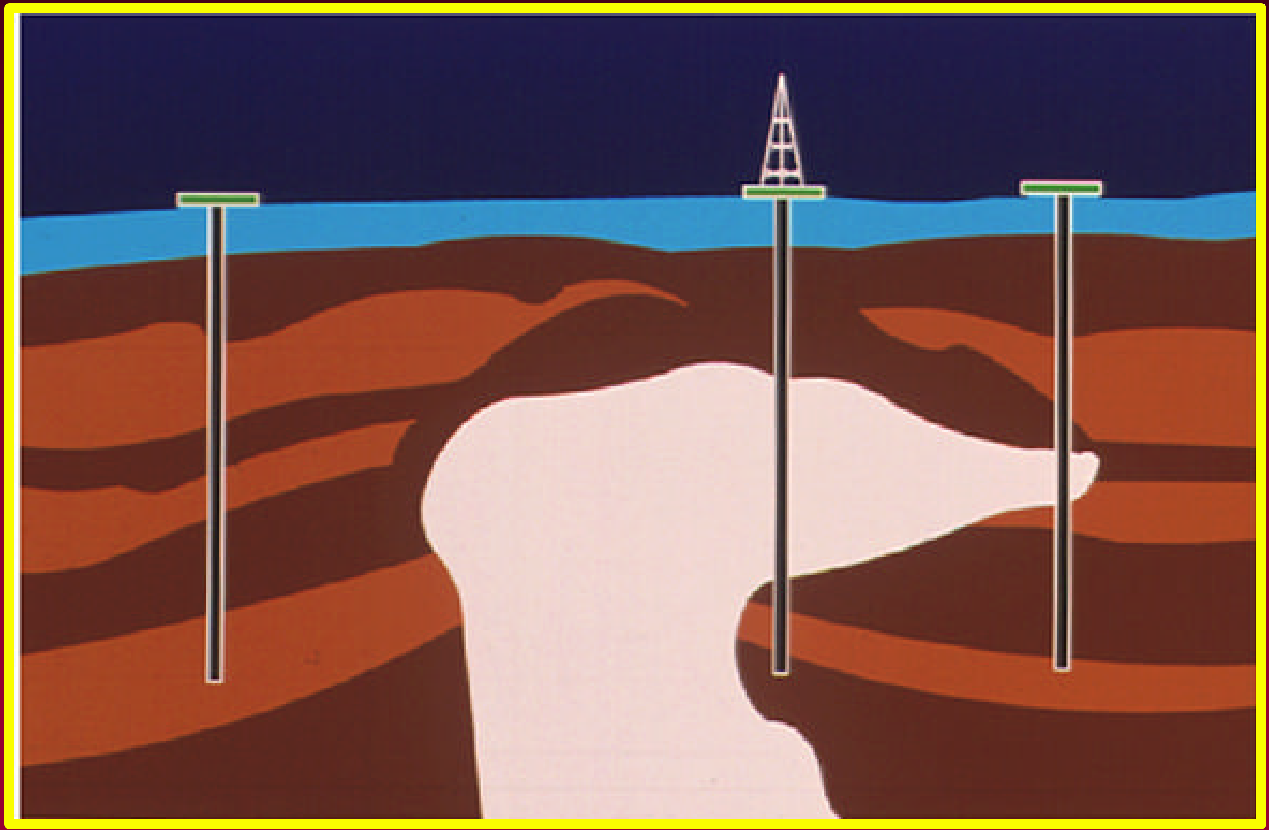
Deepwater Geohazards Workshop

Sub-Salt Formations
Presentations

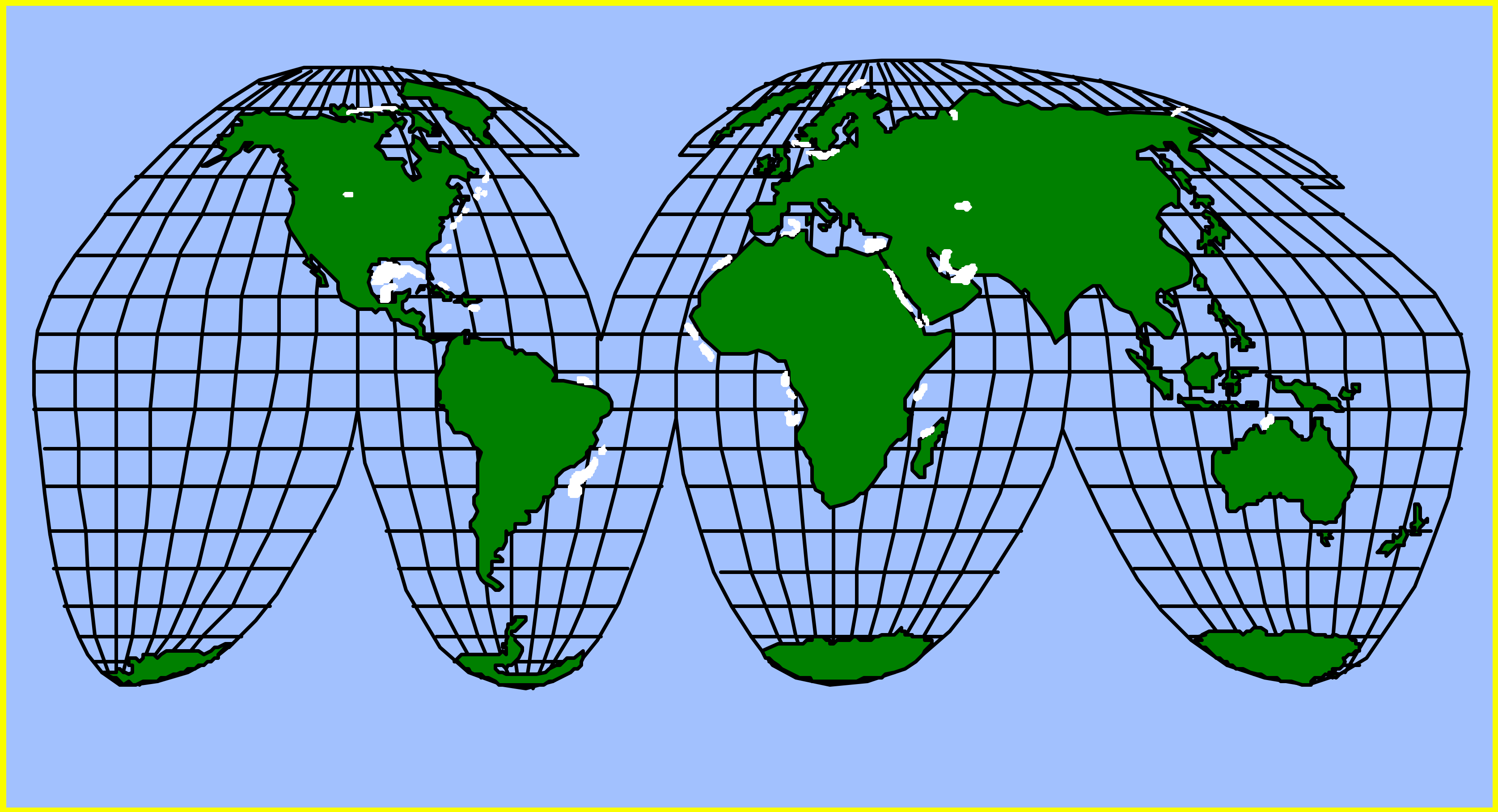
Sub-salt Well Geo-Hazards

by

Ron Sweatman

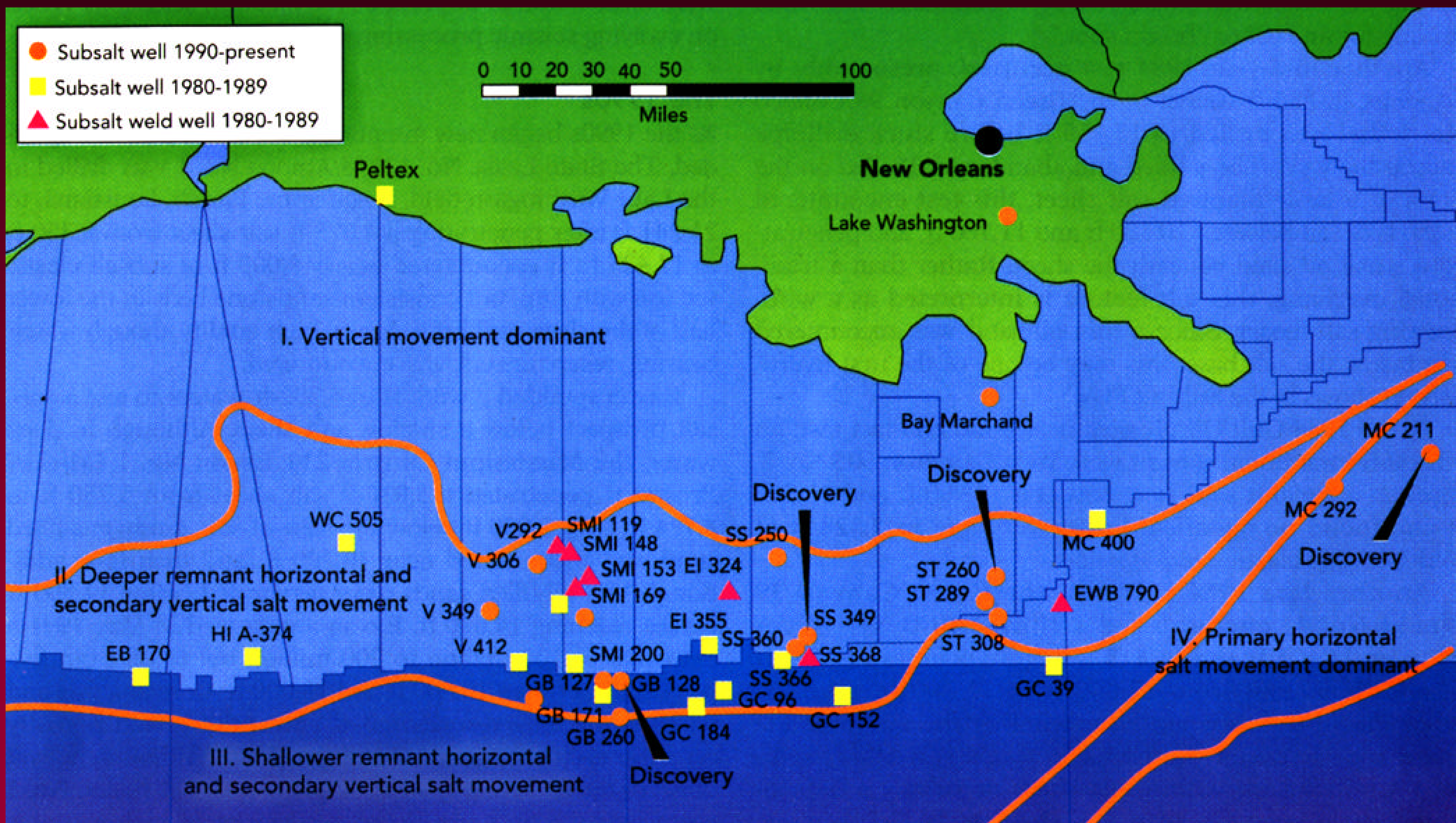


Global Sub-salt Locations



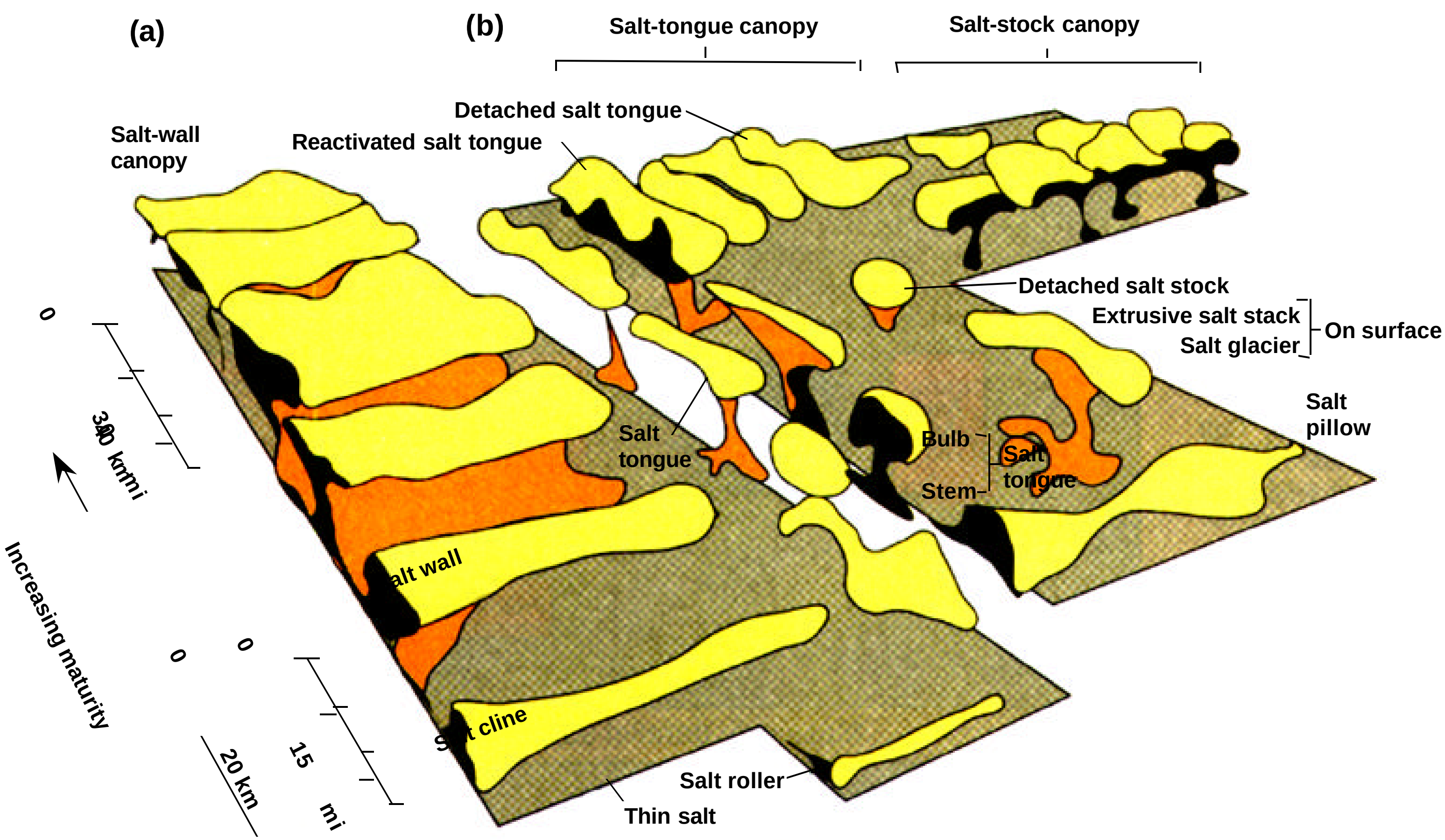
(From University of Texas Bureau of Economic Geology, Offshore, January 1994)

GOM Sub-salt Well Locations



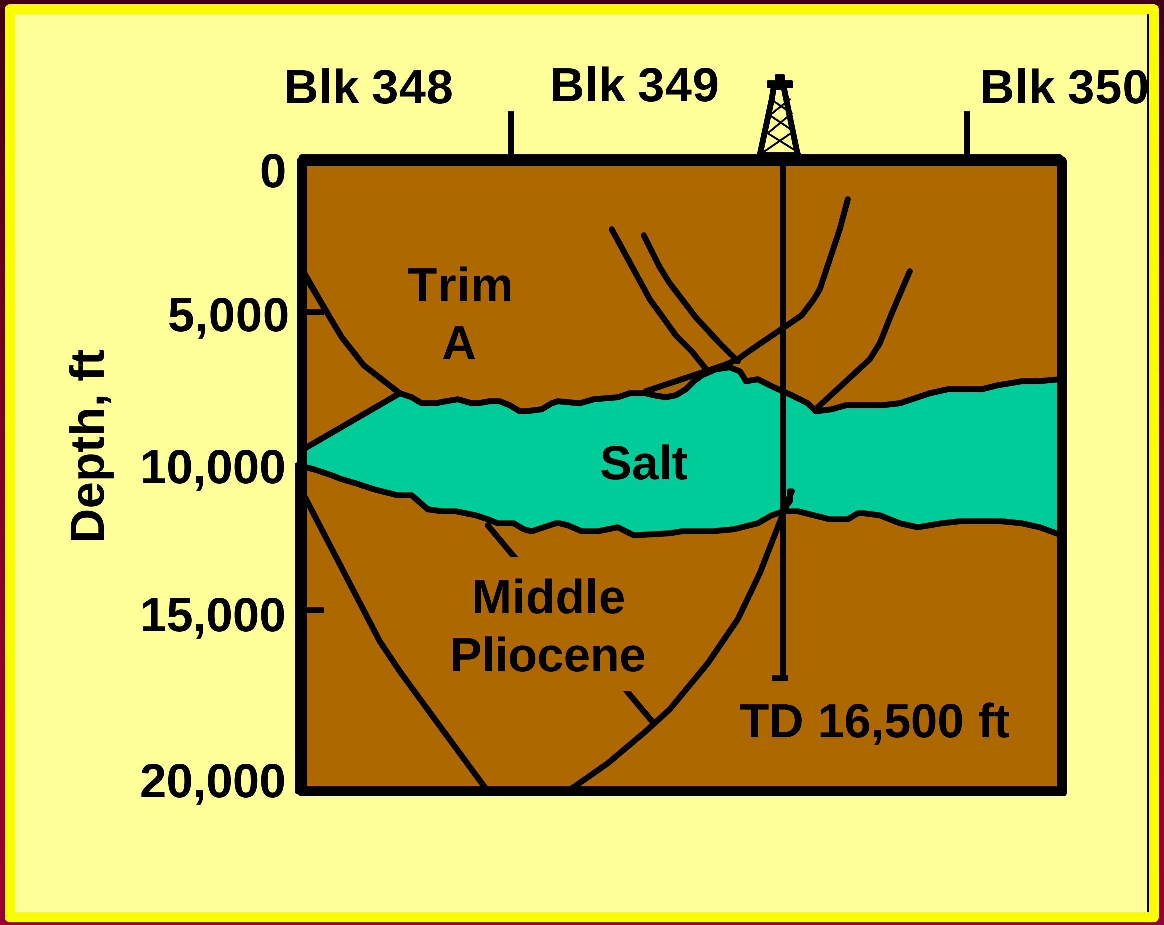
(From Moore & Brooks, P.E.I., December 1995)

Sub-salt Structures



(From University of Texas Bureau of Economic Geology, Offshore, January 1994)

Mahogany Prospect Cross Section



(Modified from Phillips Petroleum, World Oil, September, 1994)

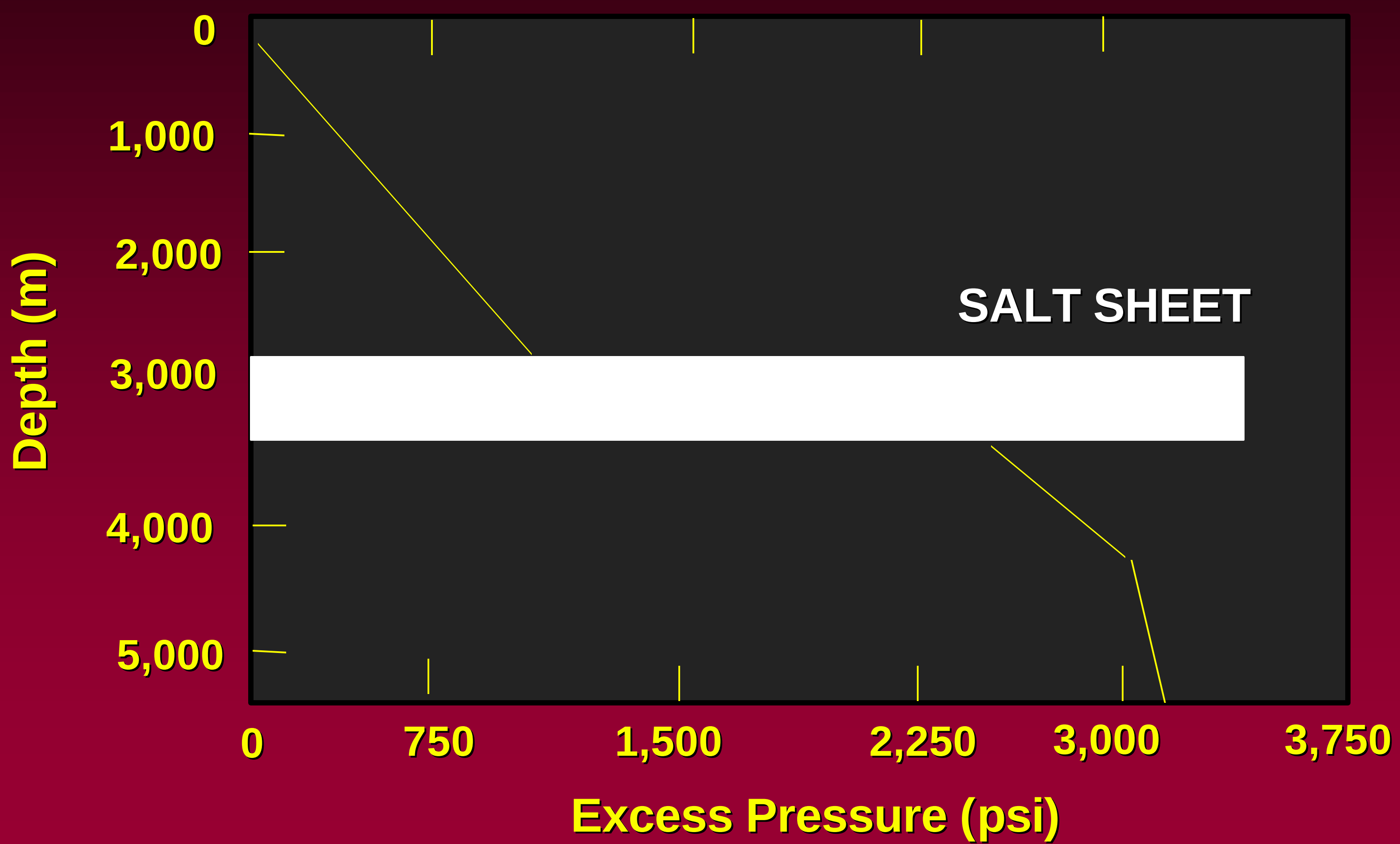
Sub-salt Well Effects on Drilling Practices

- **Safe Mud Weight Range for Zone Strength Criteria**
- **New Models May Reduce Trouble Zone Costs**
- **Vertical vs. Deviated Wellbore Paths**
- **Kicks & Underground, Uncontrolled Inter-Zonal Flows**
- **Casing Seat Depth Selection & Setting Pipe Early**
- **Contingency Drilling Liner or Plan Remedial Squeeze**
- **Slow Rate of Penetration & Gumbo**
- **LCM for Mud & Lost Circulation Squeezes**
- **Poor Results Running Casing & Cementing**

Potential Effects on Production

- **Casing Damage Across the Salt or Adjacent Zones**
  - Slow Ovalization Impairs Workover Operations
  - Possible Leaks in Tubulars
  - Premature Loss of Production
- **Loss of Zone Isolation and Annular Pressure Migration**
  - Annular Surface Pressure or SCP (Sustained Casinghead Pressure)
  - Trapped Annular Pressure Induced Casing Collapse
  - Corrosive Effects May Jeopardize Well Integrity
  - Loss of Production to Non-Productive Zones

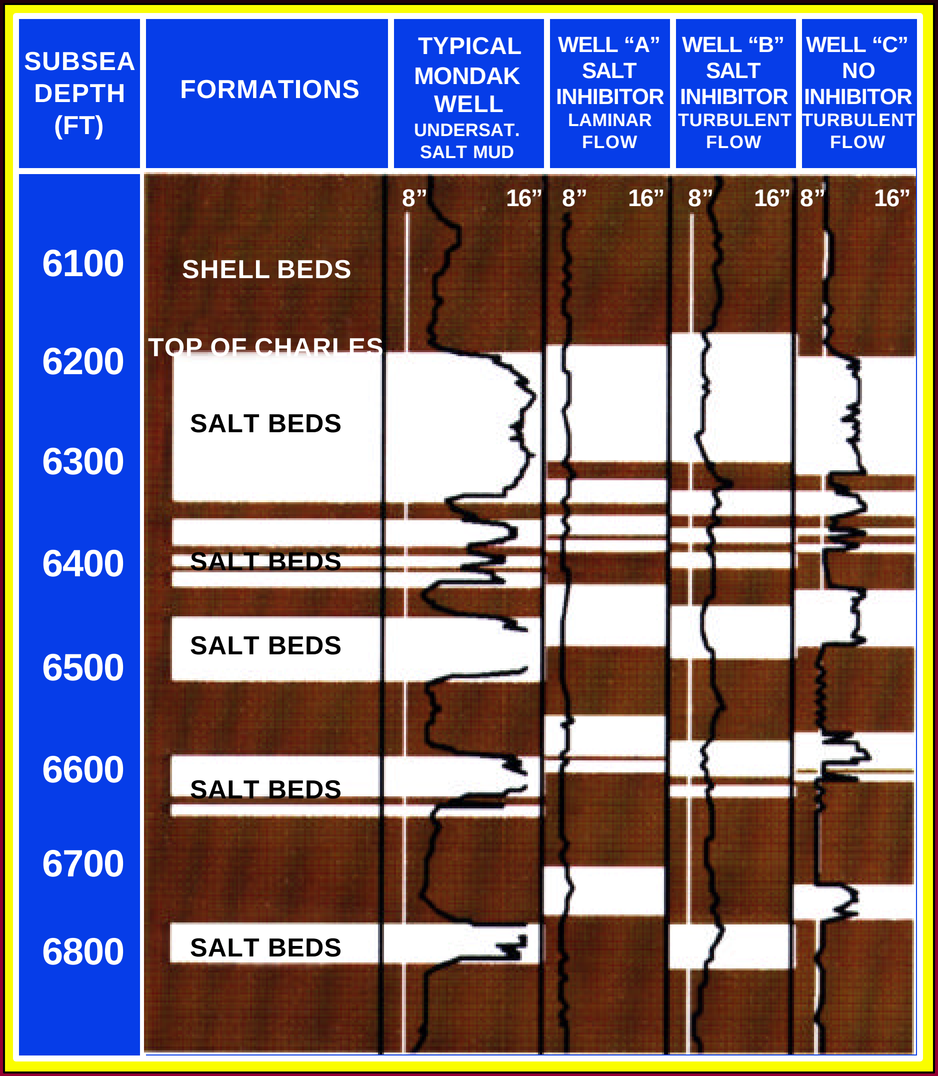
Overpressure Profile



(From Oil & Gas Journal, Jan. 24, 1994)

Salt Zone Temperature Effects

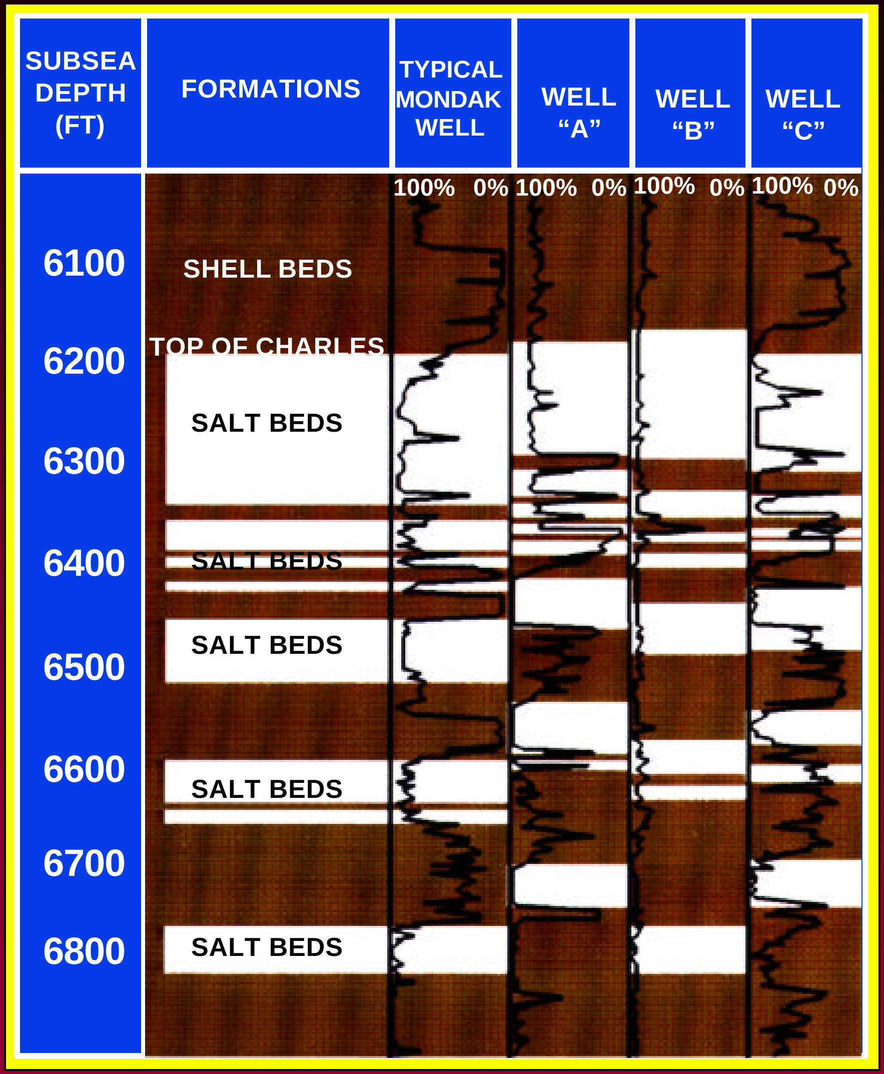
- **Higher Thermal Conductivity in Salt**
- **As Salt Zone Thickens**
  - **Under-salt Temperatures Decrease**
  - **Top of Salt Temperatures Increase**
- **Measure Temperatures for WOC Times**



Caliper Logs From Comparable Wells

(From Earl & Nahm, SPE 10097,1981)

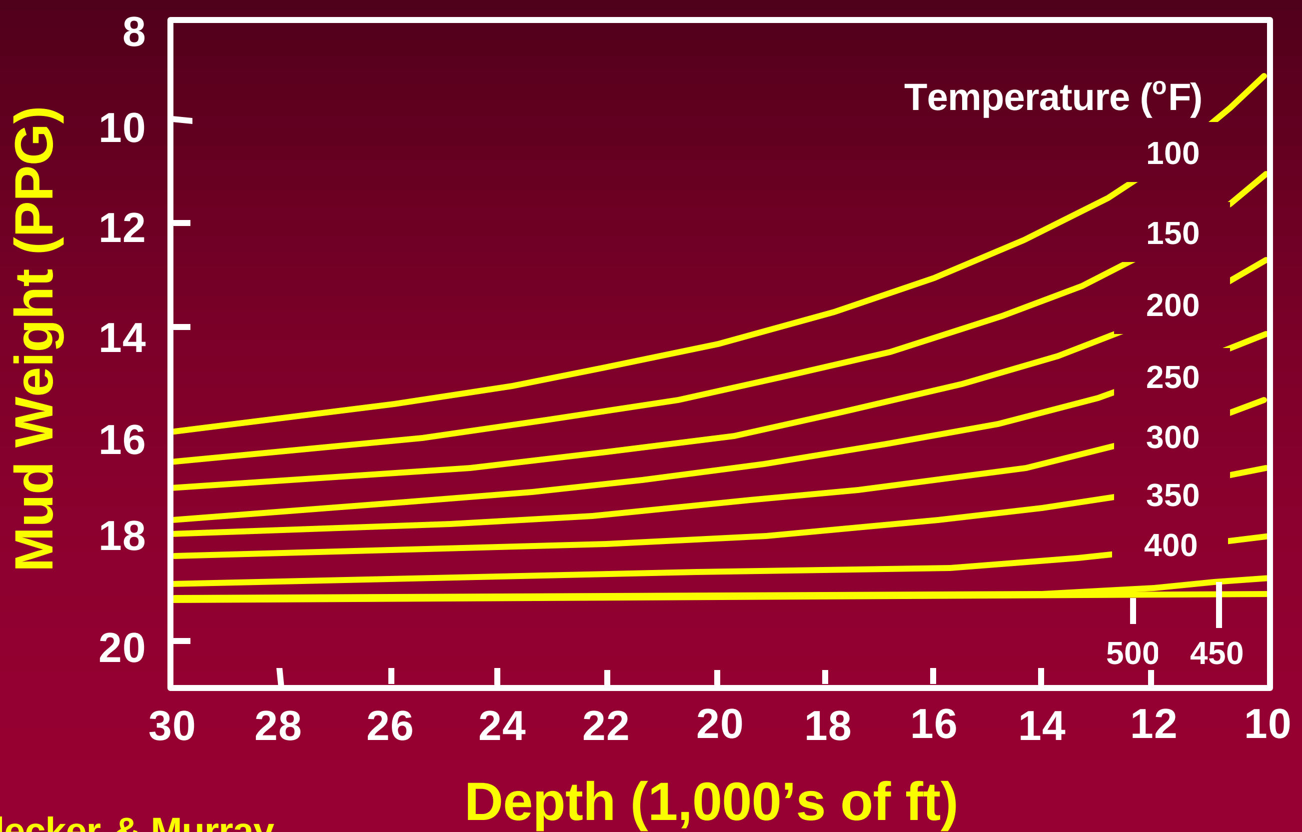
Cement Bond Logs From Comparable Wells



(From Earl & Nahm, SPE 10097, 1981)

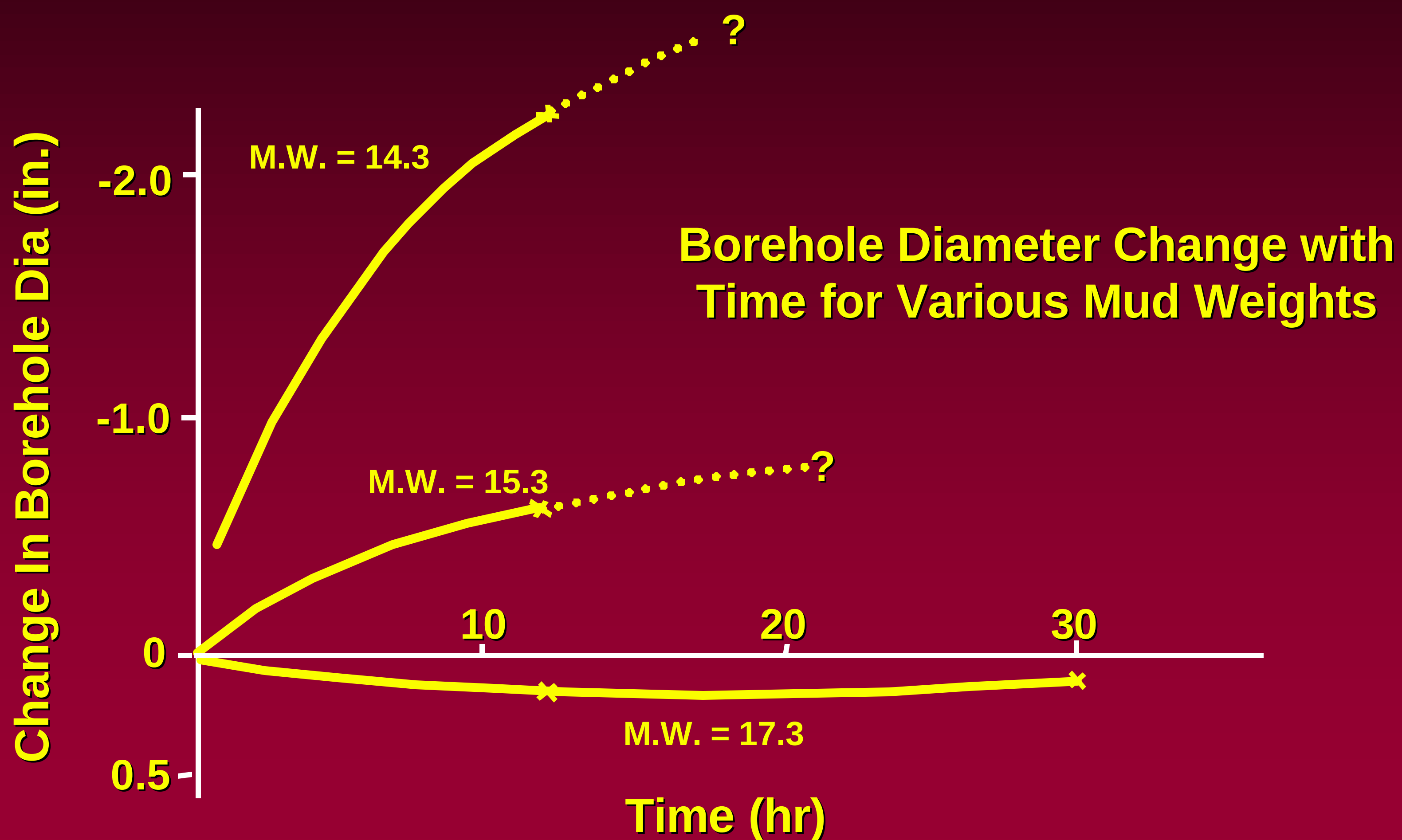
Mud Weights For Salt Creep Control

At 0.1% Closure Per Hour



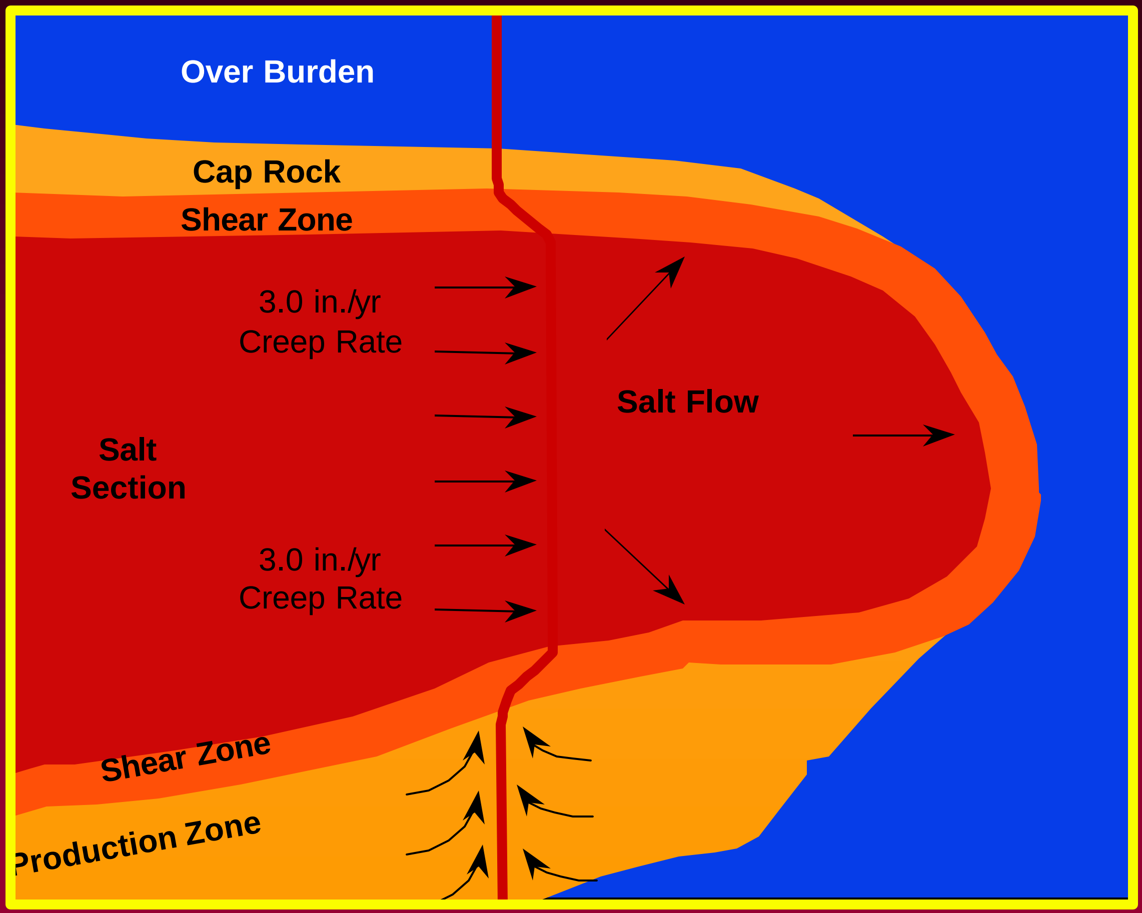
(From Leyendecker & Murray, World Oil, April 1975)

Measured Salt Flow



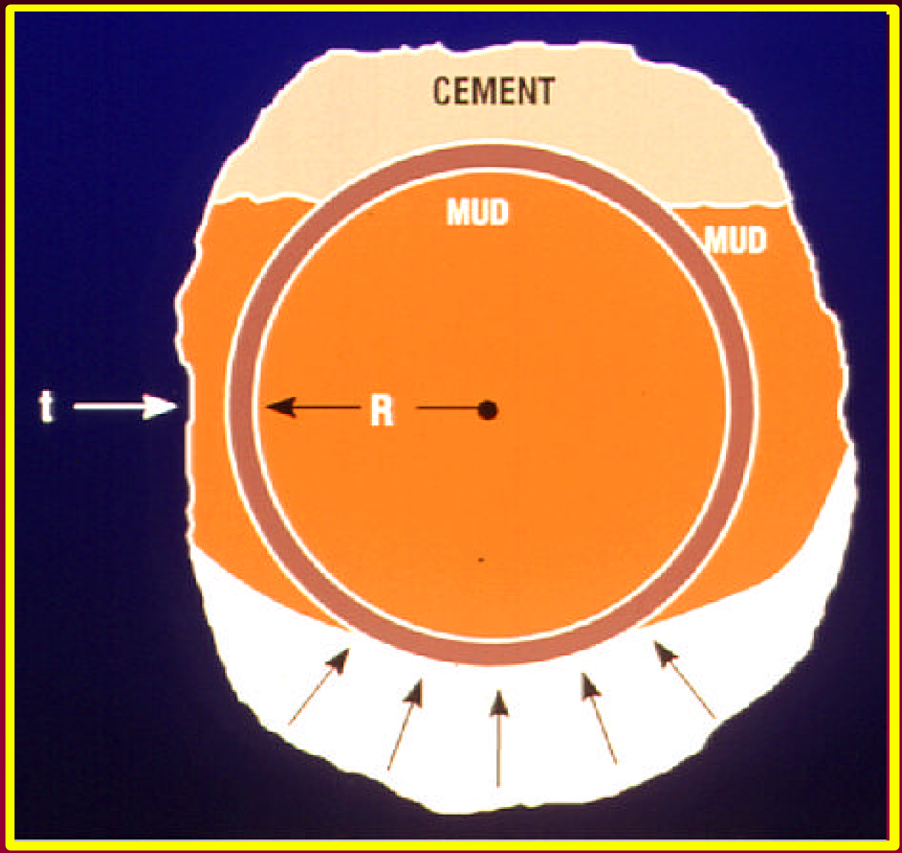
(From Kim, SPE 18030, 1988)

GOM Salt Creep



(Source: Offshore Magazine, August, 1994)

Situation Causing Point Loading

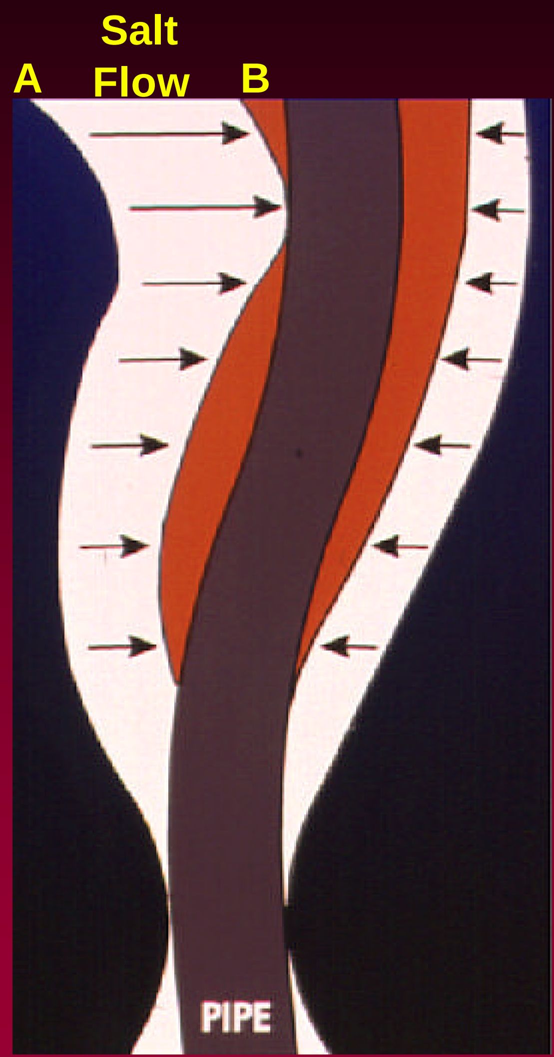


Arrows Indicate Salt Movement

(From Patillo & Rankin, P.E.I., November 1981)

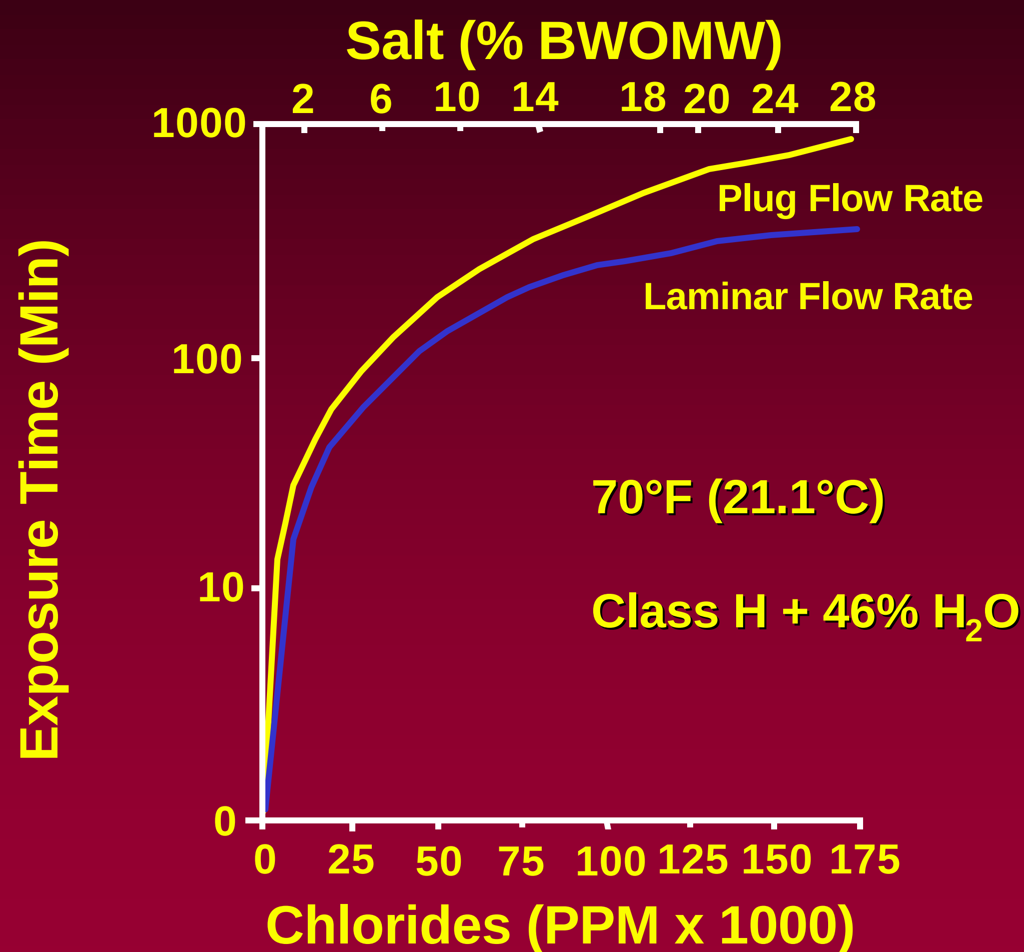
Curvature Forces Due to Salt Flow

A: Time = t
B: Time = t + ∆t



(From Patillo & Rankin, P.E.I., November 1981)

Salt Dissolution Rate



(From Goodwin & Phipps, SPE 10885, 1982)

One of the Wells from Sub-salt Hell

- **Rig Took a High Rate Kick and BOP Closed Annulus**
- **Sustained High Pressure Broke Down the Shoe**
- **Salt Water Influx from Zone Just Above Massive Salt**
- **Influx and Exit at Shoe Thought to be ~2 bpm**
- **Temperature Survey & Nodal Analysis Estimated Underground Blowout of 30,000 bbls/day (~20 bpm)**
- **Dynamic Plugging Treatment Killed the Flow at Shoe**
- **Drilling Below Salt Junked the Well by Excess Gumbo**

“Sub-Salt Drilling Challenges and Solutions”

By Tom Bowles
BP Amoco Corporation

Deepwater Geo-hazards Workshop

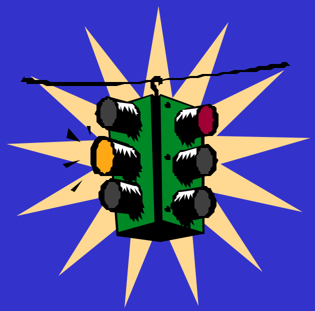
April 3-4, 2001

DEA / MMS Forum

Del Lago Resort

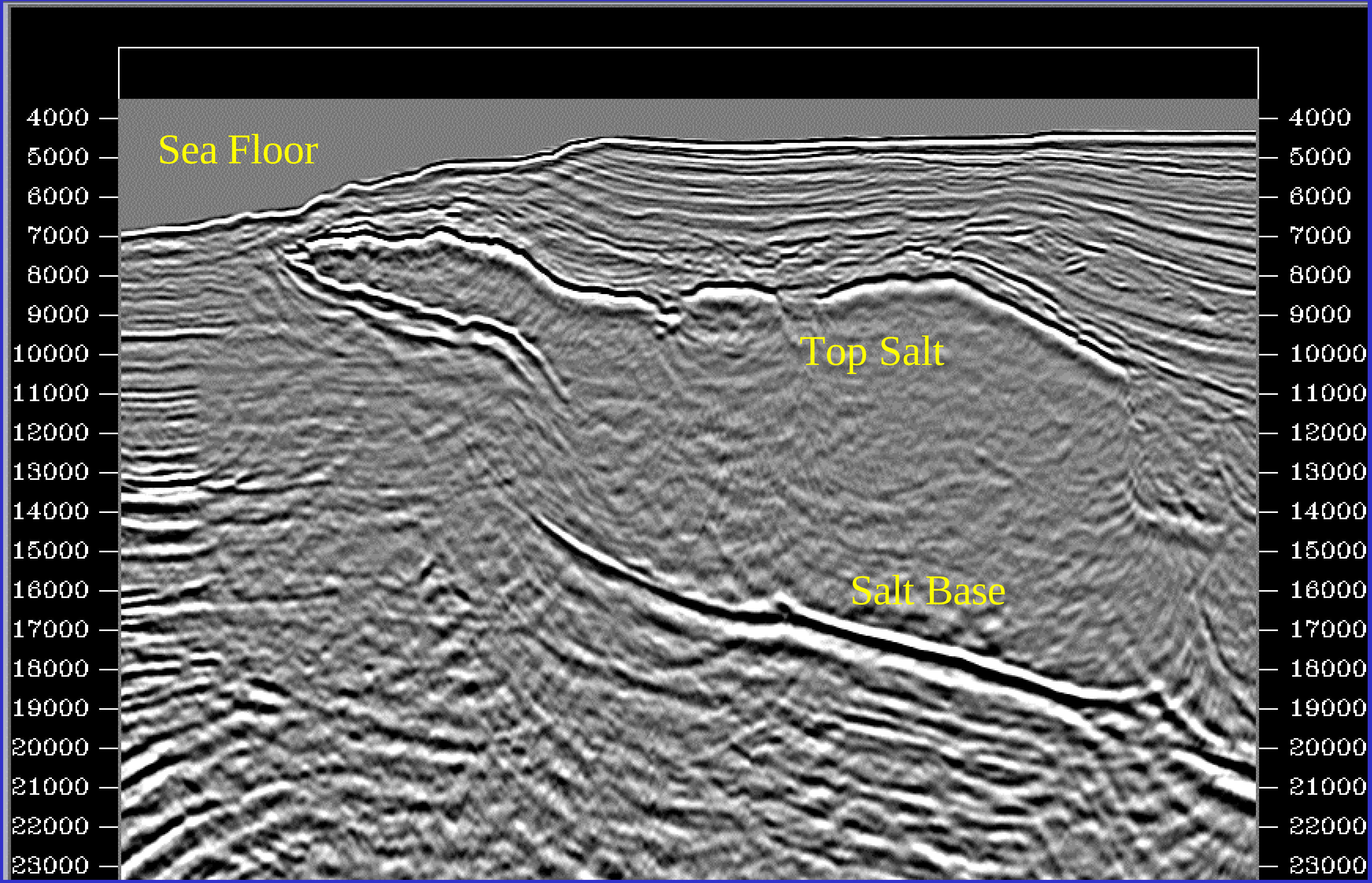
Topical Overview

- **Overview**
  - **Salt Structural Features**
  - **Salt Interface with Sediment**
- **Challenges**
  - **Sediment Pore Pressure Impacts**
  - **Wellbore Stability**
  - **Well Plan Designs & Drilling Mechanics**



- **Solutions**
  - **Improved Pore Pressure Prediction / Real-time Data**
  - **Industry Development of Drilling Tools**
  - **Creative Economical Wellbore Plans**

Typical Salt Body Profile



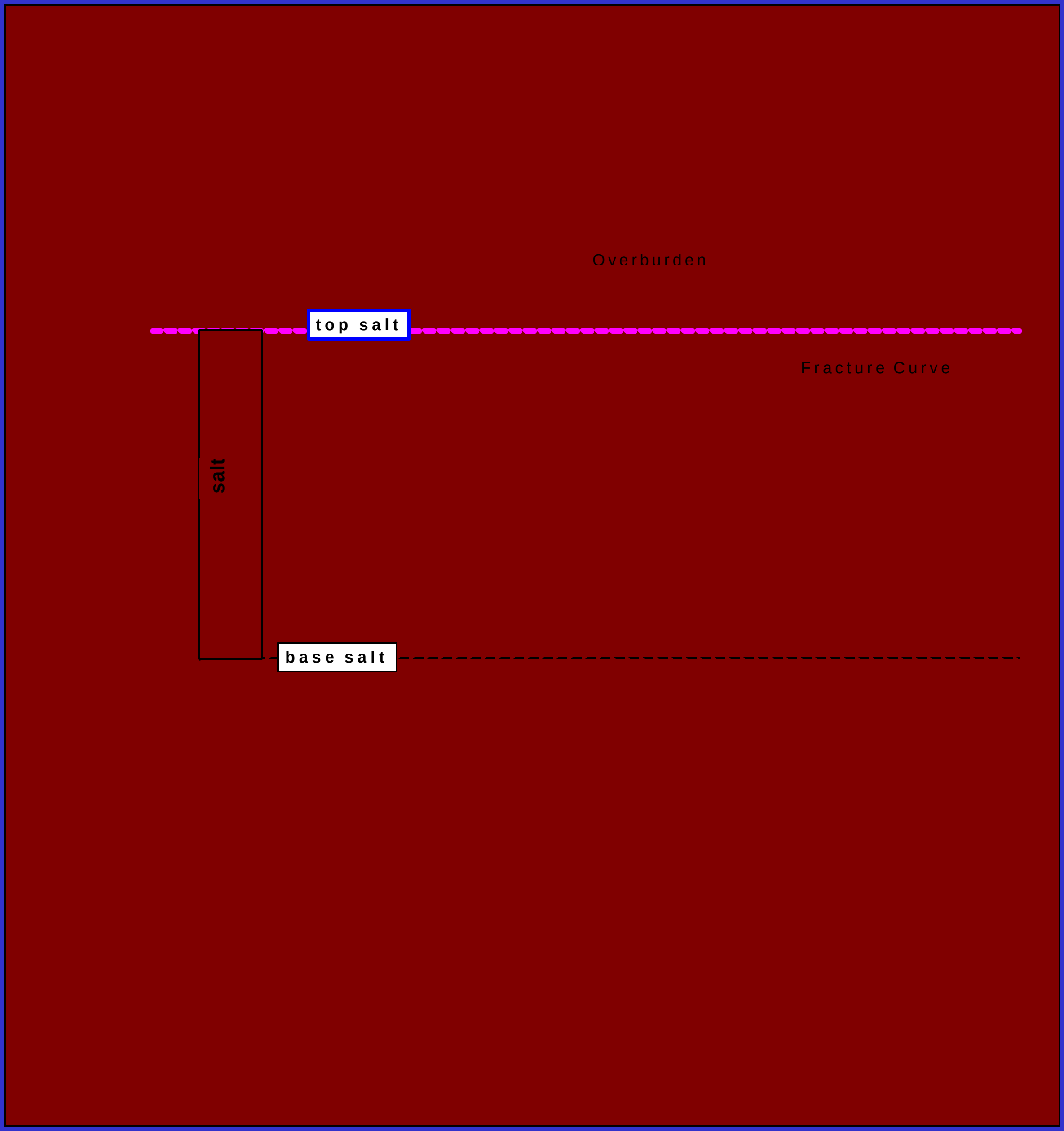
Salt Features

- Highly variable in Depth and Thickness encountered.
- Perimeter or Flank Salt Stringers extremely troublesome.
- Salt / Sediment interface to main salt body rubbled within 500 ft.
- Salt may induce or create abnormal trapped pore pressures within sediments.

Salt Features (cont'd)

- Encapsulated Sediments within salt may contain equivalent overburden pressures.
- Salt is usually "hard" yet not abrasive to drill.
- Directional wellbore control is required in salt sections as sever doglegs can be experienced.
- Normal sedimentary sequence in adjacent rock may be disrupted and non-correlative.
- Fractures and Faults may exist without seismic detection.

Salt Associated Pressures



Drilling Challenges

Pore Pressure Prediction Impacts

- Seismic and Basin Modeled pore pressure predictions limited by relatively poor quality velocities and structural complexities associated with Salt bodies.
- Probable high variation on predicted vs. actual pore pressures within near vicinities of salt.
- Current well drilling operations subjected to possible under-balanced “or” over-balanced conditions leading to wellbore kicks or conversely massive lost returns.
- Creates difficulties designing economic well casing programs.

Drilling Challenges(cont'd)

- Difficult determining casing point selection with
- High variations possible of geologic horizons.
- Potential wide ranges of pore pressures and resulting pressure differentials.
- Bore-hole size considerations for penetrating salt sections.
- Extreme possible TVD range for Salt occurrences. (Some wells have never exited salt at Total depth.)

Drilling Challenges (cont'd)

- Wellbore Mechanical Stability
  - Rumble zones associated with salt difficult to control. Extreme instability if sediments are encapsulated within salt causing "running shale's".
  - Wellbore deviation control while drilling salt intervals susceptible to high dogleg severity (>7deg/100ft).
  - Complexity increases when drilling adjacent of near main salt body walls or salt wedges (fingers). Hole Instability (pack-offs, losses, reaming).

Drilling Challenges (cont’d)

- Drilling Mechanics
- Salt drilling ROP extremely sensitive to WOB.
- For large borehole sizes require tools somewhat limited to drill at high ROP’s while maintaining wellbore deviation control.
- Directional corrections for high dogleg severity occurrence is very difficult to mitigate.
- Massive salt sections demand “long bit runs”. Current PDC bits and BHA experiencing “slip-slick” vibration and reactive torque causing down-hole tool failures.
- Bi-center bit boreholes require improved BHA stabilization tools to mitigate premature failure damage in salt sections.

Drilling Solutions

<u>Salt Structures Modeling</u>:

Improved models and deepwater experience providing greater understanding of structural and pore pressure relationships and predictions.

<u>Benefits</u>

- Improved casing seat design depths.
- Increased balanced drilling into/below salt sections.
- Less trouble time associated with kicks/lost returns.
- Eliminating Casing strings.

Drilling Solutions (cont'd)

Drilling Mechanics and Tool Designs

- Continue to develop PDC bit designs specific to salt drilling application inclusive of bi-center bits
- Concurrently develop DH tools robust enough to handle the vibrations and torque induced while drilling salt. These are required in increased borehole sizes for the future development wells drilled directionally through the salt. Inclusive are real-time DH data tools (LWD/MWD systems).
- Pursue dual-gradient drilling systems which provide reduced ECD effects while drilling salt related lost circulation or fractured zones.

Drilling Solutions (cont'd)

- Research
  - Quantify salt creep for long-term casing design benefits.
  - Consider salt as an extension of casing ("Salt is my Friend"). Develop drilling casing liners to hang-off at the base of salt where massive salt structures exist (>5000ft thick).
  - Utilize salt sealing capacities on future designs for cuttings annulus injection below shallow salt bodies.
  - Quantify salt strength relative to casing seat FIT/LOT's.

Sub-Salt Drilling Challenges and Solutions

April 4, 2001

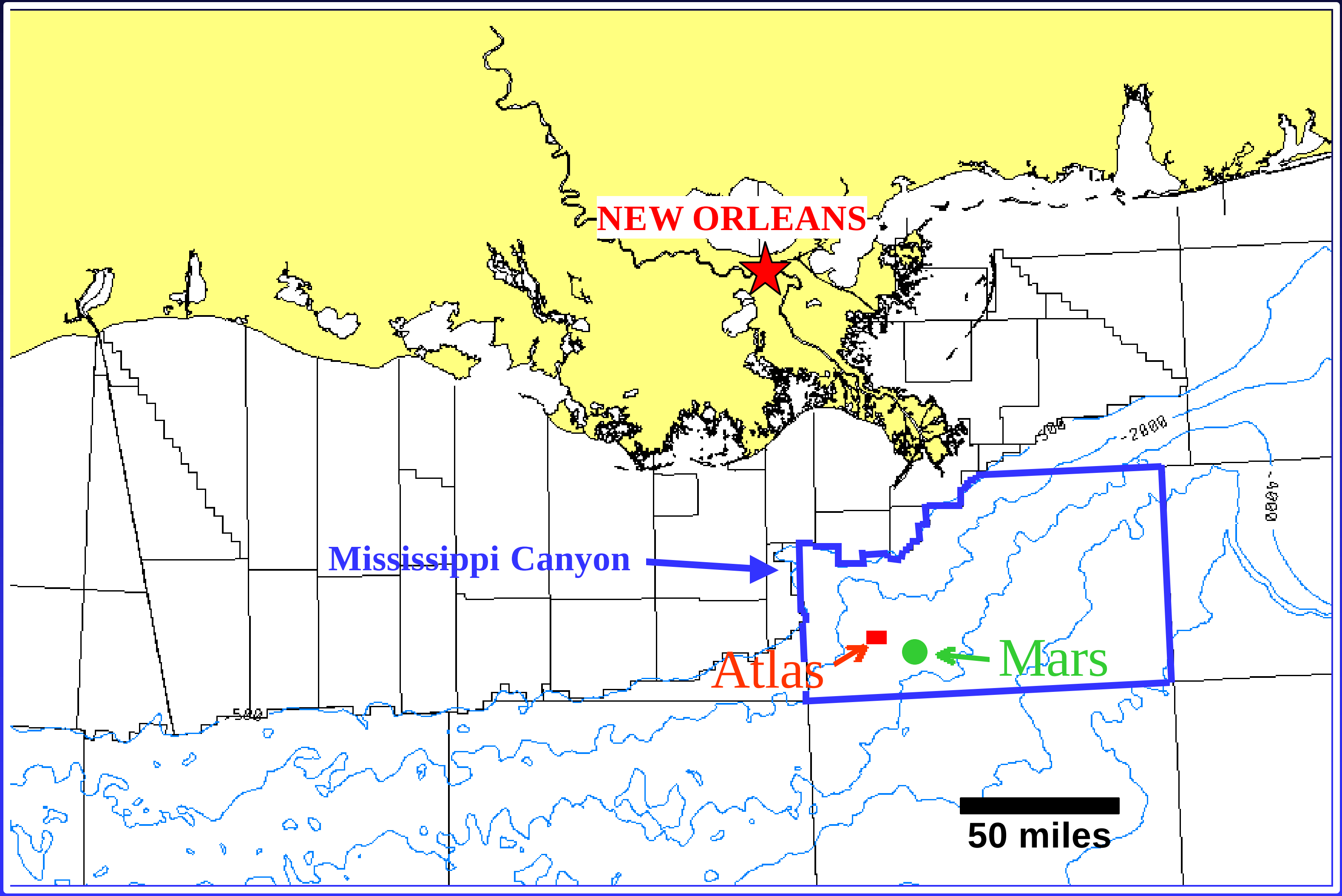
Atlas Prospect
Mississippi Canyon Blocks 713 & 714

John Karpa

Chevron North America, Deepwater Business Unit

New Orleans, LA

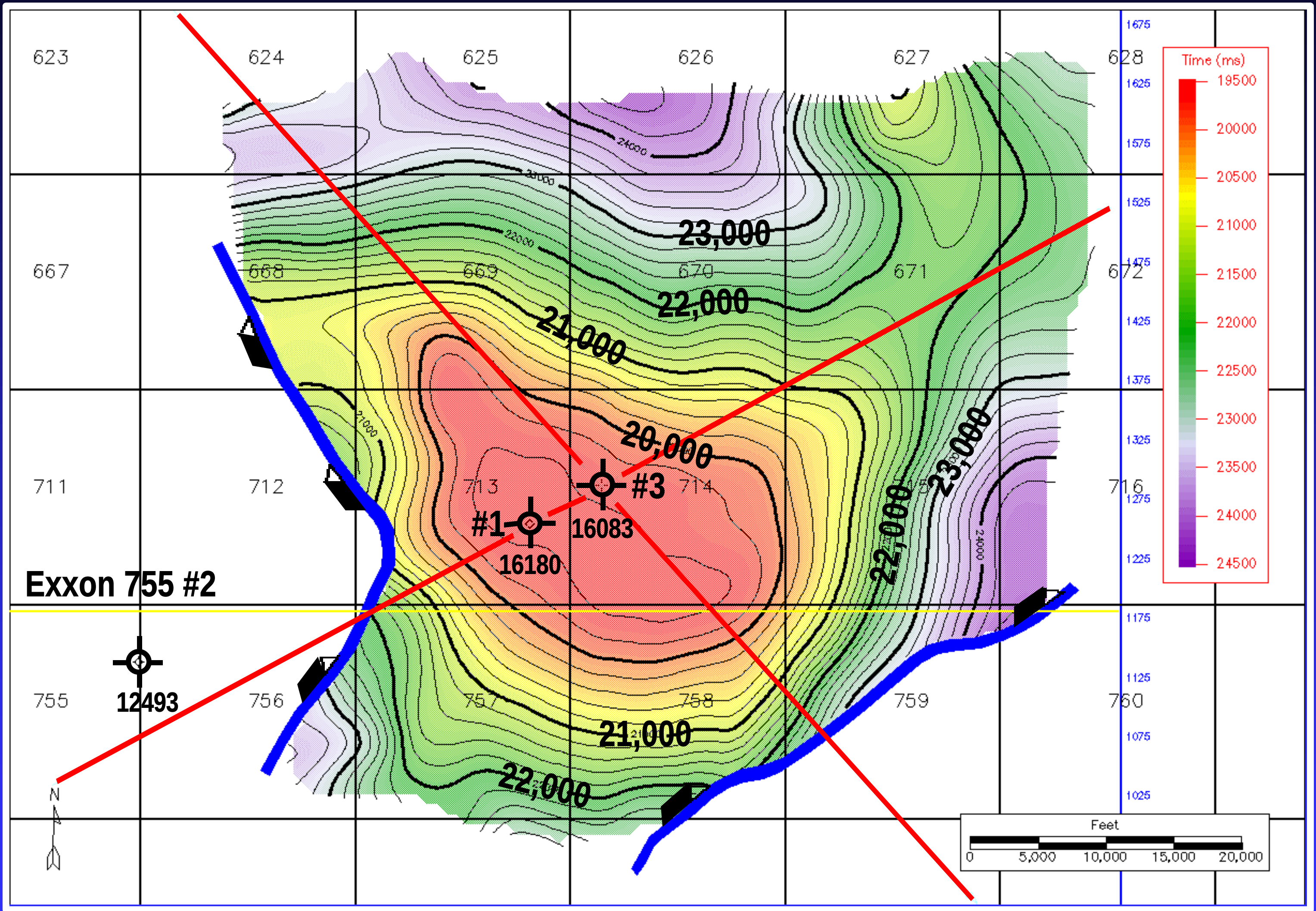
Gulf of Mexico



Atlas Prospect

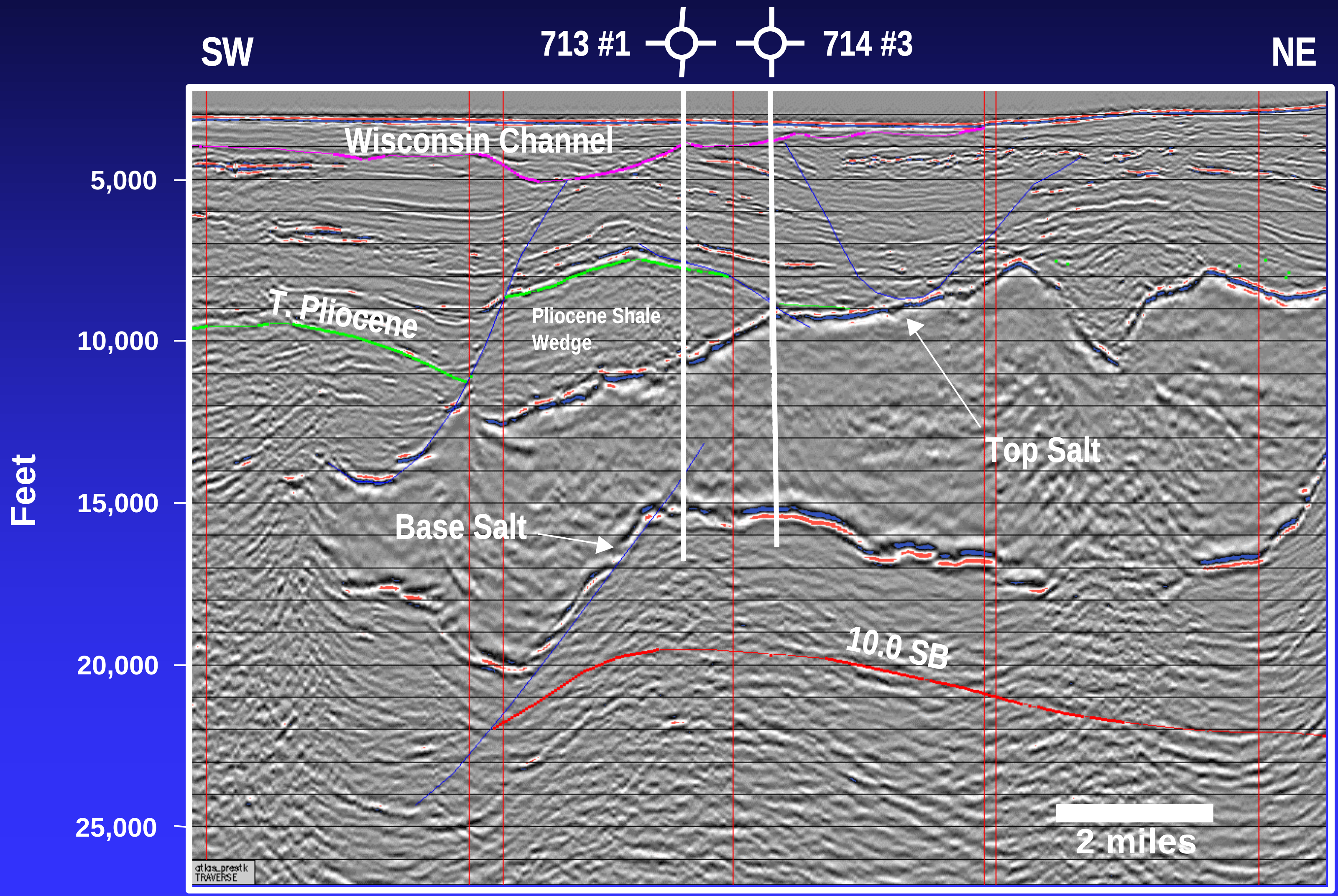
- Mississippi Canyon Blocks 713, 714, 757 & 758
- Water Depth 3200’
- Chevron 50% (operator), Texaco 50%
- Four-way closure under salt
- Mean Reserves 212 MMBO
- Objective section is Middle Miocene
- Base salt is concave down (upside-down bowl)
- Experienced problems above, in & below salt
- Partnership spent $65.4 MM on four wells
- Did not reach objective section

Atlas Prospect

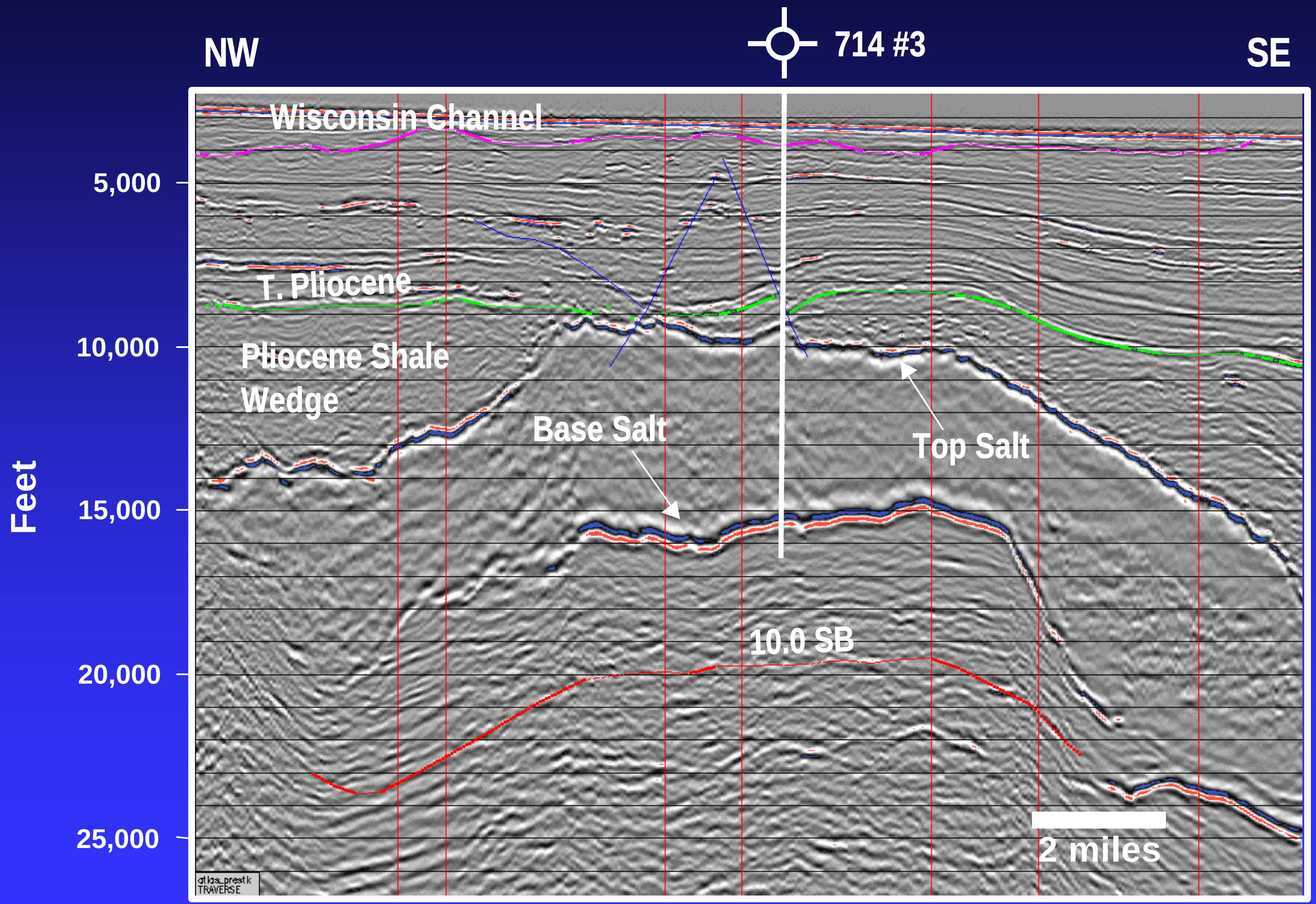


10.0 SB Middle Miocene Structure

Atlas Prospect
3-D Pre-Stack Depth Migration



Atlas Prospect
3-D Pre-Stack Depth Migration`

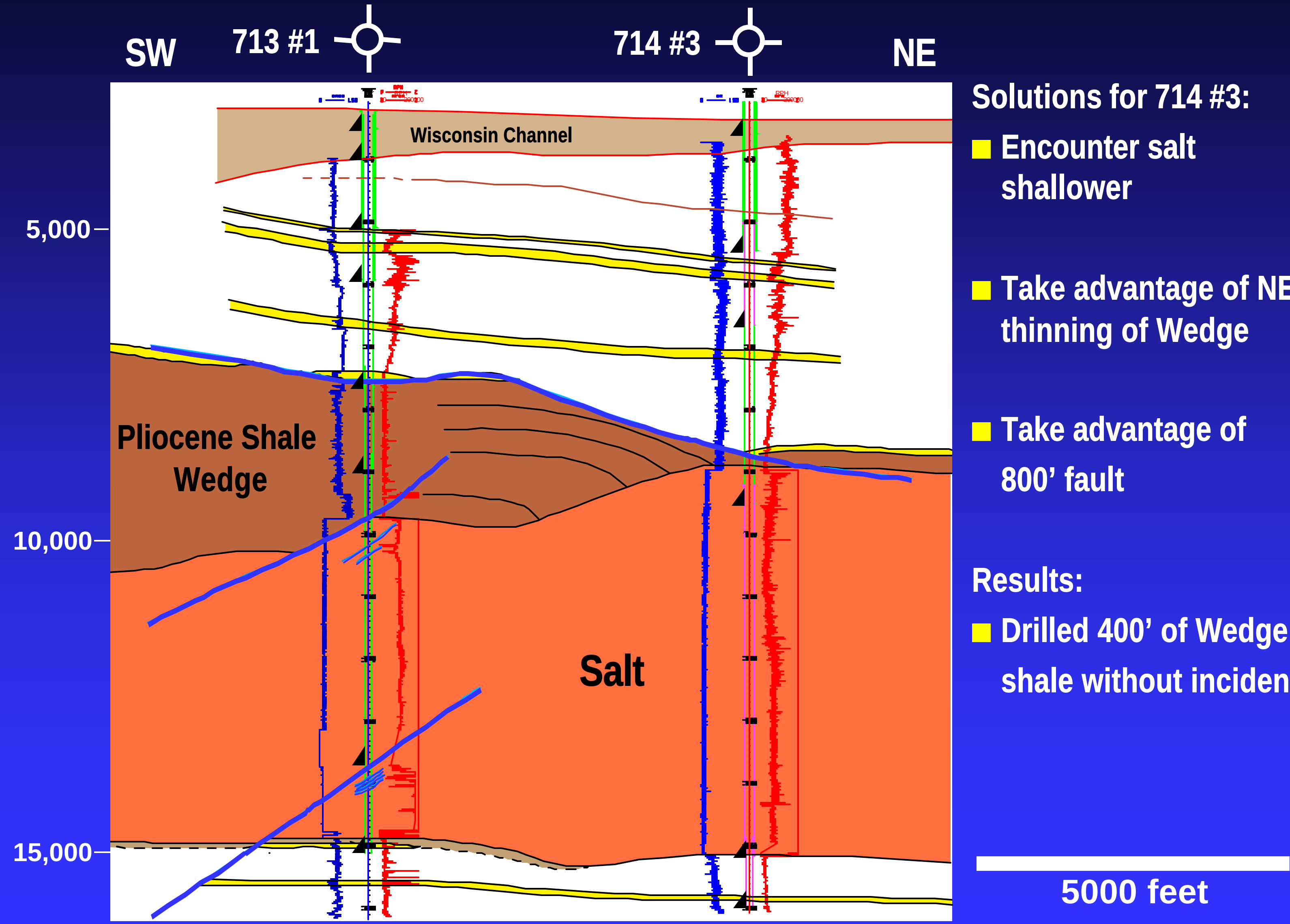


Atlas Prospect
Problems in the first well, MC 713 #1

Above Salt (Pliocene Shale section):

- Well kicks and swabs, difficulty underreaming
- Hole packing off, excessive pipe torque
- Excessive amounts of large shale in returns
- Pliocene Shale is 40-50% mixed layer clays
- Same problems with water base & synthetic mud
- Squeezed 13 5/8” shoe twice
- Lost hole after drilling 1100’ of Pliocene Shale

Atlas Prospect
True Scale Cross-section



Solutions for 714 #3:

- Encounter salt shallower
- Take advantage of NE thinning of Wedge
- Take advantage of 800' fault

Results:

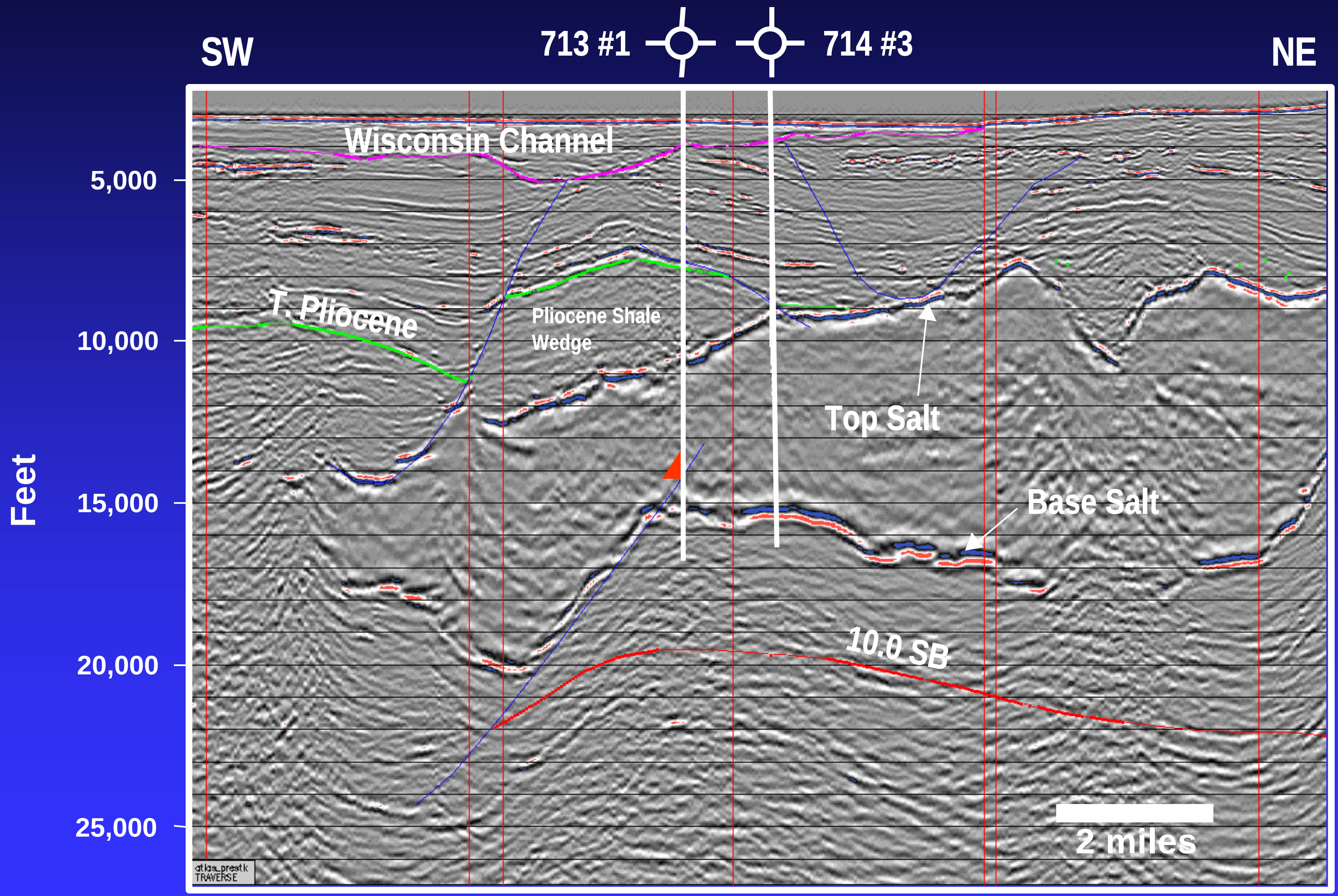
- Drilled 400' of Wedge shale without incident

Atlas Prospect
Problems in the first well, MC 713 #1

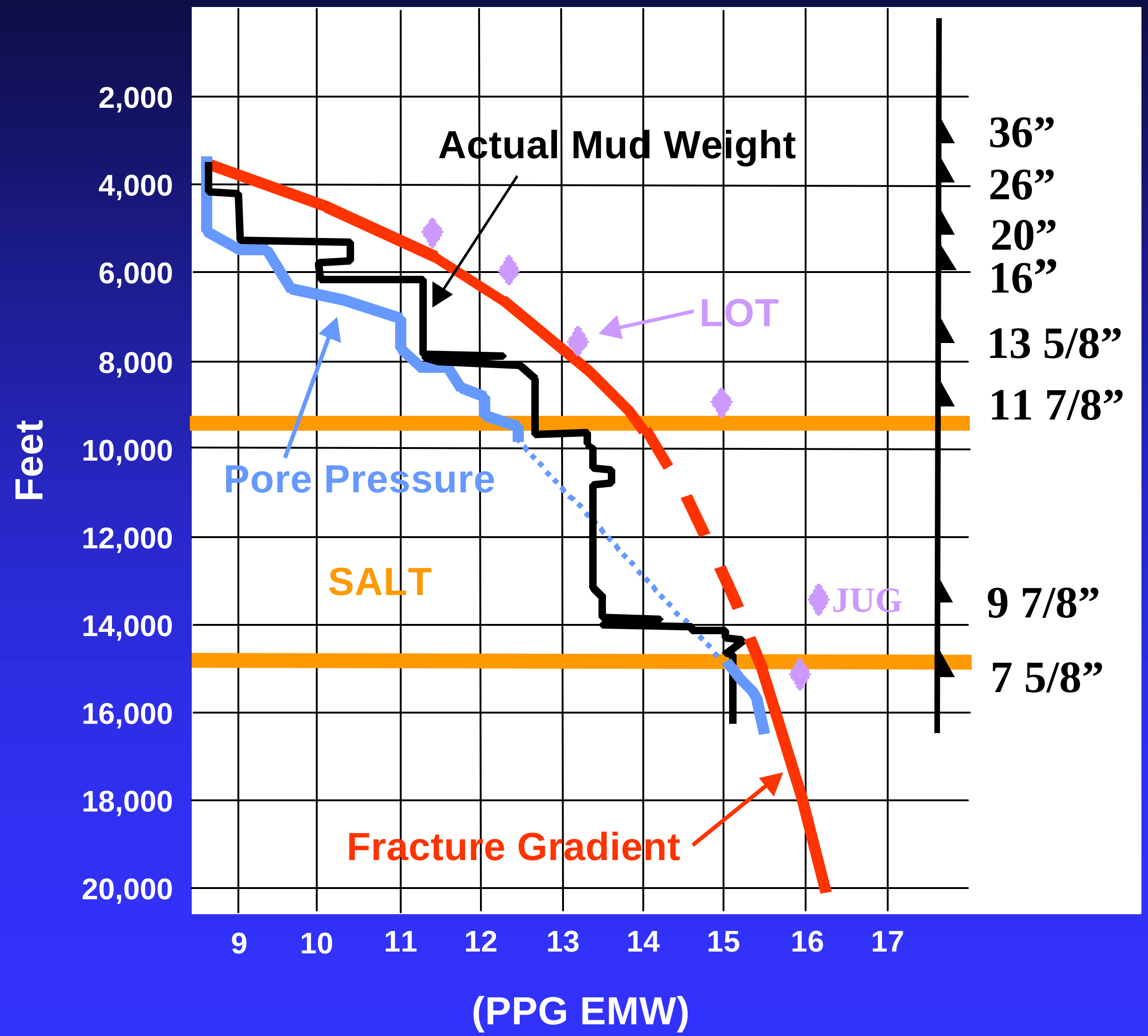
In Salt:

- Problems occur near the base of salt
- Background gas increases to 2366 units and well flows
- Mud weight raised from 13.7# to 15.1#
- Casing (9 5/8”) set in salt, 1500’ higher than planned

Atlas Prospect
3-D Pre-Stack Depth Migration

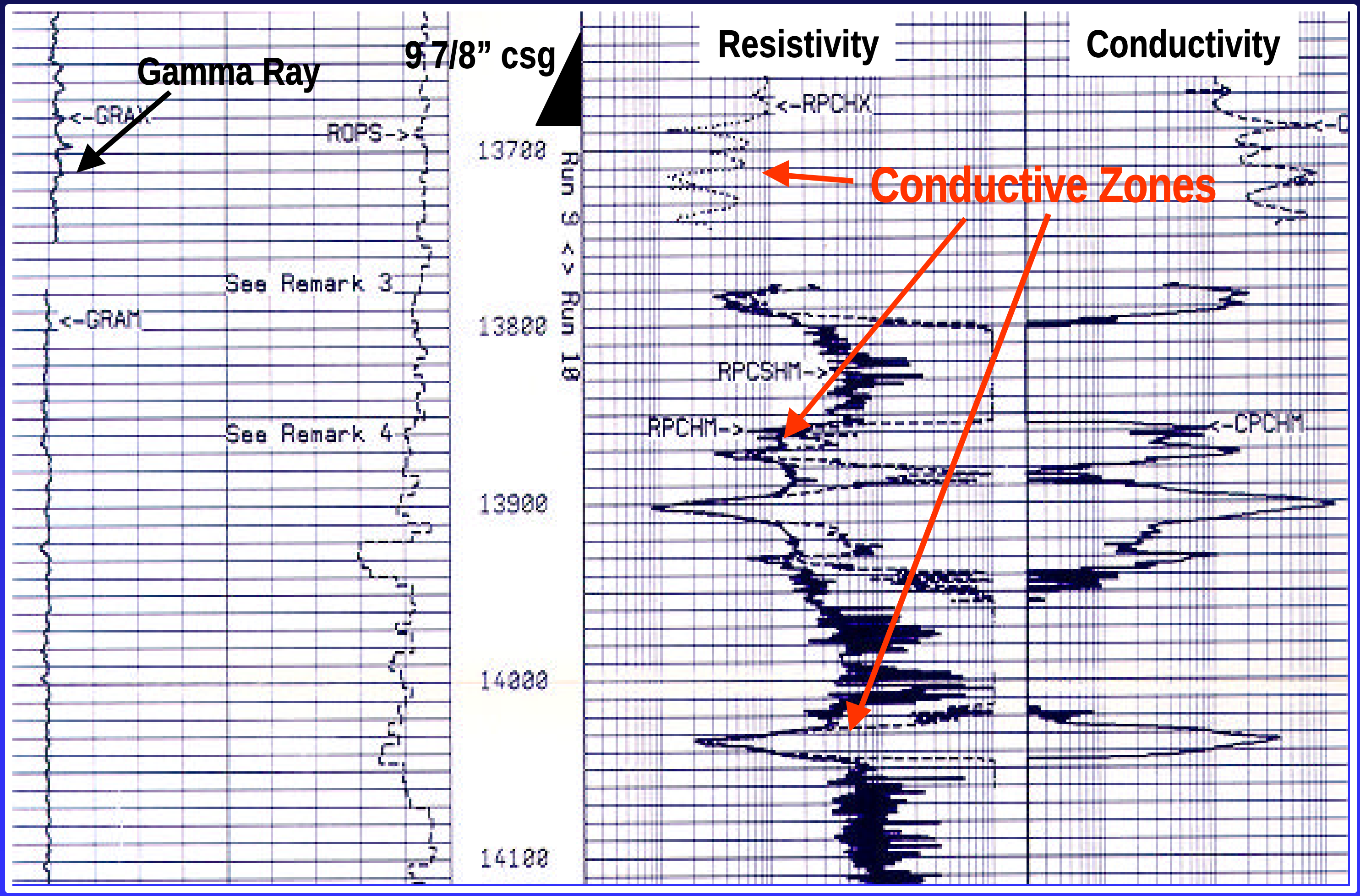


Atlas Prospect
Pressure Chart for 713 #1



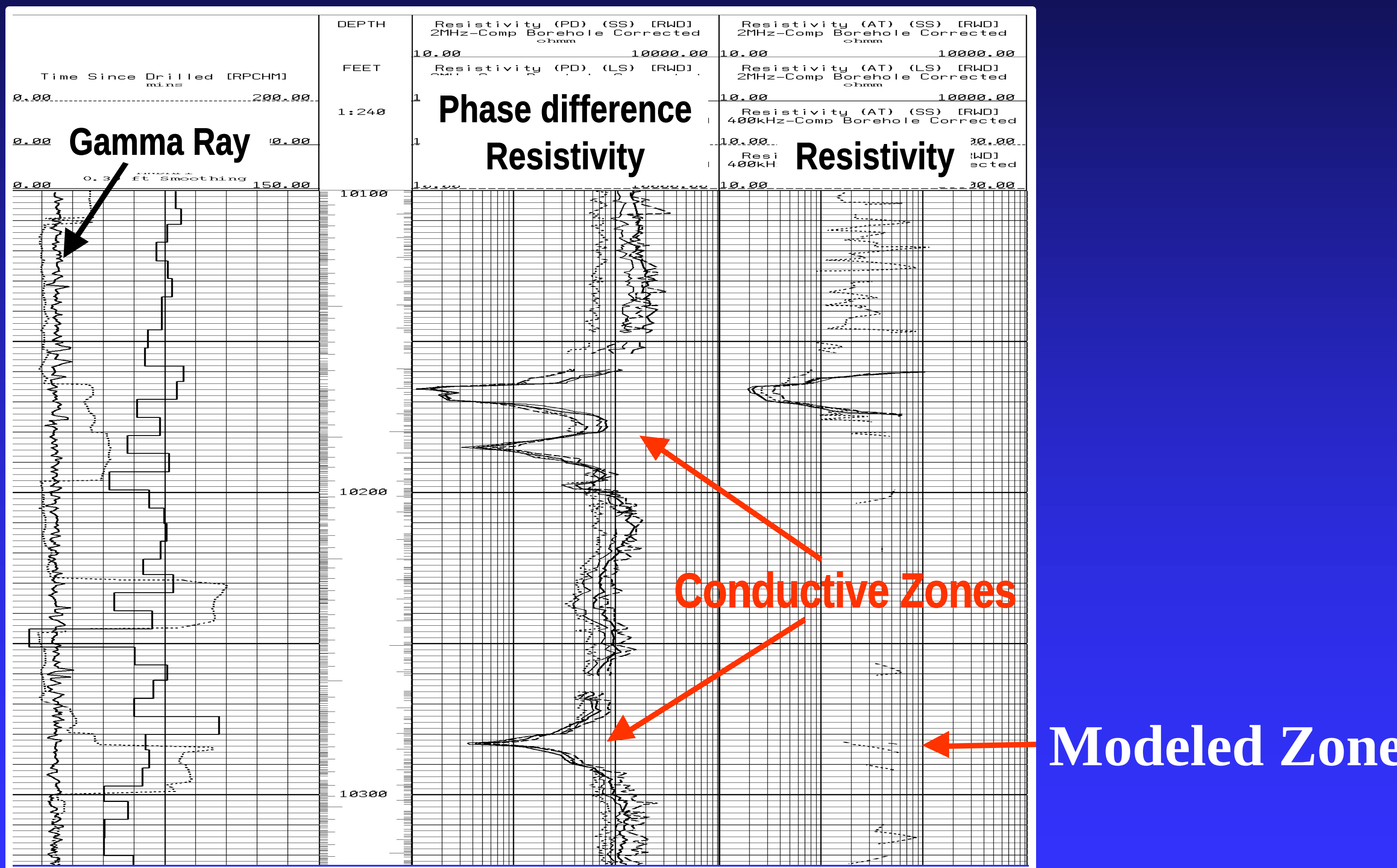
MC 713 #1
LWD log of Conductive Zone in Salt

MW 13.7# -
MW 14.2# -
MW 14.6# -
MW 15.0# -
MW 15.2# -



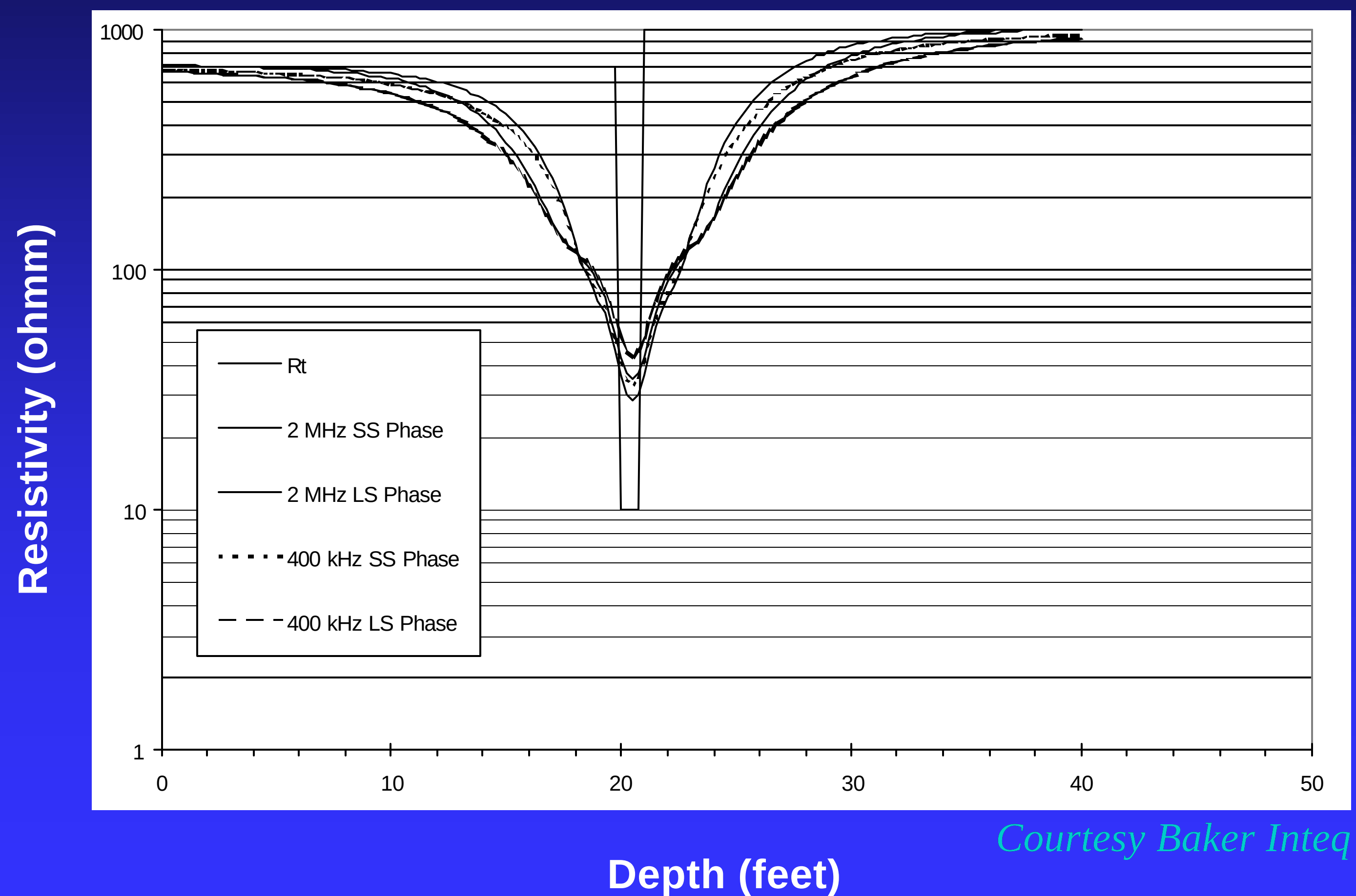
Courtesy Baker Inteq

MC 713 #1
LWD log of Thin Conductive Zones in Salt



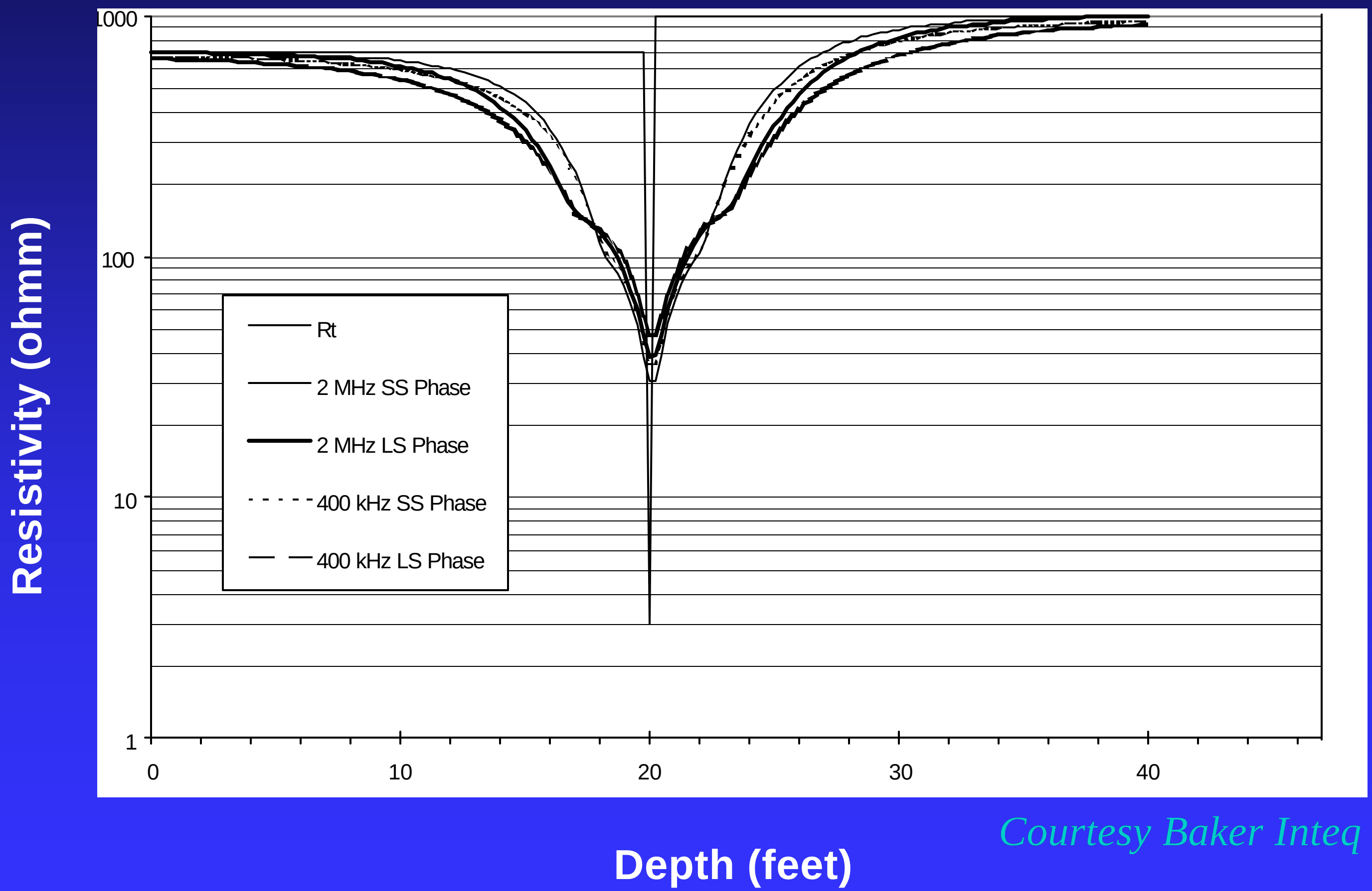
Courtesy Baker Inteq

MC 713 #1
Model of Thin Conductive Zone
Assumes 10 ohmm & 1 ft. thick



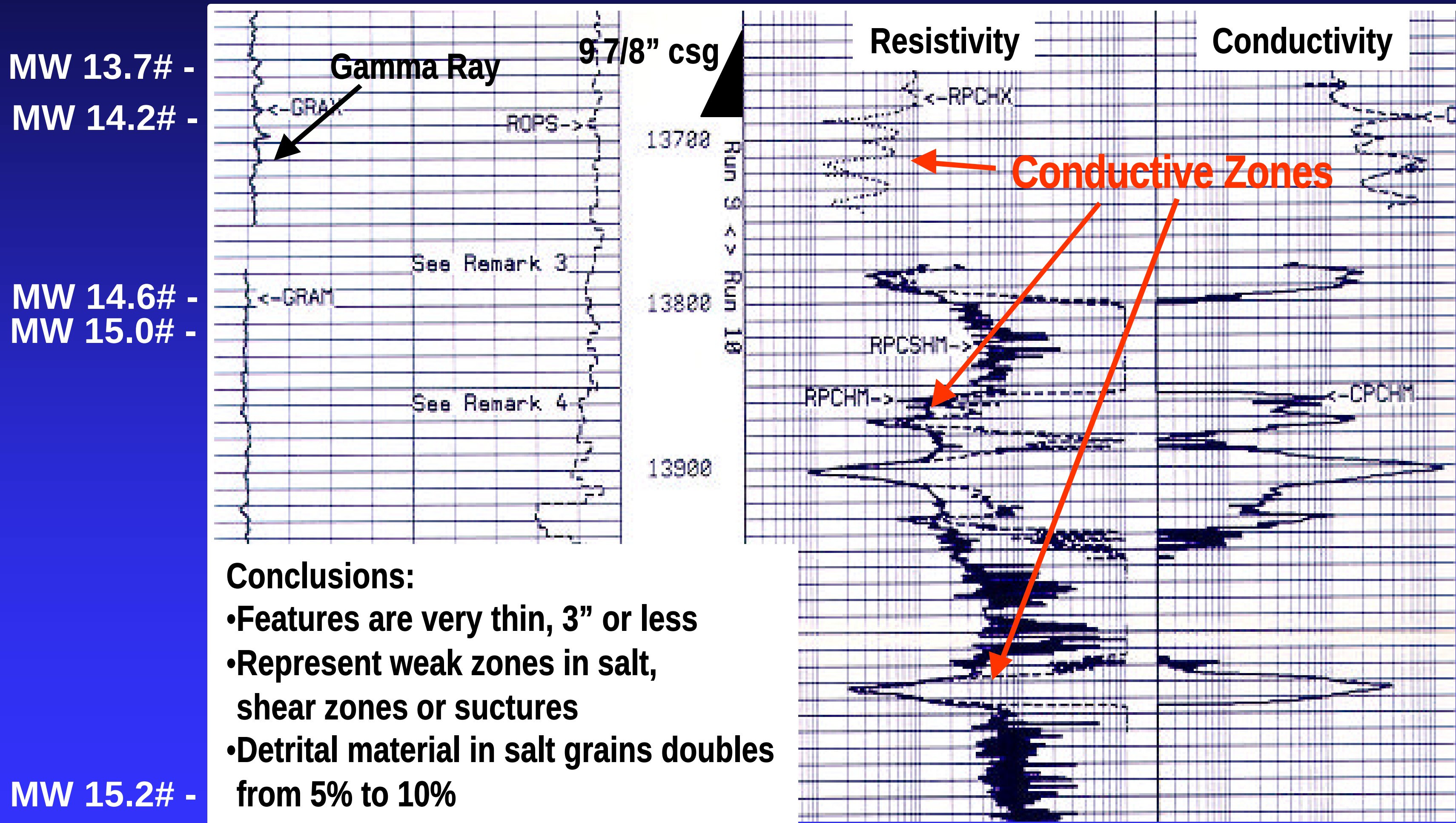
Courtesy Baker Inteq

MC 713 #1
Model of Thin Conductive Zone
Assumes 3 ohmm & 3 in. thick



Courtesy Baker Inteq

MC 713 #1
LWD log of Conductive Zone in Salt

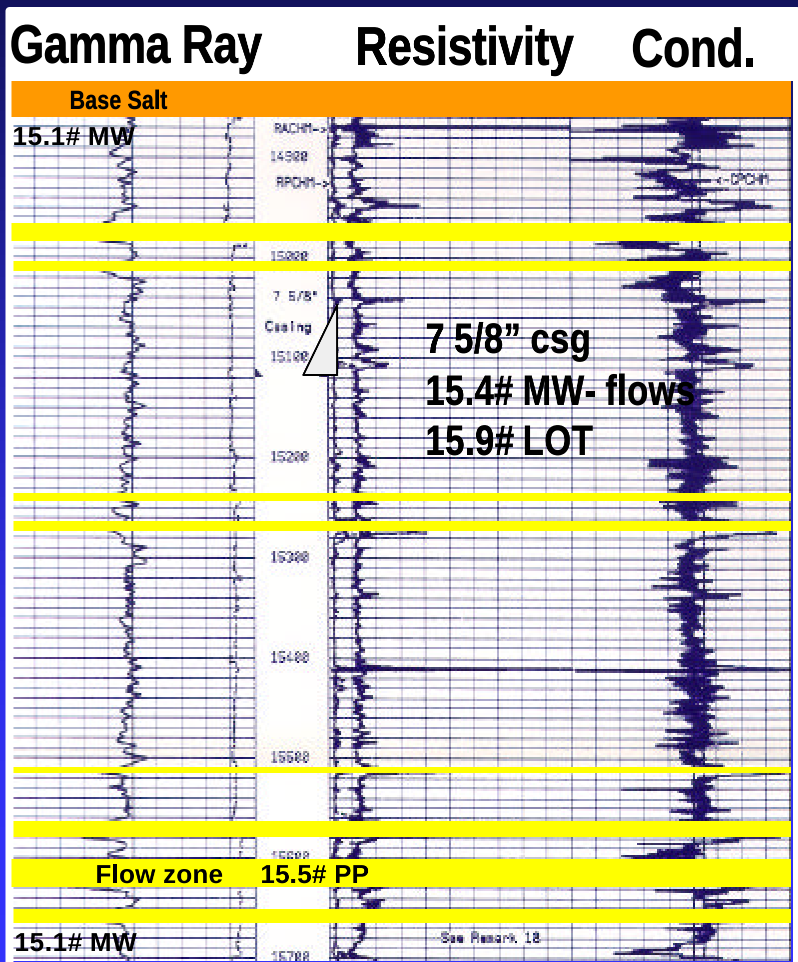


Conclusions:

- Features are very thin, 3” or less
- Represent weak zones in salt, shear zones or suctures
- Detrital material in salt grains doubles from 5% to 10%

Courtesy Baker Inteq

MC 713 #1
LWD log of Section Below Salt

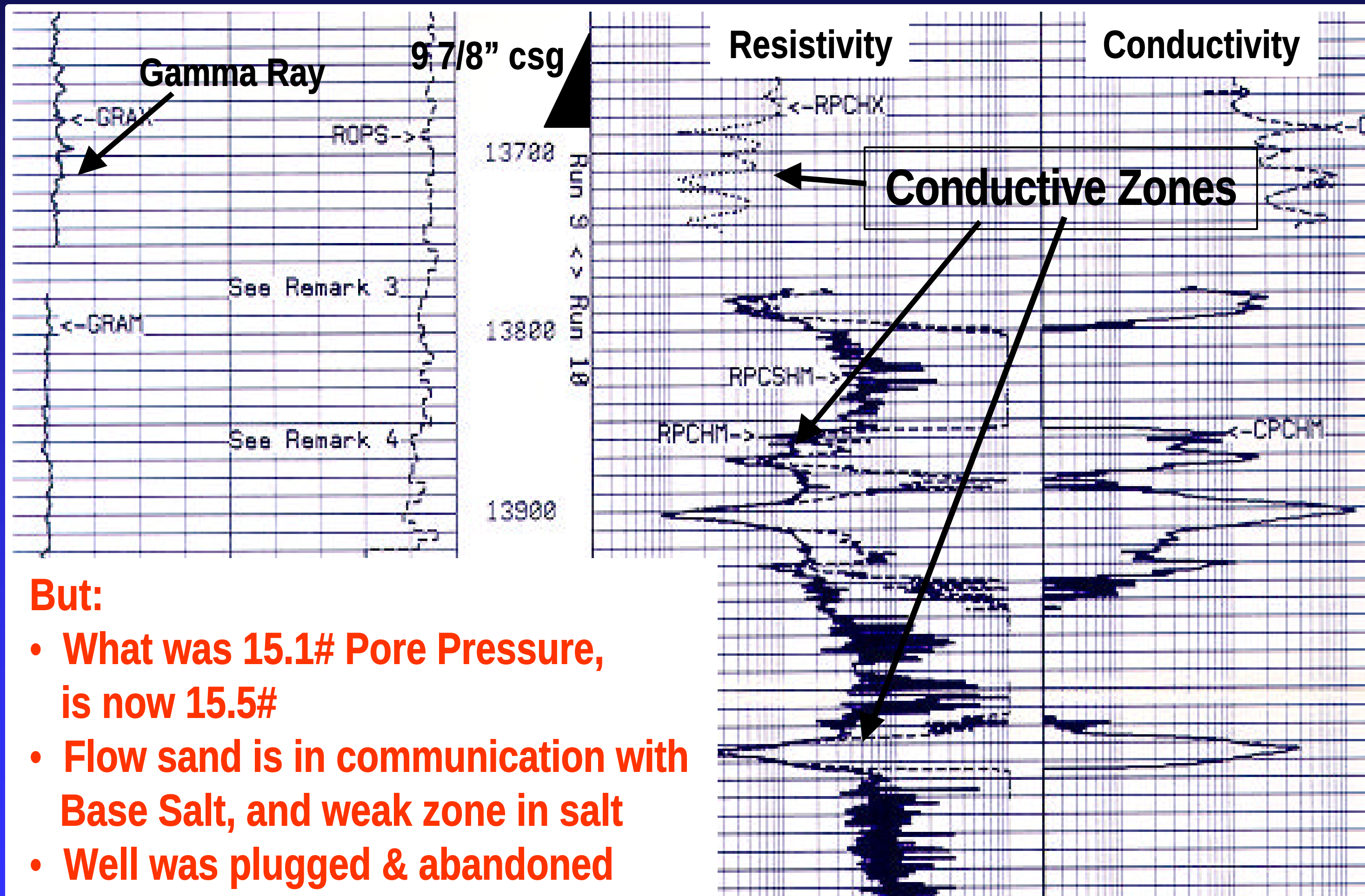


Below Salt:

- Contingency casing used uphole
- Last casing string needed to be as deep as possible
- Underground flow caused excessive erosion at the base of salt
- Casing was run, however, formation damage precluded a good cement job
- 0.5# margin between PP and FG (7 5/8" shoe)
- Well was plugged back & sidetracked
- But…...

MC 713 #1
LWD log of Conductive Zone in Salt

MW 13.7# -
MW 14.2# -
MW 14.6# -
MW 15.0# -
MW 15.2# -



But:
- What was 15.1# Pore Pressure, is now 15.5#
- Flow sand is in communication with Base Salt, and weak zone in salt
- Well was plugged & abandoned

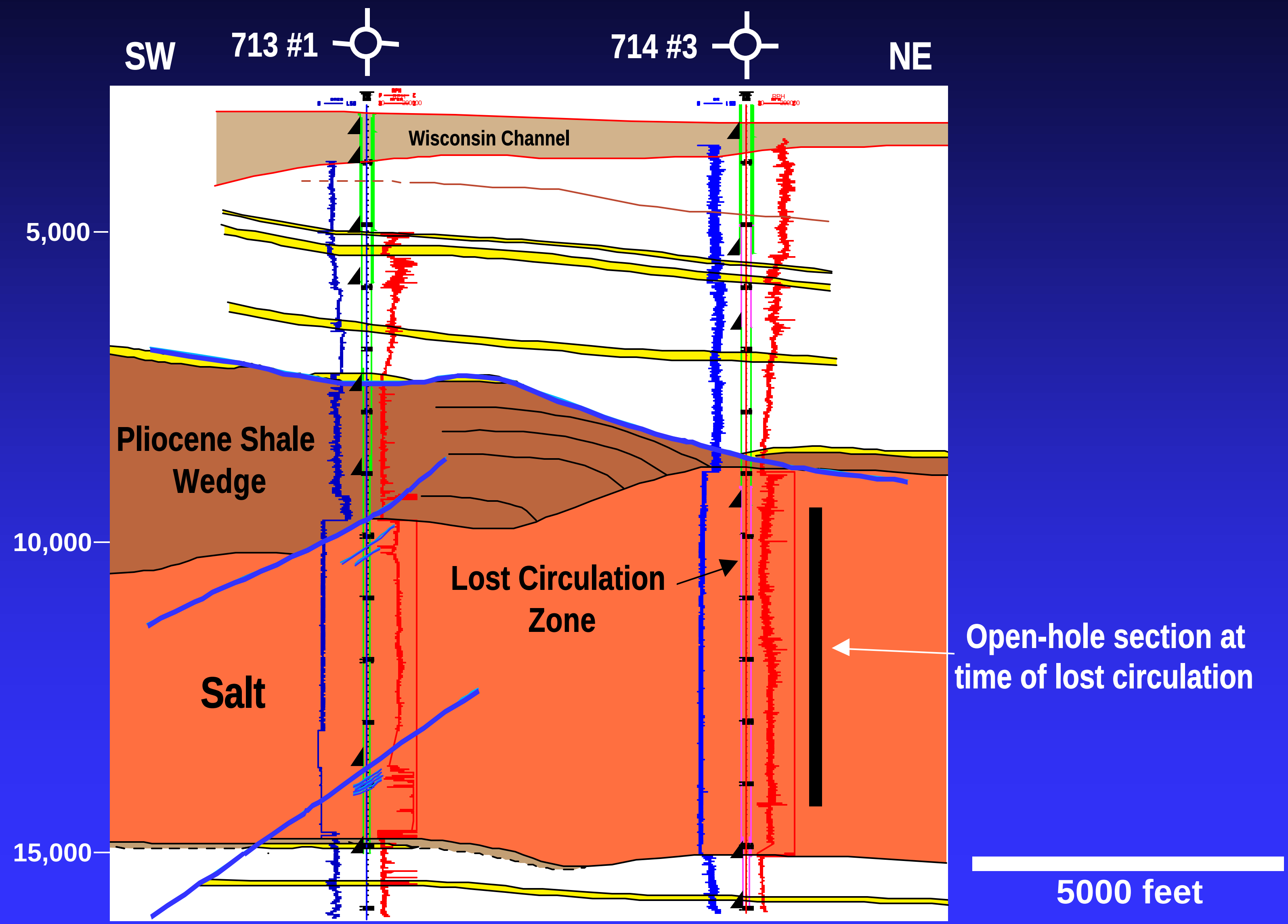
Courtesy Baker Inteq

Atlas Prospect
Problems in the second well, MC 714 #3

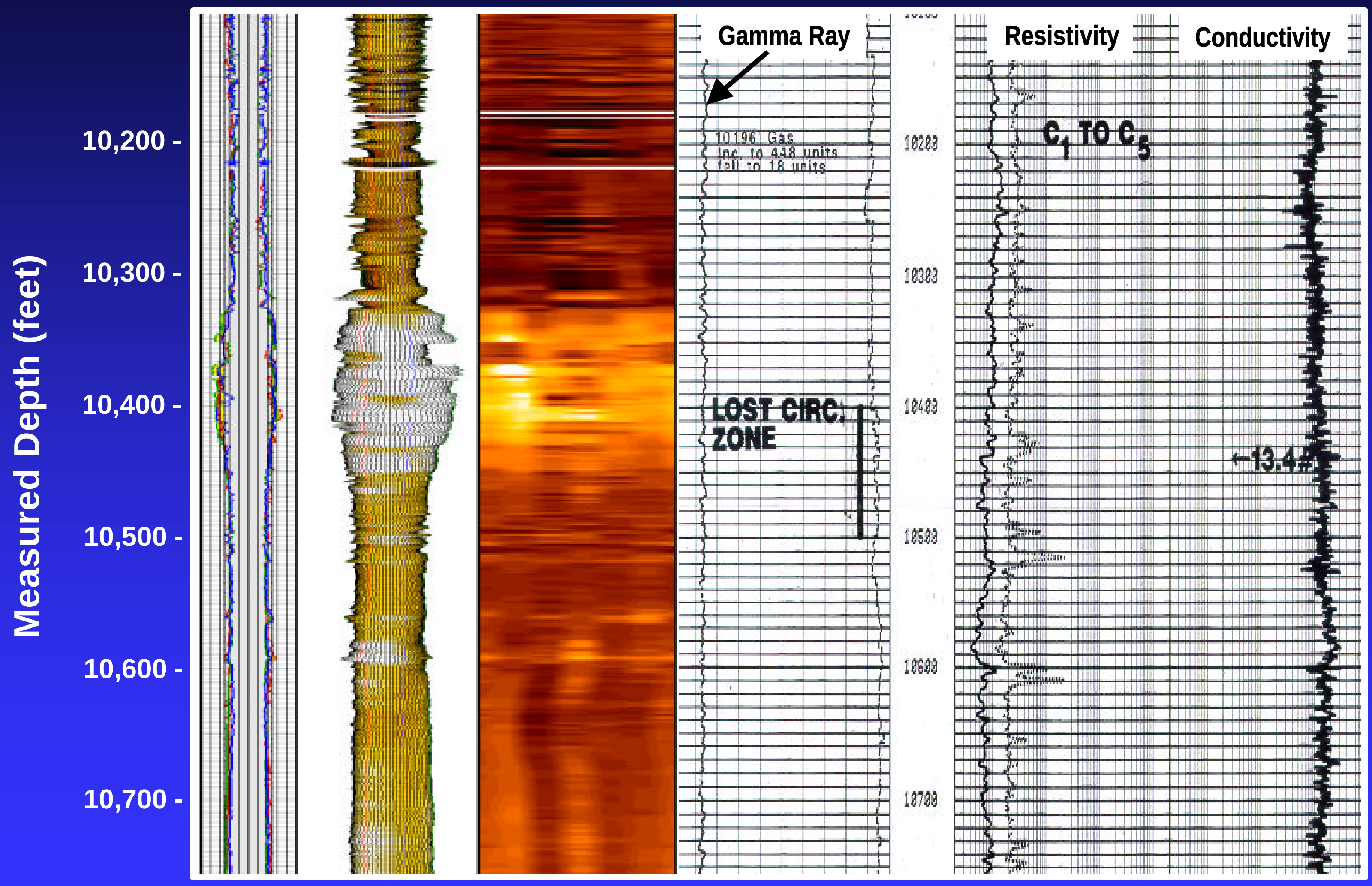
In Salt:

- Problems occur near the top of salt
- No problems drilling & underreaming 4800’ of salt
- Hole section opened 16 days before problems developed during trip out of hole
- Excessive and continuous mud loss
- Excessive mudcake first 800’ outside casing
- A 100’ lost circulation zone below the mudcake (confirmed with PDK-100 log)

Atlas Prospect
True Scale Cross-section

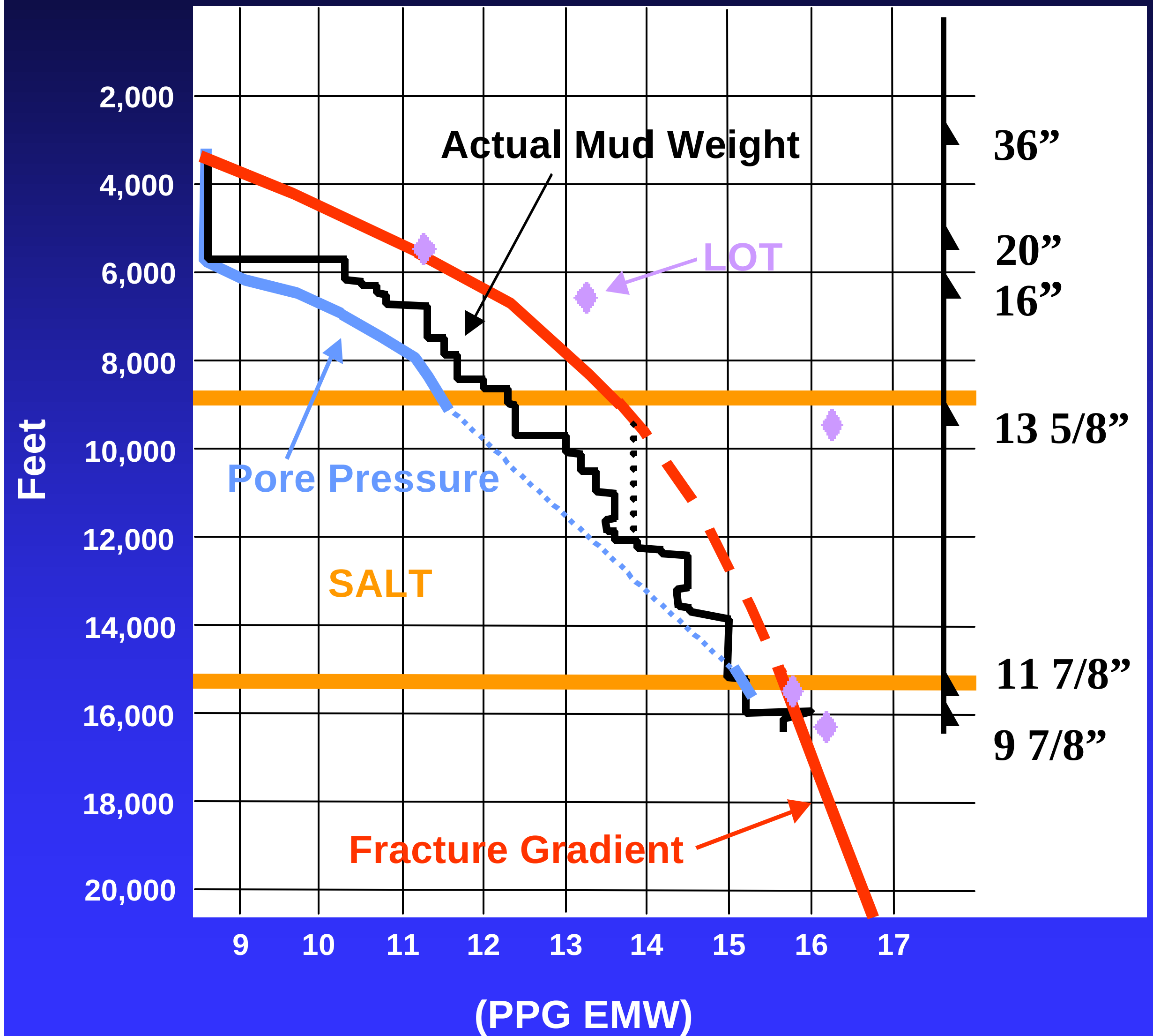


MC 714 #3, Salt section below 13 5/8” shoe



Courtesy Baker Atlas　*Courtesy Baker Inteq*

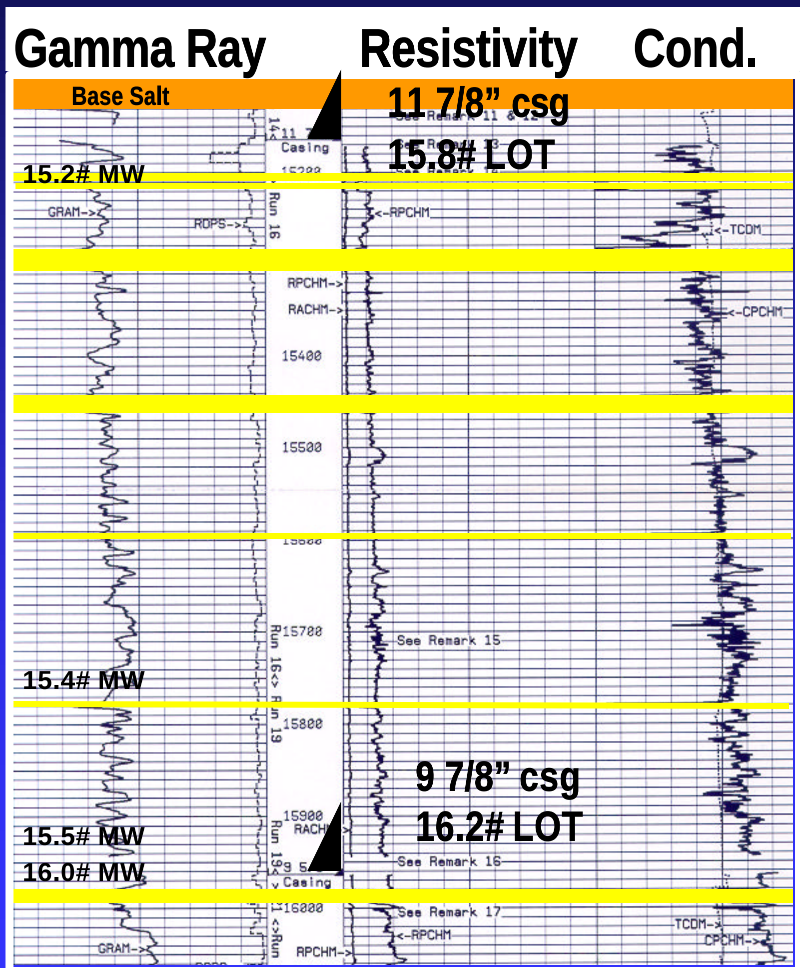
Atlas Prospect
Pressure Chart for 714 #3



Conclusions:

- Challenged the integrity of the salt
- Fractured the salt below the casing shoe
- Failure was not immediate
- Attempts to remedy failed, in fact, the problems got worse
- Casing was set 1000’ shallower than planned below salt

MC 714 #3
LWD log of Section Below Salt



Below Salt:

- Drilled to within 0.3# of the casing shoe, and 0.1# of pore pressure
- 9 7/8" casing was set
- 0.7# margin between PP and FG (9 7/8" shoe)
- Circulating ECD is 0.9# over mud weight
- IF….

Atlas Prospect

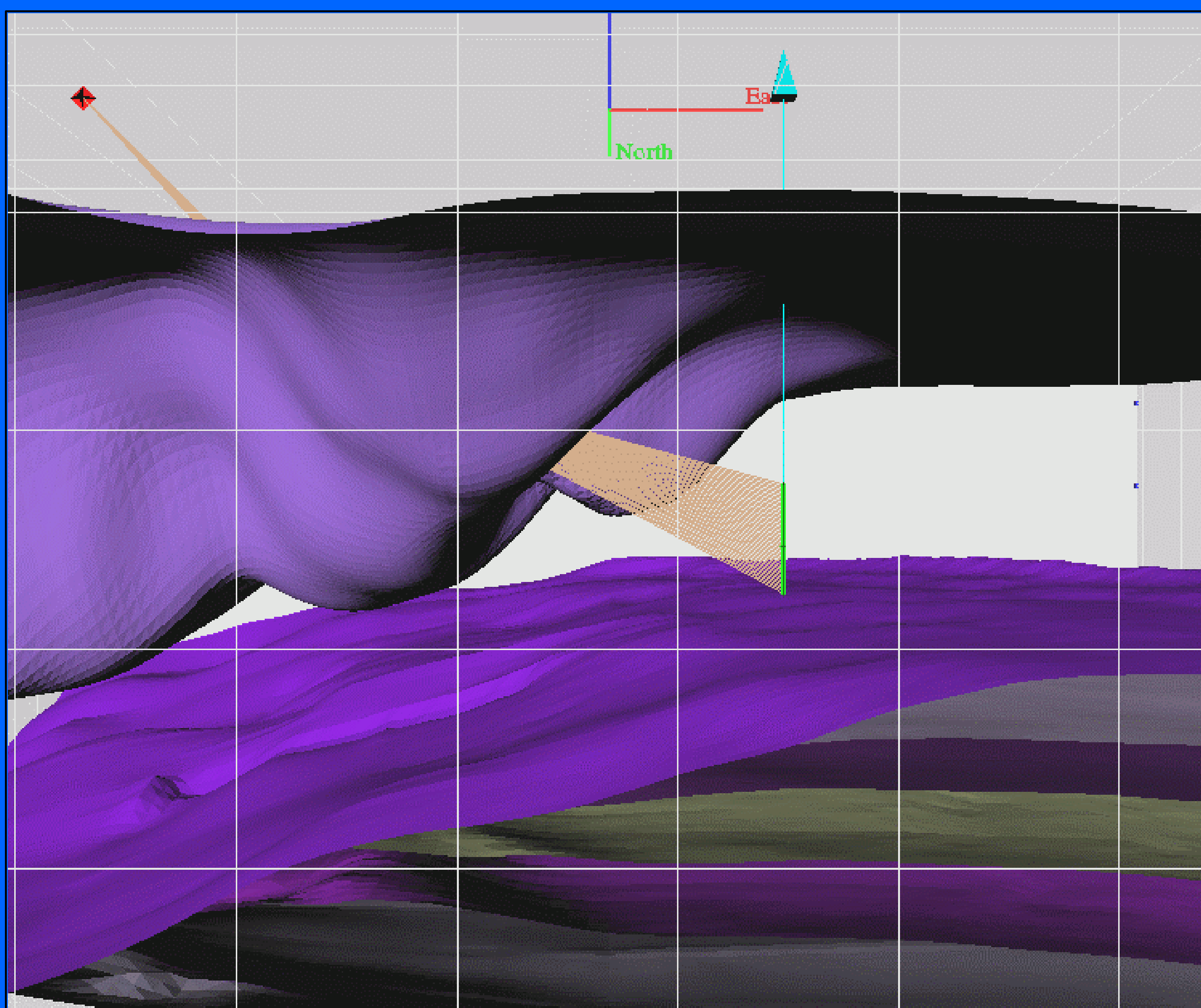
Conclusion:

- Surface Location and shallow geology are critical for success
- Mud weights in salt should not exceed the projected formation fracture gradient
- Minimize open-hole exposure time in salt
- Avoid sub-salt features which may intersect the well near the base of salt
- Casing depths are critical to increase the chances of success

Pore Pressure Prediction Ahead of the Bit

ATLAS PROSPECT MC714

Sub-Salt VSP Inversion



Drilling & Completions Technology

Overview

- Pore Pressure Relationship to Velocity-Effective Stress
- VSP Acquisition
- Atlas Prospect - Pore Pressure Calibration from Checkshot
- Acoustic Impedance Inversion
- Conclusions

Pore Pressure
Velocity - Effective Stress

Velocity is the key to effective stress and pore pressure

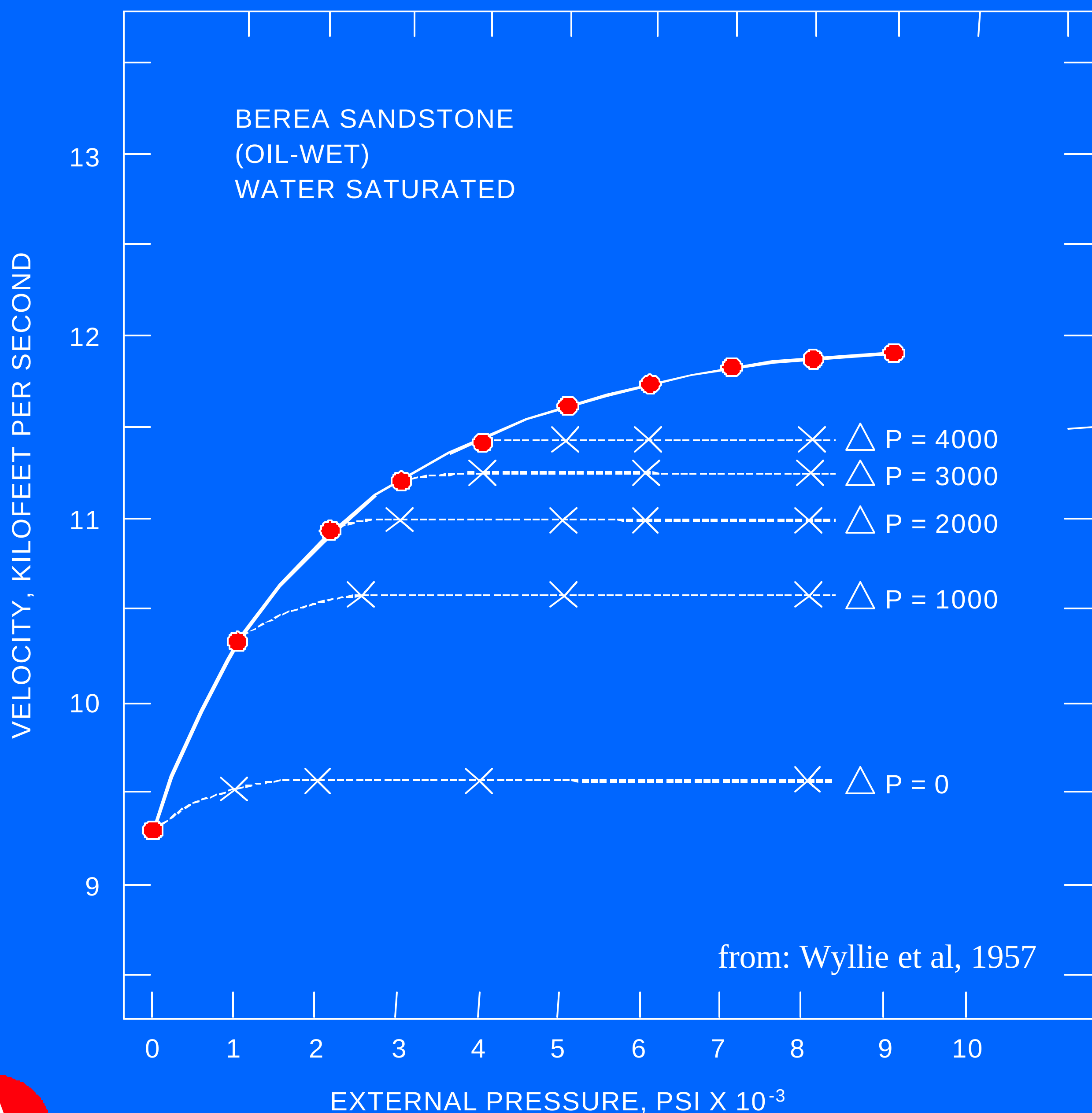
Sources of velocity are:

Seismic Stacking Velocity (low frequency)
Seismic Migration Velocity (Time and Depth)
Seismic Trace Inversion CSSI (higher frequency / post-stack and pre-stack)

Sonic Logs (wireline / LWD)
Checkshot data

Seismic while drilling (e.g.,Tomex)
Look-Ahead Conventional VSP Inversion

Pore Pressure
Velocity - Effective Stress



Drilling & Completions Technology

Velocity- Effective Stress

Terzaghi's Relationship:

Pore Pressure = Overburden - Effective Stress

- Use Velocity to Estimate Overburden
- Use Velocity to Estimate Porosity
- Use Velocity to Solve for Effective Stress
- Use Velocity to Estimate Temperature

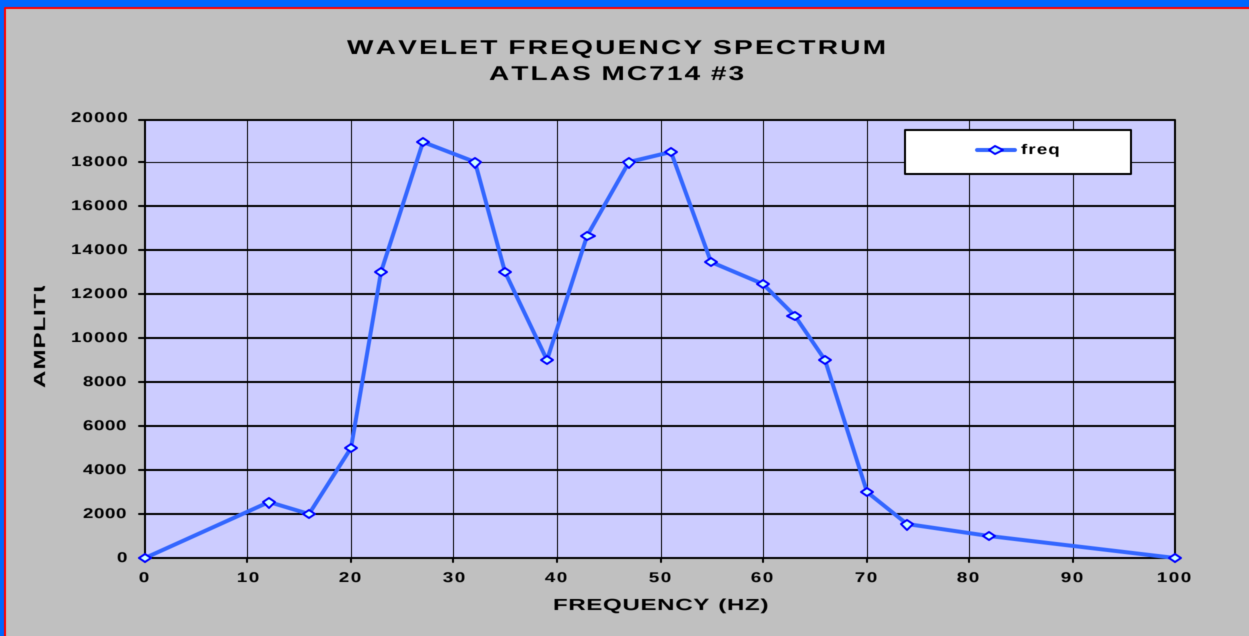
VSP Inversion Techniques

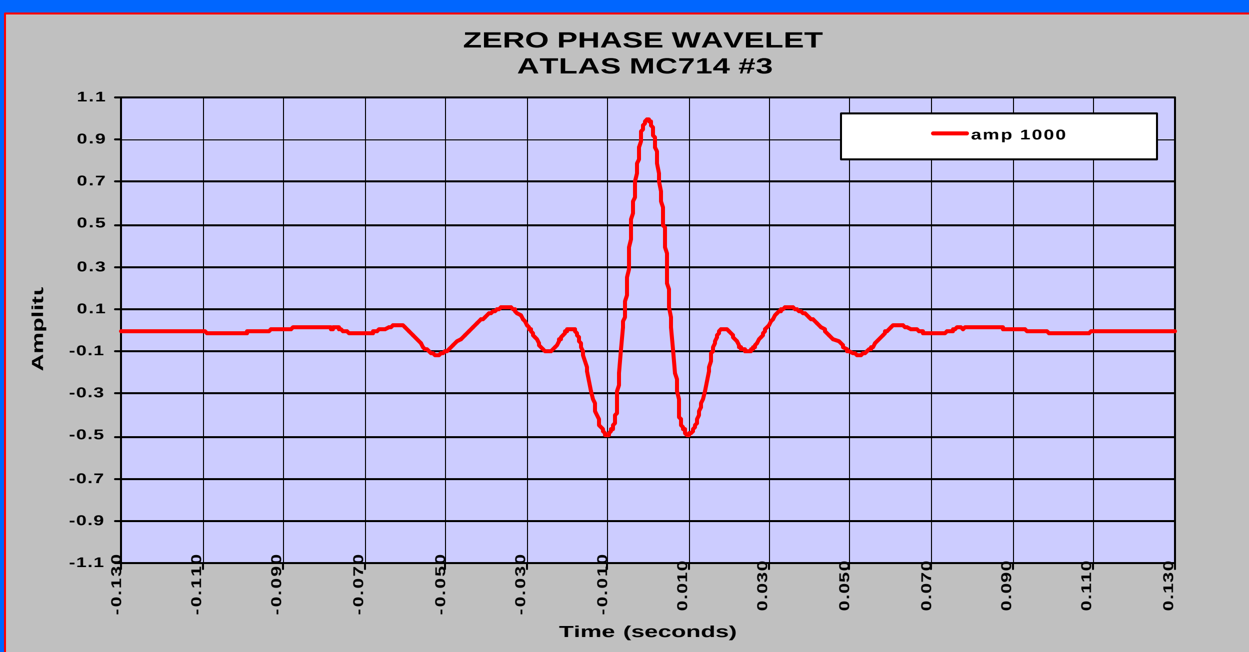
Subsalt Pore Pressure Prediction

CHEVRON-TEXACO ATLAS PROSPECT MC714

Drilling & Completions Technology

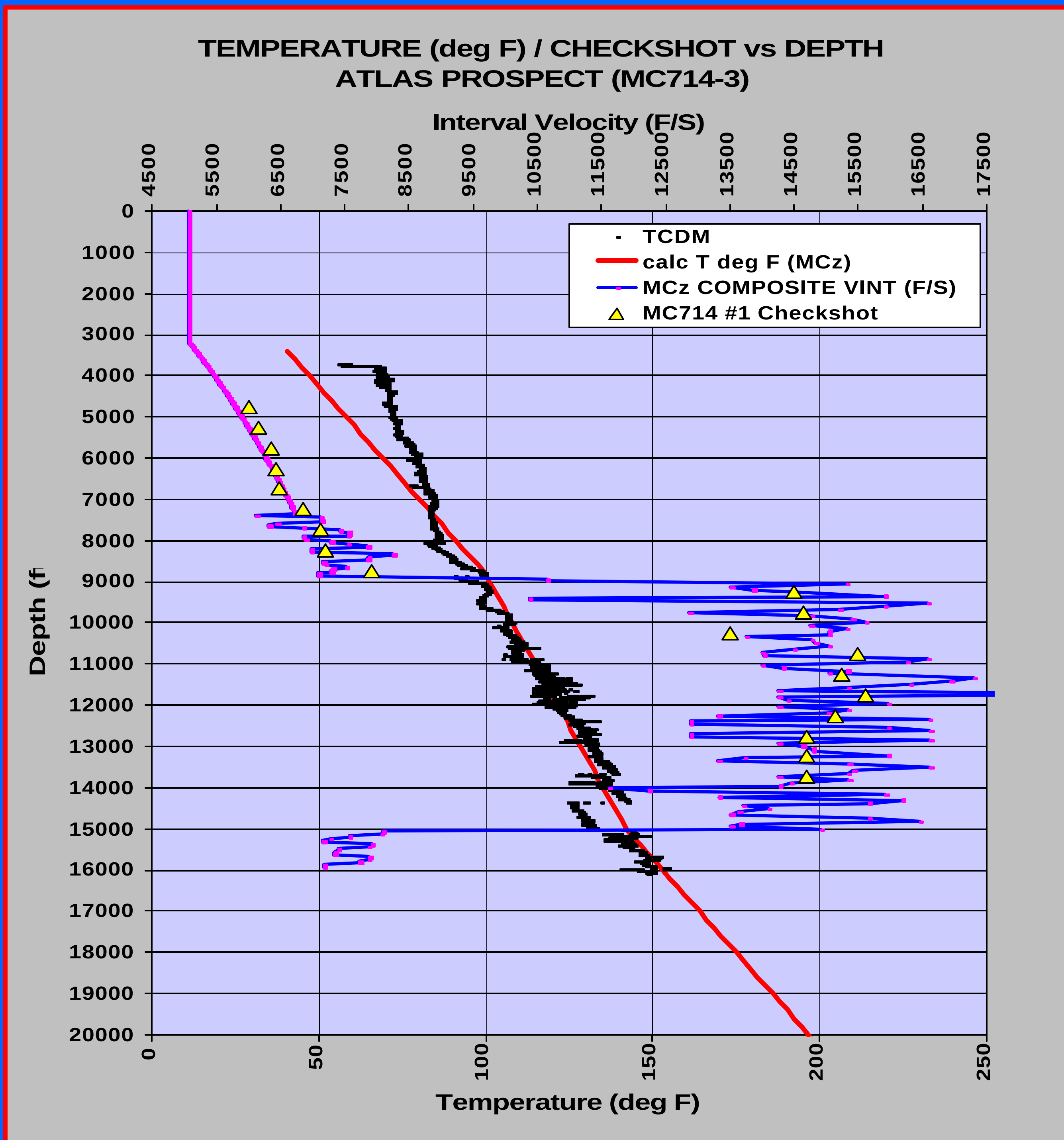
Wavelet & Frequency Spectrum





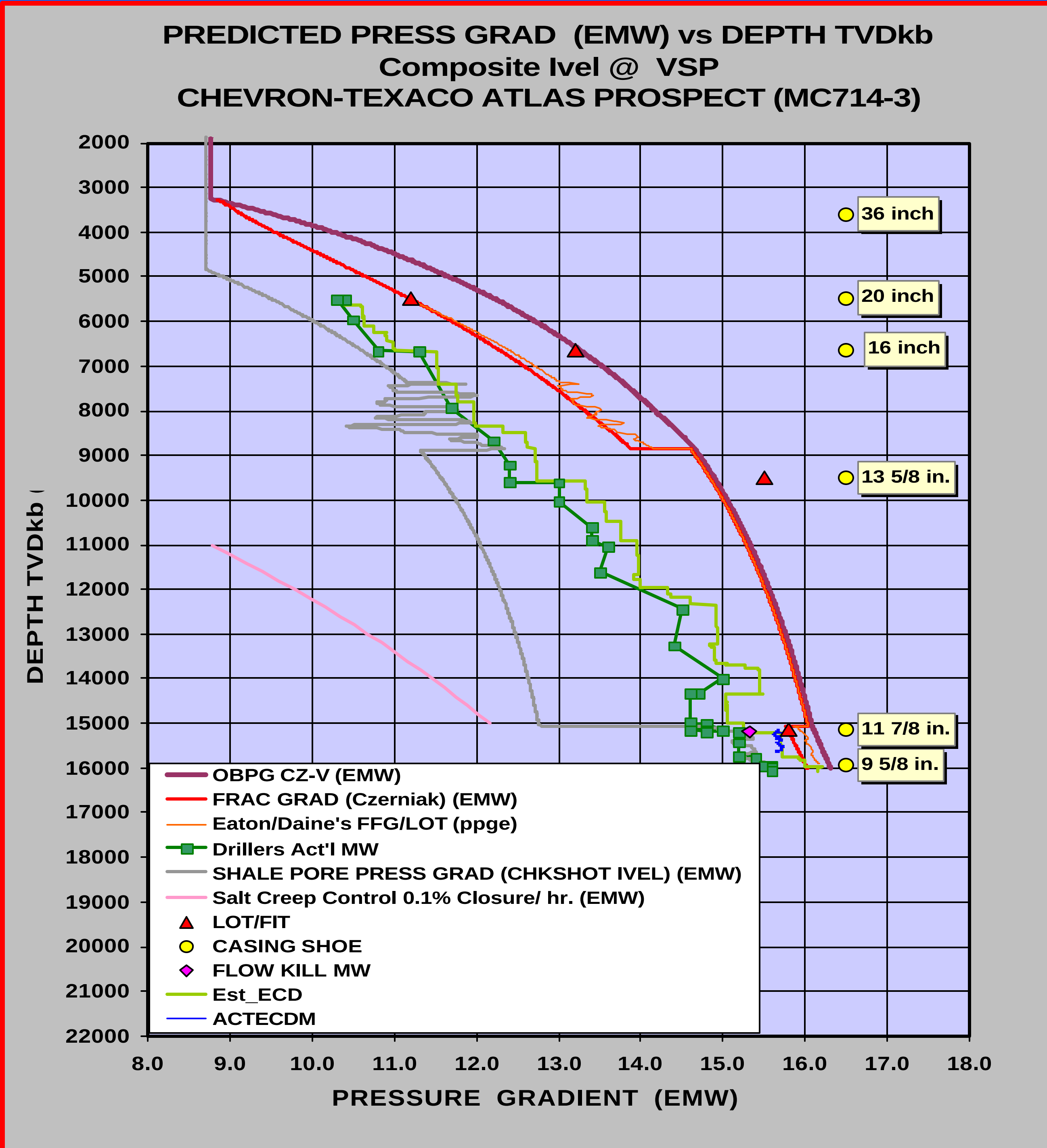
Drilling & Completions Technology

Temperature & Velocity Models



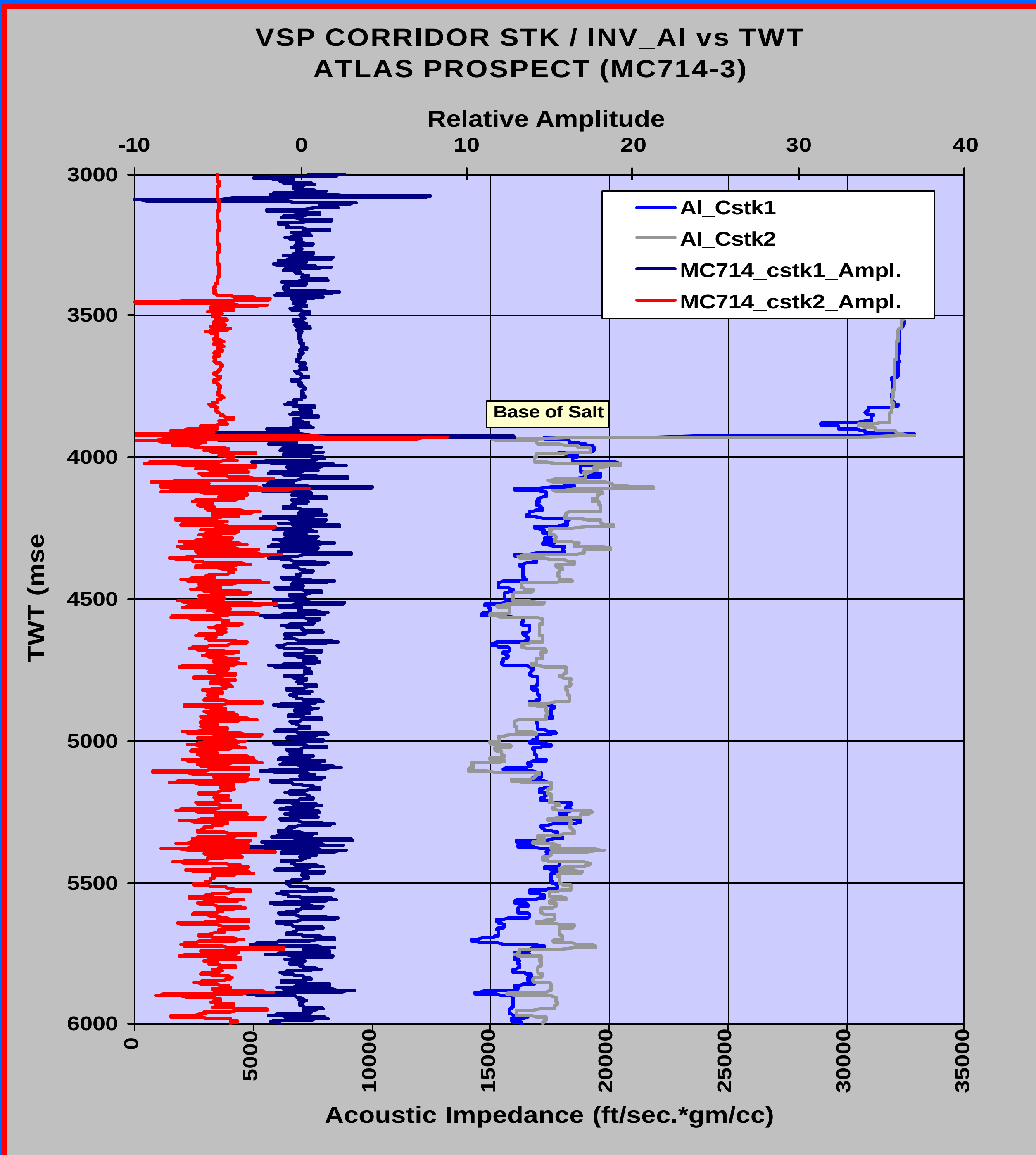
Drilling & Completions Technology

Checkshot Velocity Transformed to Pore Pressure



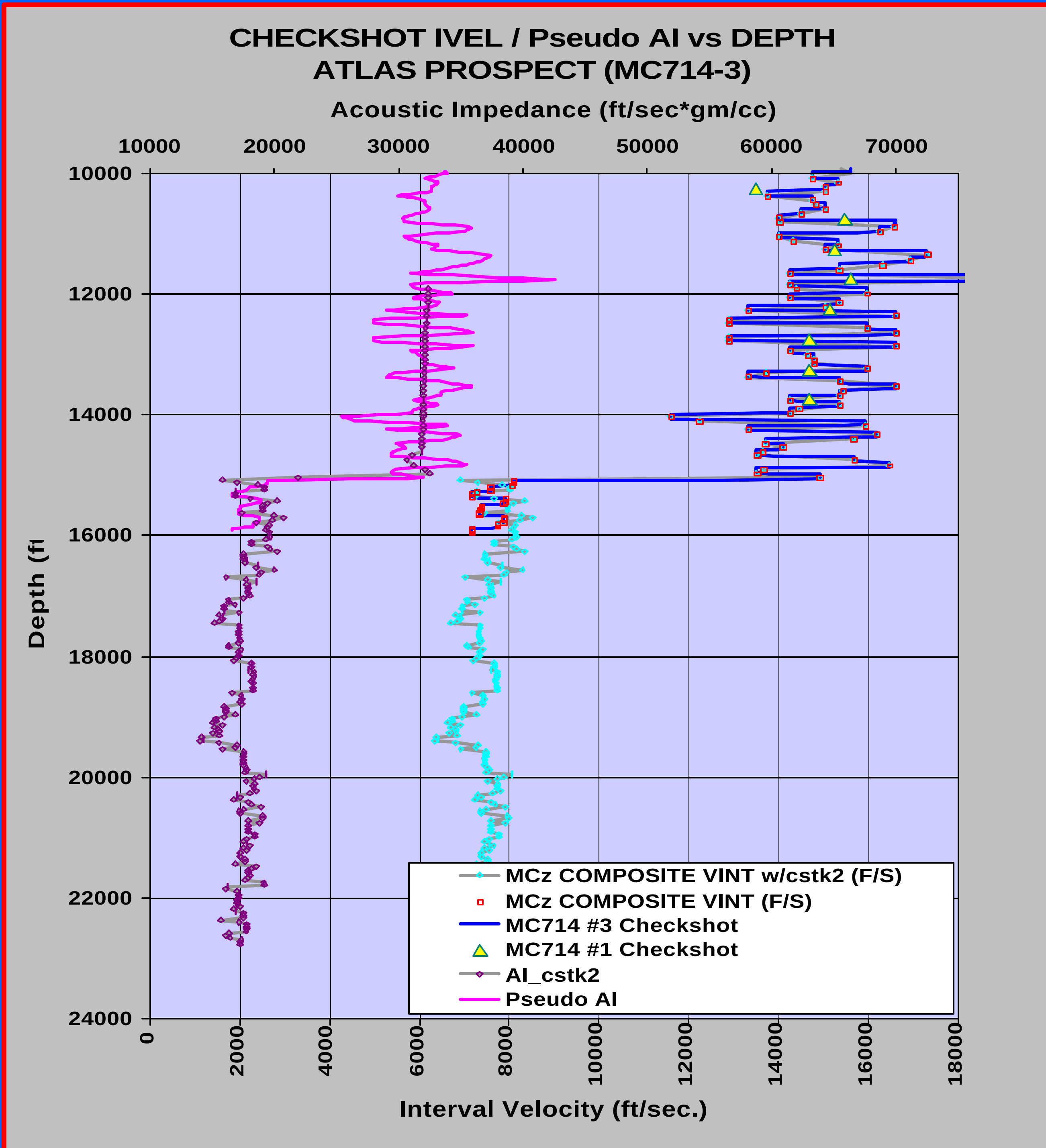
Drilling & Completions Technology

Corridor Stack(s) & Acoustic Impedance



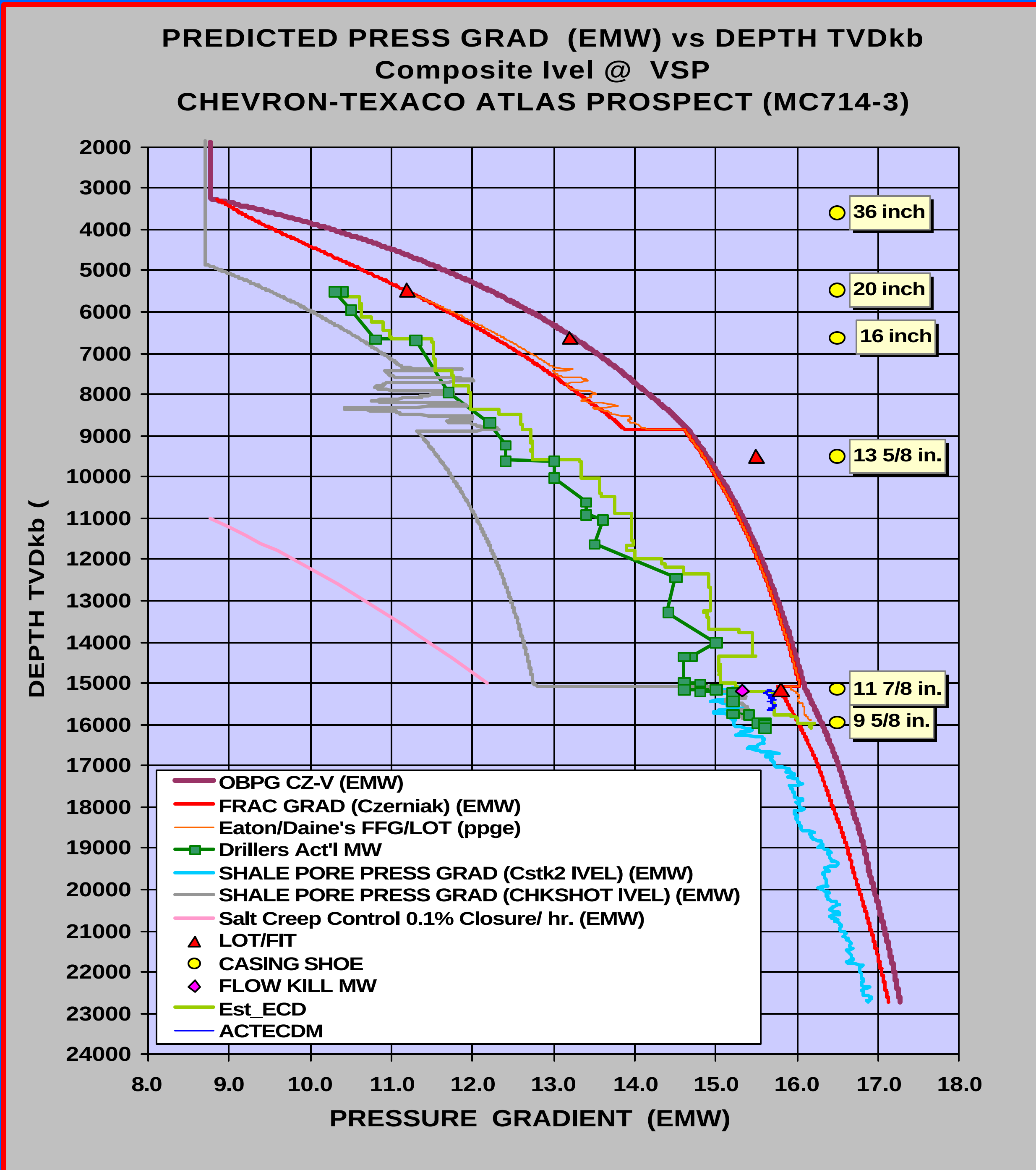
Drilling & Completions Technology

Acoustic Impedance & Velocity Inversion



Drilling & Completions Technology

Look Ahead Pore Pressure



Conclusions

- Comparison of AI profiles (*cstk1* and *cstk2*) generated by partially constrained SSI inversion confirmed the “Look-Ahead” capabilities of a conventional VSP within salt.
- Comparison of the AI profile generated from the corridor stack waveform from the MC714 #3 well (*cstk2*), and the inverted velocity profile (below the base of salt) were in close agreement with the recorded checkshot data.
- Transformation to pore pressure of the “Look-Ahead” inverted velocity-depth function from the MC714 #3 well (*cstk2*) from final TD (16,000 ft. TVDkb) onward, suggest that the Atlas Prospect MC714 #3 location remain at-or-near hard overpressures for projections down to approximately 23,000 feet TVD.
- Within the context of this study, an assessment of the drillability of this prospect, even optimized with expandable casing sections, suggest that this prospect will resist being drilled. This also reflects poorly on the seal integrity of any shales being viewed as a caprock.

Engineering Fluids for Subsalt Drilling

Michael B. Johnson

Baker Hughes INTEQ Drilling Fluids

What are the important elements to be considered during the Well Planning and Construction Process?

What must I do to drill @ the "technical limit" ("Manage Risk")?

Achieving the Technical Limit

BAKER HUGHES INTEQ DRILLING FLUIDS

- How do we facilitate achieving the Technical Limit?
  - Integrated borehole stability process
- What does an integrated borehole stability process entail?
  - Evaluating the prospect utilizing a multiple discipline approach
    - Well Engineering
    - Petophysics
    - Geology
    - Geomechanics
    - Rock mechanics
    - Fluids specialist
- When is this process utilized?
  - Preplanning phase
  - Execution phase

Integrated Borehole Stability

Issues

- Offset well reviews
- Analysis of:
  - Geology & sub-surface hazards
  - Pore pressure
  - In-situ stress
  - Formation strength & failure
- Well path optimization
- Hole cleaning
- Equivalent circulating density (ECD)
- Swab & surge analysis
- Drilling fluid recommendation

Characteristics of Subsalt Wells

- Shallow geo-pressure
- ROP / deviation problems
- Inclusions
- Pore pressure / Fracture gradient
- BHA balling
- Loss of circulation
- None of the above

Characteristics of "Rubble" Zone

- Unconsolidated/porous shale
- Unconsolidated sand
- Fractured
- Hydratable
- Dispersive

"Rubble" Zone

X-Ray Diffraction Analysis

Mineralogy	*% by Weight*
Quartz	5-10%
Feldspar	3-5%
Illite	25-30%
Mixed Layer	35-40%
Chlorite	5-10%
Kaolinite	5-10%
Siderite	5-10%
Expandable layers in mixed layer	70-80%

Drilling Problems

“Rubble” Zone

- Gas cap below salt
- Nearly overlapping pore pressure and fracture gradients
- Equivalent circulating density
- Reduced circulation rate
- Reduced rate of penetration
- Hole cleaning
- Bit and BHA balling
- Fractures/lost circulation
- Shale inhibition/stabilization

Drilling Fluid Requirements

- Maintain well bore stability
- Prevent BHA balling
- Prevent bit balling
- Control lost circulation
- Stabilize the salt/shale
- Environmentally acceptable
- Economical

Design for Shale Stabilization

- Minimize hydration/osmotic swelling
- Minimize dispersion
- Increase filtrate viscosity
- Reduce shale permeability
- Temperature profile

Fluid System Alternatives

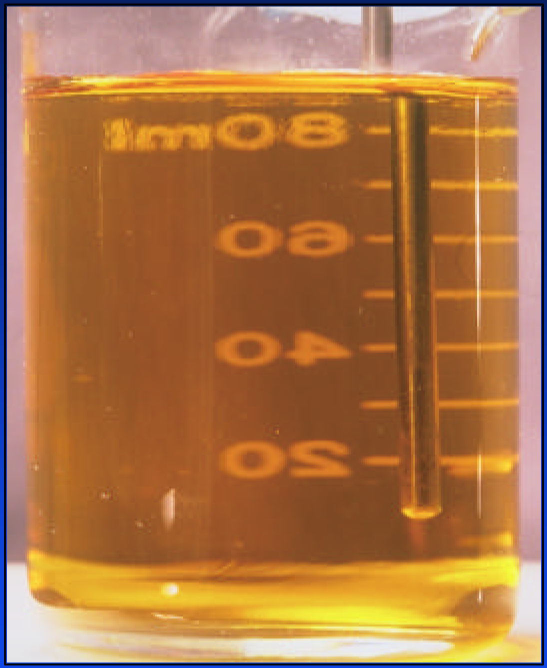
- Pseudo oil mud
- Water base mud
  - Cloud point chemistry
  - Aluminum chemistry
  - Silicates

Polyglycol/Shale Stabilization

Mechanism

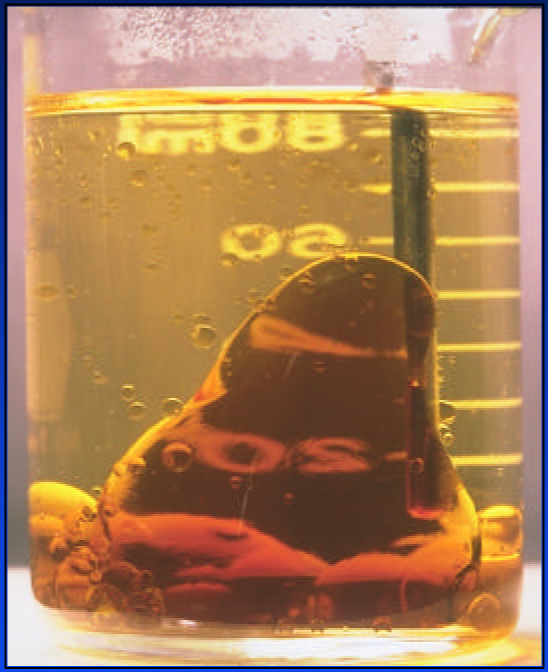
- Pore pressure transmission
- Glycol's form stable complexes with clays
- Polyglycol performance maximized when used near Cloud Point Temperature

Phase Change - A Reversible Process



Glycol and Water
As a Single Phase

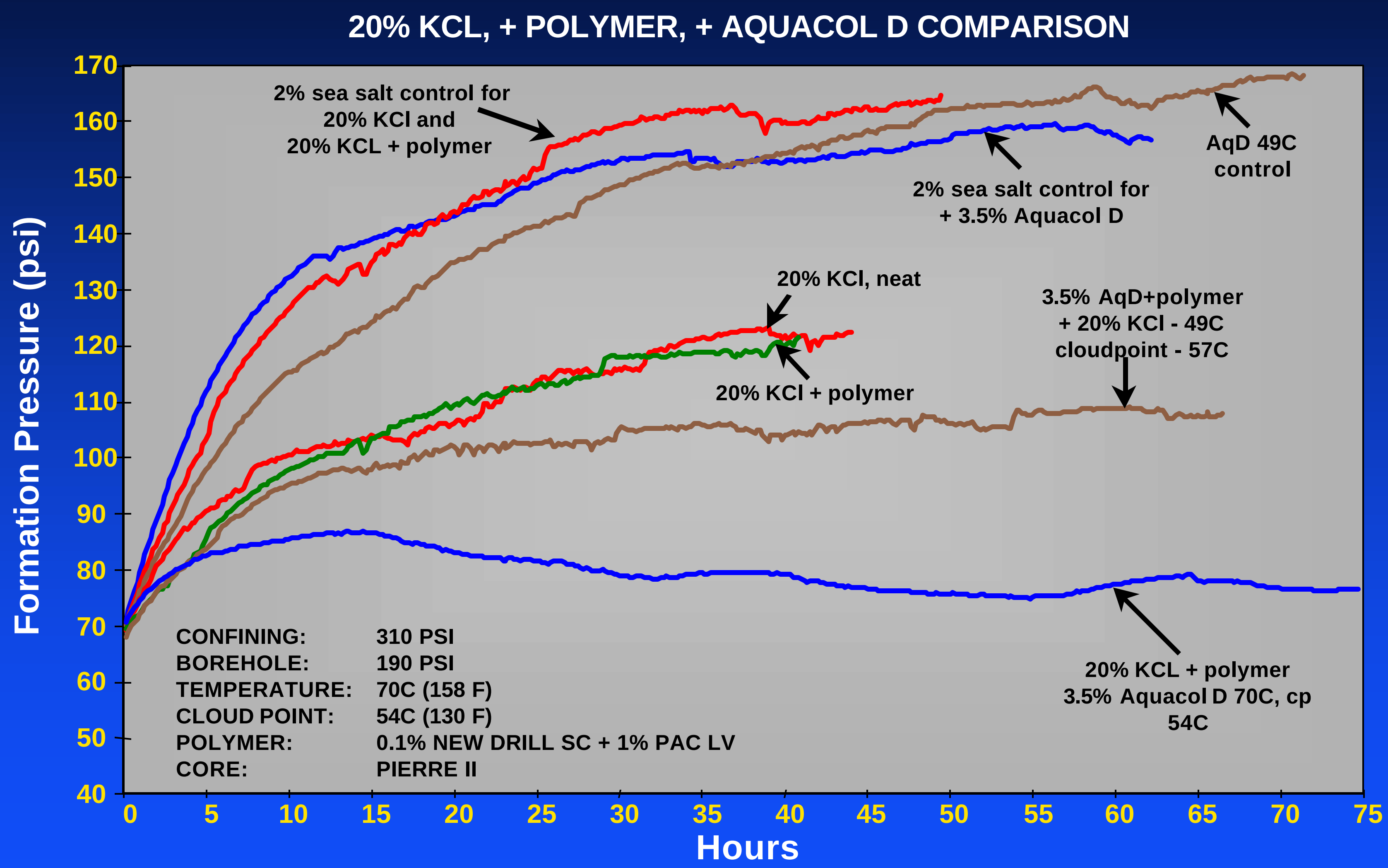
"Clouding Out"



Glycol and Water
As 2 Distinct Phases

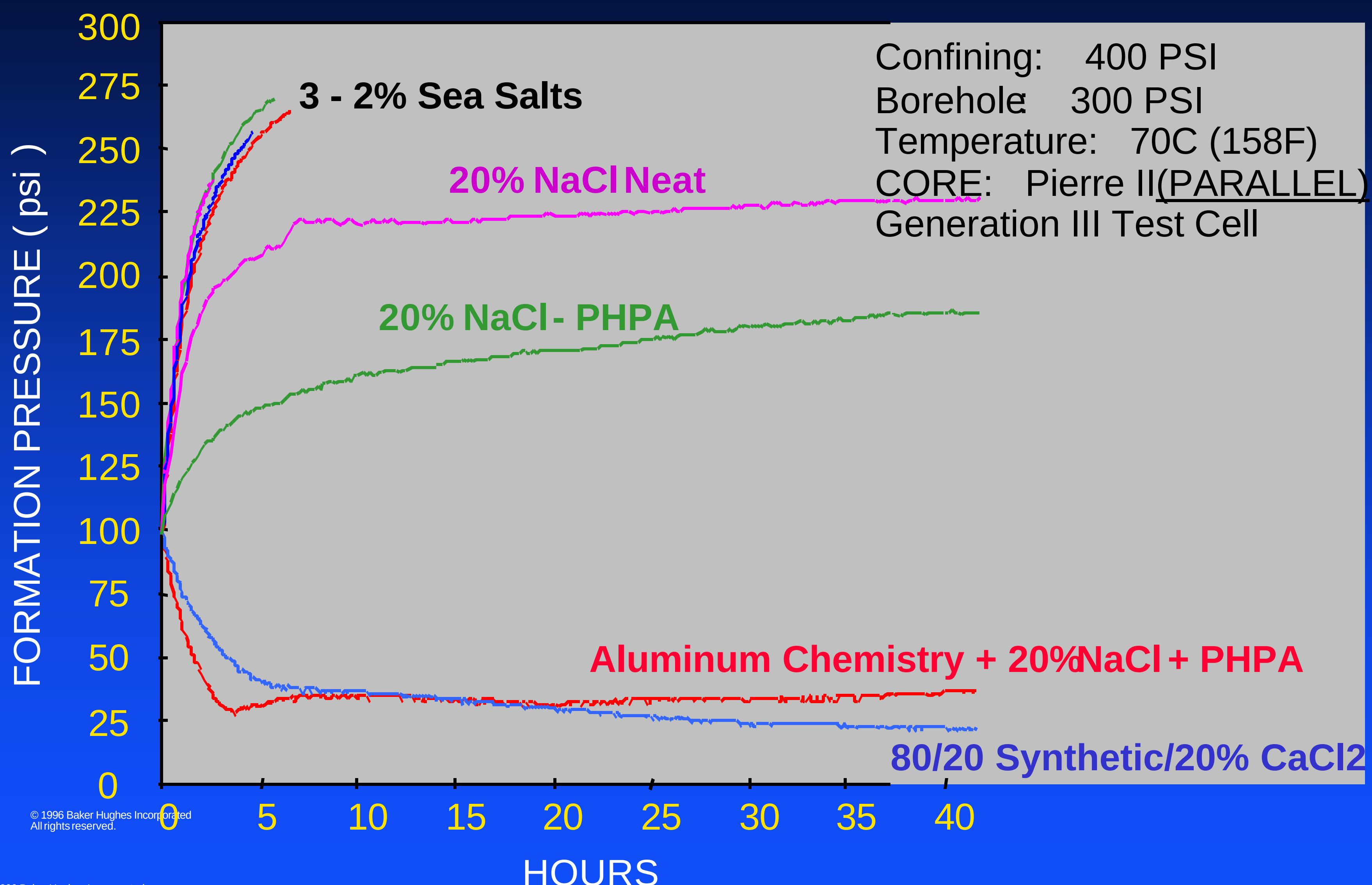
Pore Pressure Transmission

BAKER HUGHES INTEQ DRILLING FLUIDS

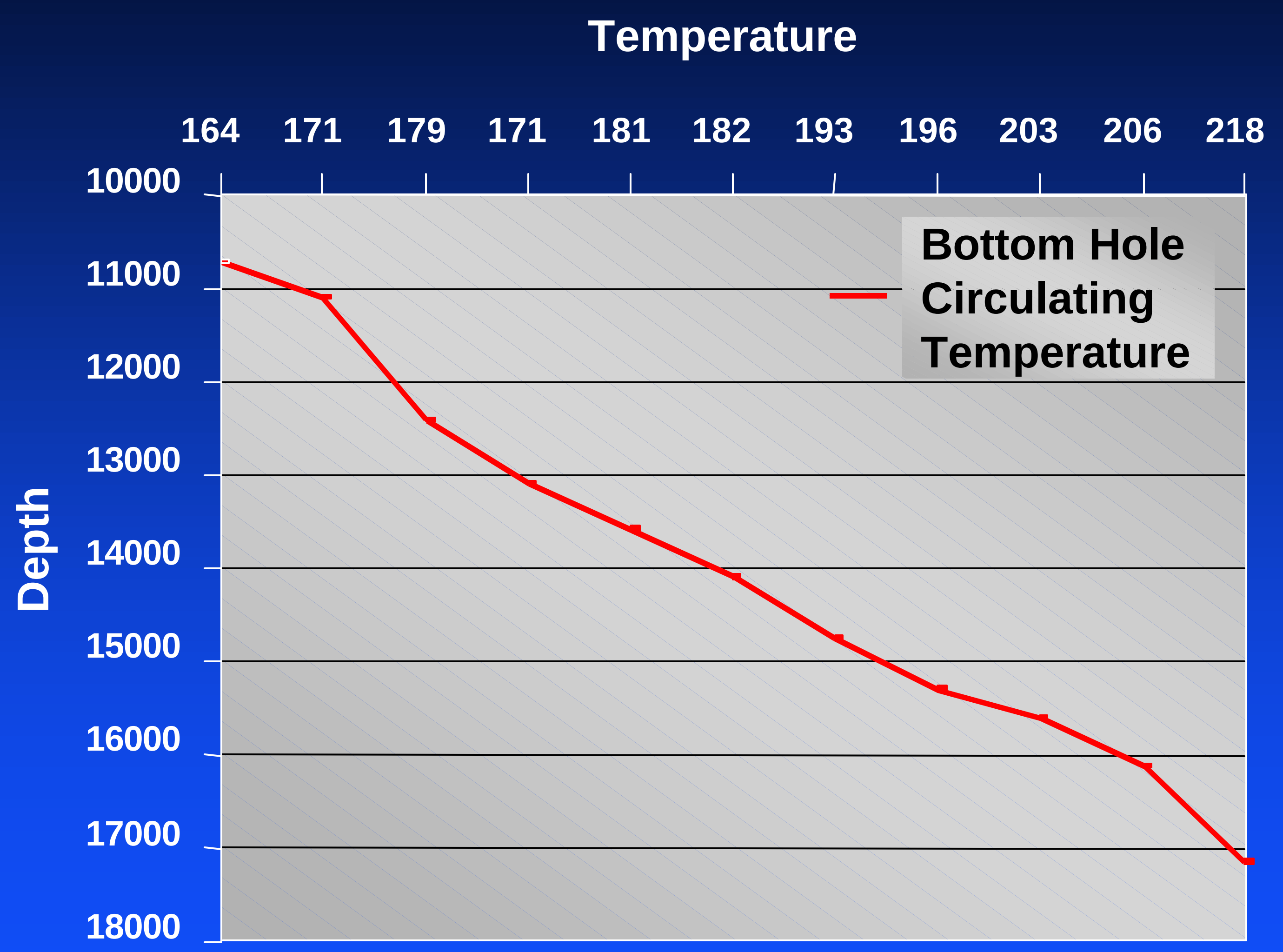


Pore Pressure Transmission

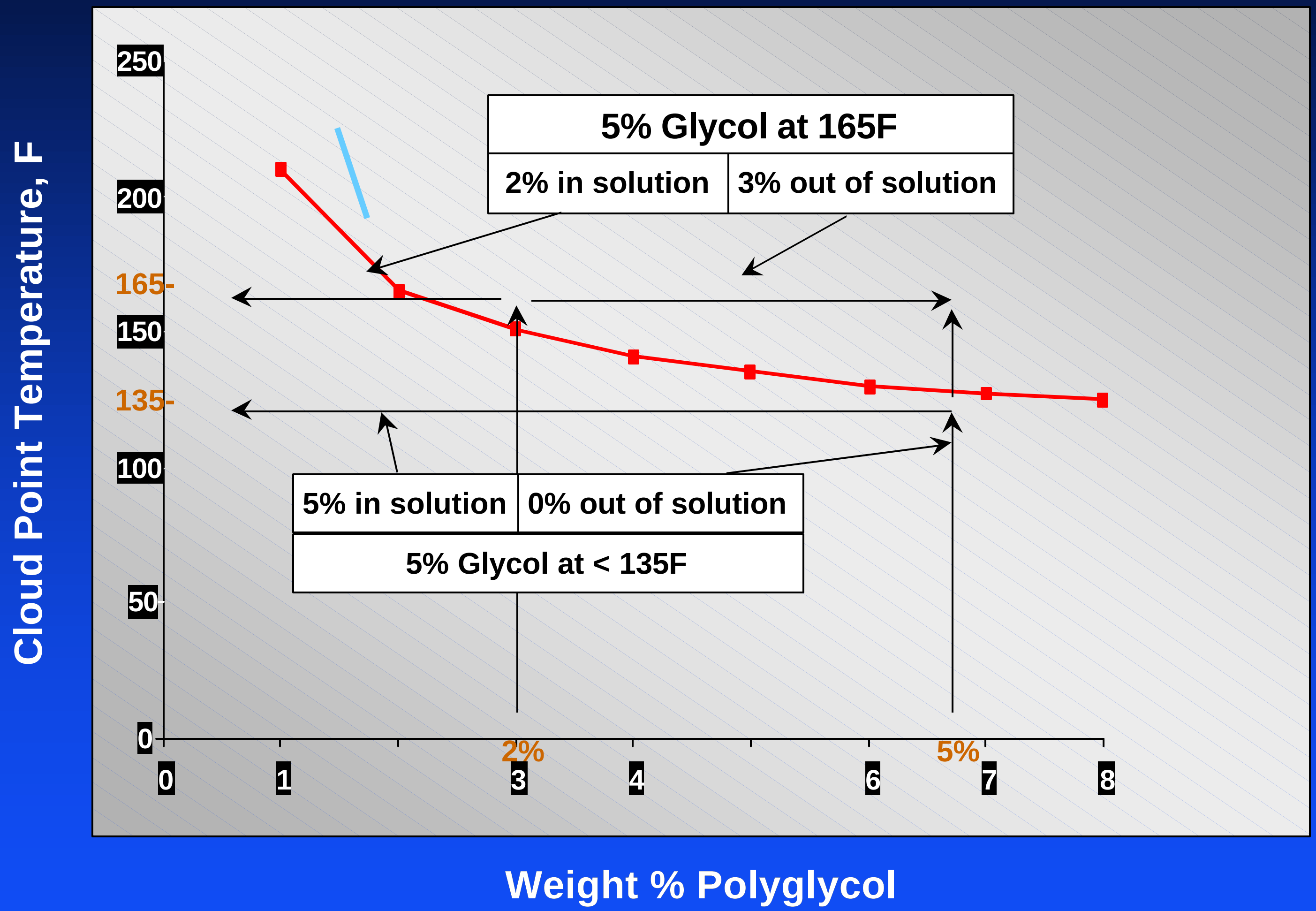
BAKER HUGHES INTEQ DRILLING FLUIDS



Subsalt Temperature Profile



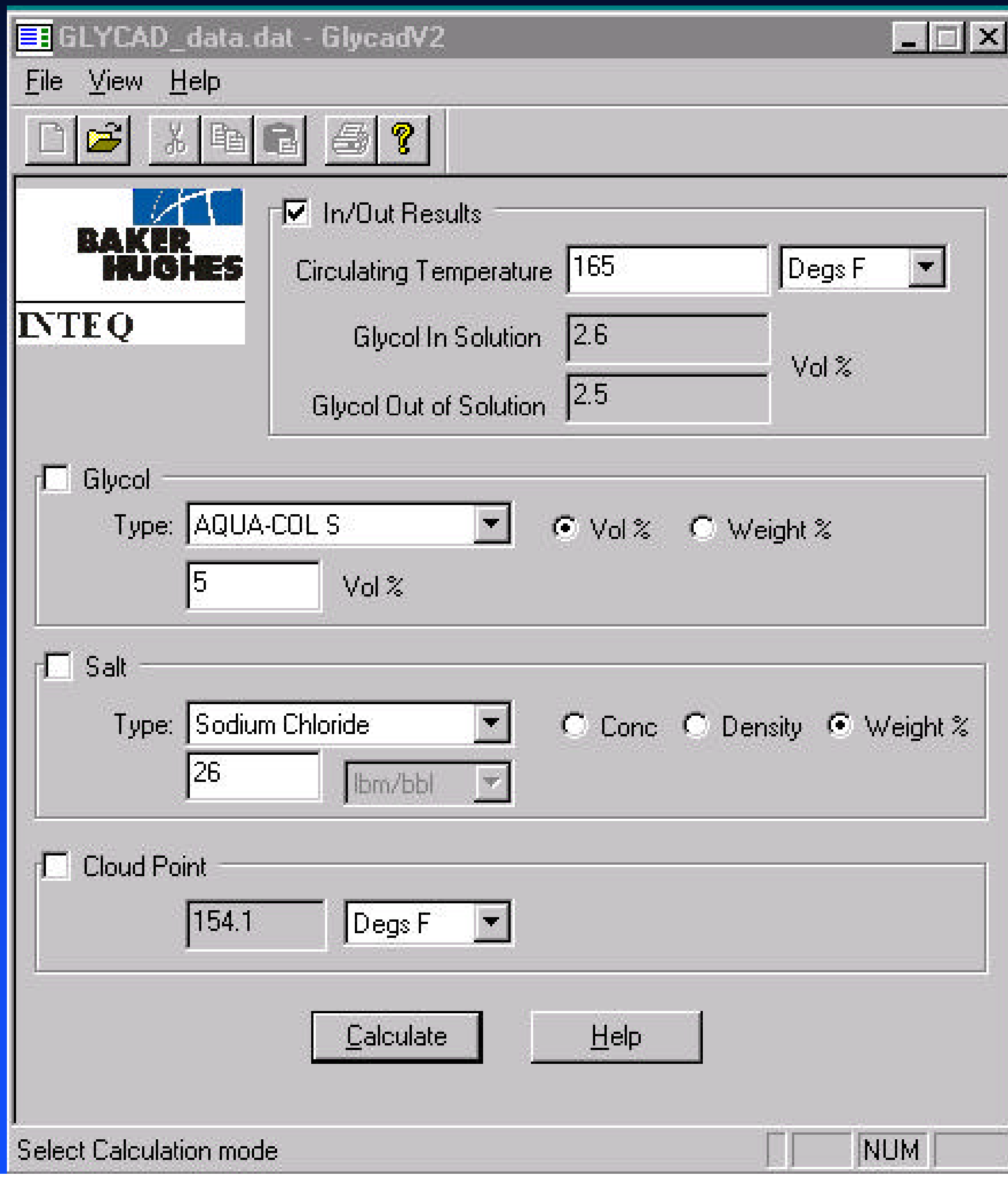
Cloud Point Temperature



Gly-Cad Software Program

- Windows based software program
- Assists in selecting optimum polyglycol and electrolyte concentration
- Used to match polyglycol solubility characteristics to bottom hole circulating temperature

Gly-Cad Display Screen



Typical Formulation

Cloud Point Glycol

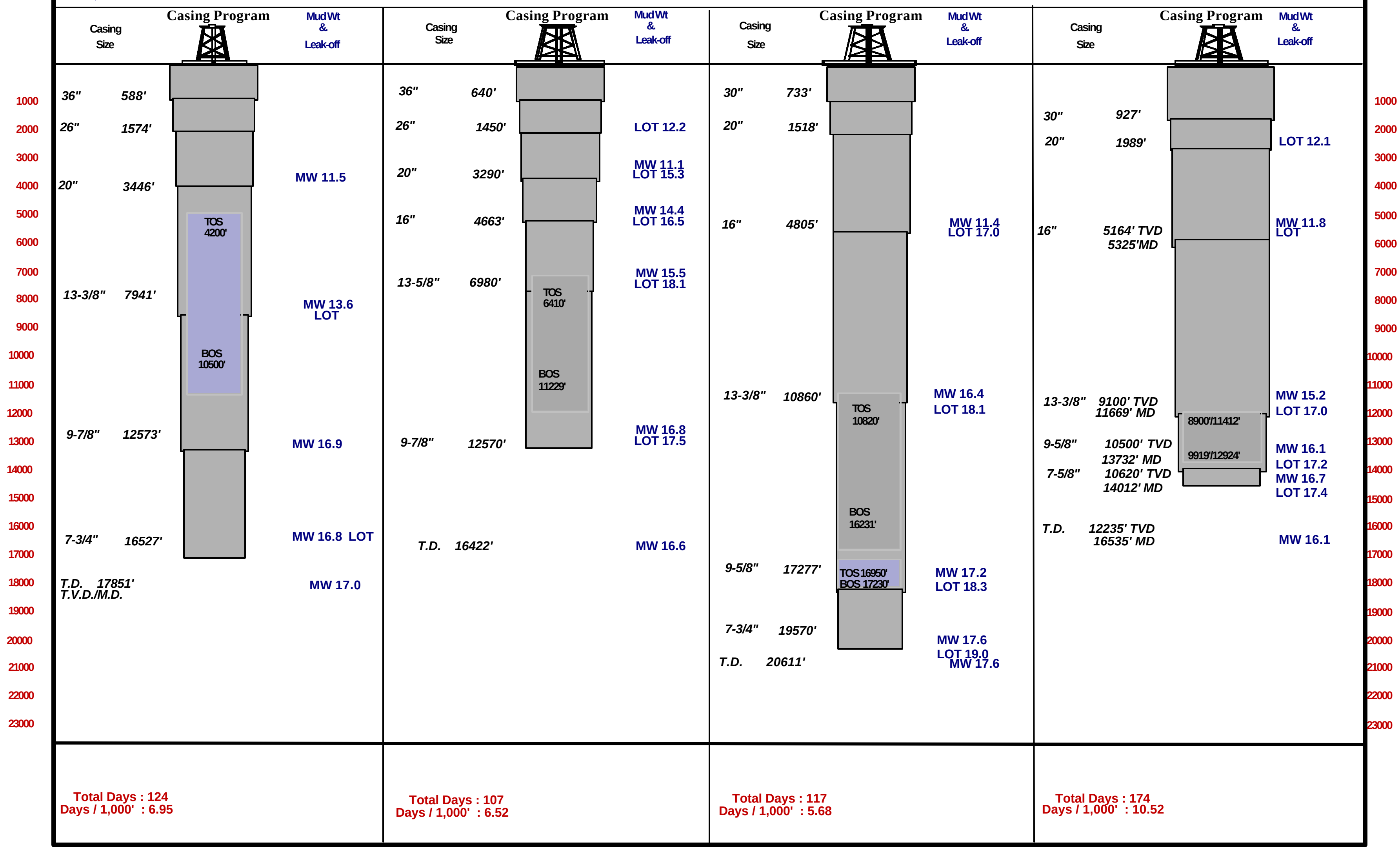
Product	*Concentration (ppb)*
Saturated Brine (NaCl)	
PHPA	1.5 – 2.0
PAC	1.0 – 3.0
Starch	1.0 – 3.0
KOH	0.5
K-Lignite	5.0
K-Asphalt	5.0
Gel	2.0 – 5.0
Glycol	3% - 5%
Zantham	0.2 – 0.4
Barite	As Req.

Typical Properties

Cloud Point Glycol

Mud Weight	14.9 – 17.7 ppg
Plastic Viscosity	30 – 55 cps
Yield Point	12 – 25 lb/100ft²
10 sec Gel Strength	4 – 12 lb/100ft²
10 min Gel Strength	8 – 22 lb/100ft²
pH	9.0 – 10.5
API Fluid Loss	2.0 – 4.0 cc
HTHP Fluid Loss	10.0 – 25.0 cc
MBT	5 – 17.5 lb/bbl equiv.

Subsalt Well Schematics

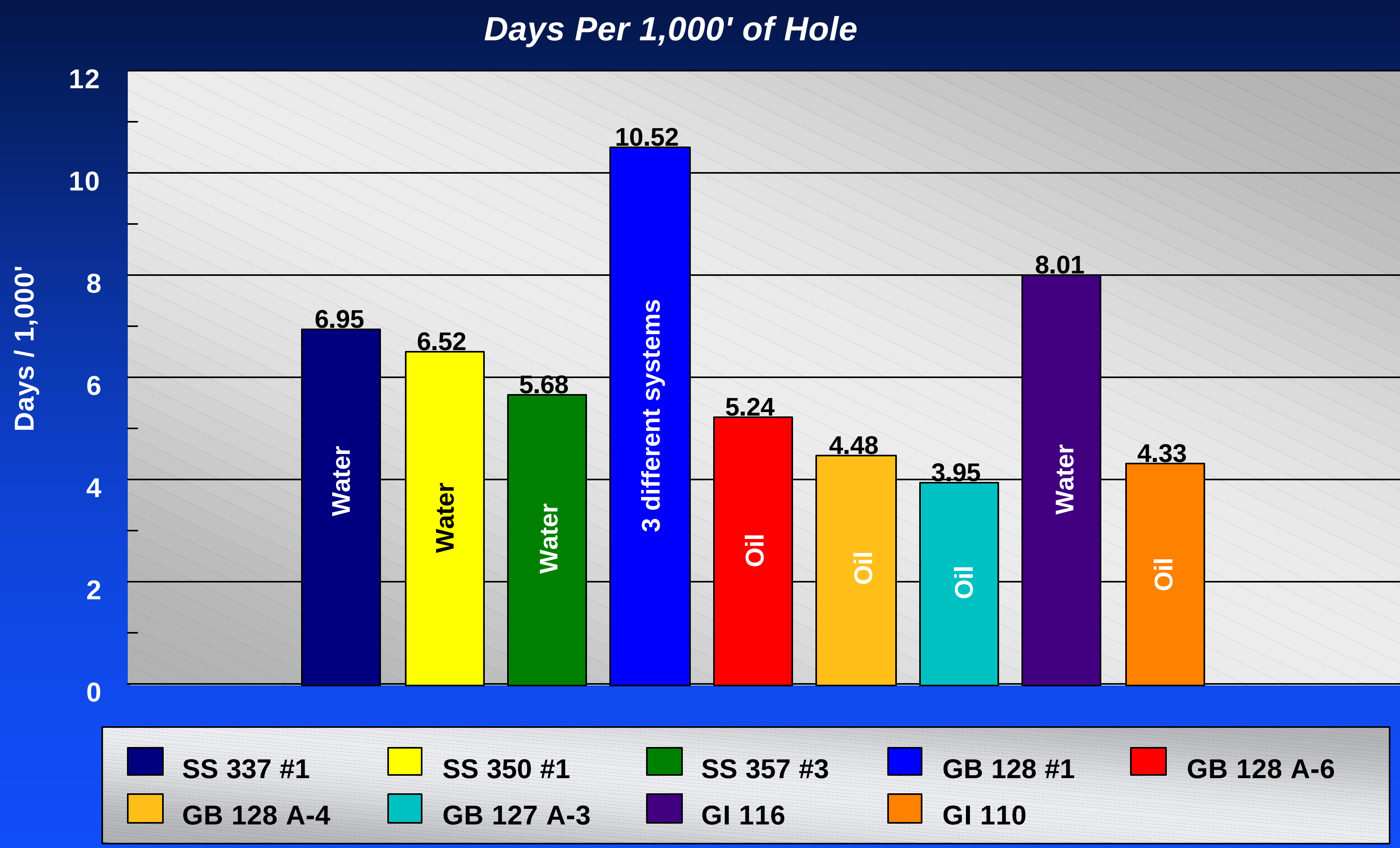


Overall Case Histories

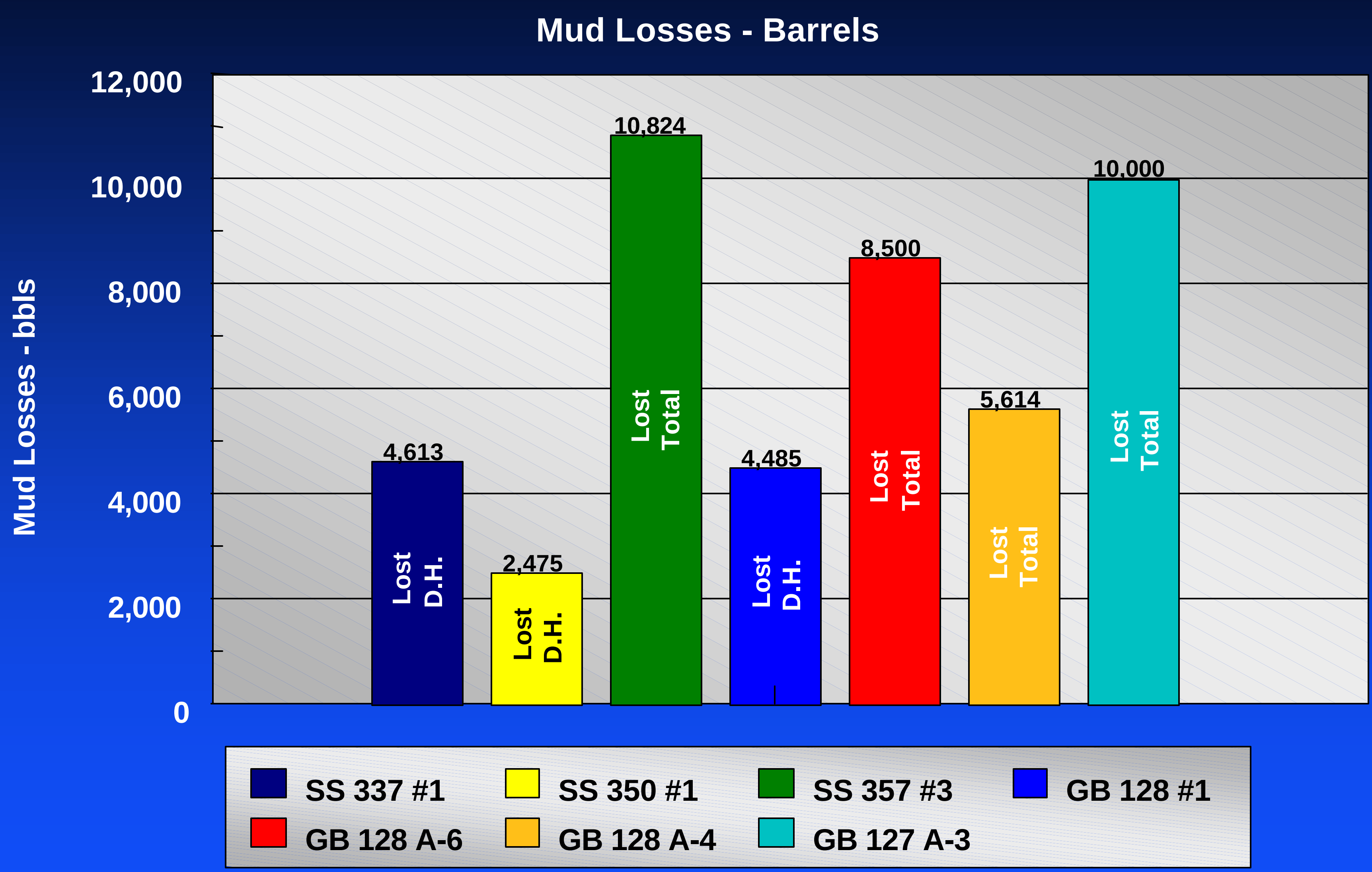
BAKER HUGHES INTEQ DRILLING FLUIDS

- Very few hole problems encountered, especially compared to offset wells
- Outstanding well bore stability
- Virtually non existent bit and BHA balling
- No hole cleaning problems
- Annular pressure sensor/PWD confirm very low ECDs
- Lost circulation in anticipated fractures
- Reduced pump rates required
- Controlled rate of penetration required

Subsalt Histories



Subsalt Histories



Conclusions

- Drilling the “rubble” zone is one of several challenging aspects of subsalt drilling
- Using polyglycol systems near their CPT maximizes performance and offers an alternative to Pseudo-Oil Mud
- Maintaining polyglycol systems near their CPT requires:
  - Knowledge of the solution behavior of the polyglycol
  - Polyglycol concentration
  - Electrolyte type and concentration
- Field results indicate engineered polyglycol systems will:
  - Successfully drill subsalt wells
  - Minimize drilling problems encountered

2001 DEEPWATER GEOHAZARDS WORKSHOP

Analysis of Salt Creep in a Deepwater GOM Well and Preventing Salt-induced Casing Damage

Colby Ballew

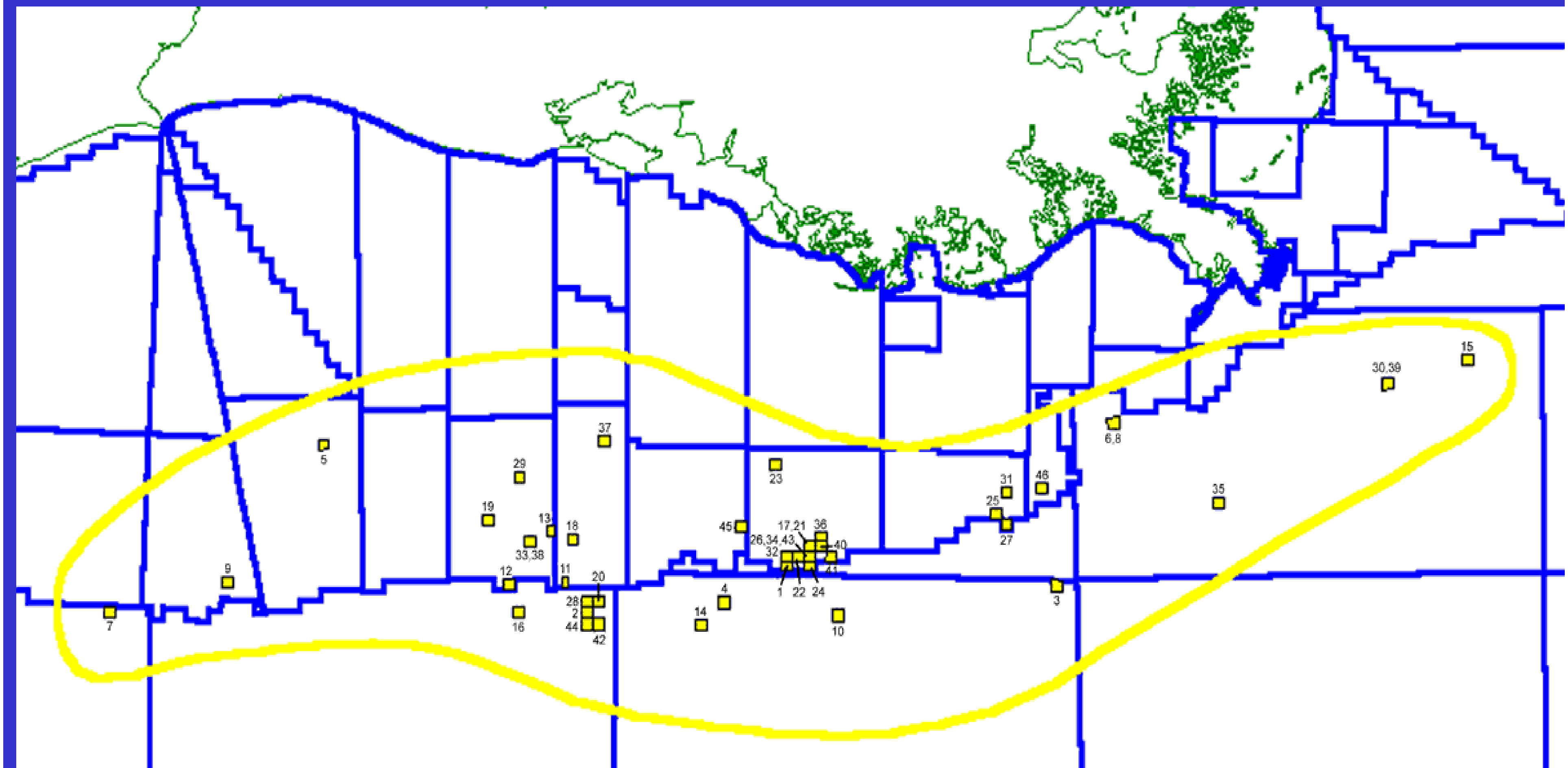
Principal Technical Professional

Halliburton Energy Services

TOPICS OF DISCUSSION

- Overview of Salts and Salt Creep
- Review of Cementing Issues
- Overview of Numerical Modeling

AREAL EXTENT OF THE SUBSALT PLAY IN THE GOM

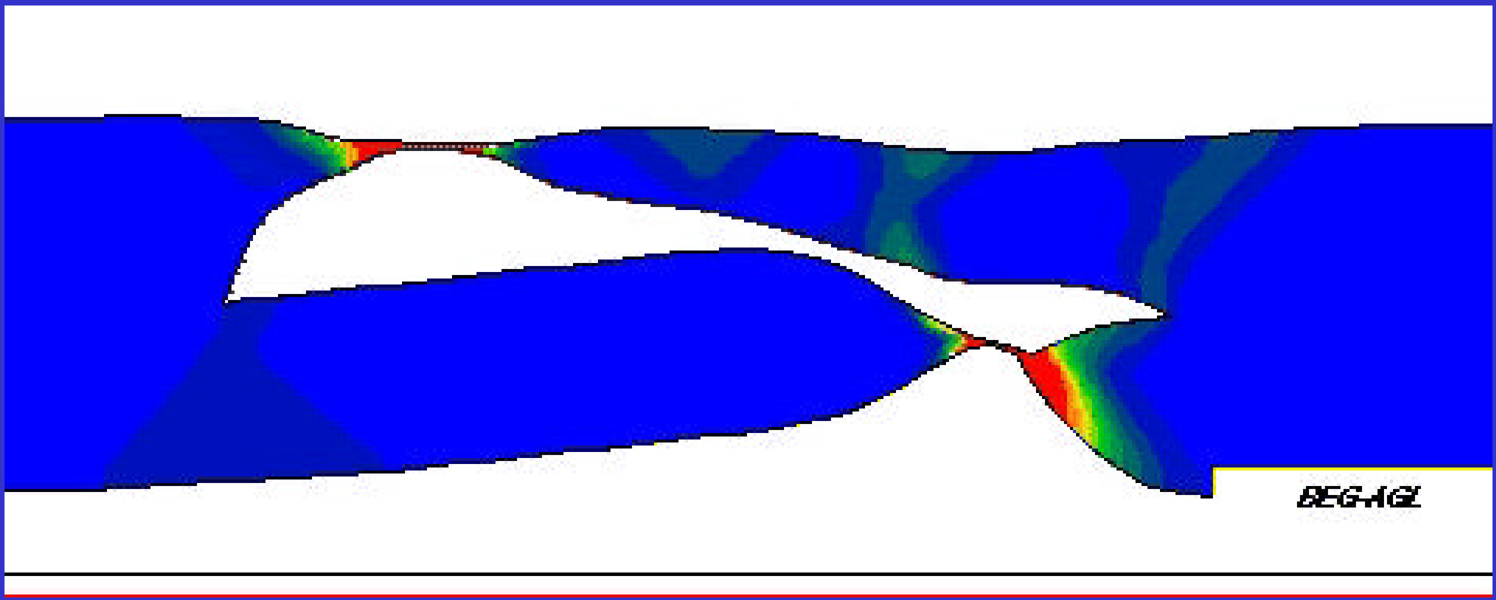


Subsalt Wells in the Gulf of Mexico (Includes non-proprietary and publicly announced wells) Last Updated 08/15/99

Taken from the MMS Web-Site

A FINITE-ELEMENT MODEL ILLUSTRATING THE EXTENSION OF A SEDIMENTARY SEQUENCE CONTAINING AN ISOLATED ASYMMETRIC SALT SHEET

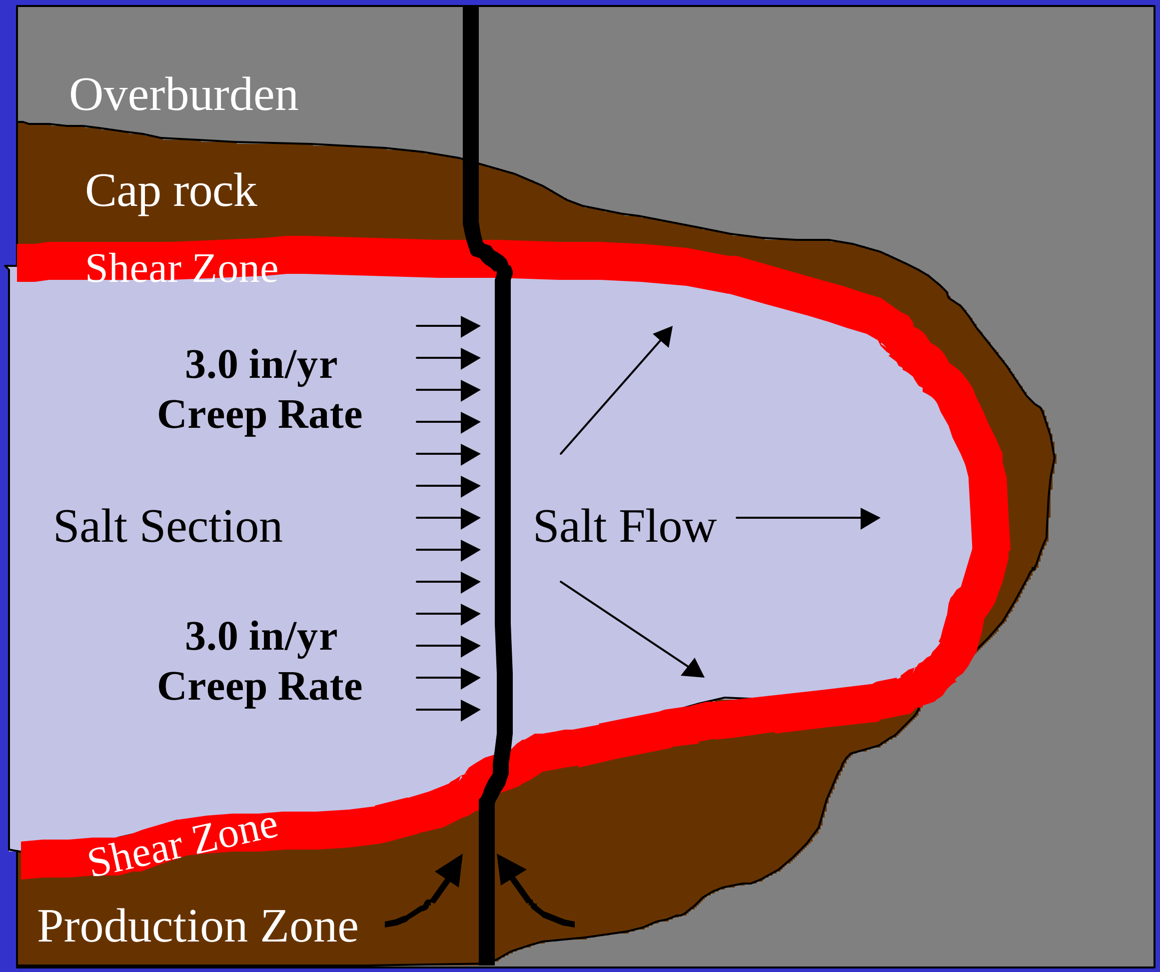
CLICK ON GRAPHIC TO RUN ANIMATED CLIP.



Guglielmo, Giovanni, Jr., D. D. Schultz-Ela, and M. P. A. Jackson 1998, Extension of a Sedimentary Sequence Containing an Isolated Asymmetric Salt Sheet: A BEG hypertext multimedia publication in the Internet at: http://www.utexas.edu/research/beg/mmedia/AGL98-MM-0010.

Creep Rates for the GOM

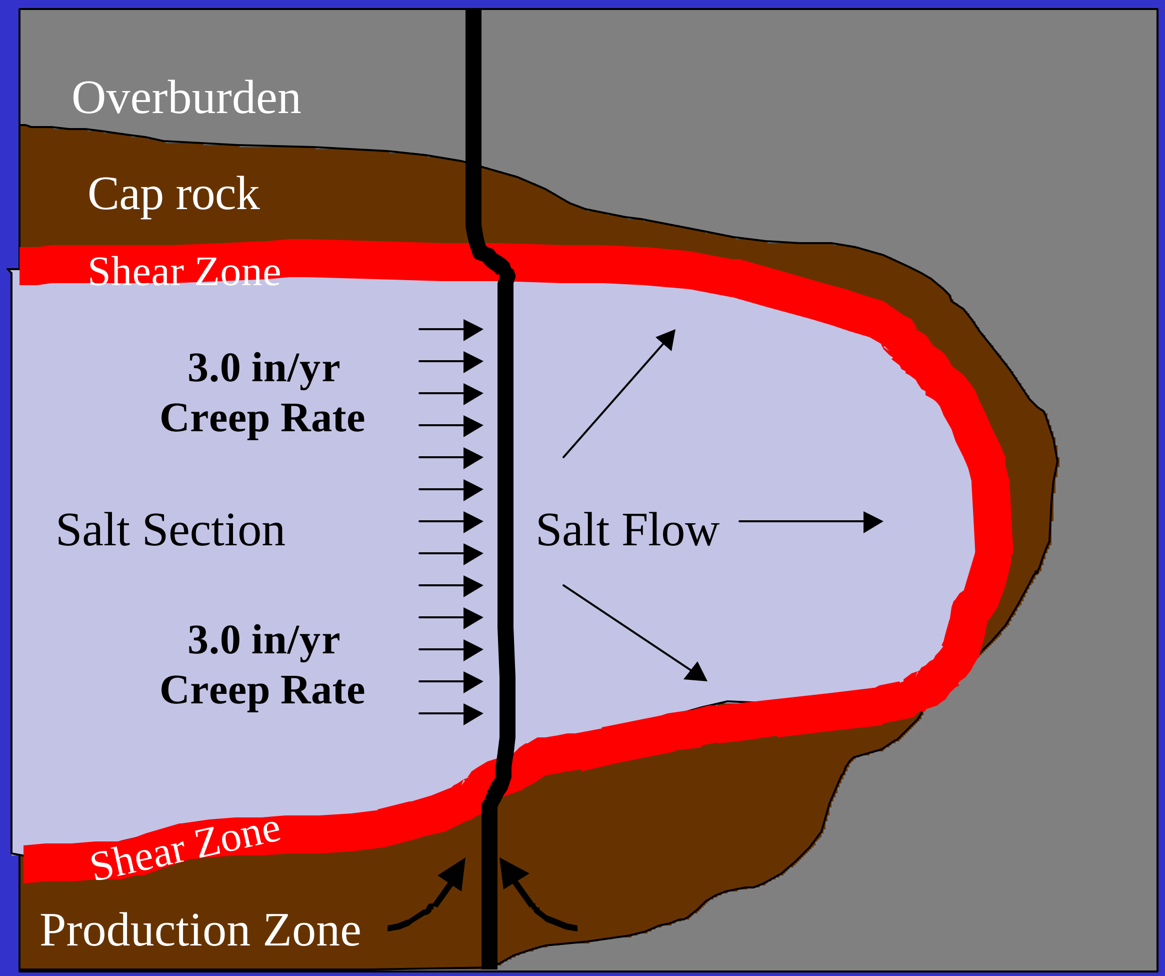
Creep Rates in the GOM average 2.5 - 3.0 inches per year.



Creep Rates for the GOM

Creep Rates in the GOM average 2.5 - 3.0 inches per year.

These rates do not pose a serious problem during drilling or completion.

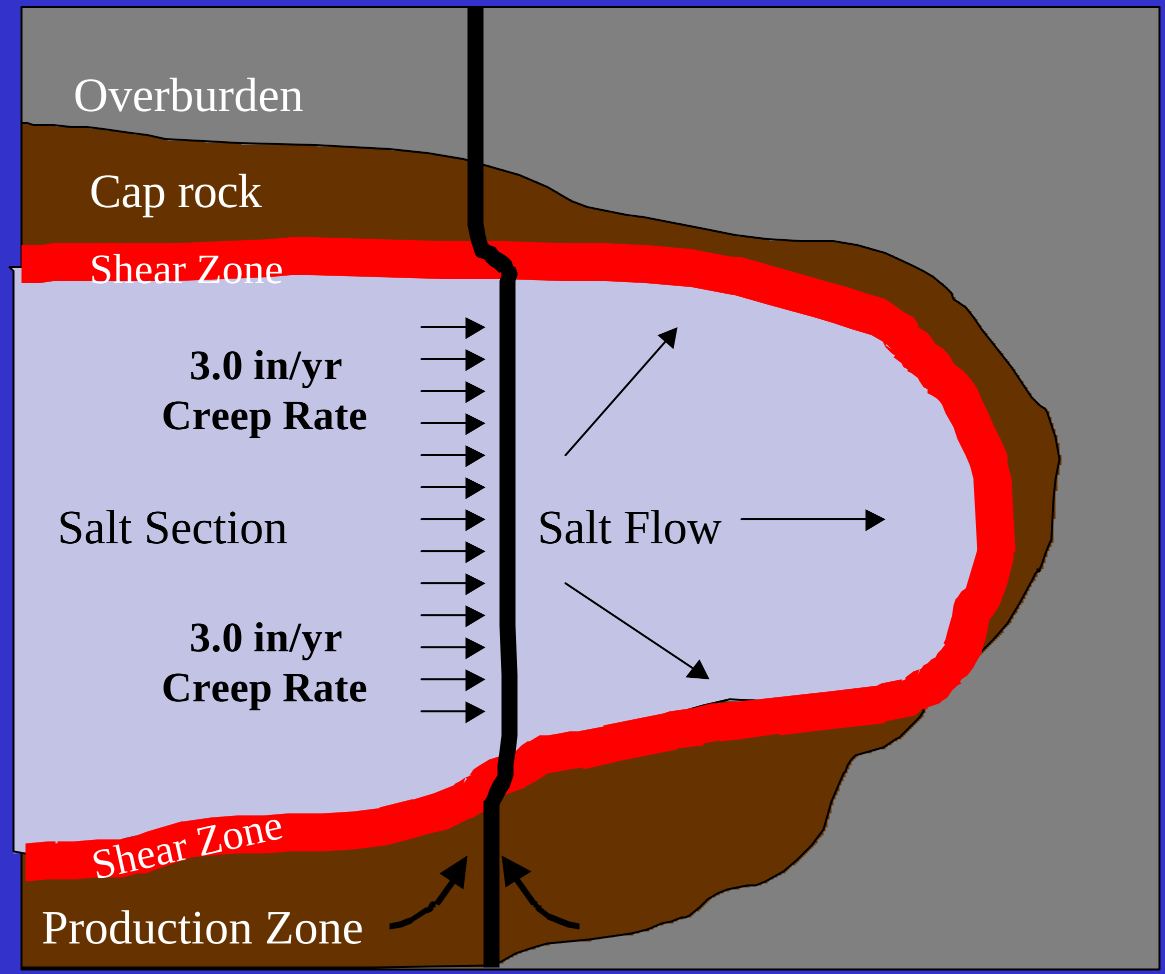


Creep Rates for the GOM

Creep Rates in the GOM average 2.5 - 3.0 inches per year.

These rates do not pose a serious problem during drilling or completion.

However problems arise when significant salt forces force the wells off trajectory.



Effects of Salt Forces on Casing

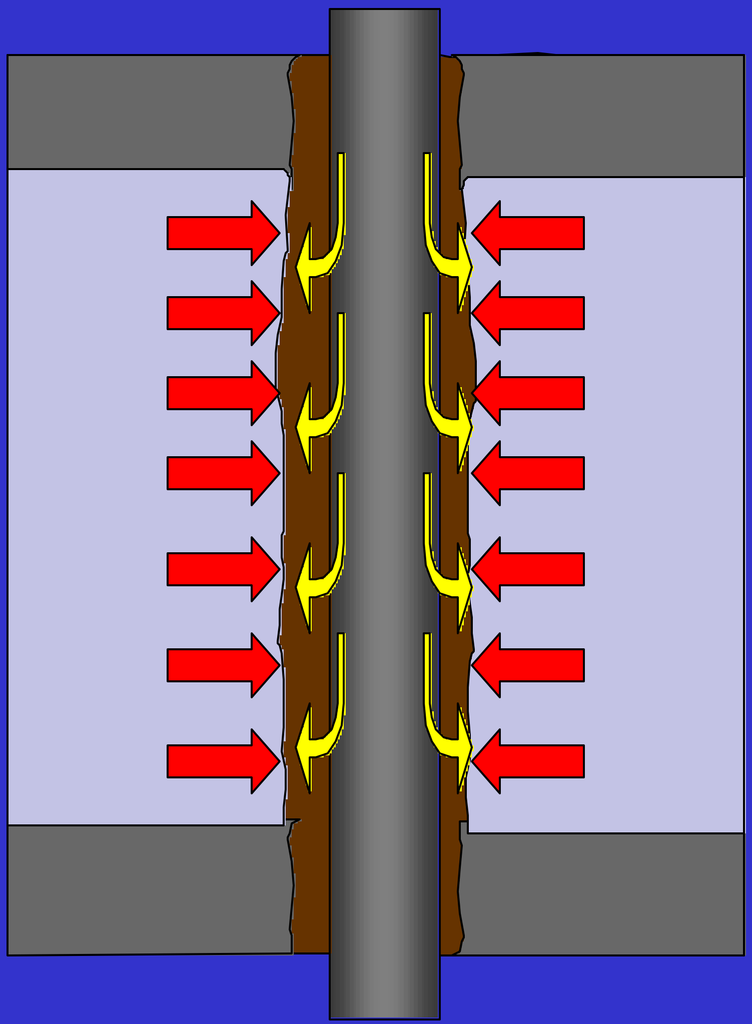
The following five damage mechanisms can be caused by the way the salt forces load the casing:

- column buckling over a short unsupported interval
- crushing of the cross section
- connection failure
- local buckling (a wrinkle in the pipe)
- bending

Hydrostatic Control of Salt Extrusion

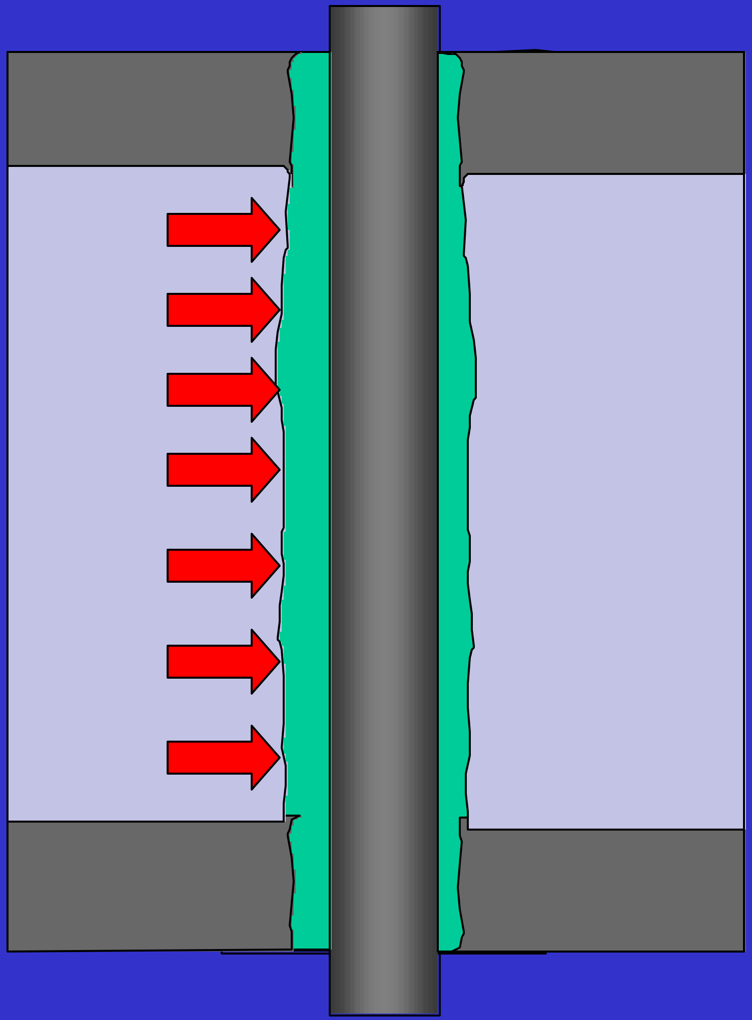
During drilling operations the extrusion of the salts into the wellbore are controlled by the hydrostatic of the drilling fluids.

For every one pound per gallon increase in the in-situ stresses the mud weight must be increased by one pound per gallon to prevent an acceleration of the salts closure rate.



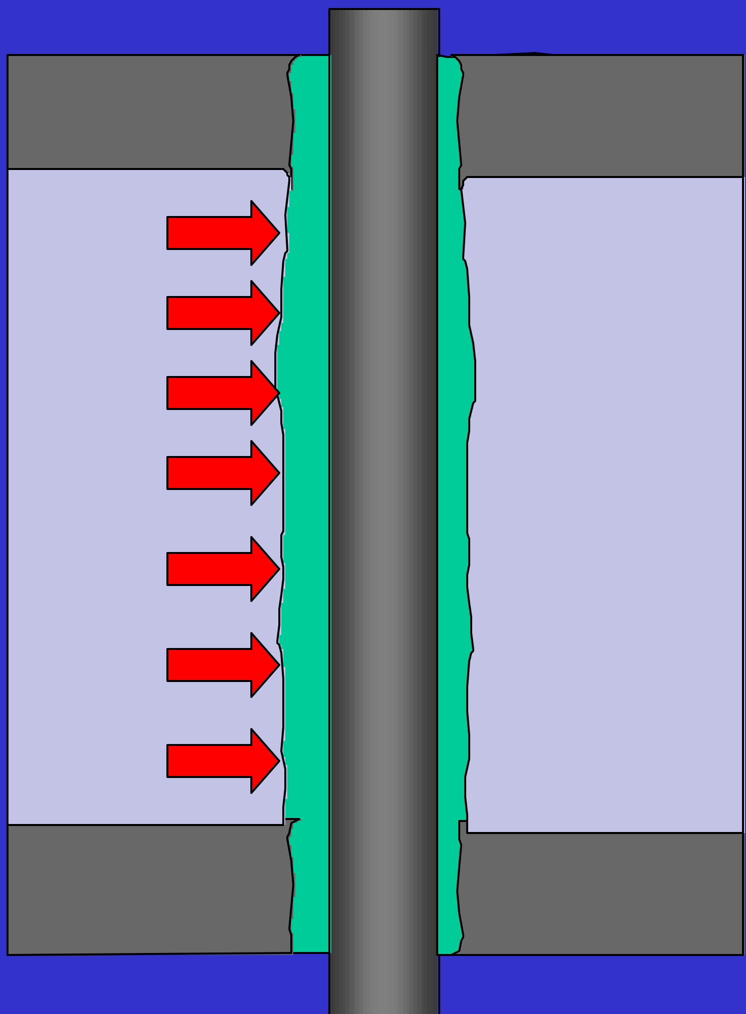
Fully Cemented Annulus

In a properly cemented annulus the shear forces will be evenly distributed throughout the length of the casing.



Effects of a Cement Slurry's Gel Strength Development

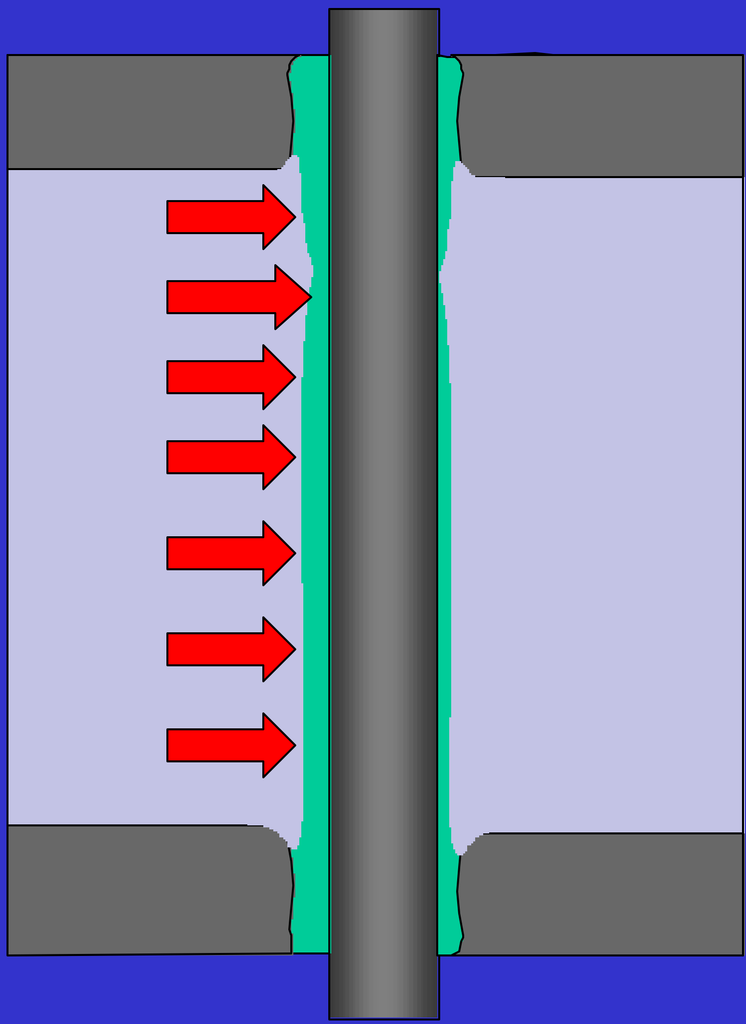
Even in a fully cemented annulus it is possible to develop point loading!



Effects of a Cement Slurry's Gel Strength Development

Even in a fully cemented annulus it is possible to develop point loading!

As a cement slurry sets it will lose it's ability to transmit it's full hydrostatic pressure as it develops gel strength.

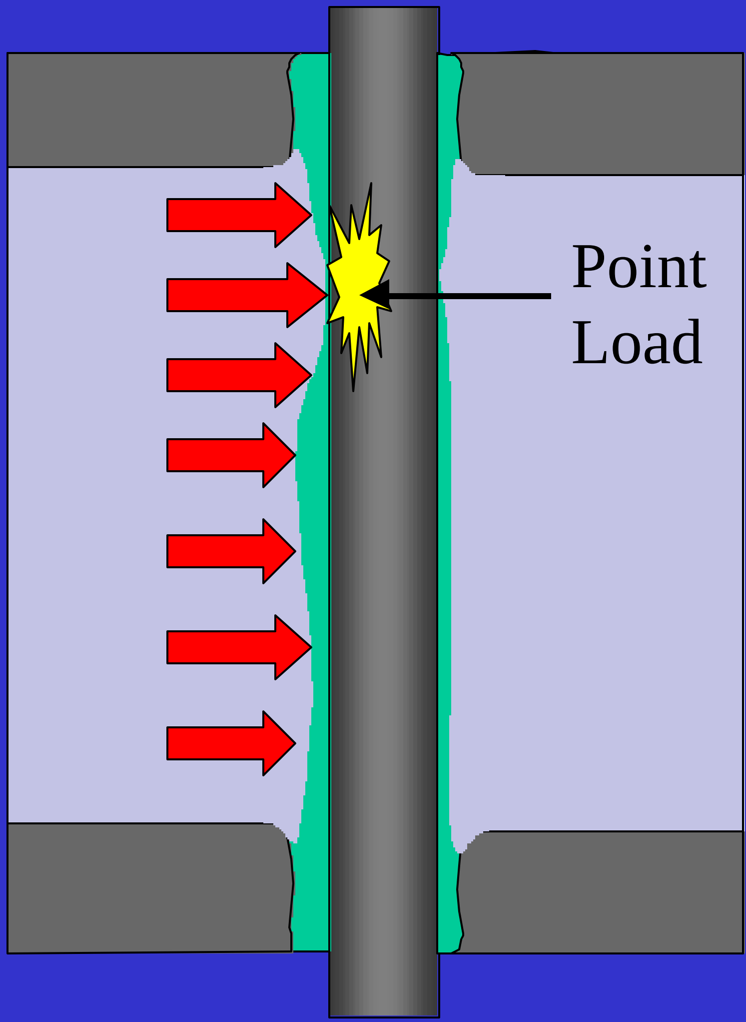


Effects of a Cement Slurry's Gel Strength Development

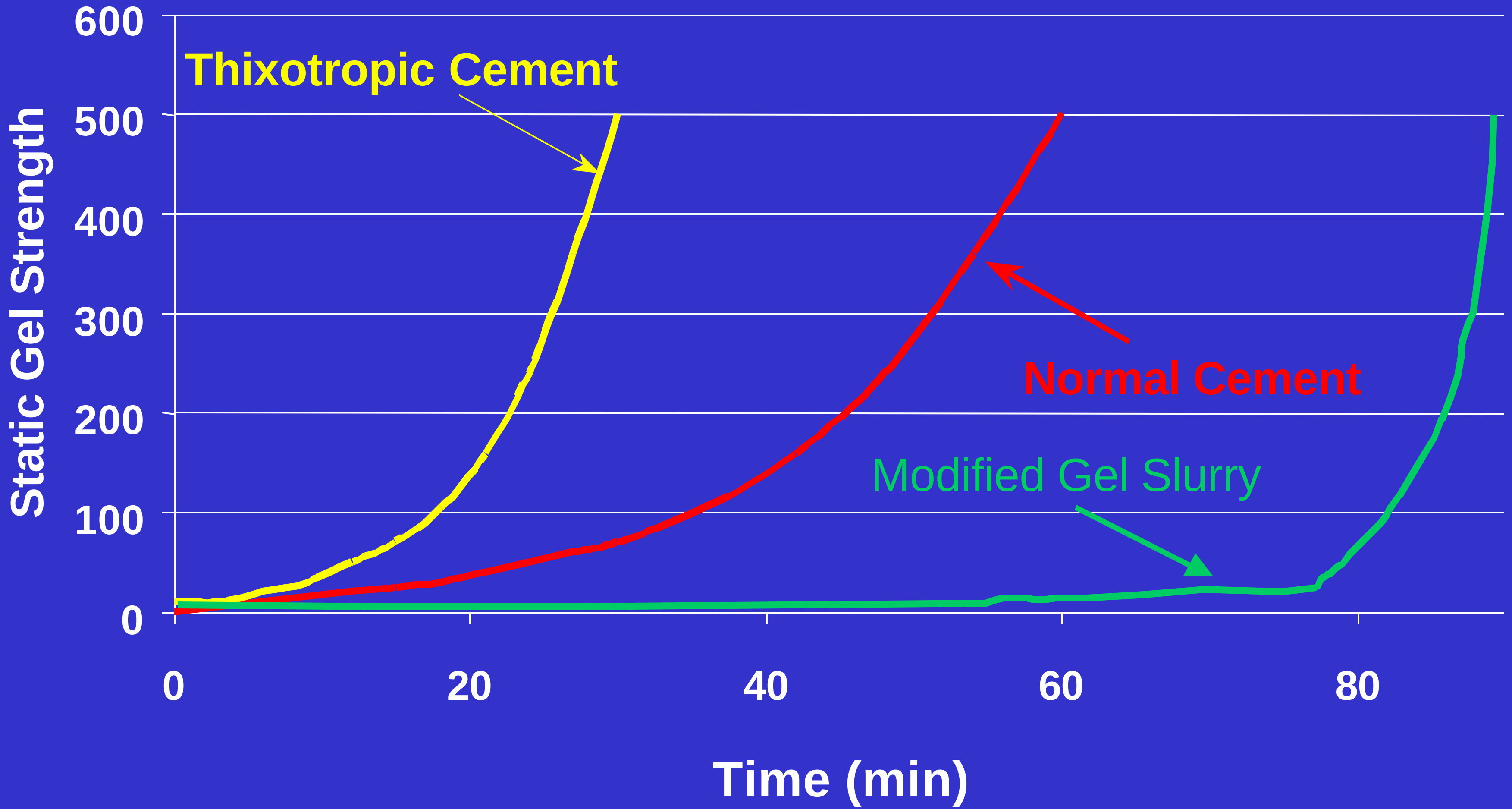
Even in a fully cemented annulus it is possible to develop point loading!

As a cement slurry sets it will lose it's ability to transmit it's full hydrostatic pressure as it develops gel strength.

Point loading may occur if a non-uniform slurry is mixed and pumped.



Gel Strength Development -vs- Slurry Type

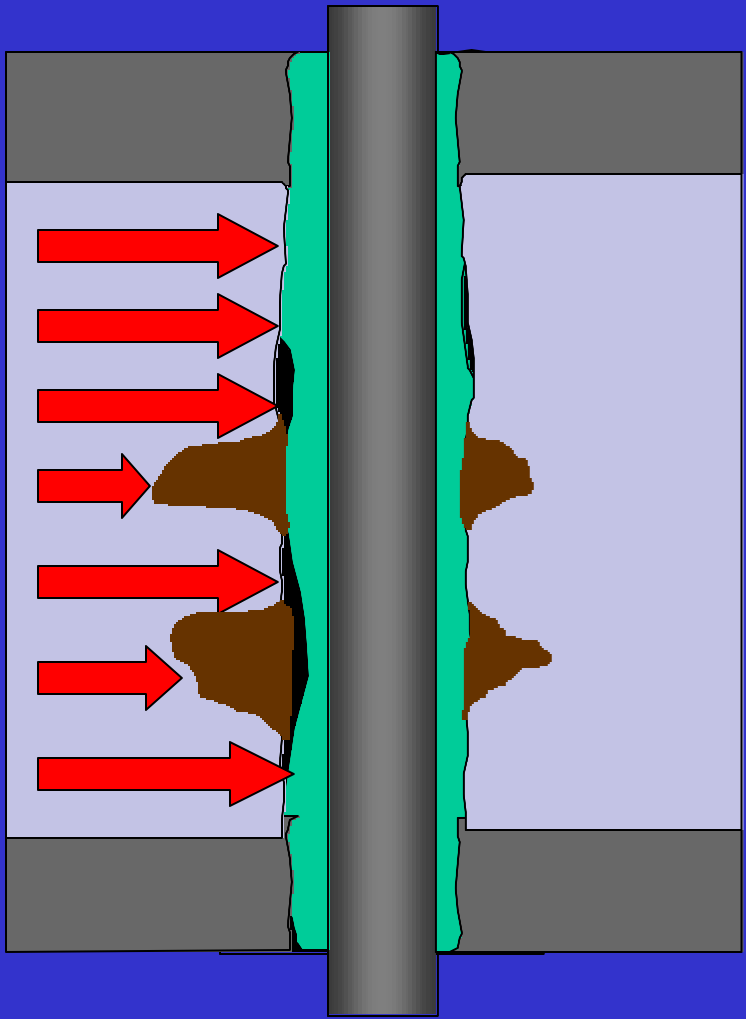


Effects of a Non-uniform Wellbore

Impurities in the salt may result in ledges or washouts due to their various levels of solubility.

These ledges may result in pinch points as the salt continues it’s movement.

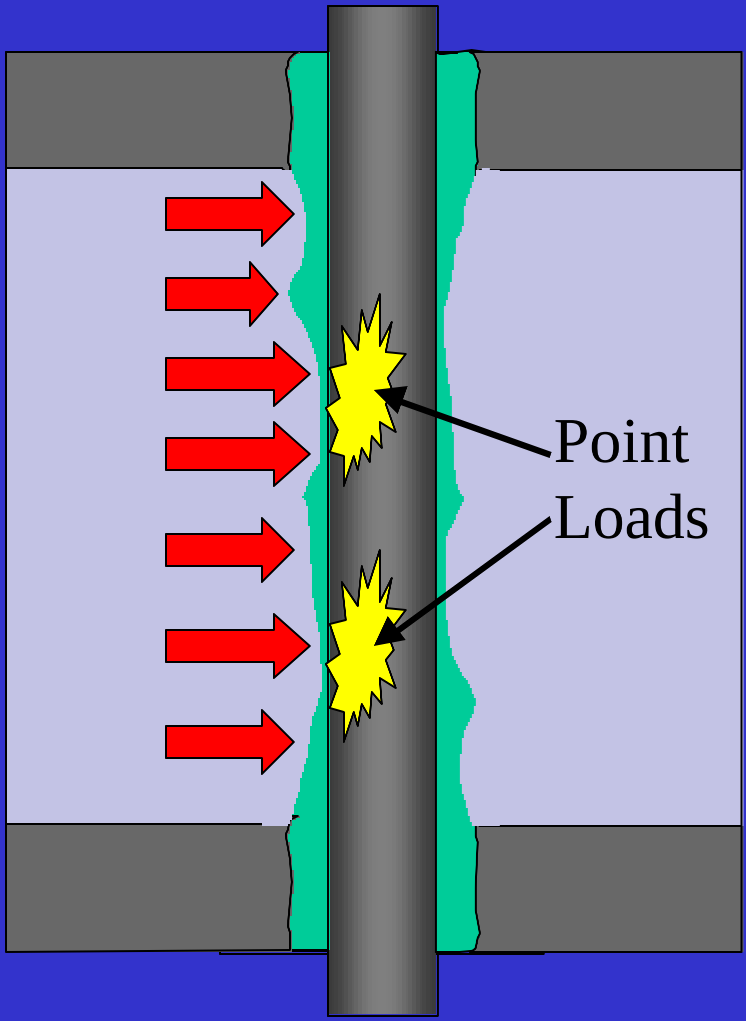
The utilization of synthetic and oil based drilling fluids minimize the creation of hole irregularities.



Improperly Cemented Annulus

In an improperly cemented annulus the shear forces will be applied unevenly resulting in point loading of the casing.

This point loading will result in early failure of the casing string!

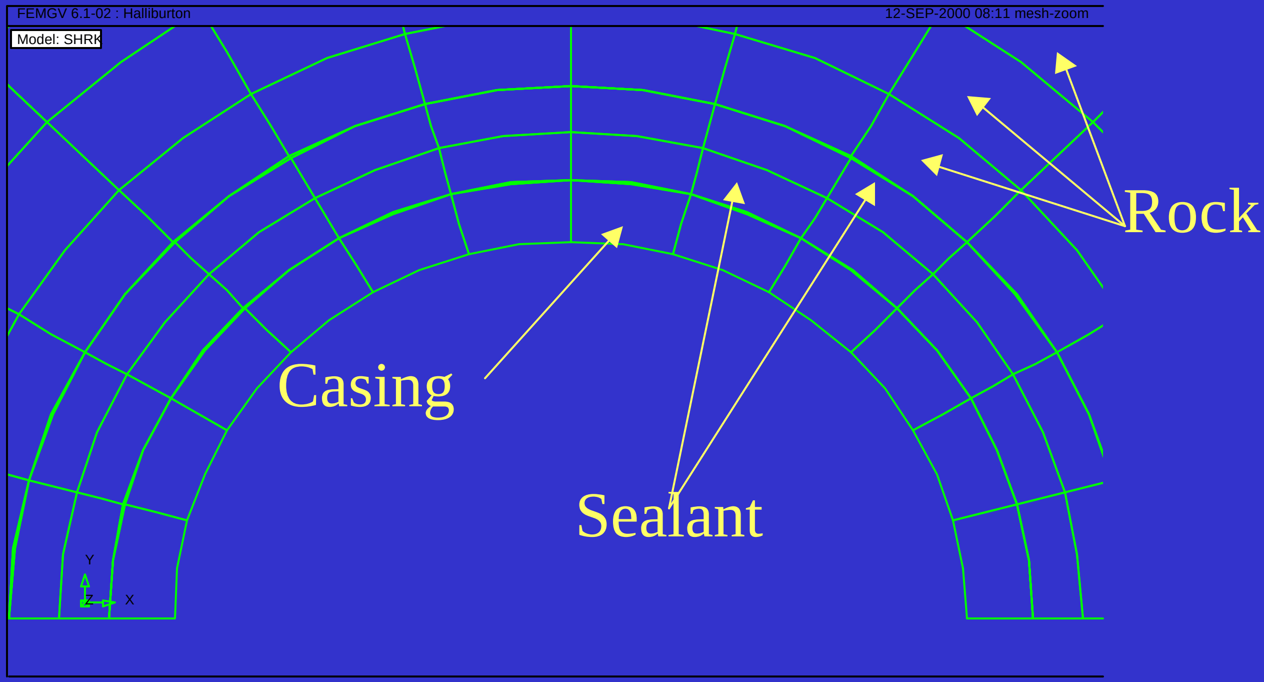


Damage Mechanisms

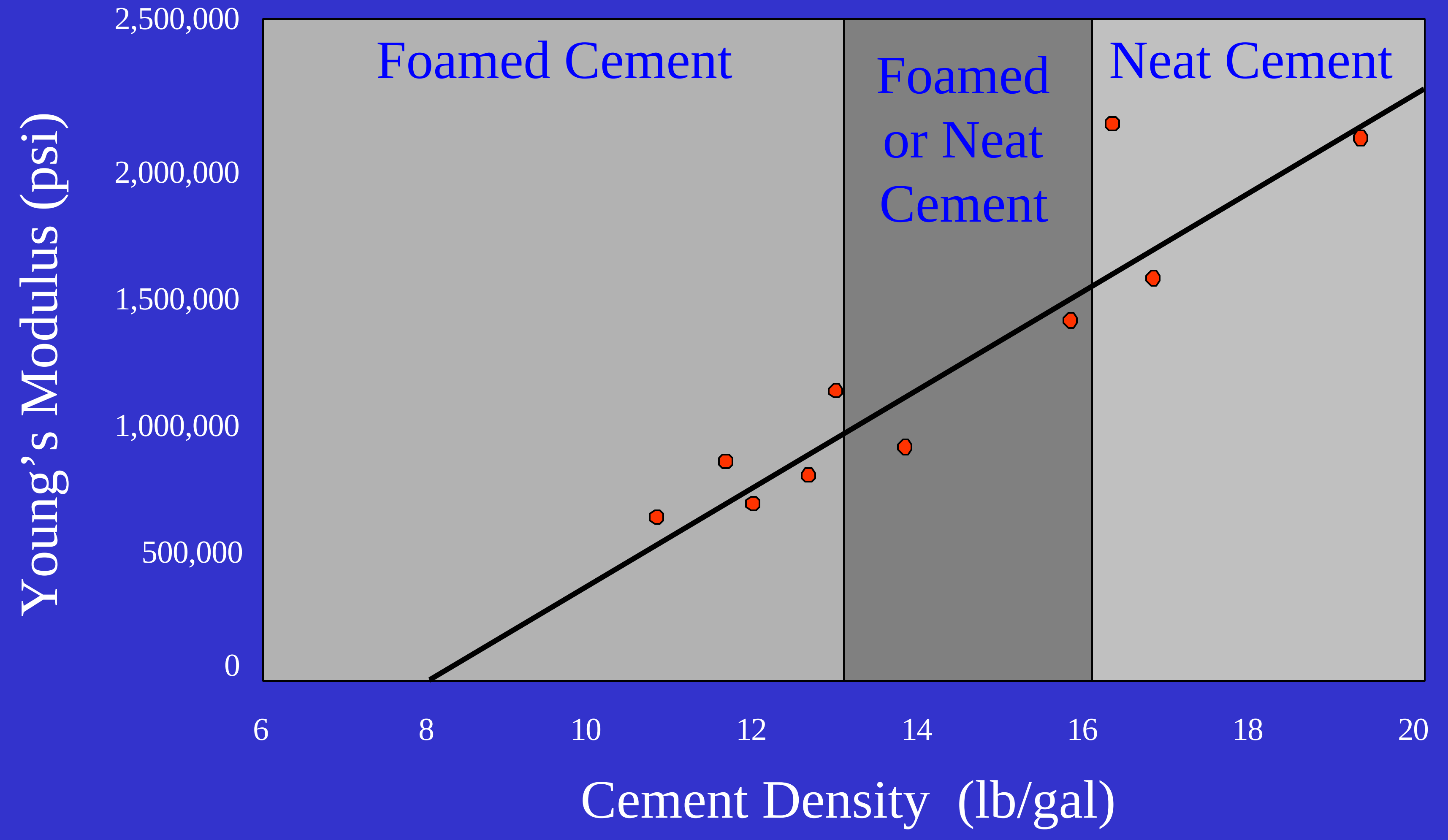
A combination of finite element analysis and analytical modeling is used to quantify and rank damage mechanisms as a function of:

- rate of creep
- depletion
- formation compaction
- cement placement
- well angle
- casing diameter-to-thickness (D/T) ratio
- casing grade

Finite Element Mesh



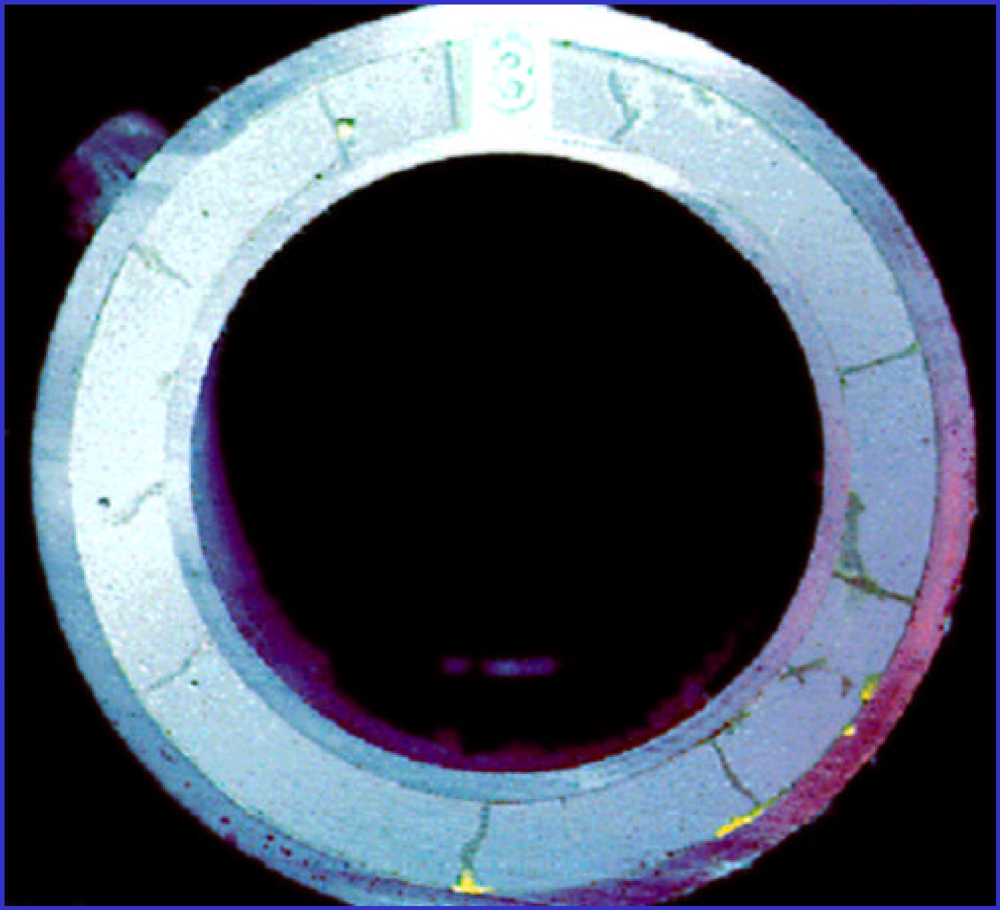
Young’s Modulus for Cements of Various Densities



Conventional Cement is Brittle

5 1/2” pipe cemented inside 7 5/8” casing

Inner pipe pressured in stages until cement failure was indicated at 4500 psi



Conventional Cement is Brittle

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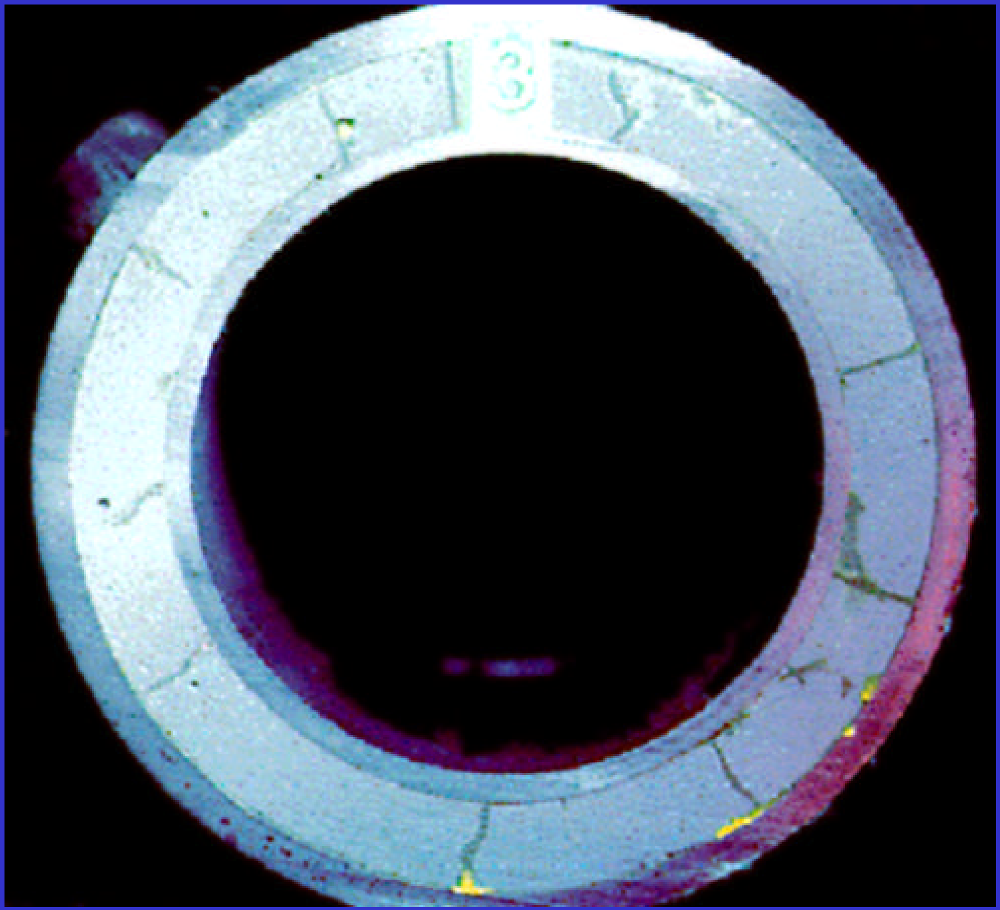
Inner pipe pressured in stages until cement failure was indicated at 4500 psi

- Cement became brittle

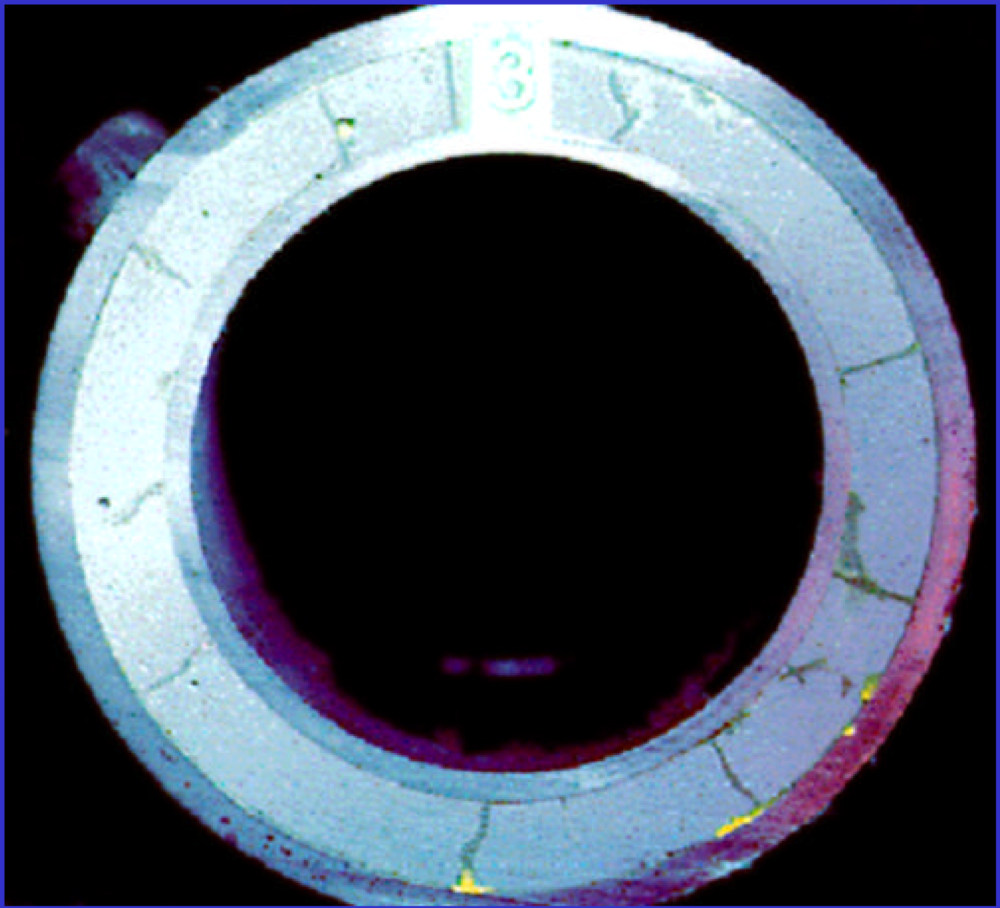


Conventional Cement is Brittle

5 1/2" pipe cemented inside 7 5/8" casing

Inner pipe pressured in stages until cement failure was indicated at 4500 psi

- Cement became brittle
- Radial cracks formed

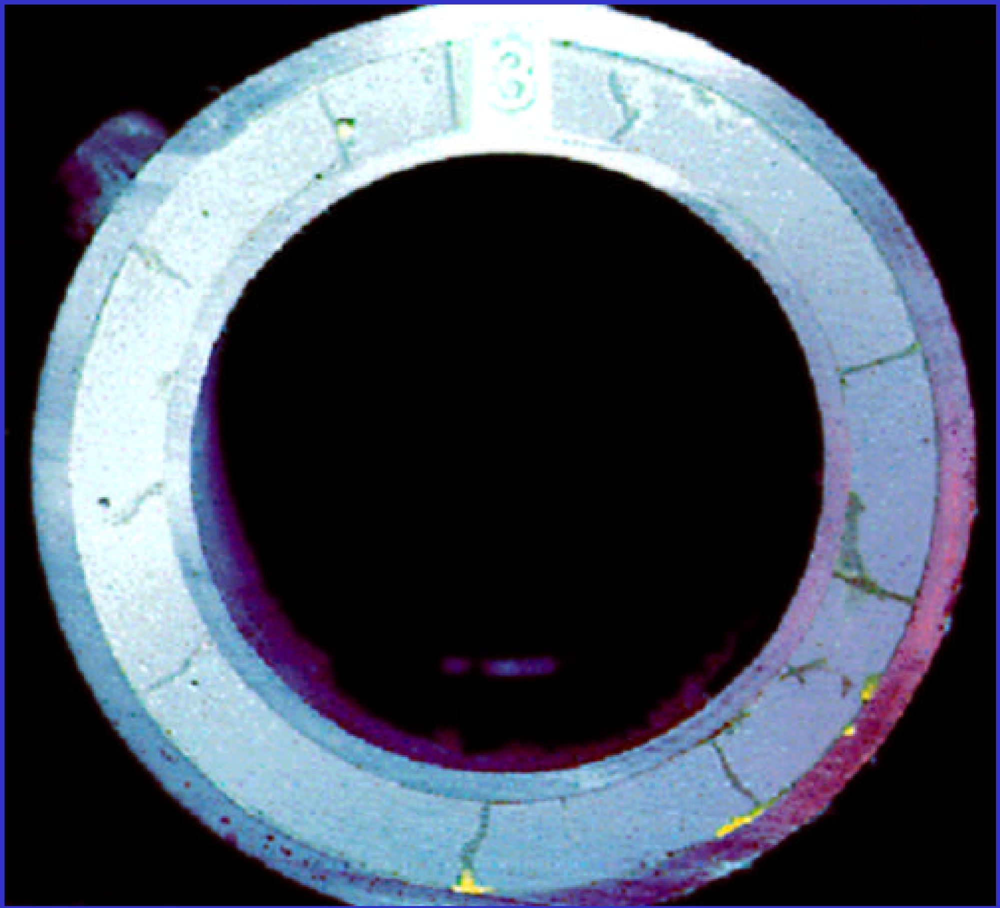


Conventional Cement is Brittle

5 1/2" pipe cemented inside 7 5/8" casing

Inner pipe pressured in stages until cement failure was indicated at 4500 psi

- Cement became brittle
- Radial cracks formed
- Longitudinal communication occurred



Conventional Cement is Brittle

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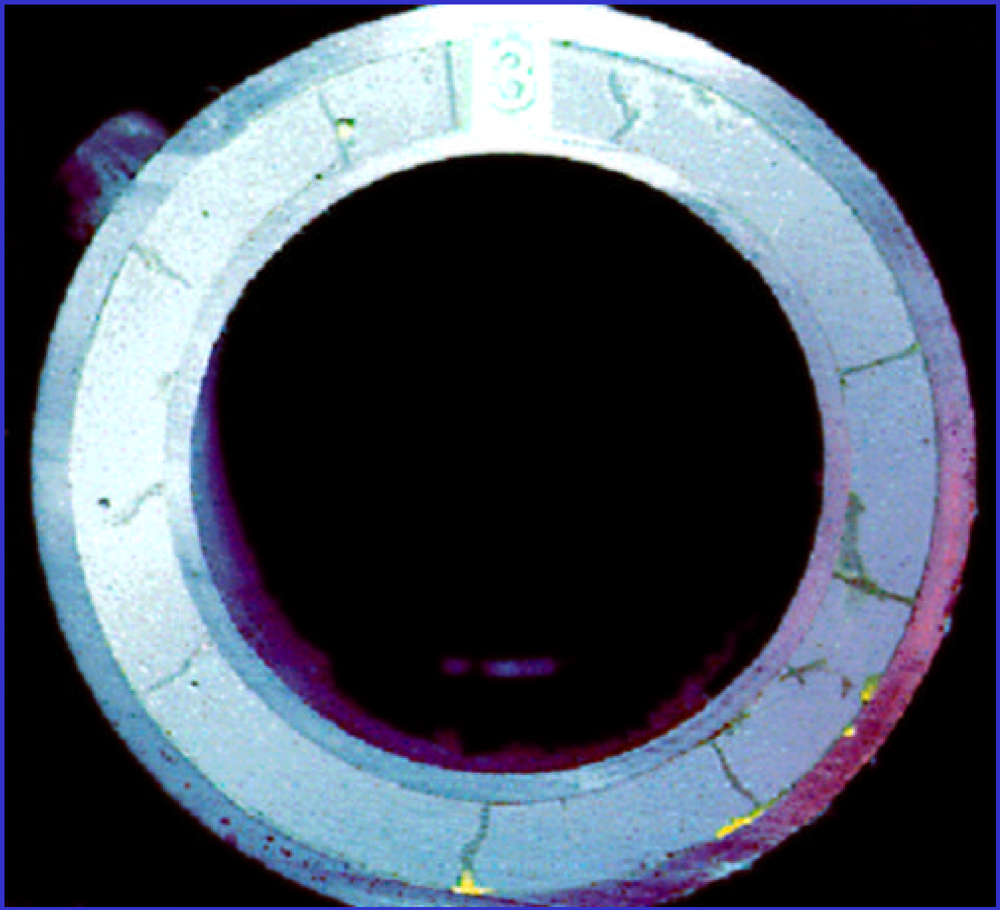
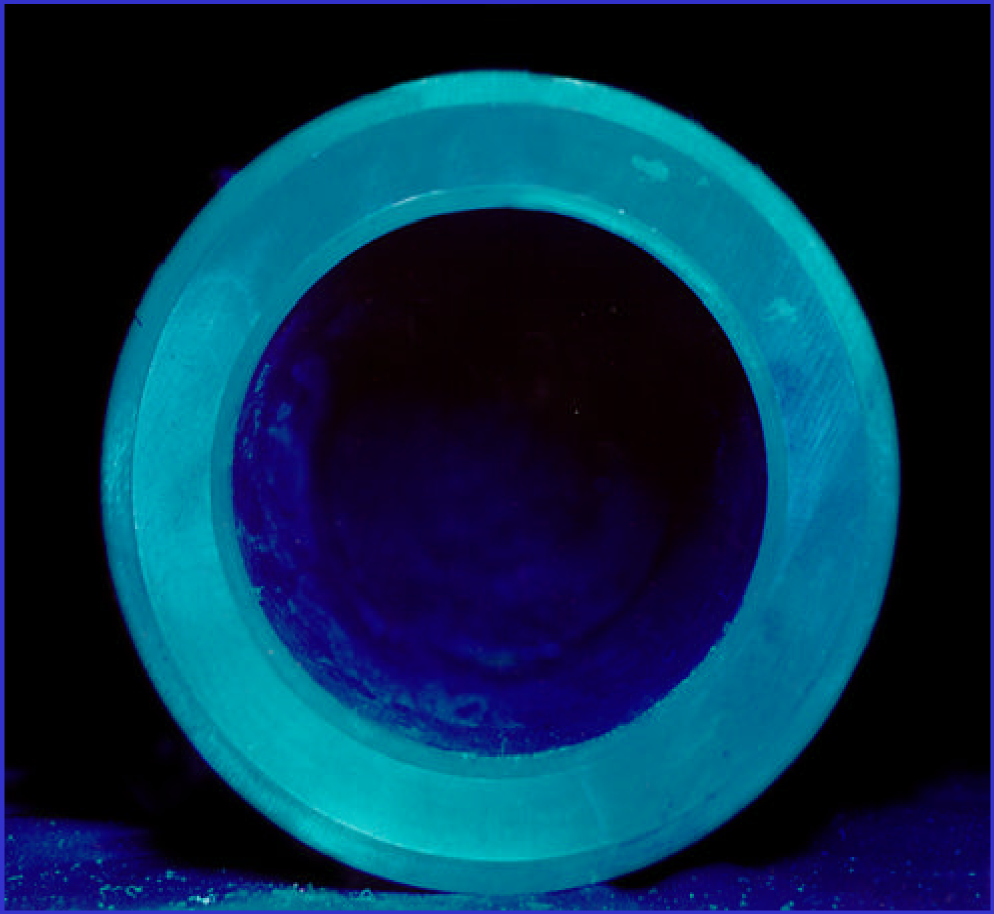


- Cement became brittle
- Radial cracks formed
- Longitudinal communication occurred
- Cement bond failed creating a microannulus

Foam Cement is Ductile

5 1/2” pipe cemented inside 7 5/8” casing

Inner pipe pressured in repeated cycles to 10,000 psi without cement failure

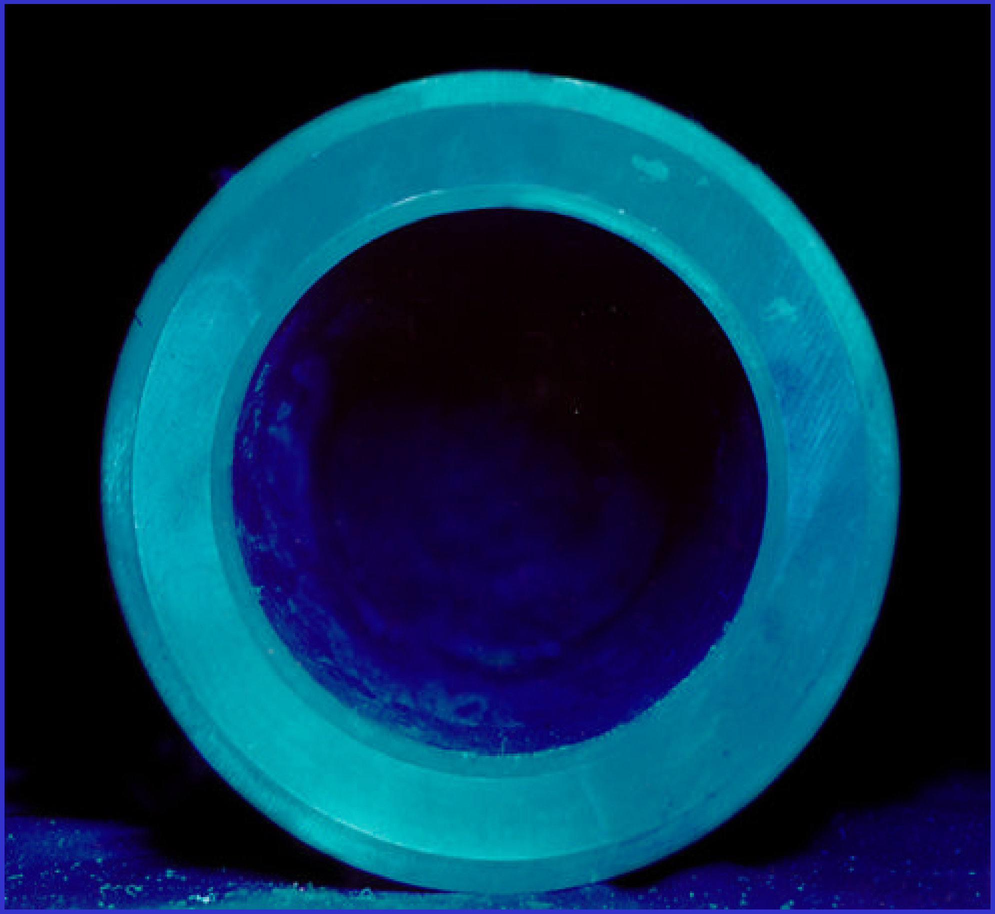


Foam Cement is Ductile

5 1/2” pipe cemented inside 7 5/8” casing

Inner pipe pressured in repeated cycles to 10,000 psi without cement failure

- No radial cracks

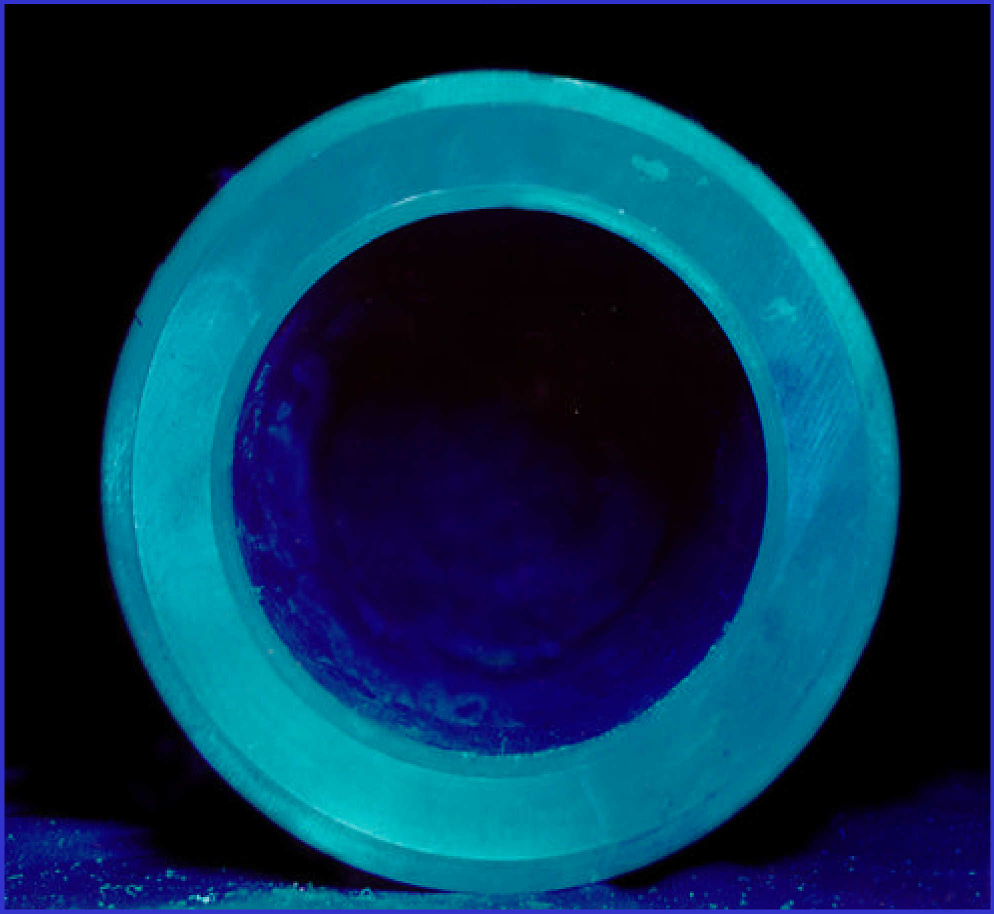


Foam Cement is Ductile

5 1/2” pipe cemented inside 7 5/8” casing

Inner pipe pressured in repeated cycles to 10,000 psi without cement failure

- No radial cracks
- Only slight debonding

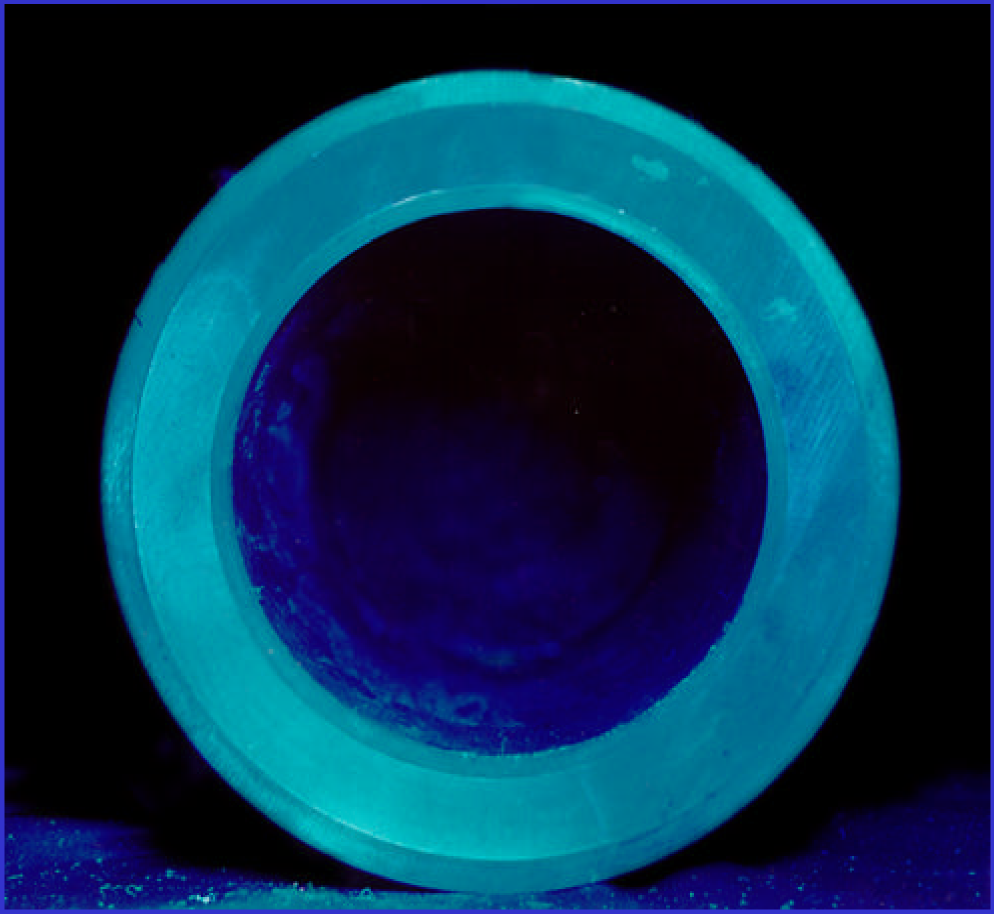


Foam Cement is Ductile

5 1/2” pipe cemented inside 7 5/8” casing

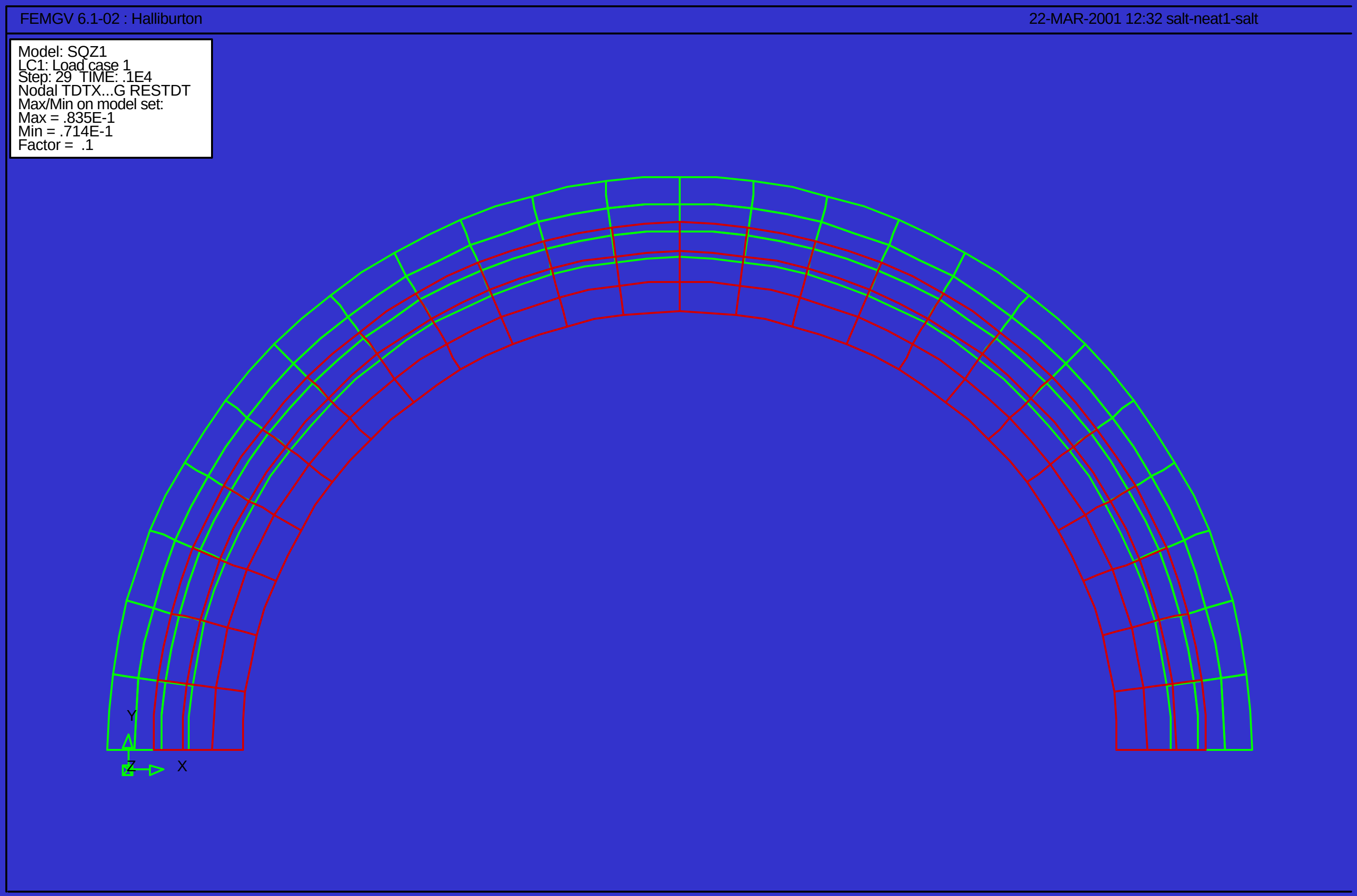
Inner pipe pressured in repeated cycles to 10,000 psi without cement failure

- No radial cracks
- Only slight debonding
- Foamed cement deformed and absorbed the expansive energy without failure due to its elastic nature



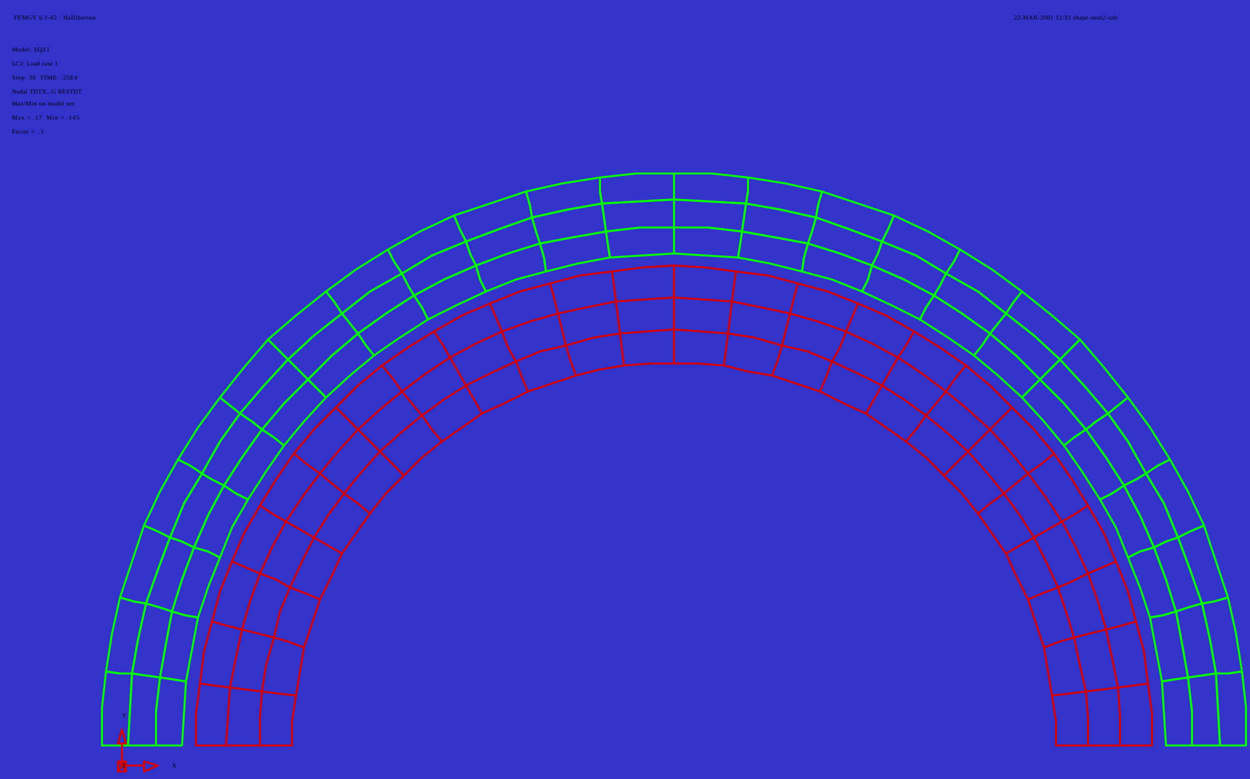
Magnitude of Casing Deformation

brittle cement, 30 min



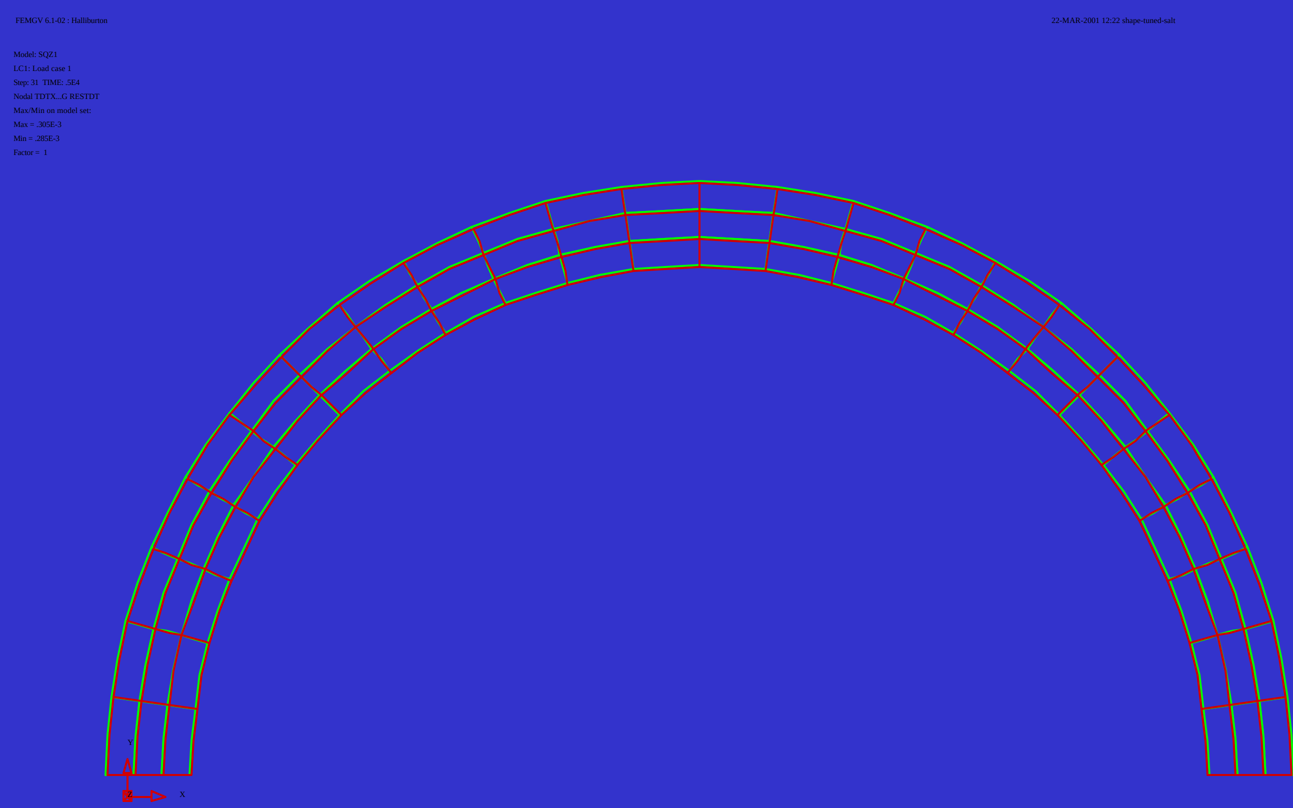
Magnitude of Casing Deformation

brittle cement, 45 min



Magnitude of Casing Deformation

non-brittle cement, 100 min - (115 days)



A List of Parameters Needed for Sealant Integrity Evaluation

Symbol	Definition
Wellbore Details	
	TVD for Sealant Integrity Evaluation[2]
	TOC
D_h	Hole diameter
E	Eccentricity
D_i	Casing inner diameter
D_o	Casing outer diameter
	Depth of various strings
	Details on any sensitive zone that need to be protected, such as aquifer, zones with “charged” fluid that will not be produced but could flow through the annulus if the cement sheath is damaged
Casing Details	
	Casing material
	Casing weight
	Casing properties such as Young’s modulus, thermal conductivity, coefficient of thermal expansion, Poisson ratio, specific heat, etc.

A List of Parameters Needed for Sealant Integrity Evaluation

Sealant (cement) Details	
	Sealant formulation
	Additional pressure while the sealant is curing
	Density, rheology and compressive strength
	Sealant properties such as Young's modulus, thermal conductivity, coefficient of thermal expansion, Poisson ratio, specific heat, cohesion, friction angle, etc.
Drilling Fluid Details	
ρ	Density
Formation Details	
	Formation type, porosity and permeability
	Formation properties such as Young's modulus, thermal conductivity, coefficient of thermal expansion, Poisson ratio, specific heat, cohesion, friction angle, etc.
σ_v	Overburden pressure gradient or vertical stress
σ_H^{max}	Maximum horizontal stress
σ_H^{min}	Minimum horizontal stress
σ_p	Pore pressure
σ_f	Fracture gradient
F_c	If applicable, formation creep rate

A List of Parameters Needed for Sealant Integrity Evaluation

Operational Details	
P_T	Pressure to test the shoe
ΔP_S	Pressure change from fluid swap, e.g.: displacement fluid to completions fluid
P_S	Pressure in the casing/tubing during hydraulic fracturing
Q	Rate of hydrocarbon production
T_R	Temperature of hydrocarbon reservoir
P_R	Pressure of hydrocarbon reservoir
I_T	If applicable, fluid injection temperature
I_R	If applicable, fluid injection rate
I_P	If applicable, fluid injection pressure
	Injected fluid properties
	Details on formation subsidence,
	Any other information to be considered in evaluating cement integrity for life of the well

Conclusions

- We are unable to prevent “creep” of a flowing salt formation
- We can minimize extrusion of the salt into the wellbore during drilling operations
- We can not prevent the long term damage associated with salt creep
- We can delay the onset of casing failure by:
  - Numerical modeling to optimize casing strings and sealants
  - Cementing best practices to eliminate point loading of the casing string
  - Concentric casing strings
  - Annular sealants that will absorb the forces placed upon them; instead of transferring them to the casing

Wednesday
April 4, 2001

SUB-SALT FORMATIONS

1. Sub-salt well geohazards
Ron Sweatman, Halliburton

Explain how the reactive plug provided additional integrity at shoe?

Spotted a mud reactive pill at 18 bpm down drillstring – reacted at shoe to form rubber consistency plug into shoe flow path (similar to gunk squeeze).

Is this type of plug spotted often?

It was experimental at the time. At present there is a better developed system, though it is still emerging technology.

2. Sub-salt drilling challenges and solutions
Tom Bowles, BP

No time for questions

3. Potential problems associated with drilling salt and sub-salt
Atlas prospect – Mississippi Canyon Blocks 713 & 714
John Karpe, Chevron

Did you do FIT or LOT on 13-5/8 casing?

Performed a JUG test.

Would you drill with bicenter bit on second thought?

The second well was drilled with a bicenter bit – faster but harder to control directionally – required underreaming with 14-15" underreamer – observed lots of rugosity – had to underream with 19" tool – current practice is NOT to use a bicenter bit

Comment: Topography of salt exit must be critical – structural highs may trap pressure.

Quality of data displays sutures in salt or teepees where sediment is encased – these must be avoided as well.

4. Pore pressure prediction ahead of the bit with VSP inversion technique for subsalt pore pressure prediction – Atlas prospect (MC 714)
Matt Czerniak, Texaco

Comment on gap between 1 hz and 10 hz: You need not only a better geophone but must improve the source – need 8 times bigger source for 5 hz increase

Used synchronized air guns and saw much improvement.

What is the status of the look ahead project?

Wave forms spotty and ringy and not yet suitable for inversion
Real time check shot info is good and may soon be commercially available
Downhole source needs more energy, but that is not feasible at this time

5. Engineering fluids for successful sub-salt drilling
Mike Johnson, INTEQ

Are there temp limits on glycol systems?

Fluid stability diminishes at about 250 degrees – over 230 degrees becomes very expensive

Uncertainty of where salt will occur – can't tell if it's a stringer or the actual anticipated salt body – affects decision to displace mud system – Temp gradient was higher than expected – stayed in the salt 2000 ft extra

6. Analysis of salt creep in a DW GOM well and preventing salt-induced casing damage
Colby Ballew, Halliburton Energy Services (HES)

How do you model transient creep occurring between drilling and cementing (flat time)?

When Shell inputs potential failure mechanisms, they can model with 3D analysis – HES works with 2D to complete analysis in a few hours. For the analysis to be valid, creep rate must be known – core samples will help provide this information.

SUB-SALT POST-SESSION QUESTIONS:

Has anyone looked at LOTs in salt to determine empirically the upper limit on FG?

Everyone is looking at that – many overburden estimates around. The failure case is likely to produce a vertical fracture right up the wellbore. Short of installing a strain gauge into the wellbore, it's still a guess.

You may temporarily achieve a LOT exceeding overburden, but it's not wise to implement it.

LOT plots show that wells that actually went to maximum and never saw anything higher than 1 ppg beyond overburden. You can encounter a suture or fracture that incurs losses.

When setting casing in the top of salt, you need to be assured that the likelihood of taking a kick does not exceed maximum allowable surface pressure (liner on 20") – most casing designs are done with shoe failure and should also consider mudline failure.

Need a model that uses LOT to predict fracture initiation point – need to 3D image leakoff paths – could be practiced on low cost wells.

What percentage of deepwater leases contain salt structures?

Some kind of salt exists in 100% of leases.

Somewhat less than 10% have a subsalt target.

Seems that salt placement covers about 1/3 to 1/2 of the shelf – may cover about 1/2 of deepwater

BP has put a lot of effort into basin modeling of pore pressure predictions – do they give acceptable agreement with actual subsalt pore pressures encountered?

Yes, definitively. At intermediate casing points we check pore pressure and establish projections about structural closures and decision to proceed with geological objective.

Has BP ever abandoned a well before reaching a target due to midpoint analysis?

Yes.

Is there a wide range of uncertainty to be improved upon?

Yes.

With real time pore pressure prediction, typically there is a 60-70 ft lag between bit depth and MWD. Do you put your receiver near bit for this reason?

We try to tie well back to seismic using a velocity function.

From drilling standpoint, we put resistivity as close to bit as possible – it provides assist with WC issues.

Good job on pore pressure transmission. How is the test conducted? You apply test results to rubble environment. Does the data transfer well?

It's not easy. We're not trying to heal fractures, but with innate instability, we must minimize pore pressure transmission (PPT) – but actual results from wells drilled show good results in the rubble. Still need a multi-disciplinary approach.

Some BP pore pressure predictions based on basin modeling are supplemented with velocity analysis – will you use it stand alone? Have you walked away from a well based on basin modeling alone?

There were some prospects in the Bass Straits that were demonstrated to be dry holes by modeling and confirmed dry by first well drilled. It's not possible to analyze a prospect without looking at all the data.

MMS Perspectives on Deepwater Geohazards And Recent Industry Drilling Results

Michael A. Smith
Minerals Management Service
New Orleans, LA

LINK TO PRESENTATION

The average depth below the mudline (bml) for setting conductor casing in recent deepwater Gulf of Mexico drilling has steadily increased from 1,579 feet in 1996 to 1,902 feet in the past year. In this paper, we analyze a dataset of 200 exploration wells drilled in the last five years that were the first well on a deepwater (>1,000 feet) block and also at least one mile from the nearest offset well. The conductor setting depth in 86 percent of the wells was greater than 1,000 feet bml, a typical setting depth for conductor in shelf wells, and in 29 percent was more than 2,000 feet bml. Moreover, 20-inch conductor with the BOP stack, which can be set with nitrified foamed cement, was the first casing string below drive pipe in 78 percent of these wells. The next casing, typically 16-inch or smaller surface liner, was set at an average depth of 3,462 feet but occurred as deep as 9,000 feet bml.

Because seawater forms much of the overburden in deepwater wells, fracture gradients are reduced and there is a narrow margin between minimum and maximum mud weights that can be used. The deepwater conductor hole section is drilled riserless using seawater as the drilling fluid until wellbore instability or shallow water flow is encountered. Weighted waterbase drilling mud is then used to kill any flow or overcome hole stability problems. Many recent deepwater wells in which moderate shallow water flow was predicted and encountered used a drilling program that successfully set conductor pipe below the problem interval. A 26-inch pre-conductor string is used typically only to isolate shallow water flow zones in high-risk areas. There is good correlation between the depth of conductor casing and both the water depth and drilling depth of deepwater wells. Wells drilled in Walker Ridge and Keathley Canyon had average water and drilling depths of 6,910 and 16,820 feet (versus 3,940 and 12,300 feet for the dataset). Conductor casing and the BOP stack in these frontier deepwater areas were set at an average depth of 2,470 feet bml, 50 percent deeper than the average for the dataset.

Current MMS research on gas hydrates, as discussed by J. L. Hunt in the Hydrates Session of this Workshop, is focused on seafloor mapping of 3-D seismic data and the use of seismic facies analysis to differentiate anomalies associated with hydrates, chemosynthetic communities, or carbonate hardgrounds. Core data and submersible observations then verify the success of the mapping program. There are 52 gas hydrate occurrences shown on MMS geohazard maps, but hydrates are most commonly found at the edges of deepwater minibasins and, like chemosynthetic communities, have been avoided during drilling operations. Seafloor stability along proposed pipeline routes, as related to gas hydrate on the continental slope, may become a factor in future deepwater development however.

In a number of recent sub-salt wells, conductor casing has been set in the salt sheet at 2,000 to 3,000 feet bml, and salt drilling has been rapid and problem-free in many cases. The correct predrill prediction of subsalt pore pressures and the effect of the rubble zone on pressure buildup have been major challenges in some wells, however, with pressure kicks or lost circulation associated with drilling out of salt. A vertical seismic profile (VSP) wireline survey run at a casing point above the base of salt provides a velocity profile to use in predicting whether the sub-salt section will be under- or overpressured.

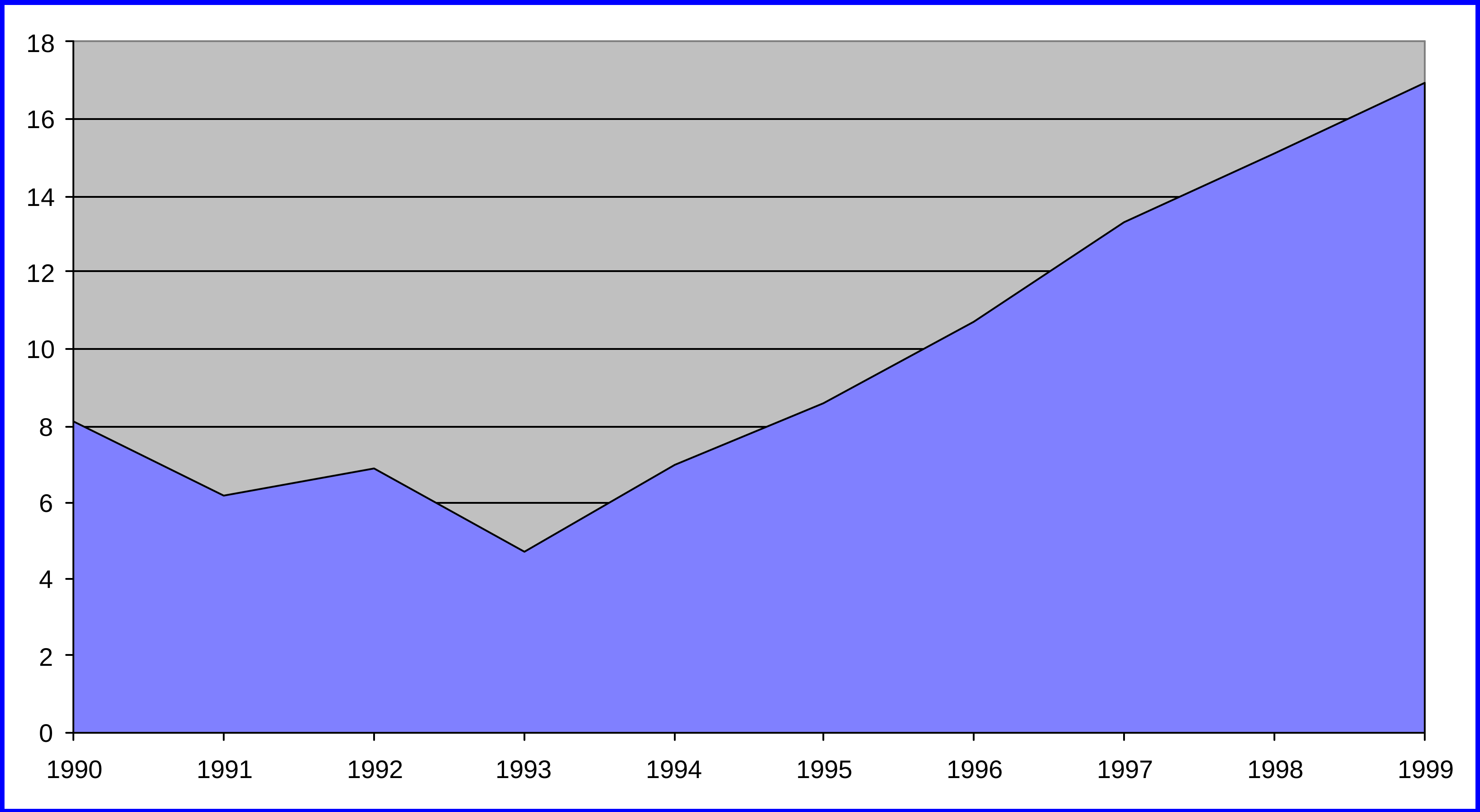
MMS Perspectives on Deepwater Geohazards and Recent Industry Drilling Results

Michael A. Smith

Minerals Management Service
New Orleans, LA

MMS

Drilling Shift to Deepwater

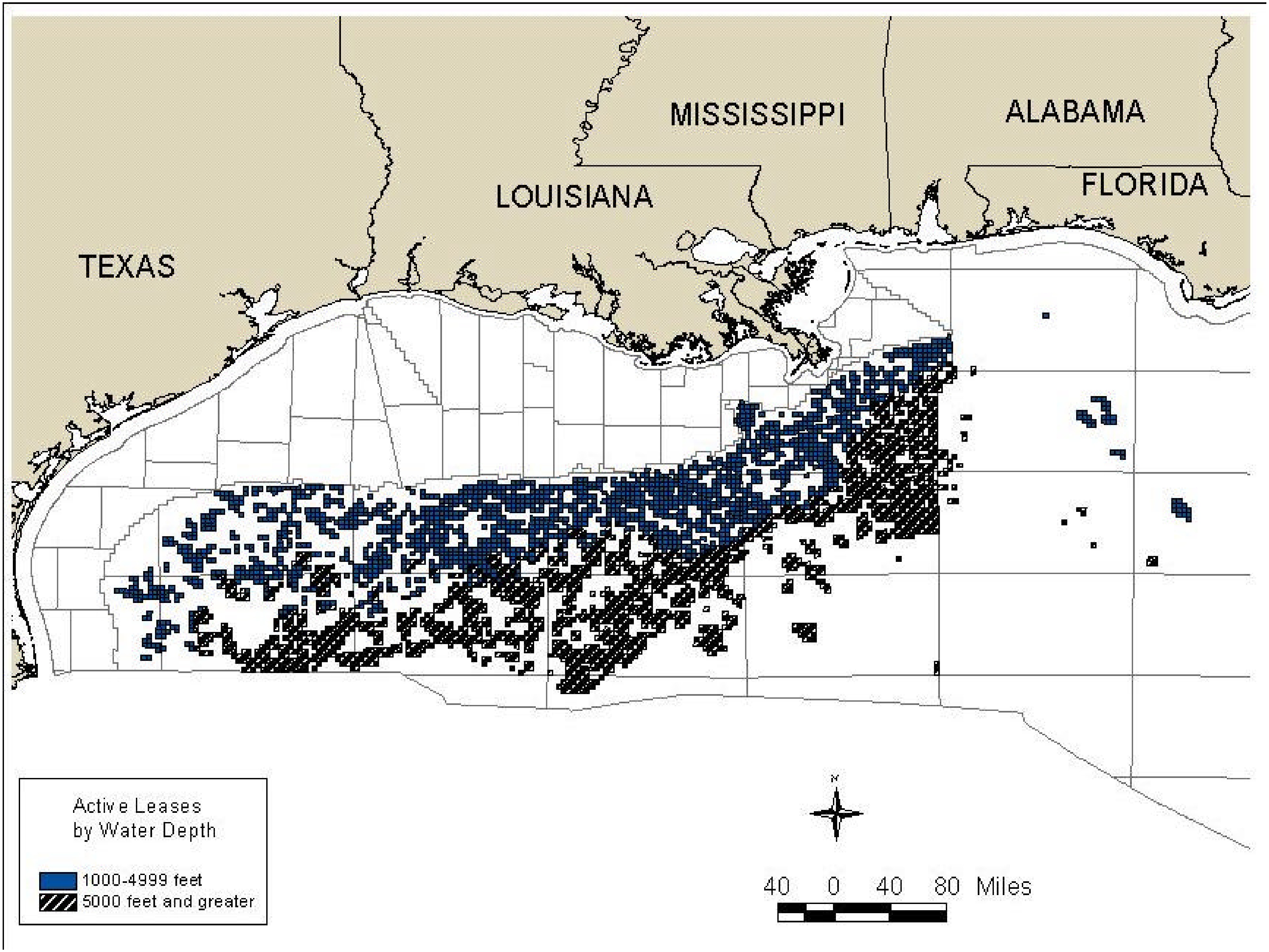


MMS

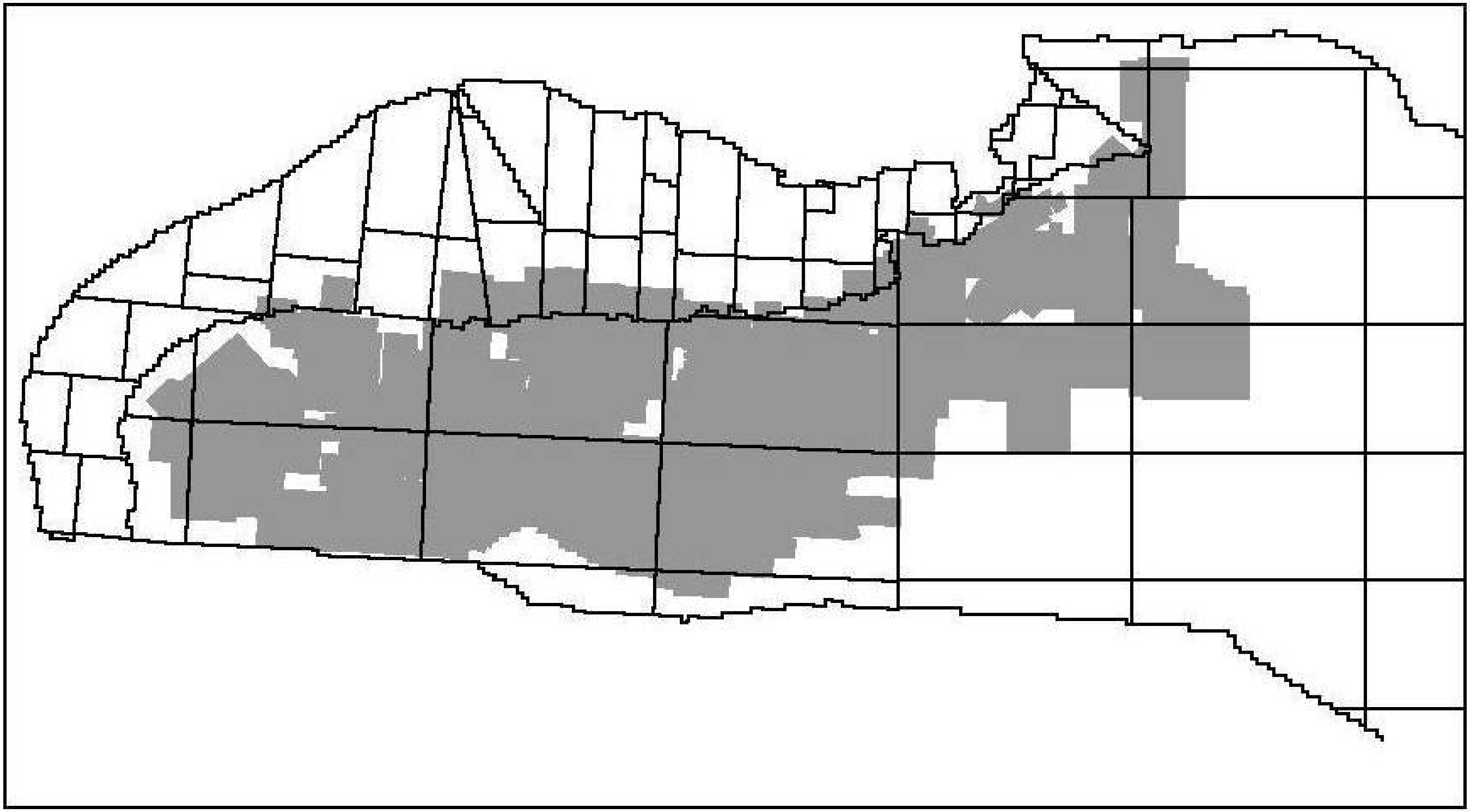
Gulf of Mexico Leasing and Exploration in Deepwater

- 48% of active leases are in >400 m of water
- Since 1992, permits for 3-D seismic coverage include almost all deepwater areas
- 17 companies are currently drilling 39 deepwater wells in an average water depth of 3,408 ft

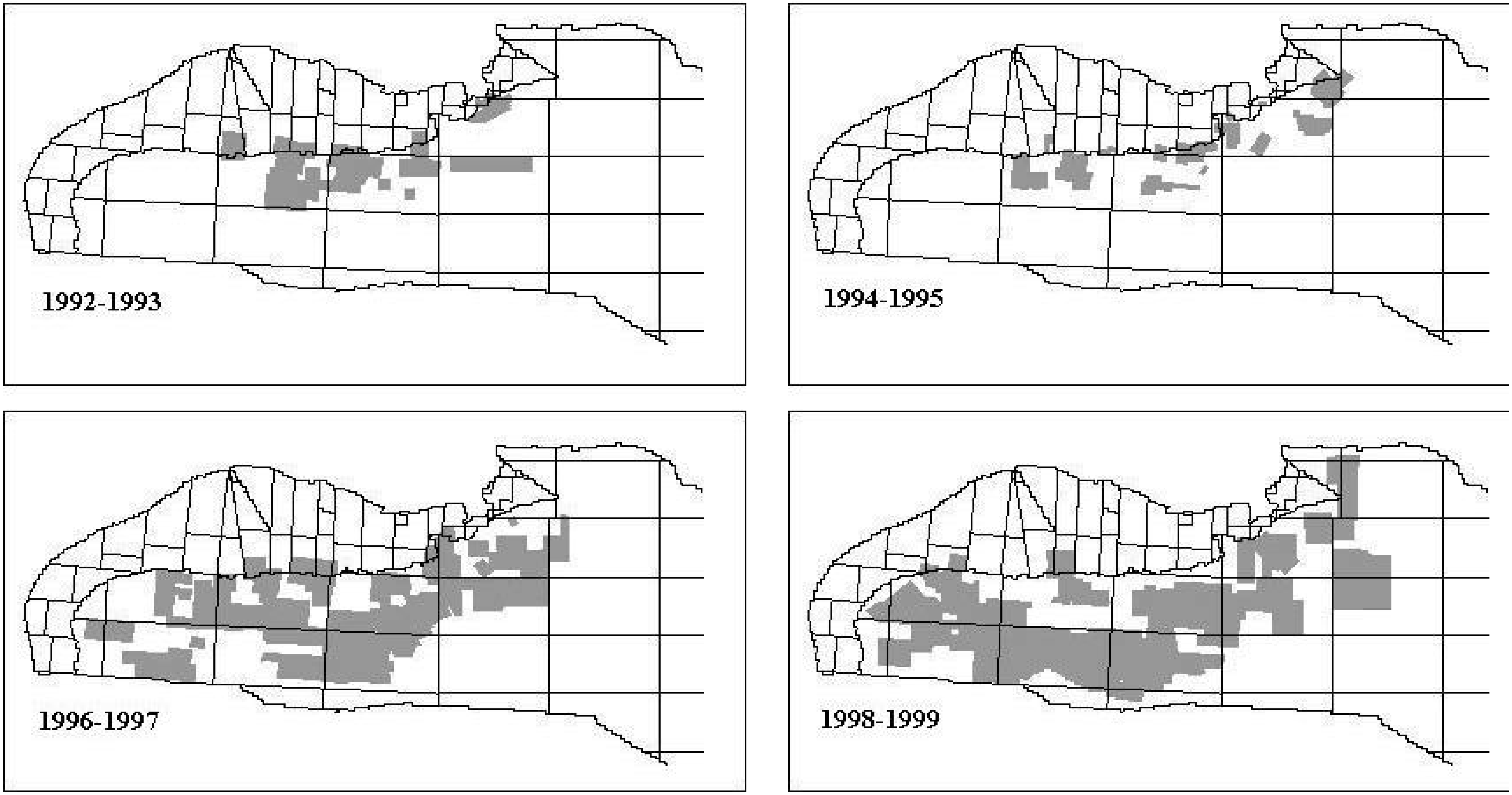
MMS



MISSISSIPPI
ALABAMA
LOUISIANA
FLORIDA
TEXAS
Active Leases
by Water Depth
1000-4999 feet
5000 feet and greater
N
40 0 40 80 Miles



Deepwater 3-D Seismic Permit Coverage from 1992-1999



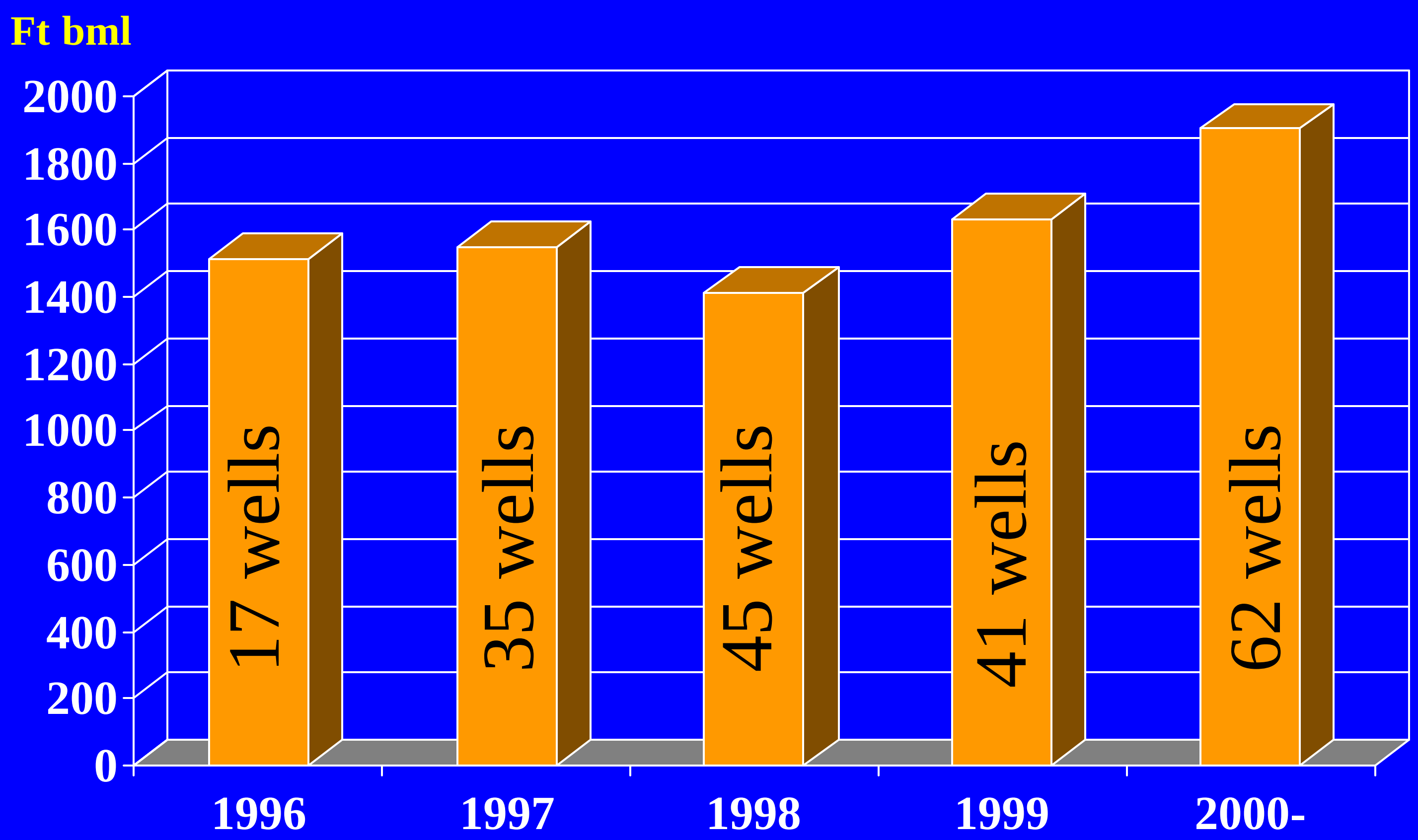
Deepwater 3-D Seismic Permit Coverage

Deepwater Exploration Wildcats Drilled Since 1995

- 200 wells were the first on a deepwater block and more than 1 mile from nearest offset
- Average depth for setting conductor casing, usually with the BOP stack, was 1,643 ft below mudline
- Conductor is set deeper with greater water depths and increased drilling depths

MMS

Average Deepwater Conductor Depth Below Mudline



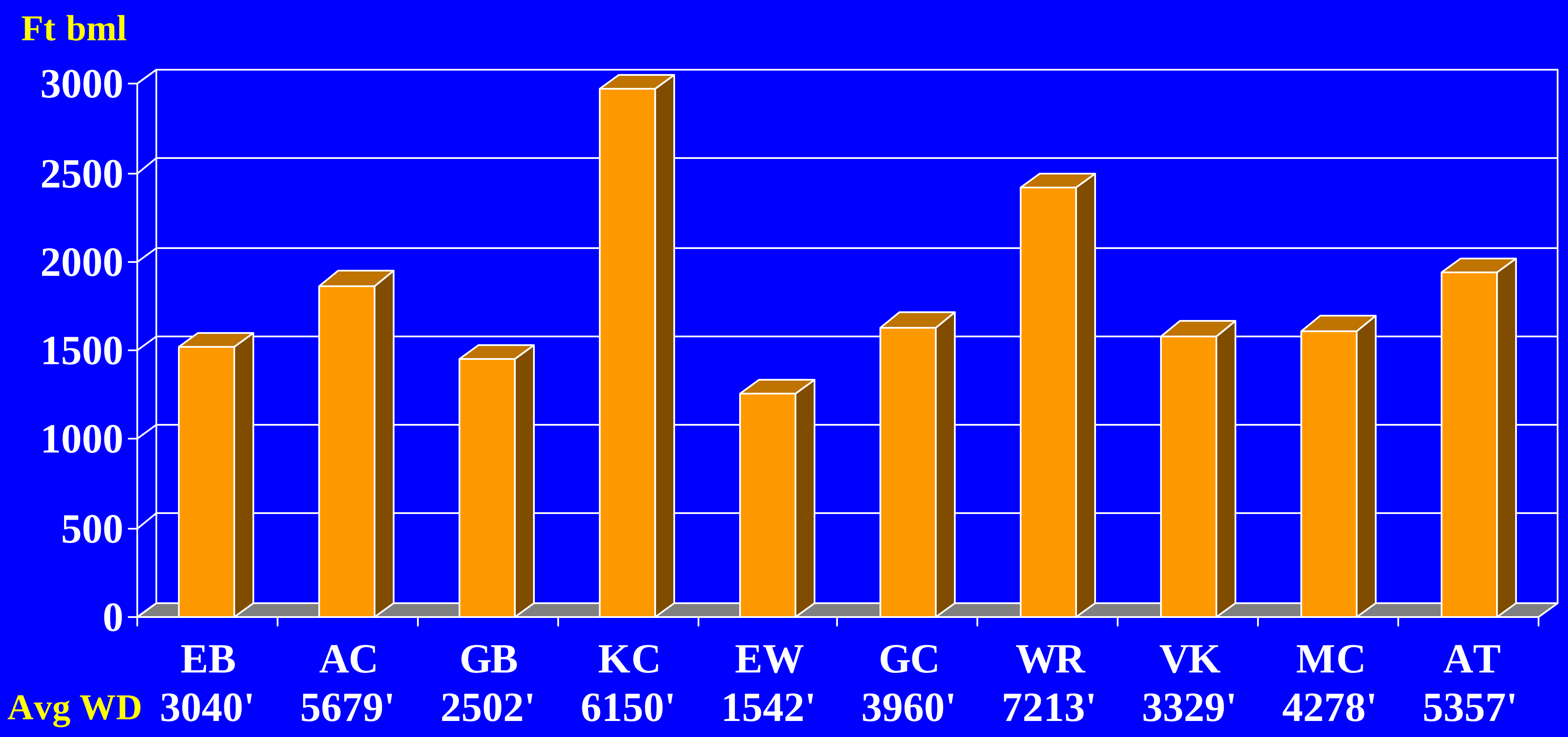
MMS

Casing Strategies For Shallow Water Flow Sands

- Conductor hole is drilled riserless with seawater, replaced with weighted mud if borehole instability or mild SWF is seen
- Unconsolidated sediment and low formation integrity require deeper conductor and BOP
- Revised MMS regulation and shallow hazards NTL will be performance- and prescriptive-based

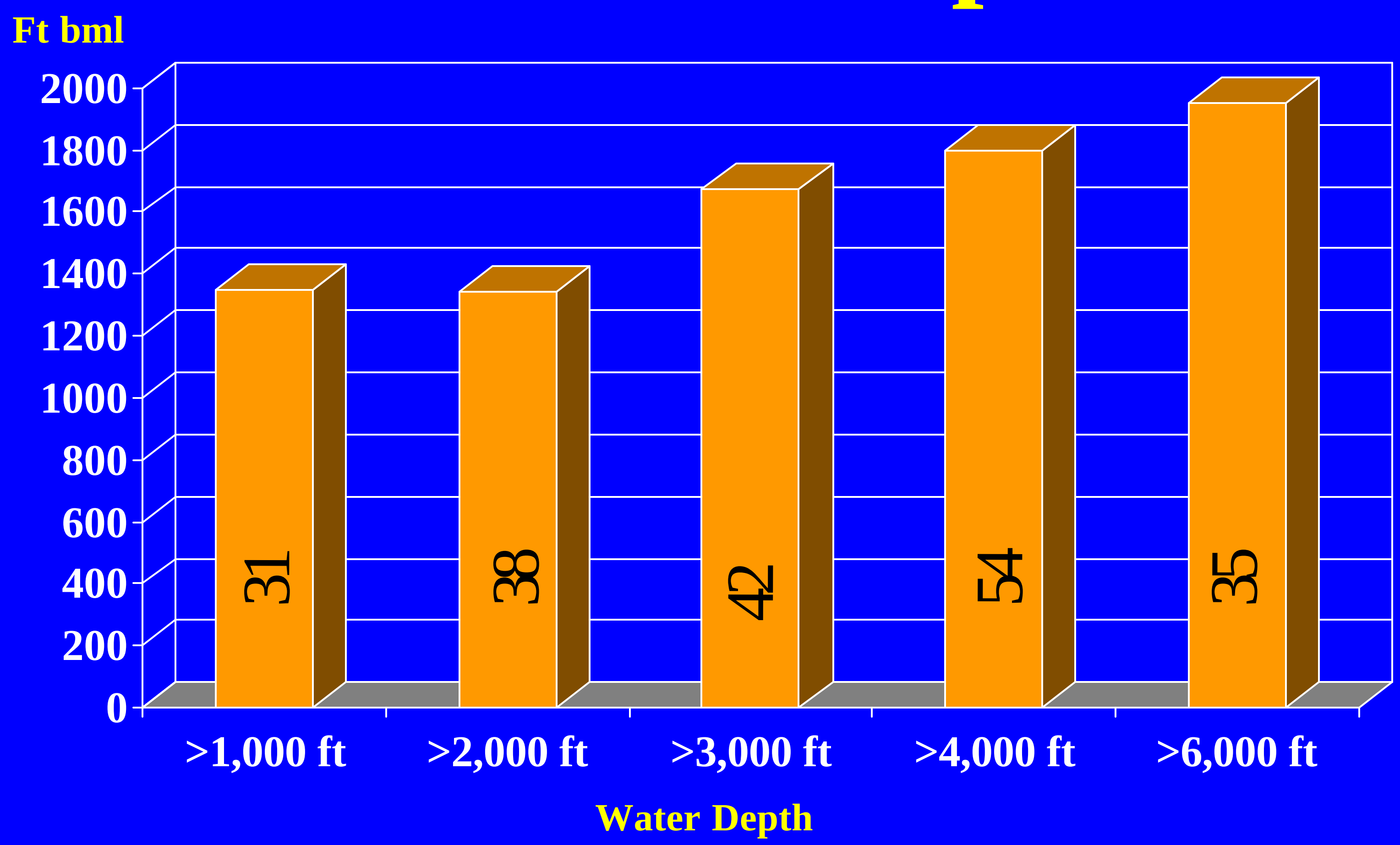
MMS

Average Conductor Depth by Area and Water Depth



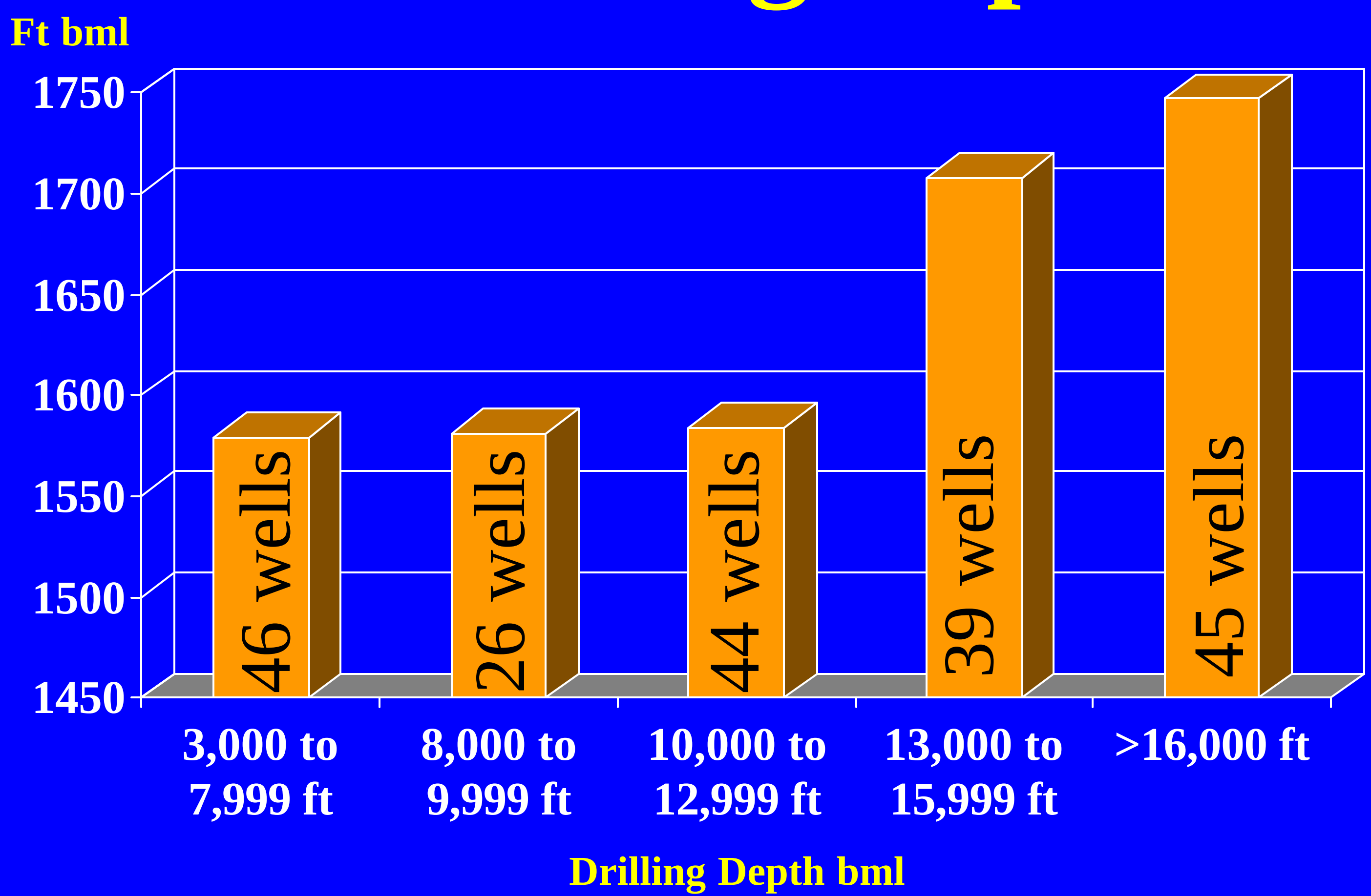
MMS

Average Conductor Depth Vs Water Depth



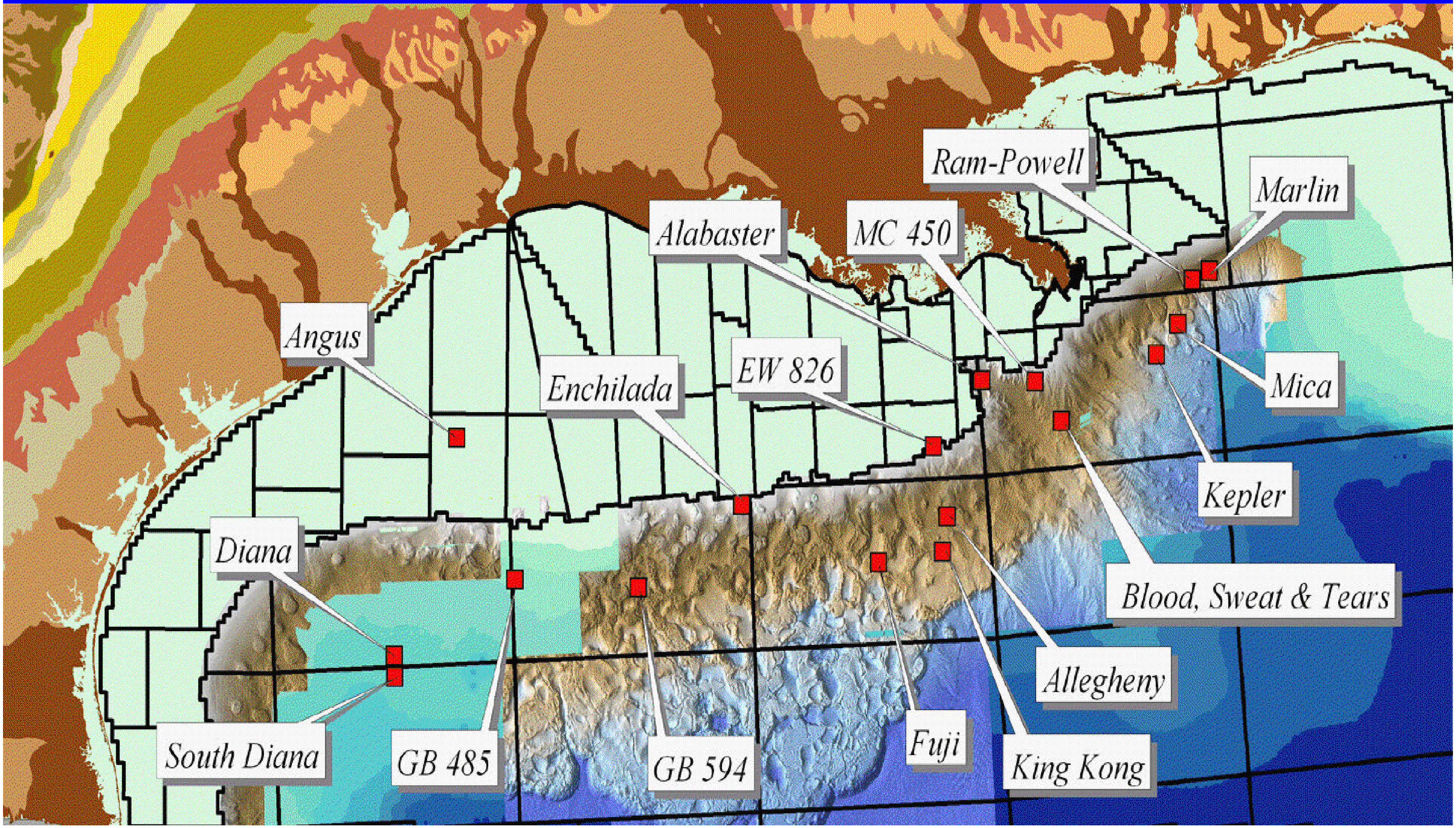
MMS

Average Conductor Depth Vs Drilling Depth



MMS

GULF OF MEXICO MULTICOMPONENT SITES



Gulf of Mexico Gas Hydrates

- Occur as hydrate mounds, usually at active gas vents, and in sediment near the seafloor
- Concentrated in water depths between 1,300 and 8,000 ft
- Mapped seafloor 3-D seismic amplitude anomalies are associated with hydrates, chemosynthetic communities, and carbonate hardgrounds

MMS

Gas Hydrate Hazard Potential

- Seafloor instability and sediment deformation can result from temperature-controlled hydrate crystallization and decomposition
- Slumping and slides represent a potential threat to drilling, production equipment, and pipelines in deep water
- Hydrate plugs in pipelines and associated with wellhead where gas bubbles are present may be additional hazards

MMS

Salt and Sub-salt Drilling

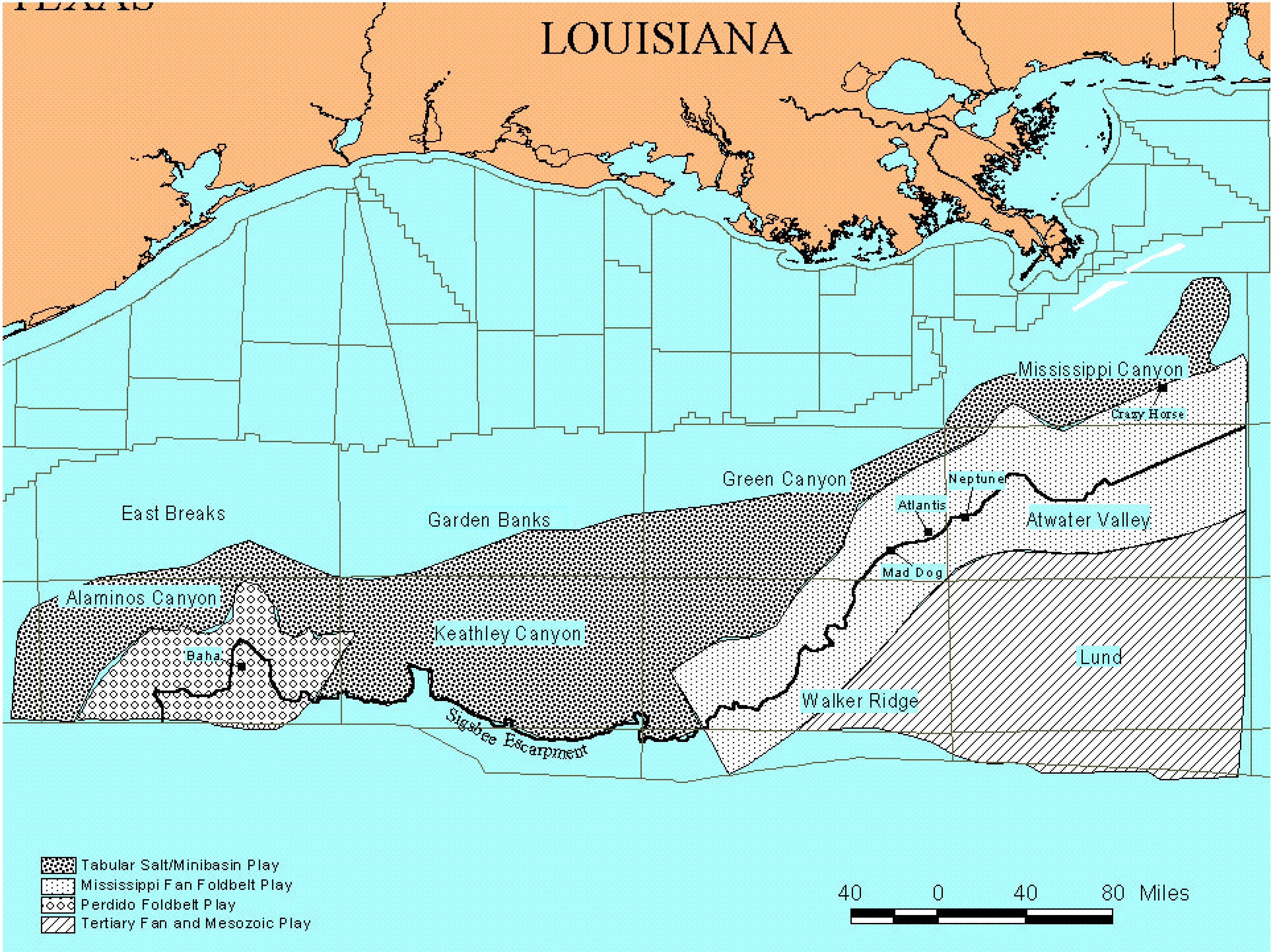
- Conductor casing can be set in salt several thousand ft bml
- Salt drilling can be fast and easy, but development wells should avoid salt if possible to avoid casing damage
- Pore pressure adjacent to and sub-salt can be difficult to predict
- Shear, rafted, or rubble zones above and below salt have low fracture gradients

MMS

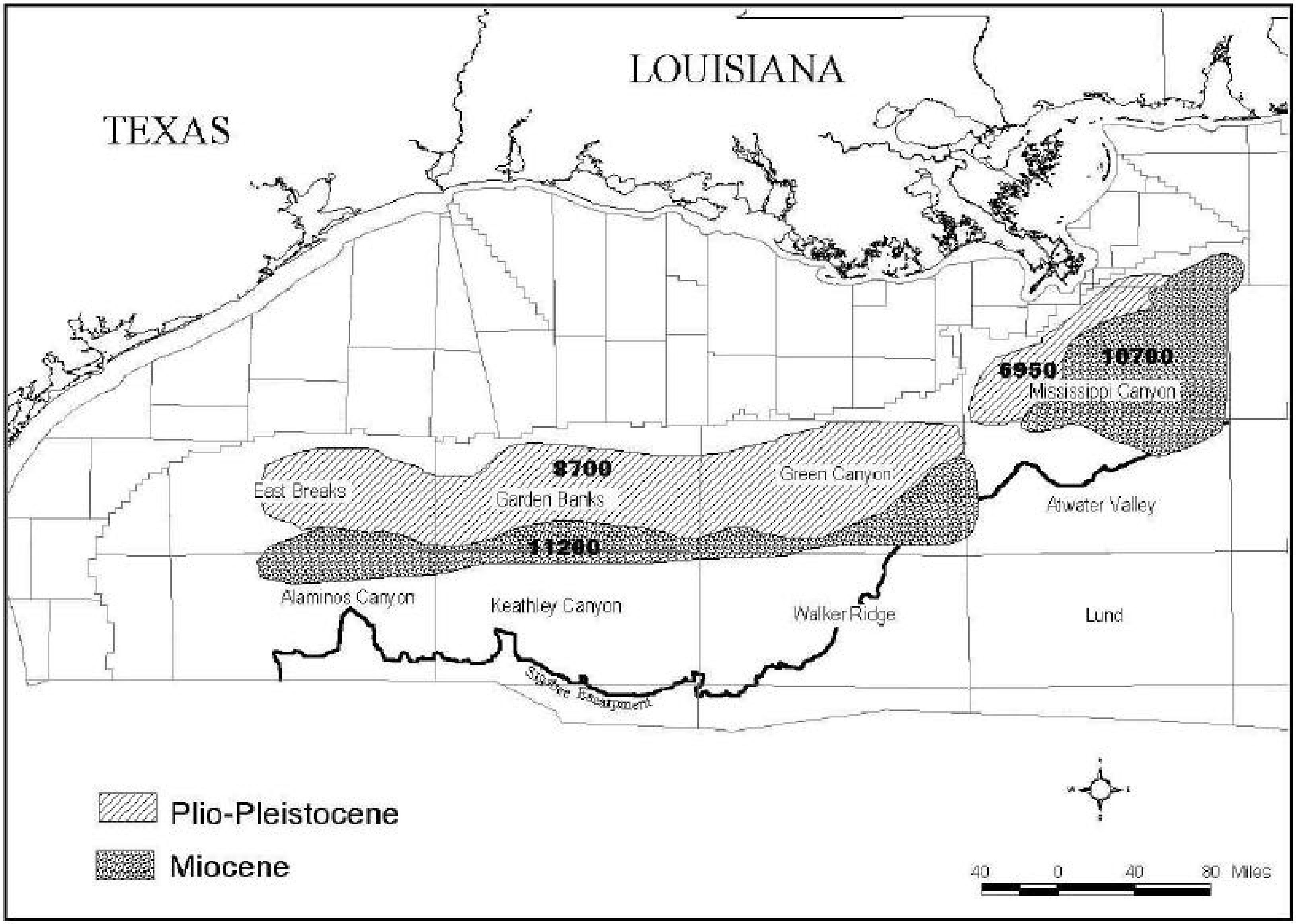
Deepwater Geological Provinces and Pore Pressures

- Most deepwater production is from salt-bounded minibasins; Miocene fold belts near the Sigsbee Escarpment are current targets
- Onset of overpressure is affected by burial rate, compaction, thermal gradient, dewatering, and diagenetic reactions
- Older, more compacted strata with lower sedimentation rate have higher pore pressure

MMS



LOUISIANA
Mississippi Canyon
Crazy Horse
Green Canyon
Neptune
Atlantis
East Breaks
Garden Banks
Atwater Valley
Mad Dog
Alaminos Canyon
Keathley Canyon
Baha
Lund
Walker Ridge
Sigsbee Escarpment
Tabular Salt/Minibasin Play
Mississippi Fan Foldbelt Play
Perdido Foldbelt Play
Tertiary Fan and Mesozoic Play
40 0 40 80 Miles



LOUISIANA
TEXAS
6950
10700
Mississippi Canyon
8700
Green Canyon
East Breaks
Garden Banks
Atwater Valley
11200
Alaminos Canyon
Keathley Canyon
Walker Ridge
Lund
Sigsbee Escarpment
Plio-Pleistocene
Miocene
40 0 40 80 Miles

Conclusions

- Many deepwater drilling problems are related to pore pressure/fracture gradient relationship
- Lack of offset wells requires better pressure models and analogs
- Rewritten MMS regulations and cooperation will help ensure that deepwater geohazards are identified and avoided

Wednesday
April 4, 2001

MMS PRESENTATION

MMS perspectives on deepwater geohazards and recent industry drilling results
Mike Smith, MMS

What about Florida leases?

Should know soon.

Will NTLs be similar to what Andy Hill (BP) submitted?

Yes, like the 1983 document. Hope it will last another 15-20 years.

Deepwater Geohazards Workshop

April 3-4, 2001

IDEAS FOR FUTURE PROJECTS, DEVELOPMENTS, WORK. . . .

1. MMS and all industry need to reach conclusions regarding **salt strength measurement related to LOT and FIT** (1 ppg may be limit) – develop modeling based on same
2. Evaluate **LOT flow paths** – do initial studies on cheaper, simpler wells to establish trends
3. Develop **remote sensing capabilities for subsea hydrates** (no seafloor indication)
4. Set mechanical packer to **use salt as a drilling casing string** if salt body is homogeneous
5. Like to **develop tri-cone bit to be used in salt section** – need a high durability bearing – PDCs produce slip stick phenomena
6. Develop **improved telemetry** rather than relying on conventional tools – need to **address drillstring dynamics, conductive drillstrings, ANACONDA – could instrument slip stick whorl** just like LWD, MWD, but need more bandwidth
7. At next meeting include speakers on seismicity in the GOM to **discuss deepseated seismic disturbances** (hazards leading to turbidite flows, etc) – there is a need to consider **earthquakes** – connection from bottom of basement to the top
8. Develop **look ahead for transitions, loss zones**
9. Improve **directional drilling through salt**
10. Study on East Breaks slump – **tsunamic wave** might have been 28 ft and impacted CC – occurred 10-15 thousand years ago – need to **model slumping and wave generation** – will affect seafloor and coastal structures
11. **Map shallow stratigraphy** as it is relatively simple, formed in last 500,000 years, just 4–5 sequences – could use MMS SWF database to map all those – extend to wider focus than Mississippi delta
12. **SWF database** should **include seismic section <u>and</u> well logs** for all wells that encountered SWFs
13. **Active faulting** may be common in deepwater – to what extent **are active faults an economic hazard in producing field** – in deepwater faults revealed by seafloor expressions – faults look fresh (no drape) – conduct workshop on this topic in future to define issue and significance, share experience, specify research objectives – concern about drilling in proximity to fault (mile or two away)
14. Need to **focus on SWF mitigation in development operations** now – previous forums have examined exploration topics – mud cost x 40 wells is exorbitant – what is MMS position on mud returns to seafloor
15. Develop **bit and WOB, RPM parameters** to accommodate very **hard, abrasive formations** in ultra deep wells (cretaceous harder drilling)
16. Classify mega depth wells for **high temp, H_2S characteristics**
17. Investigate **"mega-furrows" produced by deep currents** on seafloor
18. **Evaluate ROP improvement methods** while maintaining quality wellbore

19. **Evaluate solid tube expansion technology** (expandable casing)
20. **Obtain piston cores from seafloor amplitudes** to distinguish between gas hydrates and brine pools (ground truthing)
21. **Make hydrate CD available**
22. "Far market" users can't provide in-kind information – **provide information to scientists for evaluation**
23. **Prove gas hydrates are a drilling hazard** – no evidence of that at present – however, may affect foundation integrity in seafloor installations – in a formation where the hydrate fraction is high, there may be real risk – after running structural casing, it disappears – even 20" surface casing! – this subsidence may be hydrate related
24. **Prove gas hydrates are a resource** (and how to deal with stability issues)

DEEPWATER GEOHAZARDS WORKSHOP PARTICIPANTS, April 3-4, 2001

NAME	COMPANY	Address 1	City	State	Zip	Phone	Fax	Email
Jim Woomer	AGIP Petroleum	1201 Louisiana Suite 3500	Houston	TX	77002	713 393 6176	713 393 6211	jim.woomer@agippetroleum.agip.com
Michael L. Price	America Hess	500 Dallas Street	Houston	TX	77002	713 609 5504	713 609 5570	mprice@hess.com
Michael B. Johnson	Baker Hughes INTEQ	PO Box 671888	Houston	TX	77267-1888	713 625 4905	713 625 5905	michaelb.johnson@inteq.com
Robert J. Bruce	BHP Petroleum	1360 Post Oak Blvd. Suite 500	Houston	TX	77056-3020	(713) 961-8248	713 961-8486	bruce.bob.rj@bhp.com.au
Charles J. Fanguy	BJ Services	218 Thruway Park	Broussard	LA	70518	337 837 1044	337 837 7066	cfanguy@bjservices.com
Adam T. Bourgoyne	Bourgoyne Enterprises	6006 Boone Drive	Baton Rouge	LA	70808-5005	225 766 6536	225 766 3779	ted@bourgoyneenterprises.com
Alexander Calvert	BP	501 Westlake Park Blvd.	Houston	TX	77079	281 366 2146	281 366 7994	calveras@bp.com
Andrew W. Hill	BP	200 Westlake Park Blvd.	Houston	TX	77079	281 560 4148		hillaw@bp.com
Eric Liedtke	BP	501 Westlake Park Blvd.	Houston	TX	77079	281 366 7516	281 366 7941	liedtke@bp.com
James Thomson	BP	501 Westlake Park Blvd.	Houston	TX	77079	281 366 3446	281 366 7569	thomsoja@bp.com
Kathleen O. Horkowitz	BP	501 WestLake Park Blvd.	Houston	TX	77253	281 366 0824	281 366 2915	horkowko@bp.com
Stephen Willson	BP	501 WestLake Park Blvd.	Houston	TX	77077	281 366 5842	281 366 2915	willsonsm@bp.com
Tom Bowles	BP	501 WestLake Pk.Blvd.Rm 9.101	Houston	TX	77079	281 366 2425	281 366 7973	bowlesht@bp.com
Xu Li	BP	501 WestLake Park Blvd.	Houston	TX	77079	281 366 5526	281 366 2905	lixu@bp@bp.com
Mike McLean	BP Research Centre	Chertsey Road	Middlesex	United Kngdom	TW16 7LN	44 1 932-764135	44 1 932-764183	mcleanmr@bp.com
Donizeti de Jesus Carneiro	C & C Technologies	730 E. Kaliste Saloom Road	Lafayette	LA	70508	337 261 0660	337 261 0192	donizeti.carneiro@cctechnol.com
Michael Taylor	C & C Technologies	730 E. Kaliste Saloom Road	Lafayette	LA	70508	337 261 0660	337 261 0192	michael.taylor@cctechnol.com
Toby Kayes	Cambridge University Eng.Dept	Trumpington Street	Cambridgeshire	UK	CB3 OBN	01223 766683		tjk25@cam.ac.uk
Carole N. Fleming	Chevron	2202 Oil Center Ct	Houston	TX	77210	281 230 2680	281 230 2740	cnfl@chevron.com
Craig Lewis	Chevron	2202 Oil Center Court	Houston	TX	77073	(713) 230-2789	713 230 2669	cral@chevron.com
James C. Niemann	Chevron	935 Gravier Street	New Orleans	LA	70112	504 592 6924		jcni@chevron.com
Jay W. Bruton, Jr.	Chevron	2202 Oil Center Court	Houston	TX	77073-3333	281 230 2960	281 230 2669	jayb@chevron.com
Jen-hwa Chen	Chevron	2202 Oil Center Court	Houston	TX	77073	281 230 2787	281 230 2669	jenc@chevron.com
John B. Karpa III	Chevron	935 Gravier Street	New Orleans	LA	70112	504 592 6475	504 592 6358	jbka@chevron.com
Lawrence D. Perry	Chevron	2202 Oil Center Court	Houston	TX	77073	713 230 2634	713 230 2669	oldp@chevron
E. Dendy Sloan	Colorado School of Mines	Geophysics Dept.	Golden	CO	80401-1887			esloan@mines.edu
Jeffrey L. Mueller	Conoco, Inc.	600 N. Dairy Ashford, NS3044	Houston	TX	77079-6651	281 293 4093	281 293 2158	jeffrey.l.mueller@usa.conoco.com
Lynn B. Dooley	Conoco, Inc.	400 E. Kaliste Saloom Rd.	Lafayette	LA	70508	337 269 2199	337 269 3490	lynn.b.dooley@usa.conoco.com
Fred Holasek	Diamond Offshore	15415 Katy Fwy., Ste.100	Houston	TX	77094	281 647 2204	281 647 2158	fholasek@dodi.com
O. Allen Kelly	Diamond Offshore	15415 Katy Freeway, Ste 110	Houston	TX	77094-1812	281 647 4084	281 647 2285	akelly@dodi.com
Randal Garrett	Diamond Offshore	15415 Katy Fwy., Ste.100	Houston	TX	77094	281 647 2129	281 647 2158	rgarrett@dodi.com
Gene Sparkman	Energy Research Clearing House	4800 Research Forest Drive	The Woodlands	TX	77381	281 363 7936	281 364 6097	sparkman@erch.org
Roger Entralgo	Energy Research Clearing House	4800 Research Forest Drive	The Woodlands	TX	77381	281 363 7927	281 364 6097	roger@erch.org
Giampaolo Sesena	ENI-AGIP	Via Fabiani 1	Milano	Italy	2100	39 02 52055724	39 02 52035513	gianni.erchi@agip.it
Giani Erchi	ENI-AGIP	Via dell'Unione Europea 3	Milano	Italy		39 02 520 35604	39 02 520 35513	gianni.erchi@agip.it
Scott Leonard	Exxon/Mobil	PO Box 4778	Houston	TX	77210-4778	281 423 7129	281 423 7763	dsleona@upstream.xomcorp.com
Gary D. Humphrey	Fugro-McClelland Marine	6100 Hillcroft	Houston	TX	77081	713 773 5940		ghumphrey@fugro.com
Kerry J. Campbell	Fugro-McClelland Marine	6100 Hillcroft	Houston	TX	77081	713 778 5528	713 773 8501	kcampbell@fugro.com
Carolyn Ruppel	Georgia Tech	School of Earth & Atmospheric Sciences	Atlanta	GA	30332-0340	404 894 0231	404 894 5638	cdr@piedmont.eas.gatech.edu
Thomas J. Griffin, Jr.	Griffin Cement Consulting	1860 FM 359 #142	Richmond	TX	77469-1269	281 341 1893		tjgriffin2@earthlink.net
Gregory Rachal	Halliburton (Baroid)	10200 Bellaire Blvd.	Houston	TX	77072	281 988 2239	281 988 2103	greg.rachal@halliburton.com
Colby Ballew	Halliburton Energy Services	10200 Bellaire Blvd. 2SW24K	Houston	TX	77072-5299	281 988 2161		colby.ballew@@halliburton.com
Ron Sweatman	Halliburton Energy Services	10200 Bellaire Blvd. 2SW24K	Houston	TX	77072-5299	713 575 4389	713 624 2899	ronald.sweatman@halliburton.com
Ronald R. Faul	Halliburton Energy Services	10200 Bellaire Blvd 91-1SW-14-F	Housotn	TX	77072-5299	281 575 3364	281 575 3289	ronnie.faul@halliburton.com
David M. Weinberg	INEEL	P. O. Box 1625	Idaho Falls	ID	83415-2110	208 526 4274	208 526 9822	weinbe@inel.gov
G. Michael Shook	INEEL	PO Box 1625	Idaho Falls	ID	83415-2107	208 526 6945		ook@inel.gov
Yuichiro Ichikawa	Japan Drilling Co.	3-20-16 Nishiazabu Minatoku	Tokyo	Japan	106-0031	81 3 5411 9889	81 3 5411 9208	yichi@jdc.co.jp
Tadashi Okano	Japan Marine Science & Technology Center	2-15 Natsushima-Cho	Yokosuka-City,	gawa-Pre. JAPAN	237-0061	81-468-67-3985	81 468 66 5351	okanot@jamstec.go.jp
Mike Davis	Kerr McGee Oil & Gas	16666 Northcase	Houston	TX	77060	281 618 6420	281 618 6038	mjdavis@kmg.com
Vic Estes	Kerr McGee Oil & Gas	16666 Northcase	Houston	TX	77060	281 618 6293	281 618 6038	vestes@kmg.com
James Bridges	Knowledge Systems Inc.	11104 W. Airport Blvd. Suite 125	Stafford	Texas	77497-1279	281 879 1400 x-206	281 879 1499	bridges@knowsys.com
Bill Abreo	Kvaerner Oilfield Products Inc.	1255 N. Post Oak Road	Houston	TX	77055	713 683 2801	713 862 1022	bill.abreo@kvaerner.com
Larry Myer	Lawrence Berkeley National Lab	One Cylcotron Rd., MS 90-1086	Berkeley	CA	94720	510 486 6456	510 486 5686	lrmyer@lbl.gov
Richard B. Knapp	Lawrence Livermore	L204, 7000 East Avenue	Livermore	CA	94550-9900	925 423 3328	925 423 1997	knapp4@llnl.gov
Jim Parker	Marathon Oil	P. O. Box 3128	Houston	TX	77253-3128	713-296-3010		jmparker@marathonoil.com
John F. Jones	Marathon Oil	5555 San Felipe	Houston	TX	77056-2725	713 296 3331		jfjones@marathonoil.com
Paul D. Scott	Marathon Oil	5555 San Felipe	Houston	TX	77056	713 296 2221	713 296 3363	pscott@marathonoil.com
Peter Trabant	MarineGeohazards.Com	2000 N Loop W. Suite 126	Houston	TX	77018	713 956 5404		trabant@worldnet.att.net
Alan K. Hadfield	Mariner Energy, Inc.	580 WestLake Park Blvd., Ste.1300	Houston	TX	77079	281 584 5626	281 584 5620	ahadfield@mariner-energy.com
Ahmed Adnan	MMS	1201 Elmwood Park Blvd.	New Orleans	La	70123-2394	504 736 2501		adnan.ahmed@ mms.gov
Buddy R. Stewart	MMS	201 Energy Pkwy., Suite 410	Lafayette	LA	70508	337 289 5108	337 262 6620	buddy.stewart@mms.gov
David Trocquet	MMS	990 North Corporate Blvd.	New Orleans	LA	70123	504 736 2506	504 736 2836	david.trocquet@mms.gov
Ed Smith	MMS	Lake Jackson District Office	Clute	TX	77531-3959	979 266 1001	979 265 7206	edmond.smith@mms.gov
Jesse L. Hunt, Jr.	MMS	1201 Elmwood Park Blvd.	New Orleans	LA	70123	504 736 2440		jesse.hunt@mms.gov
Lars Herbst	MMS	990 North Corporate Blvd.	New Orleans	LA	70123	504 736 2504	504 736 2836	lars.herbst@mms.gov
Michael A. Smith	MMS	1201 Elmwood Park Blvd, MS 5222	New Orleans	LA	70123-2394	504 736 2500	504 736 2941	michael.smith@mms.gov
Robert Kuzela	MMS	1201 Elmwood Park Blvd.MS 5220	New Orleans	LA	70123	504 736 2996		robert.kuzela@mms.gov
Ronald Lee Fowler	MMS	102 Oak Park Dr., Suite 200	Clute	TX	77531	979 266 1004	979 265 7206	ronald.fowler@mms.gov
William Hauser	MMS/US Dept. of Interior	381 Elden Street, MS4700	Hearndon	VA	22070	703 787 1613	703 787 1575	william.hauser@mms.gov
W. David Harris	Murphy E&P	550 Westlake Park, Blvd.1000	Houston	TX	77079	281 249 1021	281 249 1041	david_harris@murphyoilcorp.com
Joseph Gettrust	Naval Research Lab	Bldg.1005 Rm B-40 Code 7430	Stennis Space Center	MS	39529-5004	228 688 5475		joe.gettrust@nrlssc.navy.mil
David Reister	Oak Ridge National Lab	Bethel Valley Rd., Bldg.6010, MS 6355	Oak Ridge	TN	37831-6355	865 574 2272	865 241 0381	dbr@ornl.gov
Lorie Langley	Oak Ridge National Lab	Bethel Valley Road	Oak Ridge	TN	37831-6094	865 574 4185	865 574 7721	LL8@ornl.gov
Olivia R. West	Oak Ridge National Lab	PO Box 2008, Bldg. 1505, MS6036	Oak Ridge	TN	37831	865 576 0505	865 576 8543	westor@ornl.gov
Gene Pollard	Ocean Drilling/Texas A&M	1000 Discovery Drive	College Station	TX	77845-9547	979 845 2161	979 845 2308	pollard@odpe.tamu.edu
Tom Pettigrew	Ocean Drilling/Texas A&M	1000 Discovery Drive	College Station	TX	77845-9547	979 845 2329	979 845 2308	pettigrew@odpemail.tamu.edu
Wayne Cox	PanCanadian Petroleum Ltd.	150 - 9th Ave.S.W.	Calgary, Alberta	Canada	T2P 2S5	403 290 3579	403 290 3039	wayne_cox@pcp.ca
Walt Lynn	PGS	16010 Barker's Point Lane, Ste.600	Houston	TX	77079	281 589 7935	281 589 8267	walt.lynn@pgs.com
Joseph Gagliardi	PGS Reservoir	738 Hwy.6 South, Ste.1000	Houston	TX	77079	281 589 8829		joe.gagliardi@pgs.com
Colin Davidson	Santa Fe International Corp.	5420 LBJ Freeway, Ste. 1100	Dallas	TX	75240-2648	972 701 7666	972 701 7940	cjdavidson@sfdrill.com
Mike Simpson	Santa Fe International Corp.	5420 LBJ Freeway, Ste. 1100	Dallas	TX	75240-2648	972 701 7829	972 701 7940	msimpson@sfdrill.com
William G. Archibald	Santa Fe International Corp.	5420 LBJ Freeway, Ste. 1100	Dallas	TX	75240	972 701 7828	972 701 7940	barchibald@sfdrill.com
Chris Lenamond	Schlumberger	3623 Tartan Lane	Houston	TX	77025	713 819 2108		lenamond@slb.com
Arlette C. Nunez	Shell Deepwater Dev. Inc.	P.O. Box 60833	New Orleans	La.	70160-0833	504 728 6188		an142695@msxsepc.shell.com
Vernessa Bradford	Shell Deepwater Dev. Inc.	P.O. Box 60833	New Orleans	La.	70160-0833	504 728 4426		vr158906@msxsepc.shell.com
Jack Dvorkin	Stanford Rock Physics Lab	Geophysics Department	Stanford	CA	94305-2215	650 725 9296	650 72 7344	jack@rpangea.stanford.edu
Neil S. Summer	TDI-Brooks Intern'l Inc.	1902 Pinon	College Station	TX	77845	979 693 3446	979 693 6389	neilsummer@aol.com
Ben Bloys	Texaco	3901 Briarpark	Houston	TX	77042-5301	713 954 6348	713 954 6113	bloysjb@texaco.com
Matthew Czerniak	Texaco	4800 Fournace	Bellaire	TX	77401-2324	713 432 3719		czernim@texaco.com
Roger Sassen	Texas A&M University	833 Graham Road Mail Stop: 3149	College Station	TX	77845-9668	979 862 2323 x-110	979 862 2361	sassen@gerg.tamu.edu
Andrew Hume	Thales GeoSolutions Inc.	3624 Westchase	Houston	TX	77042	713 784 4482	713 784 8162	andrew.hume@thales-geosolutions.com
Peter B. Flemings	The Pennsylvania State University	442 Deike Building	University Park	PA	16802	814 865-2309	814 863-7823	flemings@austin.emsadm.psu.edu
Ken E. Gray	The University of Texas at Austin	3930 Sierra Drive	Austin	TX	78731	512 345 0057	512 346 5025	ken_gray@mail.utexas.edu
Peter Wells	TIA, Inc.	7880 San Felipe, St.200	Houston	TX	77063	713 975 0081	713 975 9812	pwells@tiainfo.com
Eric Cauquil	Totalfina-elf	24, cours Michelet - L Defense 10	Paris	France	92069	00 33 141 35 88 58	33 1 41 35 36 96	eric.cauquil@totalfinaelf.com
Terri Smith	TS Consulting	PO Box 6672	Kingwood	TX	77325	59 0094 or 359 6015	281 359 2090	terrismith@mindspring.com
Frances Toro	U.S. Department of Energy (DOE)	3610 Collins Ferry Rd.	Morgantown	WV	26507	304 285 4403		frances.toro@netl.doe.gov
James L. Barnes	U.S. Department of Energy (DOE) NPTO	One West Third St., Suite 1400	Tulsa	OK	74101	918 699 2076	918 699 2005	jbarnes@npto.doe.gov
Patrick Hart	U.S. Geological Survey	345 Middlefield Rd., MS-999	Menlo Park	CA	94025	650 329 5160	650 329 5190	hart@usgs.gov
William J. Winters	U.S. Geological Survey	384 Woods Hole Rd.	Woods Hole	MA	2543	508 457 2358	508 457 2310	bwinters@usgs.gov
David Hopgood	Unocal	14141 Southwest Freeway	Sugar Land	TX	77478	281 287 5226		
John Hoffmann	Unocal	14141 Southwest Freeway	Sugar Land	TX	77478	281 287 5478	281 287 5333	jhoffmann@unocal.com
Michael E. Utt	Unocal	14141 Southwest Freeway	Sugar Land	TX	77478-3465	281 287-5215	281 287-5390	mike.utt@unocal.com
Nader C. Dutta	WesternGeco	3600 Briar Park Dr.	Houston	TX	77042-5275	713 689 6370	713 689 6200	nader.dutta@westerngeco.com
Randall Davis	WesternGeco	10001 Richmond Ave.	Houston	TX	77042-4299	713 689 5801	713 689 2471	randy.davis@westerngeco.com
Robbert de Kok	WesternGeco	10001 Richmond Ave.	Houston	TX	77042	713 689 5760	713 689 5757	rob.dekok@westerngeco.com
Bayram Kalpakci	Westport Technology	6700 Portwest Dr.	Houston	TX	77024	713 479 8439	713 864 9357	bayram.kalpakci@westport1.com

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