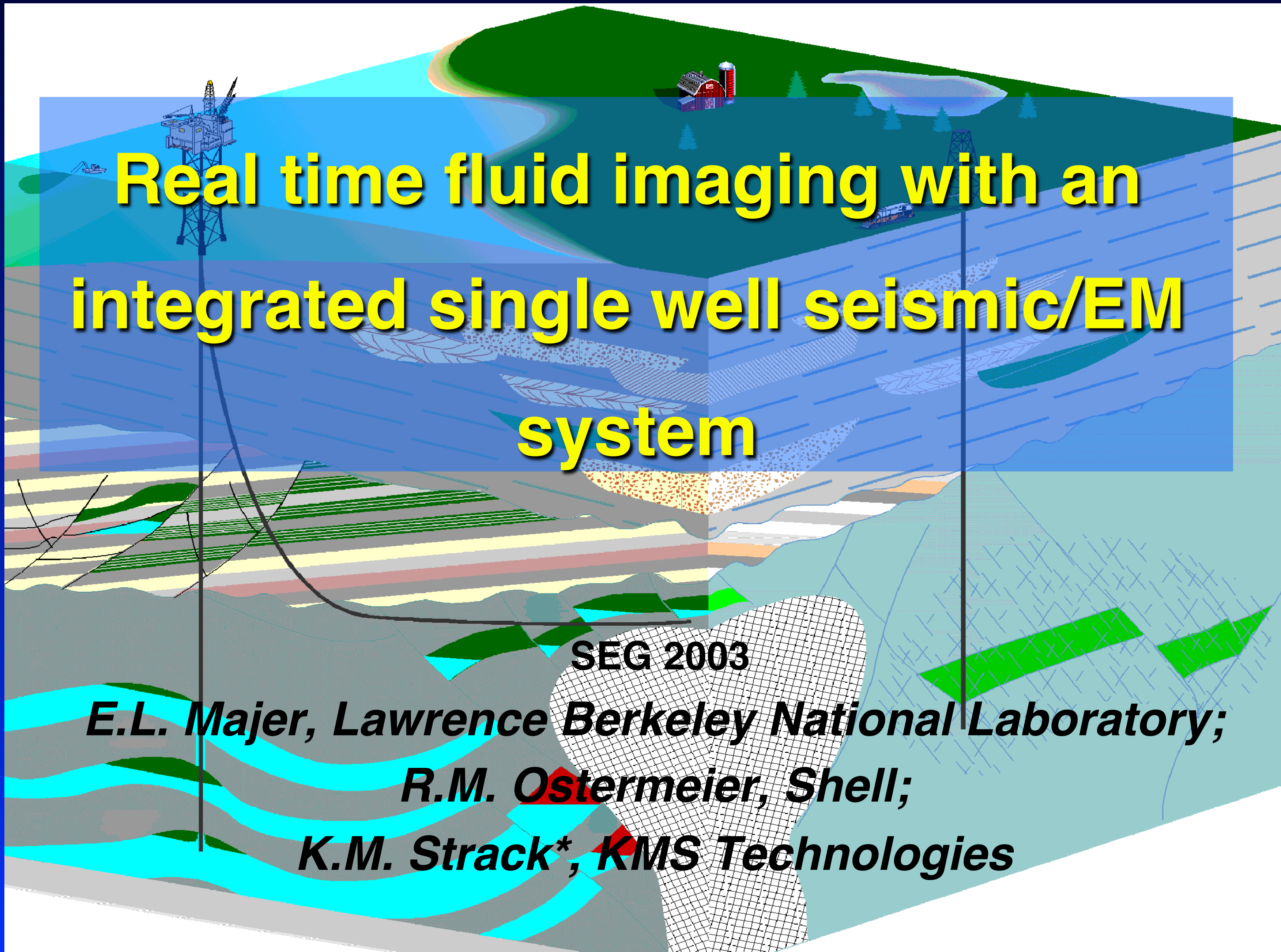


Real time fluid imaging with an integrated single well seismic/EM system

SEG 2003

E.L. Majer, Lawrence Berkeley National Laboratory;
R.M. Ostermeier, Shell;
K.M. Strack, KMS Technologies*

Outline

- Setting the scene
- Project scope
- Progress example
- Perspective

Funded by: DOE, DeepLook (bp, Chevron, Conoco, Shell, Texaco), Shell/Agip

DeepLook

The Challenge

Breakthrough needed

Now → Vision 2010

Services - delivery vehicle

Subsurface Sensors

Integration

Reservoir Modeling

Surface sensors

- Bypassed production
- Mis-positioned wells
- Low well productivity
- Expensive testing
- Reserves uncertainty
- Aquifer drive ??

70%+ recovery

- Optimal well targeting
- Right facilities
- Minimum water production

<35%

70%

Needs to meet challenge

- Accurate fluid characterization of commercial quantities up to 200 m away from well bore
  - Independent structural information (seismic)
  - Measure of Fluid properties (EM)
  - Coupled solution for fluid imaging
- Start integrating EM into existing seismic systems
- Commercial solution
  - Easy to use and deploy
  - Global accessibility
  - High resolution (Equivalent to Logs)
  - Rapid results for drilling guidance

Project Objectives & Goals

Create critical mass to combine state-of-art technology

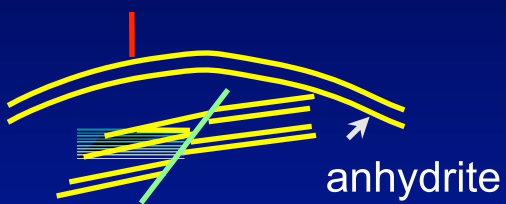
The methods

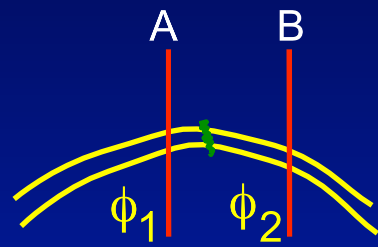
- Develop EM single well technology (starting with Pre-feasibility)
- Improve single well seismic
- Integrate the systems & methodology
- Demonstrate

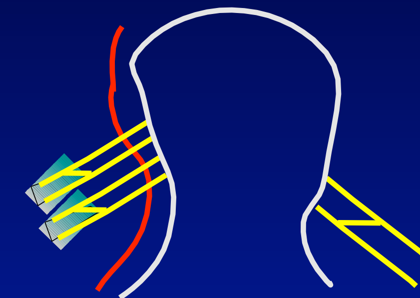
DeepLook

Class of problems

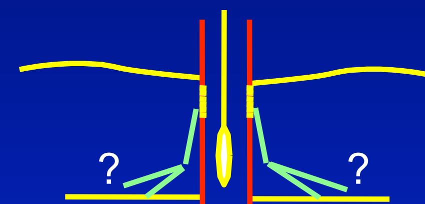
- **Find pockets of hydrocarbons / structural**



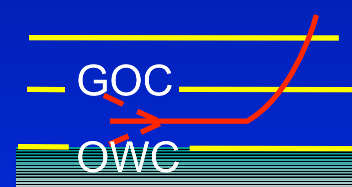


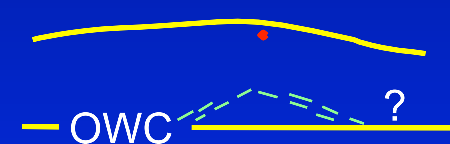


- **Monitor production**

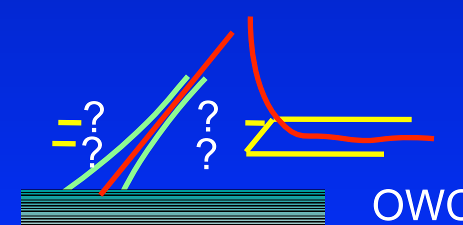


- **Control / steer well path**

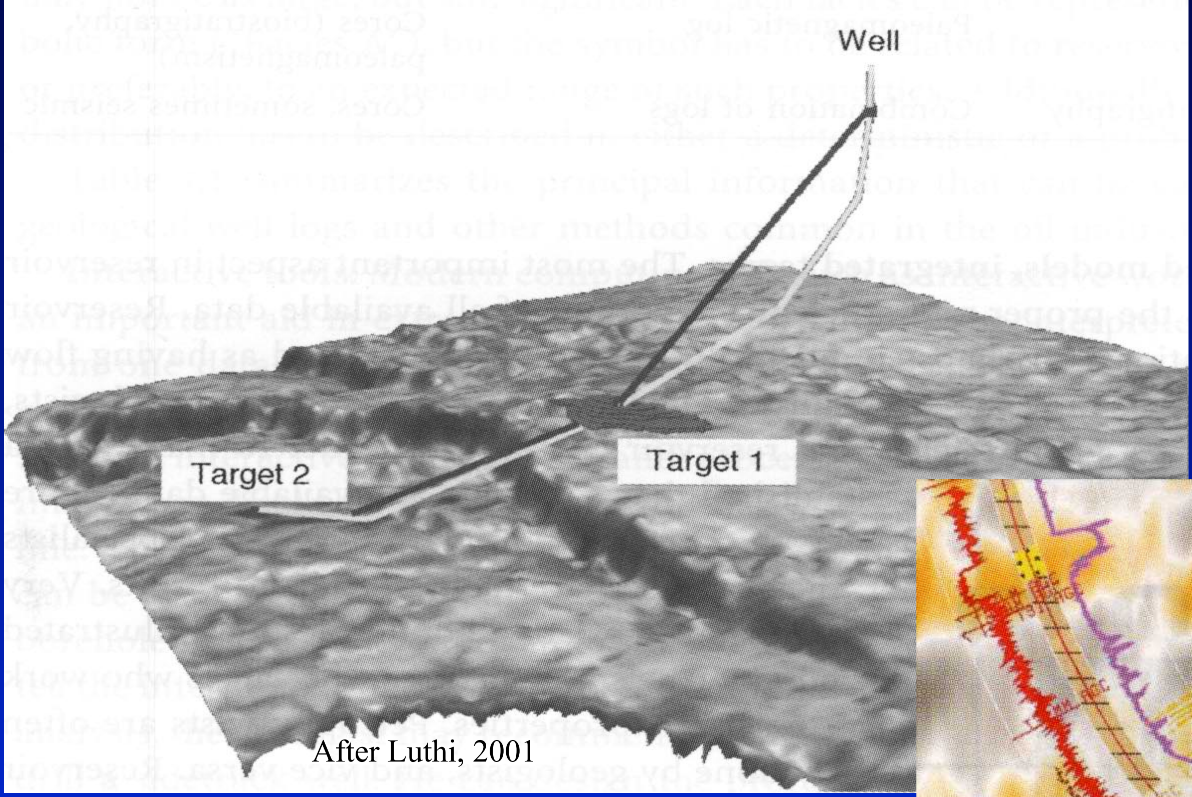




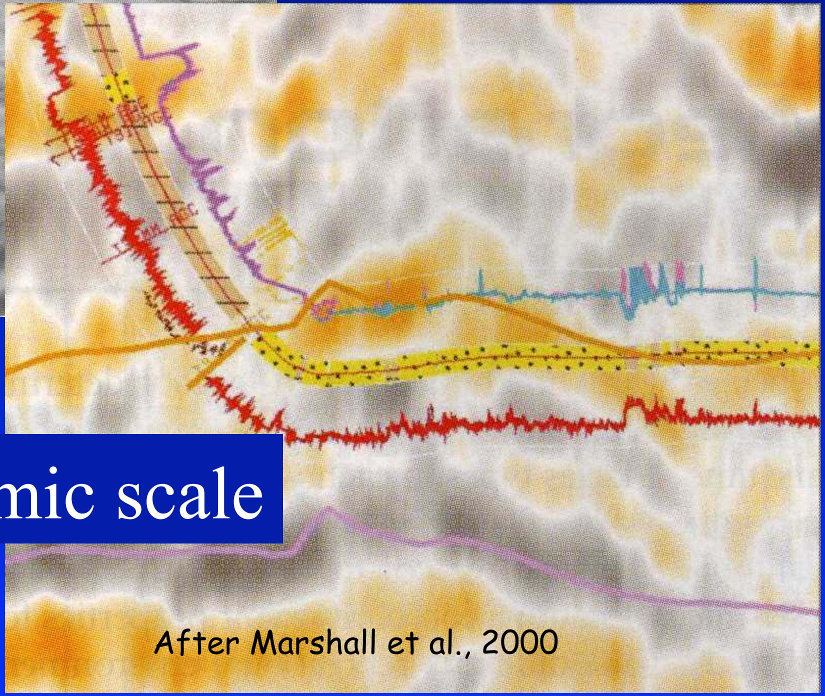
- **Control safety / environmental aspects**



LWD/MWD geosteering examples



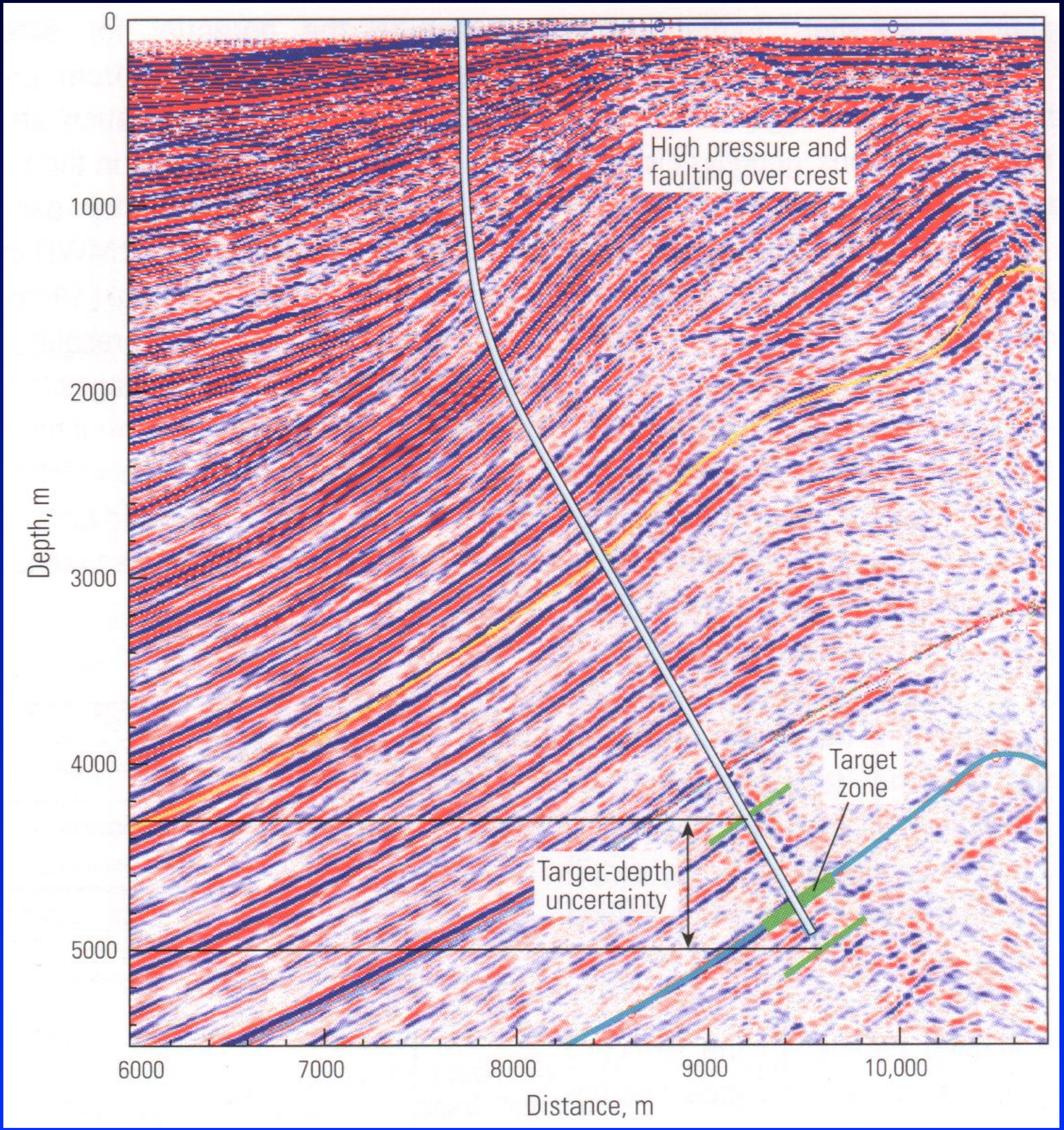
After Luthi, 2001



After Marshall et al., 2000

Most targets are at sub-seismic scale

Geosteering in a seismic section



(Breton, et al.,2002)

Outline

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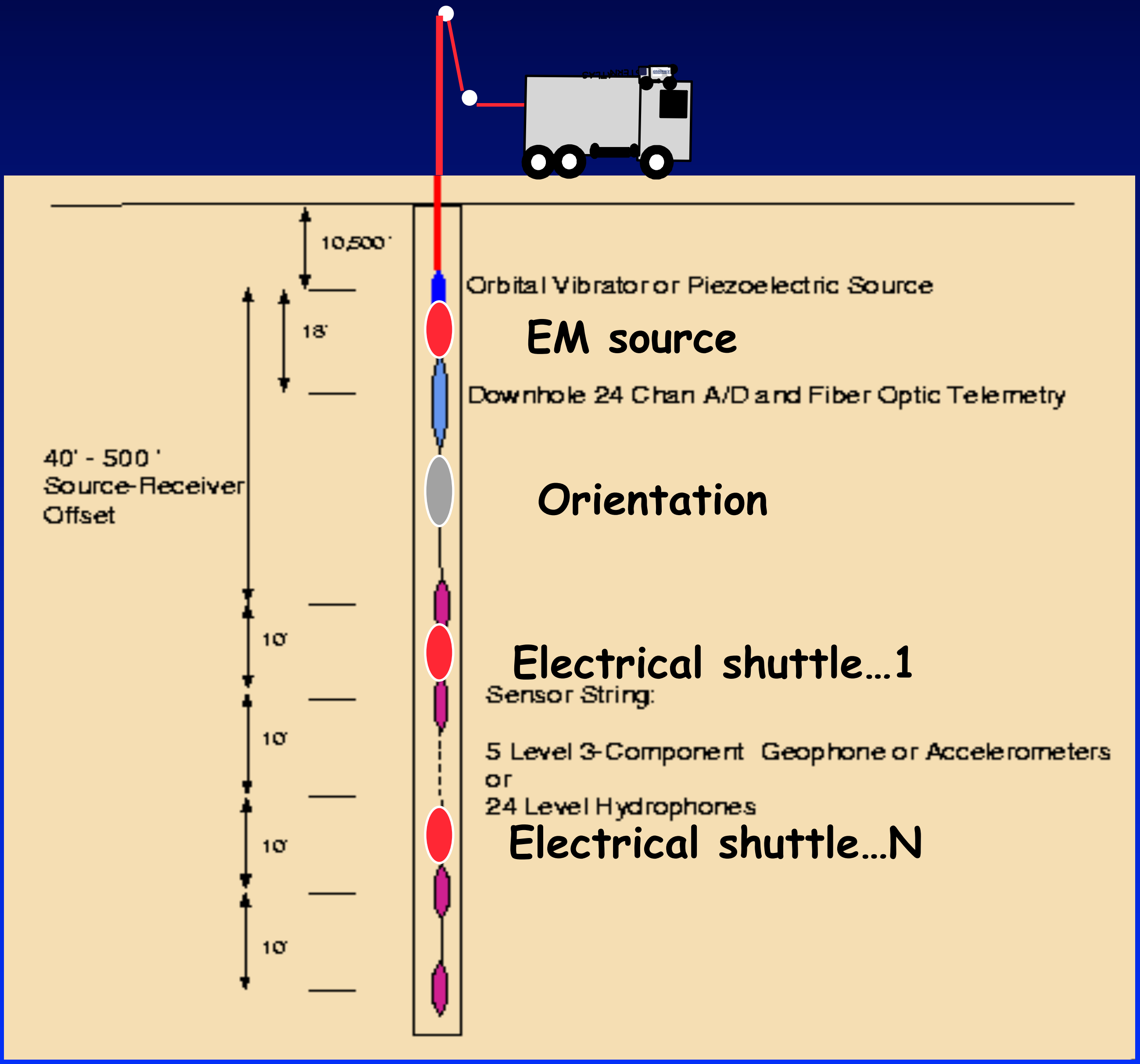
Funded by: DOE, DeepLook (bp, Chevron, Conoco, Shell, Texaco), Shell/Agip

Project phases:

- Pre-feasibility (Can we do it?) √
- Feasibility (Can we design it?) √
- Prototype (Can we build it?) next year
- Field test (Can we demonstrate it?)
- Commercialization

Integrate with seismic single well system



Project Deliverables -
A Commercial Solution
DRILLING DECISIONS

- Acquisition
  - Similar to known systems — seismic integrated
  - Easy to QC — real time image
- Processing - within 24 hours
  - Little difference from known methods
  - Stable results — conductivity image
- Post-processing — integrated model

Scientific tasks

- Modeling
  - EM system modeling (KMS)
  - Seismic sensitivity (Sandia)
  - EM Sensitivity (LBNL)

- EM – Seismic system Integration (KMS- LBNL)
- Field tests:
  - Single well tube waves
  - EM noise

Modeling

- Shell provided three models with varying geometry and parameters for EM and Seismic modeling
  - Velocity (P and S)
  - Density
  - Conductivity
  - thickness
  - source-receiver distances

→ **218 combinations**

Outline

- Setting the scene
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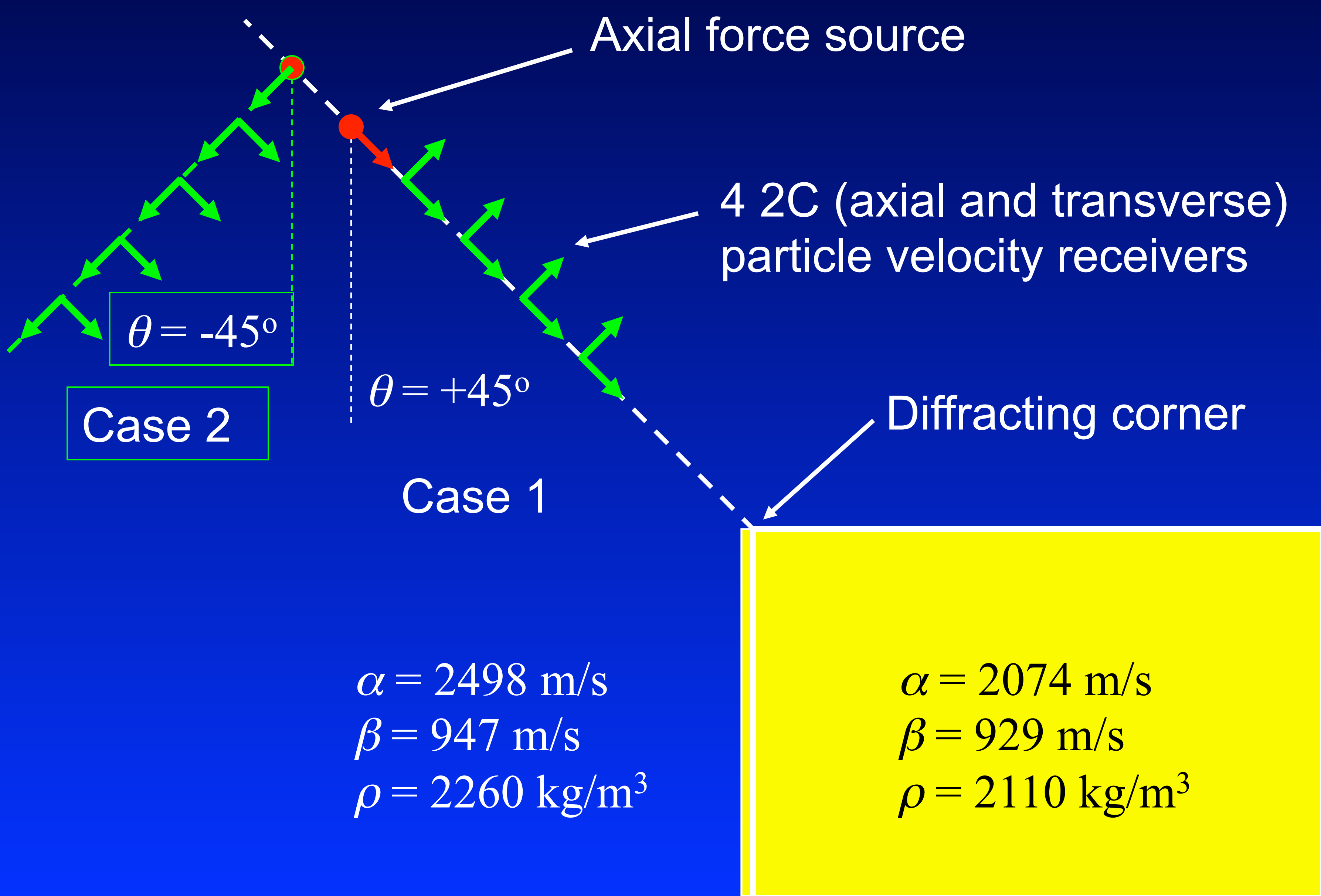
Modeling - Seismic

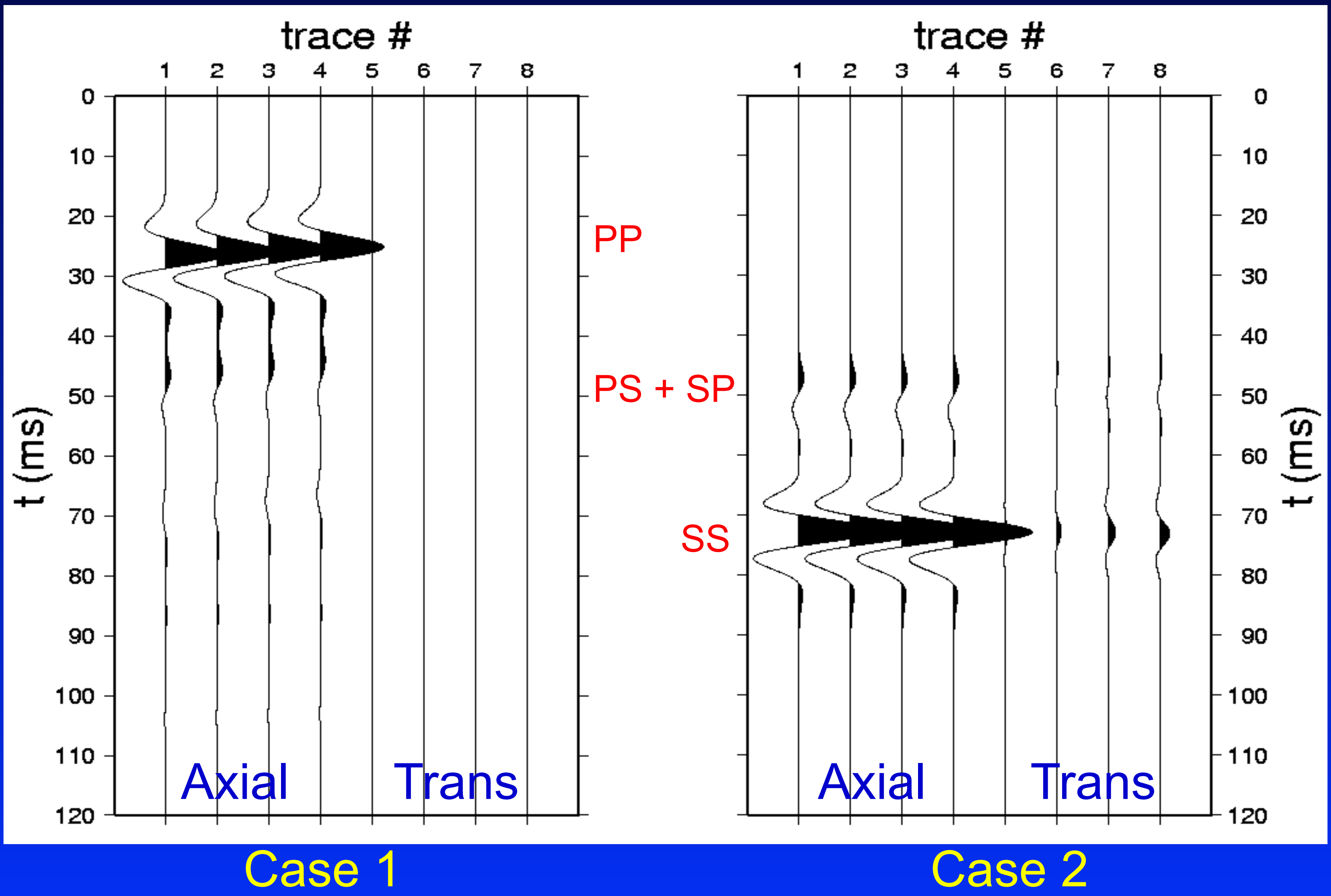
- Focus on bedded and faulted models Velocity (P and S)
  - Examine sensitivity as a function of
    - Density
    - Thickness
    - Source-receiver distances

Seismic Modeling

- Sensitivity of Seismic Imaging
  - Modeled critical parameters for industry cases
    - Different source responses
      - Point versus torque
      - Pressure versus 3-C motion
    - Receiver levels
      - N-Levels
    - Full elastic 3-D solution

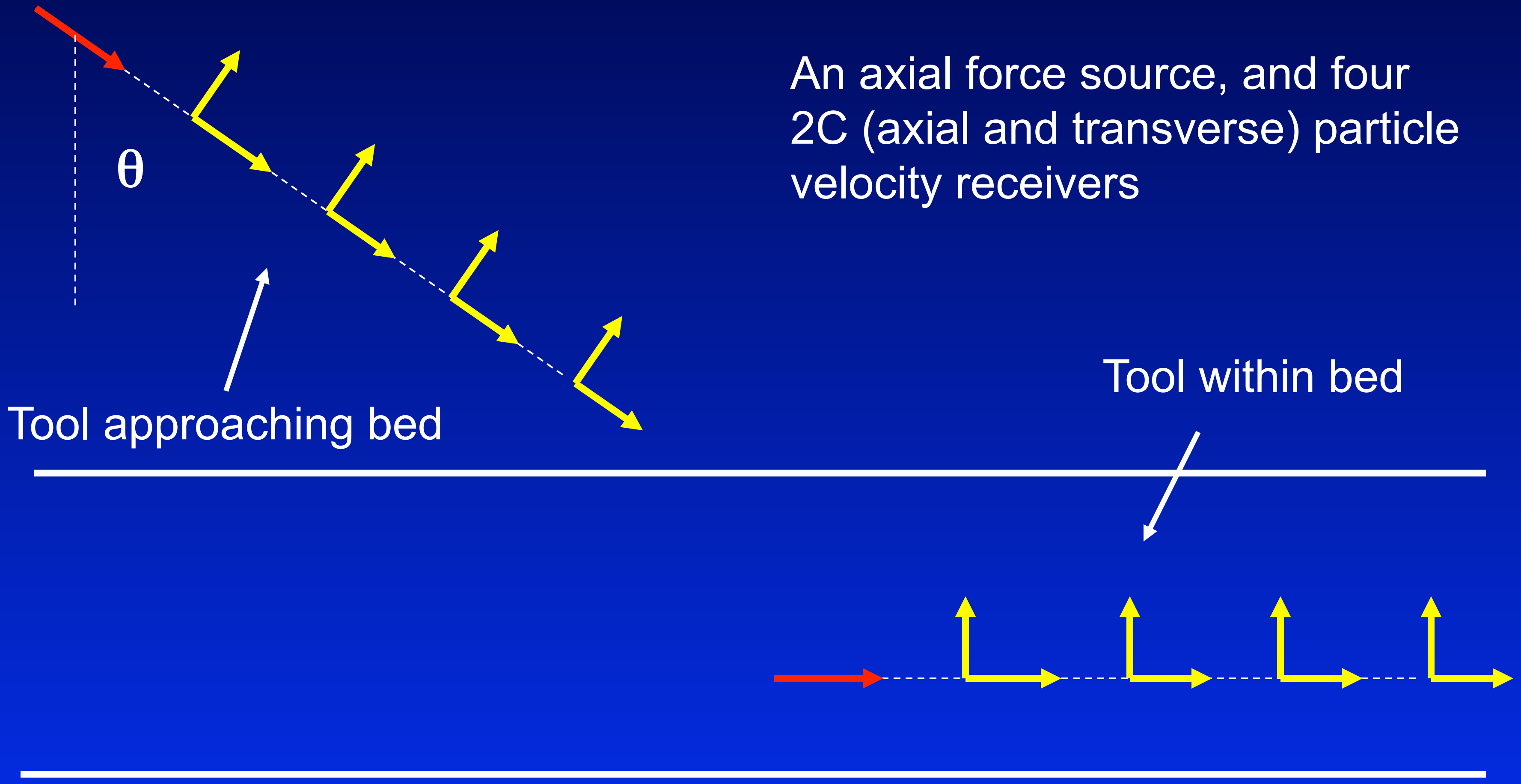
Corner Diffraction Responses




trace #
1 2 3 4 5 6 7 8
t (ms)
0 10 20 30 40 50 60 70 80 90 100 110 120
PP
PS + SP
SS
Axial
Trans
Case 1
Case 2

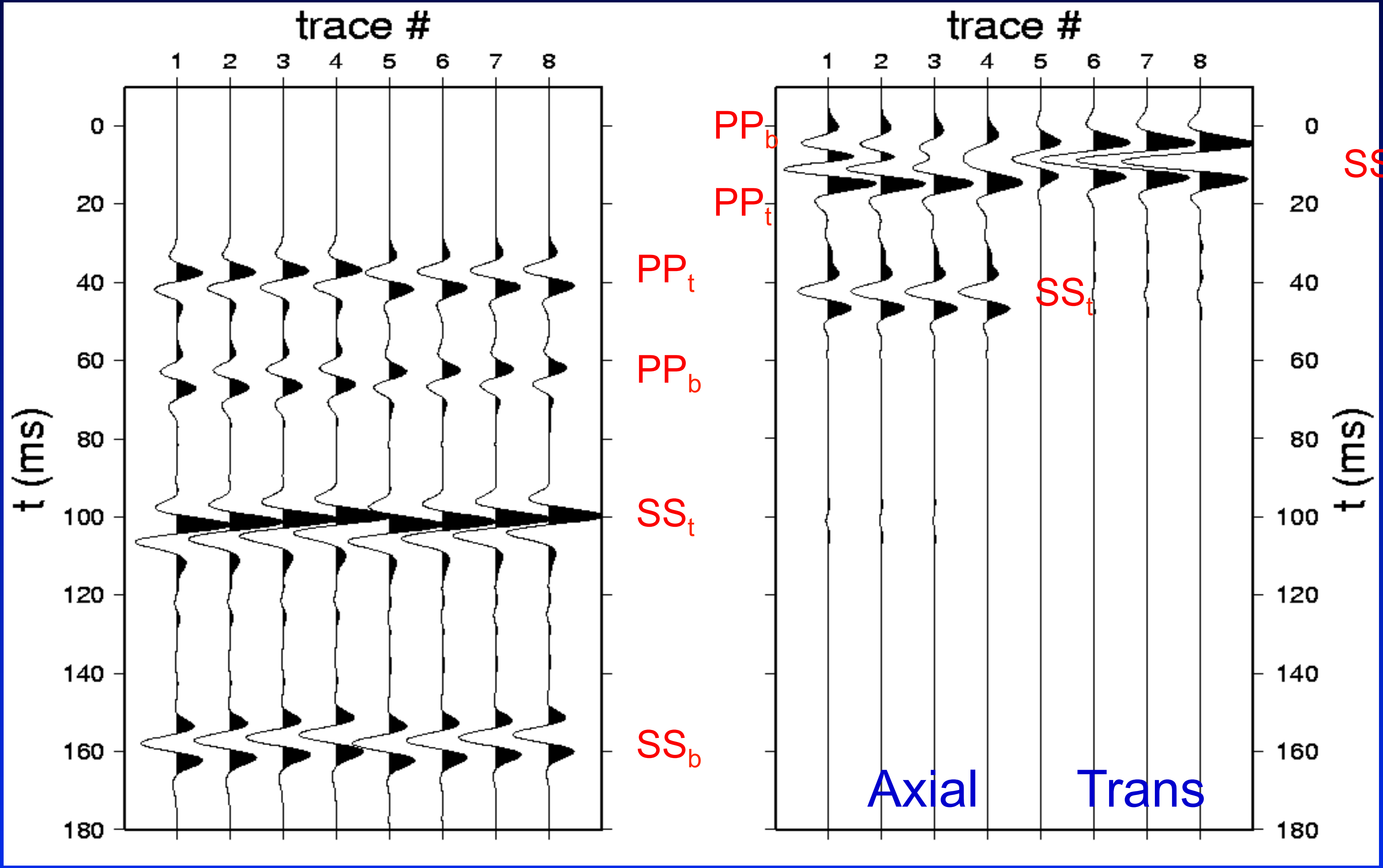
Single-Well Seismic Responses

An axial force source, and four 2C (axial and transverse) particle velocity receivers



Min / max source-receiver offset: 1 m / 4 m
Tool orientations: 45°, 90°

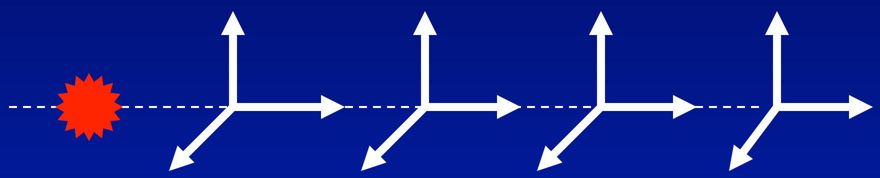
Axial Trans



Tool approaching bed

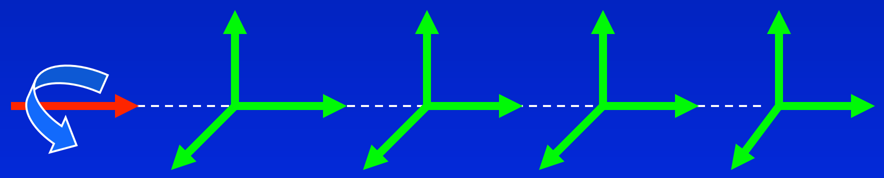
Tool within bed

Two Moment Sources

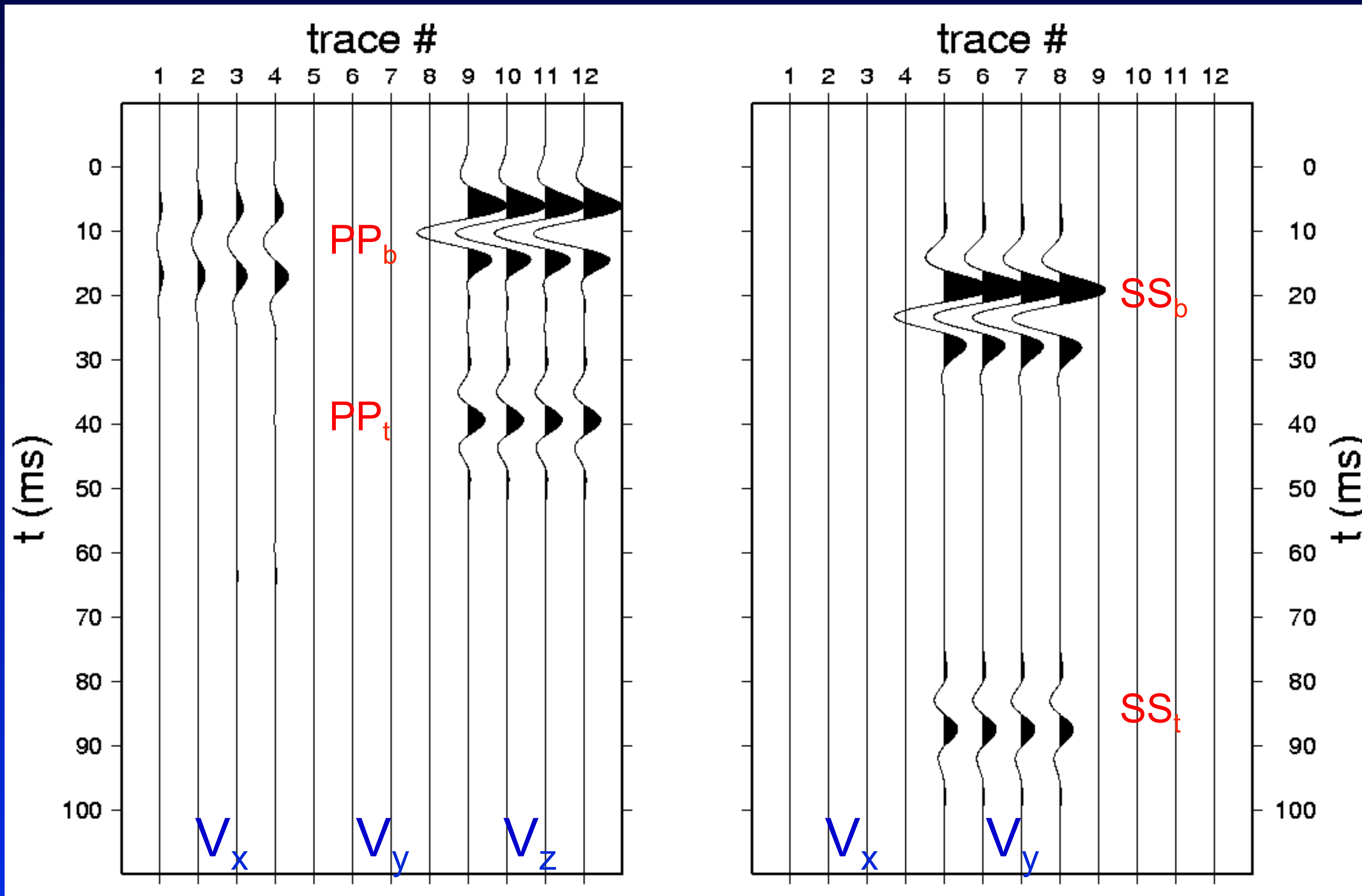


Explosion source: pure P

Torque source: pure S



Min / max source-receiver offset: 1 m / 4 m



Explosion source

Torque source

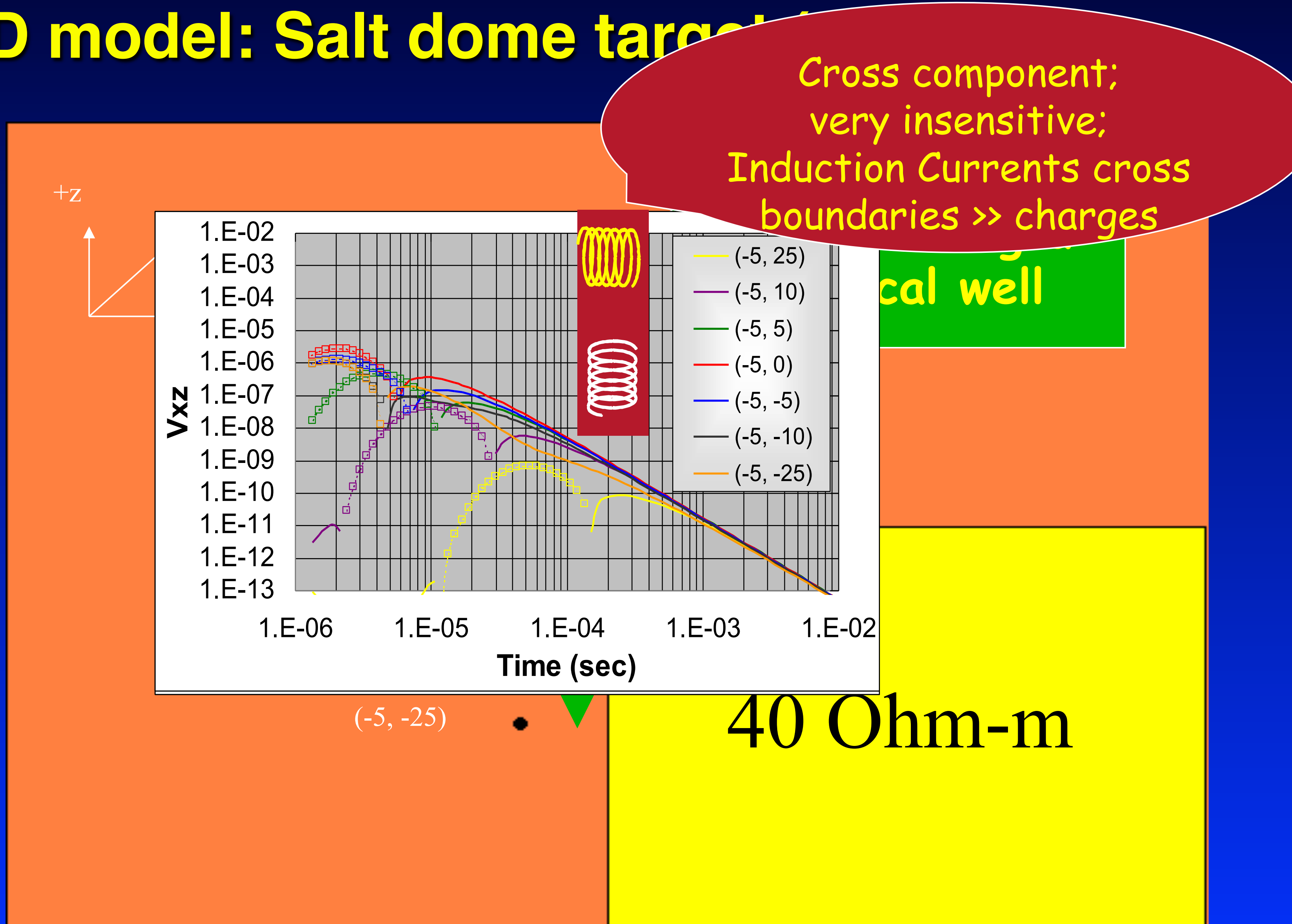
Seismic Modeling: Results

- Sensitivity of Seismic Imaging
  - To adequately image:
    - → Multi-component and Multi-receiver
      - ★ PP, PS, SS, SP Separation
      - ★ Directionality
      - ★ Trace summing, subtracting, rotation
    - → High Frequency (500 to 1KHZ)
      - ★ Reduce arrival interference
      - ★ Tube wave reduction
    - → Pure mode sources
      - ★ Isotropic best for amplitude preservation
      - ★ Torque SH give limited conversion (good)

EM modeling

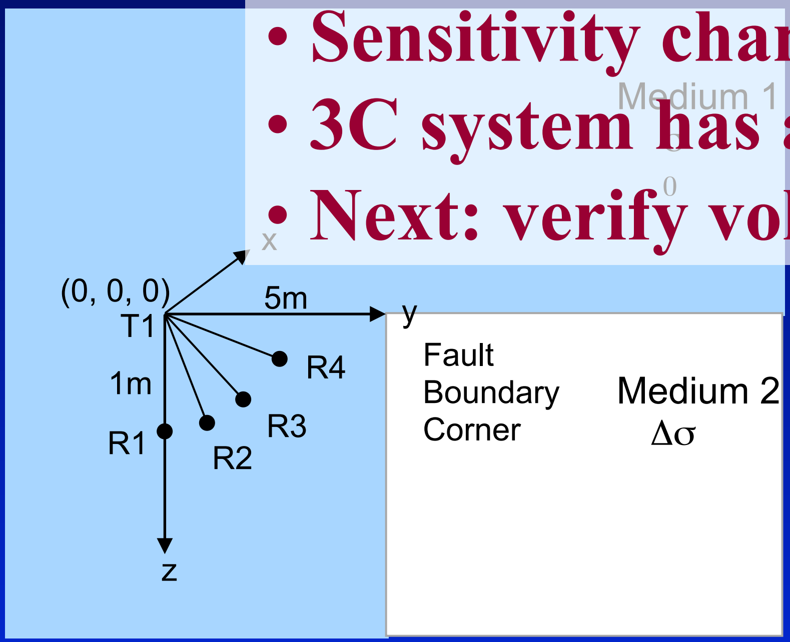
- 3D modeling
  - Benchmarked codes
  - 3D response to selected benchmarks
- Perturbation analysis
  - Directionality
  - Integration with seismic (real time goal)

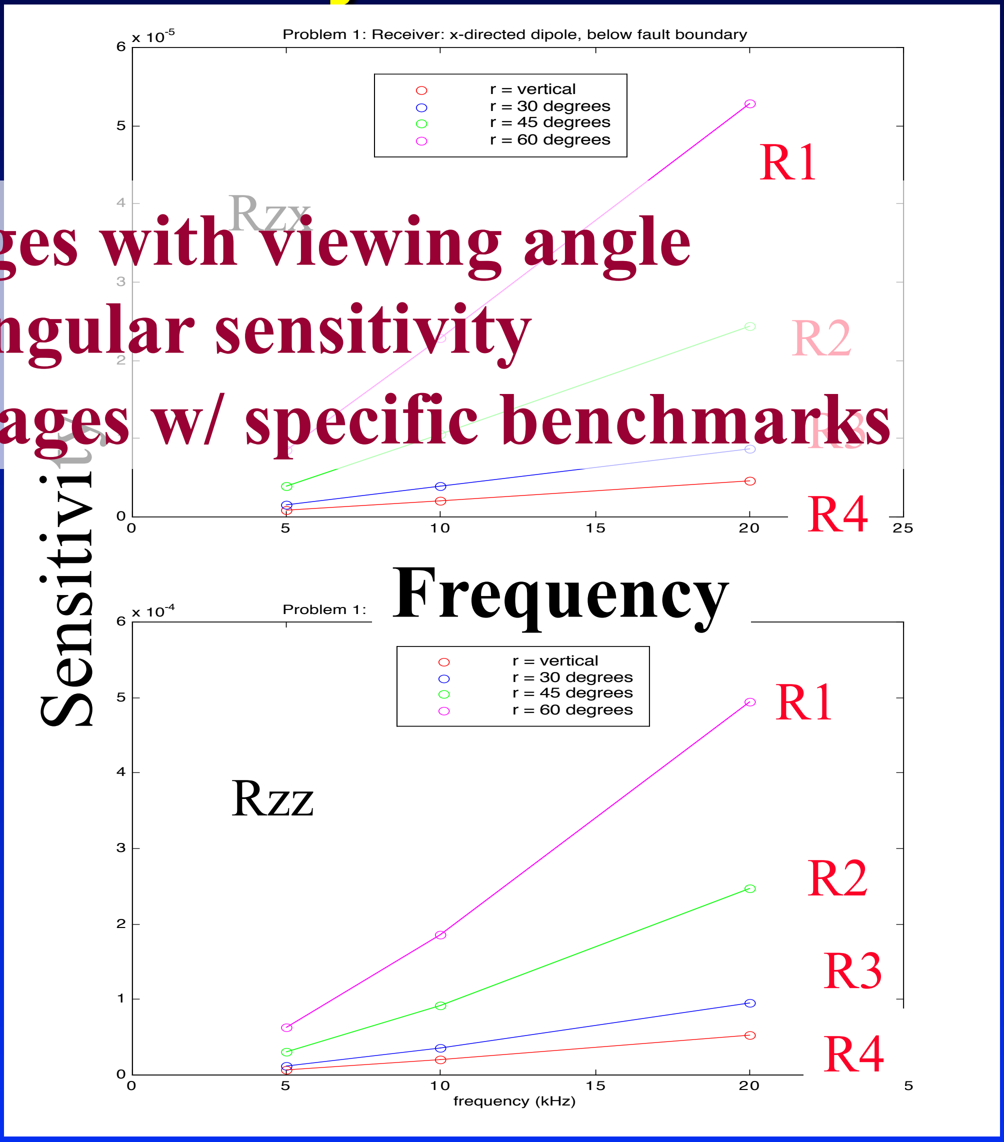
3D model: Salt dome targ



Directionality sensitivity

- Sensitivity changes with viewing angle
- 3C system has angular sensitivity
- Next: verify voltages w/ specific benchmarks

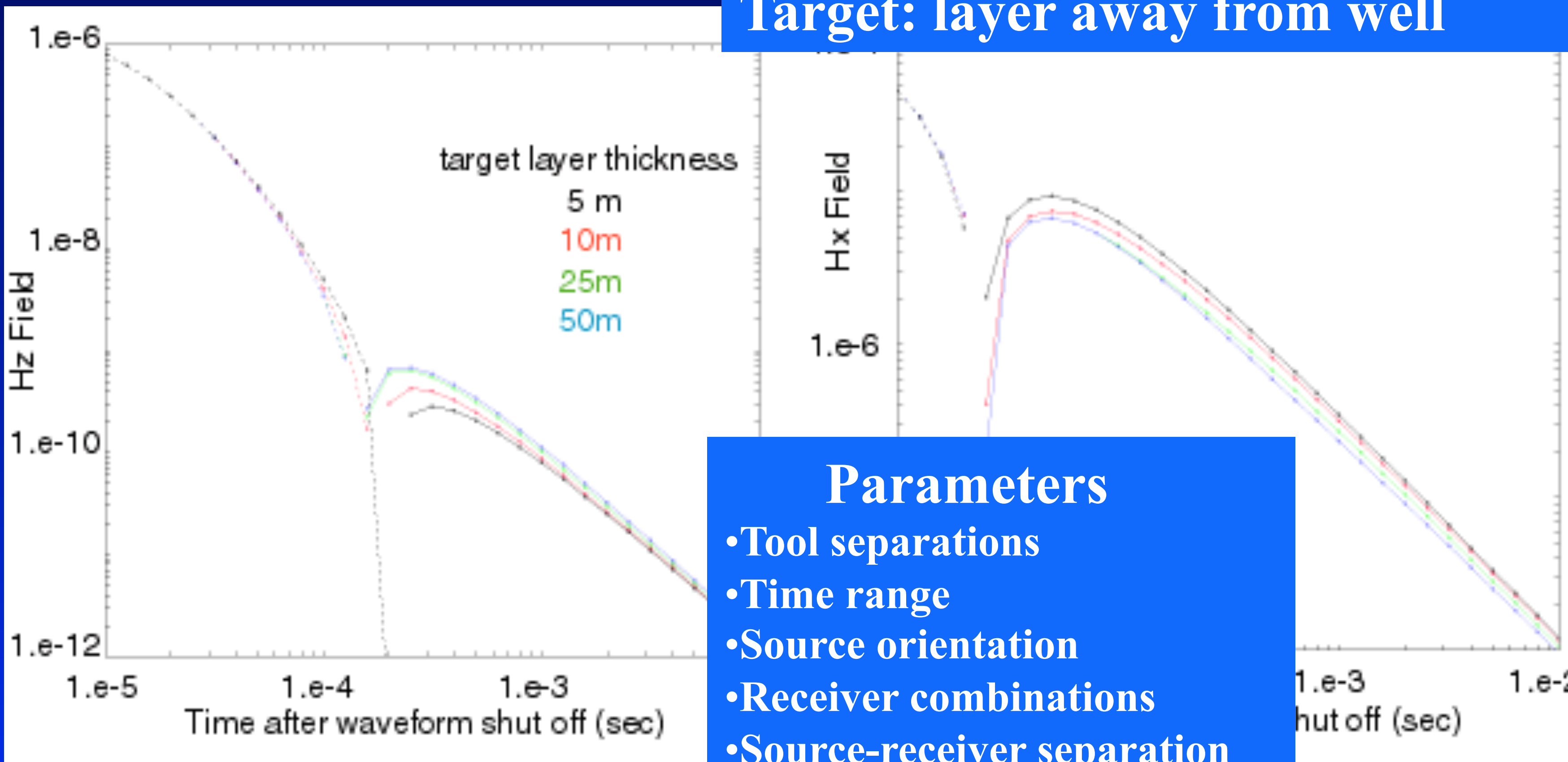




EM Tool Design

Model: Horizontal well

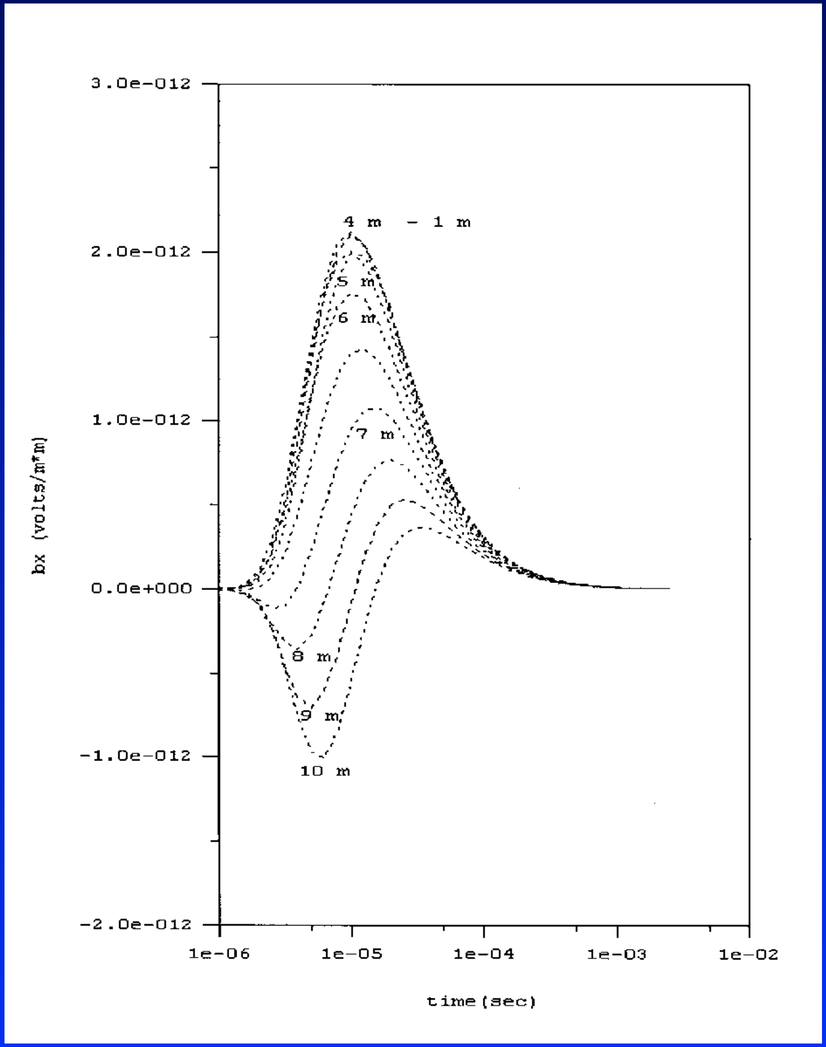
Target: layer away from well

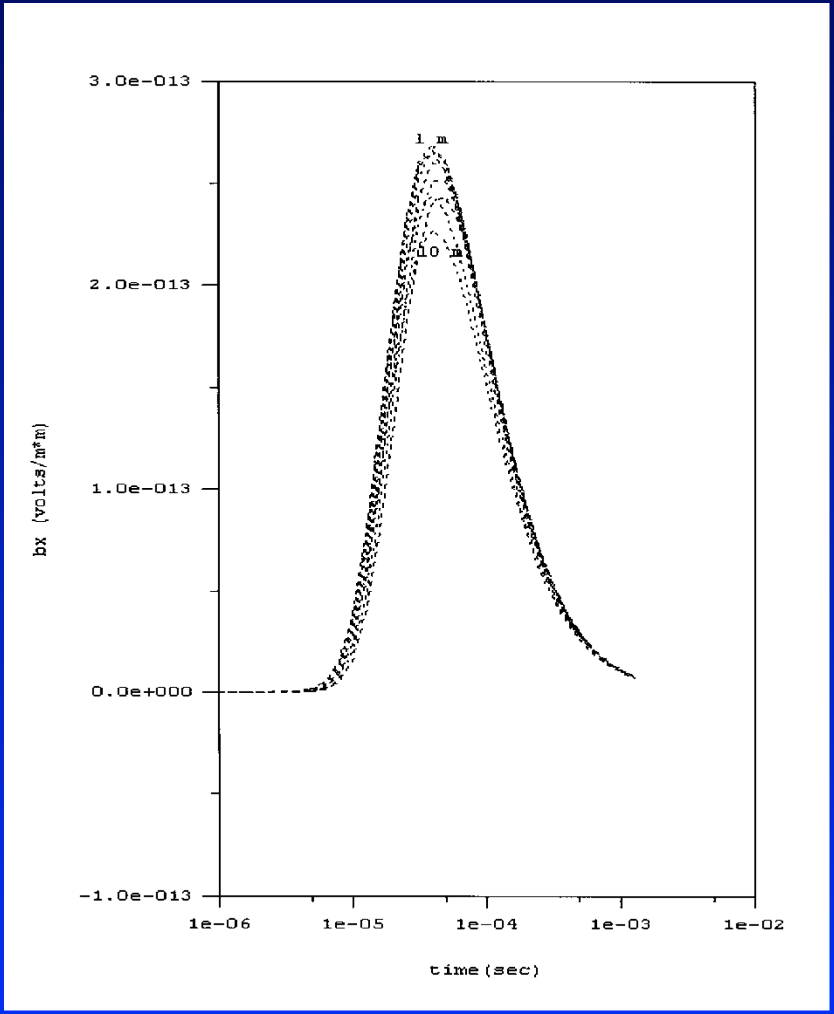


Parameters

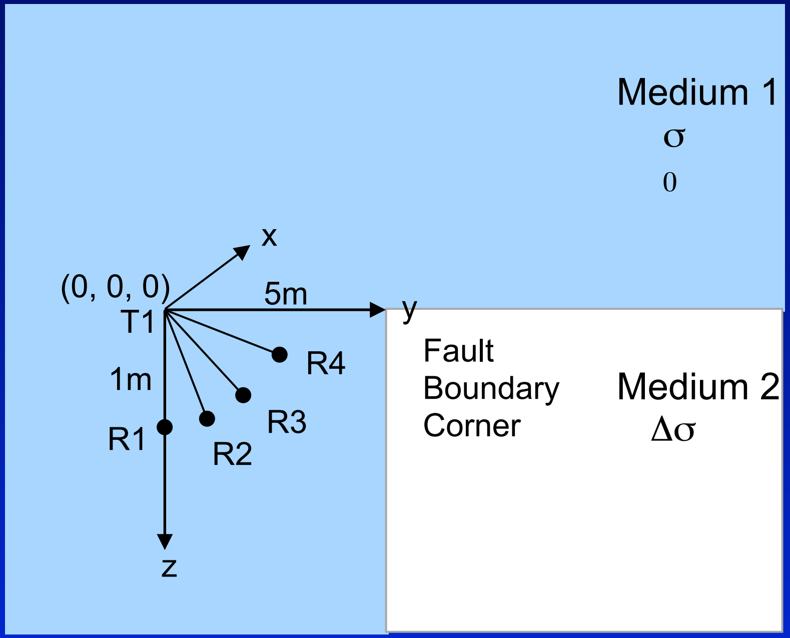
- Tool separations
- Time range
- Source orientation
- Receiver combinations
- Source-receiver separation
- Distance from target
- Target thickness, resistivity

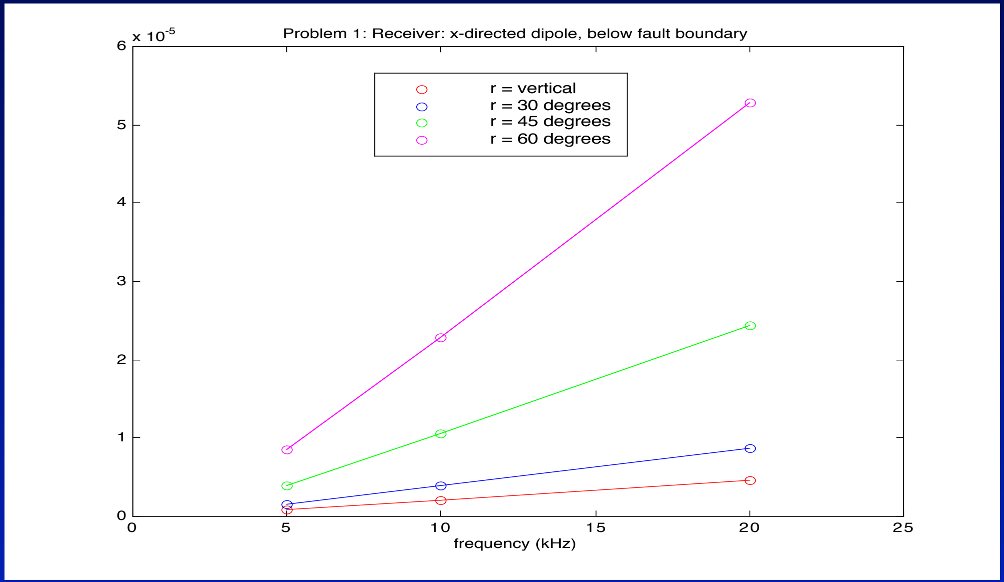
3-D EM Modeling

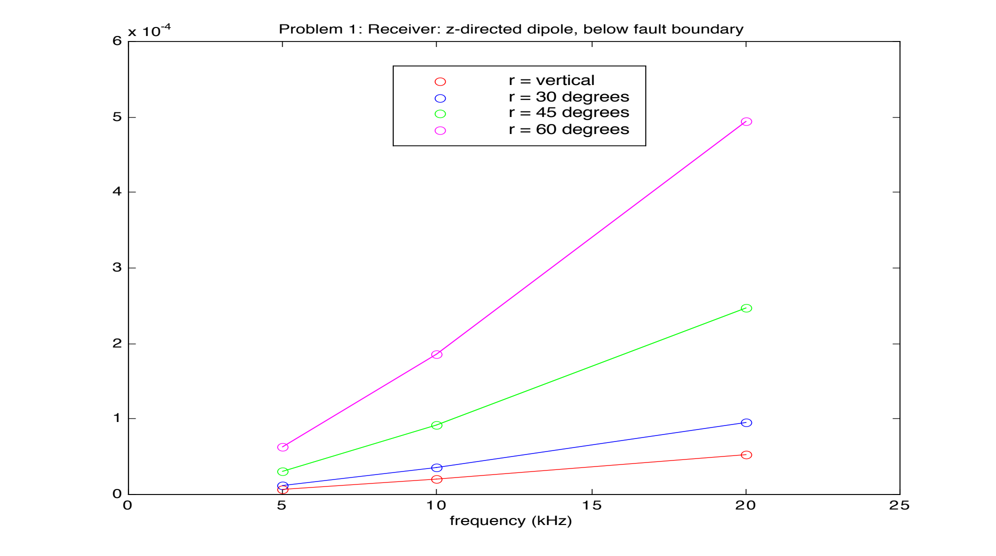




Relative error vs. frequency with a z-directed magnetic dipole at the transmitter and a x-directed (a) and z-directed dipole (b) at the receivers.





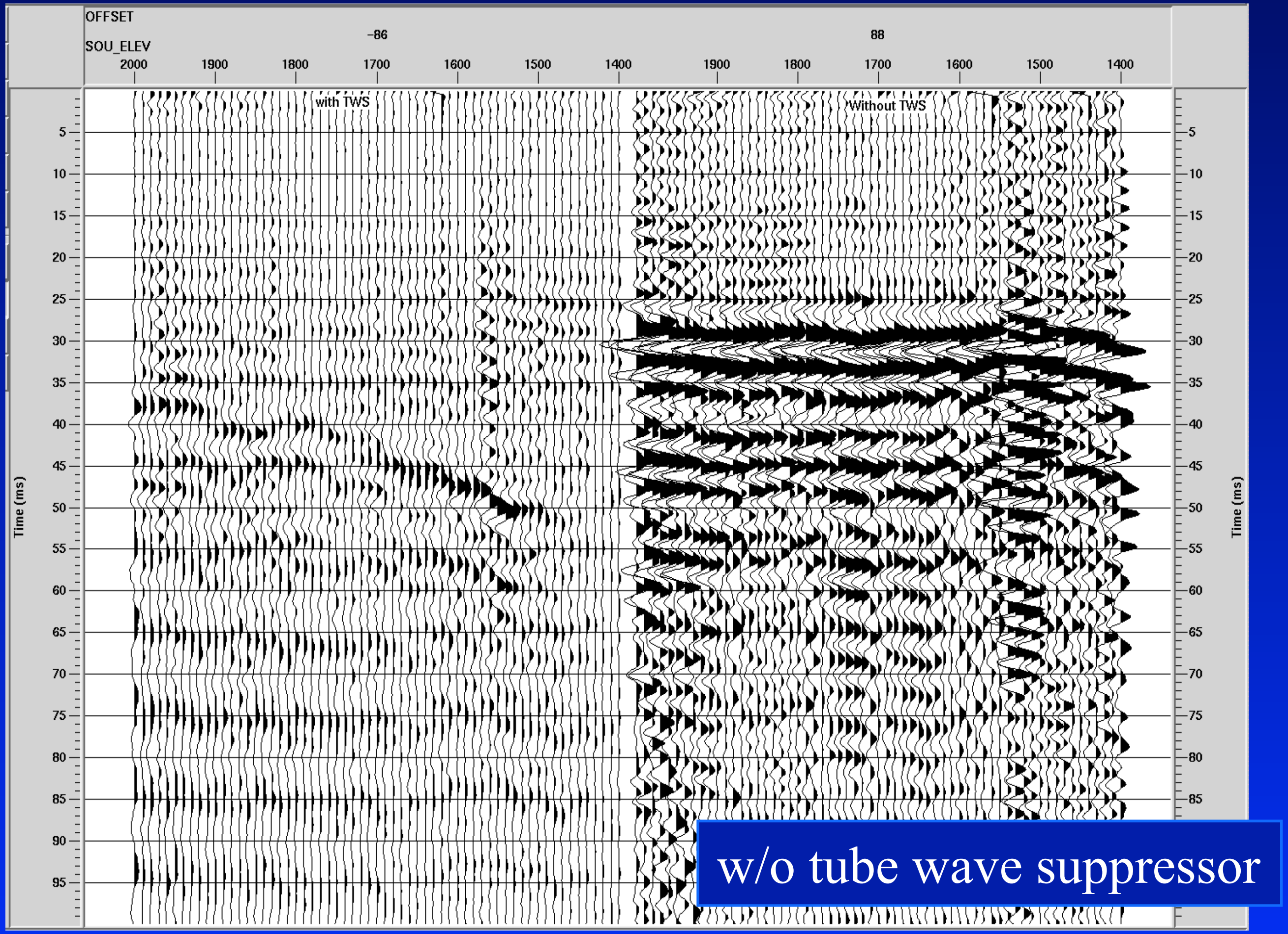


EM-Seismic System Integration

- **Objective**
  - Assess current state-of-art capabilities for achieving critical bandwidth, S/N levels and sensitivity
- **Tasks**
  - Improve seismic source
  - Increase reliability
  - Integrate EM system with Seismic
  - Advance towards real time
  - Test in field environment

Lost Hills SWSI tube wave test with AC orbital vibrator & INEEL TWS

S-wave



Tube - wave

With TWS

Without TWS

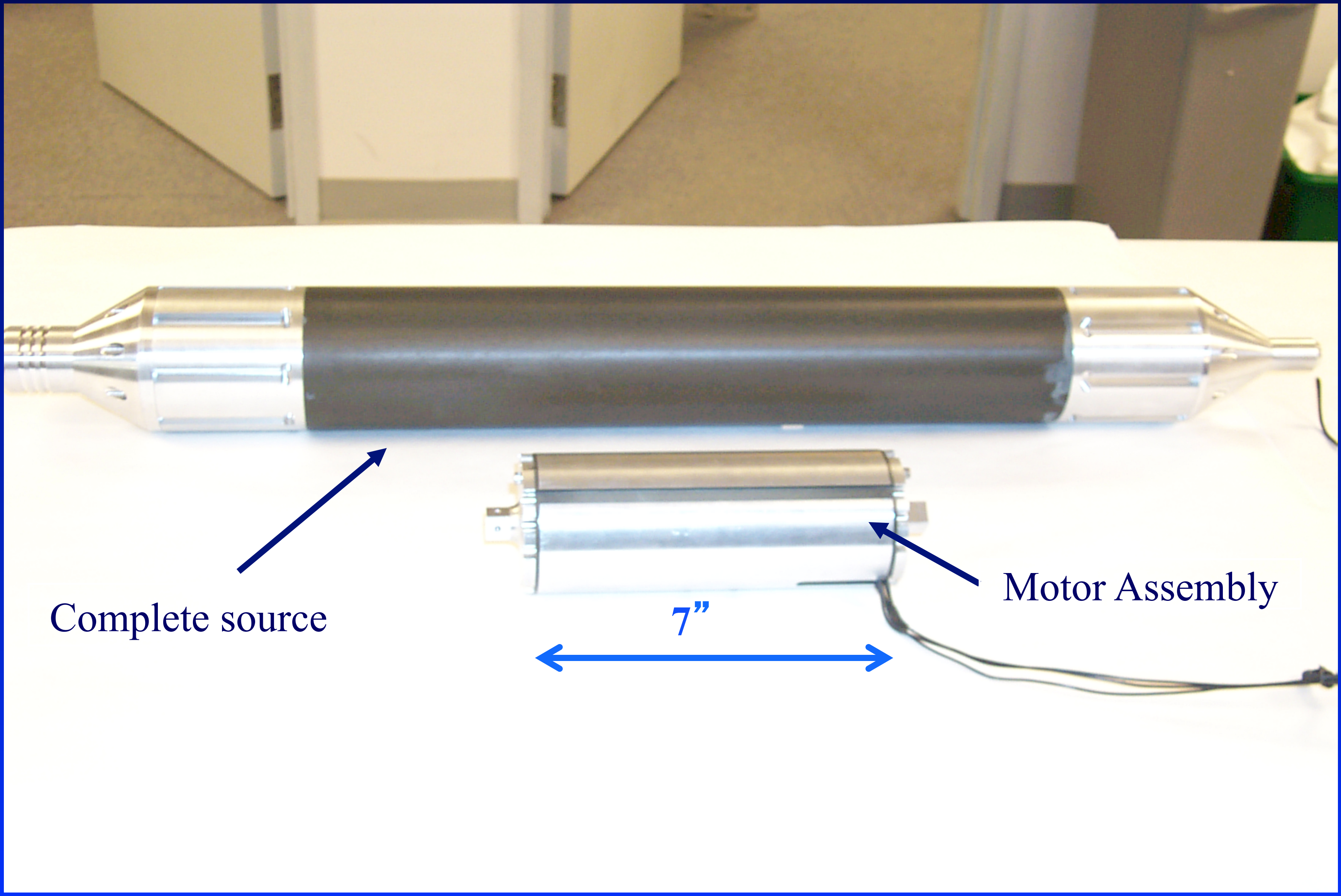
Borehole Electronics Modifications

- Fiber Optic
  - Single mode to Multi-mode through sources (EM noise reduction)
- Orientation
  - Open hole
  - Cased hole

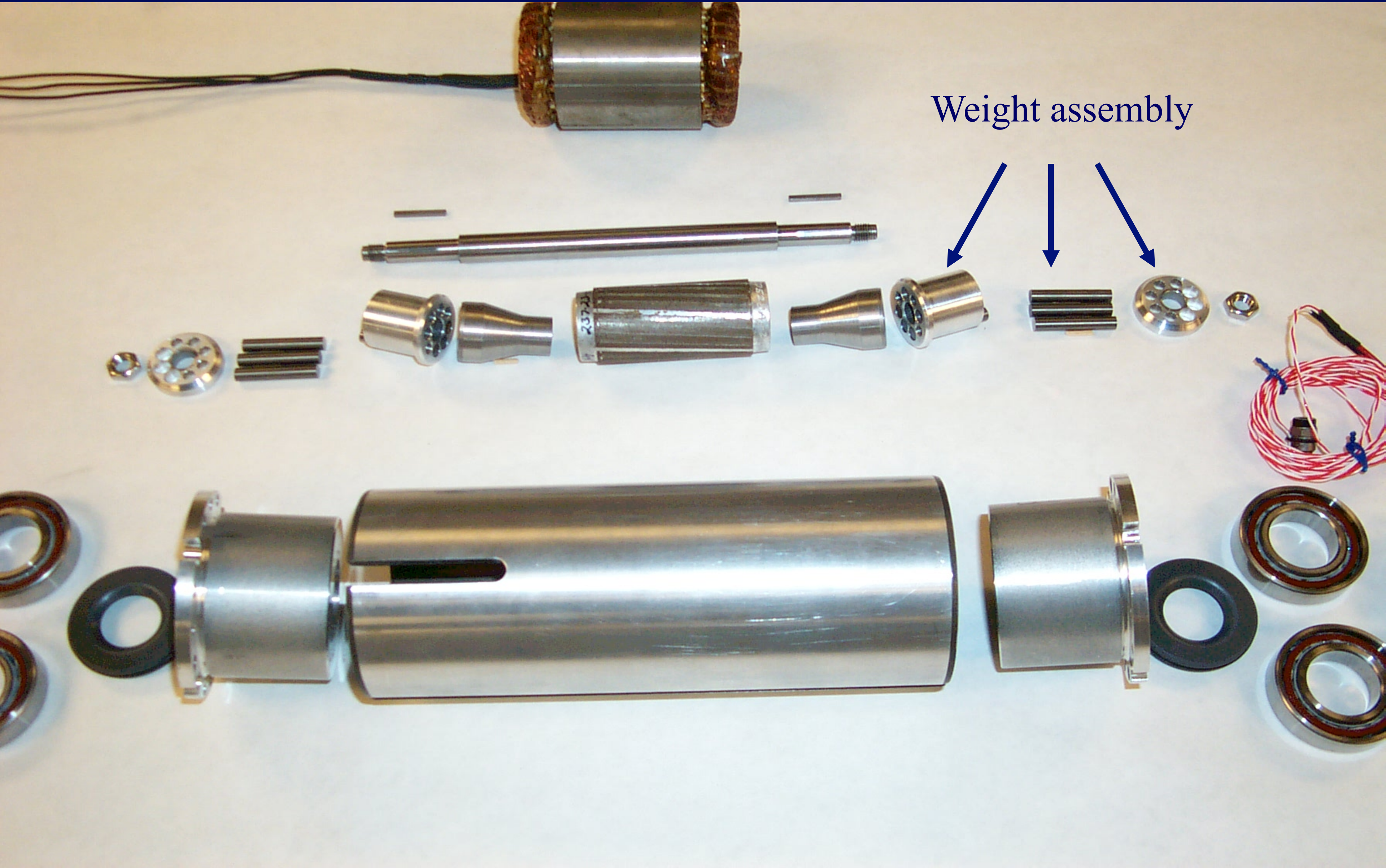
Source Modifications

- Orbital Source Modification
  - 4.25” to 3.5”
  - 400 Hz up to 1000 Hz
  - Fiber optic feed through
  - Maintain power

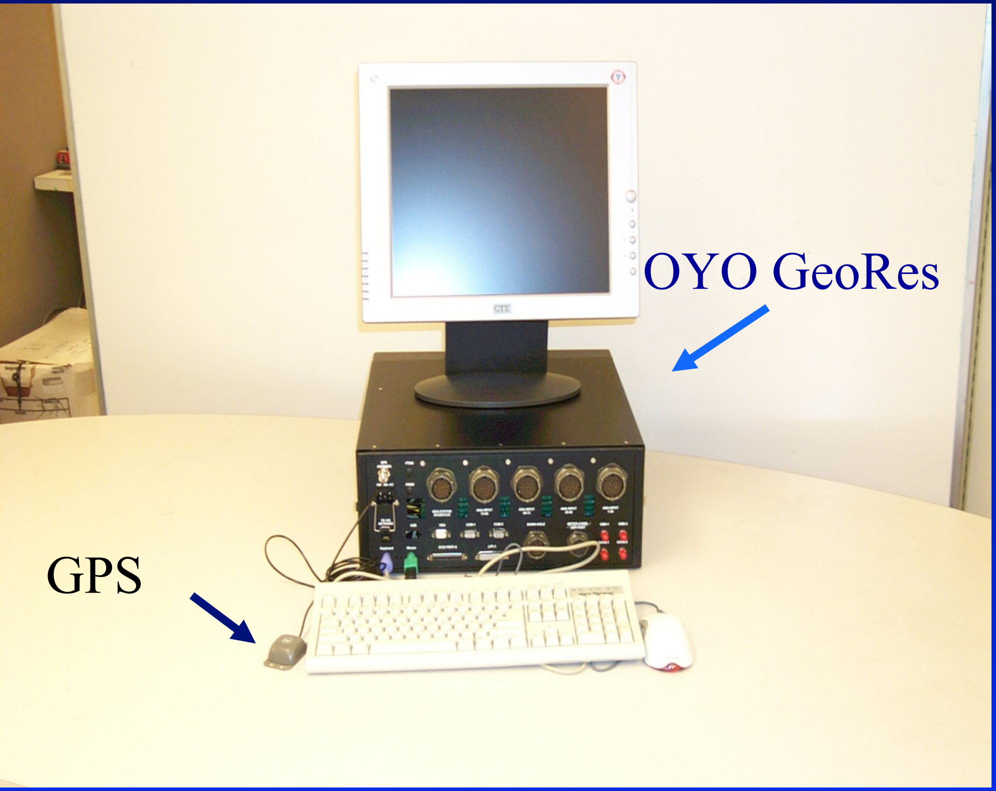
New source (3.5“, 1000 Hz)



Motor Assembly Parts

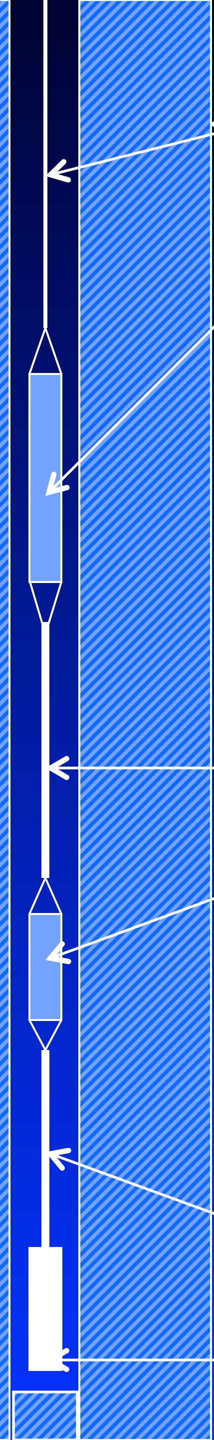


Real Time Acquisition and Processing Electronics



- Multi-channel High Speed Acquisition
  - 24-bit
  - 32K Sample rate
  - Analog/digital
- Real Time
  - GPS interface
  - Internet access

Coil: EM sensor set up



Fiber optic logging cable

Geospace HD Digitizer ADC

- OD: 2 ½” , 63.5 mm
- Length: 96.5 mm
- Weight: 8.5 kg
- Temp. range: 125 C
- Max sampling rate: 8 kHz
- Bandwidth: 3.6 kHz
- Dynamic range: 106 dB
- Input noise: 1.8 microV

5 m cable

Coil sensor

- OD: 3 ¼ “
- 400 turns,
- single layer copper wire OD 0.5 mm
- Ferrite core (toroids)
- Preamplifier 4nV/sqr Hz, 6000 gain
- Power from HD Digitizer

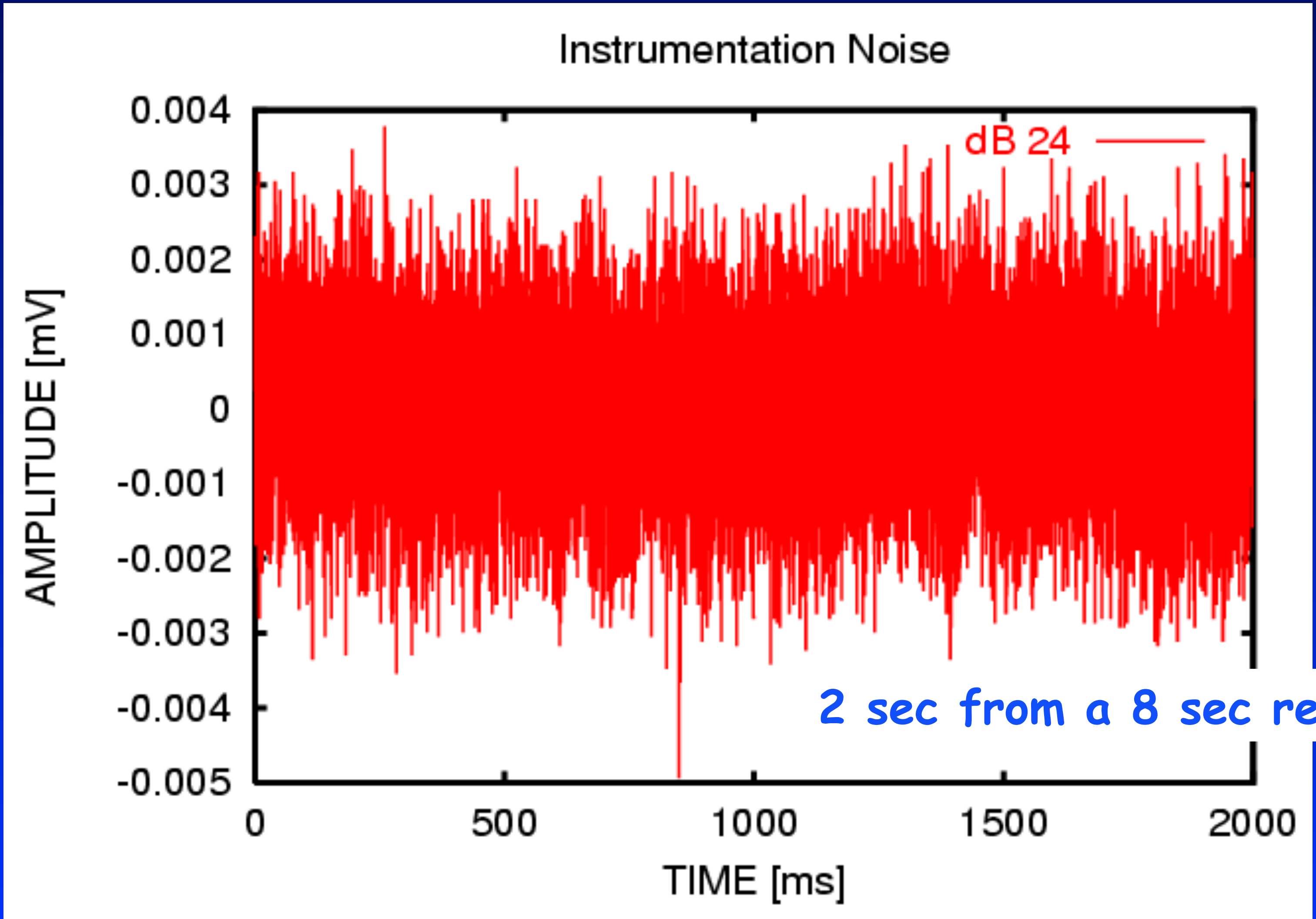
5 m cable

Additional load

For smooth down hole travel

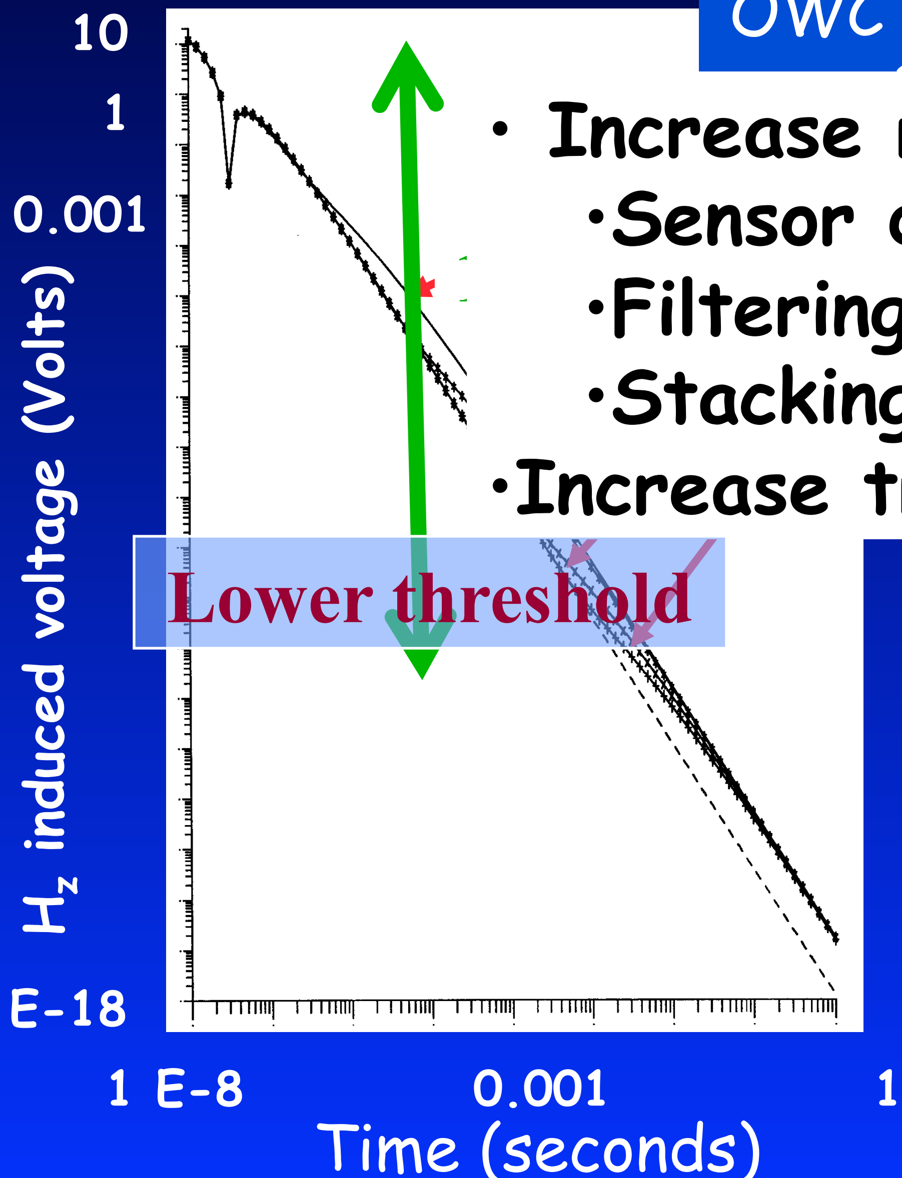
The Coil Sensor

Input noise with 24 dB amplification



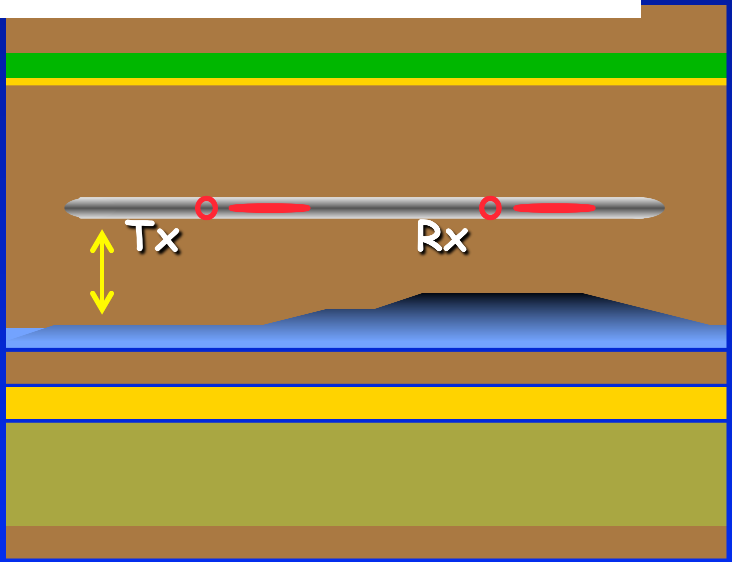
2 sec from a 8 sec record

Noise results in extended dynamic range



- Increase receiver moment:
  - Sensor design
  - Filtering
  - Stacking etc
- Increase transmitter moment

in a
well



System integration accomplishments

- Tube wave suppression implemented
- Seismic source modifications
  - ➔ 3.5” source from 4.25”, >freq.
- Improved Fiber Optic System
  - ➔Mode improvement
- Integrate KMS-Technologies’s EM coil
- Real time hardware implemented
- Field tests (noise) verify use of current technology

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Summary

- Industry leveraged project
- Addresses high priority needs
- Utilize existing technology & augment with specific expertise where needed
- Commercialization path identified
- Several breakthroughs accomplished
- Successfully moved from

  Conceptual Design →Feasibility → Prototype

Acknowledgement

- **Our sponsors:** DOE, DeepLook (bp, Chevron, Conoco, Shell, Texaco), Shell/Agip
- **Collaborators:** Dave Aldridge, Greg Newman, Chester Weiss of Sandia and Dave Alumbaugh of University of Wisconsin.
- **Peers** at LBNL, KMS Technologies and Shell