Hi-Res, Low Cost VSP Imaging Technology for Long Term Monitoring

E. L. Majer and T. M. Daley: LBNL
J.H.Queen: Hi-Q Geophysical
J. Thompson: LANL
R. Long: USDOE/NETL

Crosscutting Roadblocks to Increased Success of Fluid Imaging

- **Basic Need**
  - Increase recovery rate from existing reservoirs (from current average of 35% to 70%)
  - Monitor containment of fluids
- **Fundamental Obstacles**
  - Lack of data on the the distribution of rock and fluid properties.
    - Porosity, permeability, Lithology and structure
    - Liquid, gas, oil, water content and ratio, etc.
  - Dynamic response of reservoir components as it is produced
    - State of Stress
    - Fluid redistribution and change of state
    - Fracture creation/opening/closure
    - Etc
  - Cost Effectiveness

Must recognize that reservoirs are constantly changing due to recovery and to optimize production we must have a means to identify and measure the success of manipulation

Critical Advances Needed for Improved Subsurface Fluid Recovery

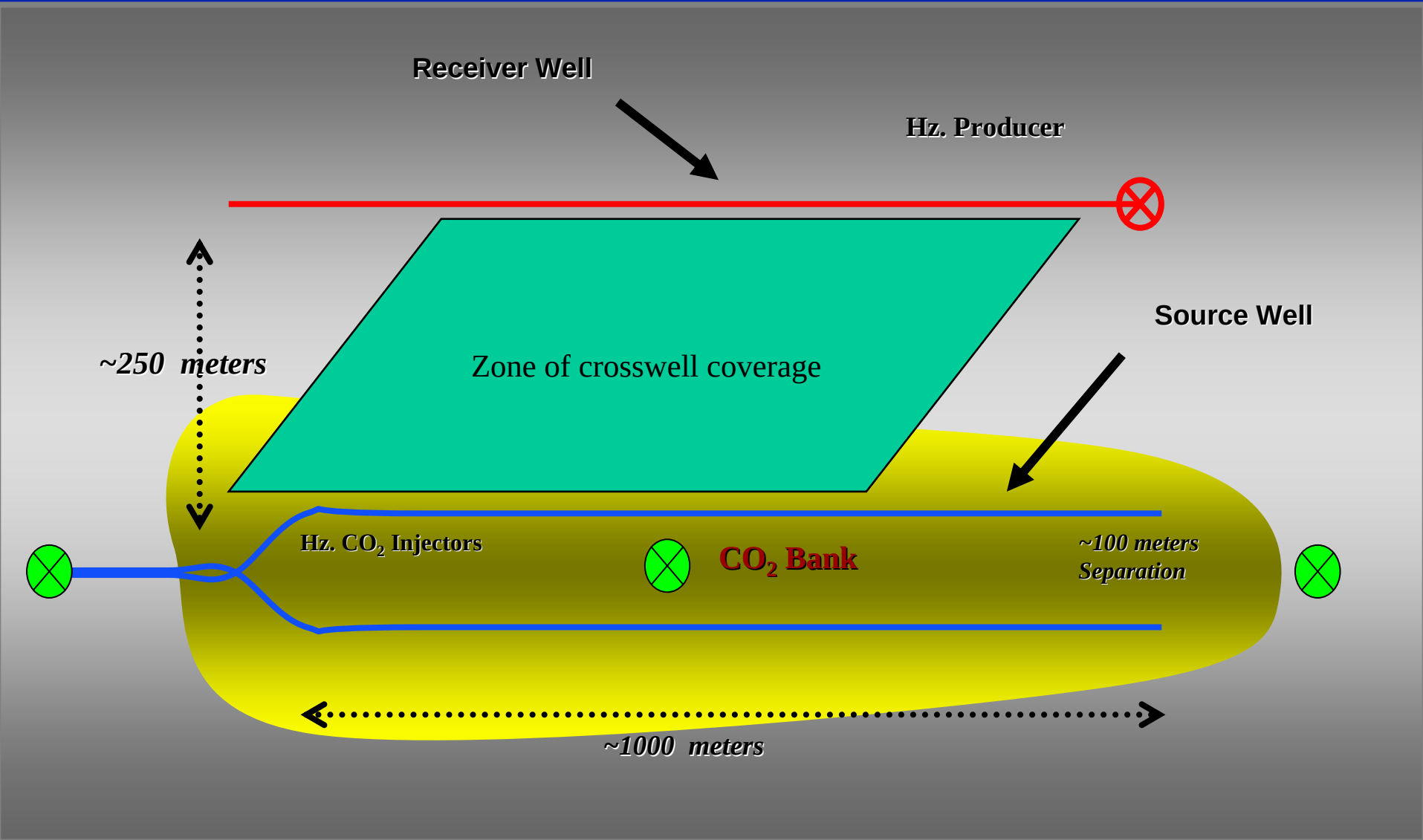
- 1. High resolution characterization of fluids
- 2. High resolution of matrix properties in which the fluid resides
- 3. Physical , Chemical and biological methods for manipulation of fluids

- <u>All three require improved subsurface access (microholes) and instrumentation*</u>

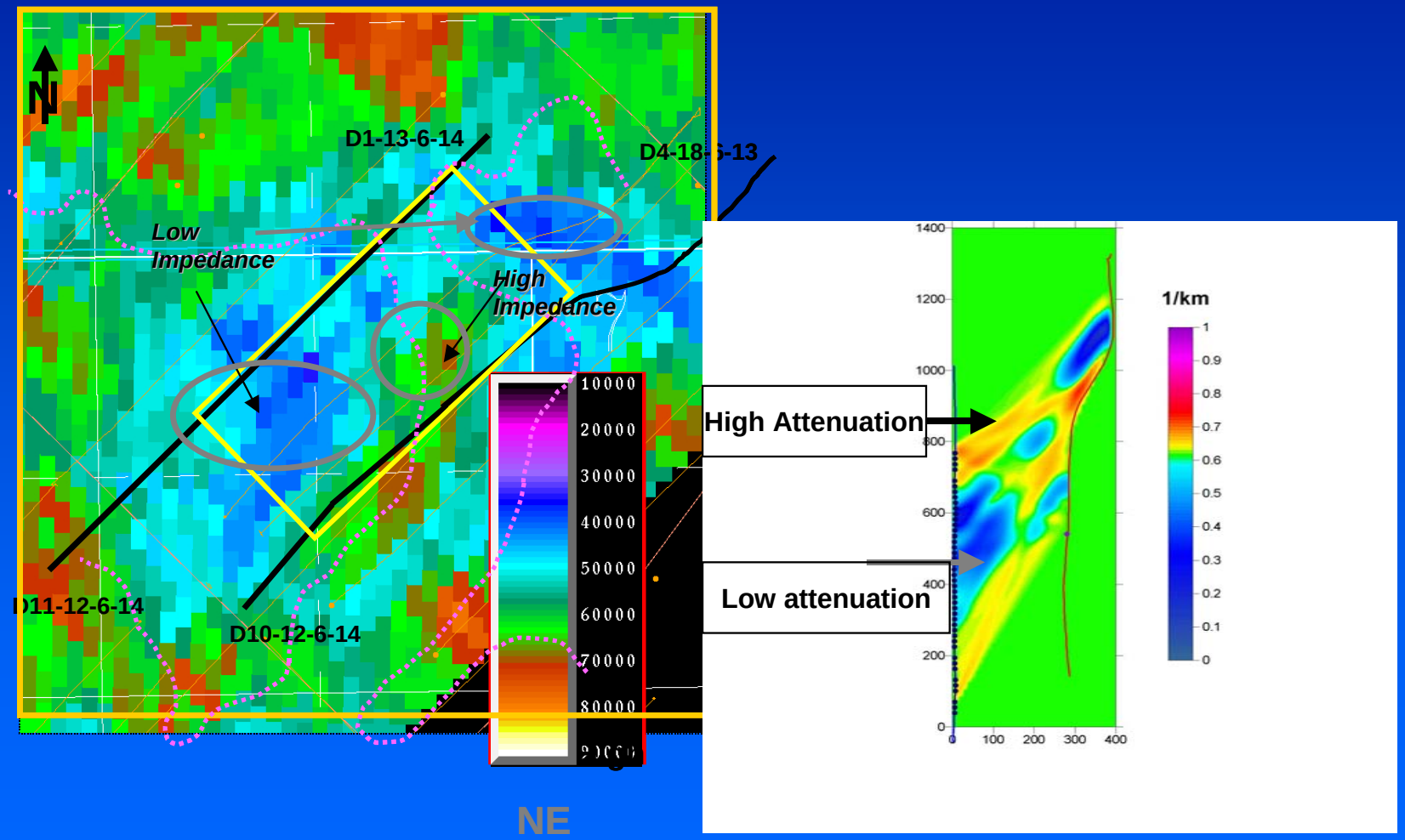
Requirements and Advantages of High Resolution Seismic Imaging of Reservoirs

- **Seismic Methods**
  - Long history and experience in industry
  - Developed rock-physics models
  - Can leverage current processing and instrumentation technology
  - Ability to measure and separate rock and fluid properties
  - Can measure at multiple scales
- **Optimal Seismic Data Needs**
  - Wide band (hertz to kilohertz) high resolution data
  - Large dynamic range (low level to high energy sources)
  - Short and long term monitoring (repeatability and stability of amplitude and velocity measurements)
  - True 3-d Spatial coverage
  - Time Lapse
  - Multi-component
- **All requirements can be met with microhole technology!**

Weyburn Crosswell

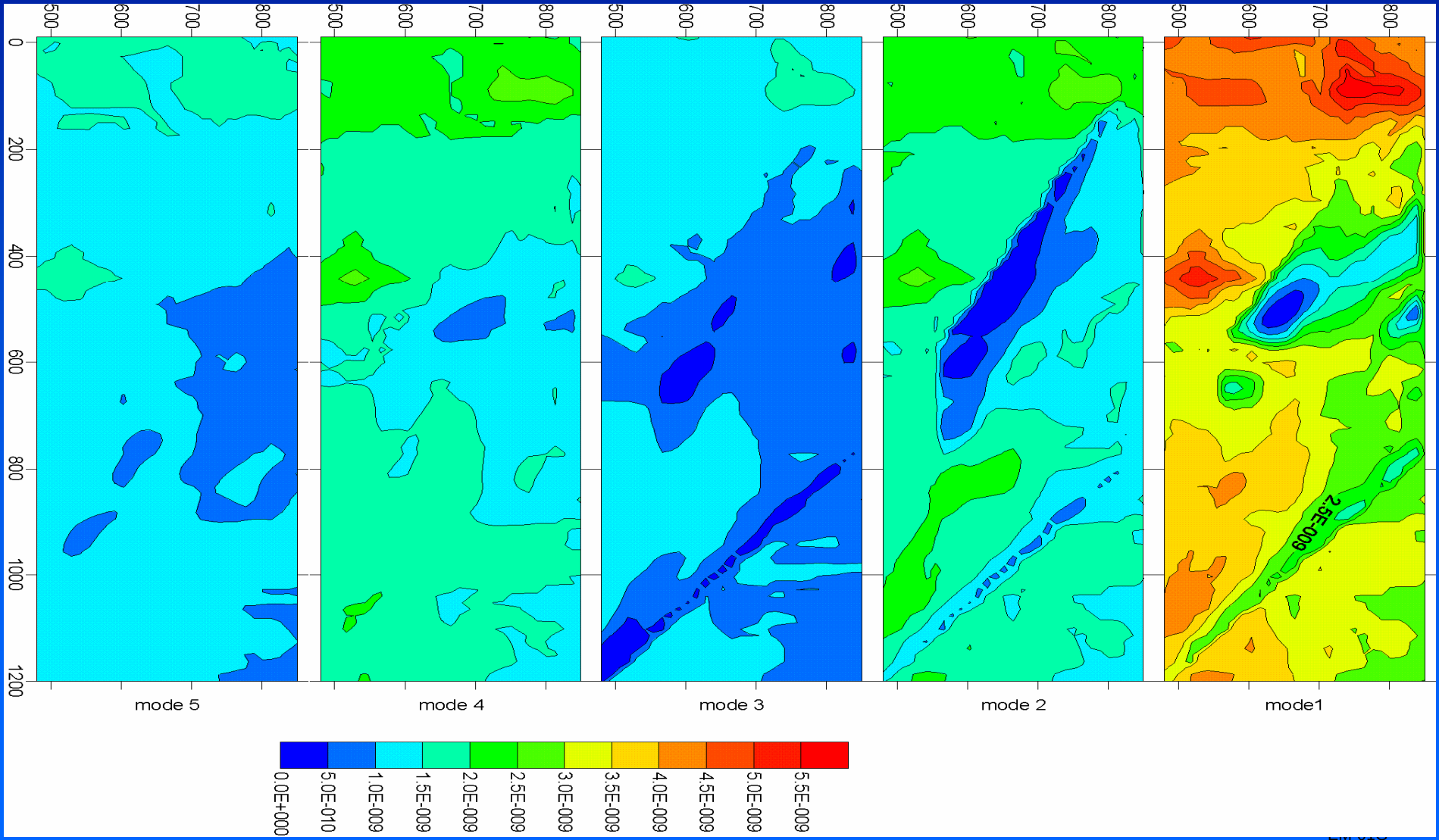


Crosswell versus Surface seismic



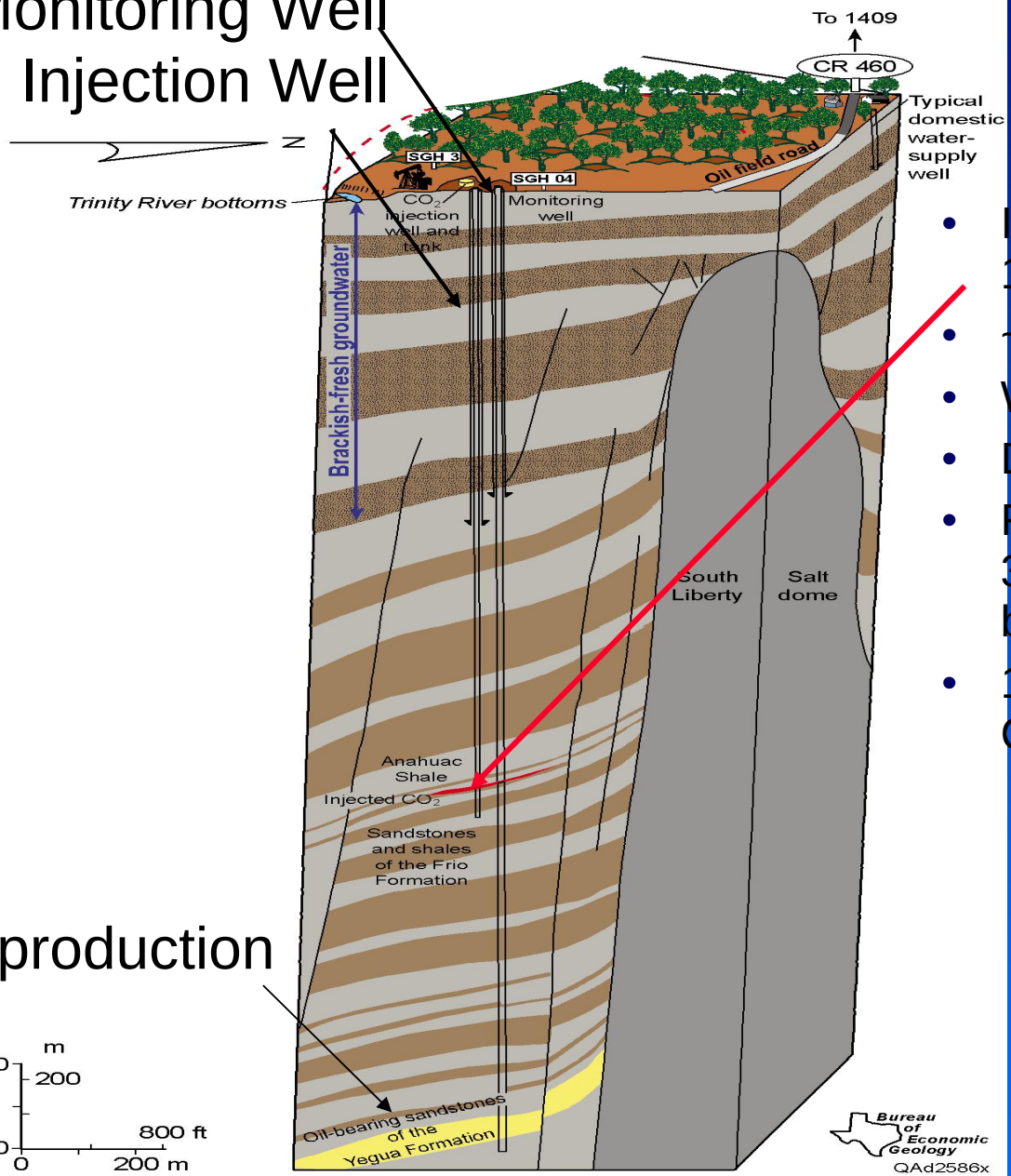
Surface 3-D Seismic Impedance Map

Permeability Estimates



Frio Brine Pilot, Dayton, Tx

Monitoring Well
Injection Well

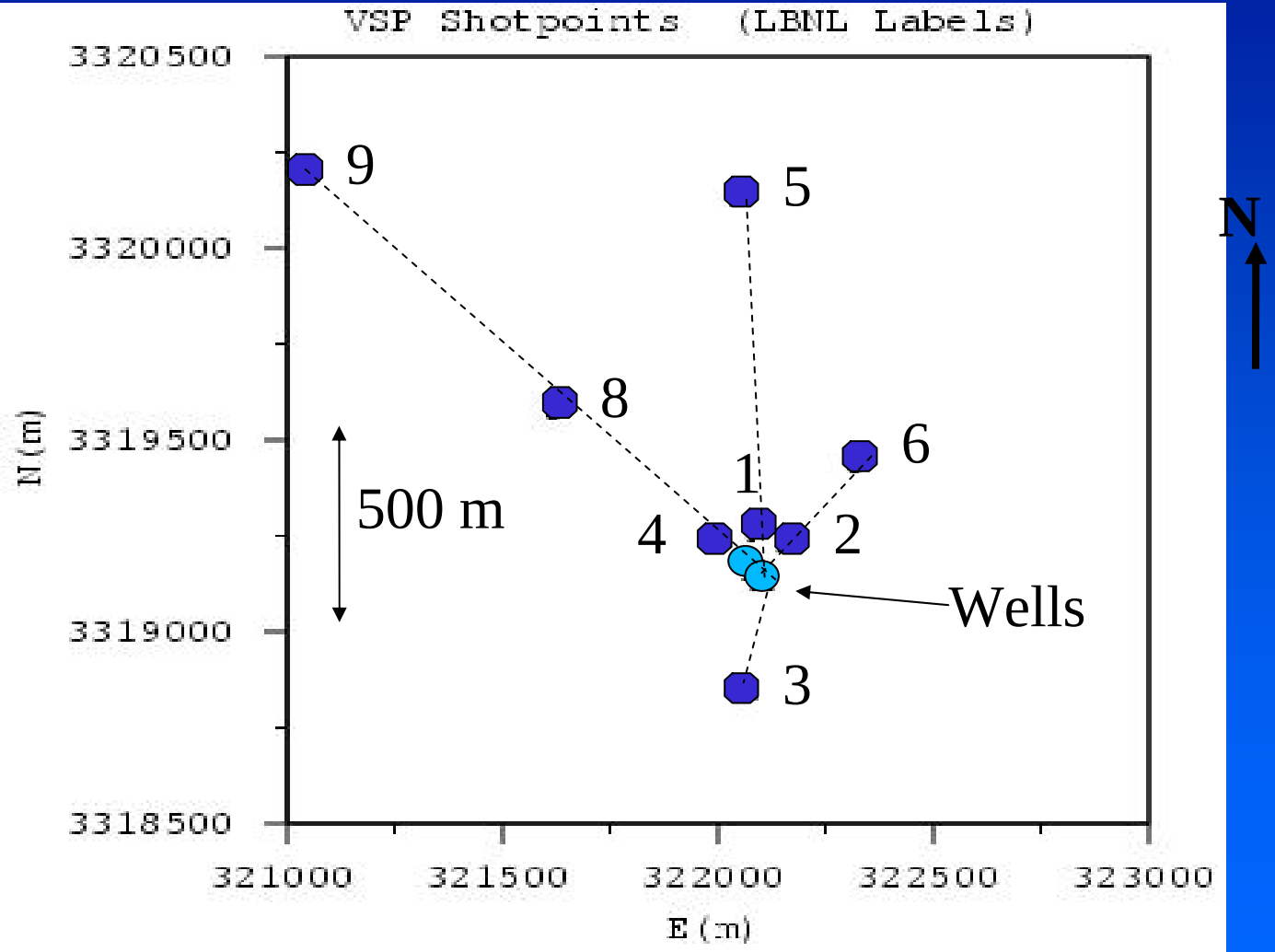


Oil production

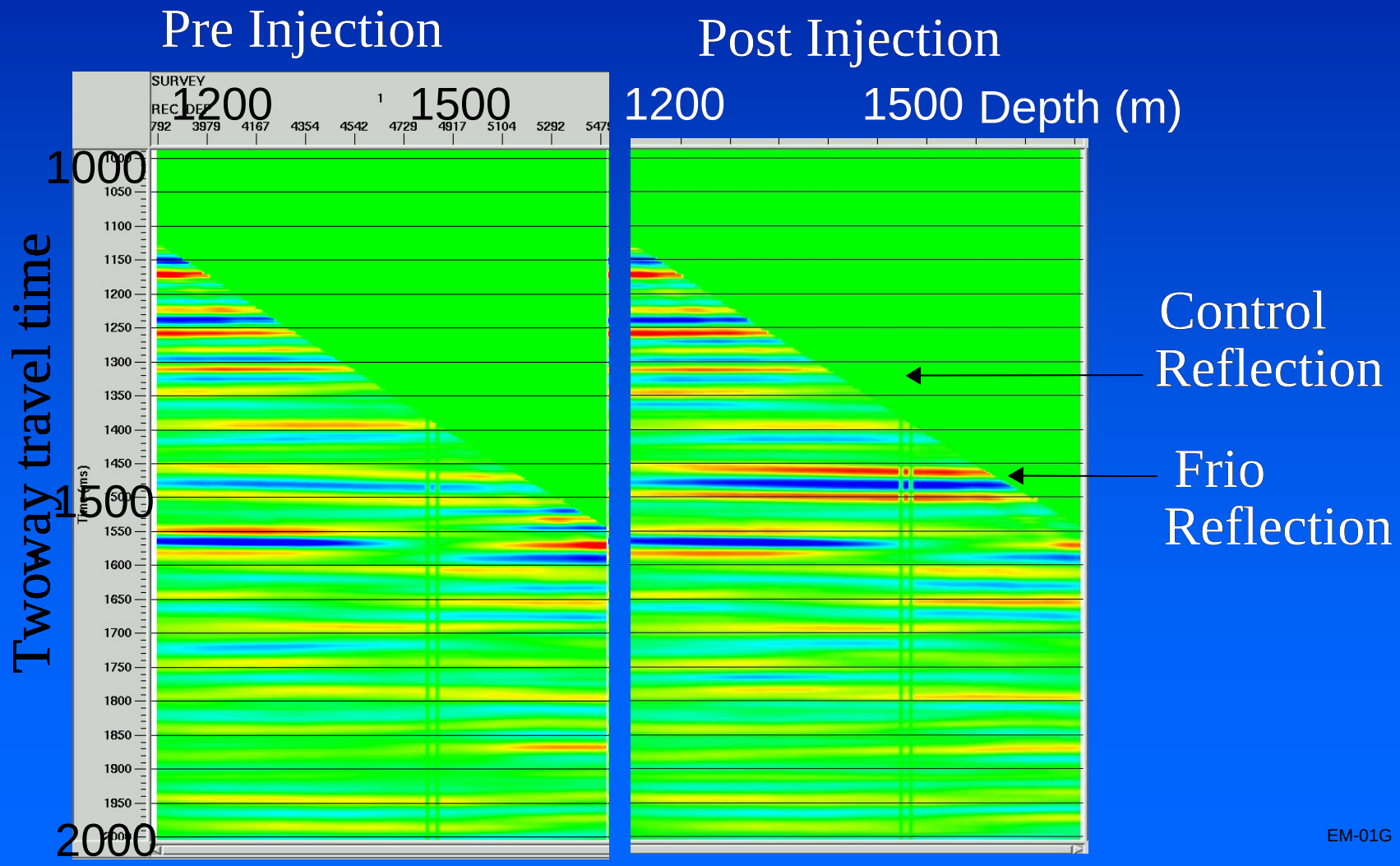
- Injection interval ~7 m thick at 1530 m depth
- ~1600 metric tons CO2
- Well spacing ~30 m
- Dip ~20 deg.
- Frio ‘C’ Sandstone: porosity 30%, permeability 1.5 Darcys, brine filled
- 150 bar, 53 deg. C, supercritical CO_2

EM-01G

Frio VSP and Crosswell

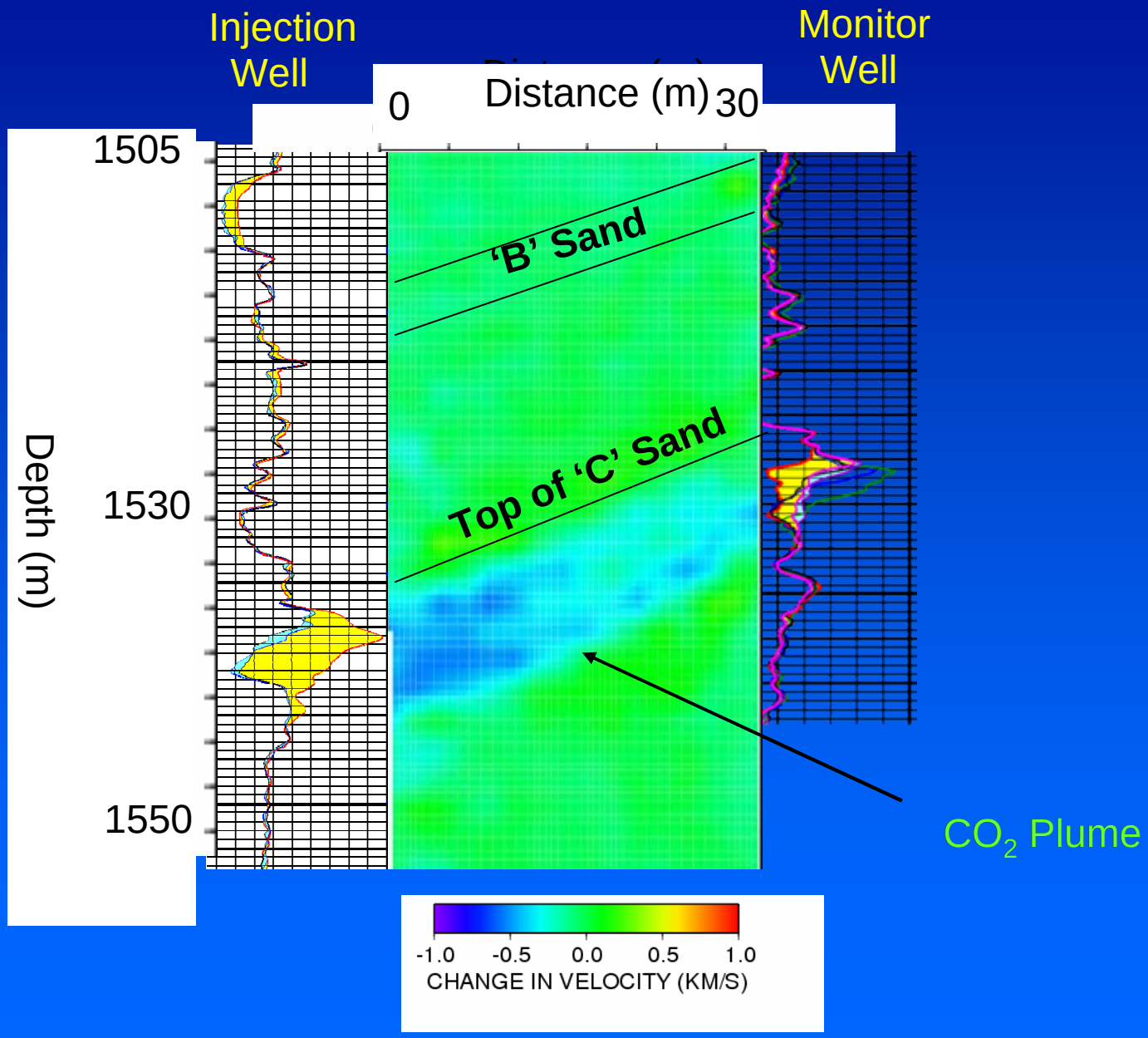


VSP Results



EM-01G

Seismic P-wave and Pulsed Neutron Logs



Weyburn Crosswell Seismic Acquisition

Commercial Multi-level VSP

Requirements

- Rig rental
- Support vehicles
- 5” or larger well
- 1-2 days to place in well
- 1 day to remove

Goal of Microhole Seismic methods

- **Active Seismic**
  - Define fine scale structure and lithology controlling fluid flow and content
    - Fracture flow versus matrix flow
    - Fault locations, bedding, pinch outs, compartment size and geometry, etc.
  - Discriminate fluid type and content in near and long term
    - Oil/water/gas interface
    - CO_2, steam, water drive efficiency, etc
  - Cost effective!!!
- **Passive Seismic**
  - Low cost means to monitor dynamics of reservoir as fluid is produced and/or injected
    - Hydrofracture creation
    - Interaction in the long and short term of natural fractures with induced fractures
    - Effect and interaction of reservoir properties with changing stress
  - Provide validation of reservoir manipulation

Los Alamos National Lab Drilling Rig

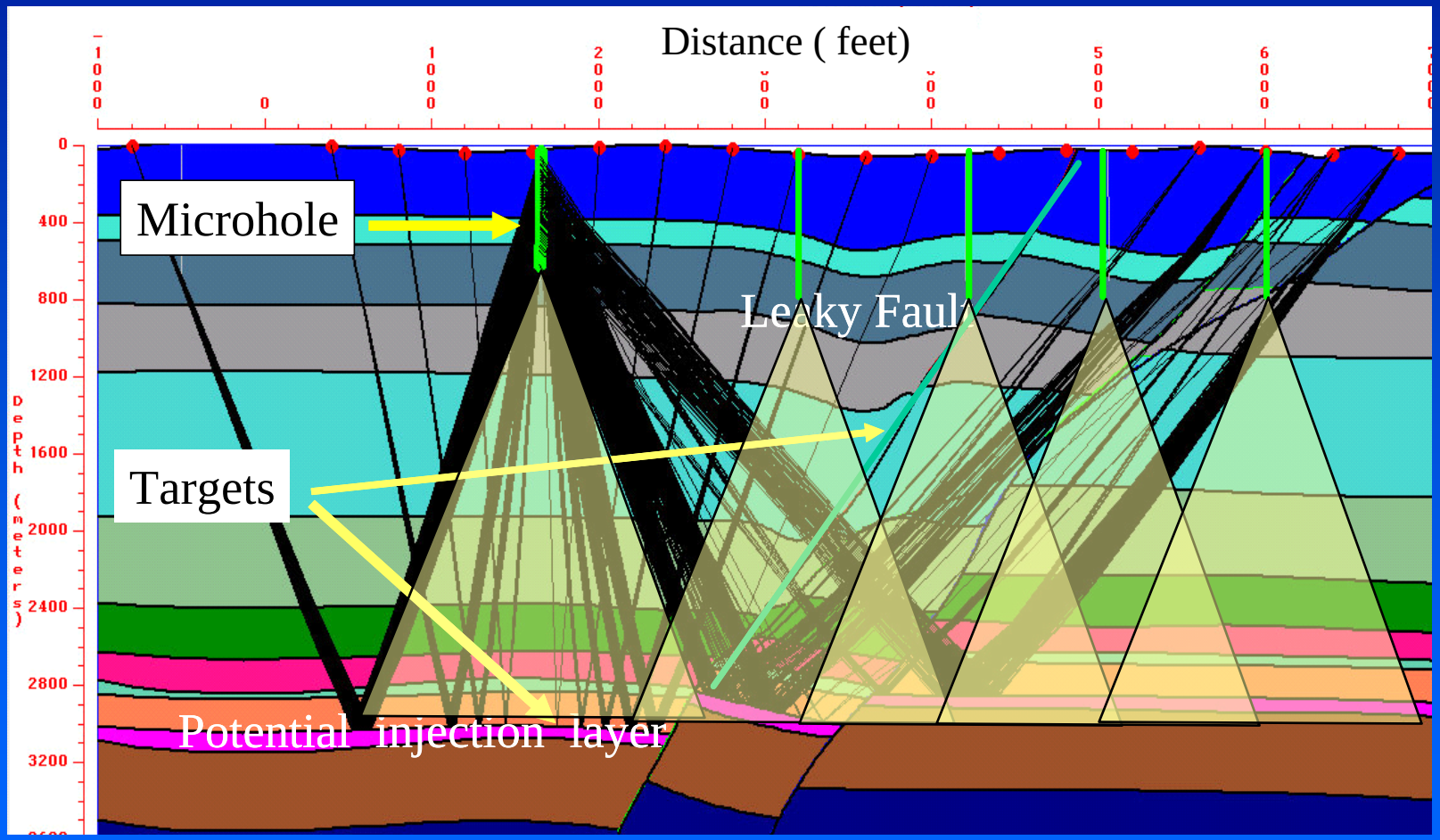
Micro-Drillrig

Entire VSP Microhole System

EM-01G

48 level Sensor String (30 minutes), 1500 feet

Basis of Imaging Work at RMOTC: Establish Potential of Deep VSP Using Microholes

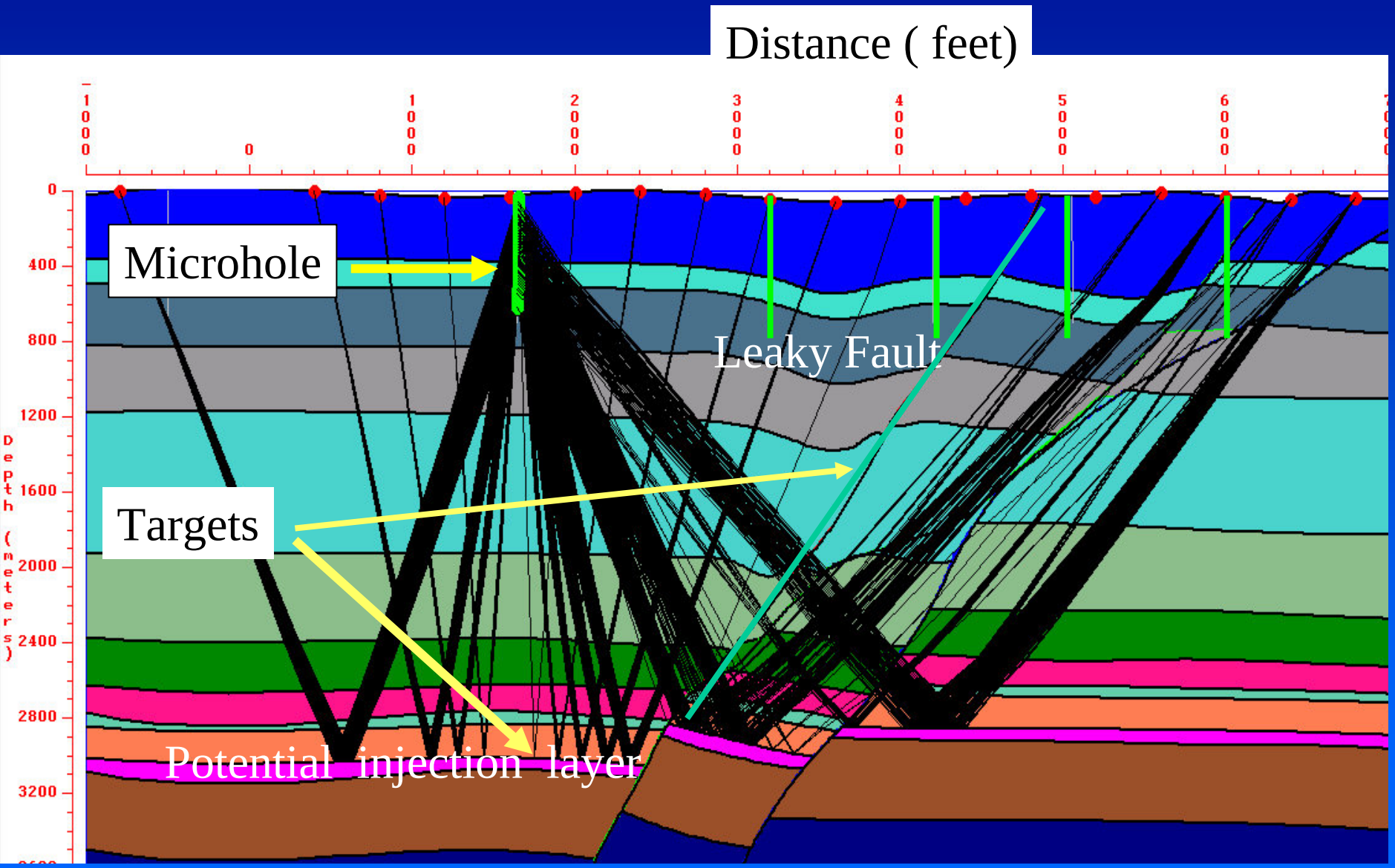


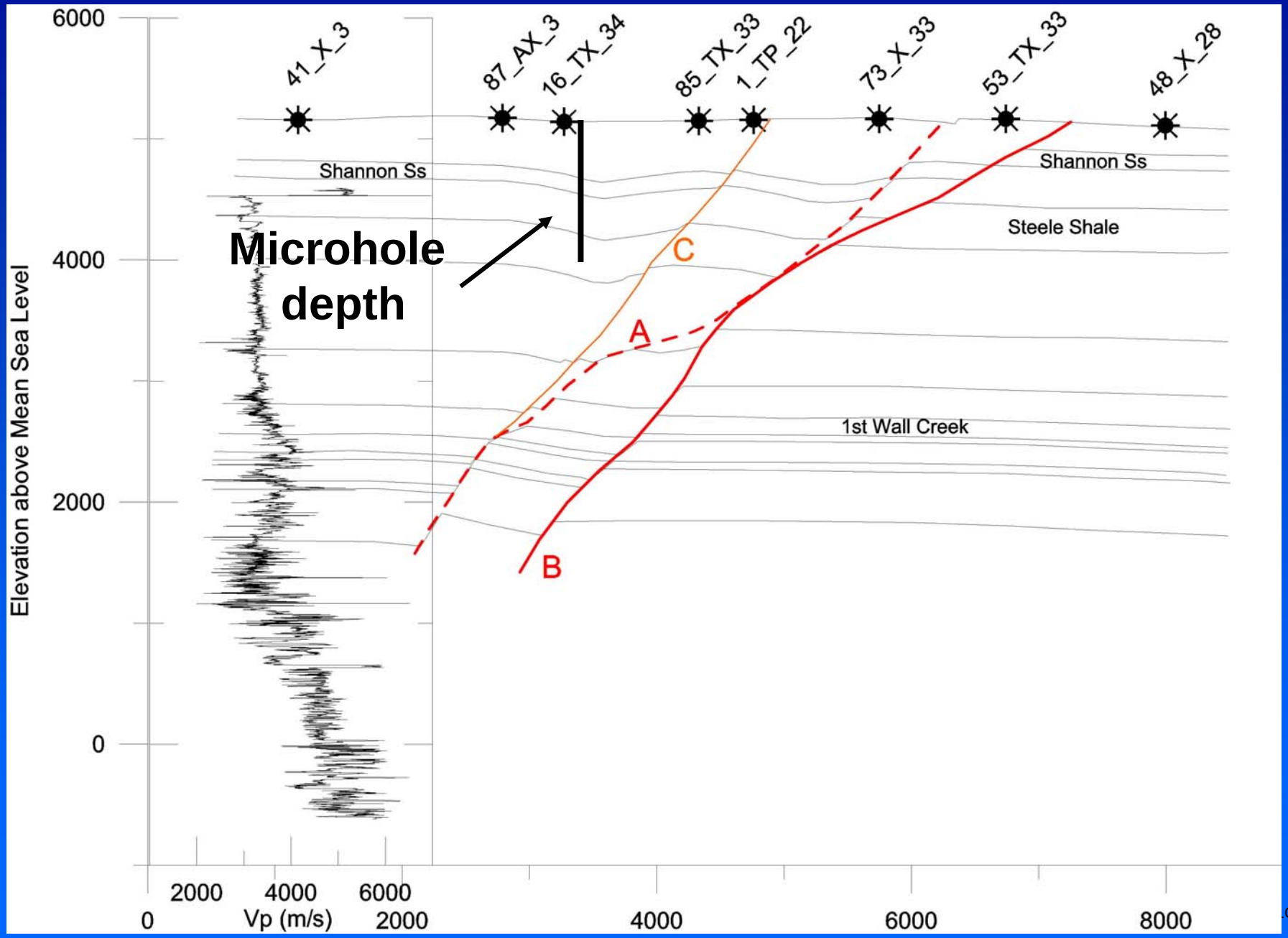
Examples

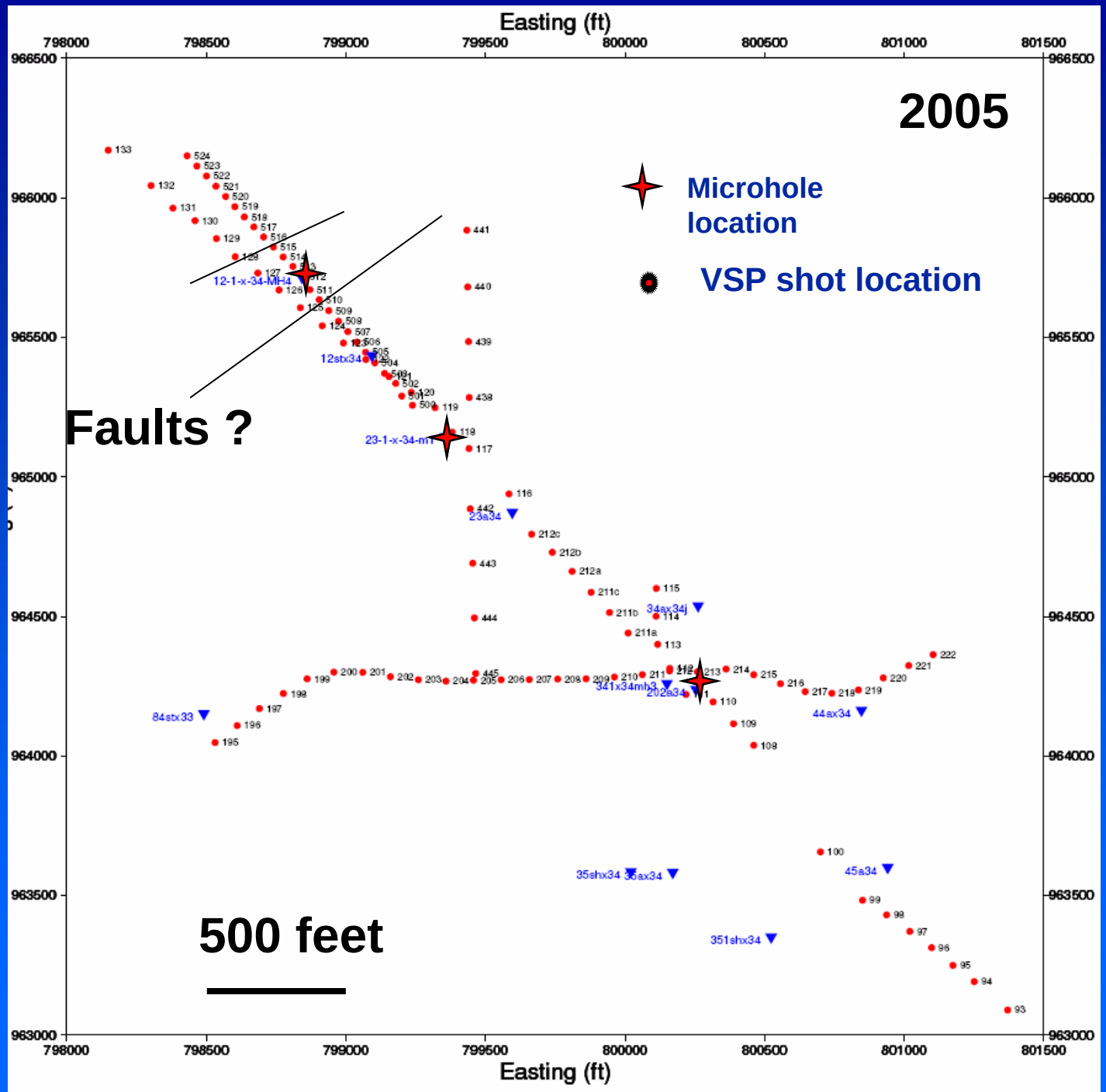
- Active Seismic
  - RMOTC Microhole VSP
- Passive seismic
  - Hydrofracture monitoring

RMOTC Microhole VSP

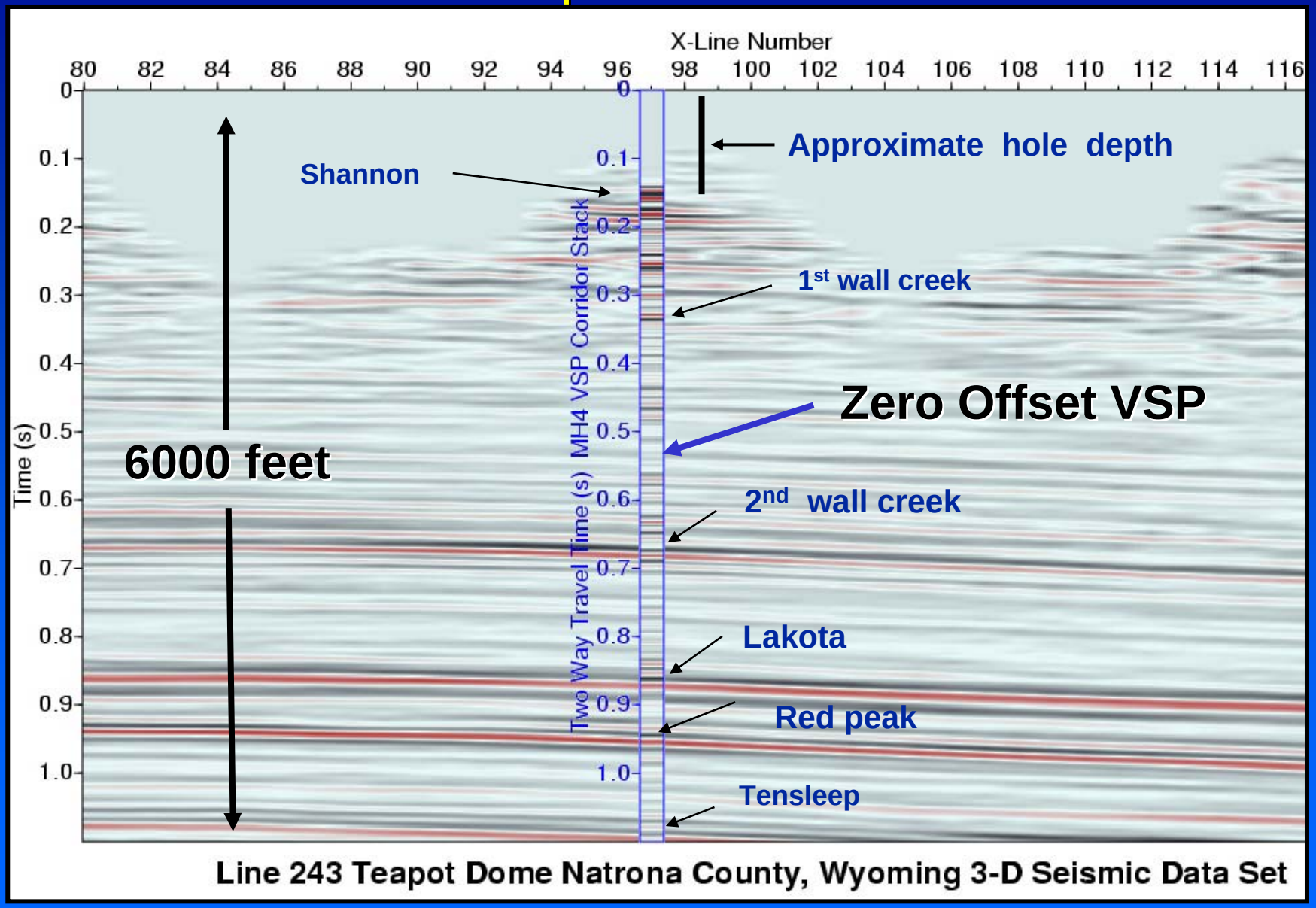
RMOTC Deep VSP using Microholes



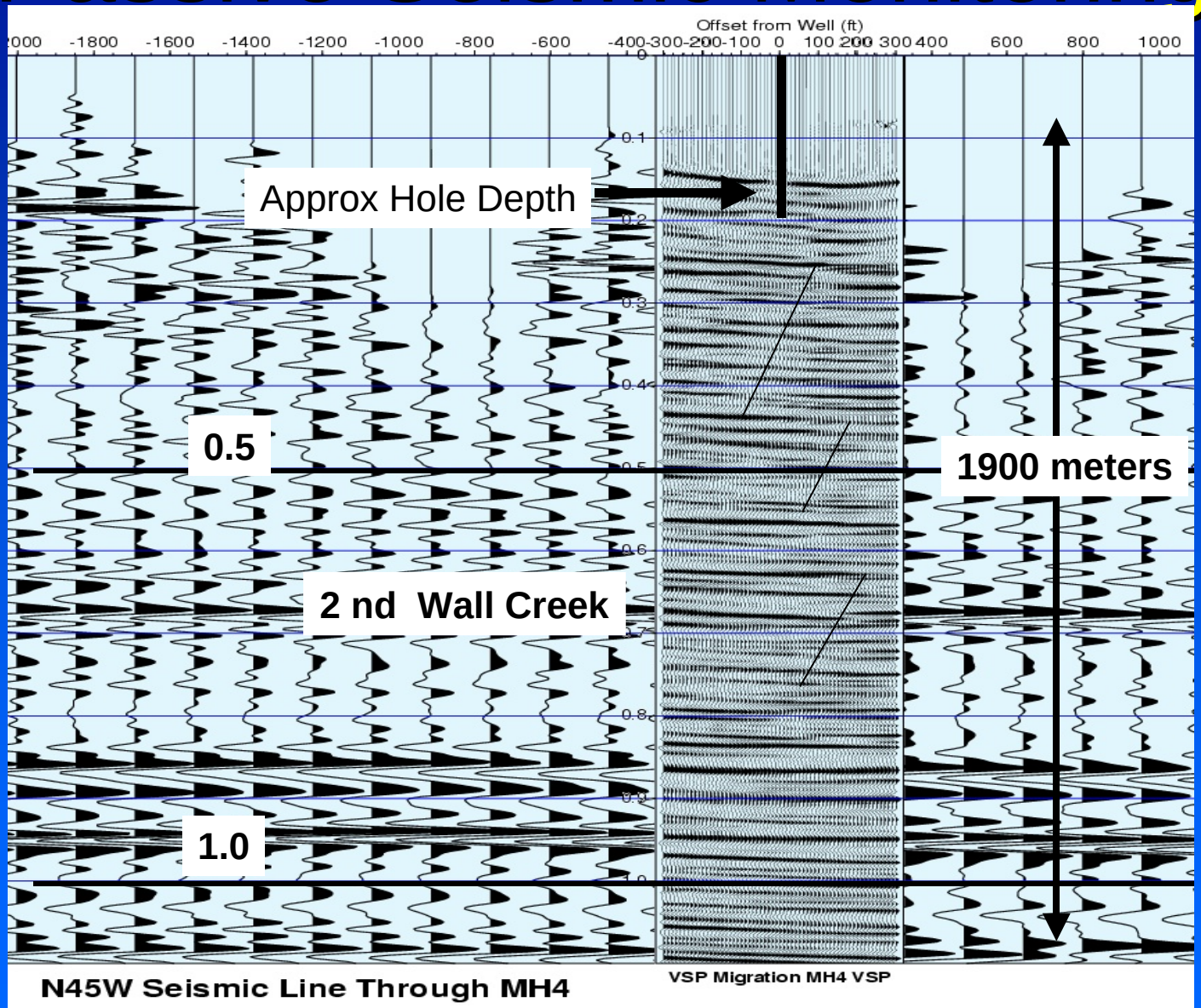

6000
4000
2000
0
Elevation above Mean Sea Level
41_X_3
87_AX_3
16_TX_34
85_TX_33
1_TP_22
73_X_33
53_TX_33
48_X_28
Shannon Ss
Shannon Ss
Steele Shale
1st Wall Creek
Microhole depth
A
B
C
2000
4000
6000
0
Vp (m/s)
2000
4000
6000
8000

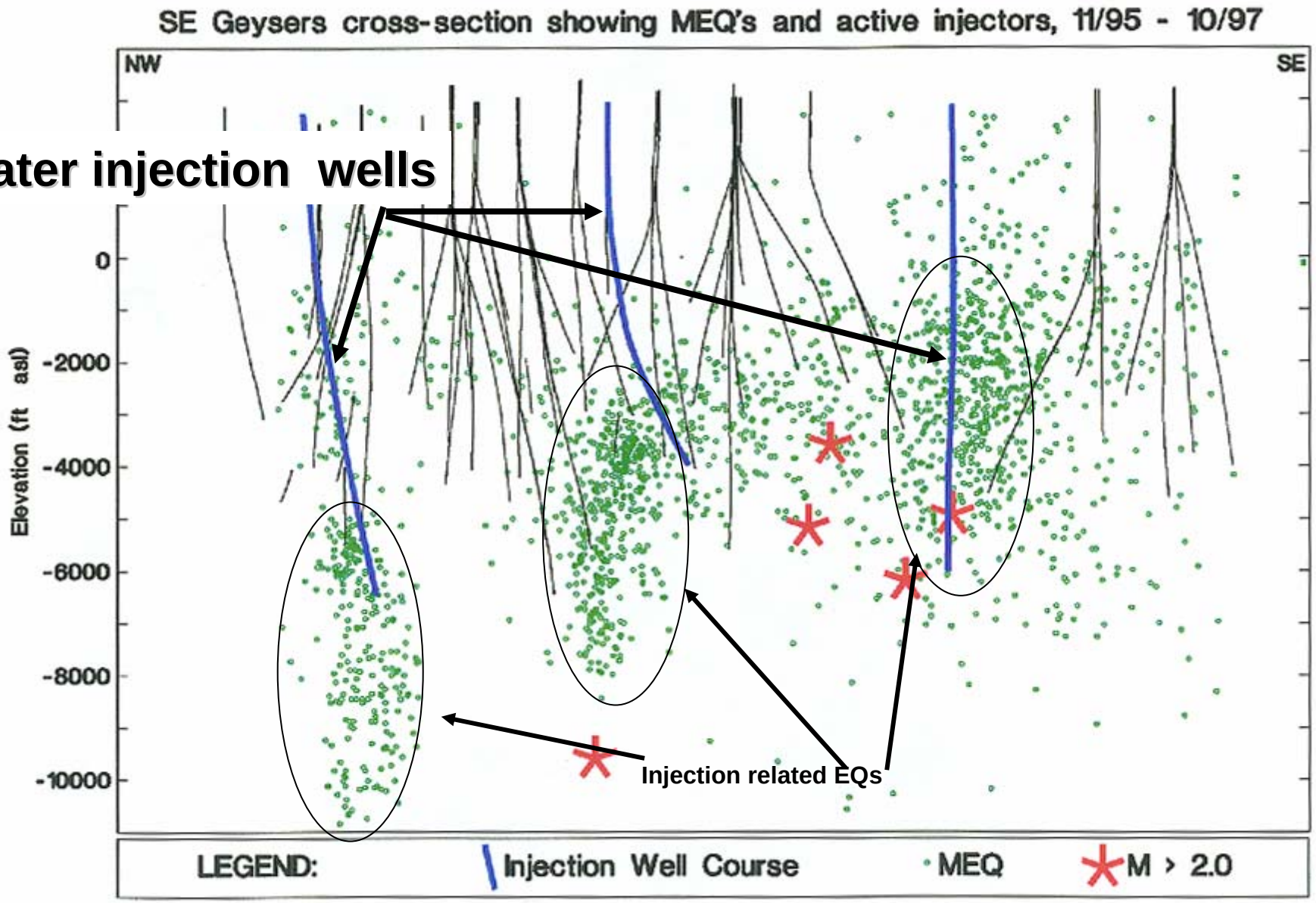

Easting (ft)
2005
Microhole location
VSP shot location
Faults ?
500 feet
12-1-x-34-MH4
12stx34
23-1-x-34-mh
23a34
34ax34j
341x34mh3
202a34
44ax34
84stx33
35shx34
36ax34
45a34
351shx34
Easting (ft)

RMOTC VSP compared to Surface seismic



Passive Seismic Monitoring




SE Geysers cross-section showing MEQ's and active injectors, 11/95 - 10/97
NW
SE
Water injection wells
Elevation (ft asl)
0
-2000
-4000
-6000
-8000
-10000
Injection related EQs
LEGEND:
Injection Well Course
MEQ
M > 2.0

(Stark, 1999)

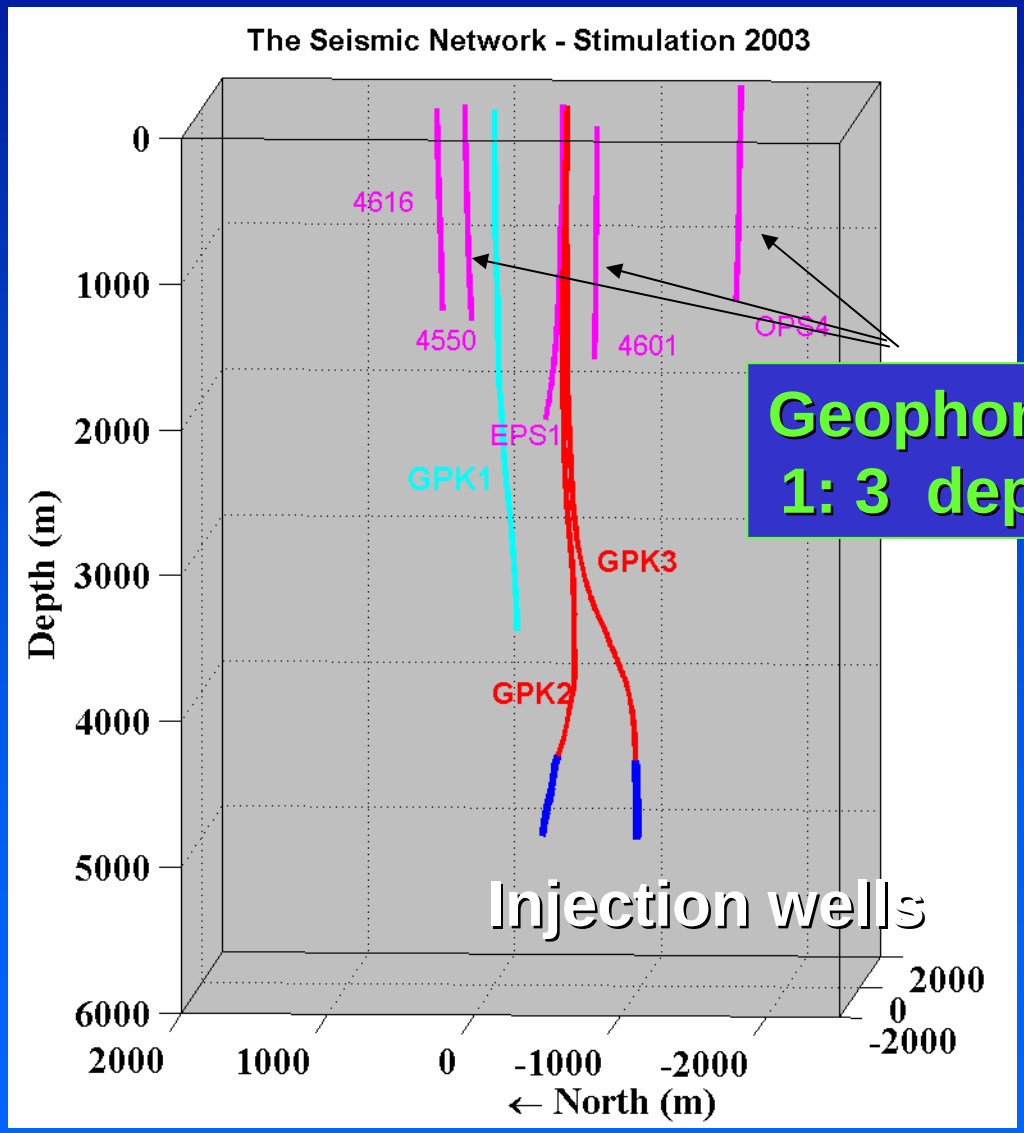
Borehole Seismic Network For Injection Monitoring

3 accelerometers

+

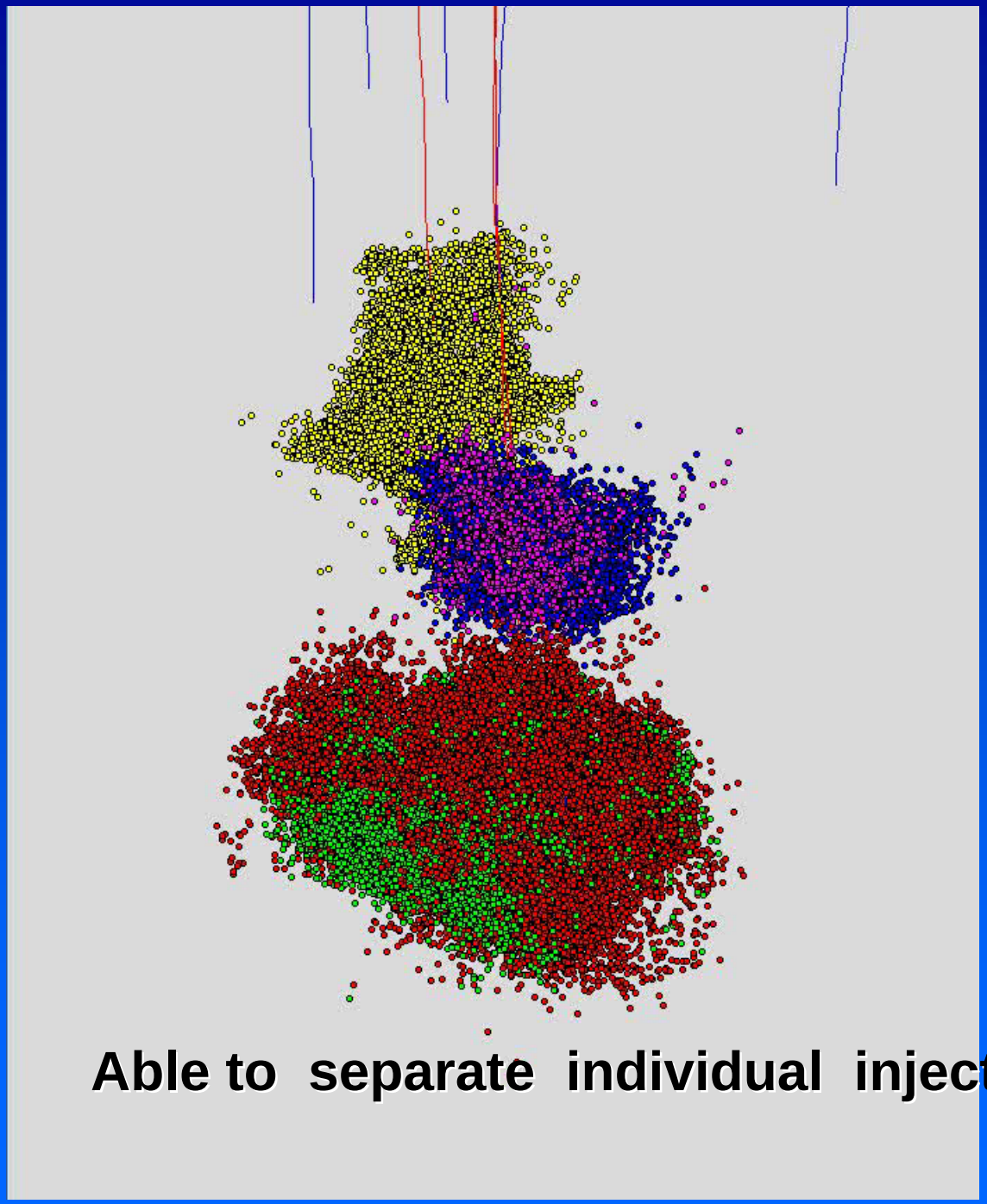
2 geophones

were recording microseismic events during the stimulation



From Michelet, 2005

The History



Upper Reservoir

1987 - 1997

Deep Reservoir

1988 - 2003

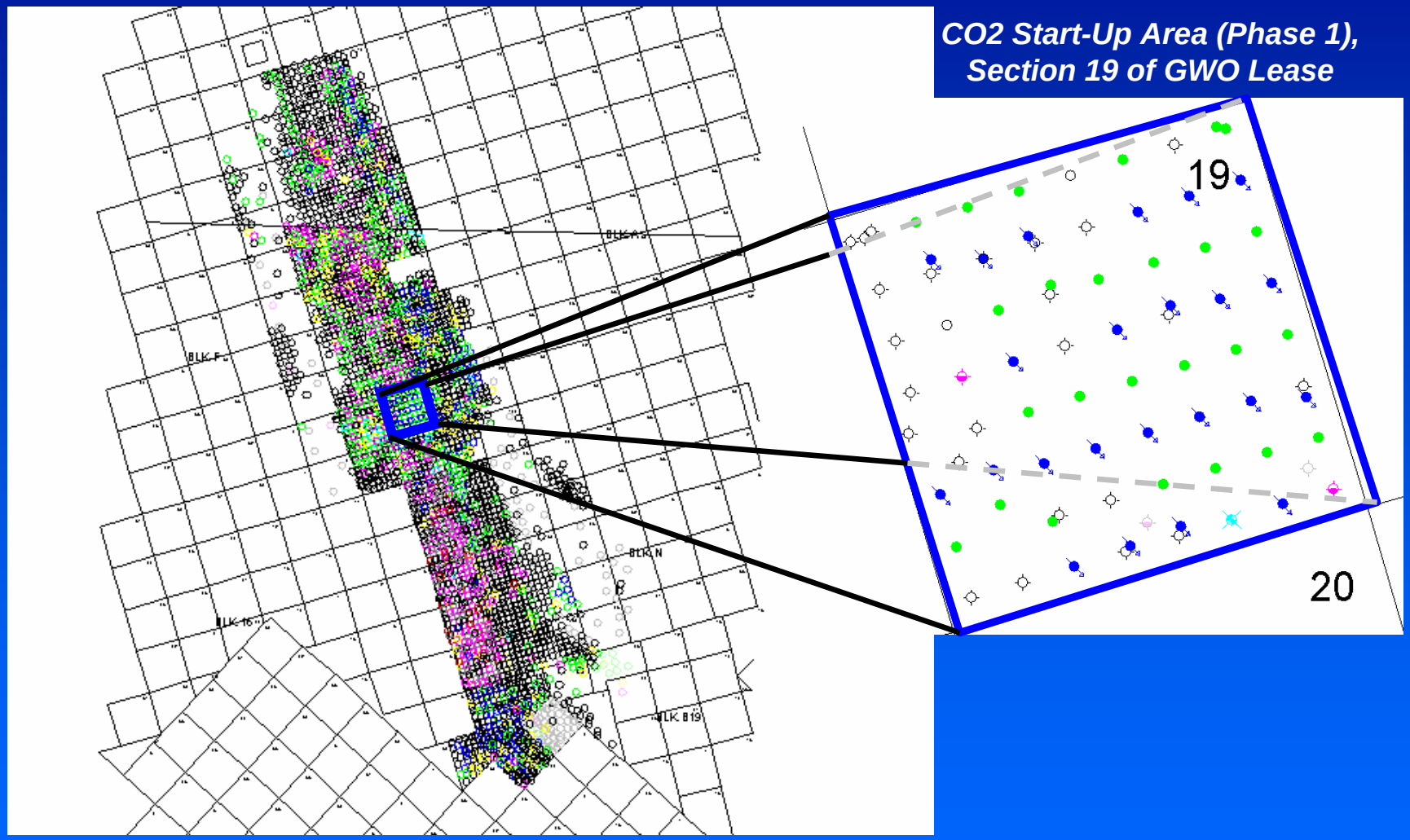
- 1993
- 1995
- 1996
- 2000
- 2003

Able to separate individual injection events

2006 Designer Seismic Microhole Milestones

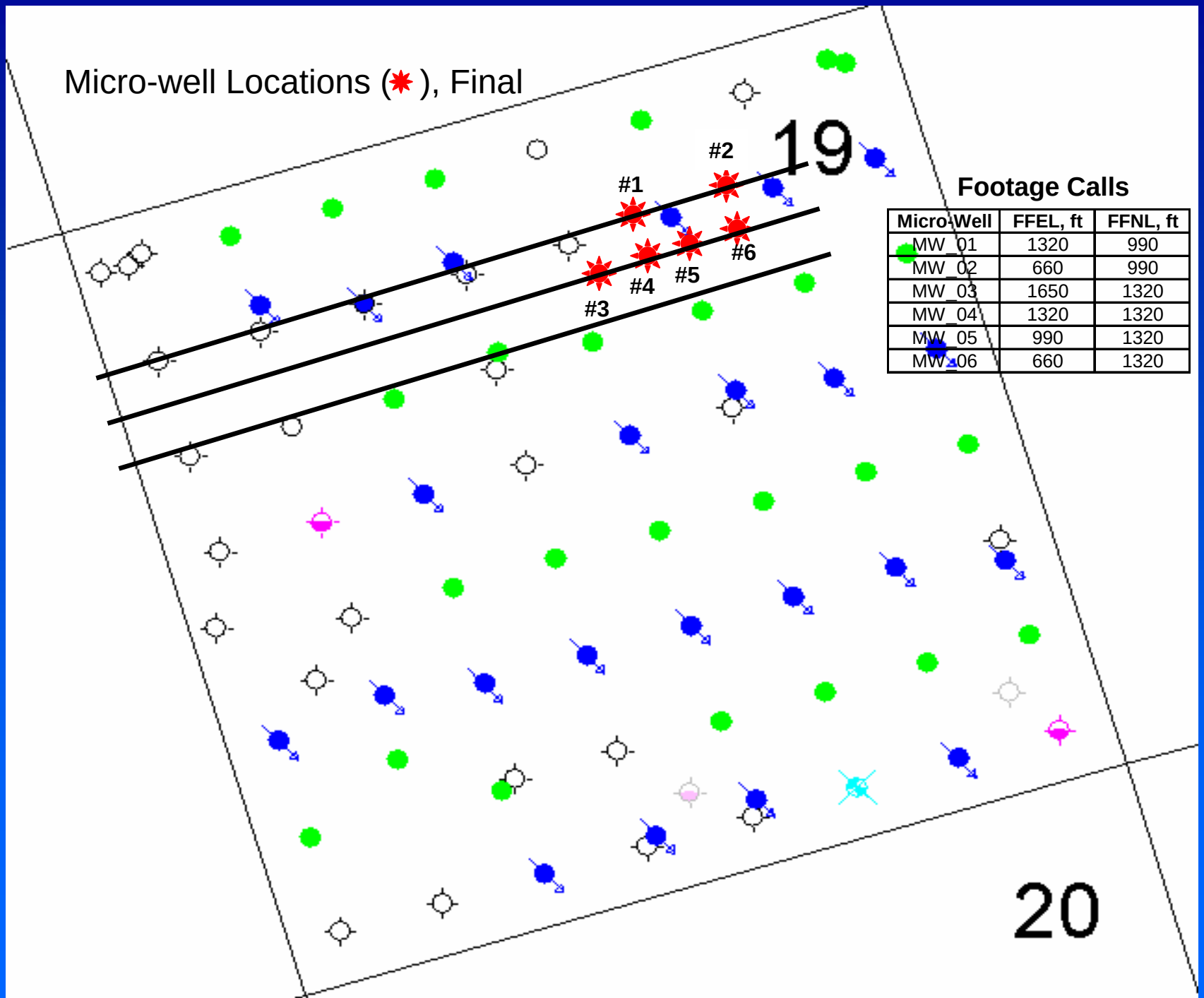
- 2006
  - Complete processing of RMOTC 2005 Data
    - Compare and contrast to 3-D surface seismic
  - Extend application to commercial sites (Oct - Nov 2006)
    - CO2 EOR Projects
      - Permian Basin
      - Passive monitoring of reservoir between time lapse measurements
    - Whiting Oil Field Active and Passive (6 Microholes) Investigate next generation of instrumentation
  - Adapt processing for improved “look ahead” capability (in progress)
    - Improved methods of imaging vertical features in homogeneous geology

Wickett Field



CO2 Start-Up Area (Phase 1), Section 19 of GWO Lease

Micro-well Locations (✸), Final



Footage Calls

Micro-Well	FFEL, ft	FFNL, ft
MW_01	1320	990
MW_02	660	990
MW_03	1650	1320
MW_04	1320	1320
MW_05	990	1320
MW_06	660	1320

Summary / Observations to Date

- Active seismic
  - Microhole VSP can look over 5 times hole depth
  - Resolution (due to reduced signal to noise) is better than "conventional" VSP
  - Makes seismic surveys faster and much cheaper
  - Less "invasive" on operations
  - Allows operator to easily customize/change surveys for changing reservoir conditions and varying reservoir conditions across any particular field ("Designer Seismic")
- Passive Seismic
  - Critical information on fracture generation, fluid interactions and fluid paths can be obtained from borehole seismic data
  - Sensors do not need to be placed at reservoir level
  - Sensors can be placed away from surface and in sufficient azimuthal coverage to eliminate path effects and obtain data for analysis of source mechanisms critical to understanding fracture generation and stress analysis.