Geophysics at the borehole and cross-borehole scale

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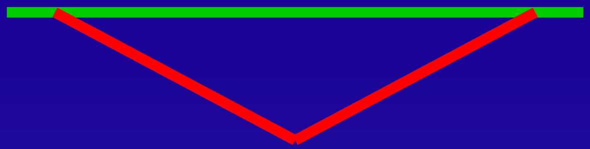
and John Williams

OGW-Branch of Geophysics

Overview

- **Historical data and Geologic maps**
- **Surface geophysics**
- **Borehole geophysics**
- **Cross-hole Testing**
- **Hydraulic Measurements** hydraulic testing, water levels, sampling, pumping tests
- **Integration and iteration**

Historical application of surface geophysics



Electromagnetics (EM)

- Conductive fluids in overburden and shallow bedrock

Seismic Refraction

- Saturated thickness and bedrock topography

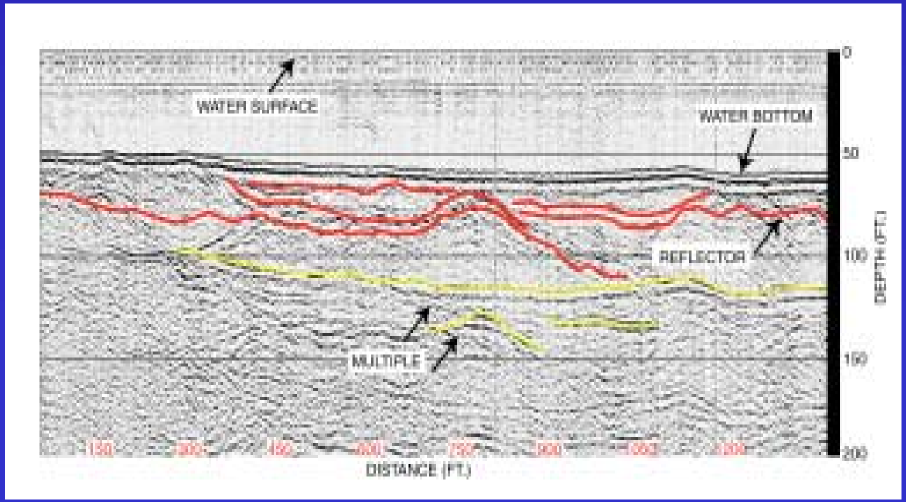
Shallow conductive anomalies

Surface geophysics

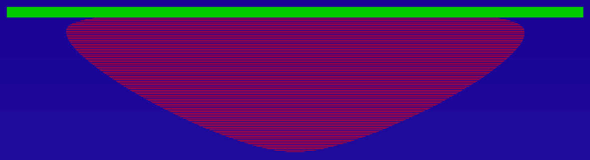
Seismic reflection

Ground penetrating radar (GPR)

- Subsurface stratigraphy
- Bedrock topography



Surface geophysics



Electromagnetics (EM)

- Sheet-like conductive fluids or layers in bedrock

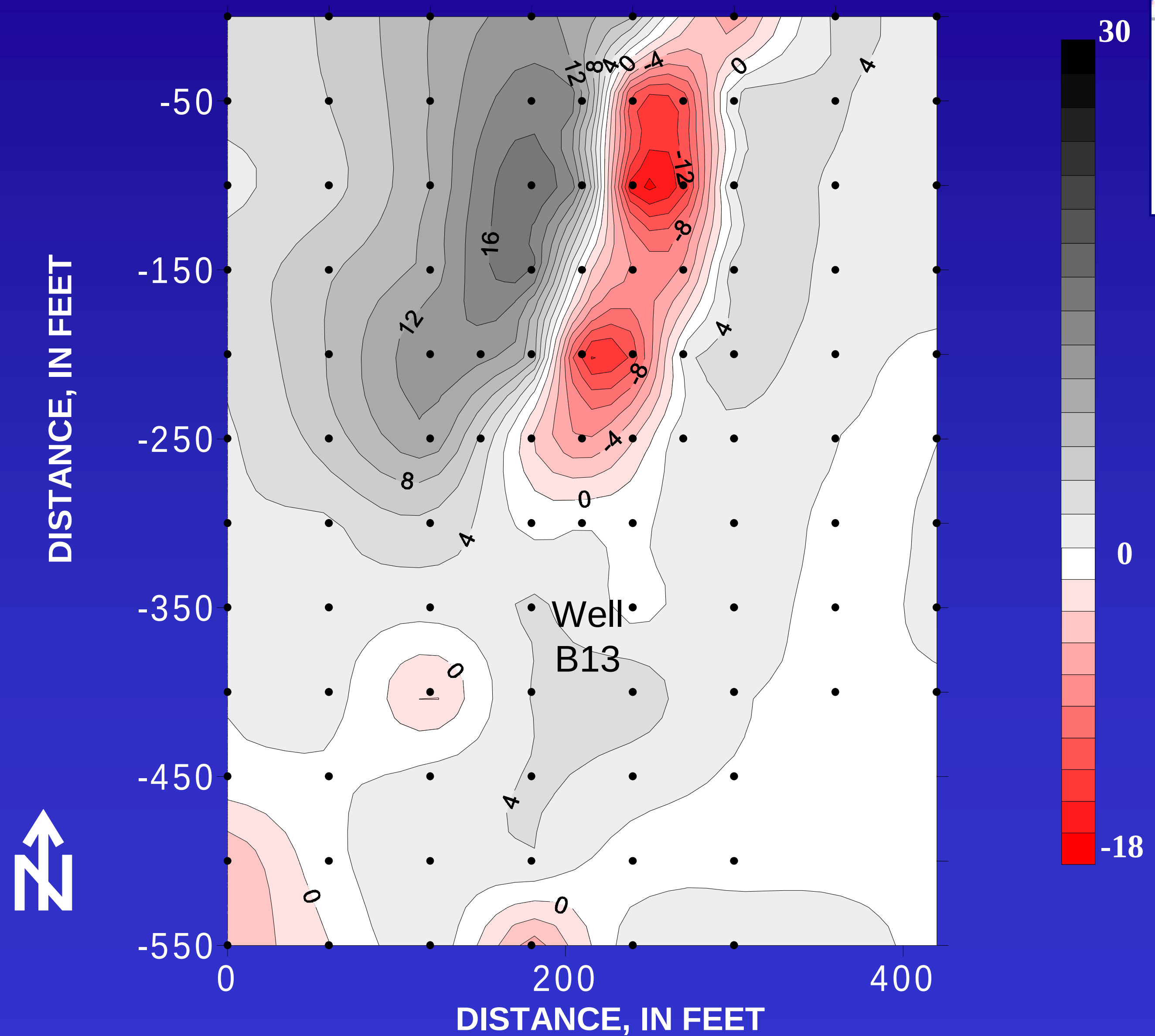
DC resistivity profiling

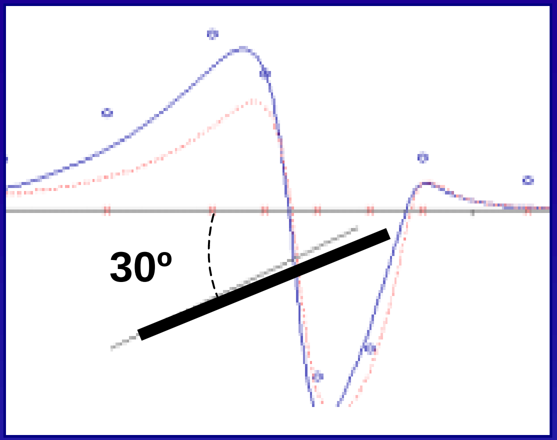
- Subsurface bedrock structure

Azimuthal square-array resistivity

- Bedrock anisotropy – fractures and/ or lithology

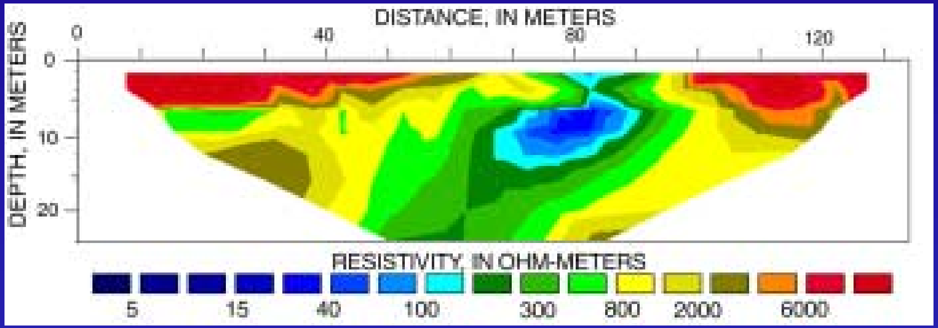
EM 34 anomaly





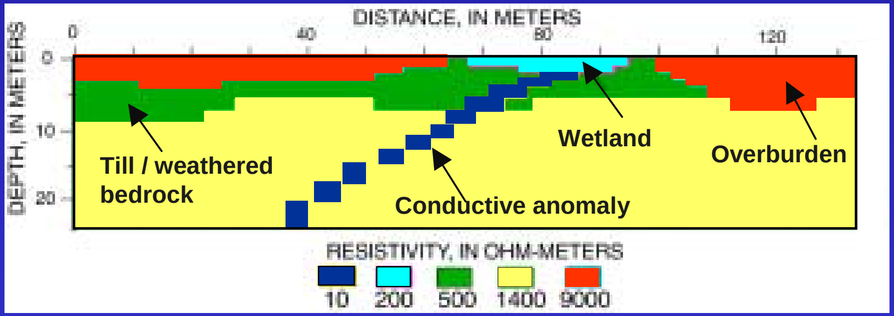
Modeling 2D Resistivity Data

Inverted Resistivity Section



RES2DINV (Loke, 1997)

Forward Model

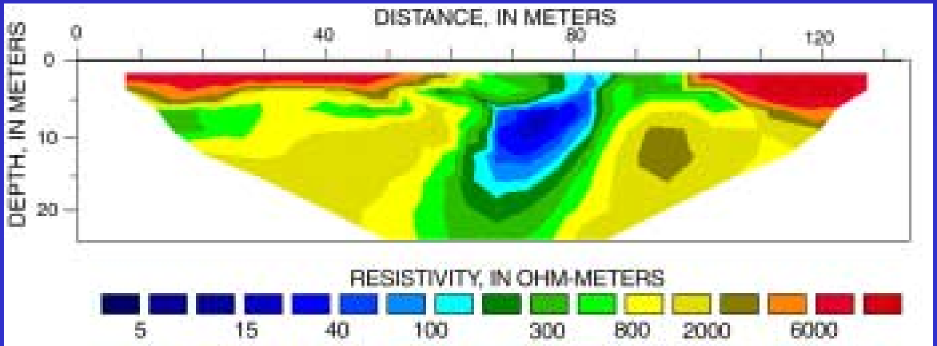


RES2DMOD (Loke, 1997)

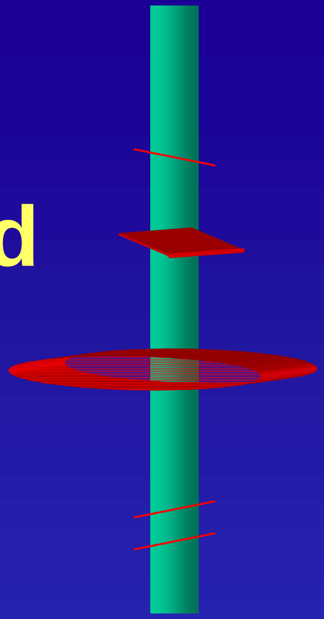
Inverted Resistivity

Section of Forward Modeled

Synthetic Data



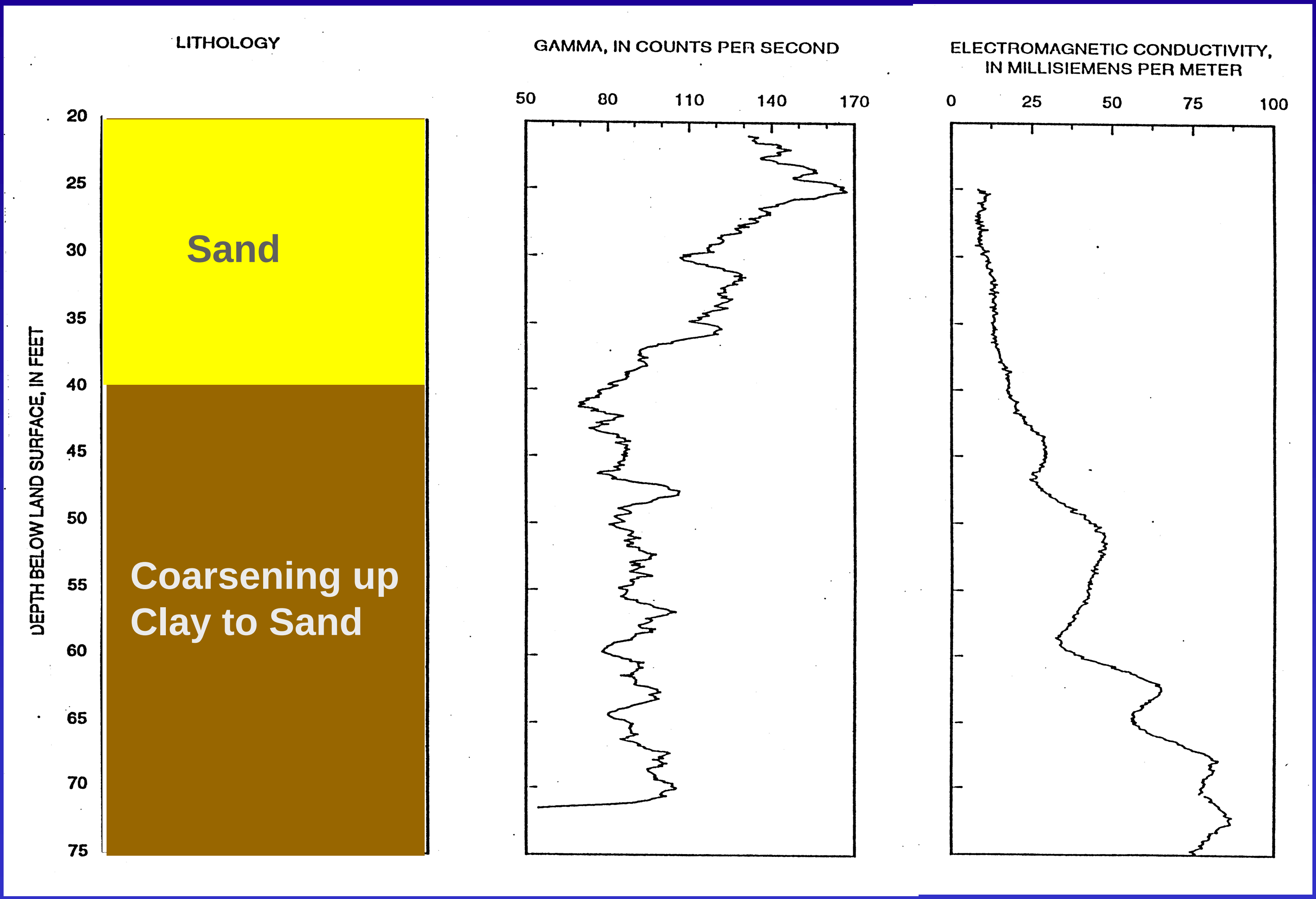
Borehole geophysics



Characterize hydrogeology in and surrounding the borehole

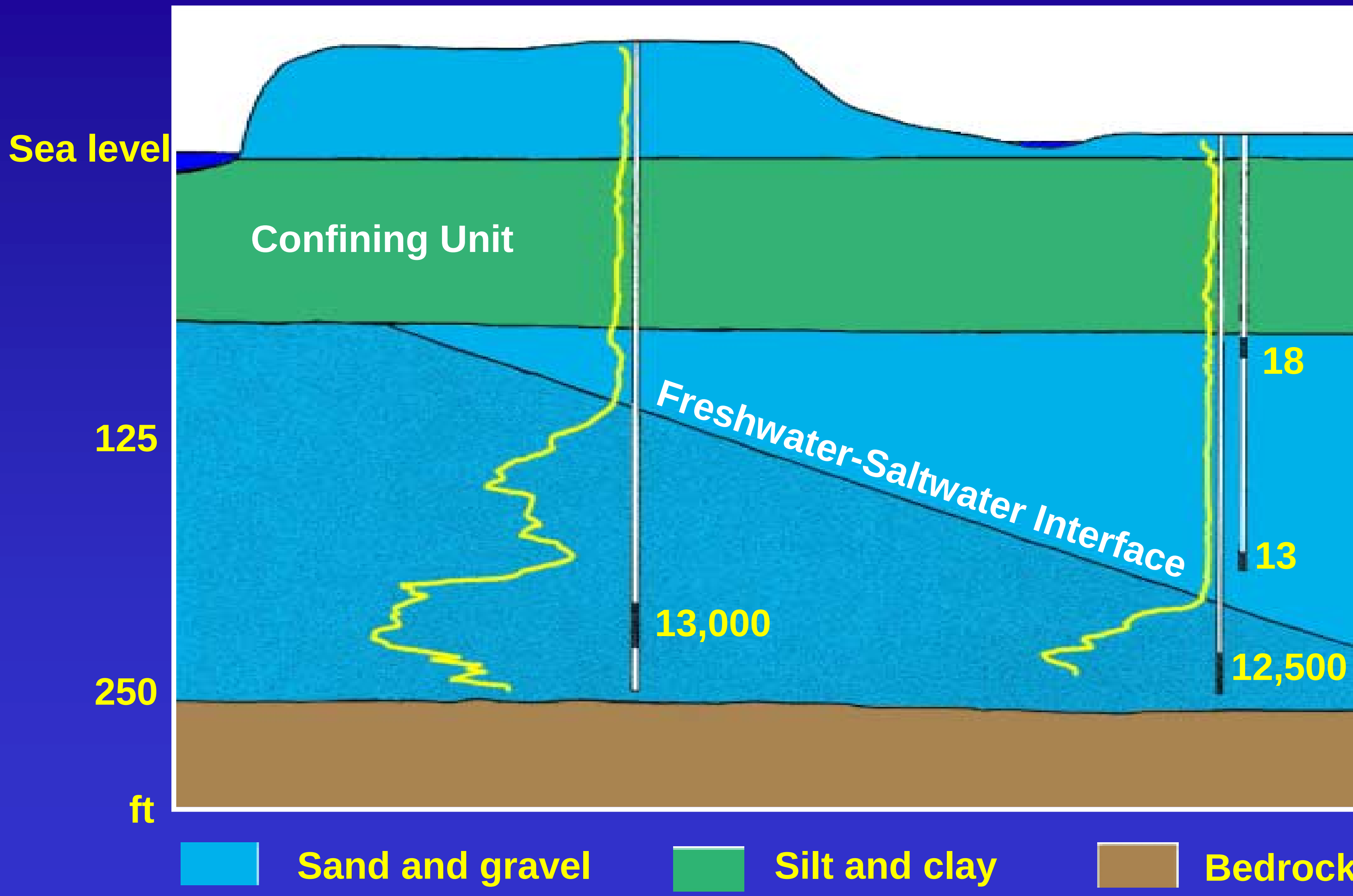
- Conventional logs
- Acoustic televiewer
- Optical televiewer

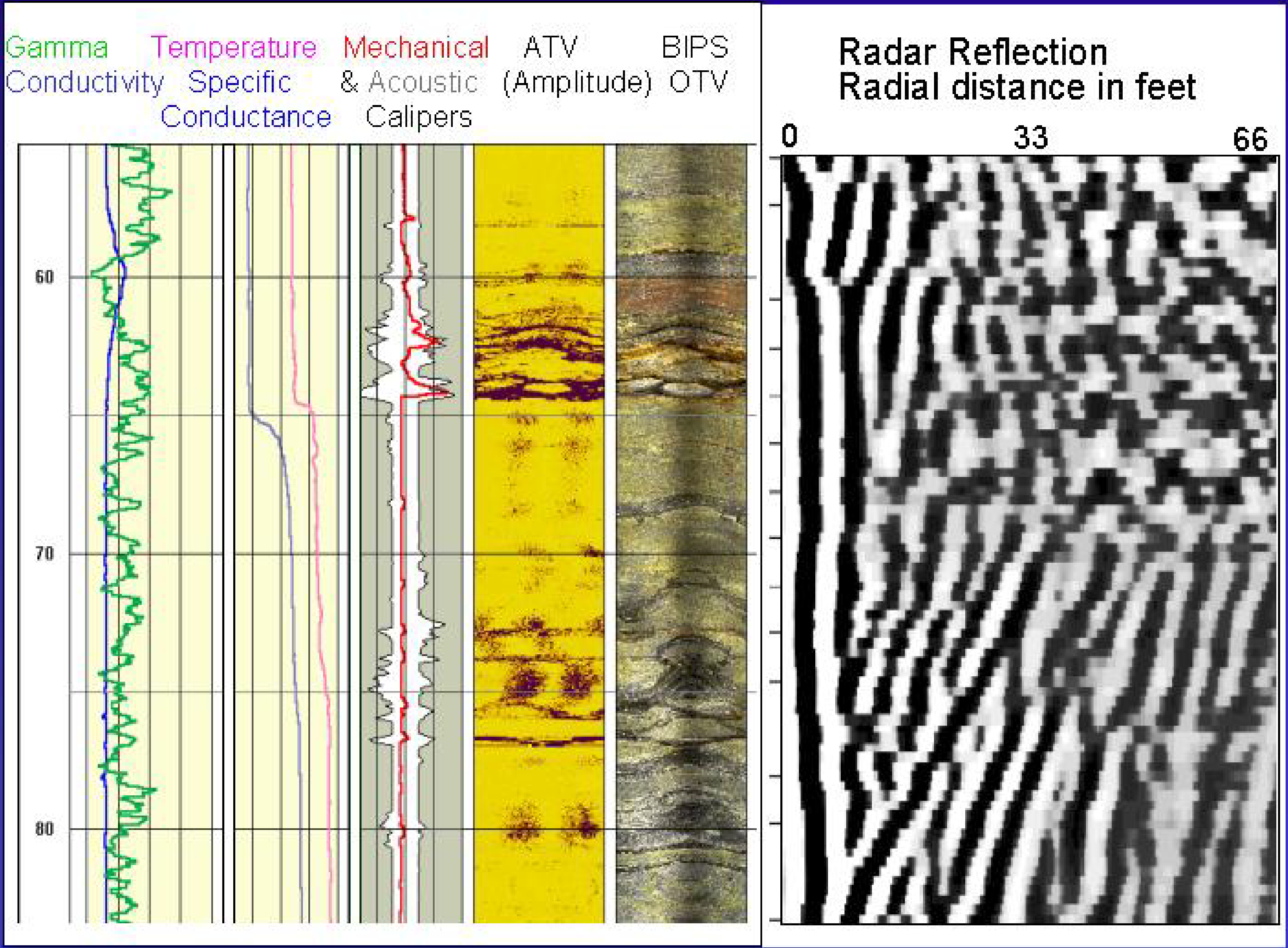
- Radar
- Borehole flowmeter
- Hydraulic and geochemical testing



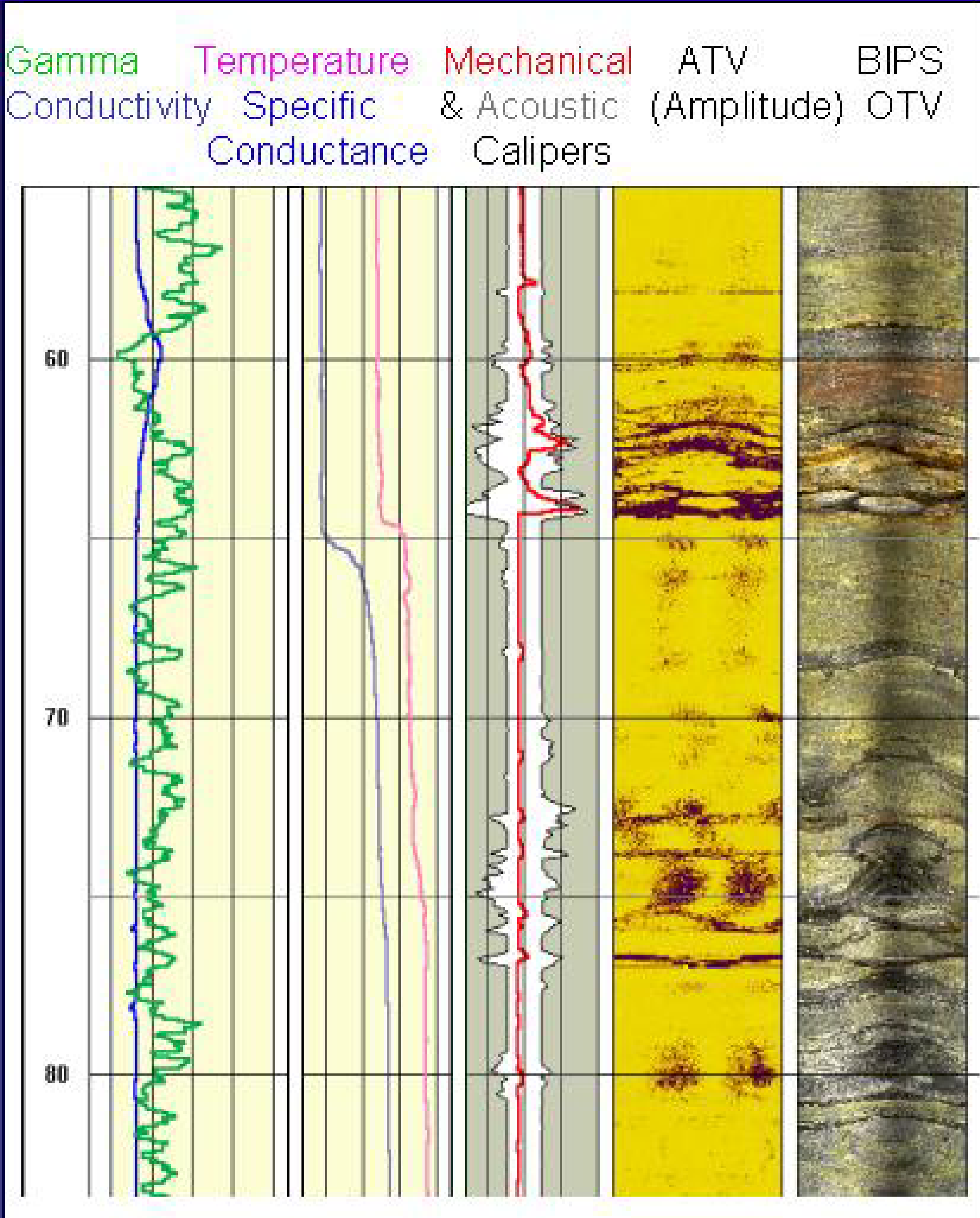
VIRGINIA COASTAL PLAIN

EM CONDUCTIVITY LOGS AND DISSOLVED CHLORIDES
Great Neck, Long Island





Gamma
Conductivity
Temperature
Specific
Conductance
Mechanical
& Acoustic
Calipers
ATV
(Amplitude)
BIPS
OTV
60
70
80
Radar Reflection
Radial distance in feet
0
33
66


Gamma
Conductivity
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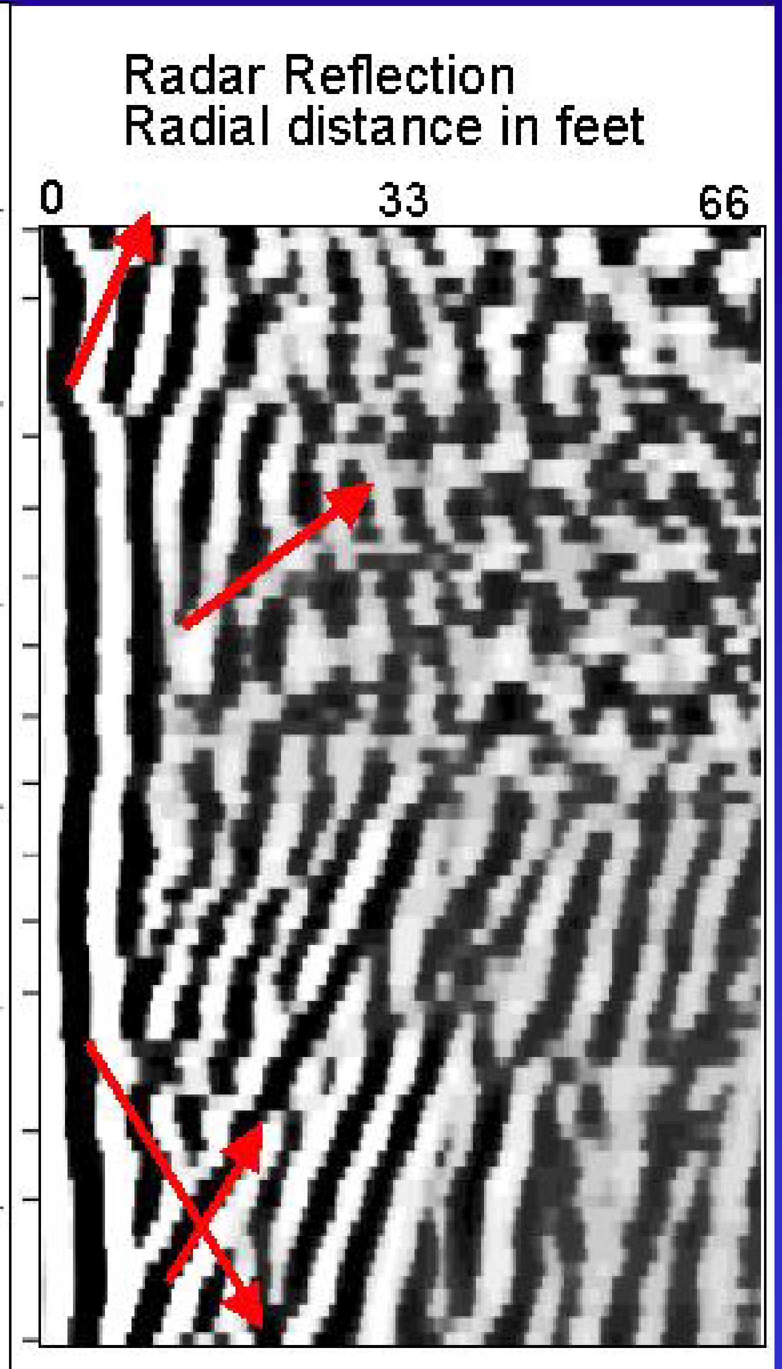
Radar Reflection
Radial distance in feet
0
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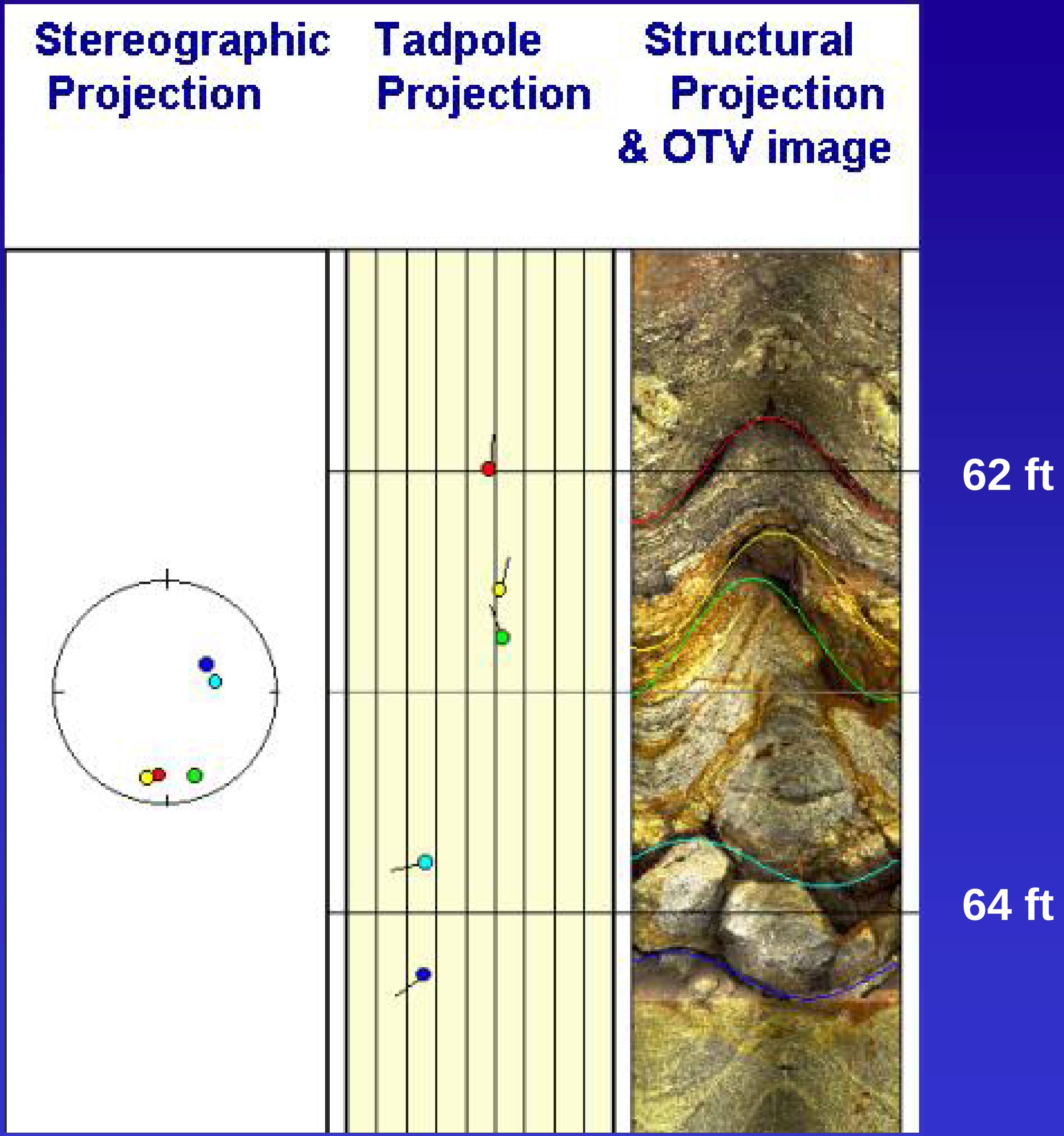


Stereographic Projection
Tadpole Projection
Structural Projection & OTV image
62 ft
64 ft

Evaluate orientation of hydraulically active fracture sand structure at the field scale and site scale

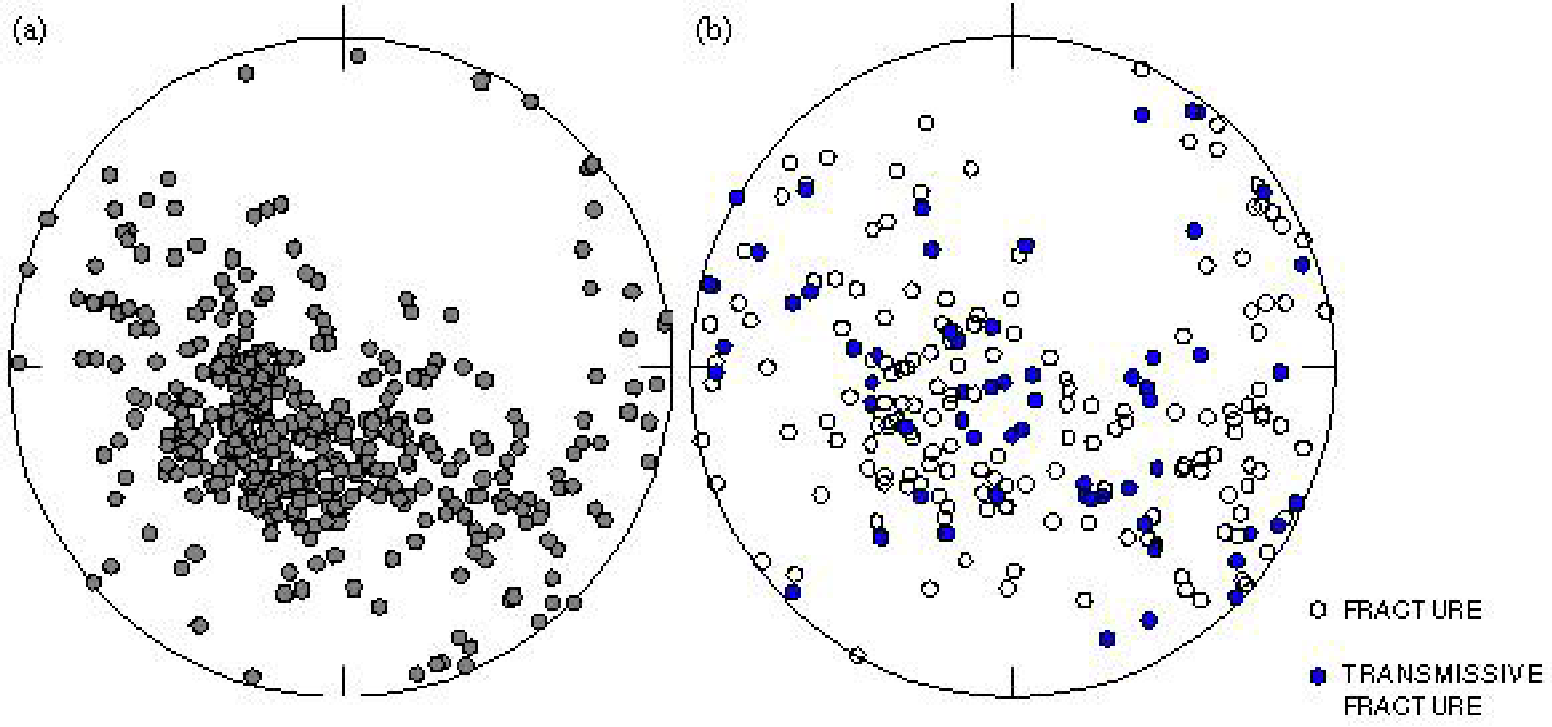
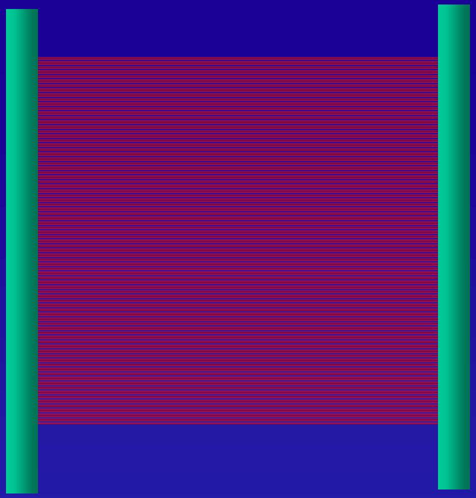


Figure 3. Equal-area stereonets of (a) foliation and (b) fractures, in 11 boreholes at the study area, Norwalk, Connecticut.

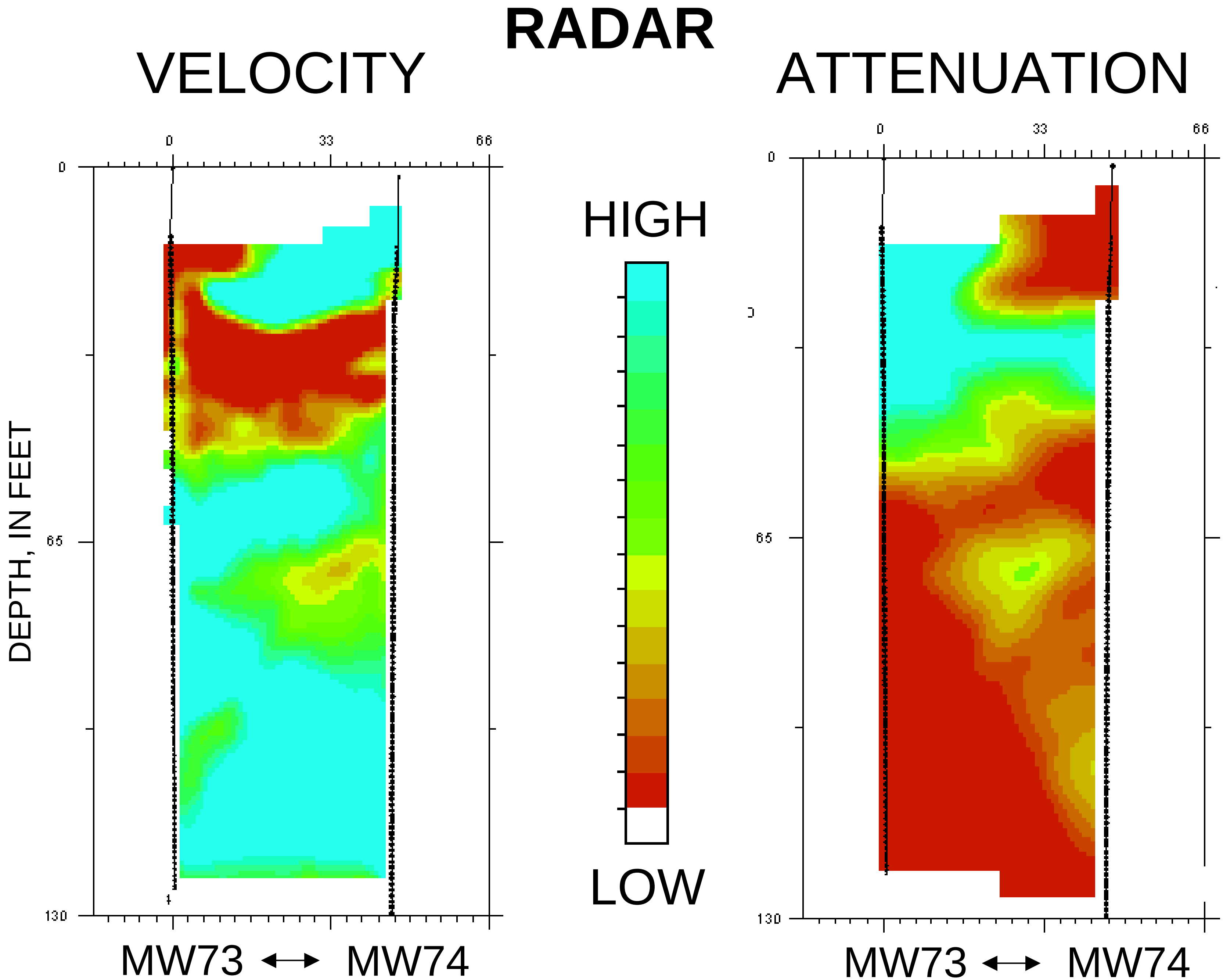
Cross-hole geophysics



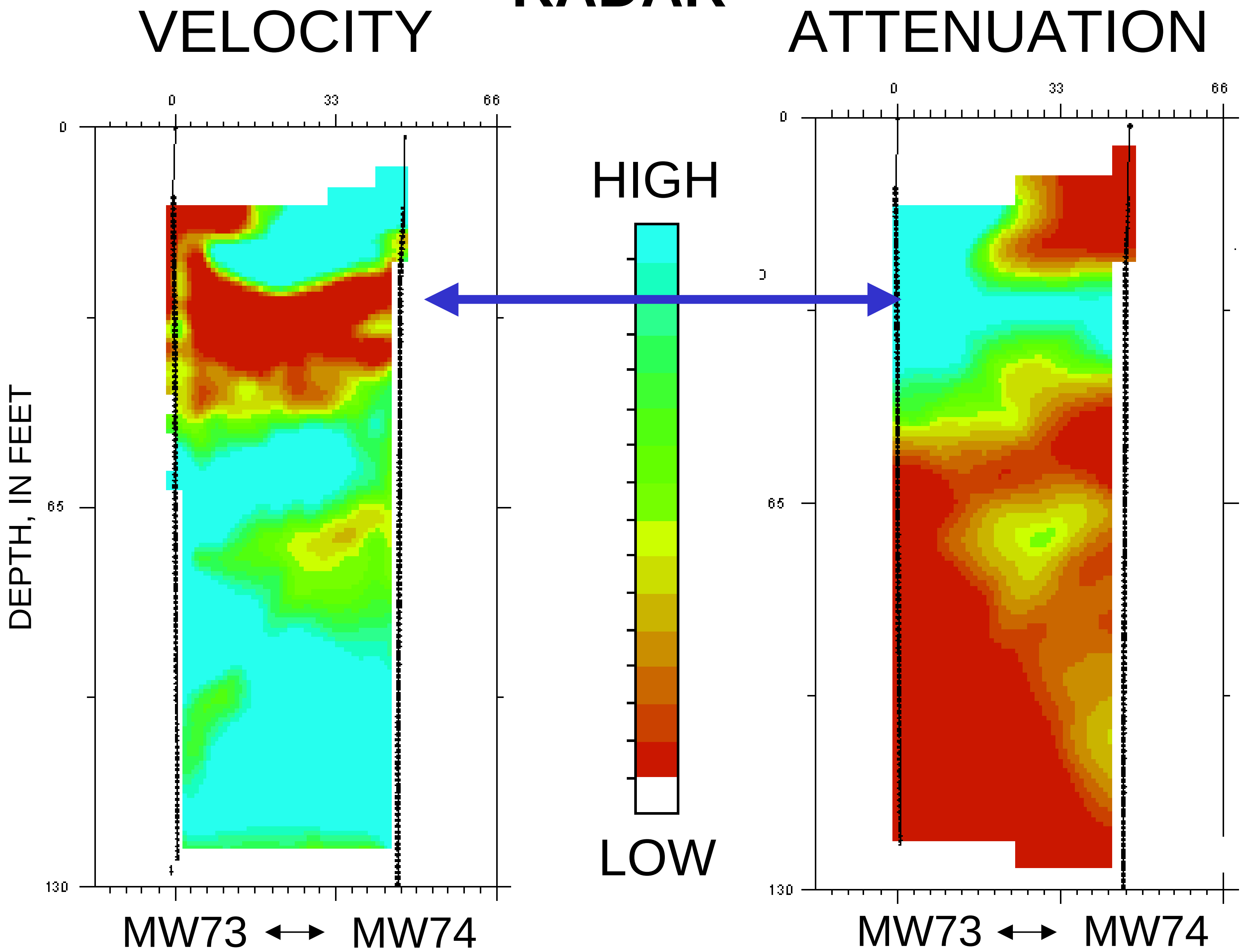
Radar tomography - 30 to 100m

Resistivity tomography – up to100 m

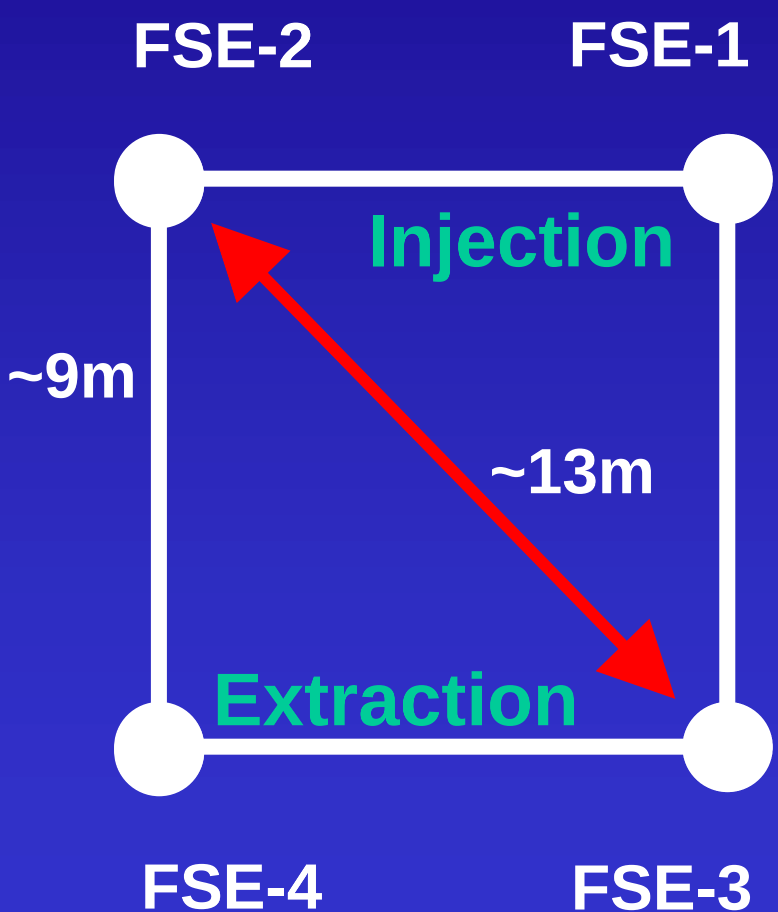
Seismic tomography – 10 to 1 km

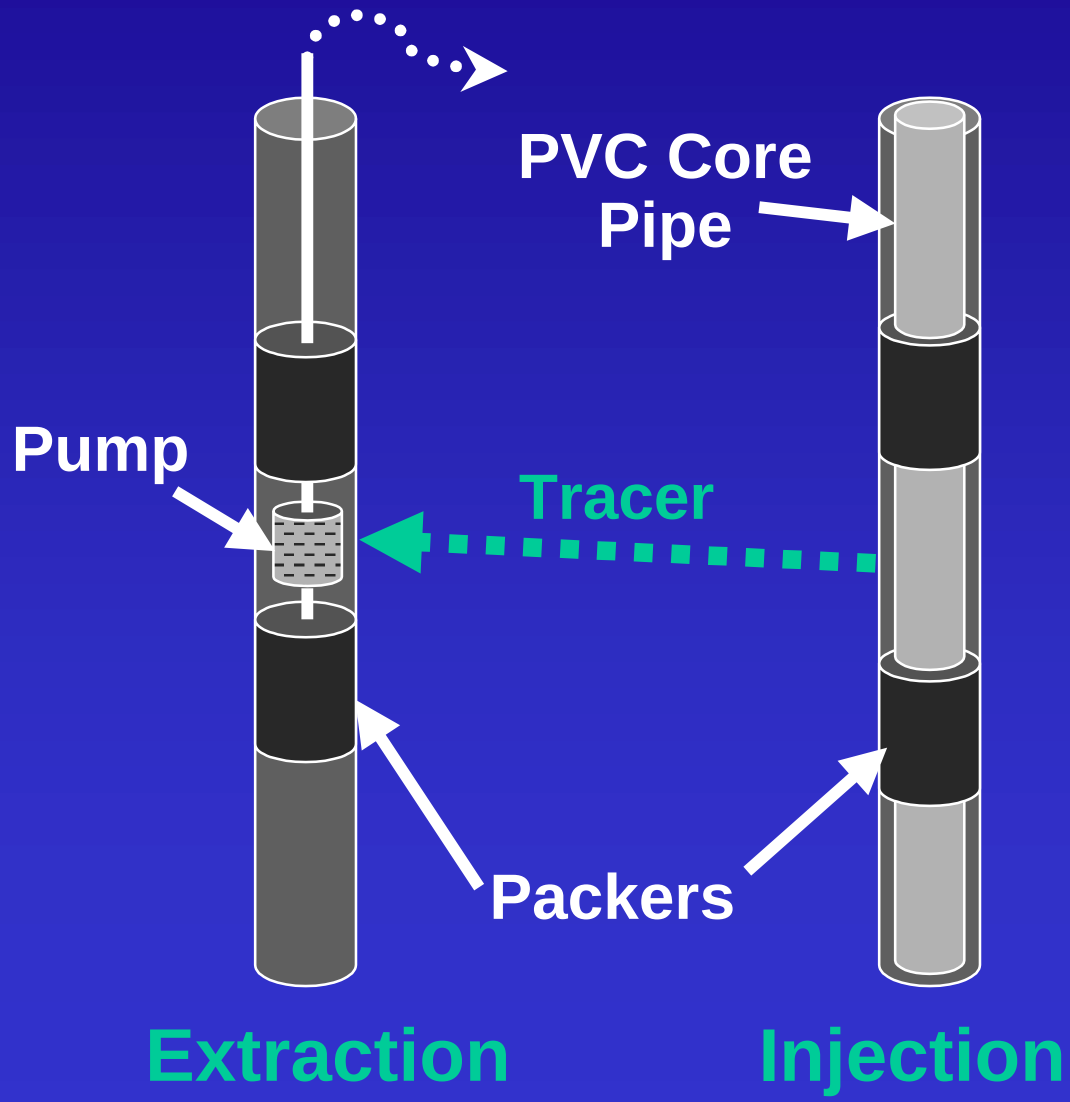

RADAR
VELOCITY
ATTENUATION
HIGH
LOW
DEPTH, IN FEET
0
33
66
0
65
130
MW73 ↔ MW74
MW73 ↔ MW74

RADAR

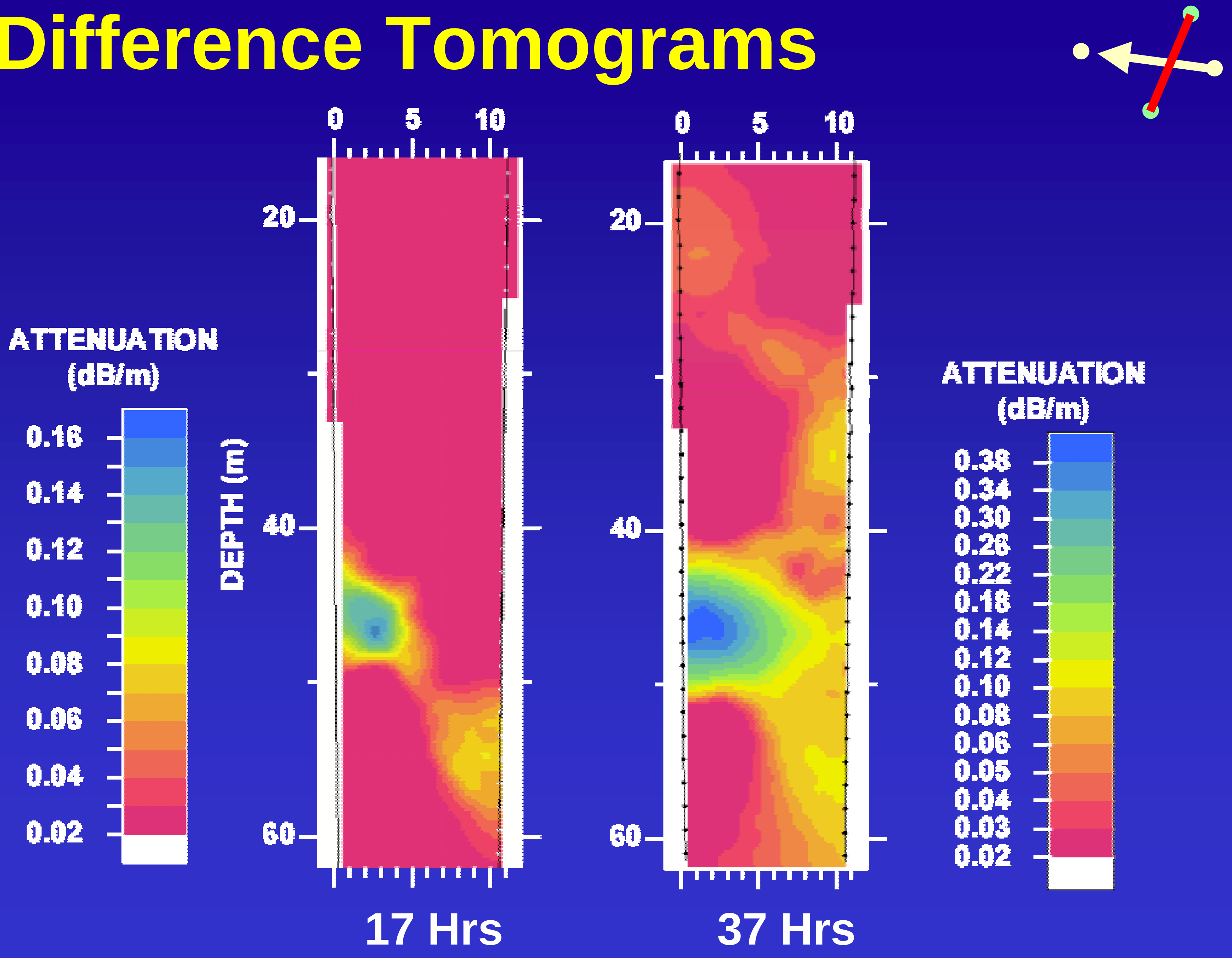

VELOCITY
ATTENUATION
0
33
66
0
65
130
DEPTH, IN FEET
HIGH
LOW
MW73 ↔ MW74
MW73 ↔ MW74

FSE Well Field Site Map & Tracer Injection Method





Difference Tomograms

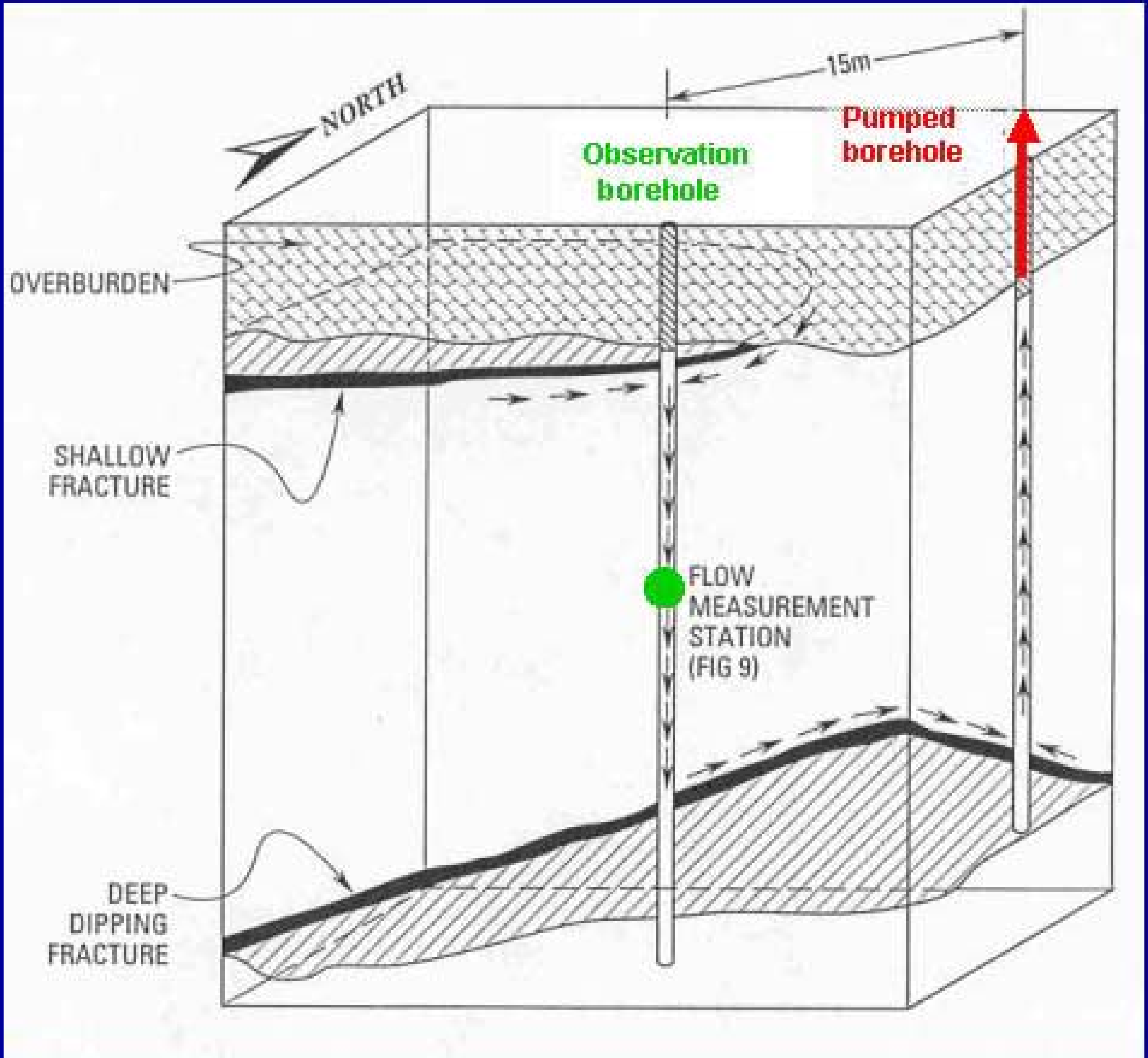


Hydraulic evaluation

Conventional single hole flowmeter logging – ambient and pumping conditions (flow prevention)

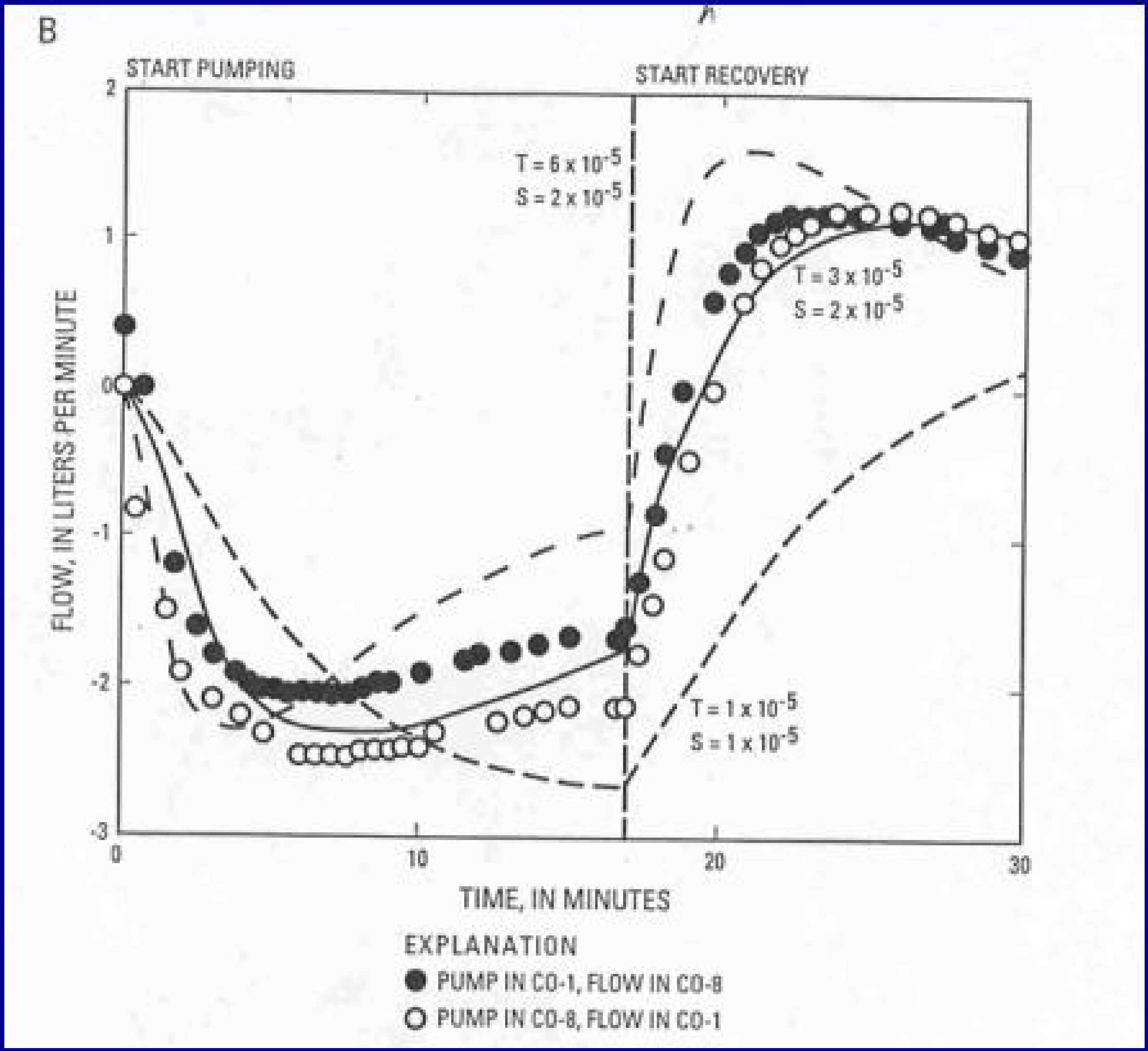
- Discrete interval hydraulic testing - pumping or injection conditions
- Discrete interval geochemical sampling
- Discrete interval, long-term head monitoring
- Cross-hole flowmeter logging

CROSSHOLE TRANSIENT FLOWMETER MEASUREMENTS

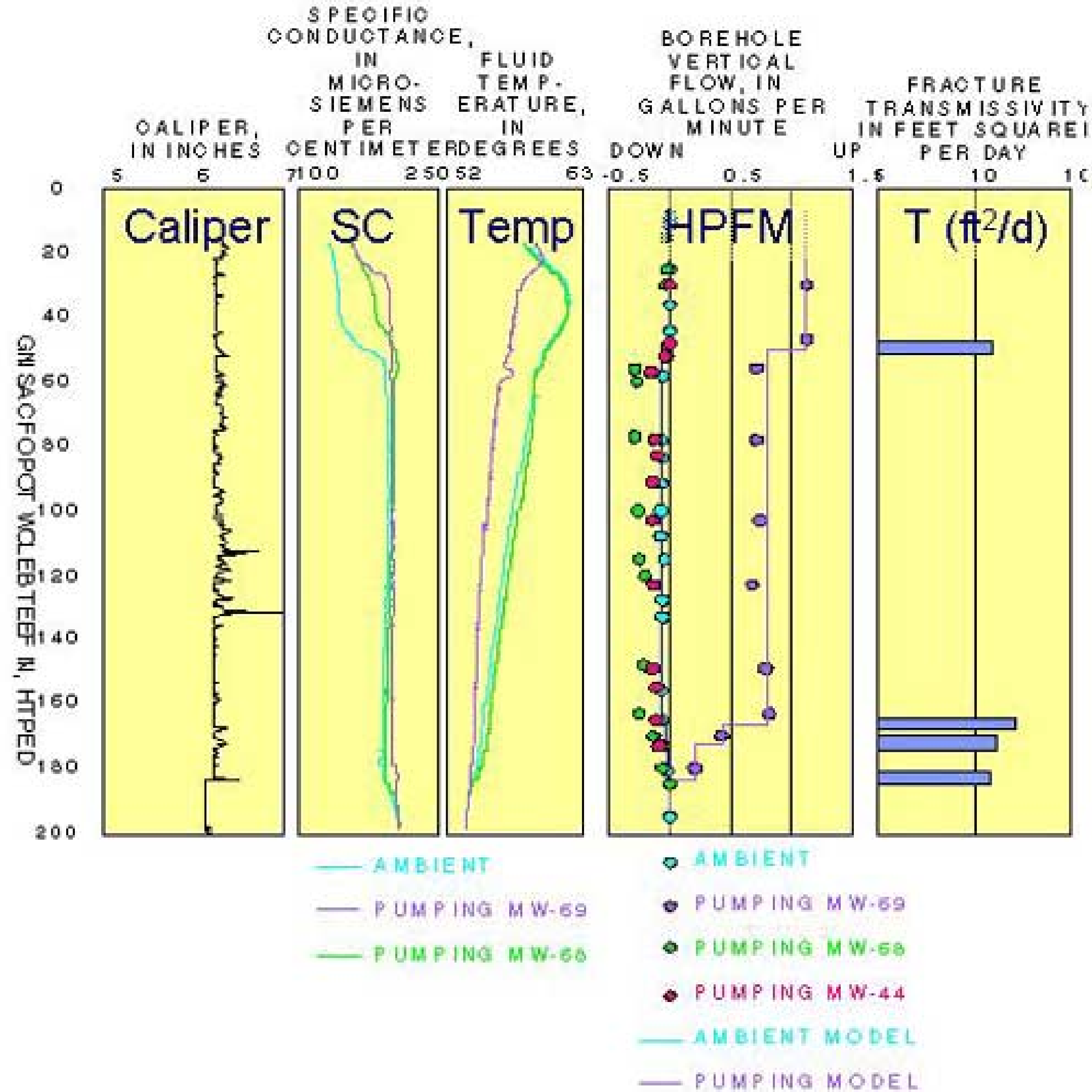


Paillet (2001)

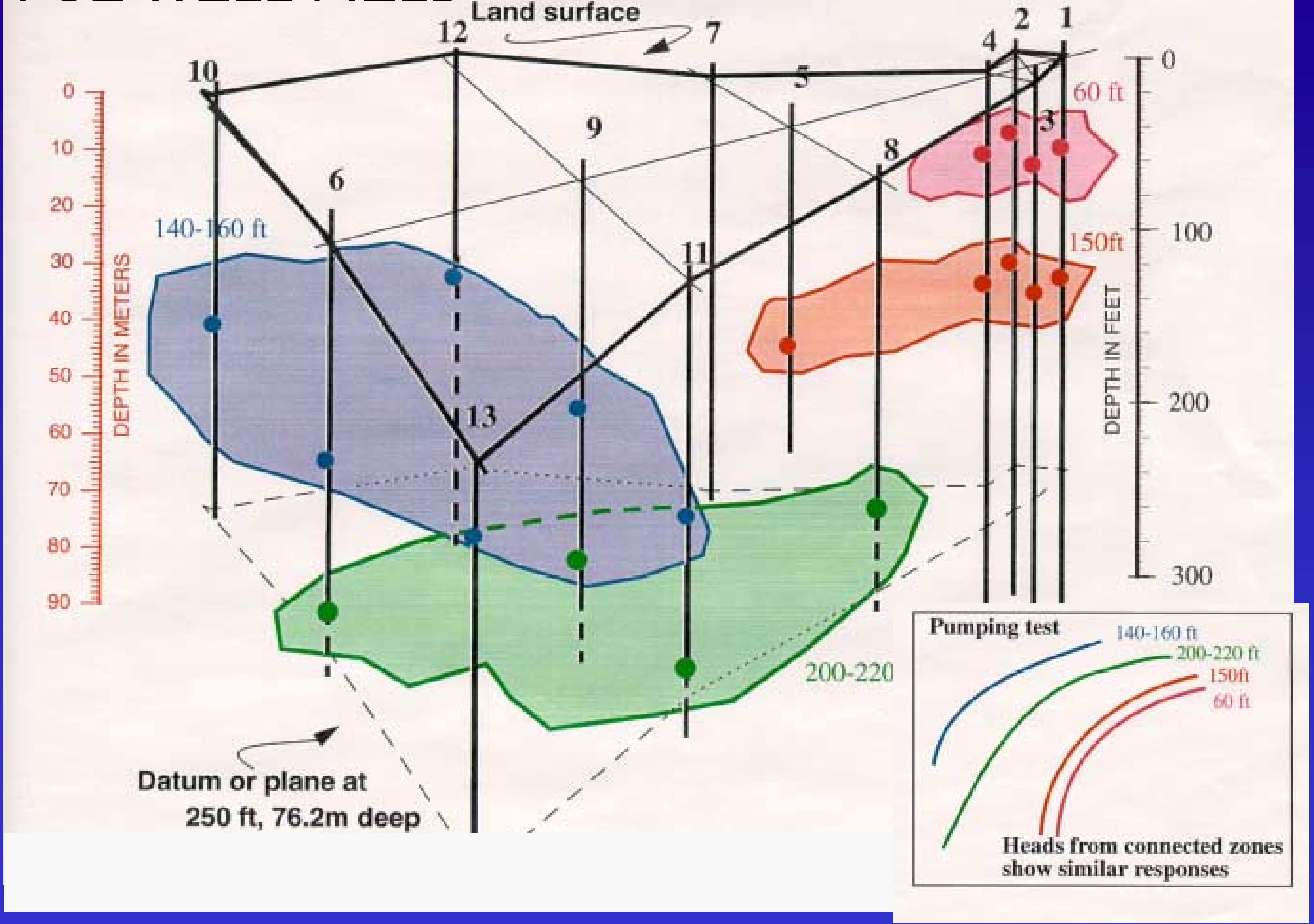
CROSSHOLE TRANSIENT FLOWMETER MEASUREMENTS



Paillet(2001)


CALIPER, IN INCHES
SPECIFIC CONDUCTANCE, IN MICRO-SIEMENS PER CENTIMETER
FLUID TEMP-ERATURE, IN DEGREES
BOREHOLE VERTICAL FLOW, IN GALLONS PER MINUTE
DOWN
UP
FRACTURE TRANSMISSIVITY IN FEET SQUARE PER DAY
5 6 7
100 250
52 63
-0.5 0.5 1.5
1 10
0 20 40 60 80 100 120 140 160 180 200
Caliper
SC
Temp
HPFM
T (ft²/d)
AMBIENT
PUMPING MW-69
PUMPING MW-68
AMBIENT
PUMPING MW-69
PUMPING MW-68
PUMPING MW-44
AMBIENT MODEL
PUMPING MODEL

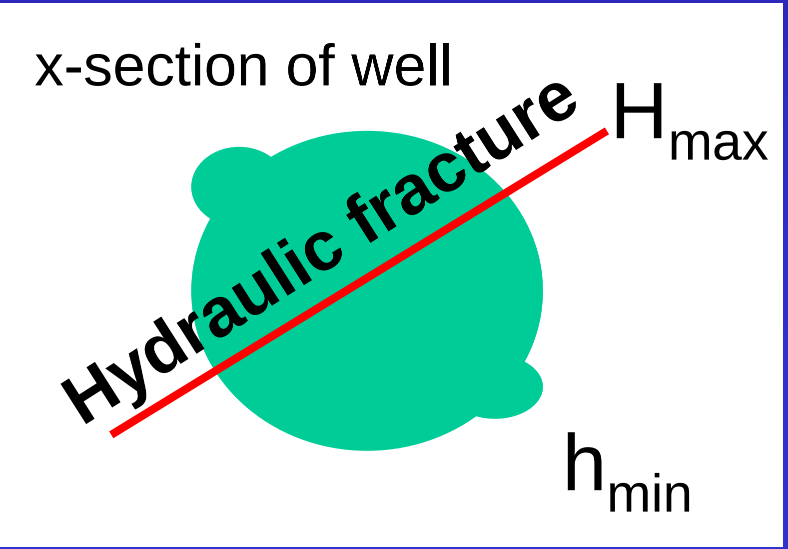
FSE WELL FIELD



Research Topics

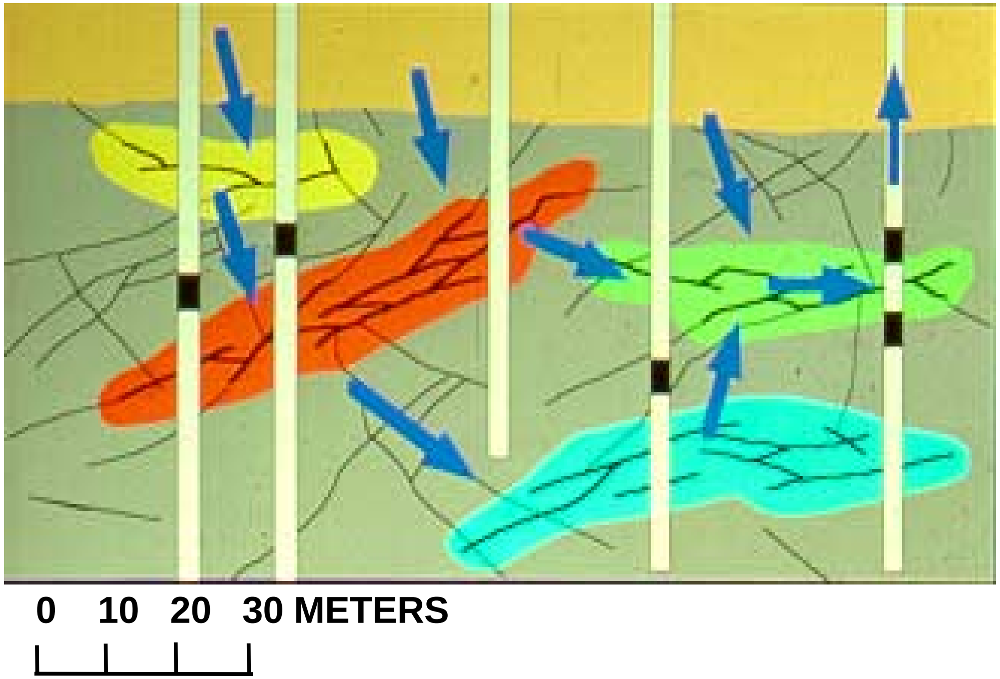
- **Seismo-electric effect – work proposed by Ellefsen, and others**
- **Borehole stress measurements – evaluation of the stress field from induced fractures in boreholes (Hickman and others)**

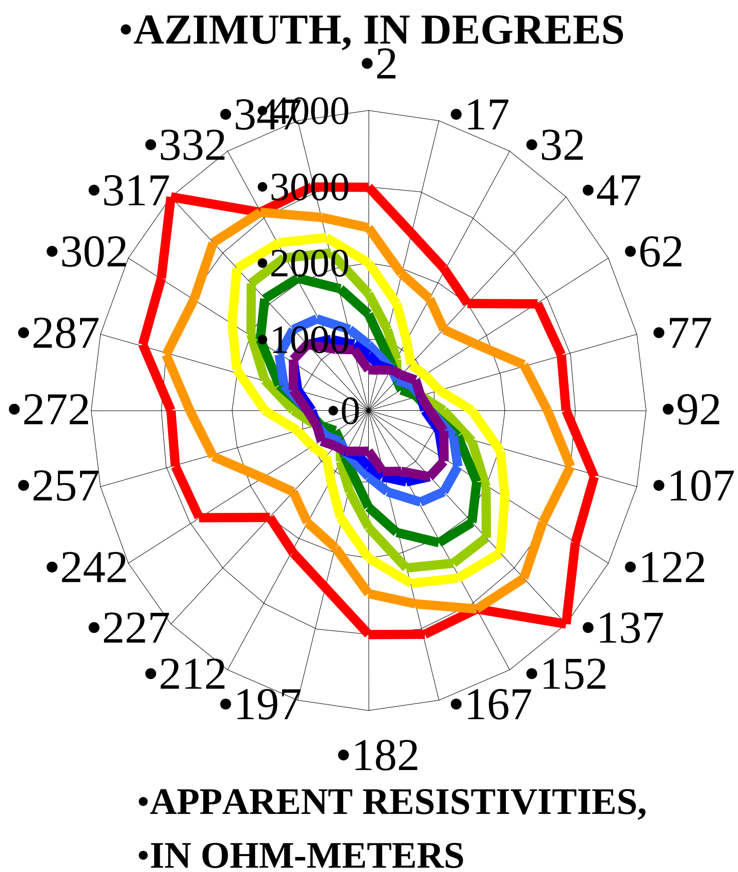
With concurrent tomographic diff-erencing methods (Lane and Wright)



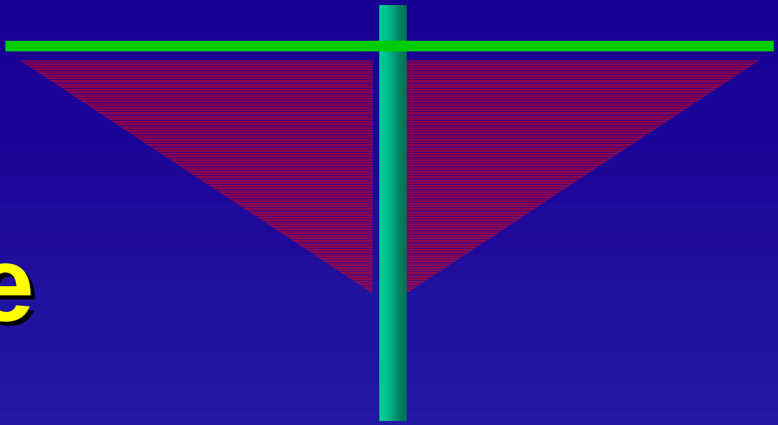
Research topics - continued

- **2D-Azimuthal resistivity – before and after pumping to evaluate anisotropy and potentially contributing recharge area**





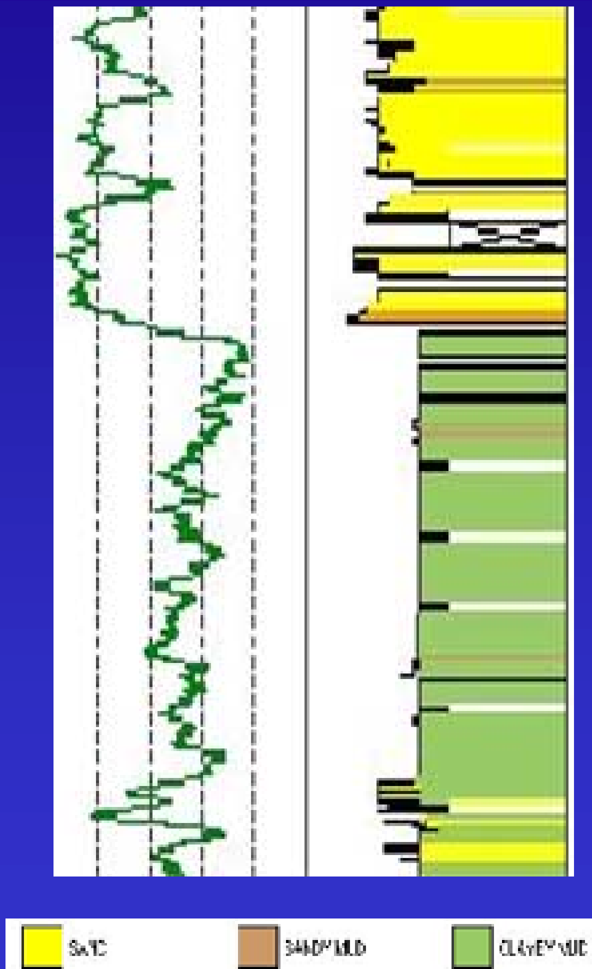
Research topics– continued



Surface to borehole

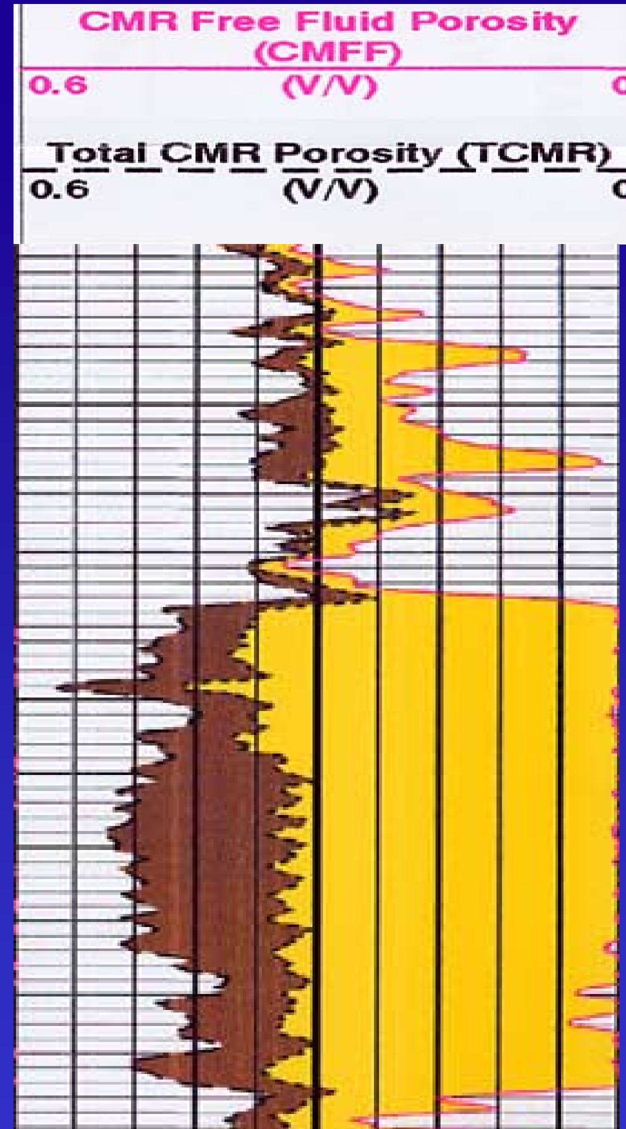
- Borehole to surface measurements – Resistivity, EM, and Seismic (tube waves)
- Surface or borehole NMR may be useful
- Identify correlations with surrogate data. Collect surrogate data, such as tomography data and hydraulic data and combine geostatistically (soft kriging or anealing process, Day-Lewis)

GAMMA LITHOLOGY



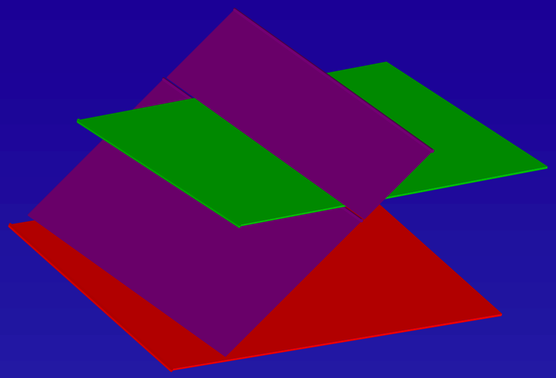
800 ft

900 ft



USGS Long Beach Pier C Test Well

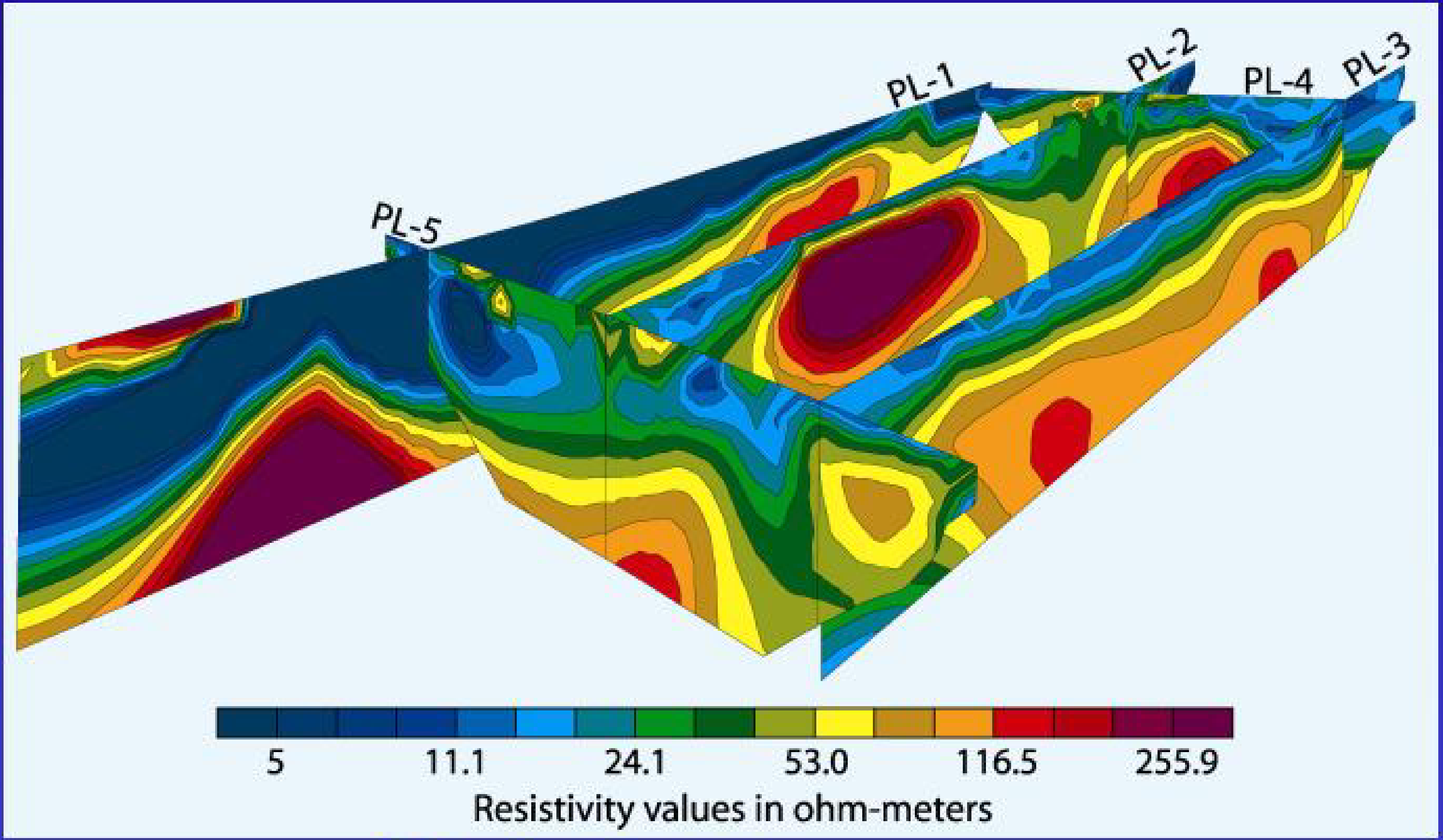
Research topics– continued



3D Data collection and processing

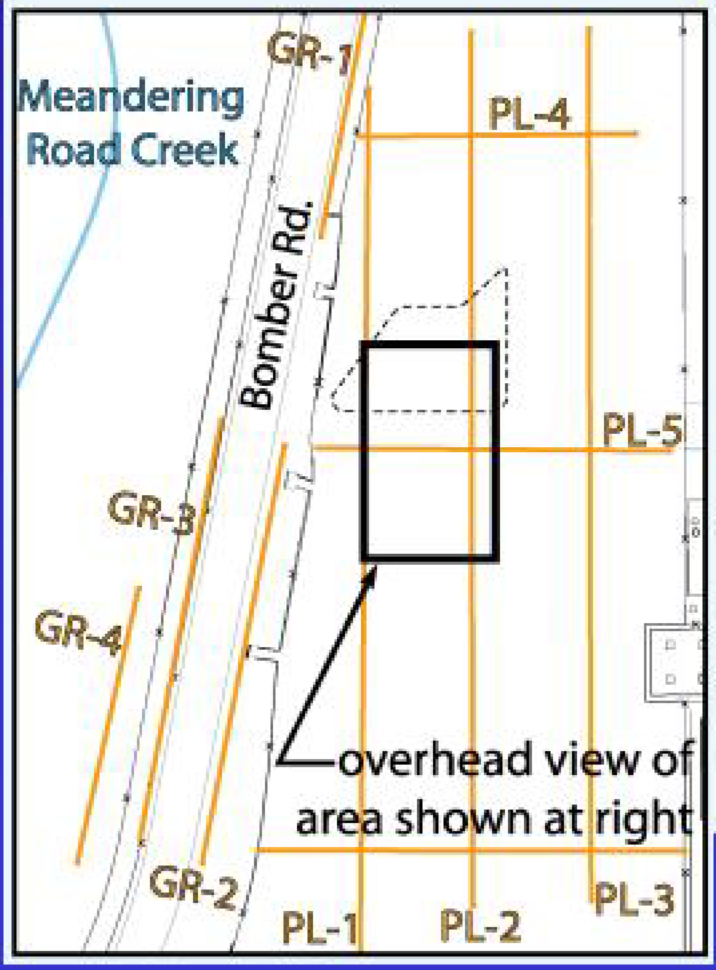
- **2-D and 3-D resistivity**
- **3-D Radar** (Mark P. Grasmueck, RSMAS University of Miami)
- **Seismic reflection**

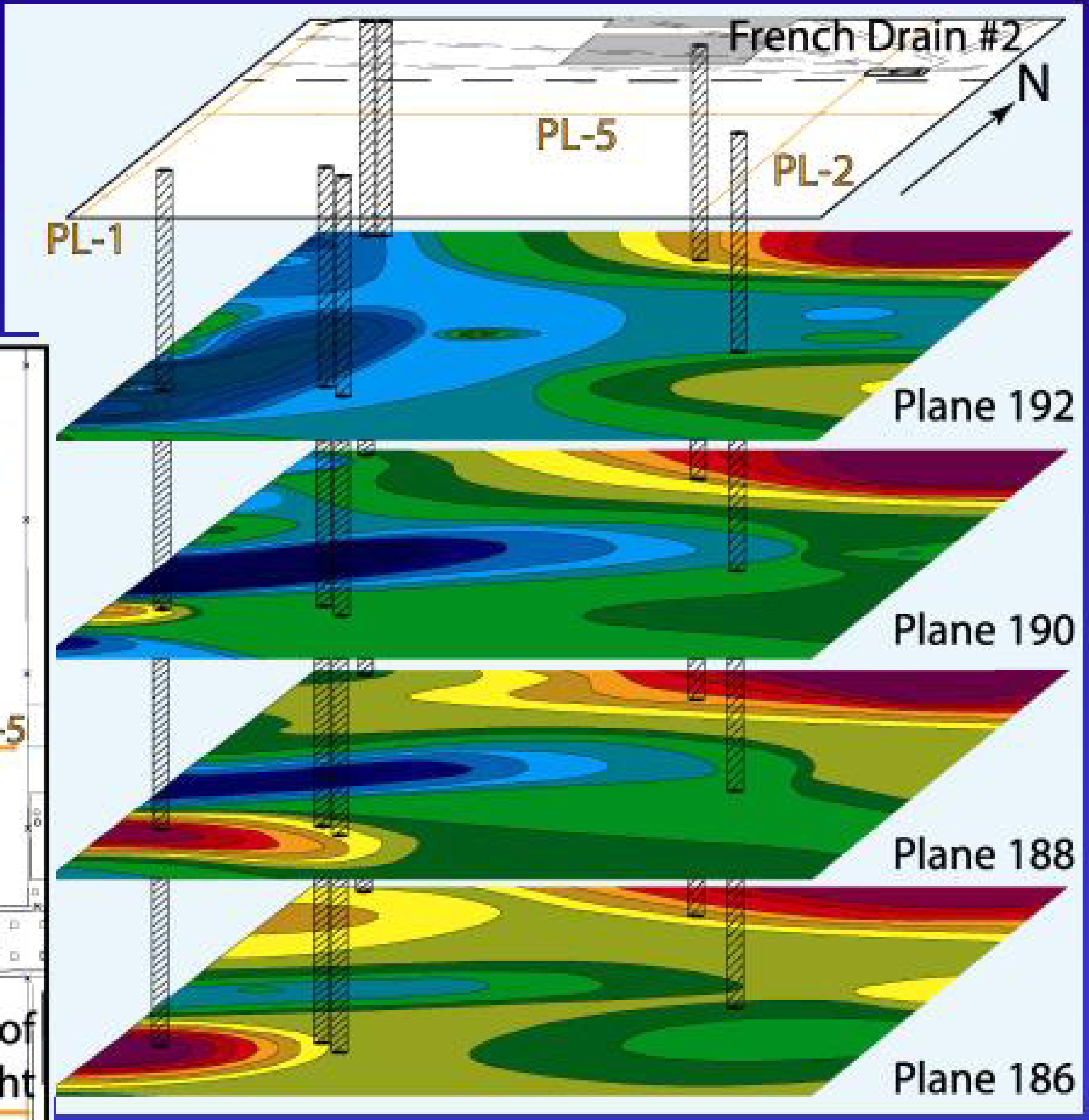
2D resistivity in a 3-D Fence Diagram



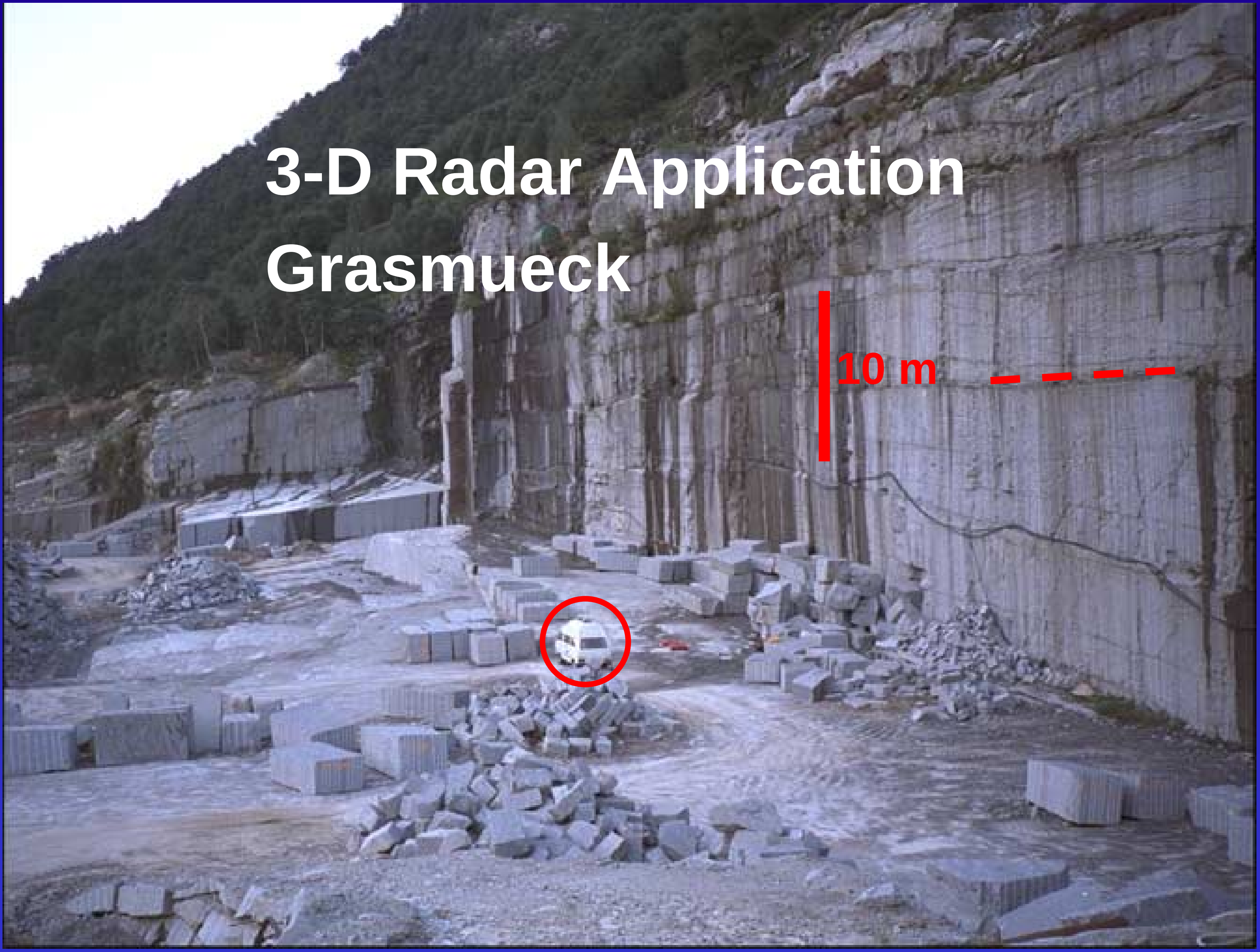
Example from **Chris Braun** ABF in Fort Worth, TX

3D representation of inverted resistivity values along four horizontal planes at elevations of 192, 190, 188, and 186 m.

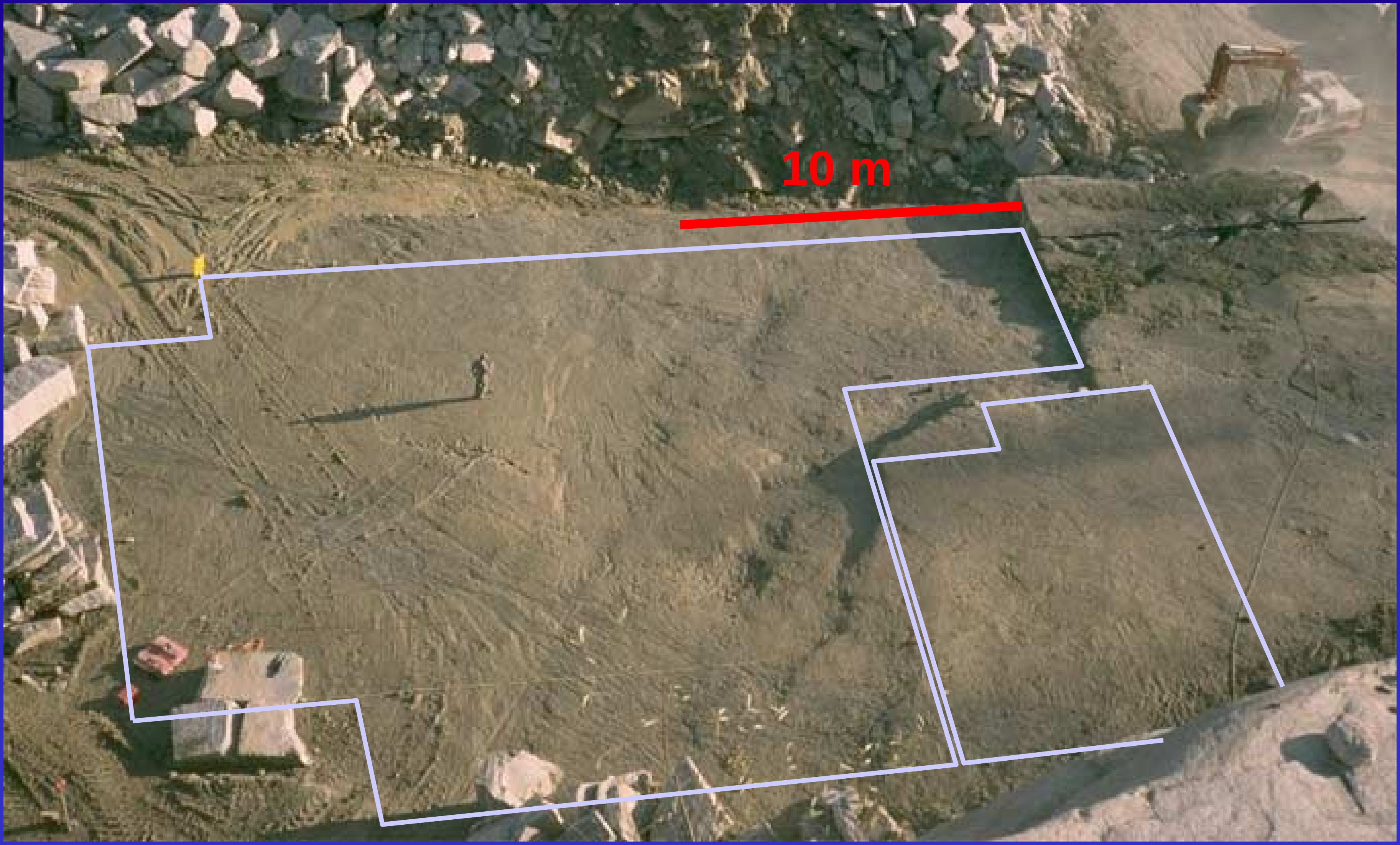




Braun, Dodec 2001

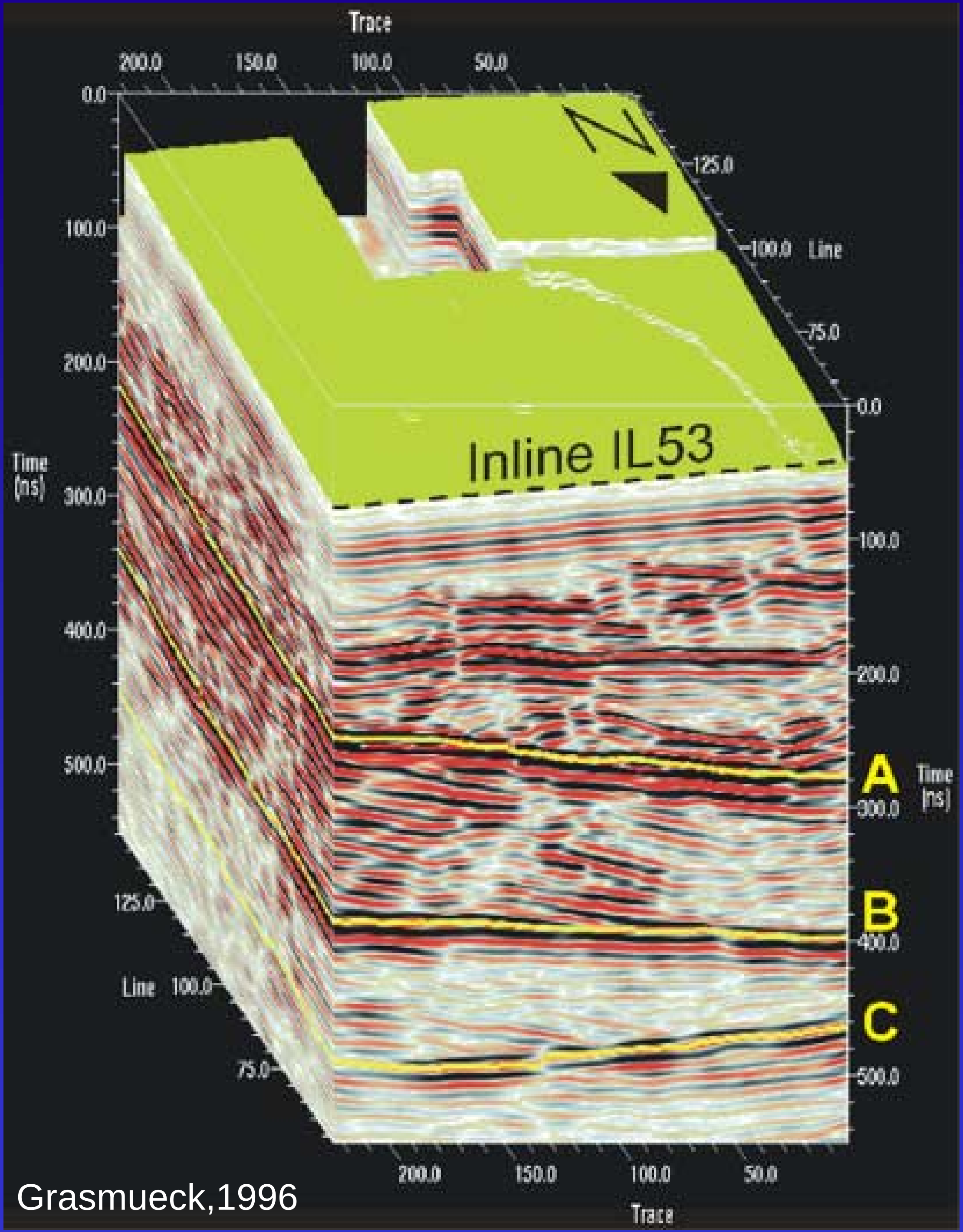

3-D Radar Application
Grasmueck
10 m

3-D GPR Survey Outline

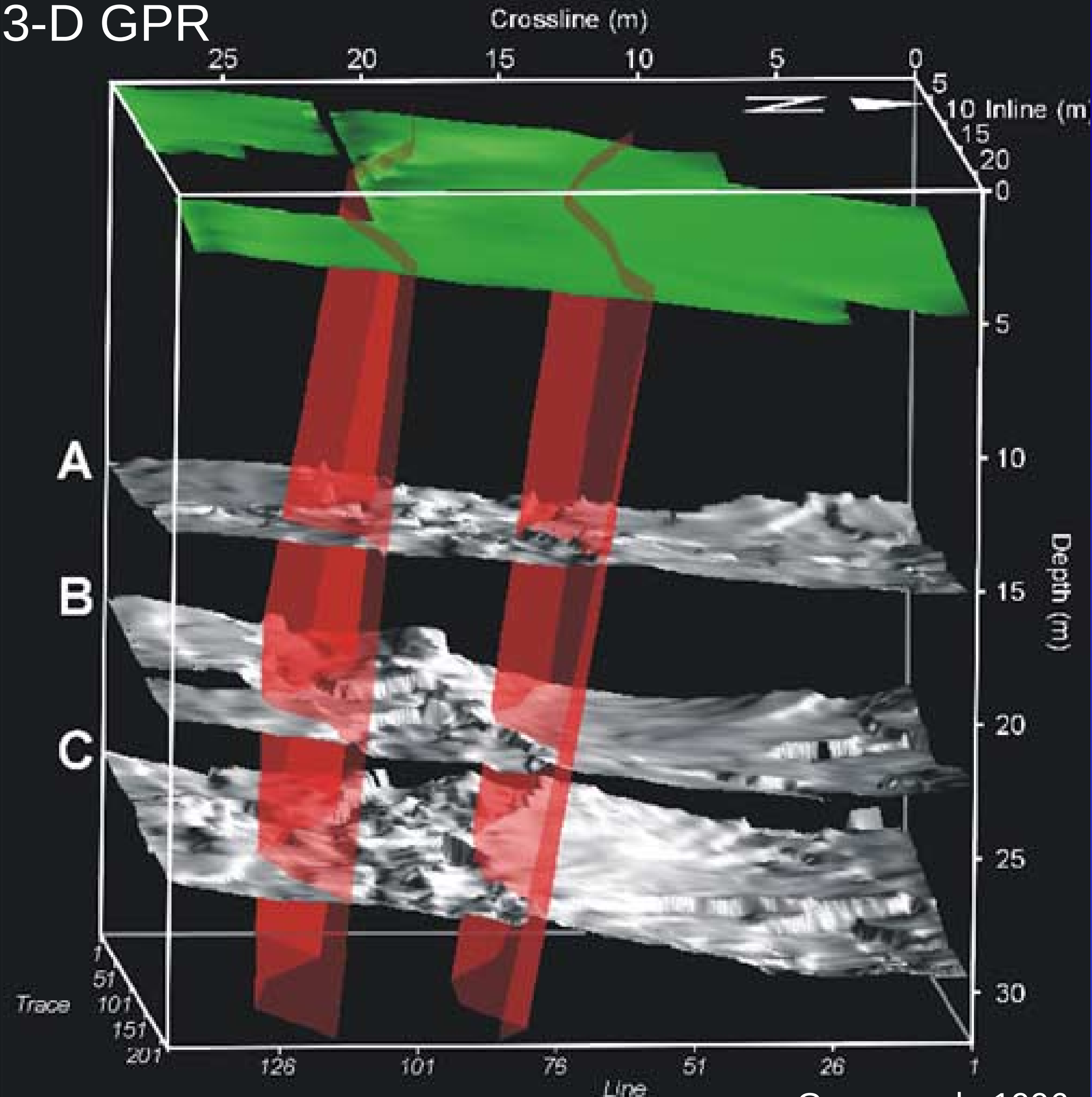


3-D Ground Penetrating Radar Acquisition

3-D GPR


Trace
200.0
150.0
100.0
50.0
0.0
100.0
200.0
Time (ns)
300.0
400.0
500.0
125.0
Line
100.0
75.0
N
125.0
100.0 Line
75.0
0.0
Inline IL53
100.0
200.0
A
Time (ns)
300.0
B
400.0
C
500.0
200.0
150.0
100.0
50.0
Trace
Grasmueck,1996

3-D GPR

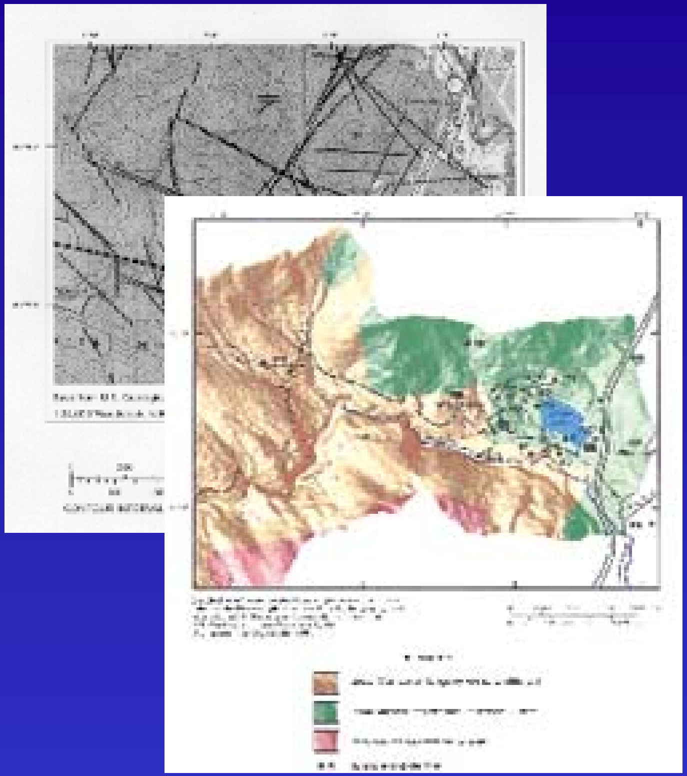


Grasmueck, 1996

Interpretation Needs

- Integrate data over various scales
- Upscaling: Integrate data from multiple disciplines, including geologic mapping, geochemical data – NAWQA, isotope dating
- Assess transferablility:
  Can data collected at multiple sites be statistically or geostatistically meaningful?
  Is the measurement parameter meaningful, and at what scale?

Measurements at Regional Scale



Remote sensing:

- Thematic mapping
- Airborne EM
- Temperature – non urban areas

- Seismic Reflection: 1 Kilometer deep and apart (Odum)