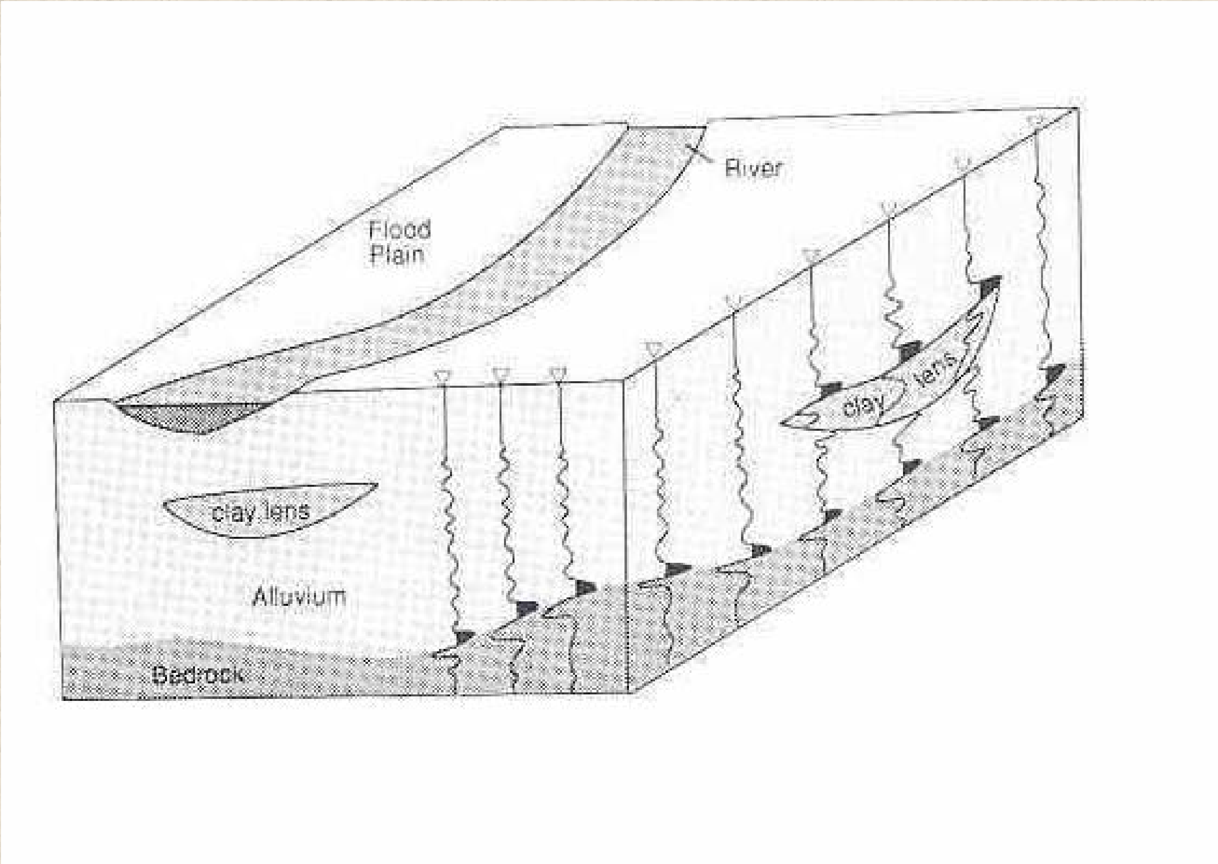
High Resolution Geophysics: A Better View of the Subsurface



By John Jansen, P.G., Ph.D., Aquifer Science and Technology

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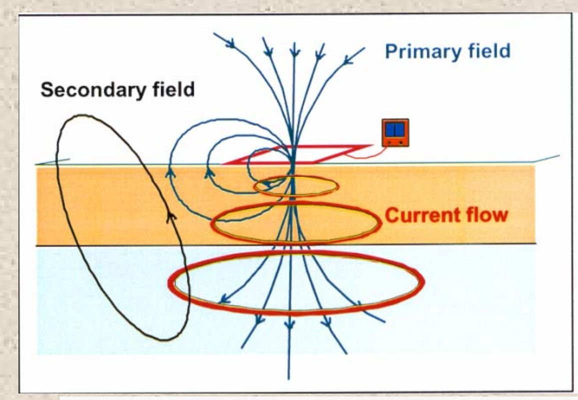
Geologist Use Only Part of the Information Available To Them

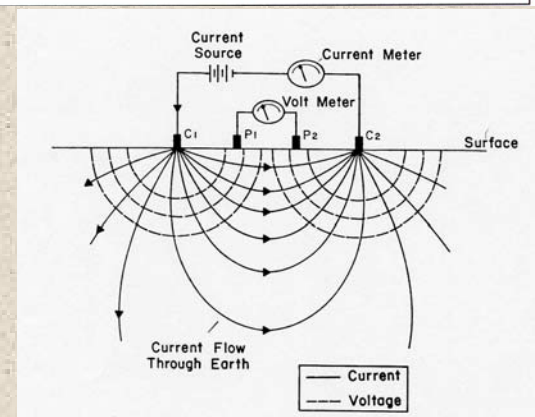
•Most Geologist rely primarily on visual information
•Some use one or more of their other four senses in special cases
•Unfortunately its hard to see through dirt
•Fortunately the earth radiates and propagates many other forms of energy
•Usually this information is never measured and never used
•Most Geologists are nearly deaf to the earth

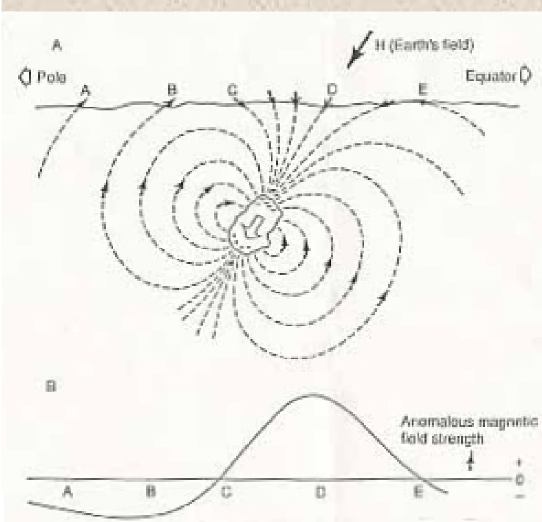
So why has the use of Geophysics been limited?

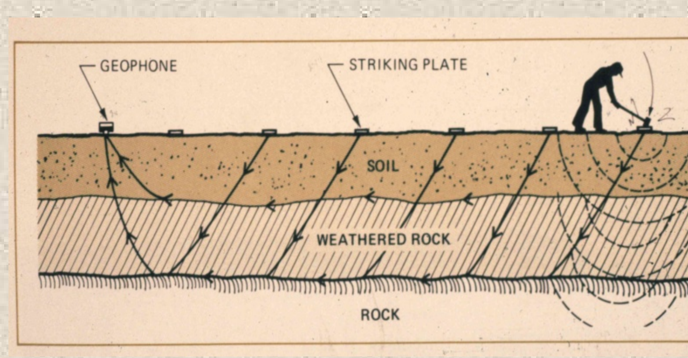
Common Geophysical Methods

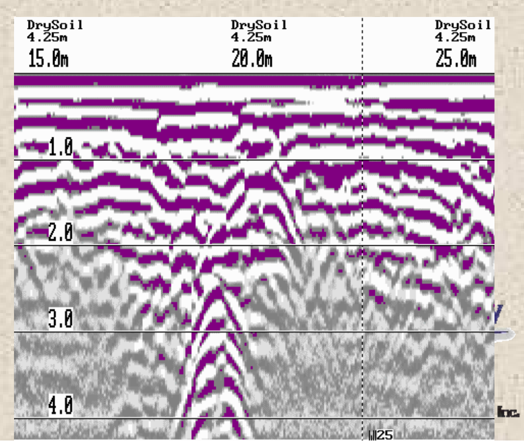
- Electromagnetics (EM)
- Seismic (Refraction or Reflection)
- Electrical Resistivity (ER)
- Magnetometry
- Gravity Surveys
- Ground Penetrating Radar (GPR)











Factors to Consider When Specifying Survey Parameters

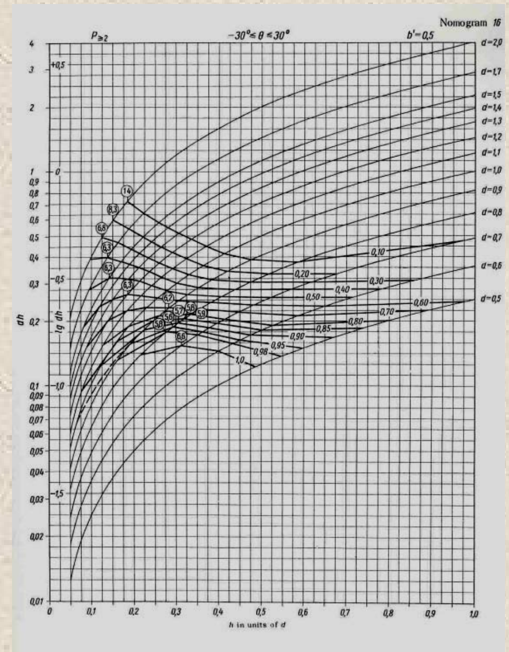
- Characteristics of the target
- Characteristics of the Site
- Desired Resolution
- Optimal Geophysical Method
- Minimum sampling density
- Signal to noise ratio

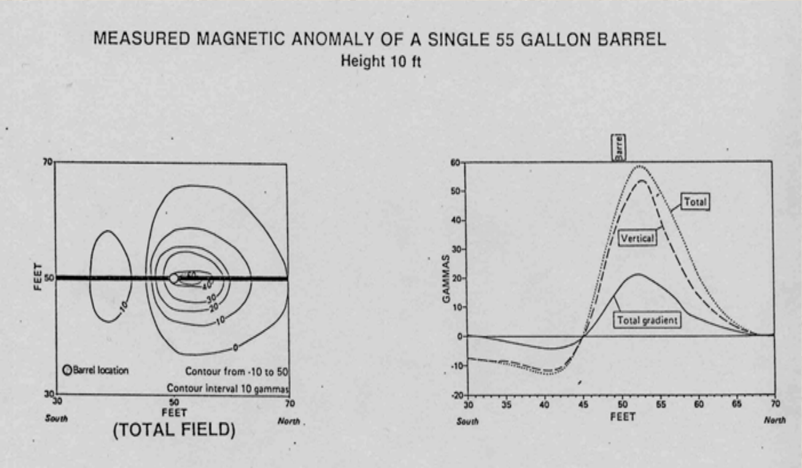
Minimum Resolution

- What level of detail do you want to see?
- How big is the target?
- Are you looking for the center of the mass or do you want to define the edges?
- Resolution of the major methods varies

Probability of Detection

- Sampling density must be high enough to detect anomaly
- Must determine size and magnitude of expected anomaly relative to ambient noise level
- Use probability tables to pick minimum station spacing
- Cutting station interval in half increases stations four-fold
- 20 by 20 foot grid too coarse for most USTs
- 10 by 10 foot grid too coarse for finding barrels
- "Continuous" sampling systems increase density along line, but line spacing still an issue





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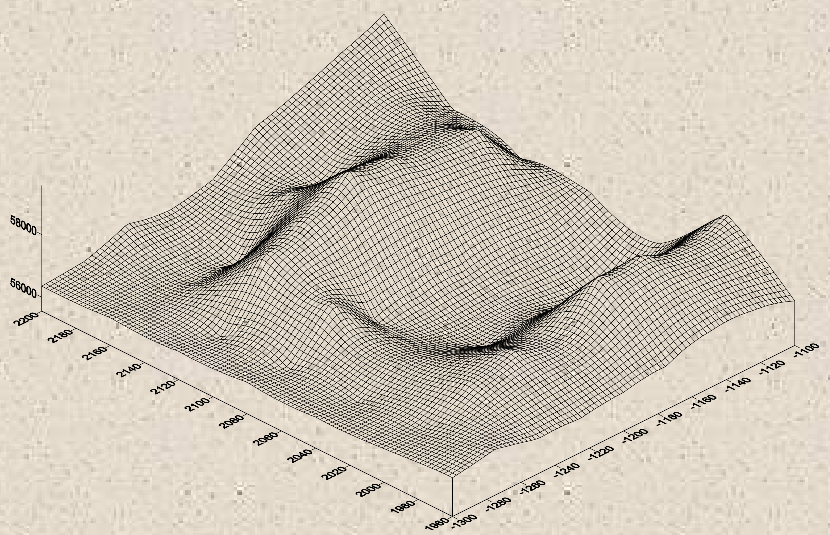
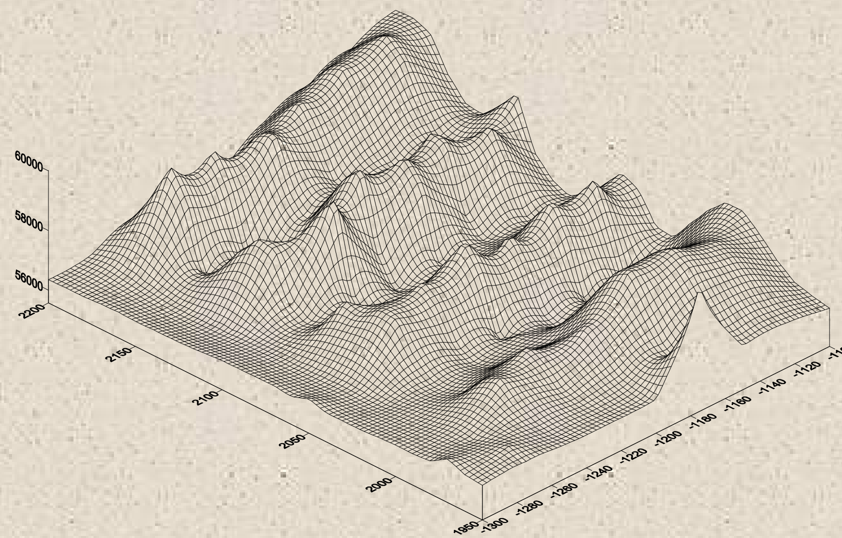
Spatial Aliasing

- **Sampling density must be high enough to resolve feature of interest**



Barrel disposal area at 40 feet station interval



Same survey at 10 foot station interval

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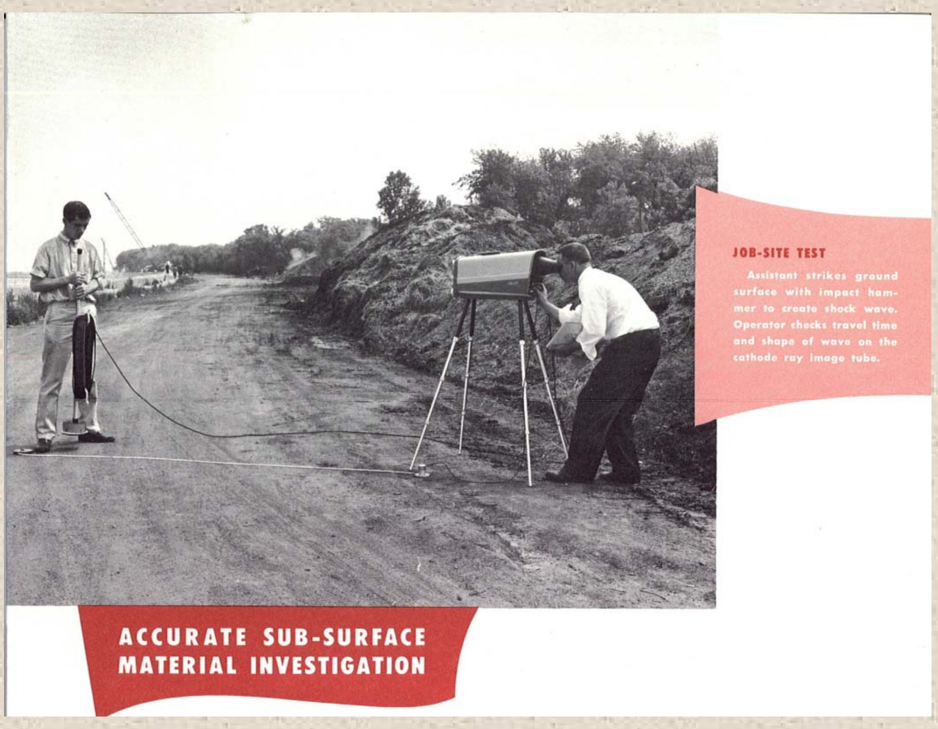
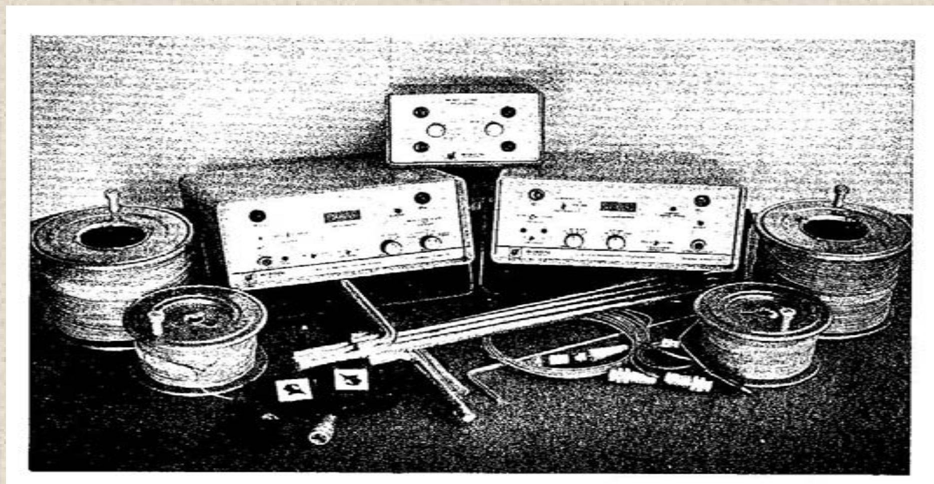
State of the Art 1970's



Single channel seismograph with no memory



Simple resistivity systems with four electrodes

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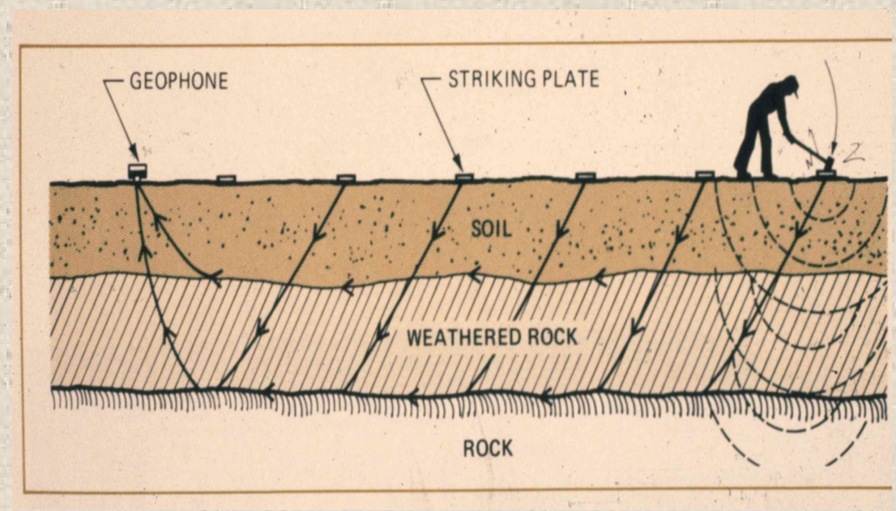
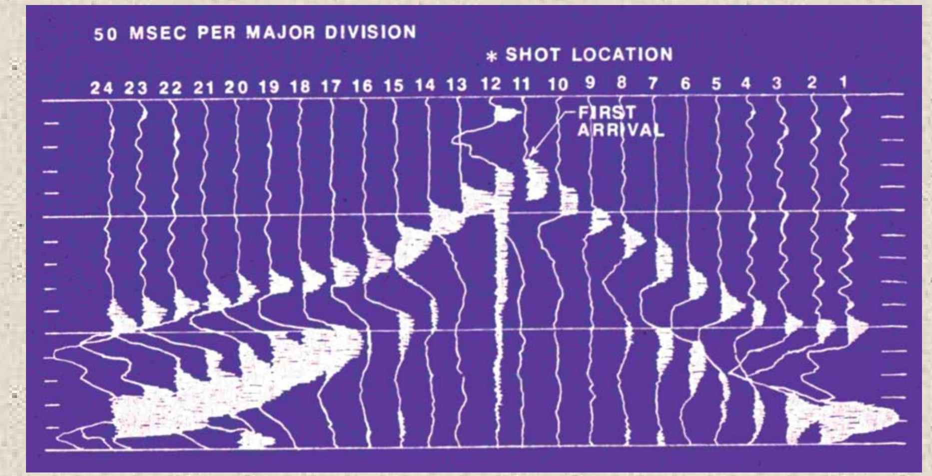
Refraction Theory





- Measures seismic velocity of soil and rock.
- The first arrival used for interpretation.
- Multiple shots are used to increase resolution and correct for dipping beds.
- Shear wave surveys used for foundation studies
- Thin layers, lower velocity layers at depth, and steep dips will all produce erroneous interpretations

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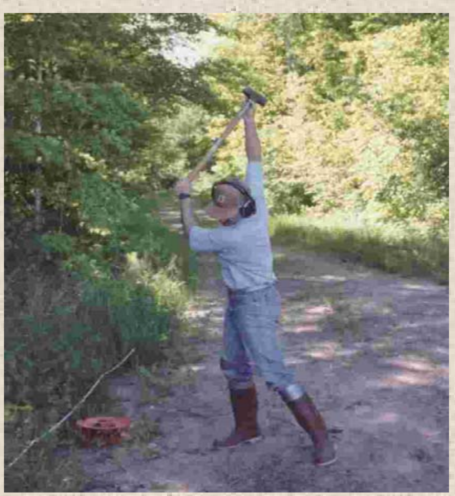
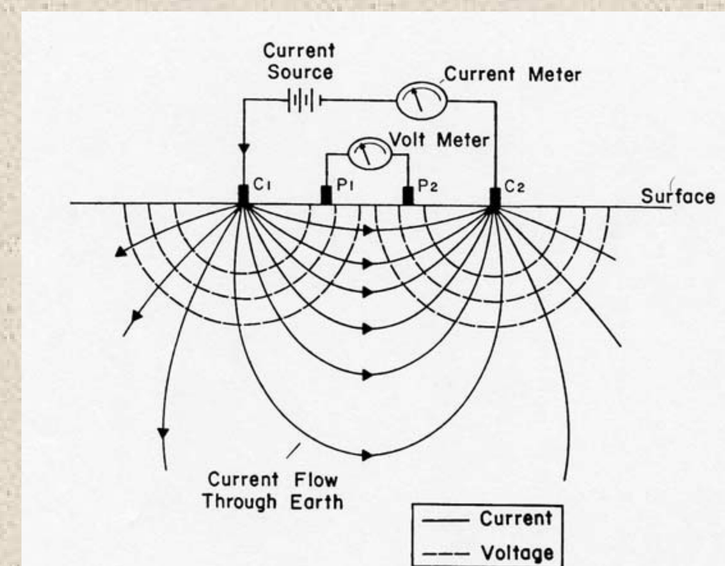
Seismic Equipment

- **Seismic Source** (explosives, shot gun, hammer & plate)
- **Multiple Channel Seismograph**
- **Geophones**
- **Spread Cables**



Electrical Resistivity Theory

- **Electrical Current is induced into the ground through two current electrodes.**
- **Voltage drop is measured across potential electrodes.**
- **Electrode array is expanded to increase depth.**
- **Measured in ohm-meters**
- **Modern systems use 48 to 56 (or more) electrodes with automated switching system**



Manual Resistivity Surveys

- Four electrodes moved by hand
- Surveys generally limited to vertical soundings or single depth profiles
- Typical productivity of 10 to 20 measurements in an hour or two

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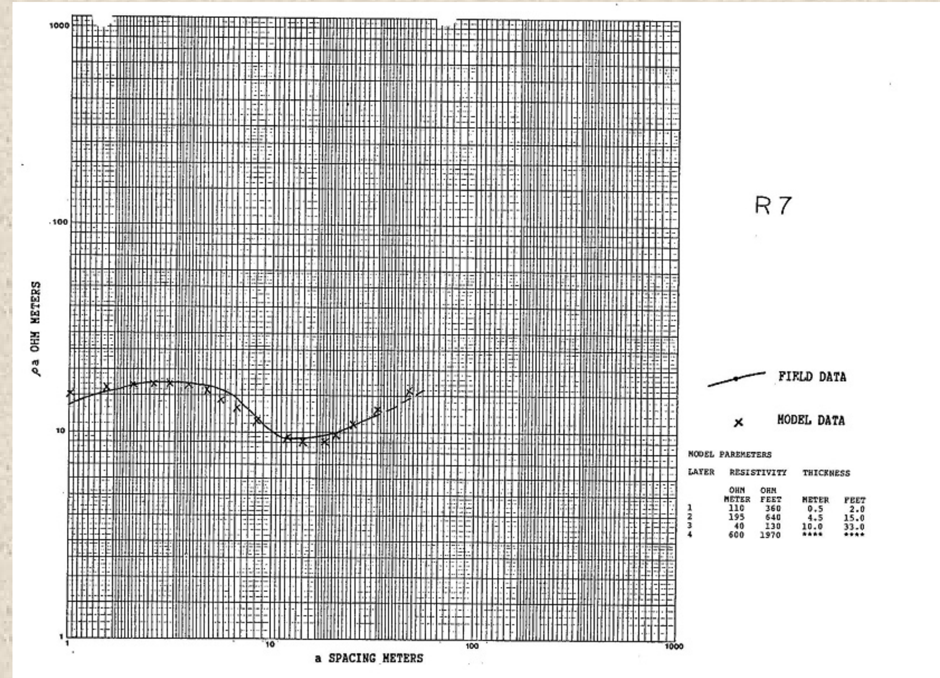
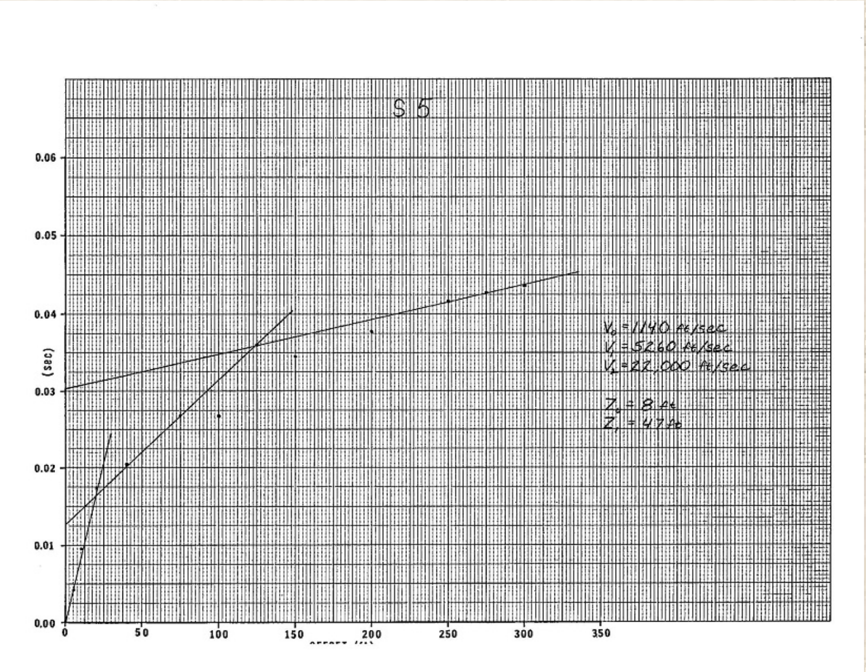
Layer Cake Processing





- Curve Matching
- Simple one Dimensional modeling
- Poor two dimensional resolution

- Layer cake or dipping layer refraction processing

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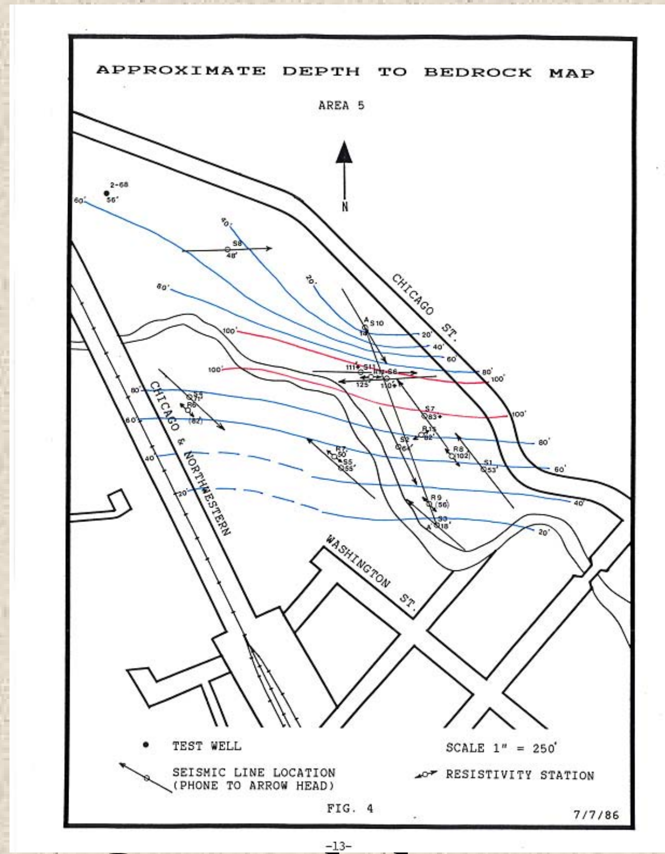
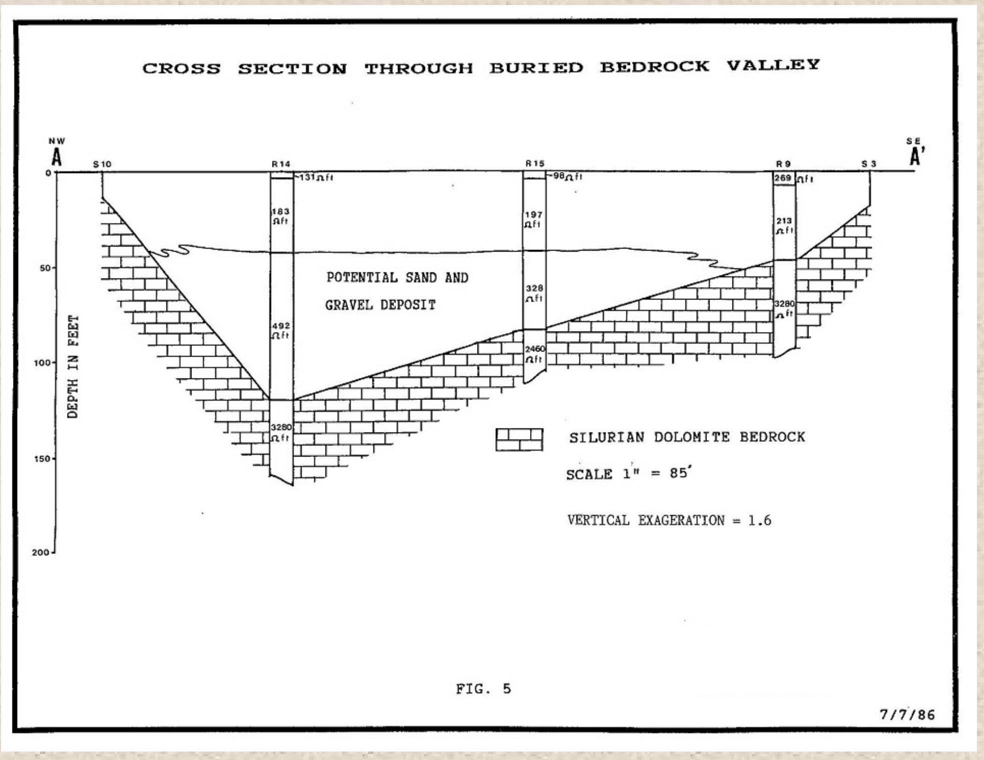
Typical 1980s Survey Results





- **General shape and stratigraphy of aquifer**
- **Poor lateral resolution**
- **Results highly dependent on skill of geophysicist and site conditions**

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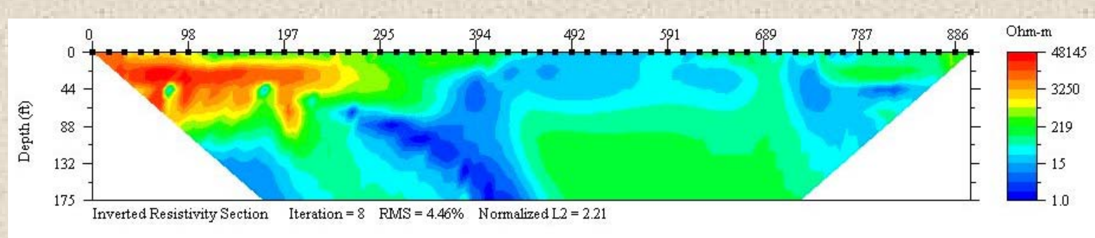
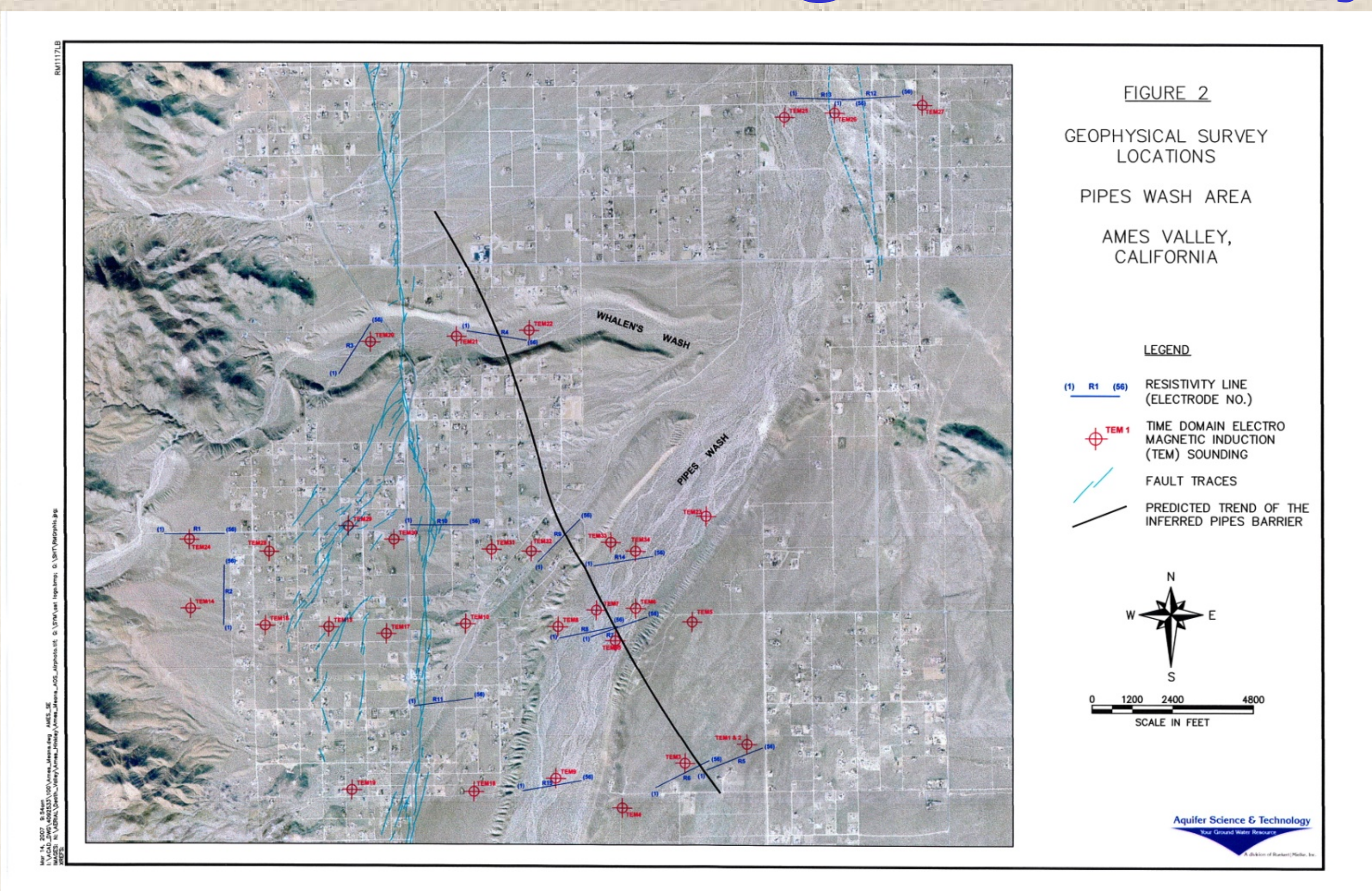
Contemporary Resistivity System

•56 channel, 5 to 10 meter spacing (900 to 1,800 foot spread length)
•Electronic switching system swaps electrode pairs
•Much greater sampling density
•Typical Productivity hundreds of reading per hour



Ames, Means and Johnson Valleys Artificial Recharge Feasibility Study



- •15 resistivity soundings and 35 TEM soundings
- •Mapping faults and distribution of grain size to bedrock
- •Supporting a Basin Conceptual Model by KJT

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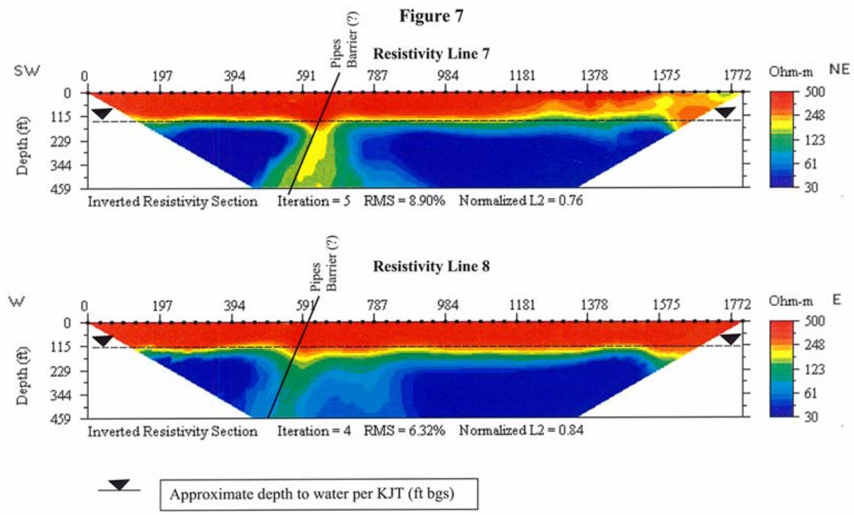
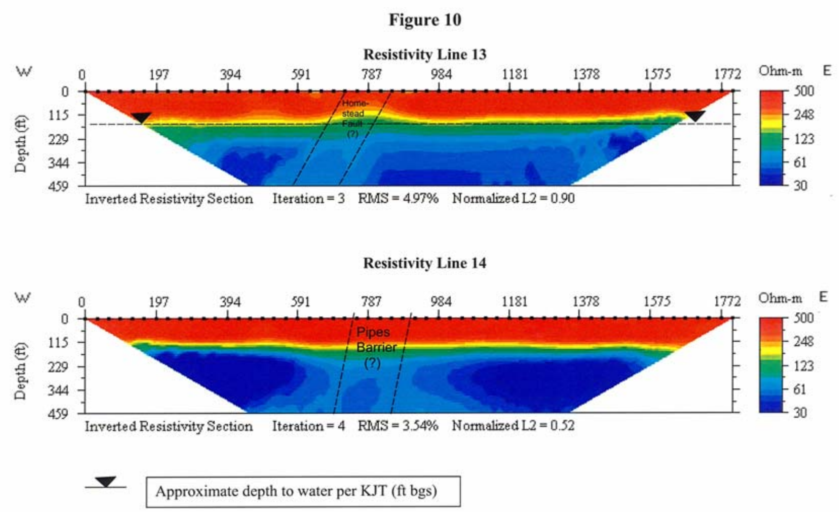
Faults and Depth to Water Stood Out





- Faults show up as resistive anomalies due to paradox of anisotropy
- Water table shows up as drop in resistivity

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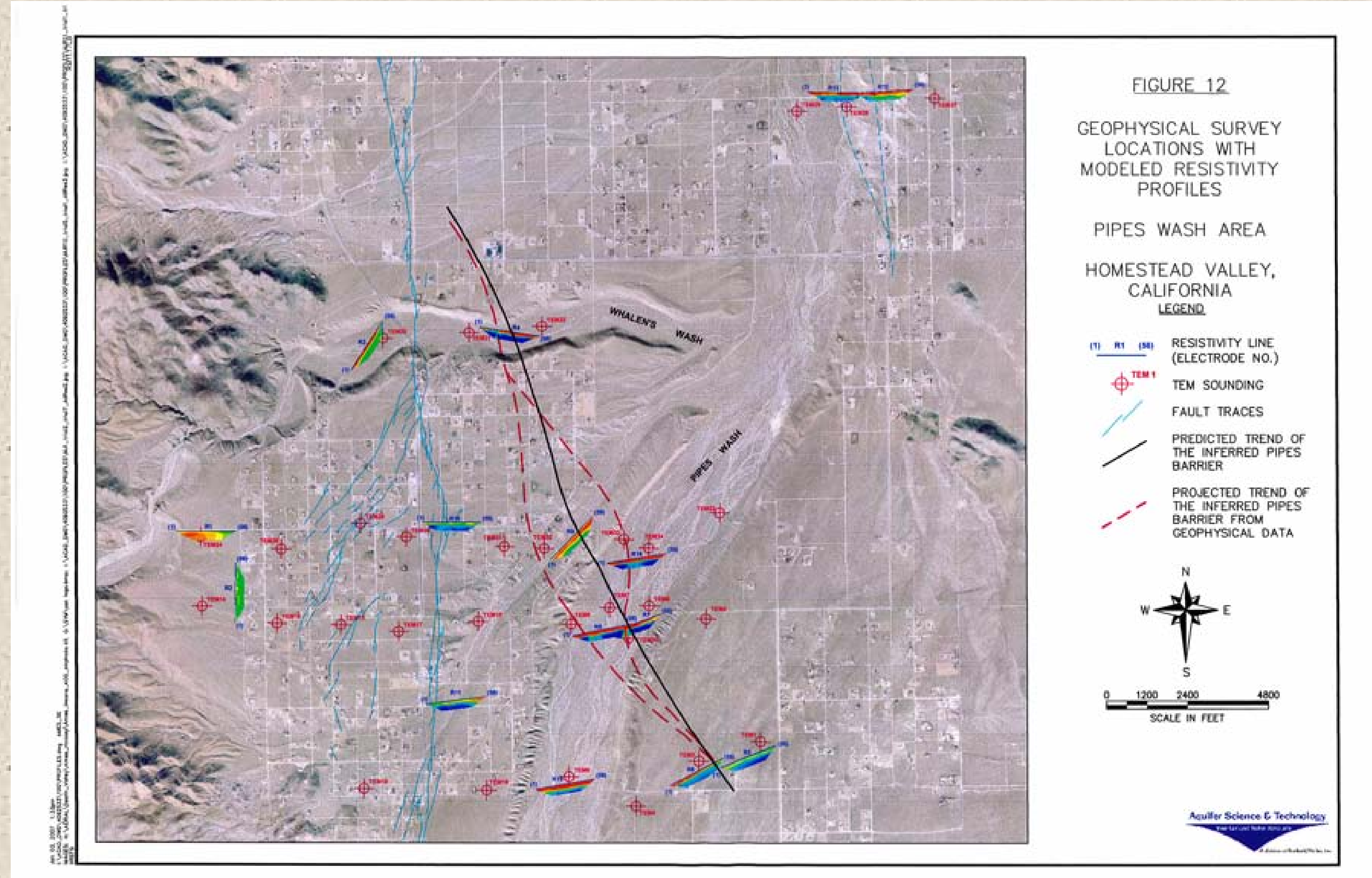
Resistivity Data Refined Regional Fault Interpretation



- Inferred Pipes Barrier appears to have fault splay
- Homestead Valley Fault appears to have splay
- Additional fault splays off Johnson Valley Fault

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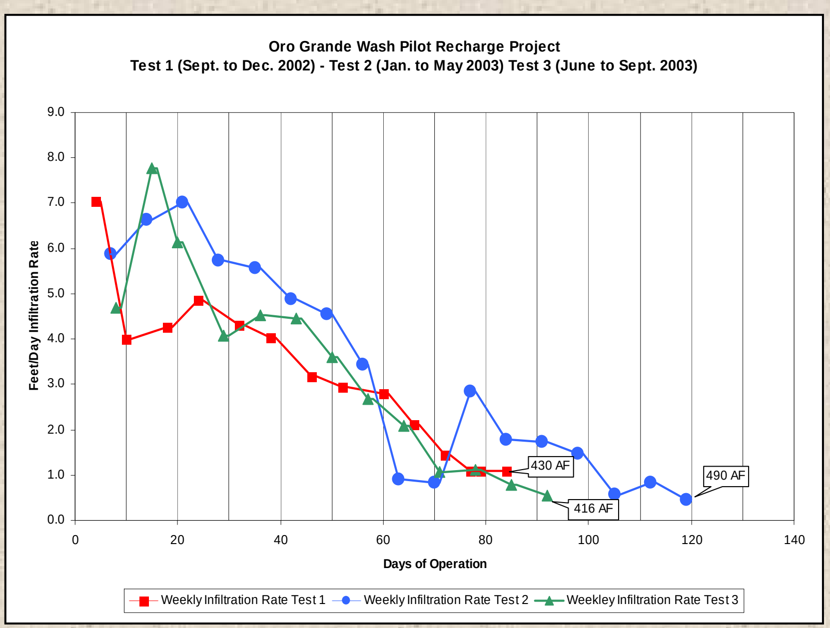
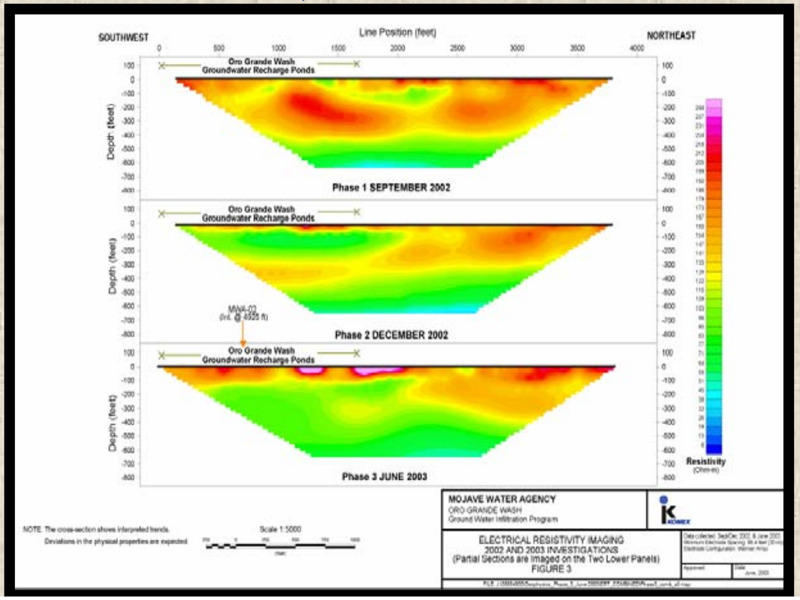
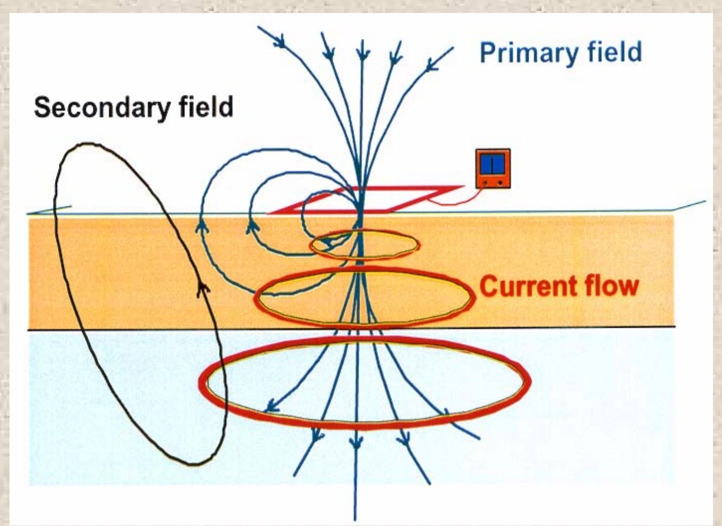
2002 – 2003
Recharge Pilot Project





- Recharged 1,336 AF in three tests over one year
- ~3.25 ft/day average recharge
- Resistivity indicated water reached saturated zone
- Site could take water easily

Physical Principles of TEM Soundings



- Square transmitter loop of 10 to 1000 meters on a side laid out on surface
- Current of several amps cut off nearly instantaneously
- Creates broad frequency EM pulse
- Nearly vertical propagation of pulse induces eddy currents in conductive units
- Receiver measures magnetic field from eddy current over time
- Data is modeled into layered system

TEM Survey Mapped Clay Layer at Depth, Oro Grande Wash, CA

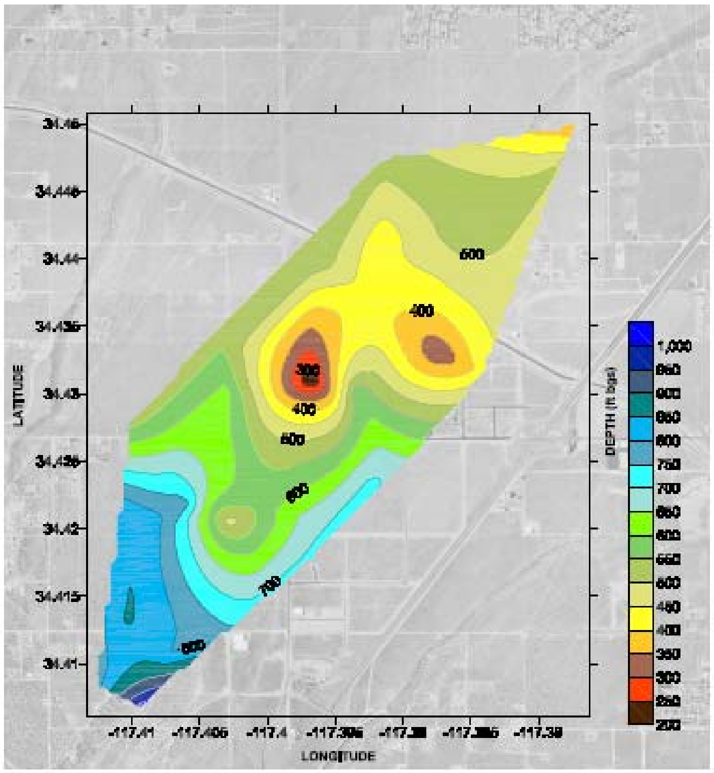
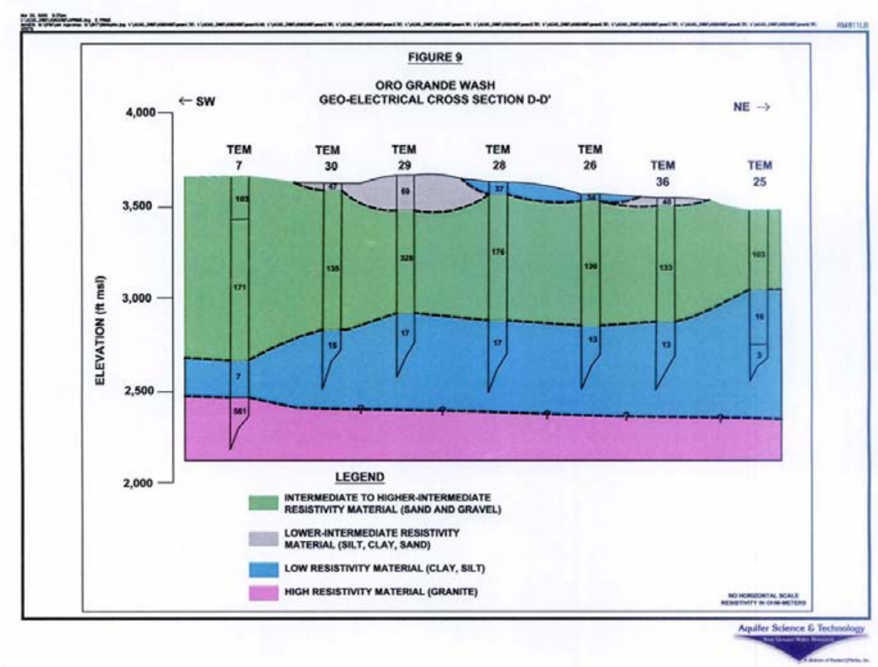


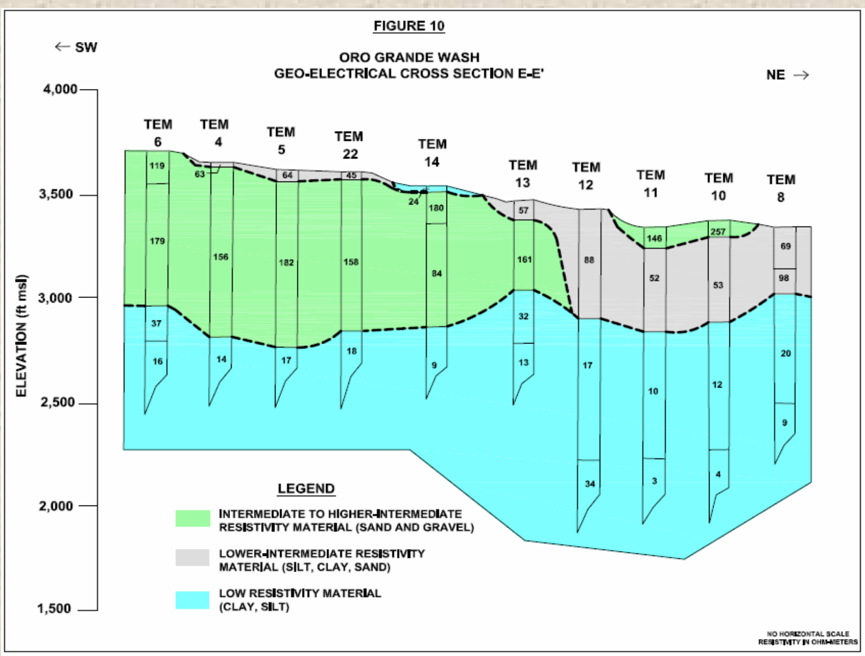
FIGURE 15

DEPTH TO TOP OF THE LOWER CLAY

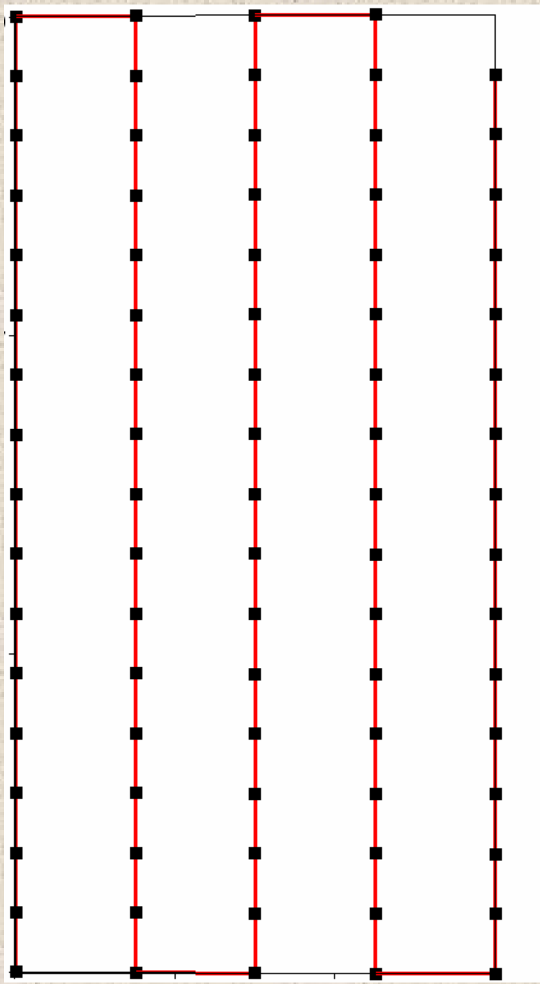
ORO GRANDE WASH

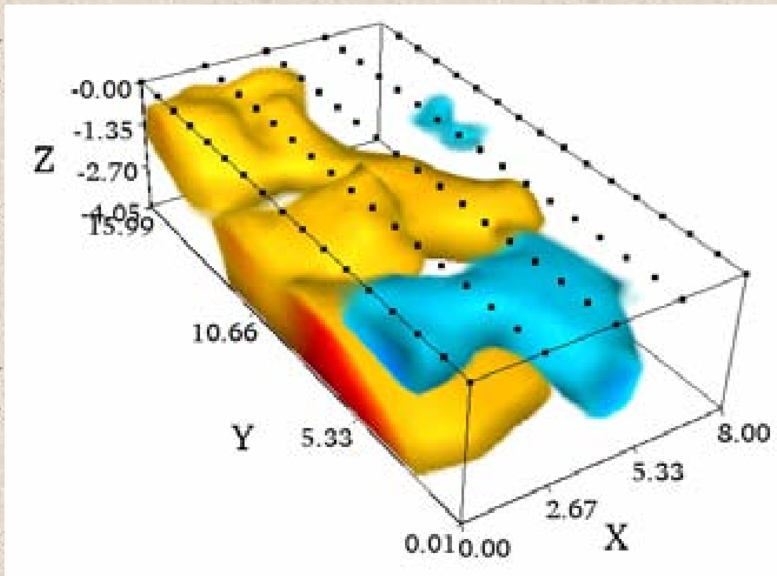
MOJAVE WATER AGENCY
VICTORVILLE, CA





Three Dimensional Resistivity Surveys





From *Xianjin Yang and Mats Lagmanson, Advanced Geosciences, Inc., Austin, Texas, 2006*

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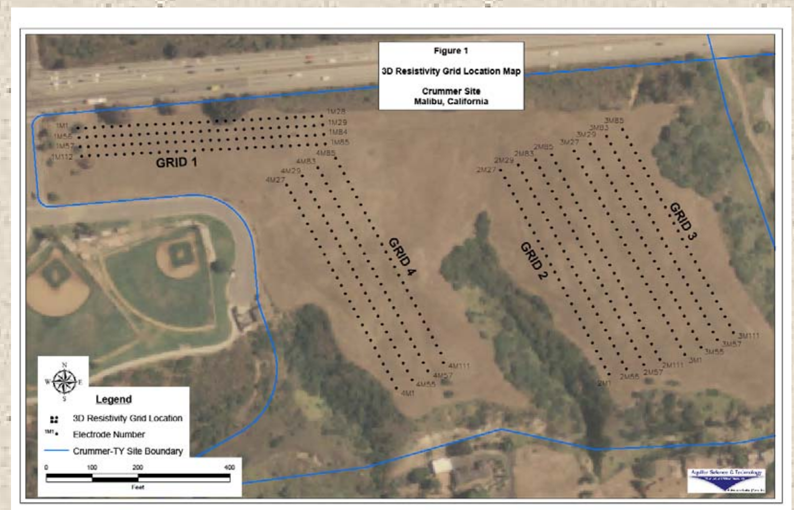
Mapping Faults and Slump Blocks in Malibu, CA



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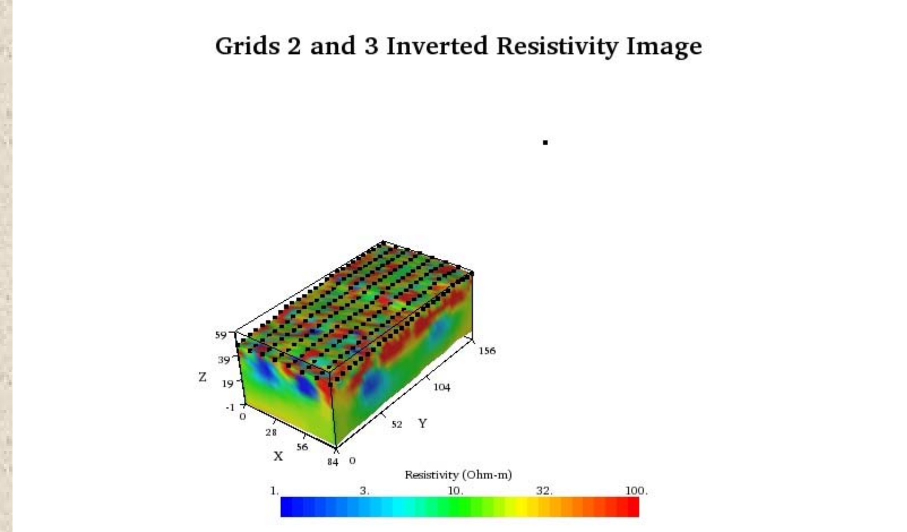
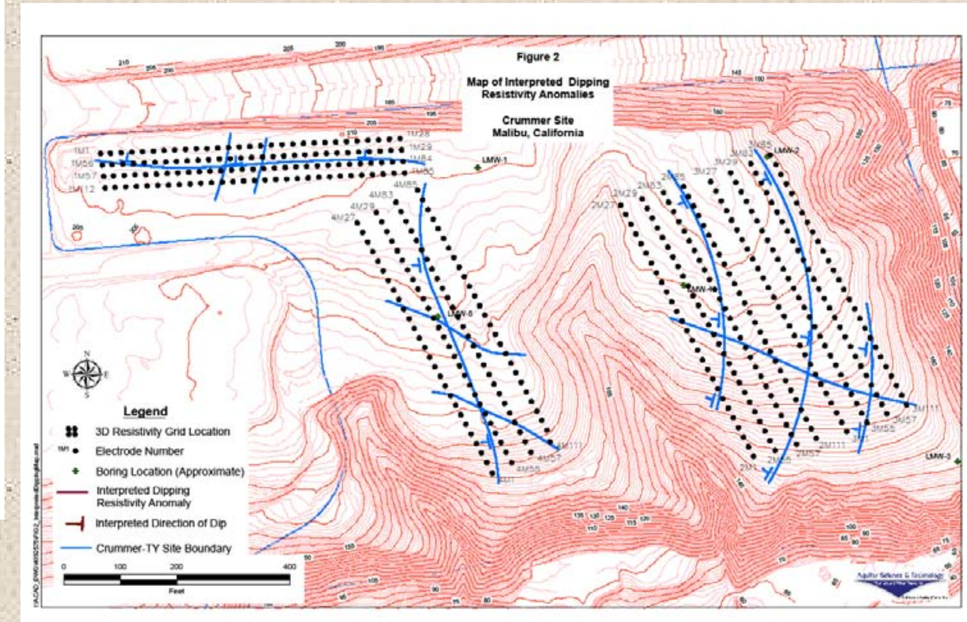
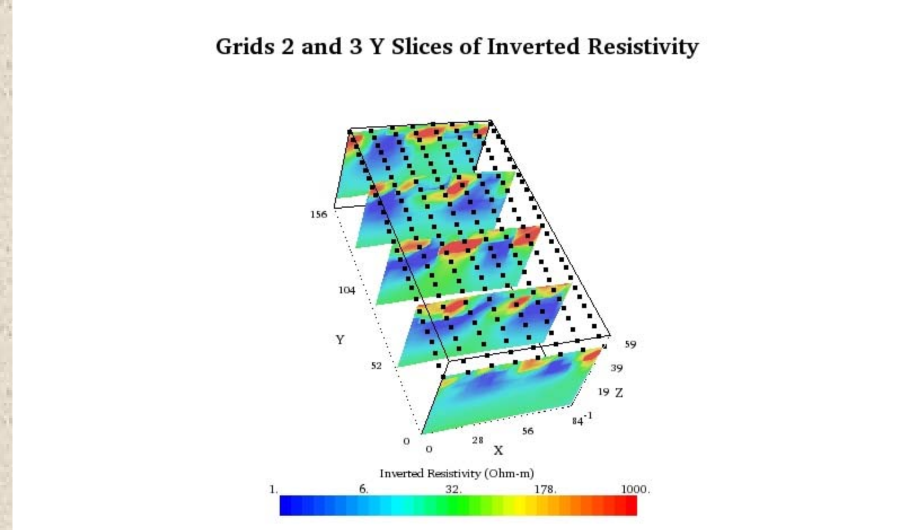
3D Resistivity Volume



Interpreted Faults and Scarps



Resistivity Slices of Block



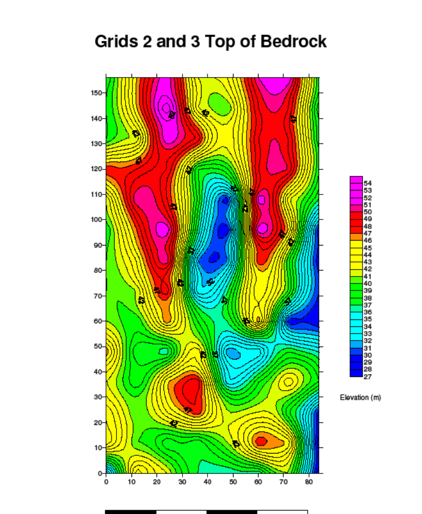


Figure 5

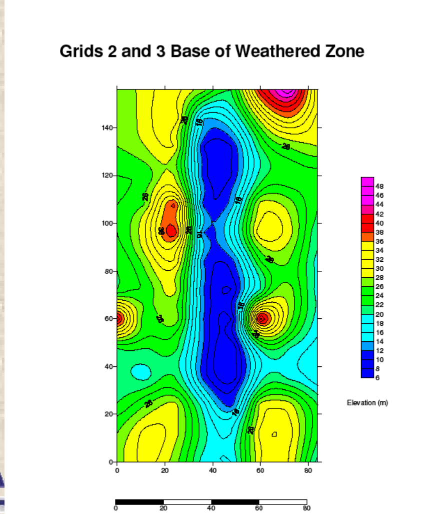
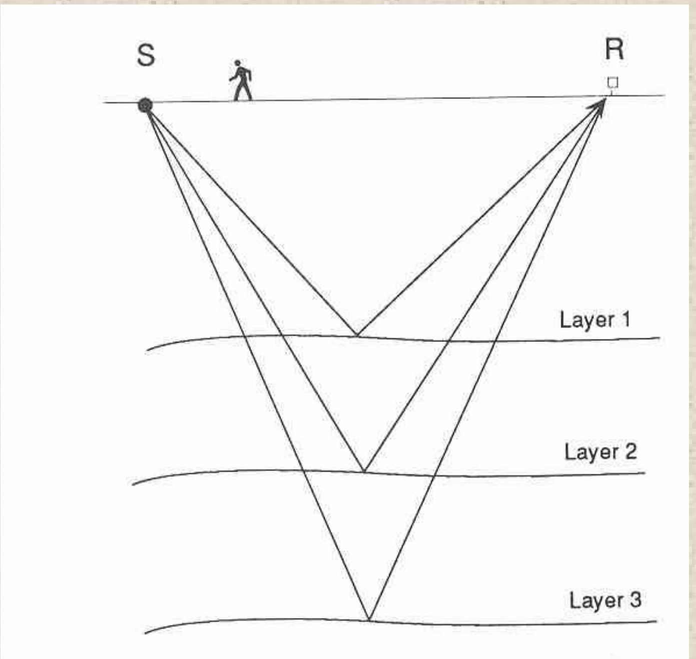
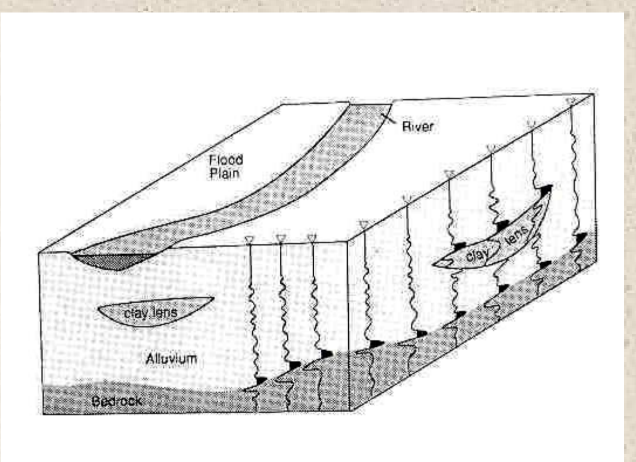


Figure 6

Seismic Reflection

- Not a common application in ground water studies
- The depth of penetration can be several times surface array length.
- Produces a continuous image of the subsurface that provides a time cross-section that can be converted into a depth cross-section.
- Can handle low velocity layers beneath high velocity layers.
- Requires more sophisticated field equipment, processing, and field procedures.
- Can be difficult to apply to shallow targets (above approximately 50 to 100 feet).





Typical Reflection Crew and Vibroseis Source

nology

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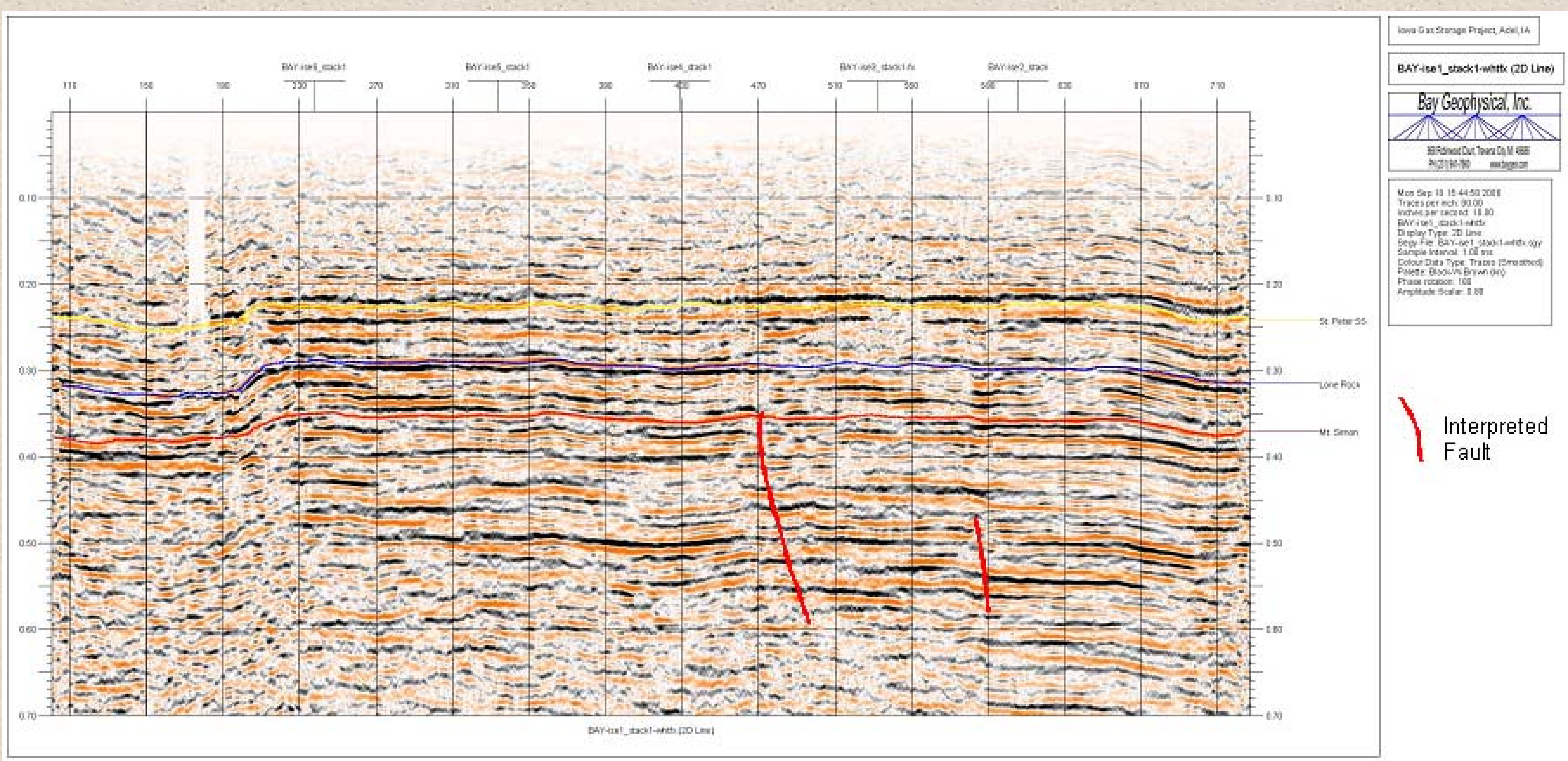
Line 1



- Steep fold on southern end
- Gentler fold on northern end
- One fault cutting Mount Simon
- Deeper fault terminates in fold below Mount Simon

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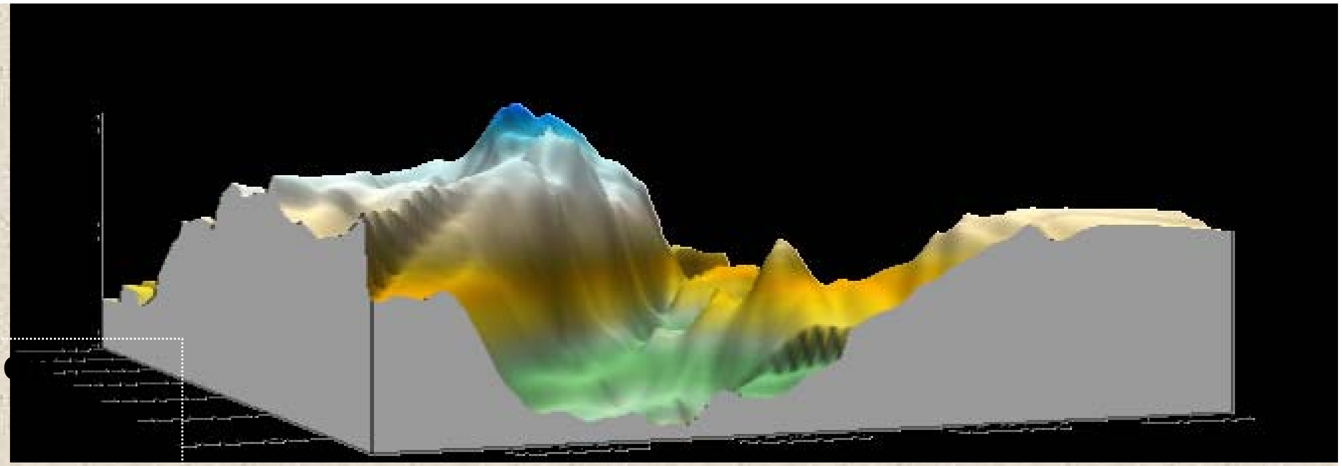
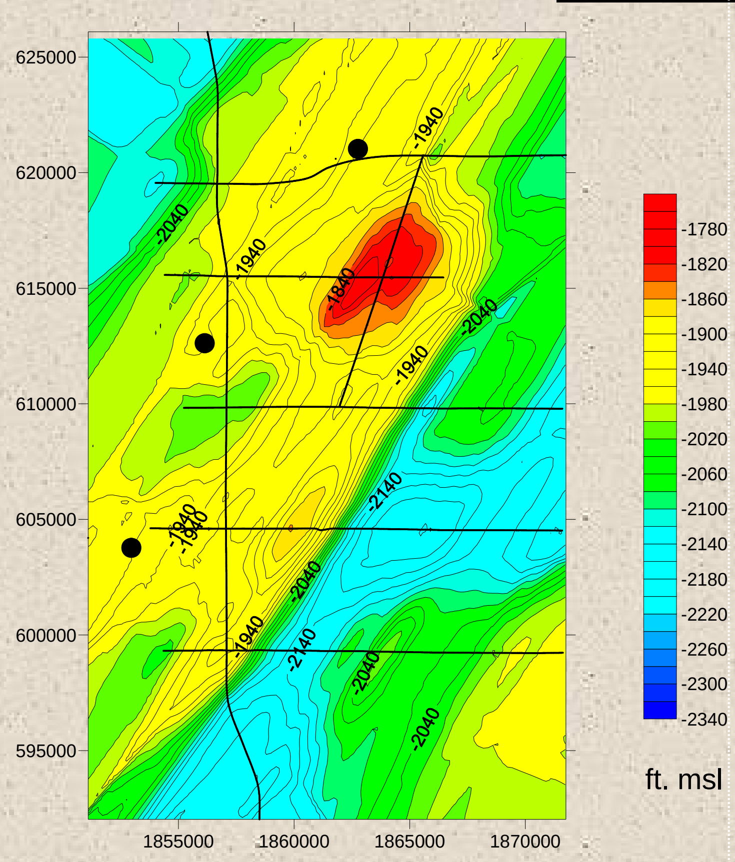
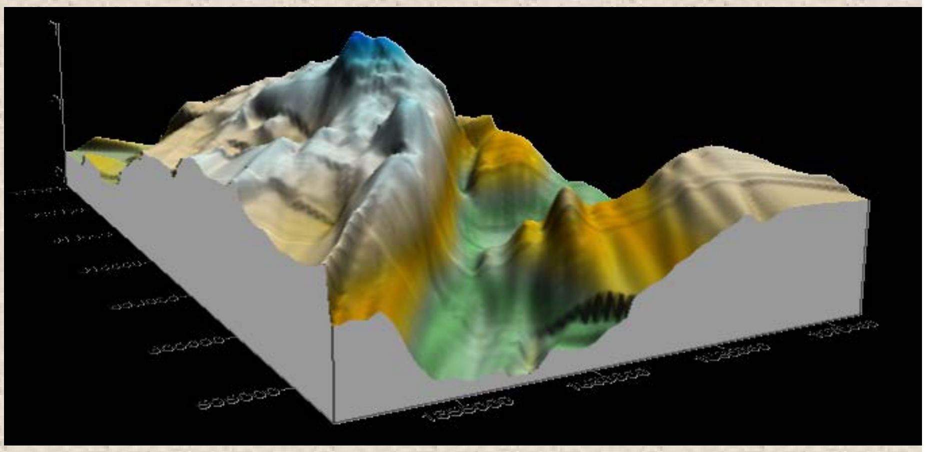


Mount Simon Elevation

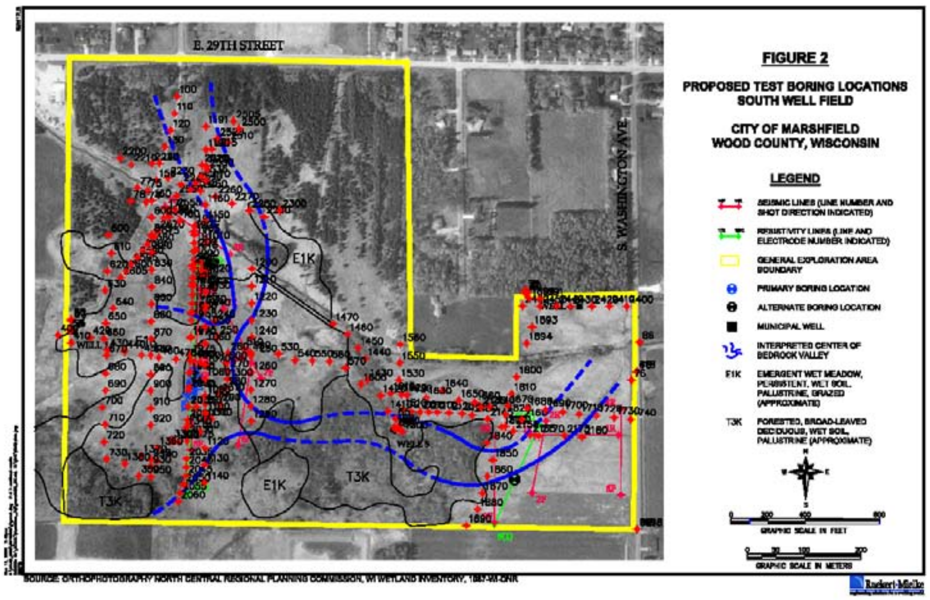


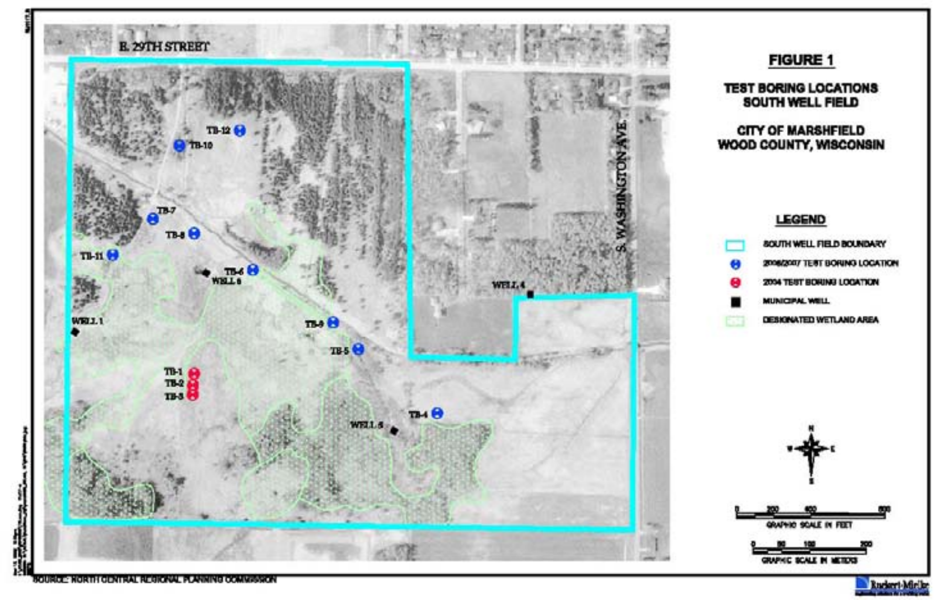
Mount Simon Surface



● Well location

Mapping Bedrock Valleys Where Seismic Refraction Fails





- •Mapping a shallow bedrock valley system in Marshfield, Wisconsin
- •Existing well field with several aging sand and gravel wells
- •Seismic refraction and electrical resistivity survey identified simple valley shape with some areas of thick sand and gravel deposits
- •Borings hit shallow bedrock

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Gravity Surveys

- The gravity method uses a sensitive balance, called a gravimeter, to measure variations in the force of gravity at the surface caused by variations in the density of the subsurface.
- Often used to estimate depth of basins, map bedrock valleys, find faults, or map other geologic structures
- Microgravity uses a more sensitive gravimeter to detect small near surface features, such as voids or cavities.
- Can handle steeper dips than seismic methods
- Produces non-unique solution
- Structures that with similar density to background aren't detectable

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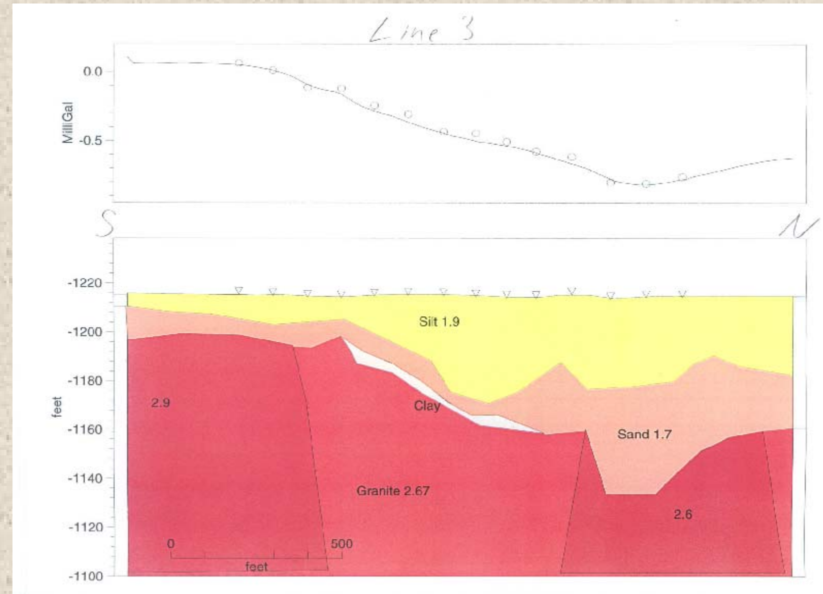
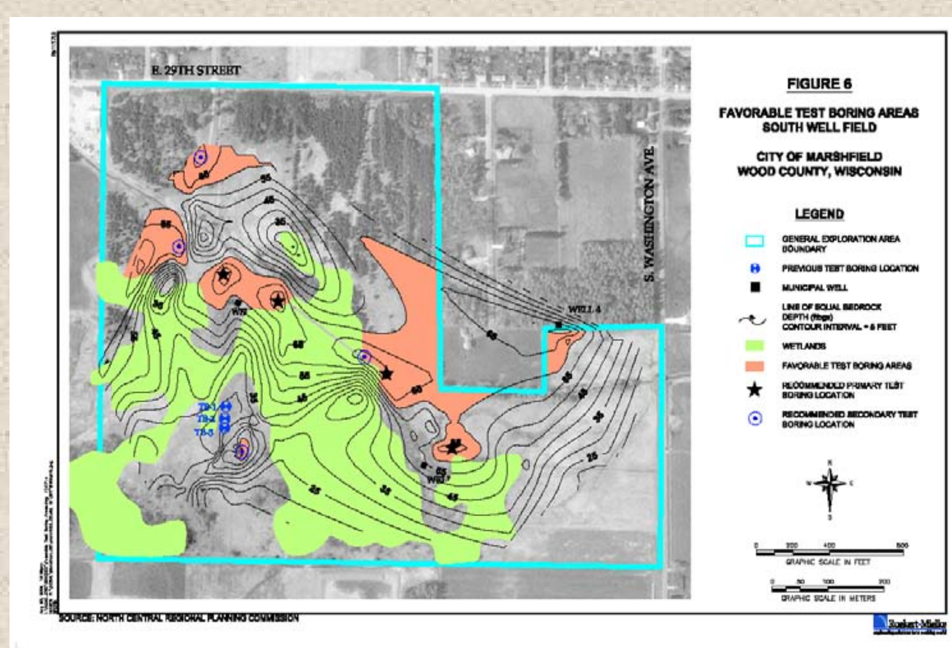
Mapping Complex Bedrock Surface With Gravity Surveys





- Gravity survey identified steep bedrock ridges too steep to map with seismic refraction
- Bedrock ridges looked like sand and gravel on resistivity data
- Next borings hit gravel deposits in valley center

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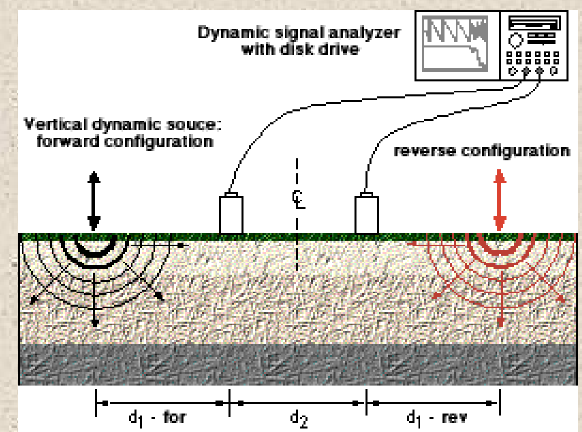
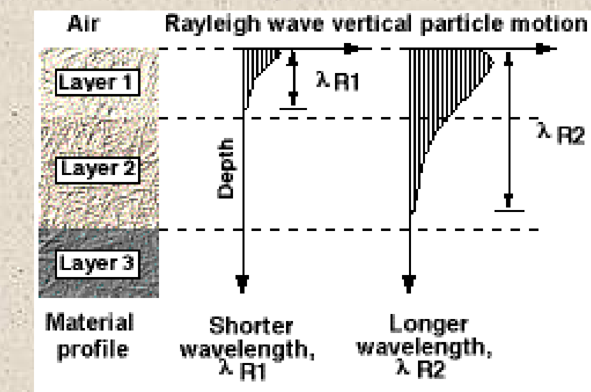
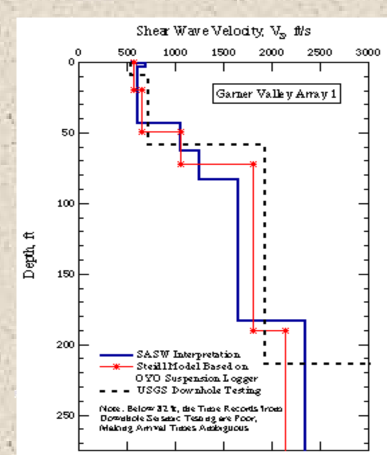
Spectral Analysis of Surface Waves (SASW)

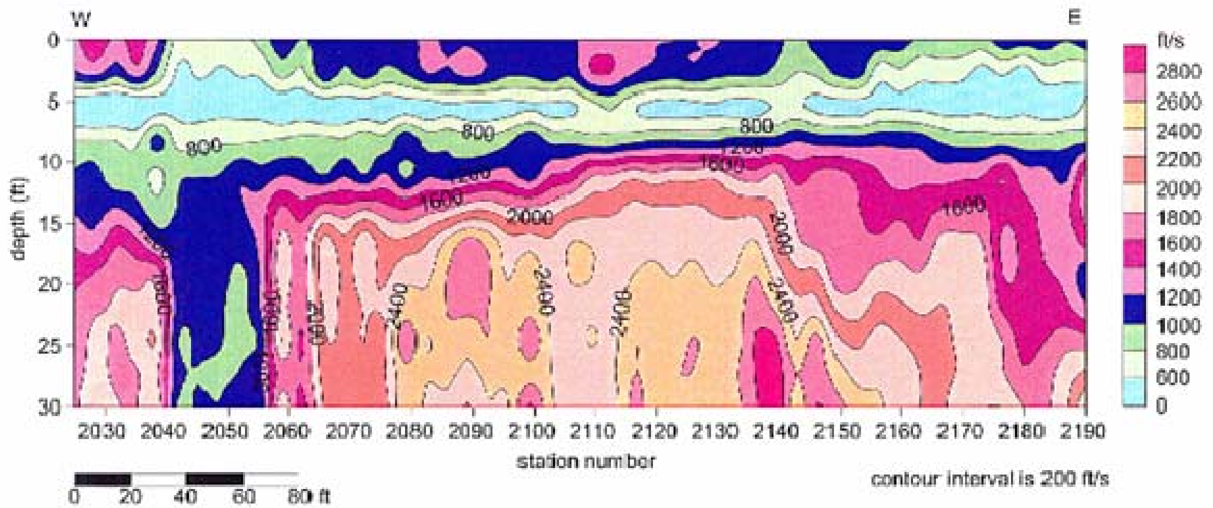


•Uses shear waves of different frequency to probe material properties to different depths
•Higher frequencies probe shallow zone
•Lower frequencies probe deeper
•Used to detect voids, measure shear wave velocity, shear modulus, and Poisson's Ratio
•Commonly used for foundation studies, seismic risk, liquefaction, pavement studies, and stratigraphic analysis
•Not subject to same limitations as shear wave refraction surveys
•Multi-Channel methods (MASW) now the standard





MASW Survey of Bedrock Velocity



From KGS OFR 99-9

Figure 5. S-wave velocity contours along line 2 at Olathe, Kansas, site.

- Apparent fracture zone at station 2050
- Large channel feature stations 2160 to 2190
- Bedrock low stations 2030 to 2040

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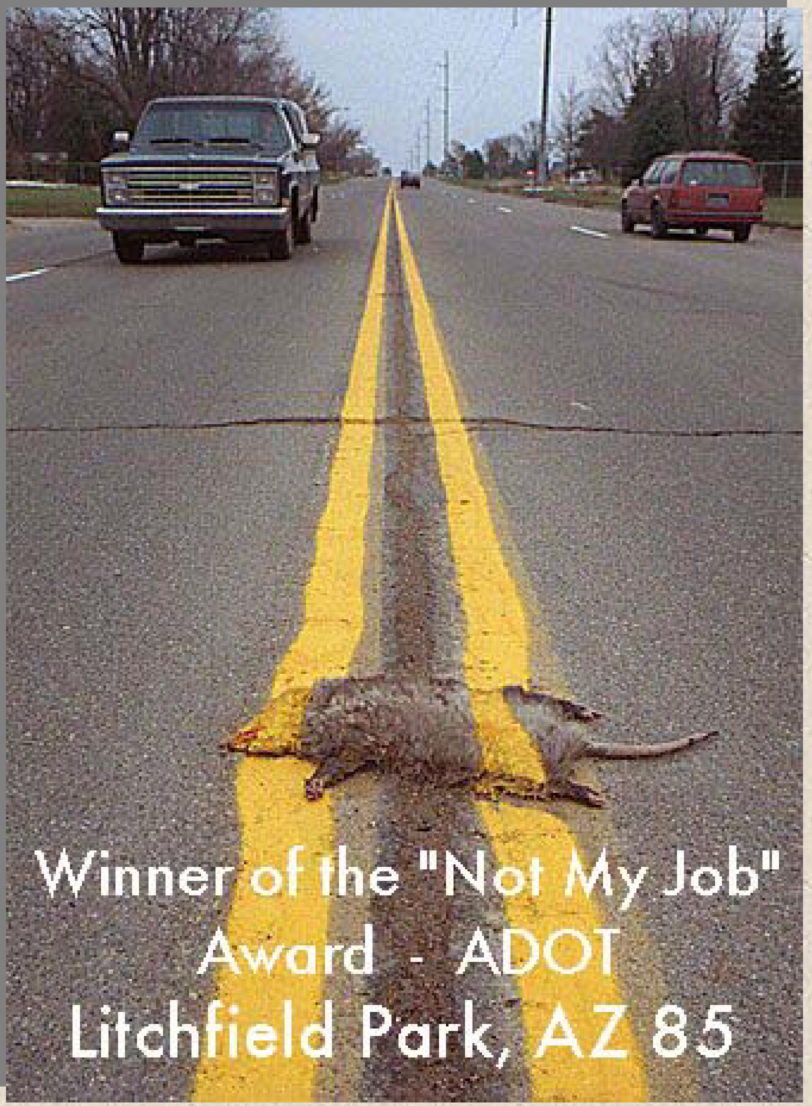
The Road Ahead …



Data acquisition has become easier, faster, and cheaper

- Proper survey design is crucial to getting a satisfactory result
- Better equipment means better signal to noise ratios and higher sampling density
- Expect higher resolution and better data on more sites
- Expect to get a much clearer image of the subsurface
- Stay tuned for more new technologies and case histories