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The Role of Geophysics in Radioactive Waste Management

KHNP Training Program
Module 4: Repository Siting and Characterization

June 26, 2007

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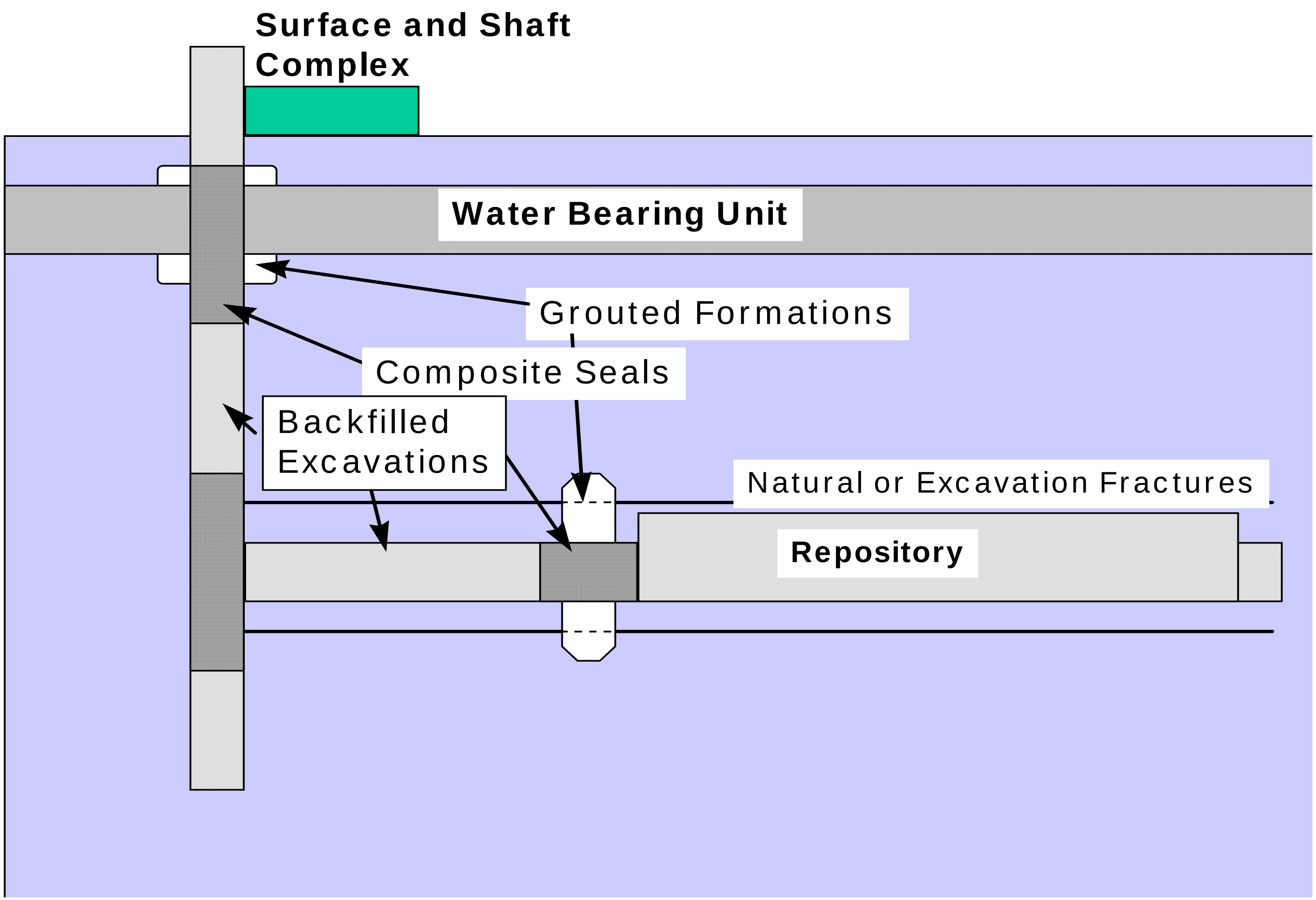
Geophysics in Radioactive Waste Management

- *Issue 1:* Site Characterization
- *Issue 2:* Hydrogeology Specific Studies
- *Issue 3:* In-situ Experiment Support
- *Issue 4:* Design and Engineering Support
- *Issue 5:* Verification and monitoring of Seals, Barrier, and In-situ Containment Systems
- *Issue 6:* Long Term Repository Monitoring

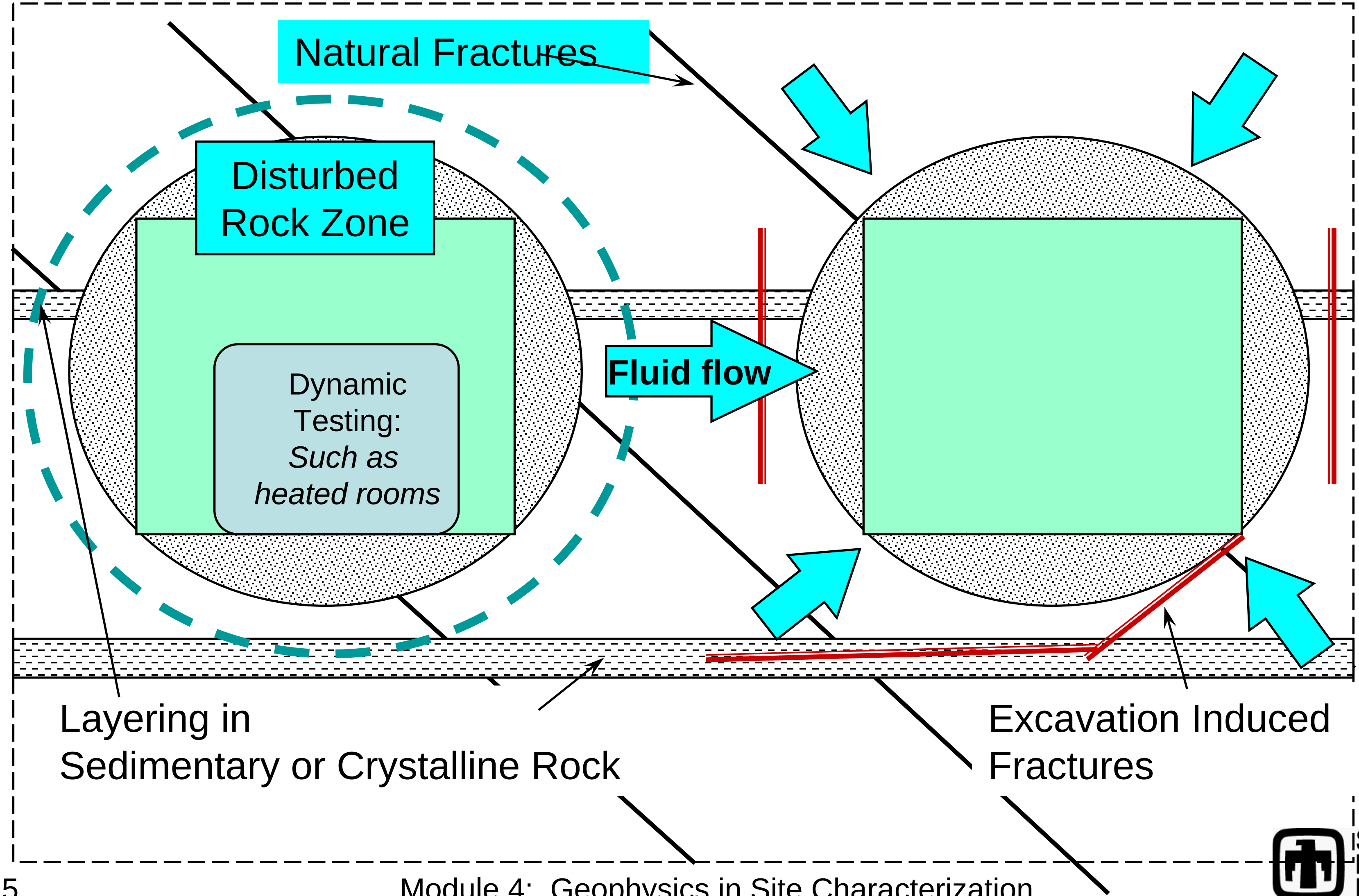
Geophysics in Radioactive Waste Management

- Research and development is required to address significant issues for compliance,
- Better understanding of the interrelationship between parameters and processes,
- Increased resolution and increased understanding of what is resolution means to geophysicist and enduser,
- In general, more understanding between geophysicists and enduser, from design through interpretation
- Given the current stage of large projects and the emphasis on interim storage and underground research laboratories, the days of large geophysical programs to support site characterization are waning.
- The growth will be for In-situ experiment support; design and engineering support, verification and monitoring of containment systems, and long term post closure monitoring.

Geophysics in Radioactive Waste Management



Geophysics in Radioactive Waste Management



Barriers to the Use of Geophysics

- Expectations
- Envisioned Capabilities
- Deliverable Capabilities

Geophysics in Radioactive Waste Management

Table 1: Partial List of Uses of Geophysics in Nuclear Waste Disposal Programs

Country	Site Characterization	Hydrogeolgy Specific Studies	In-situ Experiment Support	Design and Engineering Support	Verification and Monitoring of Containment Systems	Long-Term Post Closure Monitoring
USA WIPP	1. seismology 2. borehole logs 3. seismic imaging 4. resistivity 5. gravity 6. magnetics 7. airborne SAR	1. Transient Electromagnetic Methods 2. borehole logs 3. in mine electrical imaging	1. borehole logs 2. cross-borehole seismic 3. electrical, EM, and acoustic imaging 4. GPR	Excavation effects and disturbed rock zone 1. electrical, EM, and acoustic imaging 2. GPR	1. borehole logs 2. cross-borehole seismic	
YMP	8. seismology 9. seismic imaging 10. resistivity 11. gravity 12. magnetics	4. electrical	5. electrical imaging of heated rock experiments	3.	3.	
In-situ Containment Savannah River, Idaho, Rocky Flats, Oak Ridge	13. seismology	5. electrical potential arrays	6.	4. GPR	4. electromagnetic imaging 5. Seismic Imaging	
Canada URL	14.	6.	7. electrical and seismic imaging	5. surface and borehole seismic 6. GPR	6. electrical and seismic imaging	
Sweden Stripa	15.	7. electrical and seismic imaging 8. cross borehole GPR	8. electrical and seismic imaging 9. cross borehole GPR	7. electrical and seismic imaging 8. cross borehole GPR	7.	
Aspo	16.	9.	10.	9.	8.	

Geophysics in Radioactive Waste Management

Table 1: Partial List of Uses of Geophysics in Nuclear Waste Disposal Programs

Switzerland Grimsel	1.	1.	1. GPR, seismic, electrical and seismic imaging	1. GPR, seismic, electrical and seismic imaging	1.	
sedimentary basins	2. geophysical logging	2.	2.	2.	2.	
Japan sedimentary (Tono Mine)	3. seismology	3.	3.	3.	3.	
granite (Kamaishi Mine)	4.	4. radar and electrical imaging correlated to permeability measurements	4.	4.	4.	
Germany	5.	5.	5. GPR, seismic, electrical and seismic imaging	5. passive acoustic 6. GPR, seismic, electrical and seismic imaging	5.	
Russia tuffs	6.	6.	6.	7.	6.	
salt	7.	7.	7.	8.	7.	
	8.	8.	8.	9.	8.	
France	9.	9.	9.	10.	9.	
Finland	10.	10.	10.	11.	10.	

Geophysical Methods

- Seismic Methods
- Electromagnetic Methods
- Electrical Imaging
- Radiometric Methods
- Field Methods
  - ➢Gravity
  - ➢Magnetics
  - ➢Heat Flow

Seismic Methods

- The principle of seismic methods is to initiate elastic waves at one point (the transmitter) and to determine at another point (the receiver) the arrival time, phase and attenuation of the transmitter impulse. These seismic impulses can be directly transmitted point-to-point or refracted and reflected. Therefore, seismic methods can be conducted from the surface, surface to borehole, and borehole-to-borehole. Seismic methods have proven to be of great use in the petroleum industry and large-scale engineering application.

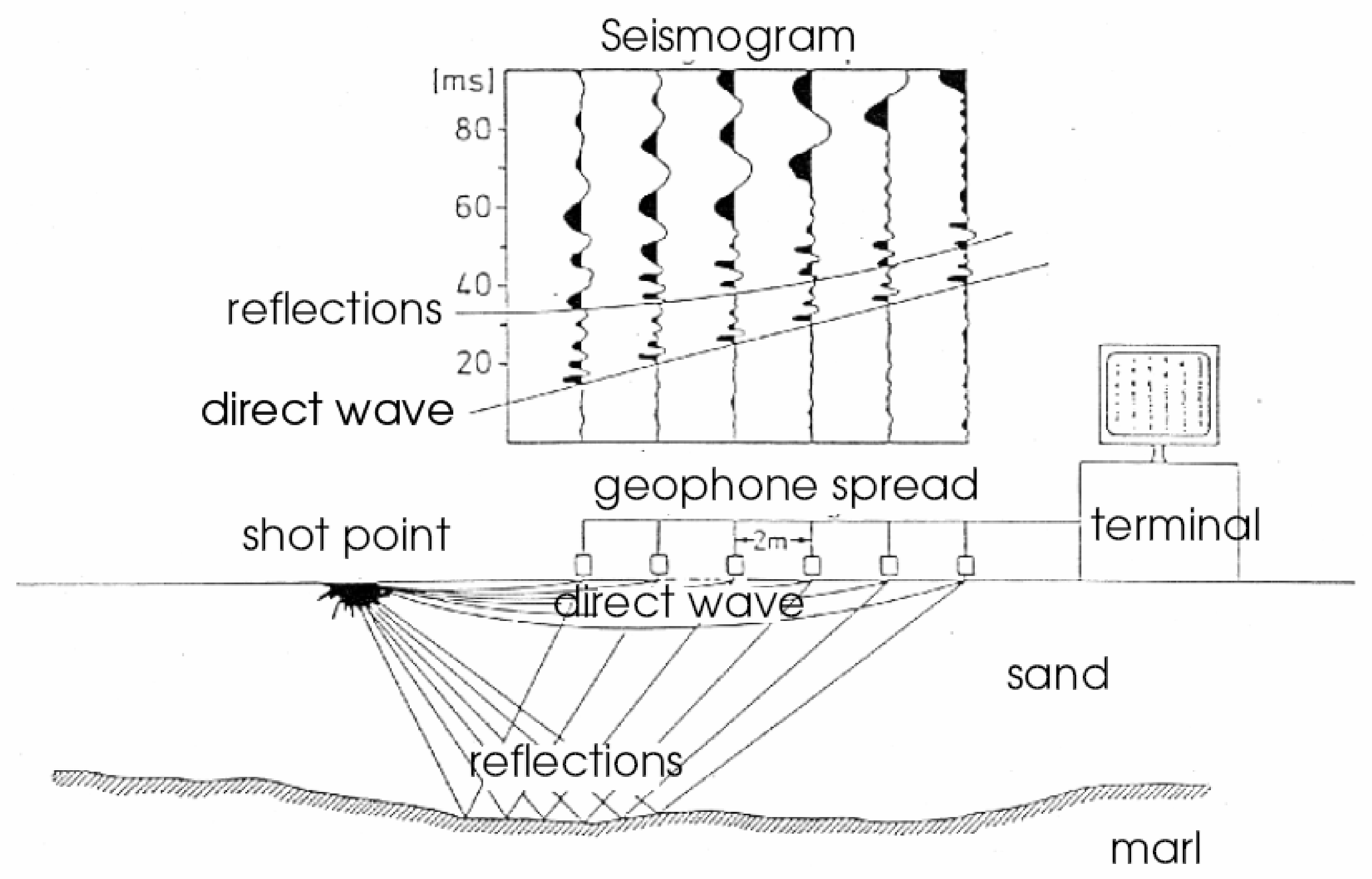


Figure 1: Seismic Field Work: Source, Geophone Spread, and Terminal

Electromagnetic Methods

- Electromagnetic methods are sensitive to variations in electrical conductivity or dielectric constant in the soil or rocks. These properties are some of the most responsive geophysical indicators of metallic, acidic and water-based subsurface contaminants. These electrical properties as determined by electromagnetic (EM) methods are unique amongst geophysical measurements, since the electrical property is directly related to the hydrologic properties of the geologic medium and the chemical composition of the fluid passing through the geologic medium.

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A transmitter coil can be used to generate the primary electromagnetic field which propagates above and below the ground.

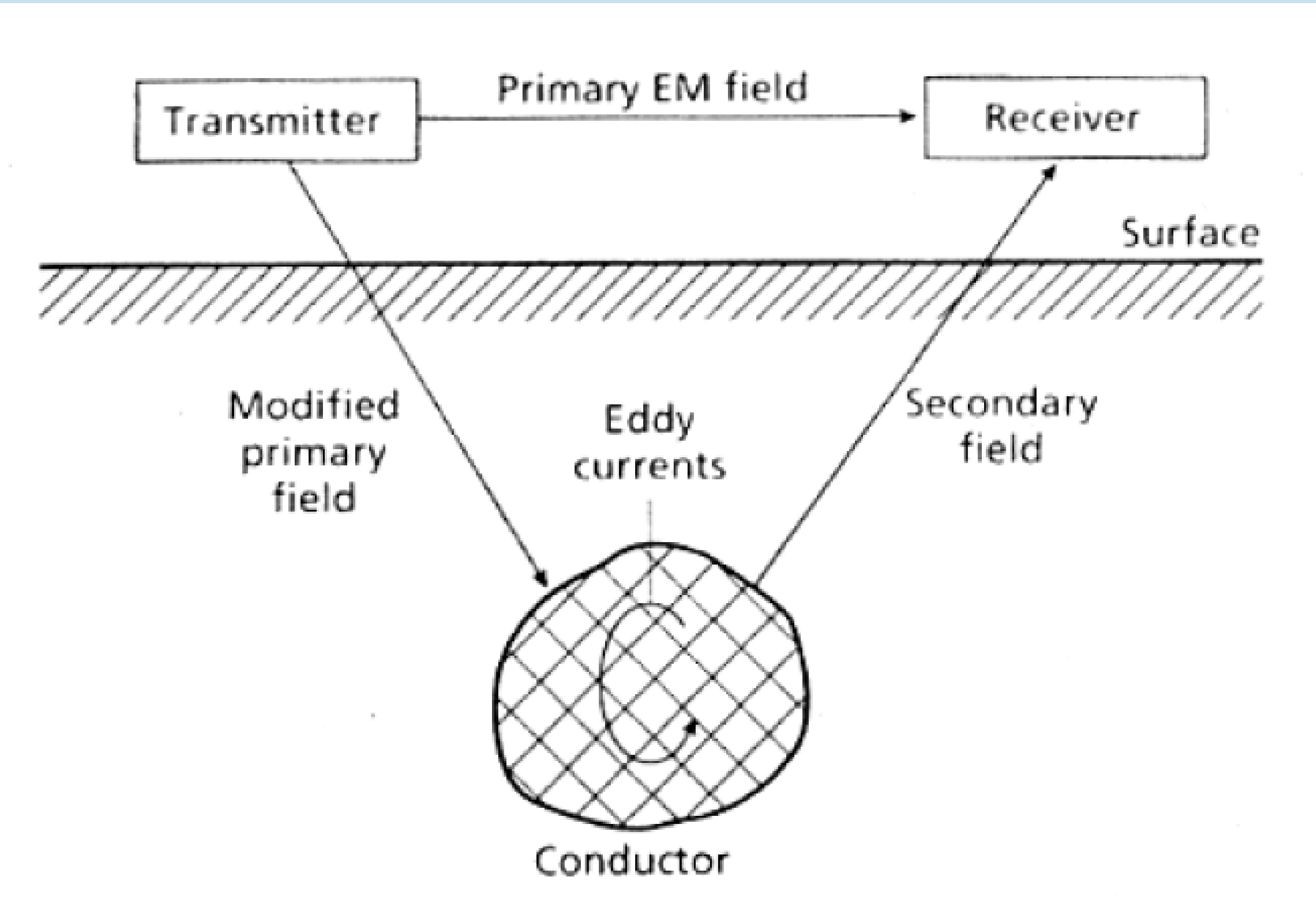
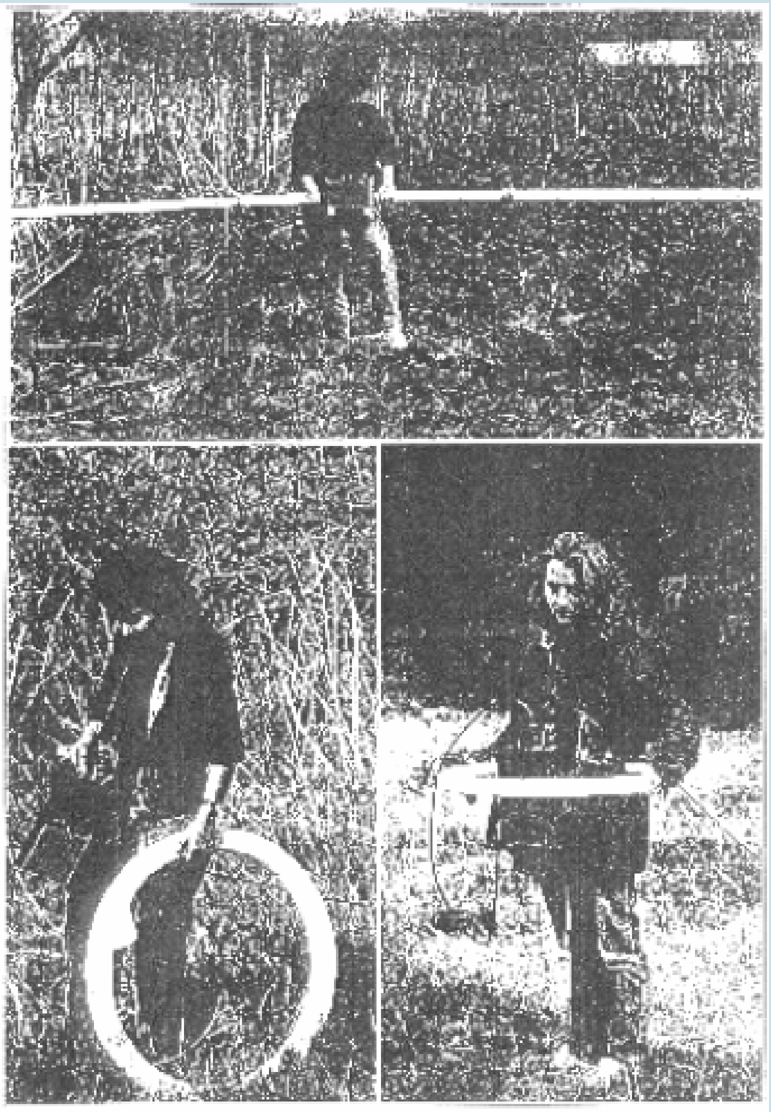


Figure 2: General Principle Of Electro-magnetic Surveying

Two devices: EM31 and EM 34-3



EM 31:

3.7 m coil spacing f=9.8 kHz

EM 34-3:

10 m coil spacing f=6.4 kHz

20 m coil spacing f=1.6 kHz

30 m coil spacing f=0.4 kHz

Figure 3: Electromagnetic Equipment

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Application of Electromagnetic Methods to Hydrogeology

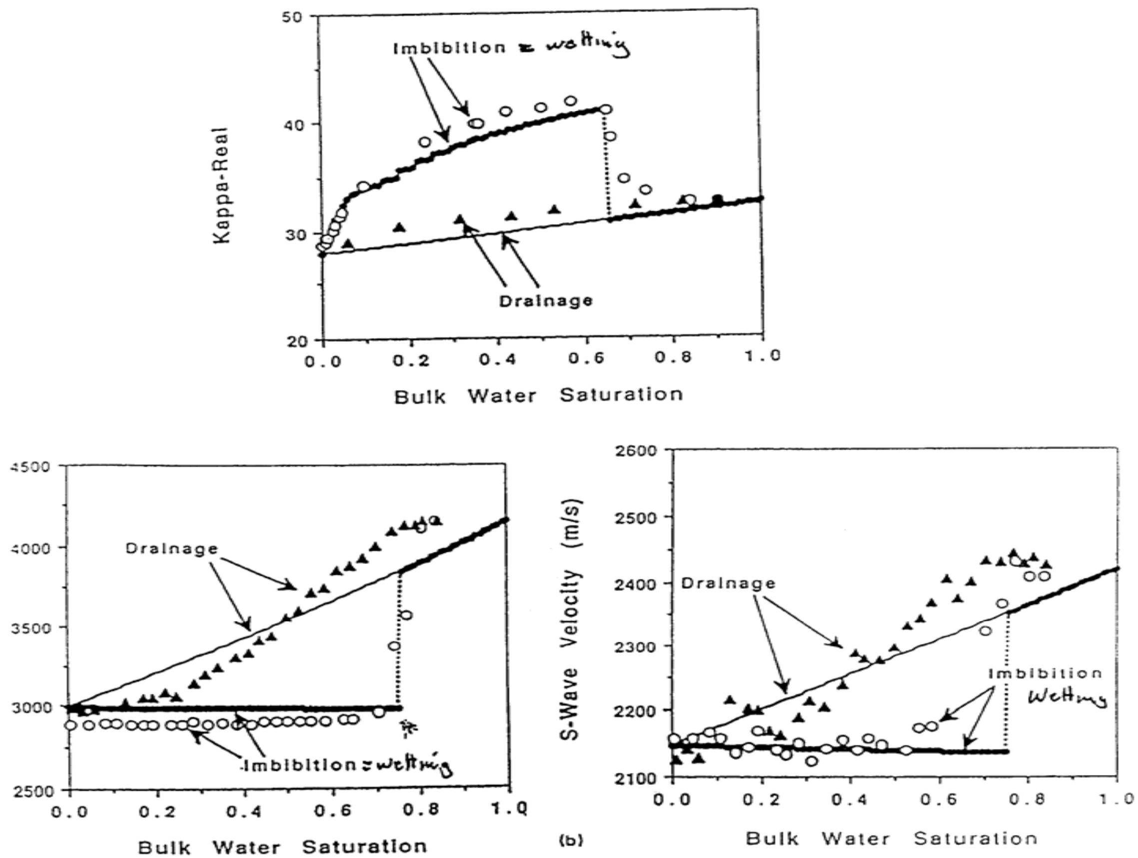
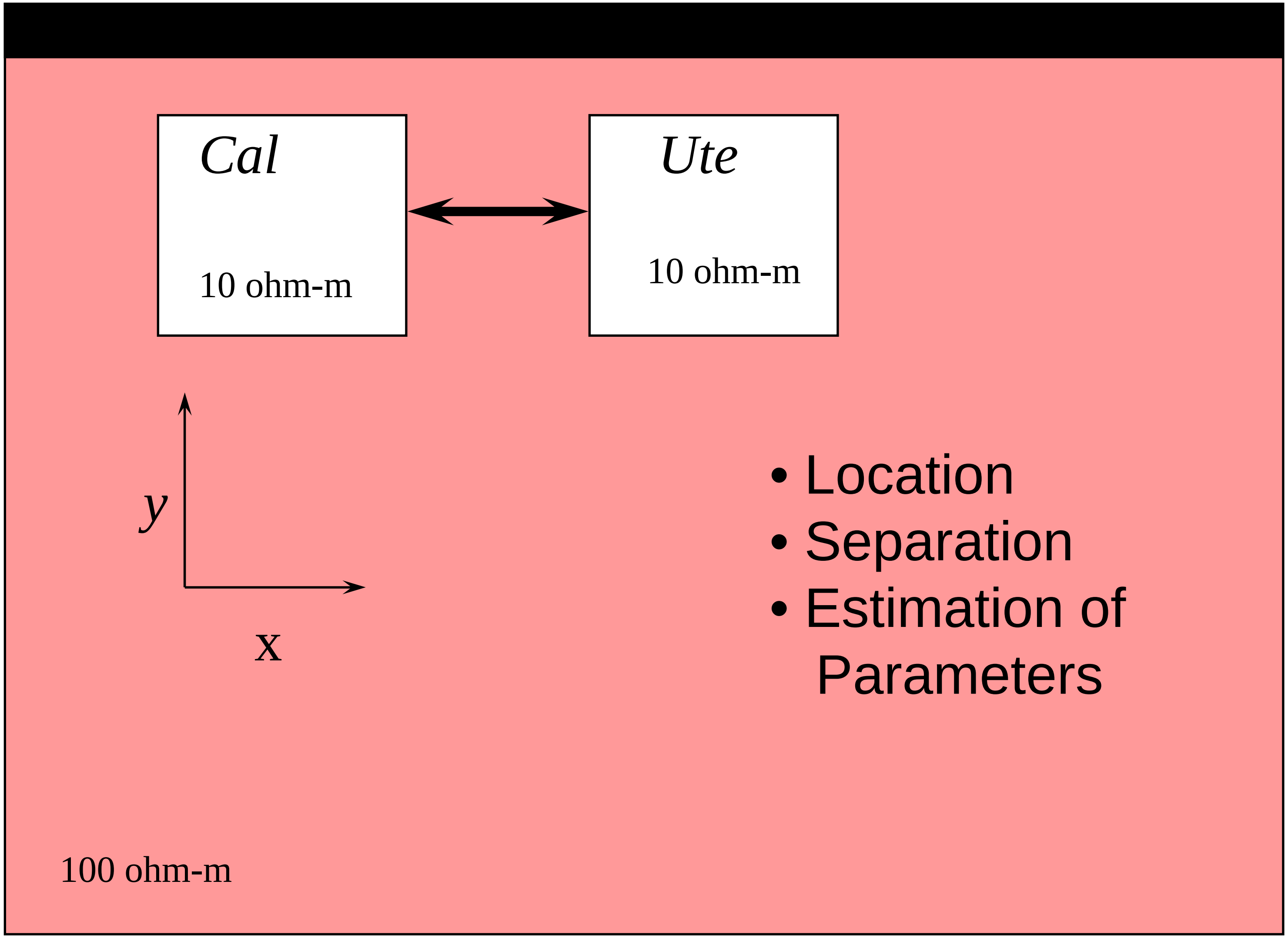


Figure 4: Computed Velocities for Wetting-Drainage Cycle; (a) compressional wave velocities; (b) shear-wave velocities. Experimental data for Fig.2 are superimposed

Electrical Imaging

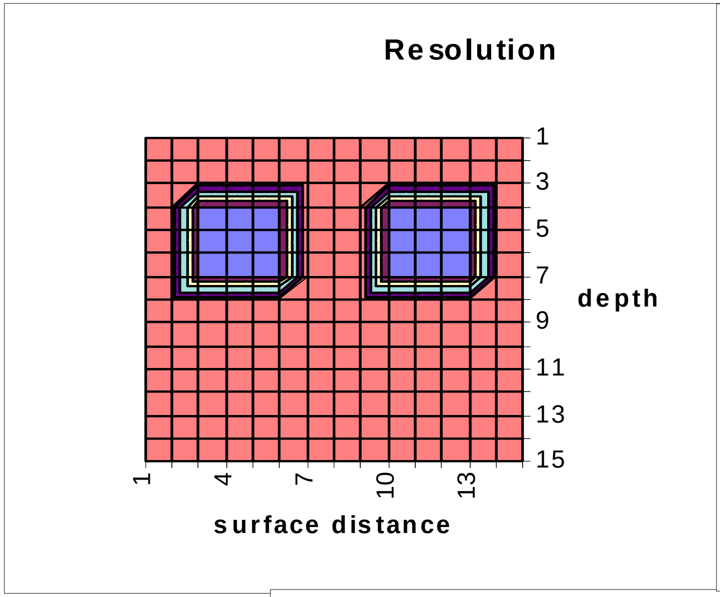
- Direct current resistivity imaging methods have the advantages of ease of automation, low cost and expendable electrodes. These methods have been implemented to detect leaks in earthen dams and monitor ground water flow in fluvial sediments. The electrical resistivity tomography (ERT) method developed by Raimeriz and Daily at Lawrence Livermore Laboratory and LaBrecque at the University of Arizona is a commonly cited example of this family of methods. Schima, et al. (1993) tracked fluid flow in the vadose zone using cross borehole electrical imaging. The German nuclear waste program has used borehole electrode arrays to monitor underground seal performance.

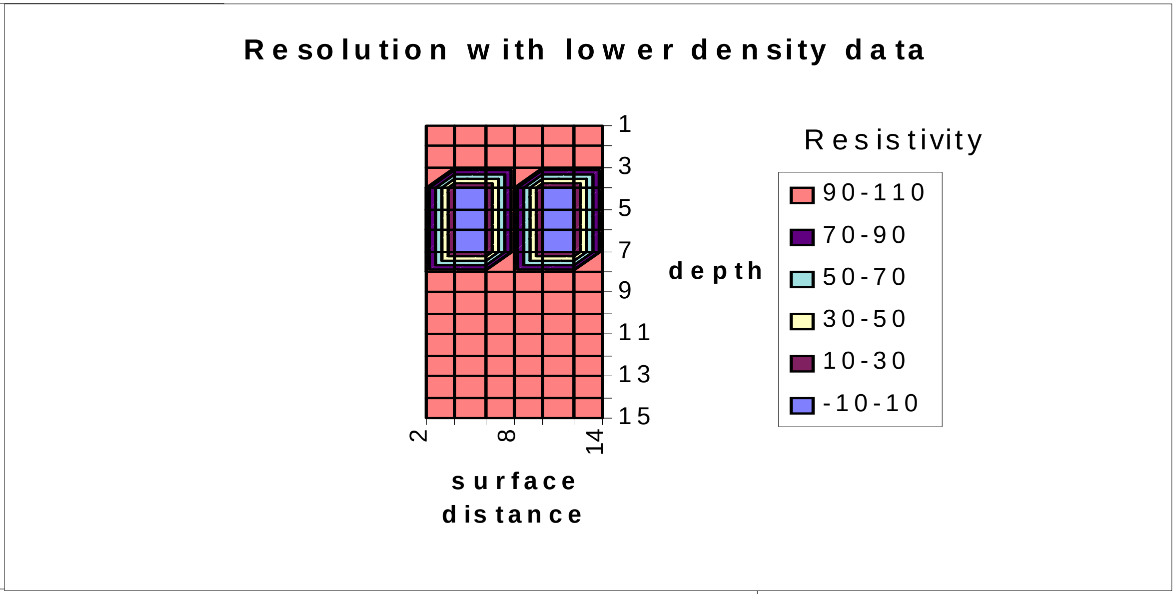
Issues of Resolution

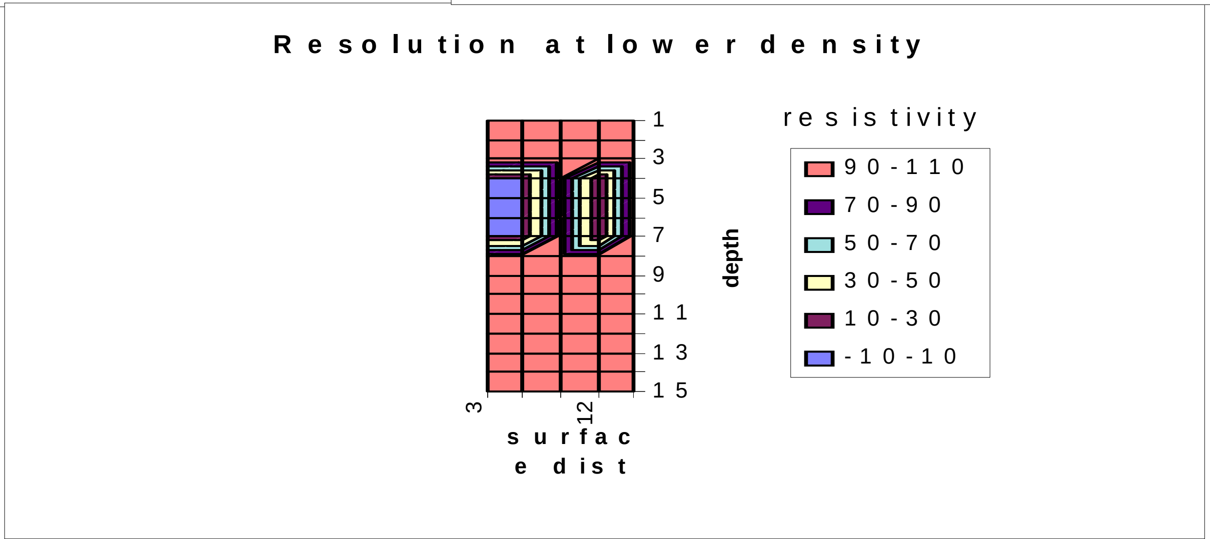


- Location
- Separation
- Estimation of Parameters

Variable Resolution of Like Objects







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Radiometric Methods

- A number of geophysical methods are used in boreholes. These methods are a suite of geophysical borehole logging approaches, which include electrical, nuclear and acoustic methods.
- Radiometric logging includes both passive and induced methods. Passive methods measure natural radiation, which mainly results from 40K concentrated mainly in clays.
- Hence, from a penetrating borehole, the method can be used to detect the presence on bentonite backfills.
- Induced radiometric methods bombard the formation around the borehole with gamma rays or neutrons. This induces changes in the nuclei of atoms and results in secondary emissions that can be measure by borehole sonde.
- Such tools include gamma-gamma, neutron-gamma, and neutron-thermal-neutron logs. The gamma-gamma logs are used to measure formation density and in turn porosity. Neutron logs are used to measure porosity and water-content.

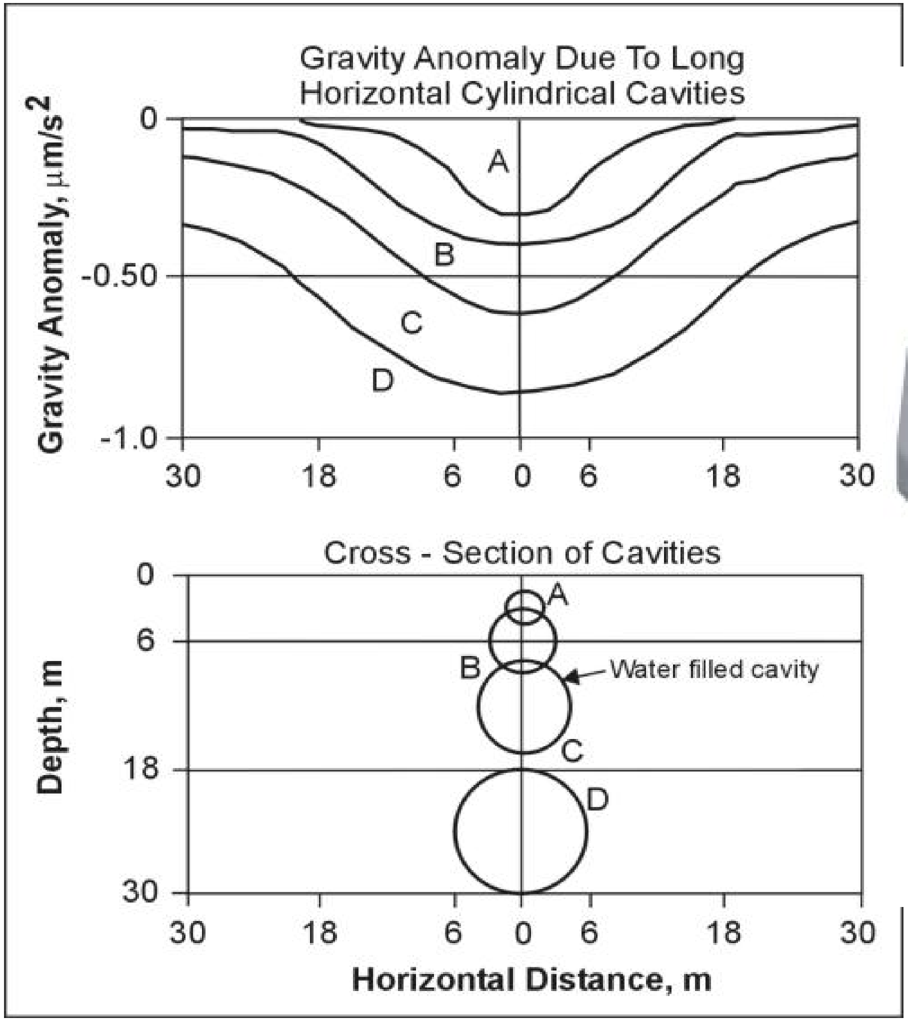
Potential Field Methods

- ***Gravity***
- ***Magnetics***
- ***Heat Flow***

Gravity

- Gravity measurements define anomalous density within the Earth; in most cases, ground-based gravimeters are used to precisely measure variations in the gravity field at different points. Gravity anomalies are computed by subtracting a regional field from the measured field, which result in gravitational anomalies that correlate with source body density variations. Positive gravity anomalies are associated with shallow high density bodies, whereas gravity lows are associated with shallow low density bodies.

Gravity

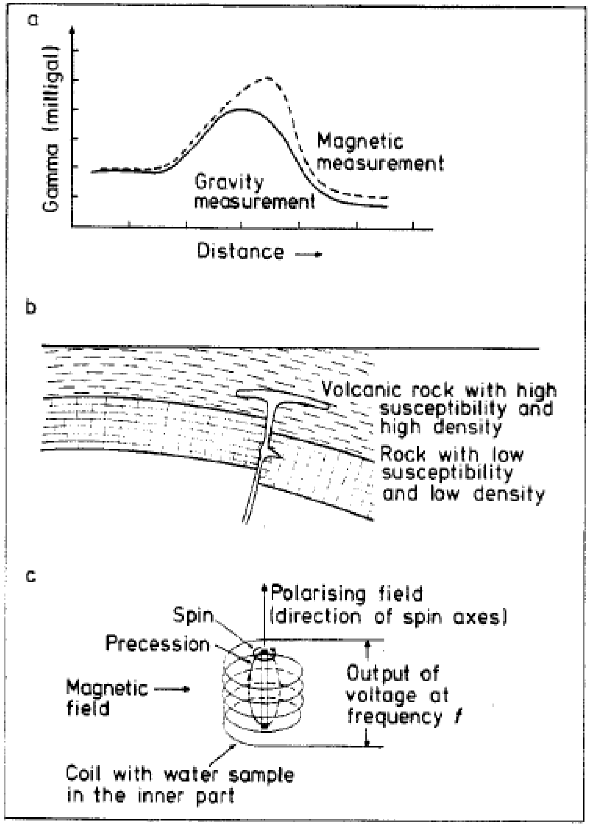


Gravity Anomaly Due To Long Horizontal Cylindrical Cavities
Gravity Anomaly, μm/s²
0
-0.50
-1.0
A
B
C
D
30
18
6
0
6
18
30
Cross - Section of Cavities
Depth, m
0
6
18
30
A
B
C
D
Water filled cavity
Horizontal Distance, m

Magnetics

- The magnetic method exploits small variations in magnetic mineralogy (magnetic iron and iron-titanium oxide minerals) among rocks. Measurements are made using fluxgate, proton-precession, Overhauser, and optical absorption magnetometers. In most cases, total-magnetic field data are acquired; vector measurements are made in some instances. Magnetic rocks contain various combinations of induced and remnant magnetization that perturb the Earth's primary field. The magnitudes of both induced and remnant magnetization depend on the quantity, composition, and size of magnetic-mineral grains.

Figure 7 a – *Schematic of measured gravity and magnetic anomaly of a volcanic intrusion.*
b – *Principle of the proton magnetometer*



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Heat Flow

- Two distinct techniques are included under thermal methods (table 1): (a) borehole or shallow probe methods for measuring thermal gradient, which is useful itself, and with a knowledge of the thermal conductivity provides a measure of heat flow, and (b) airborne or satellite-based measurements, which can be used to determine the Earth's surface temperature and thermal inertia of surficial materials, of thermal infrared radiation emitted at the Earth's surface. Thermal noise includes topography, variations in thermal conductivity, and intrinsic endothermic and exothermic sources.

Heat Flow

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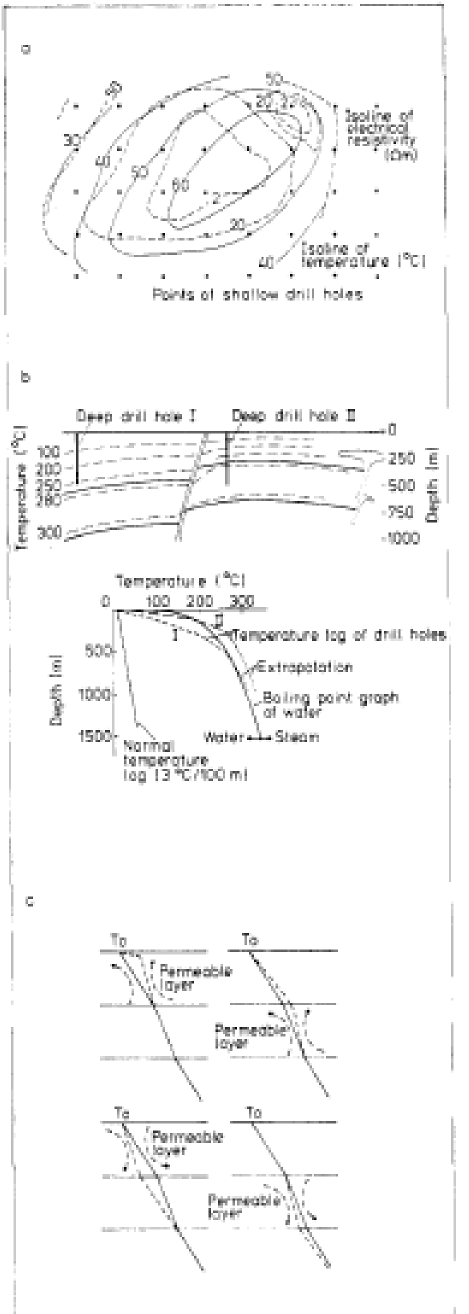
- **Figure 5 a** - *Top view; isolines of measured temperatures and electrical resistivities (see also figure 36).* **b** - *Temperature distribution in the subsurface and the temperature logs of two drill holes. Only on the steam site of the boiling point graph can we expect steam.* **c** - *Water movements in the surrounding of* ***a*** *drill hole; To = mean annual temperature at the earth's surface. The thick graph's the standard curve measured outside the anomaly: the dashed curves are measured temperatures in the geothermal area. Arrows give the direction of water movement in the permeable layer*
- Physics in Technology September 1977



HISTORY OF GEOPHYSICAL STUDIES AT THE WASTE ISOLATION PILOT PLANT

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Module 4: Repository Siting and Characterization

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Core Issues

***Issue 1*:** **Site Characterization**

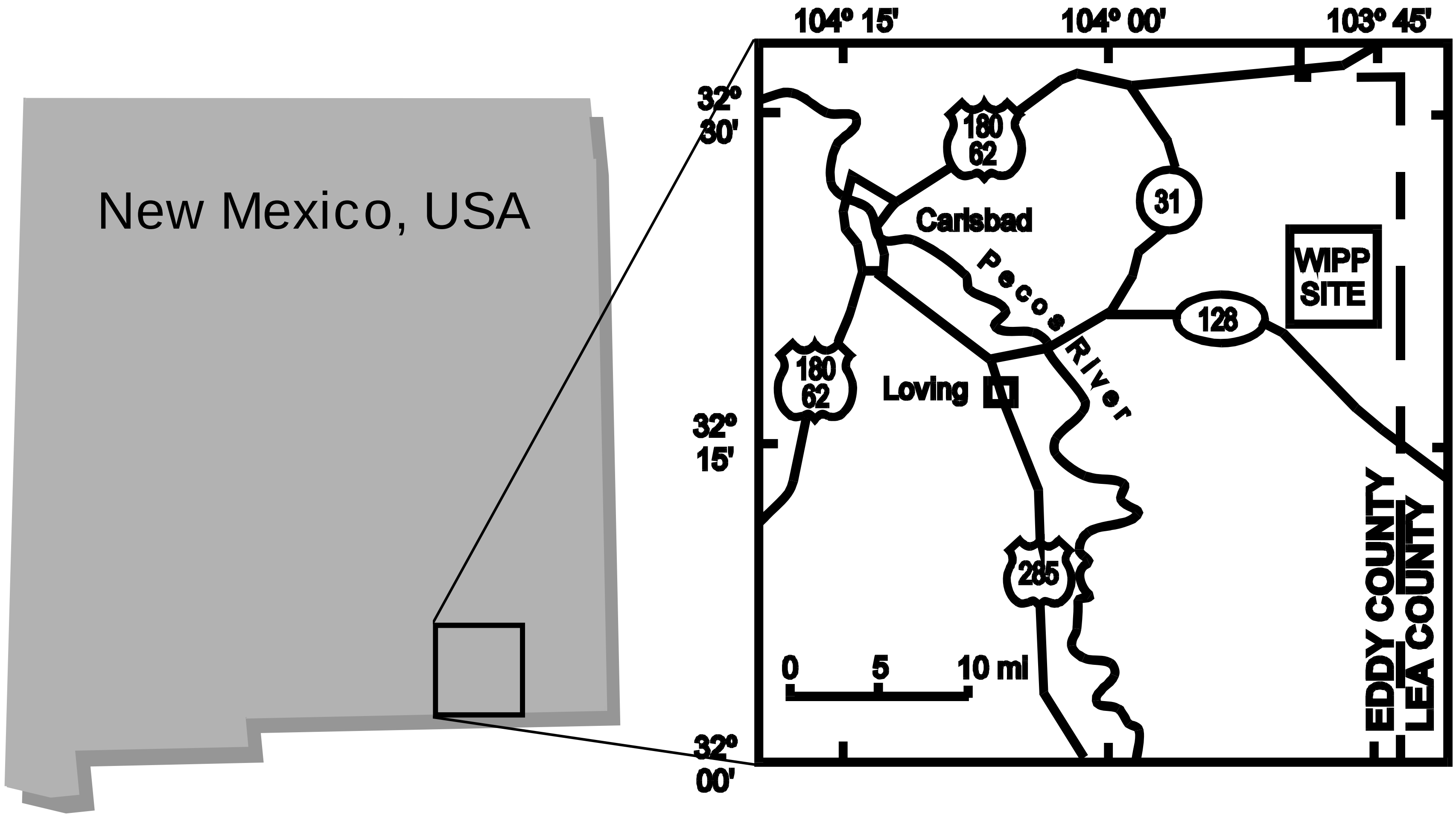
Issue 2: **Castile Brine Reservoirs**

Issue 3: **Rustler /Dewey Lake Hydrogeology**

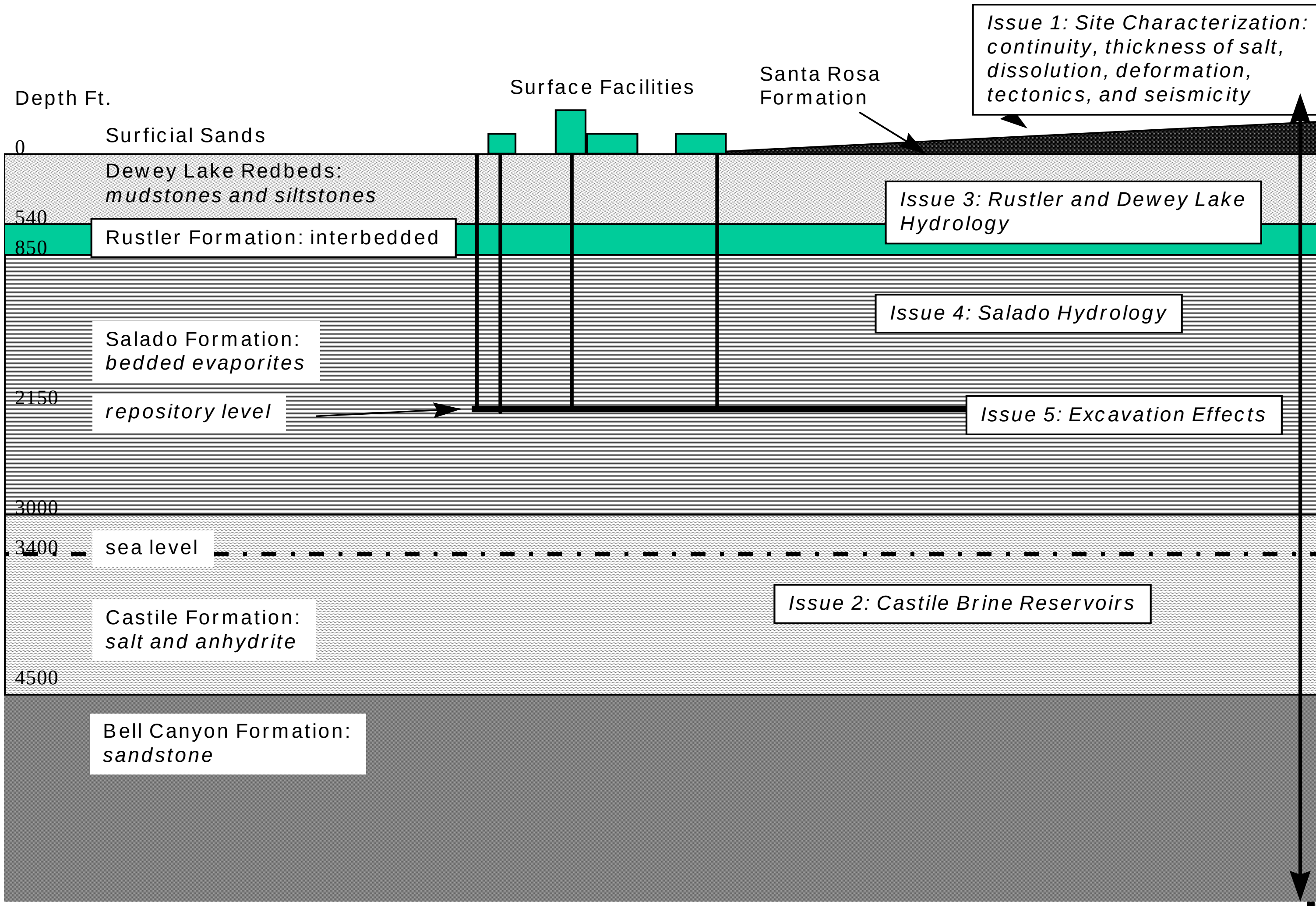
Issue 4: **Salado Hydrogeology**

Issue 5: **Excavation Effects**

Location of the WIPP Site Southeastern, New Mexico



WIPP site geology and stratigraphy relative to facilities and issues addressed by geophysics



Issue 1: Site Characterization

Continuity and predictability of strata

- Thickness of salt
- Extent of dissolution
- Deformation: faults, halokinesis, breccia pipes, uplift and subsidence, igneous activity
- Tectonics: seismicity

Issue 1: Site Characterization

Early site selection criteria and factors

Reference: Weart, W. (1983) Summary Evaluation of the Waste Isolation Pilot Plant (WIPP) Site Suitability, SAND83-0450. Sandia National Laboratories, Albuquerque, NM

Resolution:

– Layering showed continuity and maintained the required thickness.

– The seismic risk was determined and no known Quaternary tectonic faulting near the site was observed.

– Surface studies indicated an absence of breccia pipes or similar dissolution features in site area

Issue 1: Site Characterization

Continuity and predictability of strata

Resolution:

– Chaotic reflectors detected in Castile Formation near site. These were determined to be halokinetic effects on Castile and Salado structures.

– Characterization studies confirmed gentle basin tilt and continuity of bed thickness

Issue 1: Site Characterization

Thickness of Salt

Resolution:

– Characterization studies confirmed gentle basin tilt and continuity of bed thickness

Issue 1: Site Characterization

Extent of Dissolution

Resolution:

- Surface studies were ambiguous on shallow dissolution
- Continuity or relation to halokinesis provides evidence against deep dissolution

Issue 1: Site Characterization

Deformation: faults, halokinesis, breccia pipes, uplift and subsidence, igneous activity

Resolution:

- Surface studies and electrical profiling indicate an absence of breccia pipes or similar scale dissolution features in the Los Medanos site area

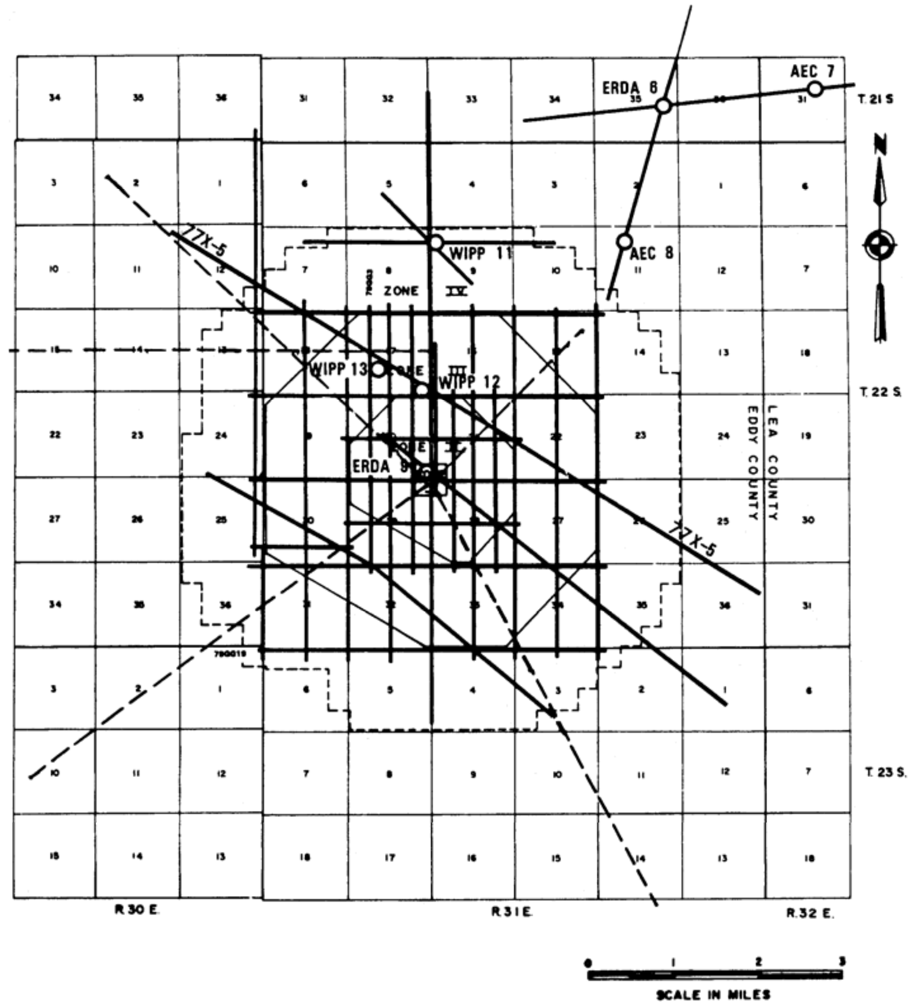
Issue 1: Site Characterization

Tectonics: seismicity

Resolution:

- Seismicity is related to two main clusters, the Rio Grande Rift to the southwest and the Central Basin Platform to the east.
- The upper magnitude limit for the WIPP site was set at 4.5 to 5. The possible acceleration was set at 0.3 g. The possibility of an event at the site of a magnitude that could significantly affect the repository was determined to be very low.

Seismic Surveys of the 1970's



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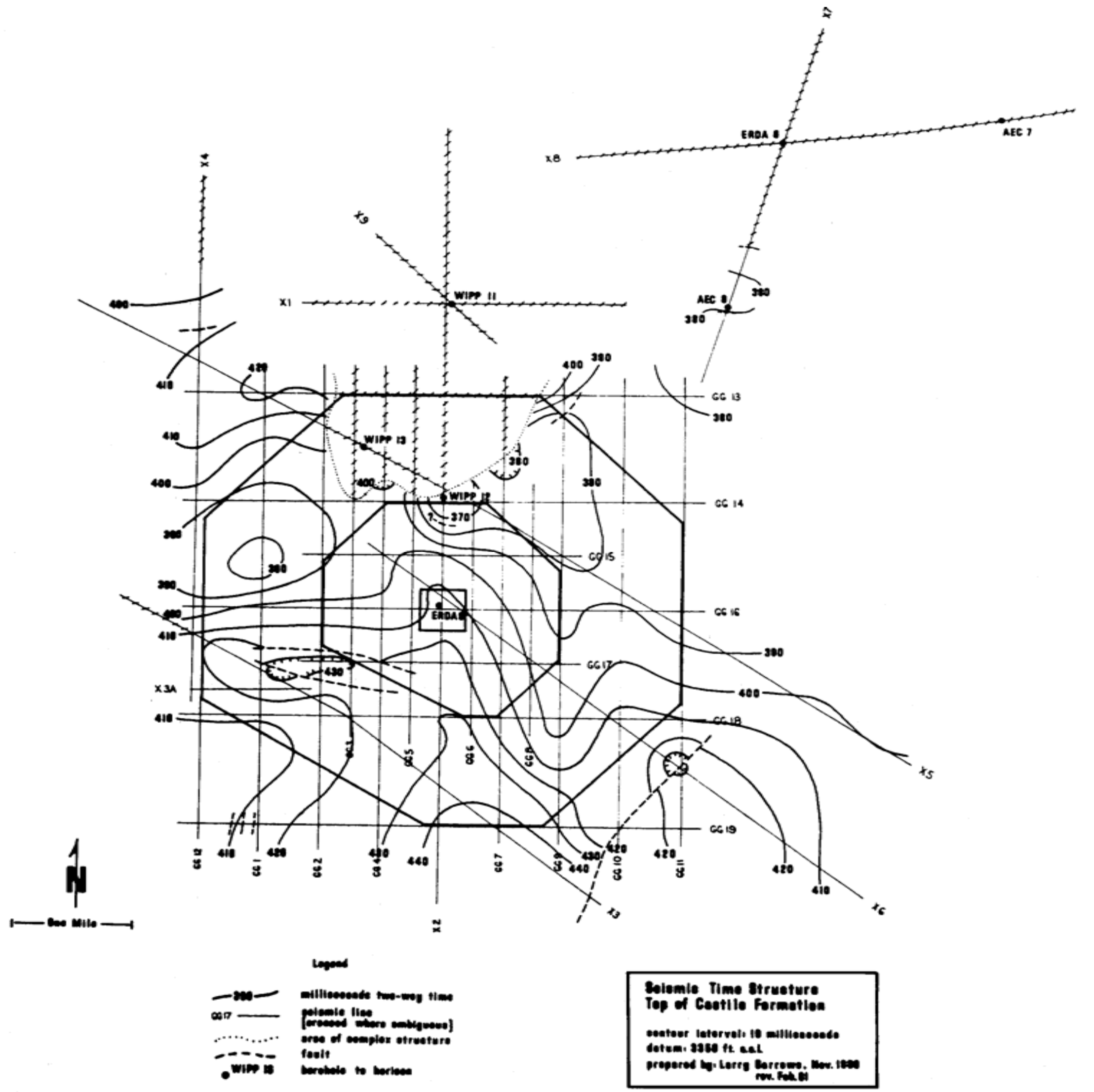


Issue 2: Castile Brine Reservoirs

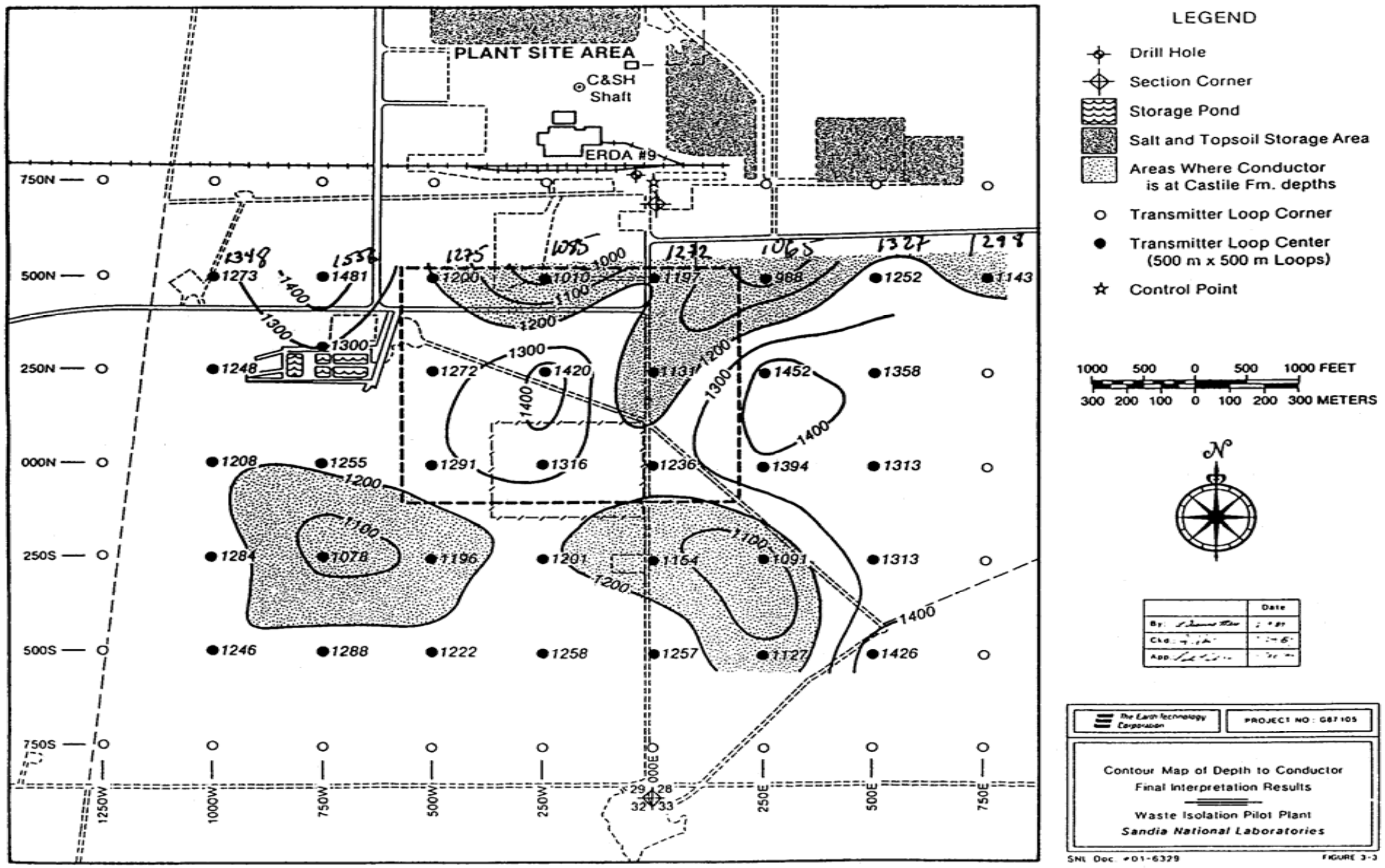
Development/validation of methods for use at WIPP

Delineation of reservoirs beneath the WIPP site

Resolution:

- TDEM survey conducted above the waste panel area. One dimensional inversion of data indicated high electrically conductive regions within the Castile beneath the repository. These high conductivity regions are interpreted to represent brine reservoirs.

TDEM Survey (1987)



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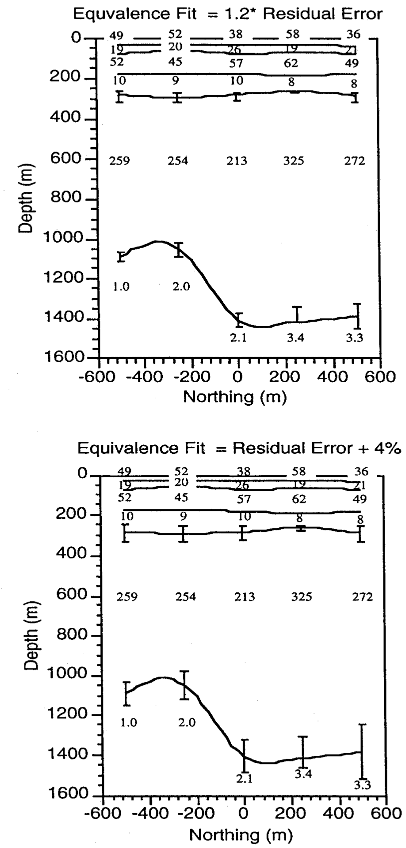
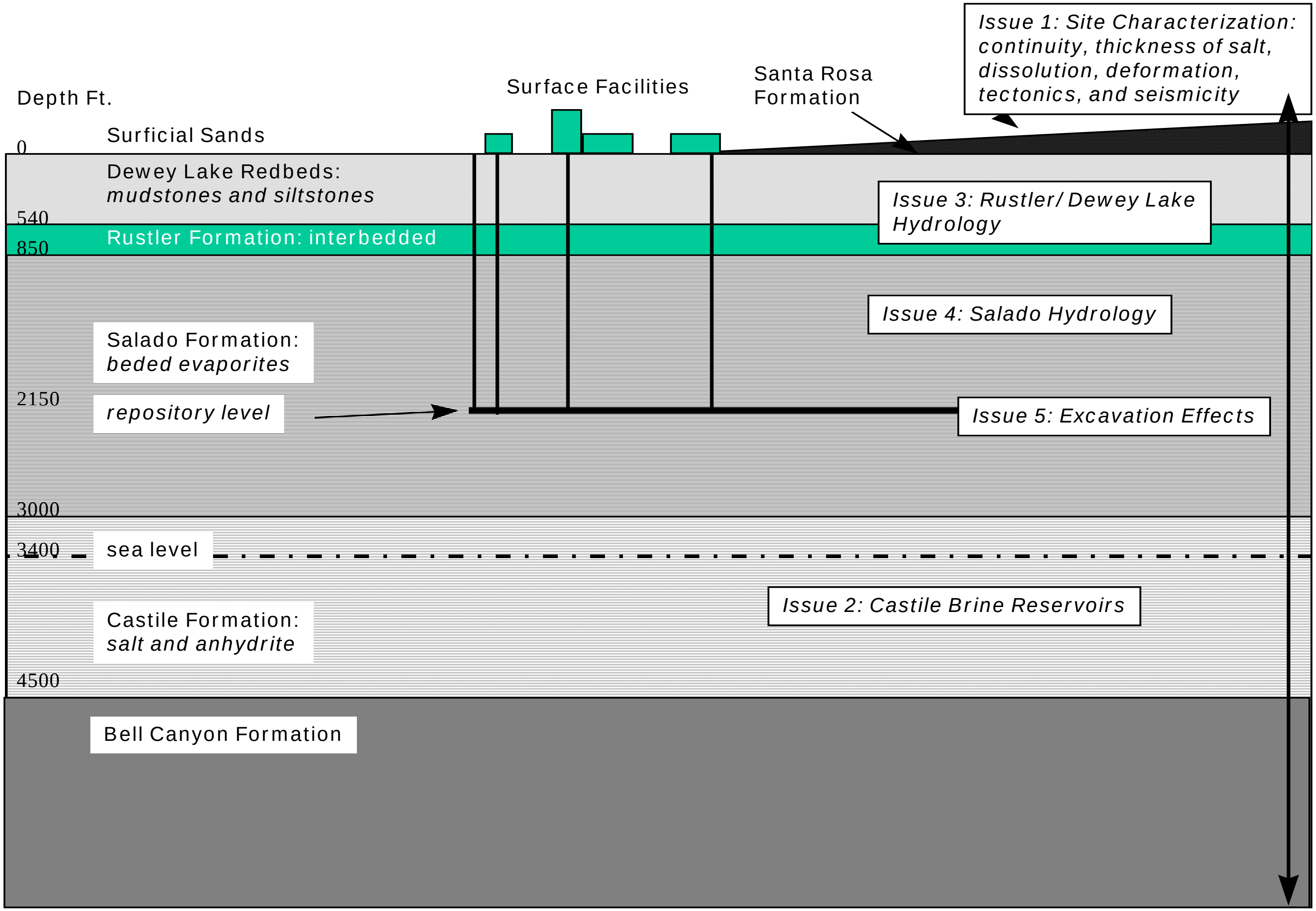
TDEM Survey



1997 Reinterpretation of 1987 Data

WIPP site geology and stratigraphy relative to facilities and issues addressed by geophysics



Issue 3: Rustler /Dewey Lake Hydrogeology

Dissolution features, Karst, Fractures, and Faults

Resolution:

- Variations in microgravity were interpreted to represent mass removal in the near surface, possibly representing dissolution. The resolution of the model came from core, stratigraphic, and geochemical studies
- The small observed changes in density are attributed primarily to lateral facies changes within the near surface stratigraphic units.

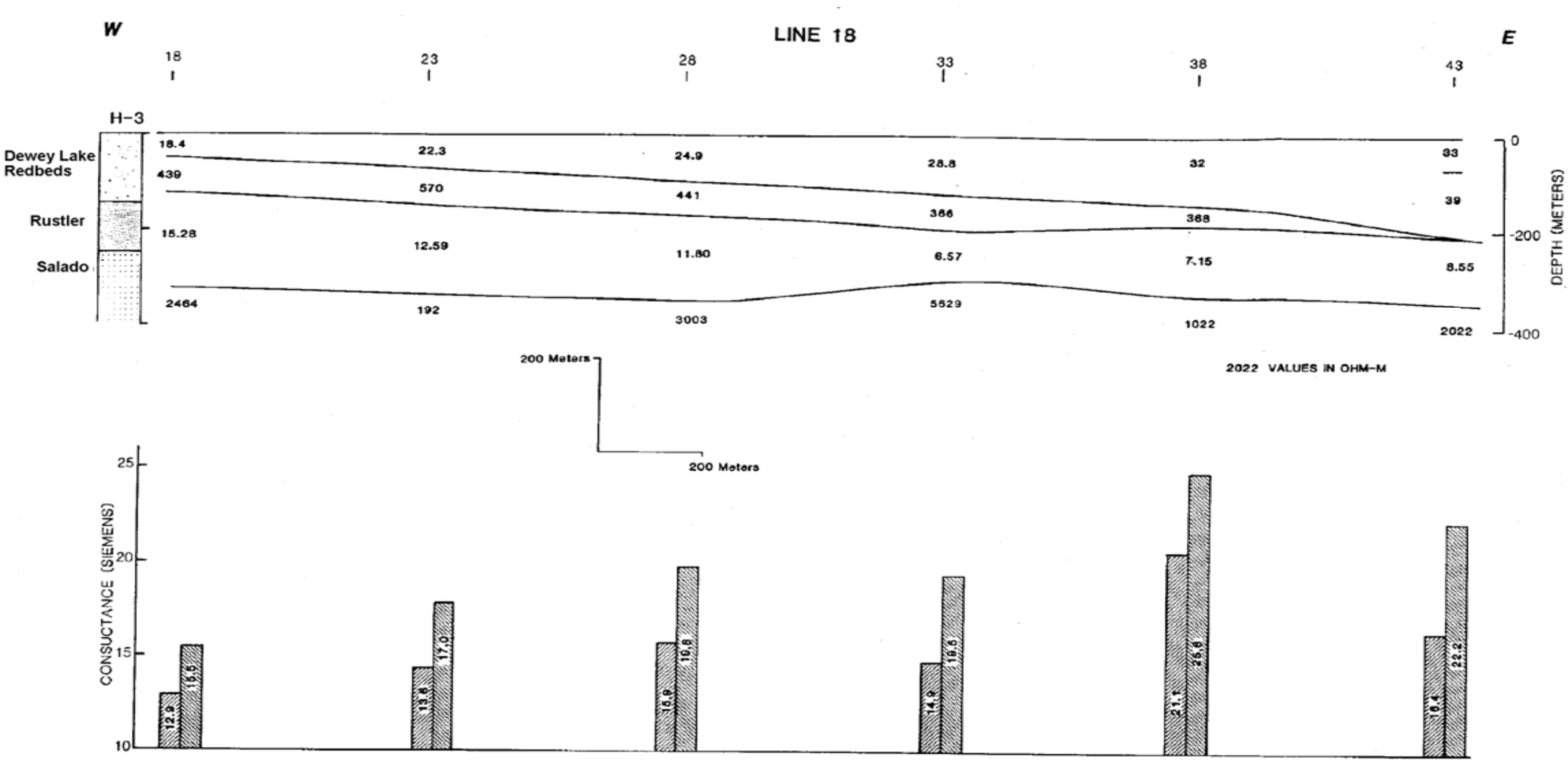
Issue 3: Rustler /Dewey Lake Hydrogeology

Variations in porosity and permeability

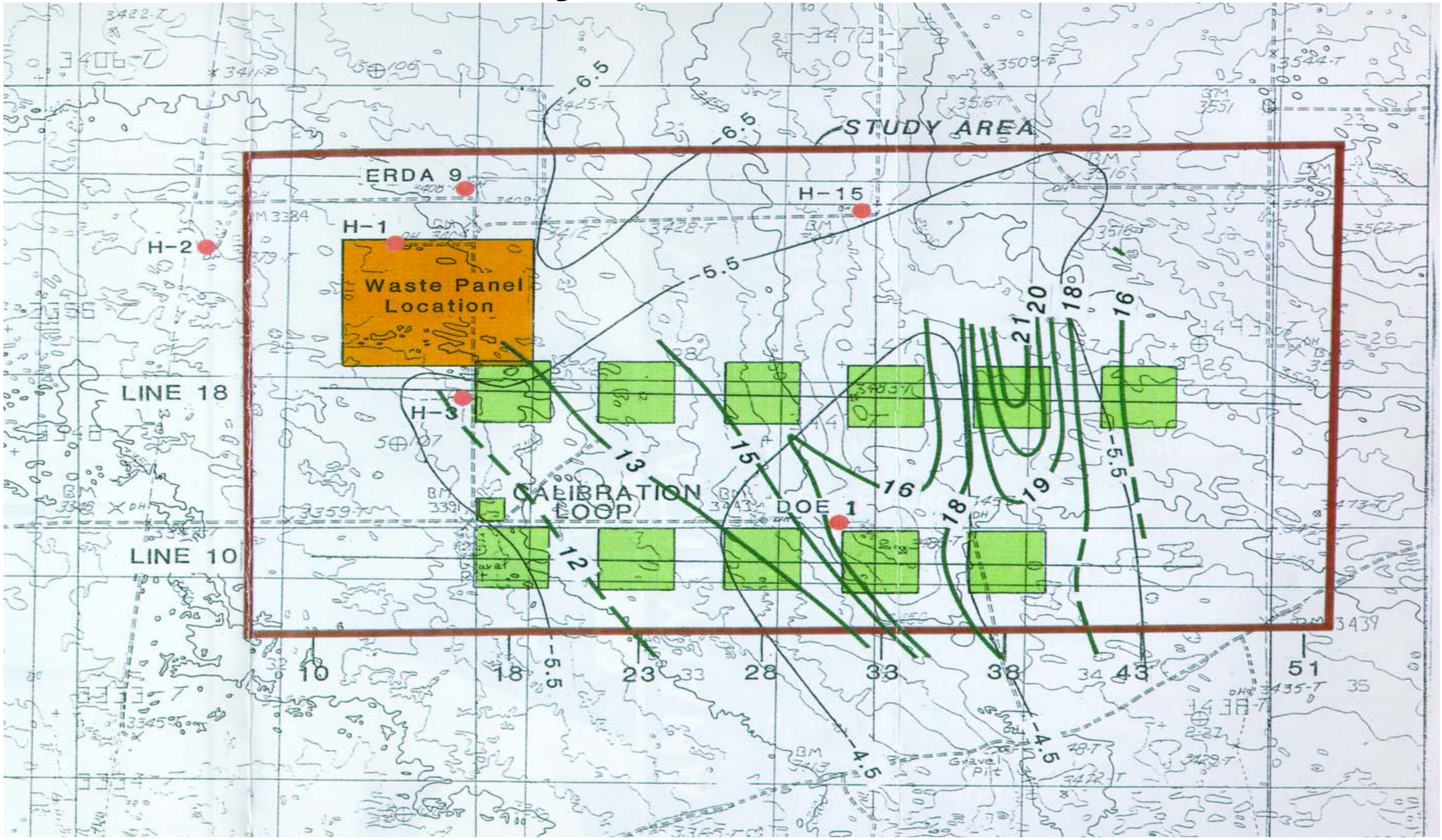
Resolution:

- Identified two north-south conductive features.
- The western feature lies in the lower Dewey Lake Formation and may overlie the storage facility.
- The eastern feature lies in the Rustler Formation, 1000 meters east of the storage facility.
- Suggestion that the feature in the Rustler, about 2500 meters to the east of the storage facility, may extend upward into the Dewey Lake.

TDEM Survey of the Rustler and Dewey Lake Formation



TDEM Survey of the Rustler and Dewey Lake Formation



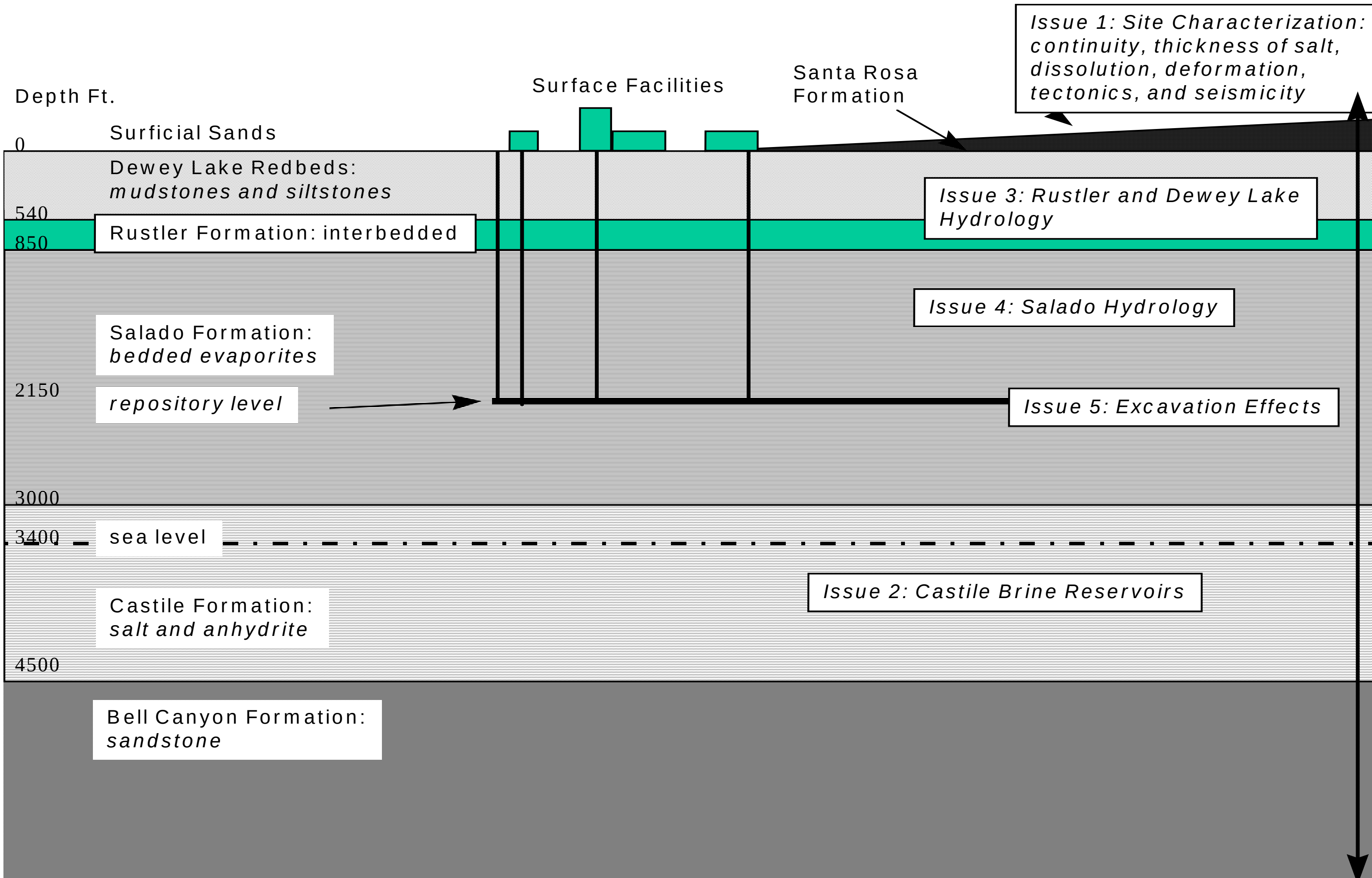
Issue 4: Salado Hydrogeology

Brine flow around excavations; Brine flow in fractures; and Variation in porosity and permeability

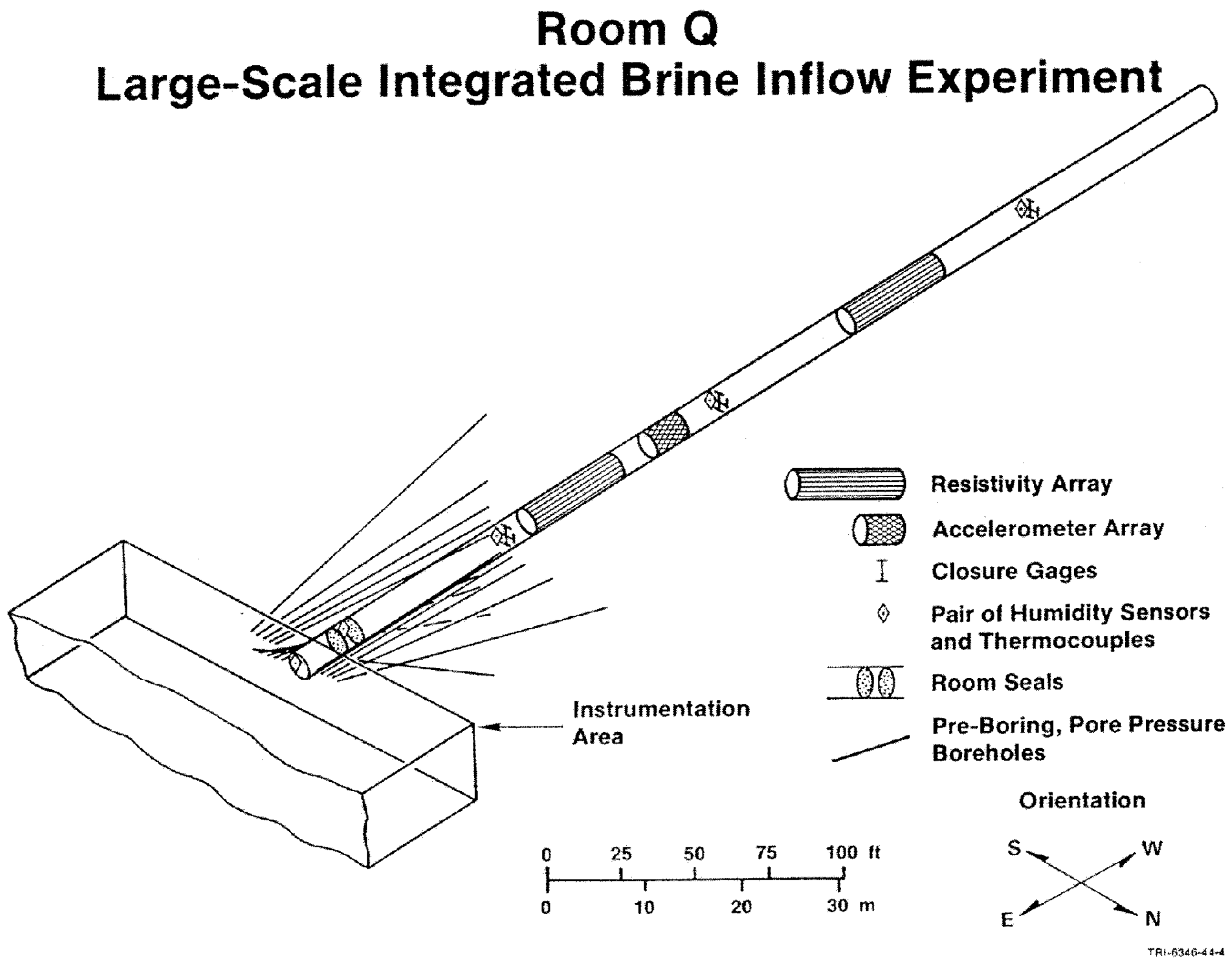
Resolution:

- Established the relationship between brine inflow to changes in electrical properties
- Electrical used to estimate hydrologic properties and predict brine inflow
- Desaturation and the formation of new porosity occur in the Disturbed Rock Zone (DRZ) early after excavation.
- Electrical surveys have delineated brine-filled fractures and non-filled fractures

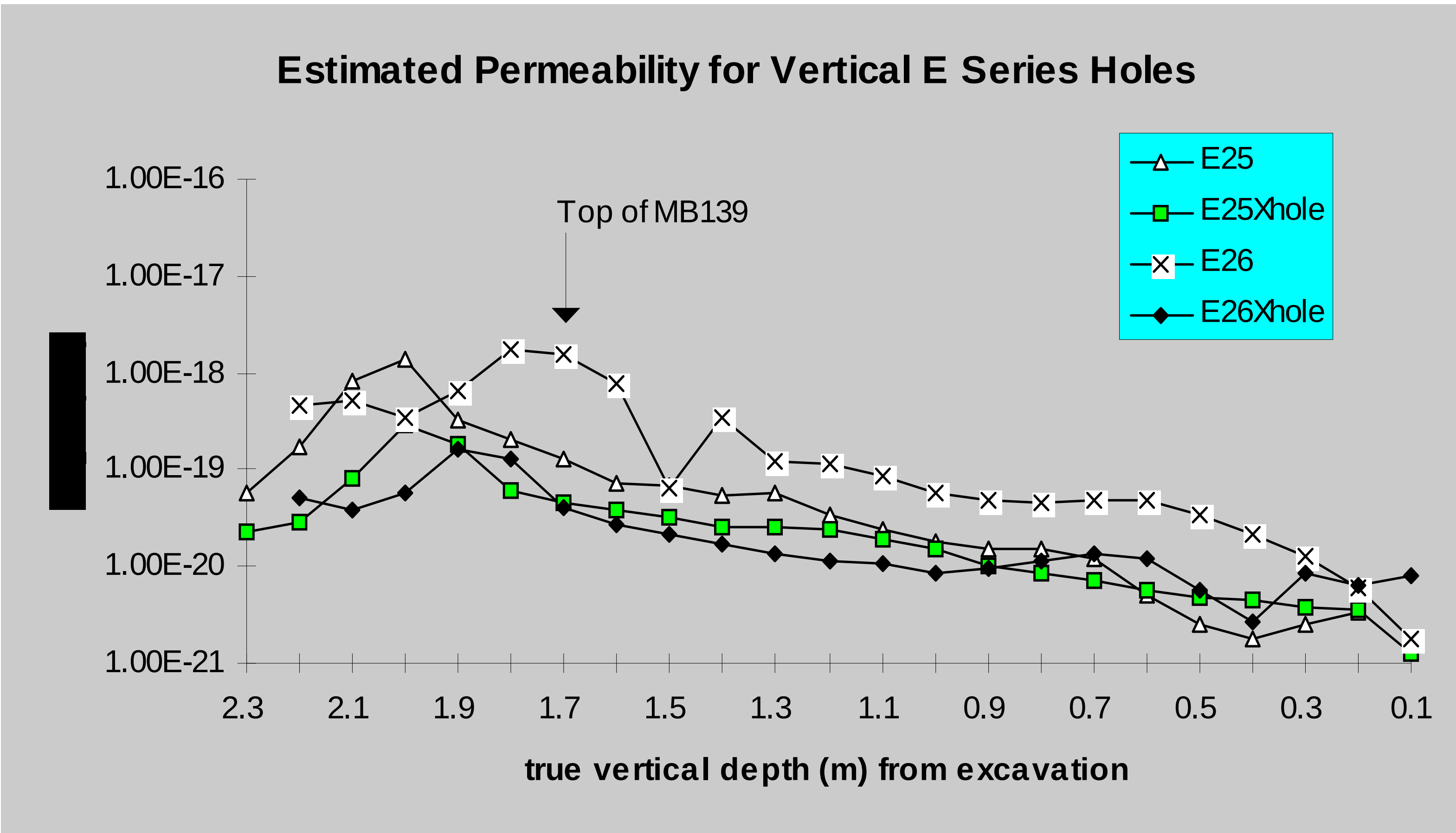
WIPP site geology and stratigraphy relative to facilities and issues addressed by geophysics



Room Q Configuration



Core Logging Relative to Permeability



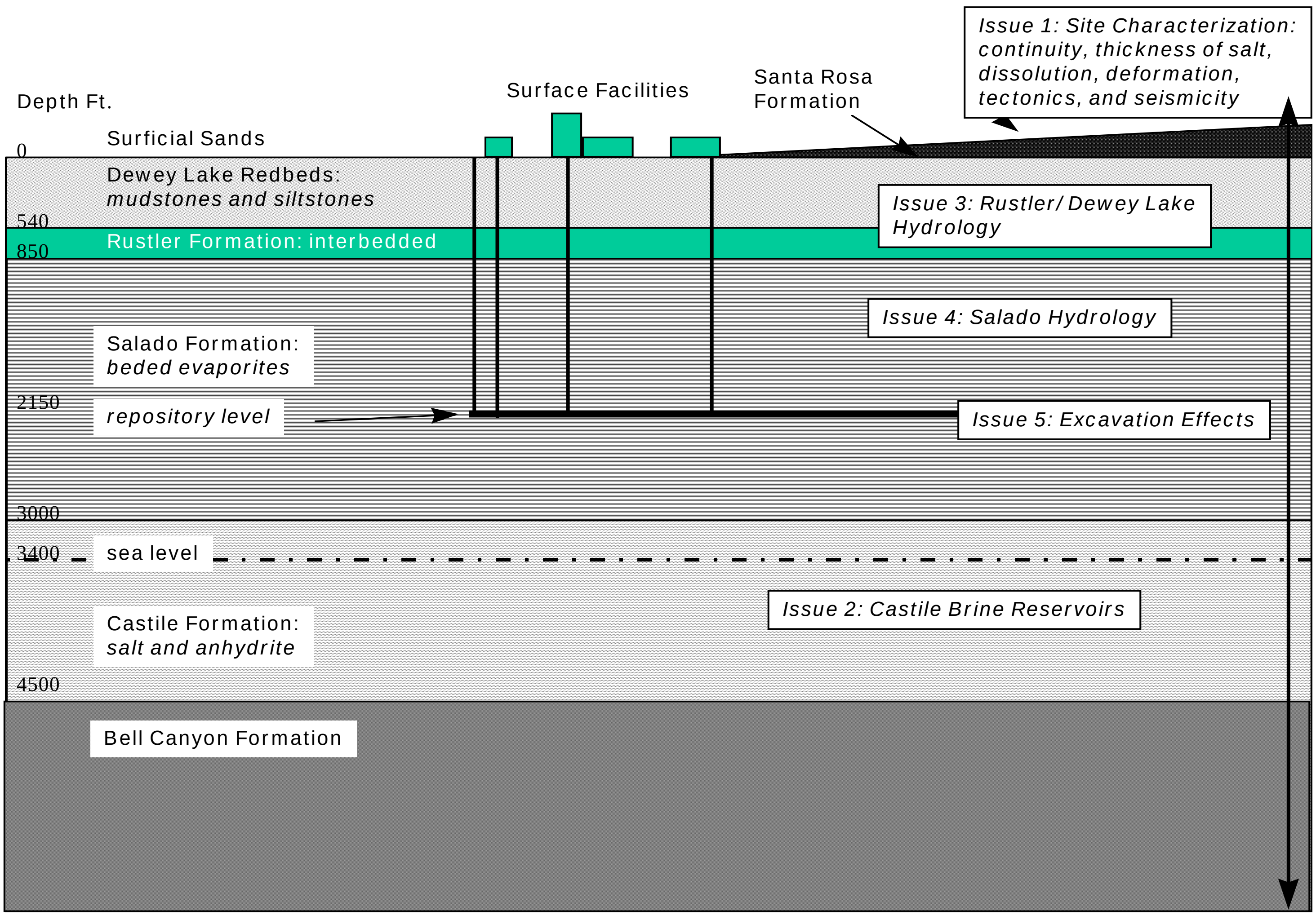
Issue 5: Excavation Effects

Extent of the Disturbed Rock Zone (DRZ); Changes in the mechanical and hydrologic properties of the DRZ with time; and Effects of the DRZ on seal design and location

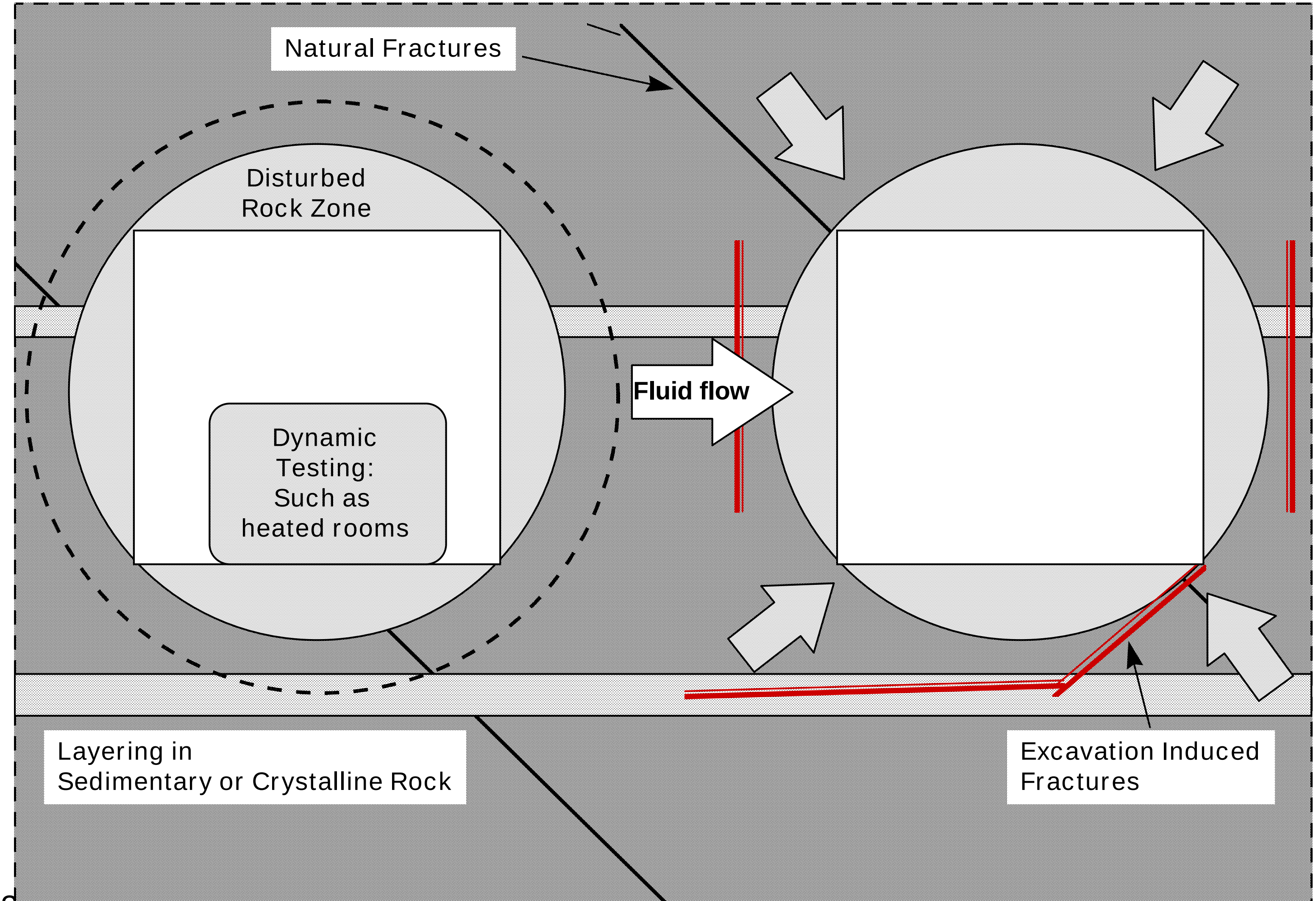
Resolution:

- Fractures affect both brine inflow and the dissipation of gases around the WIPP excavation.
- Both fracturing and fluid flow are difficult to observe in boreholes alone.
- Resistivity and seismic velocity methods map fracturing in the DRZ

WIPP site geology and stratigraphy relative to facilities and issues addressed by geophysics



Features and Processes associated with underground repository excavations



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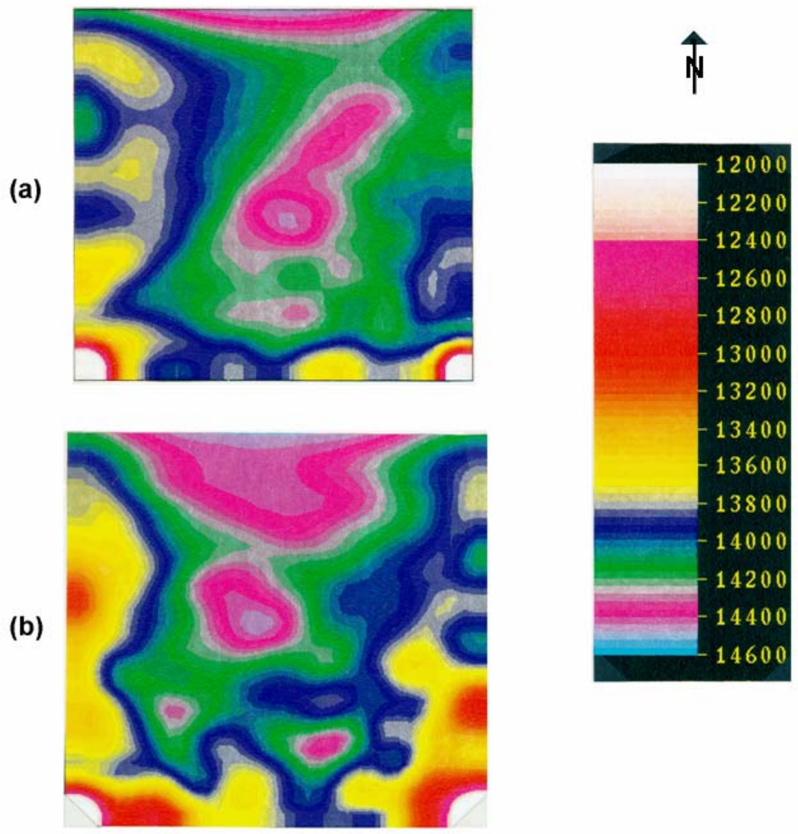
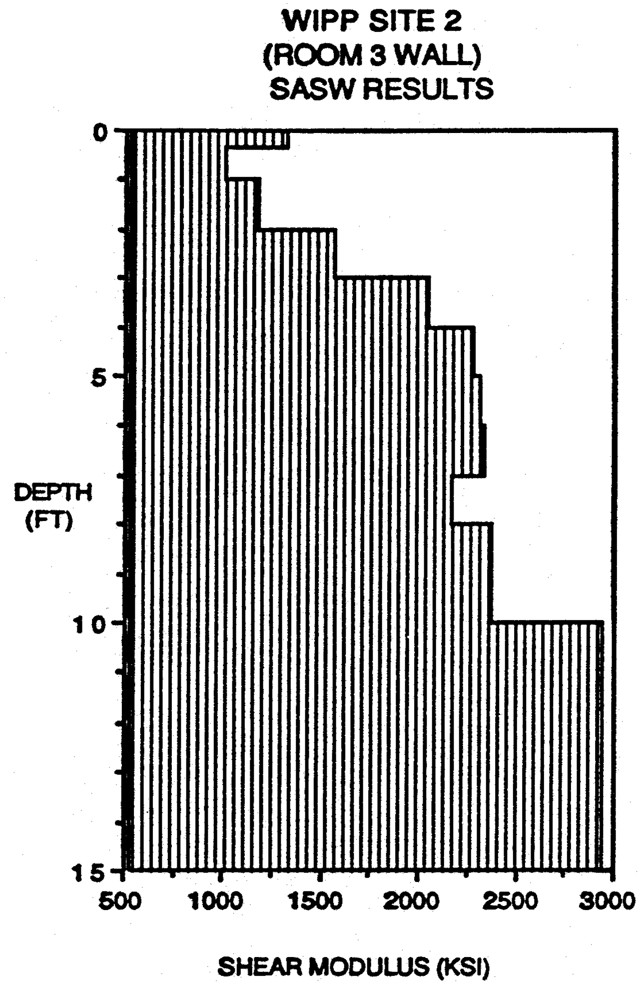
Cross Excavation Pillar Seismic Tomography

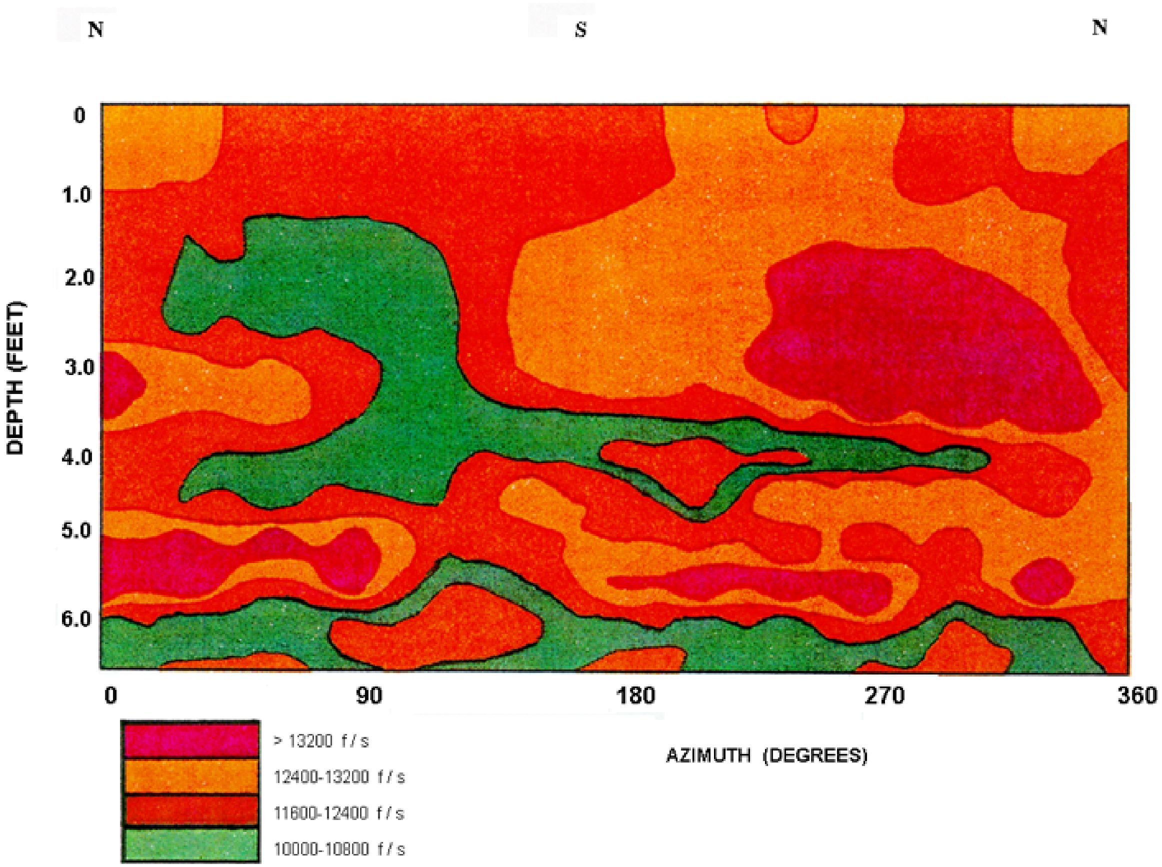


(a) Tomogram of three year old pillar. (b) Tomogram of six year old pillar. The two tomograms show remarkably different velocity distributions.

Spectral Analysis of Surface Wave Profile

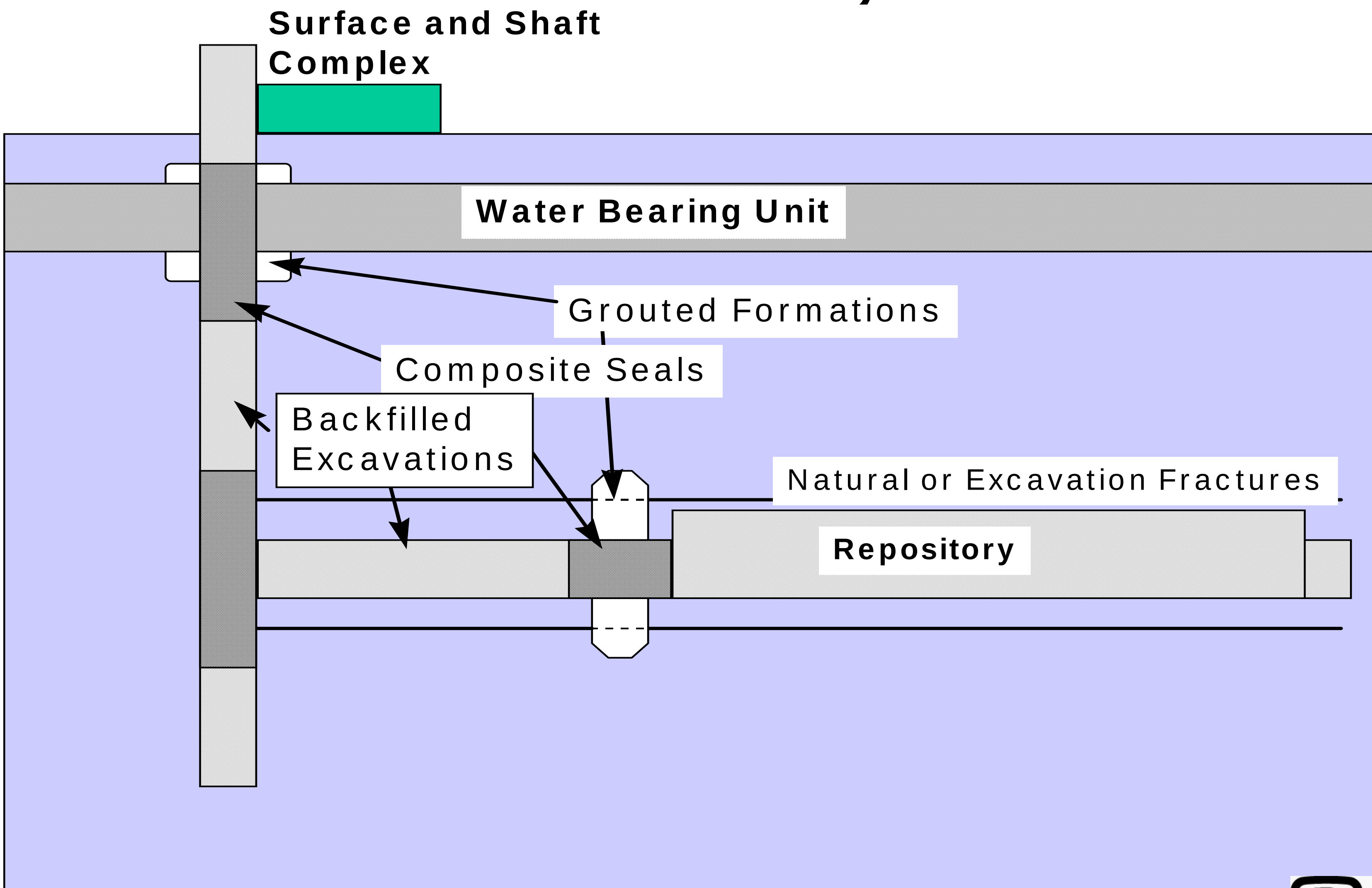


Borehole to Surface Profile of Excavation Floor

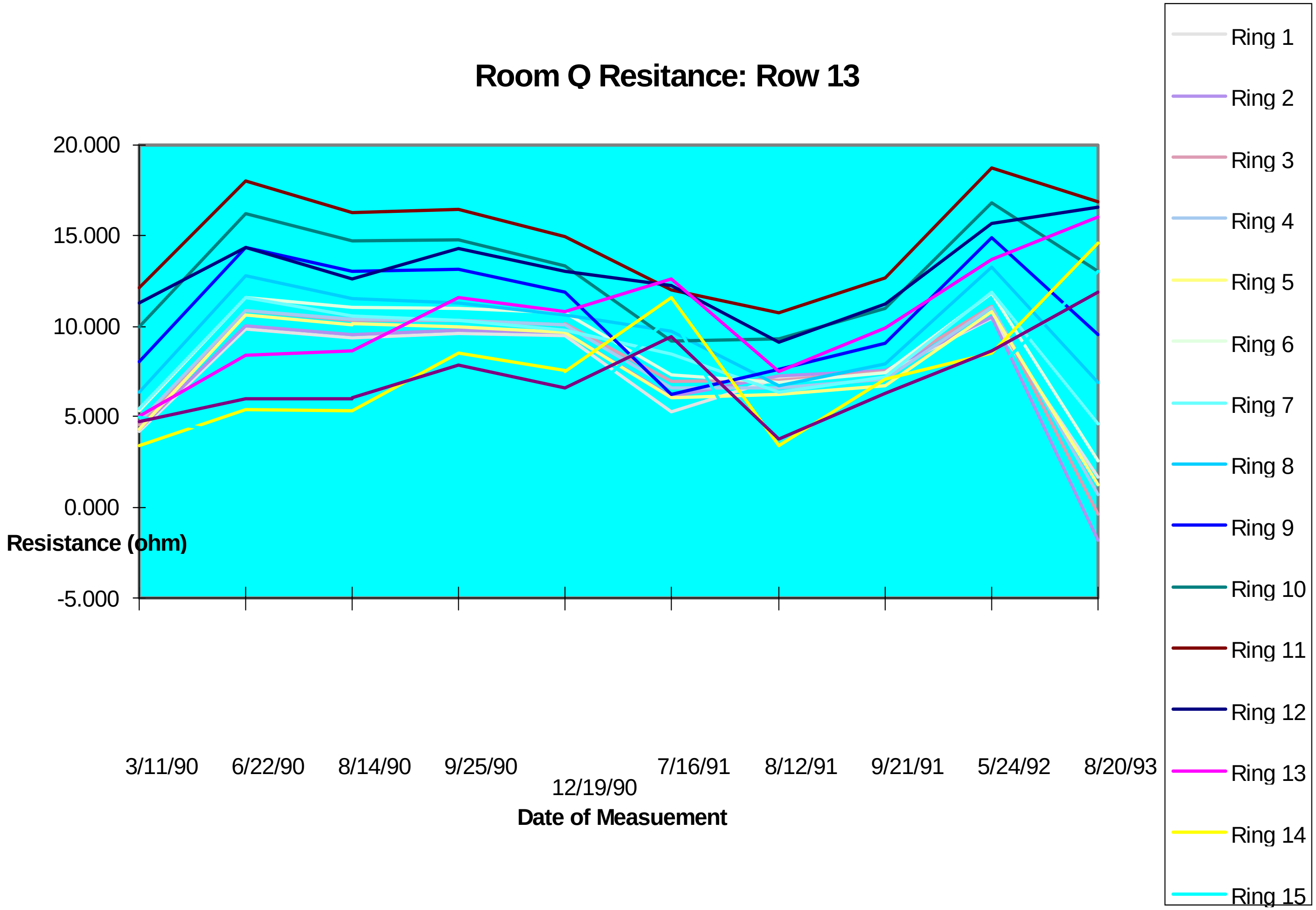


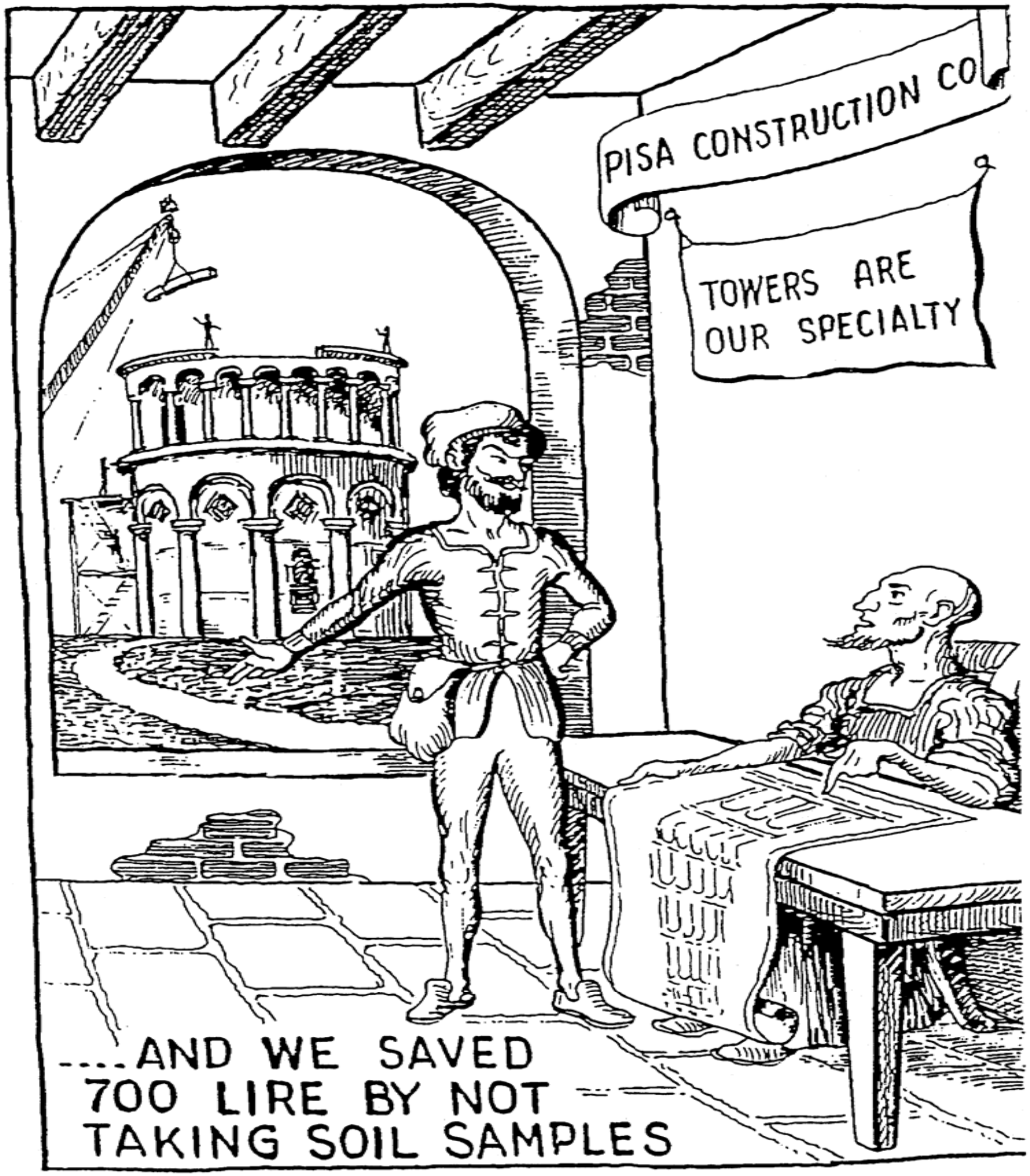
P-WAVE VELOCITY DISTRIBUTION AS A FUNCTION OF DEPTH AND AZIMUTH AROUND TEST HOLE QPB02 IN Q ROOM ACCESS.

Components of a repository containment system



Changes in Resistivity with DRZ




PISA CONSTRUCTION CO
TOWERS ARE OUR SPECIALTY
....AND WE SAVED 700 LIRE BY NOT TAKING SOIL SAMPLES