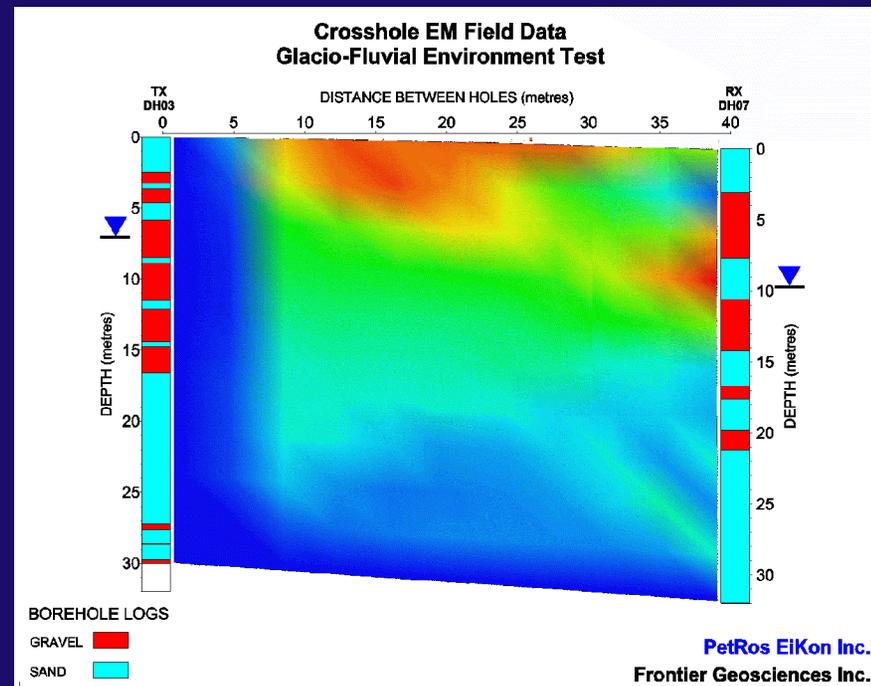


Developments in a Normal Model Helical Electrical Antennae Crosshole Instrumentation and Integrated Interpretation System



PetRos EiKon Inc.

Frontier Geosciences

Electrical Antennae - 100 KHz - 1.5 MHz

RIM Imaging Technologies

- electromagnetic waves in the radio-frequency band

FROM SIMULATION EXERCISES

Electric Field Transmitter and Receiver Antennae

provides sensitivity advantages for a wide range of applications

- **weak resistivity contrasts**
- **electrical permittivity variations**
- **magnetic susceptibility variations**
- **Phase variations diagnostic of scattering mechanism**

Low Frequency Required

- **lower frequencies enables minimization of scattering noise from near- hole fracturing**
- **reduced attenuation with distance**

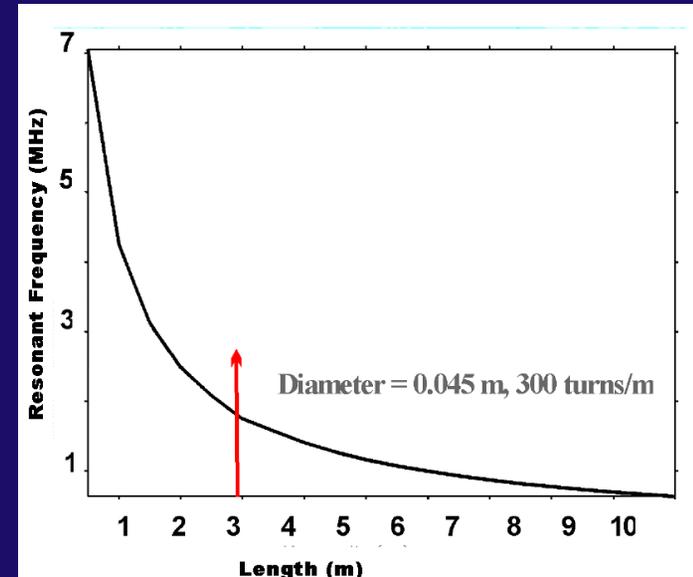


Electrical Antennae - 100 KHz - 5 MHz



- ◆ Conventional 1/8 and 1/4 wavelength antennae too long - **7-40m!**
- ⇒ **Normal Mode Helical Antennae**

⇐ **Conductive wire wrapped
around non-permeable core**



Free Air Resonance Example

∴ **More suitable lengths**

Electrical Antennae - 100 KHz - 5 MHz



+



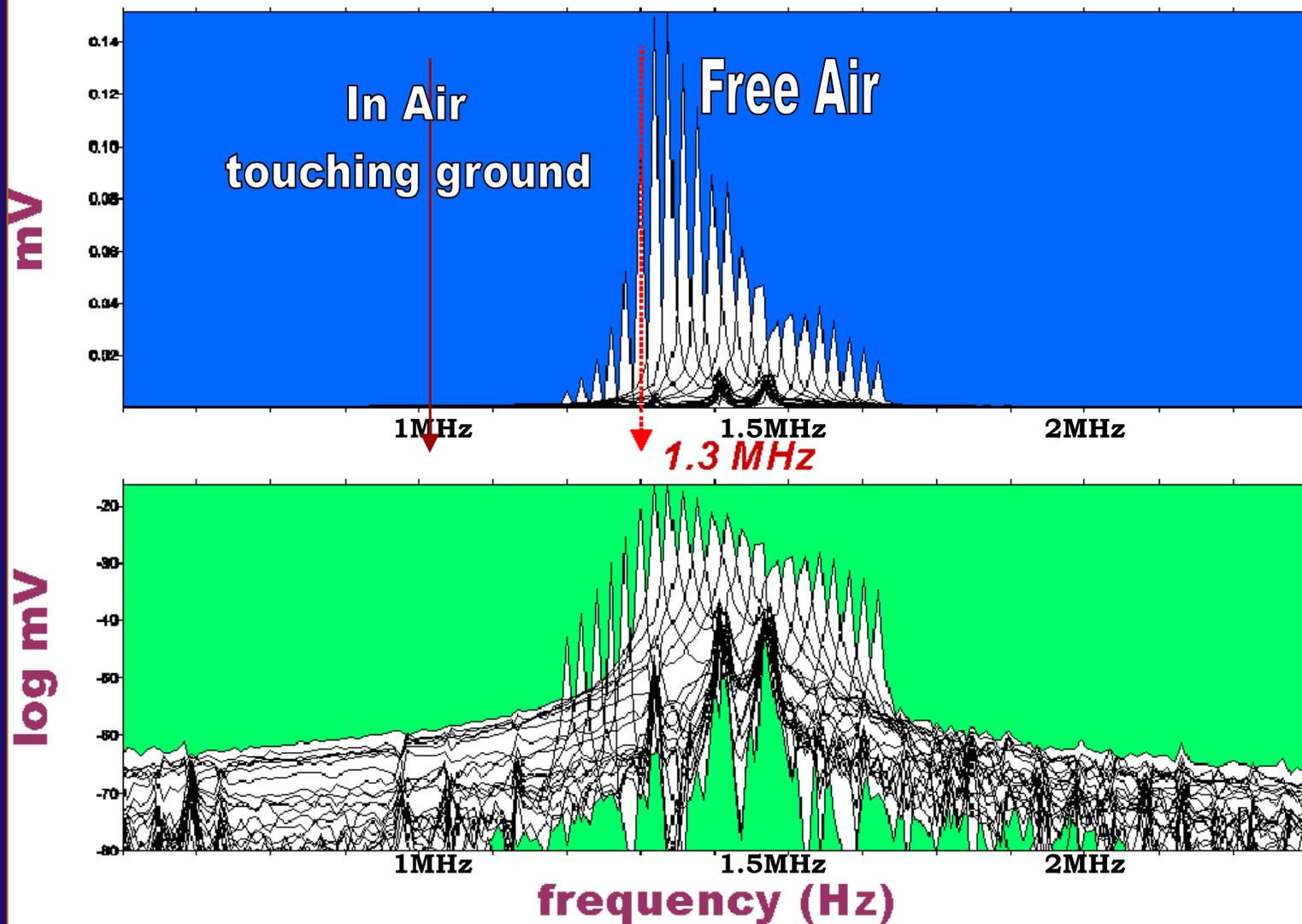
Radiation Patterns

- ▼ $1/r$ - far-field
- ▼ $1/r^2$ - inductive
- ▼ $1/r^3$ - galvanic

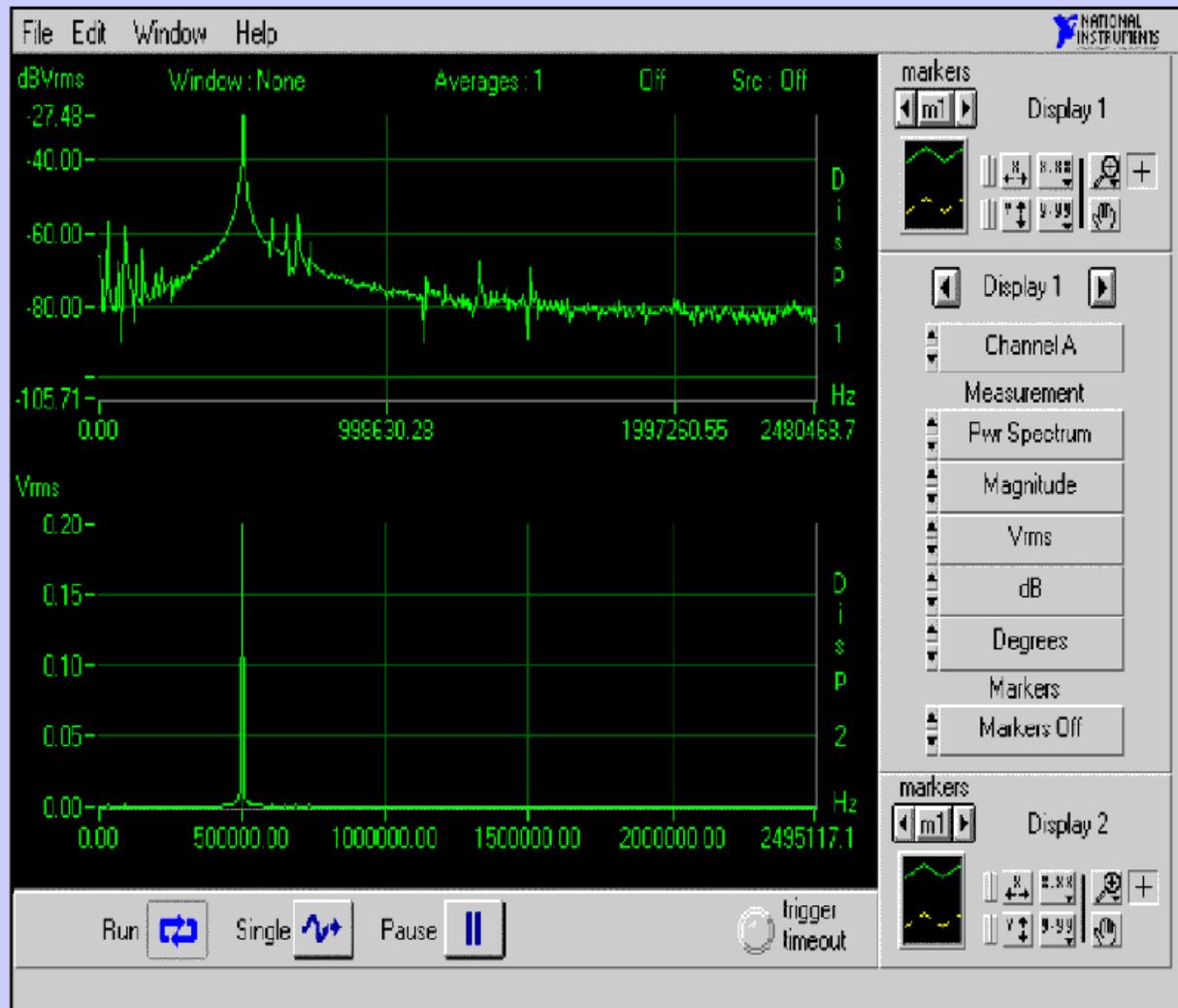
Conductive wire wrapped
around non-permeable core

Antenna Example - 3m, 833 turns, 125m

Free Air Resonance Test



IN-FIELD SPECTRA CAPTURE



Received Power from 500KHz radiation in glacial till

PetRos EiKon Inc

Normal Mode Helical Antennae

▼ Small antennae
(3 or 1.5 m long,
1.6 " or 2 " diameter)

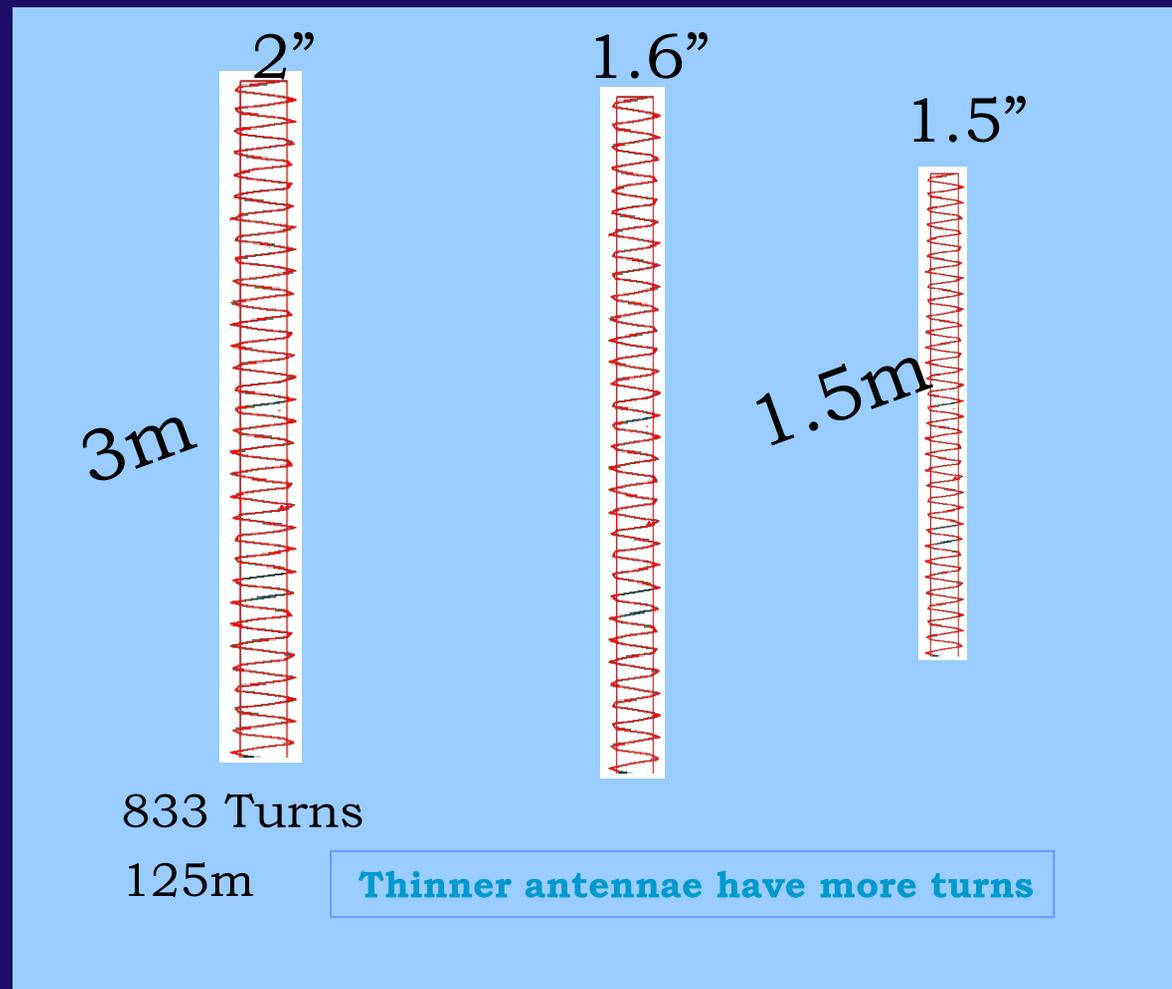
▼ Flexible for twisting holes

▼ Ungrounded

▼ Inexpensive design

▼ Free-Air Resonance
1.33-1.67MHz

▼ Broad band efficiency
characteristics (100KHz -
1.5MHz)



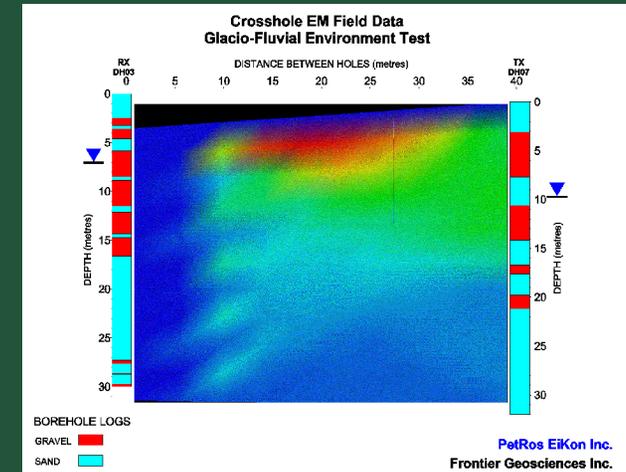
▼ Multiple frequency data
with a single antennae

Overview of Development Program Objectives

Applications:

- ▼ Geotechnical
- ▼ Environmental
- ▼ Mine Development
- ▼ Oil Recovery Applications

subsurface structural investigations for waste site and tailing applications, ore delineation, reservoir characterization, rock weaknesses, fluid and viscous boundary investigations monitoring



X-hole RIM Imaging

Crosshole Instrumentation

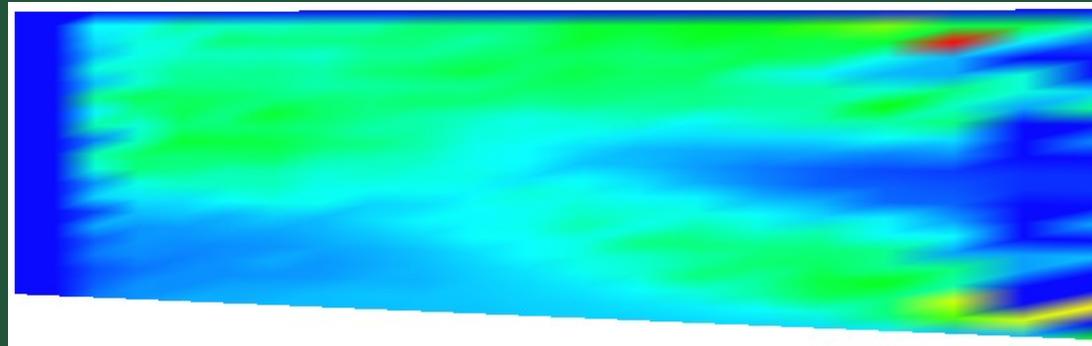
Data Interpretation Software Tools

† Simulation

† Tomography

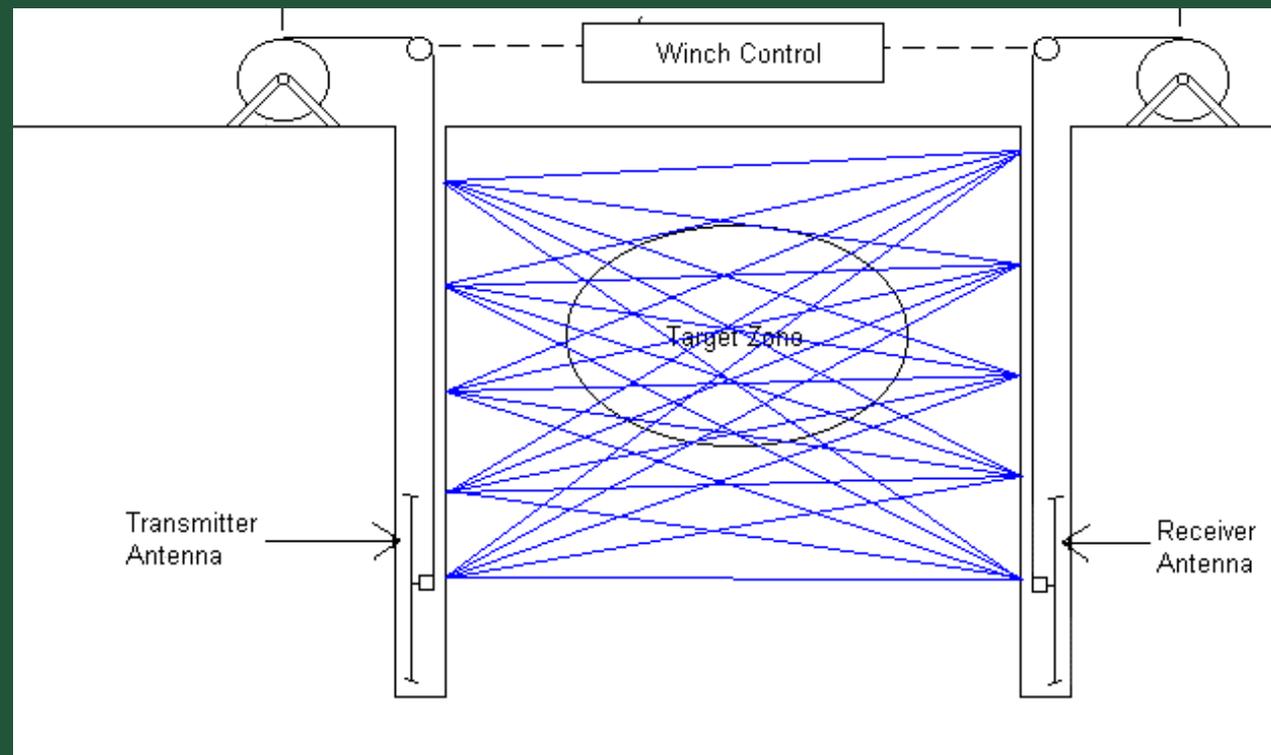
† Inversion

➔ Imaging Electrical properties between holes



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Cross Borehole Data Survey Panel



Crosshole Instrumentation

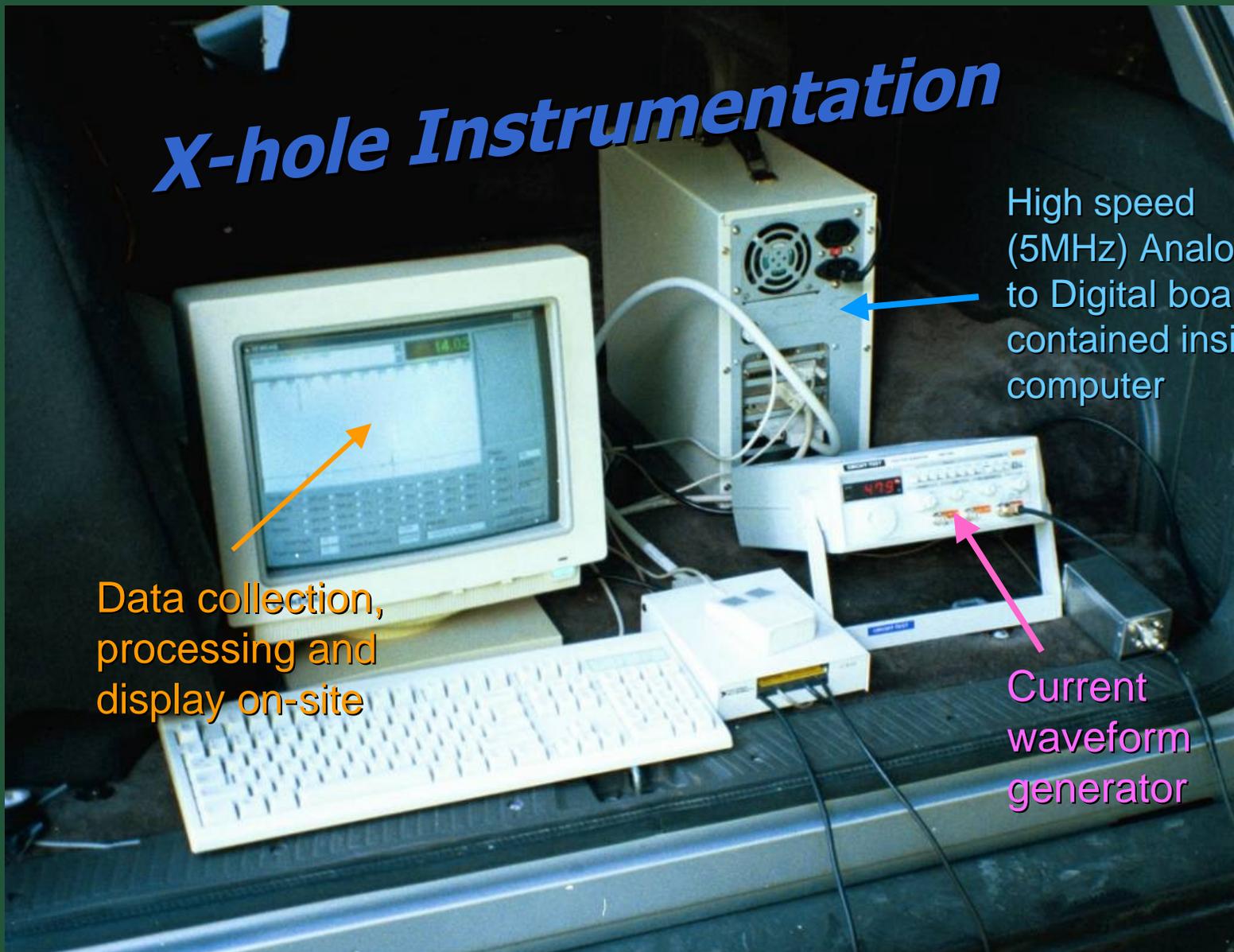


X-hole Instrumentation

Data collection,
processing and
display on-site

High speed
(5MHz) Analogue
to Digital board
contained inside
computer

Current
waveform
generator



Data Collection

Rapid Surveying Technique

- ▼ Log data as antennae moves virtually in free-fall
- ▼ Monitor reflected voltage from antennae as a function of Tx position in ground
- ▼ Collect data at $\Delta z < 1$ m with automated triggers
- ▼ 1 time series every .5 second
- ▼ Log a 35 m deep Xhole panel with a single frequency in less than an hour

Test Survey Results:

- 1 Aquifer Evaluation**
- 2 Mine Setting Test**
- 3 Municipal Landfill Test Site**

Examples of other Case Studies Completed:

- 1 Glacial Fluvial Reservoir Fill**
- 2 Earthen Dam Sinkhole**
- 3 Dry Cleaning Fluid Contamination**
- 4 Fracture Zone Test**
- 5 Ore Resolution**

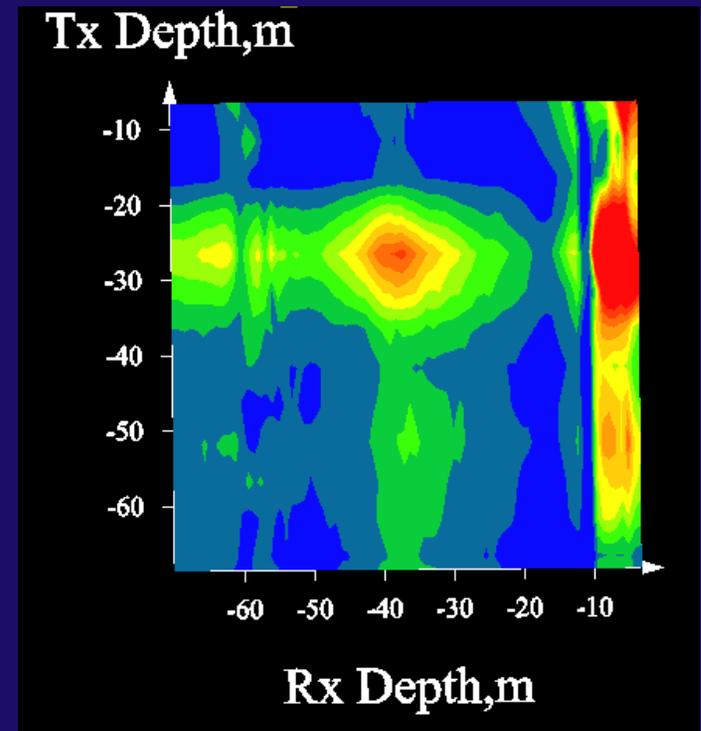
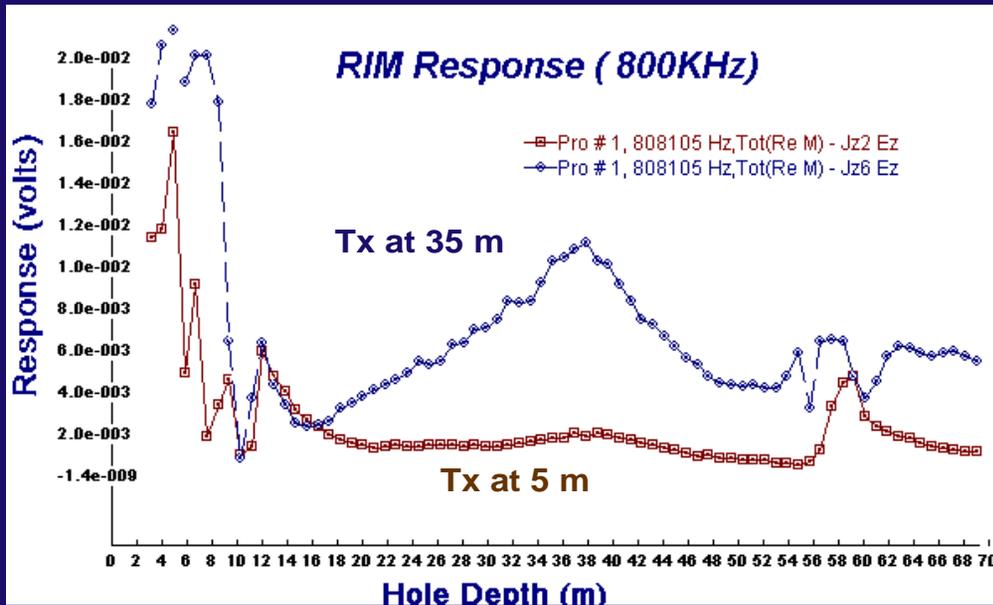
Aquifer Evaluation

15m collar offset - 70m depths

800Khz

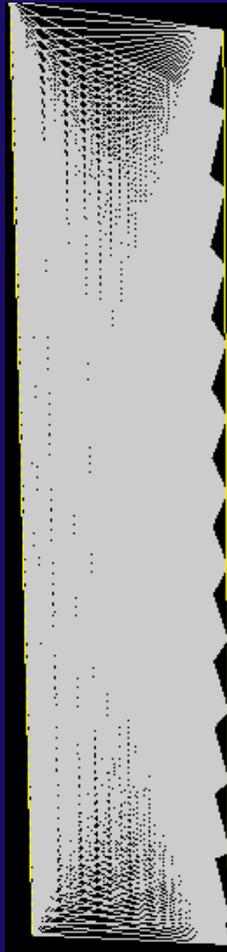
- * 0-10m Fine Sand and Silty Sand
- * 10m - Wet filled Sand
- * 38m - Muddy medium grained sand
- * 57m - Coarse Sand

Tx vs Rx Plots



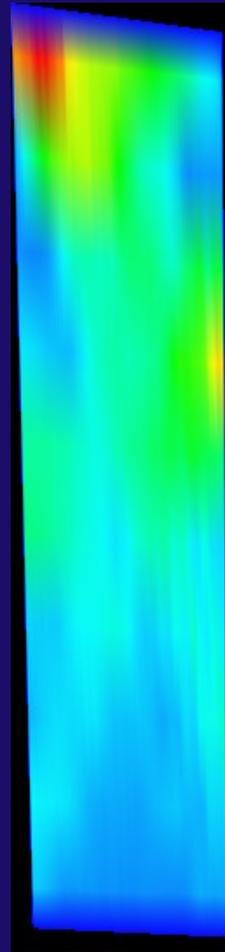
Aquifer Evaluation

15m collar offset - 70m depths



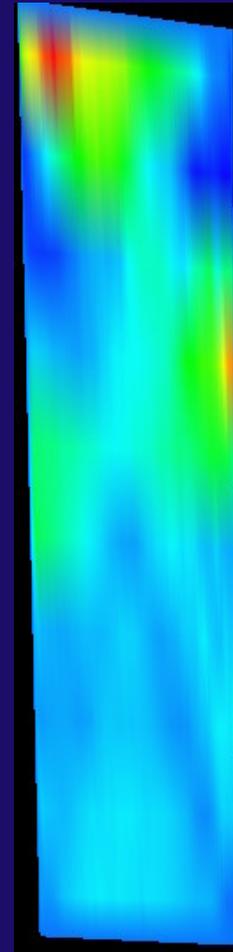
(a)

Ray Paths



(b)

Weighted Ray Paths



(c)

Weighted Attenuation

Glacio-Fluvial Environment Test

Shallow monitoring holes

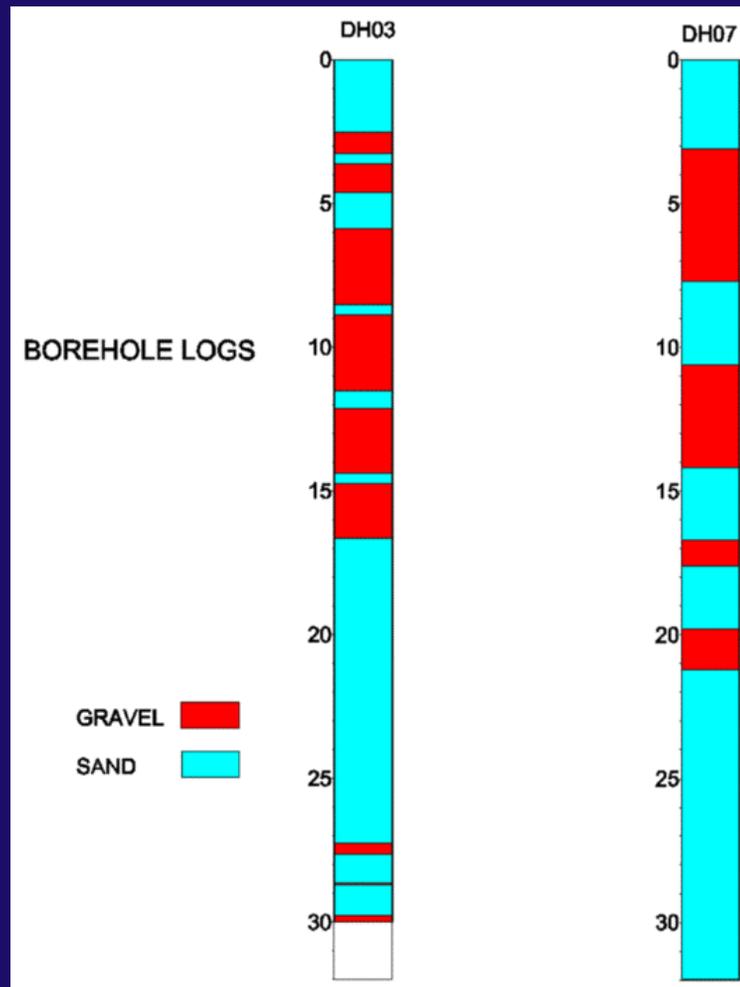
- glacio-fluvial fill fill outside a water-reservoir earthen dam
- One reverse panel of data

Results:

- revealed structure
- indicated several scattering characteristics of the system
- normal mode helical antenna have broad band efficiency in the key range of frequencies when operated in earth materials

- the resonant frequency of the antenna is lowered and made considerably broader when the antennae are operated in earth materials
- provides a wide operating spectra
- the lower range of which are frequencies thought to be most sensitive for dam safety and environmental investigations involving overburden and placer granular materials

Glacio-Fluvial Test - 500 KHz - 40m offset



▼ Relatively low frequency gives greater sensitivity in this weak contrast environment

▼ Short antennae design (3m) enables use in shallow applications (20 m holes).

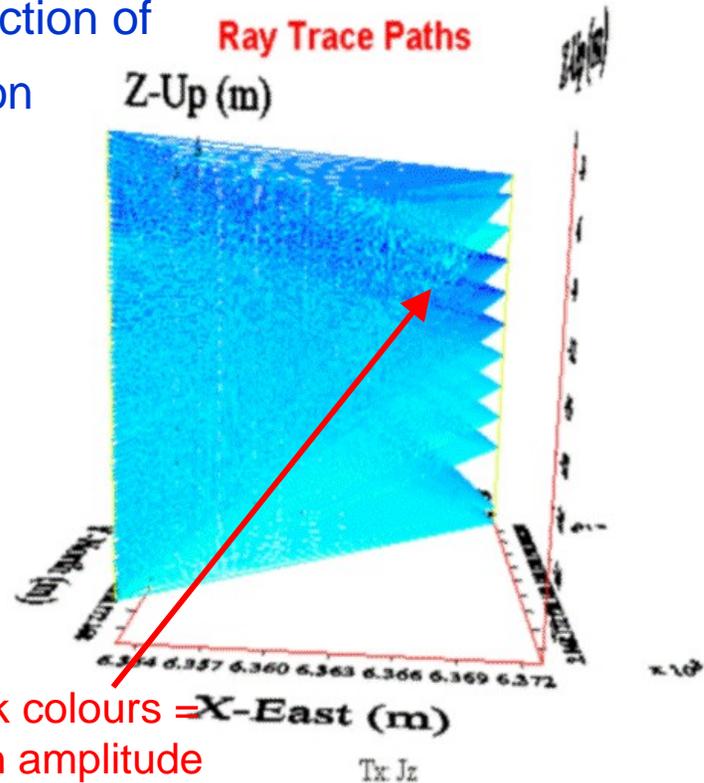
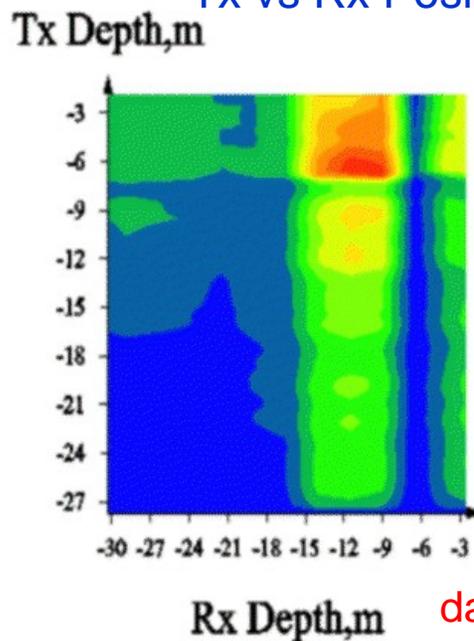
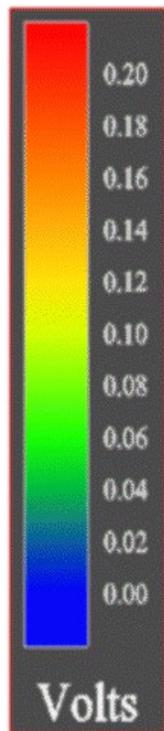
▼ Low frequency reduces attenuation allowing for larger hole separations

Crosshole EM Field Data

hole 07

TX in hole DH07

Data Display as a function of
Tx vs Rx Position



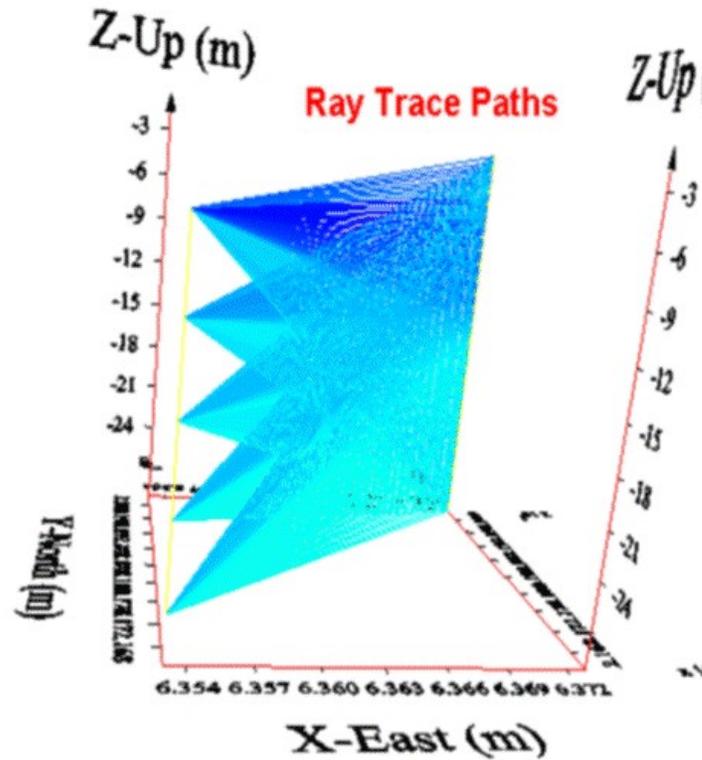
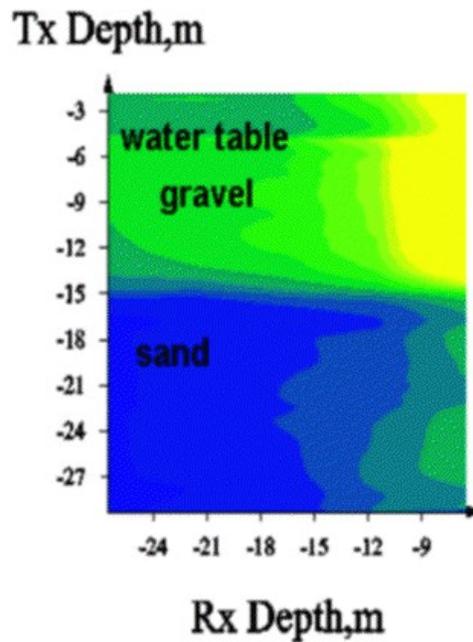
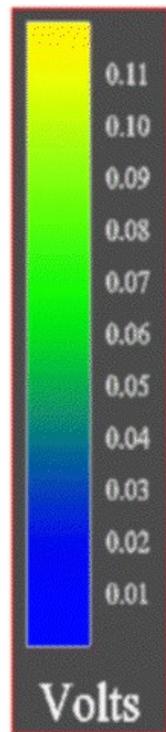
Ray Trace Paths weighted by
amplitude

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Crosshole EM Field Data

Hole 03

TX in hole DH03



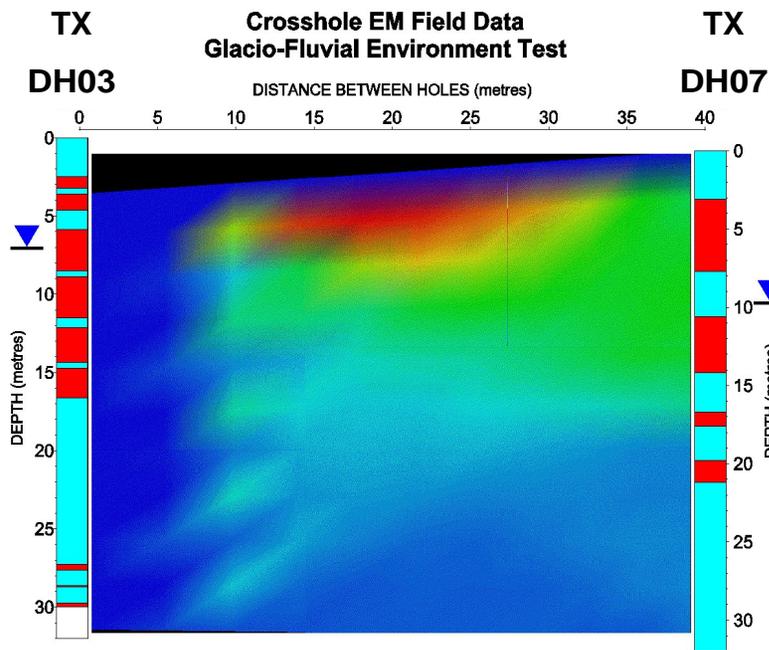
Tx: Jz
Rx: Ez
Freq# 1
Measured

PetRos EiKon Inc.
Frontier Geoscience

Reciprocal Surveying

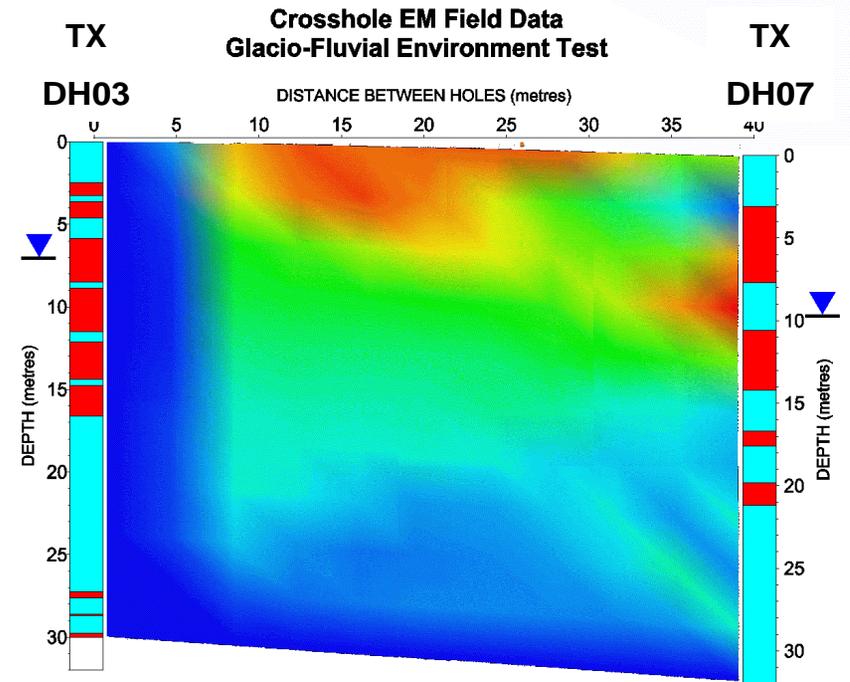
500 KHz

Panel 1: 
11 Tx positions used



BOREHOLE LOGS
GRAVEL 
SAND 

PetRos EiKon Inc.
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BOREHOLE LOGS

GRAVEL 
SAND 

PetRos EiKon Inc.
Frontier Geosciences Inc.

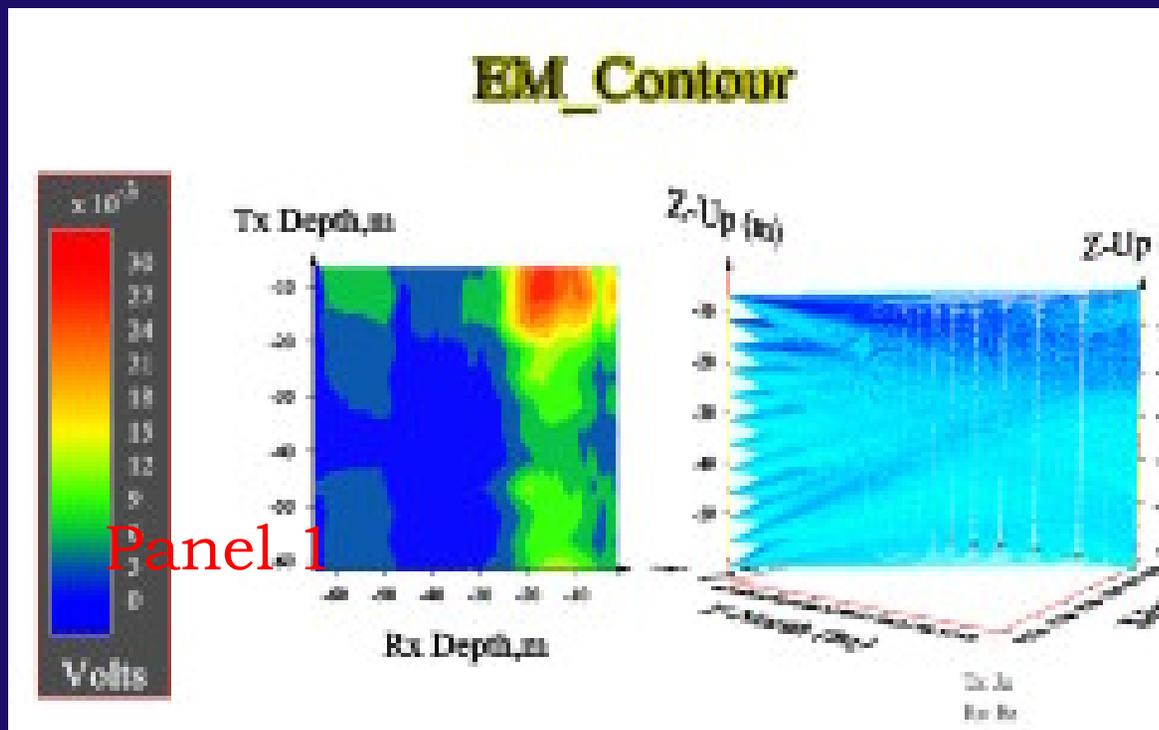
Panel 2:
Reduced Resolution
Only 5 Tx positions used

Earthen Dam Test Site Data

- Xhole RIM surveys carried out in 3 borehole pairs.

- 2 in sections through a sinkhole

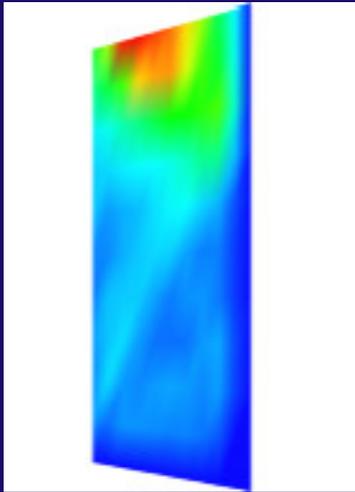
- 1 in undisturbed core material.



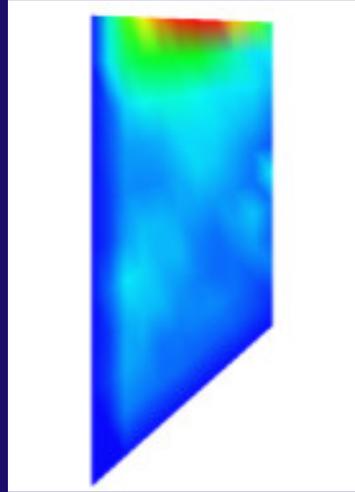
- Low attenuation shallow zone
 - interpreted as coarse shell material and shell materials that collapsed into the sinkhole during a 1996 event.
- the water table is clearly seen in this data

Sinkhole with Earthen Dam

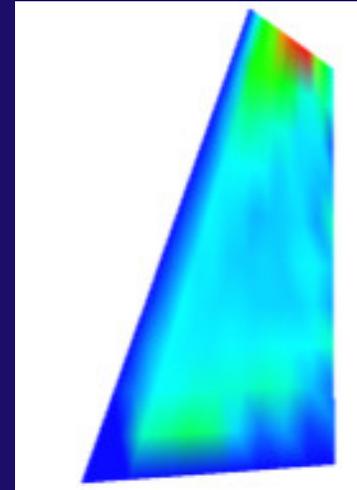
Panel 1



Panel 2



Panel 3



- sinkhole in the dam crest
- Borehole based geophysics proved to be the most diagnostic techniques
- The essential objective is to image changes in the 'core' consisting of medium to fine grained material that has been rendered very dense during placement. The core is encased in very coarse (.5 m plus) shell materials for protection.

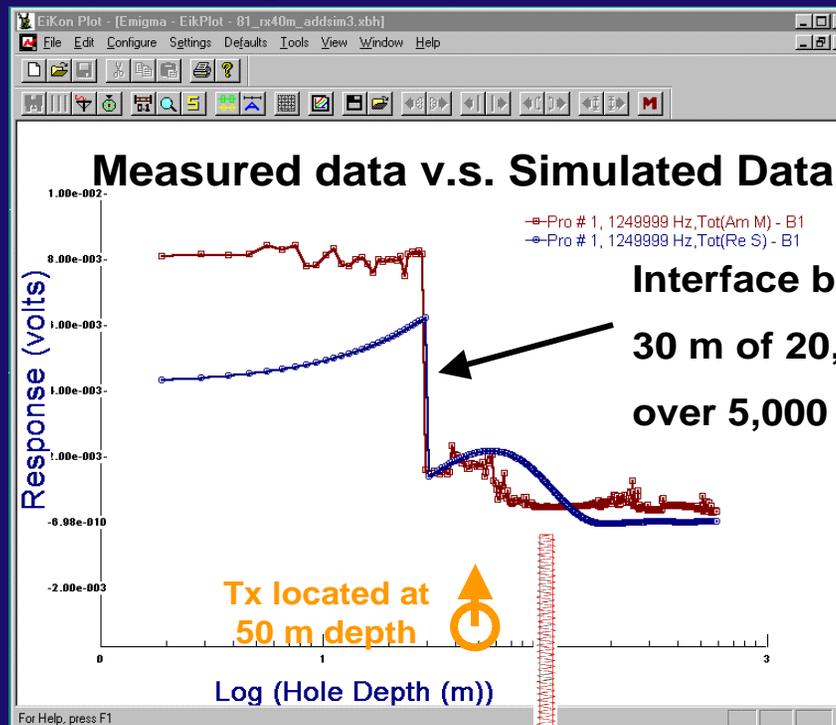
Ore Exploration Holes

125m collar offset - 600m depths

Instrumentation performed well with:

- ▼ Electrically Resistive Environment
- ▼ Strong wideband cultural noise present (holes located close and between two operating mines)

- ▼ Cold weather conditions (-20C)
- ▼ Deep holes (600m)
- ▼ Tx,Rx offsets greater than 600m



Municipal Landfill

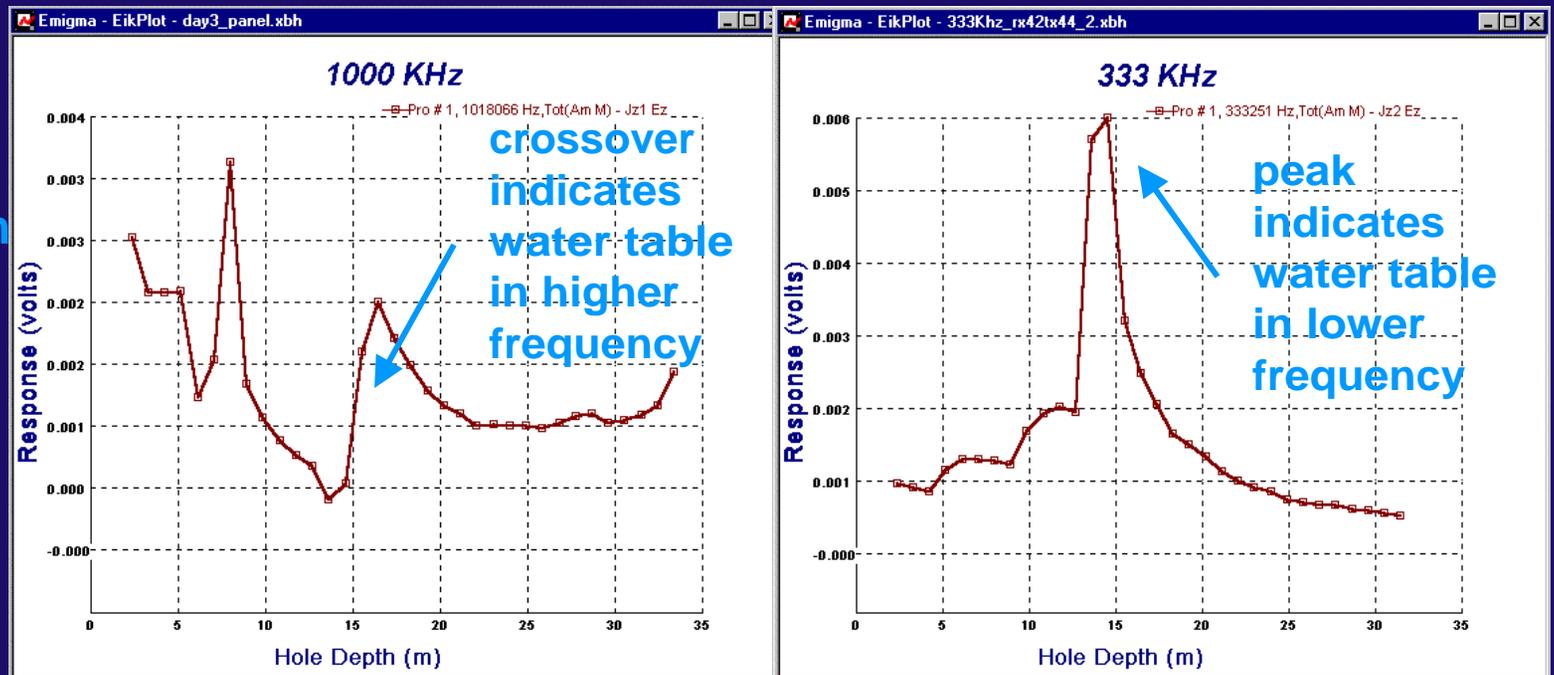
contains suspected leachate plumes

Multiple frequency tests - 333, 600, 750 and 1000 KHz

Instrumentation performed well with:

- wide Tx, Rx separations (100m) in conducting soil, till and bedrock
- strong cultural noise present (commercial arc-welding plant within .5 km of site, power lines, buildings, truck traffic)

- ▼ Moving Tx
- ▼ Rx, z= 3.0 m

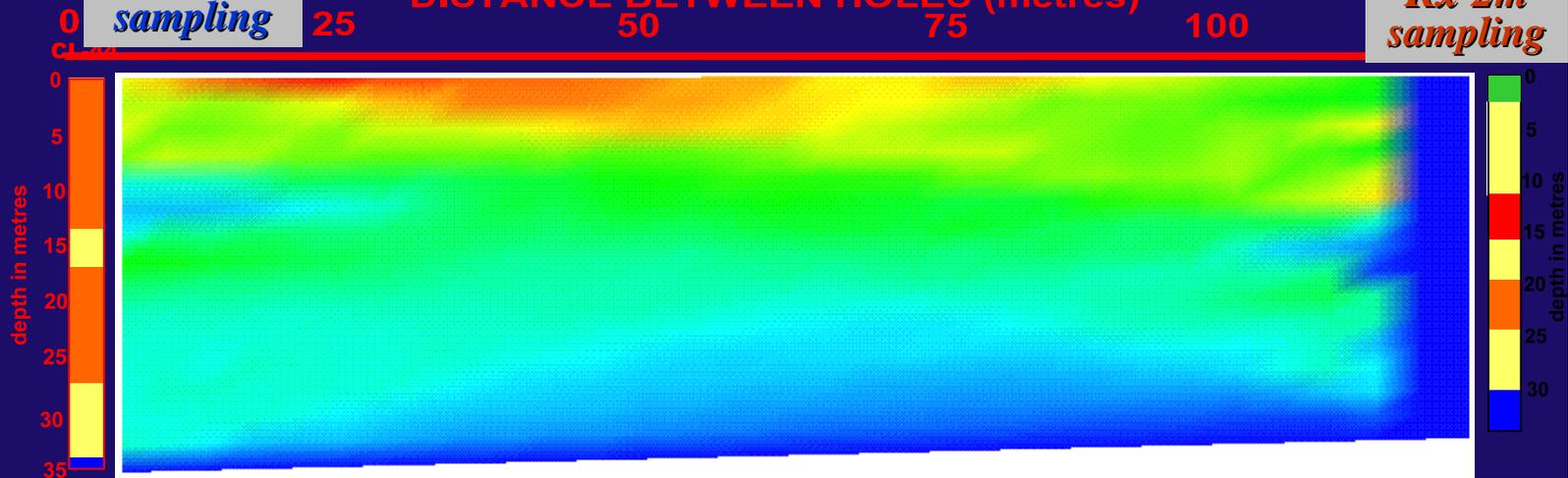


Reciprocal Panels

*Tx 0.94m
sampling*

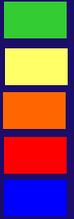
DISTANCE BETWEEN HOLES (metres)

*Rx 2m
sampling*



Reverse Pattern Sampling for the same frequency - 1 MHz

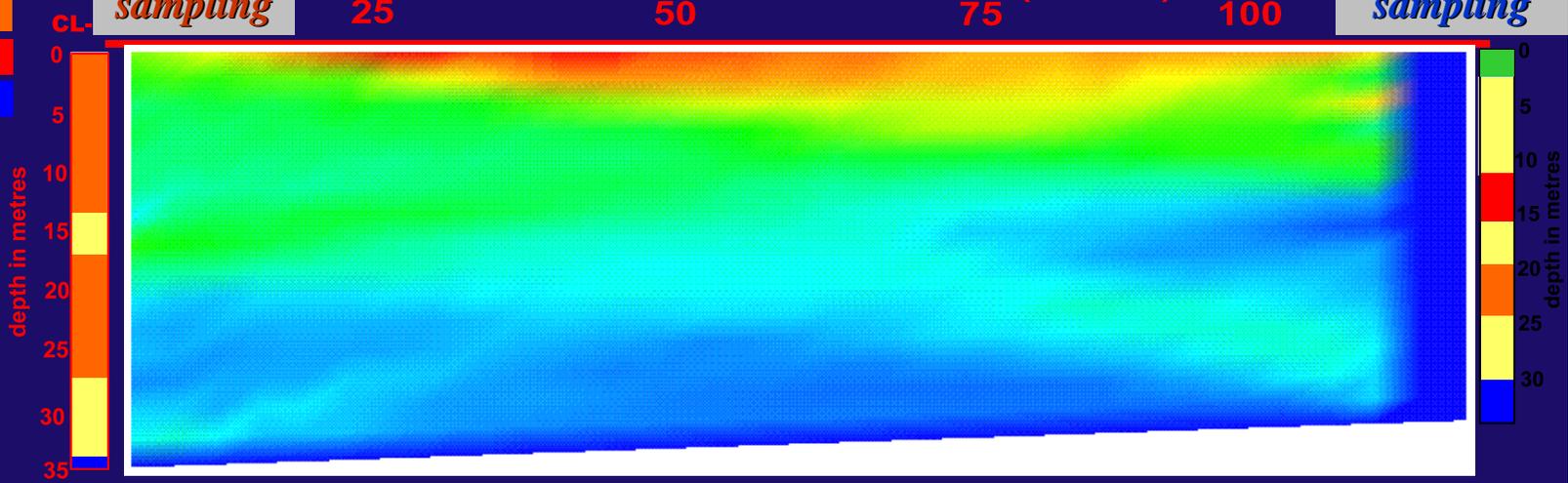
- FILL
- SAND
- SILTY SAND
- SILT
- BEDROCK



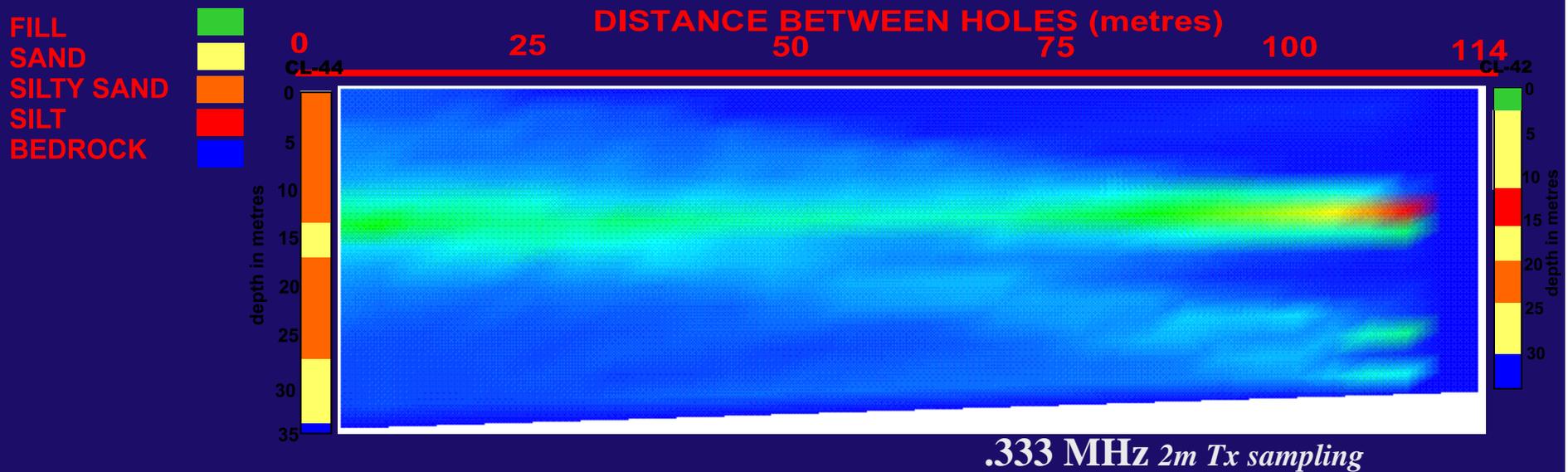
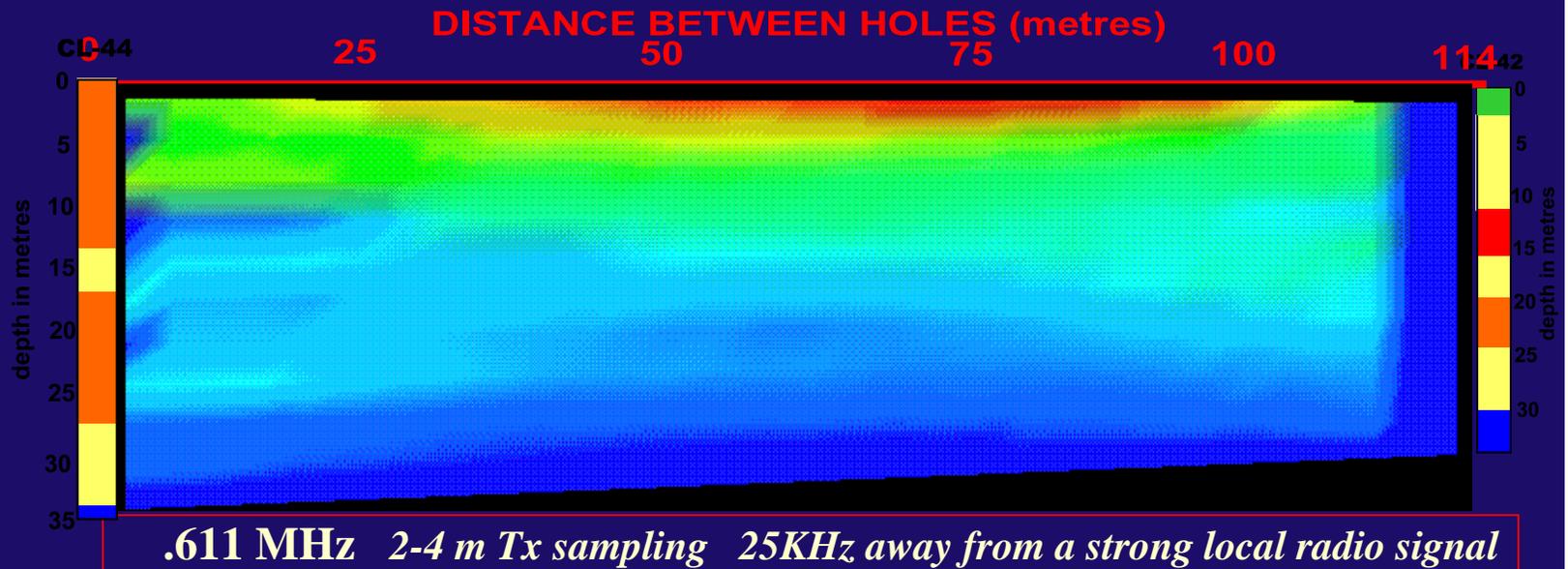
*Rx 1.5m
sampling*

DISTANCE BETWEEN HOLES (metres)

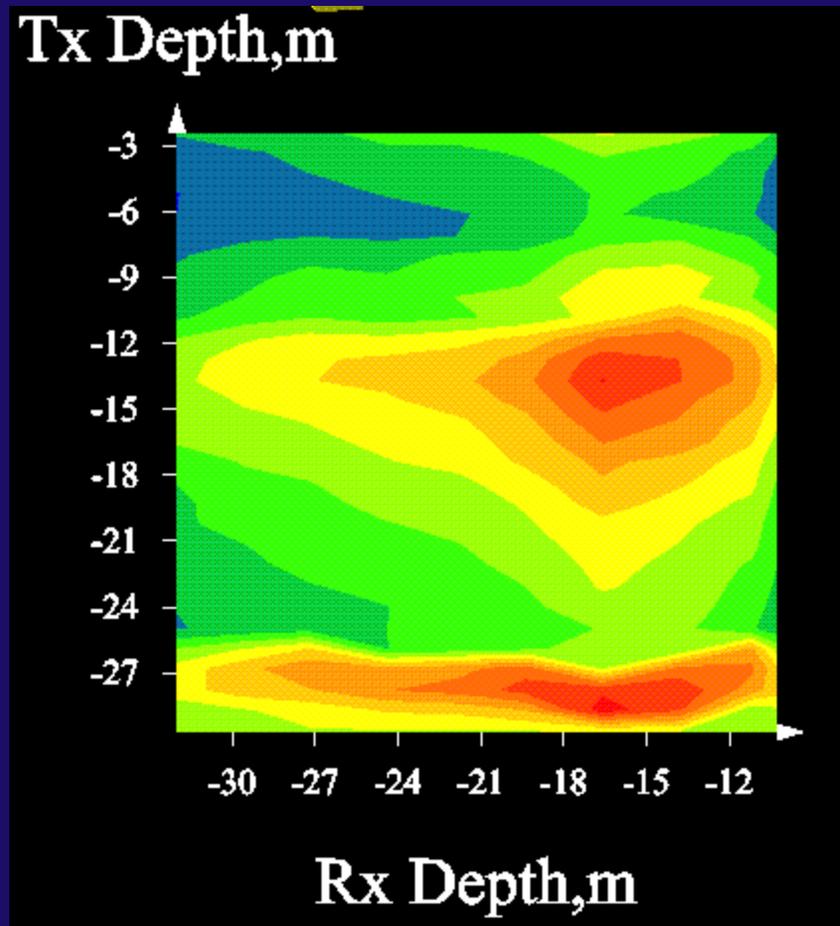
*Tx 0.94m
sampling*



Frequency Dependent Scattering



Contour Tx position vs rx



Status:

- initial development extremely successful
- excellent data repeatability
- interpretable multi-frequency data
- developed signal-to-noise estimation procedures to ensure data quality
- reliable field procedures developed
- dependable pre-commercialization equipment
- all necessary software now available

Conclusions:

- NMHA can operate between low KHz and low MHz using compact broadband antennae
- Rapid data collection with sufficient redundancy for noise estimates

Present Research Focus

- Relationship between freespace resonance and broadband underground
- Radiation pattern in lossy medium for more effective tomography and inversion techniques
- Placement of Amplifiers on Tx and Rx antennae
- Development of an automated data collection system

Major Objectives:

- 1 Secure additional test sites
- 2 Collect more than 4 pairings of data in order to image the subsurface in 3D

Minor Objectives:

- 1 Survey holes with greater than 25 m offsets to test the equipment's distance limitations
- 2 Survey a site with cultural noise to determine equipment's noise tolerance