X-hole Tomography
A new frontier in Equipment and Software

PetRos EiKon Inc. and Frontier Geosciences Inc.
X-hole Tomography

An Electrical Antennae
Crosshole Instrumentation and Interpretation System

*PetRos EiKon Inc* and Frontier Geosciences Inc.
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
Electrical Antennae

RIM Imaging Technologies

- electromagnetic waves in the radio-frequency band

**Electric Field Transmitter and Receiver Antennae**

provides sensitivity advantages for a wide range of applications

- weak resistivity contrasts
- permittivity variations
- IP effects and
- discrimination of magnetic structures

**Low Frequency to reduce interference with near hole scattering**

- lower frequencies enables minimization of scattering noise from near-hole fracturing
Crosshole EM Block Diagram

- Frequency Generation
- Amplifier
- Impedance Matching
- Storage Control and Display Computer
- Analog to Digital Conversion
- Signal Conditioning and Amplification
- Winch Control
- Target Zone
- Transmitter Antenna
- Receiver Antenna
- Ray path
- Preamplifier
Normal Mode Helical Antennae

- Small antennae (3m long, 4.5 cm diameter) effective even for short, narrow holes
- Flexible for twisting holes
- Inexpensive design
- Depths greater than 600m
- Broad band resonance characteristics (100KHz - 1.5MHz)
- Thinner antennae have more turns
- Collect multiple frequency data with a single antennae

NORMAL MODE HELICAL ANTENNA
883 TURNS
DIAMETER - 4.5 cm
WIRE LENGTH - 125 m
Free-Air Resonance: 1.67 MHz
Free Air Resonance Test

mV

log mV

frequency (Hz)

1.3 MHz
X-hole Instrumentation

No instrumentation down hole
X-hole Instrumentation

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

Data collection, processing and display on-site

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 0.94 m intervals with automated triggers
- 1 Data sample every second
- Log up to 600 m in 15 min
- Log a 35 m deep Xhole panel with a single frequency in less than an hour
NMHA FreeSpace Radiation Pattern

Project Developments include
Simulation Capabilities for both antennae radiation patterns and scattering effects

Frontier Geosciences

PetRos EiKon Inc
Digital Signal Analyzer Software
analyze noise characteristics and power
Tune dial to an optimum frequency

IN-FIELD SPECTRA CAPTURE

View Spectra on Computer Screen
Select a radiating frequency within a quite zone of the broad resonating band.
Test Survey Results:

1. Glacio-Fluvial Environment Test
2. Earthen Dam Test
3. Mine Setting Test
4. Municipal Landfill Test Site
Glacio-Fluvial Environment Test

Tests performed in shallow monitoring holes within glacio-fluvial fill outside a large water-reservior earthen dam

• One reverse panel of data collected (first with the TX in one hole and the Rx in the other and then reversing the configuration)

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

- Relatively low frequency (500 KHz) gives greater sensitivity in this weak contrast environment.

- Short antennae design (3m) enables use in shallow applications (20 m holes). Other commercially available RIM antennae are 10x longer for low frequencies and 2x longer for high frequencies.

- Low frequency reduces attenuation allowing for larger hole separations.
Data Display as a function of Tx vs Rx Position

Ray Trace Paths weighted by amplitude

dark colours = high amplitude
Data Display as a function of Tx vs Rx Position

Ray Trace Paths weighted by amplitude

dark colours = high amplitude
Reciprocal Surveying

Tx-Rx antennae reversed and re-run in the second panel

Panel 1:
11 Tx positions used

Panel 2
Reduced Resolution
Only 5 Tx positions used

500 KHz frequency used
large earth filled dam
• sinkhole was discovered in the dam crest
• a broad range of geophysical approaches, including seismic, electromagnetic, resistivity, magnetics and ground penetrating radar methods failed to characterize the sinkhole due to difficulty in access, dam site surface conditions, culture and impedance contrasts. 
• Borehole based geophysics proved to be the most diagnostic technique
• The essential objective is to image changes in the 'core', which consists 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.
Earthen Dam Test Site

• test crosshole EM surveys were carried out in three borehole pairs. Two of these were in sections through a sinkhole and one was in undisturbed core material.

Panel 1 - Contour Plot Tx vs Rx

• The surveys in the sinkhole area show a lower attenuation shallow zone that is interpreted to be the coarse shell material in place, and shell materials that collapsed into the sinkhole during a 1996 event.

• the water table is clearly seen in this data

Panel 1 - X-hole data in volts
Mine Test Site – Sudbury, Canada

Instrumentation performed well with:

- **Electrically Resistive Environment**
- Strong wideband cultural noise present (holes located close and between two operating mines)
- Cold weather conditions (-20°C)
- Deep holes (600m)
- Tx, Rx offsets greater than 600m

Measured data v.s. Simulated Data

- Interface boundary
  - 30 m of 20,000 Ohm-m
  - over 5,000 Ohm-m

Tx located at 50 m depth

Mine Site Data

Xhole data (red)
Simulated data (blue)
Landfill Test Site – Waterloo, Canada

contains suspected leachate plumes with the potential to threaten municipal and private water sources and local wildlife

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 configuration in the same hole for 2 frequencies
Receiver position at 3.0 m

crossover indicates water table in higher frequency

peak indicates water table in lower frequency
Landfill Test Site – Waterloo, Canada

Reverse Pattern Sampling for the same frequency - 1 MHz

Raytracing
Landfill Test Site – Waterloo, Canada

Raytracing

- 611 MHz 2-4 m Tx sampling 25KHz away from a strong local radio signal
- 333 MHz 2m Tx sampling
Landfill Test Site – Waterloo, Canada

borehole log legend

0 25 50 75 100 114

DISTANCE BETWEEN HOLES (metres)

-42 0 5 10 15 20 25 30

depth in metres

.750 MHz 2m Tx sampling
Landfill Test Site – Waterloo, Canada

borehole log legend

- **FILL**
- **SAND + GRAVEL**
- **Silty Sand**
- **SILT**
- **BEDROCK**

S Silt
Ts Trace Silt
C Clay
tC Clay

CONDUCTIVITY HIGH
CONDUCTIVITY LOW
INTERMITTENT H + L

**DISTANCE BETWEEN HOLES (metres)**

**CL-25**

**depth in metres**

.151 MHz 0.94 Tx sampling
Contour tx position vs rx
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
Status: 2000

- 5 test areas studied
- more than 12 panels of data have been collected
- 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

READY to study scattering processes which are not clearly understood in RIM technology
Test Sites Required:
- Additional test sites are sought for
- Environmental detection applications and Mine applications

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
Contact Us
For more information:

Ross Groom
Tel: 1(905)-796-0324
e-mail: sales@petroseikon.com

visit us at:
http://www.PetRosEiKon.com