GEOTECH
AIRBORNE GEOPHYSICAL SURVEYS

WORKSHOP - Métodos Não Sísmicos
Painel sobre Gravimetria Gradiométrica e Eletromagnéticos
Aplicados em Mineração, Petróleo e Gás

Potenciais aplicações e integração dos métodos AEM (VTEM e ZTEM) em alvos exploratórios em bacias intra-cratônicas e com derrames basálticos no Brasil

por Carlos Izarra, PhD
Geotech Aerolevantamentos S.A.

"Over the last decade, airborne electromagnetic (AEM) systems have evolved on different platforms with different configurations of ever-increasing moments, and processing technologies have improved data quality significantly....
The primary advantage of AEM is that hundreds to thousands of line kilometres of high resolution, multichannel EM data can be rapidly and safely acquired over large areas with zero surface disturbances and at a fraction of the cost of seismic reflection...Yet AEM systems have generally had very limited use in hydrocarbon exploration "

(Zhdanov et al., 2013)

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" The relationship between geology and geophysics has been discussed frequently. There can be little doubt, however, that geophysics and geology must cooperate to get a maximum of results..."
(Gutenberg, 1937)

VTEM – Versatile Time-domain Electro-Magnetics

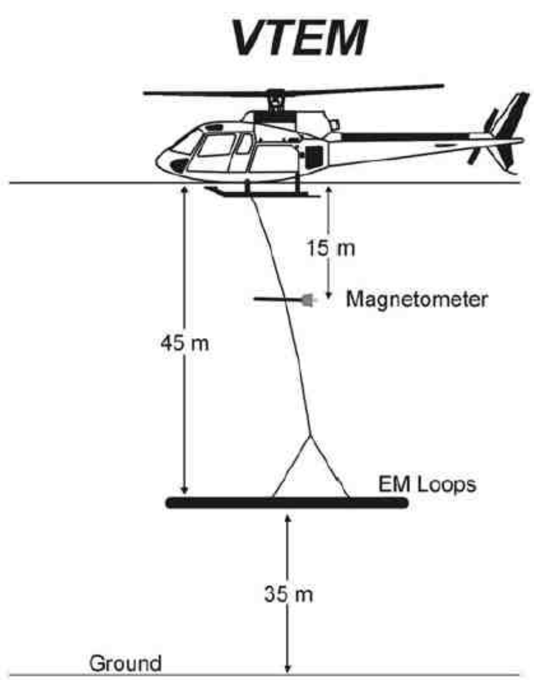
Introduction

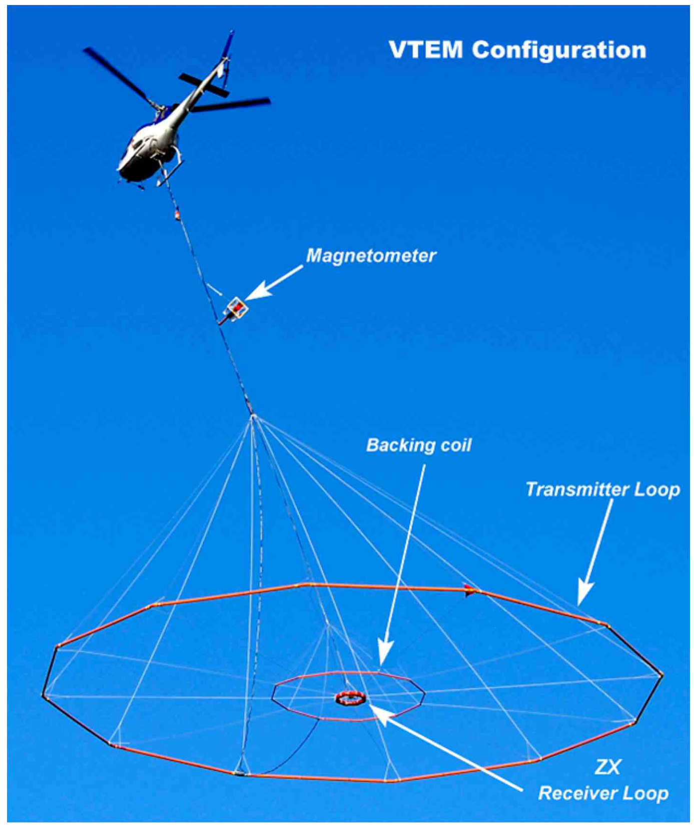
Evolution
Higher Dipole Moment & Lower Noise

Recent Advancements
Improved Signal Processing & Better Early Time Signal

Applications & 3D Inversion Advancements

- Developed in 2002 and now leading the helicopter-borne TEM industry
- A fleet of 30 systems flying worldwide
- More than 2.000.000 line-km flown worldwide
- The combination of three significant features makes VTEM system unique:
  1. -Lowest noise levels
  2. -Large dipole moment and
  3. .- In-loop Tx-Rx configuration





VTEM Plus

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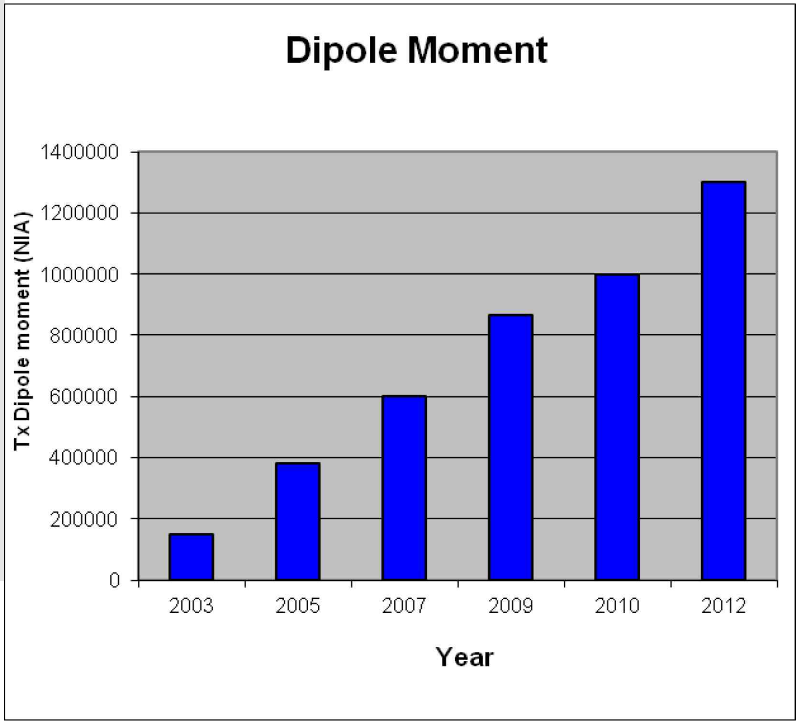
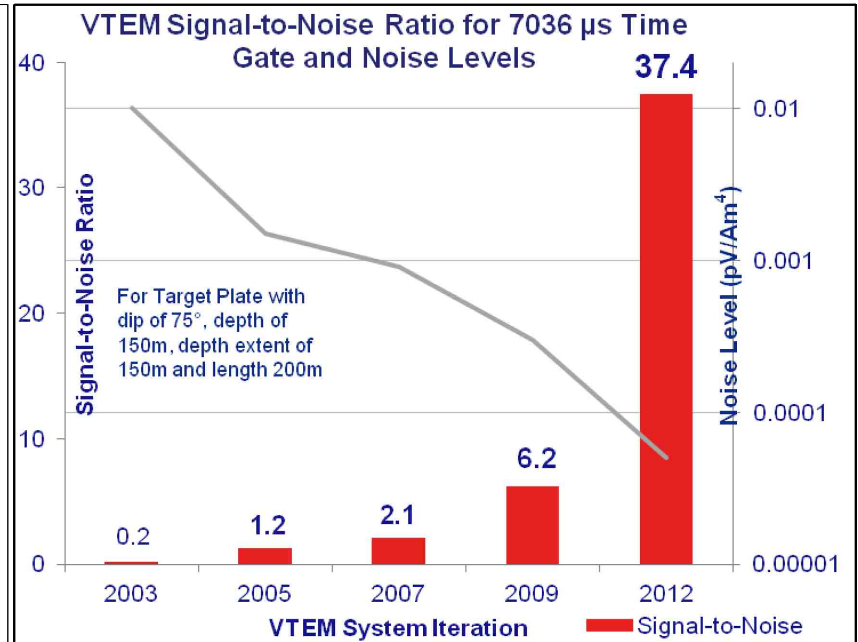
VTEM: Summary Table of Technical Evolution

	2003	2005	2007	2009	2012
Noise Level (pV/Am^4)	0.01	0.0015	0.0009	0.0003	**0.00005**
Dipole Moment (NIA)	148 000	380 000	425 000	866 000	**1 600 000**
Transmitter Coil Diameter (m)	18	26	26	35	35
Base Frequency (Hz)	30	30	30	30	30
Peak Current (A)	110	180	200	230	420





VTEM System: Evolution and Recent Advancements

VTEM dB/dt response vs. Conductance Nomogram

Decrease in noise level leads to a wider conductance sensitivity range

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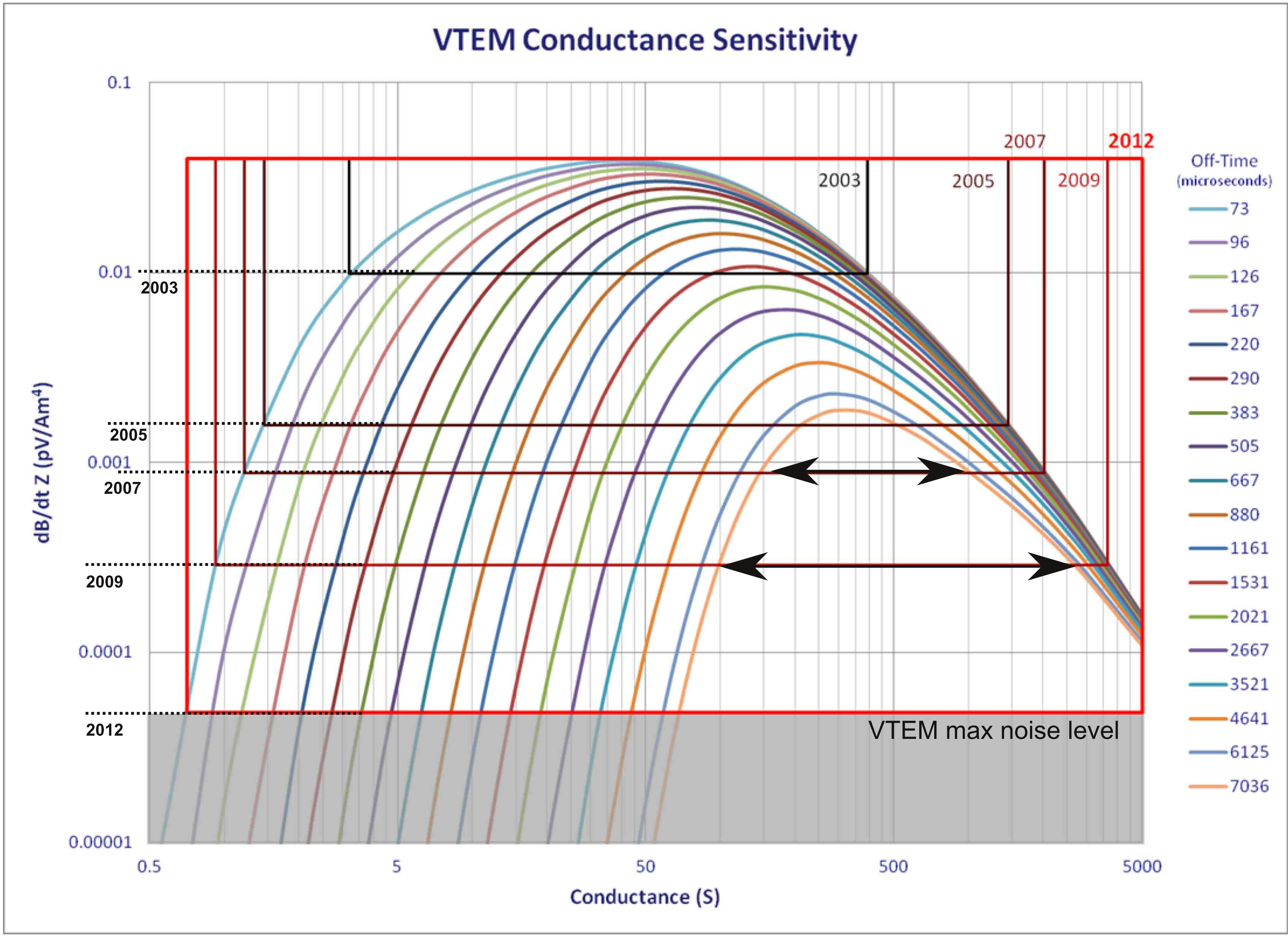

Today`s Recent Advancement

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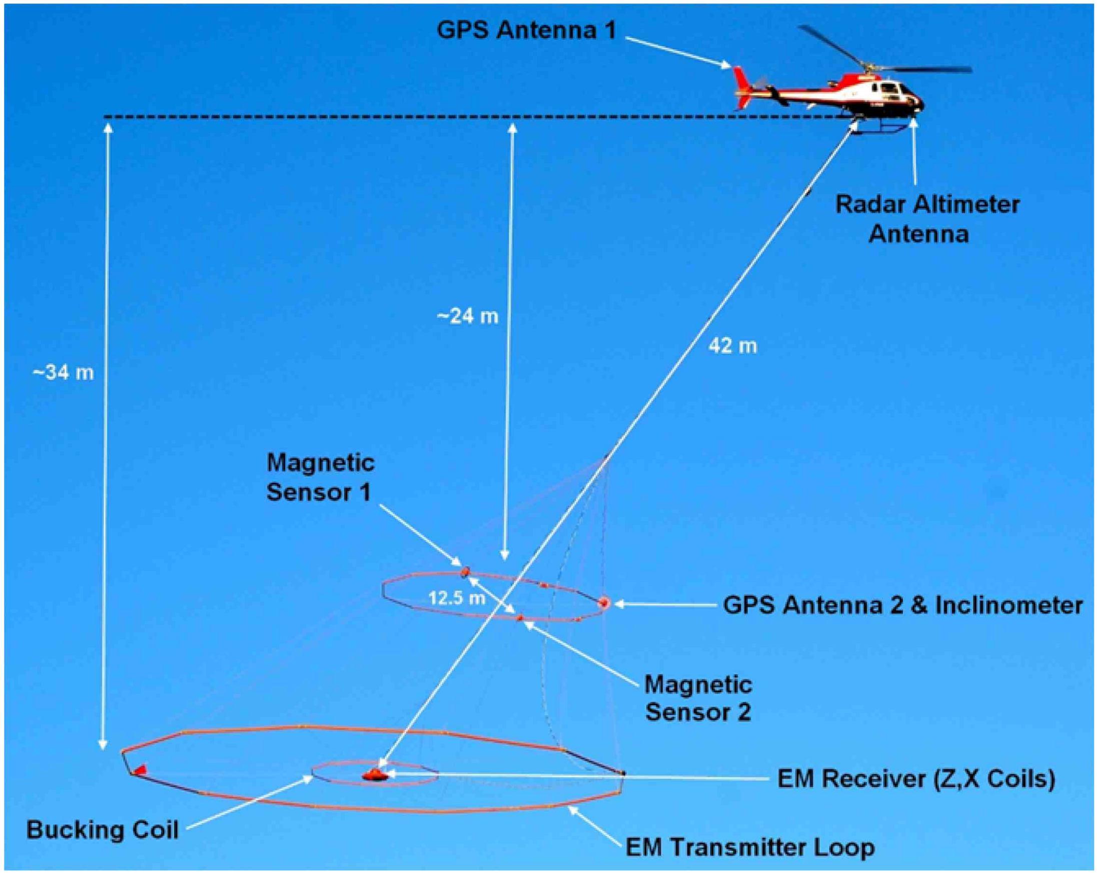
VTEM System uses full waveform, streaming, calibrated and de-convolved data



VTEM Acquisition System includes:

EM transmitter loop.

In-loop EM receiver multicomponent coils.

Horizontal Magnetic Gradiometer with two highly precise sensors.

Real time navigation and attitude system

Today`s Recent Advancement

VTEM System uses full waveform, streaming, calibrated and de-convolved data

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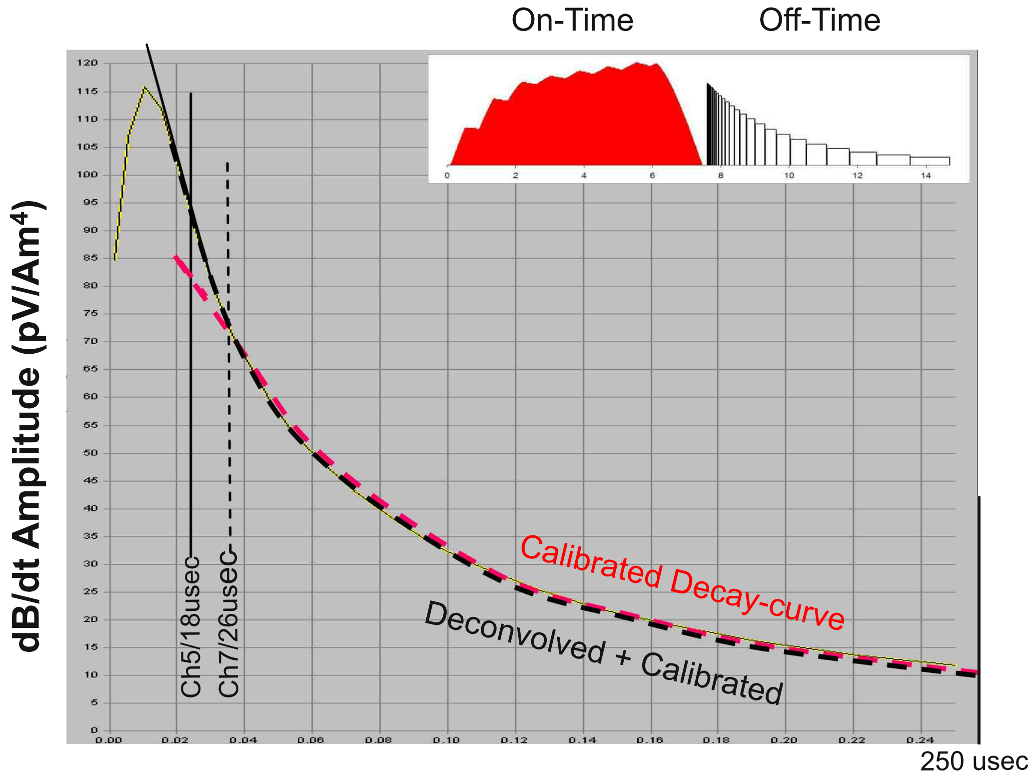
VTEM Plus dBZ/dt Decays
(with System Calibration + Waveform Deconvolution)



Comparing Improved Early Channel Decays on Standard VTEM System
using both Calibration and Transmitter Waveform Deconvolution.
There is improvement in earliest time-gates from 26 to 18us for VTEM Plus System
This latter translates into Better Near-Surface Data

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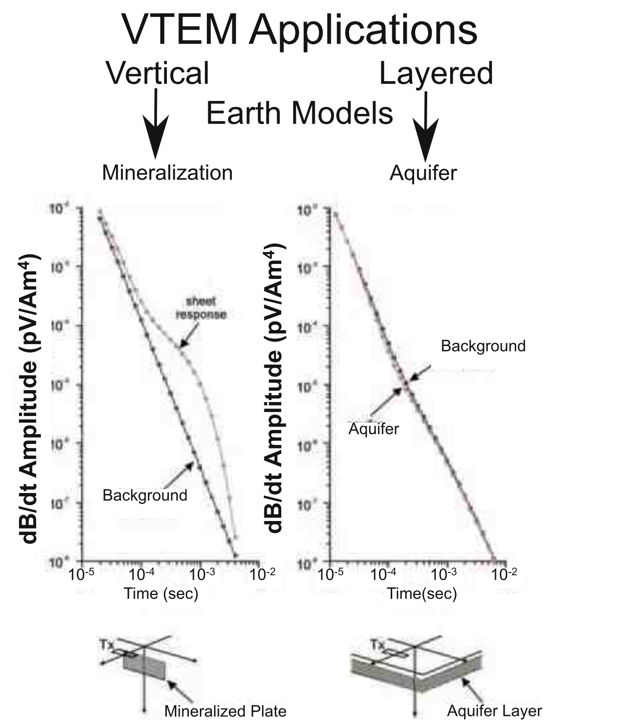

modifed from Sørensen and Auken, 2004

- **Caber and Caber North deposits, located in the Matagami Mining Camp, Western Quebec, Canada, within the Abitibi Greenstone Belt.**

- **Spiritwood Valley Aquifer, Manitoba, Canada (Sapia et al., 2013).**

3D Inversion Recent Progress

- **Fort McMurray, Alberta : A case study for Oil Sands Exploration (Zhdanov et al., 2013).**

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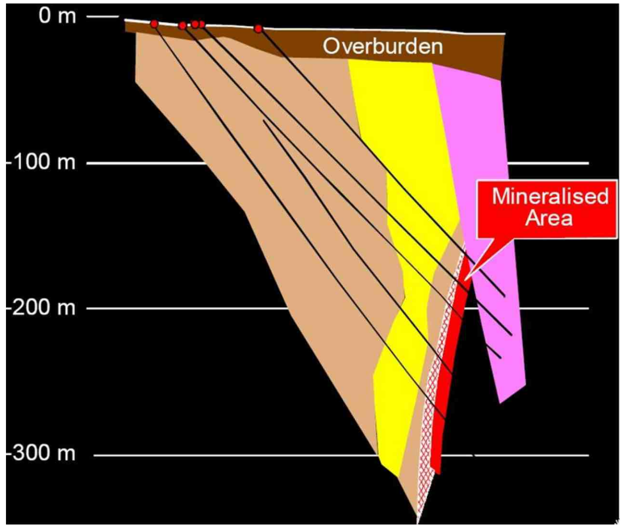
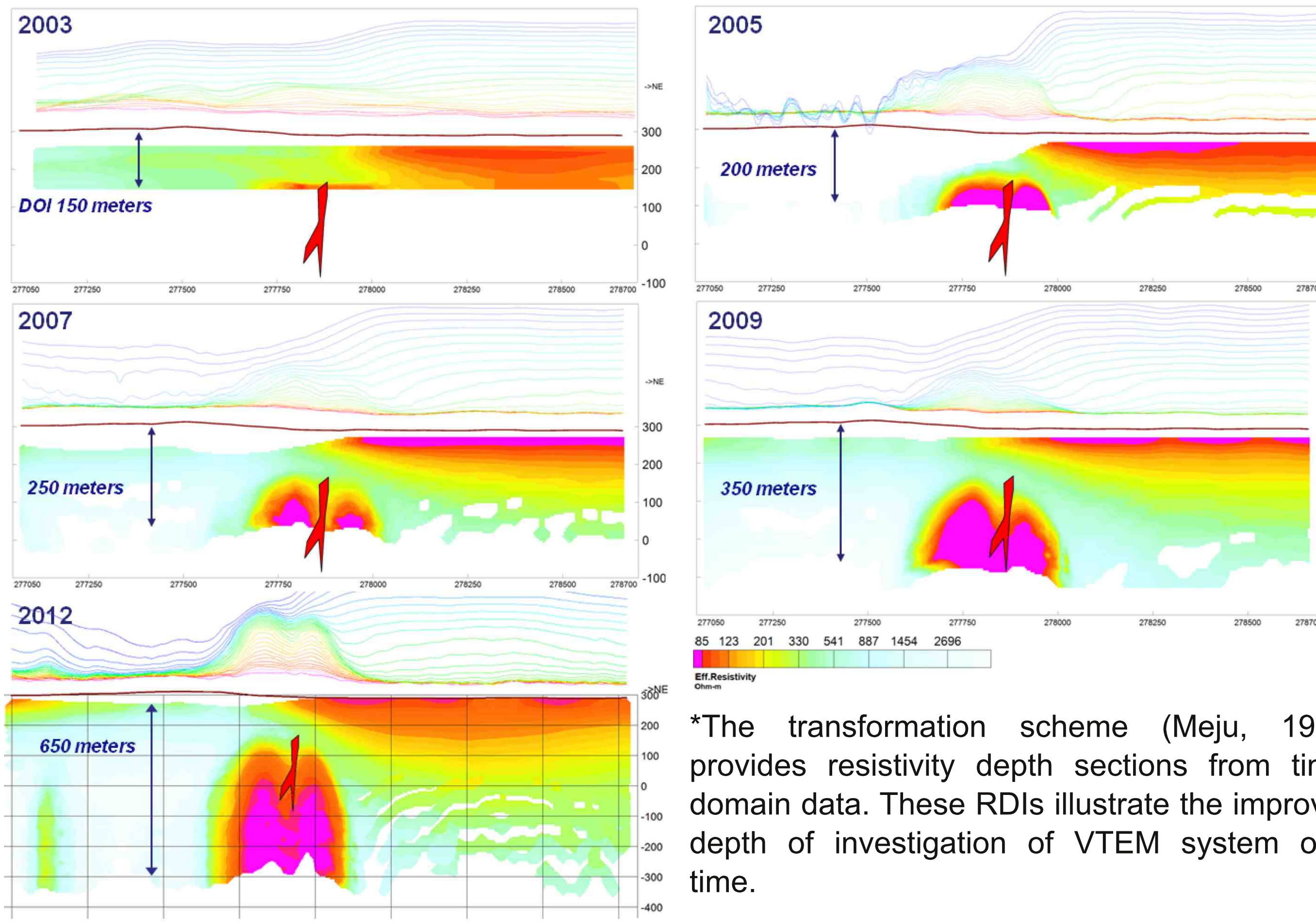


Caber Deposit:

- The deposit is sphalerite-rich, cigar-shaped, ~30m wide x ~250m strike, steeply SW-dipping and buried at ~120-350m, below ~30m of conductive clay overburden.
- Excellent for testing EM system quality.
- VTEM has flown over the Caber deposit since 2003. A Resistivity Depth Imaging (RDI)* Comparison is shown below.



*The transformation scheme (Meju, 1998) provides resistivity depth sections from time-domain data. These RDIs illustrate the improved depth of investigation of VTEM system over time.

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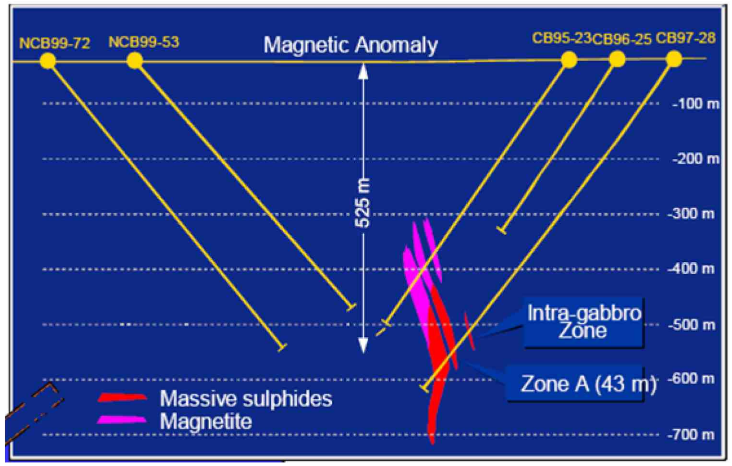
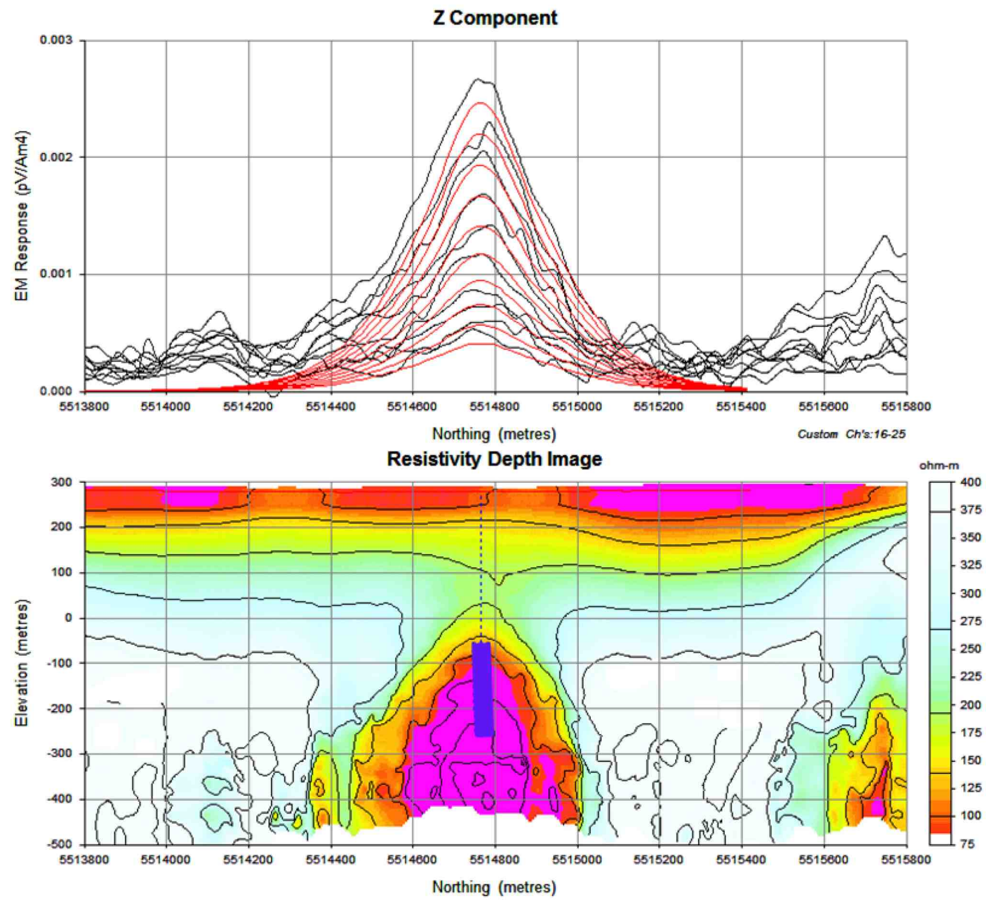
Caber North Deposit:



- VTEM is the first airborne EM system to detect Caber North deposit.
- Time gates from 1891-6581 μs were used for modeling.
- Model plate (below) has depth of 333 meters, dip of 88° and depth extent of 200 meters.
- High signal-to-noise ratio allows for accurate modeling of deep conductors.



Spiritwood Valley Aquifer, Manitoba, Canada: A Case Study of VTEM Inversion for Layered Earth (Sapia et al., 2013)

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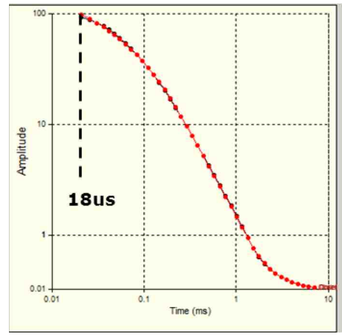
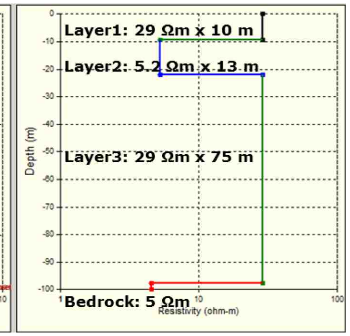
Location of Survey Area. Spiritwood Valley is a buried Aquifer that stradles Canada-USA border from southern Manitoba to North Dakota..

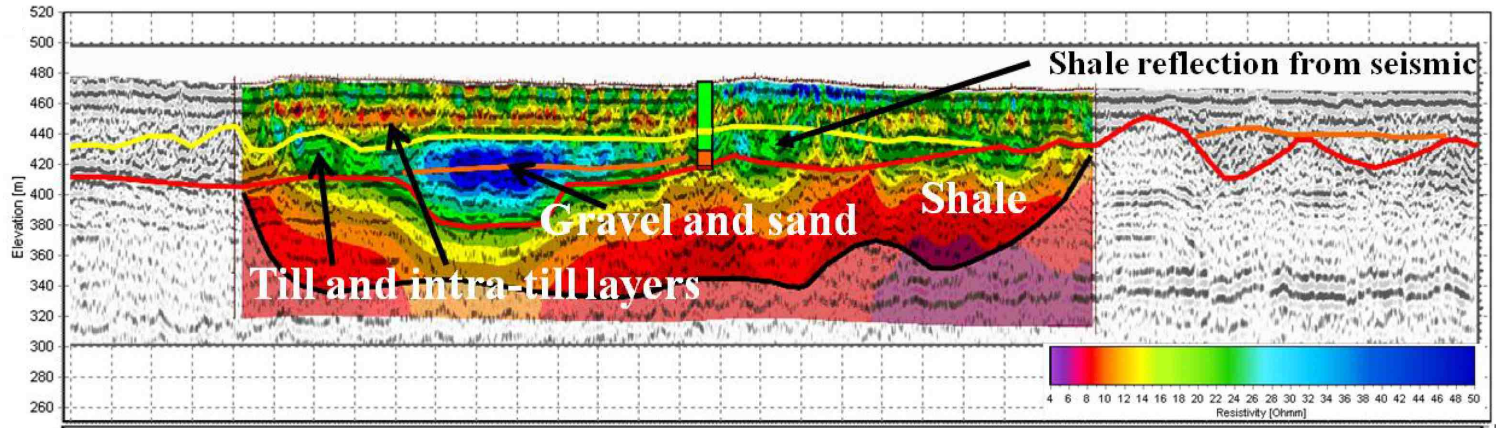
Full Waveform VTEM

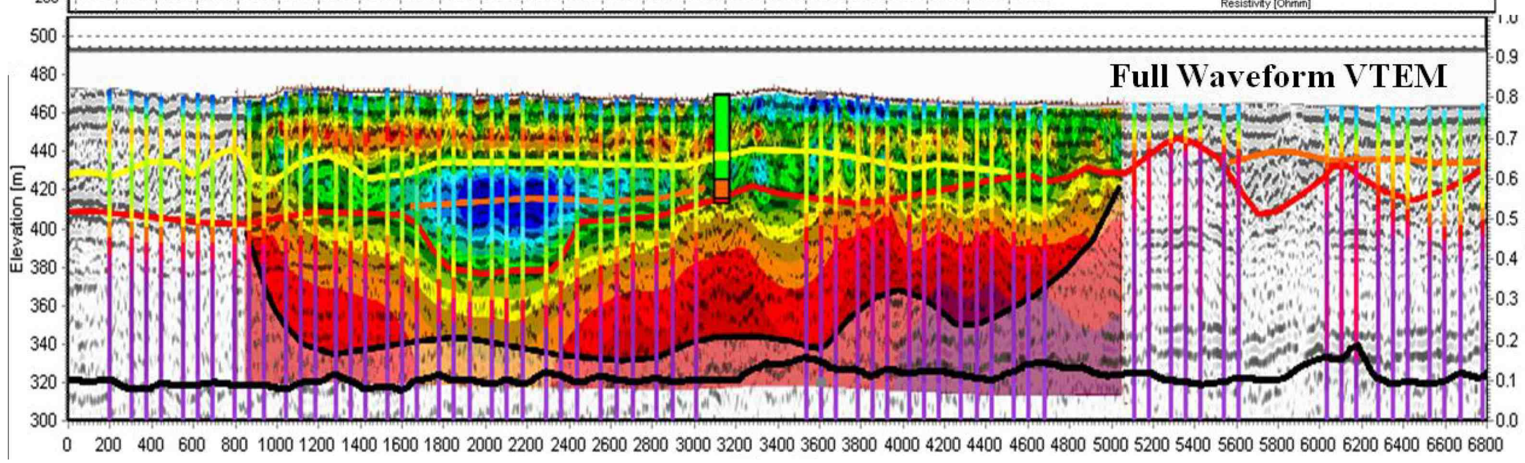




1D Synthetic Modeling

- This numerical test highlights the advantage of having accurate early times available in order to resolve shallow resistive layer that fill the channel.





"3D inversion of airborne EM surveys: case study for oil sands exploration near Fort McMurray, Alberta" (Zhdanov, 2013)

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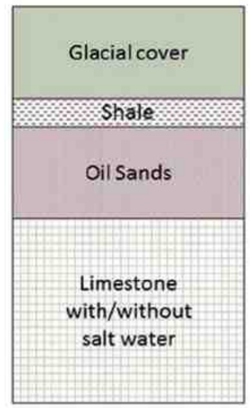
• Traditionally RDIs and 1D LCI have been used to enable quantitative AEM interpretation in an efficient way; that is reducing time and costs in exploration/production phases.

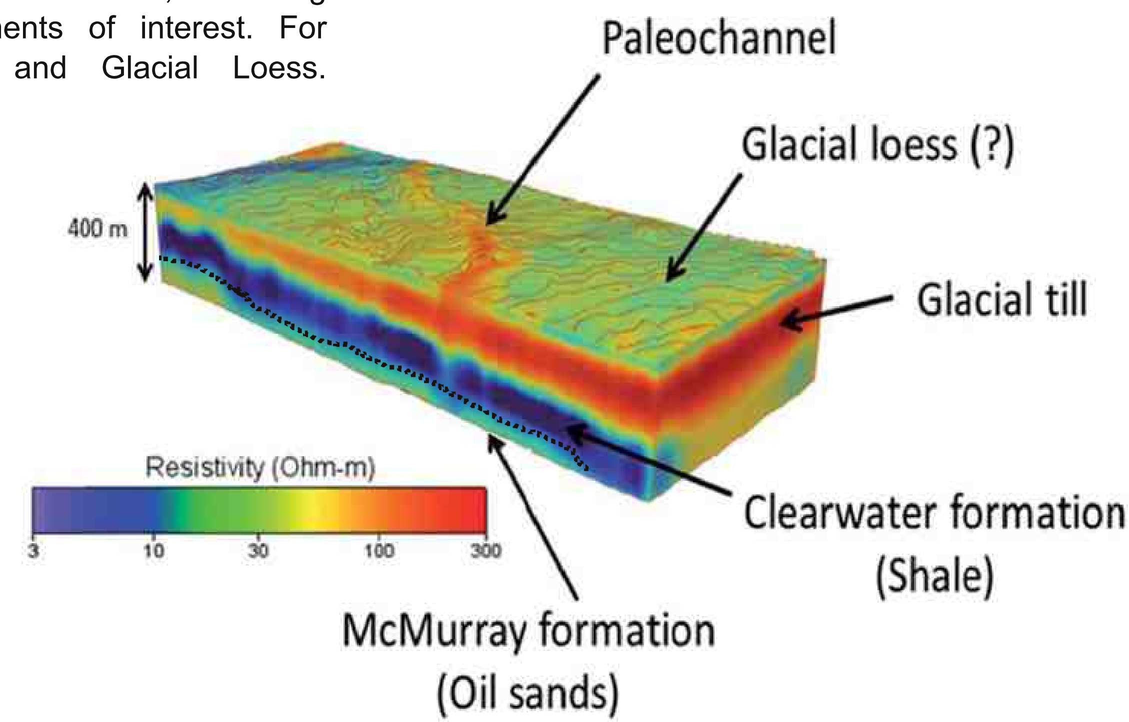
• However, the evolving improvement in scientific computing combined with faster and low-cost chips have recently opened opportunities to 3D AEM inversions (e.g. Cox and Zhdanov ,2007).

• Zhdanov et al (2013) show a case study of 3D AEM applied to Oil Sands in Fort McMurray, Alberta. The results indicated improvements in resistivity imaging and resolution, detailing different geological elements of interest. For instance, Paleochannel and Glacial Loess.

Fort McMurray:
Schematic Geological Section and Resistivity Properties



Geologic Unit	Resistivity (Ωm)	Thickness (m)
Overburden	100's	0 – 200
Clearwater Formation	2-10	0 – 30
McMurray Formation	100 – 1000	50 – 100
Devonian Basement	1 – 1000	N/A



"VTEM discoveries of massive sulphide deposits in northern Oman"
(Dr James LallyPrincipal Geologist Mawarid Mining Sultanate of Oman, 2011)

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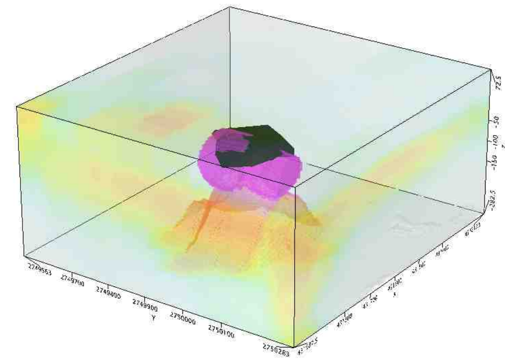
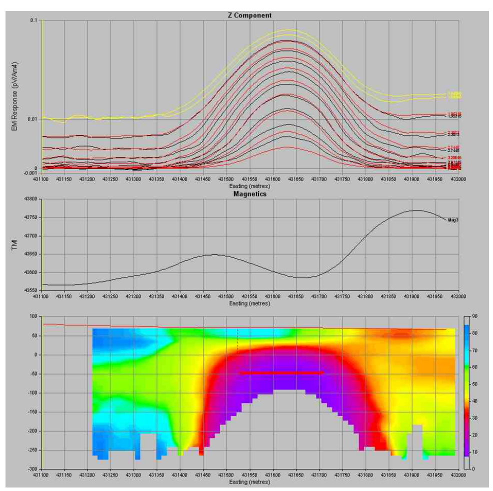
- Mawarid Mining focuses on Mafic-hosted Cu ± Au VMS deposits. Generally small size (100m to 500m strike length) and high grade (1.5 – 4.5% Cu). In general 200m deep targets.
- By 2010 existing reserves were to be exhausted.
- A VTEM survey at 100m line spacing was conducted in 2009 in their property in Oman and successfully detected 4 buried massive sulphide bodies in the area.
- VTEM provided sufficient resolution for drill targets without need for ground follow-up.
- Turnaround from VTEM survey to definition of mining reserves in about 6 months.

RDI's and Forward Modelling in minimal time allowed for Drilling to begin inmediately after final delivery



3D View of Resistivity Depth Images (RDI) with Sulphide Model (black) based on drilling.



EMIT Maxwell Plate Modeling.

AFMAG (Audio Frequency MAGnetic)
Ward, SH (1959)

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AFMAG &
Geotech's AFMAG
DAS System 2002

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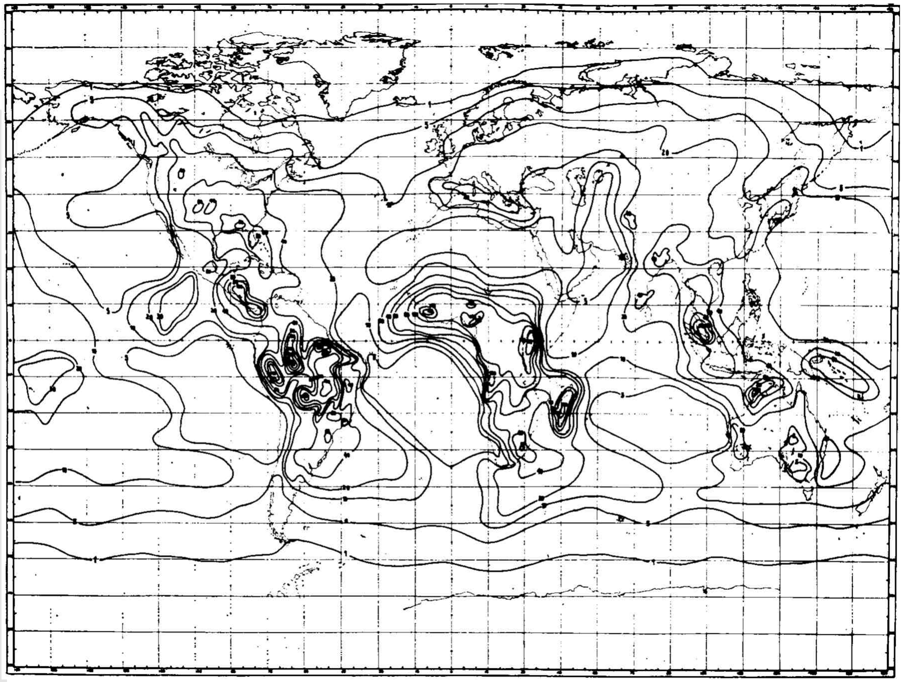
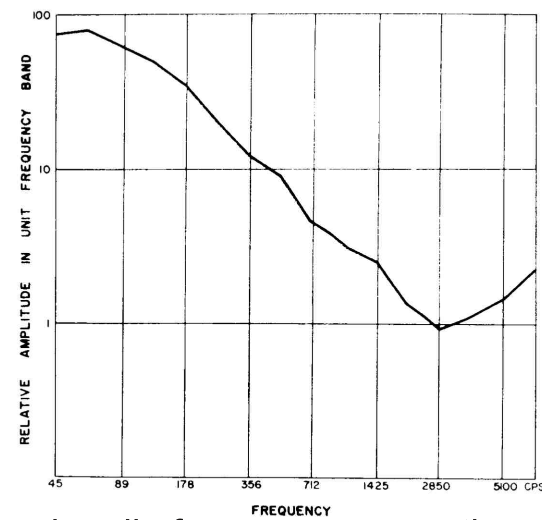
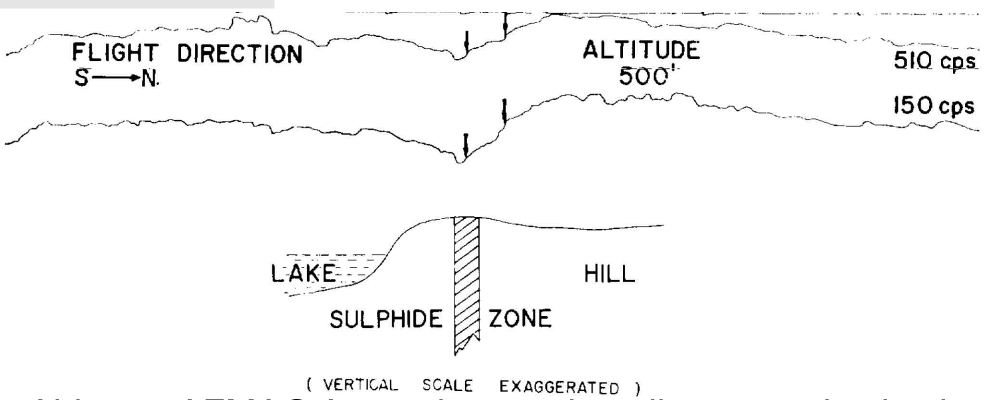


Average Number of Thunderstorm days per year
(World Met. Org., after Ward, 1959)

AFMAG (Ward, 1959)".. **AFMAG** consists of **measuring the tilt of the plane of polarization of the natural alternating magnetic tields (this is achieved by measuring the ratio of two components of the magnetic field)..AFMAG is intended to locate variations from such horizontal uniformity...**"



Natural audio frequency magnetic noise
(after Ward, 1959)



Airborne AFMAG Anomaly over long linear conductive body
(after Ward, 1959)

Geotech's AFMAG
DAS System (2002)

Passive HEM : from AFMAG to ZTEM evolution

Geotech Ltd creates in 2006 a new working concept based on AFMAG

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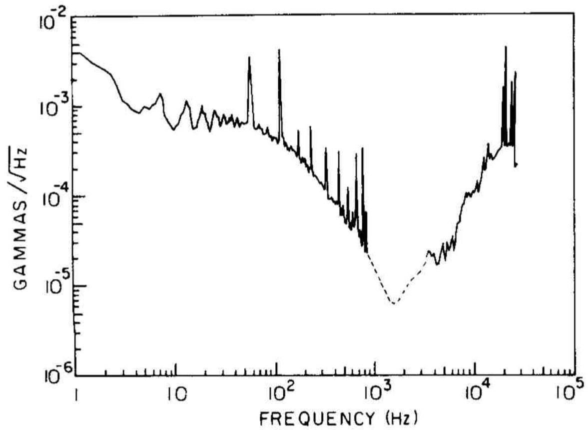
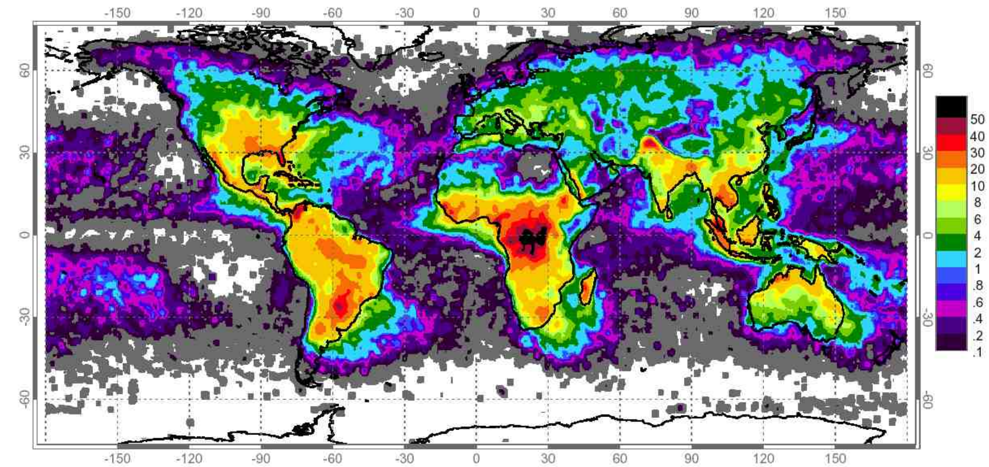
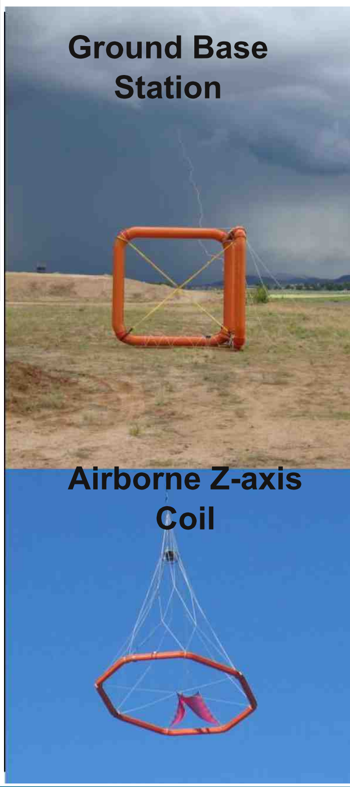


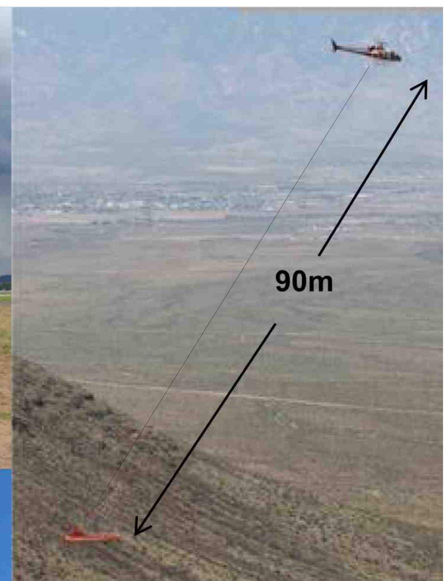
Magnetic Spectrum at San Antonio Valley
(after Labson *et al*. 1985)

ZTEM (Z-Axis Tipper EM)
(Lo and Kuzmin, 2004 and 2005)



Average Number of Lightning Activity
Units: flashes/km2/yr. Image from NSSTC Lightning Team.





ZTEM
(Z-Axis Tipper Electromagnetics)
Passive Heliborne EM

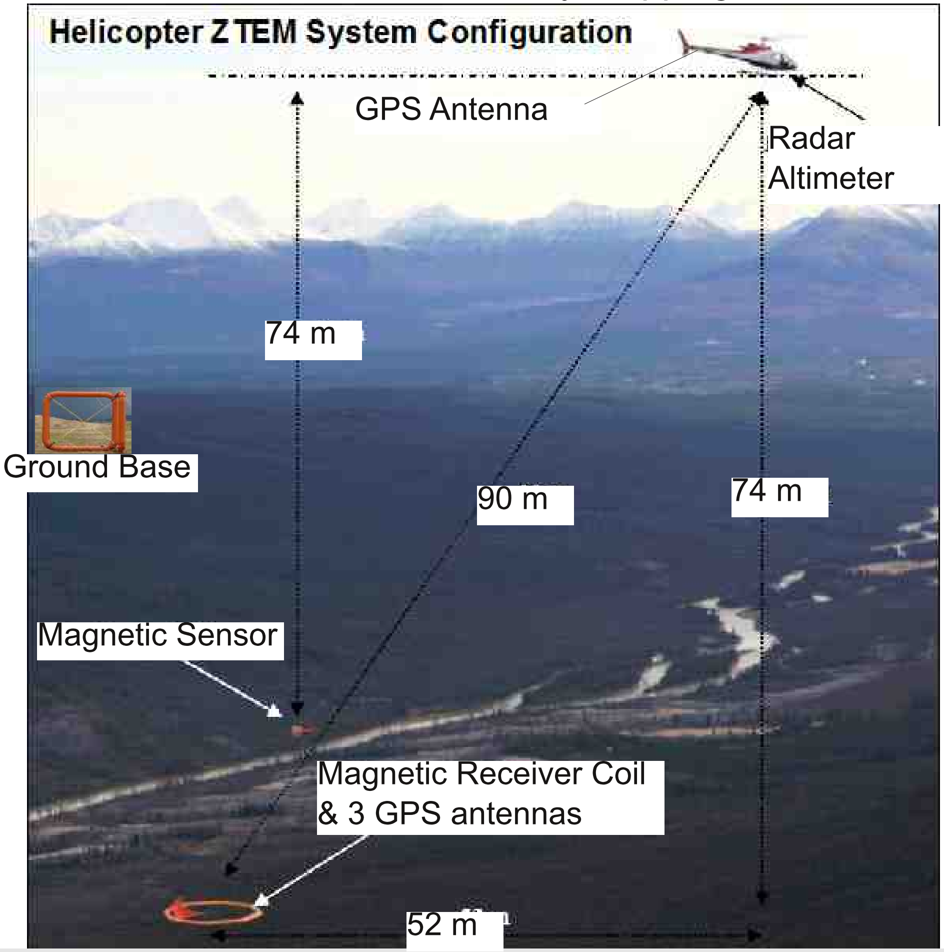
ZTEM (Z-axis Tipper Electromagnetic)

Characteristic Elements

- Natural Magnetic Field measurements and ***Tipper Computations*** in the audio frequency range, wherein vertical **Hz is measured in bird, horizontal Hx-Hy fields at fixed base station.**
- Operation audio frequency bandwidth is **25-720 Hz.**
- GPS system of three (3) antennas to correct for dynamic effects.

Passive HEM : from AFMAG to ZTEM evolution

ZTEM is a ***unique Passive HEM*** and has flown > 200,000 Km
It is multi-frequency, low noise AEM with deep depth of exploration.
Excellent for 3D Resistivity Mapping and Characterization.



Parameters	ZTEM
Sampling Rate	A/D = 2 KHz Output = 2.5 Hz (0.4s/~10m/sample)
Nominal Helicopter Speed	80 Km/h
Observed Frequencies	25, 37, 75, 150, 300 (+/- 600) Hz 30, 45, 90 180, 360 (+/- 720) Hz
Calculated Values	Magnetic Tipper (%) : **Tzx and Tzy**
Nominal Error	< 1%

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ZTEM (Z-Axis Tipper EM)
Schematic View of Basic Principles

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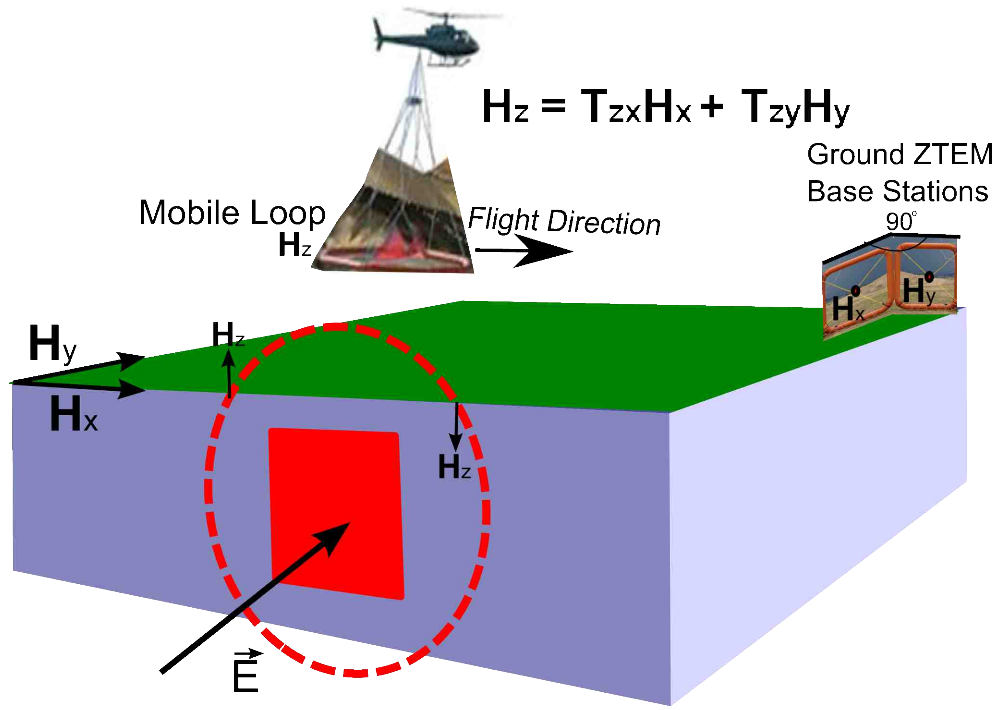

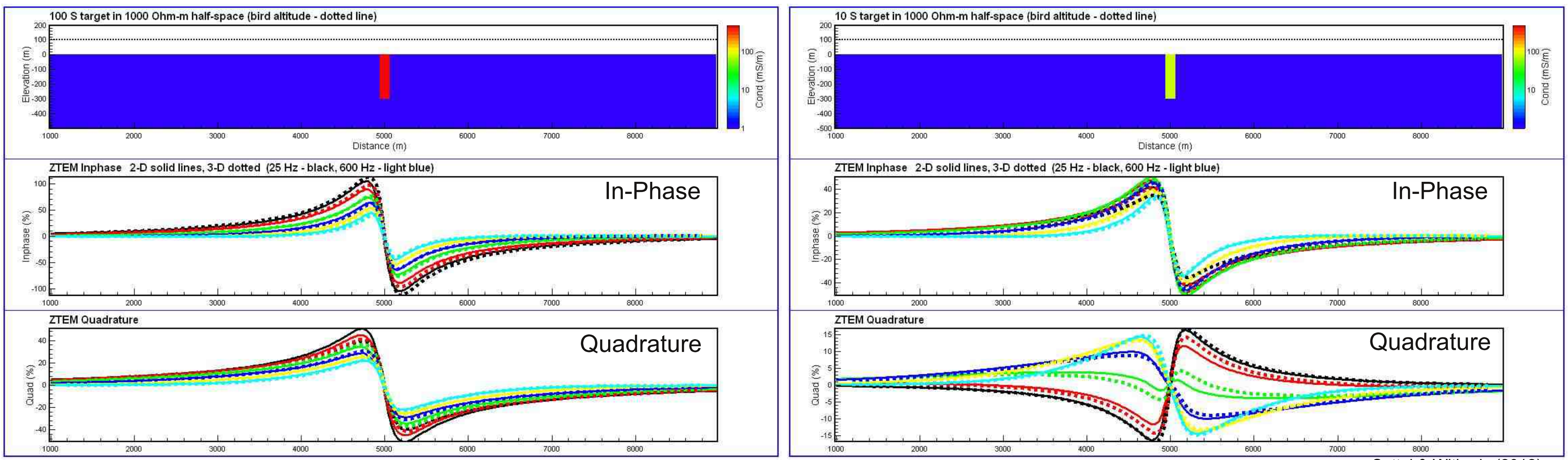

Sattel & Witherly (2012)

Natural Resources Exploration: VTEM and ZTEM Map Conductivity/Resistivity Distribution in the Subsurface associated with quemical-mineralogical alteration driven by heat and fluid content

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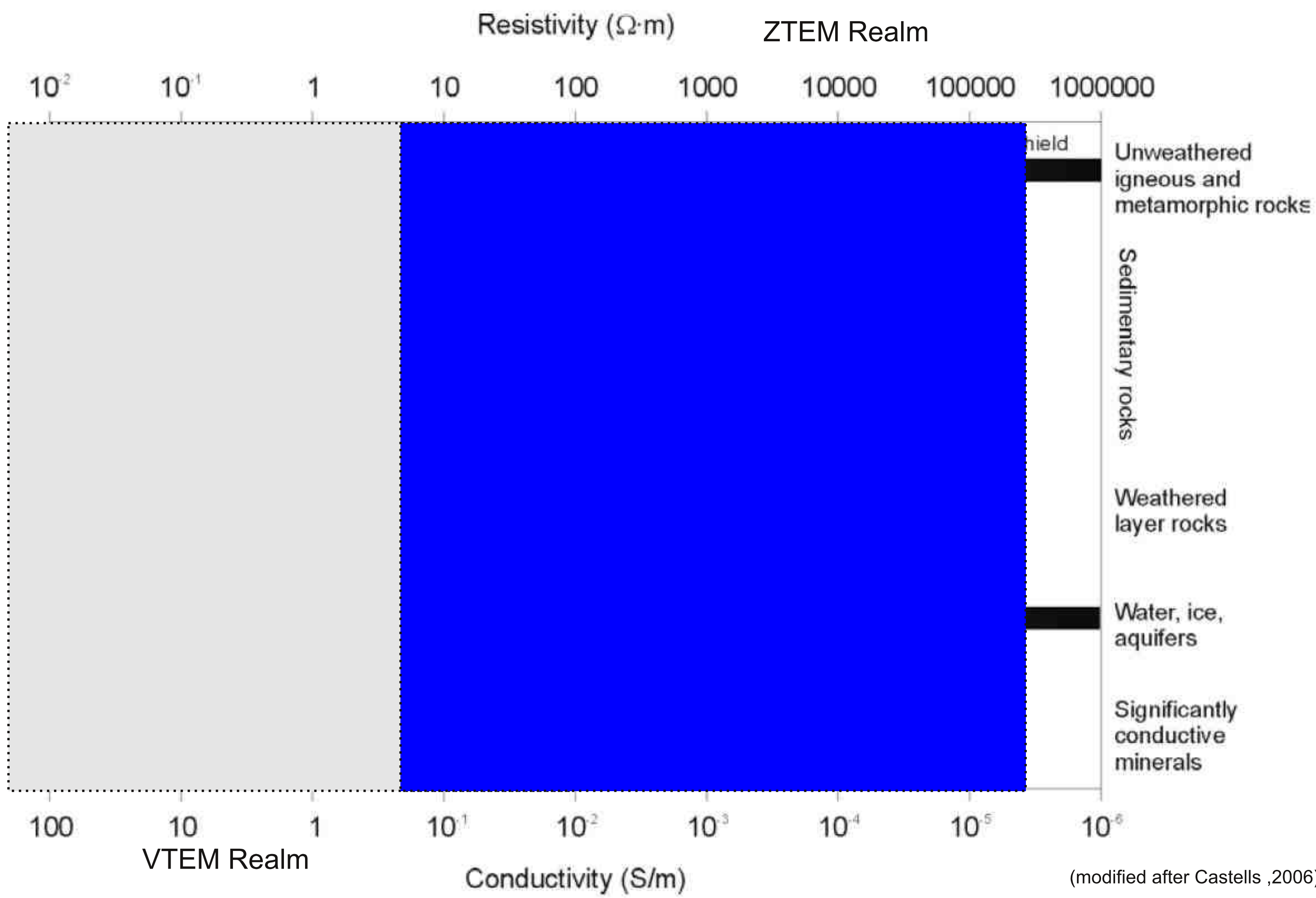

(modified after Castells ,2006)

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Passive HEM : from AFMAG to ZTEM evolution

ZTEM Anomalies
are routinely inverted in 2D to have a fast and effective first look at resisitivity distribution and line-to-line correlation features

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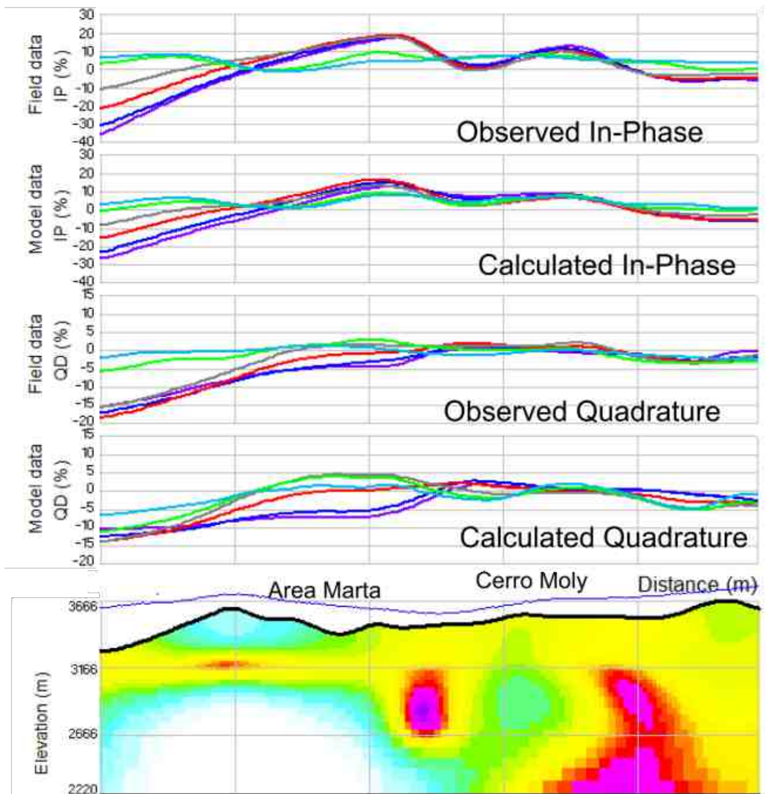
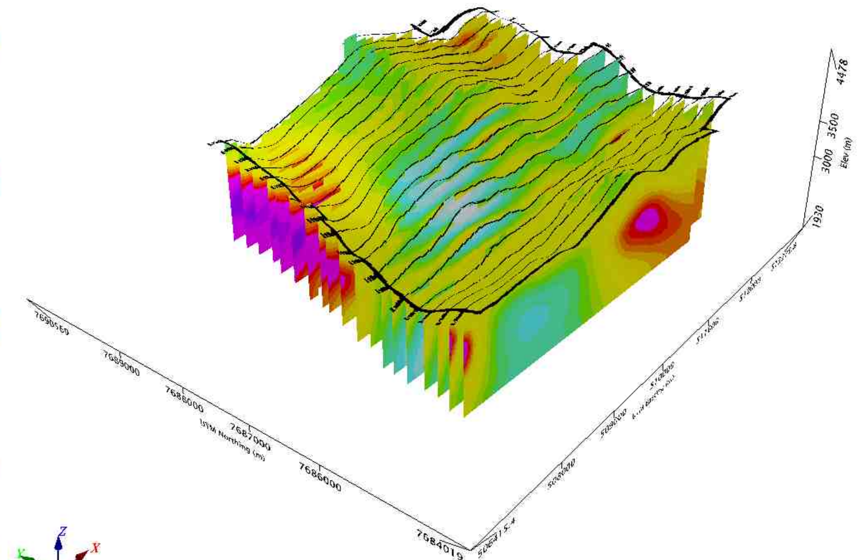
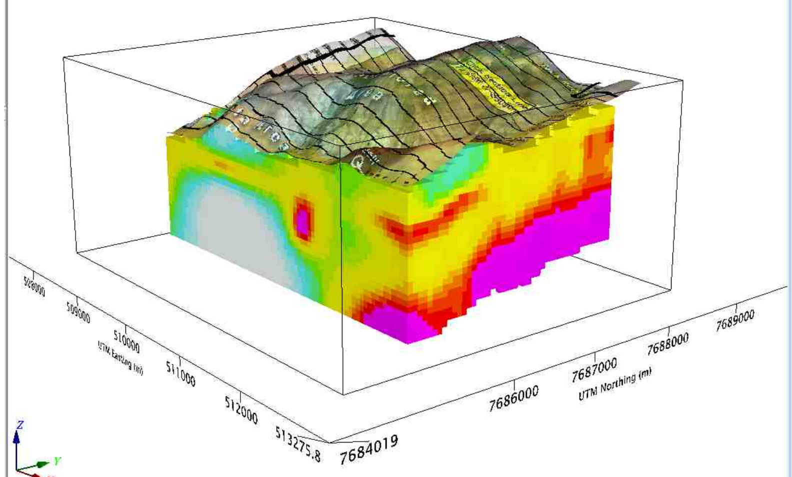
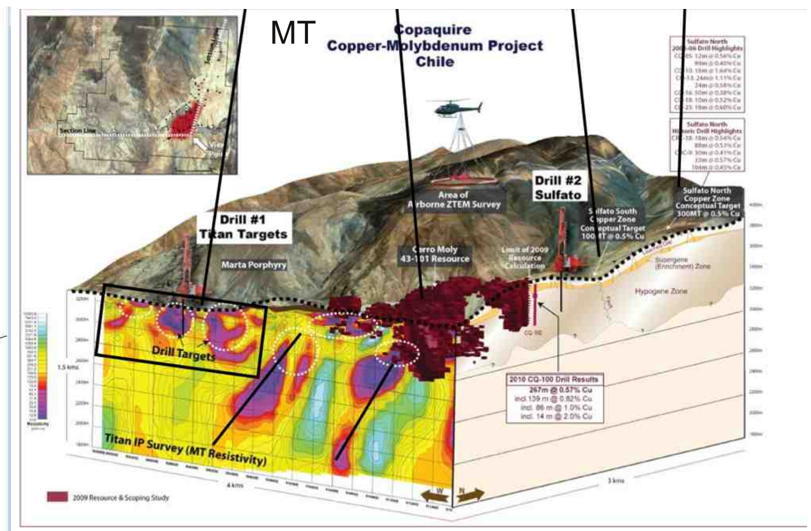


3D View of 2D Inversions



ZTEM vs MT





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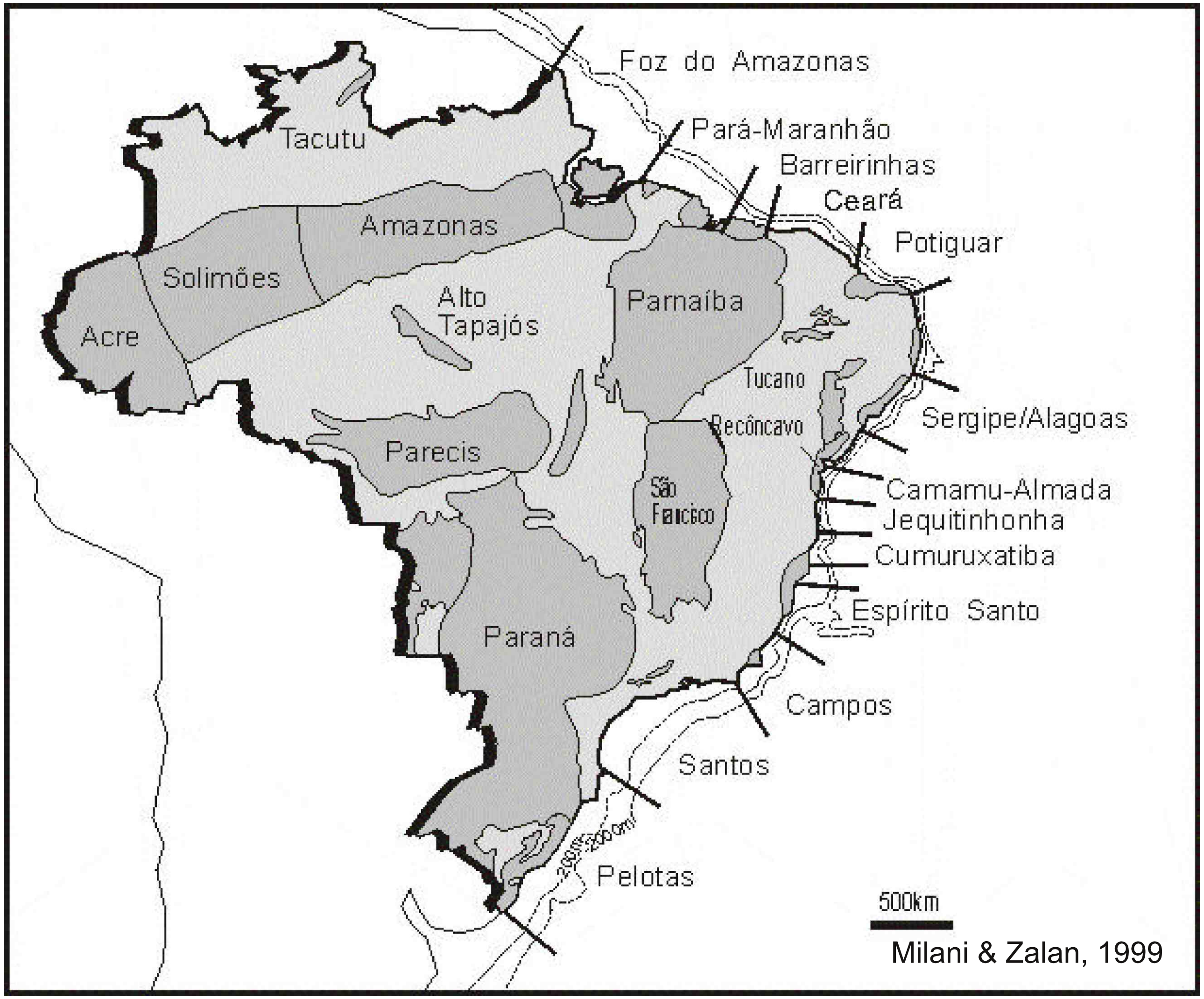
Brasil: Oil and Gas Onshore Basins

Brasil:
Magmatic Activity
and
Its role in Oil Potential

Sub-basalt Exploration:
A Case Study in Saudi Arabia

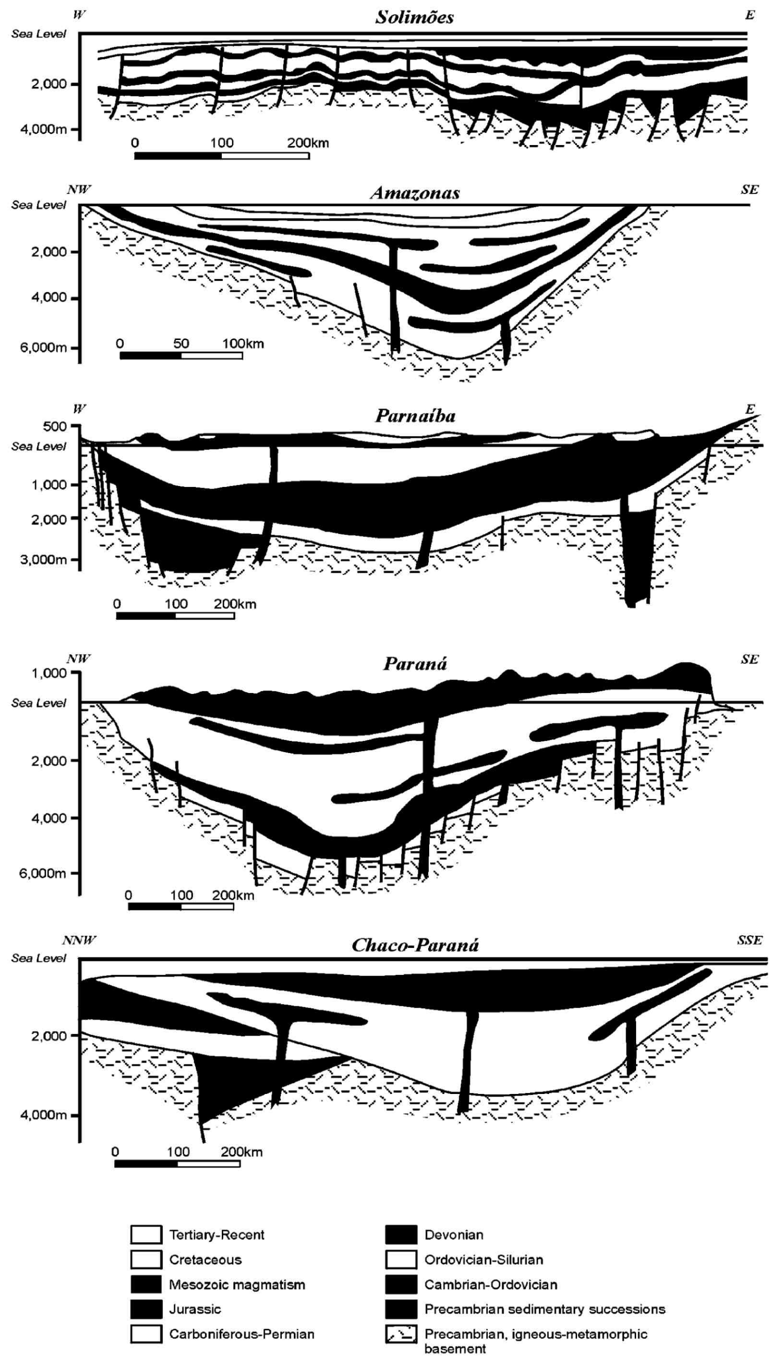
Brasil, in its evolving search for Oil and Gas Strategic Resources, has undertaken over the past years several geophysical exploration programs offshore and onshore using both conventional and unconventional methods



Milani & Zalan, 1999

Onshore, Brasil has many (Paleozoic and Proterozoic) sedimentary basins covering an area of about 4.880.000 km^2.
In the Continental Platform the economic sedimentary basins are cretaceous-tertiary and cover about 1.550.000 km^2.

In 2001, Brasil was producing about 1.500.000 oil barrels, about 70% of national use.



Milani & Zalan, 1999

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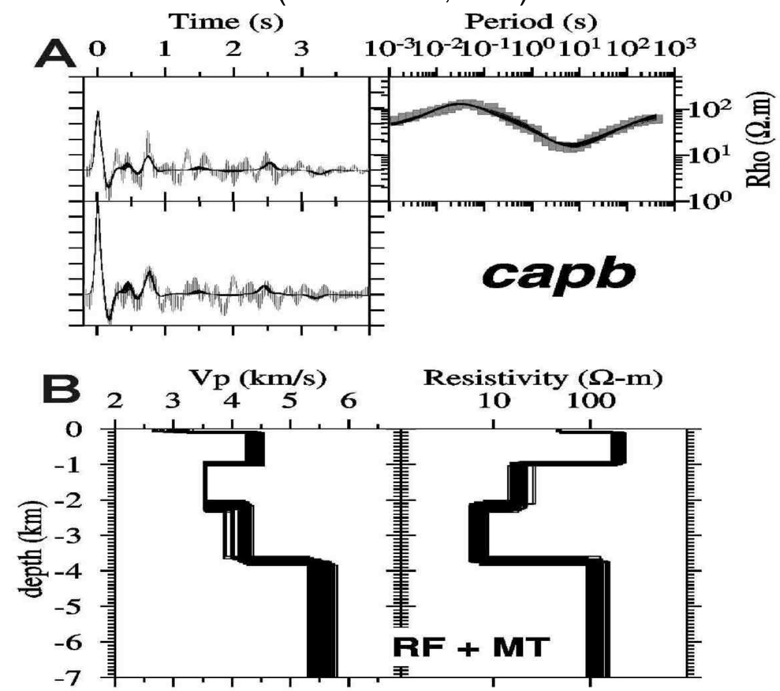
Magmatic Activity in Intracratomic Basins and its Role in Petroleum Potentials

• The magmatic activity in the Brasil´s sedimentary basins (both offshore and onshore) has played an important role in their hydrocarbon systems: generation (sediments maturation), Structural Traps, Reservoirs (fractured basalts) (Milani & Zalan, 1999).

• Intrusive magmatic material increases temprature that results in the maturation of organic rich sedimentary material (Filho et al, 2008).

Seismology and MT 1D Study in Parana Basin

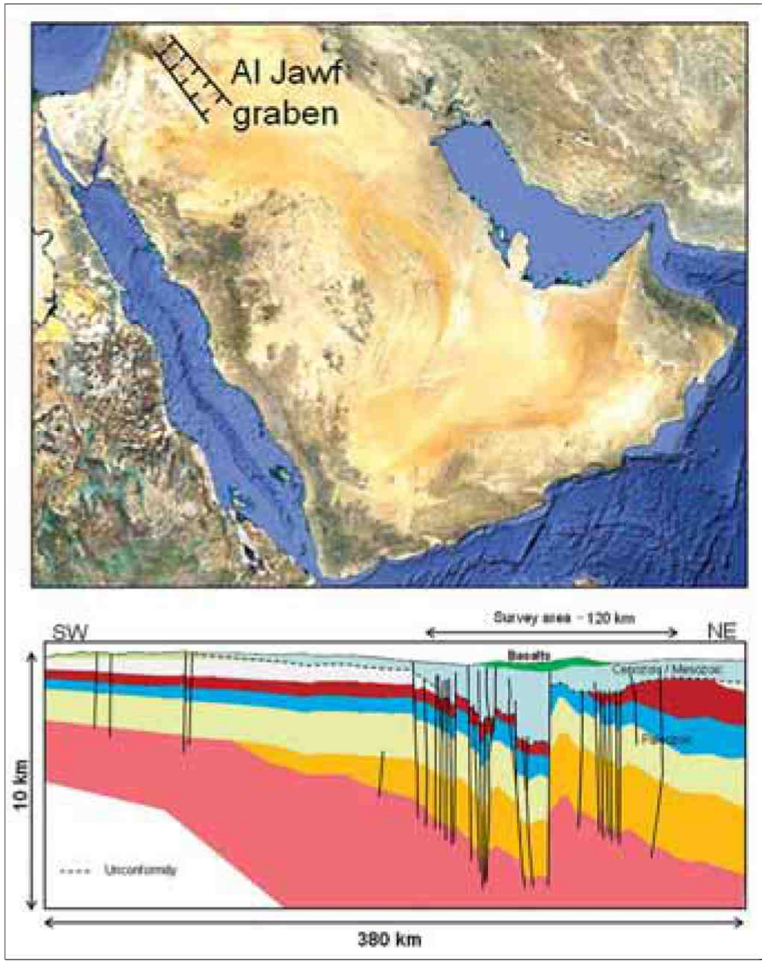
(Zevallos et al, 2004)

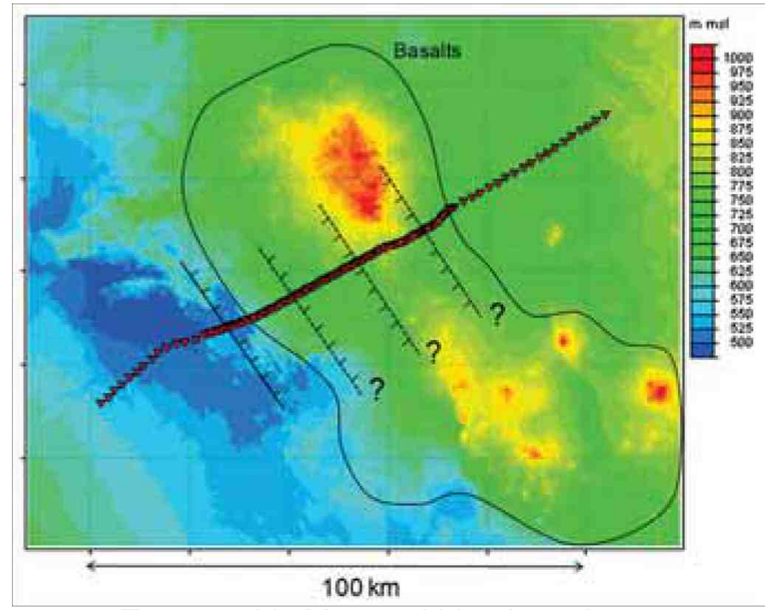


MT and Function Receiver Study in Paraná Basin has shown a baslat thickness of about 1Km and Resistivity Value of 200 Ohm-m.

Sub-basalt Exploration: A Case Study in Saudi Arabia

General Location and 2D Geological Section





Topographic Map and Line Location

Multi-geophysics (MT, TDEM and Gravity) approach to improve seismic imaging of a basalt covered section.

EM propagates through resistive Basalt with minimal attenuation.

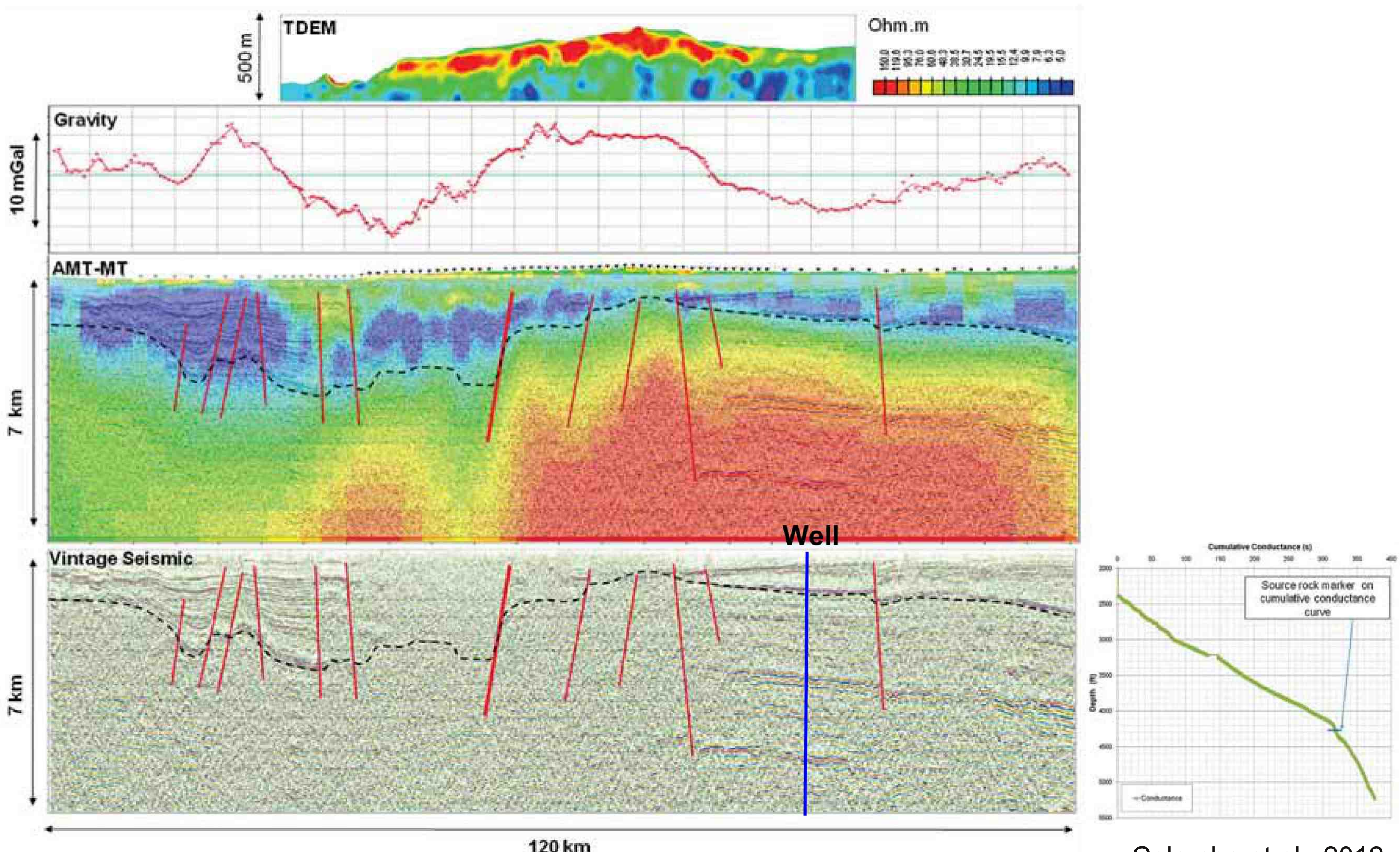
The objectives of EM was to delineate Basalt thickness and internal variations and help define deep geological structures.

Methodology	Spacing (m) core area: basalts	Spacing (m) flanks	Specifications
TDEM	250		45 and 90 m loop—only core area
AMT	500	2000	20,000 Hz–1 Hz
MT	1000	2000	100 Hz–10^{-3} Hz
Gravity	250	500	0.03 mGal repeatability

Colombo et al., 2012

Main Results from integrating EM for Subbasalt Exploration

- TDEM images well the shallow basalt layer.
- MT & Gravity delineates structural controls. MT finds a deeper basalt section.
- An appraisal well found source-rock layer. Based on resistivty logs it was possible extrapolation of such resistivty marker below basalt cap.



Colombo et al., 2012

Introduction

Ground has proven the concept.
Can VTEM & ZTEM speed up and cover more with useful results?

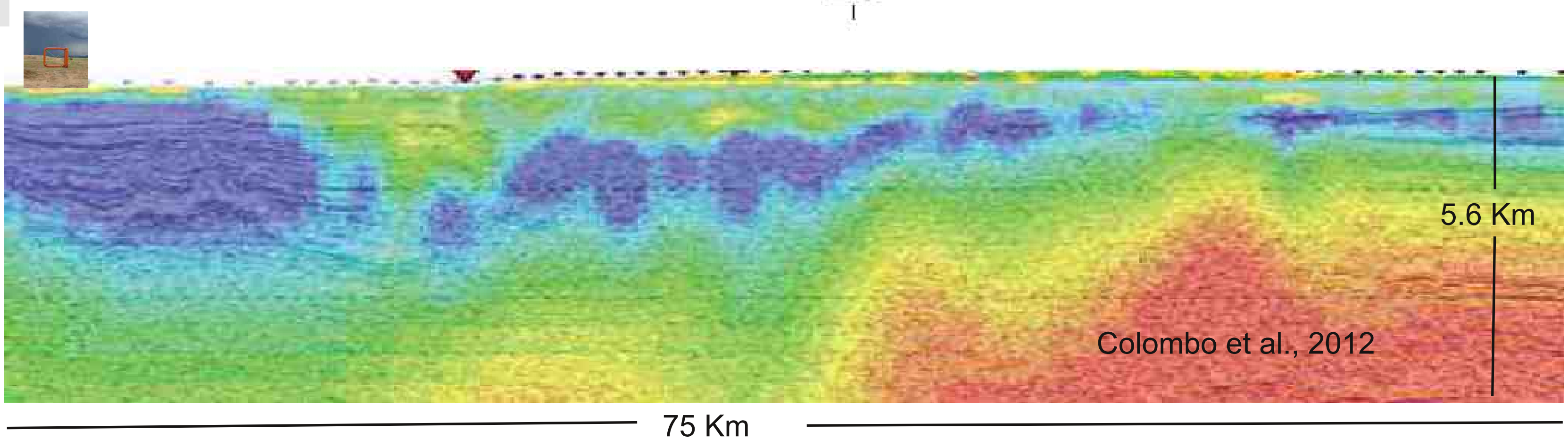
ZTEM:
Numerical Test

VTEM:
Numerical Test

Coverage and Estimated Time for Ground Geophysics along 1 Single Line

4 TDEM Stations p/km and about 7 Days of Operation
2 AMT p/km in Core and 0.5 p/km in Flanks; 1 LF-MT Station p/km in Core and 0.5 p/km in Flanks
MT is about 20 Days of Operation

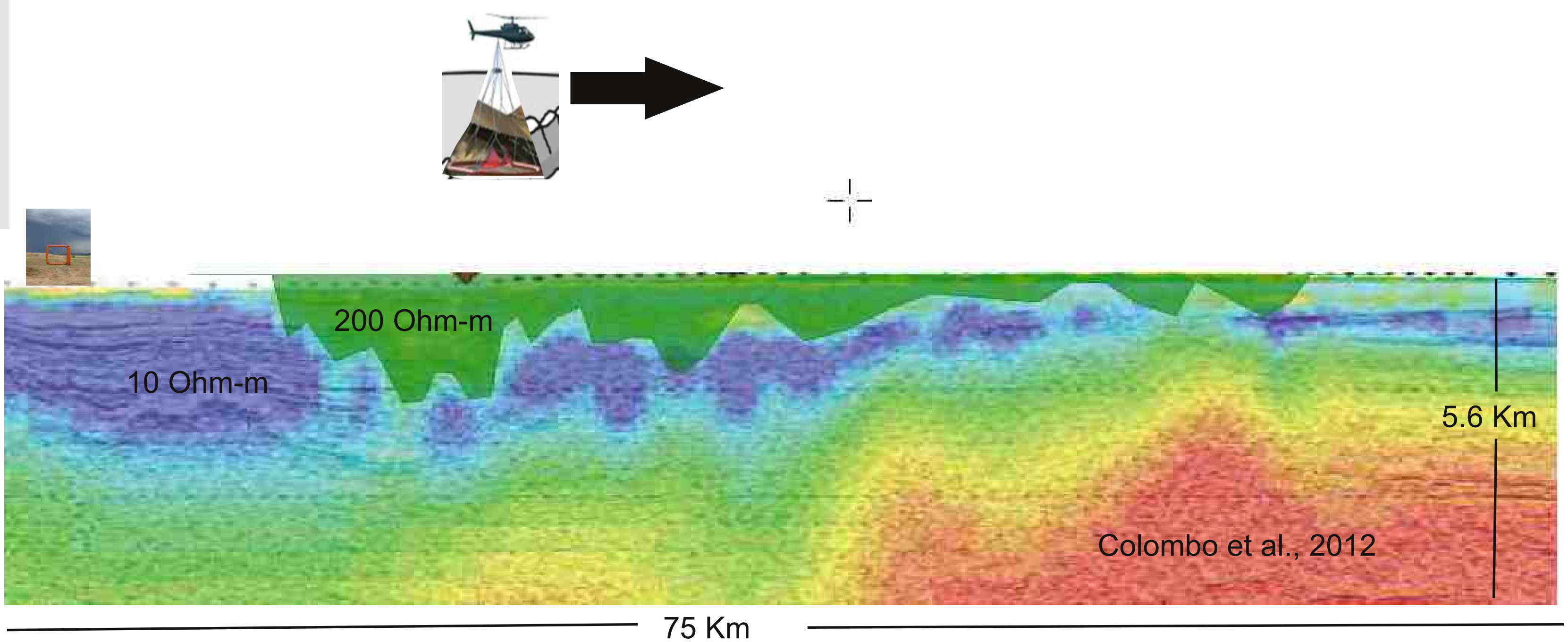
ZTEM Numerical Test



Coverage and Estimated Time for Ground Geophysics

4 TDEM Stations p/km and about 7 Days of Operation
2 AMT p/km in Core and 0.5 p/km in Flanks;
1 LF-MT Station p/km in Core and 0.5 p/km in Flanks about 20 Days of Operation

ZTEM Numerical Test



Coverage and Estimated Time for ZTEM

100 ZTEM Stations p/km and One day of Operation

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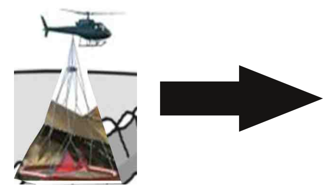
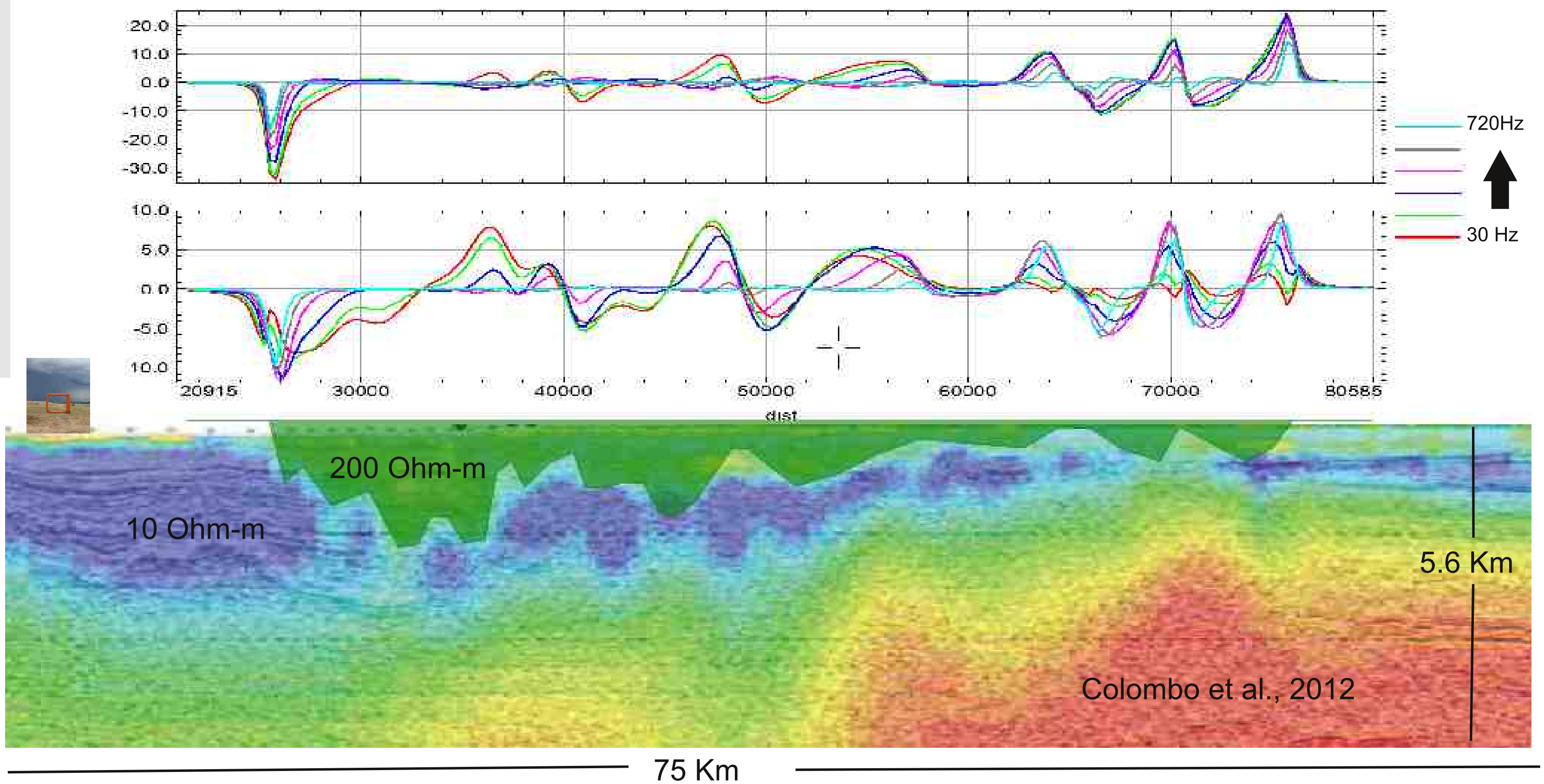


ZTEM Numerical Test



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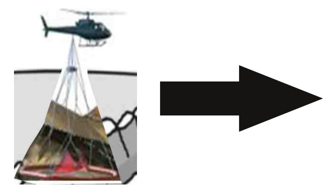
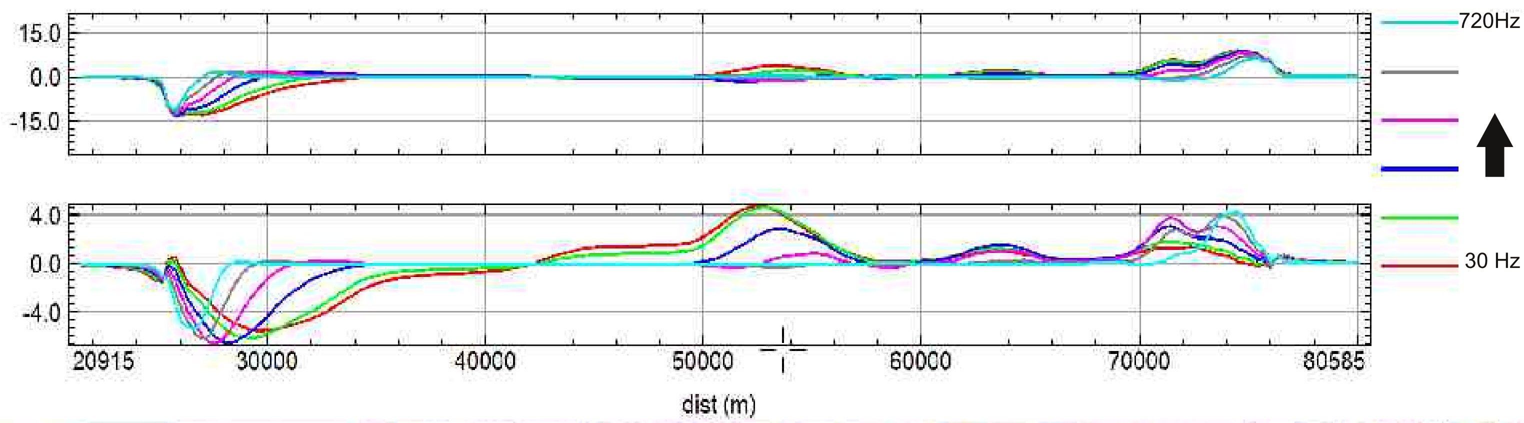
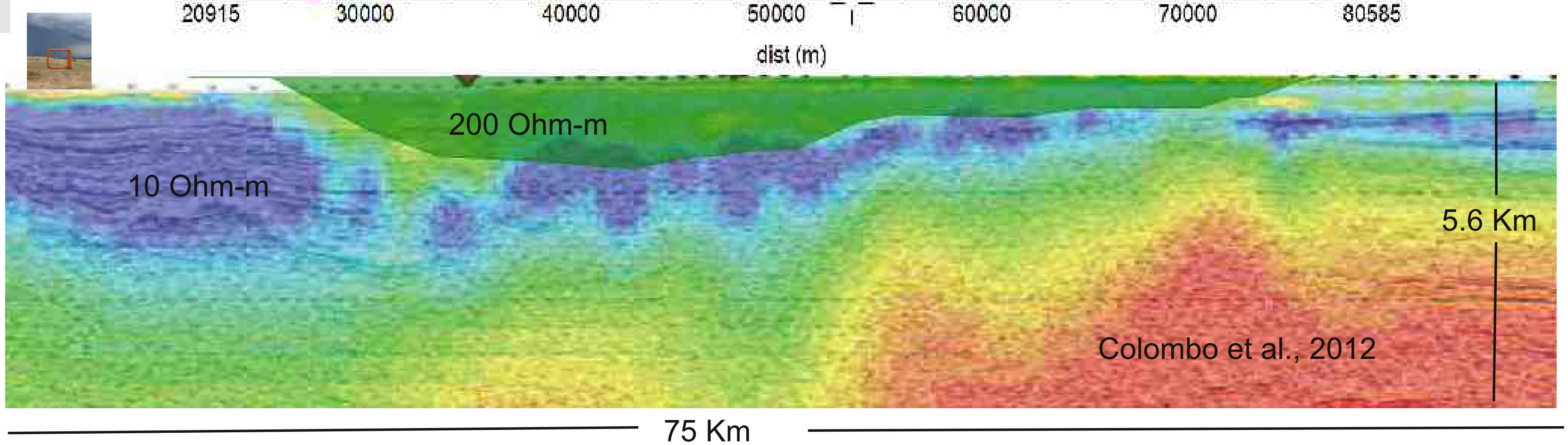


ZTEM Numerical Test





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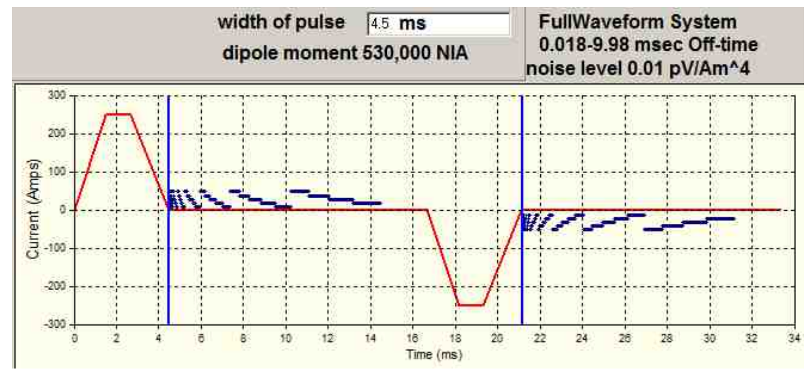
Coverage and Estimated Time for ZTEM & VTEM

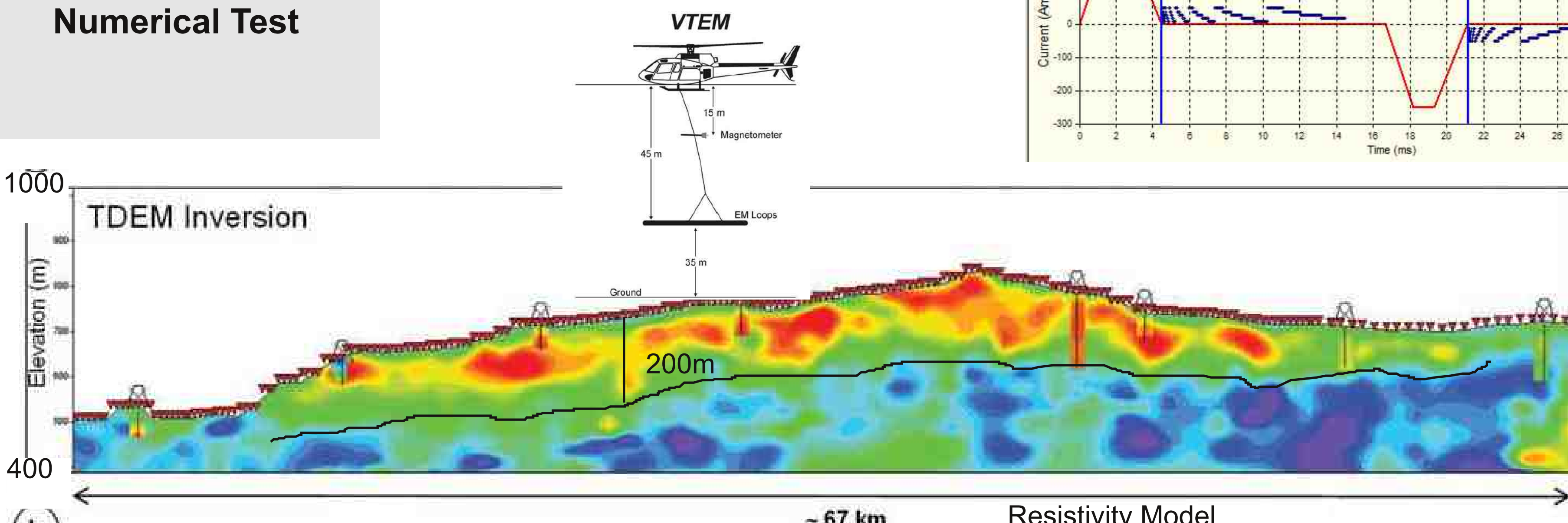
100 ZTEM Stations p/km and One day of Operation

200 VTEM Stations p/km and One day of Operation

VTEM Numerical Test

Modelling Parameters



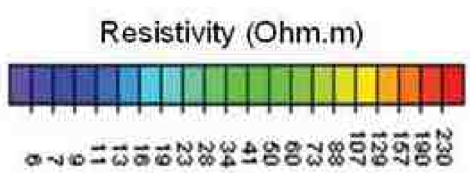


Resistivity Model

60 Ohm-m / 20m

200 Ohm/ Variable

15 Ohm-m / Half space



Colombo et al., 2012

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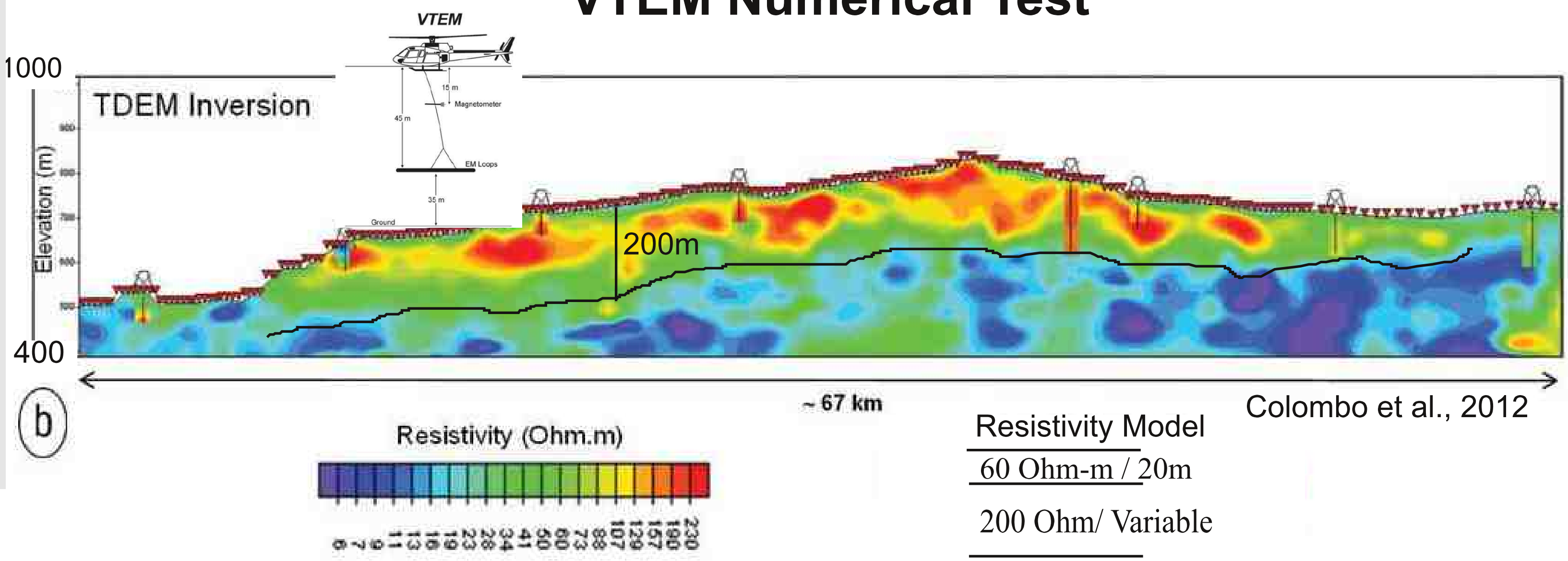
VTEM Numerical Test



Colombo et al., 2012

Resistivity Model

60 Ohm-m / 20m

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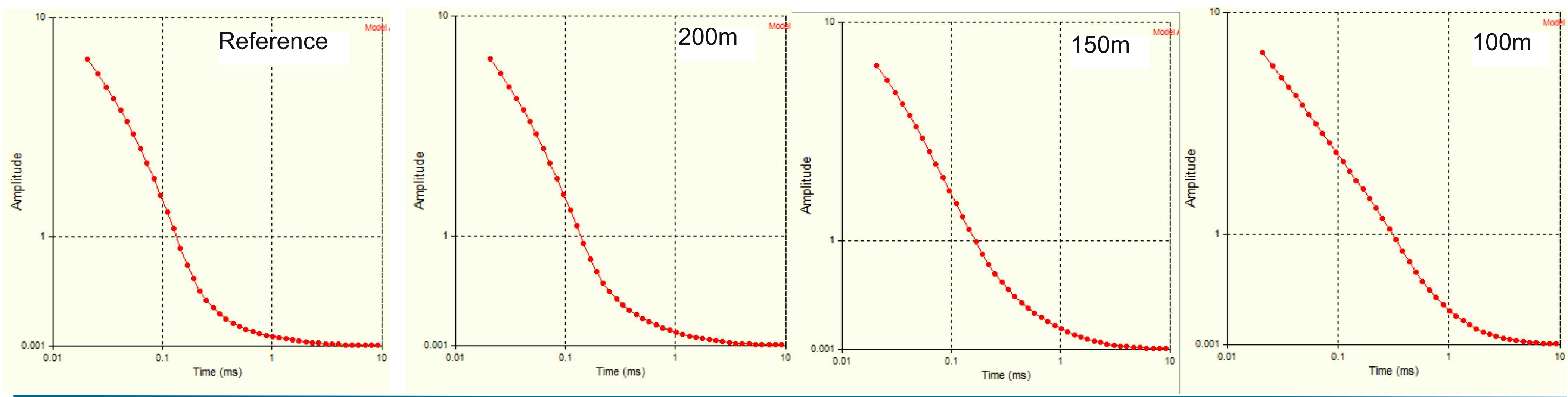
1D Modelling Results



Concluding Remarks

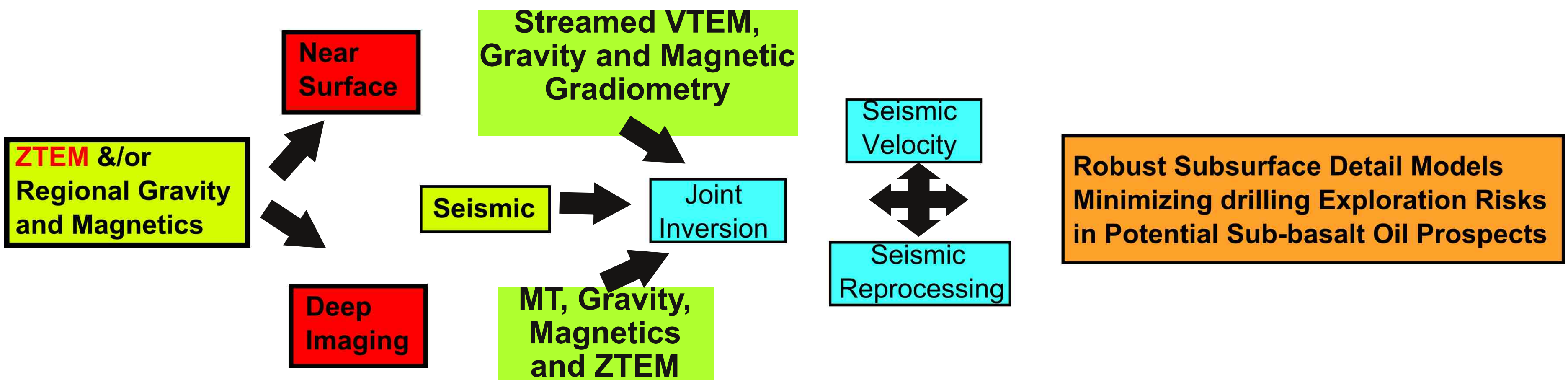
VTEM has evolved into a very efficient technology capable of providing precise and good quality EM data for Natural Resources Exploration.

VTEM and Passive EM (ZTEM) are complementing tools of exploration with good lateral resolution and penetration depths of economic interest.

ZTEM and Streamed VTEM offer the ability to effectively support traditional ground EM in integrated studies for unconventional targets in Oil and Gas.

ZTEM and Streamed VTEM can help reduce exploration costs and make more efficient use of finantial resources.

Integrated Exploration Surveys using Airborne Gravity and Magnetics, Active and Passive HEM can help mitigate risks, reduce costs, and improve quality and imaging of subsequent ground surveys. This eventually may increase the success of exploratory drills.



Modified after Colombo et al., 2012

Acknowledgments

One main condition for the successful application of geophysical methods – the disregard of which has done much injury to the cause of geophysics – cannot be overlooked: The relation of the spatial distribution of physical properties in the subsoil to the formation of fields of force, etc., on the surface of the earth can correspond to various underground arrangements. The greatest care must therefore, be taken to assure a correct geological interpretation of measurements, which in themselves are entirely correct. (Ambronn in 1926).... Taken from Fountain (1998)

Obrigado pela sua atenção

À ANP, meu muito obrigado pelo seu convite .