Investigations of Different Survey Techniques and Inversion Strategies For Detecting Water-Bearing Structures with TDEM

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TOPICS:

- Study Area – *Turpan-Hami Basin, Xinjiang*
- Fundamentals contrary to the use of in-loop TDEM
- Other strategies
- Field data examples
- Conclusions

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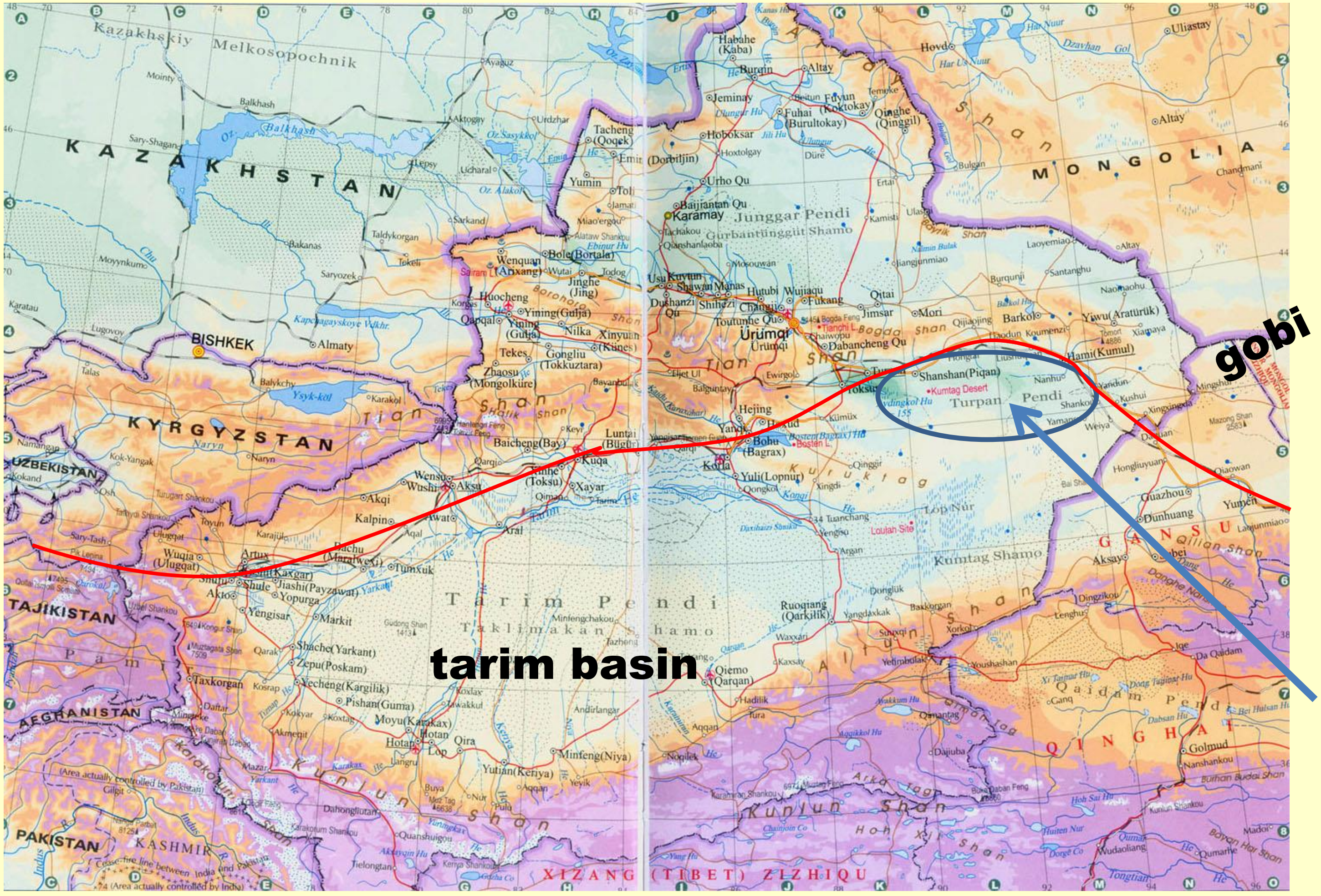
Xinjiang – Basins

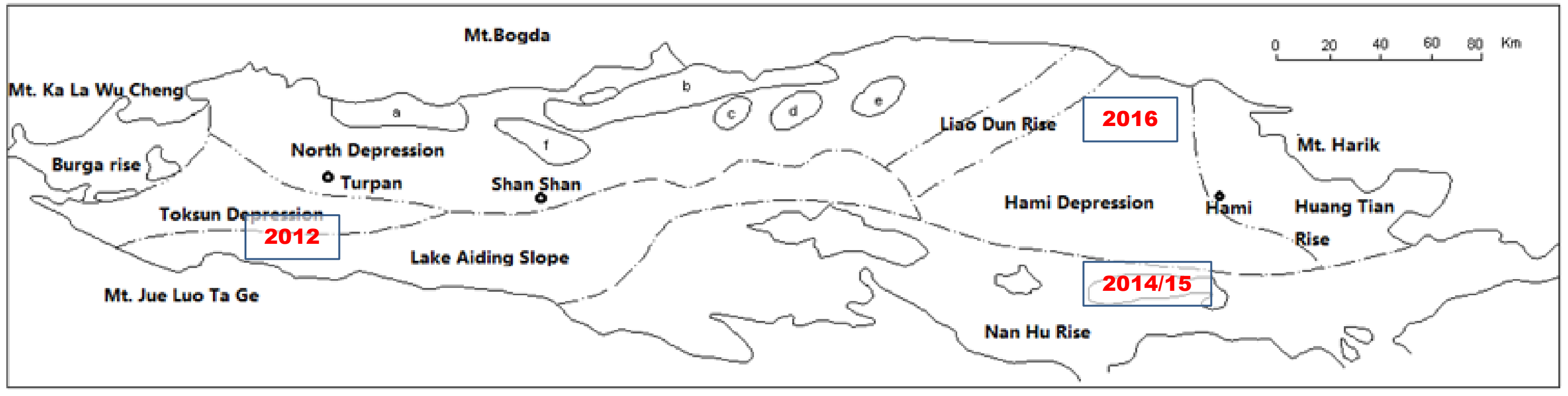


Study area

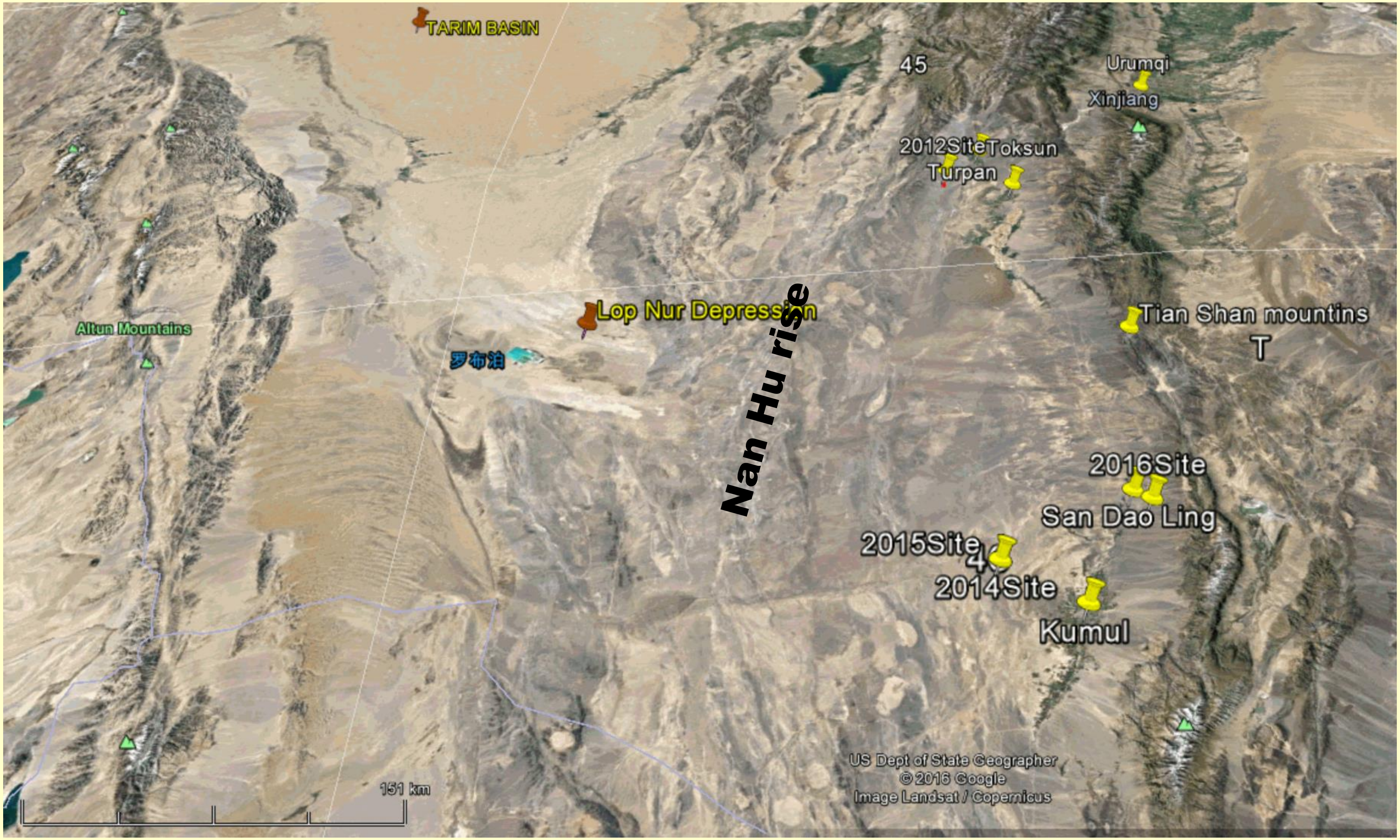
1500km

Basins of Xinjiang

TURPAN-HAMI Basin
Study area

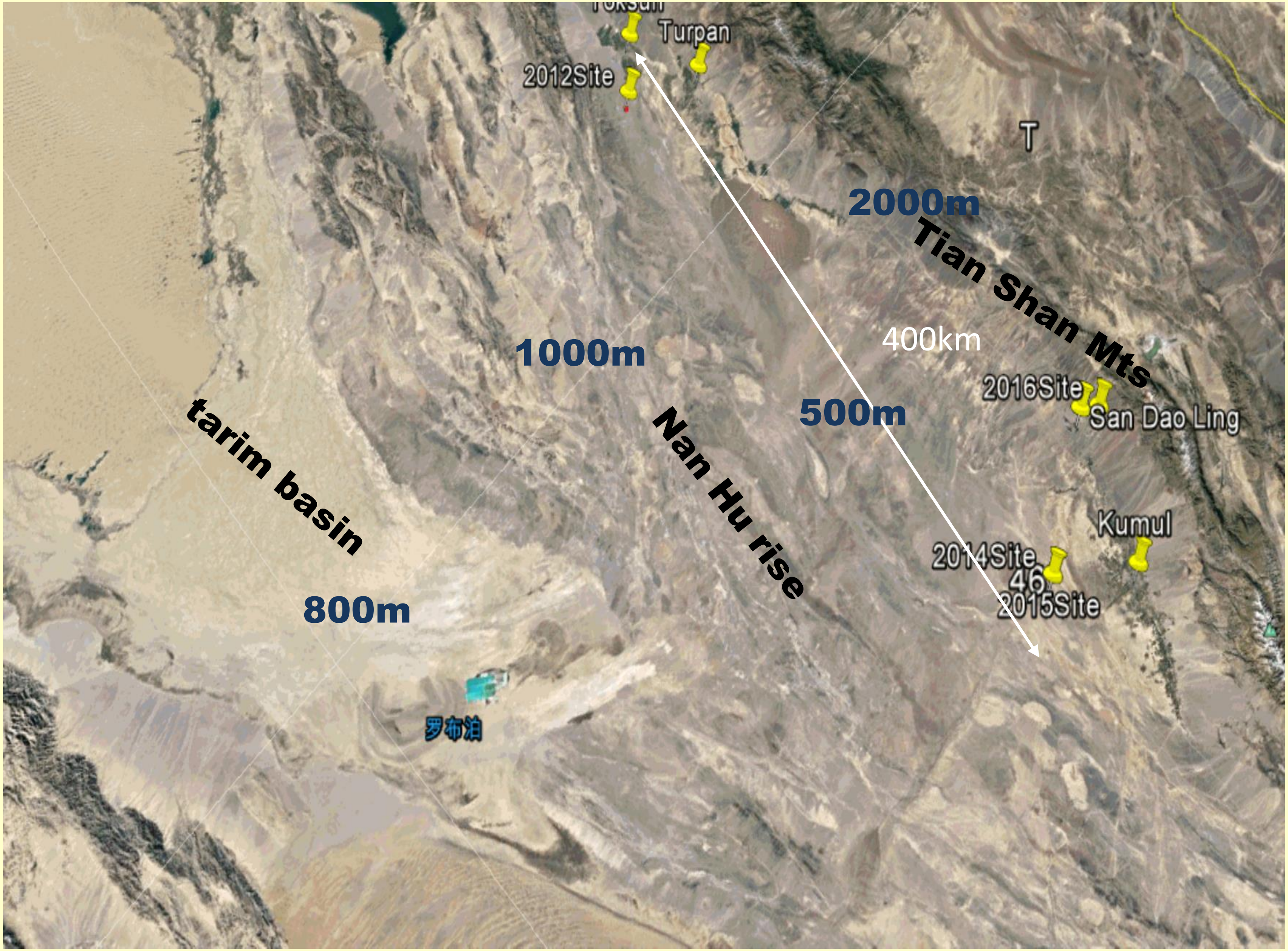


500km

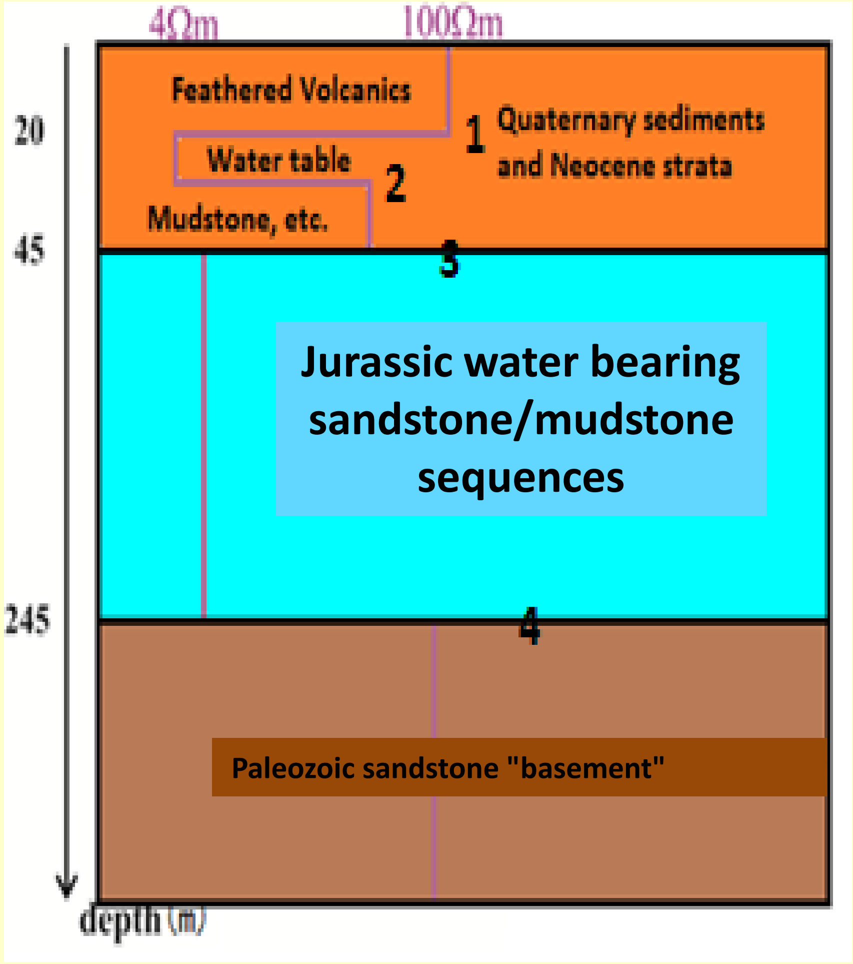


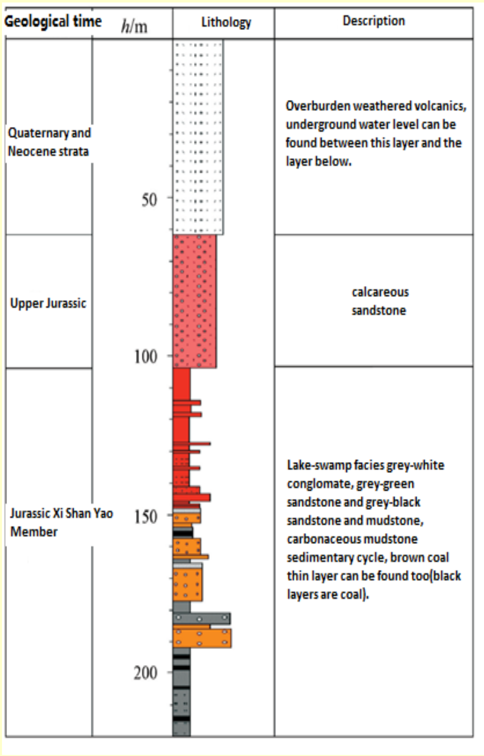
TARIM BASIN
45
Urumqi
Xinjiang
2012Site
Toksun
Turpan
Lop Nur Depression
Nan Hu rise
Tian Shan mountins
T
Altun Mountains
罗布泊
2016Site
San Dao Ling
2015Site
2014Site
Kumul
US Dept of State Geographer
© 2016 Google
Image Landsat / Copernicus
151 km

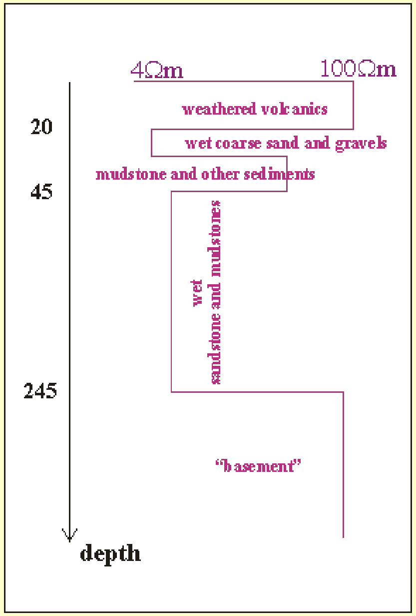
Turpan-Hami basin



Partially Saturated Jurassic target sequence







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Surveyed with TDEM since 1998

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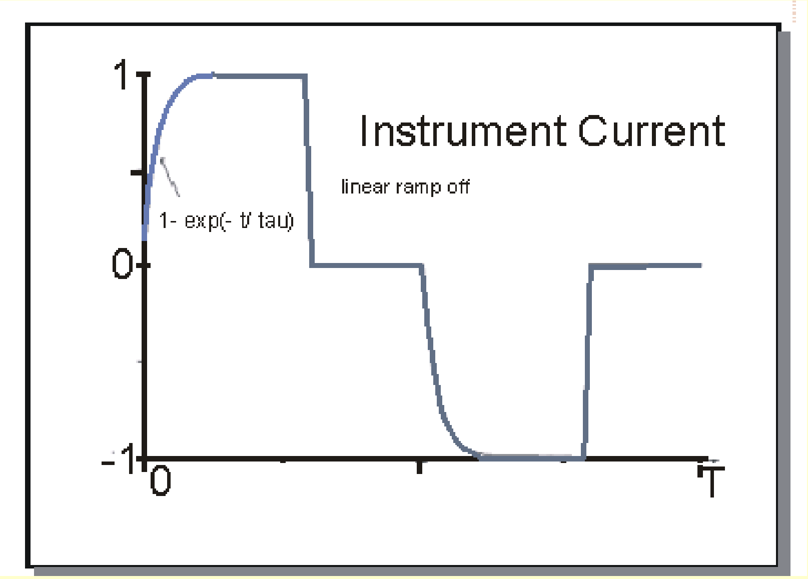
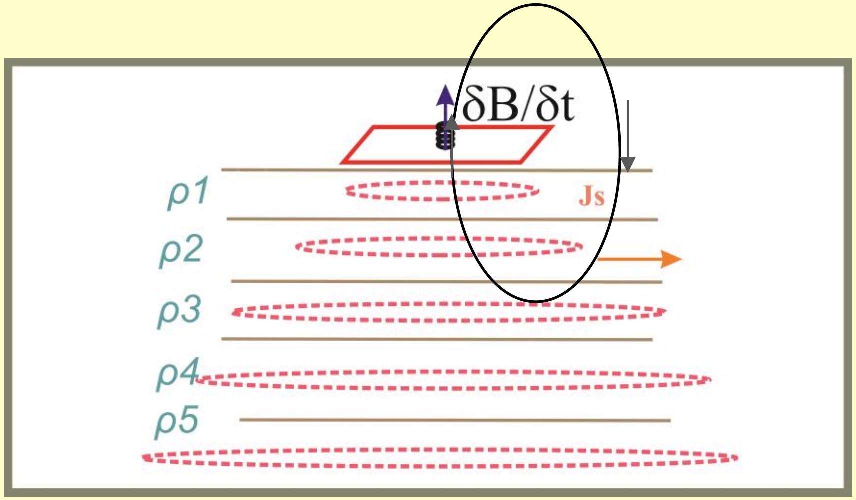
Physical Basics





- Periodic Impulse Response when using induction coil frequency band limited
- "no" primary field in the off time
- Primary B field is the source of induced currents

- Currents induced at depth proportional to primary field strength
Currents then diffuse outwards and downwards producing the offtime response

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Study Surveys Objectives

- Historical surveys – 1998 to present
  - continuous, small loop, central loop measurements
  - approximately 100km per year
  - first 10 years with domestic Chinese equipment
  - now utilizing large voltage transmitters
  - multiple base frequencies.
  - requiring long data collections
  - recently immediately outside the loop and invert as inloop

- practical concerns
  - small loops small dipole strengths without large curents
  - primary fields relatively non-uniform inside the loop
  - late time secondary currents migrating outside loop
  - do low base frequencies offer any additional information?

- Increase loop size
  - increase spatial data sampling
  - how to increase resolution
  - how to increase depth of penetration
  - decrease the need for large currents

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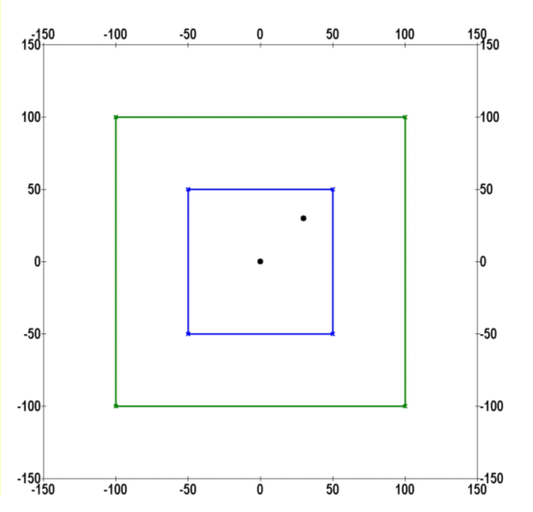
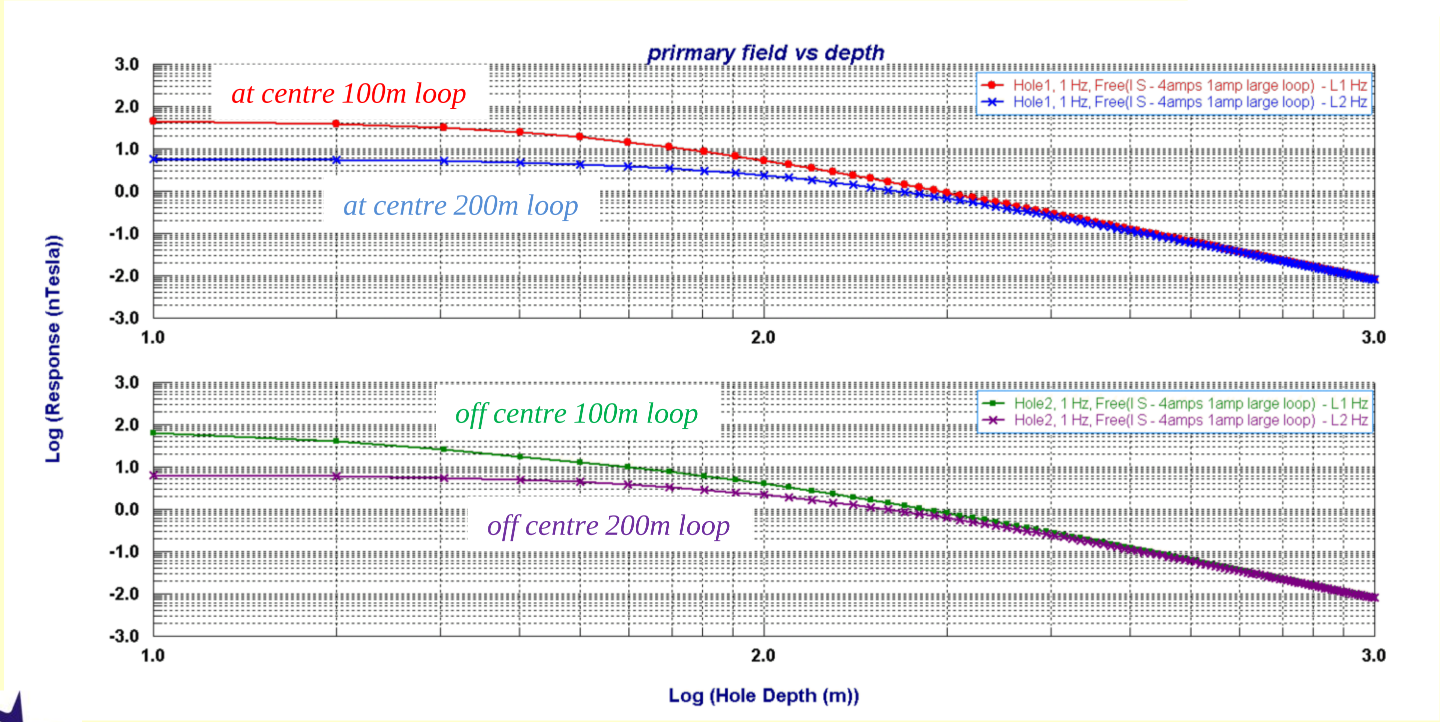
Effect of Loop Size on Primary Field Excitation

-100m loop with 4 Amps , 200m loop with 1 Amp
- larger loop more horizontally uniform
- larger loop weighted stronger at depth
- weaker effects from horizontal components





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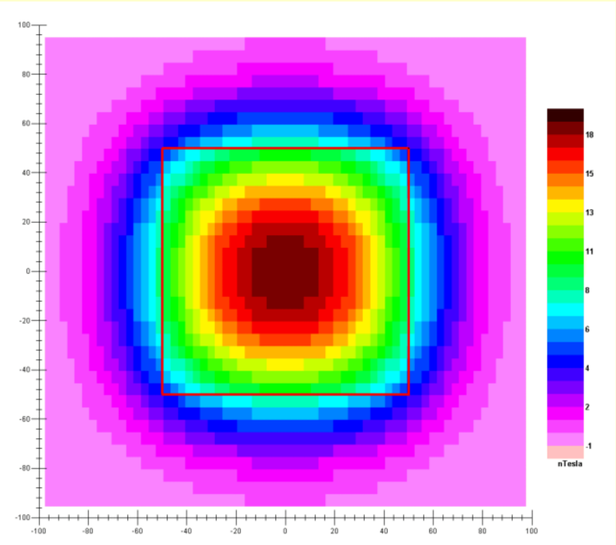
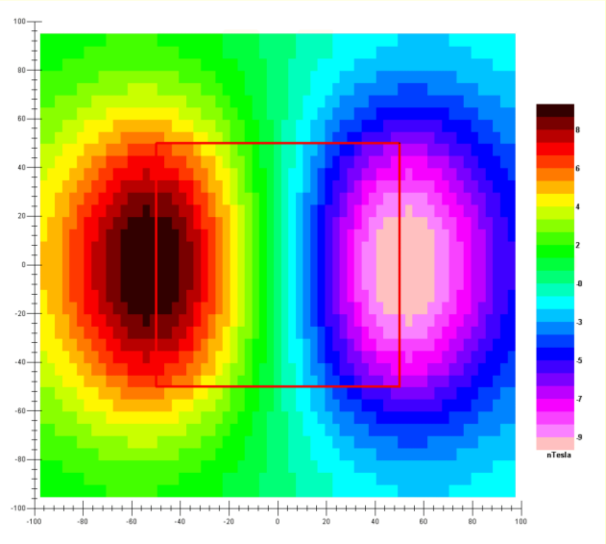
Effect of Loop Size on Primary Field Excitation

-100m loop, 4A, Z=50m

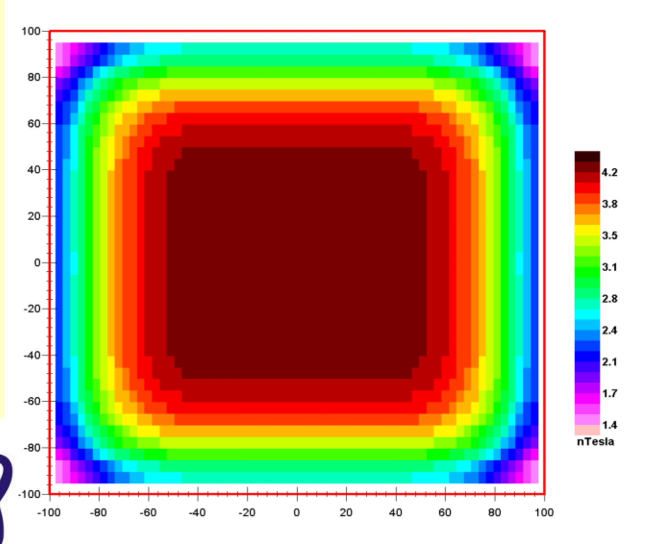
Hz

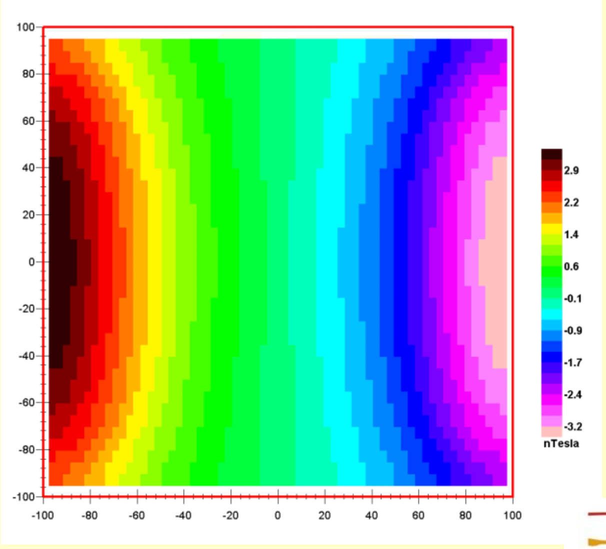


Hx



-200m loop, 1A, Z=50m





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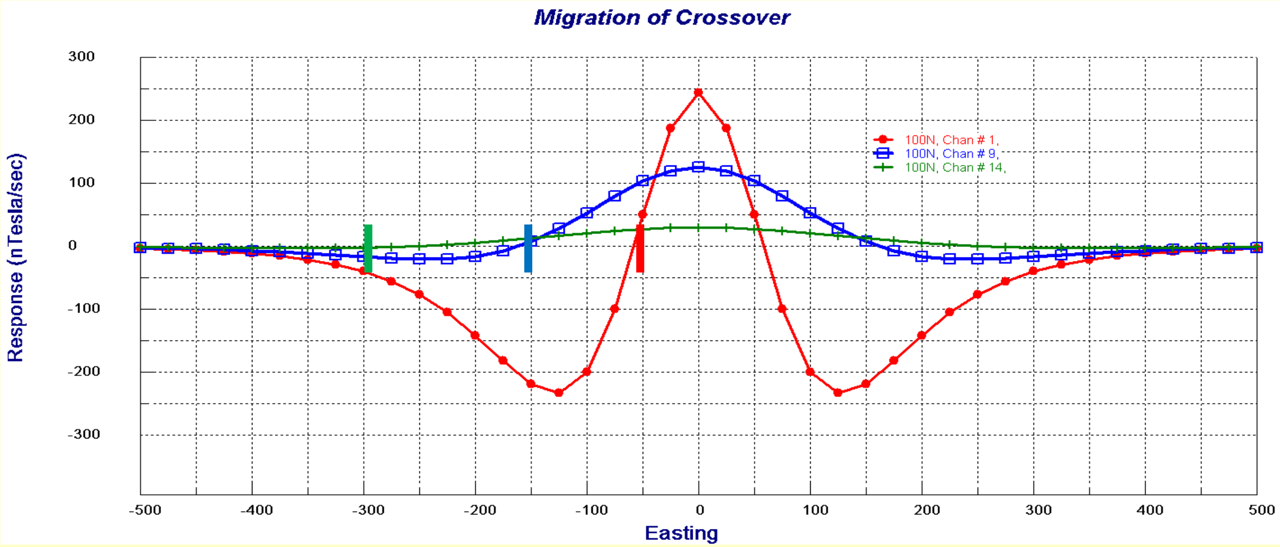
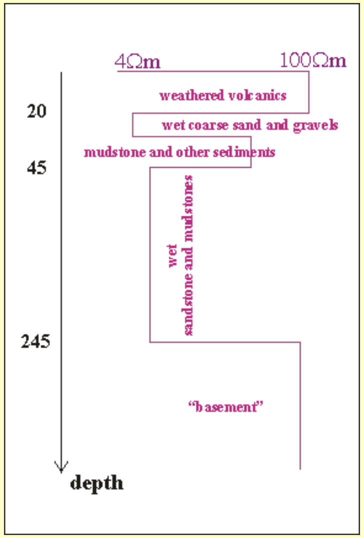
Current Migration Perspective I





In this figure: Hz (x,t)

- early-time channel (1) (Red)
- mid-time channel (9) (blue)
- late-time channel (14) (green).

- Crossover (e.g. plus to minus) shows migration past a station

The vertical magnetic field changes sign at the crossover as the station changes from being inside the current concentration to being outside the current concentration.

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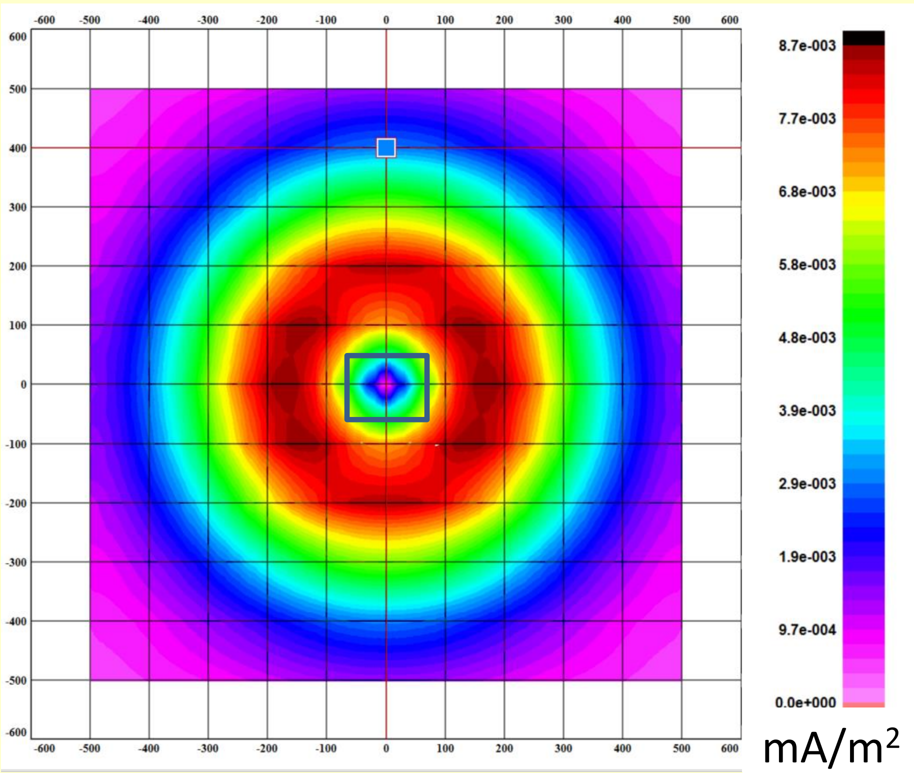
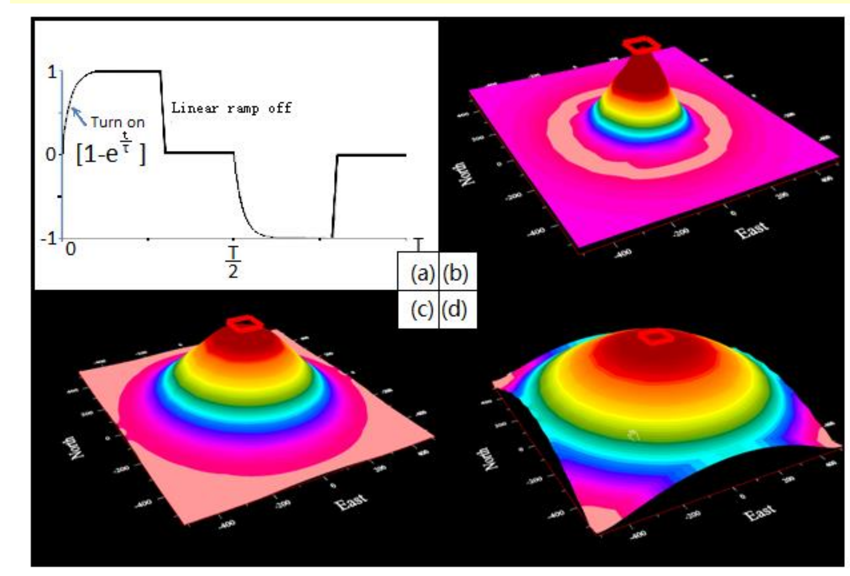
Current Migration Perspective II

Current Density at Z=200m



-the figure shows **J** (total) at 2.2msec after turn-off (2.5hz basefrequency)

Current Migration Indicated by Hz at the surface



(a) The current waveform,
(b) Early time Hz
(c) Intermediate time Hz
(d) Late time Hz

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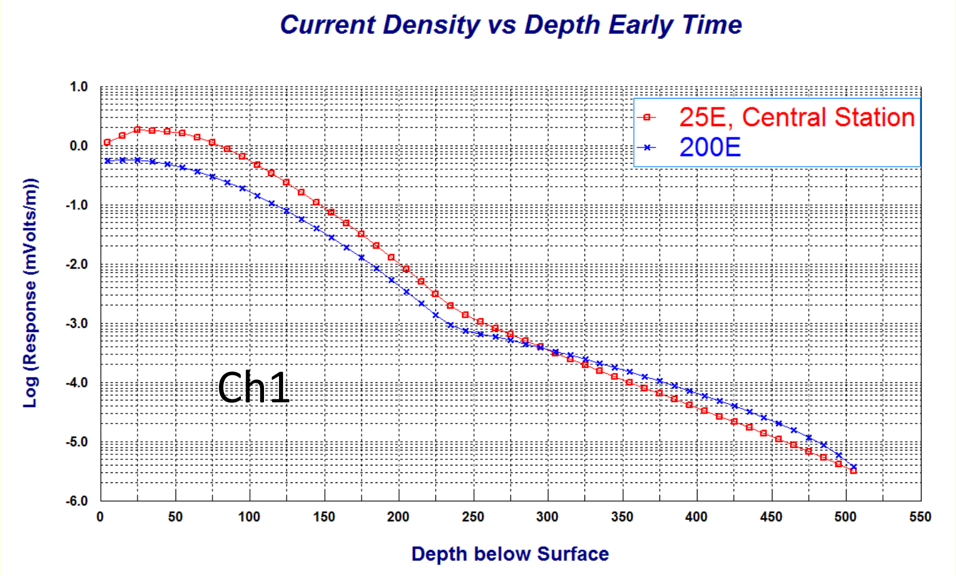
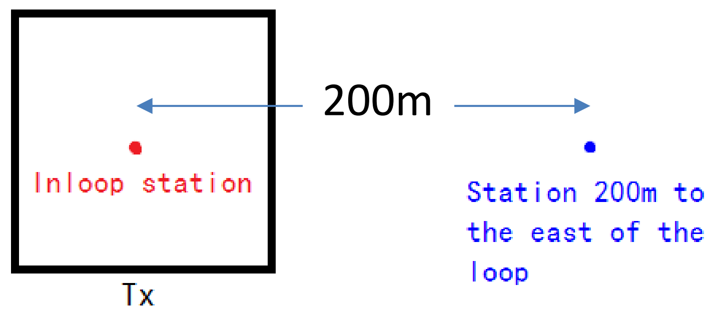
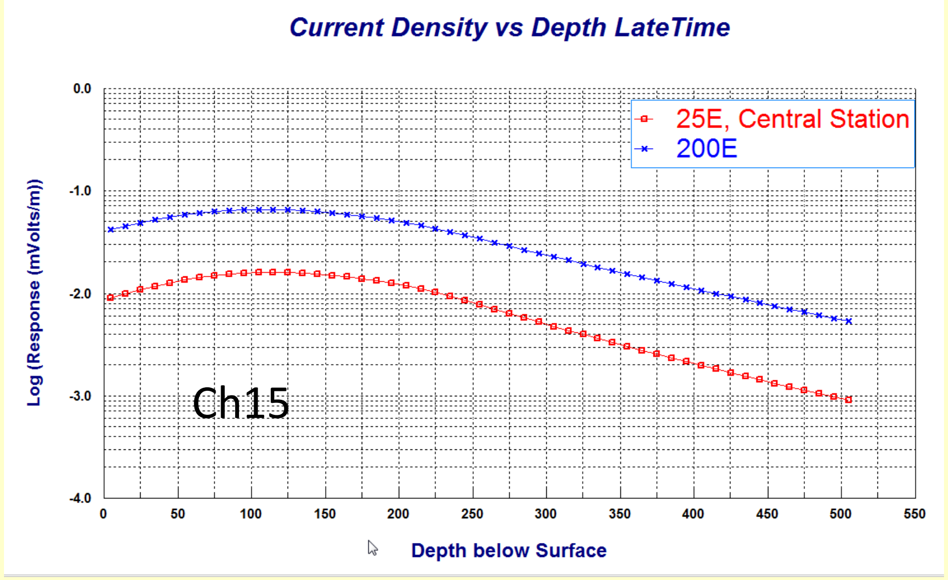
Current Migration Perspective III

- Current density below 2 positions,
  -one near the center of loop
  -one 200m east of the loop





Remove "inloop station" and "station 200m …" from this figure



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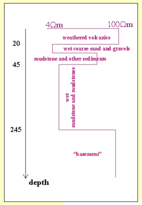
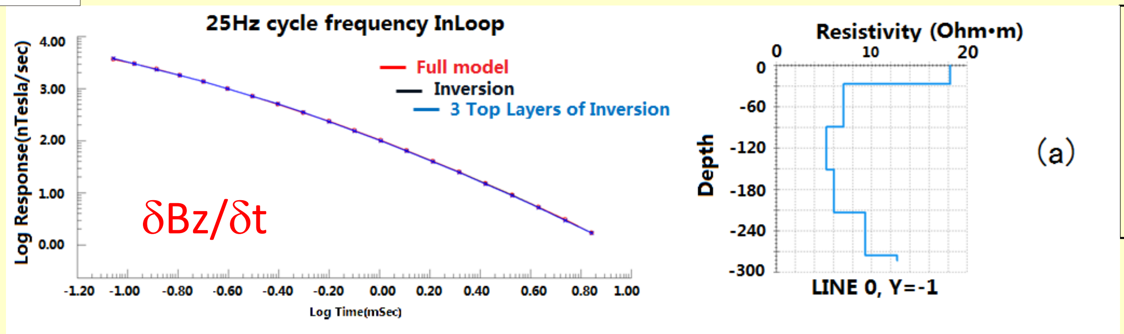


Non-Uniqueness at the Loop Center

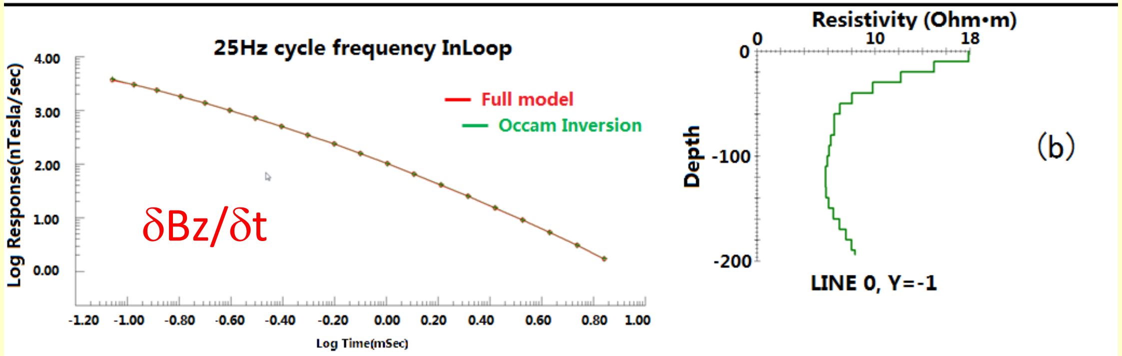


5 layer Inversion Model

Red - data

Black – inversion response

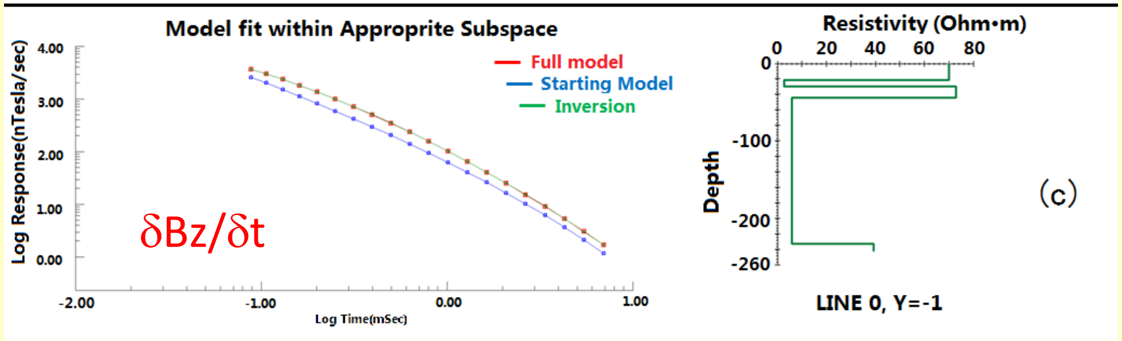
Blue – response of top 3 layers



Many layer Smooth Inversion

Red – data

Green - response of inverse model



4 layer inversion

subspace starting model

Red - data

Blue - starting model

Green- inverse model)

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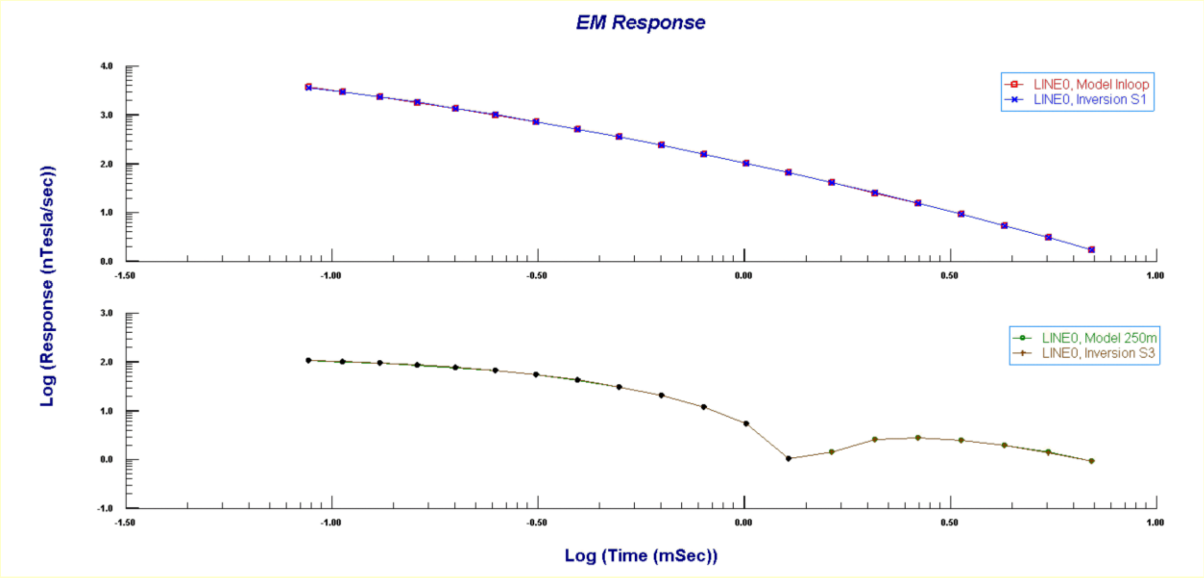
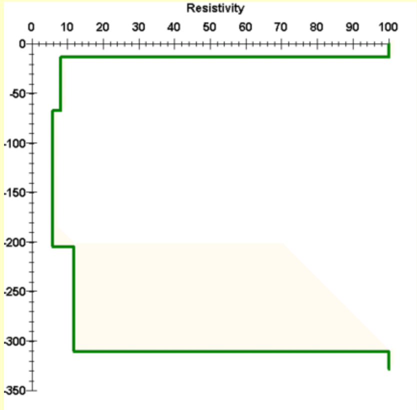
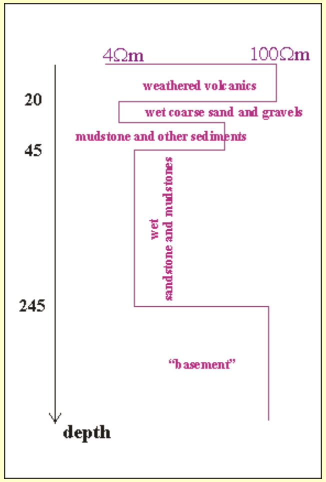
Multiple Data – In Loop plus Out-of-Loop Joint Inversion

Inversion Model

Multi-Separation Inversion Synthetics







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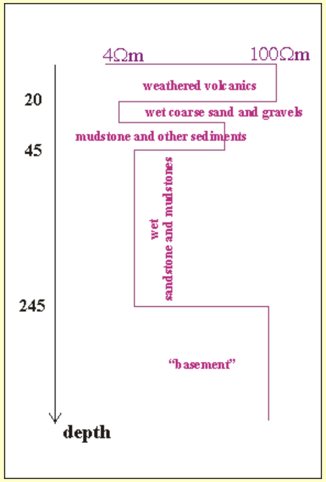
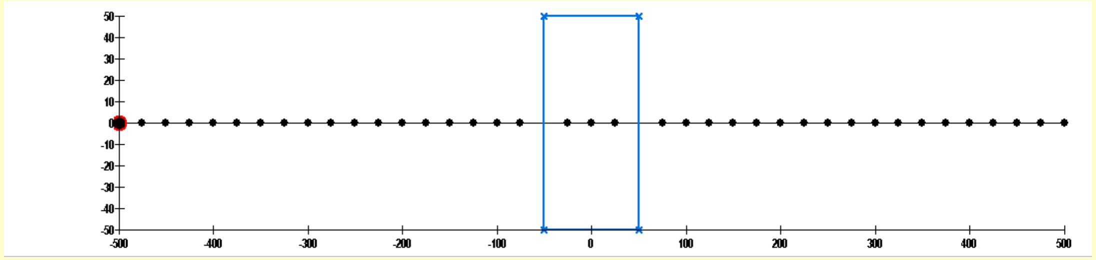
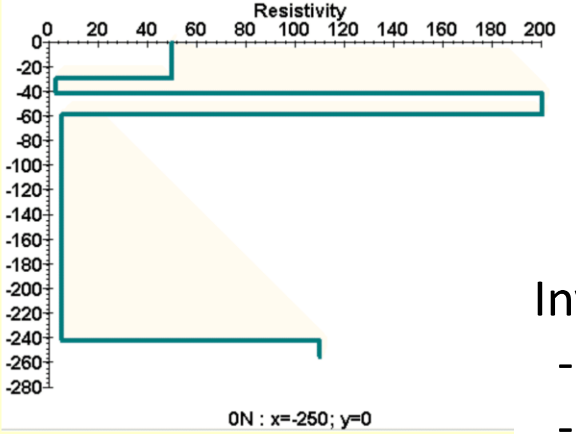
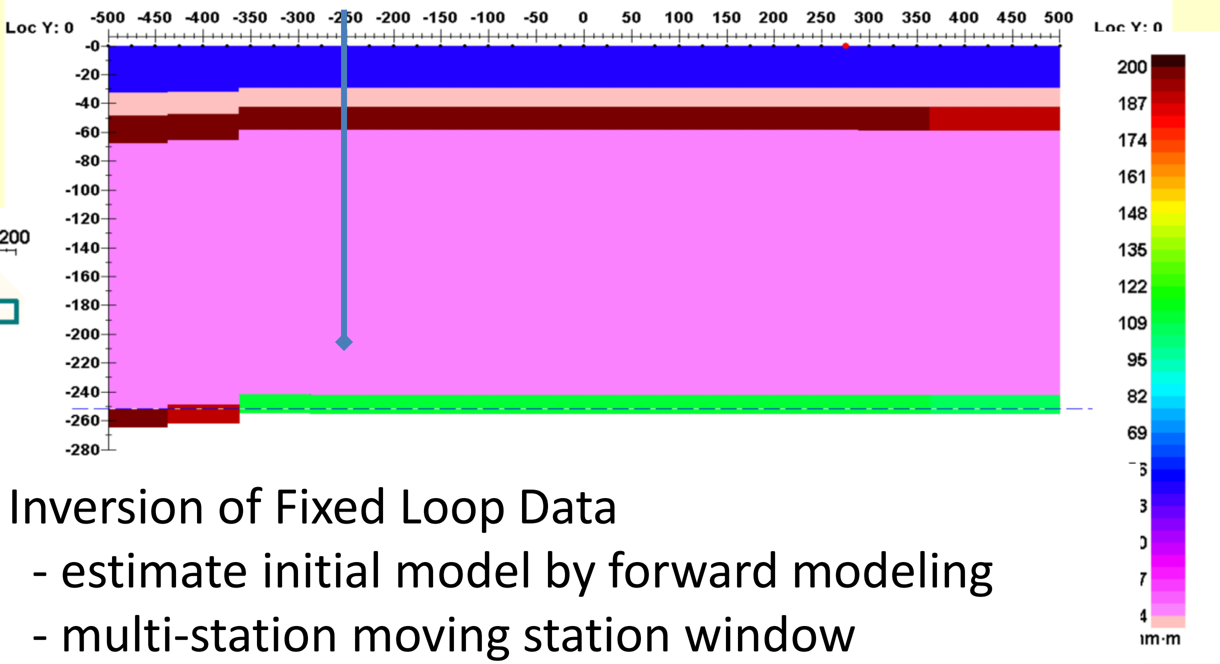
Fixed Loop Approaches

3 station window, Hz example









Inversion of Fixed Loop Data

- estimate initial model by forward modeling
- multi-station moving station window
- use previous inversion for start of next window

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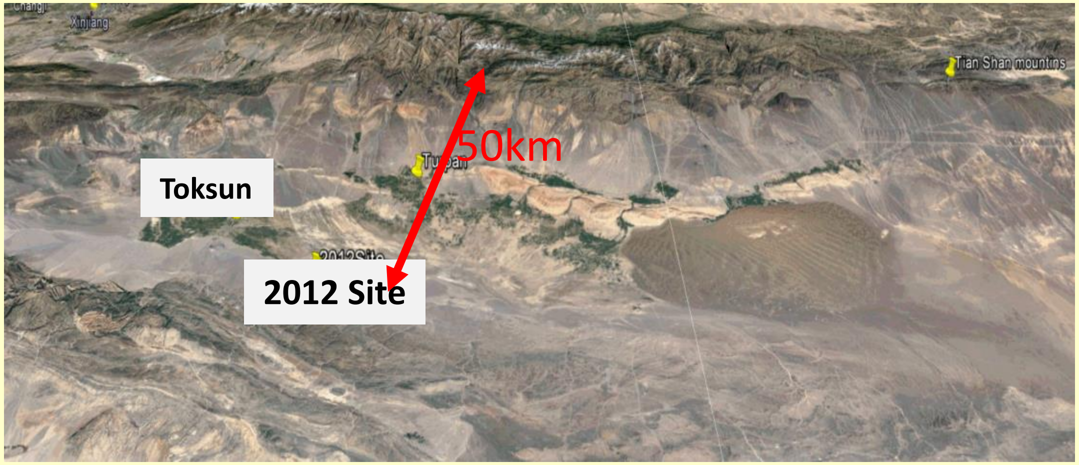
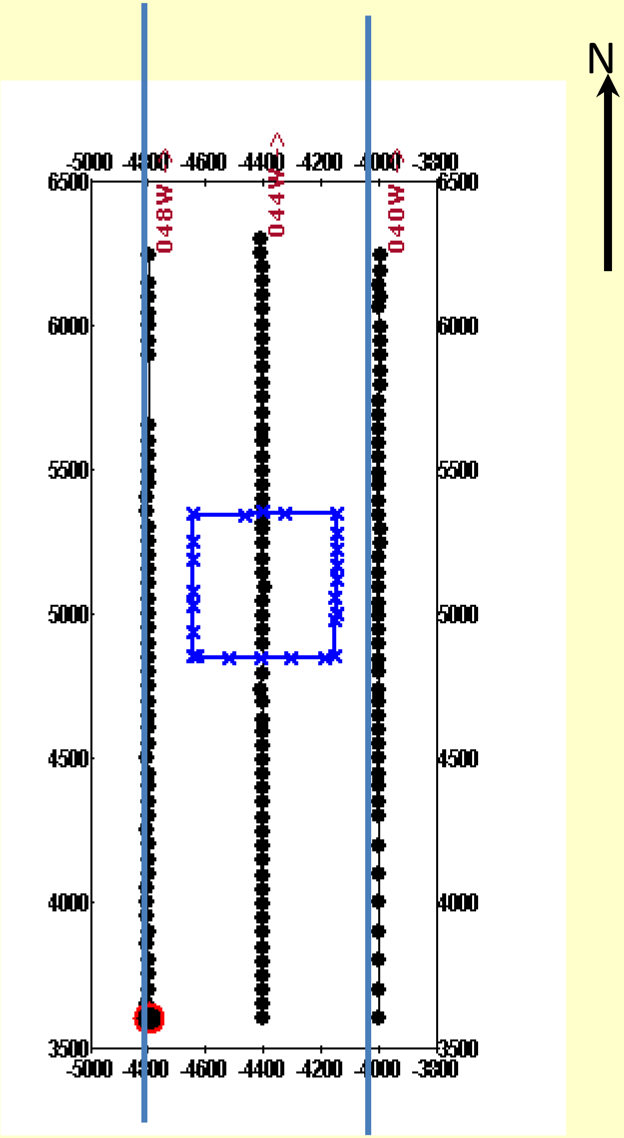
2012 Study



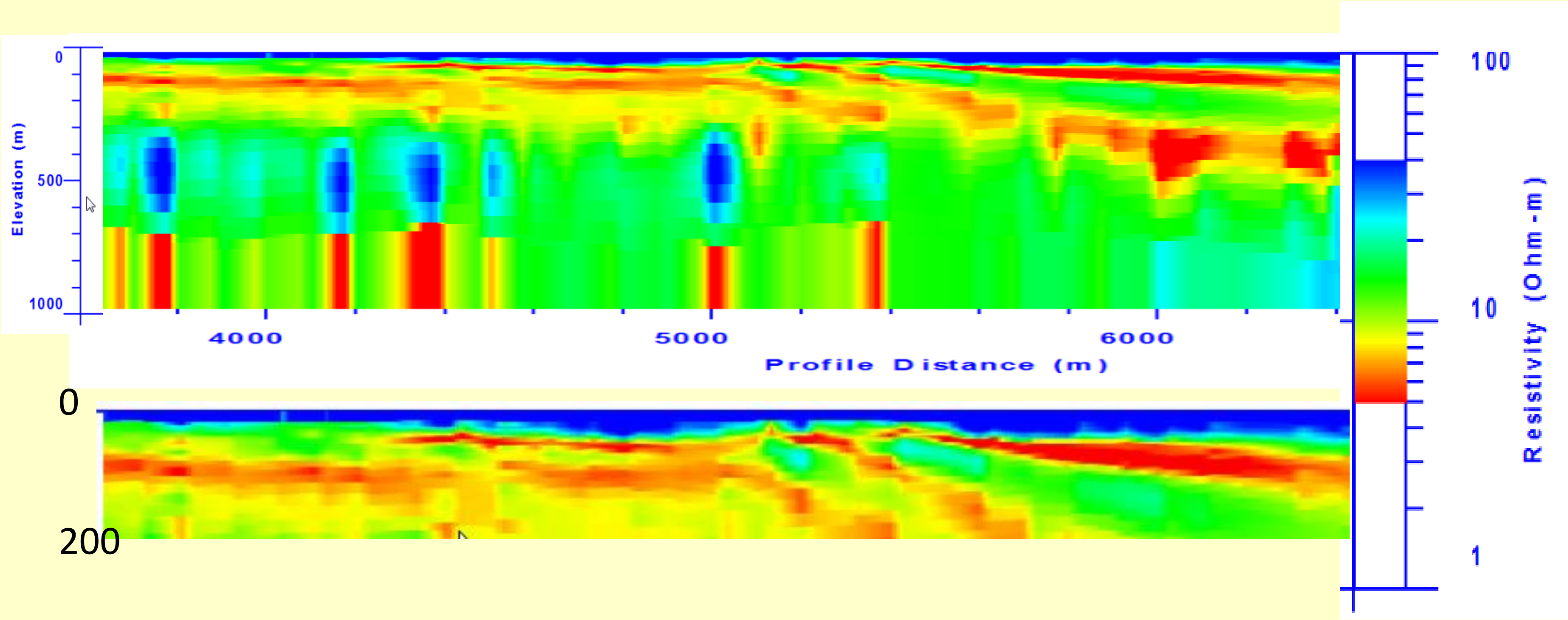


Fixed Loop and Moving Loop Survey

- 3 Lines on 500m loop with 50m stations
  25Hz – fast survey, Hy indicates 1D apsect

- 2 ML lines
  100m loop surveys with 100m stations
  2.5Hz with in loop and out of loop measurements

L48W Inloop Hz Smooth Inversion – 30layer model



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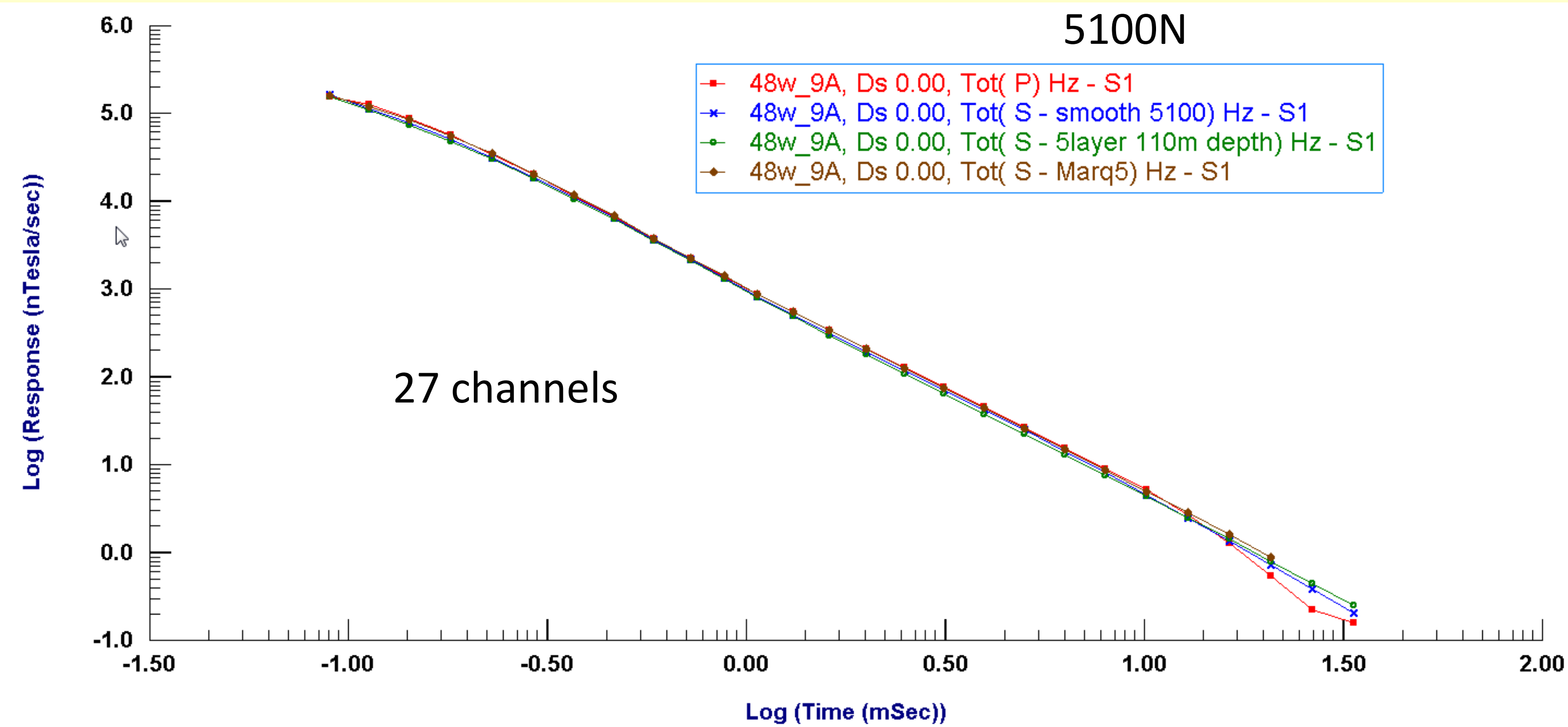
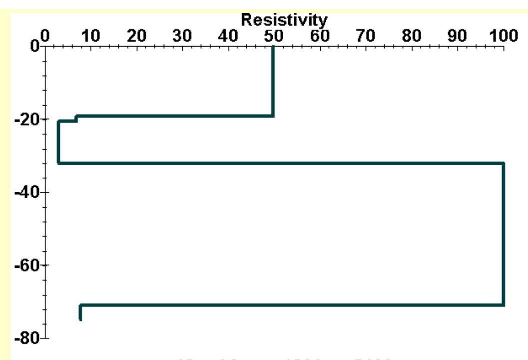
L48W Inloop Hz Smooth Inversion –
Are Model Parameters Necessary or Meaningful

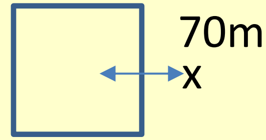


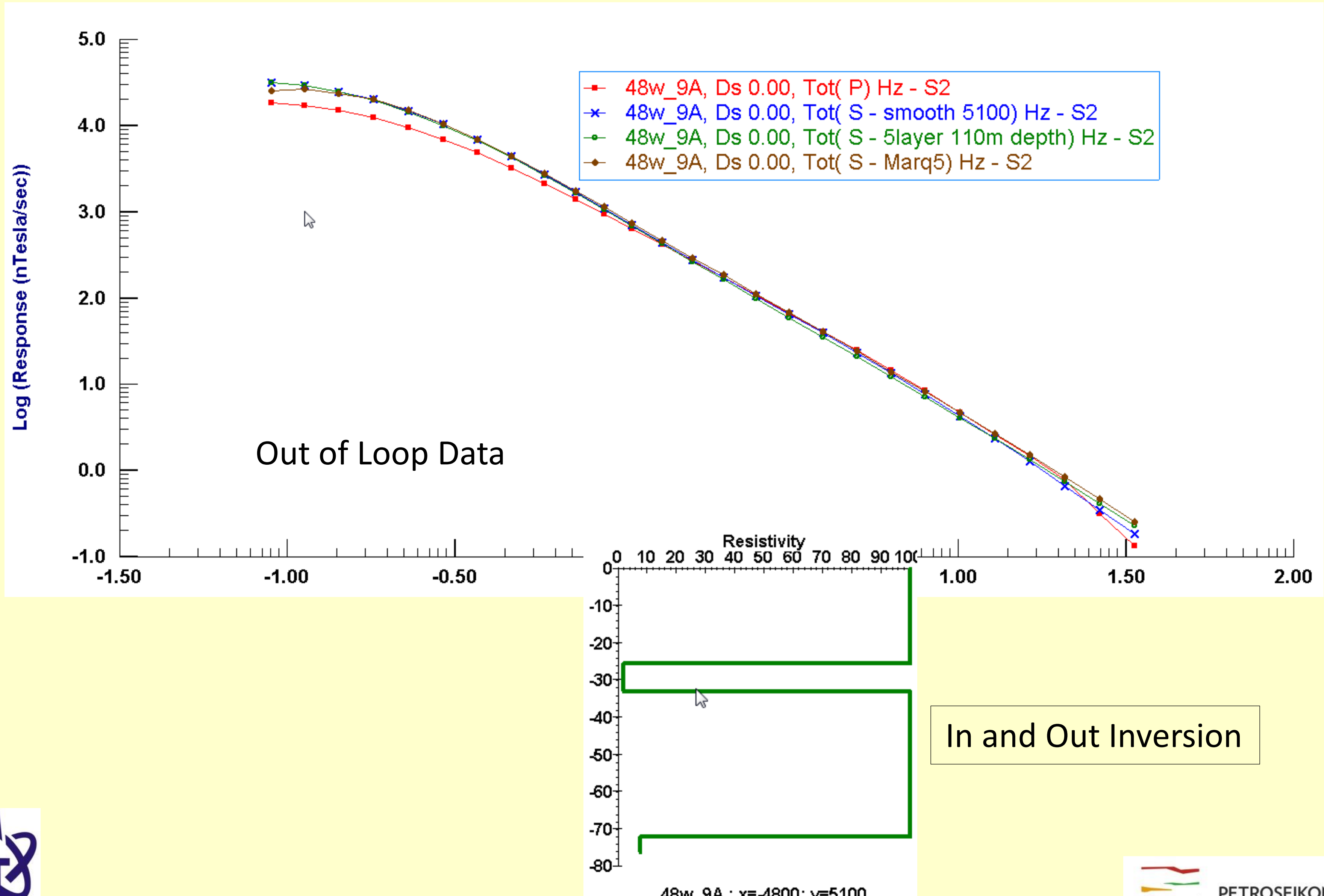
	resist	thickness	depth
1	22.0	18.6	18.6
2	10	5.3	23.9
3	6.3	15.8	39.7
4	16.5	69.6	109.3
5	7.0	124.3	233.6
6	14.1	410.0	643.6
	8.3		



4layer over
½ space

L48W Inloop Hz Smooth Inversion – Other Data Parameters





In and Out Inversion

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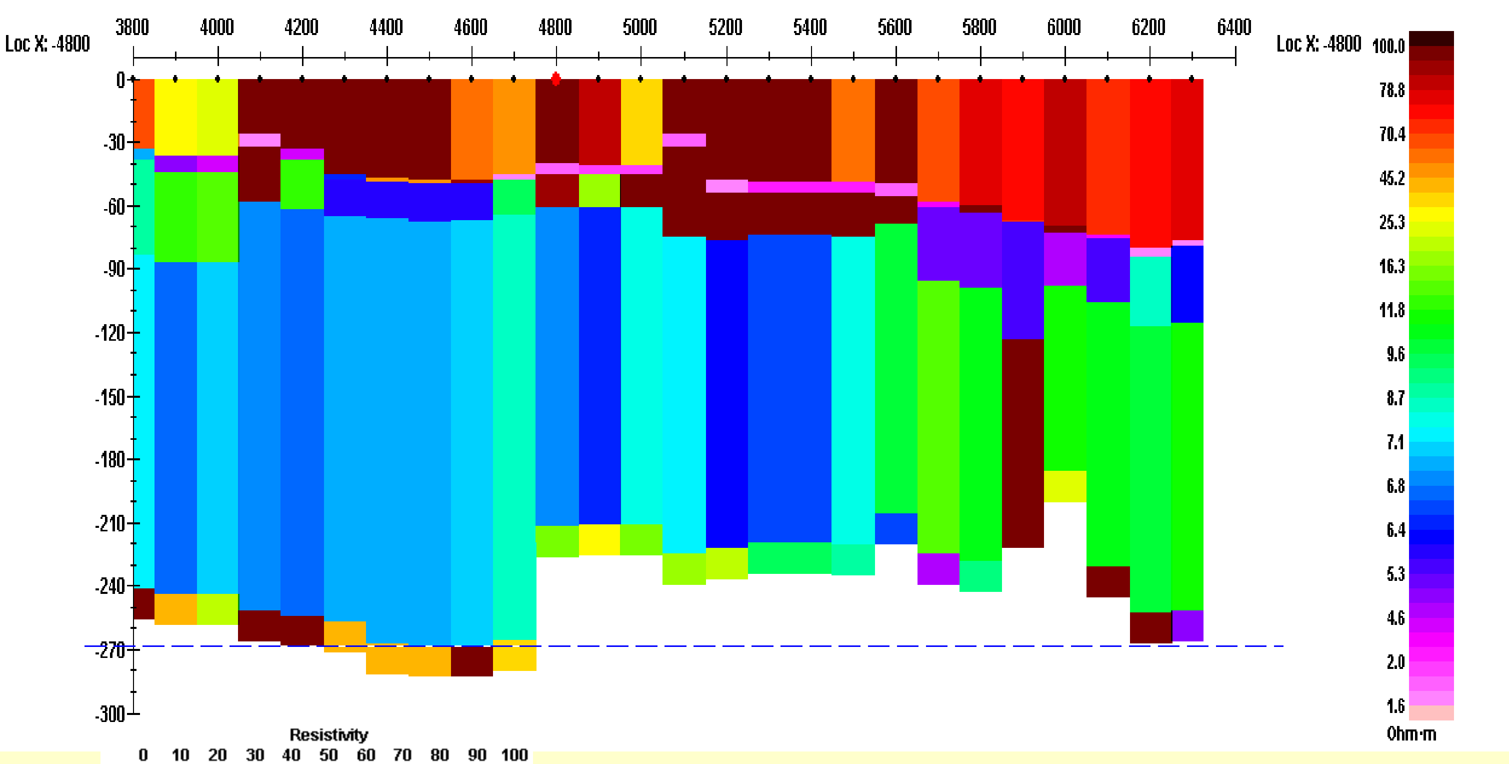
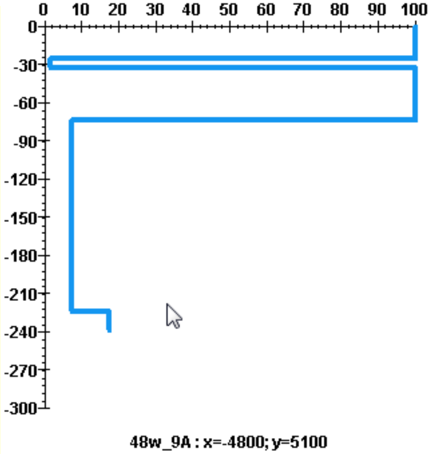
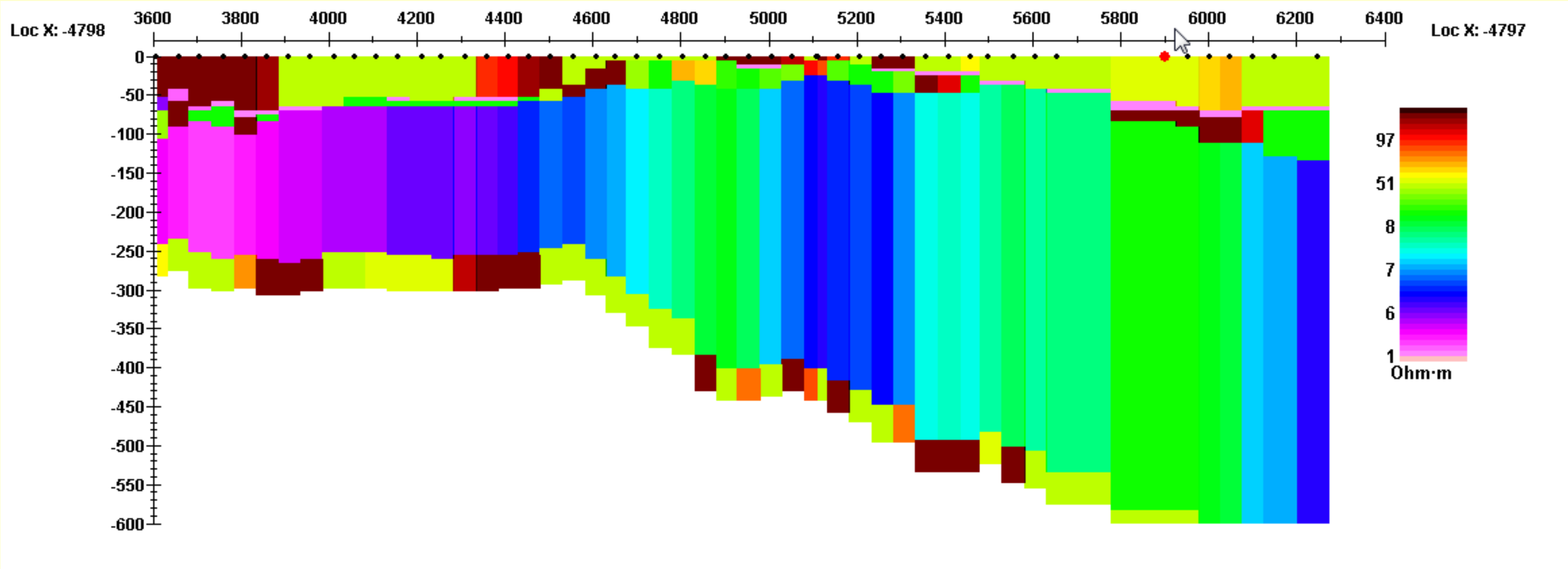
L48W Moving Loop
Inloop and Out of Loop Data Inversion



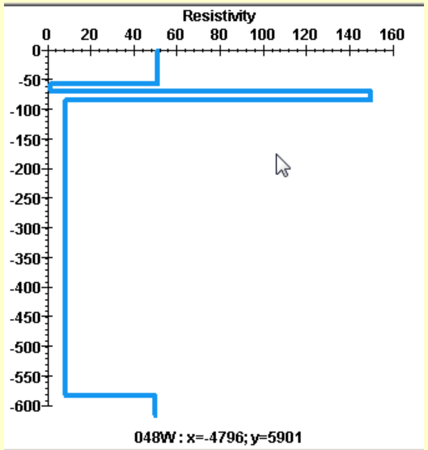


- shallow strong conductor found
- Bottom layer resolved in out of loop data

L48W Fixed Loop
Inversion of Hz data

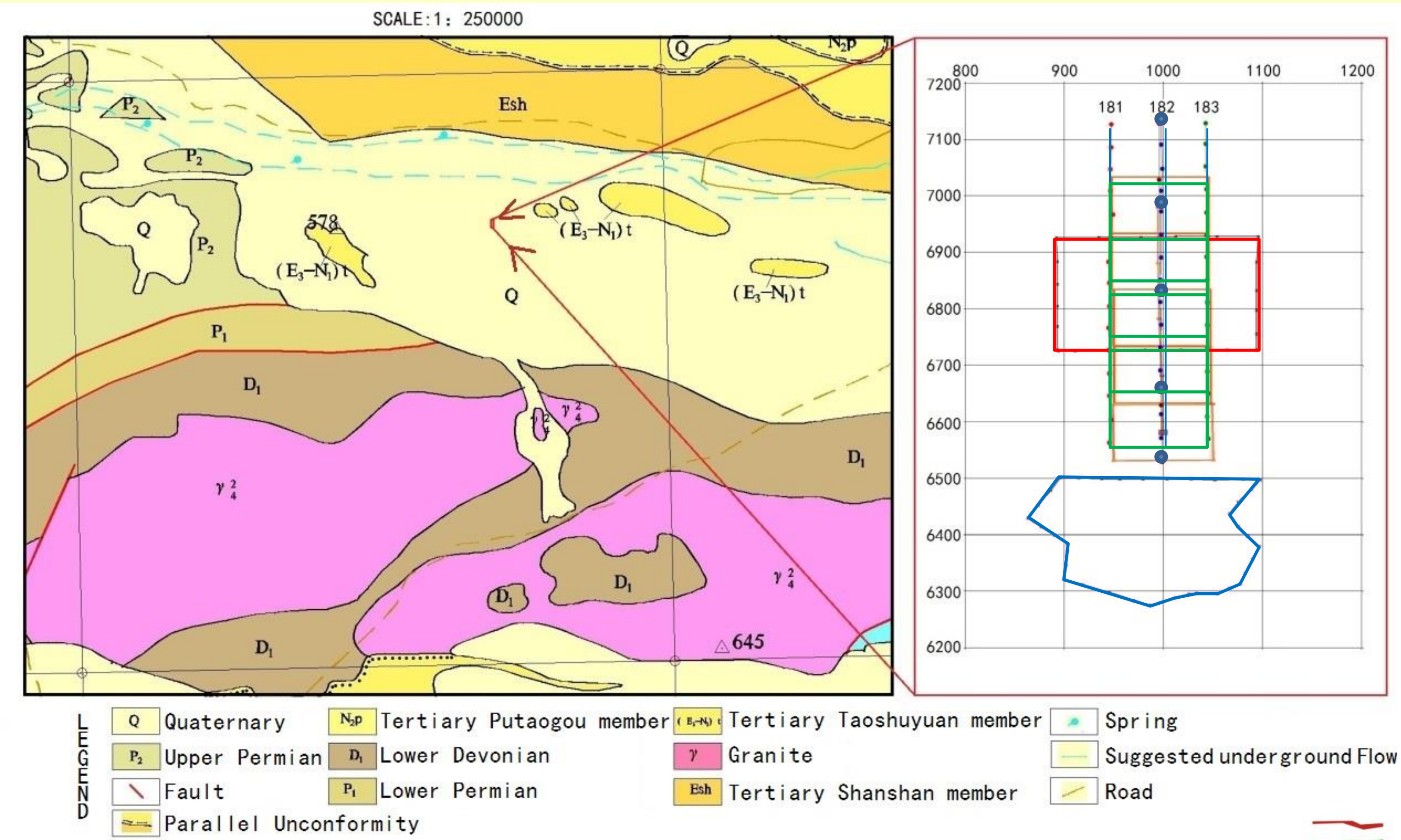


- thin conductor at approx 50m is indicated
- thick conducting Jurassic found thickening to the north
- lower resistor resolved



2015 - Field Data Examples
75km from Tian Shan

3 survey configurations
1. fixed loop, multiple lines
2. fixed loop, 5 stations
3. moving loop – 3 separations



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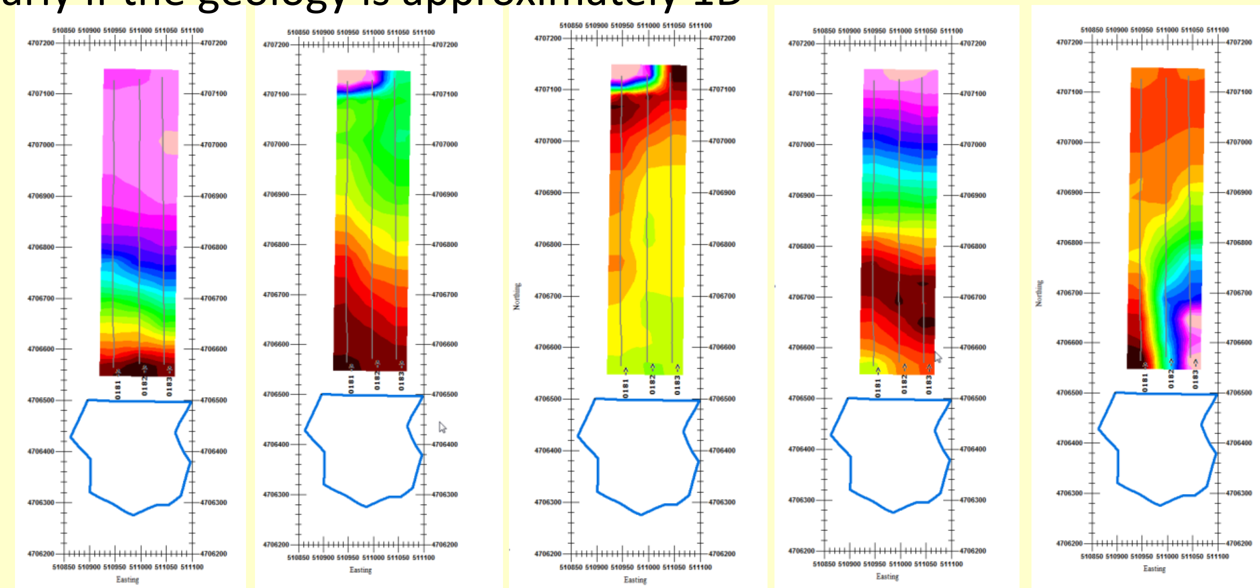
Fixed Loop Field Method – Example 1

3 Lines north of loop

This contour plots show a large amount of information about the subsurface particularly if the geology is approximately 1D

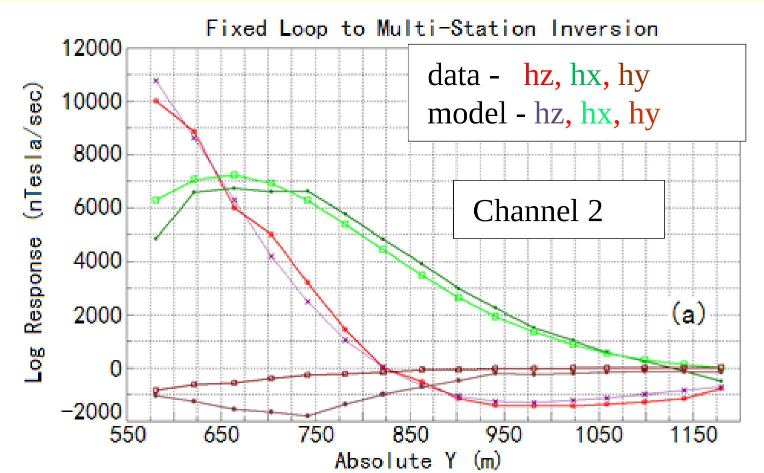


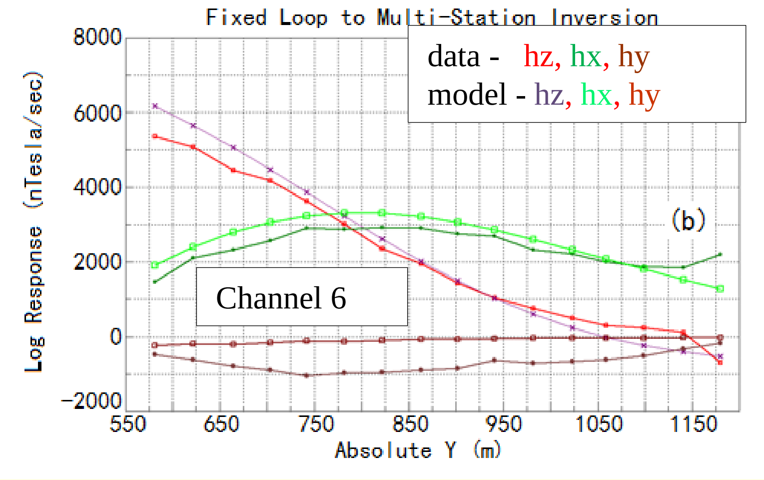
Ch.3 Hz Ch.9 Hz Ch.13 Hz Ch.14 Hx Ch.2 Hy

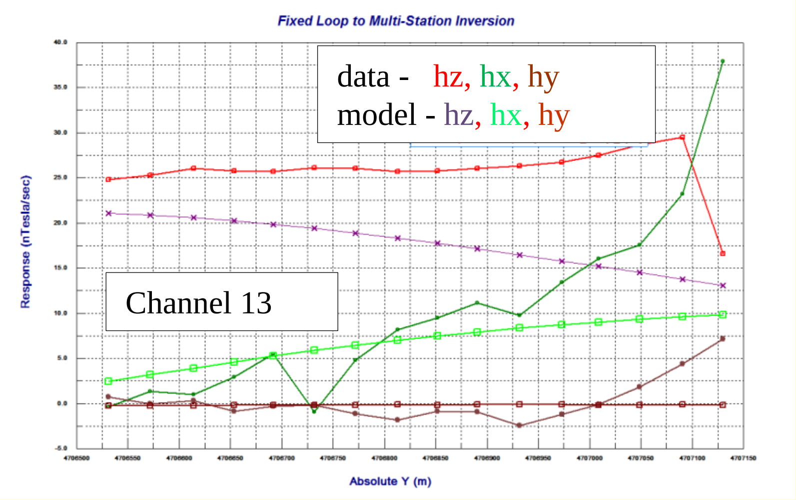
Fixed Loop Field Data Example 1

Multi-Component / Multi-Station Inversion :

- Example 1: 8 time channels and 12 stations from central line -> single model result





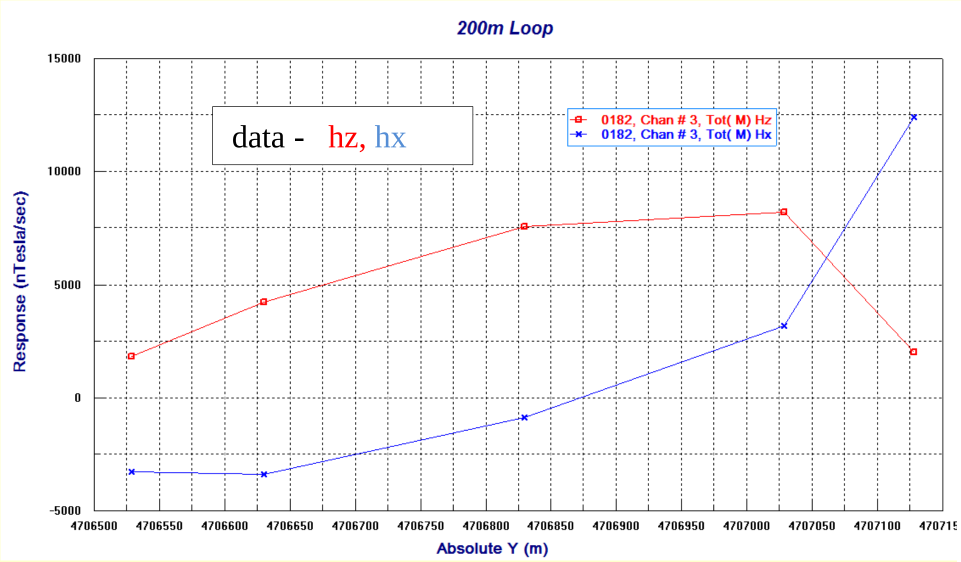


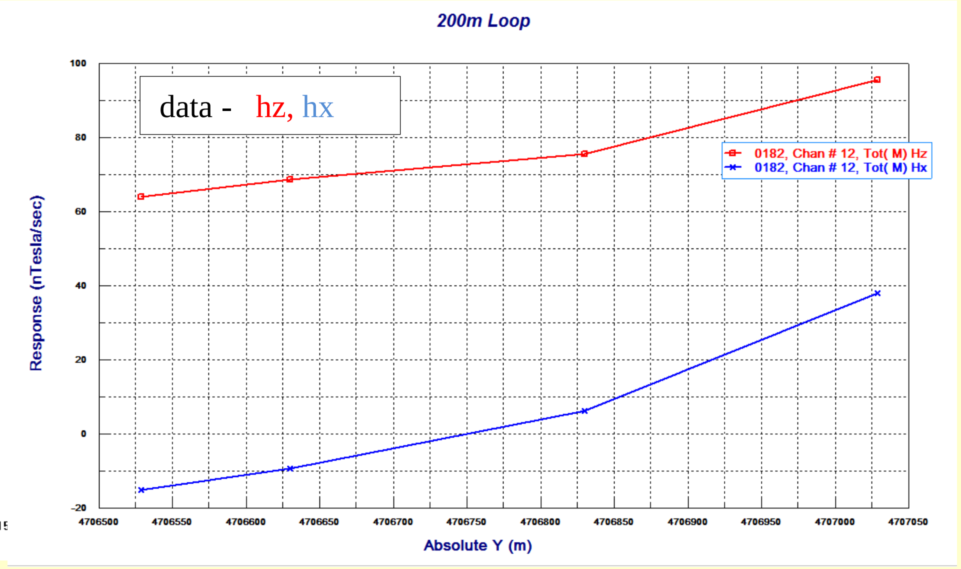
Our Inversion Model

142 Ωm to 68m
410 Ωm to 604m
basement highly resistive

Field Data Example 2 – 200m Loop 5 locations

- 200 x 200m Loop on central line





Ch3 (Hz, Hx) through the 200m loop.

Ch12 Hz, Hx through the 200m loop.

Northern most stations strongly affected by the 3D structure to the north, station immediately south of most northern station somewhat affected.

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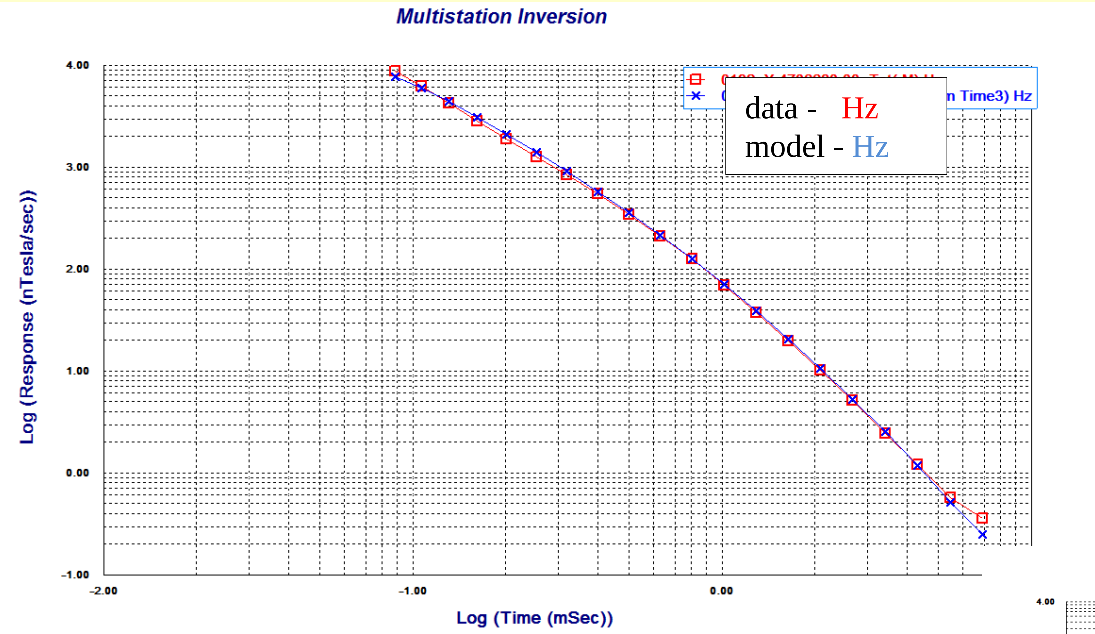
Field Data Example 2

- 3 Southern stations Multi-Station Inversion Model
  - Hz – 19Channels and 3 stations

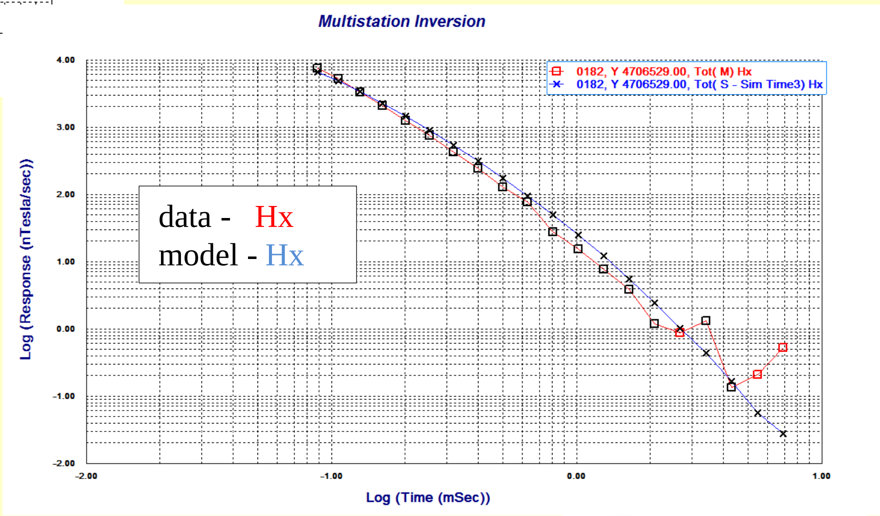


Fit to Inverse Model
Middle Station Example

Our Inversion Model

220 Ωm to 525m
basement highly resistive

-The data is unable to resolve any zones in resistivity in the upper 500m,
- Depth to a resistor is quite well resolved.
- Resistivity of the basement resistor must be over 2000 Ohm-m.



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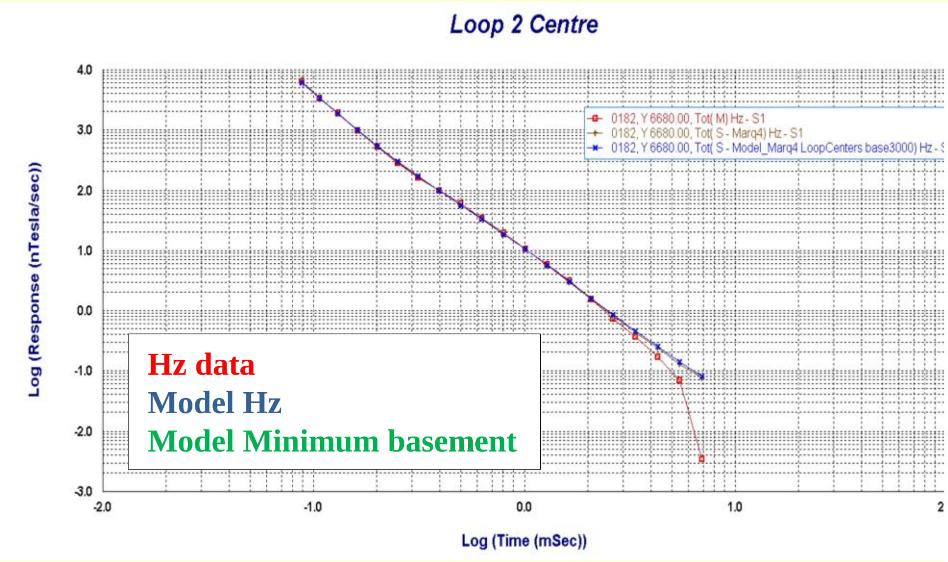
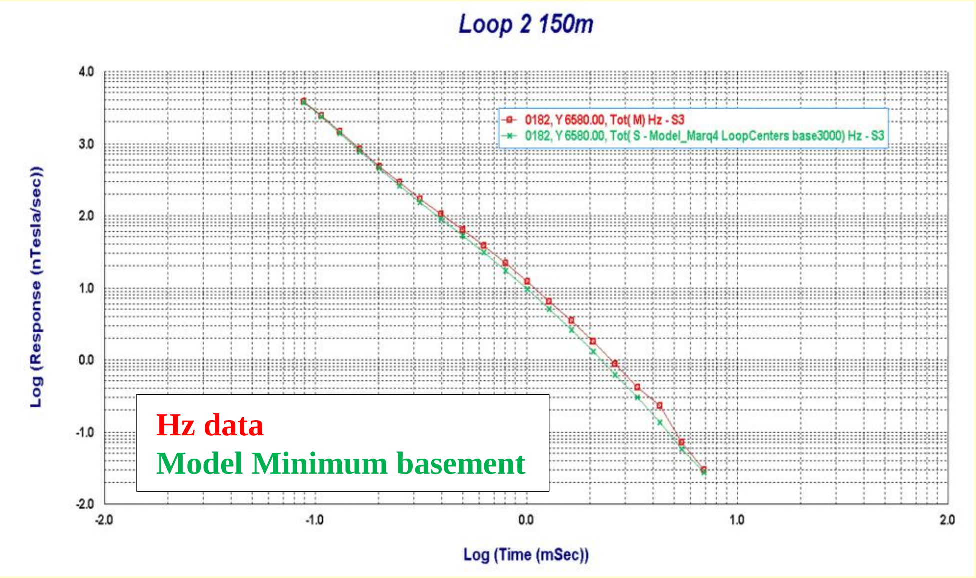
Field Data Example 3

- 100m Moving Loop Centre Loop Inversion – Loops 1 and 2

- the centre loop data can resolve a conductor, resistor, conductor , resistor sequence
- independent inversion of the centre data produces models which vary too much at depth
- joint inversion of the centre loop data produces a spatially consistent model
- model does not fit either 70m or 150m data



Loop 2: Inloop data
comparison to multiple station inversion



Loop 2: Separation 3
Inloop Model does not fit out of loop data

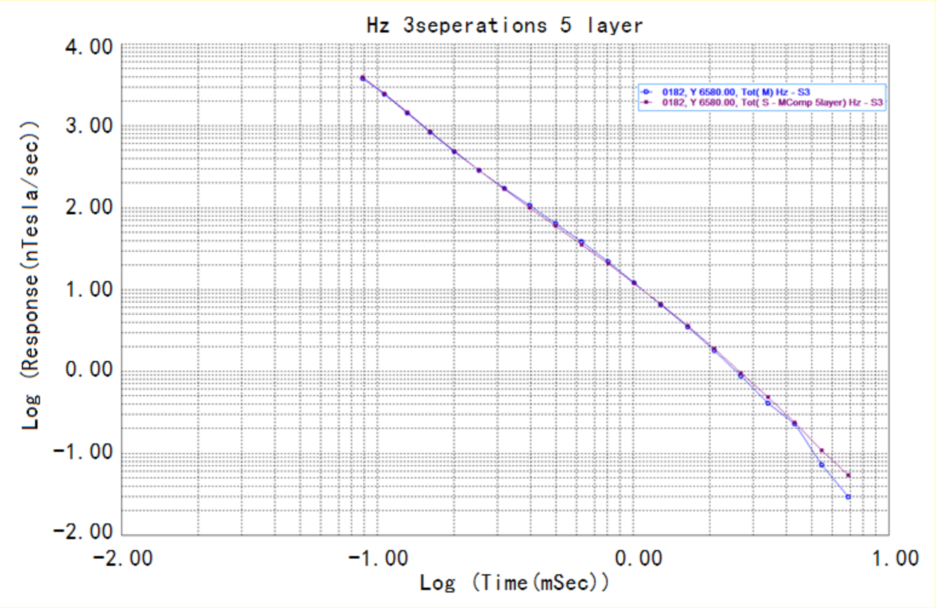
Our Inversion Model
93 Ωm to 38m
1550 Ωm to 213m
185 Ωm to 458m
basement resistive greater than 1000 Ωm

Field Data Example 3

- 100m Moving Loop Multi-Separation Applications – 25Hz
- in order to find a consistent model for all data –

multi-station, multi-separation inversion was performed

Resistivity	Thickness	Depth to Bottom of Layer
37	13	13
3920	22	35
1300	127	162
195	370	532
1064		



Loop 1: Sep3. Hz multi-station/separation (0,75,150) inversion to data.

Hz Only

93 Ωm to 38m
1550 Ωm to 213m
185 Ωm to 458m
basement resistive greater than 1000 Ωm

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CONCLUSIONS

- Inversion of in-loop data is misleading as this location senses the ground resistivity with limited extent

- If the ground is not approximately 1D, then small in-loop data often misrepresents the resistive structure.

- Measuring with a multiple separation strategy
  - May increase the resolution
  - Hx can be utilized and fewer models can fit
  - This strategy still has limitations.

- Fixed loop data gave us the most information of the entire survey area.

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