Calibration of Airborne TEM with Ground TEM

Two Case Studies in Arizona

L.J. Davis

Petros Eikon Inc.

Airborne TEM

Airborne TEM :

- **Useful for surveying large areas**

- **Historically used for locating conductors in mineral exploration**

- **Would like to use for quantitative structural interpretation**
    - **Wider range of applications including environmental and groundwater**

Recommend having a calibration site at which both airborne and ground EM are collected

Why have a calibration site?

Calibration site: single site where both ground and airborne EM collected; may be desirable to choose a site at which geological information is available

- **Use as a check for airborne data**
  - **Pinpoint any problems**
  - **Confidence in data**

How to use a calibration site

- Develop a model to fit the ground EM data and simulate the same model for the airborne EM data at that location
- Carefully analyze any discrepancies
- Need to consider differences in resolution
- Also compare with any geological data

Examples

1. Mining Example

- ***Uranium Exploration (breccia pipes) near the Grand Canyon***

2. Groundwater Example

- ***San Pedro Basin in Arizona***

Mining Example

[from Google Earth]

- North of the Grand Canyon (Arizona Strip)
- 2005-2008:
  active exploration for breccia pipe uranium deposits
- Host environment:
  a thick sequence of sedimentary rocks
- Calibration site: ground TEM + airborne TEM from multiple systems

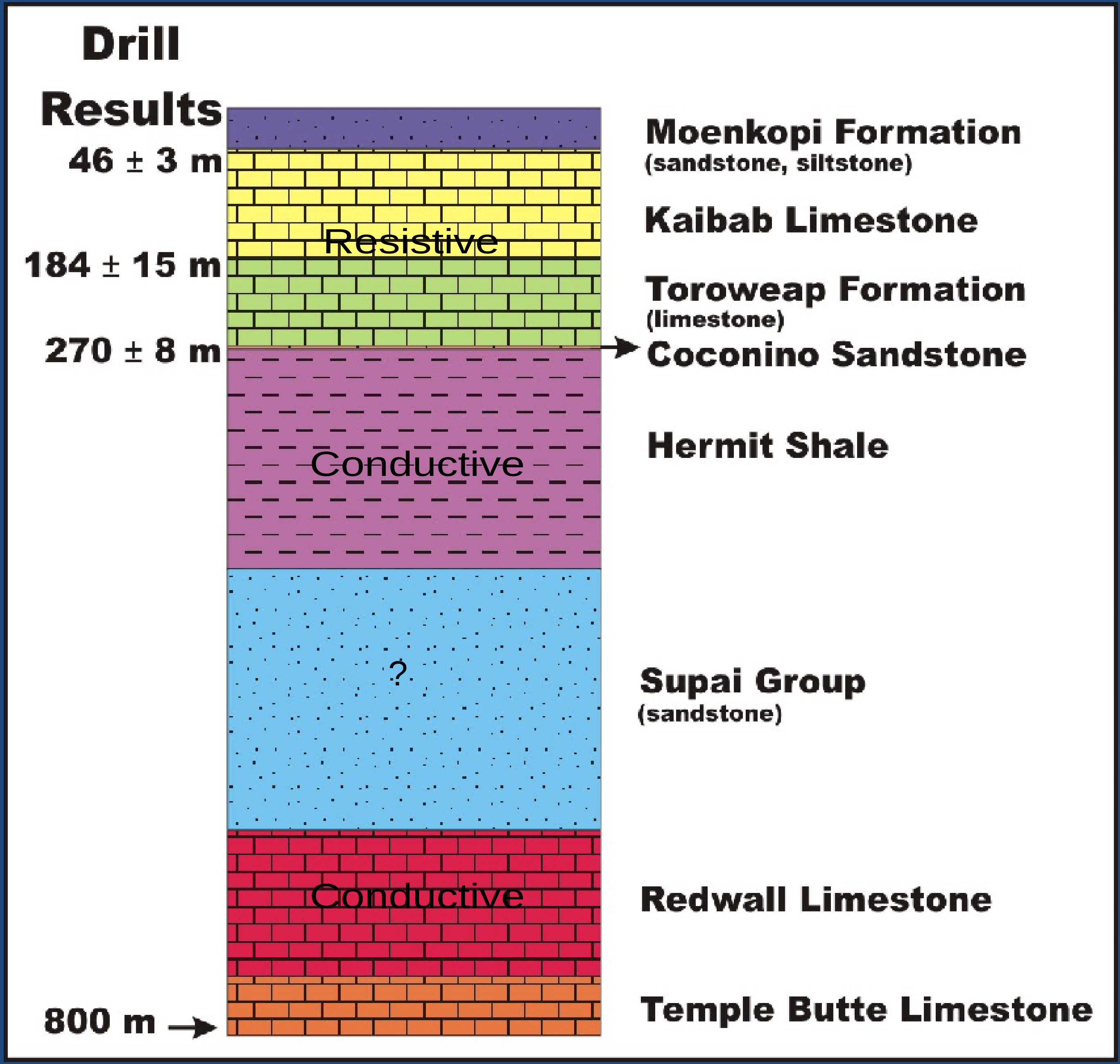
Motivation for Calibration Site

1. **Compare response over breccia pipe for different airborne systems.**

2. **Ideal site for a comprehensive study of quantitative interpretation of airborne TEM:**

    - Sedimentary layers with contrasting EM properties
    - Limited 3D structure

Geology


Drill
Results
46 ± 3 m
184 ± 15 m
270 ± 8 m
800 m
Resistive
Conductive
?
Conductive
Moenkopi Formation
(sandstone, siltstone)
Kaibab Limestone
Toroweap Formation
(limestone)
Coconino Sandstone
Hermit Shale
Supai Group
(sandstone)
Redwall Limestone
Temple Butte Limestone

Data

1) 2007 - Airborne surveys: MEGATEM, GEOTEM, VTEM

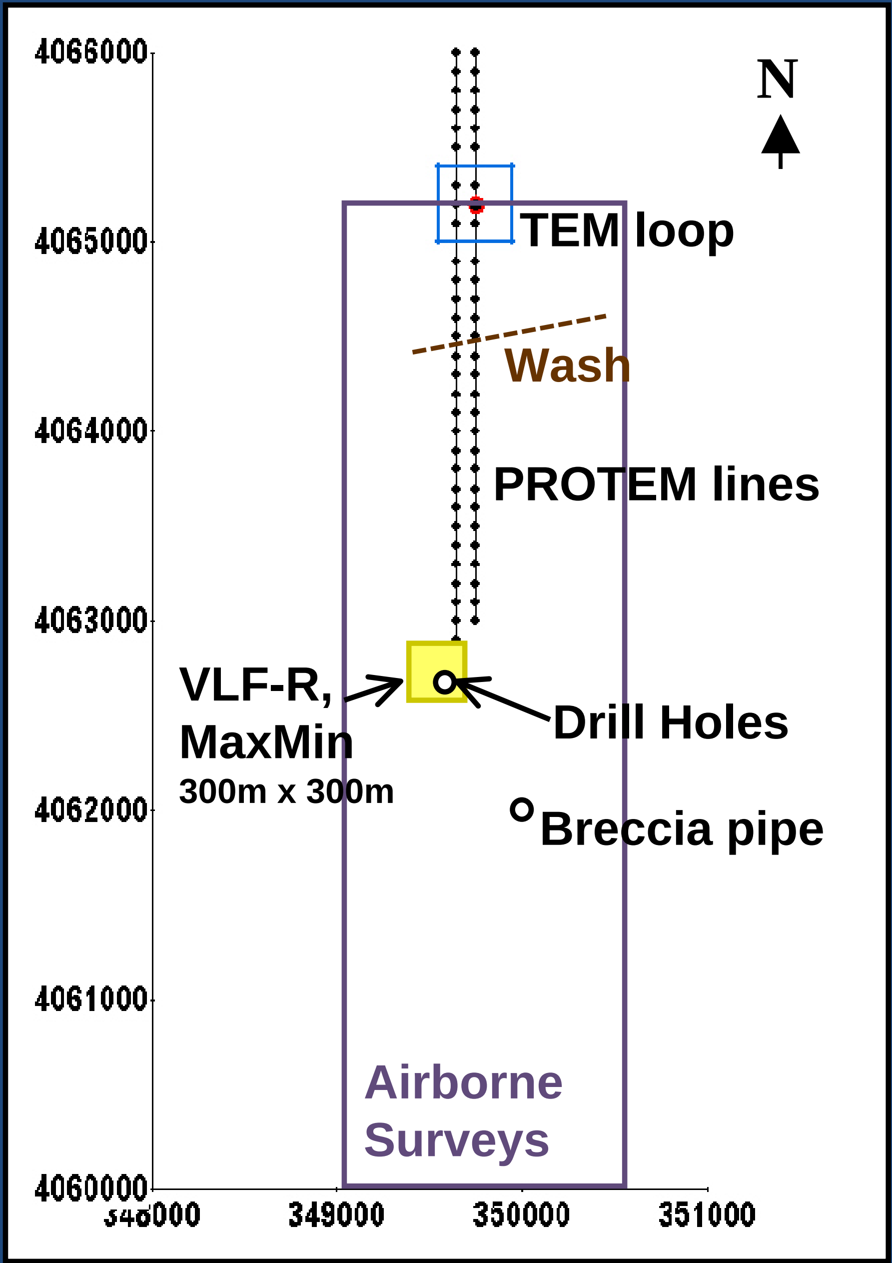
2) 2008 - ground TEM surveys: extensive PROTEM (Geonics), small GDP-32 (Zonge)

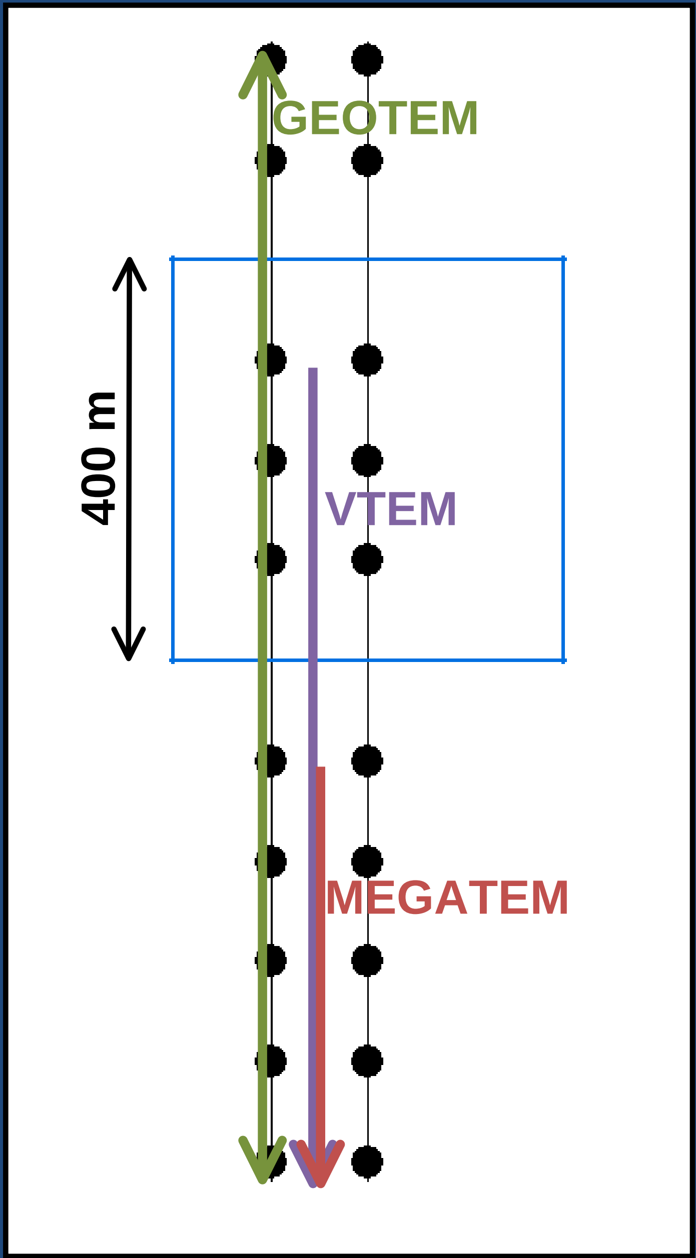
3) 2008 - ground FEM systems: VLF-R (2 frequencies), MaxMin (2 separations, 5 frequencies)

4) 2008 - drill logs

Data thanks to Uranium One USA

Survey Location

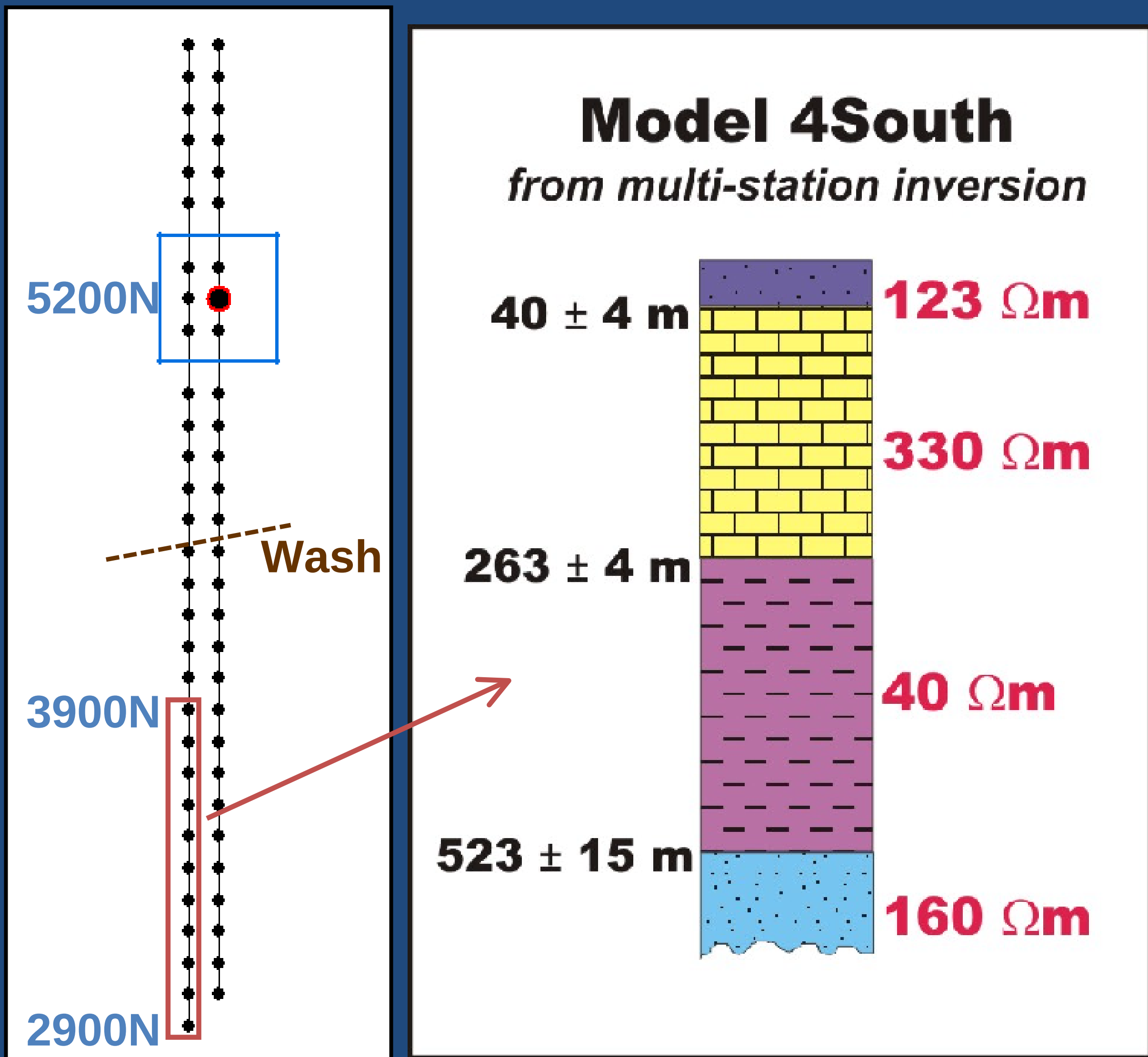




Calibration Area: 1.5 km x 5 km

Line Spacing: approx 100m

Ground TEM: Model



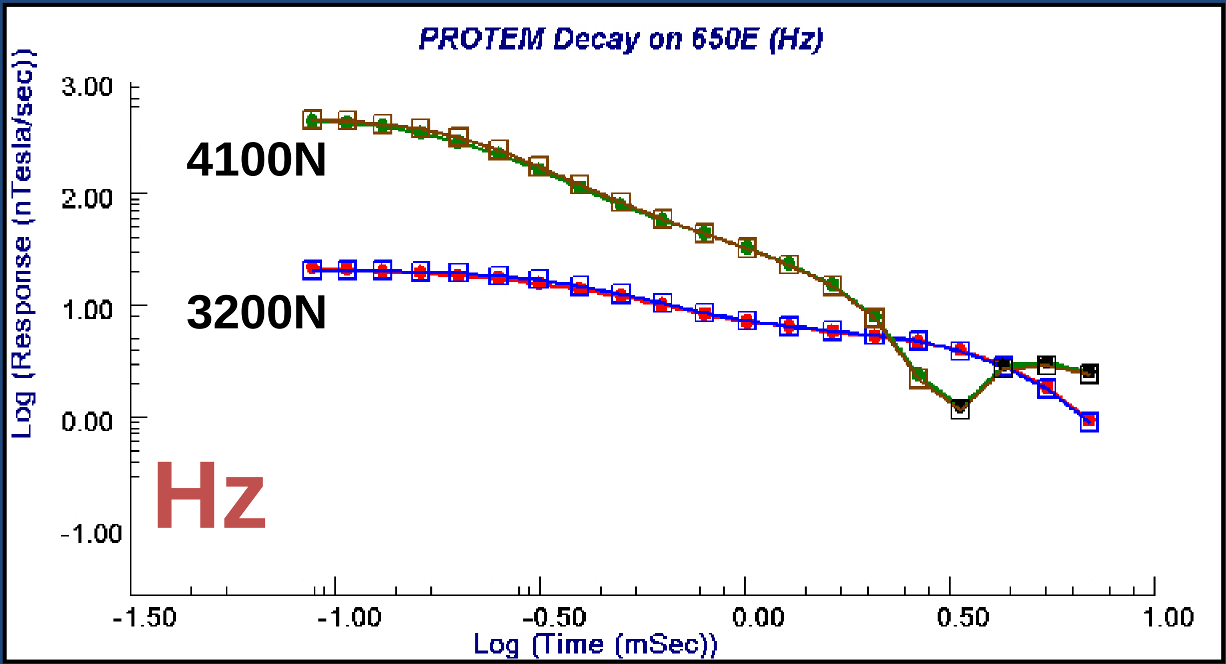
Ground Model 4South
from multi-station 1D inversion using 11 wide-offset stations (2900N-3900N).

Model 4South fits Hx, Hz
across entire survey indicating limited lateral variation.

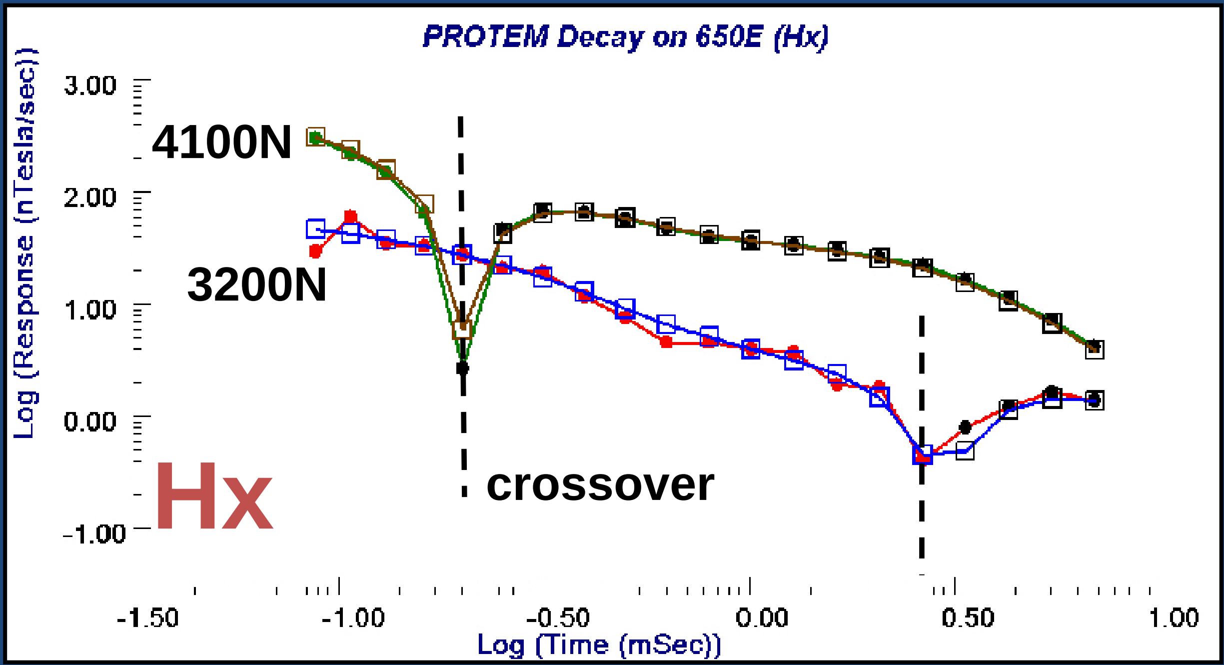
Inloop and Short Offset Data
Provide less depth resolution

Modeling and inversion were performed using EMIGMA v8.1 *(PetrosEikon, 2009)*

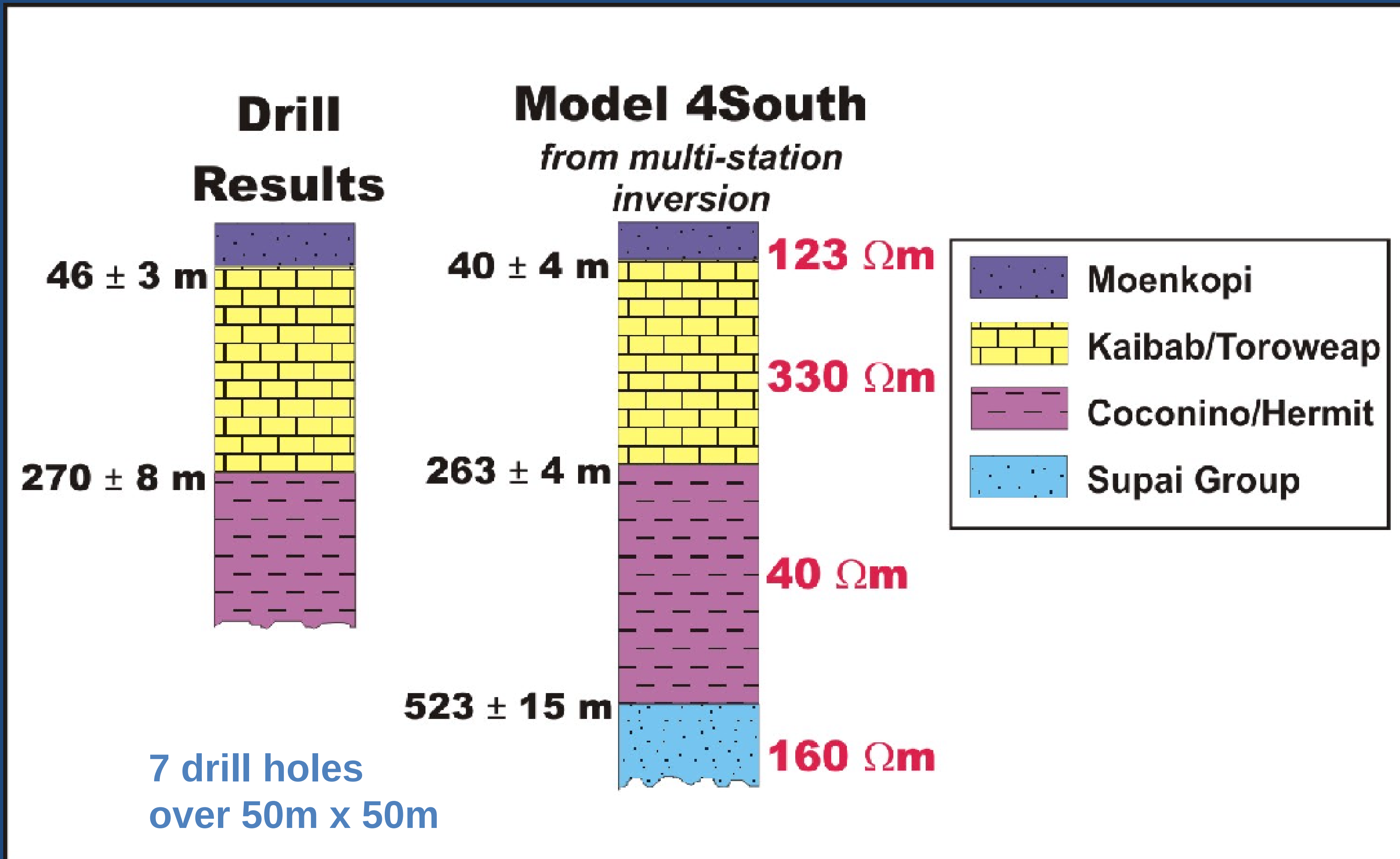
Ground TEM: Model to Data



- Measured – 3200N
- Model 4South – 3200N
- Measured – 4100N
- Model 4South – 4100N

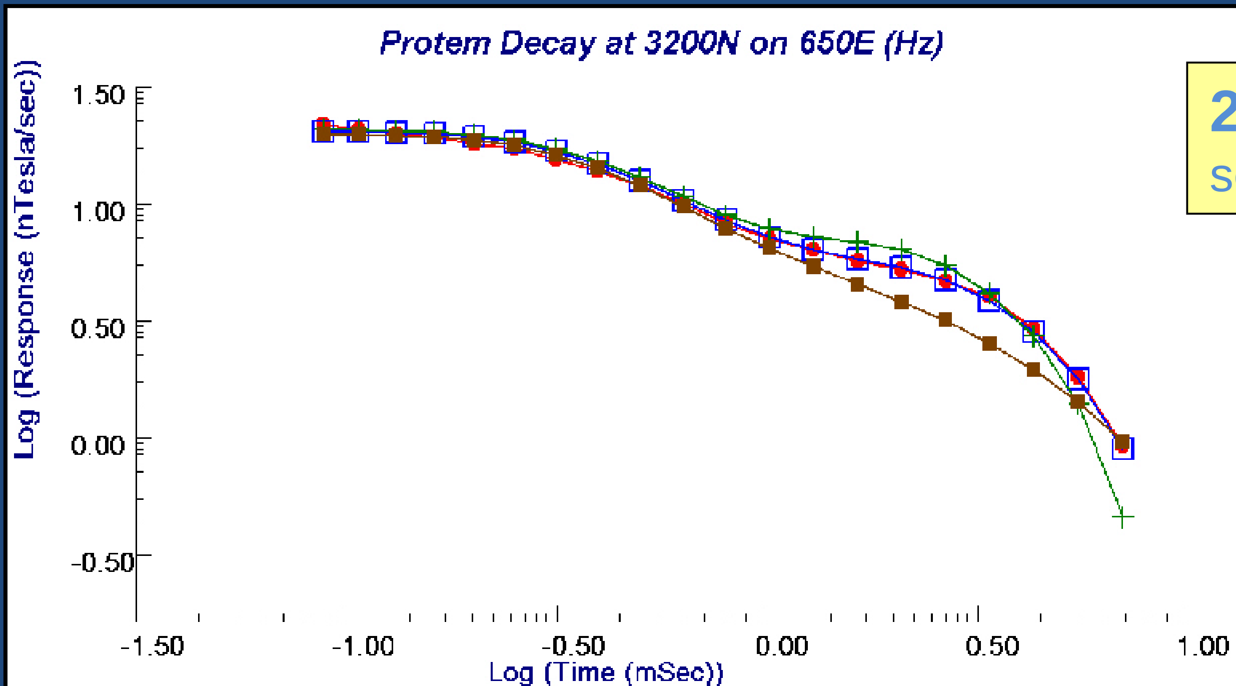


Comparison of Model with Geology



- Drill results just south of ground survey confirm Model 4South
- Moenkopi resistivity (123 Ωm) of Model 4South close to resistivity determined from VLF-R and MaxMin data (thickness uncertain)

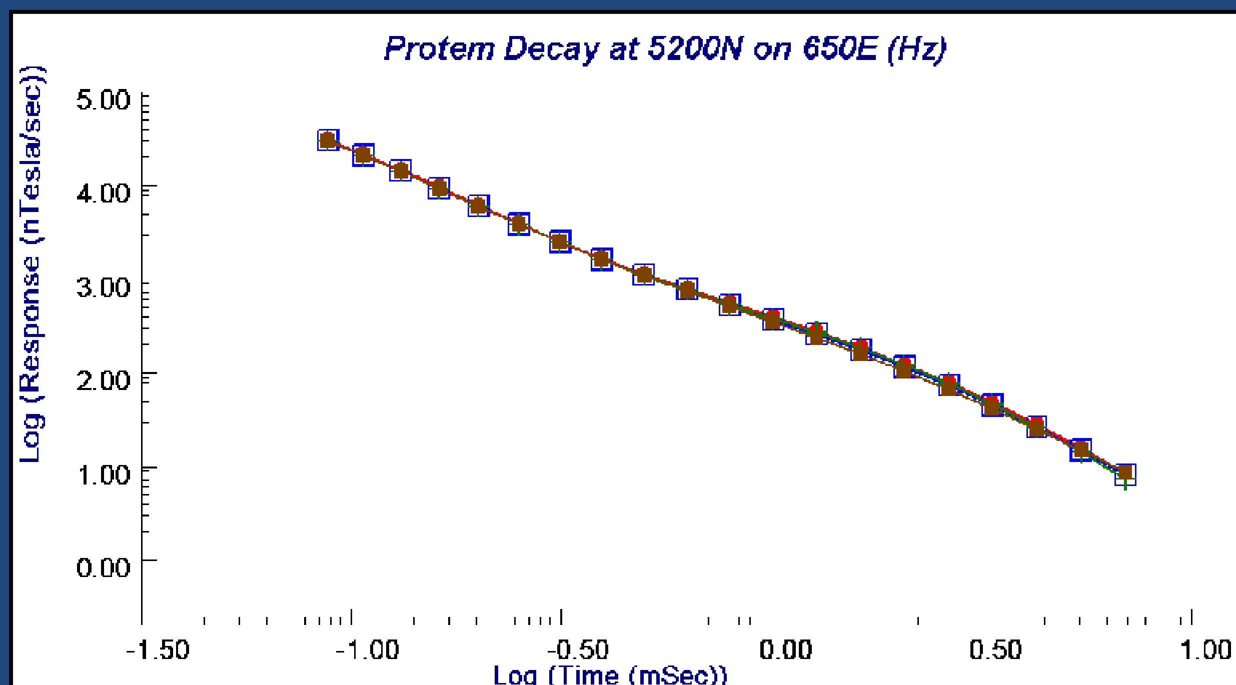
Ground TEM: Depth Resolution



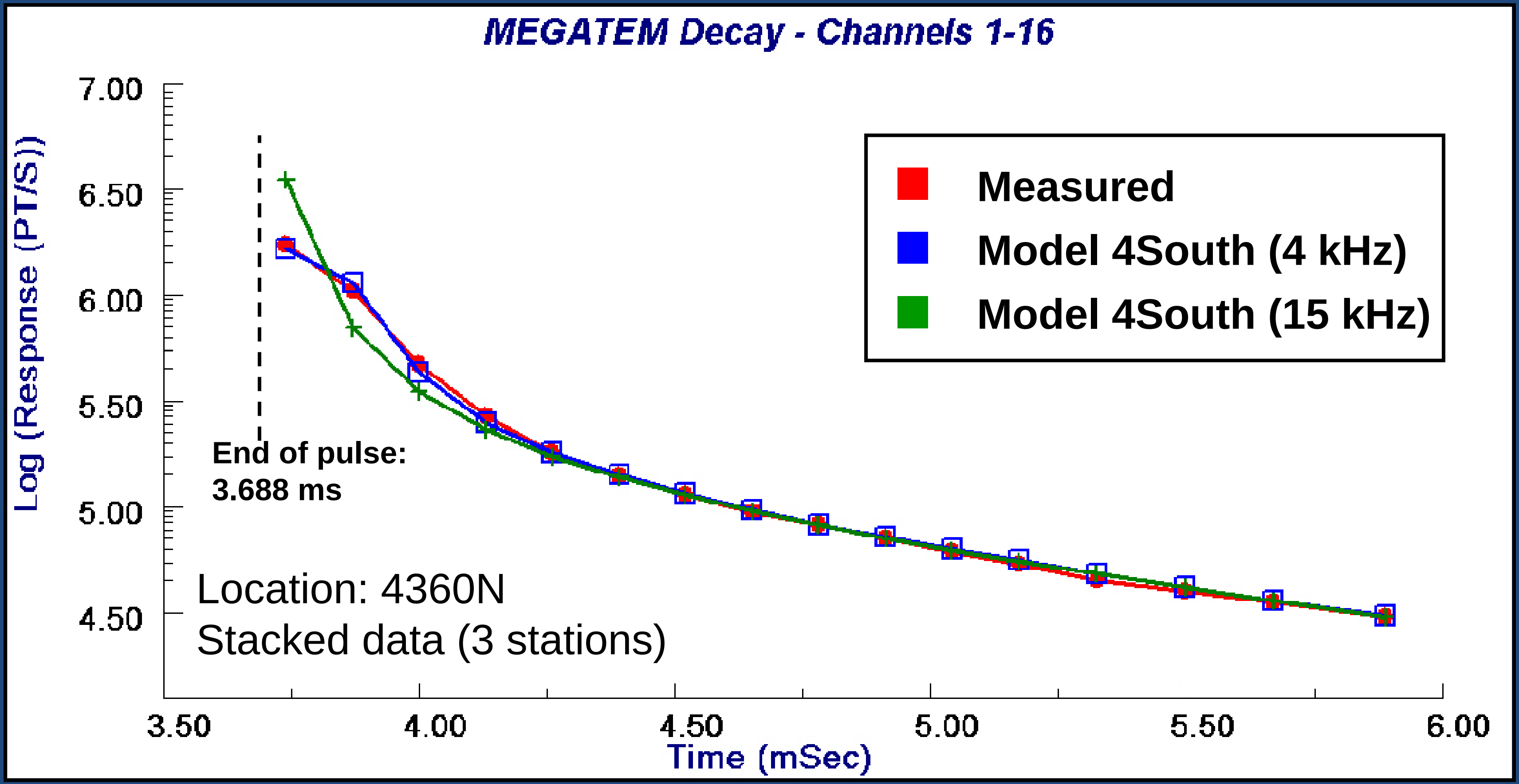
2 km south of Loop Center
sensitive to Supai Group

- Measured
- Model 4South
- No Supai Group
- Resistive Supai Group

Center of Loop
Limited sensitivity to Supai Group
All 3 models fit equally well

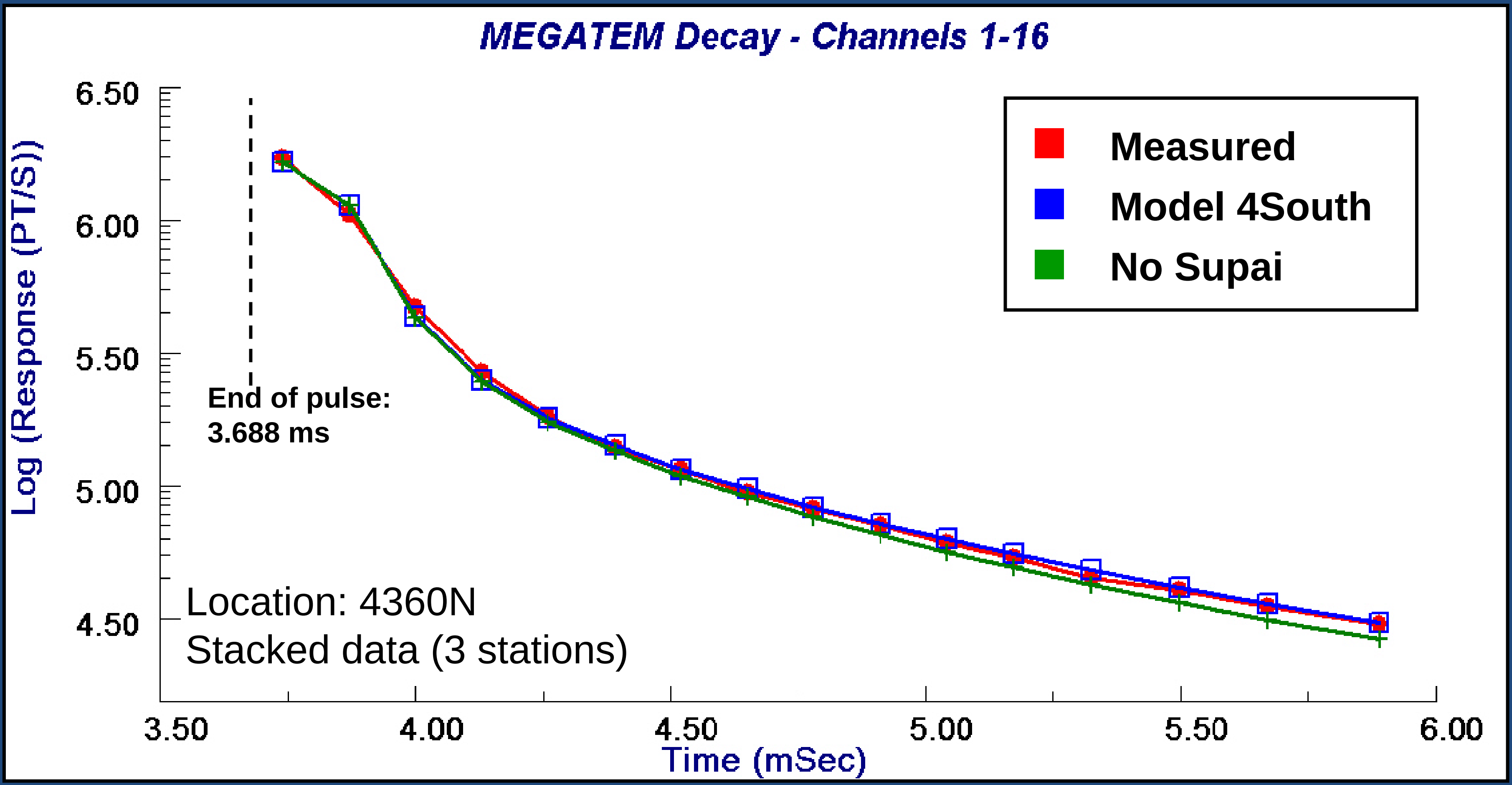


MEGATEM: Fit of Ground Model



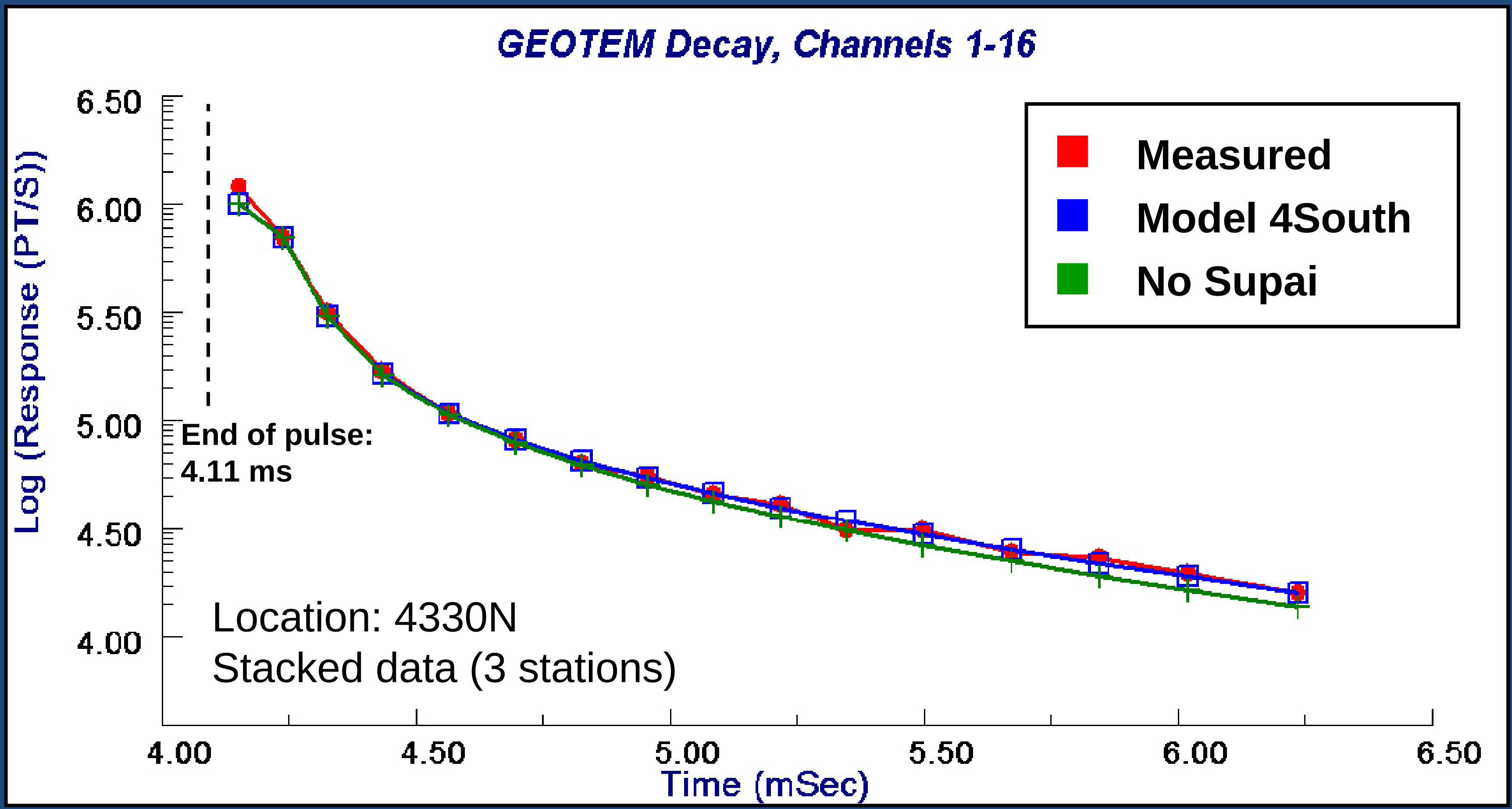
- Data rewindowed to have 20 off-time channels to increase shallow resolution – critical for understanding response.
- Waveform files were used to study pulse width, dipole moment, window positions, Tx-Rx separation and system bandwidth. Accurate modeling requires precise knowledge of settings.
- Model 4South fits the MEGATEM data just south of the wash if an upper bandwidth frequency of 4 kHz is used.

MEGATEM: Depth Resolution



Removing the fourth layer (Supai Group) has a small but definite effect on the response at mid to late times.
Note: This 4th layer has a significant effect on the ground response at wide offsets. MEGATEM offset is 128m only.

GEOTEM: Fit of Ground Model



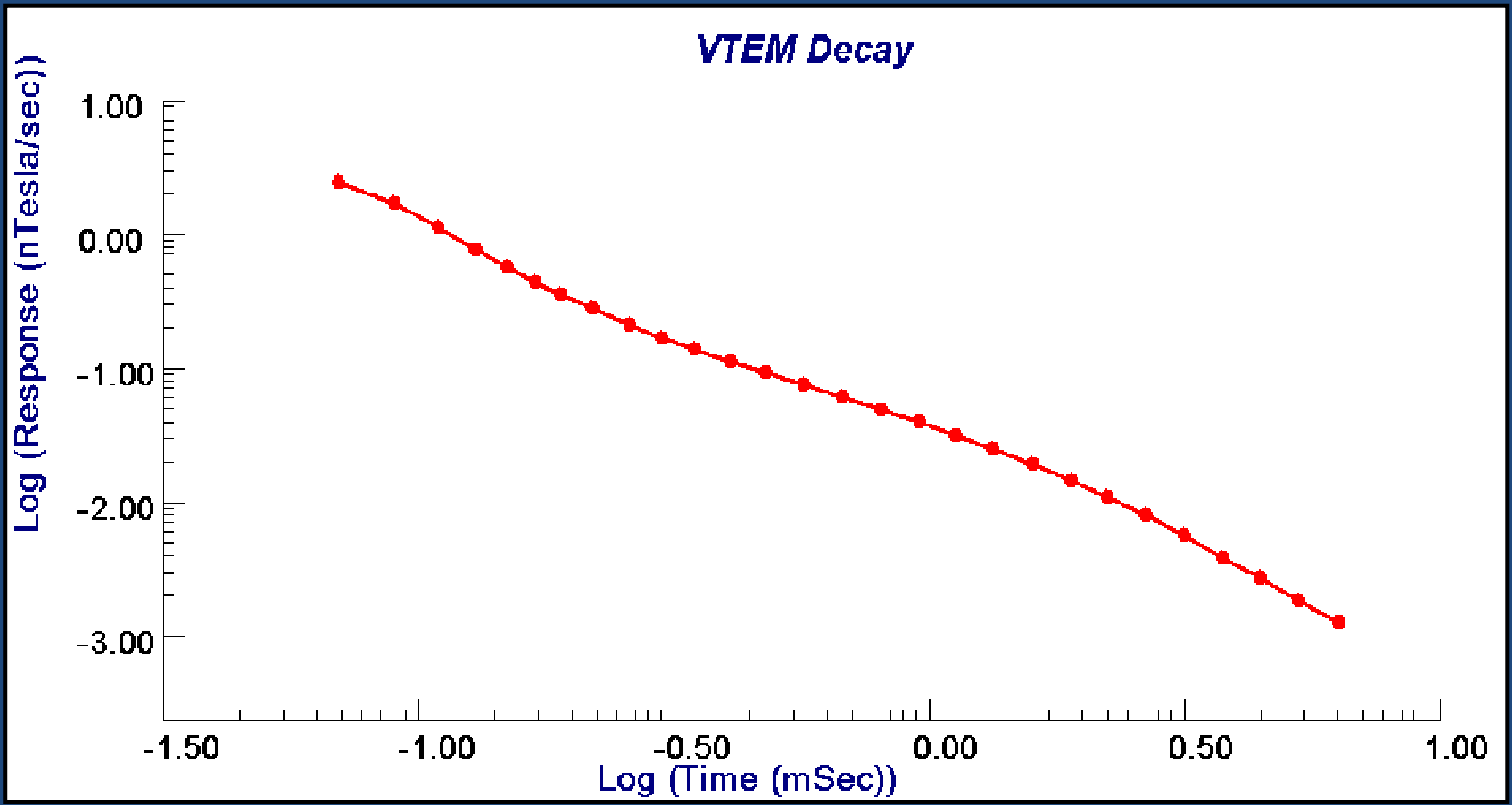
Model 4South fits the GEOTEM reasonably well just south of the wash, provided an upper bandwidth frequency of 6 kHz is used. Again the Supai Group is required to fit late time. Data is not as clean as MEGATEM.

VTEM

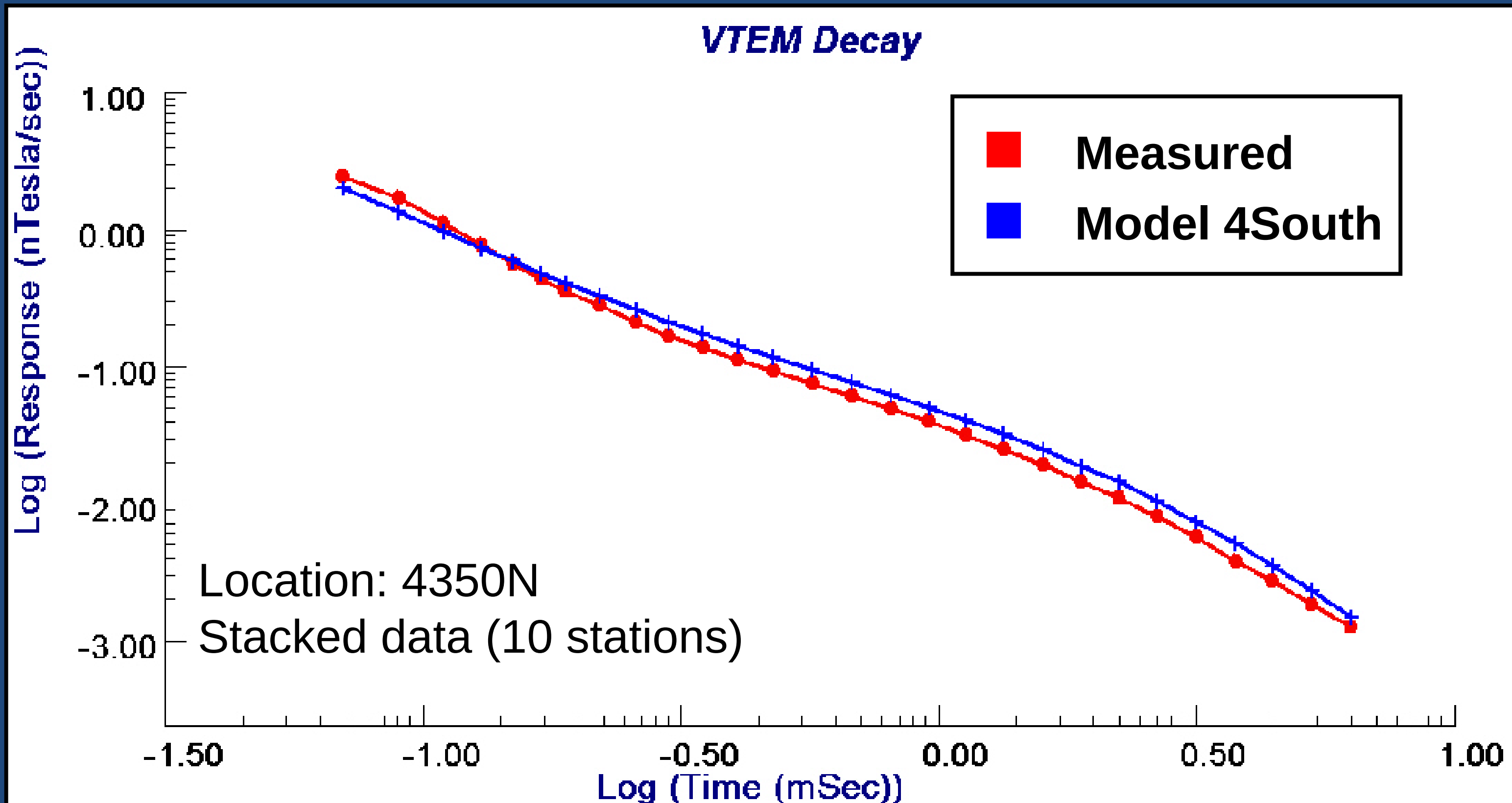
	MEGATEM	VTEM
Time Channels	20	28
Δx	128 m	0 m
Δz	46 m	0 m
Alt. of bird	70 m	35 m

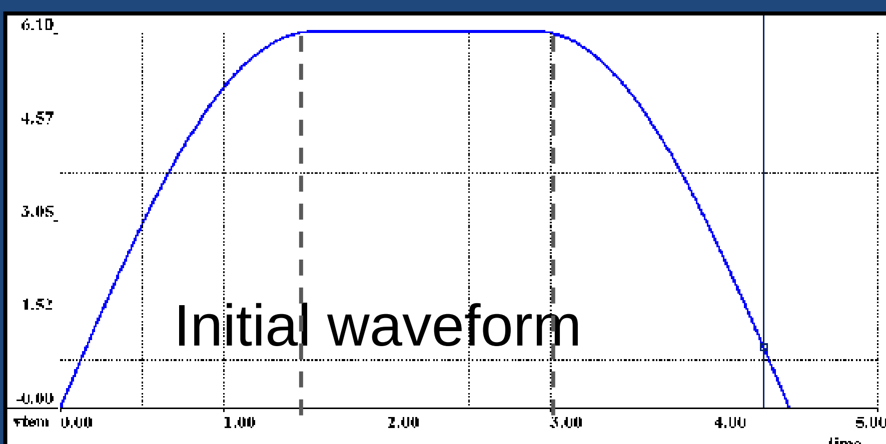
Potential advantages of VTEM system for resolving shallow structure:

- Clean decays
- More time channels (28)
- Closer to ground



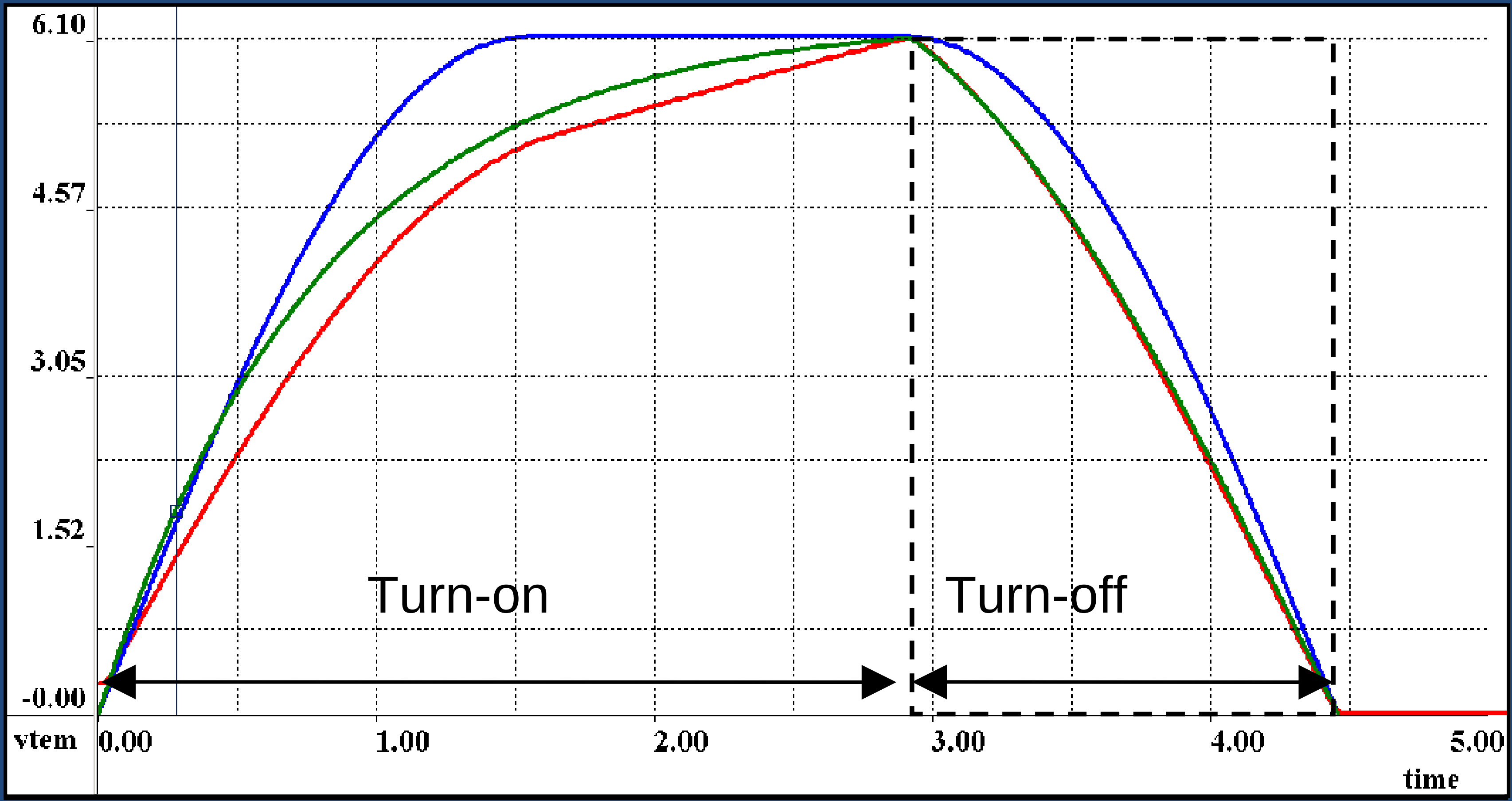
VTEM: Initial Waveform





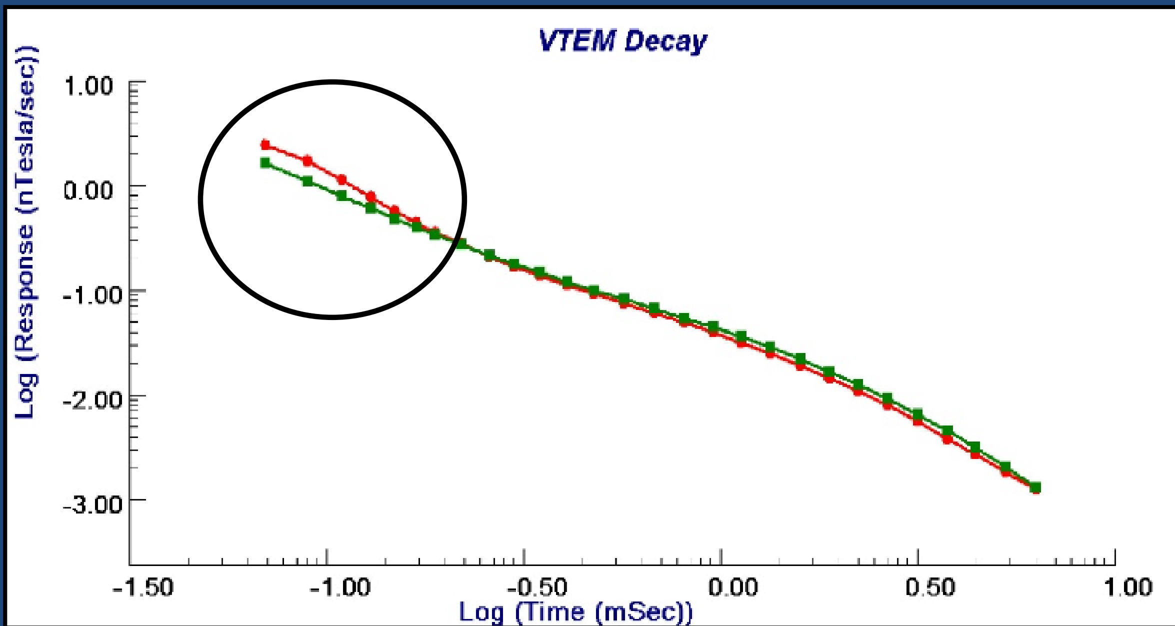
- Initial waveform for simulation: ¼ sine wave turn-on and turn-off
- Frequency = 1/(4*turnoff); turn-off time from waveform file
- Model 4South does not fit the data
- Too large at mid to late times, too small at early times

VTEM: Integrated Waveform



- Integrated Waveform
- Initial Waveform: Quarter sine turn-on and turn-off
- Modified waveform: turn-on: $f(t) = A\,(1-e^{-t/\tau})$
  turn-off: 77% of a quarter sine

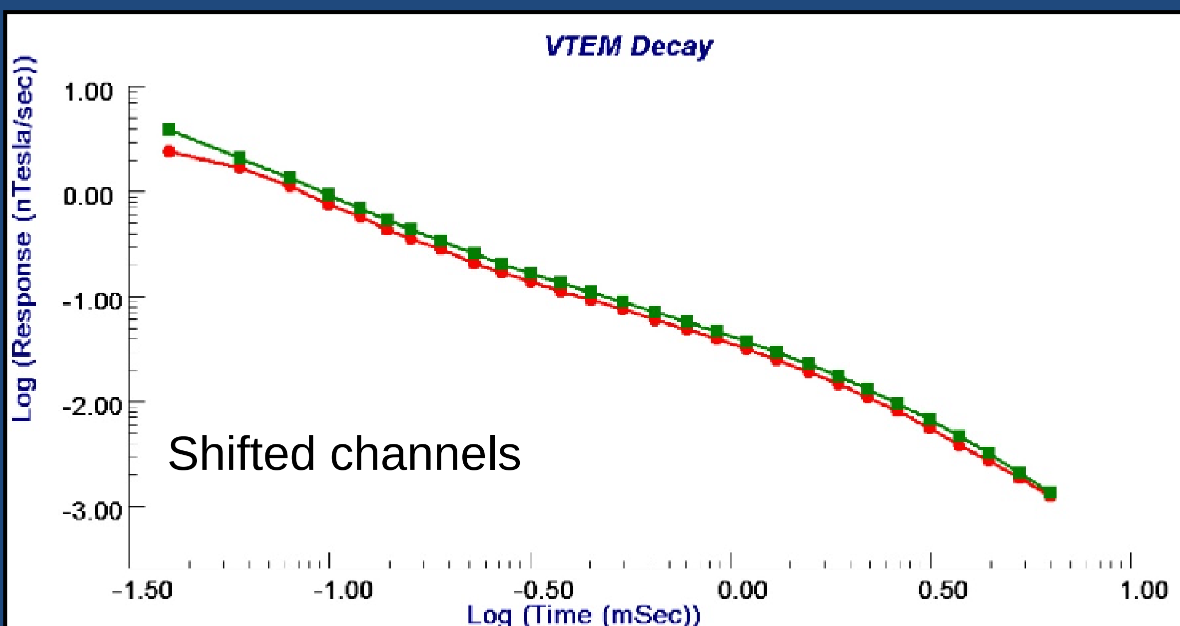
VTEM: Modified Waveform



Early-time misfit:

- Time channel positions ?

- Measured
- Model 4South (new)



Time channels shifted 30 μs earlier: 15% misfit across Channels 2-28

Summary

What was learned from calibration site:

- **Agreement between ground TEM with airborne TEM, but precise knowledge of system parameters required**
  - **Bandwidth**
  - **Issues with VTEM waveform and amplitude**
- **Comparison of response over pipe with different airborne systems – better detected by VTEM**
- **Study of depth resolution**

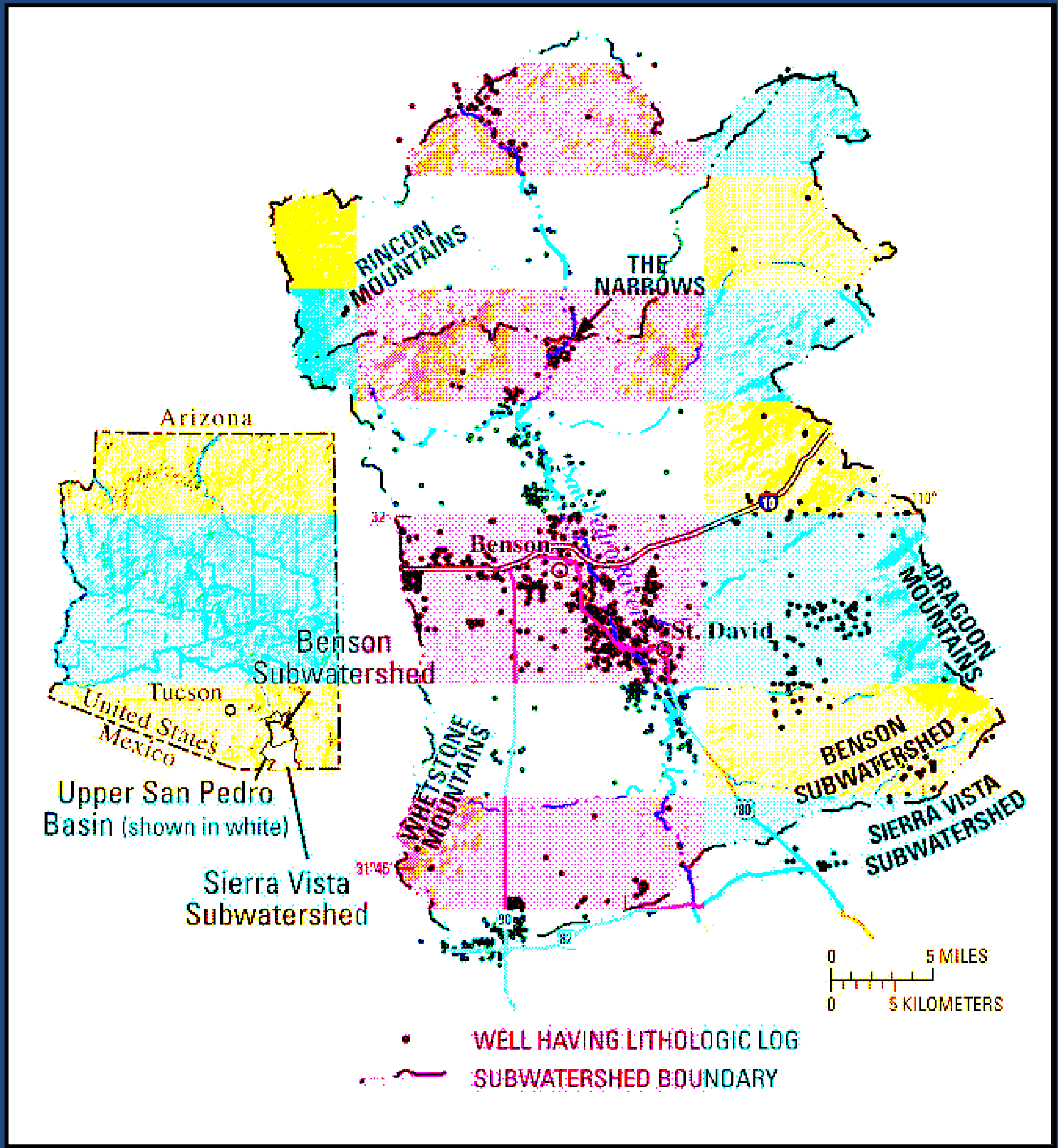
Groundwater Example

- Benson subwatershed of Upper San Pedro Basin
- Important for water supply but sparse well data
- GEOTEM survey: purpose was to map resistivity distribution, which is correlated with lithology
- The distribution of lithologies affects water volume and flow paths
- Stacked 1D inversions from GEOTEM data

Motivation for Calibration Site

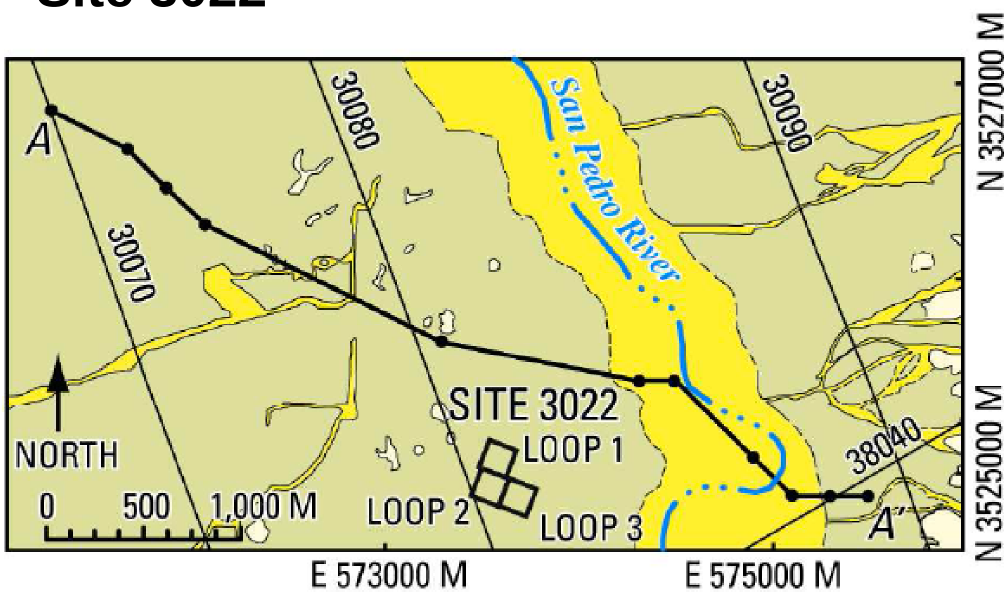
- Three ground TEM sites within airborne survey
- Allow comparison of modeling results between ground TEM and airborne TEM
- Evaluate ability of EM methods to detect lithology
- Assist in determining constraints for inversions

Survey Location

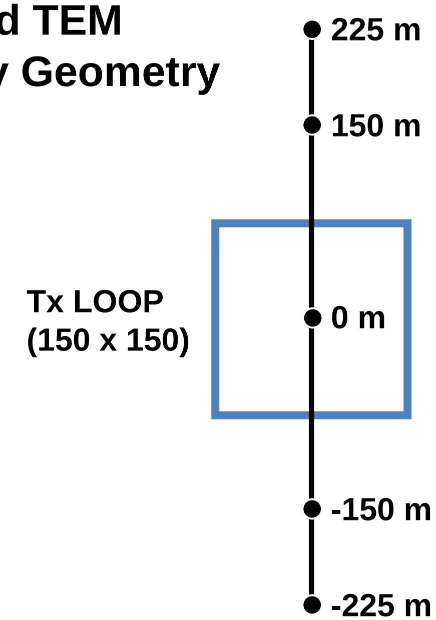


Calibration Site

Site 3022

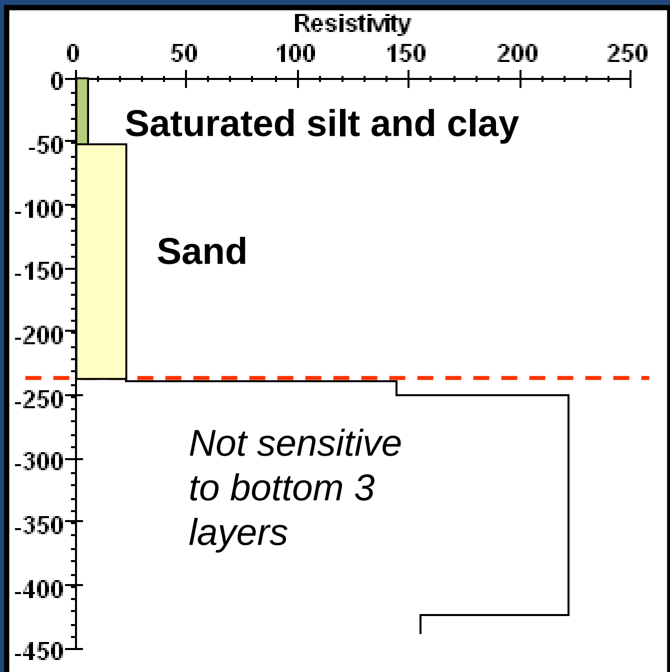


Ground TEM
Survey Geometry

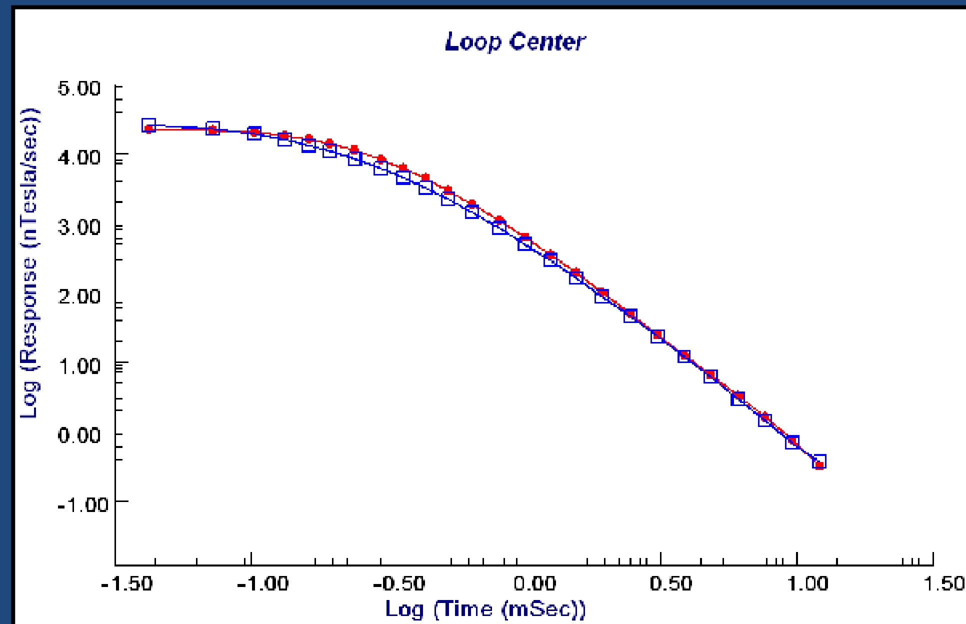


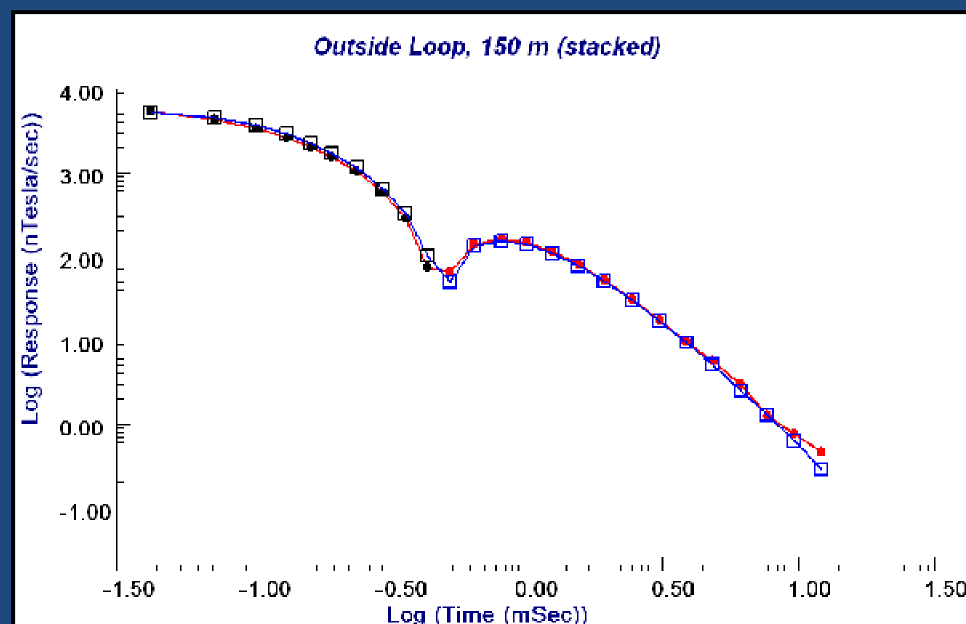
- 3022: one of three ground EM sites
- Data collected with Zonge GDP-32
- Base frequency: 8 Hz and 16 Hz
- 3 loops

Ground TEM Model



Model L1

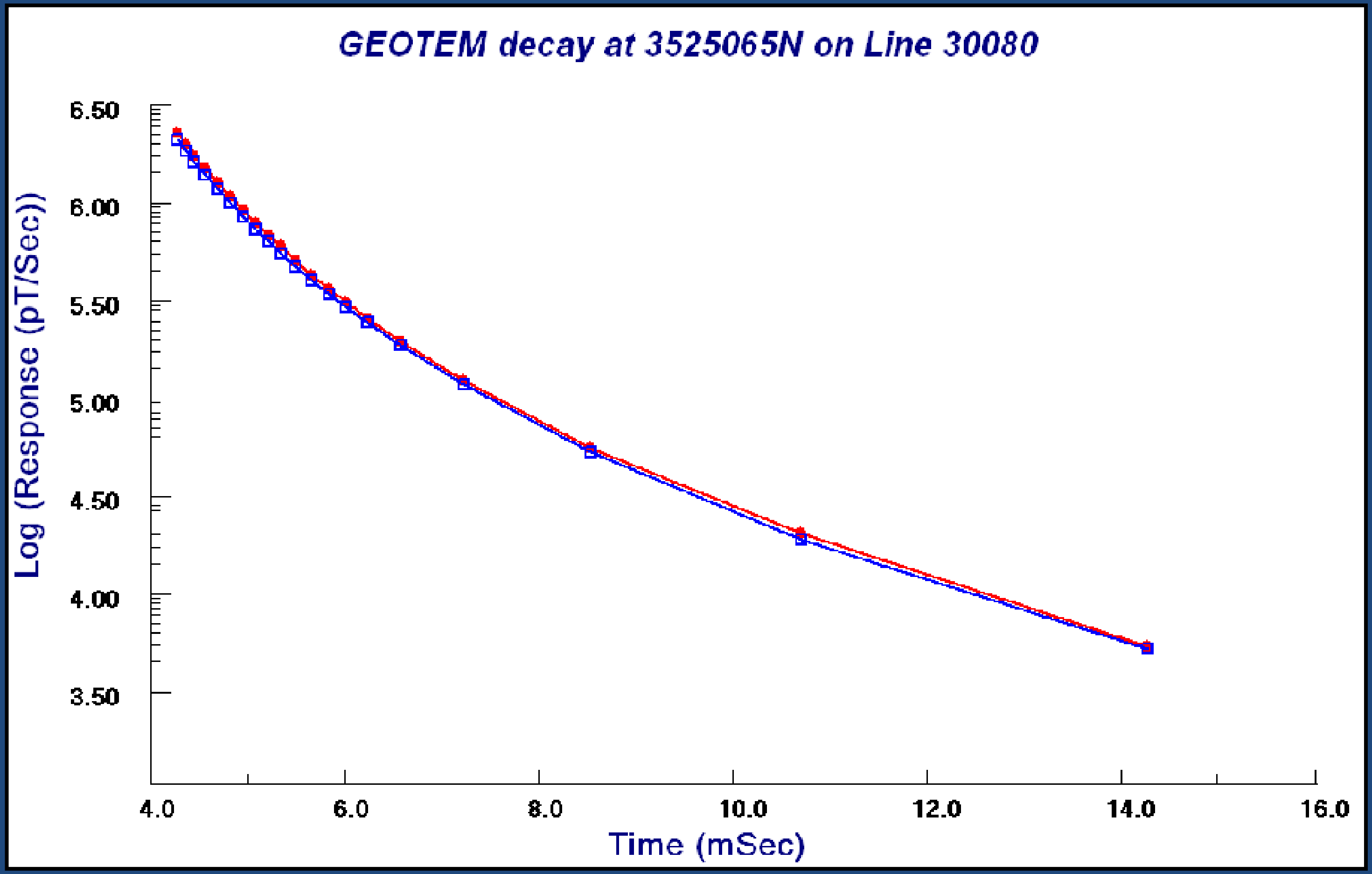




Measured

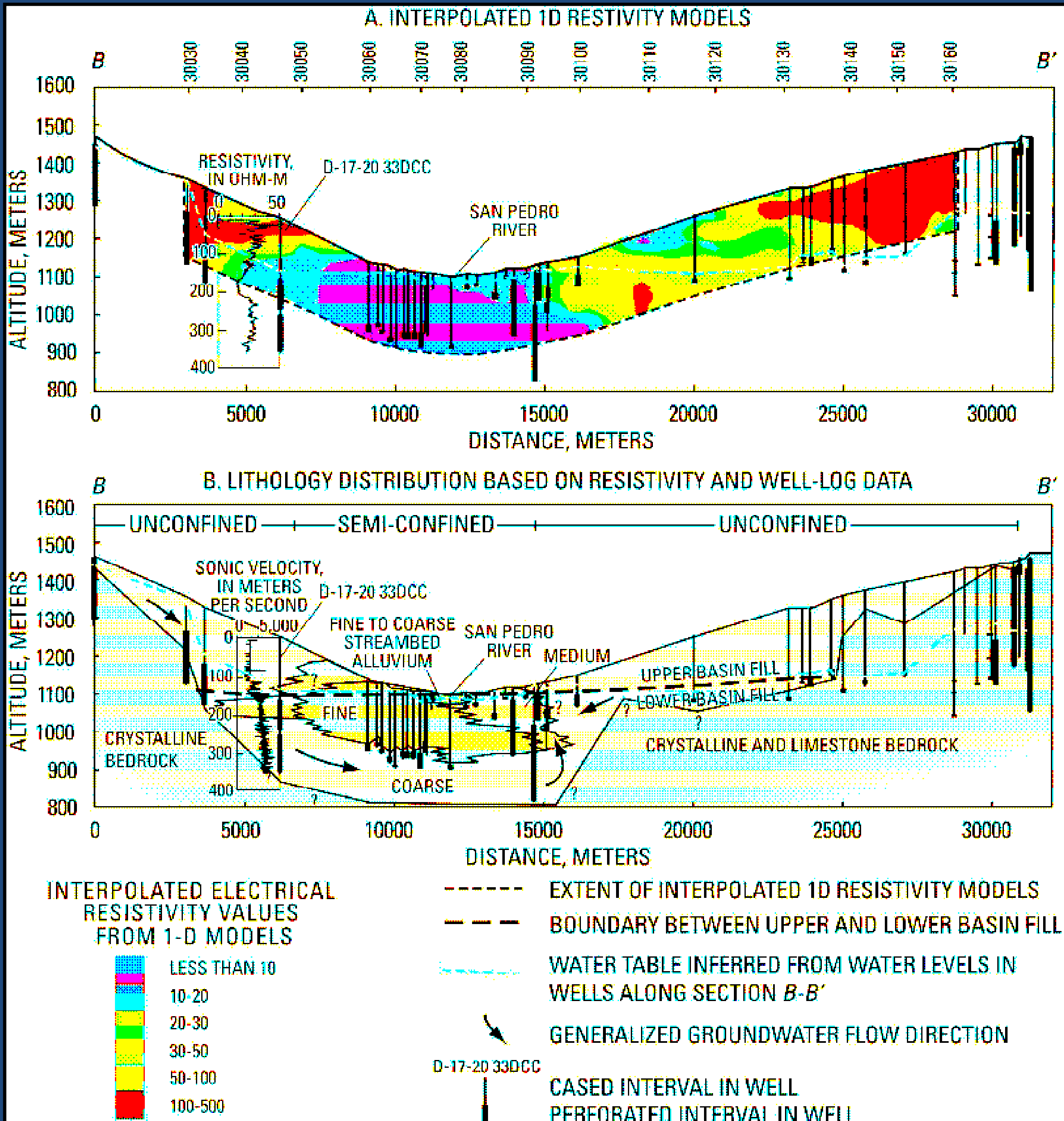
Model 4South

Model vs. GEOTEM



- Ground model generally fits GEOTEM, but slightly lower amplitude at early time – uncertainty in pulse width
- Not sensitive to lower layers at this location (like ground data)

1D Inversion Results



Summary

- 1D models from airborne TEM can be used to map aquifer lithology
- Evaluated through comparisons with ground TEM and drill logs

Conclusions

1. Usefulness of AEM in determining structure rather than locating conductors

2. Importance of having calibration site within AEM survey where ground TEM/FEM collected – confidence in airborne results

I would like to acknowledge the assistance of:

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