Deep Exploration with SQUID TDEM

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OUTLINE

A brief discussion about B-field versus dB/dt TDEM, SQUID sensors, and high signal/low noise

Lots of comparison plots: SQUID vs Coil, IPHT Jessy Deep vs CSIRO LandTEM, Slingram vs Fixed Loop, Loop Size, etc

A little interpretation (i.e. modelling)

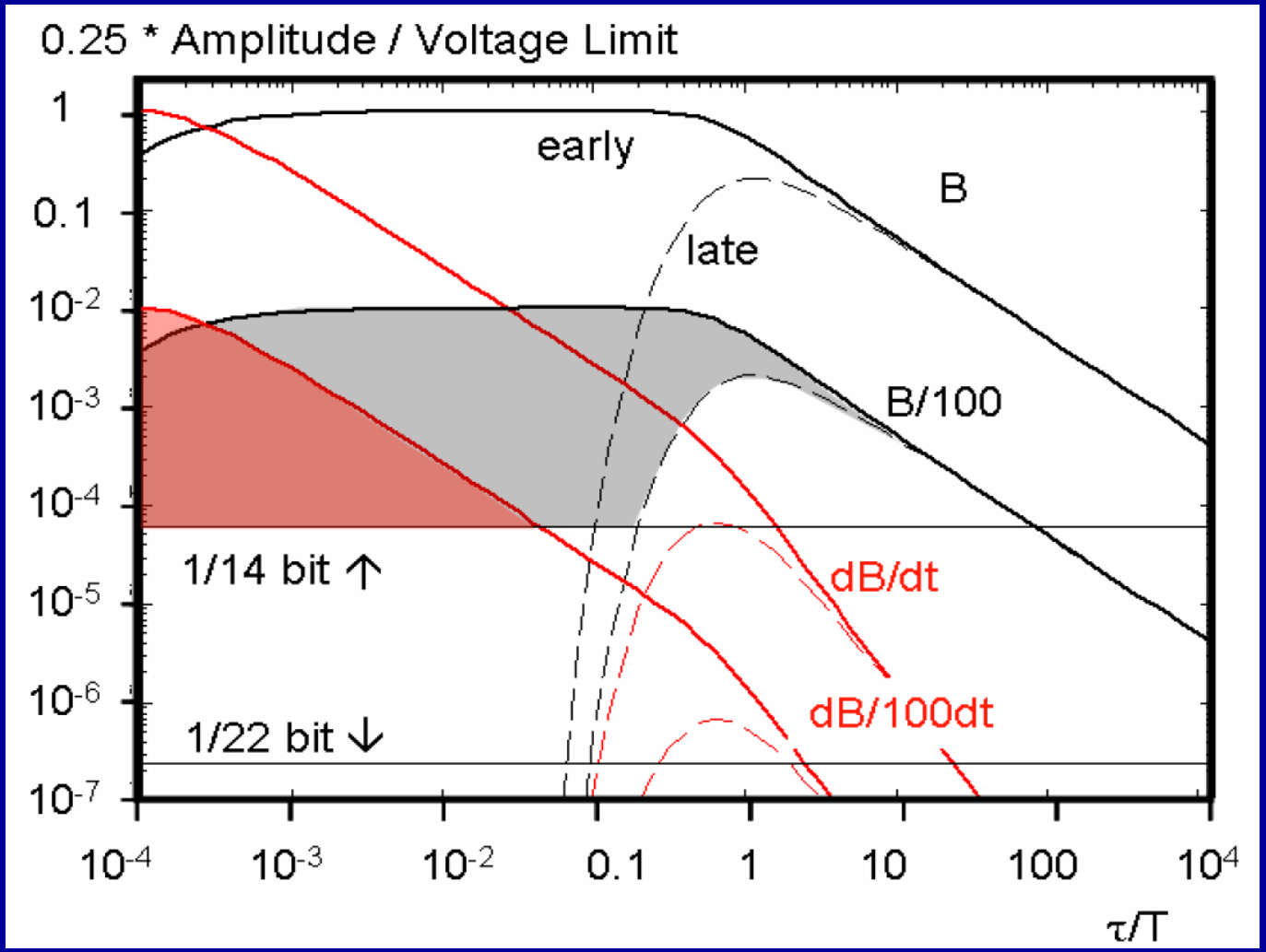
B vs dB/dt

Advantages of measuring B rather than dB/dt are well documented in papers by Macnae, Le Roux, Osmond at SEG Workshop in 2006 and at Exploration ‘07.

- Increased S/N of B relative to dB/dt at late time
- Increased S/N of B relative to dB/dt during on-time
- Greater response for higher decay constant targets
  - high conductivity (higher grade) ore bodies
  - large ore bodies
- Lower sferic noise

Disadvantages - sensor movement noise
- geomagnetic fluctuation noise

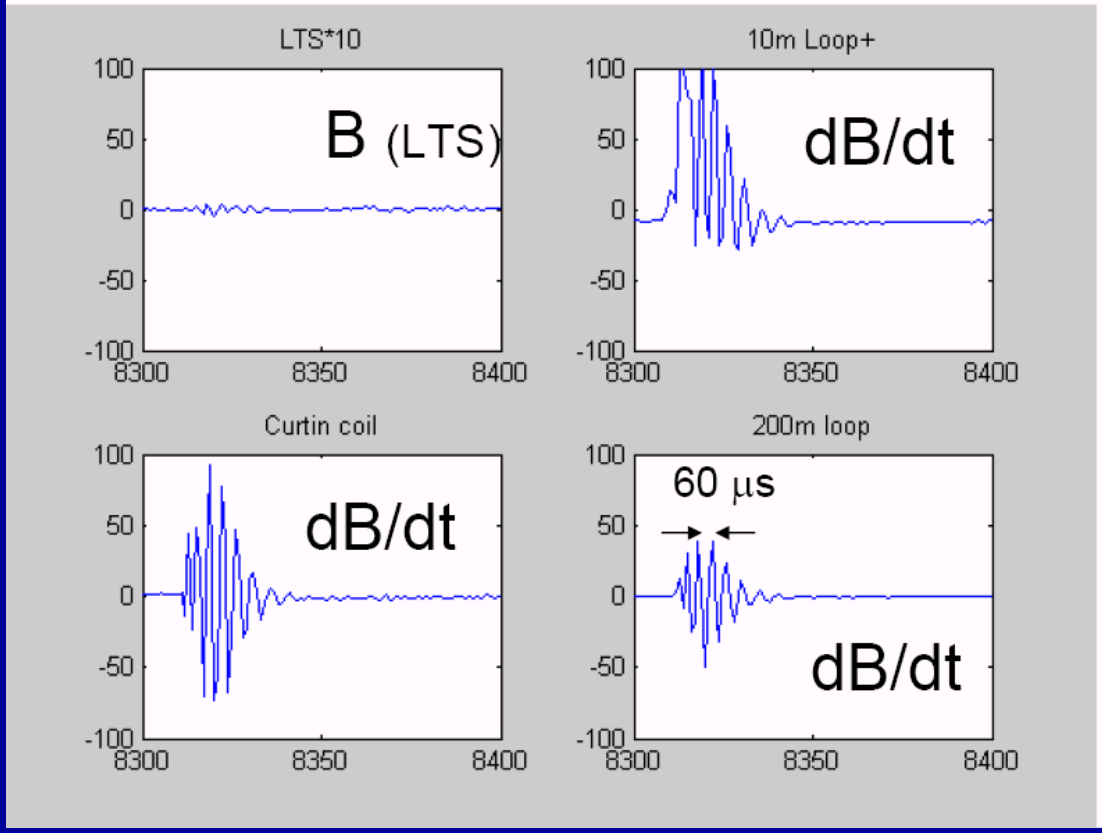
B vs dB/dt



Le Roux (2007)

B vs dB/dt

0.8 ms of data showing high frequency content of sferic wavelet

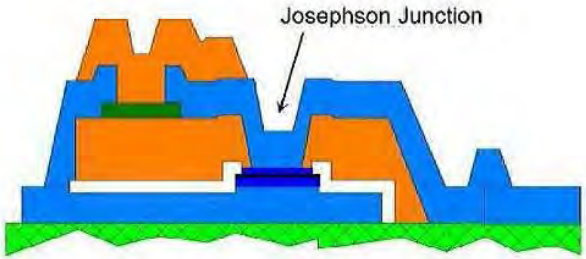


- **Sferic ~100 times larger in dB/dt sensors (compared to "quiet-time" noise)**

Macnae (2006)

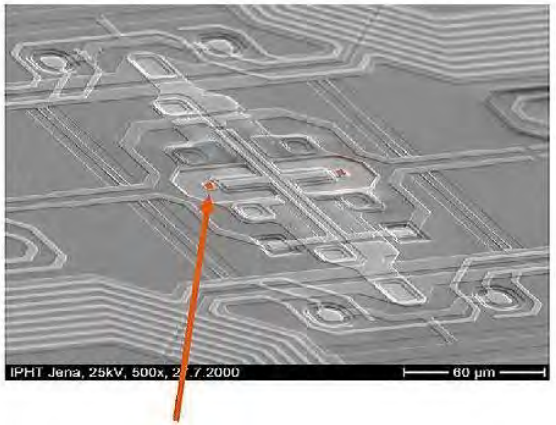
SQUID - Superconducting Quantum Interference Device

Extremely sensitive thin film processing technology comparable with semiconductor technologies

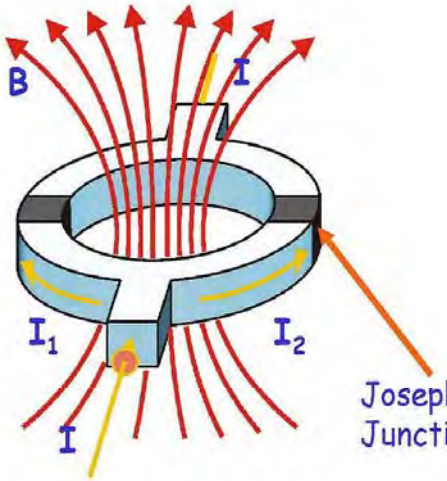


Si (Substrate)
Nb (Wiring)
Mo (Resistors)
Al_2O_3 (Barrier)
Nb (Trilayer)
Nb_2O_5 (Anodization)
SiO (Isolation)

Niobium technology with 11 layers



Josephson junction
(3.1µm×3.1µm)



Stolz, et al. (2006)

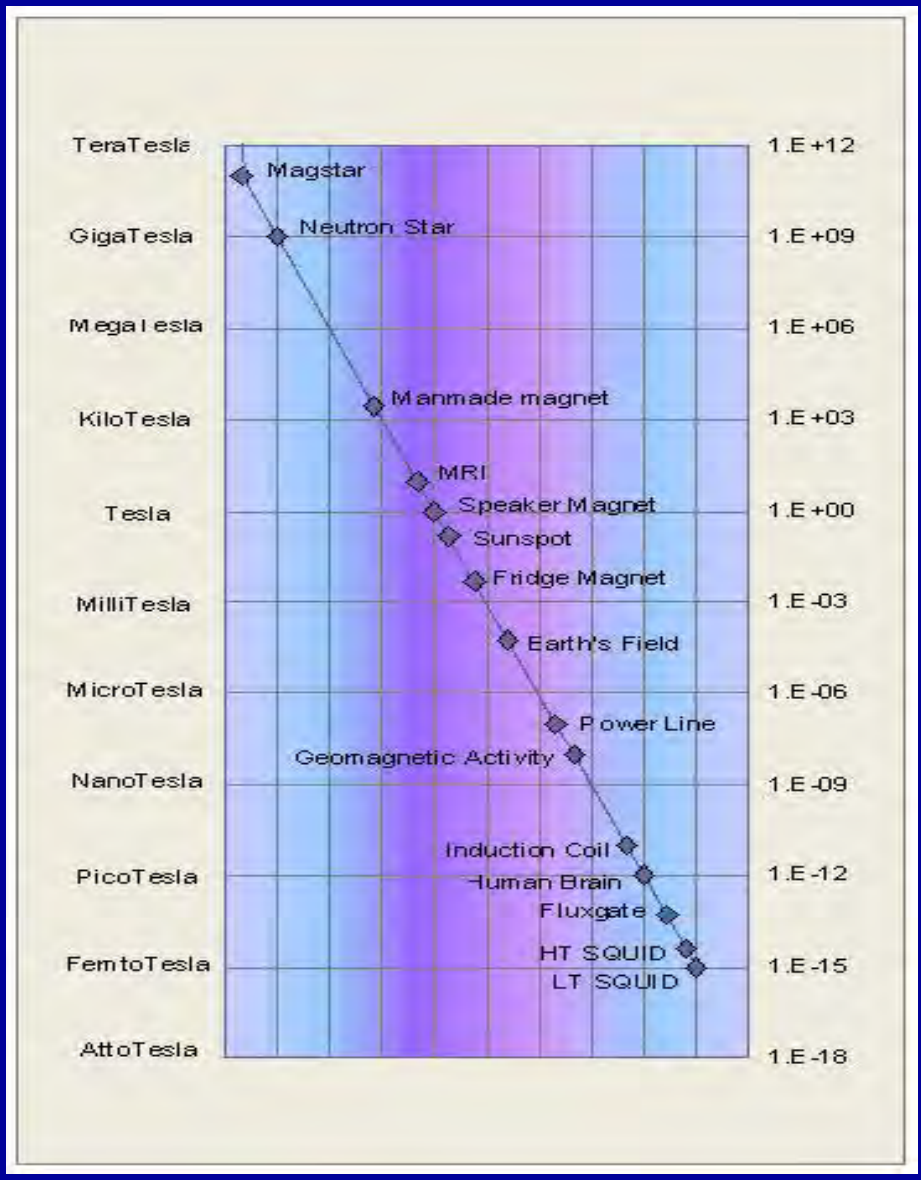
Materials:

- "Low temperature": Classical: Niobium, working at 4.2 K
- "High Temperature": YBCO, working at 77 K
- Diameter mm to cm, application dependent

Filling High Temperature SQUID (HTS) with Liquid Nitrogen

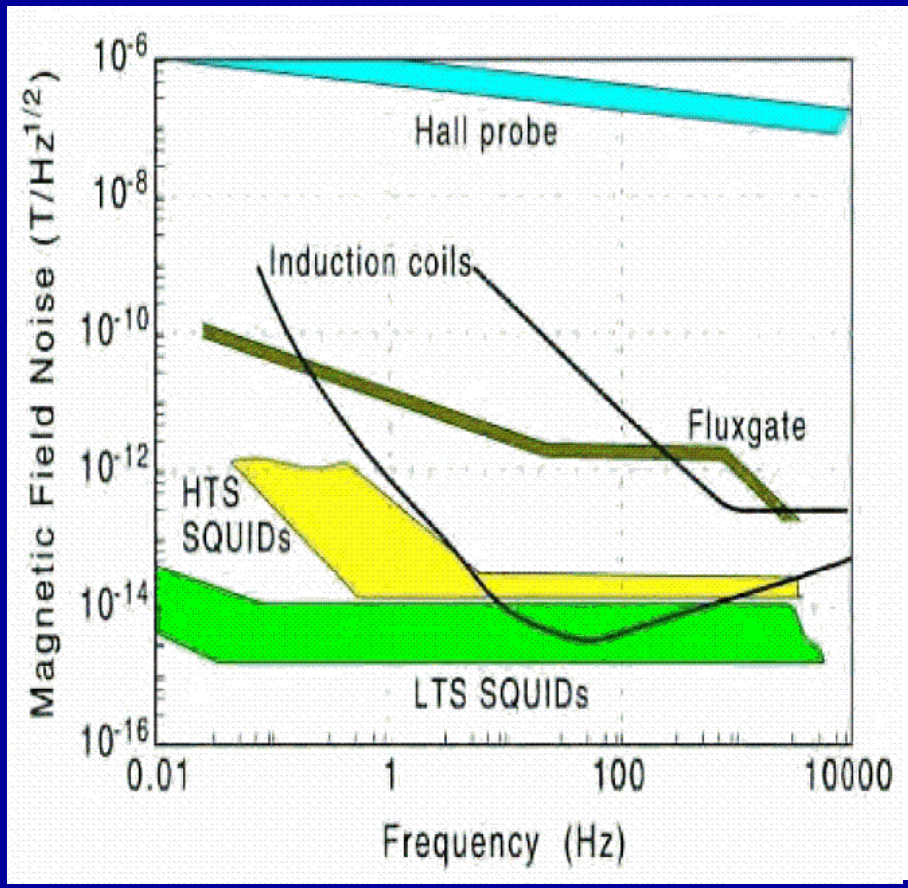
Filling Low Temperature SQUID (LTS) with Liquid Helium

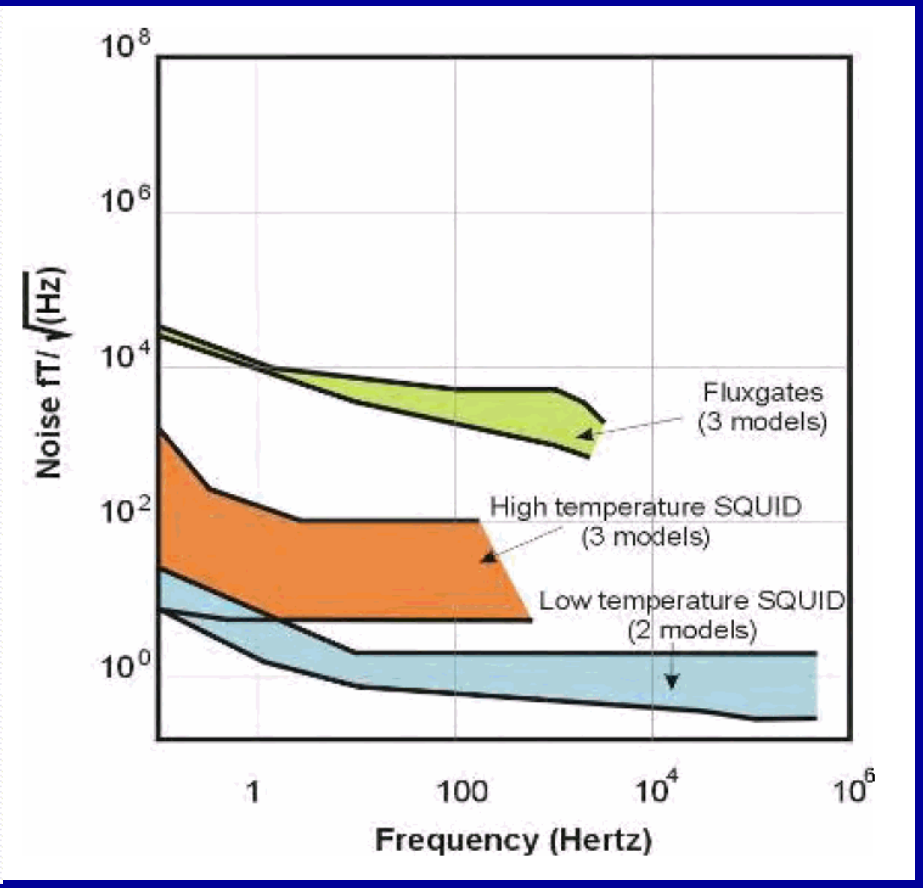
SQUID and the Magnetic Field Spectrum



After Bingham (2009)

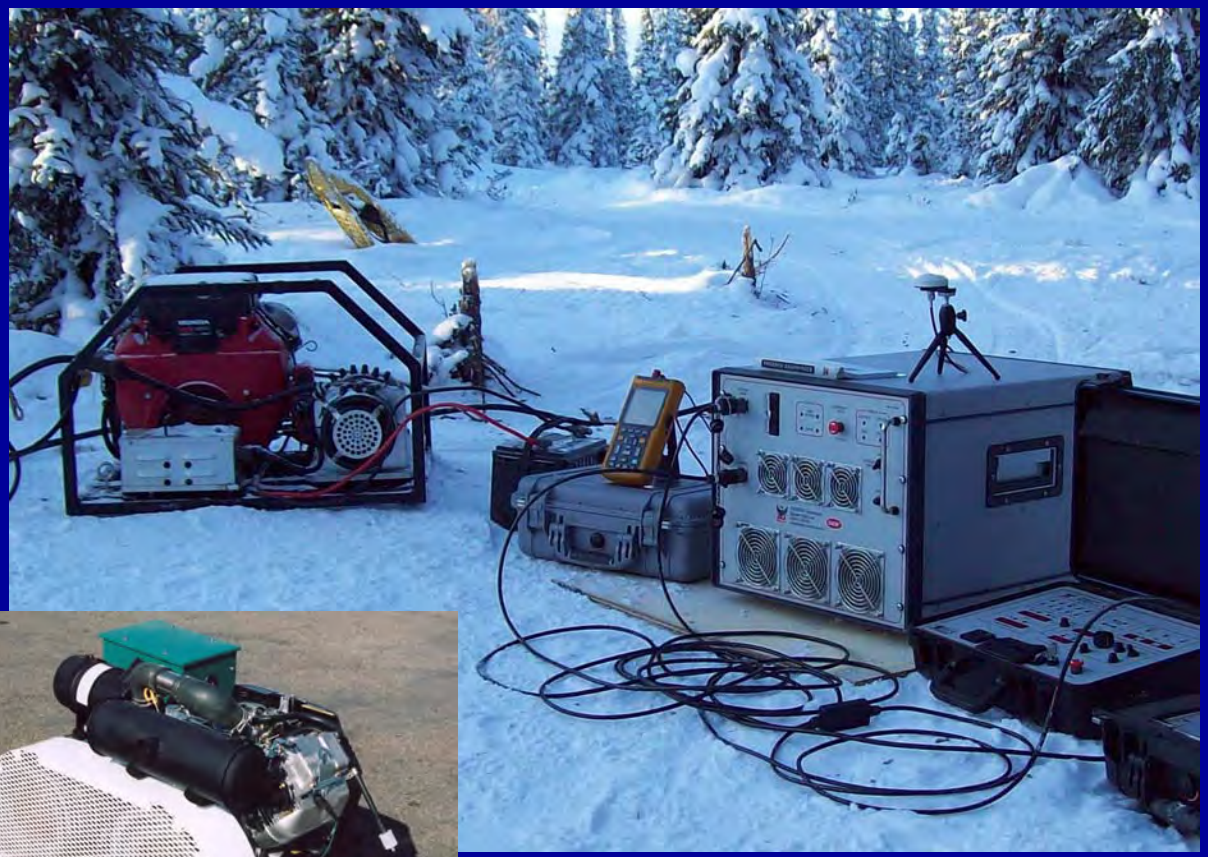
SQUID and EM Sensor Noise Spectrums





Le Roux (2006)

Deep Exploration Requires High Signal and Low Noise



Phoenix TXU-30

- **20 kW**
- **40 Amps**
- **120 lbs**

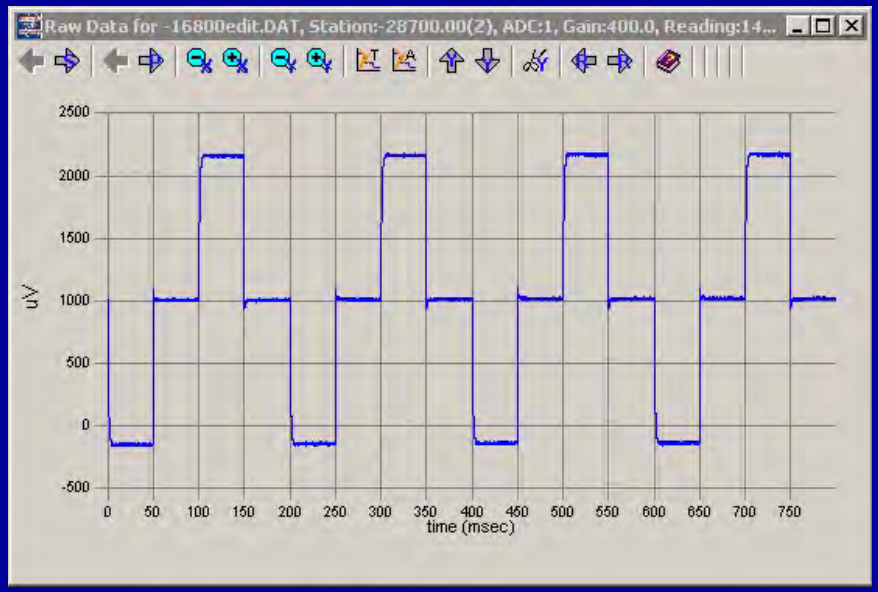
Walcer Generator

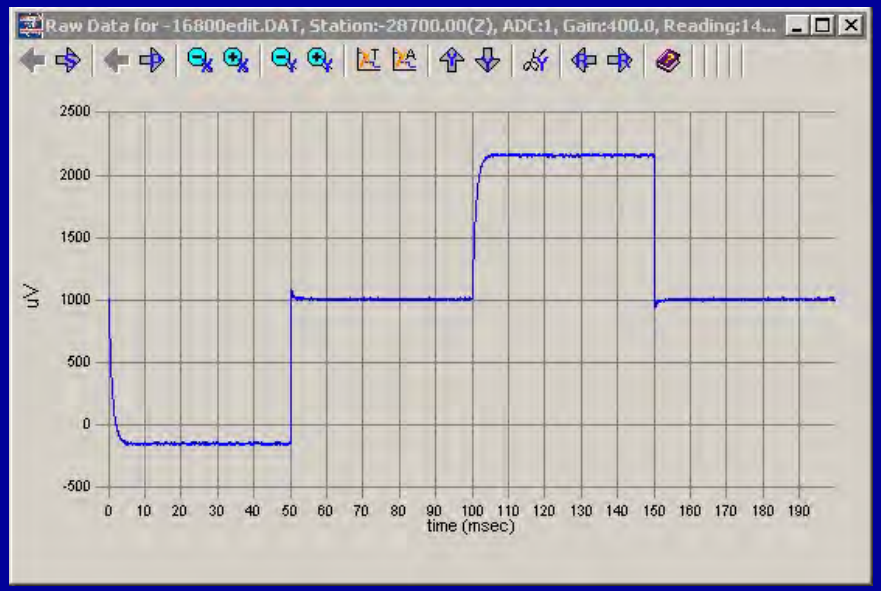
- **12.5 kW**
- **25 Hp gas motor**
- **200 lbs**

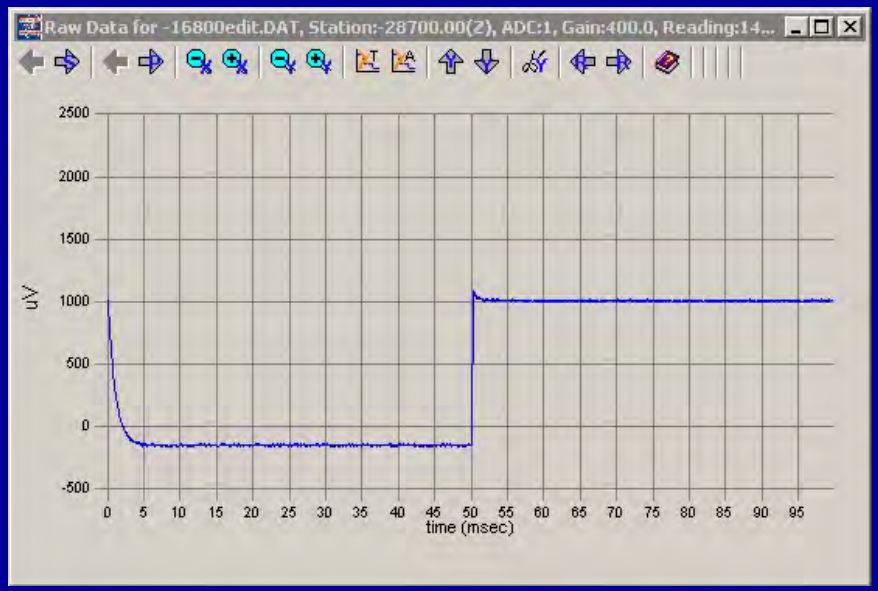
400 Hertz Generator

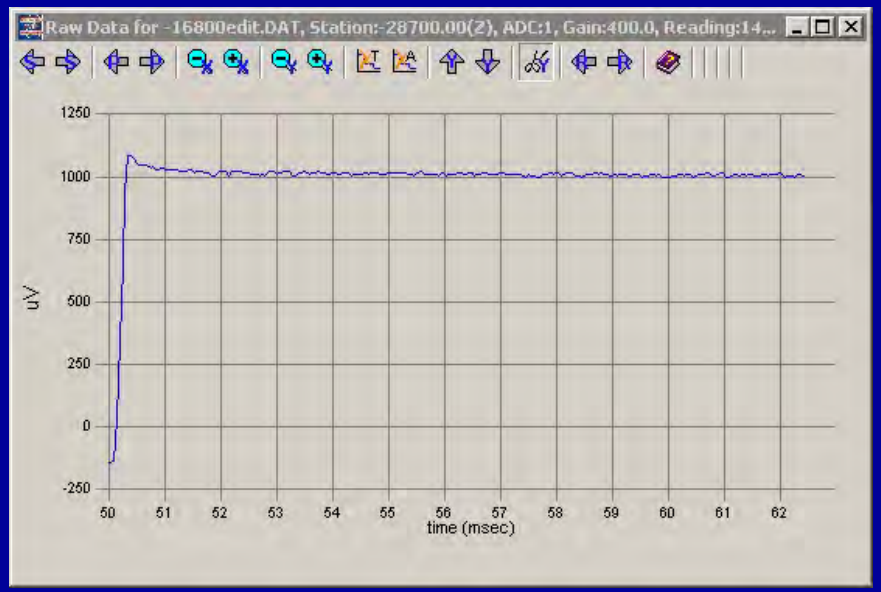
- **20 kW**
- **40 Hp gas motor**
- **350 lbs**

TEM Waveforms

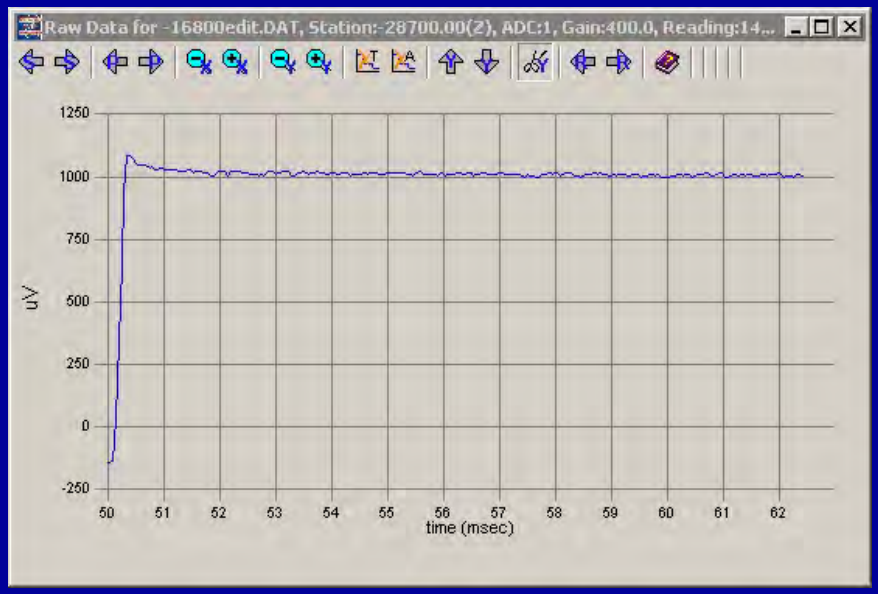


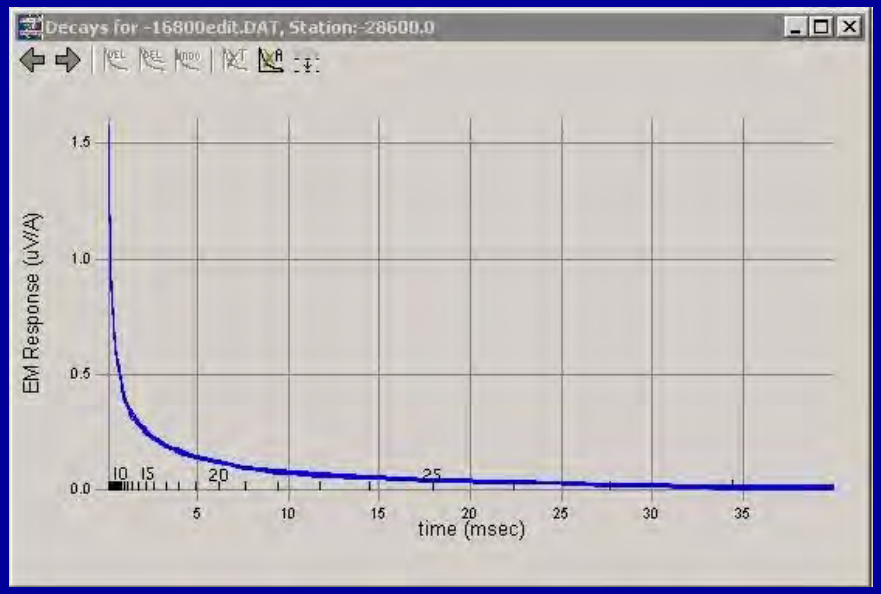


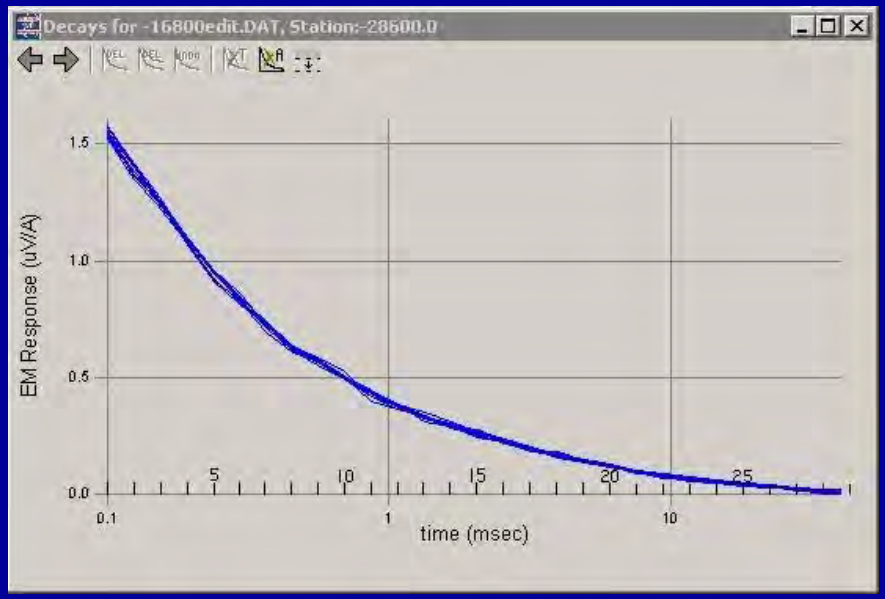


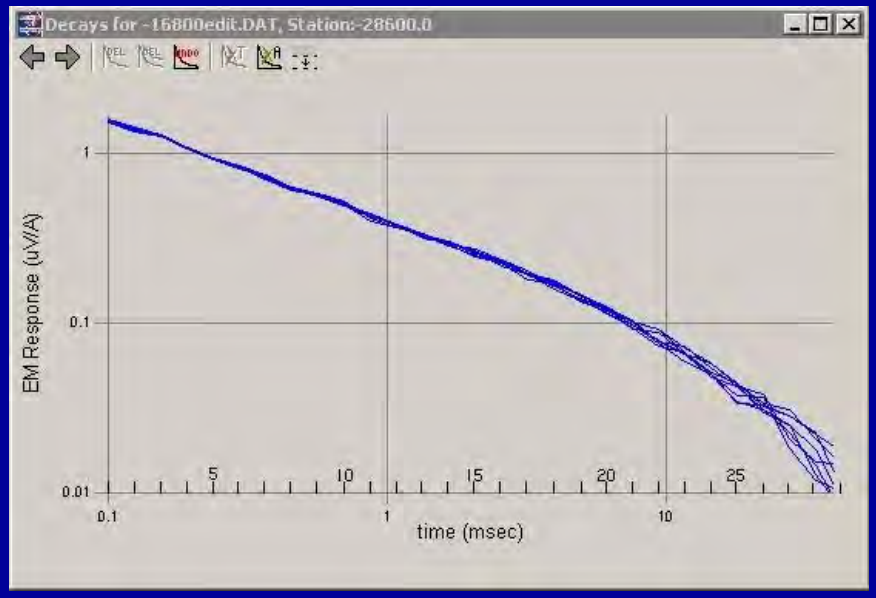


TEM Decay Plots



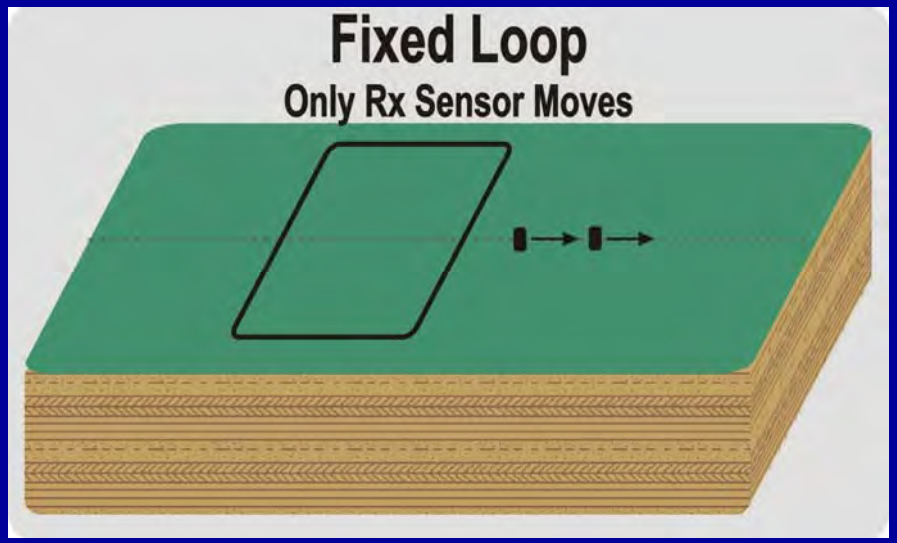


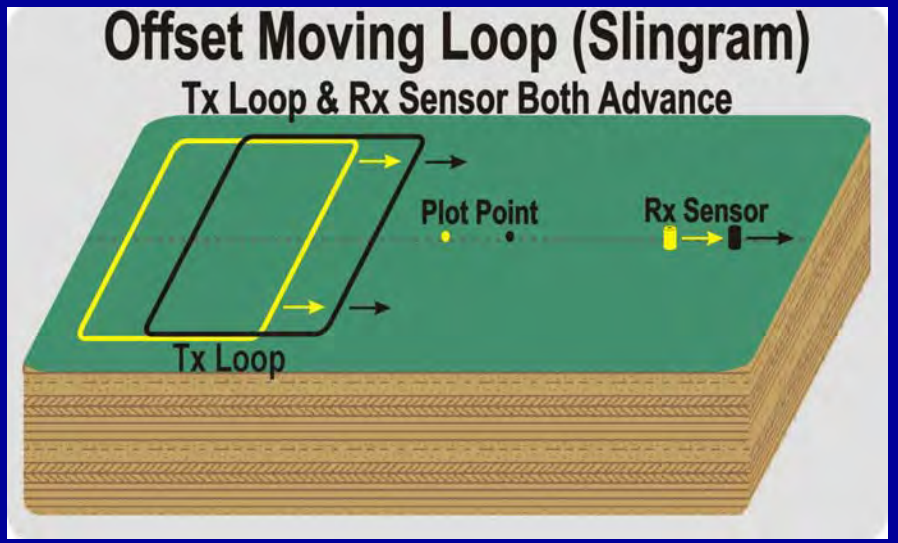


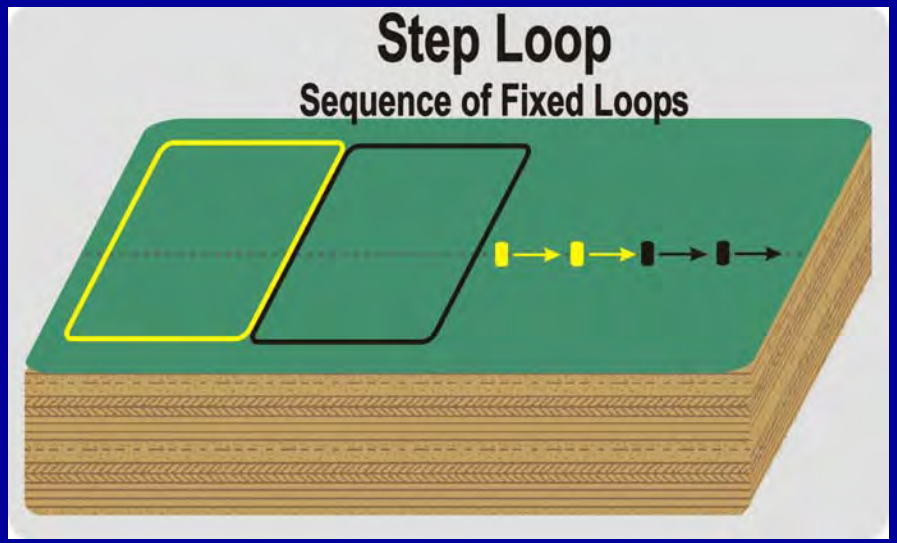


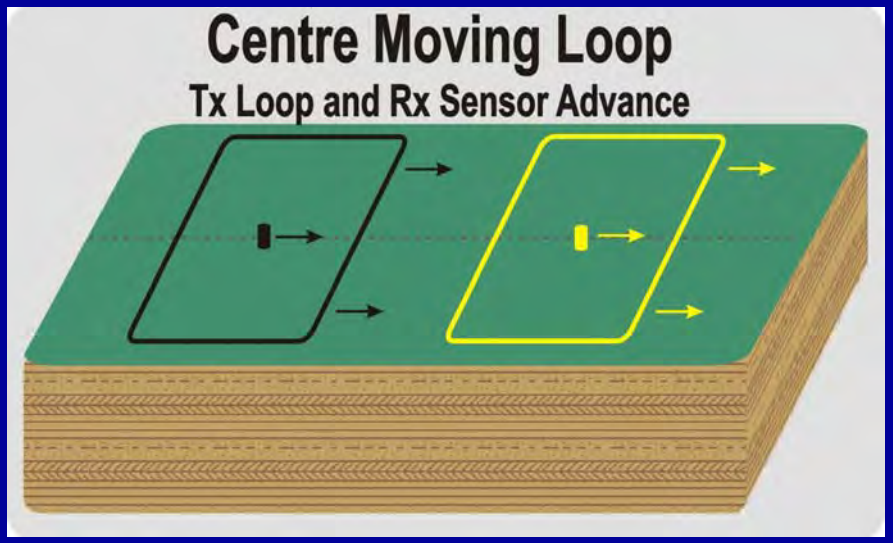
SQUID TDEM Surveys

Transient Electromagnetic (TEM) Surveys



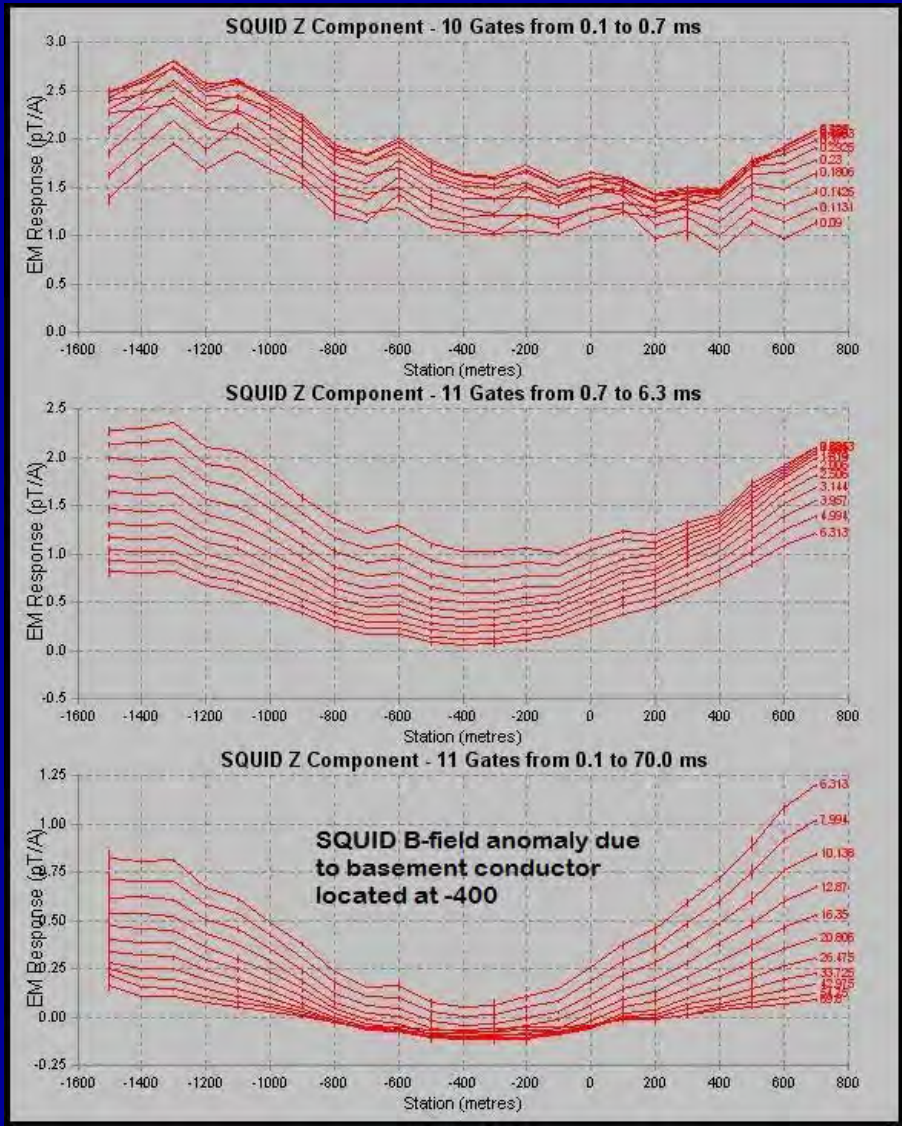


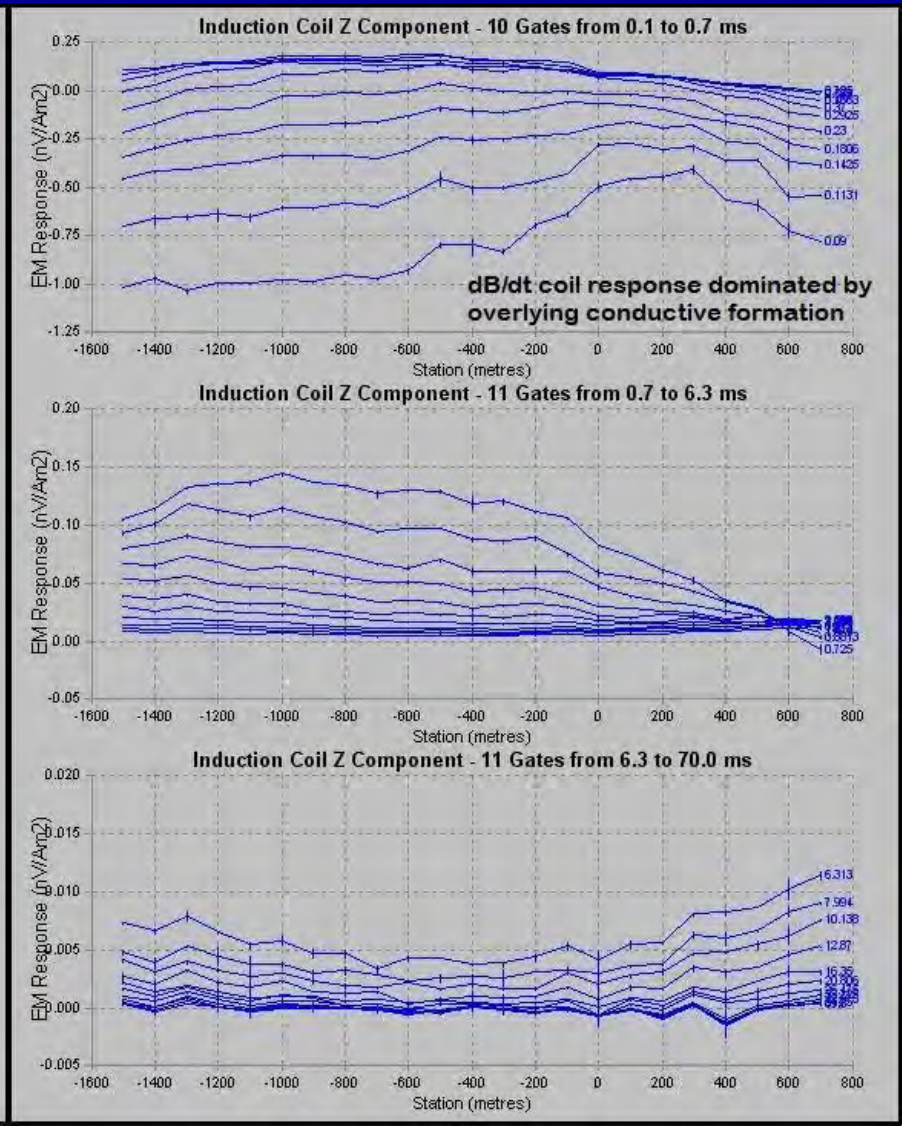




Slingram - Z - SQUID vs Coil

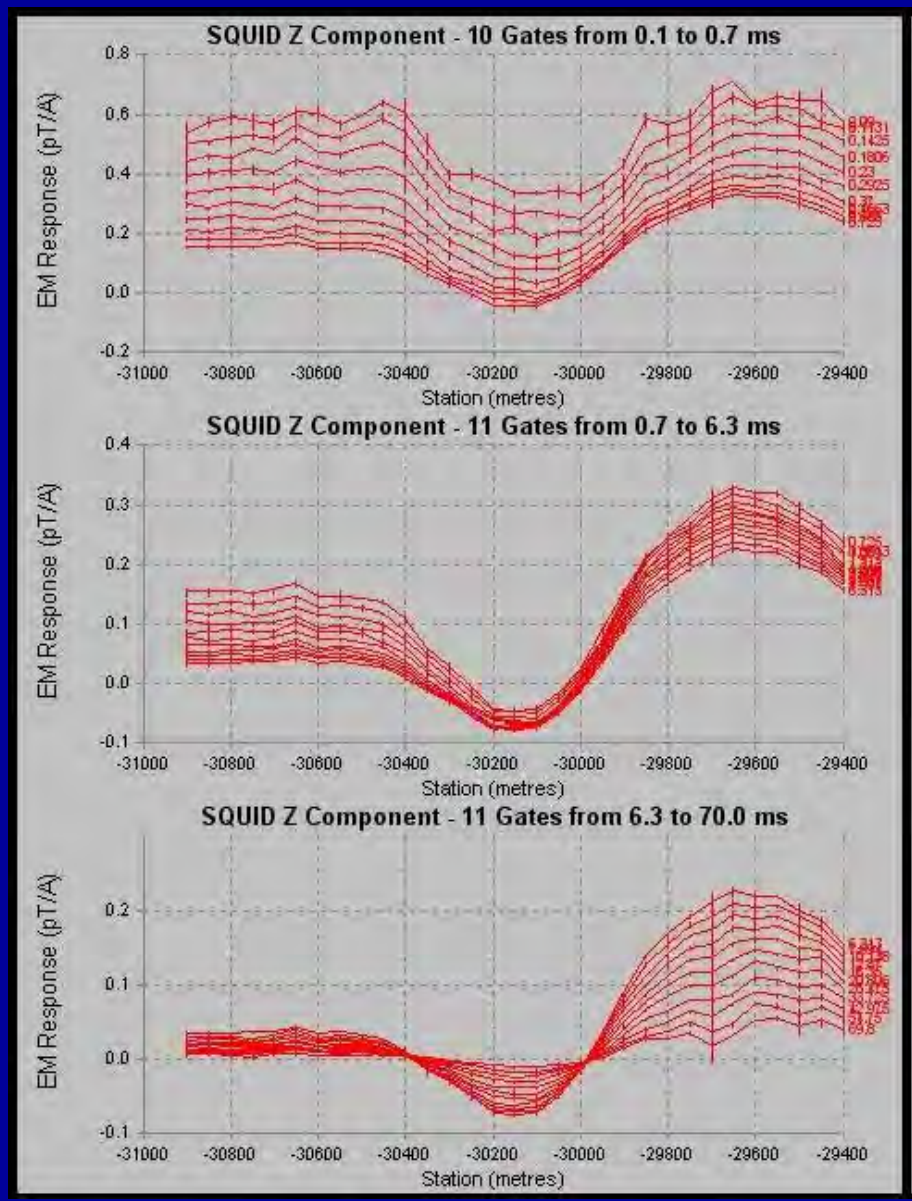
800m x 800m Loop, 15A, Rx-Tx = 1800m, Depth = 750m

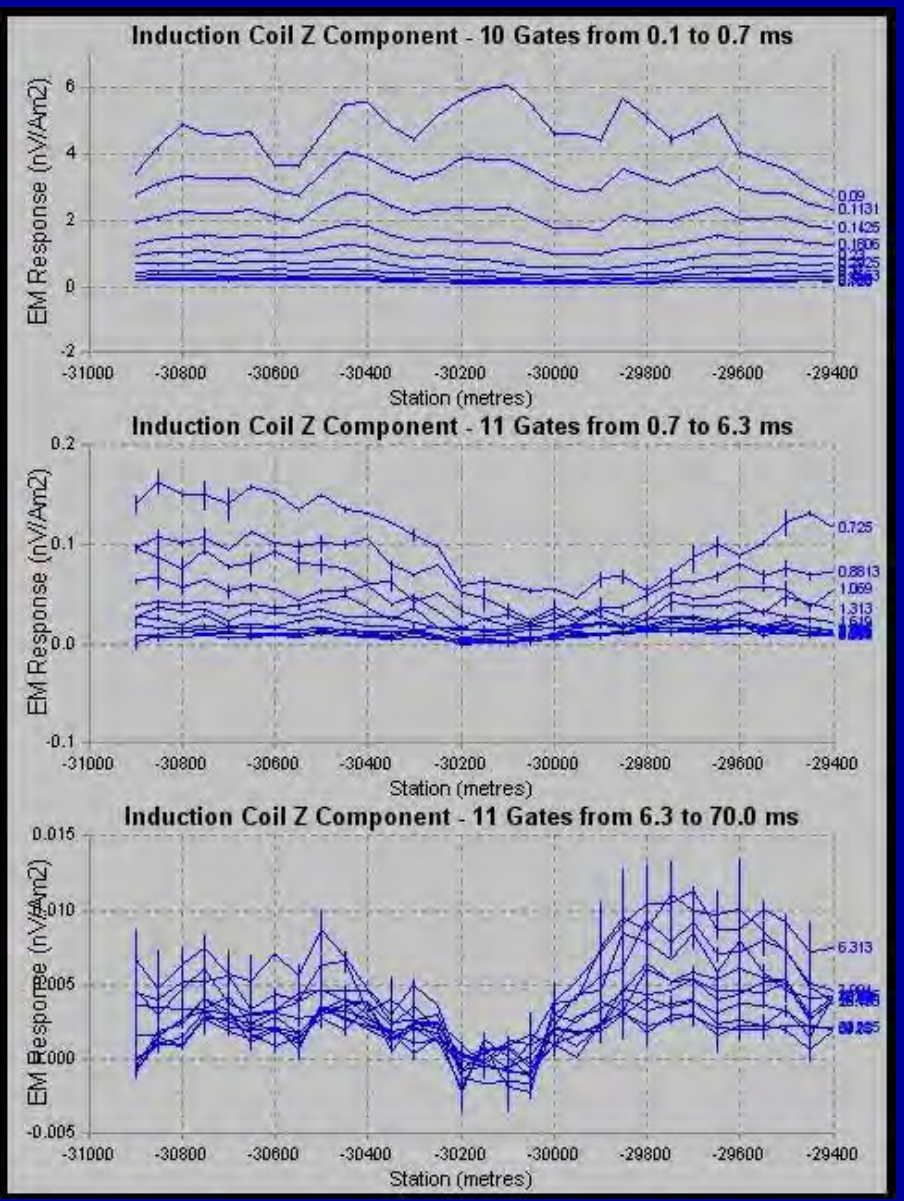




Slingram - Z - SQUID vs Coil

100m x 100m x 2 Turn Loop, 20A, Rx-Tx = 400m, Depth = 250m

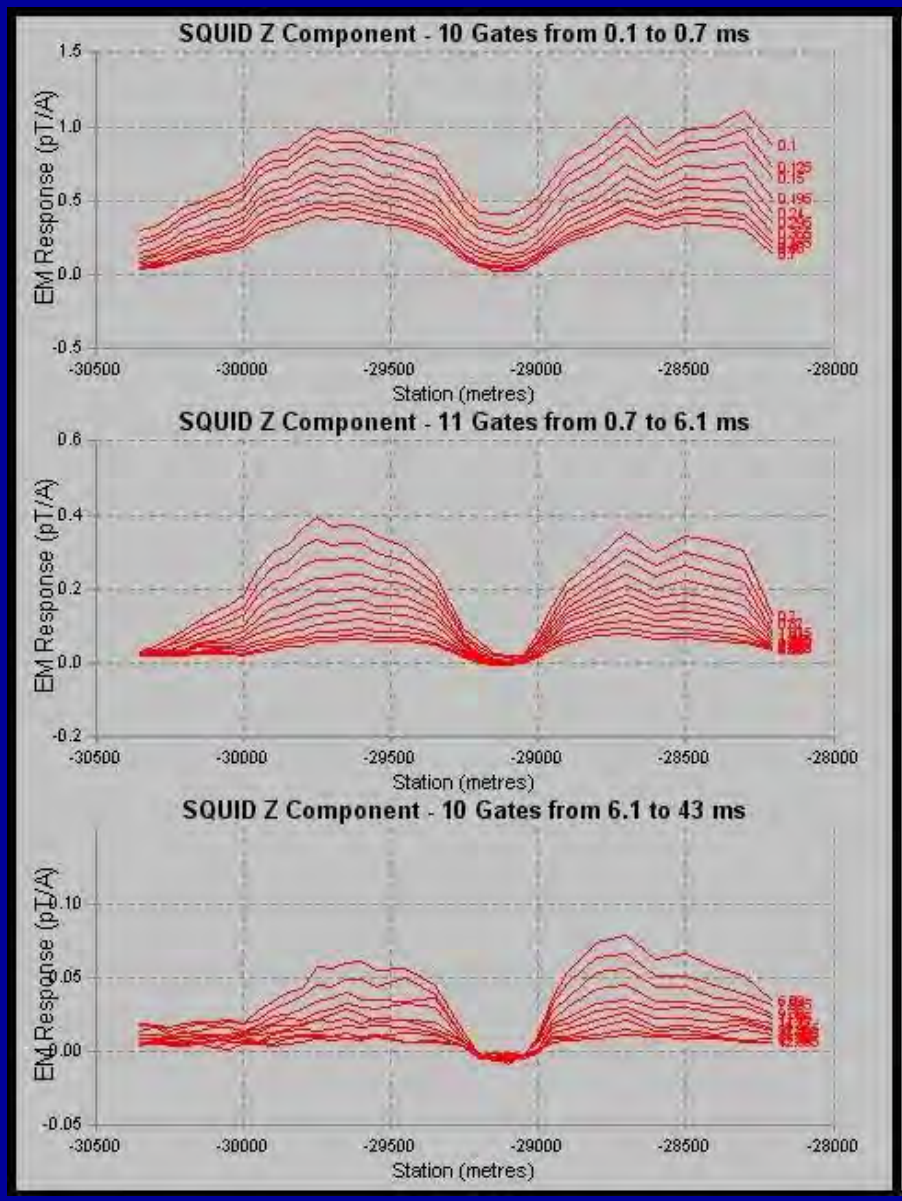


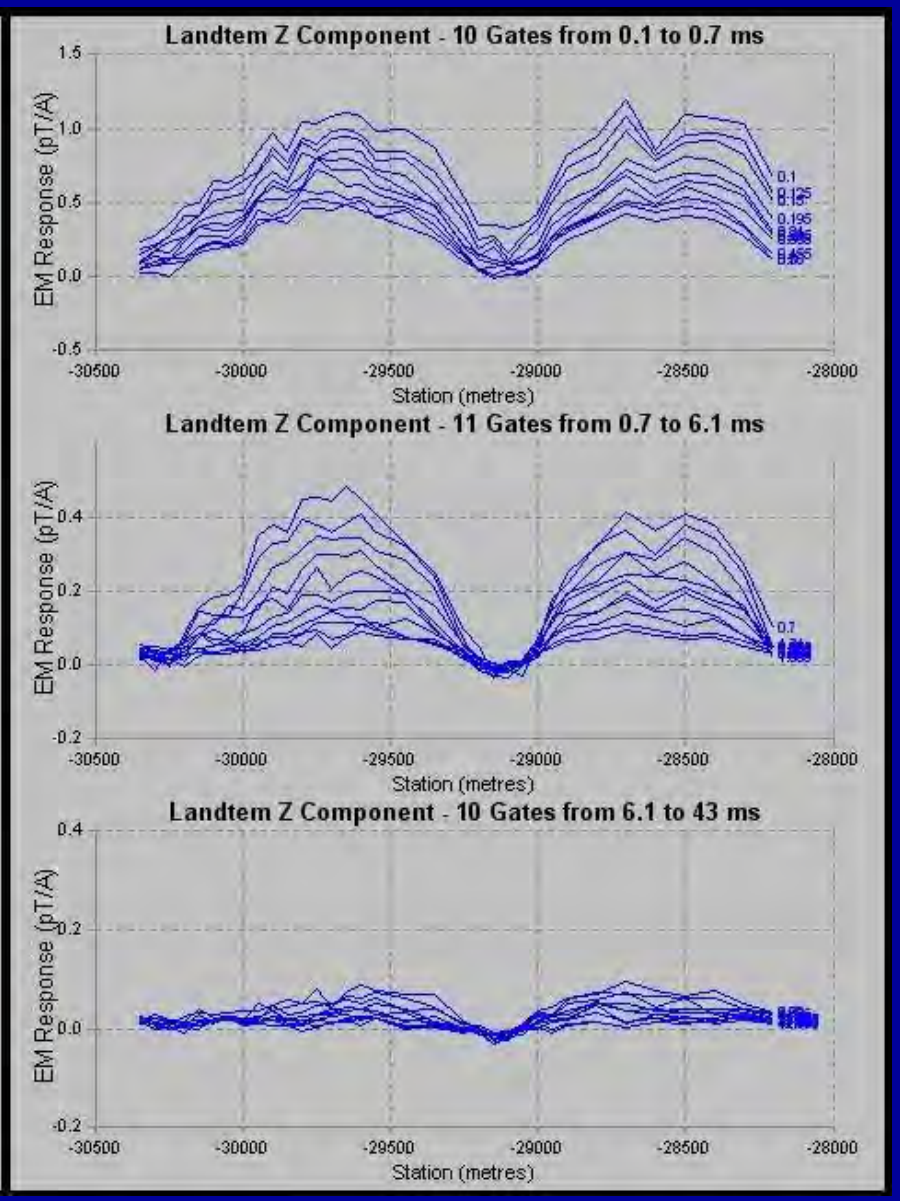


Jessy (IPHT, Germany)
vs
Landtem (CSIRO, Australia)

Slingram - Z - Jessy vs LandTEM

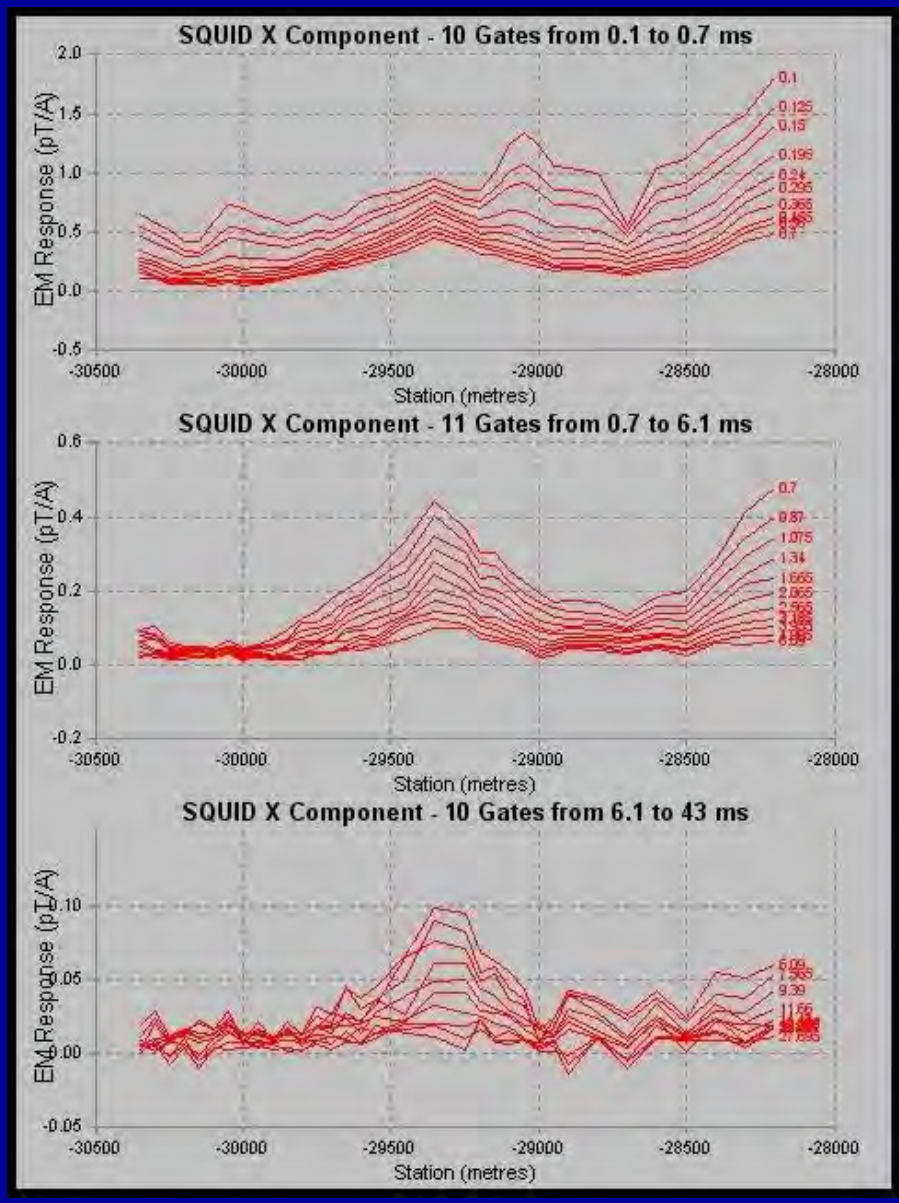
100m x 100m x 2 Turn Loop, 20A, Rx-Tx = 400m, Depth = 250m

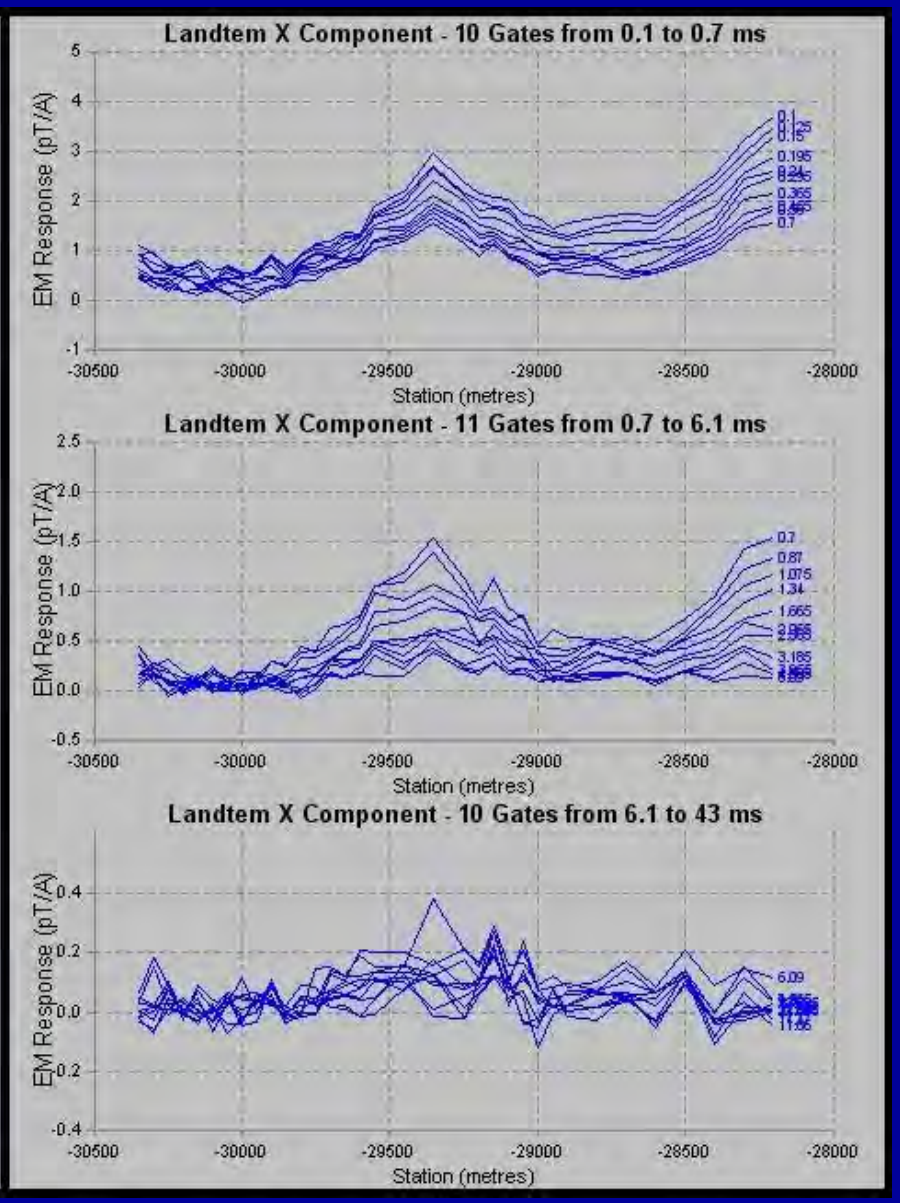




Slingram - X - Jessy vs LandTEM

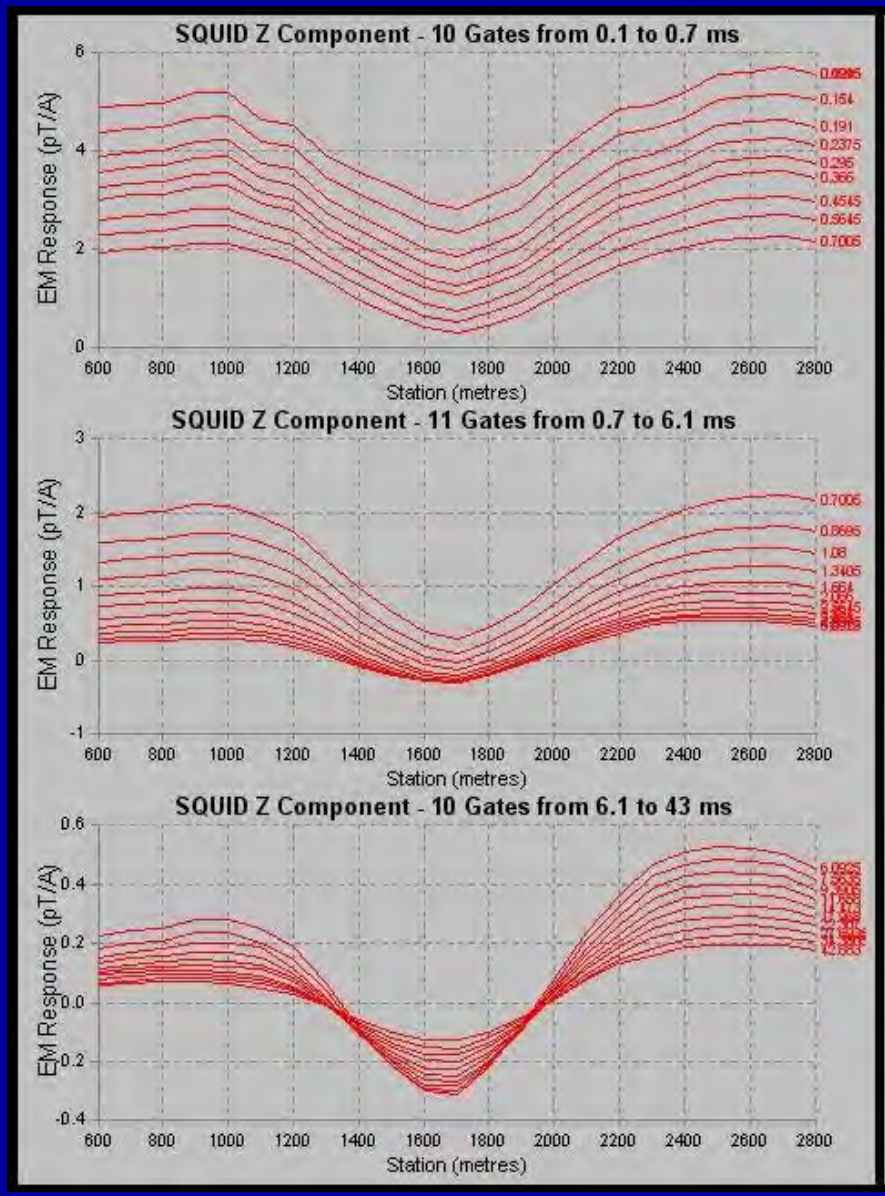
100m x 100m x 2 Turn Loop, 20A, Rx-Tx = 400m, Depth = 250m

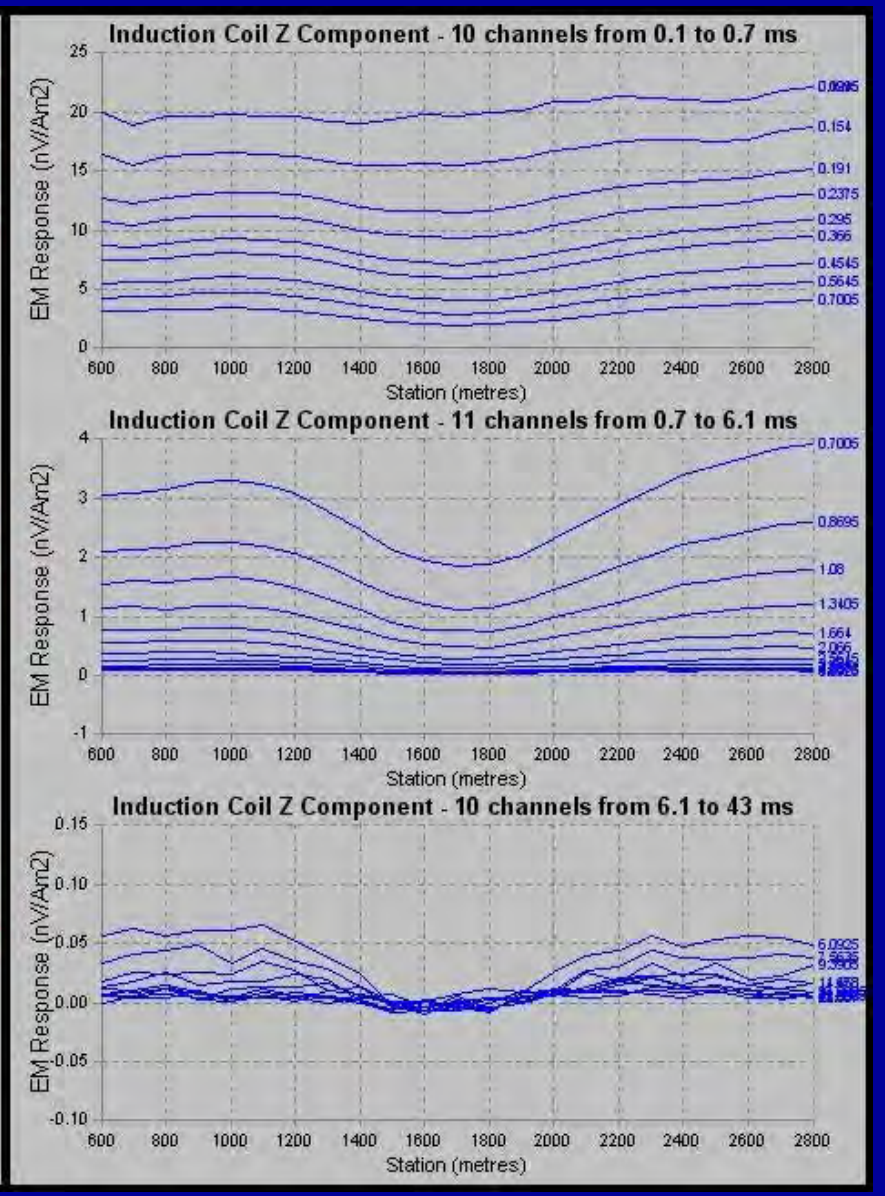




Slingram - Z - SQUID vs Coil

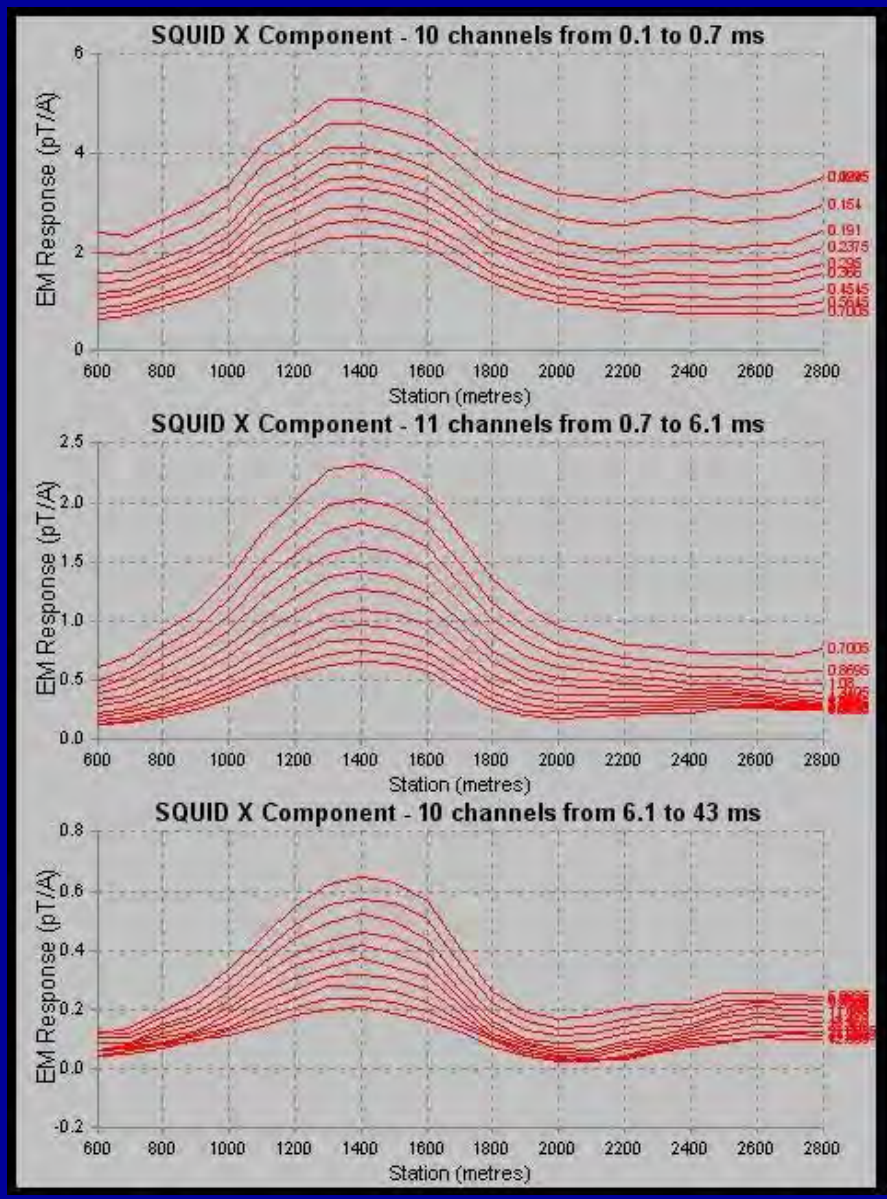
800m x 800m Loop, 20A, Rx-Tx = 800m, Depth = 400m

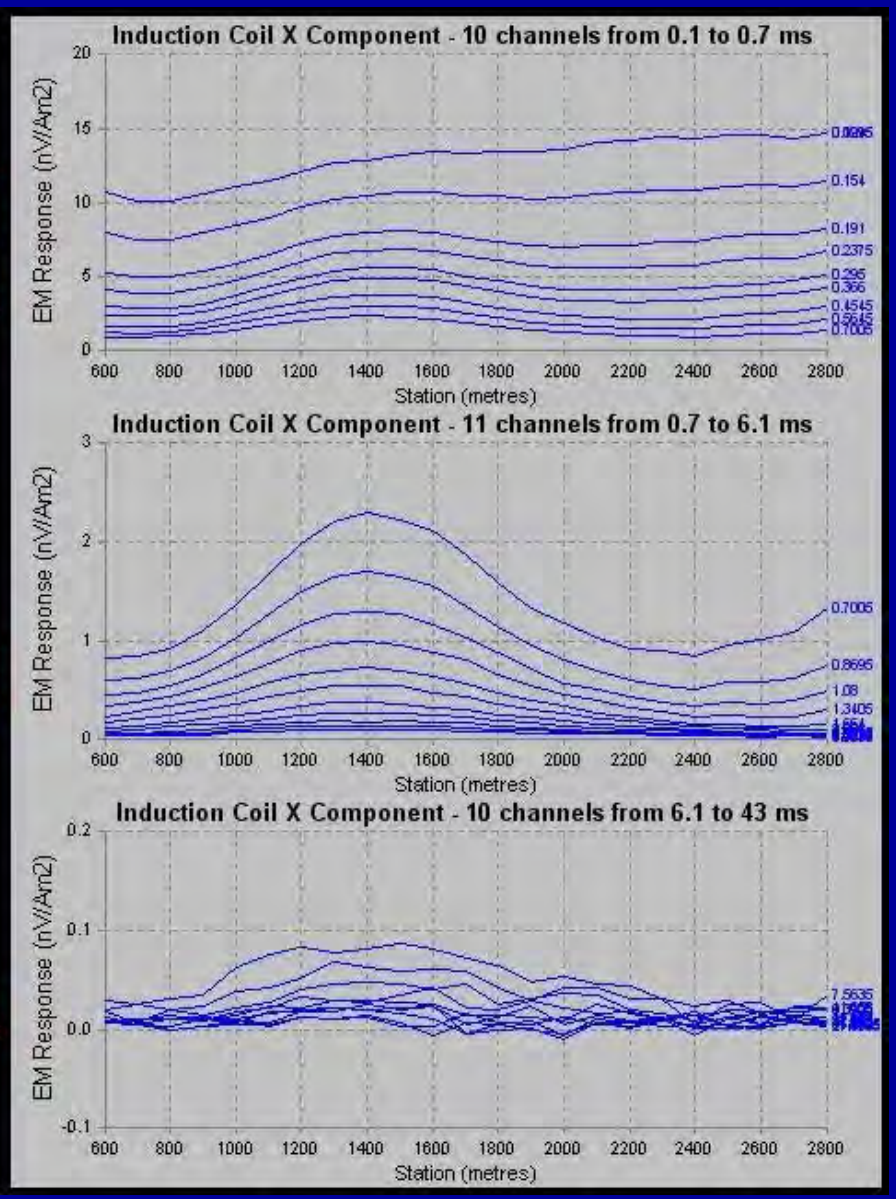




Slingram - X - SQUID vs Coil

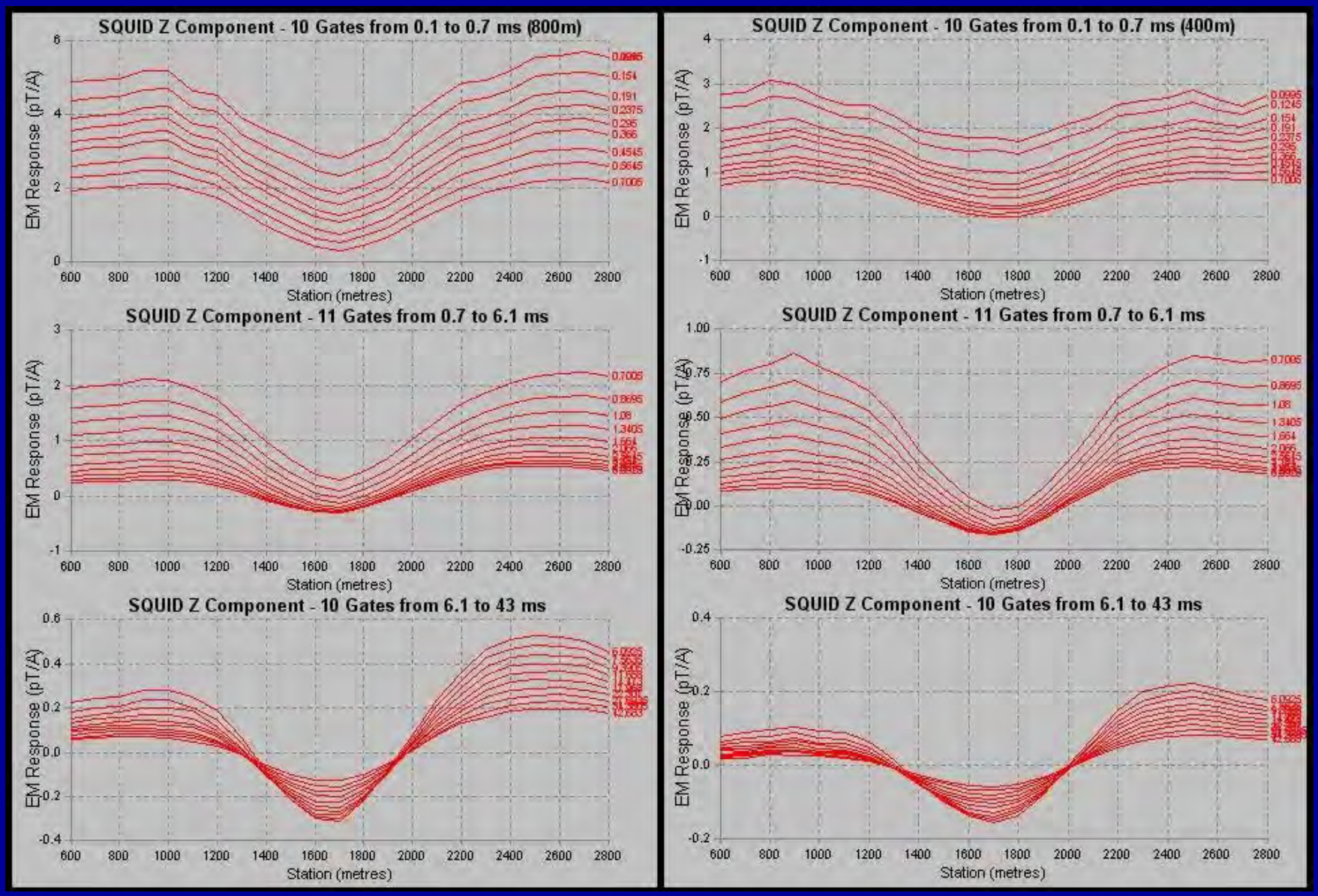
800m x 800m Loop, 20A, Rx-Tx = 800m, Depth = 400m





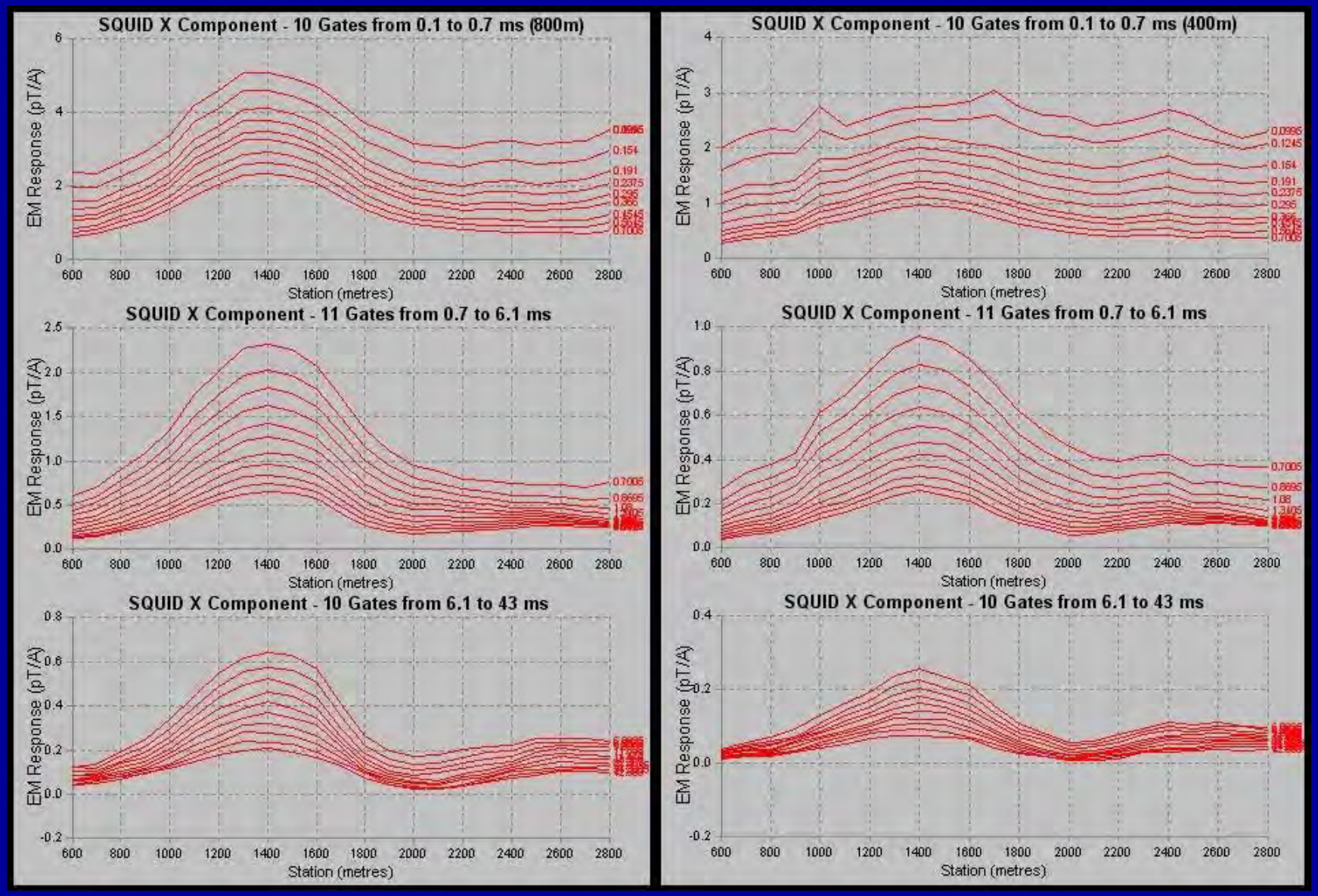
Slingram - Z - 800m vs 400m x 2 Loop

20A, Rx-Tx = 800m, Depth = 400m



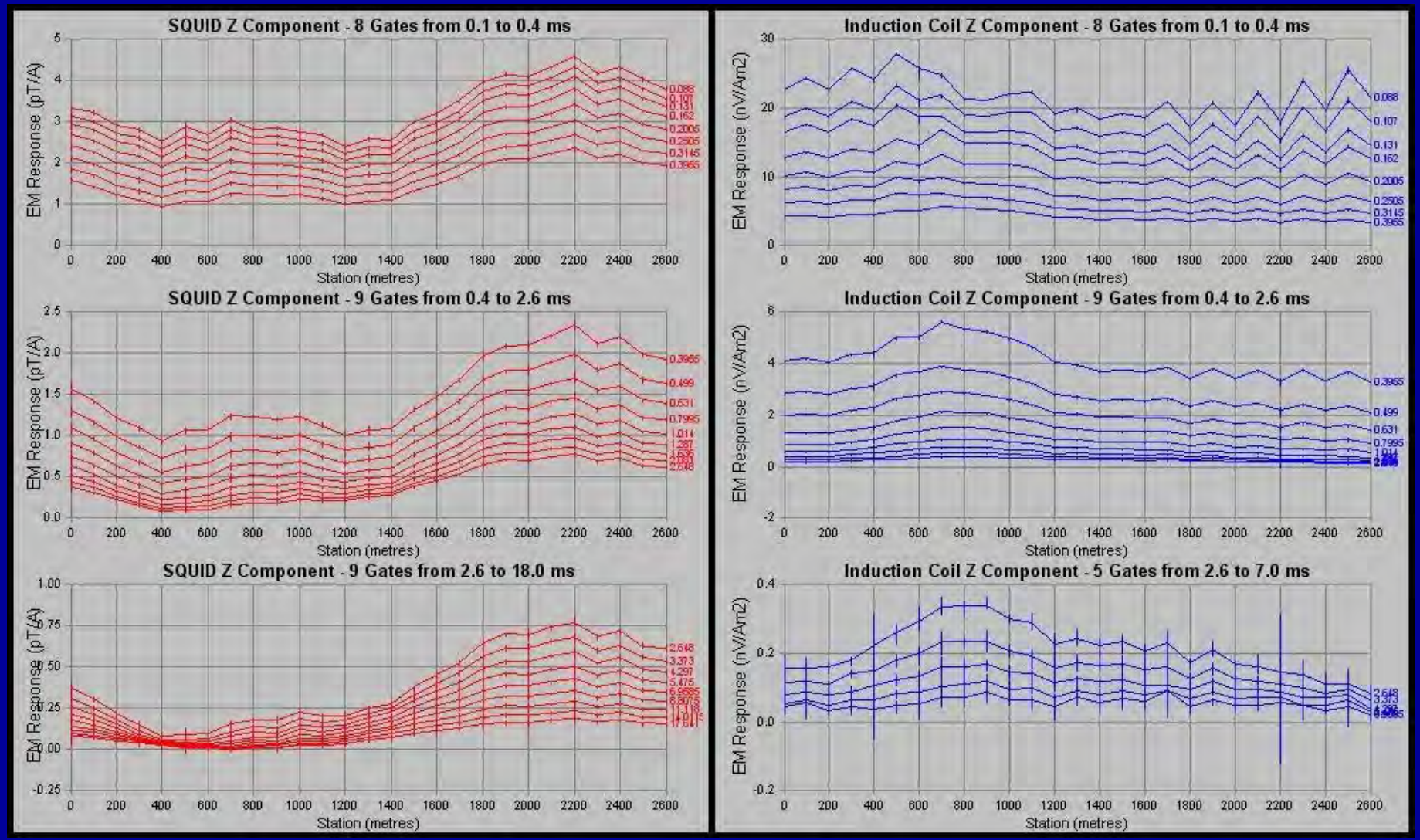
Slingram - X - 800m vs 400m x 2 Loop

20A, Rx-Tx = 800m, Depth = 400m



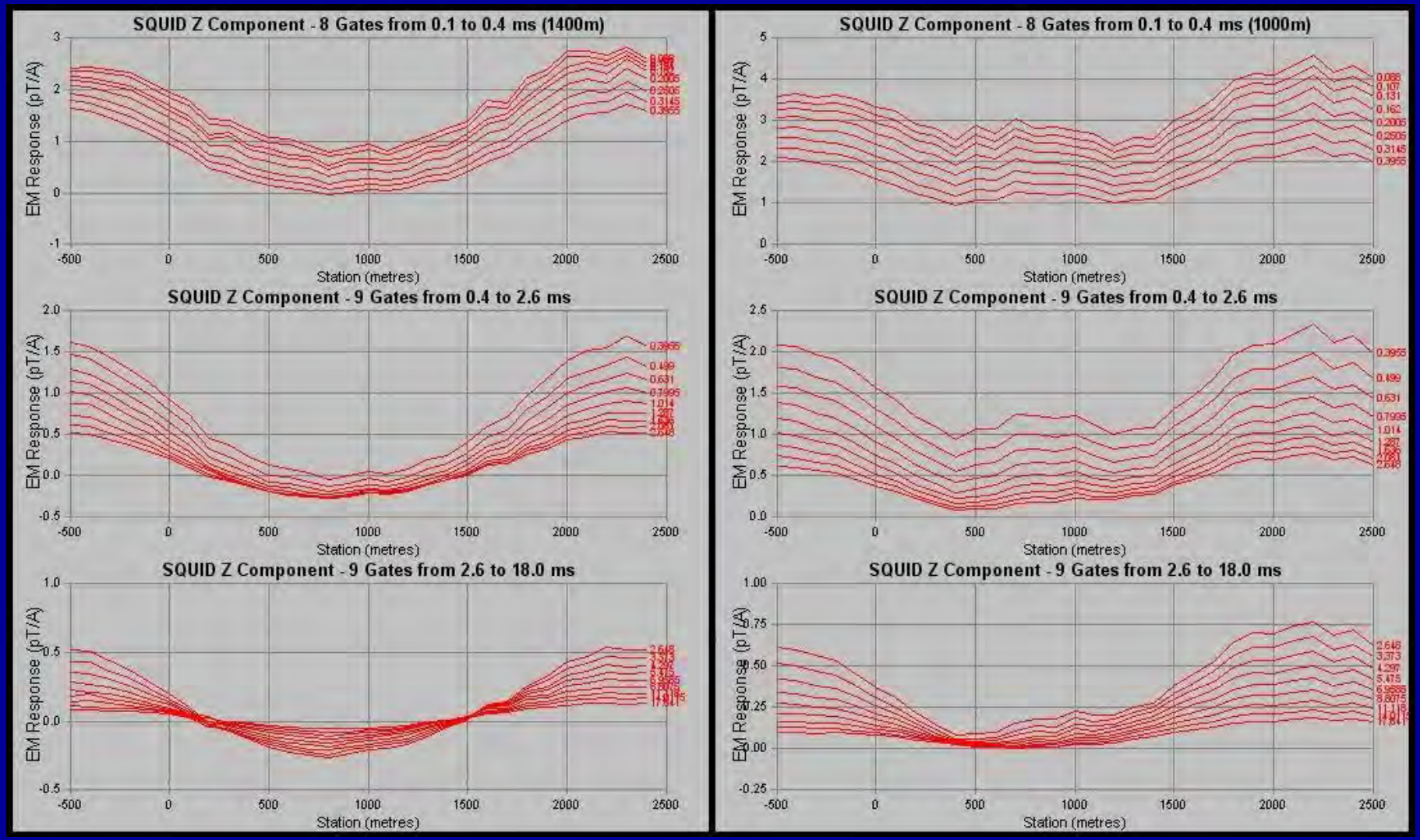
Slingram SQUID vs In-Loop Coil - Z

600m x 800m Loop, 17A, Rx-Tx = 1000m, Depth = 650m



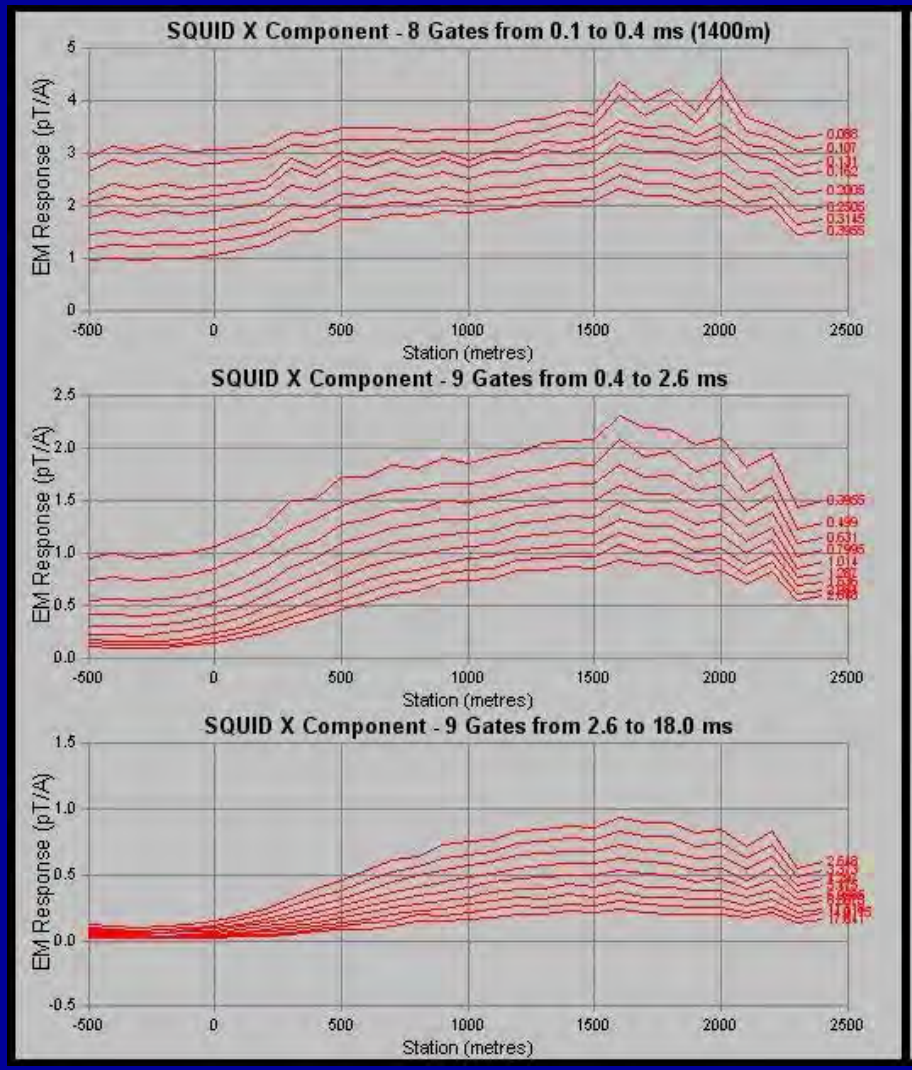
Tx

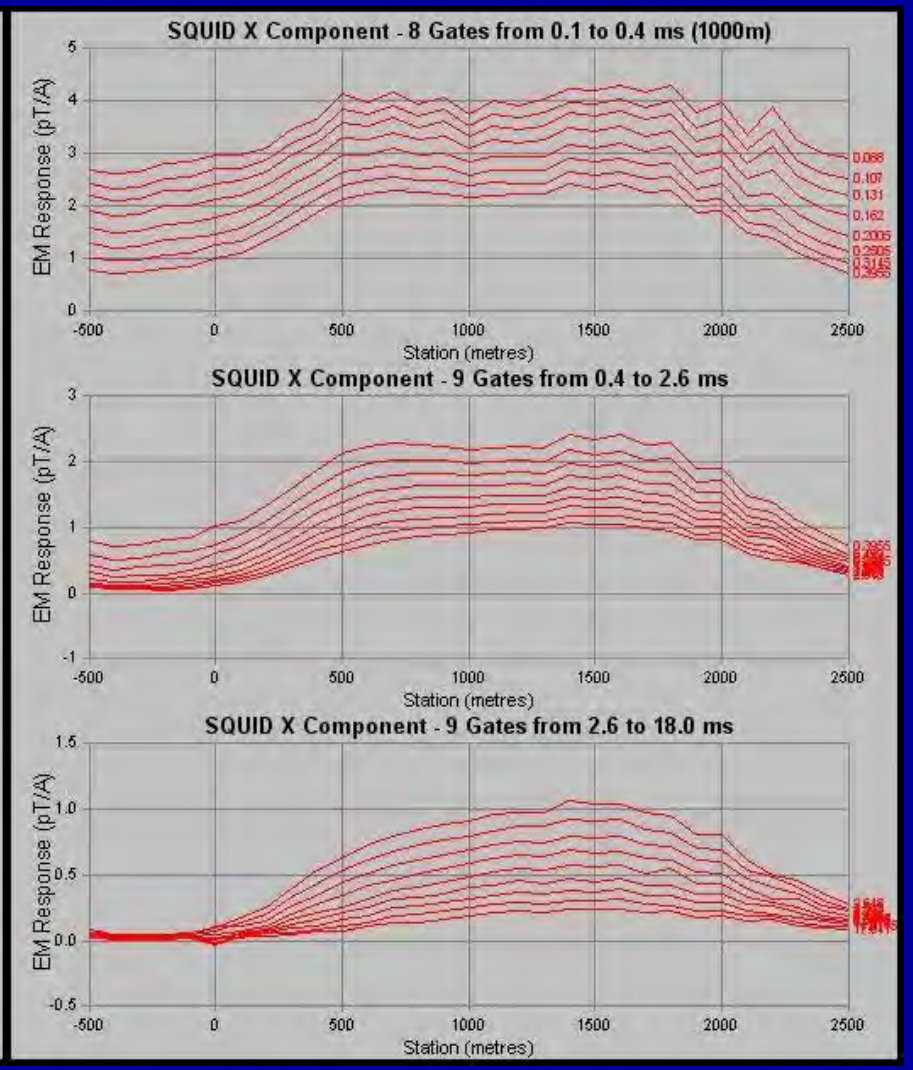
600m x 800m Loop, 17A, Depth = 650m



Slingram - X - 1400m vs 1000m Rx-Tx

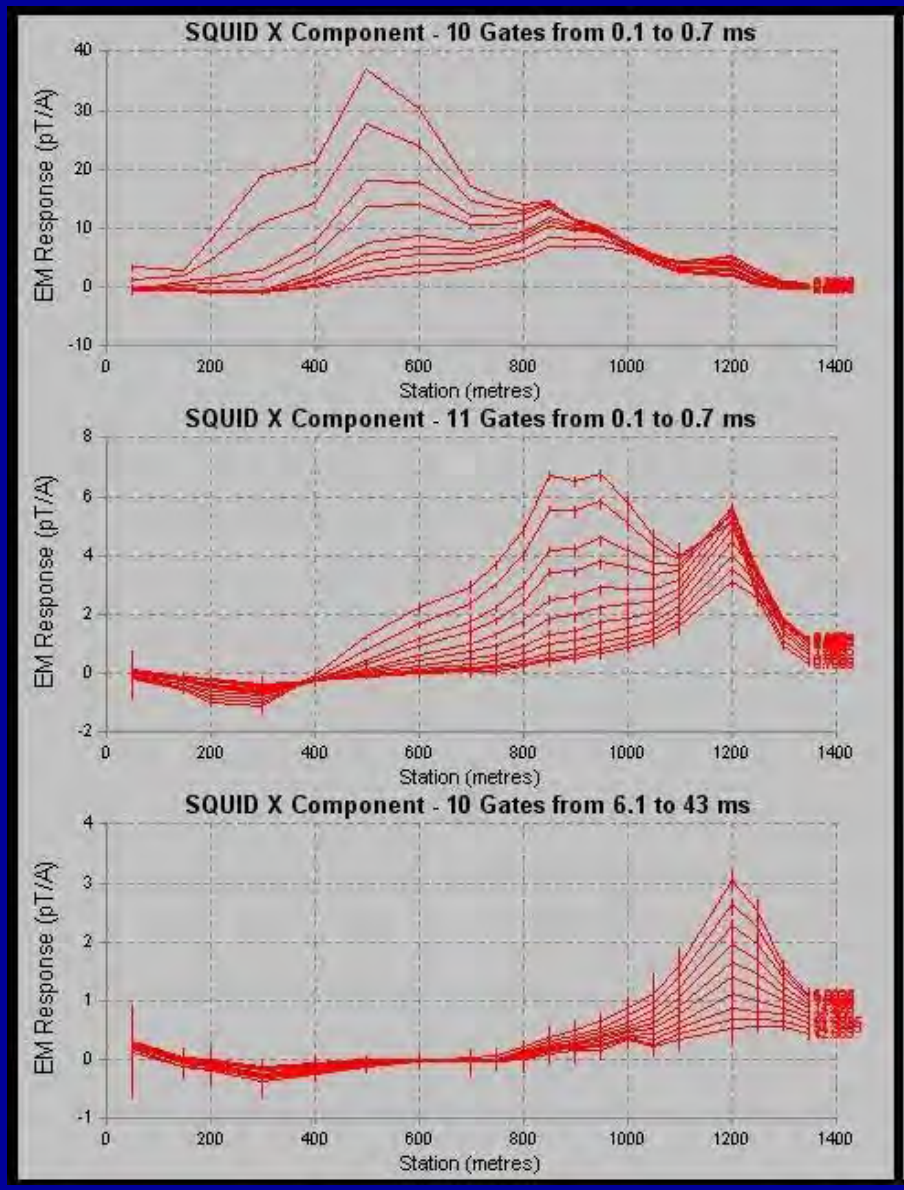
600m x 800m Loop, 17A, Depth = 650m

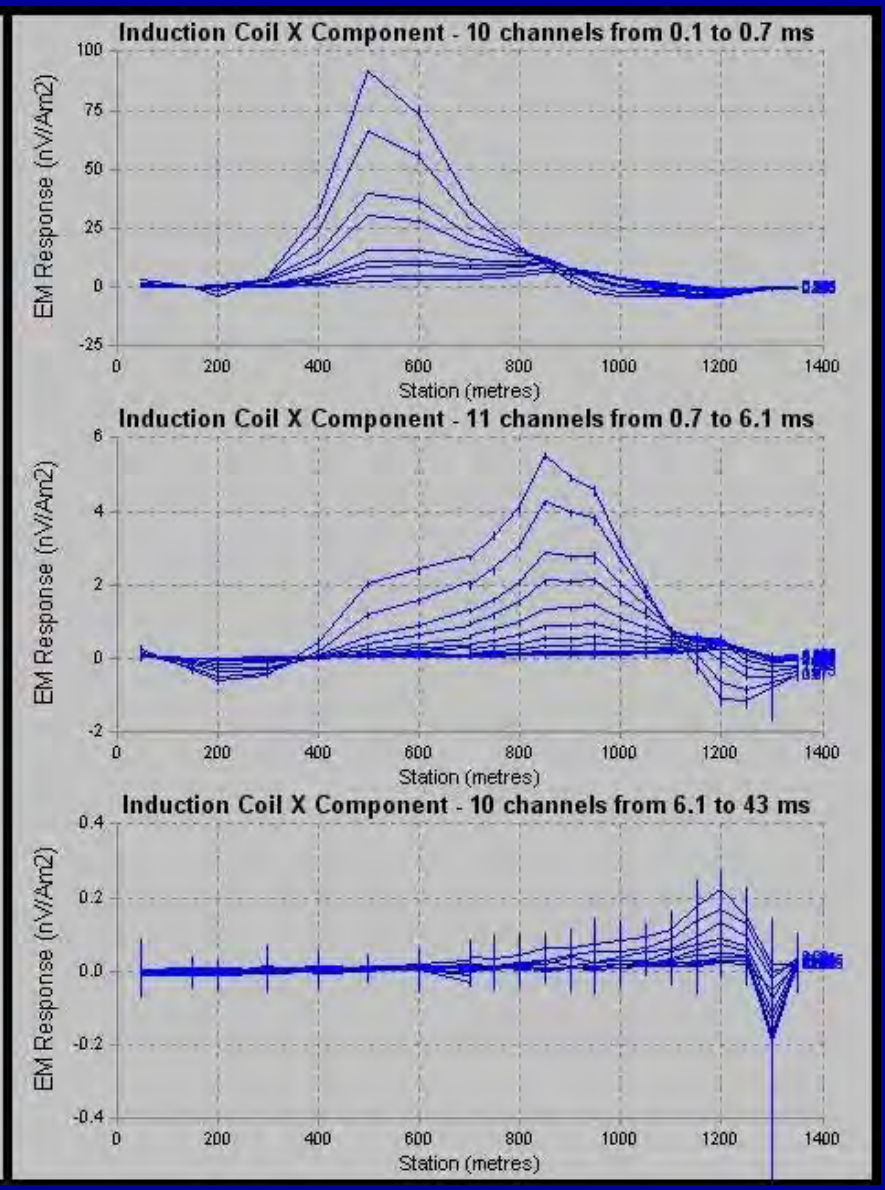




Fixed Loop - X - SQUID vs Coil

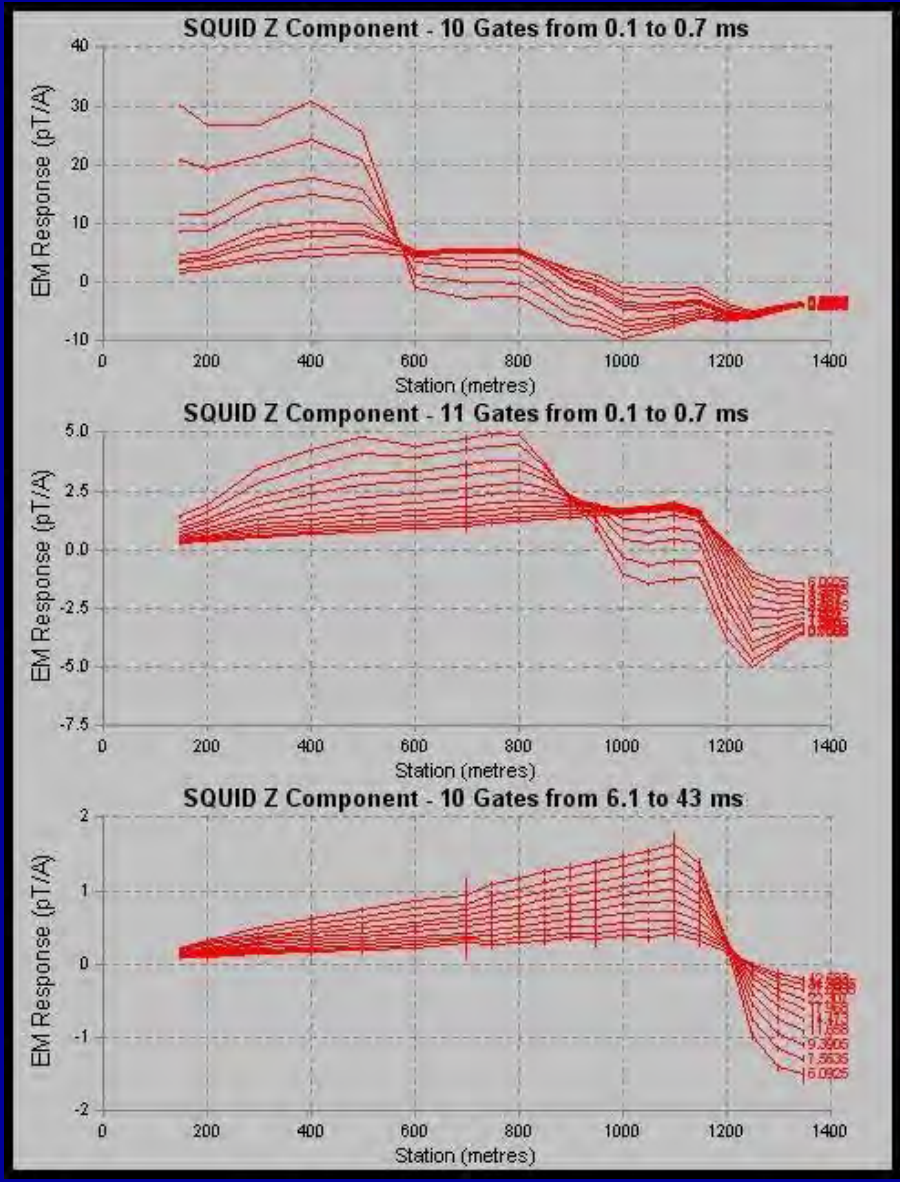
250m x 250m Loop, 24A, 0E-250E, Depth = <100m

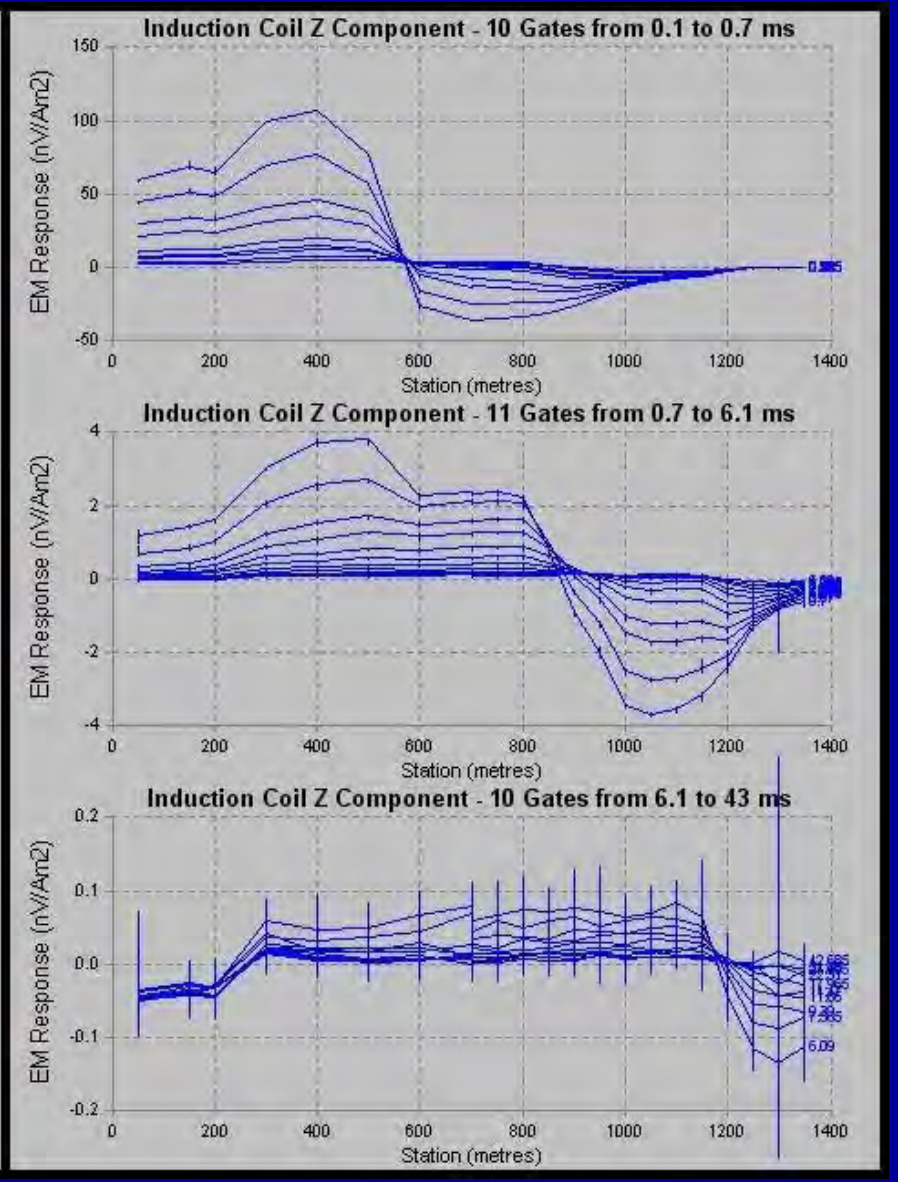




Fixed Loop - Z - SQUID vs Coil

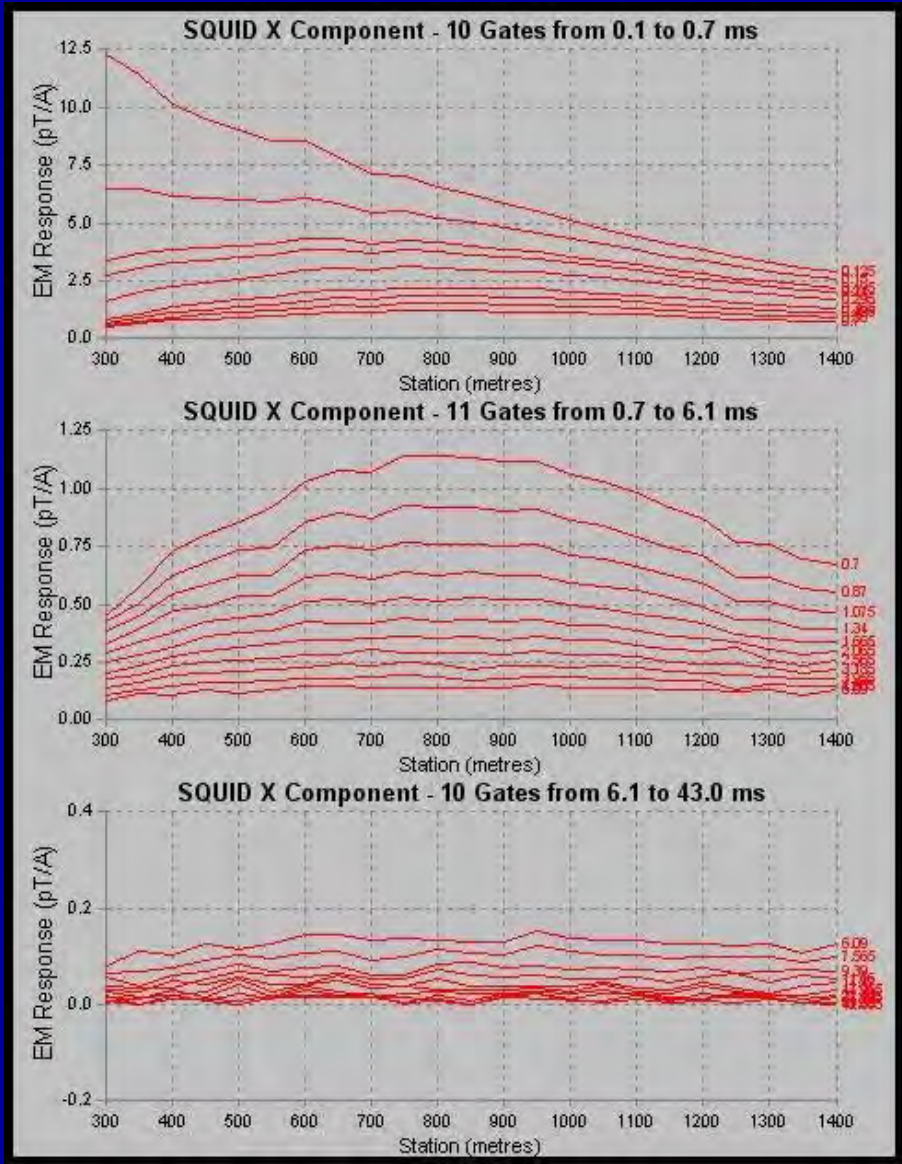
250m x 250m Loop, 24A, 0E-250E, Depth = <100m

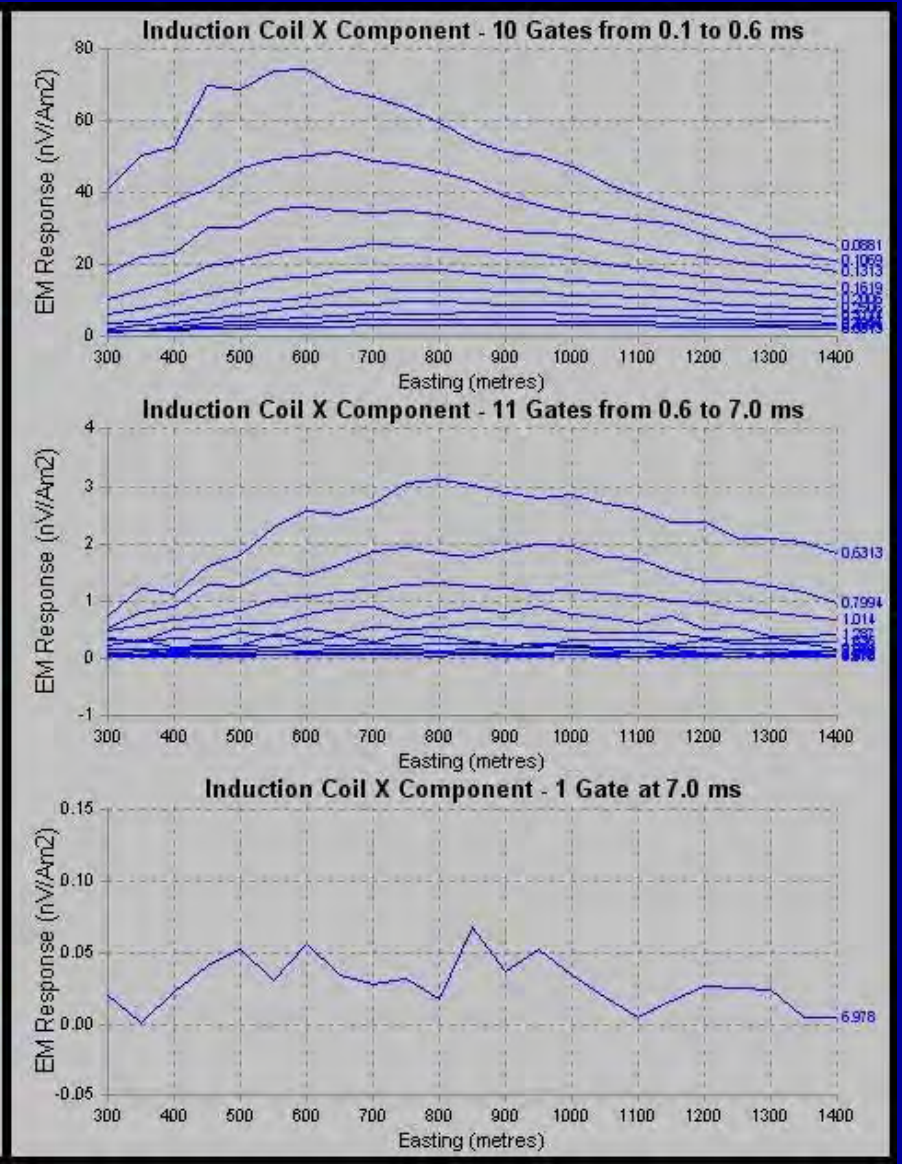




Fixed Loop - X - SQUID vs Coil

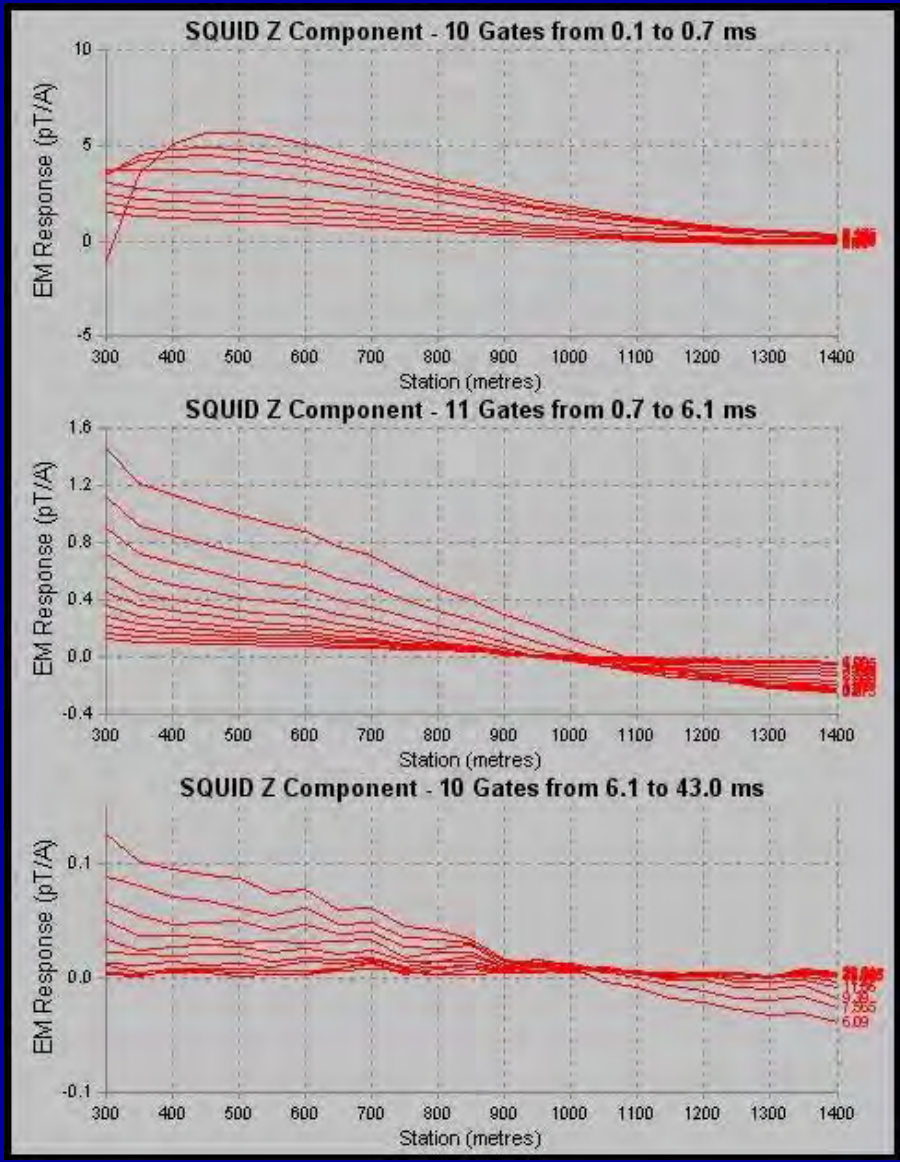
400m x 400m Loop, 22A, 200W-200E, Depth = 550m

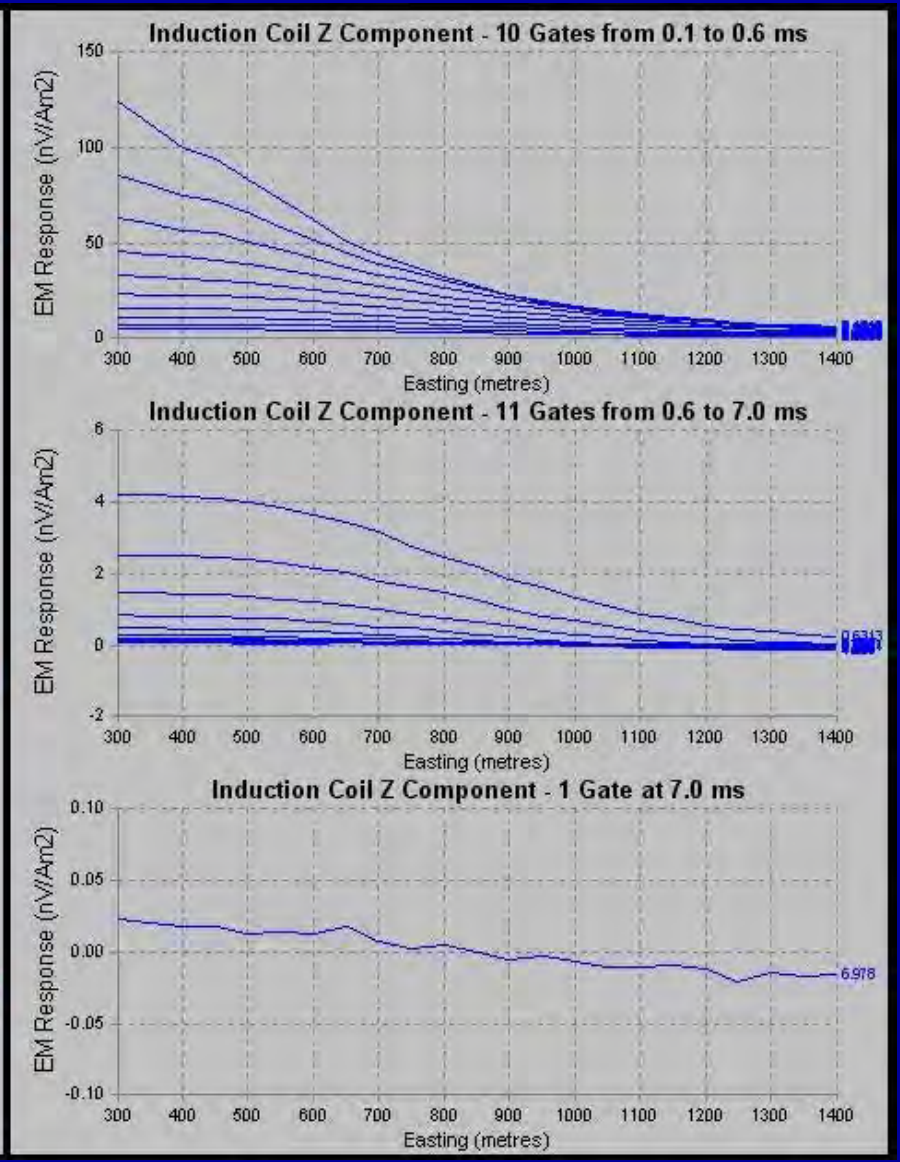




Fixed Loop - Z - SQUID vs Coil

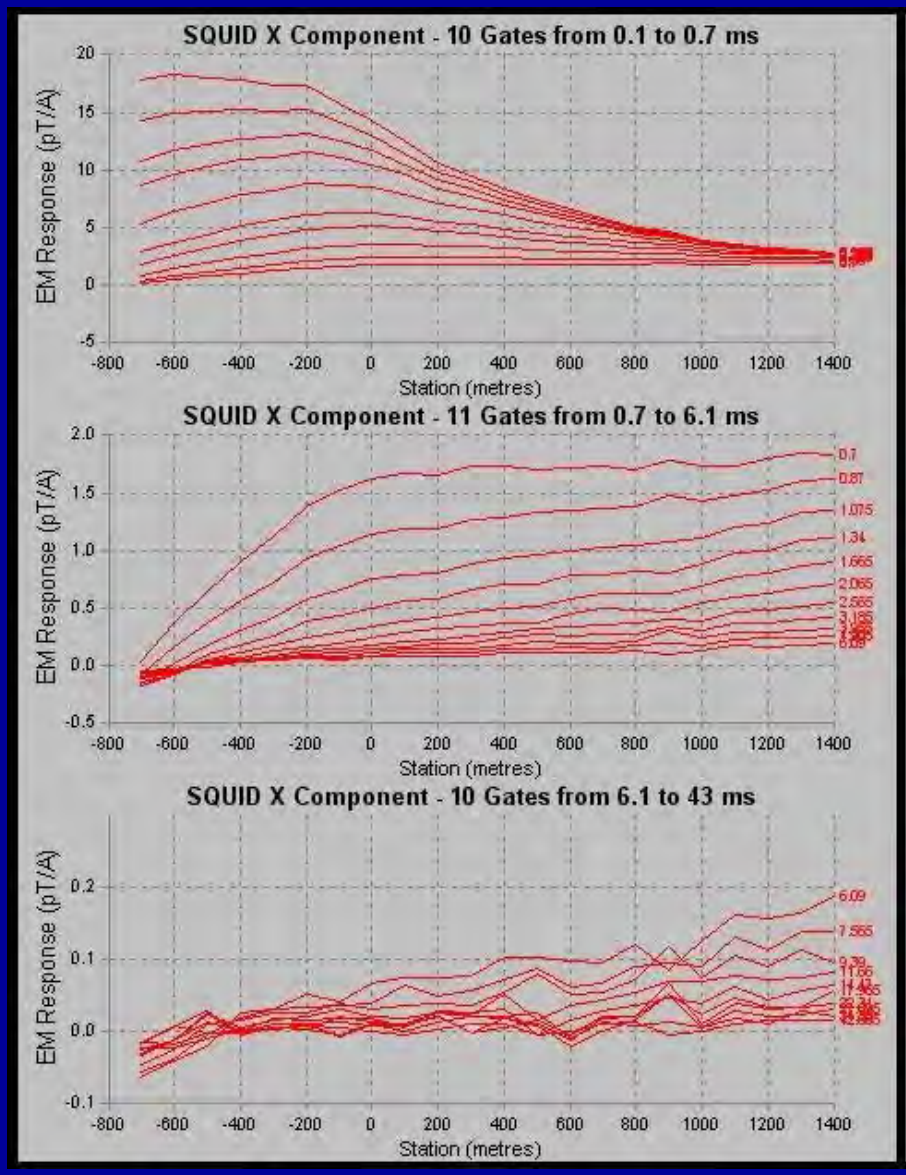
400m x 400m Loop, 22A, 200W-200E, Depth = 550m

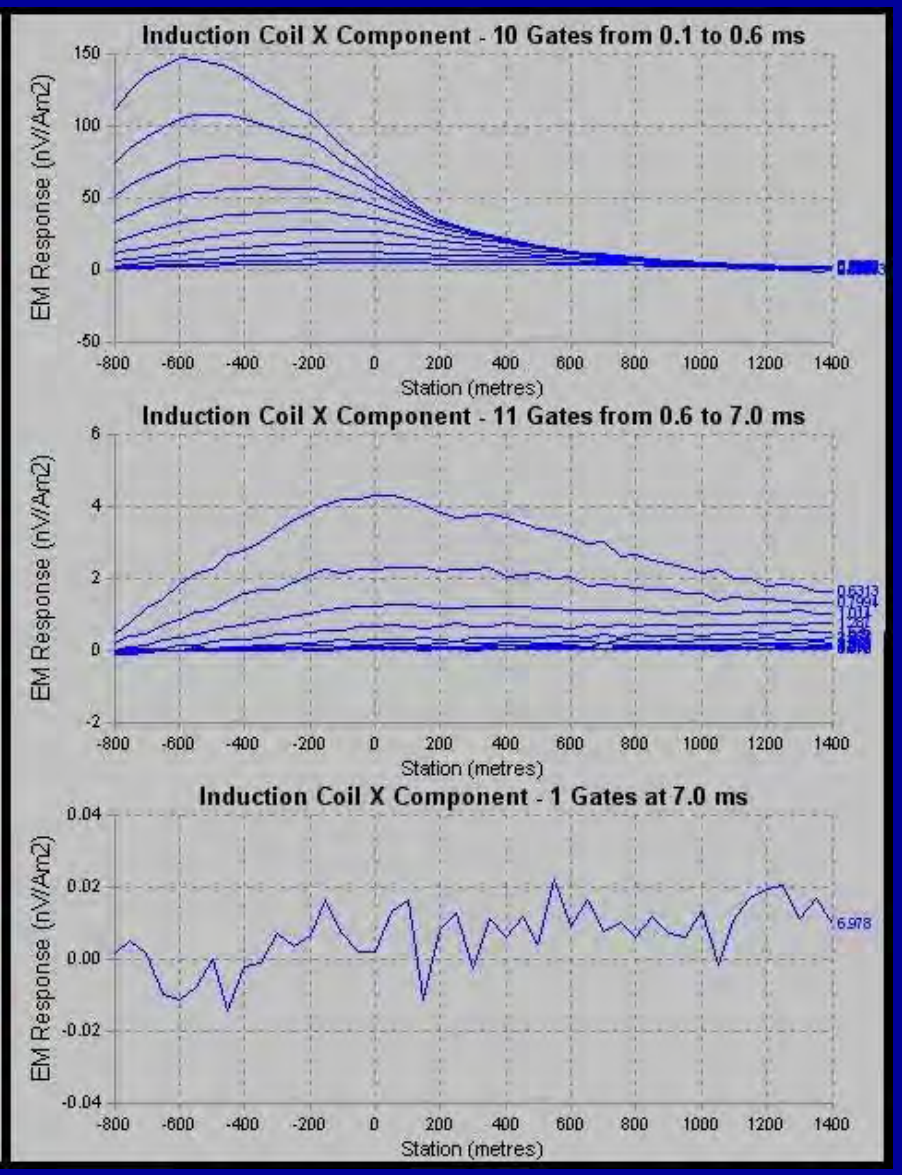




Fixed Loop - X - SQUID vs Coil

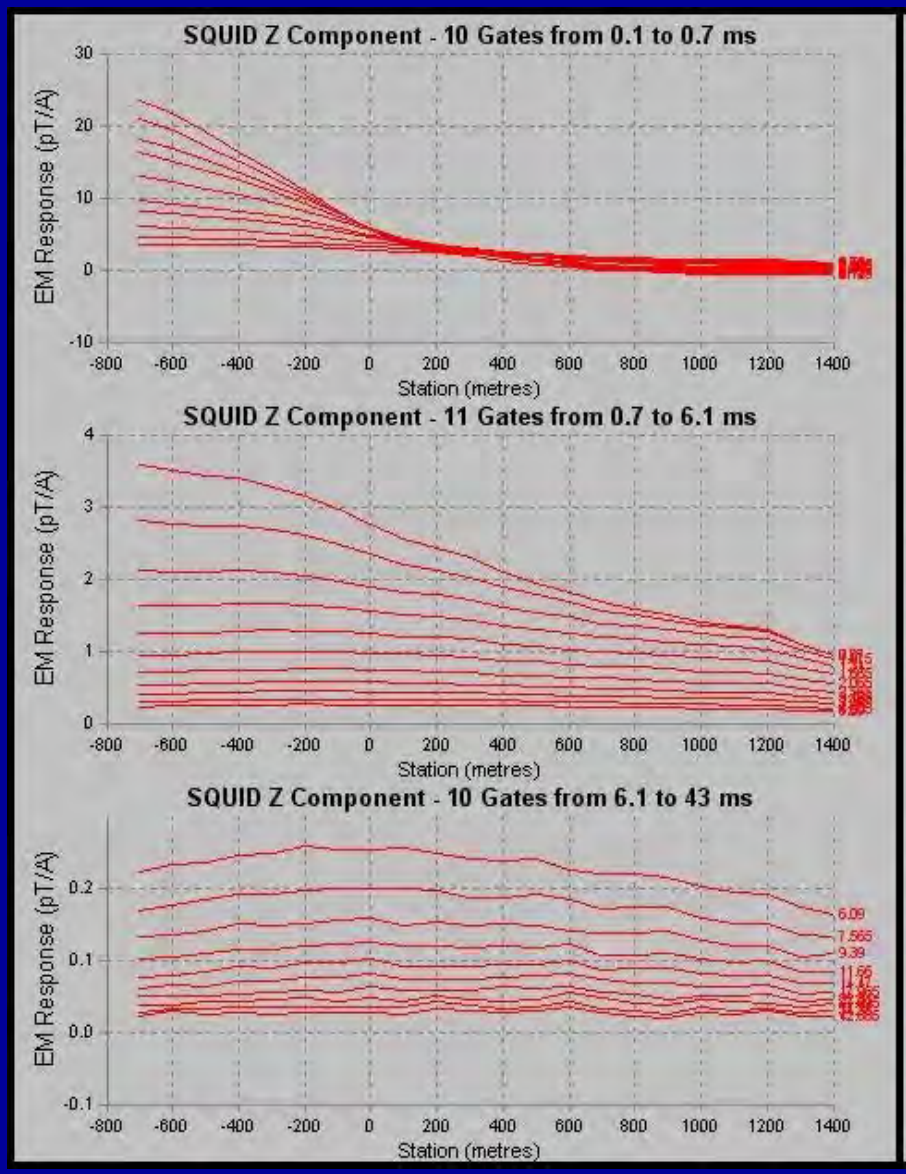
600m x 800m Loop, 16A, 1400S-800S, Depth = 500m

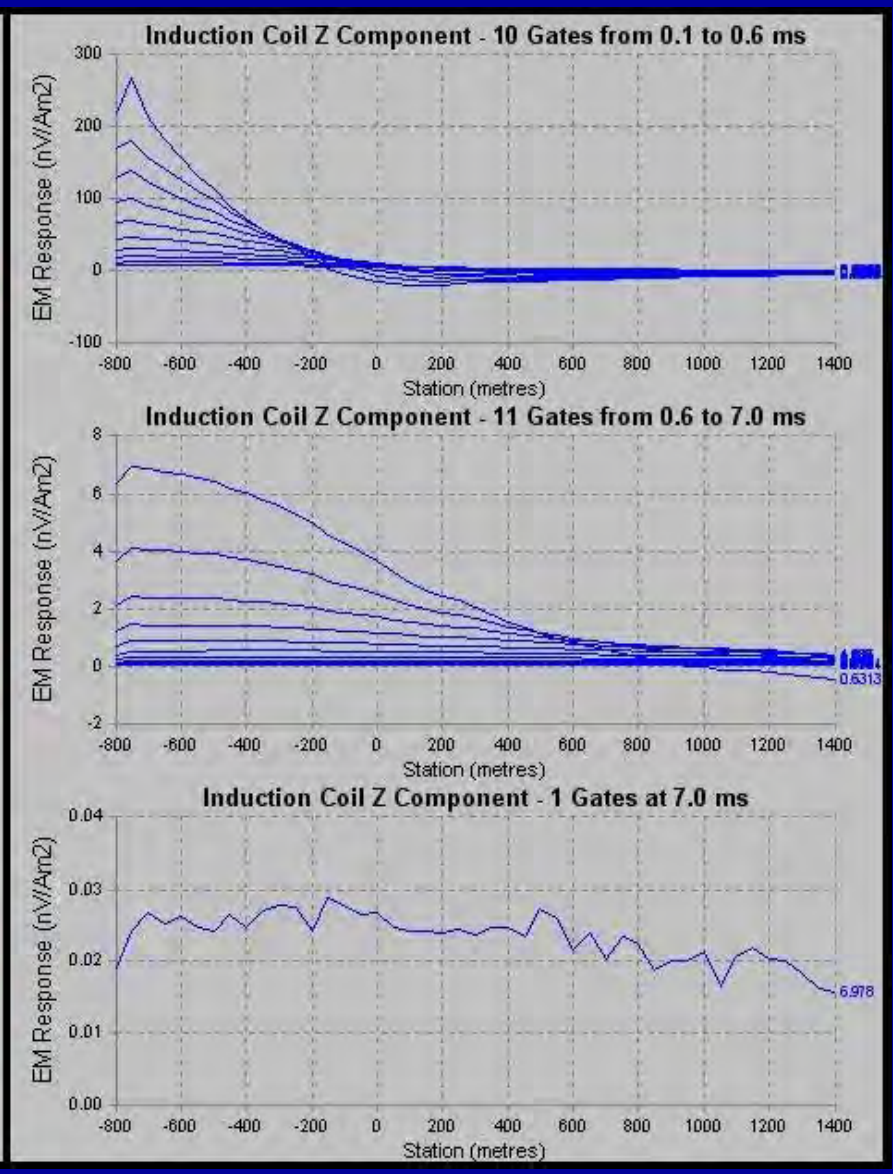




Fixed Loop - Z - SQUID vs Coil

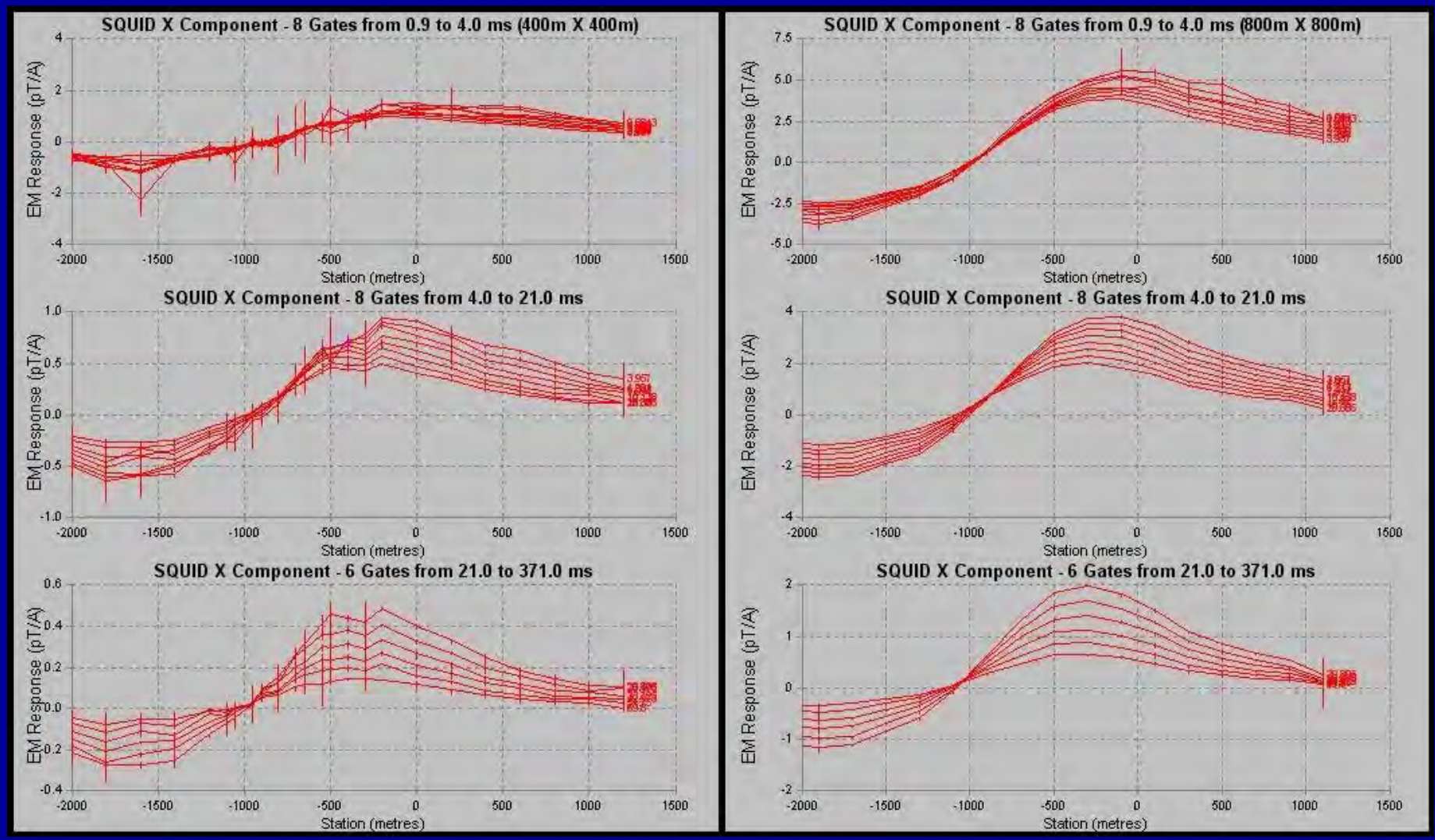
600m x 800m Loop, 16A, 1400S-800S, Depth = 500m





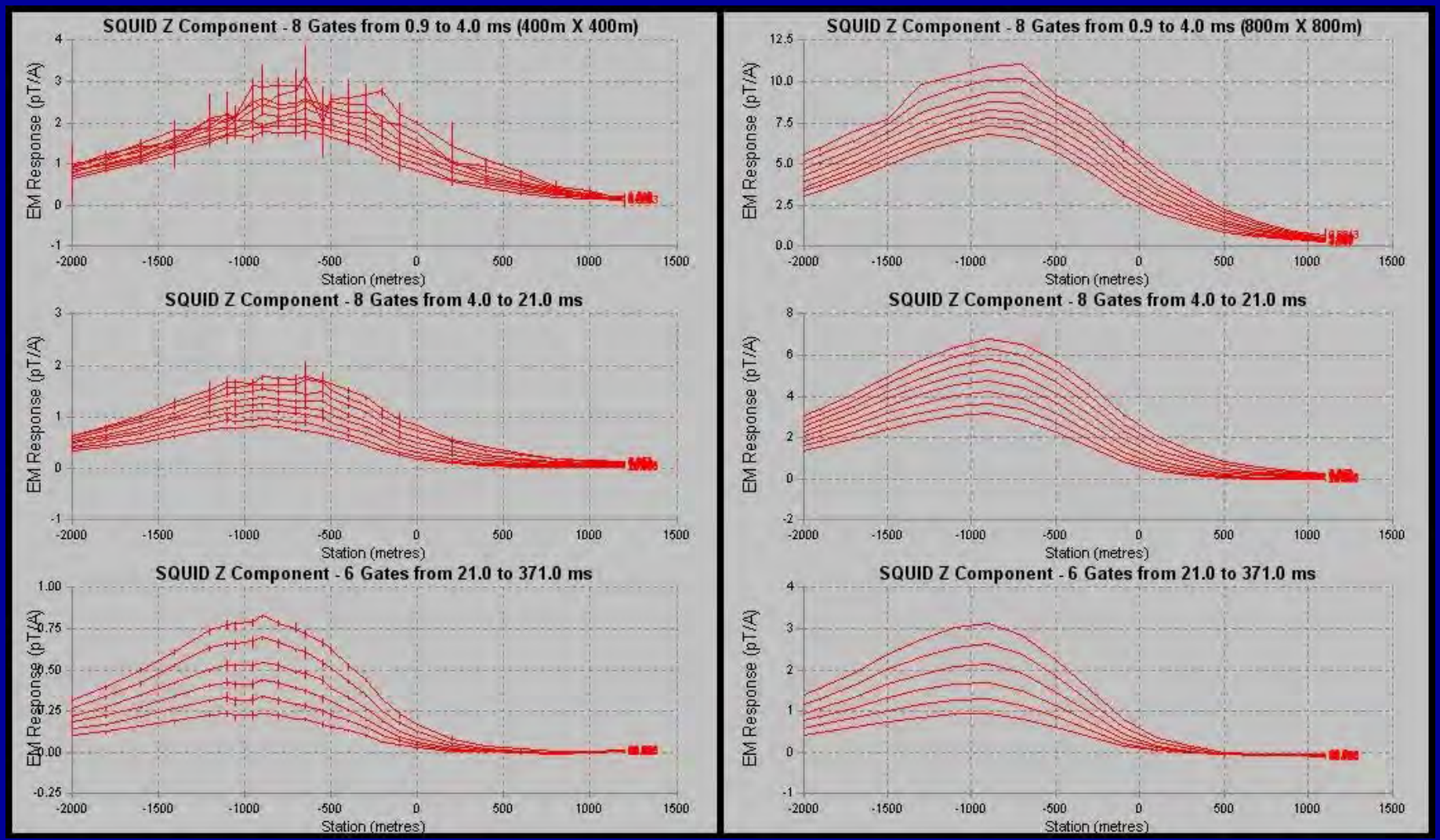
Fixed Loop - X - 400m vs 800m Loop

1000W-600W and 1400W-600W, 18A, Depth = 750m



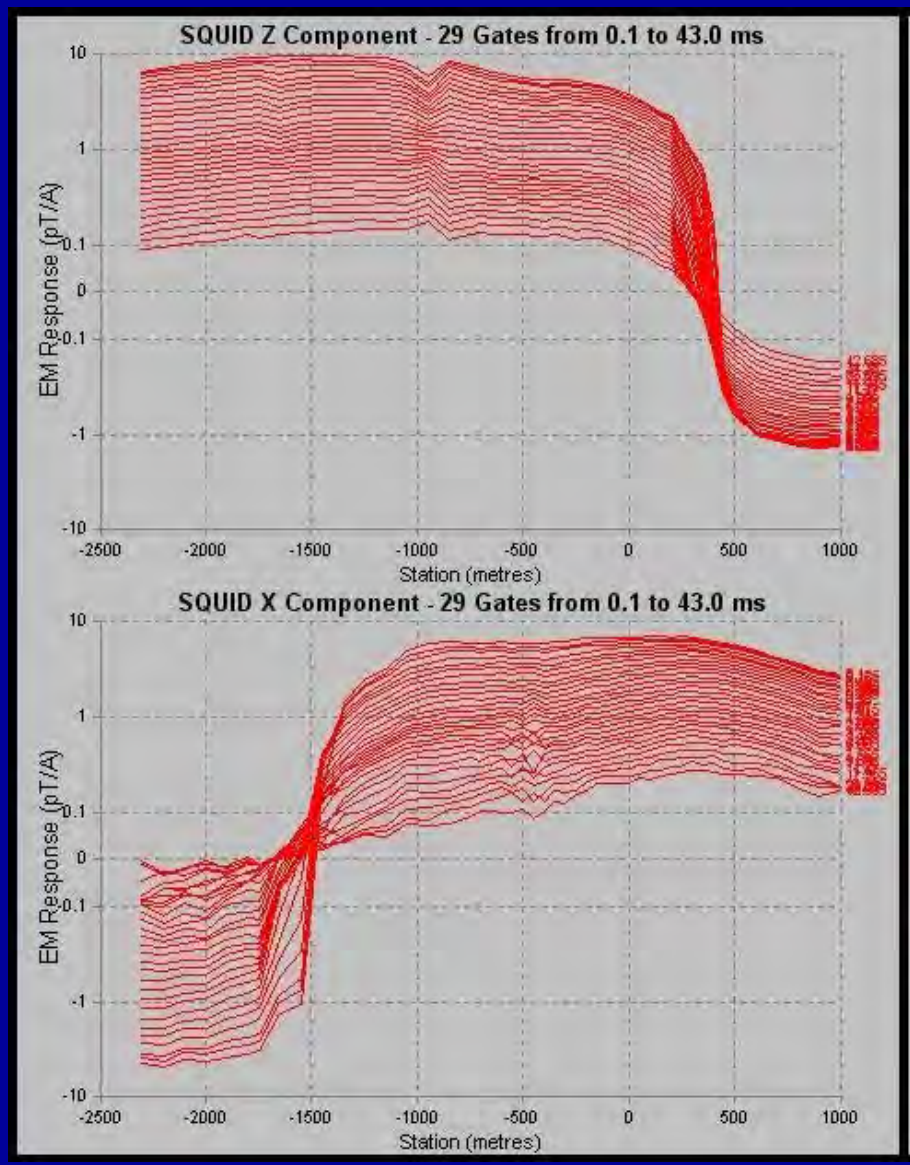
Fixed Loop - Z - 400m vs 800m Loop

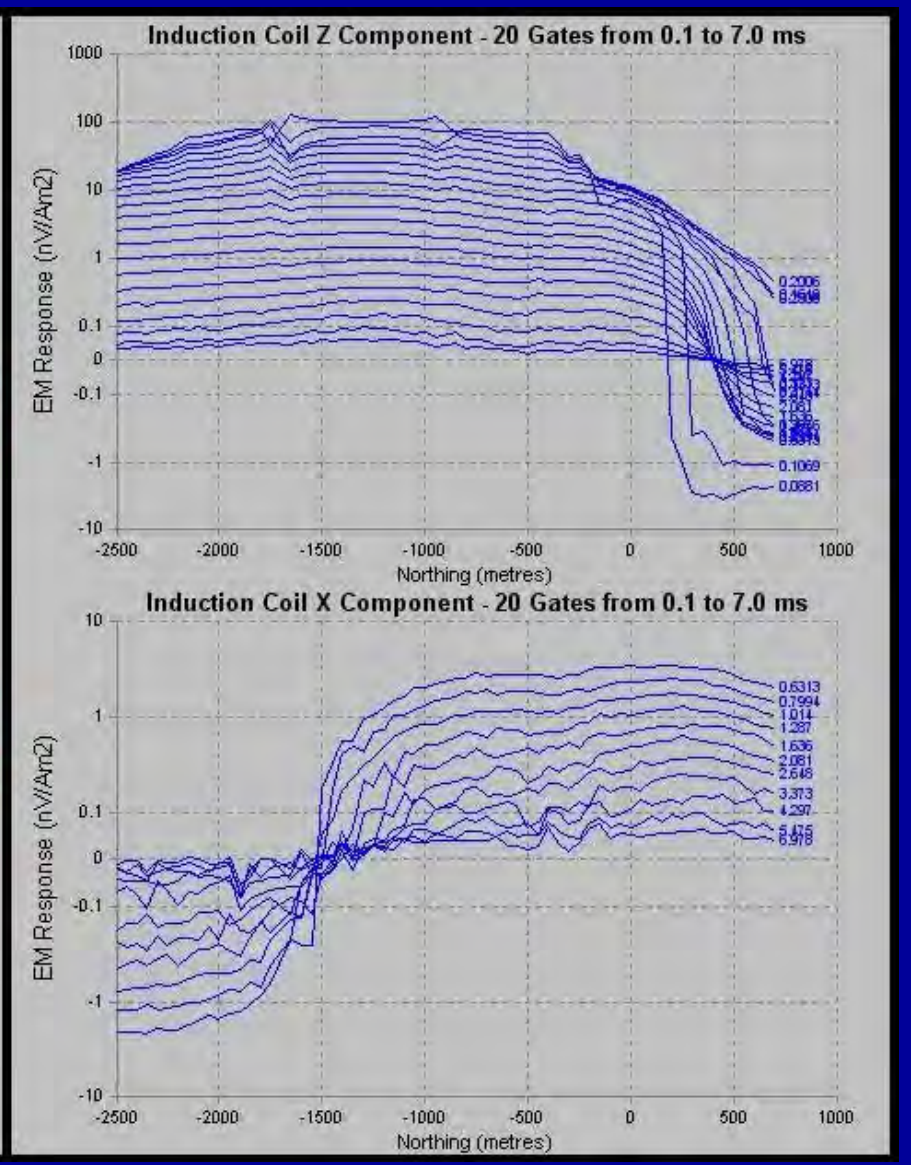
1000W-600W and 1400W-600W, 18A, Depth = 750m



Fixed Loop - Z & X - SQUID vs Coil

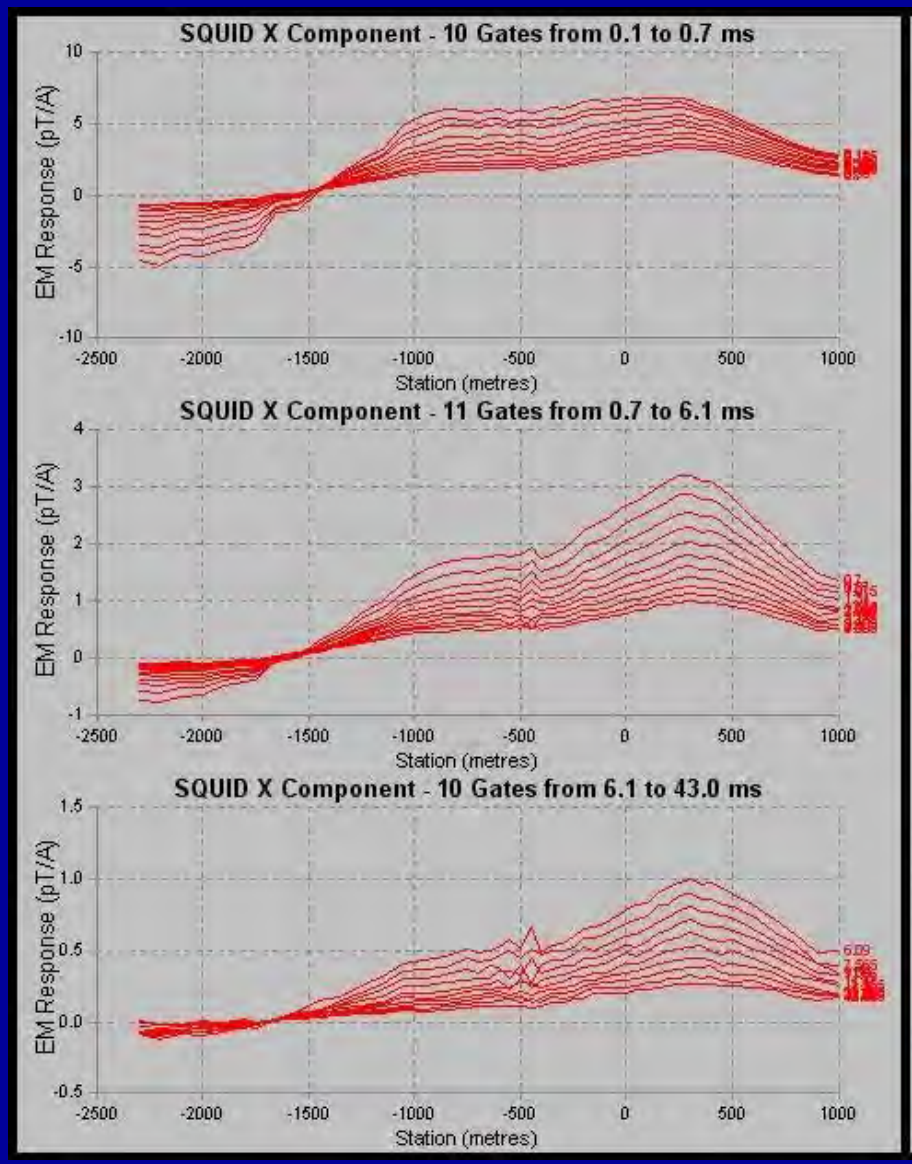
800m x 1200m Loop, 13A, 1600W-800W, Depth = 500m

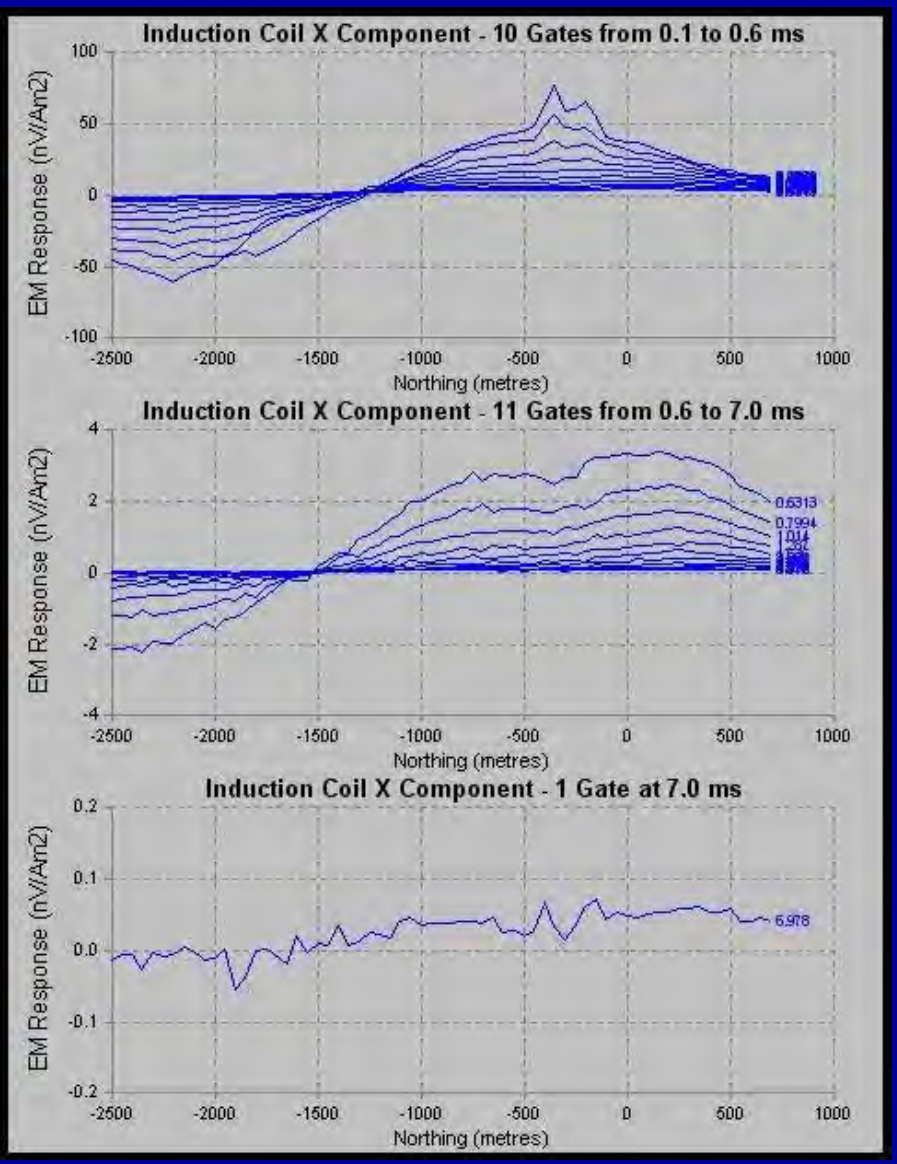




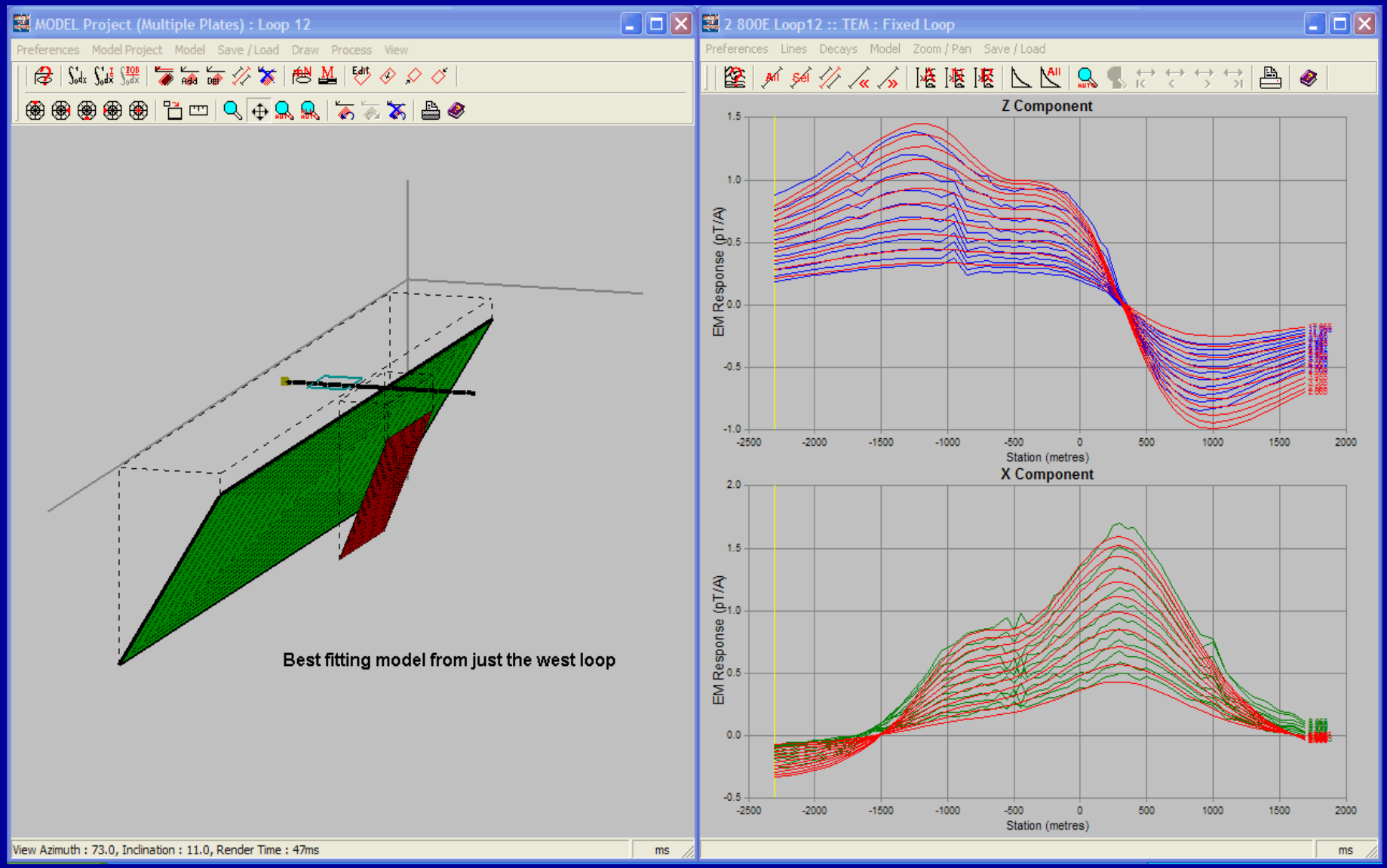
Fixed Loop - X - SQUID vs Coil

800m x 1200m Loop, 13A, 1600W-800W, Depth = 500m

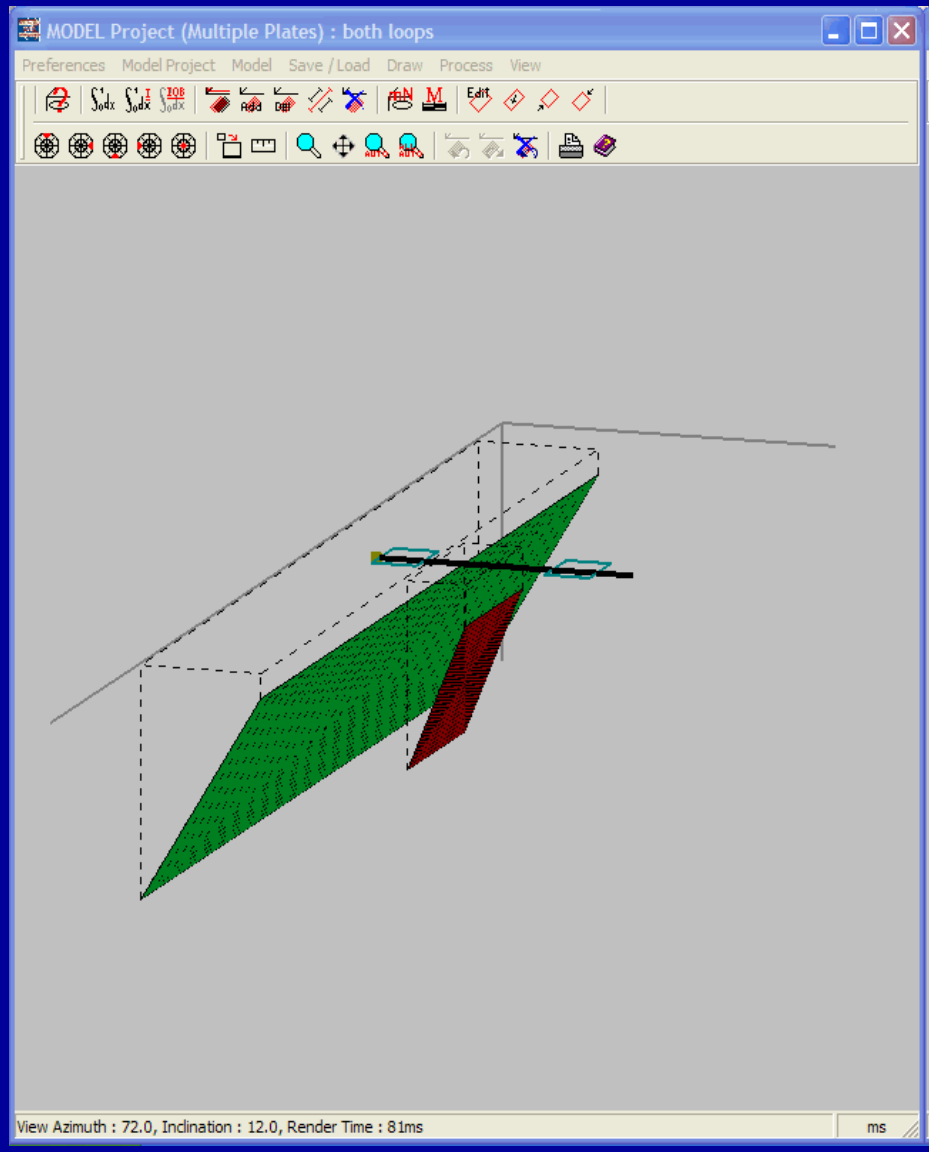


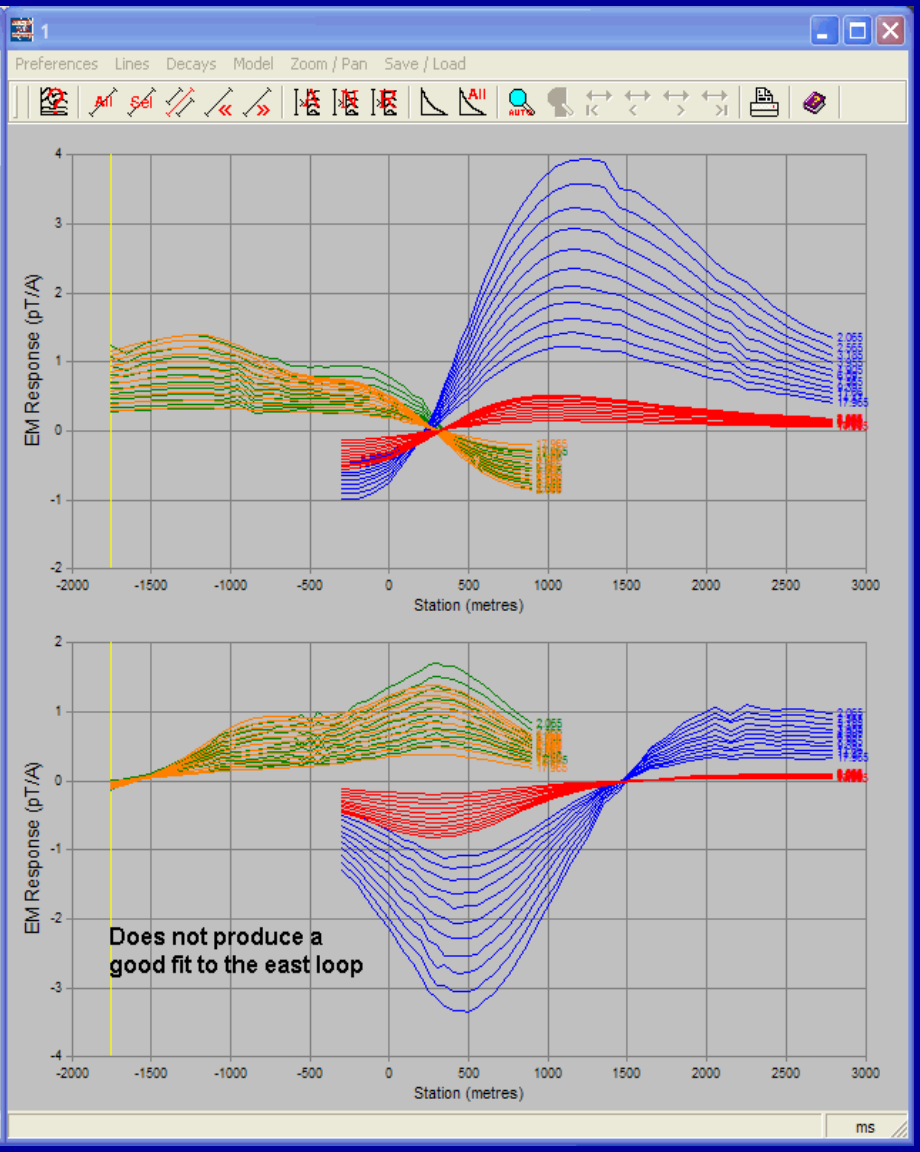


SQUID TEM Modelling - West Loop - West Conductors

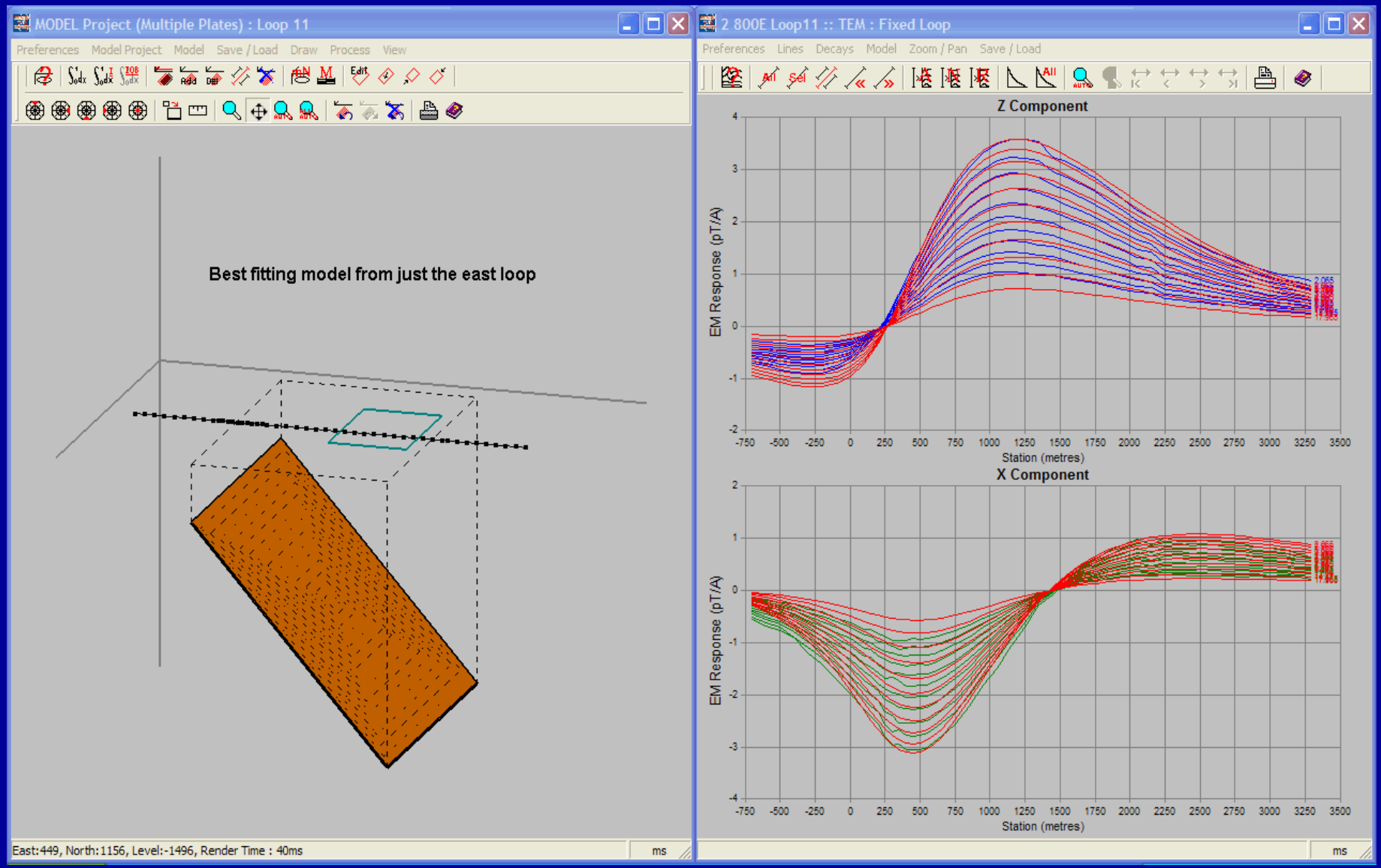


SQUID TEM Modelling - Both Loops - West Conductors

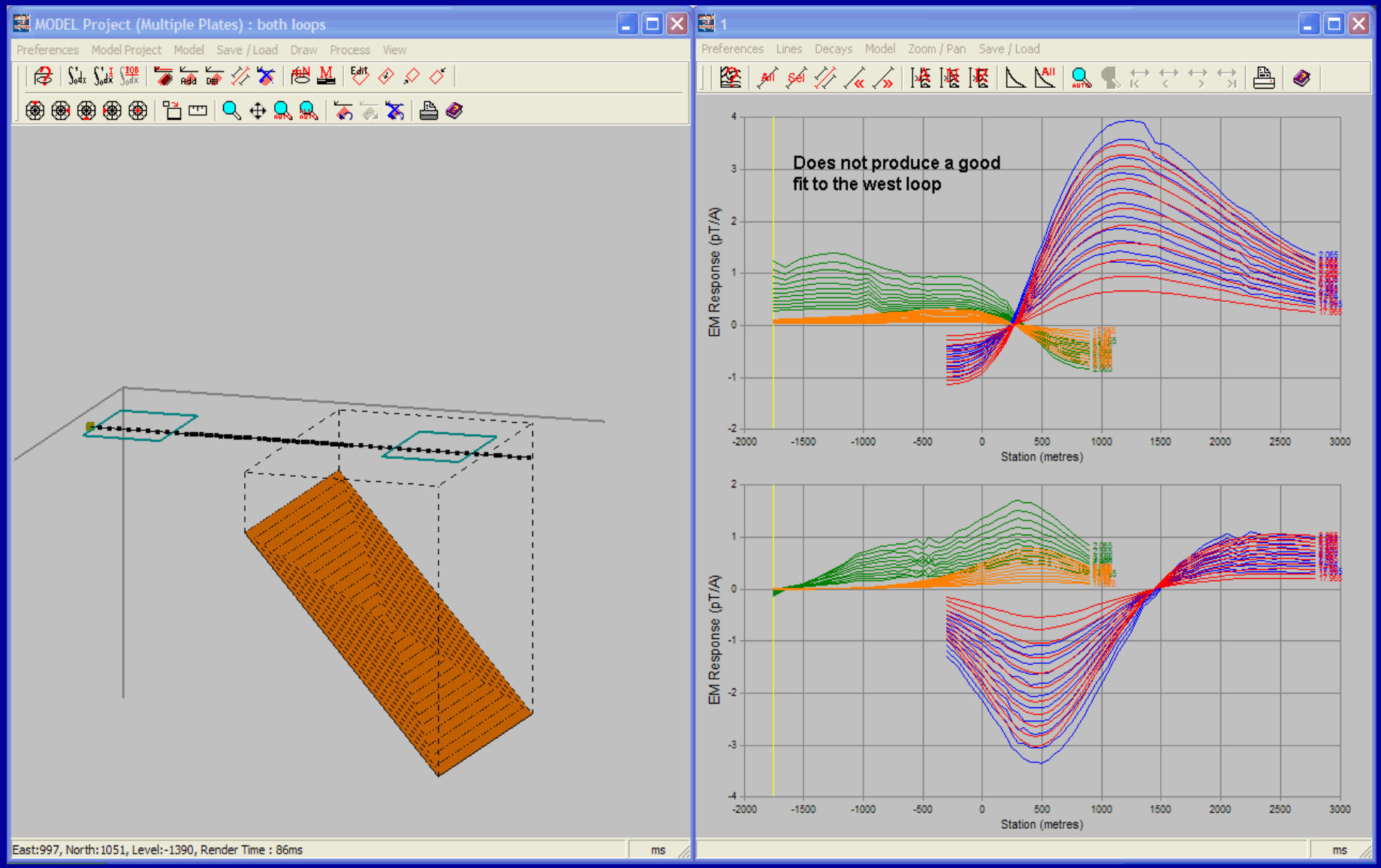




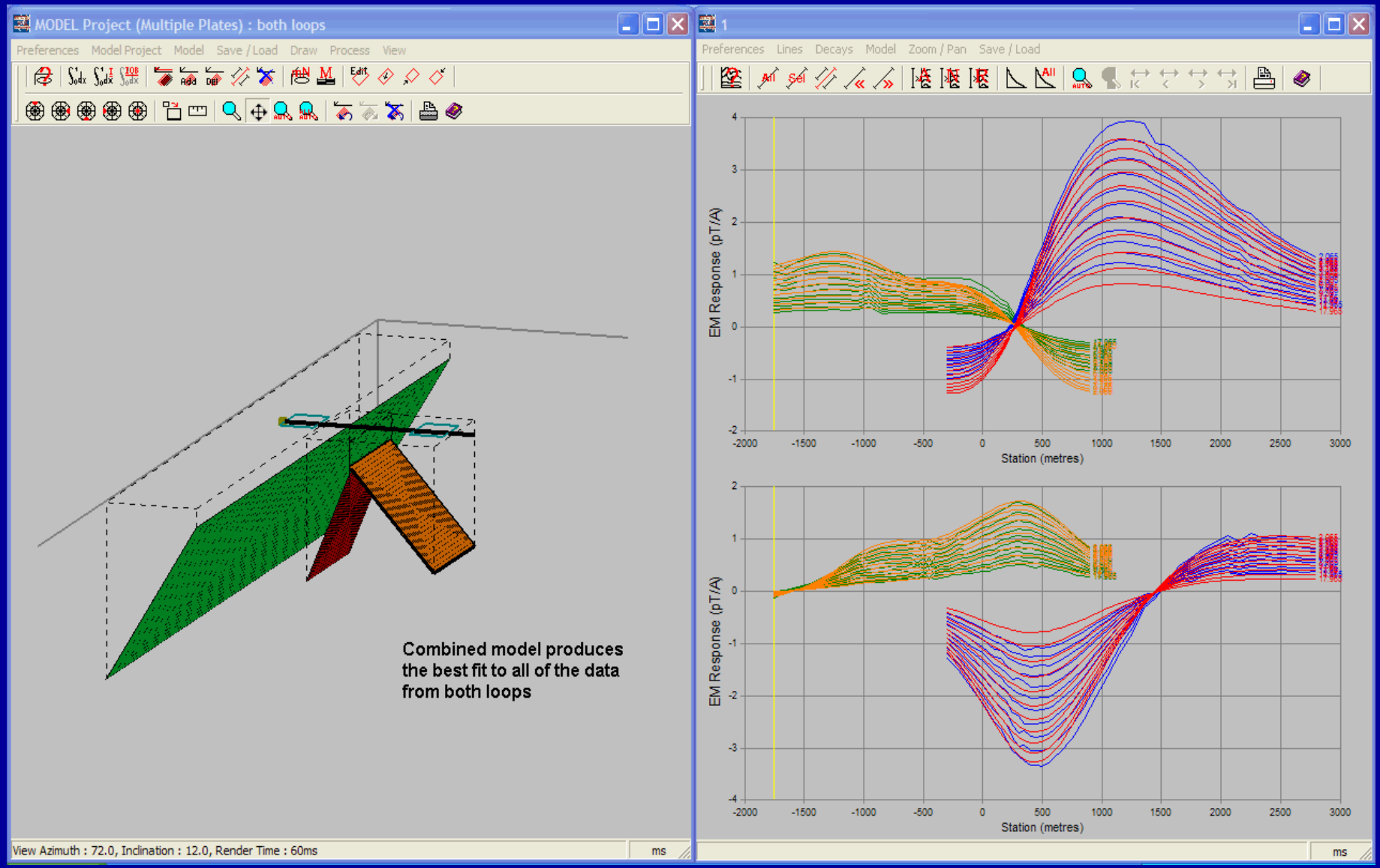
SQUID TEM Modelling - East Loop – East Conductor



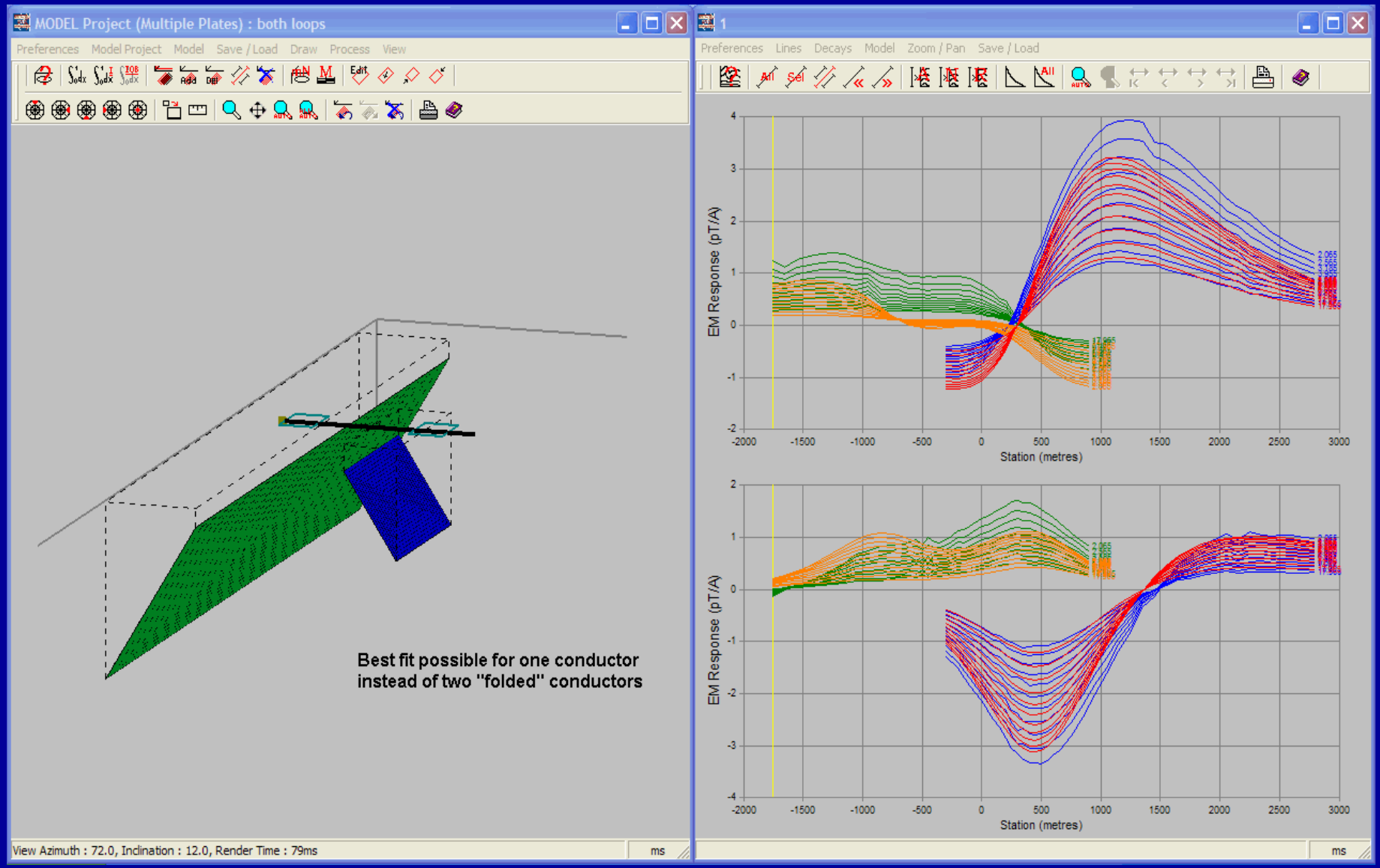
SQUID TEM Modelling - Both Loops - East Conductor



SQUID TEM Modelling - Both Loops - Both Conductors

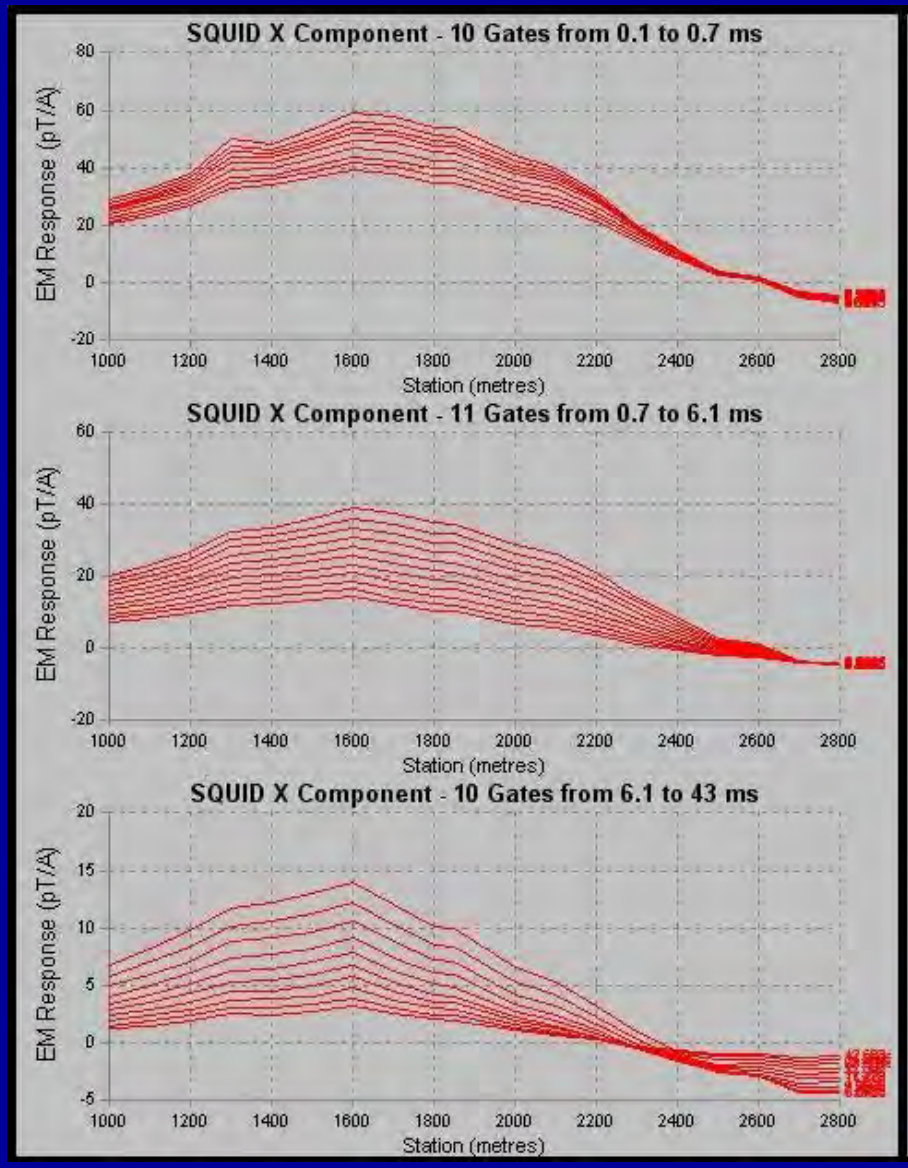


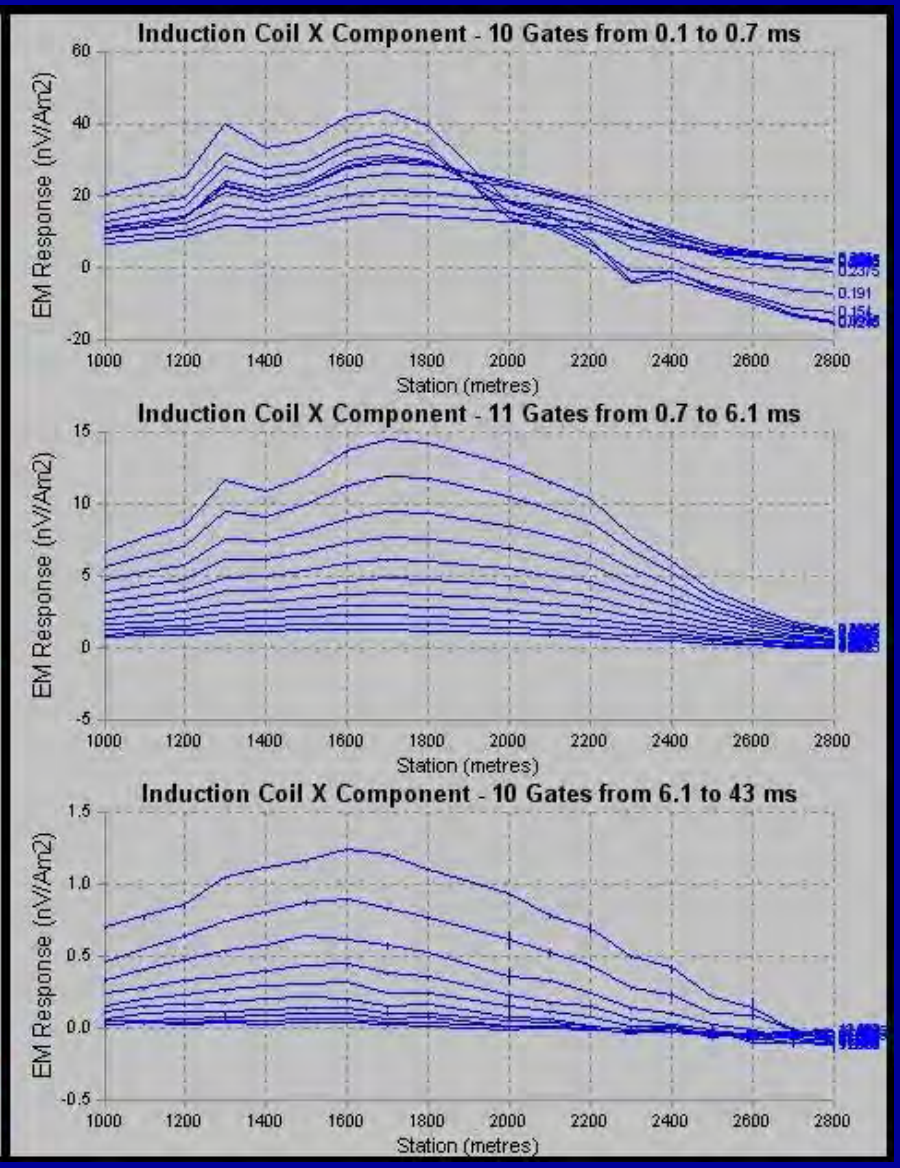
SQUID TEM Modelling - Both Loops - Two Conductor



Fixed Loop - X - SQUID vs Coil

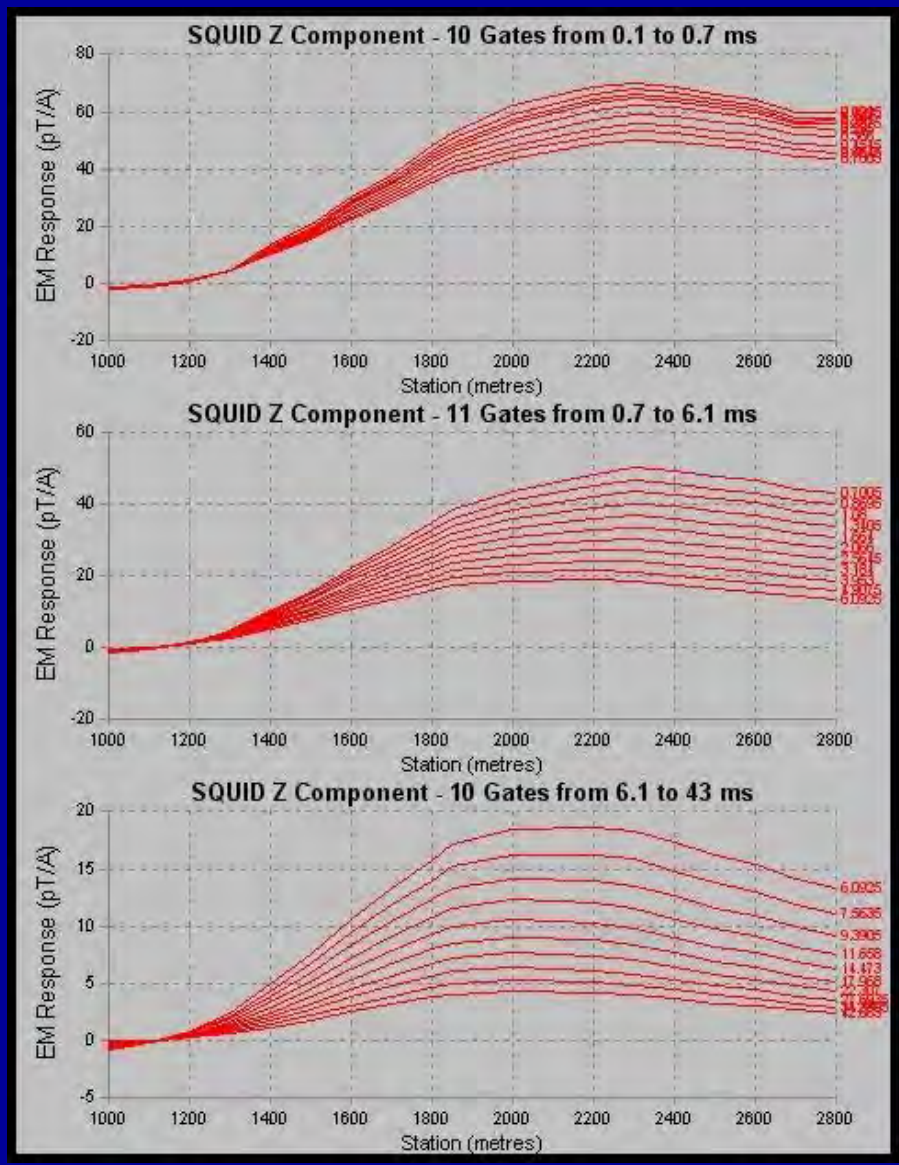
2000m x 2700m Loop, 20A, 1900E-3900E, Depth = 900-1200m

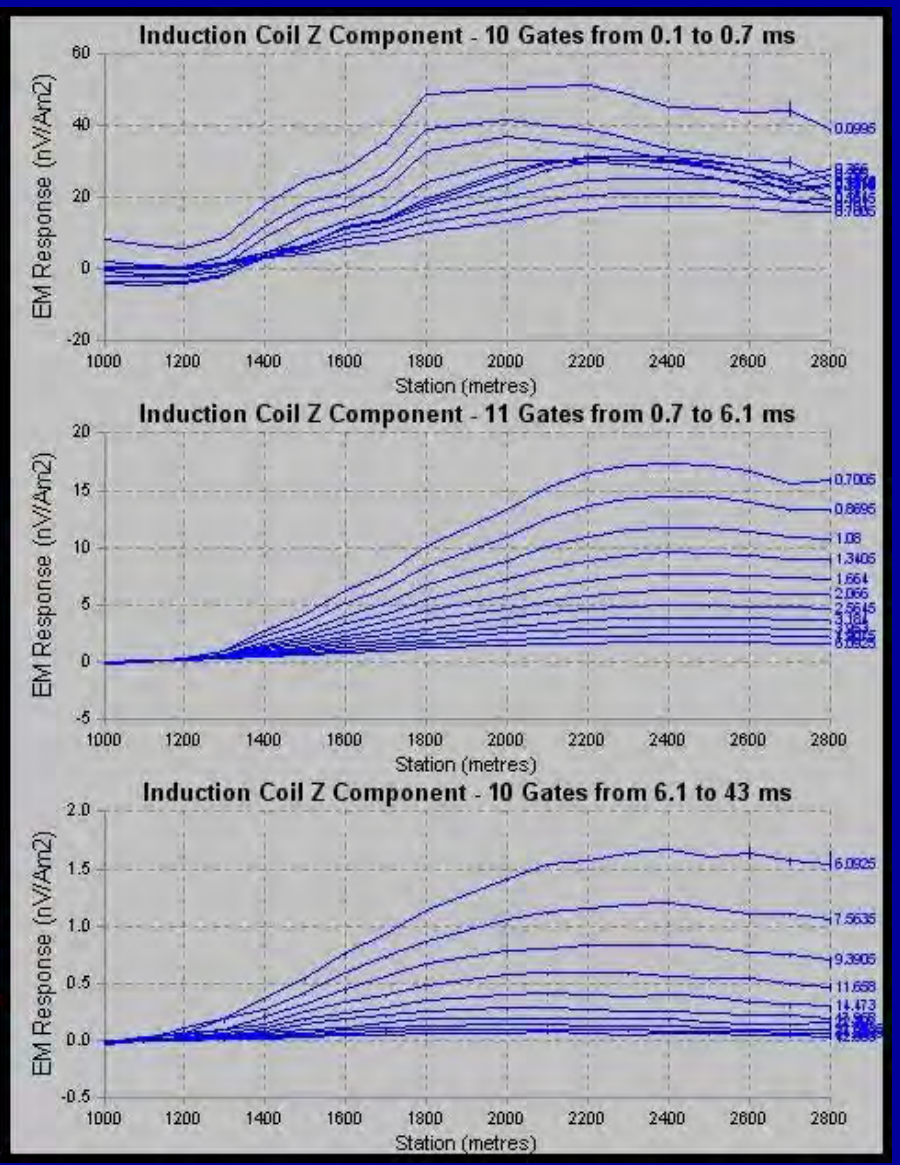




Fixed Loop - Z - SQUID vs Coil

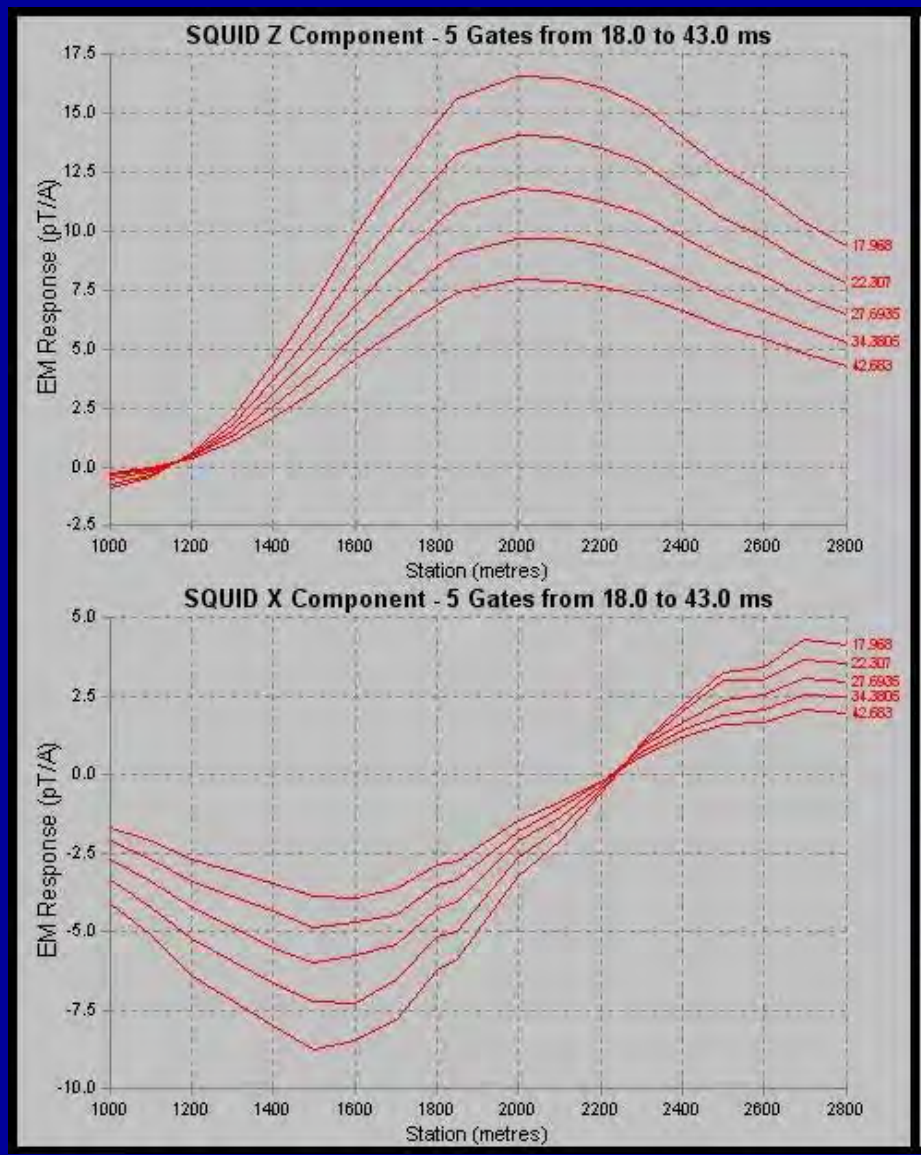
2000m x 2700m Loop, 20A, 1900E-3900E, Depth = 900-1200m

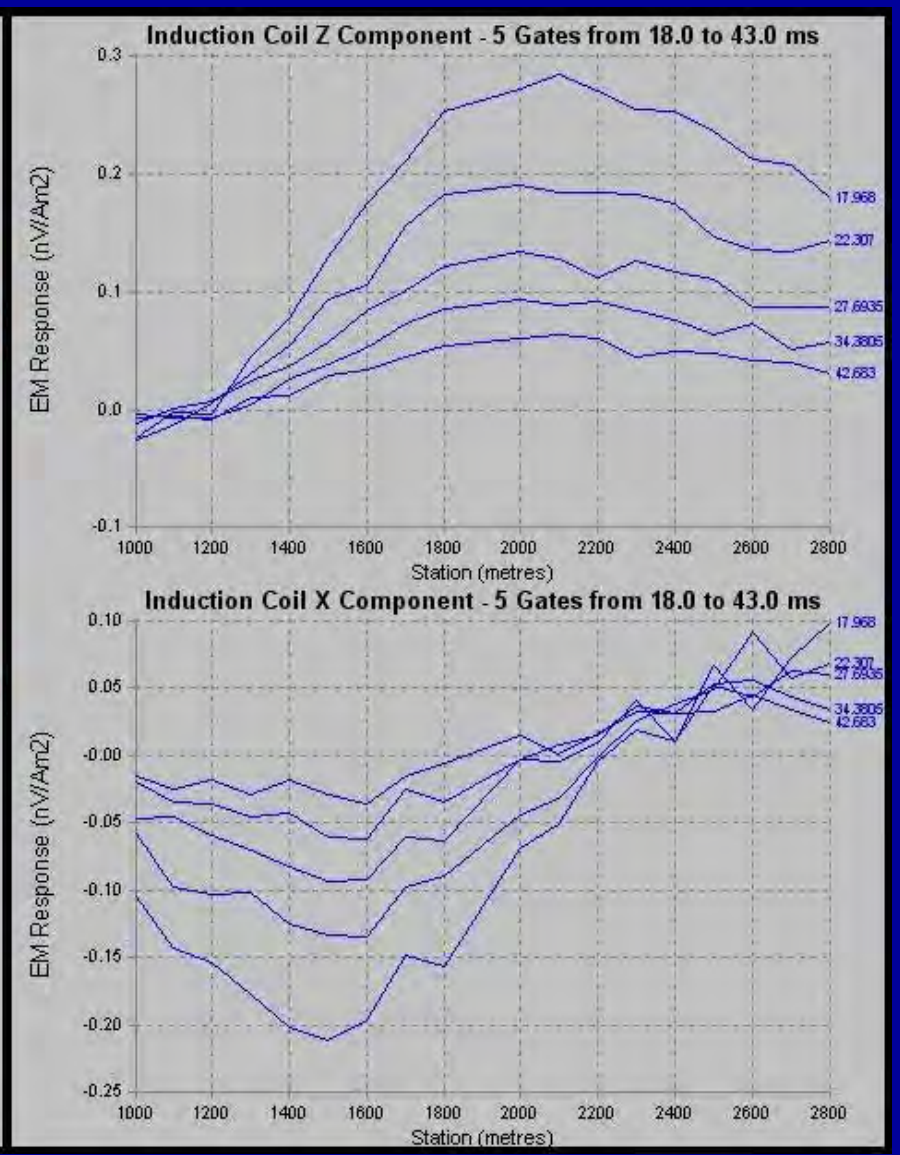




Fixed Loop - X & Z - SQUID vs Coil

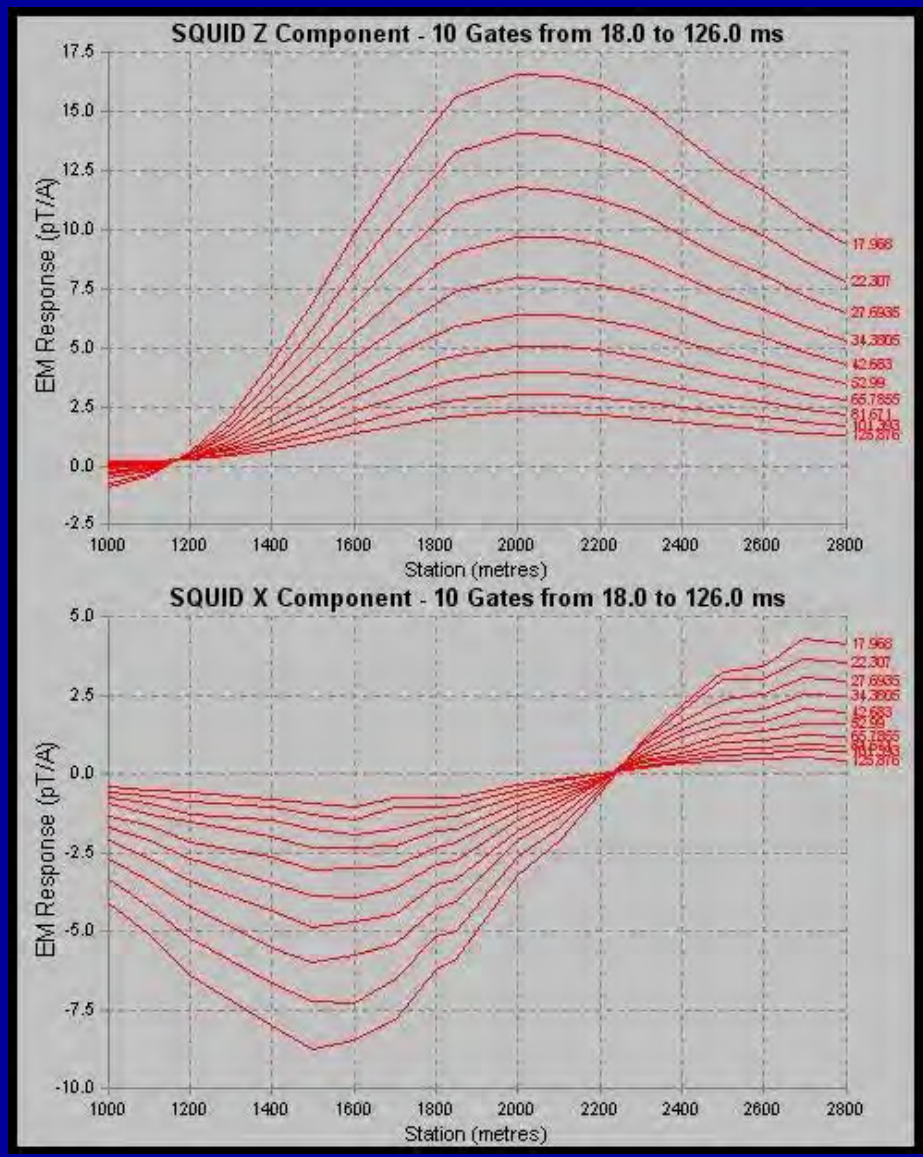
2000m x 2700m Loop, 20A, 1900E-3900E, Depth = 900-1200m

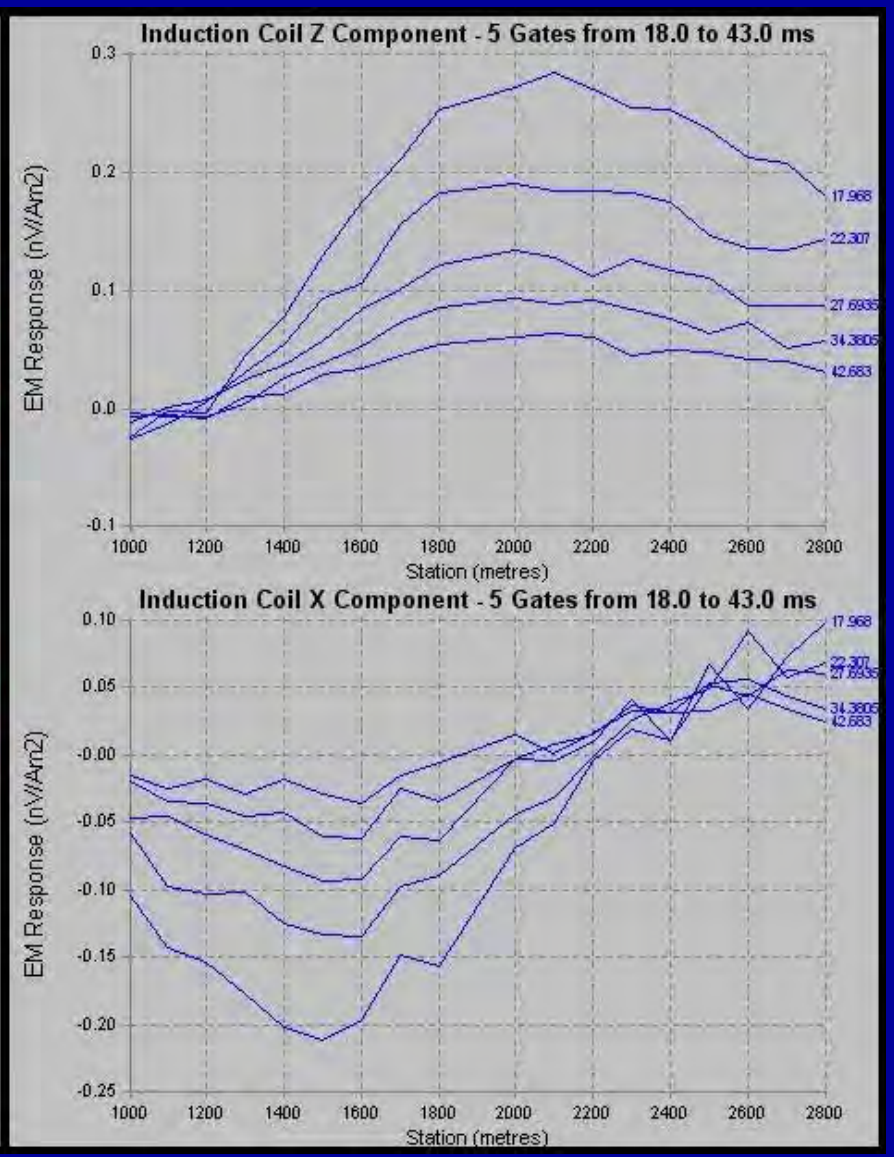




Fixed Loop - X & Z - SQUID vs Coil

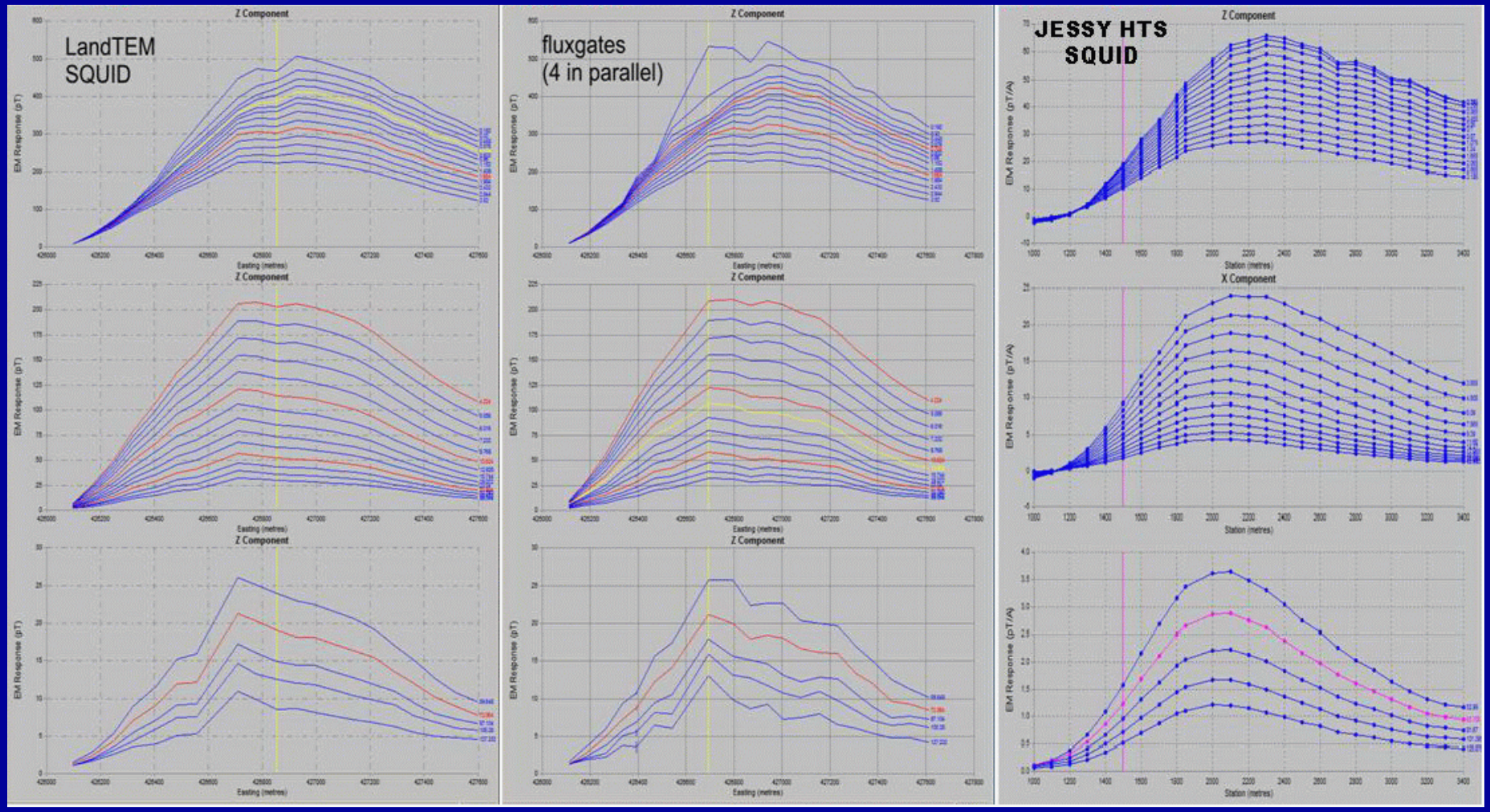
2000m x 2700m Loop, 20A, 1900E-3900E, Depth = 900-1200m



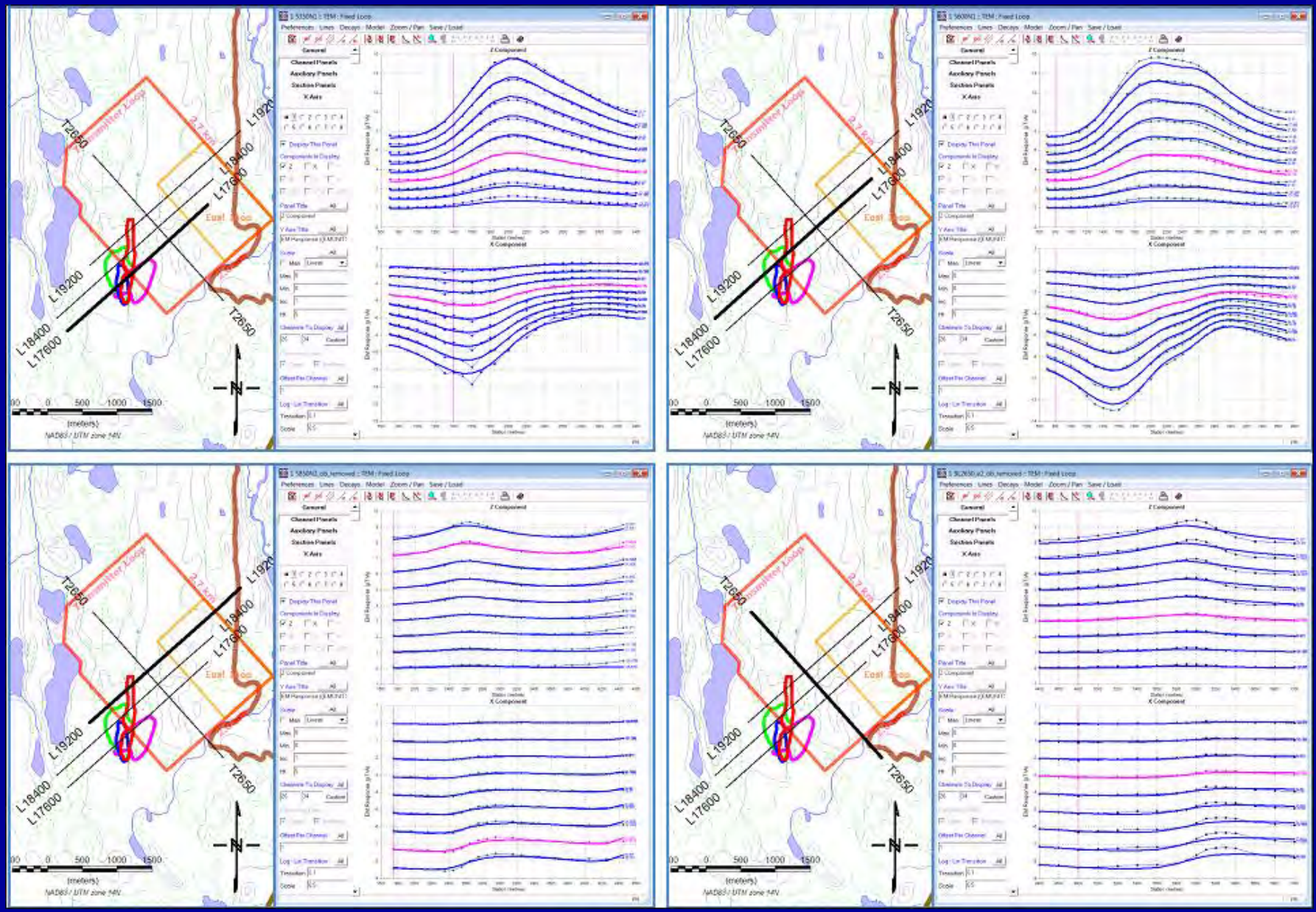


Fixed Loop - Z
LandTEM vs fluxgates vs Jessy

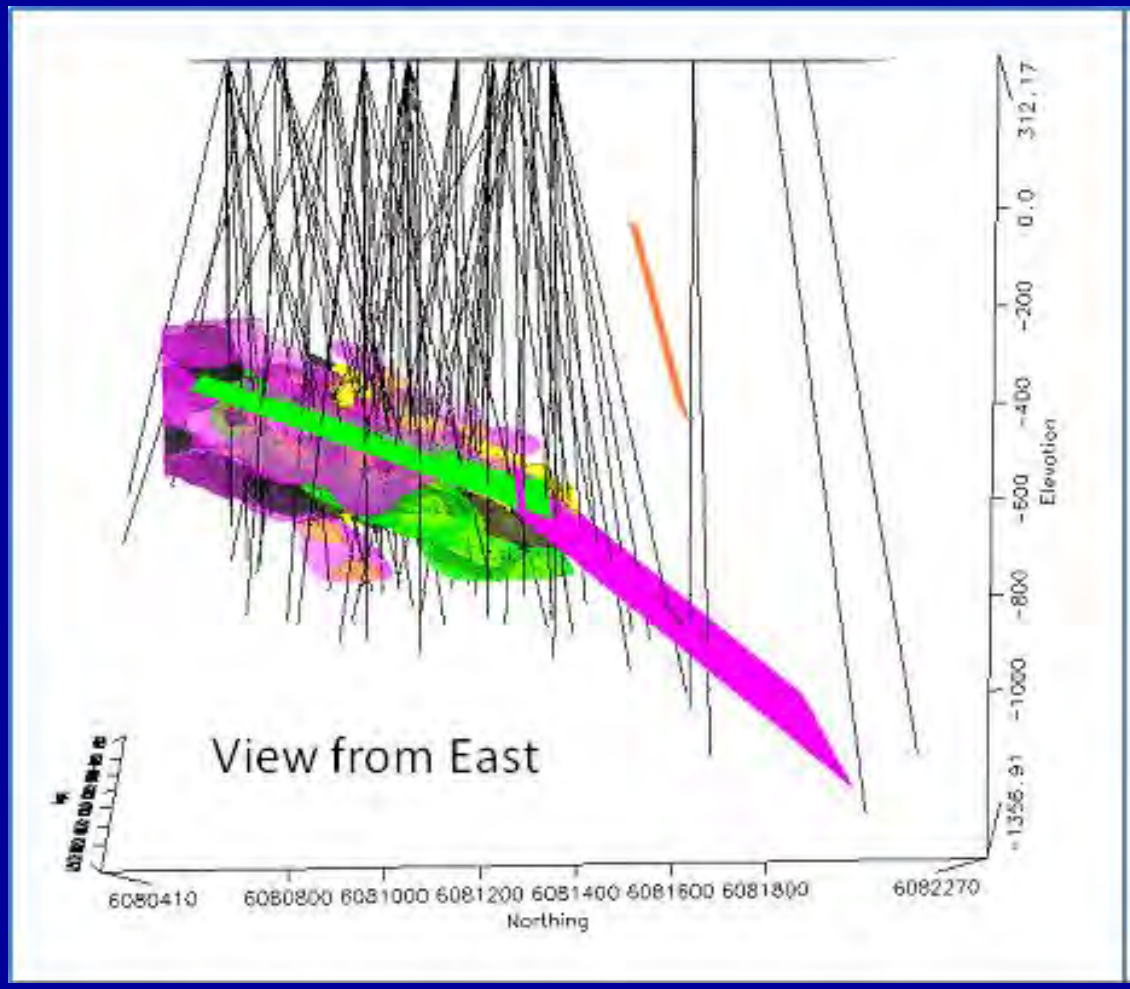
2000m x 2700m Loop, 20A, 1900E-3900E, Depth = 900-1200m

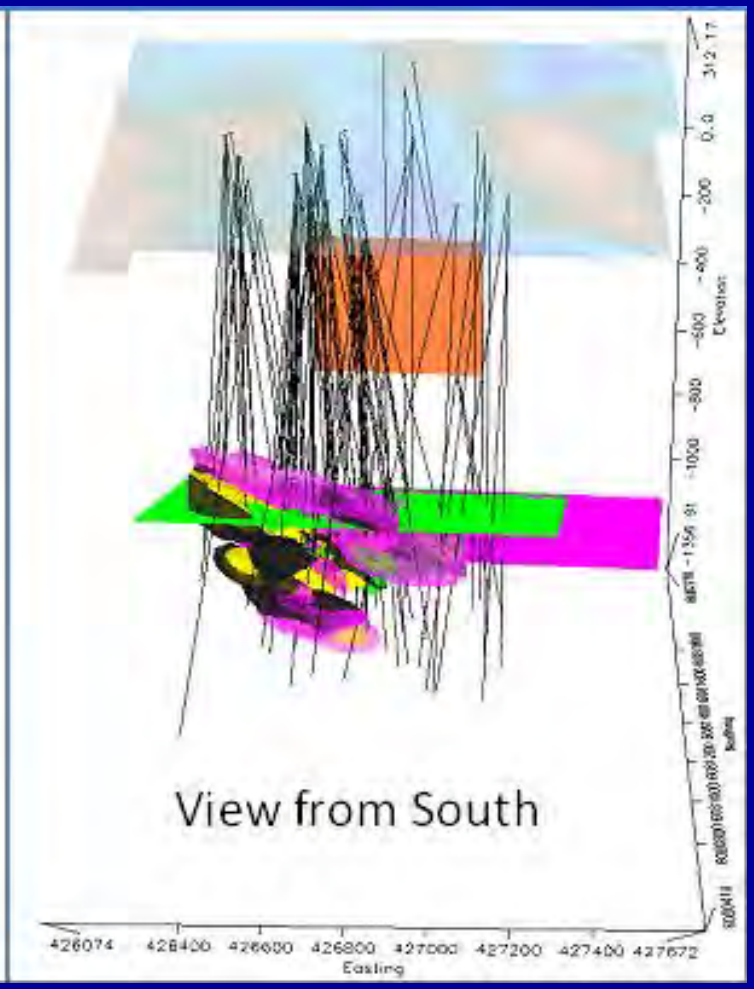


Lalor TEM Modelling - All Loops - All Data

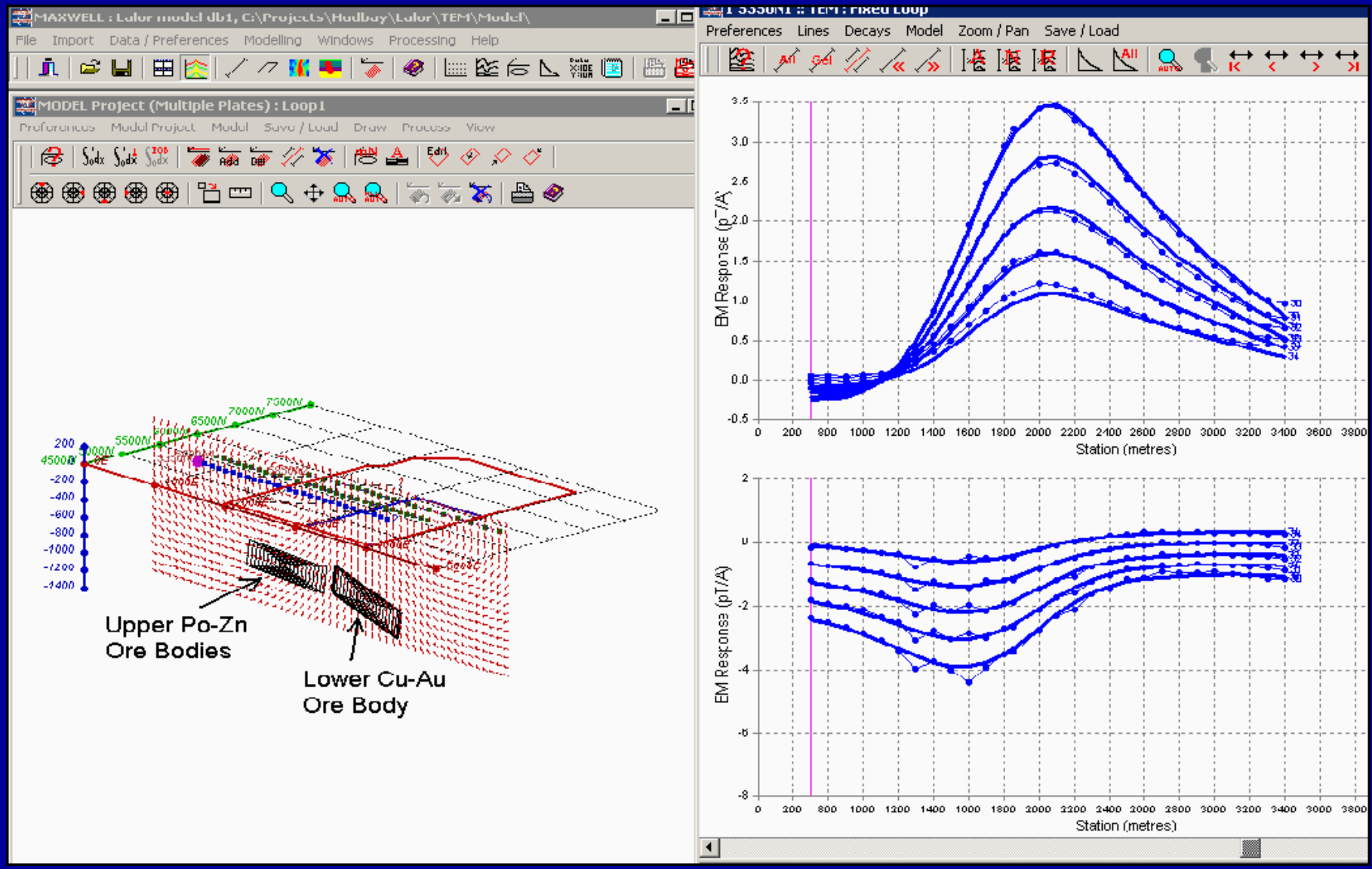


Lalor TEM Modelling - Final Model

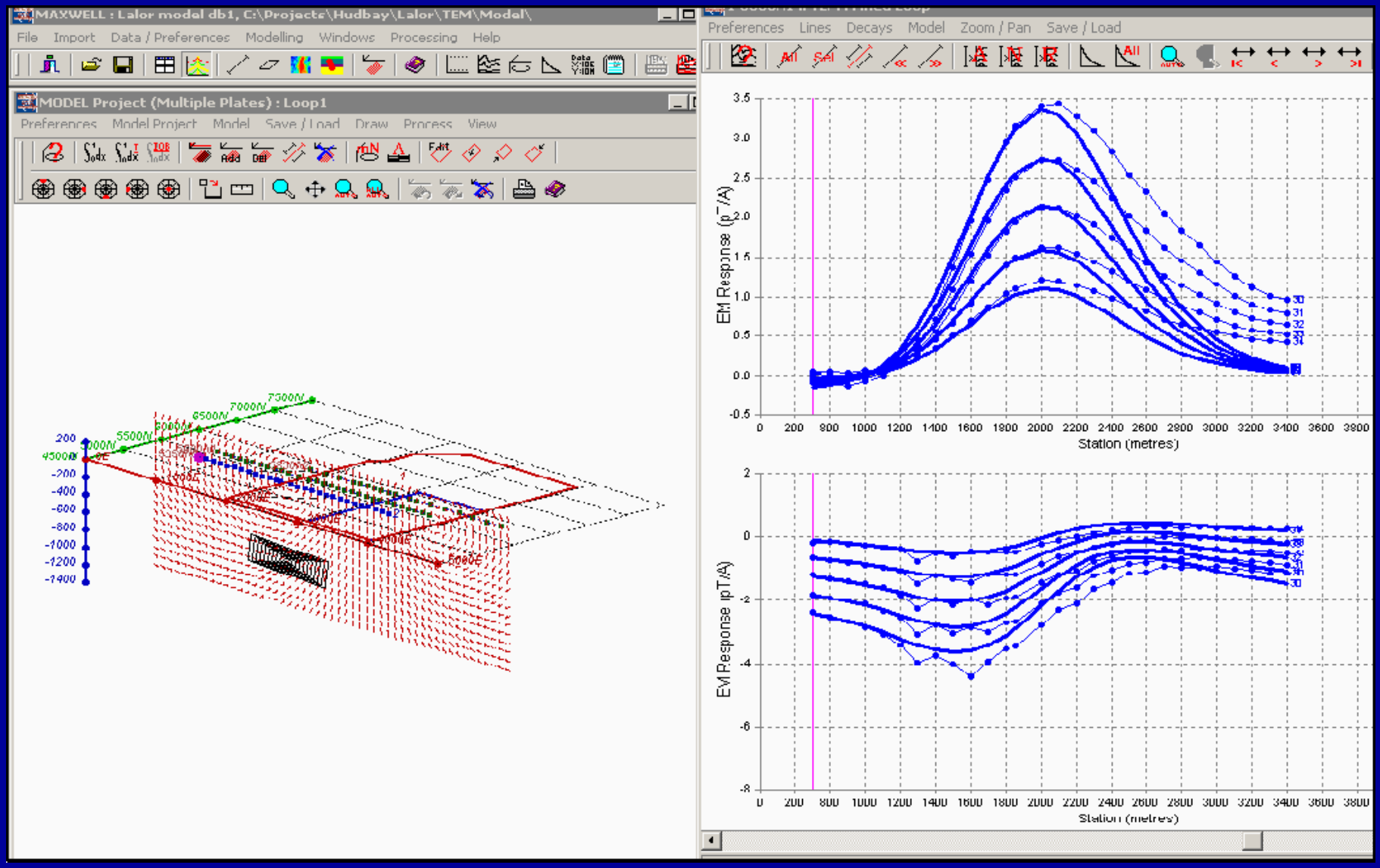




Lalor TEM Modelling - Final Model with Deep Cu-Au Ore Body



Lalor TEM Modelling - Final Model without Deep Cu-Au Ore Body



CONCLUSION

(It's not rocket science!)

- If you want to explore deep with TDEM you need lots of signal and as little noise as possible.
- To get lots of signal, use the largest transmitter available, that can still be moved about efficiently.
- To minimize noise, use the most sensitive B-field sensor available - the Supracon/IPHT SQUID