Commanding **Business Resilience.**

Rock Properties from Lightning Databases: Transforming Geotechnical Operations and Accelerating the Time-to-Value

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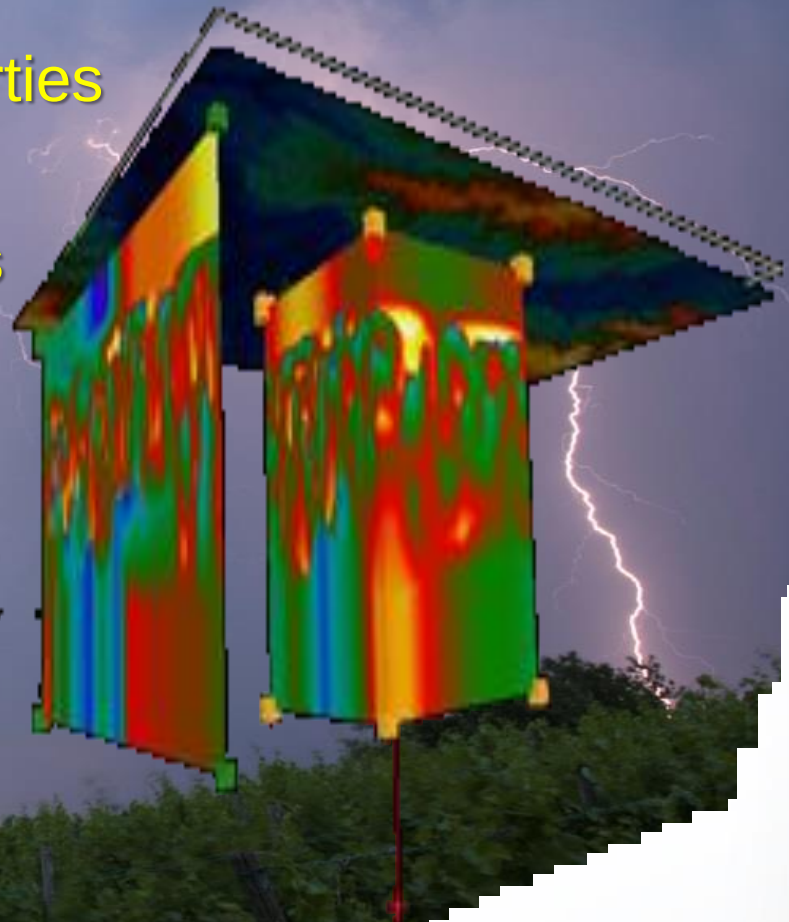
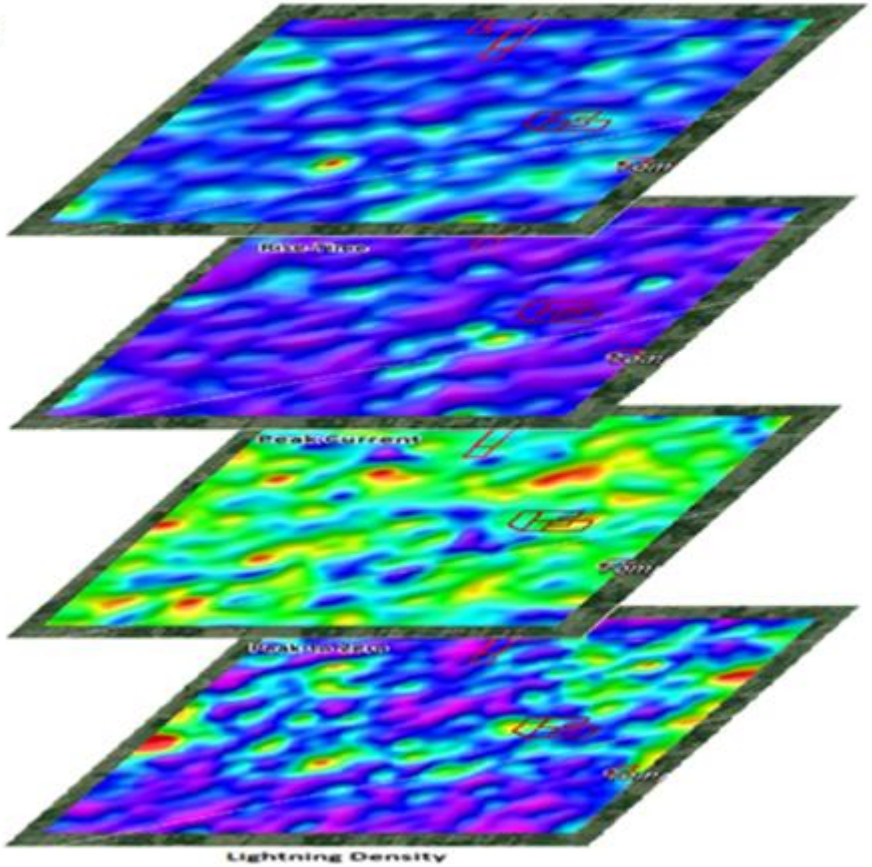
Introduction

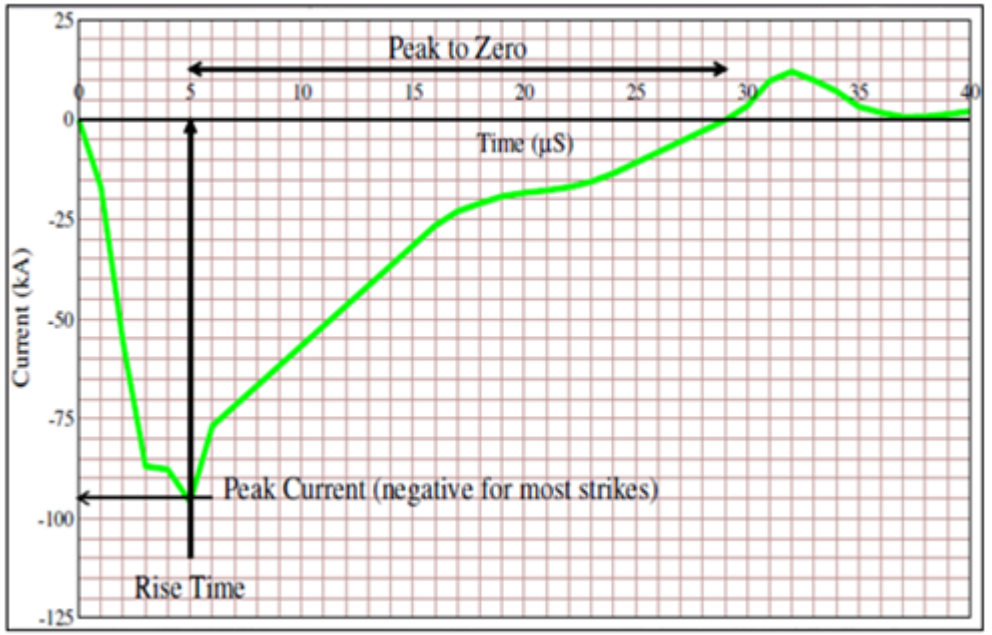
- Understanding spatial distributions of rock properties is key in exploring for natural resources.
- Boreholes are limited to providing rock properties at discrete locations.
- Lightning Rock Property Volumes demonstrate:
  - integration with other geophysical techniques (including seismic and potential field data)
    - to maximize areas evaluated, and
    - to minimize drilling requirements.



Lightning Strike Measurements

- Location
- Time and Duration
- Rise Time
- Peak Current
- Polarity
- Peak-to-Zero
- Density

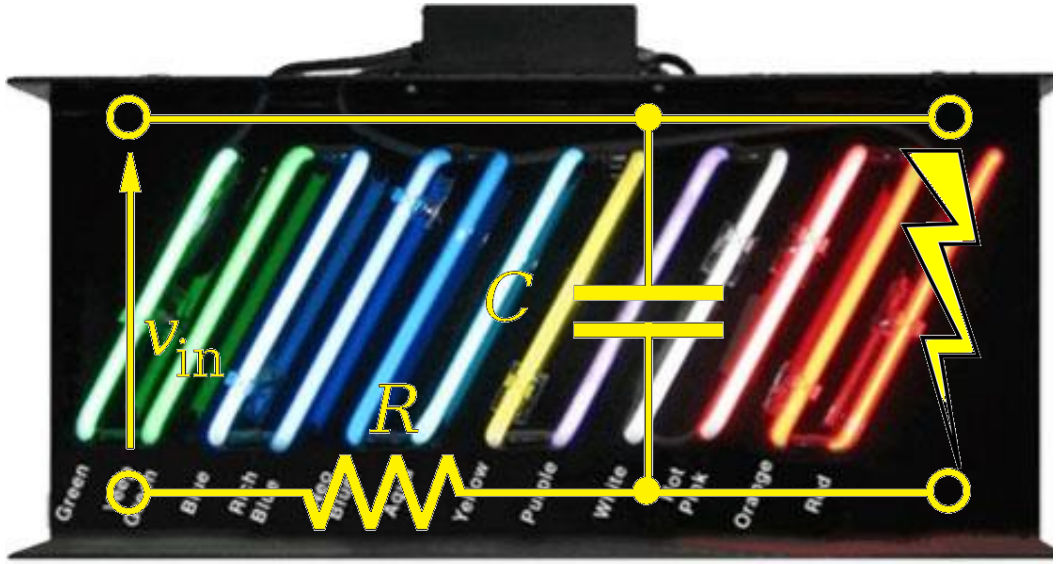


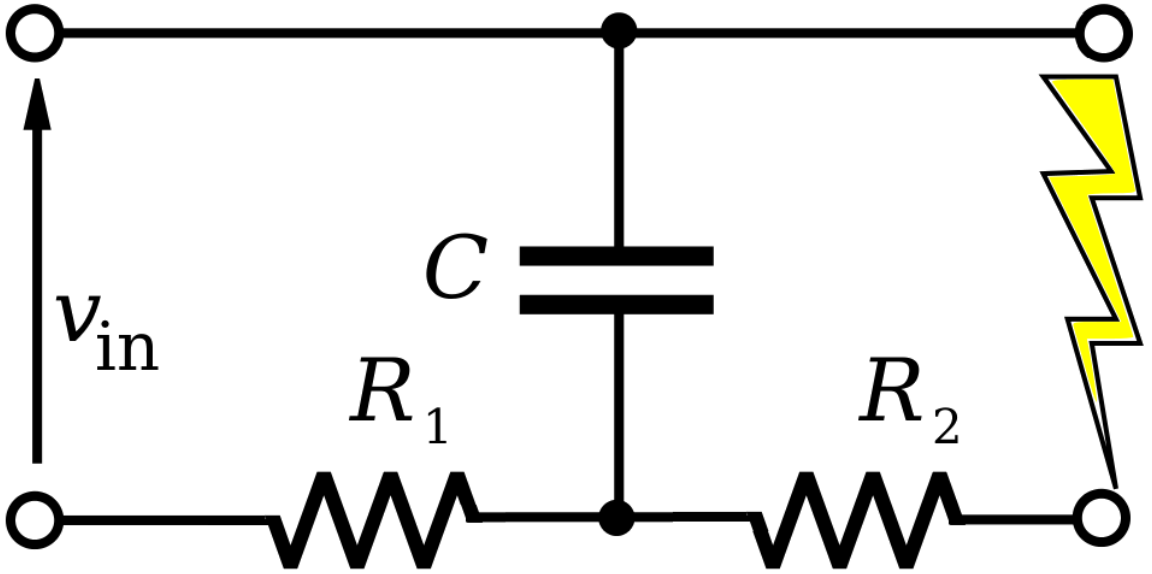


Up-Going Lightning Strike & Terralevis Current Implications

New infrastructure, where questions asked:
"Does lightning strike twice in the same spot?
And does it mean I have oil on my property?"

Lightning Physics is analogous to Relaxation Oscillator Physics





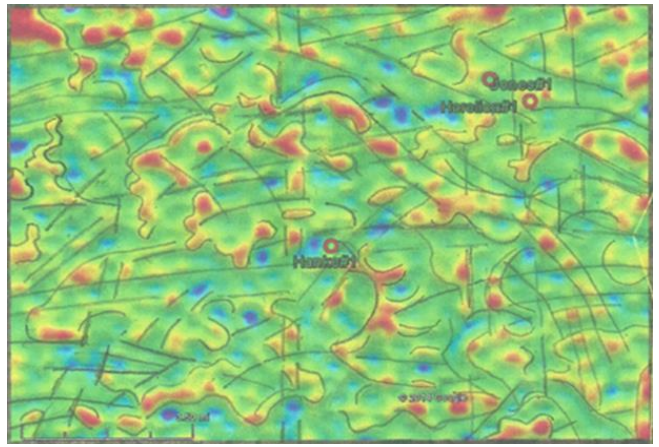
- The atmospheric capacitor is nearly the same physics
- Just an additional resistance (R_2) limiting the current
- R_2 is the resistance between the lightning strike point and the bottom plate of the capacitor

Lightning analysis is a new and cost effective data type

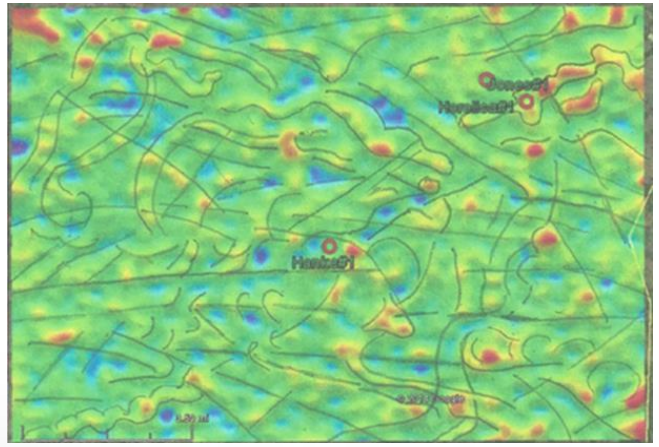
- Lightning occurs everywhere.
- Extensive evergreen lightning databases exist:
  - No permitting nor site access required.
  - DML quickly identifies sweetspots.
- Calculations are cost effective:
  - More lightning attributes than seismic attributes.
  - Results tie to seeps, aquifers, anisotropy, faulting, and the basement.
- Innovative new lightning attribute applications:
  - Mapping the near surface.
  - Knowing fault orientation before fracking.
  - Improving velocity and geological models.

Attributes Calculated or Displayed with DecisionSpace®

Surface Resistivity:



Peak-to-Zero:



Seismic Attributes

- Instantaneous
- Wavelet
- Geometrical
- Reflective
- Curvature
- Dip
- Semblance/Coherence
- AVO / AVA
- Derivatives

Lightning Map Attributes

- Rise-Time
- Peak Current
- Peak-to-Zero
- Total Wavelet Time
- Symmetry
- Density
- Rise-Time-Rate
- Temporal Versions
- Tidal Gravity

Lighting Volume Attributes

- Resistivity
- Instantaneous Resistivity
- Curvature Resistivity
- Permittivity
- Wavelet Permittivity
- Dip Permittivity
- Temporal Versions:
  - Before Event
  - After Event

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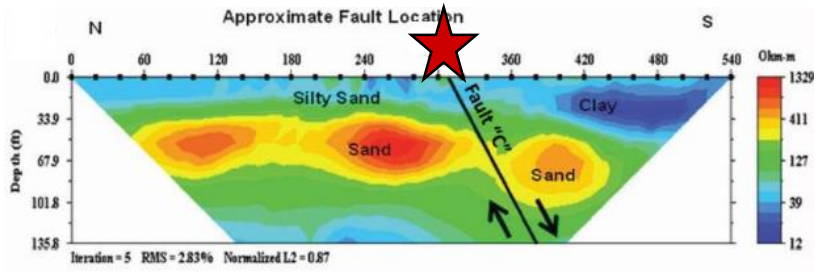
What Rock Properties are Critical to Geotechnical Operations?

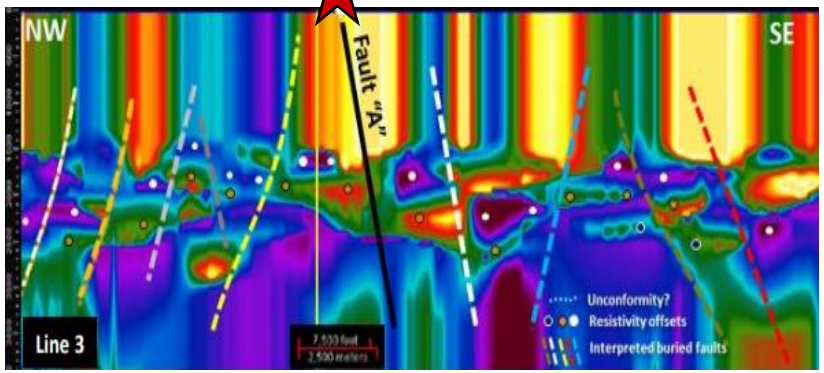
- Rock Type: Sedimentary, Metamorphic, or Igneous.
- Density
- Porosity, Formation Factor, and Archie's parameters
- Thermal
- Electrical
- Migration Pathways
- Geopressure
- Mineralization and Hydrocarbon Halos

2-D Resistivity Imaging



Resistivity imaging data taken across the Katy-Hockley fault. Note the south-dipping sand layers and thickening clay layers in the downthrown side. After M. Saribudak, Fast Times, Vol 17, No. 1, March 2012

Lightning Resistivity Faults



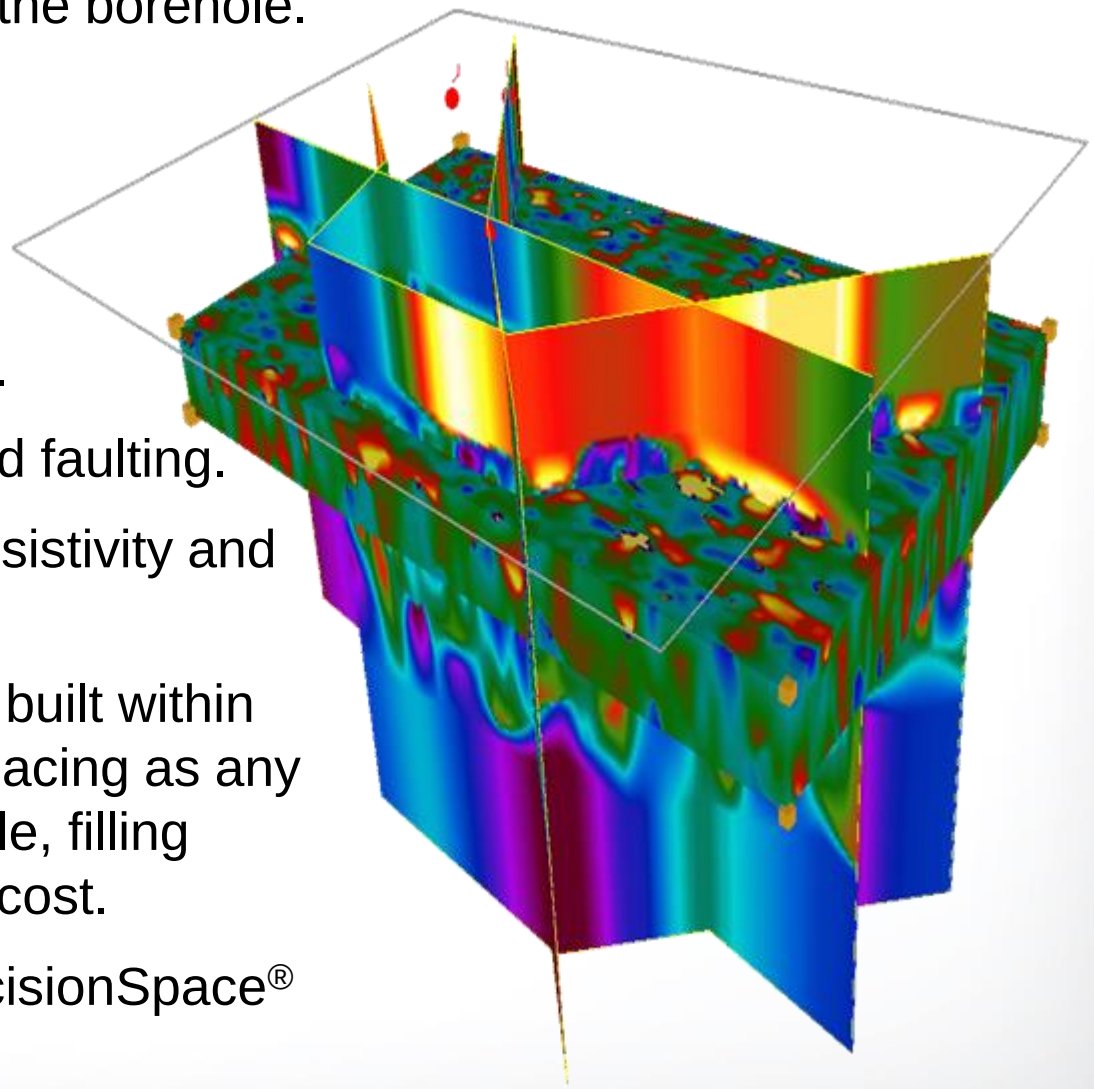
Resistivity and Permittivity are related to each of these Rock Properties!

Rock Property Specifics

Method	Type of measurement	Physical property detected
Gravity	Spatial variations in the strength of the Earth's gravitational field	Density
Magnetic	Spatial variations in the strength of the Earth's magnetic field.	Magnetic susceptibility
Seismic	Travel times of seismic waves	Density and elastic moduli
Electrical Resistivity	Electrical resistance	Resistance
Electromagnetic	Response to electromagnetic radiation	Resistance and Inductance
Induced Polarization (IP)	Apparent permittivity	Capacitance
Ground Penetrating Radar (GPR)	Travel time of radar pulses	Dielectric constant
Lightning	Location, Time, Rise-Time, Peak Current, Peak-to-Zero	Resistivity and Permittivity

Expansion of Borehole Rock Properties, limited to Discrete Locations

- Rock properties are determined within a few feet of the borehole.
- Expensive, and can provide physical samples
- 2-D seismic enables estimation along a line.
- 3-D seismic enables estimation within a volume.
- Gravity enables density estimates over a large area.
- Magnetics enables estimates of basement depth and faulting.
- IP (Instantaneous Potential) enables estimates of resistivity and permittivity along survey lines.
- Lightning resistivity and permittivity volumes can be built within 2 months, at the same line and trace and sample spacing as any 3-D seismic survey where lightning data are available, filling Rock Property gaps between other surveys, at less cost.
- Easy to integrate with all other data types using DecisionSpace®



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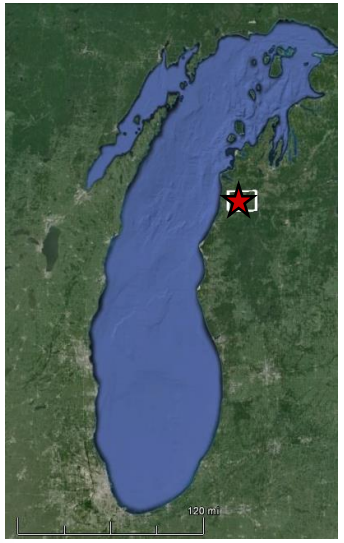
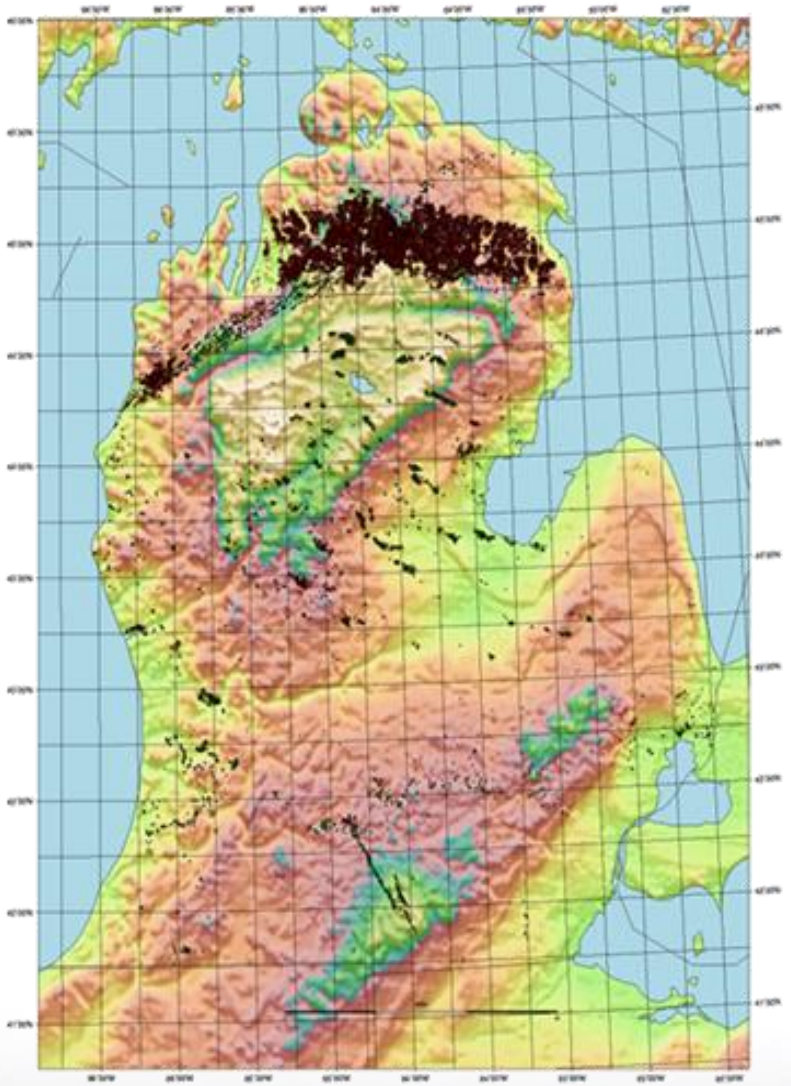
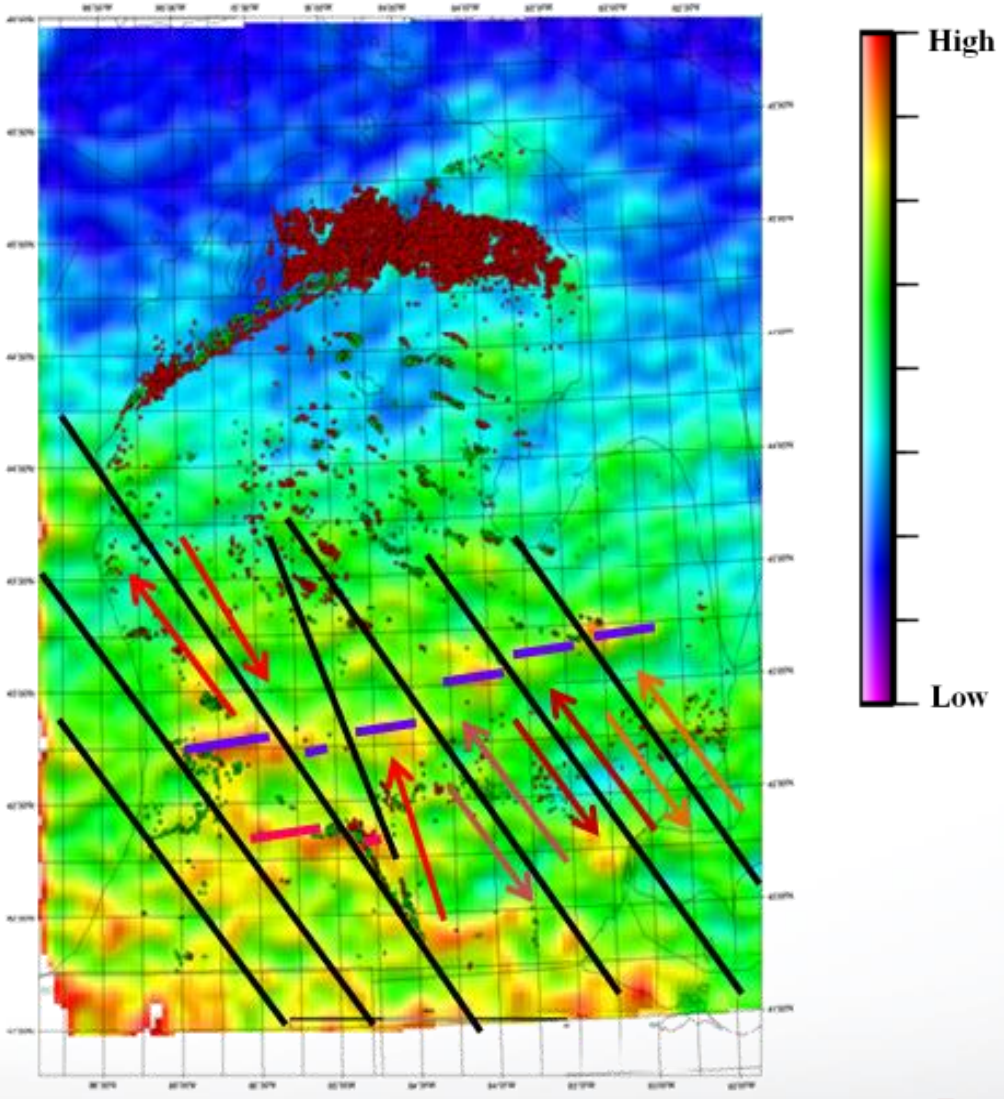
Michigan Examples (display on the right with SeisWorks in 2009)







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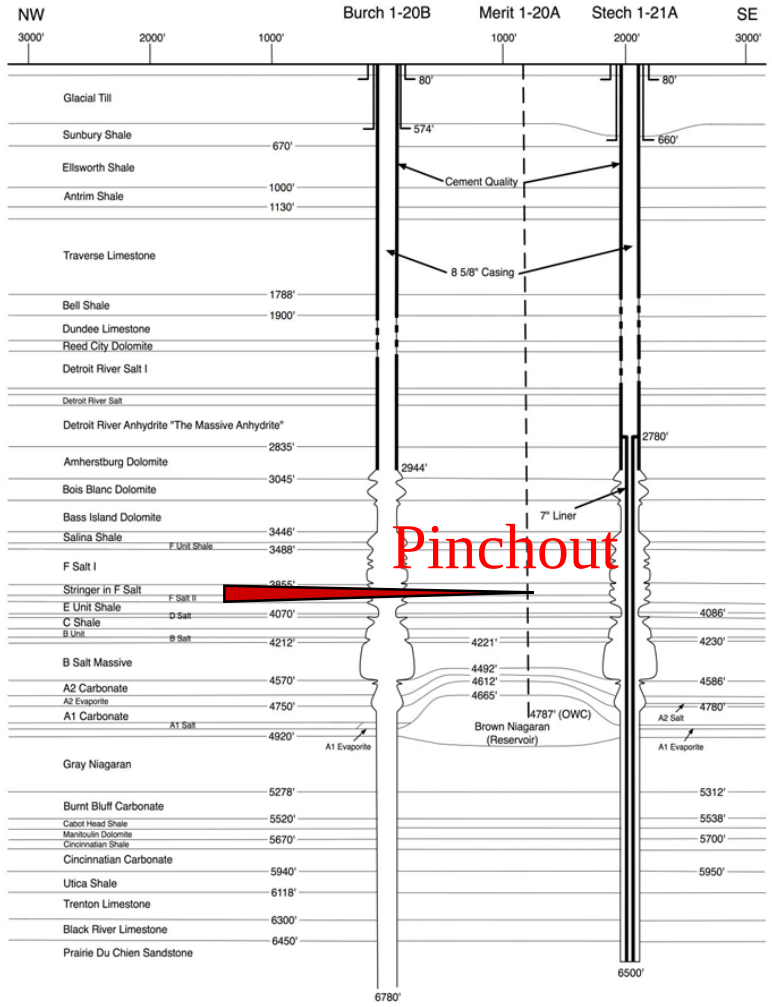
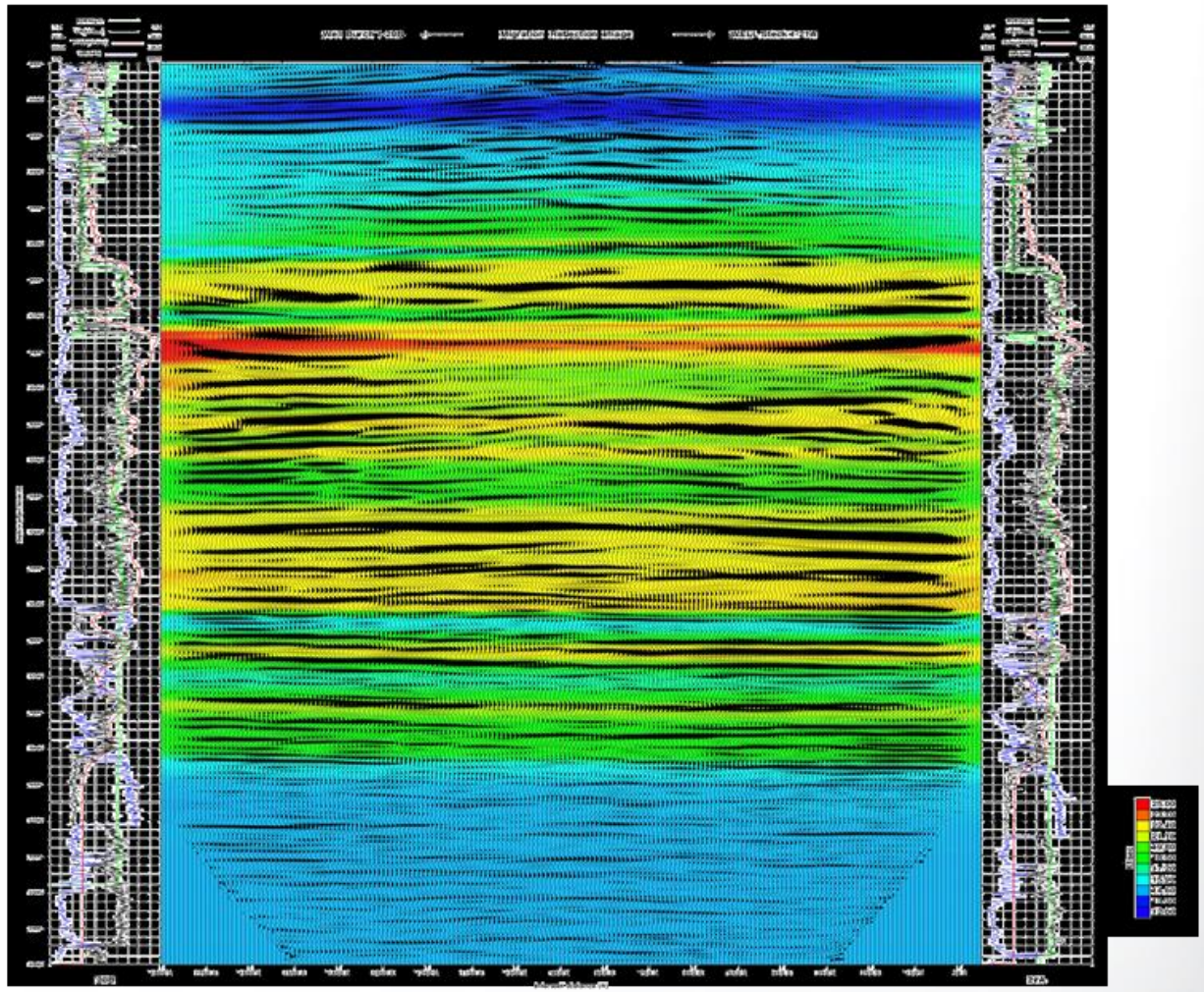
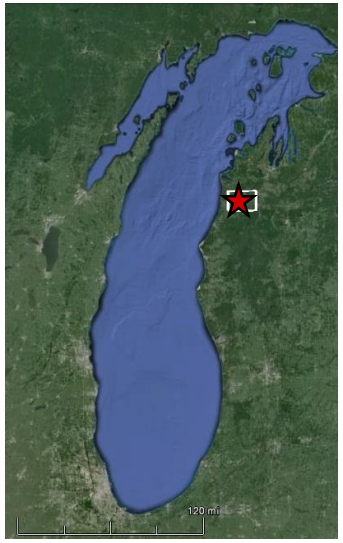
MTU Test Site with Cross-Well Tomography Example

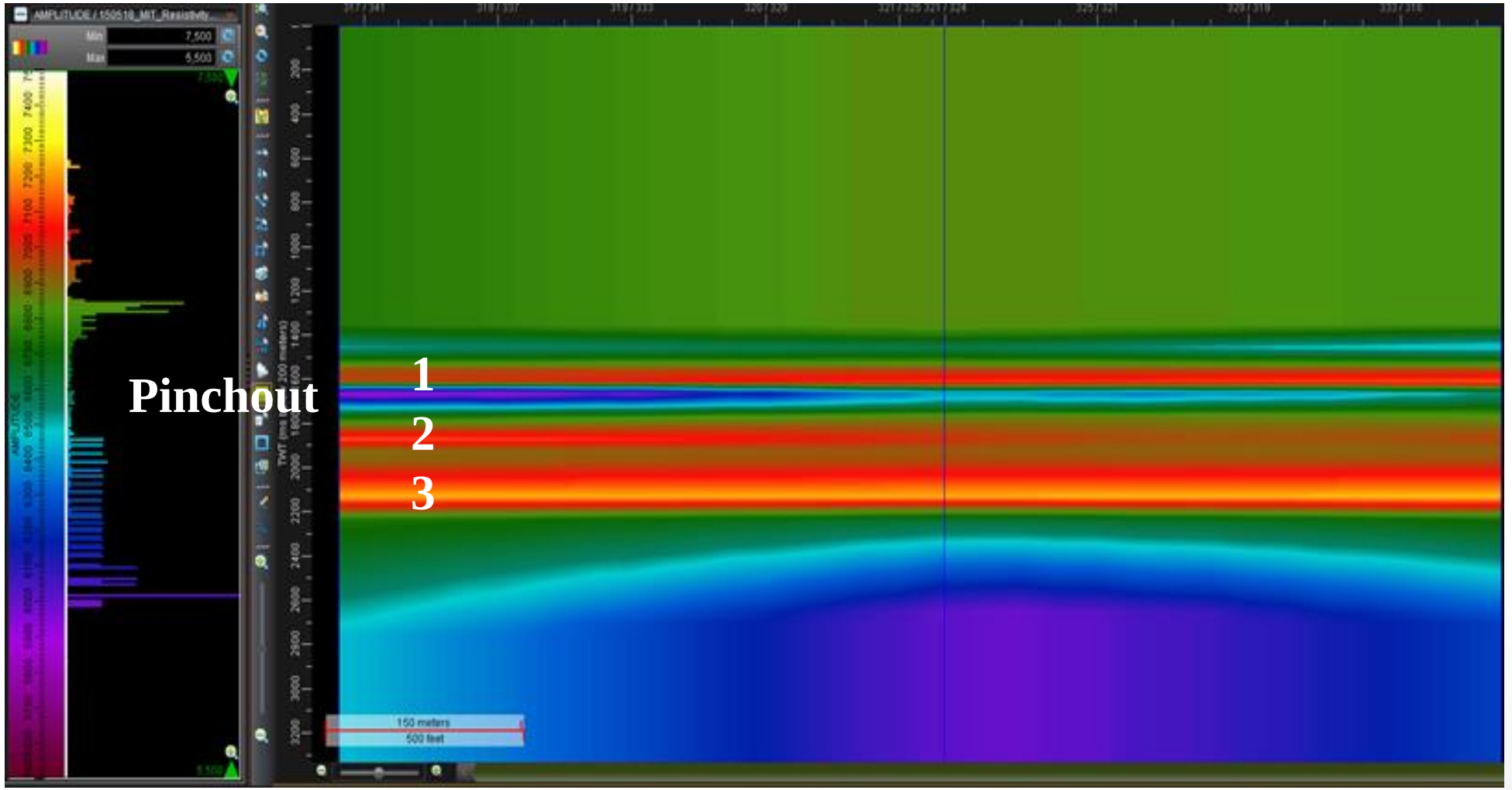




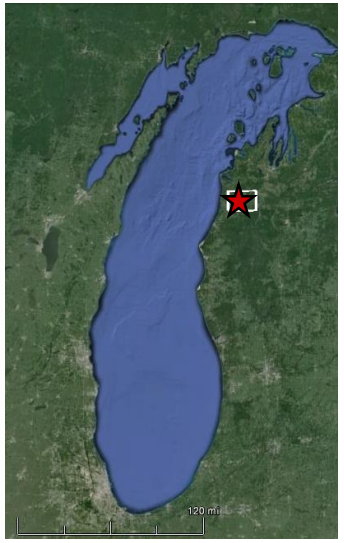
Courtesy Dr. Roger Turpening, Michigan Technology University

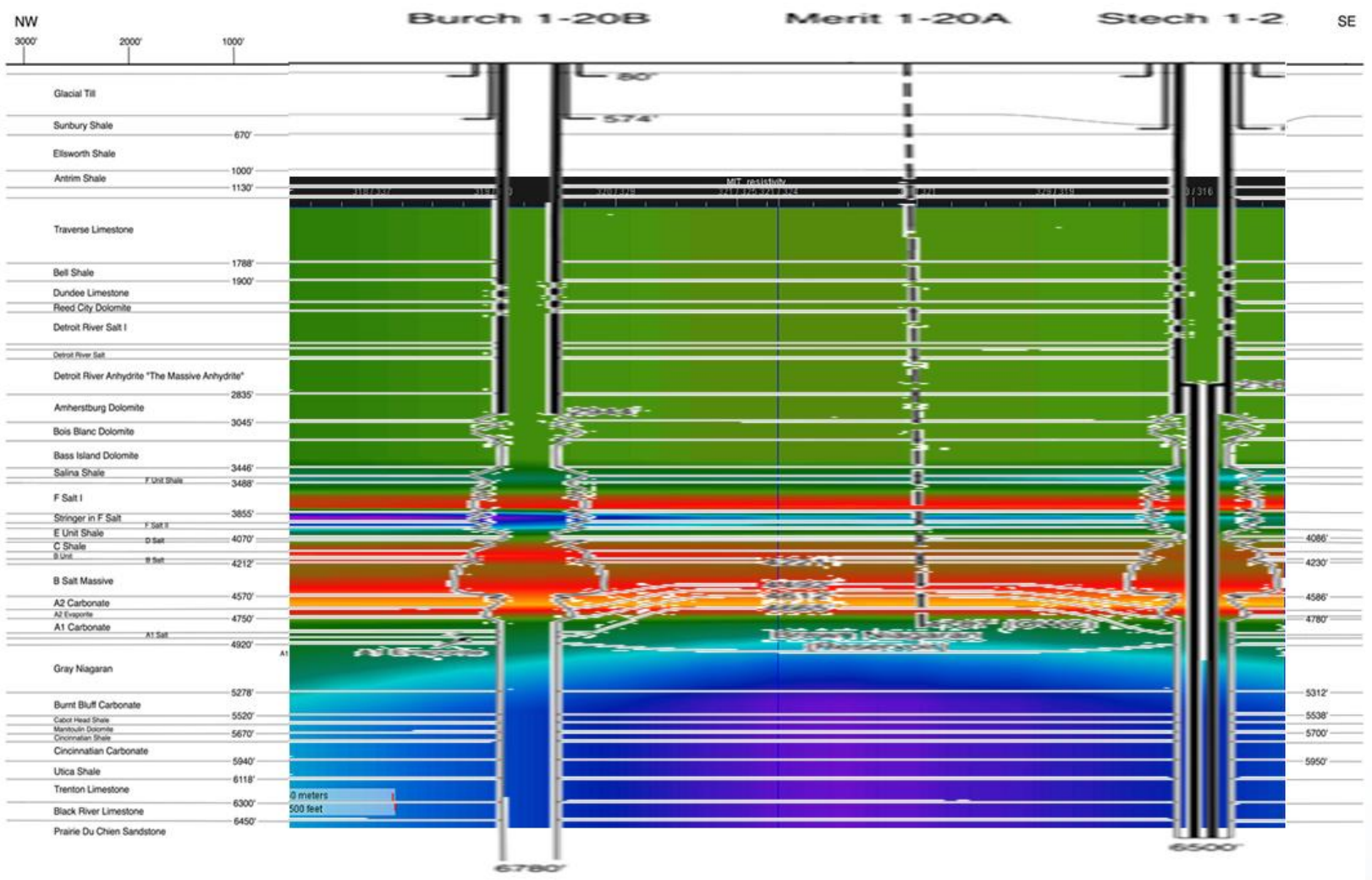
Resistivity Section Between MTU Test Site Wells (displayed with G1)

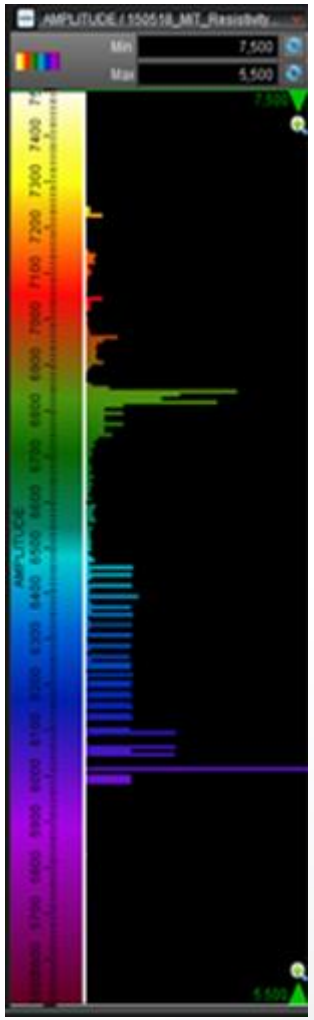




MTU Test Site Wells Overlaid on Resistivity Section







Courtesy Dr. Roger Turpening, Michigan Technology University

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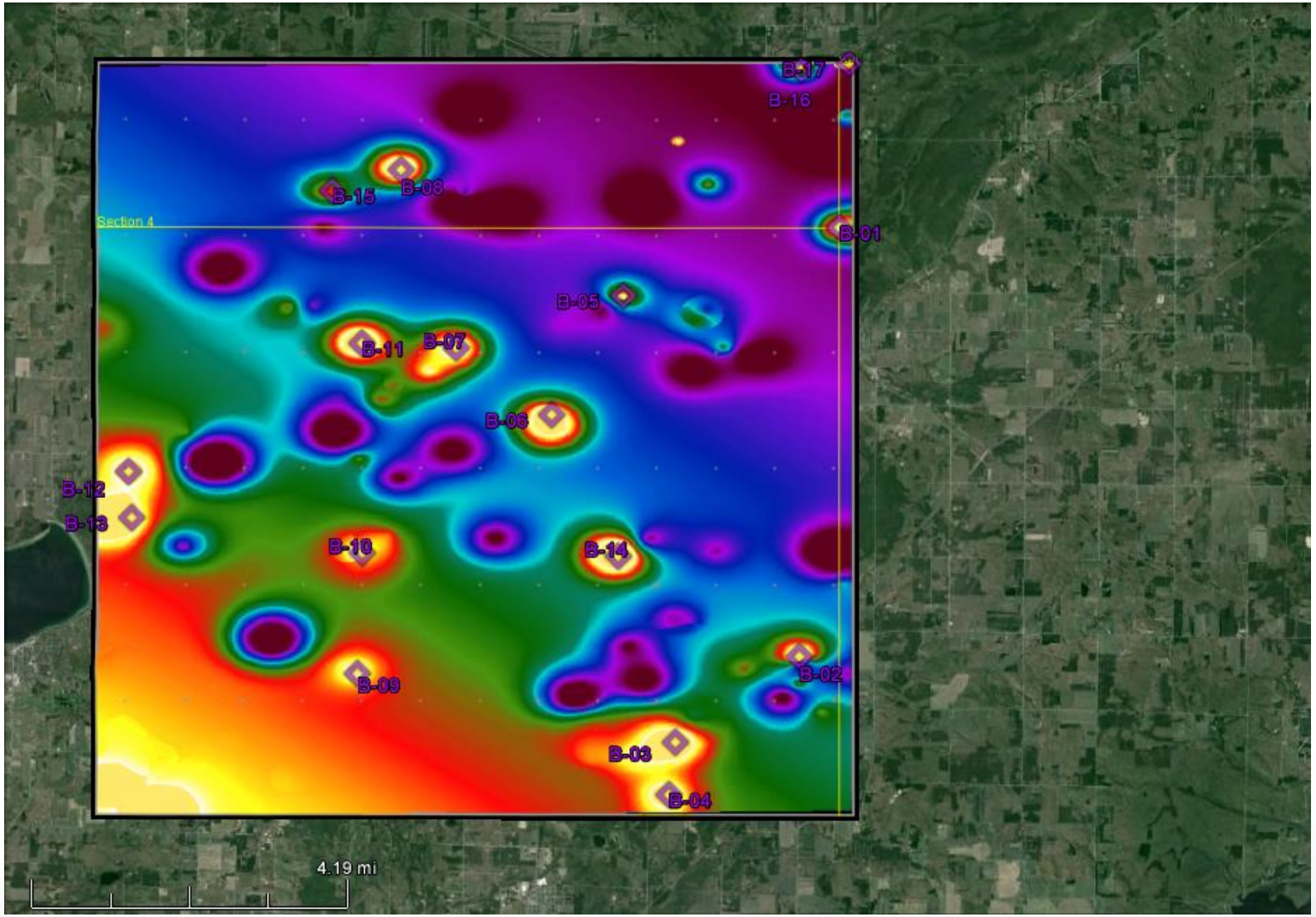
Location of Type 1 Cylinder Anomalies in Analysis Area
Horizontal-Slice through possible pinnacle reefs



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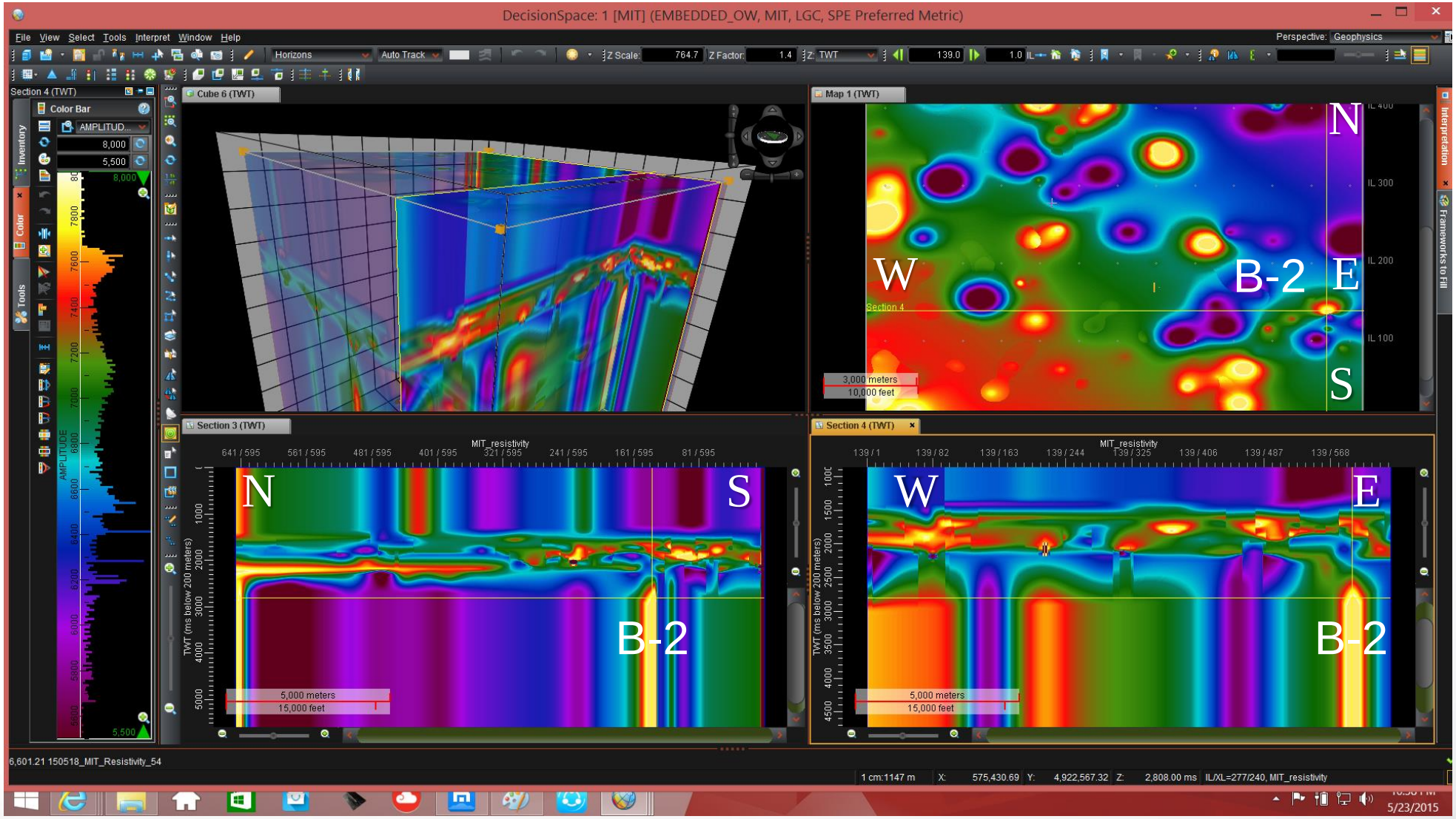
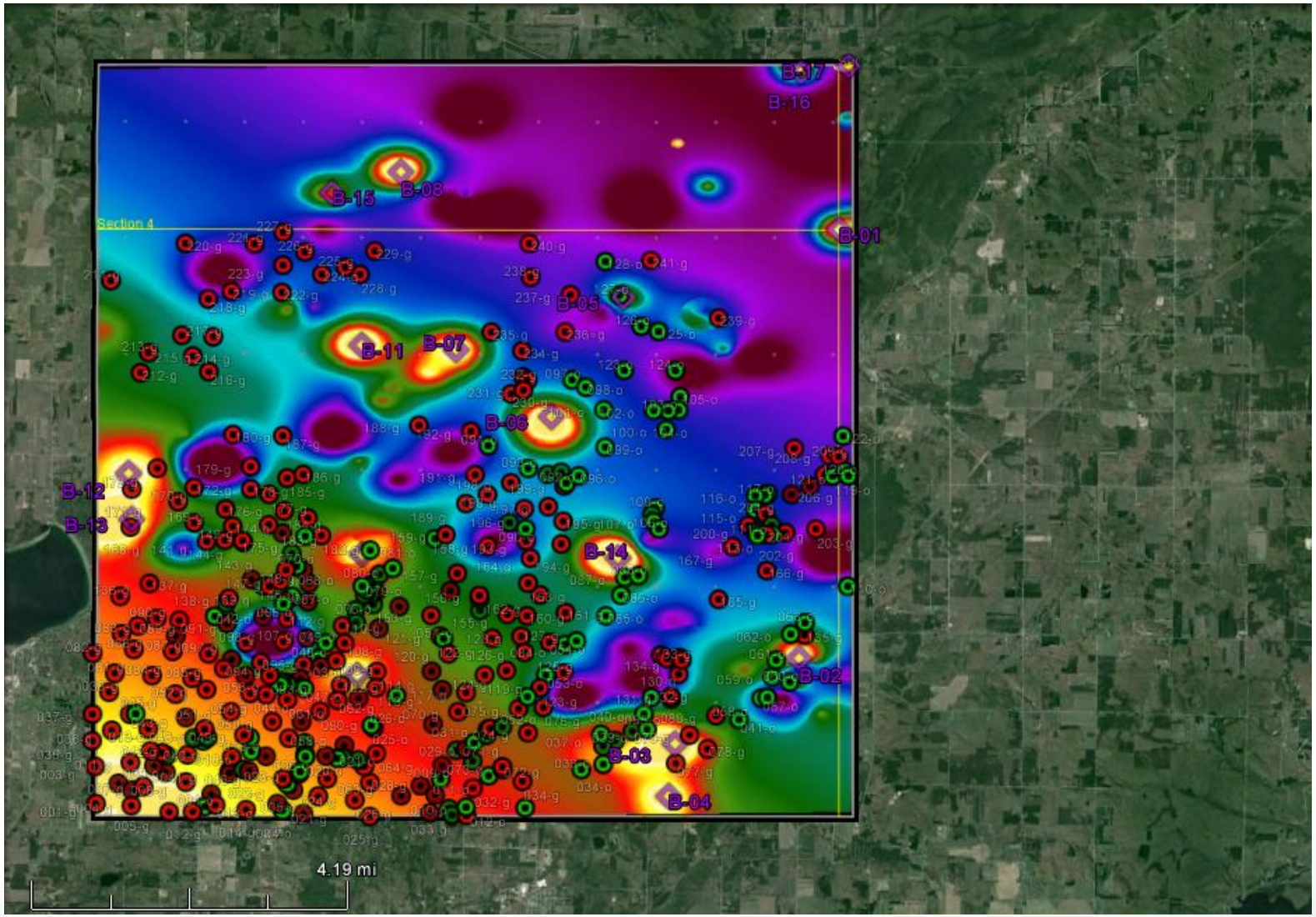
Type 1 Anomalies in Analysis Area: Resistivity Cylinders (B2)



High Resistivity to southwest on B-2 Horizontal-Slice with Oil & Gas Wells in Analysis Area posted (note lineaments)



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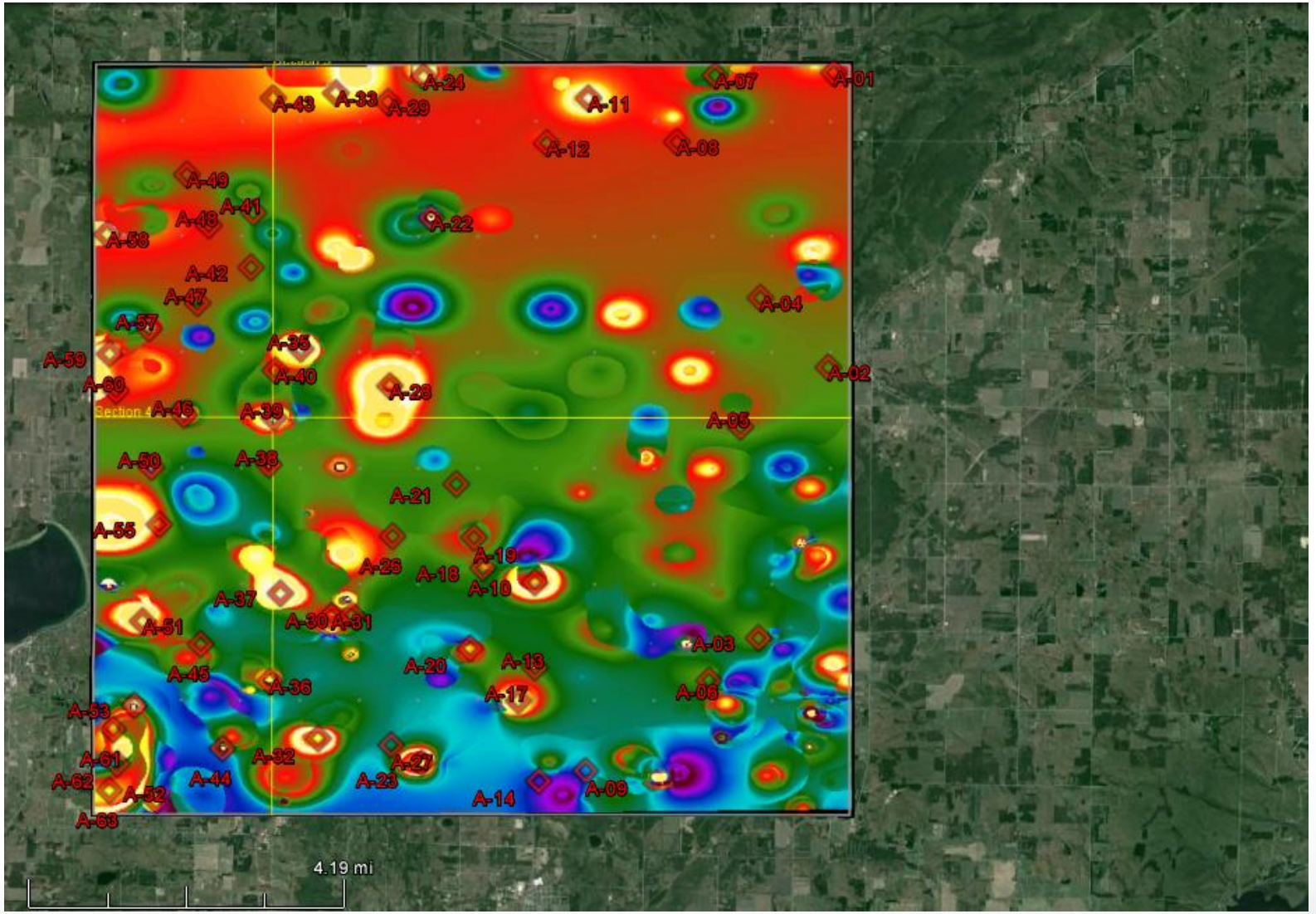
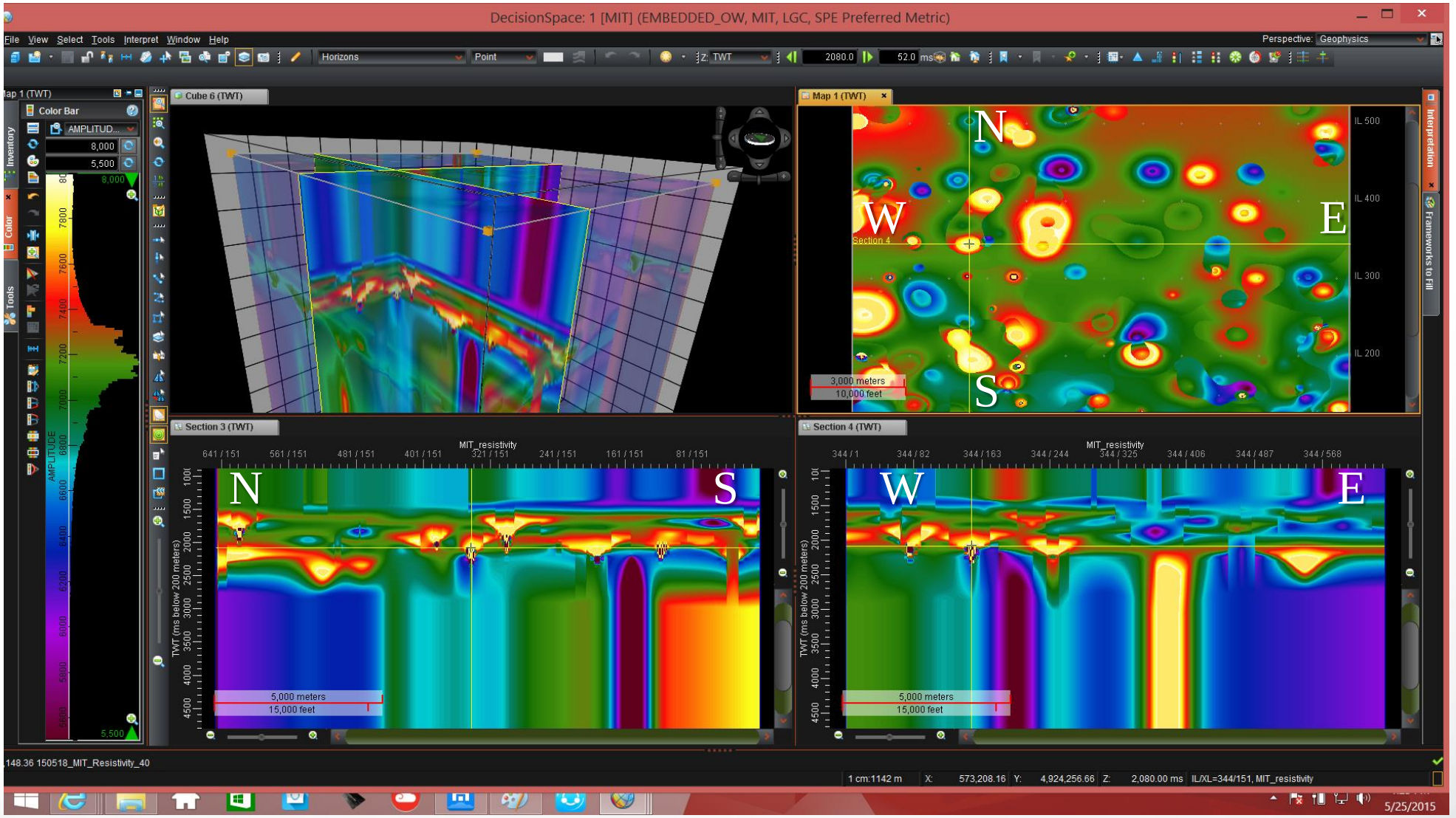
Type 2 Lens (A-39) – a possible bioherm reef

At Cross-Hairs on Horizontal-Slice in Analysis Area



Type 2 Anomalies in Analysis Area: Lenses (A-39)

Note 4 Lenses in W-E section & 1 Cylinder, and 7 Lenses in N-S section and 1 large Cylinder



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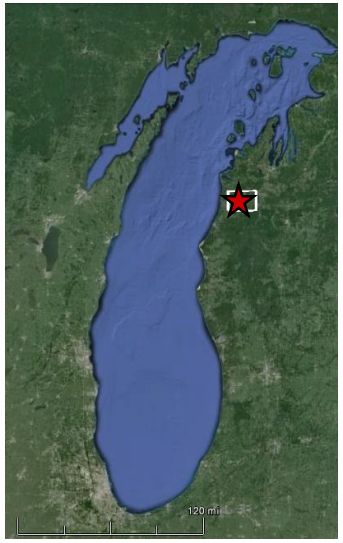
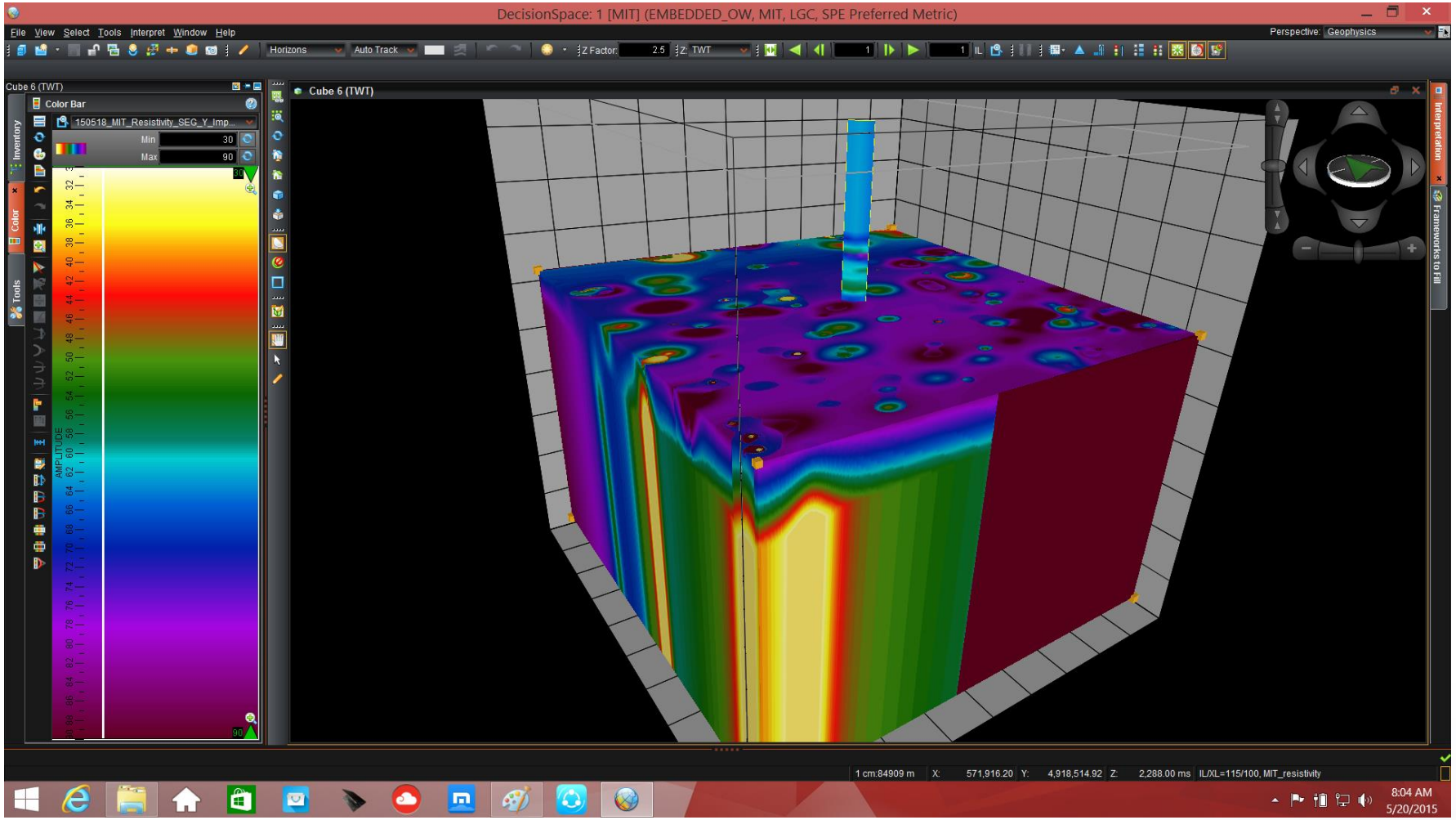
Resistivity Cube Probe with Resistivity Section at MIT Test Site Horizontal-Slice through Type 2 Lens Anomalies in Analysis Area





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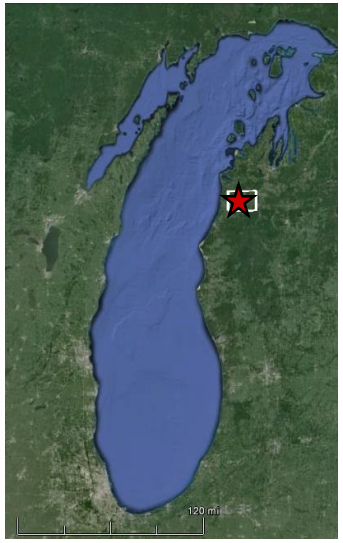
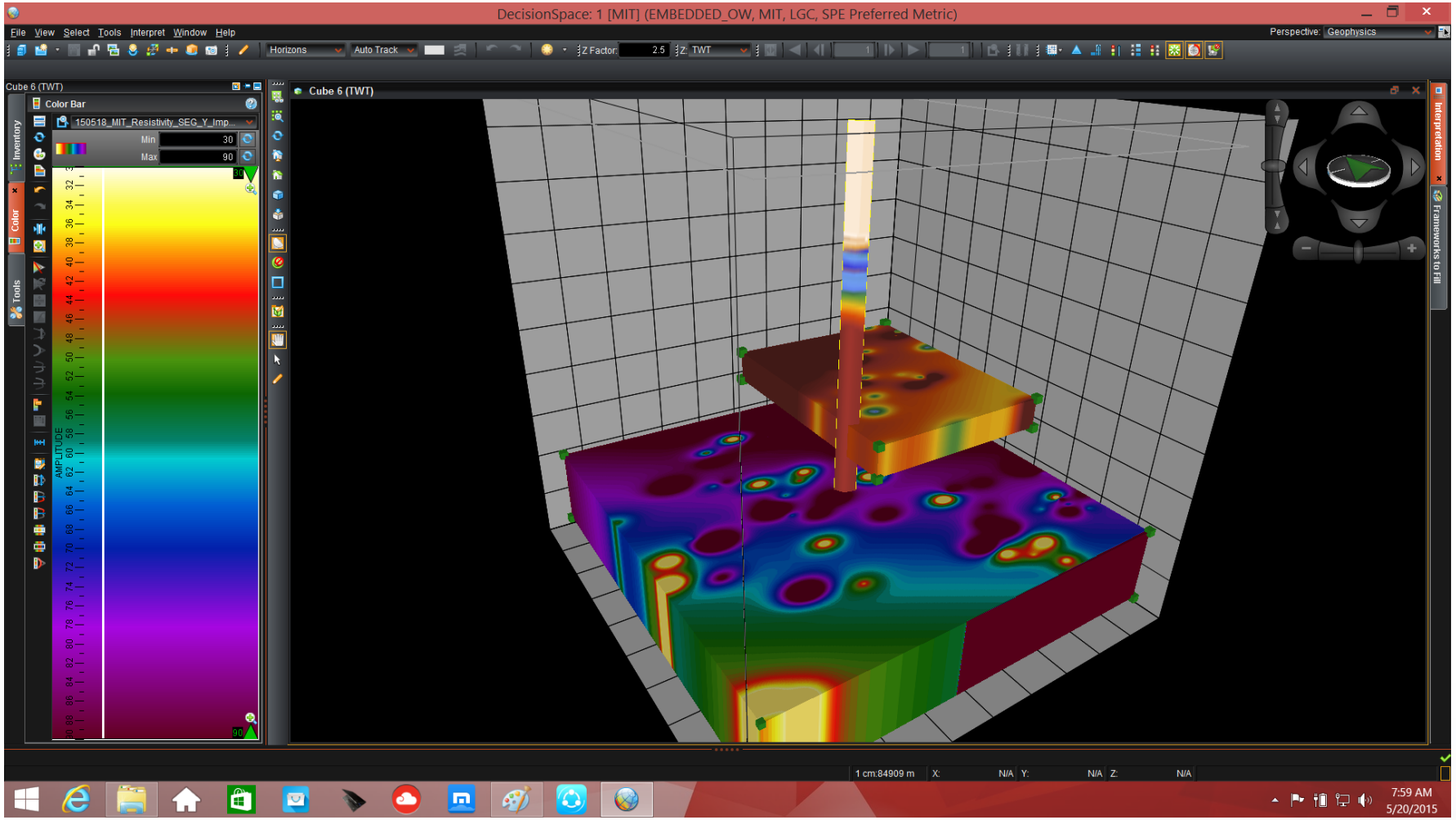
Permittivity Cube Probe with Permittivity Section at MIT Test Site and Horizontal-Slice through Type 1 Cylinder Anomalies in Analysis Area





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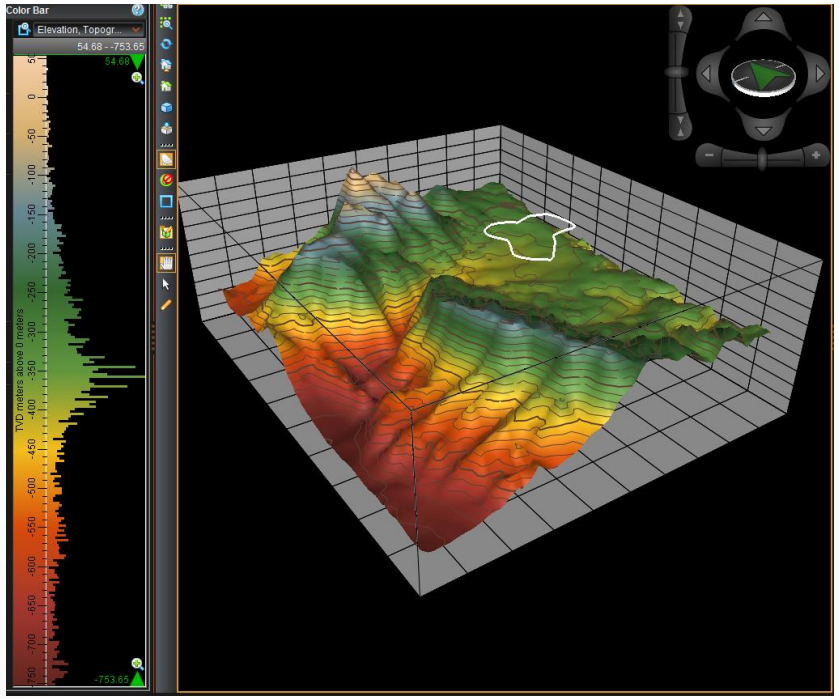
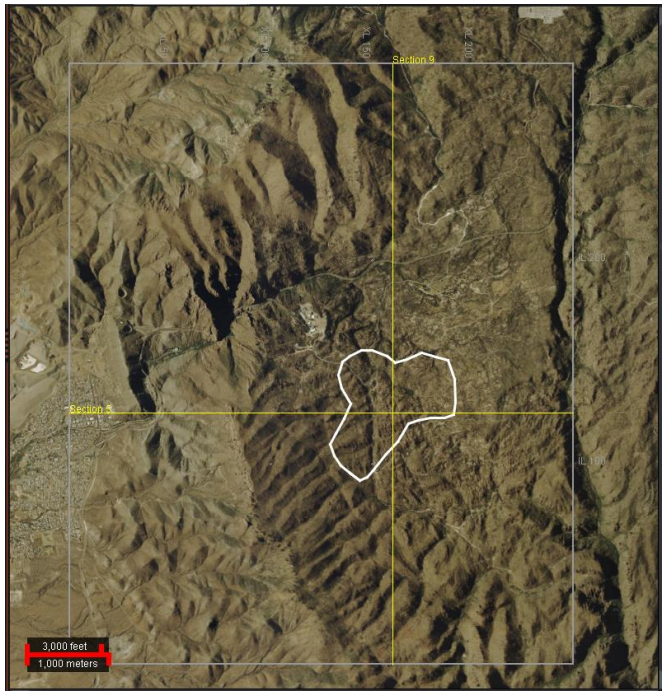
Arizona Example: Resolution Copper Mine

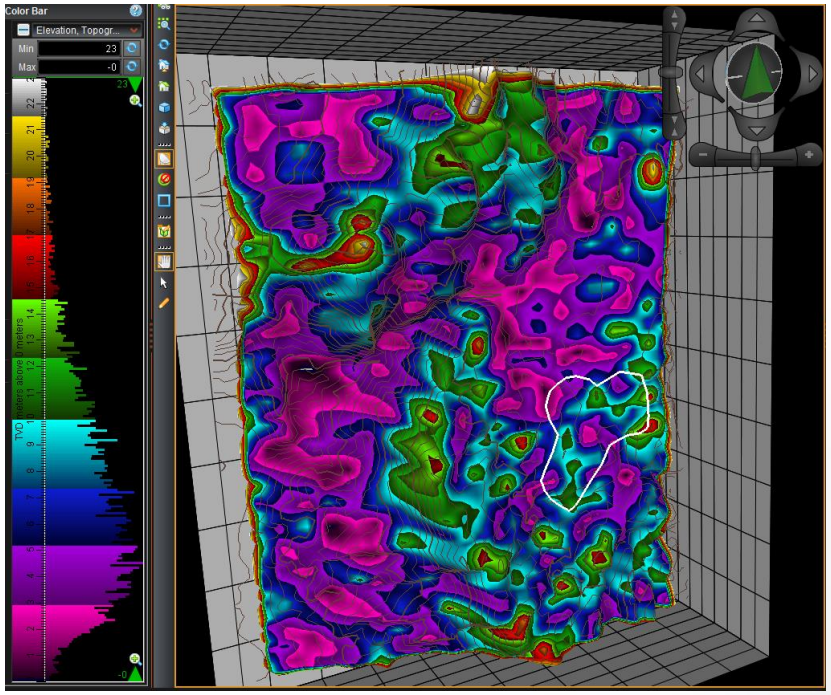
Topography



Satellite



Lightning Density



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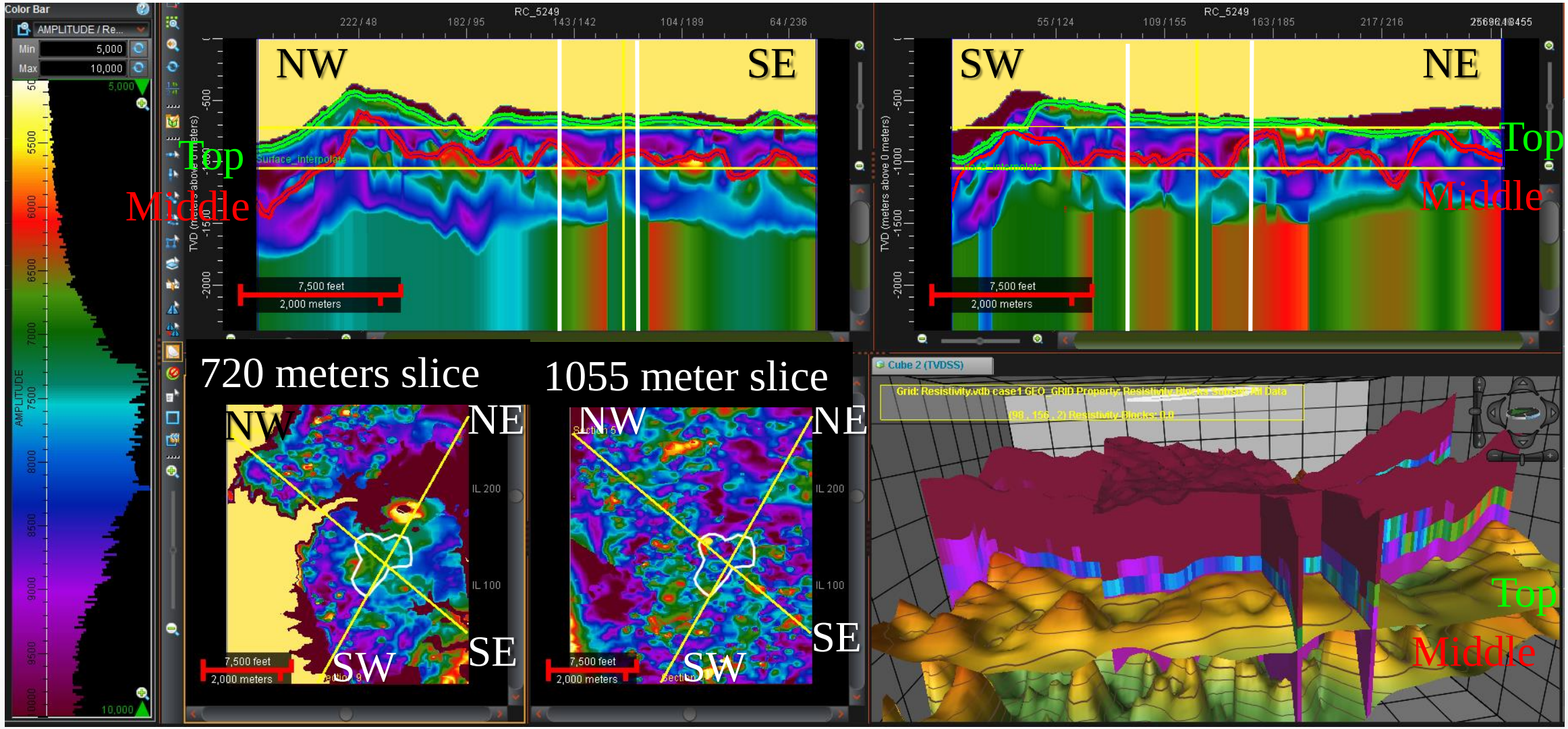
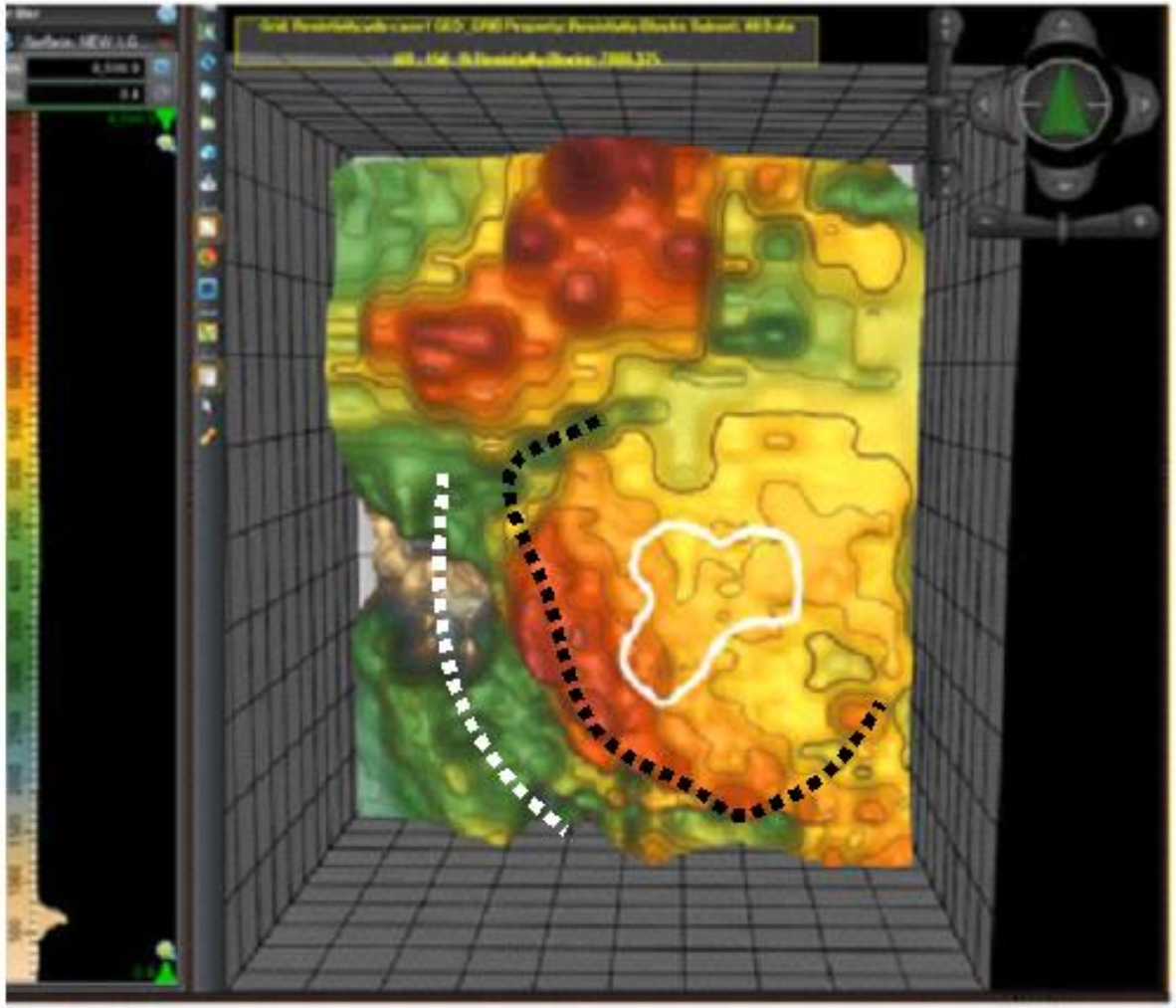
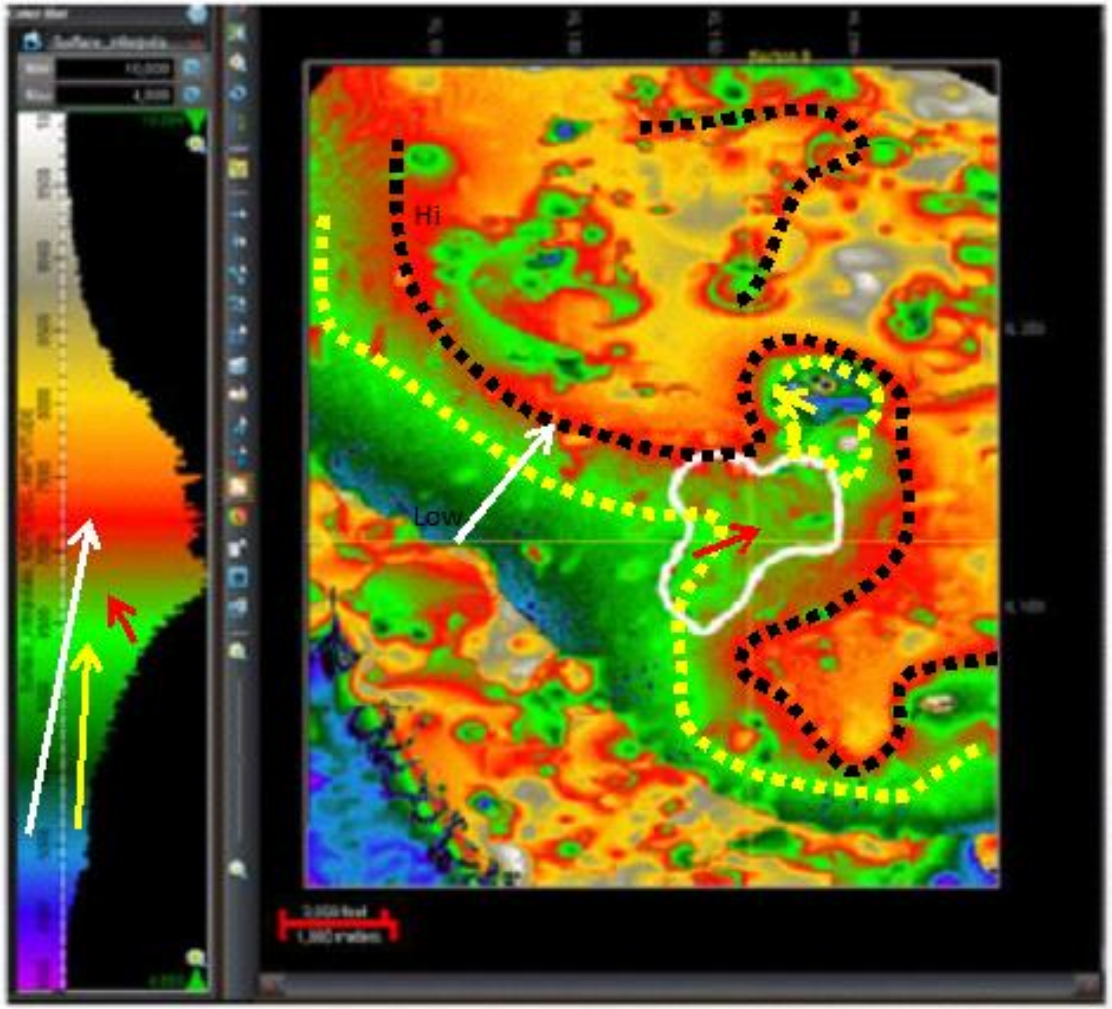
Resolution Copper Resistivity Sections: Top & Middle Horizons



Resolution Copper Mine

Top Resistivity Depth - Minimum Resistivity 200 meters beneath surface





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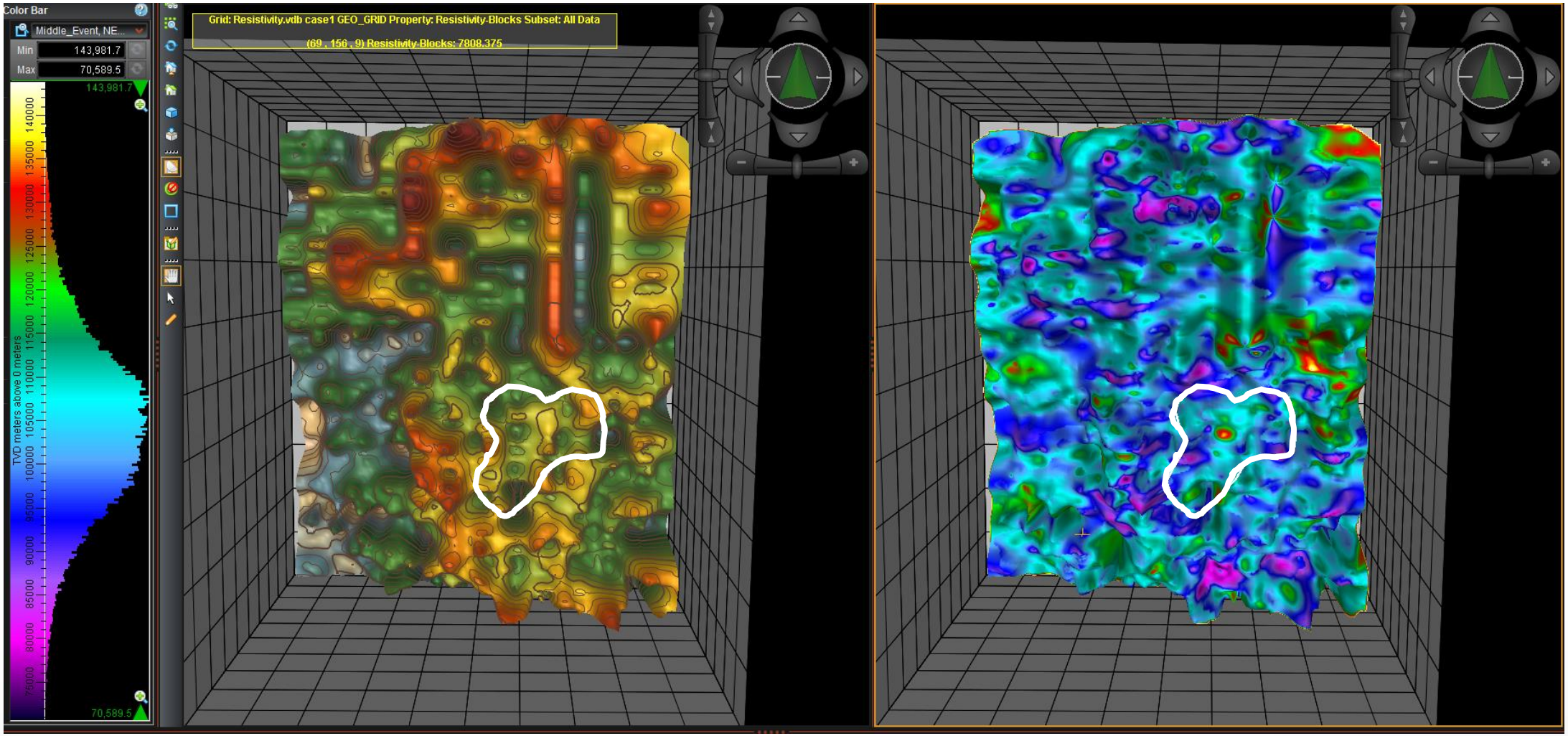
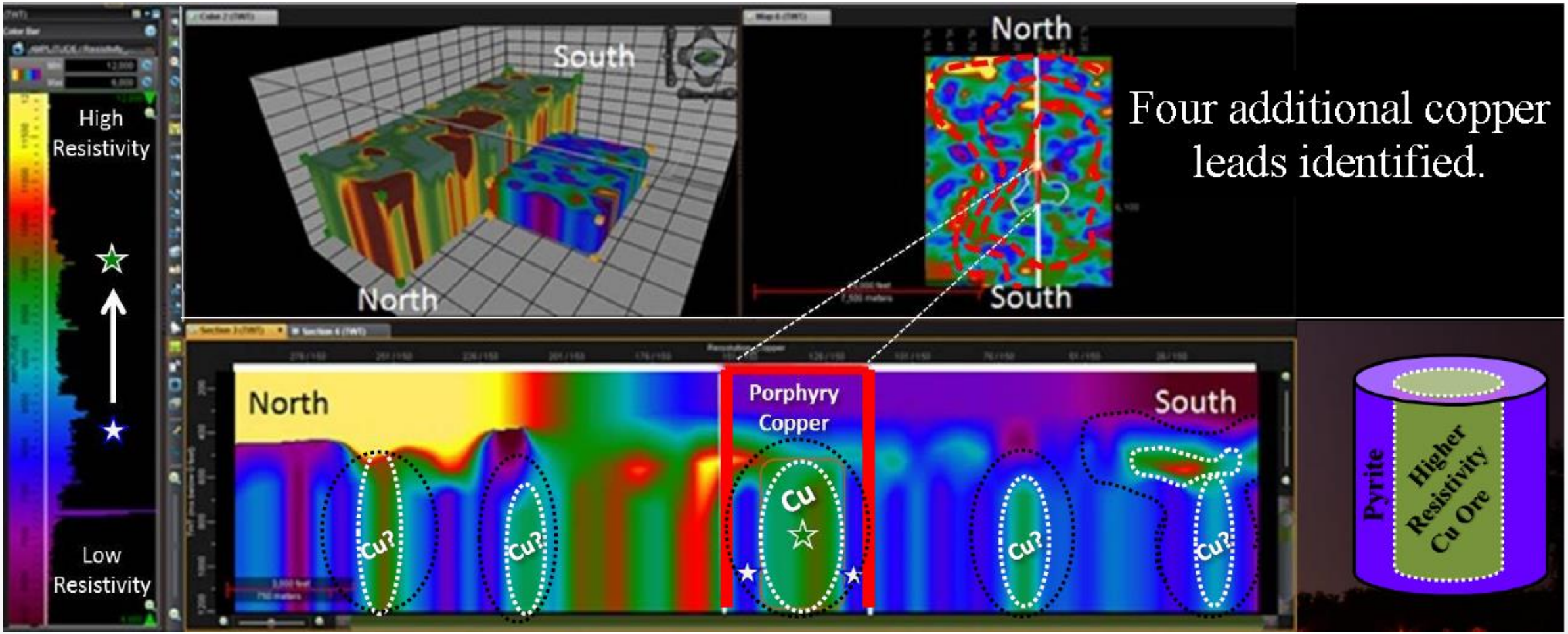
Resolution Copper Mine

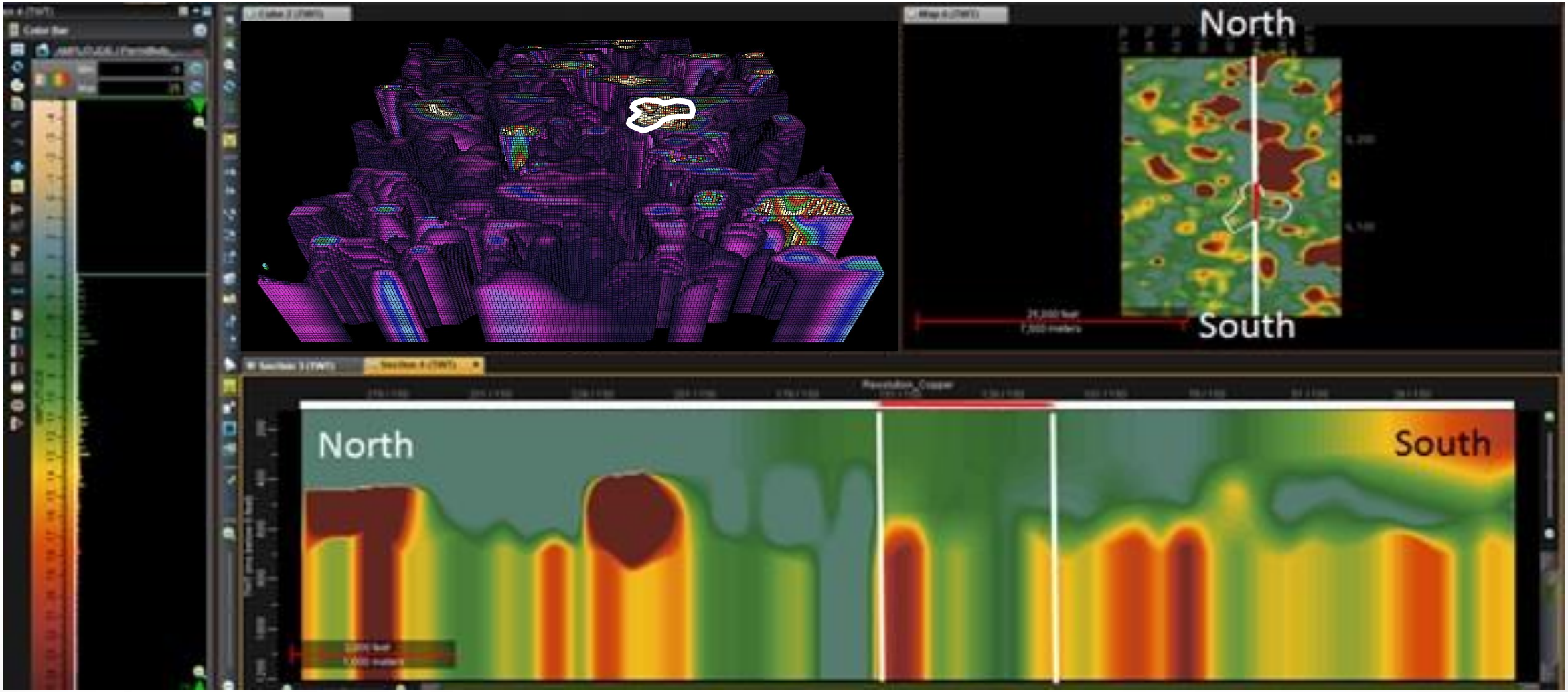
Middle Resistivity Depth – Average Absolute Resistivity 200 meters beneath surface



Resistivity Volume, Resolution Copper Mine



Permittivity Volume, Resolution Copper Mine



Next Steps

- Michigan: will seek well logs, seismic data, and production histories and will integrate this data with the lightning rock properties to quantify calibration.

- Arizona: have a follow-up Lightning Analysis Project with a major mining company working in Arizona where they will compare lightning rock properties with other geophysical surveys they have before and after opening the mine.

Conclusions

- Geophysical surveying does not dispense with the need for drilling, and
  - properly applied, it can optimize exploration programs by:
    - maximizing the rate of ground coverage, and
    - minimizing the drilling requirement.
- The importance of geophysics deriving geological information is so great, the basic principles and scope are appreciated and used by most practicing earth scientist.
- Lightning Databases, and lightning derived Resistivity and Permittivity Volumes are the latest innovative geophysical data types.
- Application of these new geophysical data types will open new doors of understanding.
- This next year DML will be calibrating Rock Properties against well and seismic data, again using DecisionSpace®.

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