New E&P Tool
Lightning Databases

Dynamic Measurement LLC

06 October 2015

Outline

1. NSEM - A new geophysical data type
2. The meteorology behind lightning databases
3. Calculating rock property volumes from lightning databases
4. Examples of using lightning databases to map geology

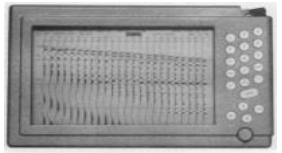
1. NSEM – (Natural Source ElectroMagnetics) – a new geophysical data type

A time-line of new Geophysical Data Types

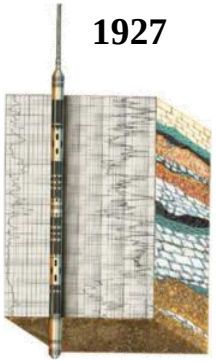
1752

1833

1920s

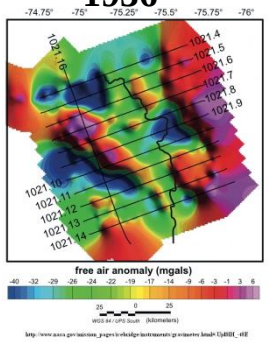


1927



1931

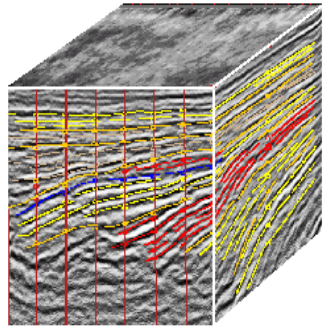
1936



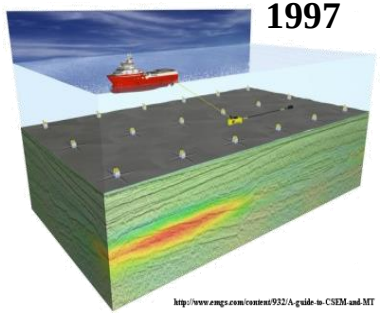
1950s

1960s/70s

1974

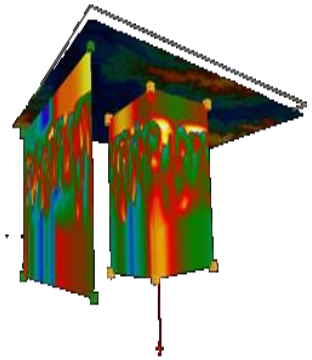


1997



2008

2015

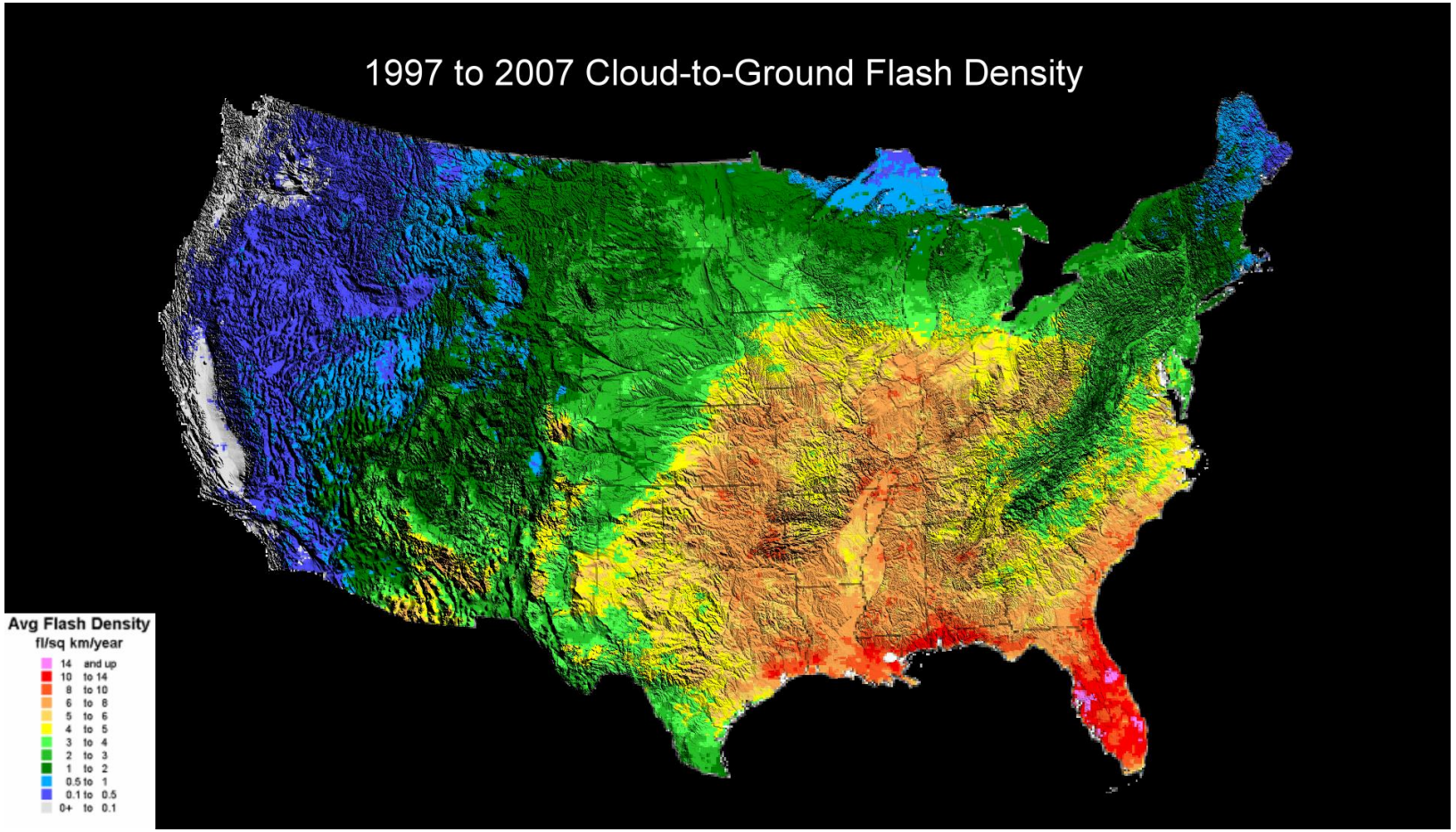


Each new data type has sparked a step change in new revenues and cost avoidance for upstream oil and gas companies

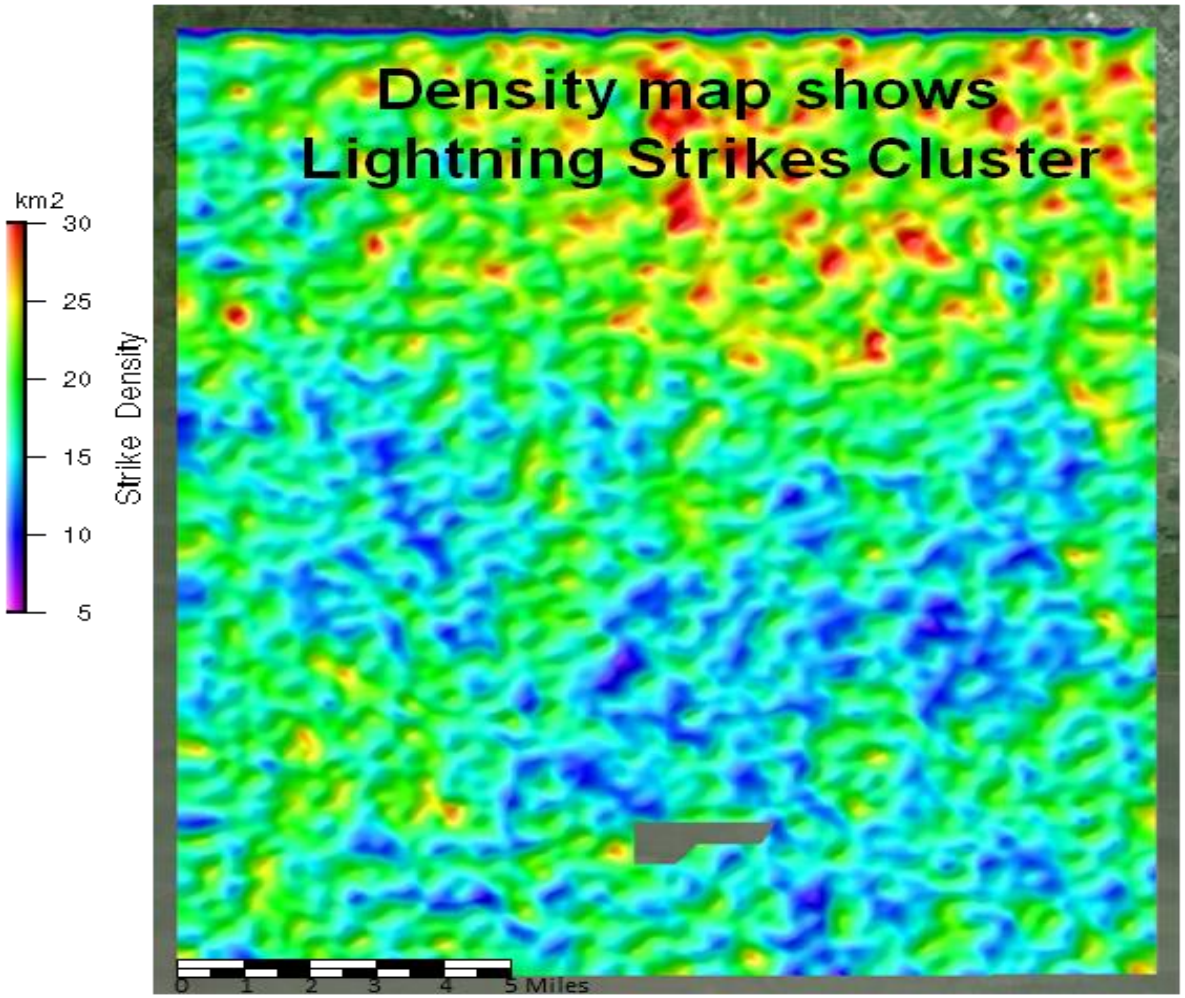
Upward Lightning tied to geology

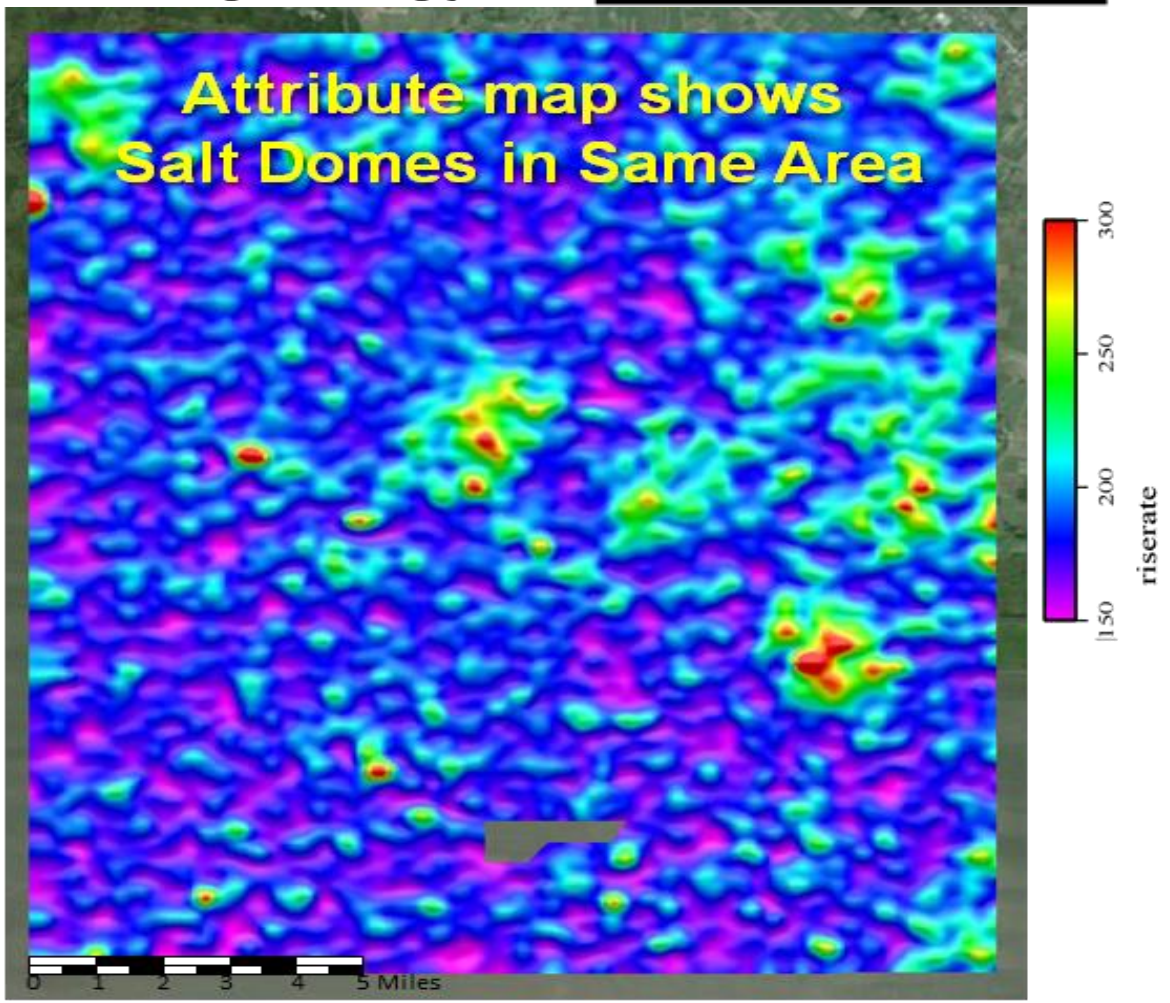
Main lightning bolt tied to geology

Lightning Occurs Everywhere and Lightning Databases Exist

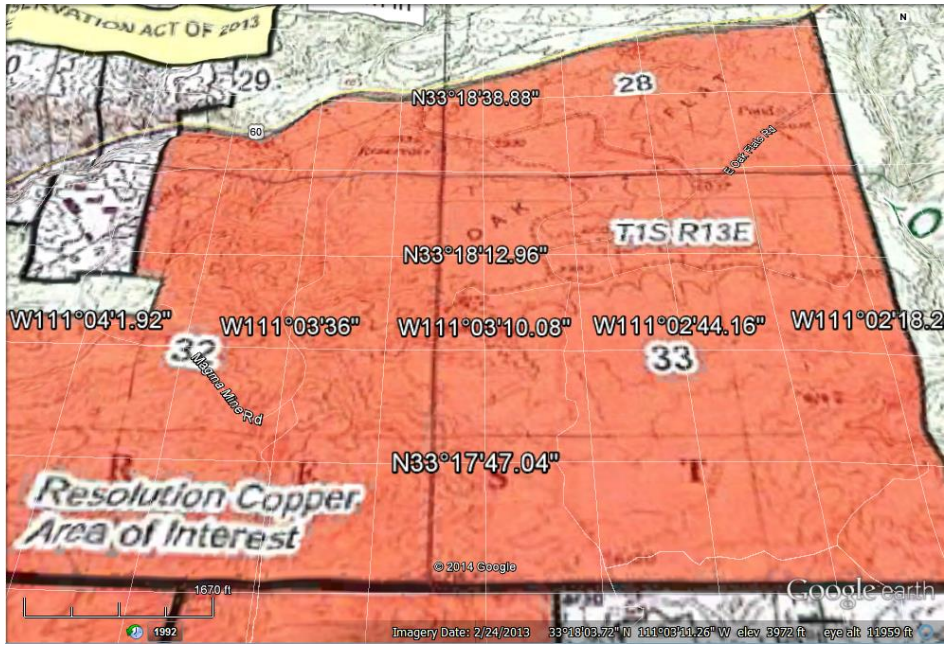


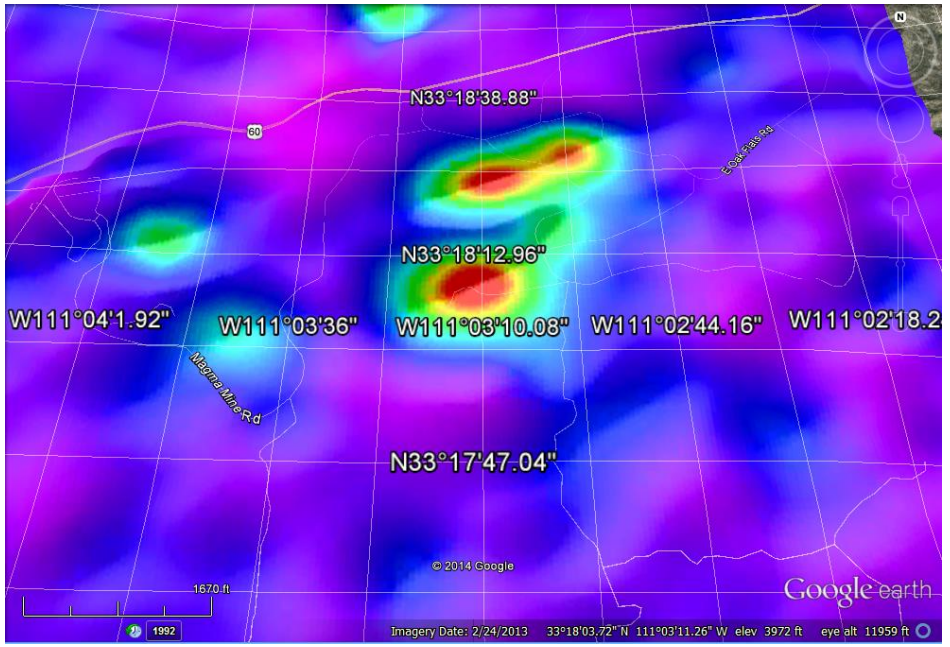
Lightning Data Analysis
demonstrates strikes are tied to geology

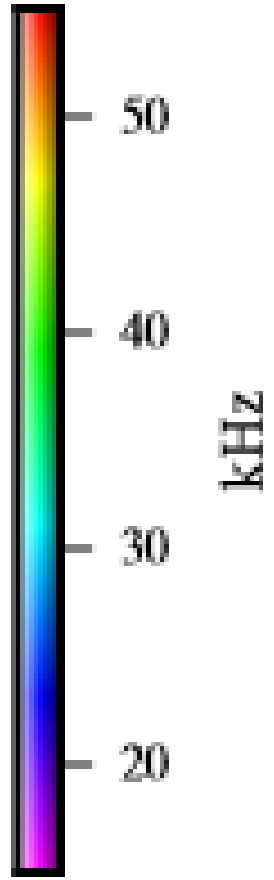




Attribute Maps related to major copper mine being developed in Arizona







GULF COAST ASSOCIATION OF GEOLOGICAL SOCIETIES

www.gcags.org

Dear Kathleen,

Congratulations! You have been selected to receive the First Place Grover E. Murray Best Published Paper Award for your paper, “Aquifers, Faults, Subsidence, and Lightning Databases” published in the 2014 GCAGS *Transactions*.

• • •

Mary Broussard
2013-2014 GCAGS President
Email: Mary_Broussard@fmi.com

DML's Business is based on Patents and an Exclusive License to Lightning Databases

Fig. 1

US008344721B2

(12) **United States Patent**
Nelson, Jr. et al.

(10) **Patent No.: US 8,344,721 B2**
(45) **Date of Patent: Jan. 1, 2013**

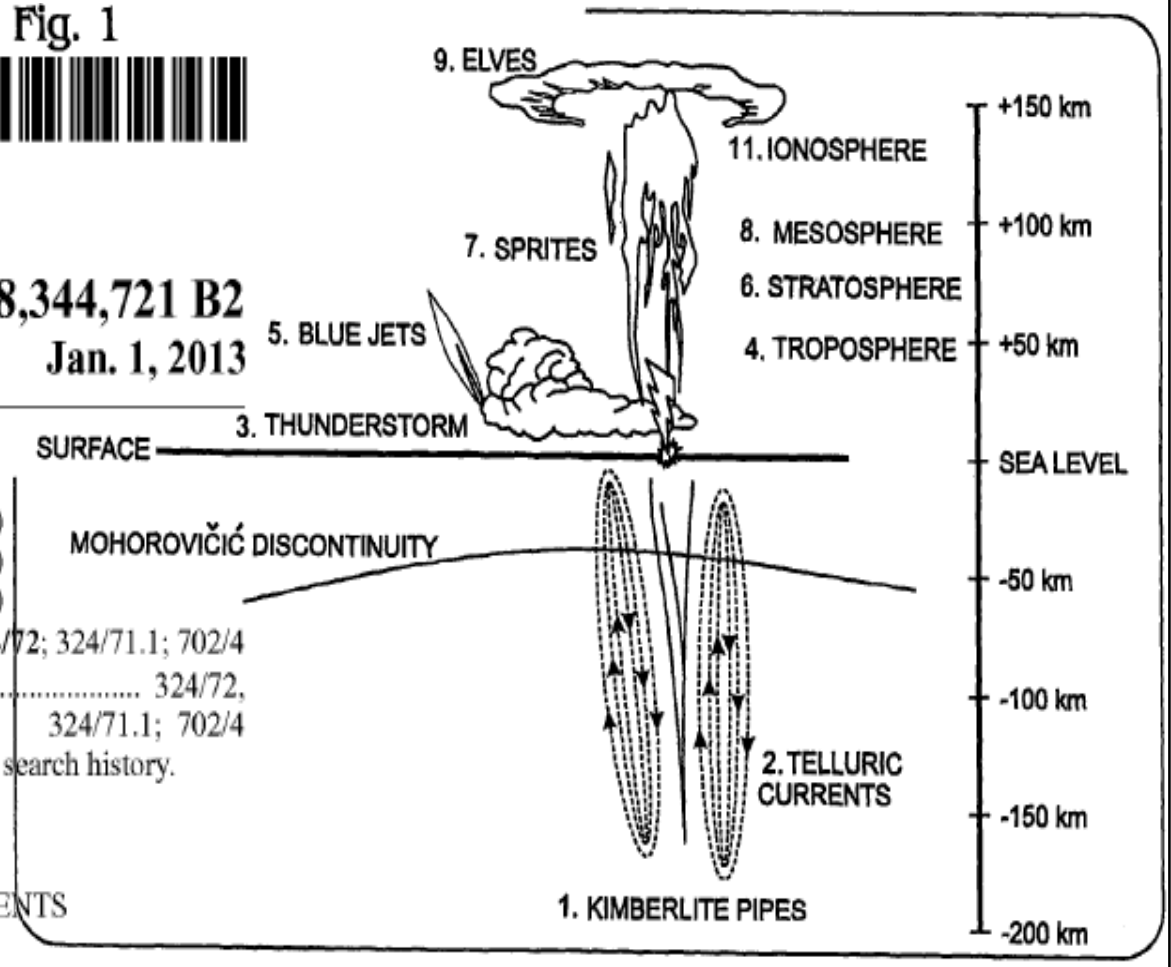
(54) **METHOD FOR LOCATING SUB-SURFACE NATURAL RESOURCES**

(75) Inventors: **H. Roice Nelson, Jr.**, Houston, TX (US); **Joseph H. Roberts**, Houston, TX (US); **D. James Siebert**, Katy, TX (US); **Wulf F. Massell**, Conroe, TX (US); **Samuel D. LeRoy**, Houston, TX (US); **Leslie R. Denham**, Houston, TX (US); **Robert Ehrlich**, Salt Lake City, UT (US); **Richard L. Coons**, Katy, TX (US)

(51) **Int. Cl.**
G01R 31/02 (2006.01)
G01N 27/00 (2006.01)
G01W 1/00 (2006.01)
(52) **U.S. Cl.** 324/72; 324/71.1; 702/4
(58) **Field of Classification Search** 324/72, 324/71.1; 702/4
See application file for complete search history.

(56) **References Cited**

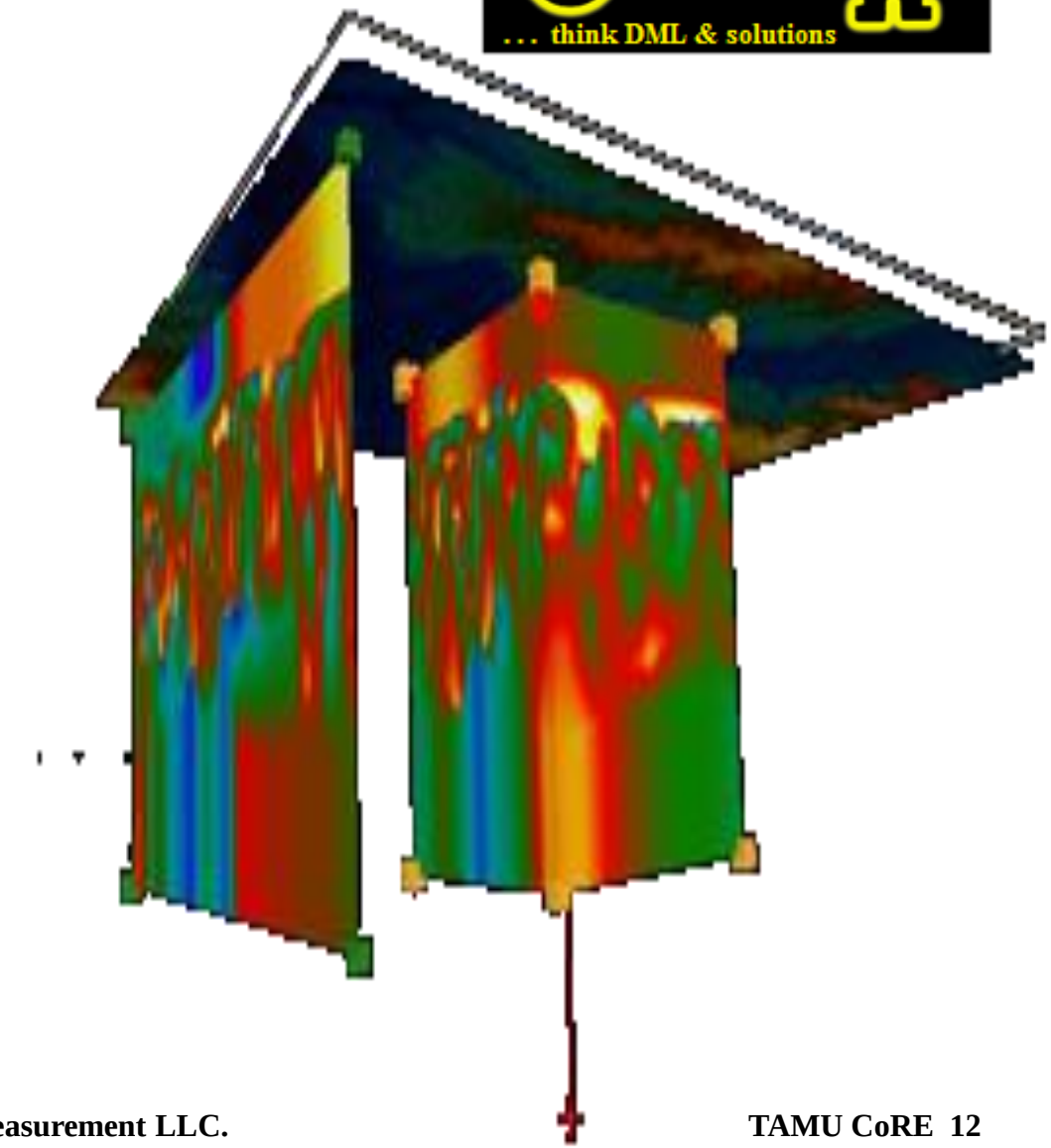
U.S. PATENT DOCUMENTS



Technical Merit & Economic Benefits

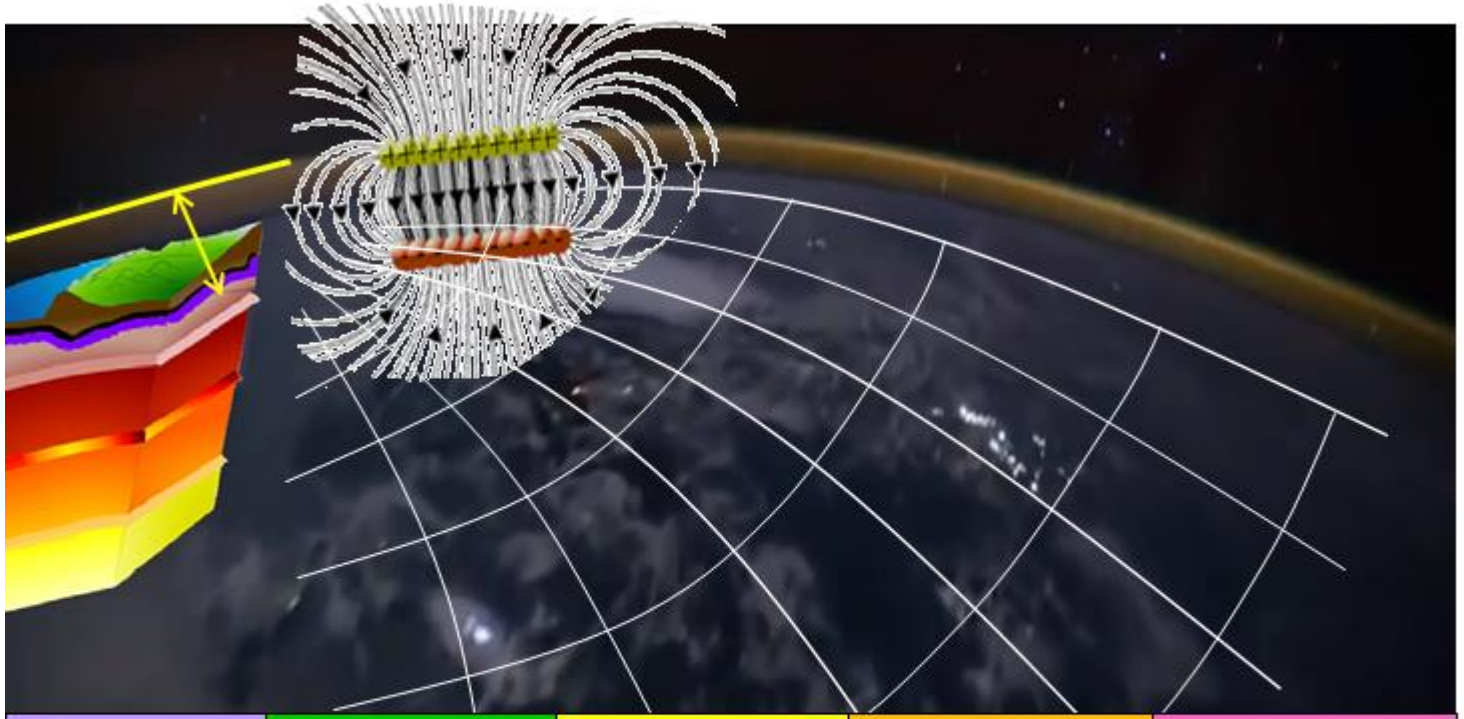
- Maps, Sections, and Volumes
- Evergreen Data
- 17 year database US & Canada
- 4 year database worldwide
- Integrates with other data
- Simple Solution
- Patented, & Patent Pending

- 2 month project turnaround
- Larger Area – Less Expense compared to 3-D seismic

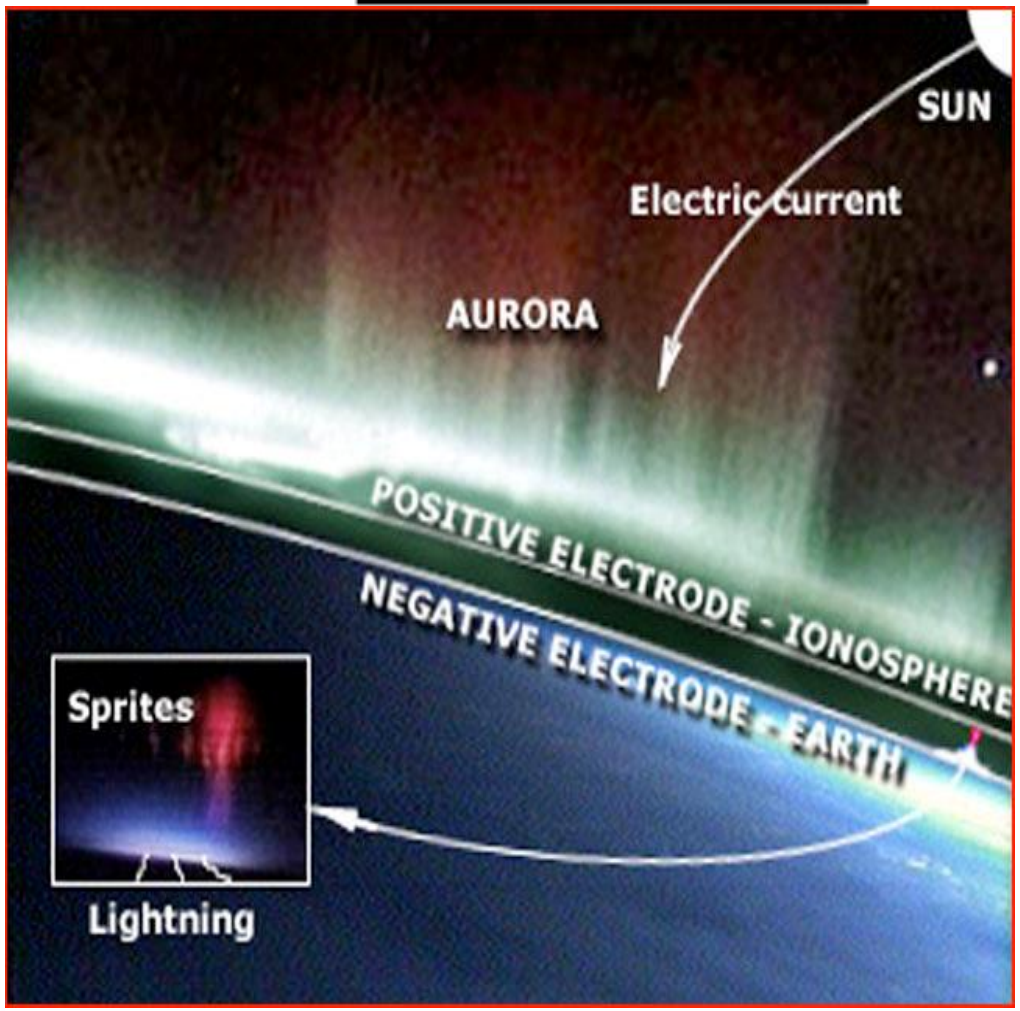


2. The meteorology behind lightning databases

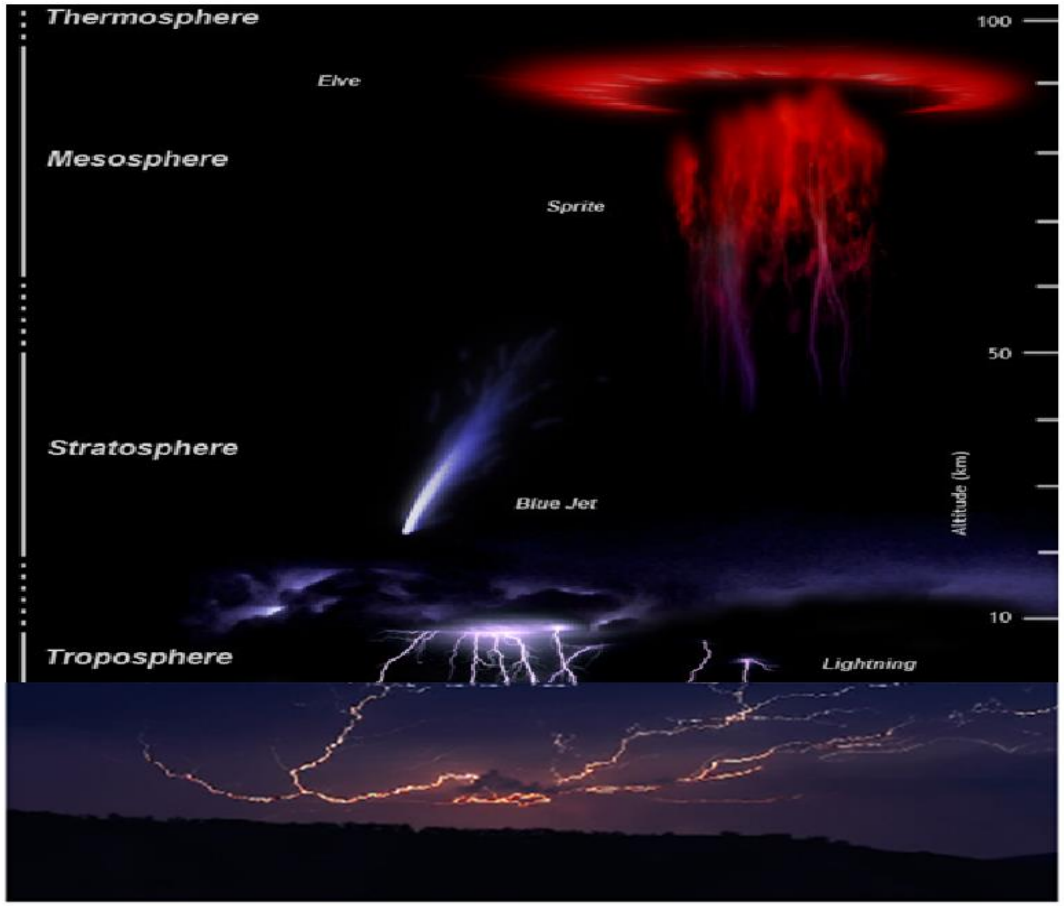
Earth: A Self-Repairing Capacitor

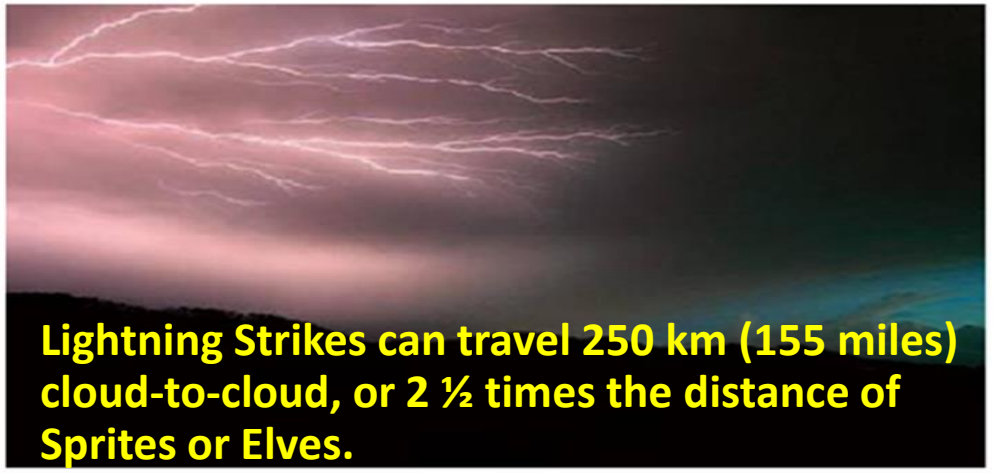


1	2	3	4	5
Lightning Charges Telluric Currents	Evergreen Lightning Database Created	IG Index for Each Lightning Strike	Interpolated to Project Grid (e.g. 3D Seismic)	Vertical Interpolation Tied to Strike Cloud Height



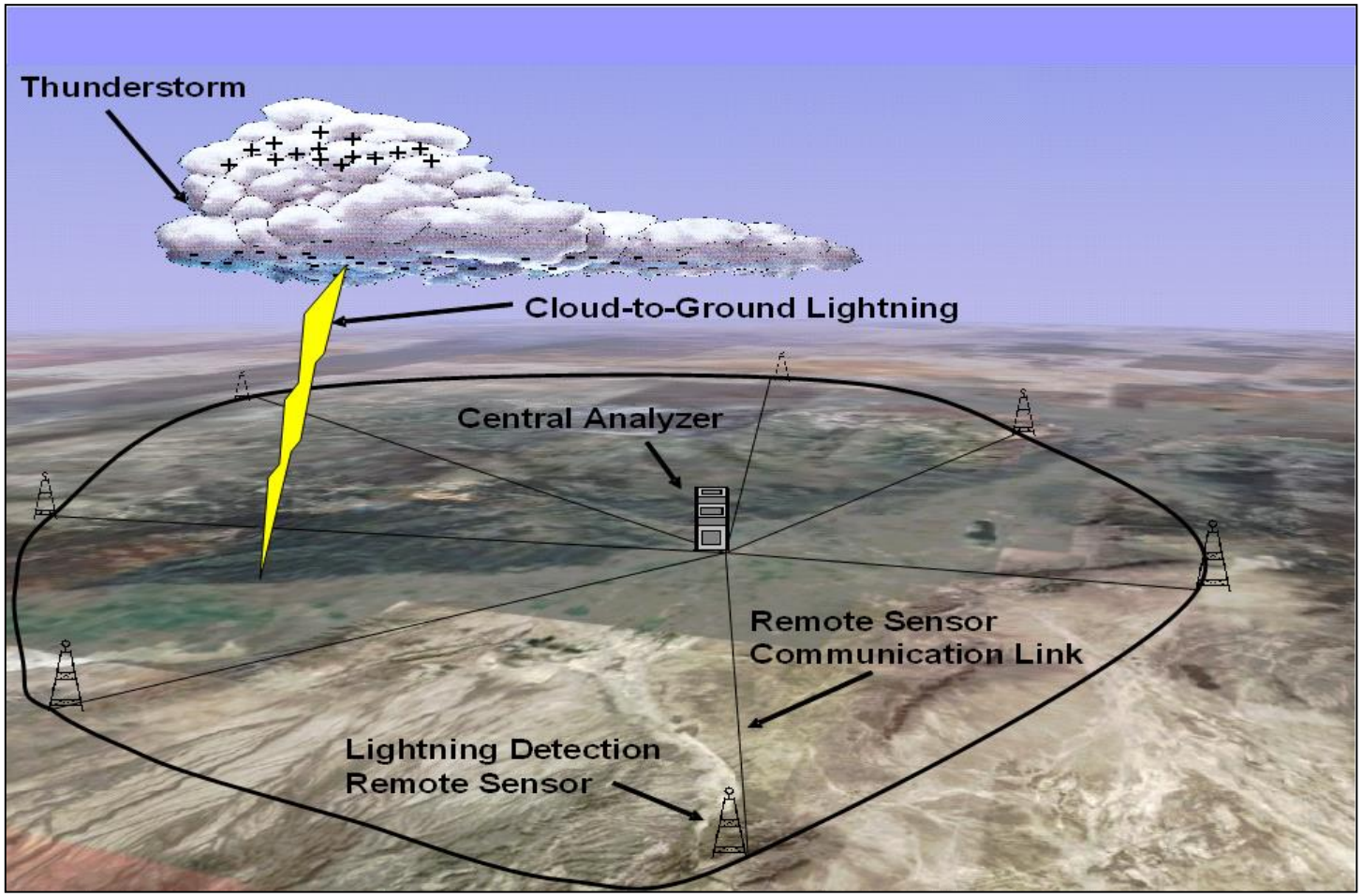
350 million annual Lightning Strikes - a rich database to mine





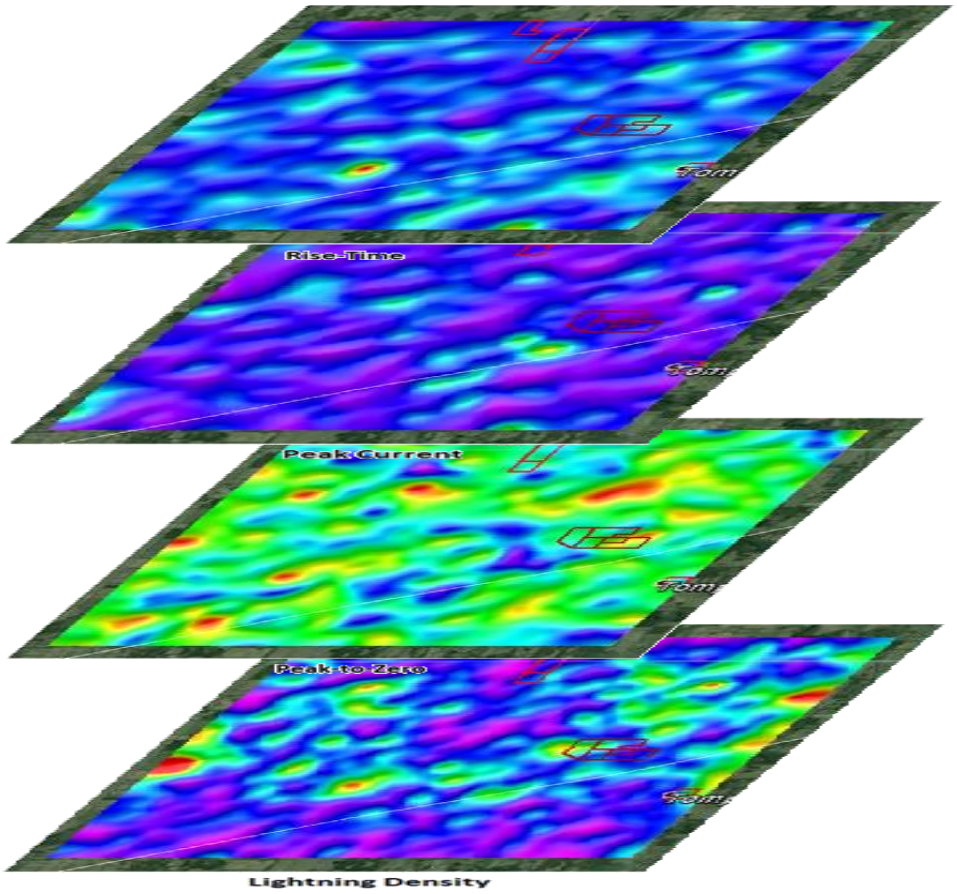
Lightning recorded for early storm warning, safety, **insurance**, and meteorological purposes

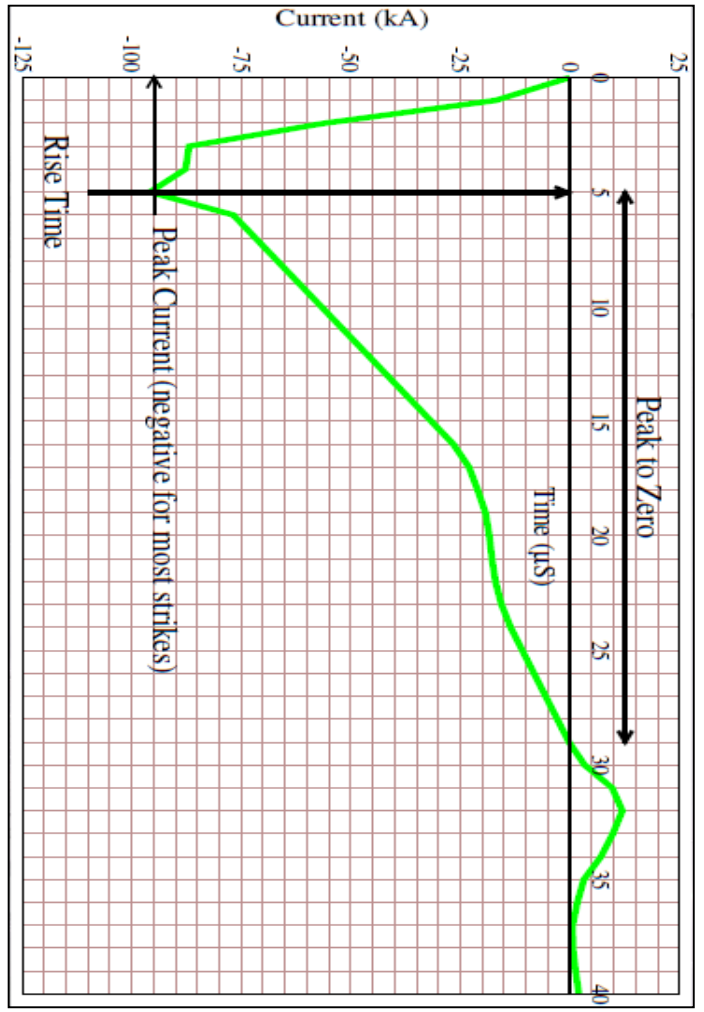
110 Sensors record U.S. lightning strike locations
with 650-980 feet (200-300 meter) horizontal resolution



Lightning Strike Measurements

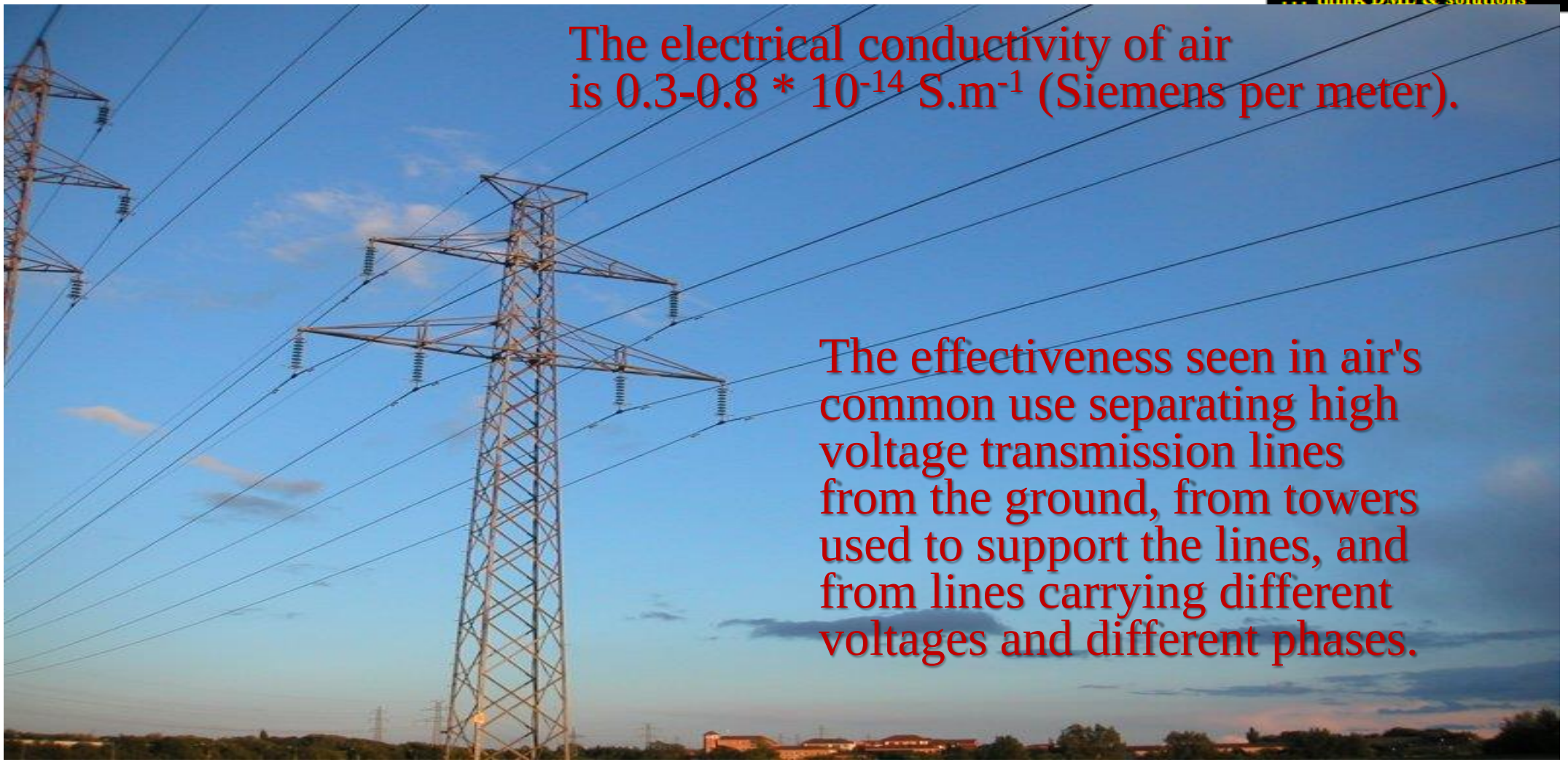
- Location
- Time and Duration
- Rise Time
- Peak Current
- Polarity
- Peak-to-Zero
- Density





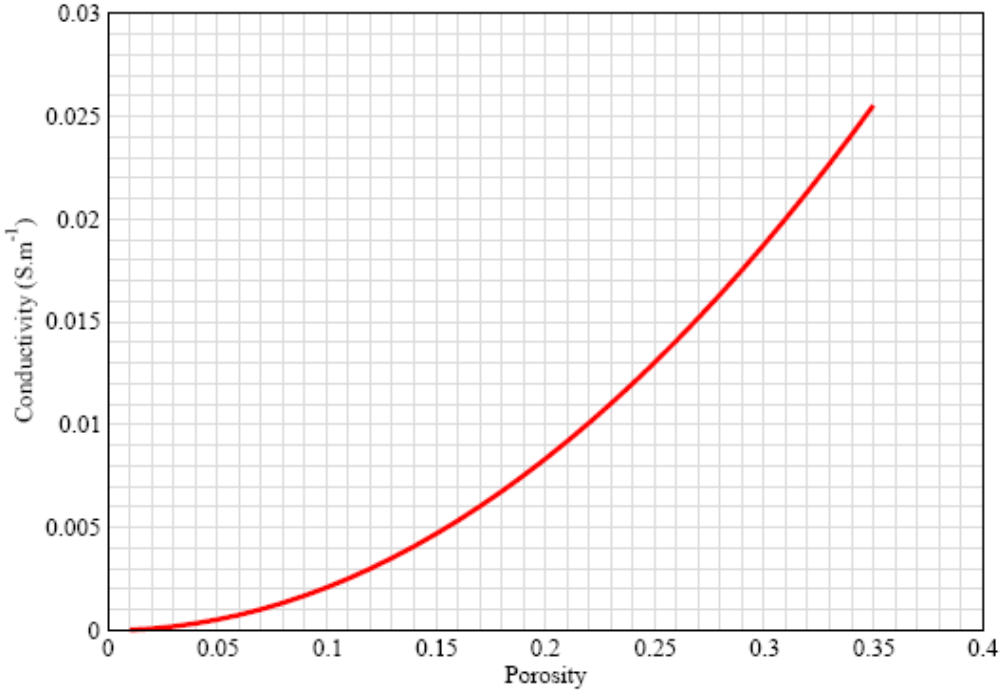
3. Calculating rock property volumes from lightning databases

The atmosphere is an effective insulator



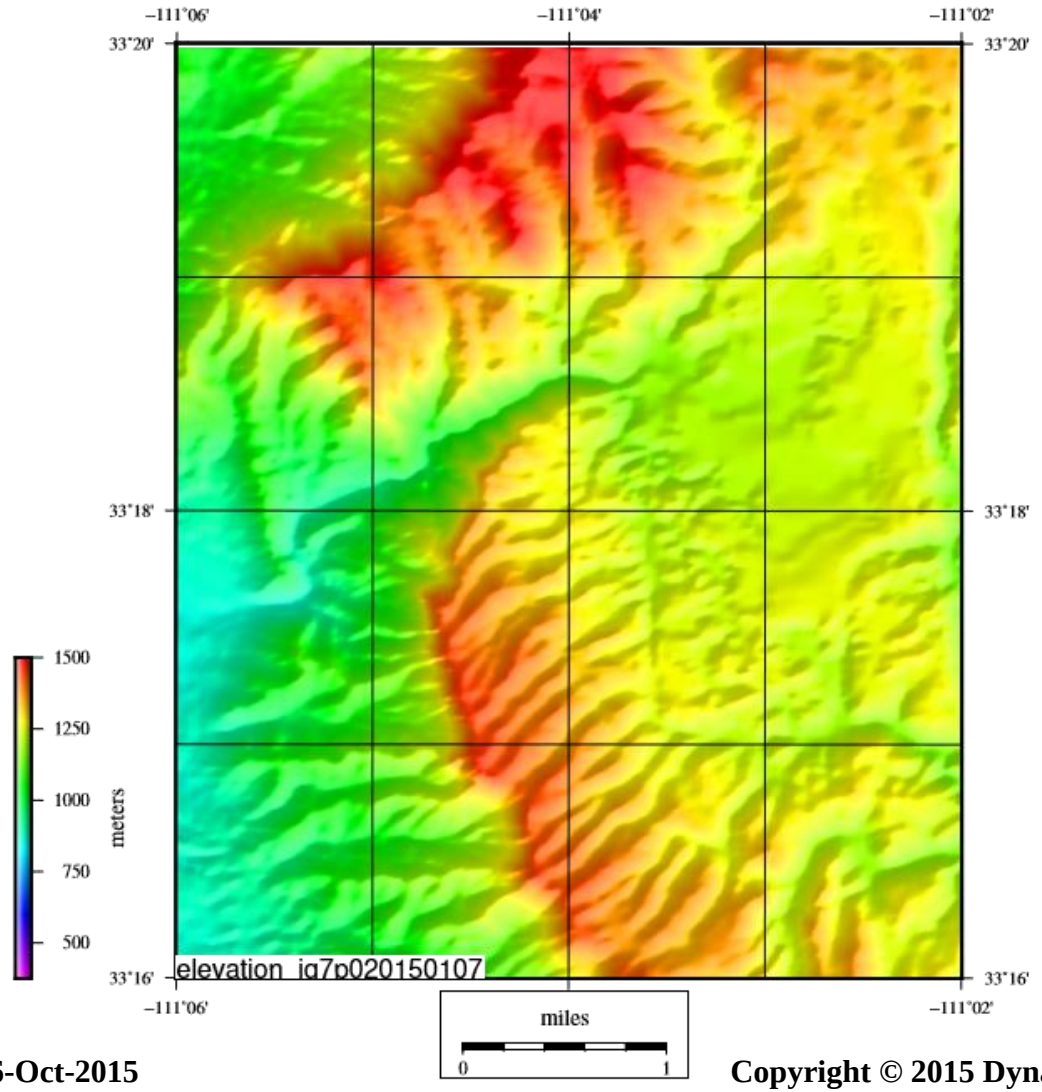
The earth is much more conductive than air

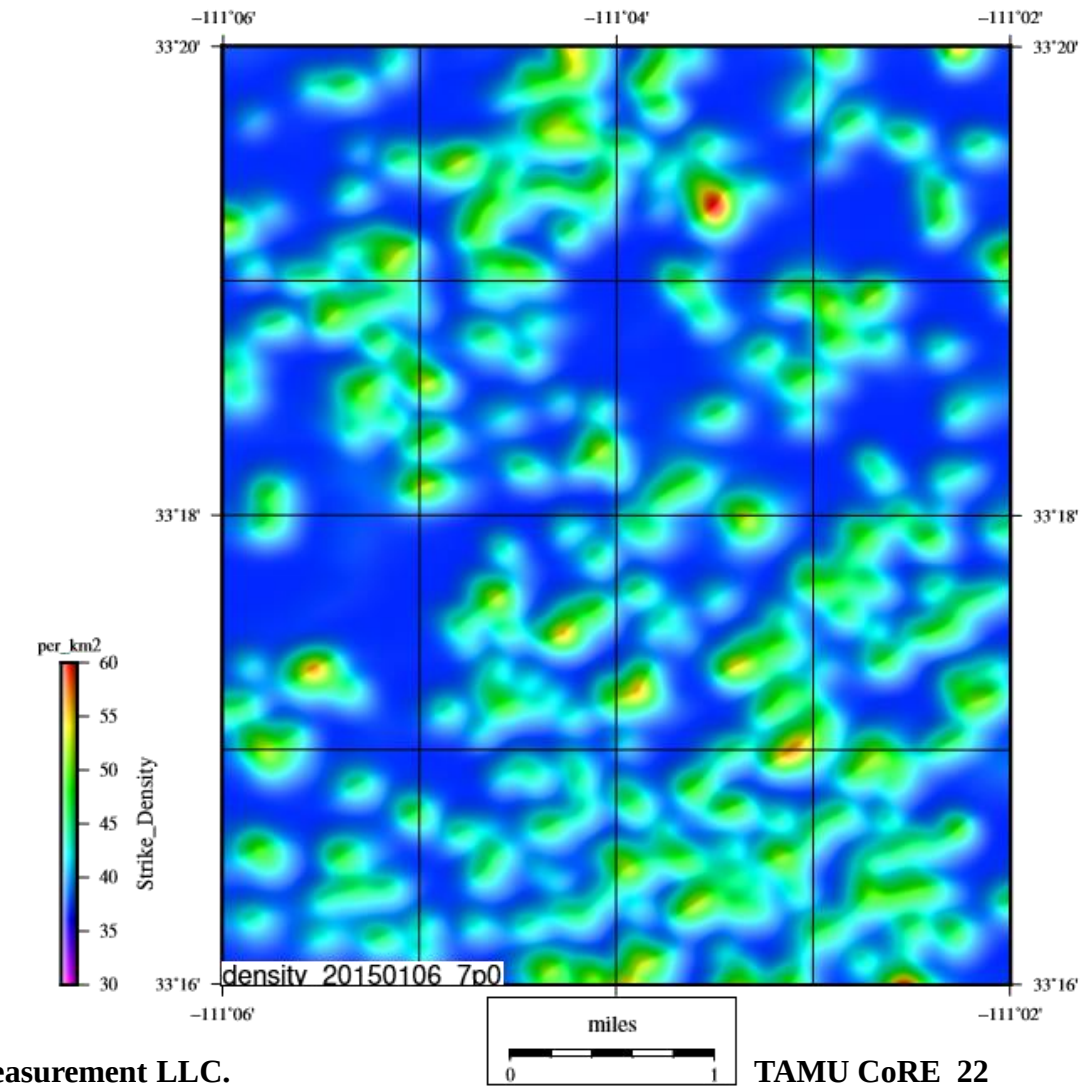
Assuming a typical sedimentary rock has 5% porosity, the electrical conductivity of rocks is $5.0 * 10^{-4}$ $S.m^{-1}$, or about 10^{10} times the conductivity of air.



Rock Conductivity Graph computed for a porous rock with 100% brine saturation using Archie's equation

Topography and Lightning Density Arizona





The Atmospheric Capacitor

Plate 1

- The charged thundercloud is one plate of a capacitor
- The other plate of the capacitor is the earth underlying the charged cloud
- The dielectric is the air
- Energy from a lightning strike is converted to heat, partly in the air, but largely in the subsurface

Dielectric

Plate 2

Lightning a Dielectric Breakdown

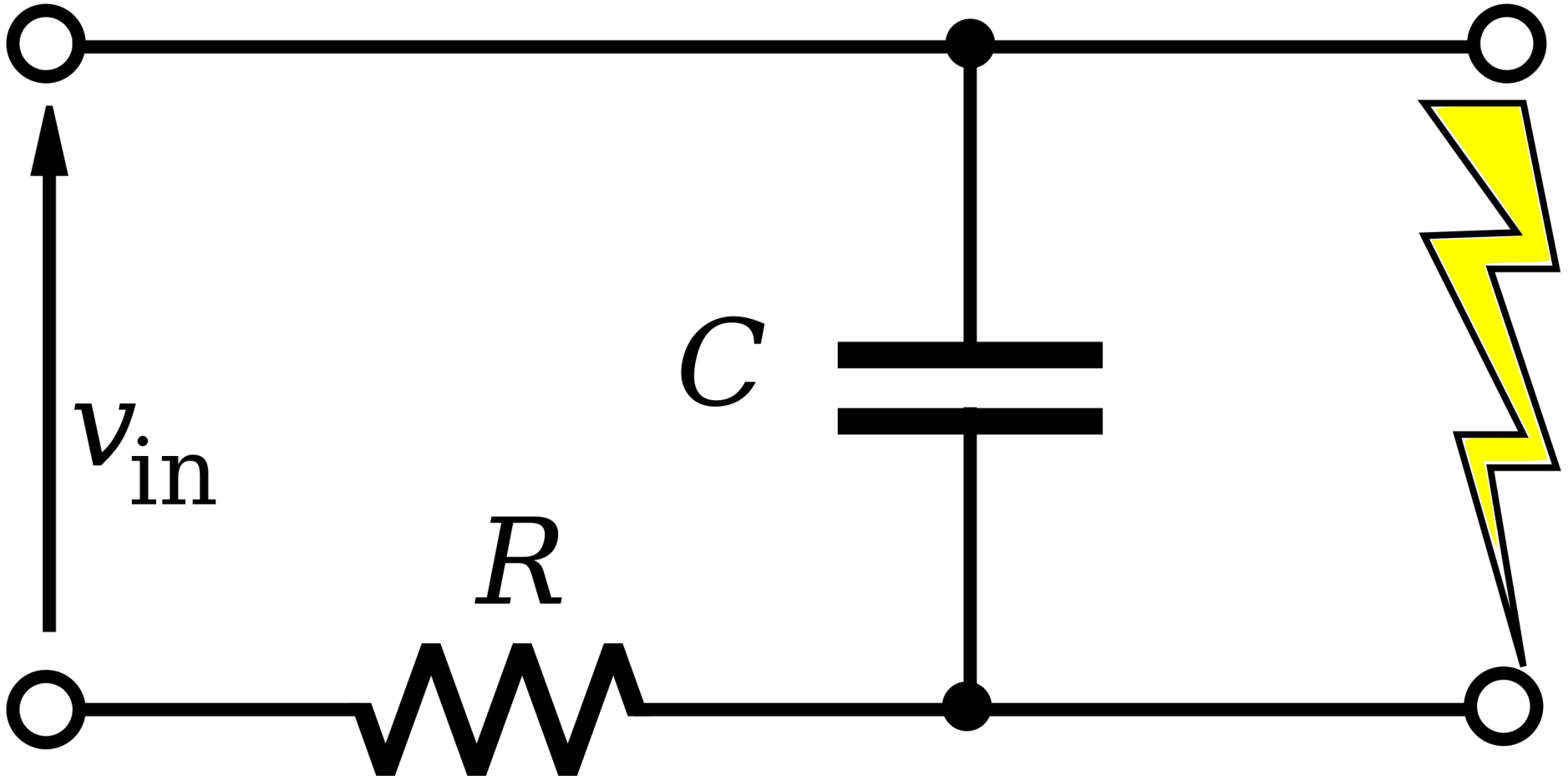
- Lightning occurs when the voltage across the atmospheric capacitor exceeds the dielectric strength of the air.
- Resistance in the atmosphere is very low once the path is ionized.
- Resistance in the subsurface is approximately constant over long periods of time.
- Atmospheric factors vary with each stroke.

Can we separate rock resistance?

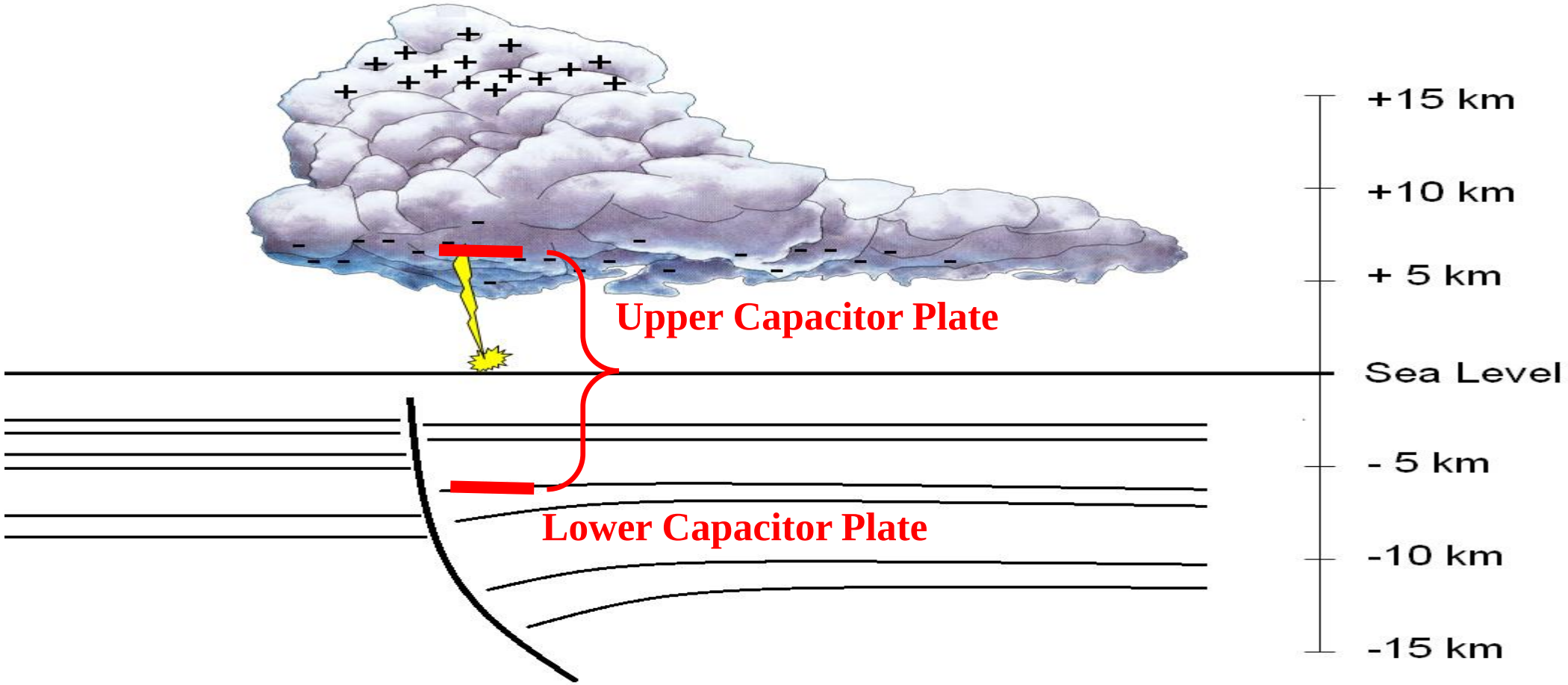
- The physics of lightning discharge are similar to the physics of a neon-tube relaxation oscillator.

- In each case, voltage builds across a capacitor until an insulating gas ionizes and becomes a conductor

Relaxation Oscillator

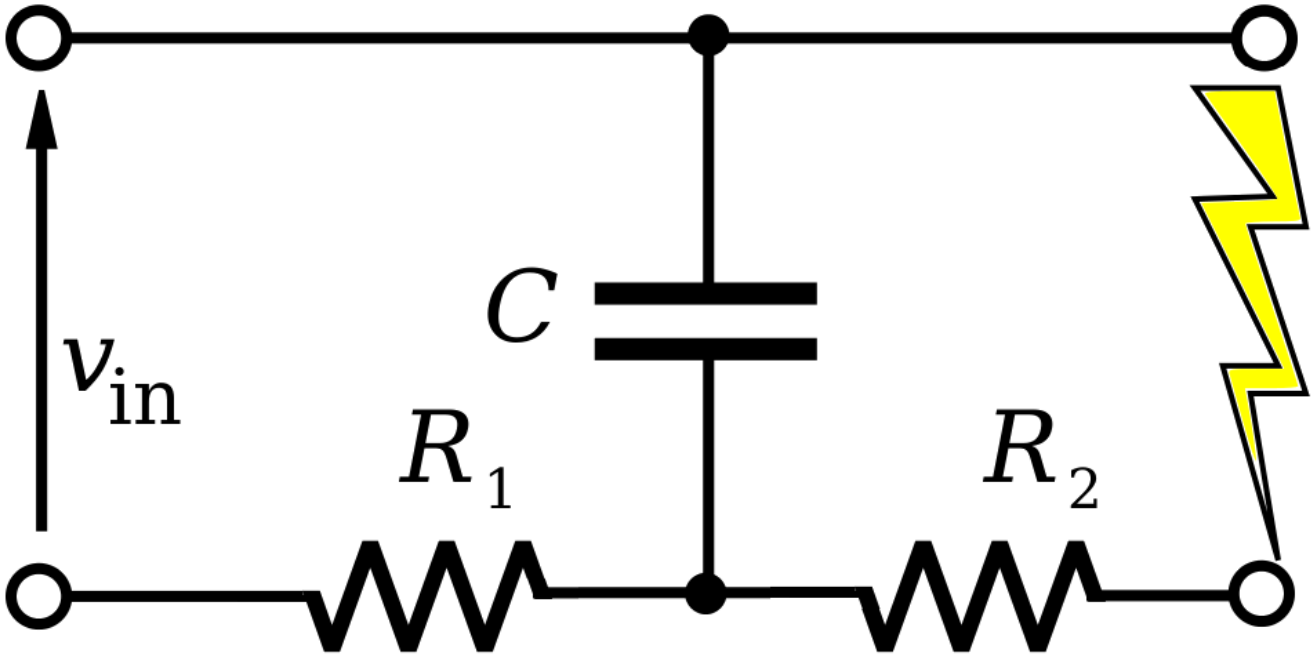


Each Strike Represents a Unique Capacitor



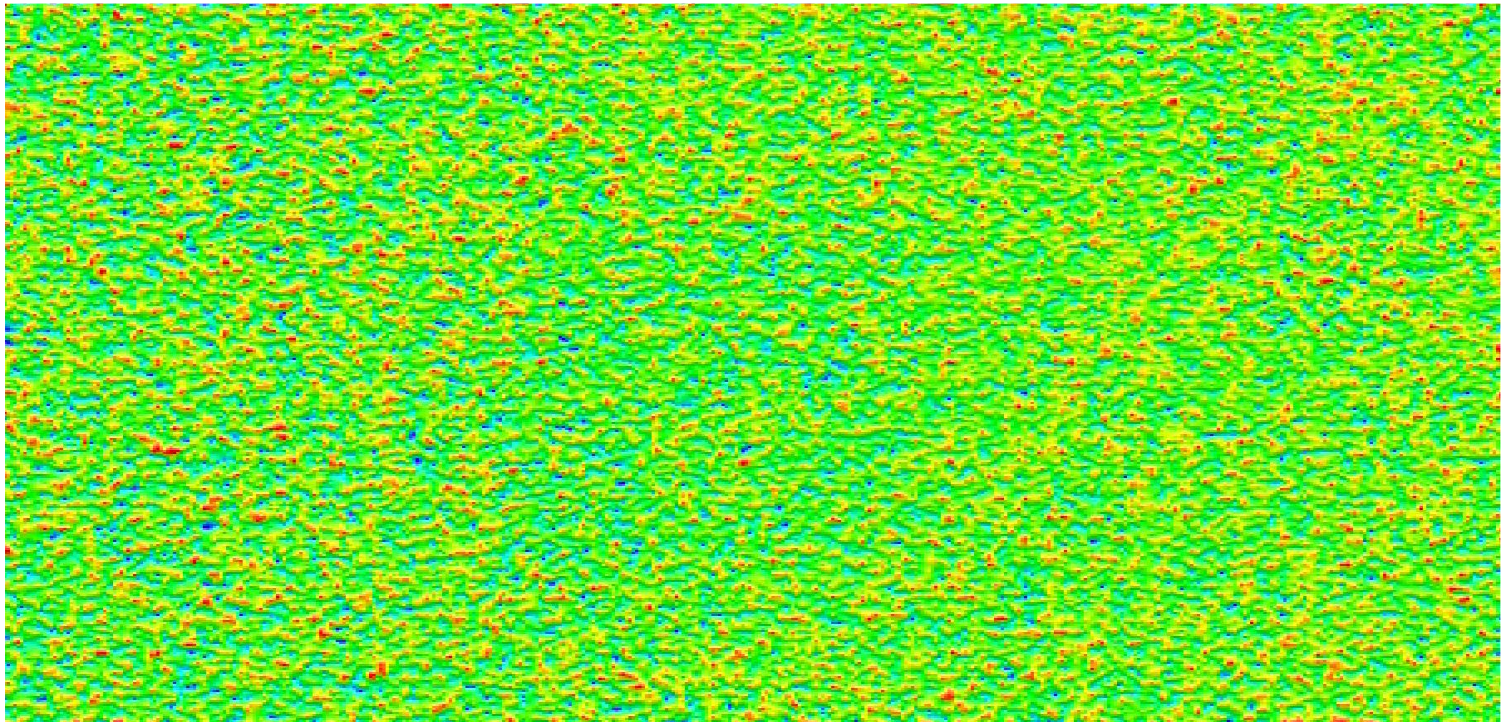
Lightning

- The atmospheric capacitor is nearly the same
- 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

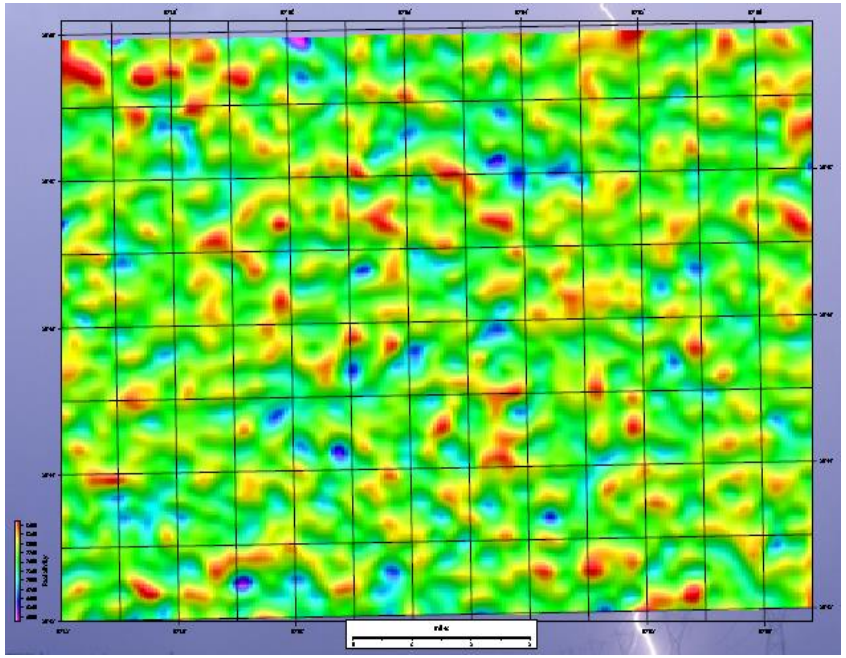


Resistivity Maps

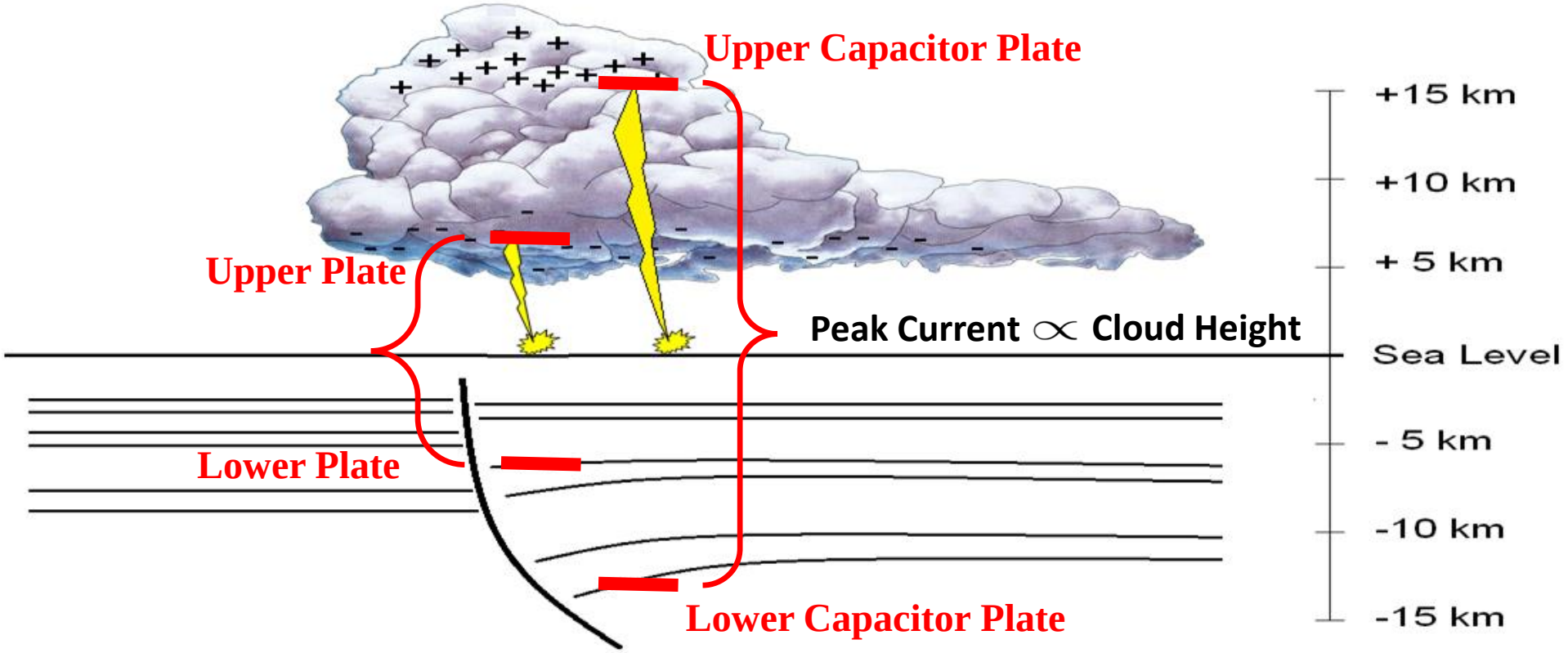
Houston Area



Milam County



Millions of Lightning Strikes
Millions of Measurements



Resistivity and Depth

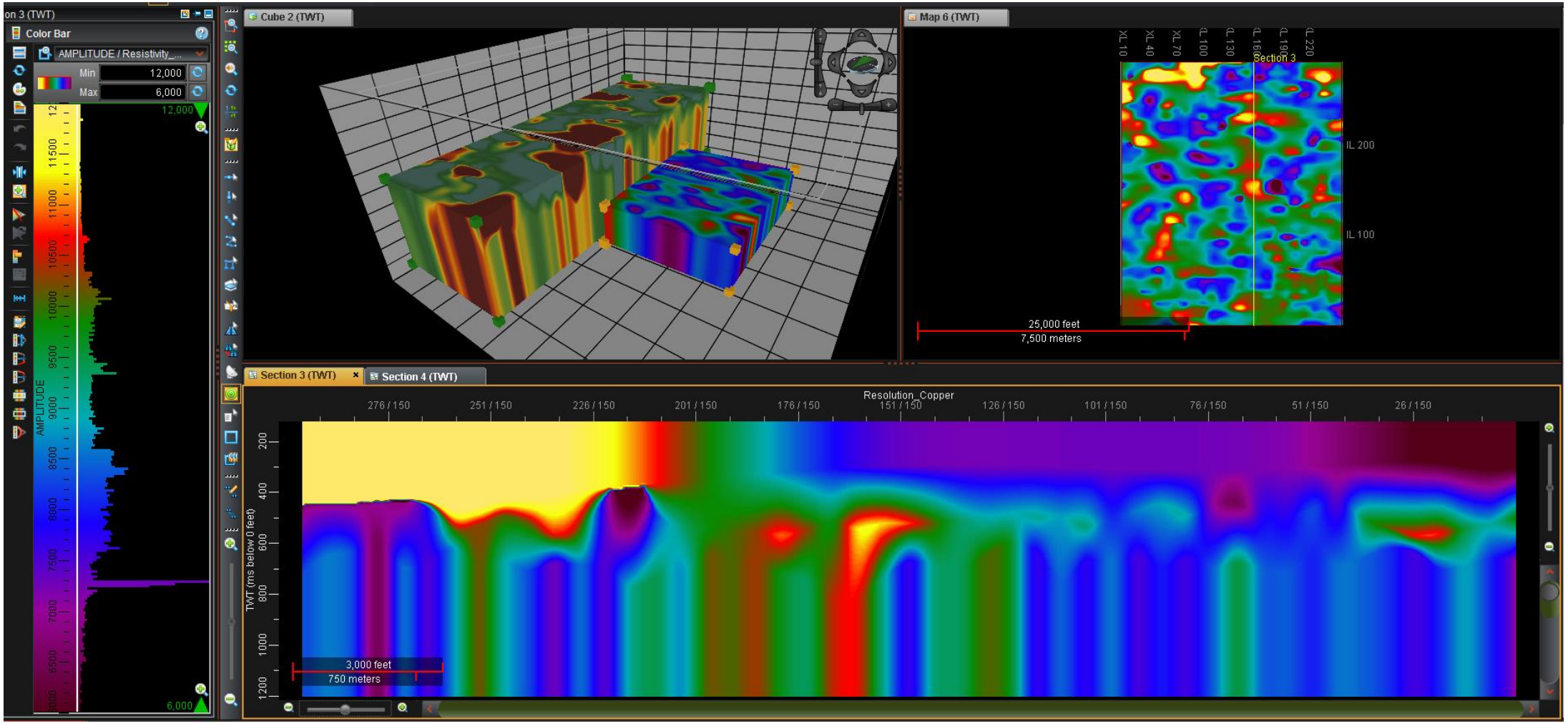
- As mentioned above, electrical energy from more powerful strikes is partially dissipated at greater depths.

- So grouping strikes by peak current will give resistivities grouped by depth.

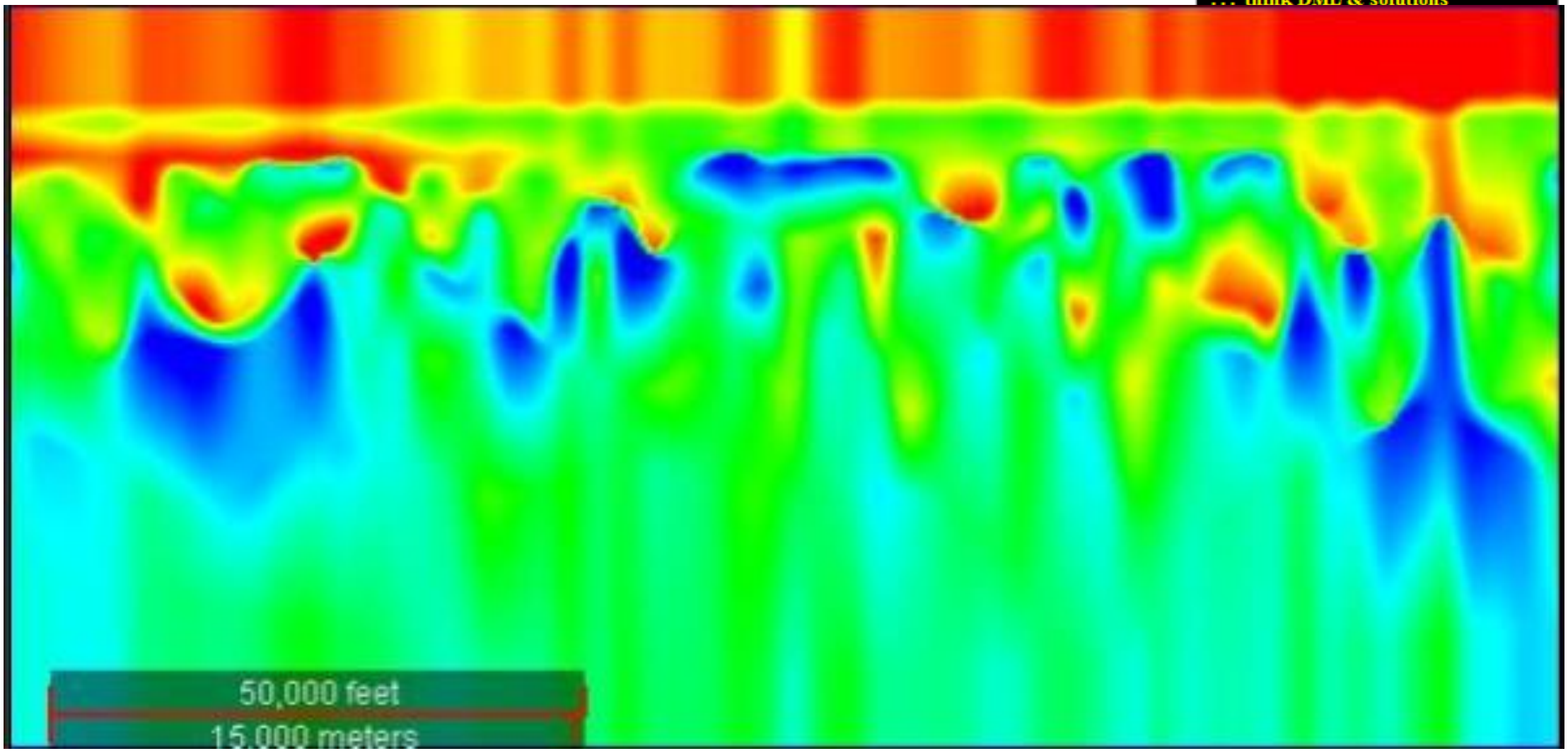
A Resistivity Trace

- For standard seismic interpretation software, data traces need to be uniformly sampled in time or depth, with the same number of samples in each trace
  - At latitude and longitude for the trace, each depth grid is sampled and each resistivity grid is sampled.
  - Resistivity values are interpolated with depth between these points to give samples at uniform intervals.
- Typical sample interval is 48 meters.
- Typical trace length is 125 samples.
- There is no restriction in sample interval or length beyond those imposed by the SEG-Y format.

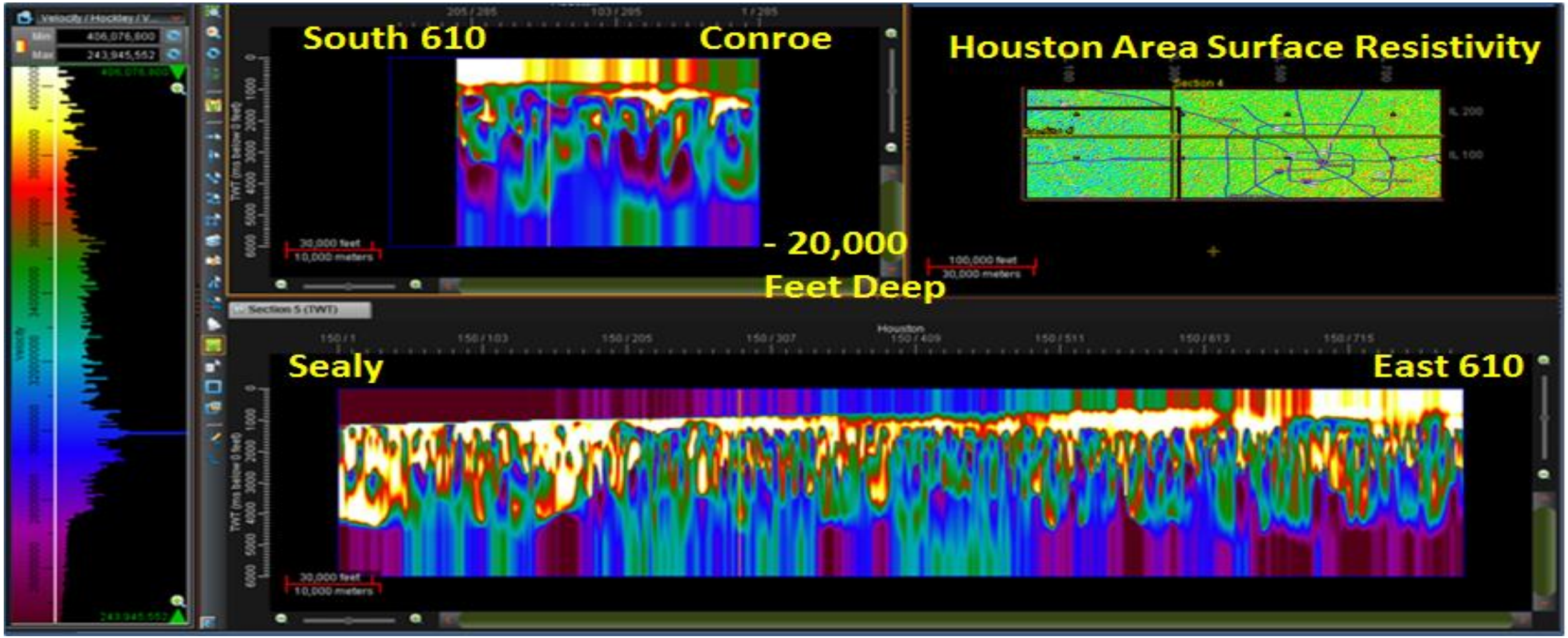
Resistivity Volume Arizona



Resistivity Volume Cross-Section



Houston Area Resistivity Volume Example



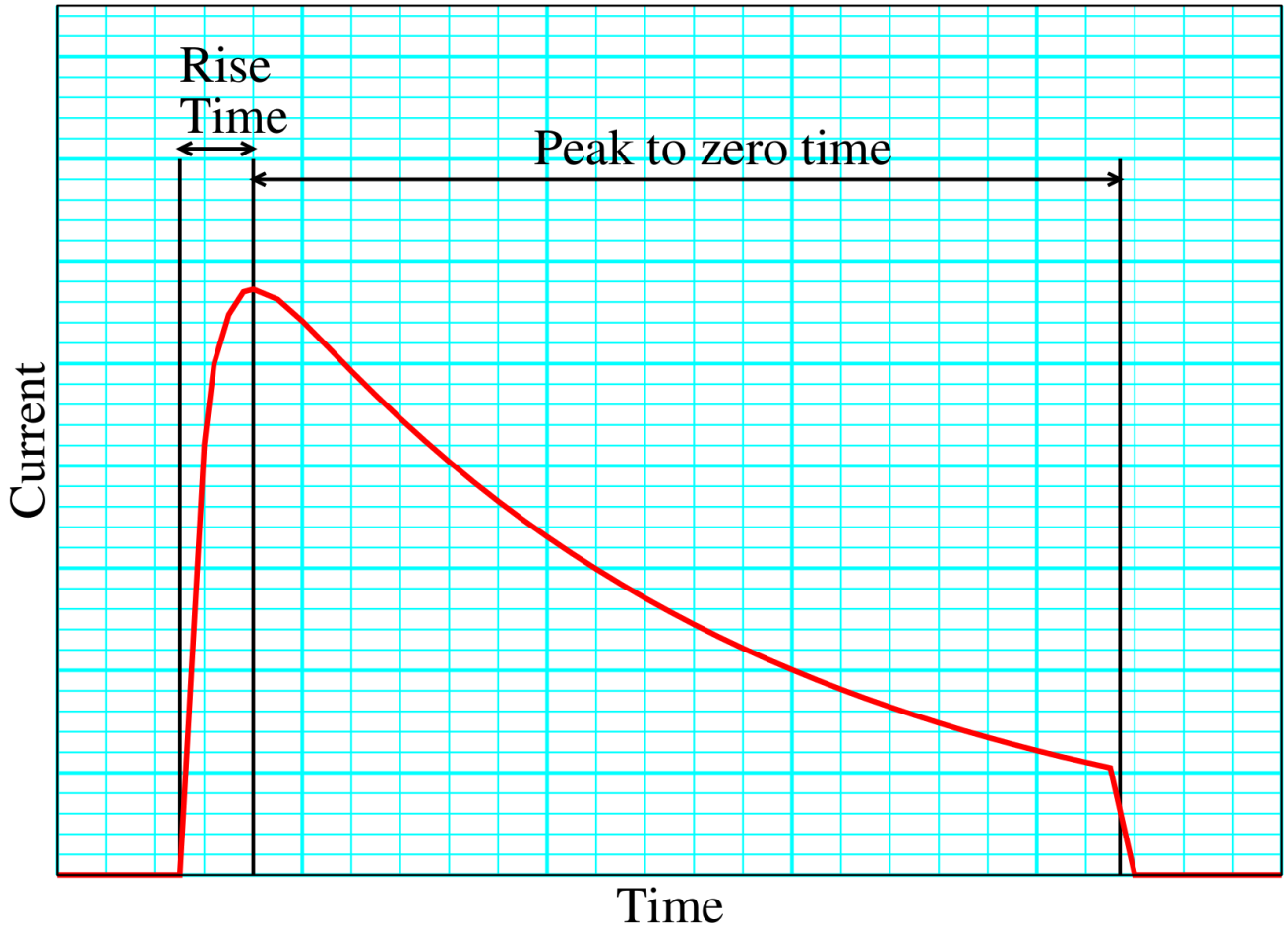
IP (Induced Polarization) Effect

- IP Effect is the departure of measured voltage from the square wave input current

- It can be measured on either the decay curve or on the charging curve

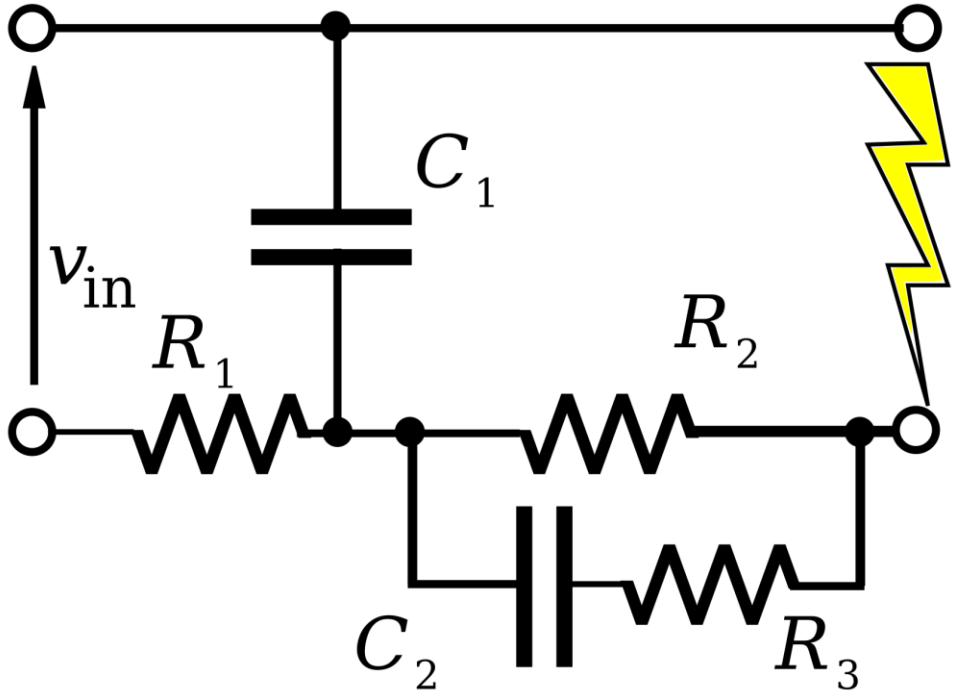
Lightning and the IP Effect

- Lightning does not have a square waveform
- But it does have a very steep onset
- Variations in the onset as measured (rise-time) show the IP Effect



The equivalent circuit

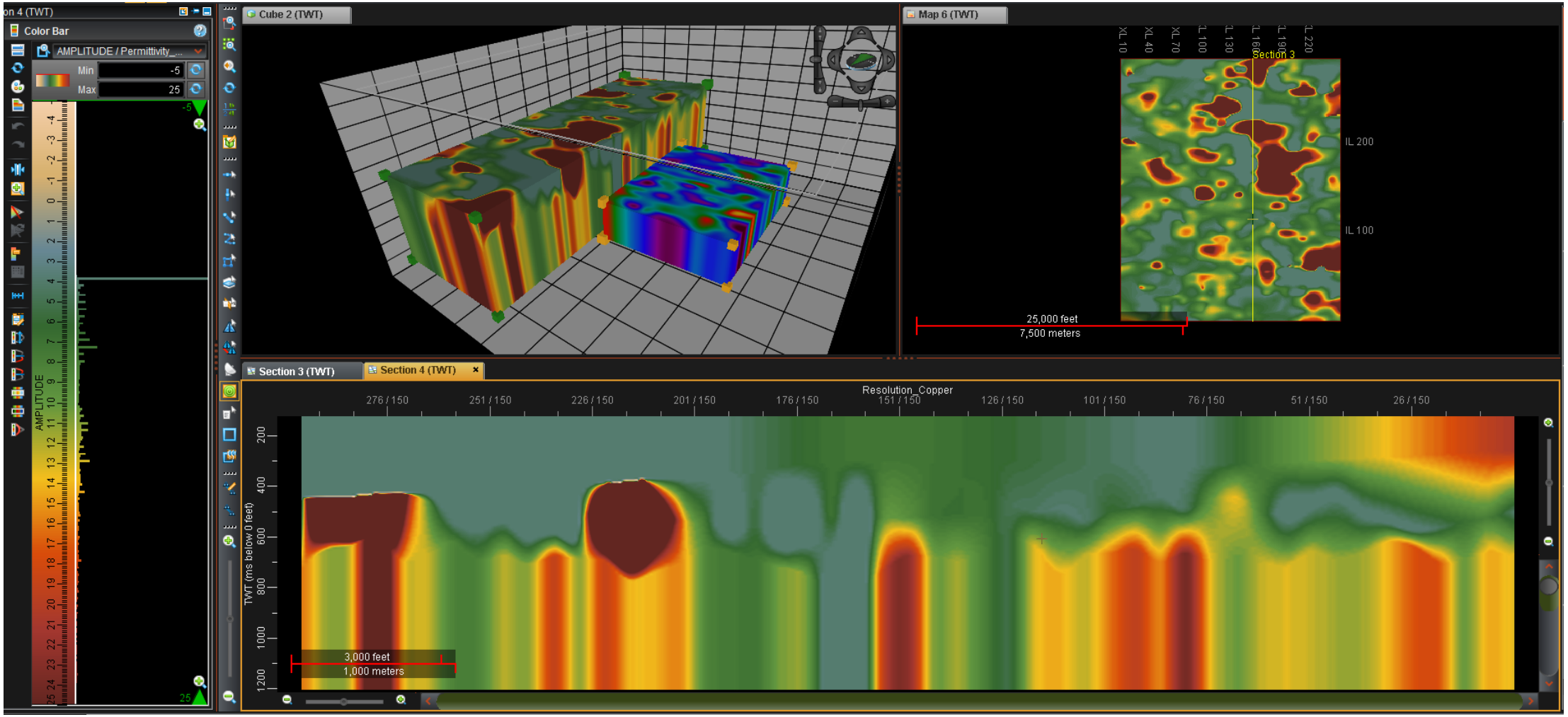
- By treating this as charging a capacitor (C_2) through a resistor (R_3), an apparent capacitance can be calculated
- From apparent capacitance a value for average permittivity can be calculated



Permittivity volumes

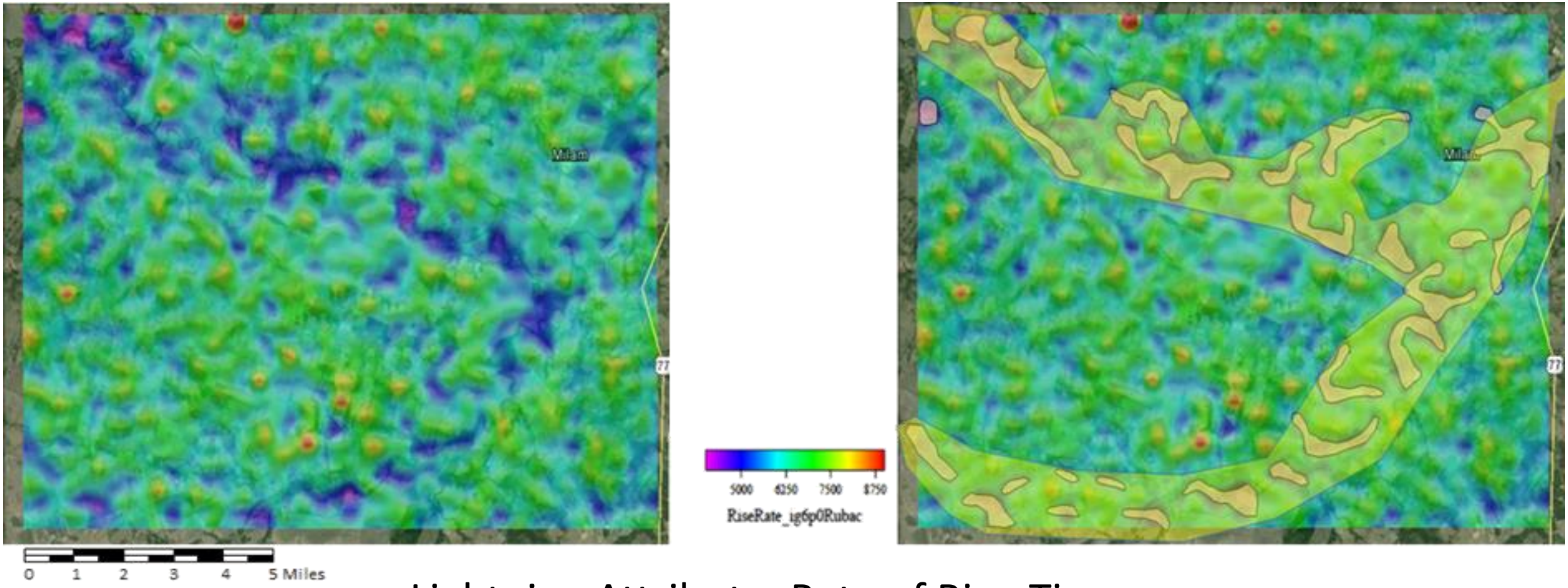
- Depth of penetration for permittivity depends on lightning stroke energy
- Lightning strokes at any location vary in energy due to meteorological variations
- Over time a permittivity-depth function can be constructed at any location
- This allows construction of a three-dimensional model of permittivity covering any area and with any geometry
- Resolution and depth range are limited by the number of lightning strikes and the variation in their energy

Permittivity Volumes Arizona



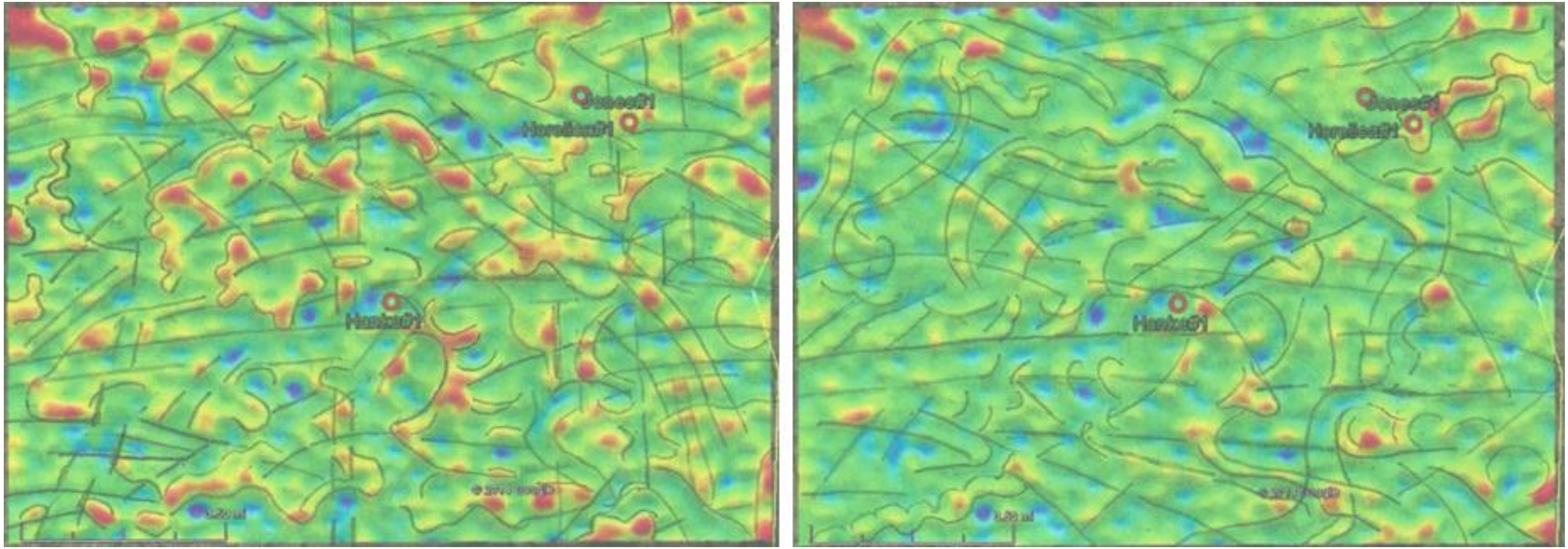
4. Examples of using lightning databases to map geology

Lightning Analysis
Defines Stratigraphy



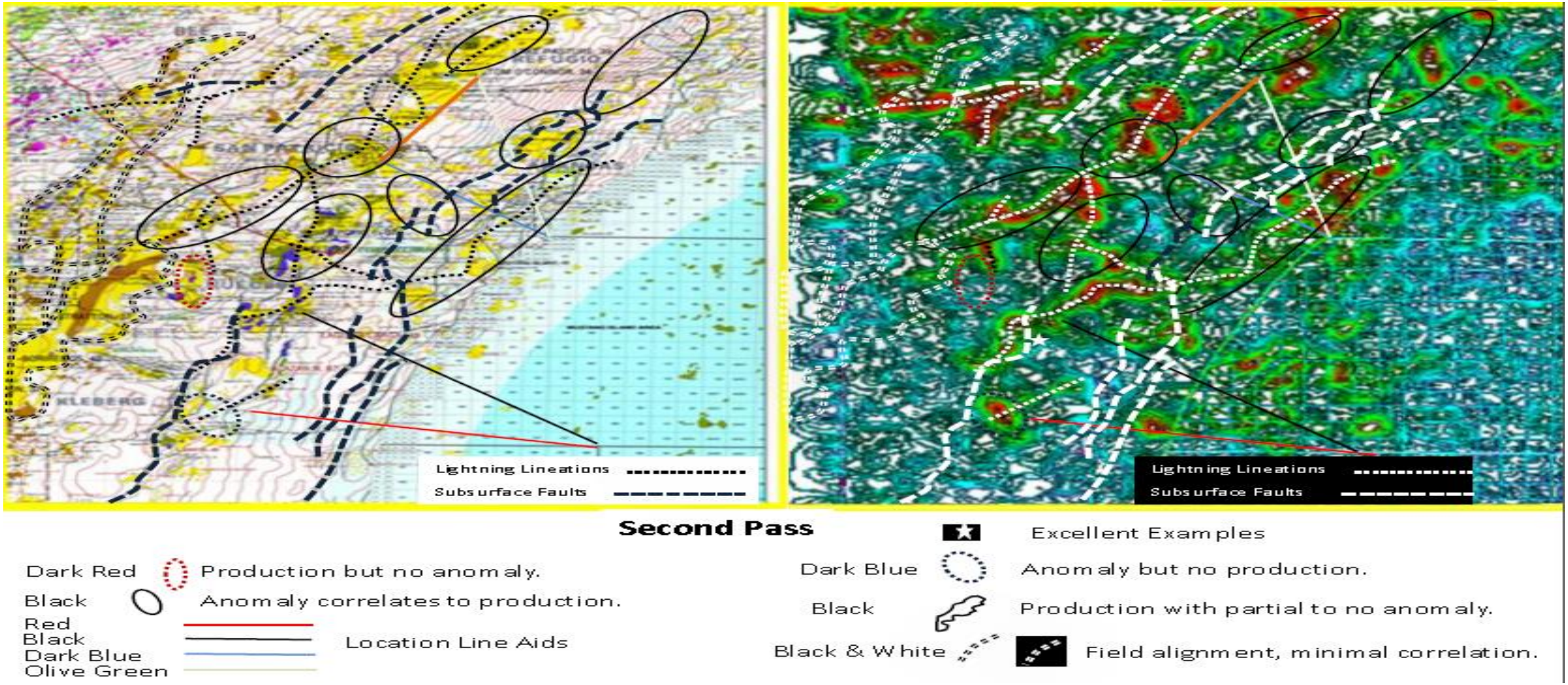
Lightning Attribute: Rate of Rise-Time

Lightning Analysis
Interprets Paleochannels and Meander Schrolls

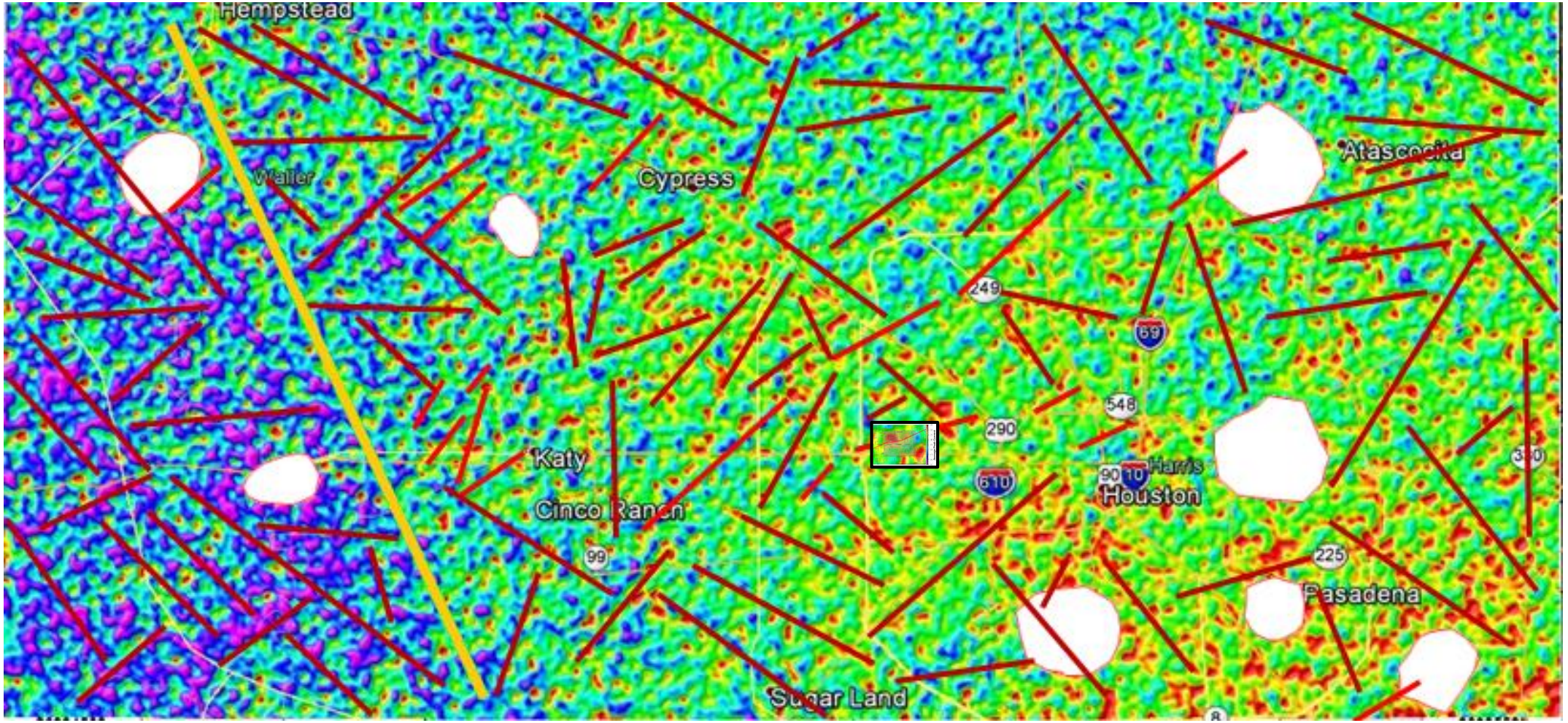


Lightning Attributes: Surface Resistivity (left) Peak-to-Zero (right)

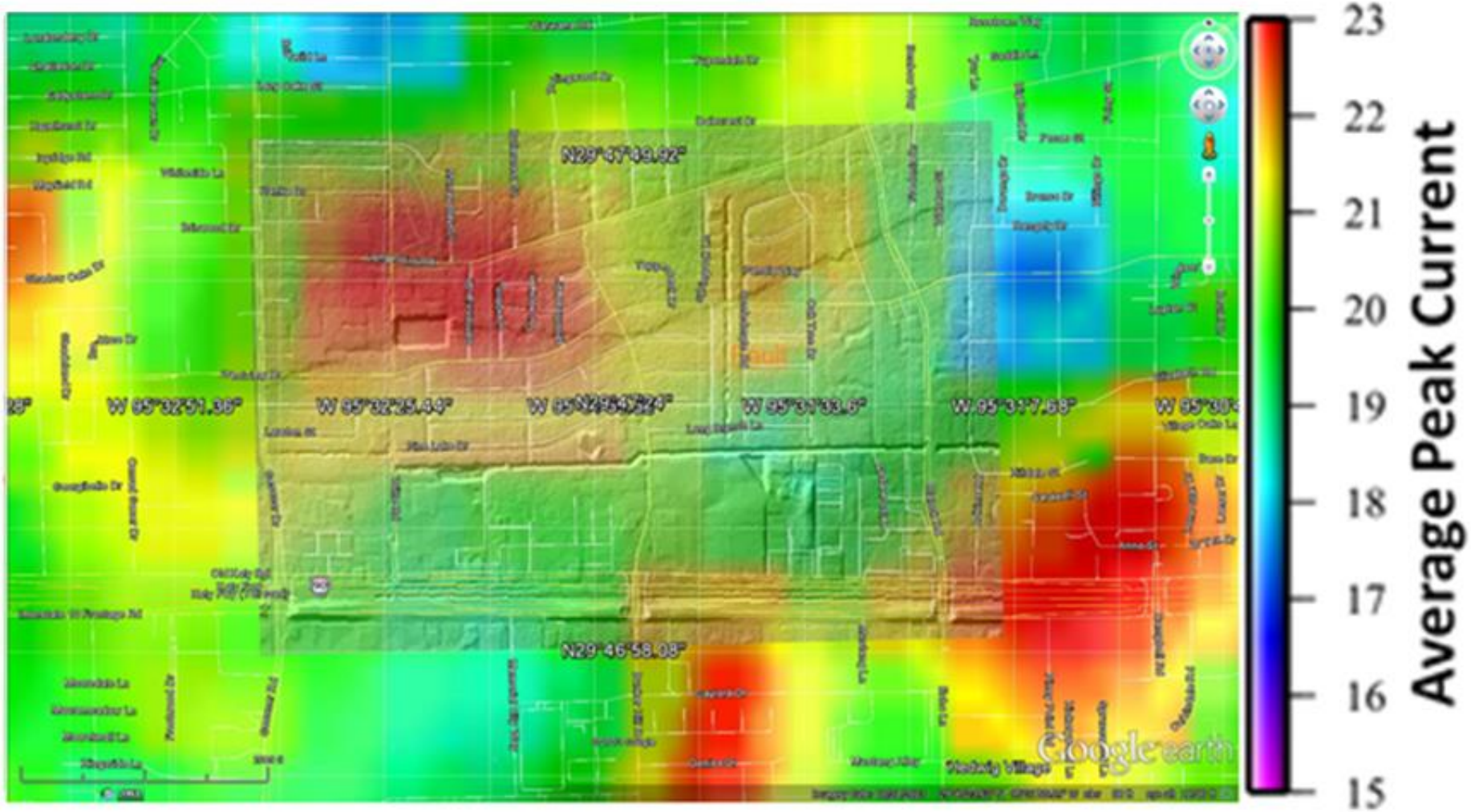
Lightning Analysis
Correlates with Fields



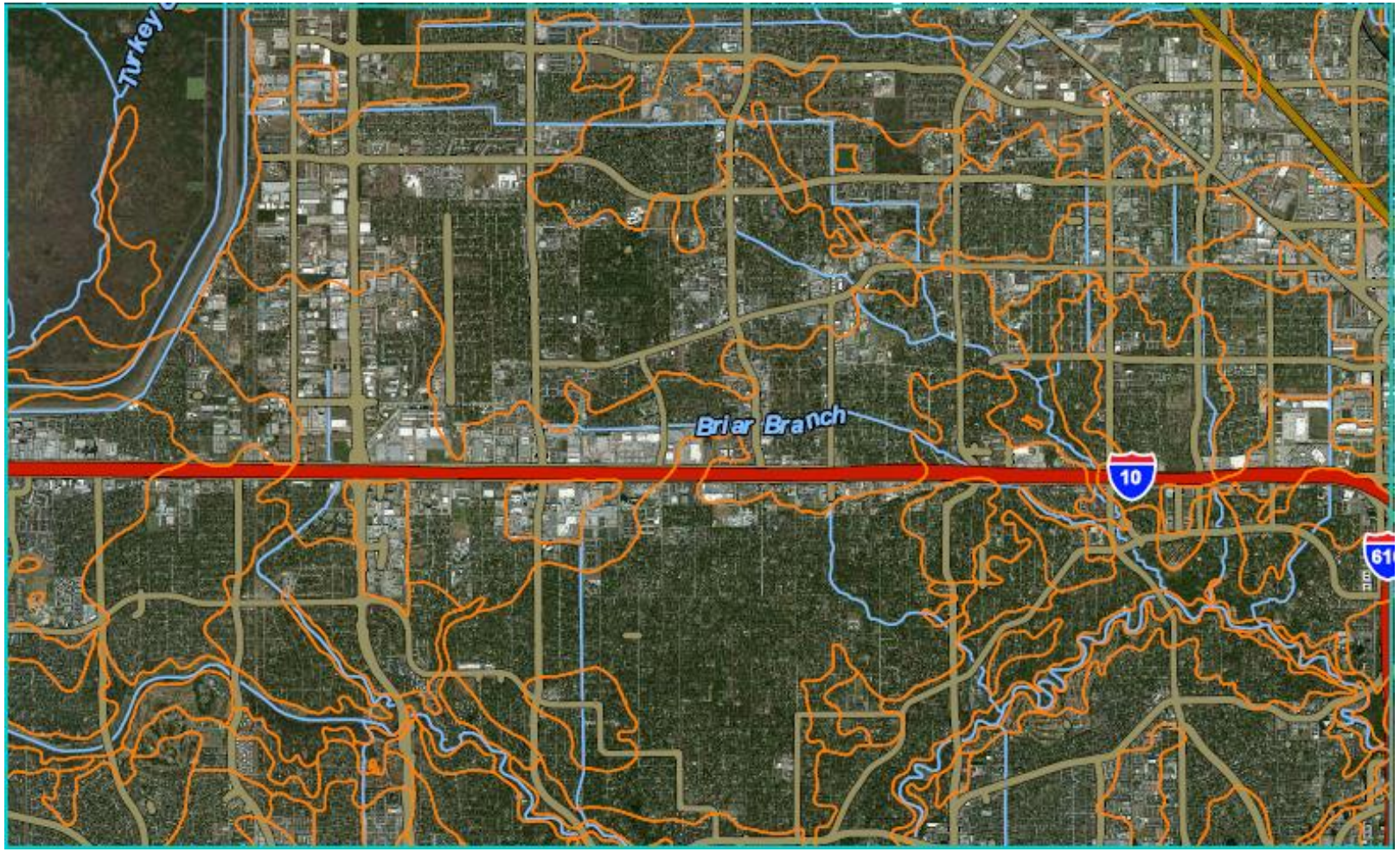
Peak Current from Sealy to East Houston



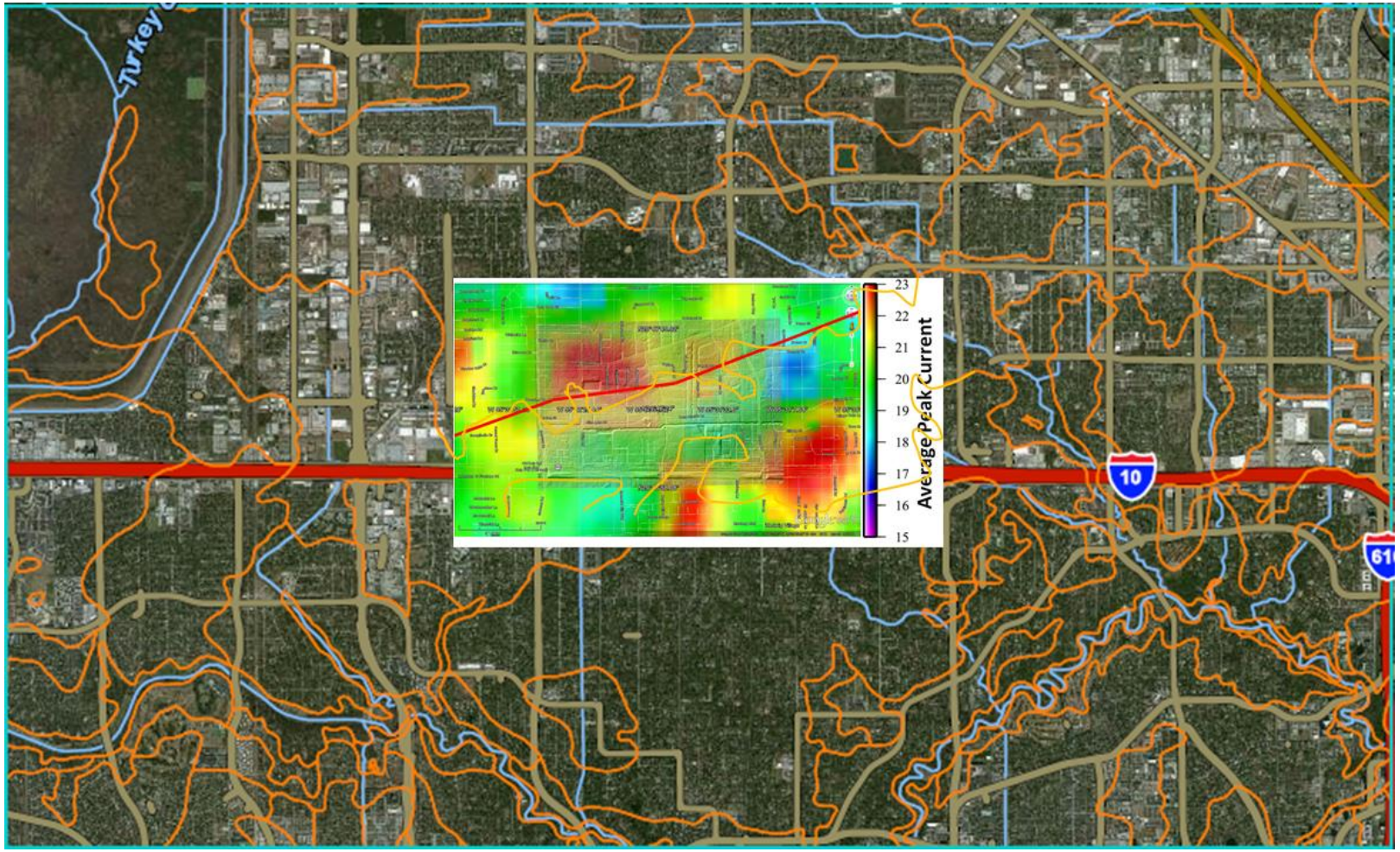
Peak Current Zoom
with LIDAR & Long Point Fault



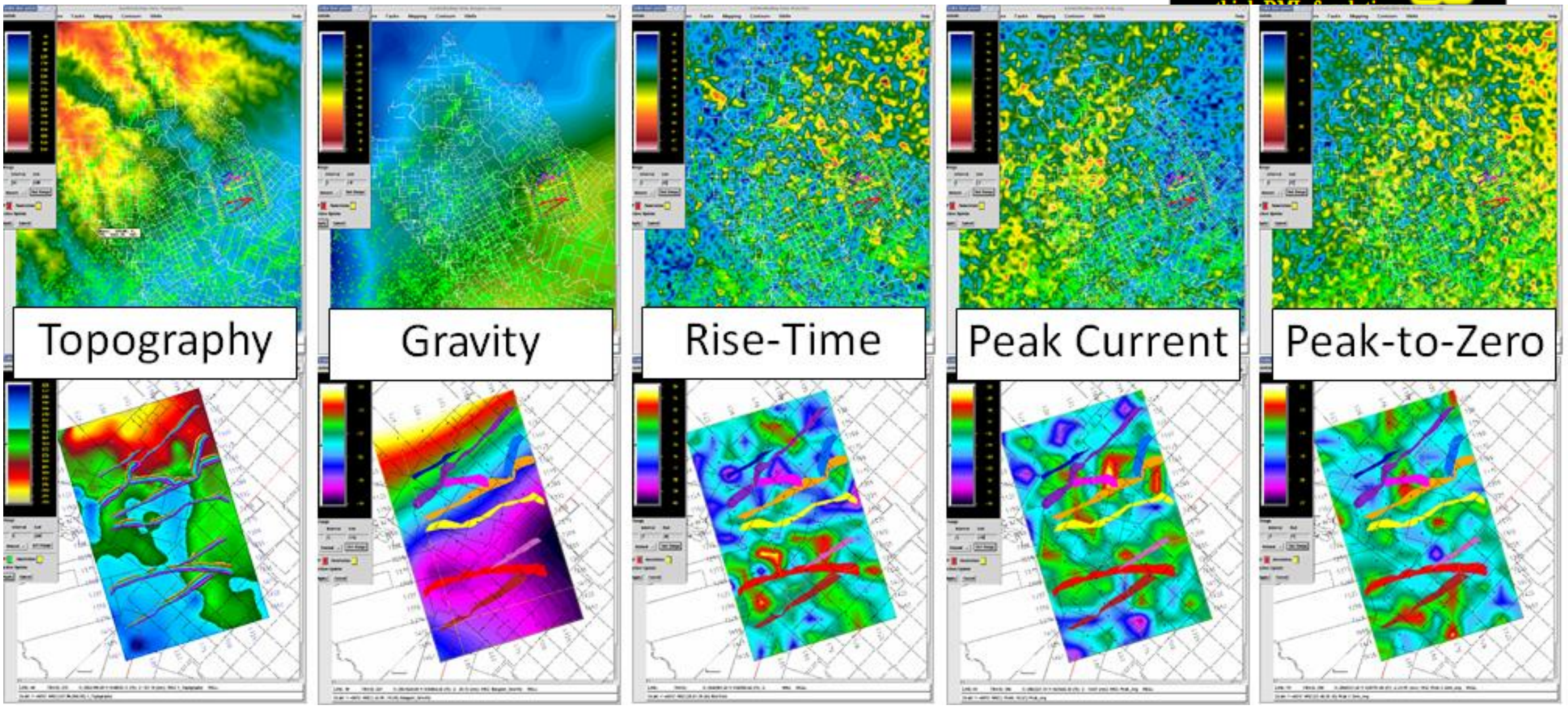
Soils Map over GoogleEarth™ Map



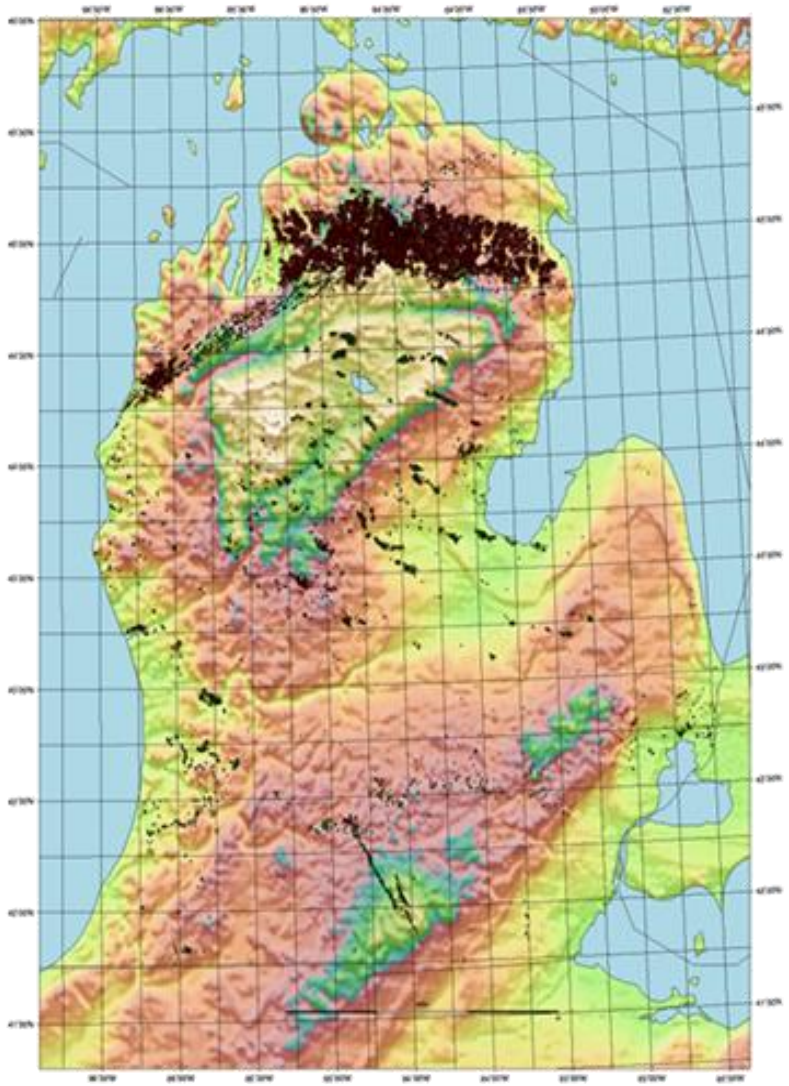
Integration with Long Point Fault over Soils over LIDAR over Peak Current over GoogleEarth™

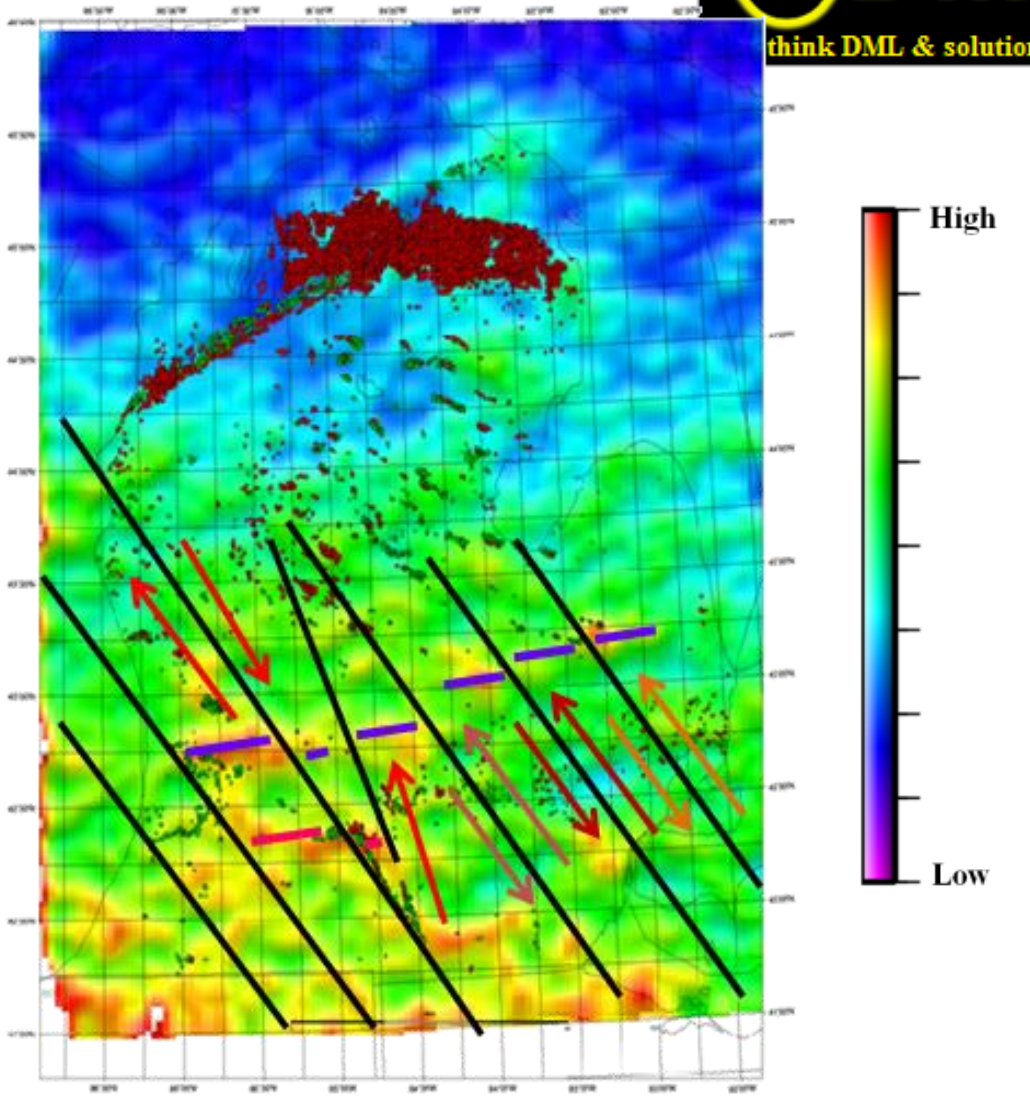


A New Potential Fields Method,
Supplementing Gravity & Magnetics

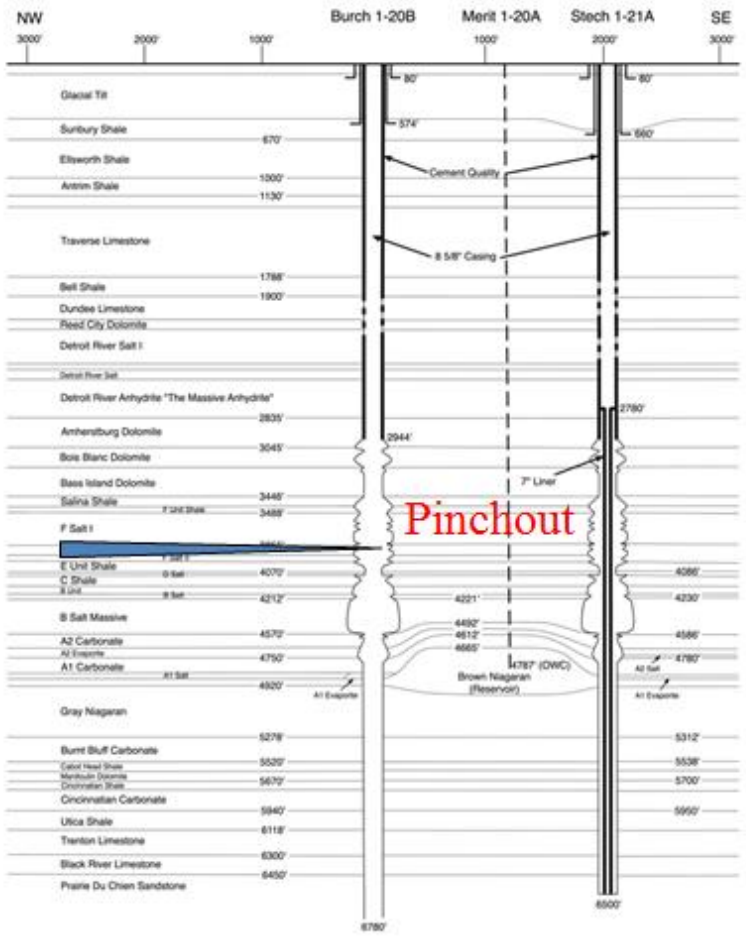


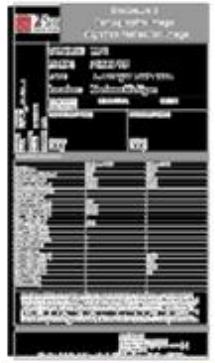
Michigan Basin Topography & Strike Density

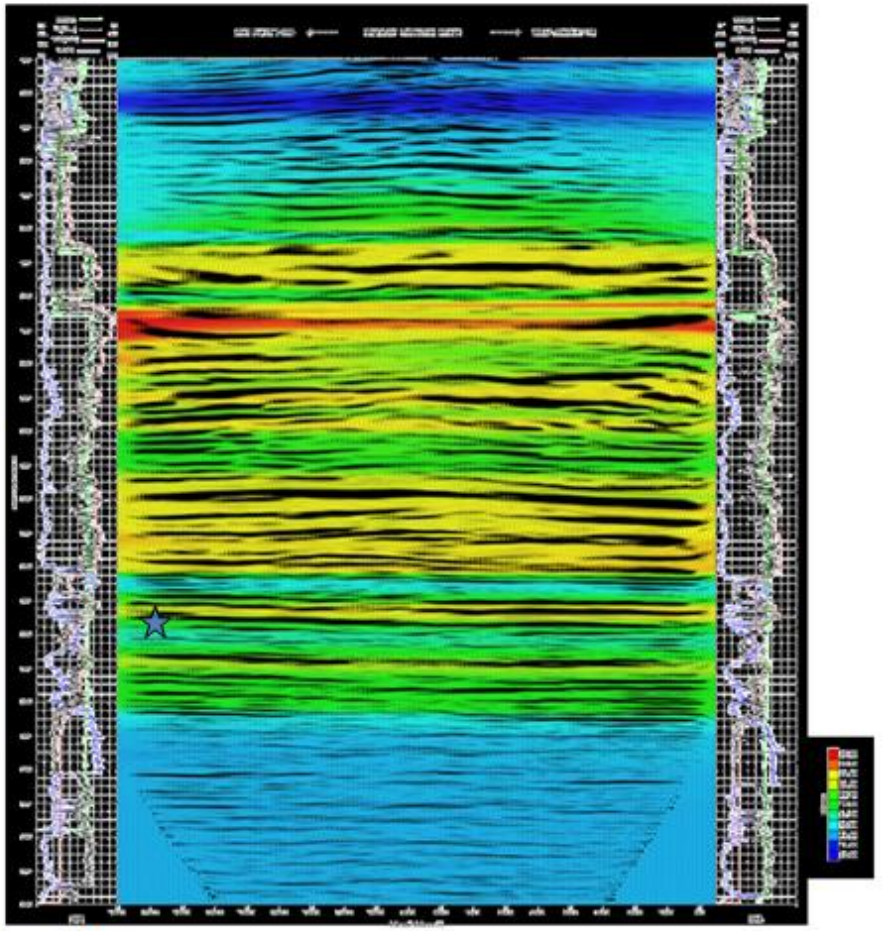




MTU Well Test Site

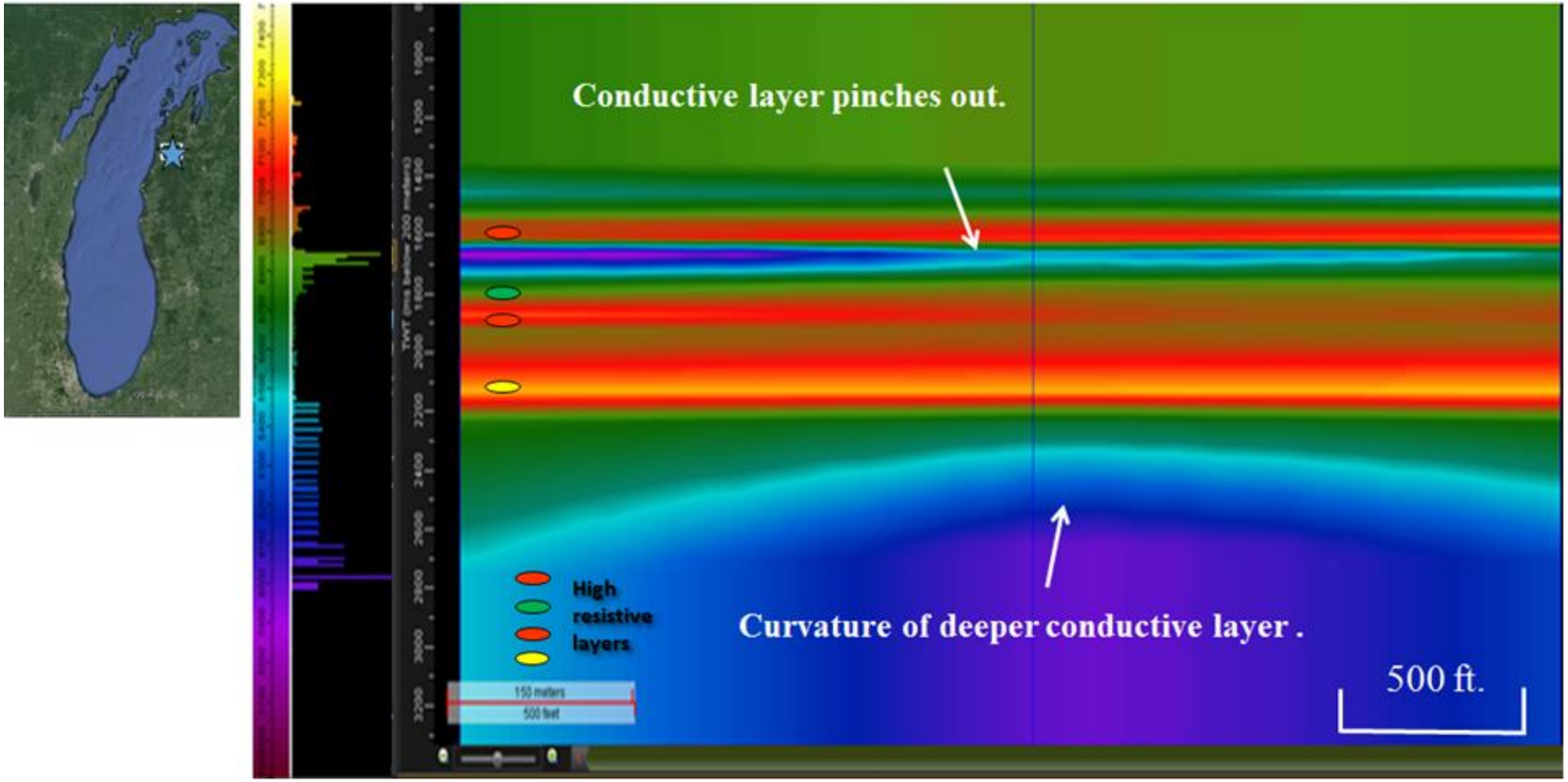




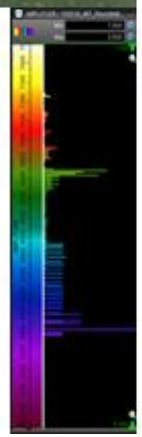


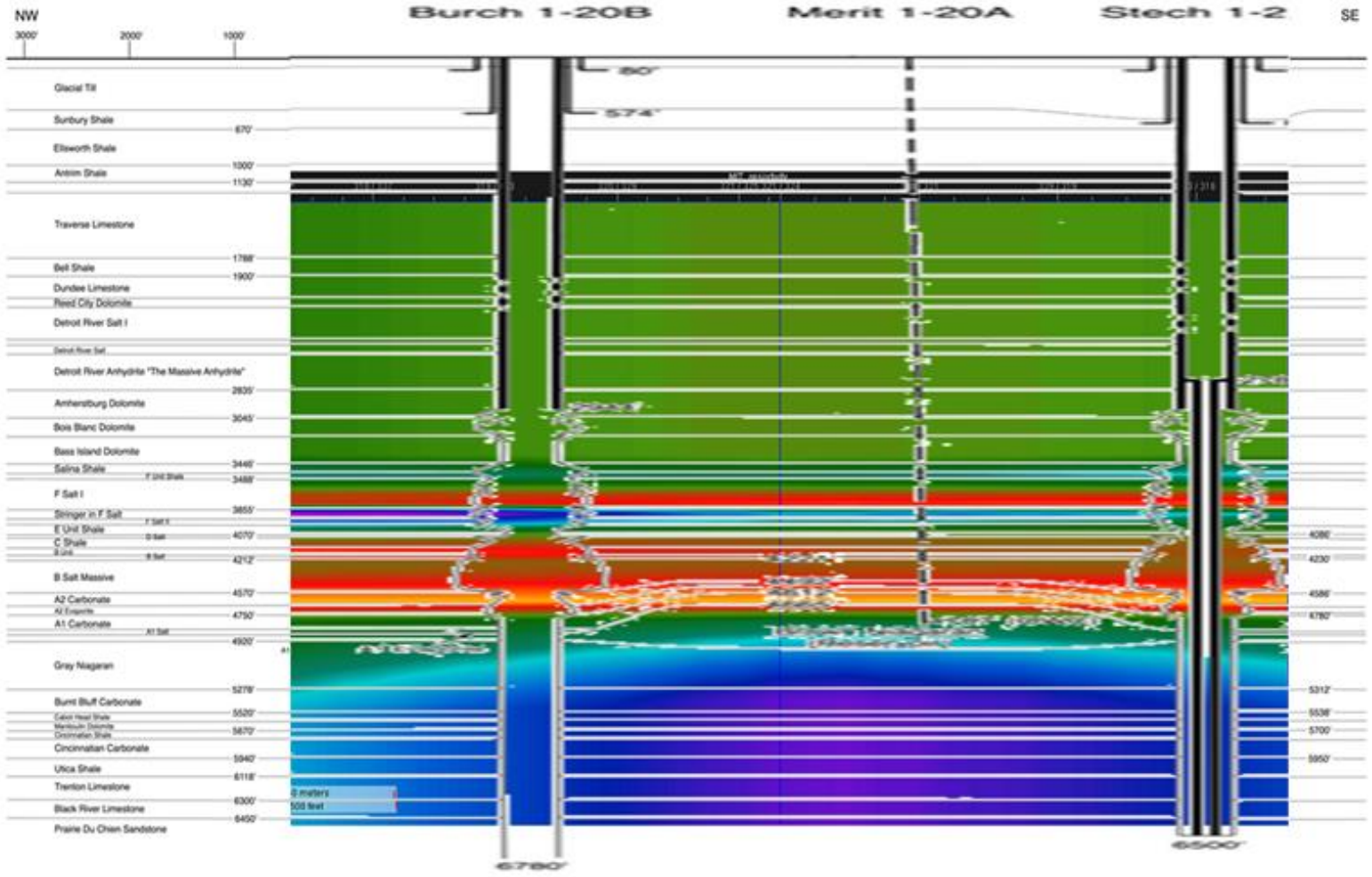
Courtesy Dr. Roger Turpening, Michigan Technology University

Resistivity Section between MTU Test Wells

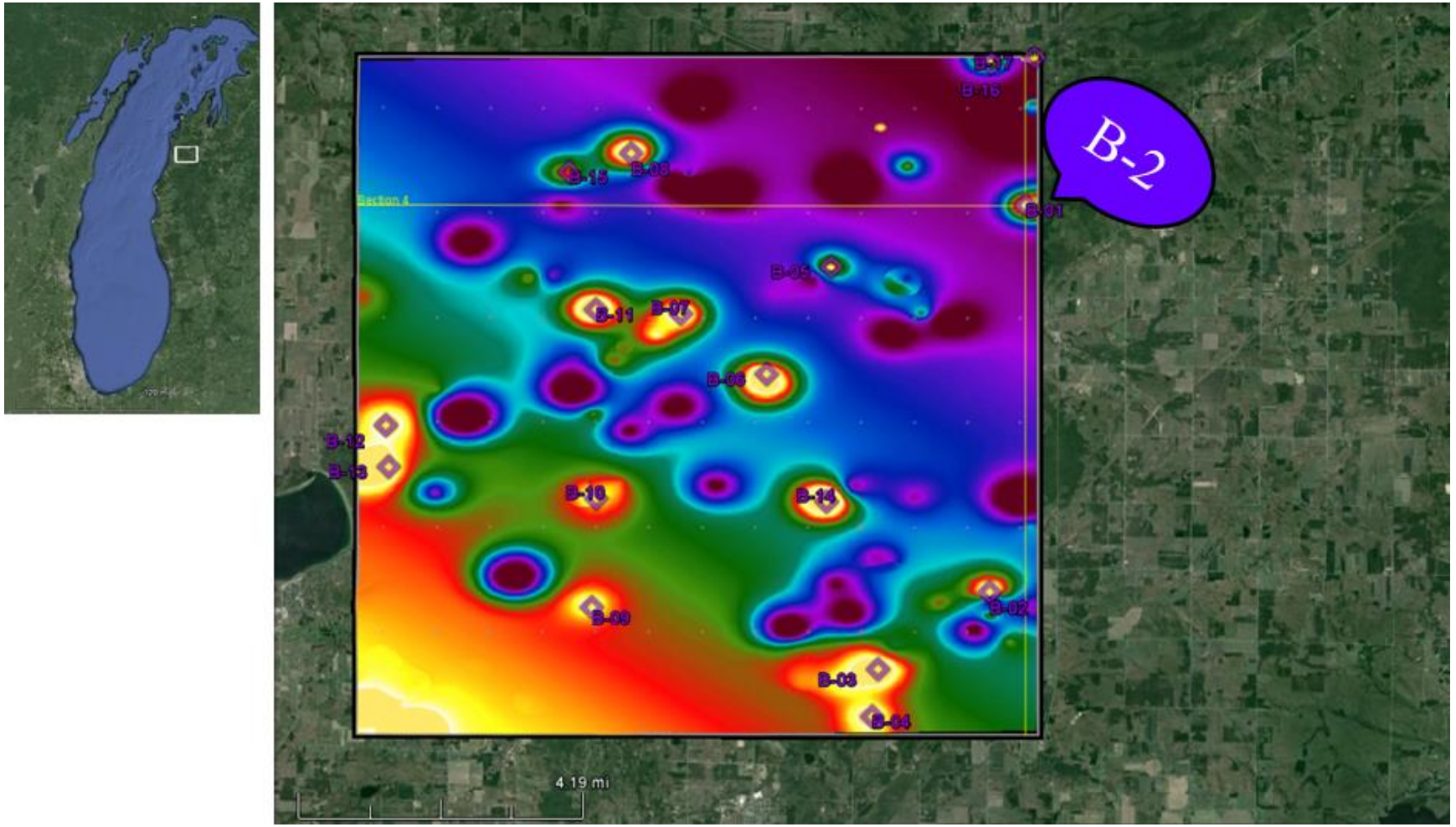


MTU Test Site Wells Overlaid
on Lightning Derived Resistivity Section

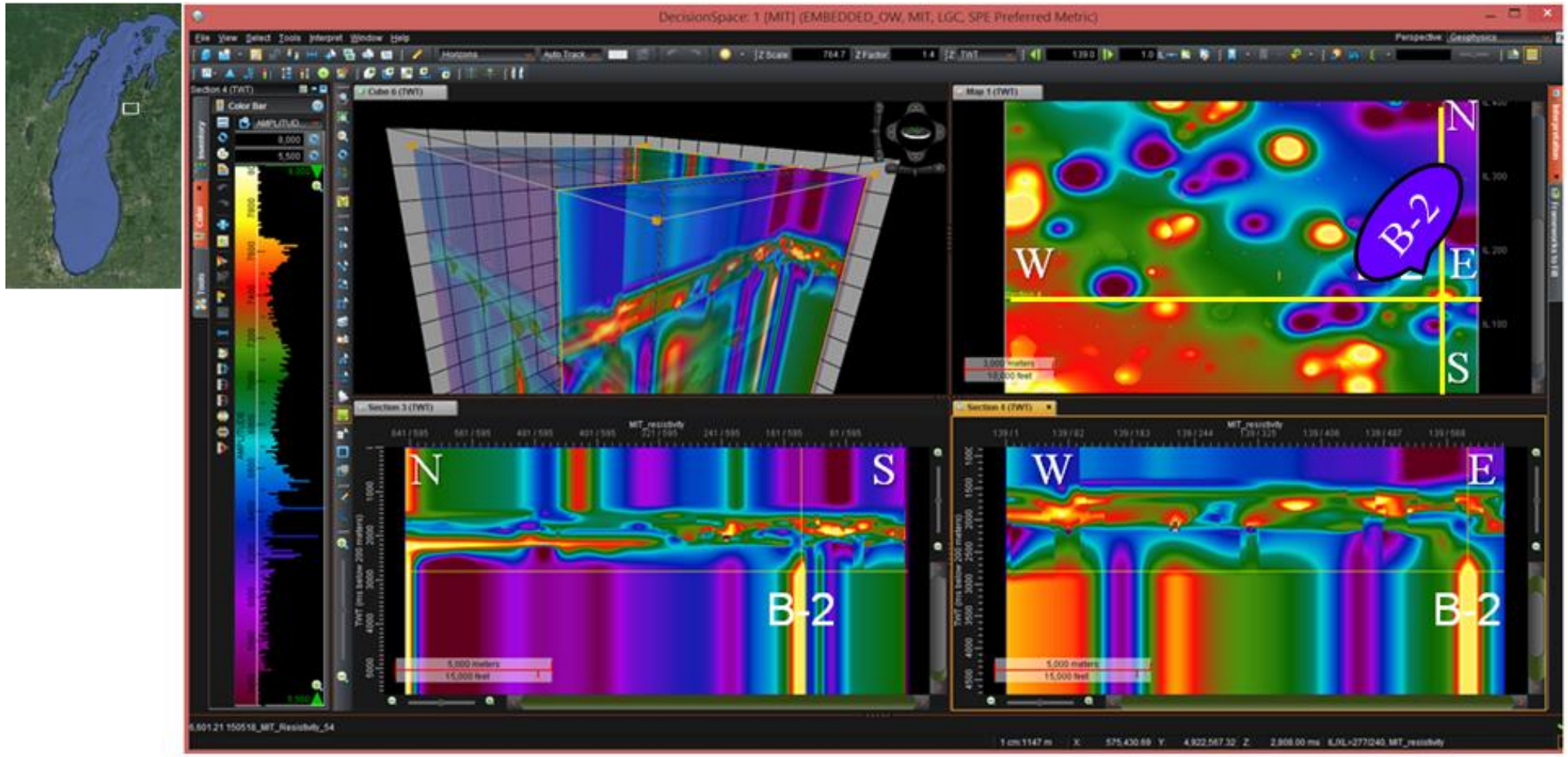




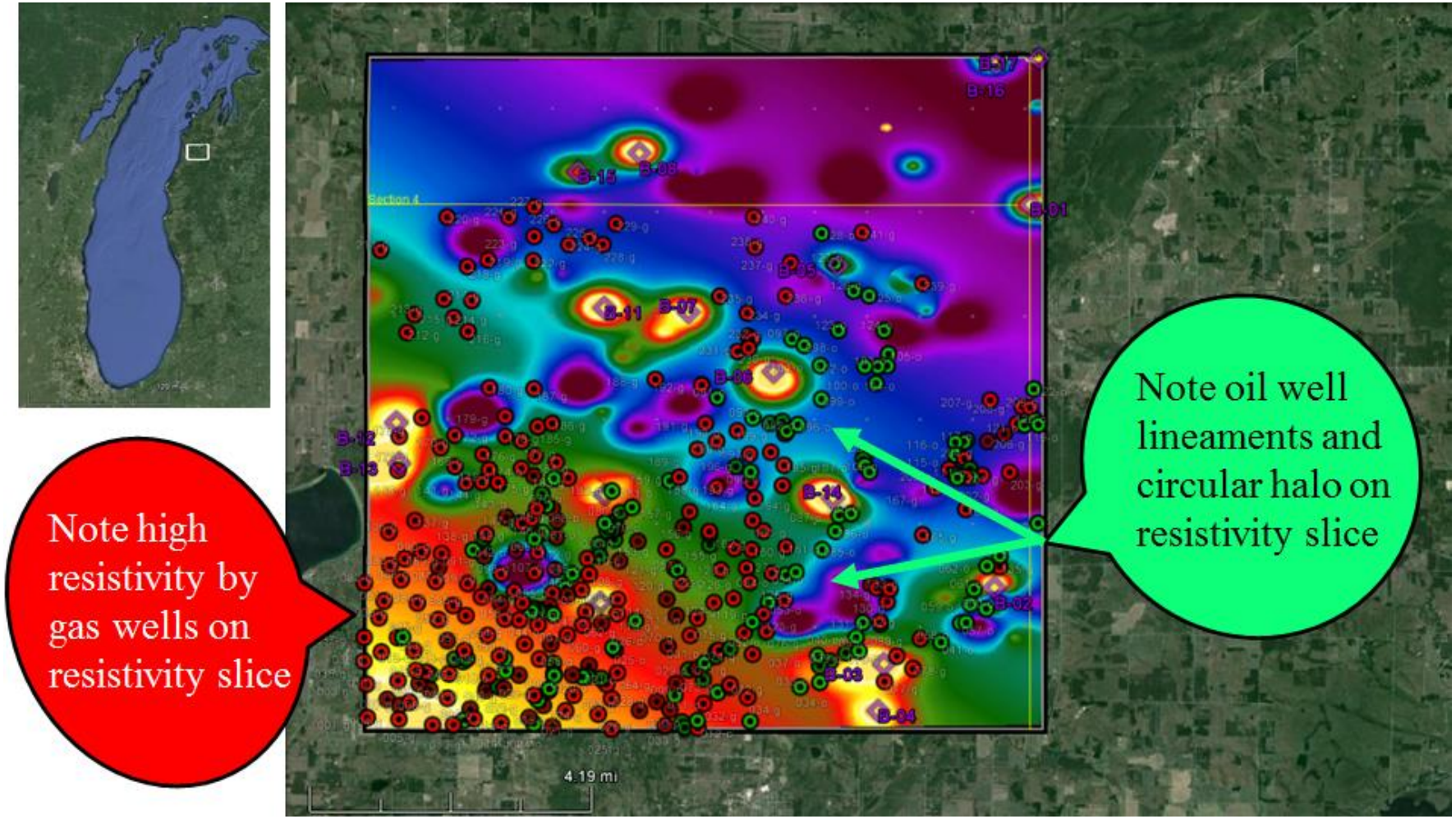
Type 1 Cylinder Anomalies (B-2)
Horizontal-Slice through possible pinnacle reefs



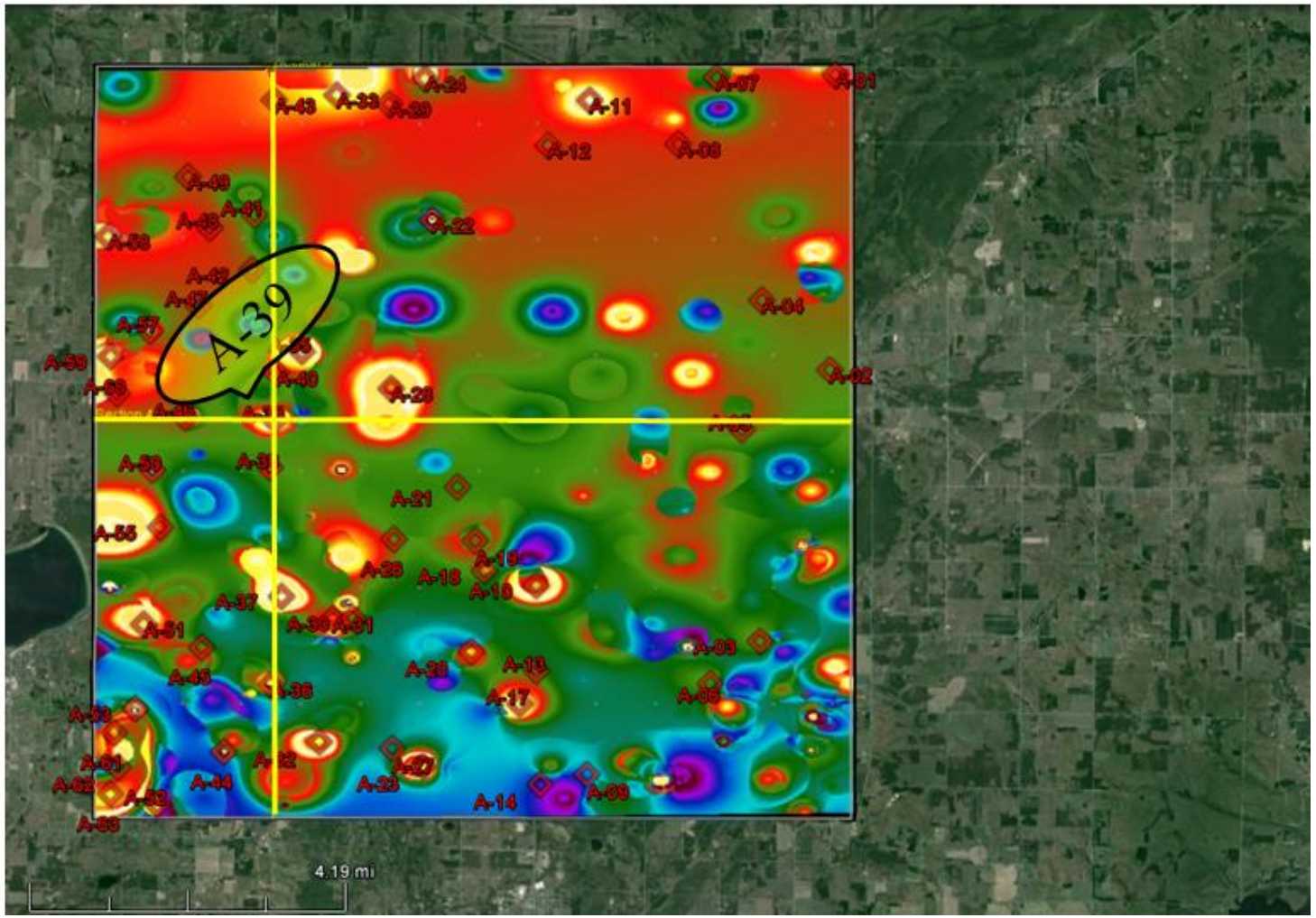
Type 1 Anomalies in Analysis Area: Resistivity Cylinders (B2)



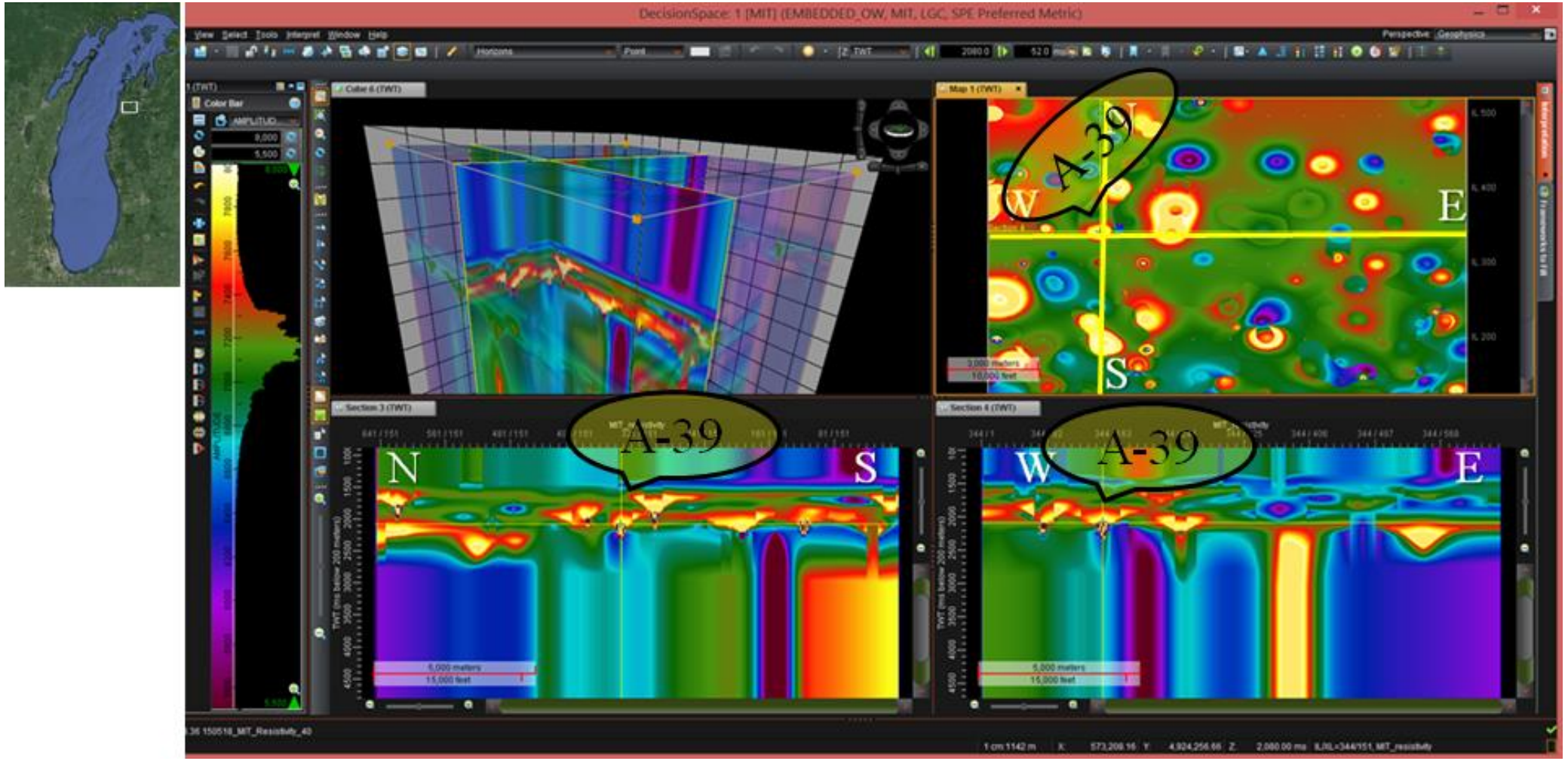
High Resistivity to southwest on B-2 Horizontal-Slice
Ties Oil & Gas Wells in Analysis Area posted



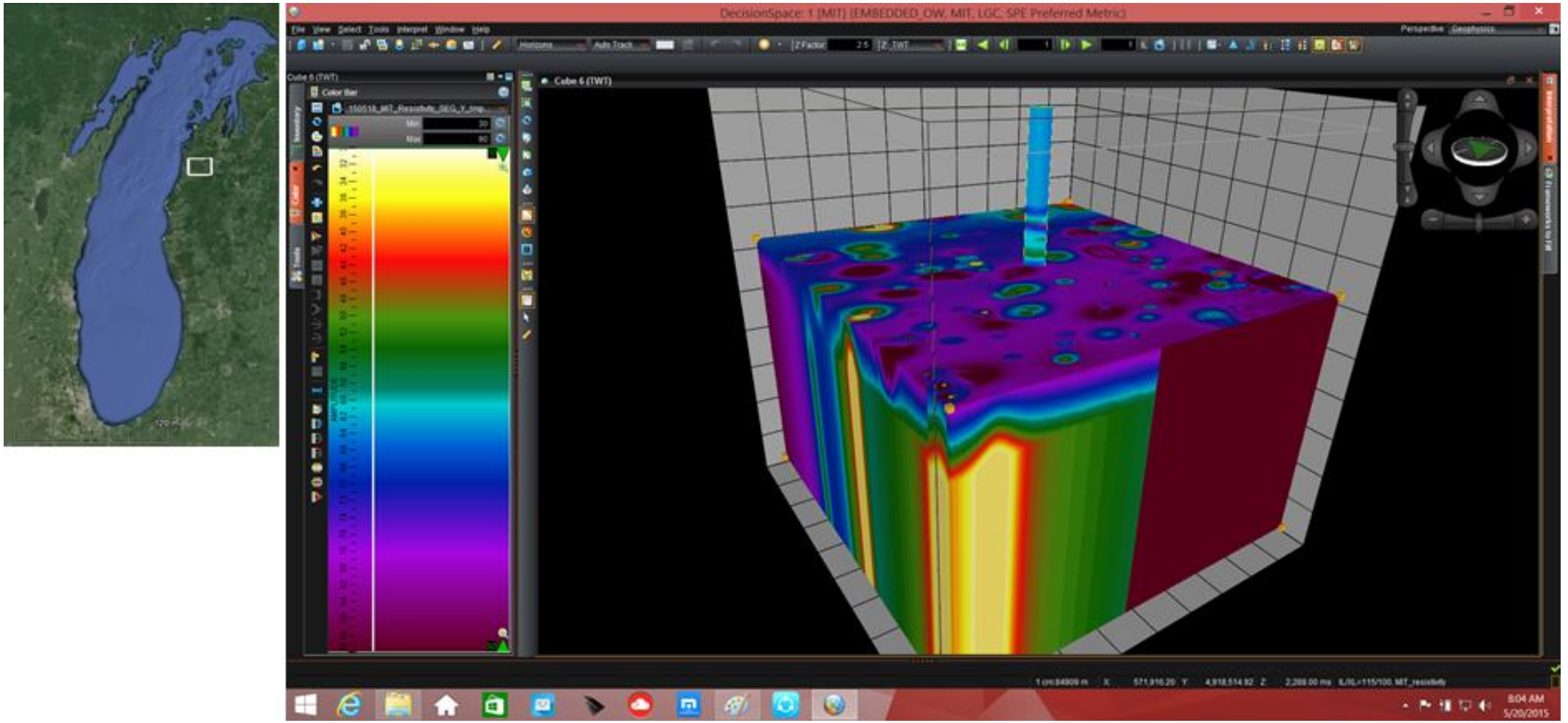
Type 2 Lens Anomalies (A-39) possible bioherm reefs



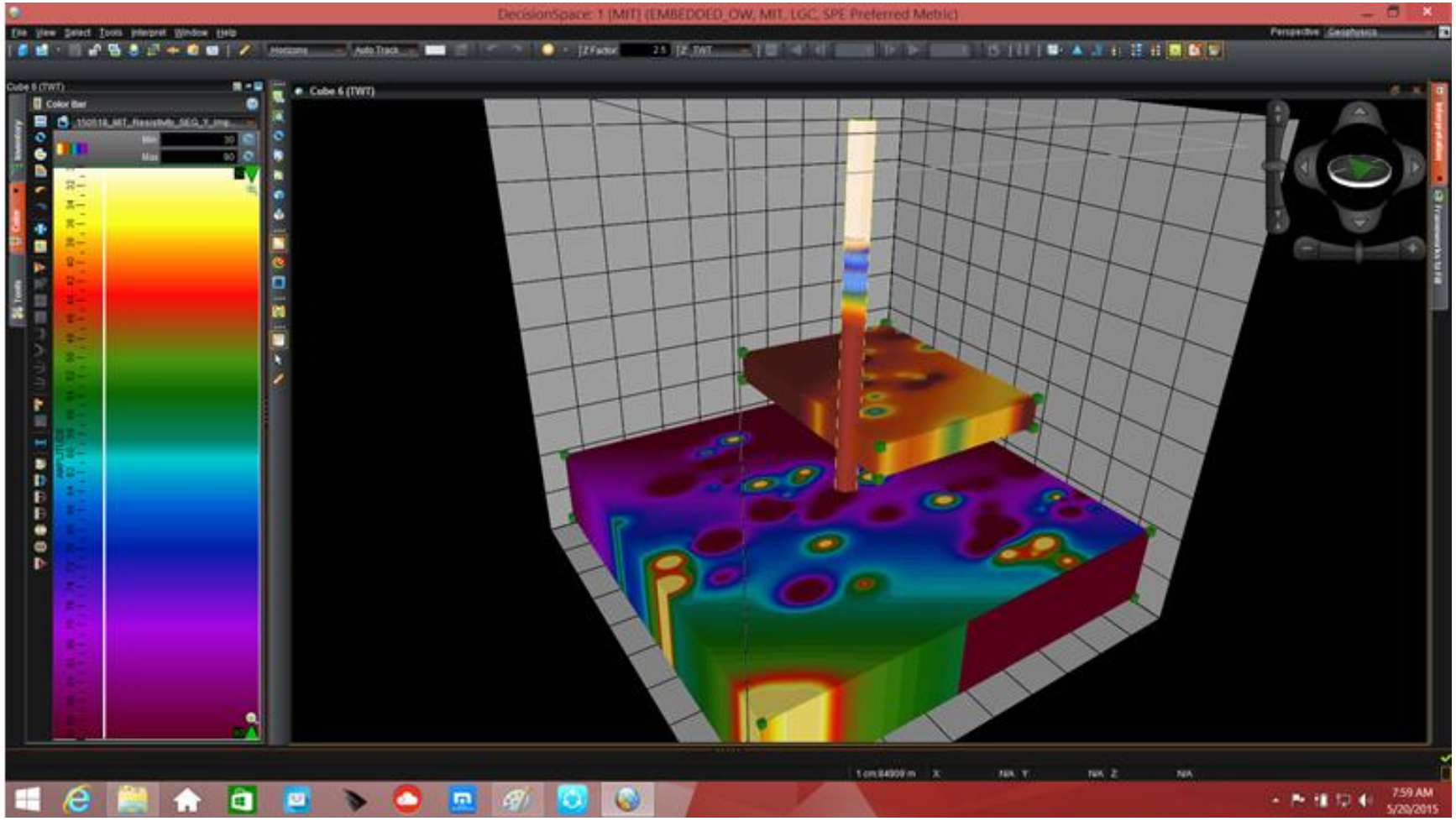
Type 2 Anomalies in Analysis Area: Lenses (A-39)



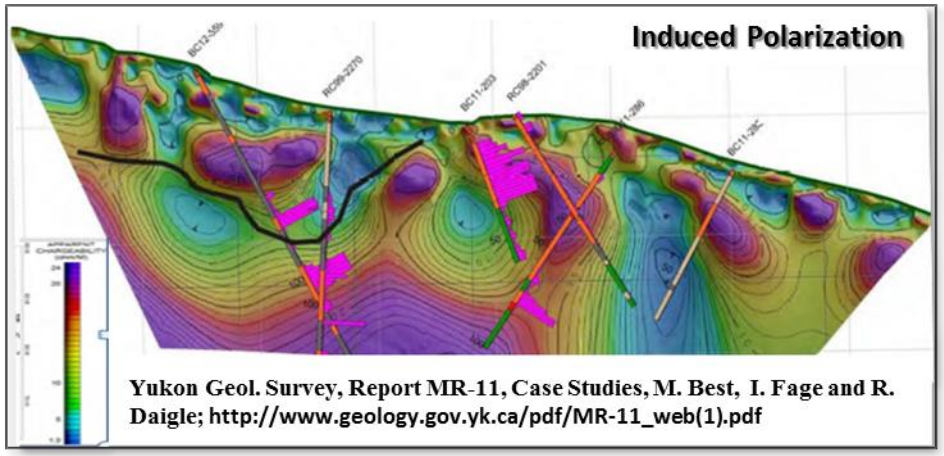
Resistivity Cube Probe with Resistivity Section at MIT Test Site



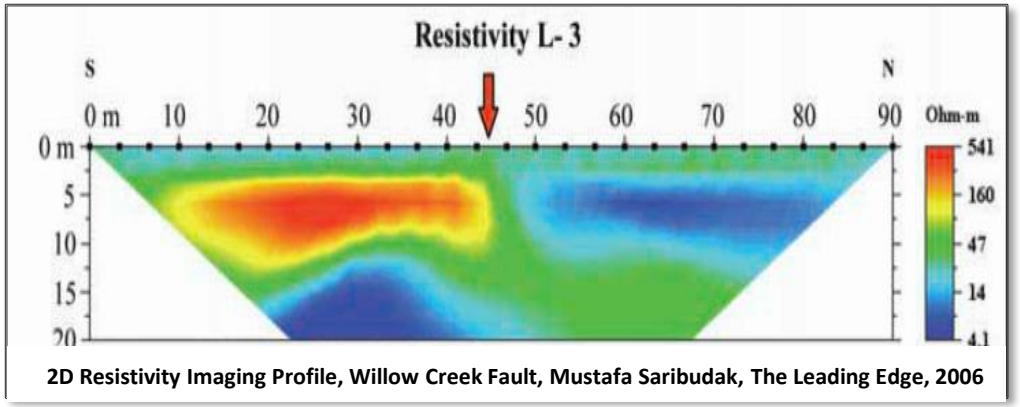
Permittivity Cube Probe with Permittivity Section at MIT Test Site



Resistivity & Permittivity Volumes Easily Integrated with Near-Surface Geophysical Data

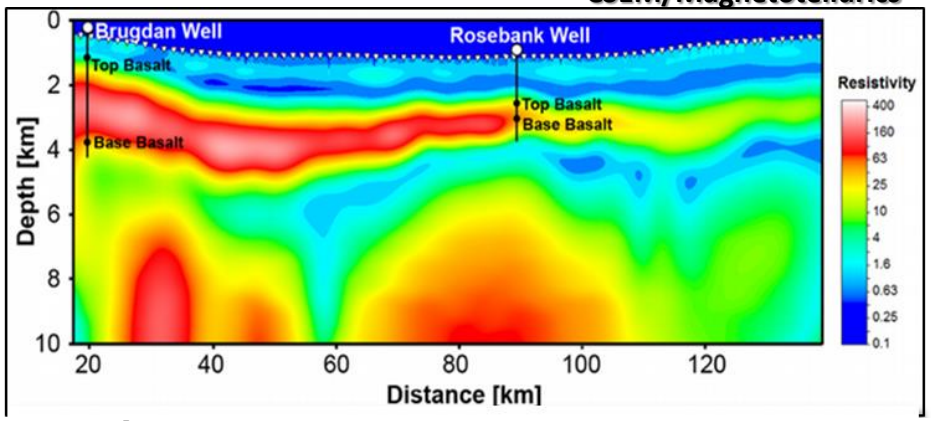


Yukon Geol. Survey, Report MR-11, Case Studies, M. Best, I. Fage and R. Daigle; http://www.geology.gov.yk.ca/pdf/MR-11_web(1).pdf

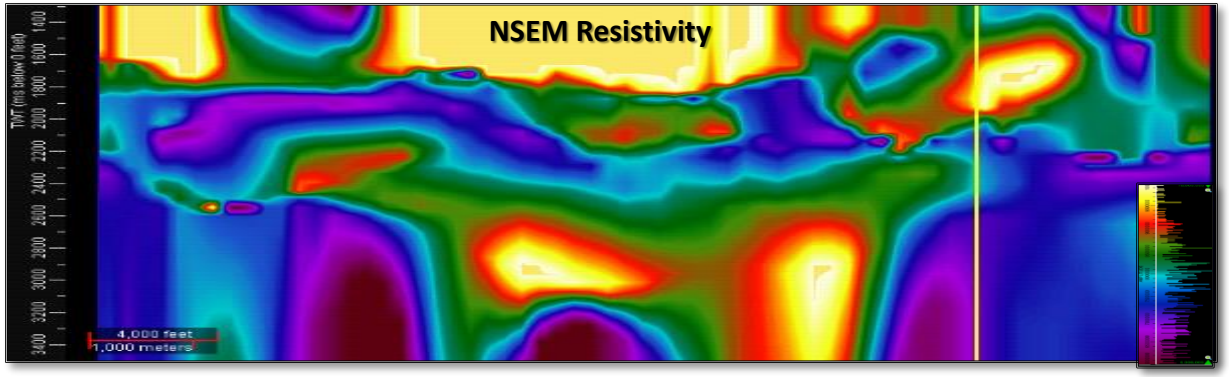


2D Resistivity Imaging Profile, Willow Creek Fault, Mustafa Saribudak, The Leading Edge, 2006

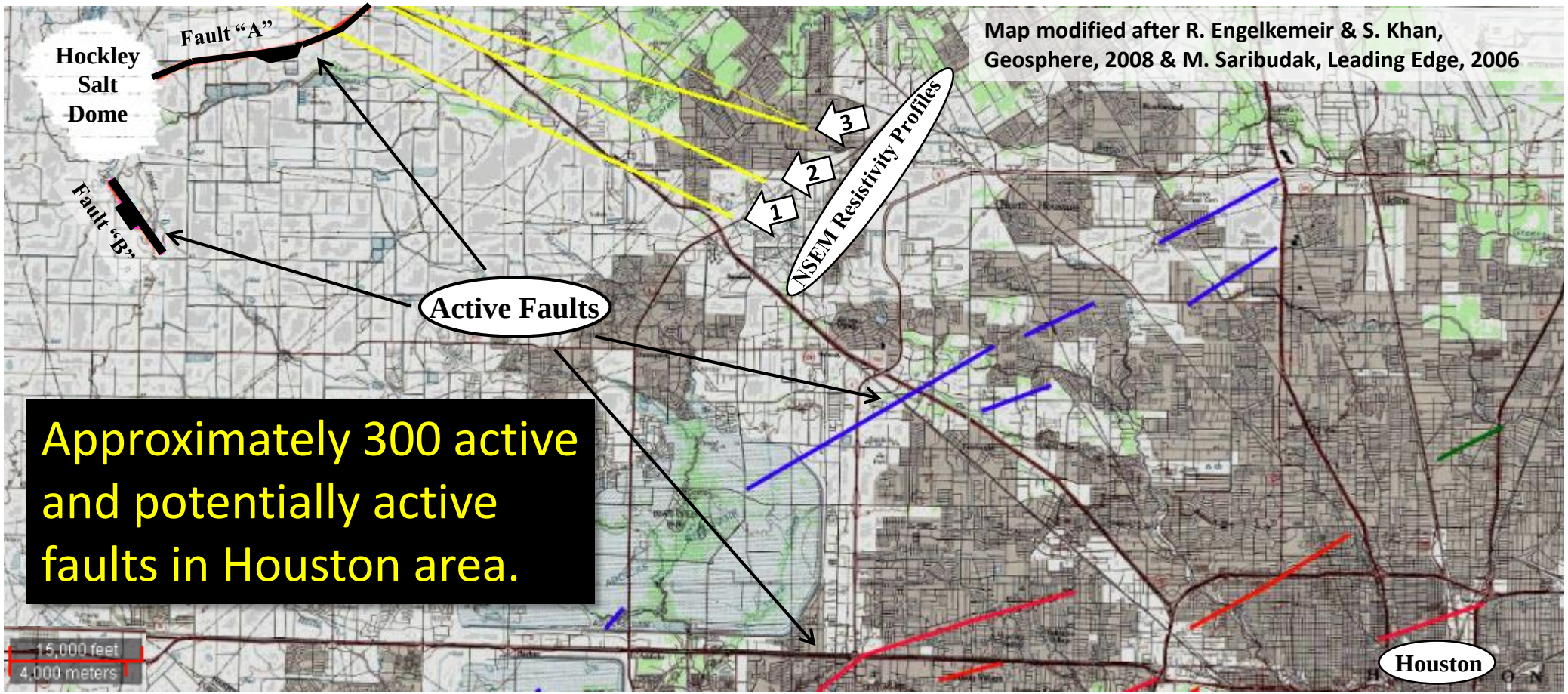
CSEM/Magnetotellurics



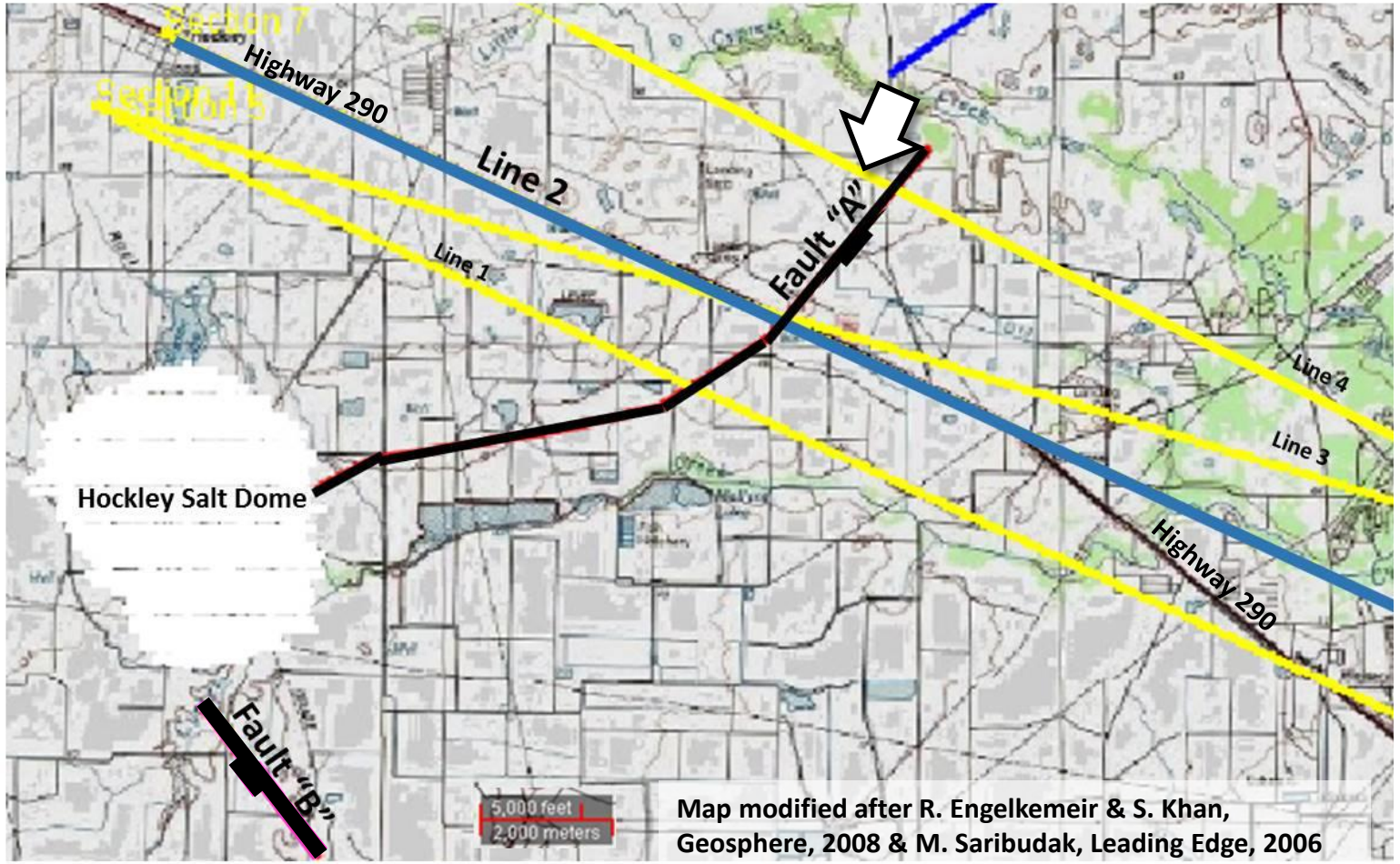
EMGS http://www.emgs.com/content/1234/MT



Houston/Harris County Area Active Faults



NSEM Correlates To Geology:
Active Faults, Harris Co., TX



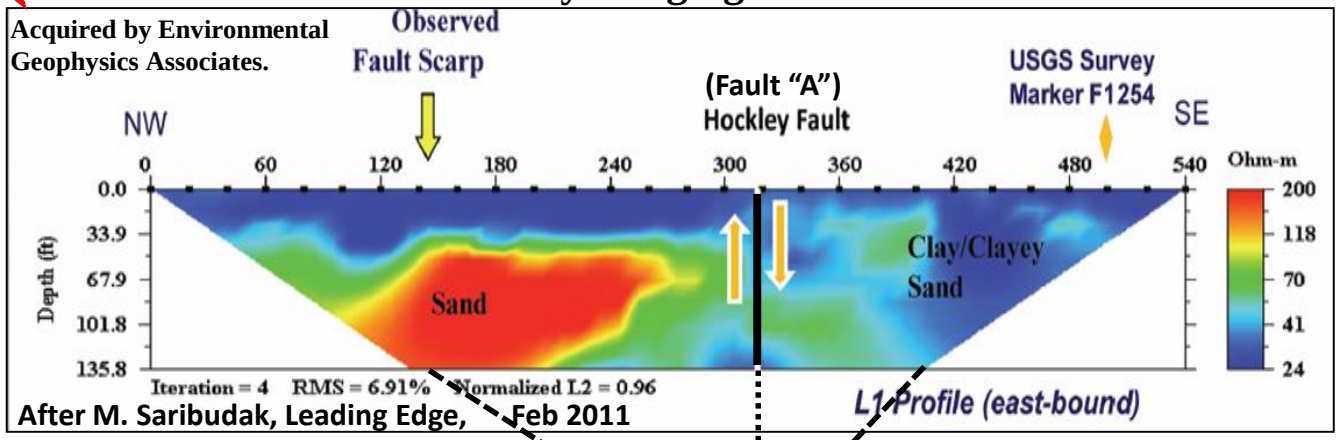
Map modified after R. Engelkemeir & S. Khan, Geosphere, 2008 & M. Saribudak, Leading Edge, 2006

Hockley Radial Fault "A"

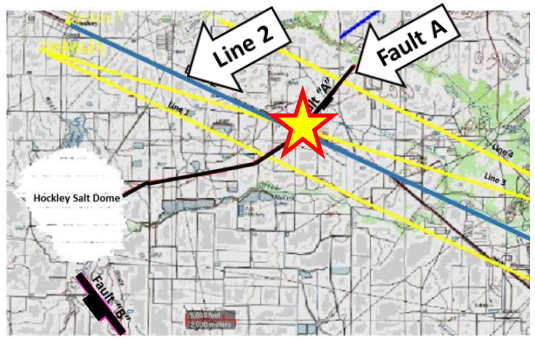
Resistivity profile "Line 2" displayed in next slide.

Line 2 Ties Fault "A" to Subsurface

Conventional 2-D Resistivity Imaging Profile

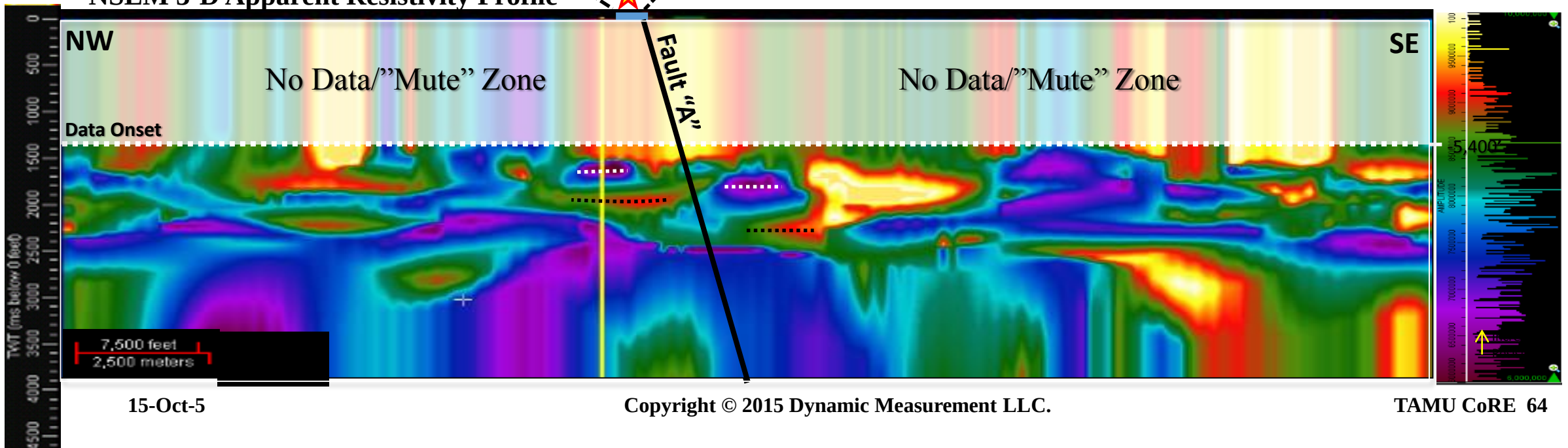


After M. Saribudak, Leading Edge, Feb 2011



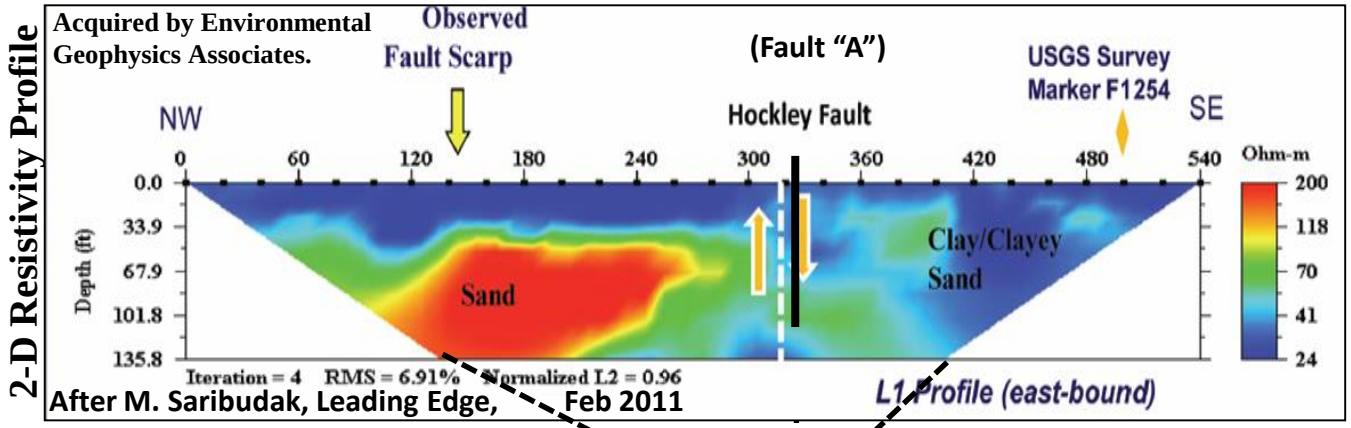
Line 2

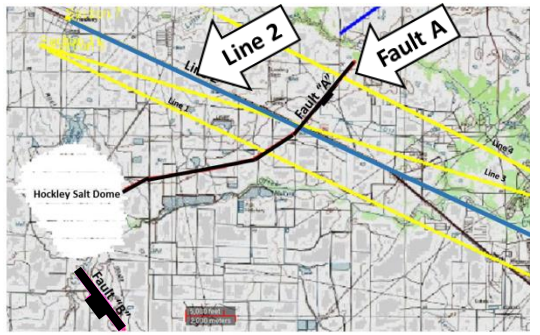
NSEM 3-D Apparent Resistivity Profile



NSEM Reveals Additional Faulting

3-D Data Provides Interpretive Checks & Balances

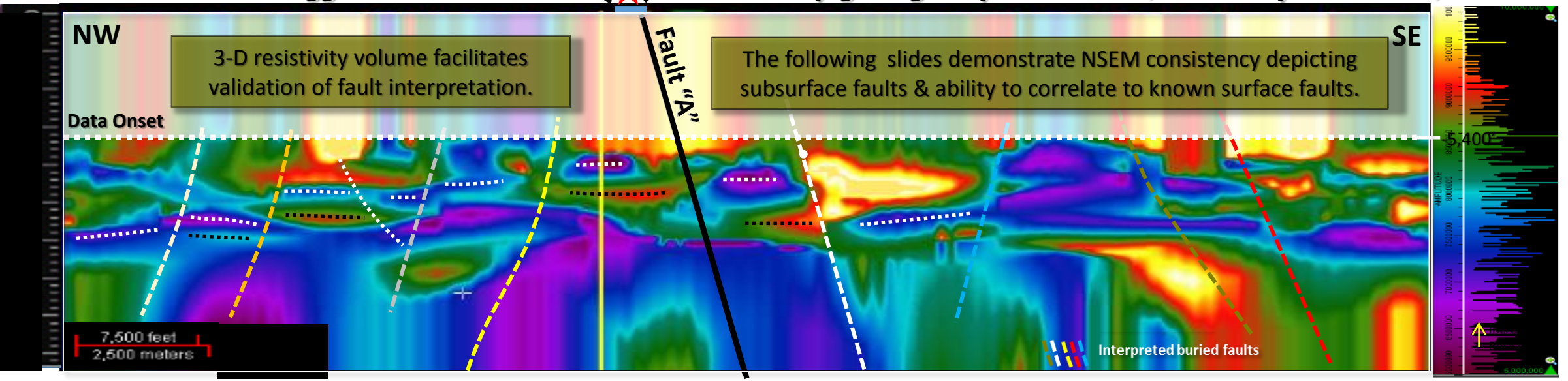




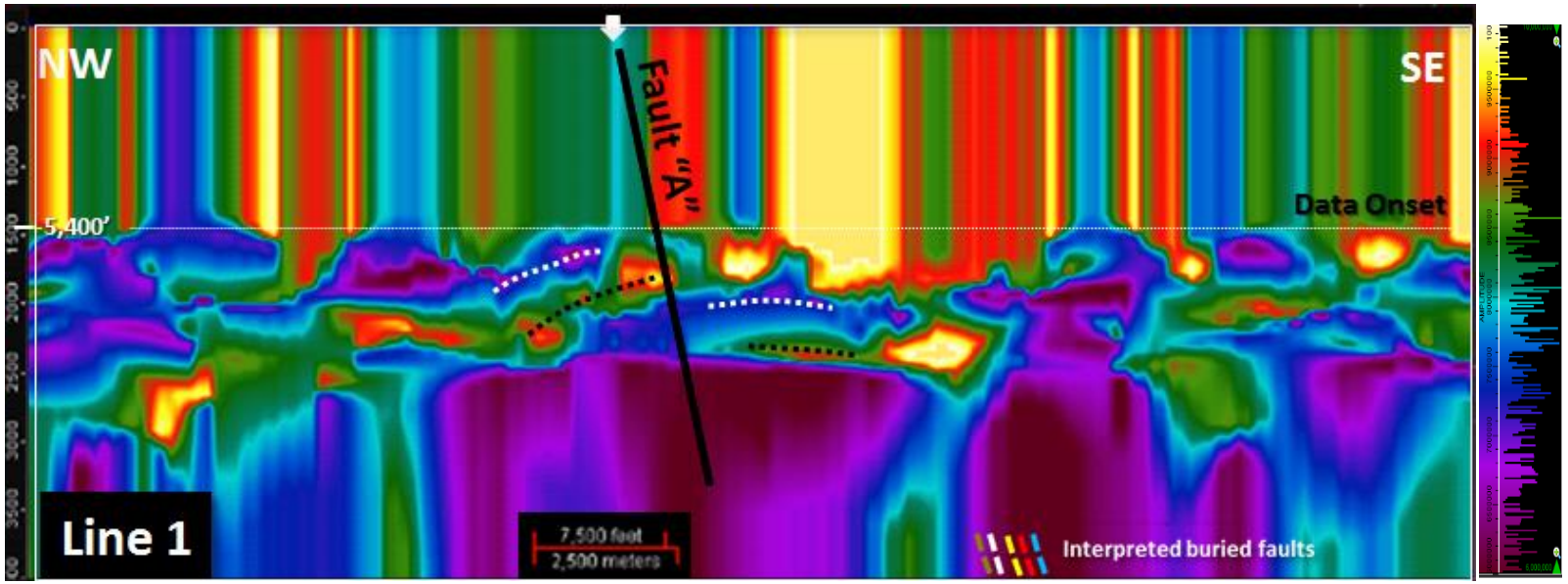
Line 2

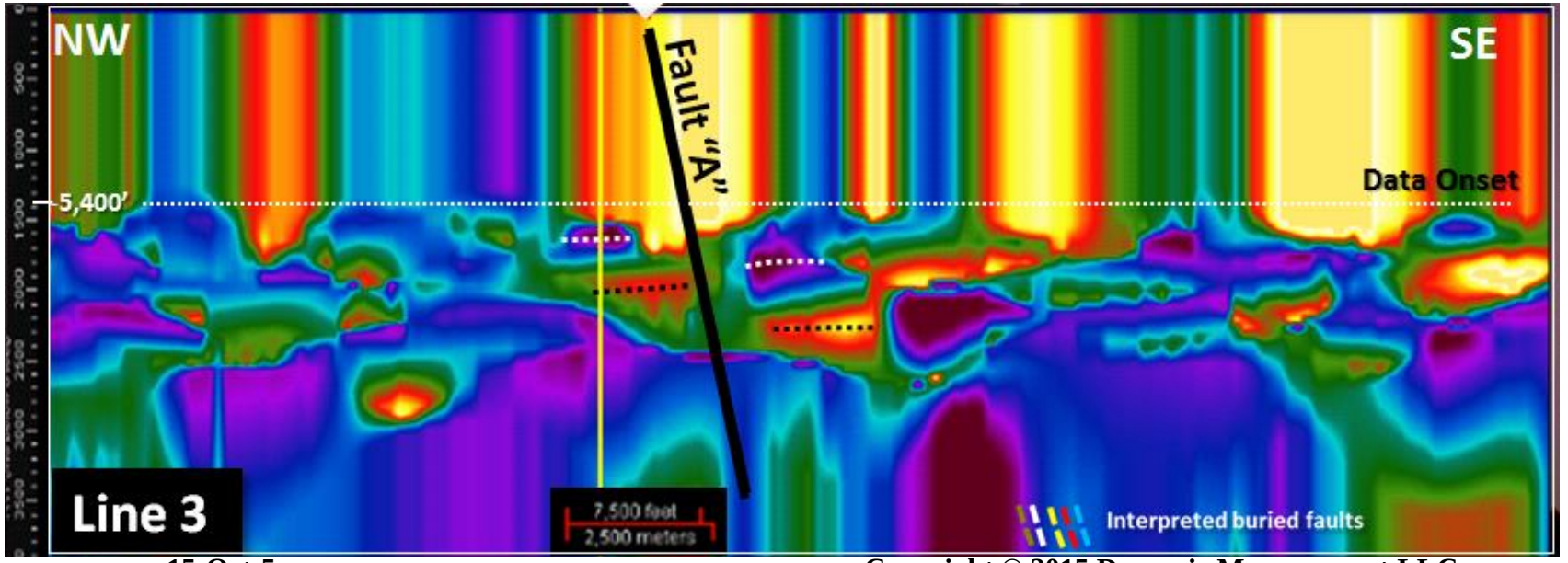
Additional faults suggested.

Are they geologically reasonable, internally consistent, valid?

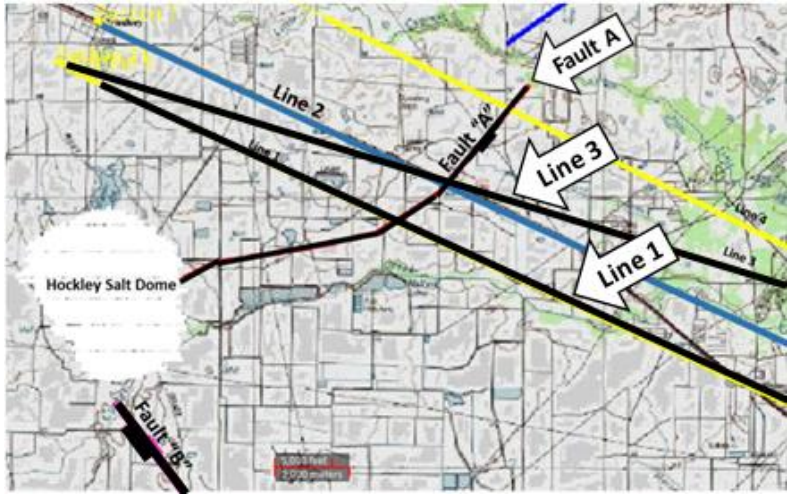


Lines 1 & 3 Tie Fault "A" to Subsurface

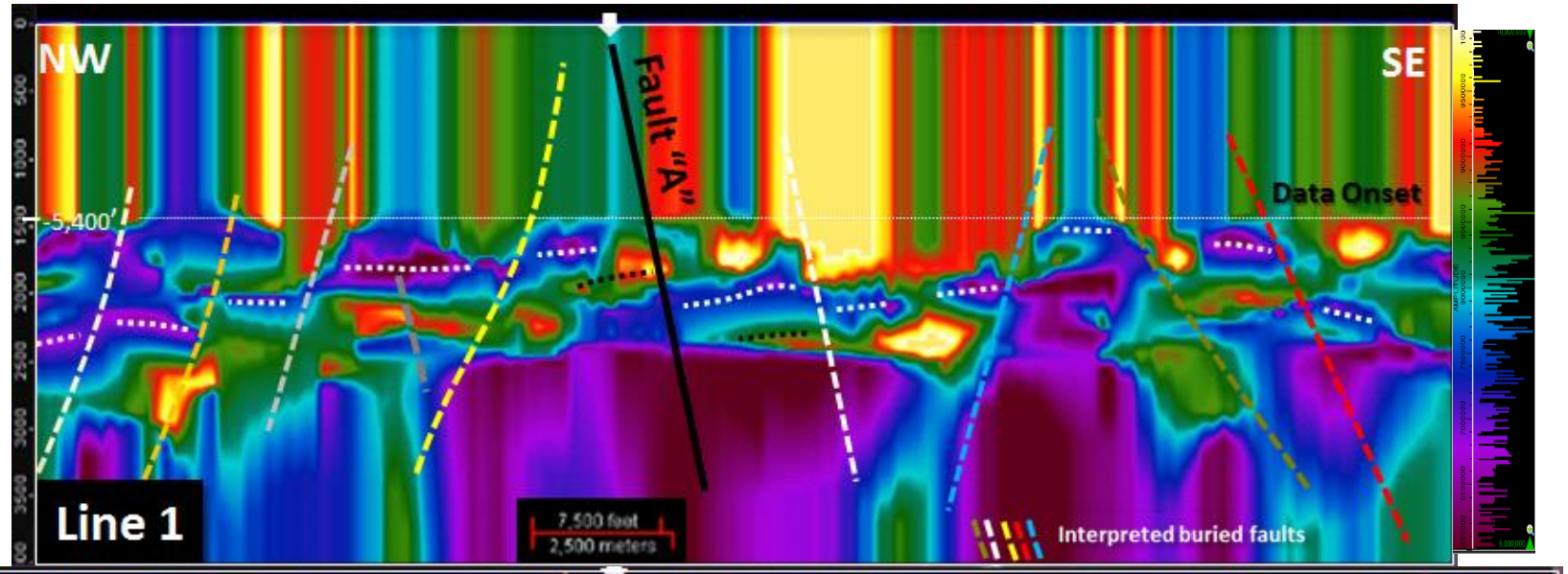


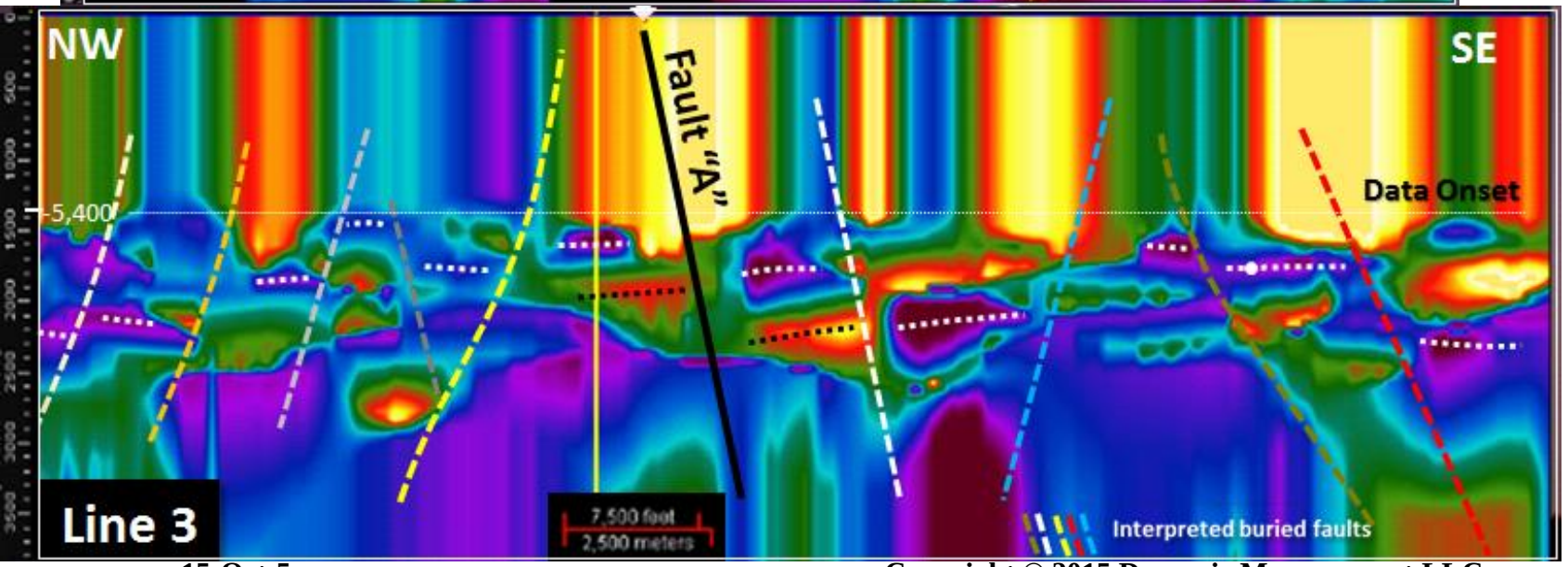


NSEM demonstrates consistency identifying Fault "A'.

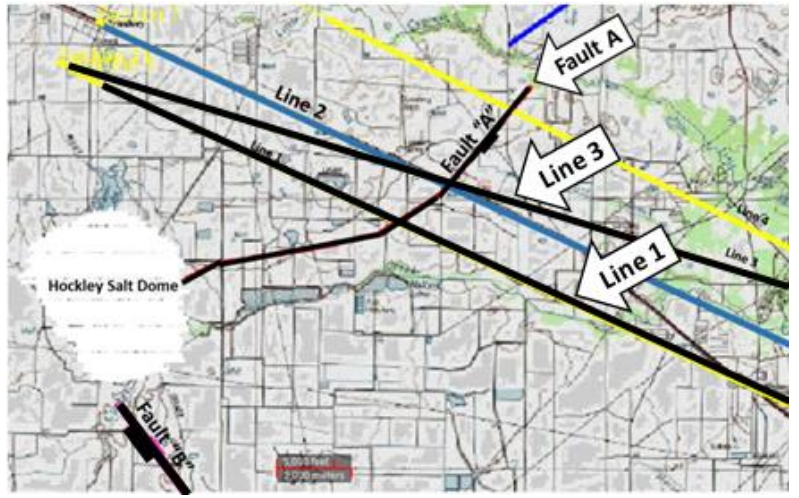


Lines 1 & 3 Also Reveal Additional Faults

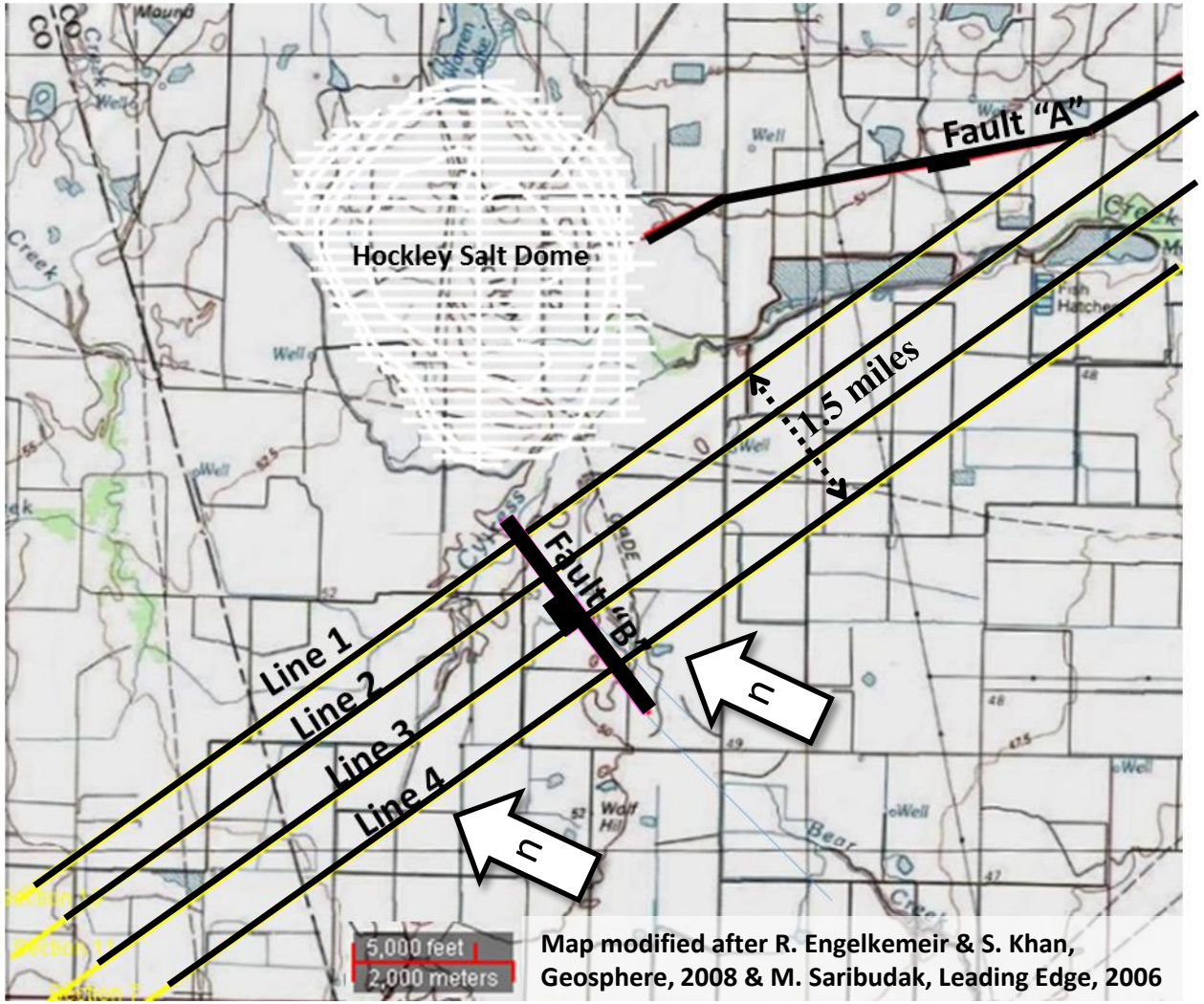




NSEM demonstrates internal consistency mapping nine faults on multiple profiles.



Hockley Radial Fault "B"

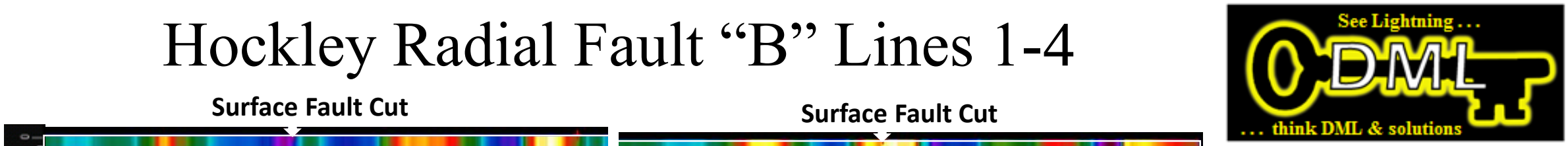


Map modified after R. Engelkemeir & S. Khan, Geosphere, 2008 & M. Saribudak, Leading Edge, 2006

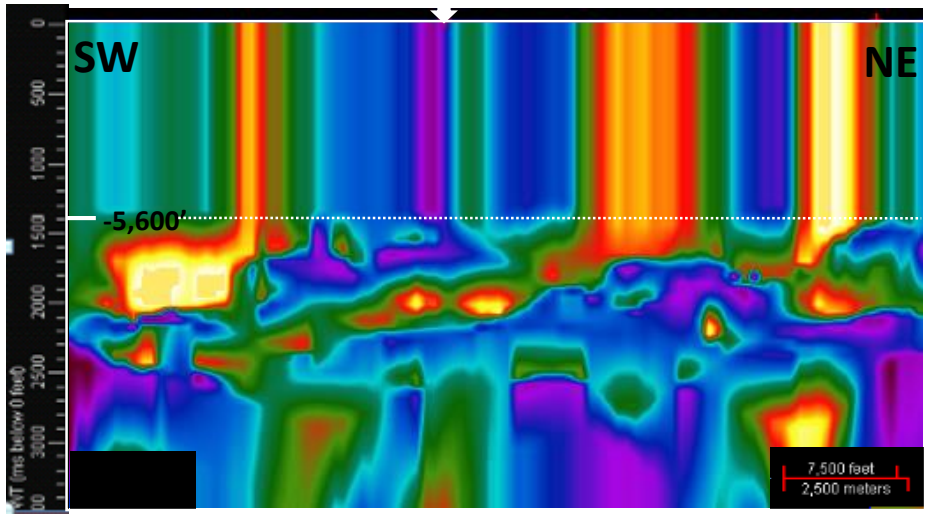
A 1½ mile distance along the Fault "B" trace is sampled with resistivity profiles.

Resistivity Lines 1-4 are displayed on next slide.

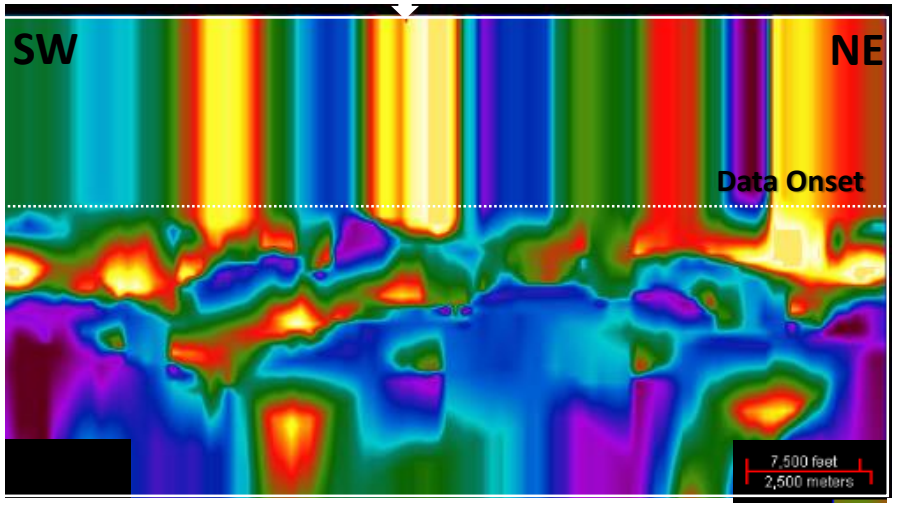
Hockley Radial Fault "B" Lines 1-4



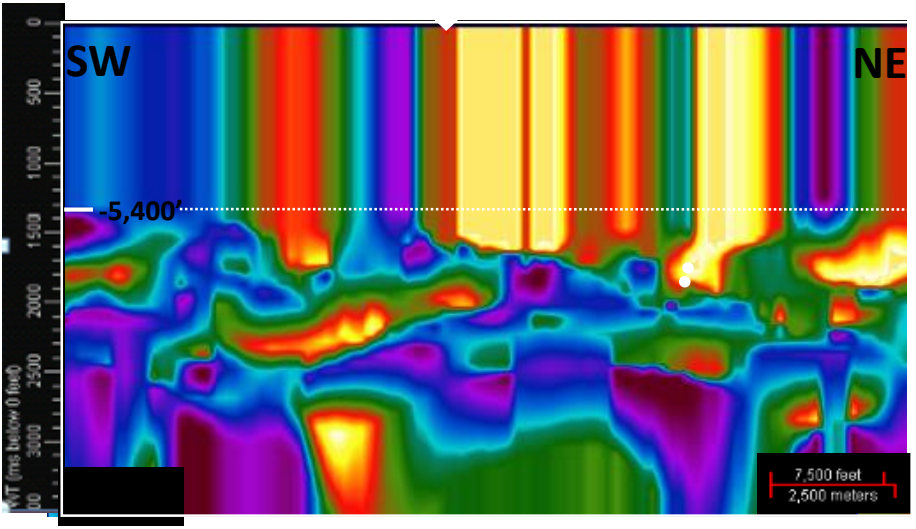
Surface Fault Cut

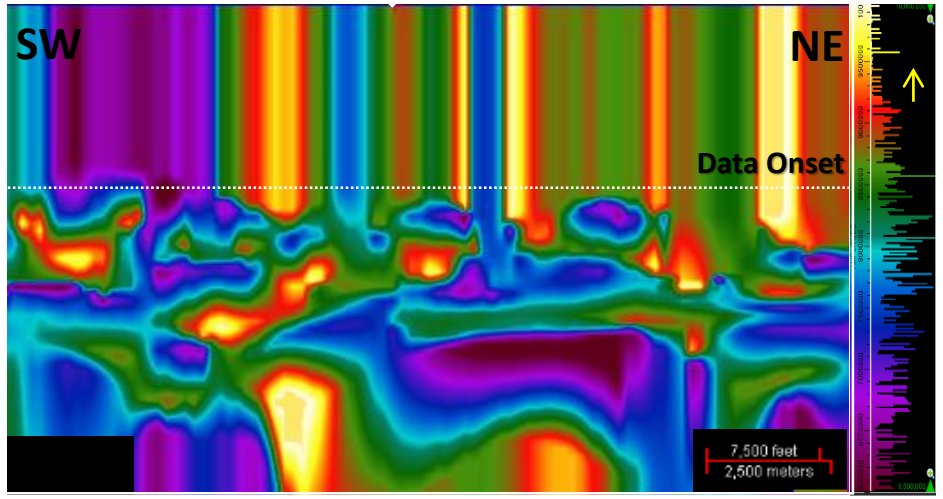


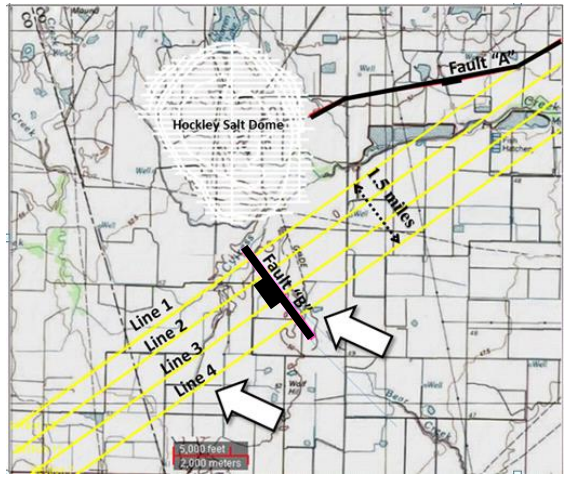
Surface Fault Cut



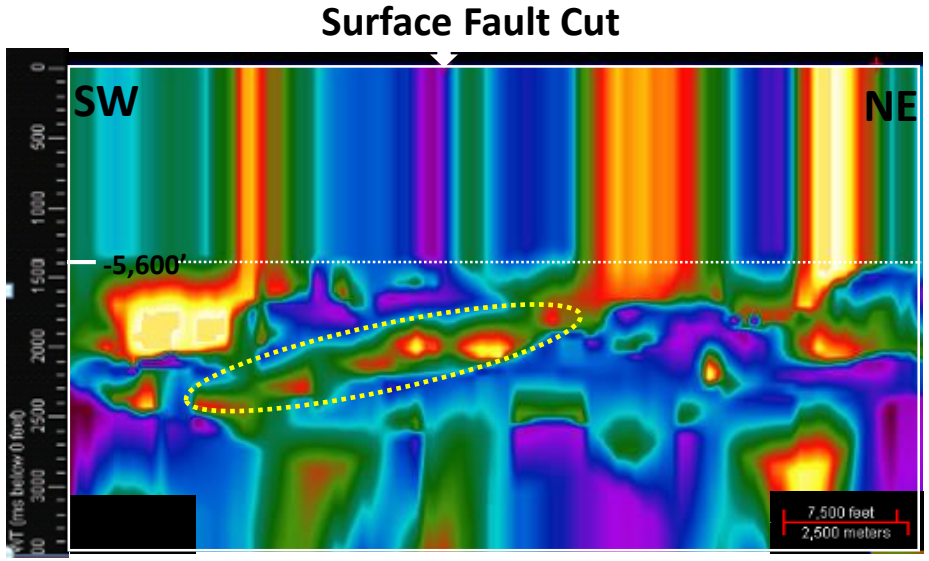
Lines ½ mile apart.
Note similar character.

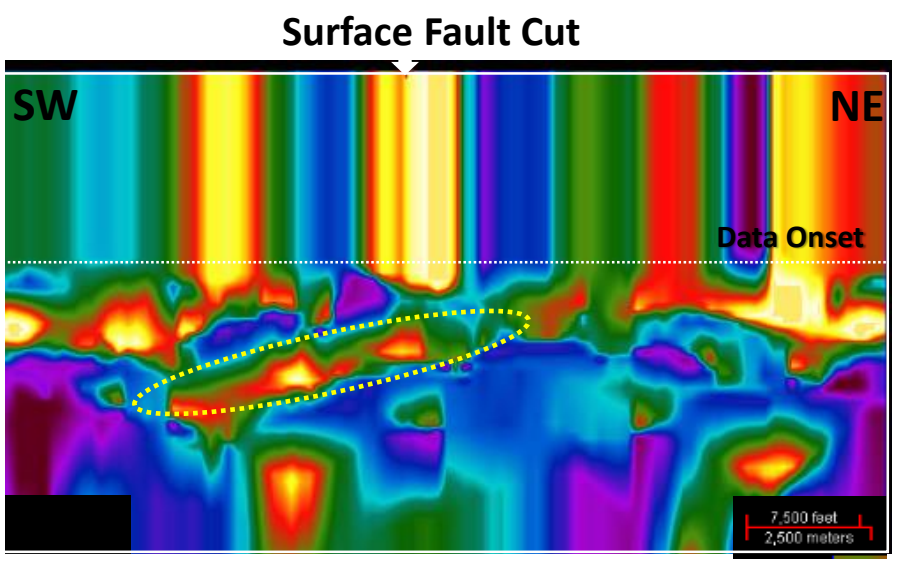


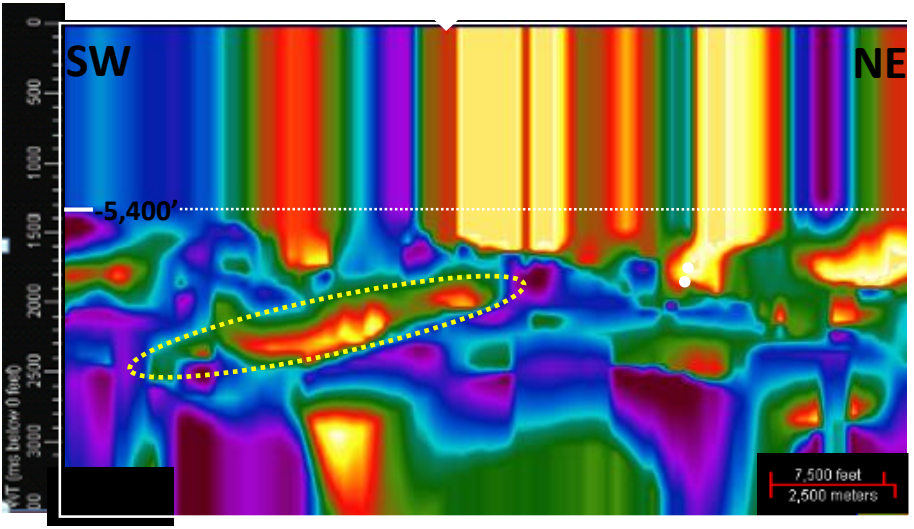


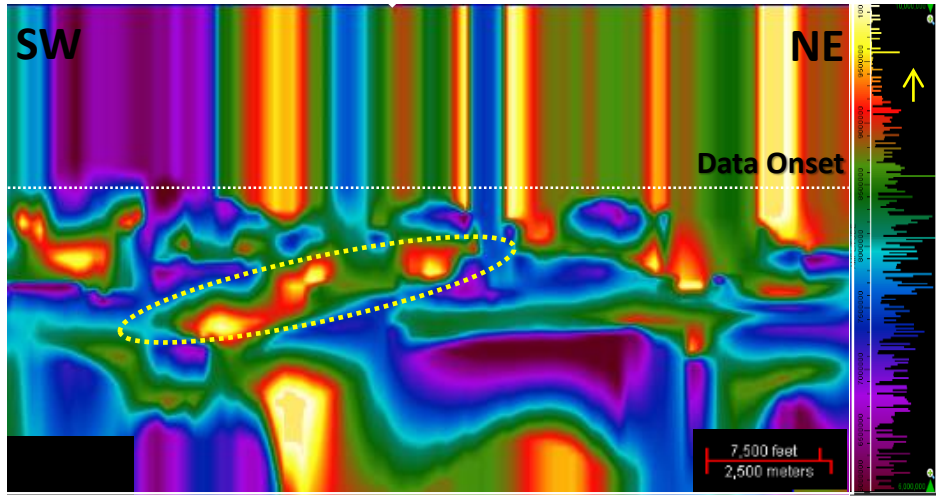


Similar Character Spanning 1.5 Miles

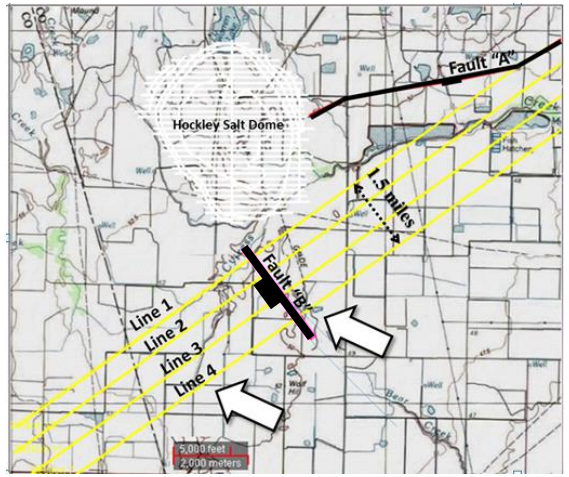




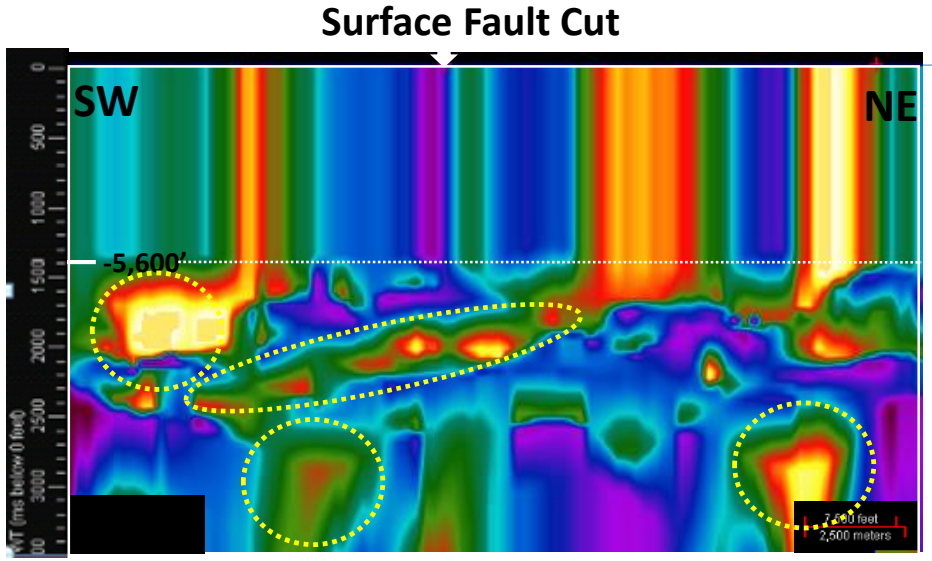


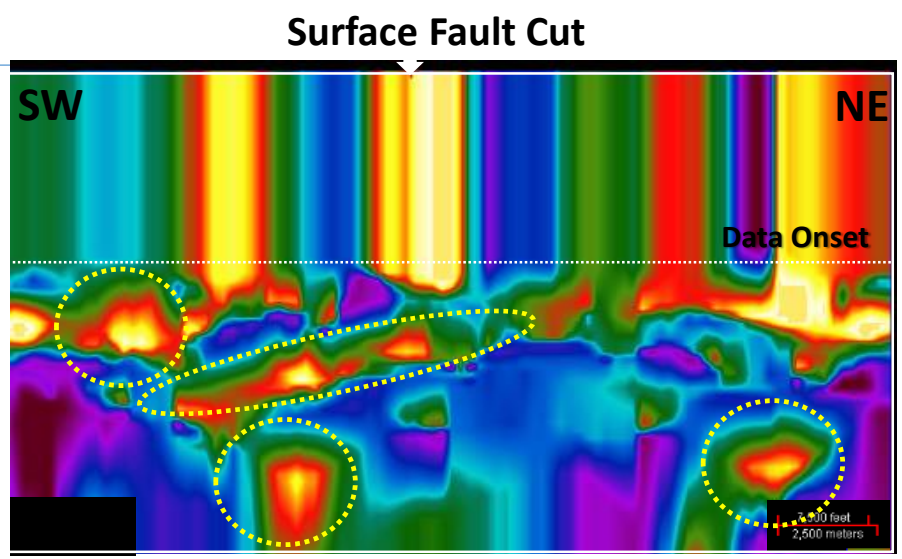


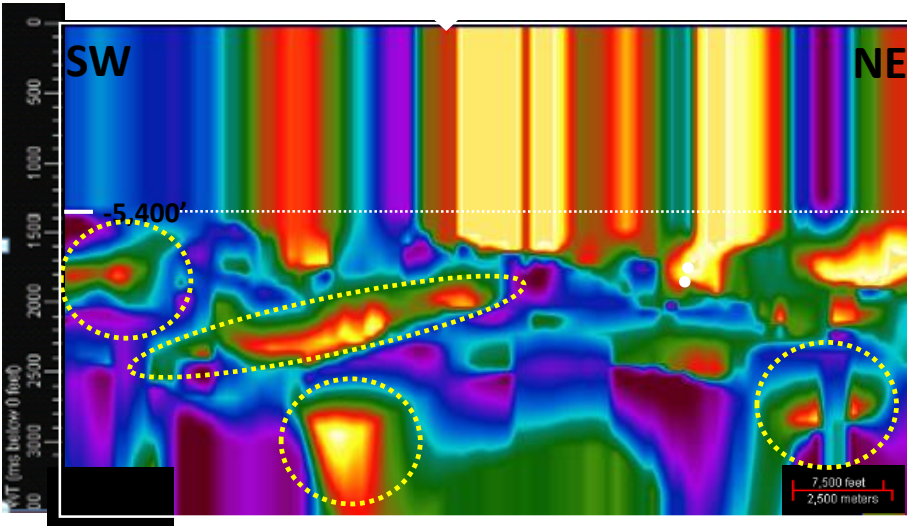
Lines ½ mile apart.
Note similar character.

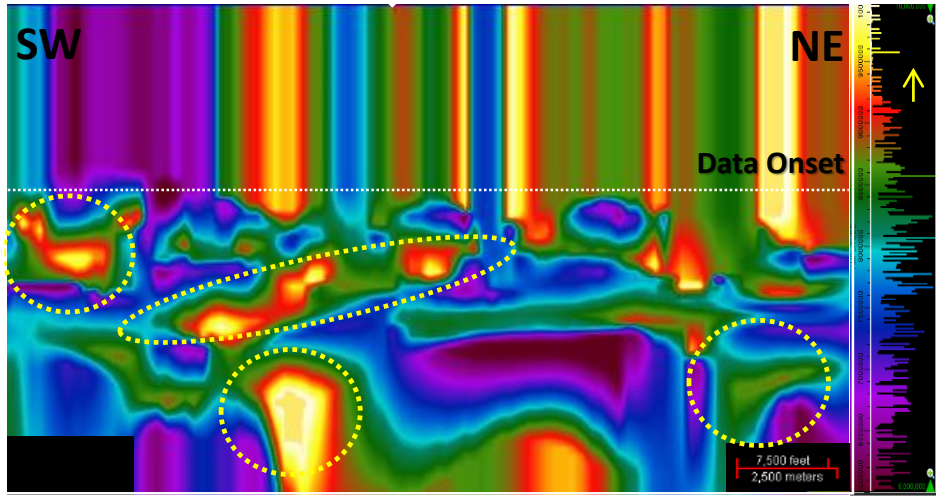


Numerous Features Correlate Line to Line

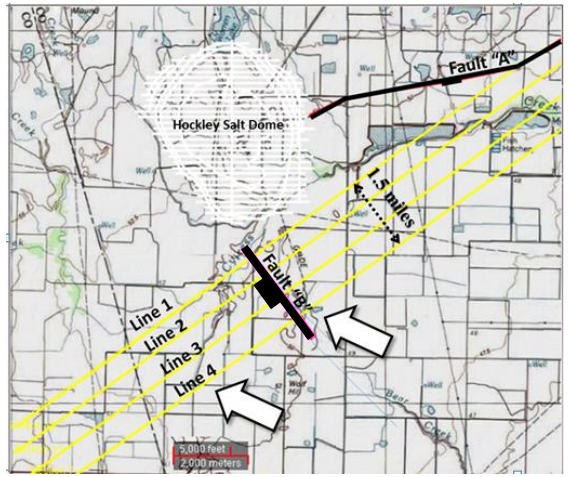




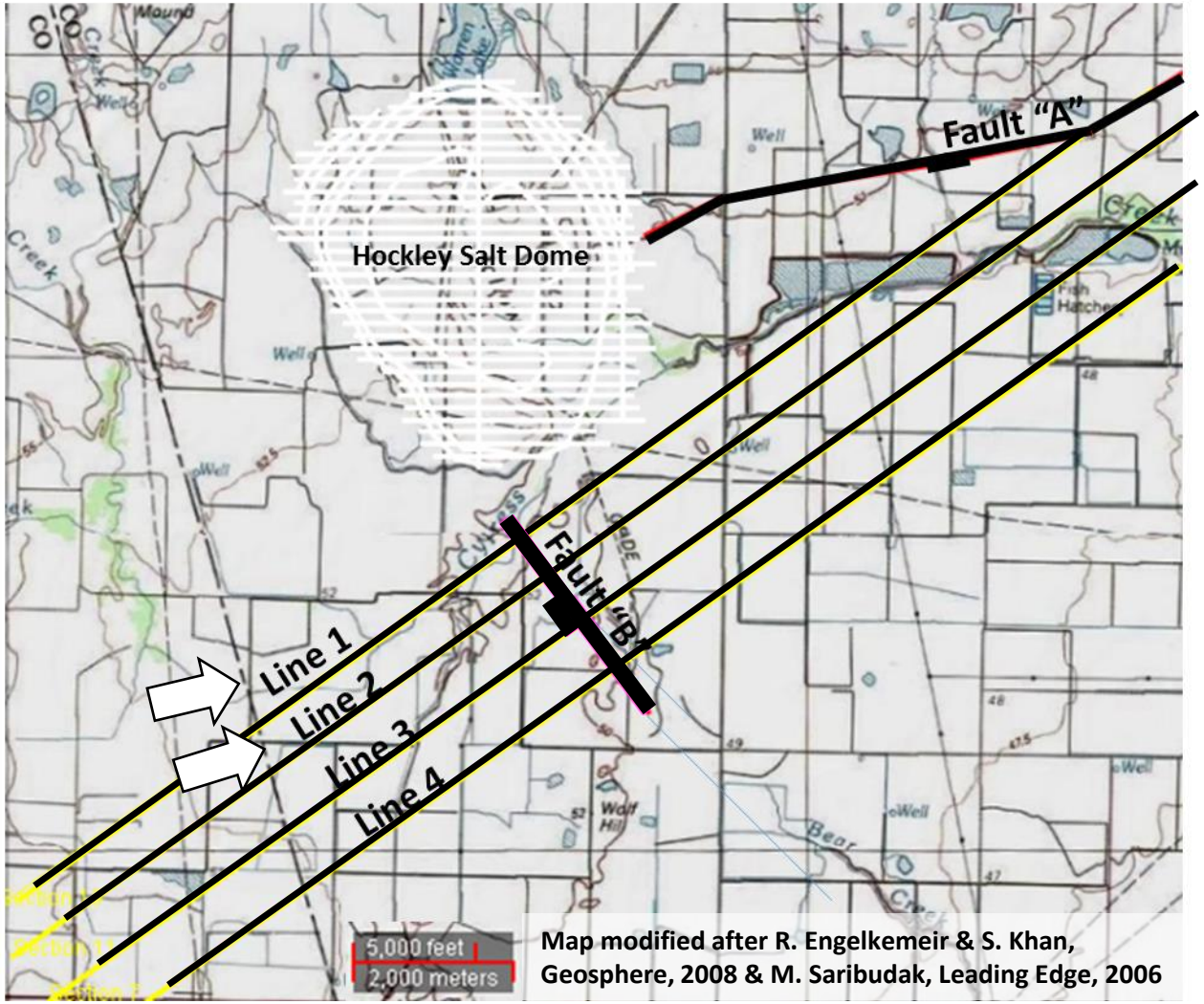




Lines ½ mile apart.
Note similar character.



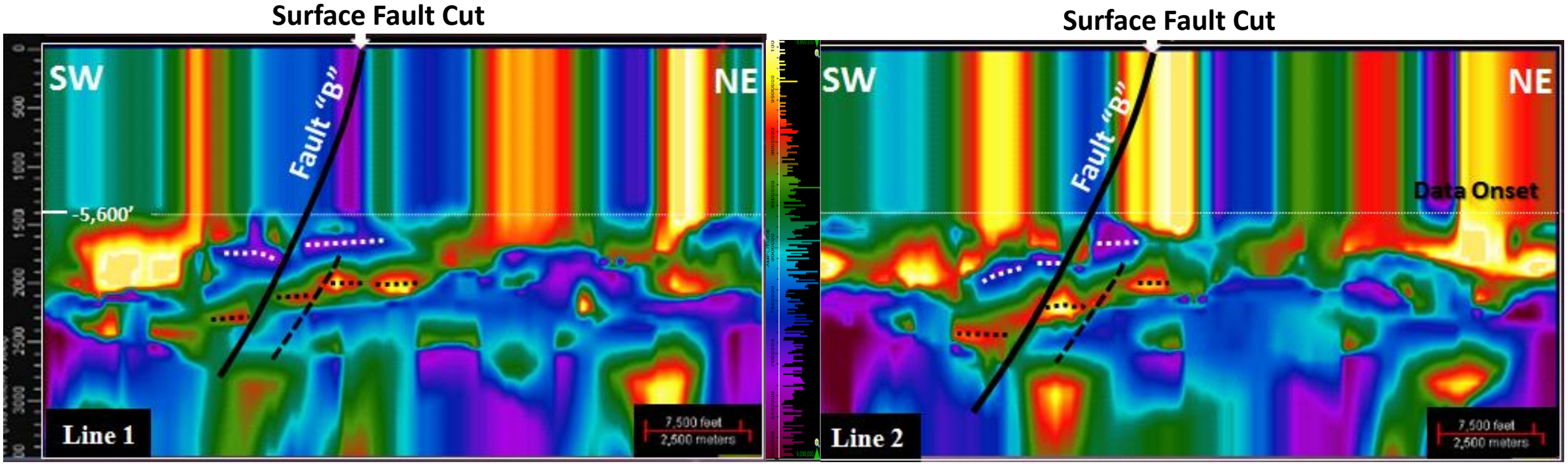
Hockley Radial Fault “B”



Map modified after R. Engelkemeir & S. Khan, Geosphere, 2008 & M. Saribudak, Leading Edge, 2006

Do these four apparent resistivity lines show any evidence for the subsurface presence of Fault “B”?

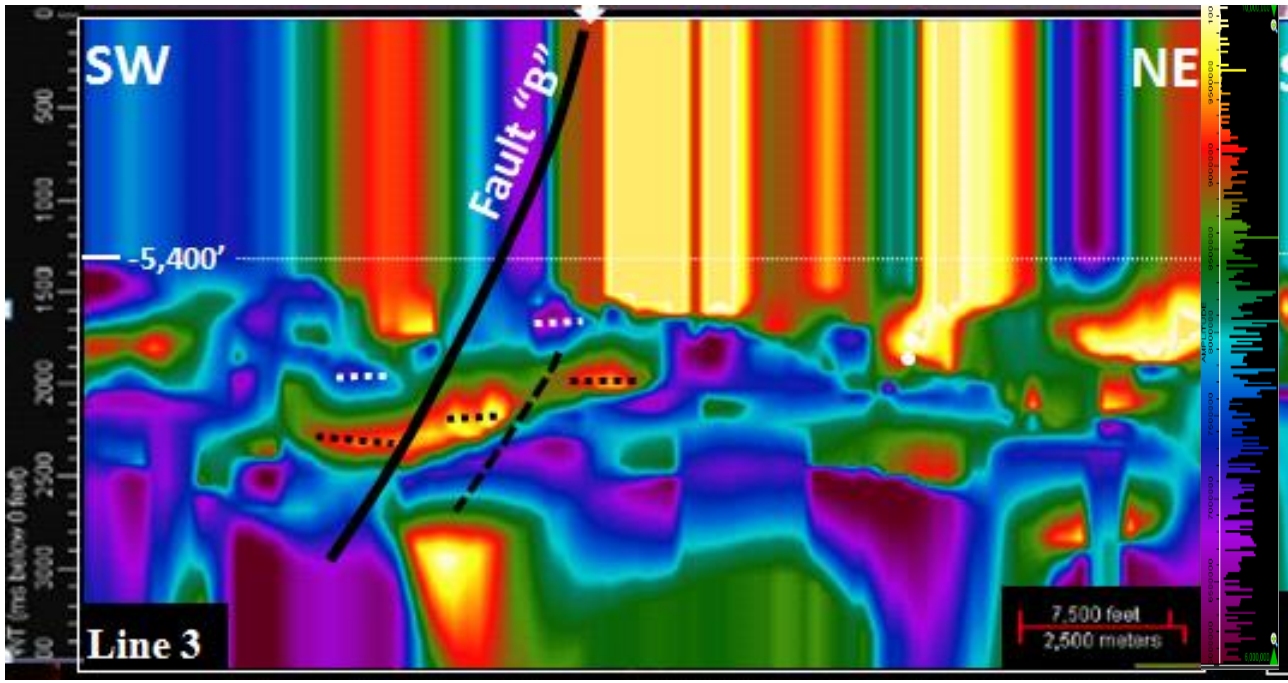
NSEM Ties Surface Fault "B" to Subsurface



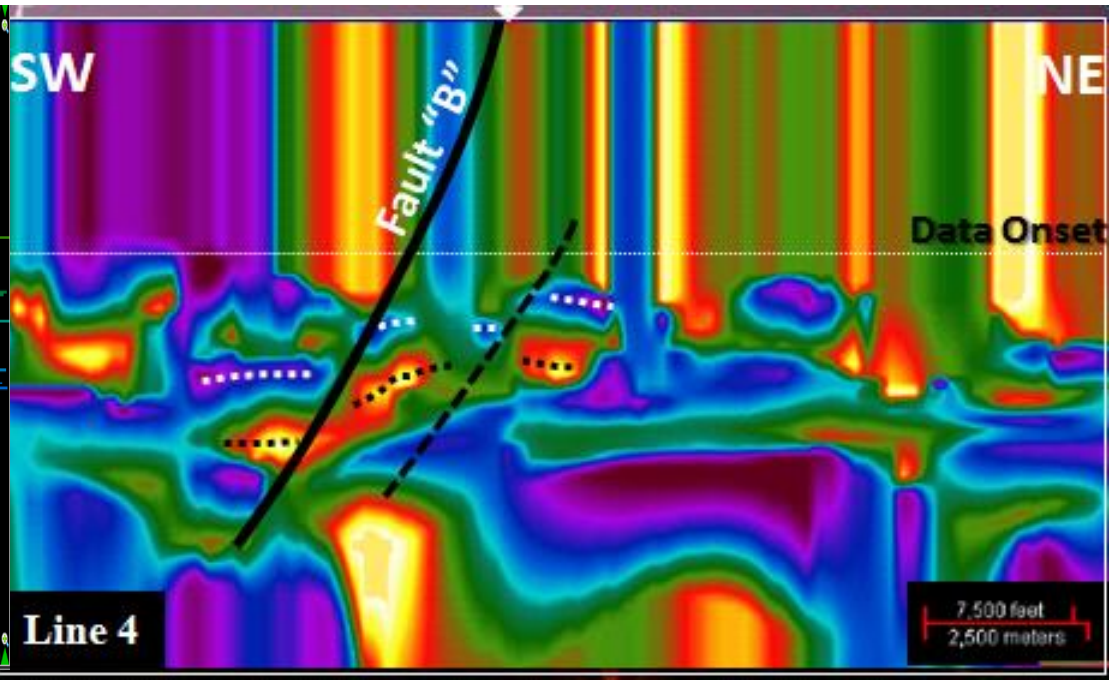
Lines 1 & 2 show consistent subsurface fault criteria.

NSEM Ties Surface Fault "B" to Subsurface

Surface Fault Cut



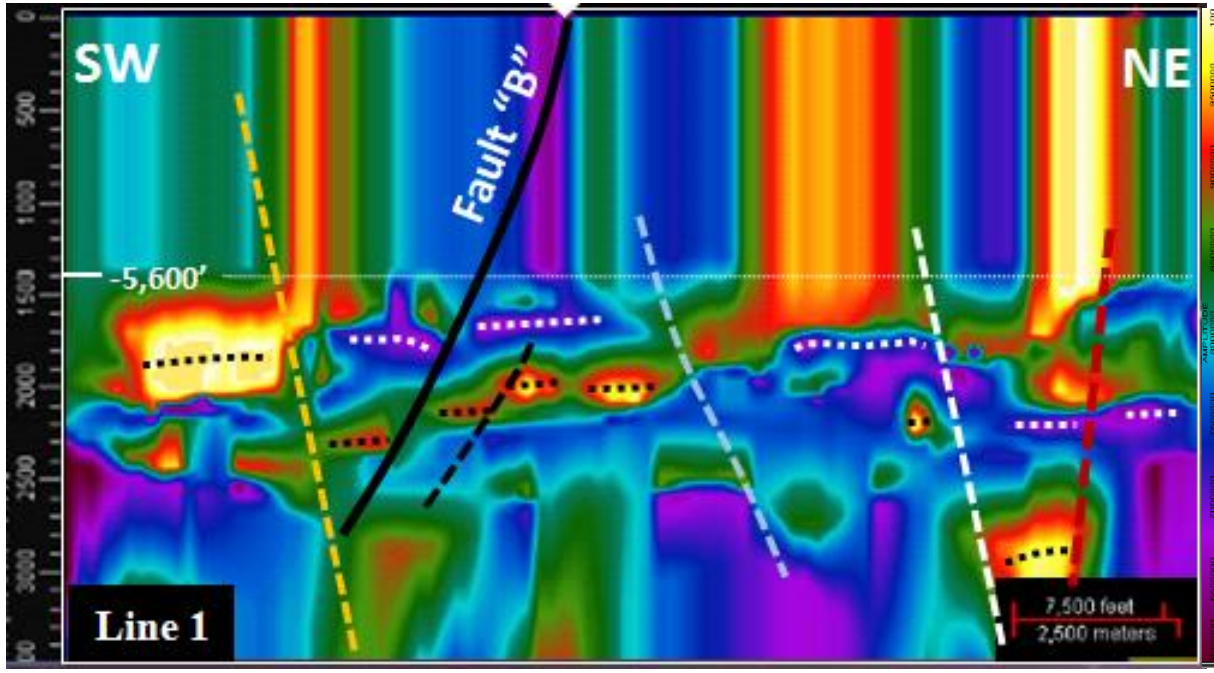
Surface Fault Cut



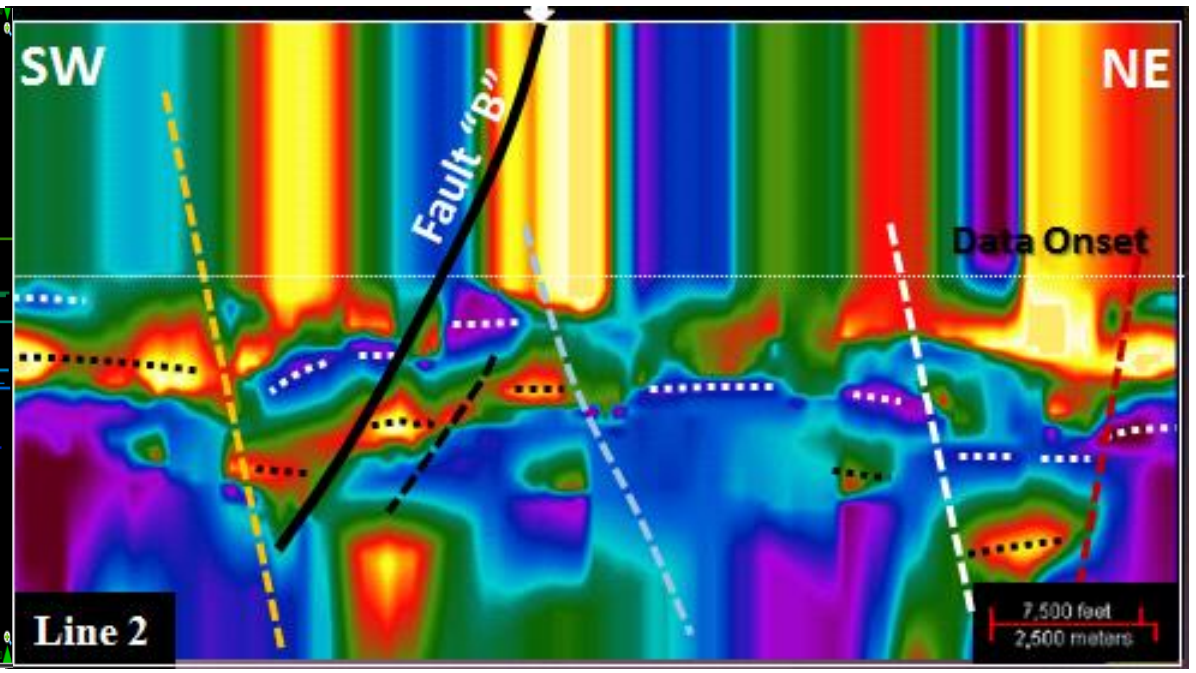
Lines 3 & 4 show similar consistent subsurface fault criteria.

NSEM Shows Additional Faulting
Lines 1 & 2

Surface Fault Cut

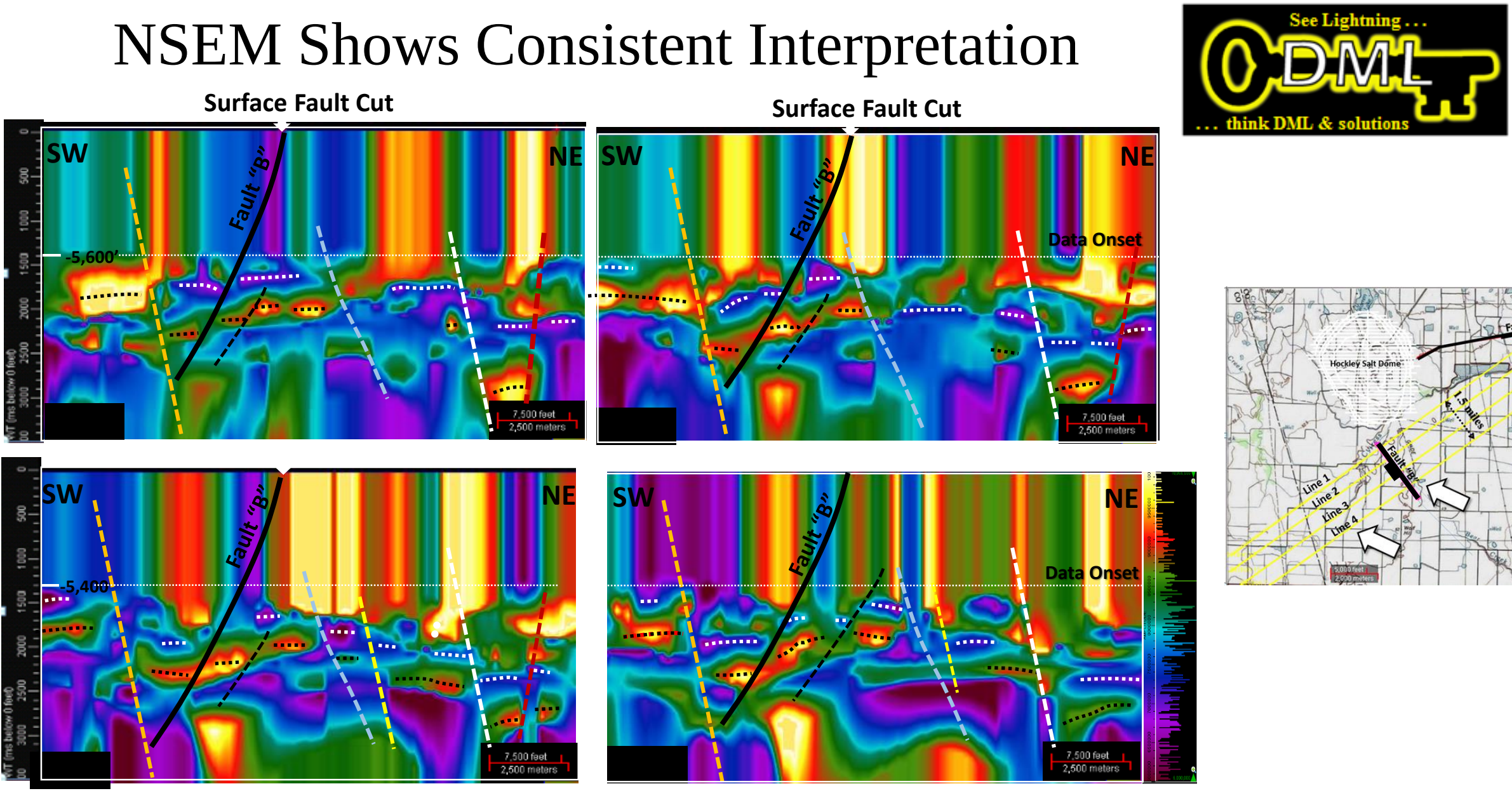


Surface Fault Cut



Six geologically reasonable faults consistently interpreted on both lines.

NSEM Shows Consistent Interpretation



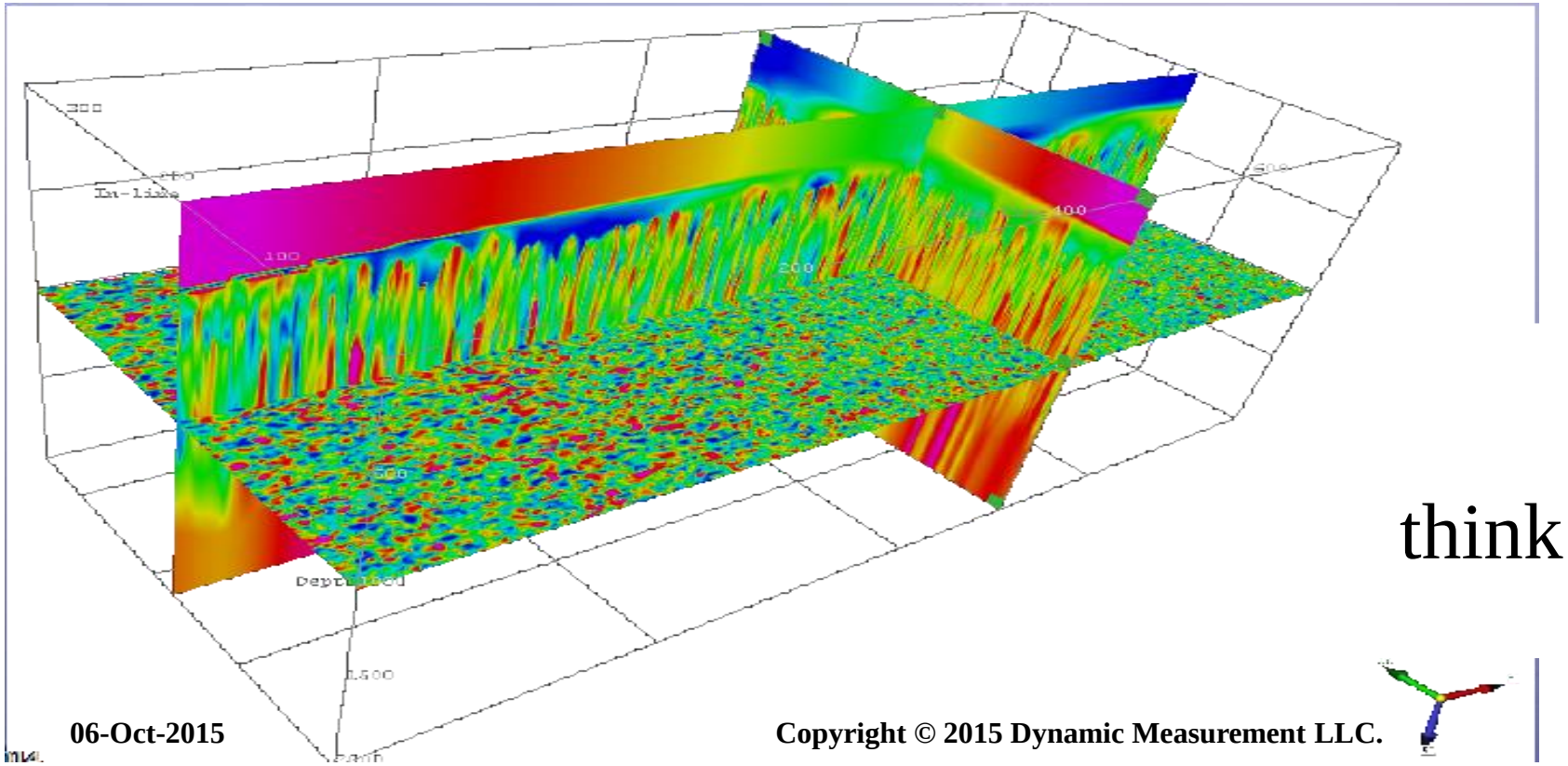
What we have covered:

1. NSEM - A new technology to identify geologic hazards
2. The meteorology behind lightning databases
3. Calculating resistivity volumes from lightning databases
4. Examples of using lightning databases to map geology

Find out more at

http://www.dynamicmeasurement.com/TAMU

Thank You!



See Lightning,
think DML & solutions!

See Lightning, Think DML

- Contact Information:
  - H. Roice Nelson, Jr.

    cell: 713.542.2207

    e-mail: roice@dynamicmeasurement.com
  - Dr. Jim Siebert

    cell: 832.423.2355

    e-mail: jim@dynamicmeasurement.com

- www.dynamicmeasurement.com
- 2155 West 700 South #31

  Cedar City, UT 84720
  - Fax: 435.267.2668
- 211 Baker Road #382

  Barker, TX 77413

  Office: 281.579.0172

Discussion