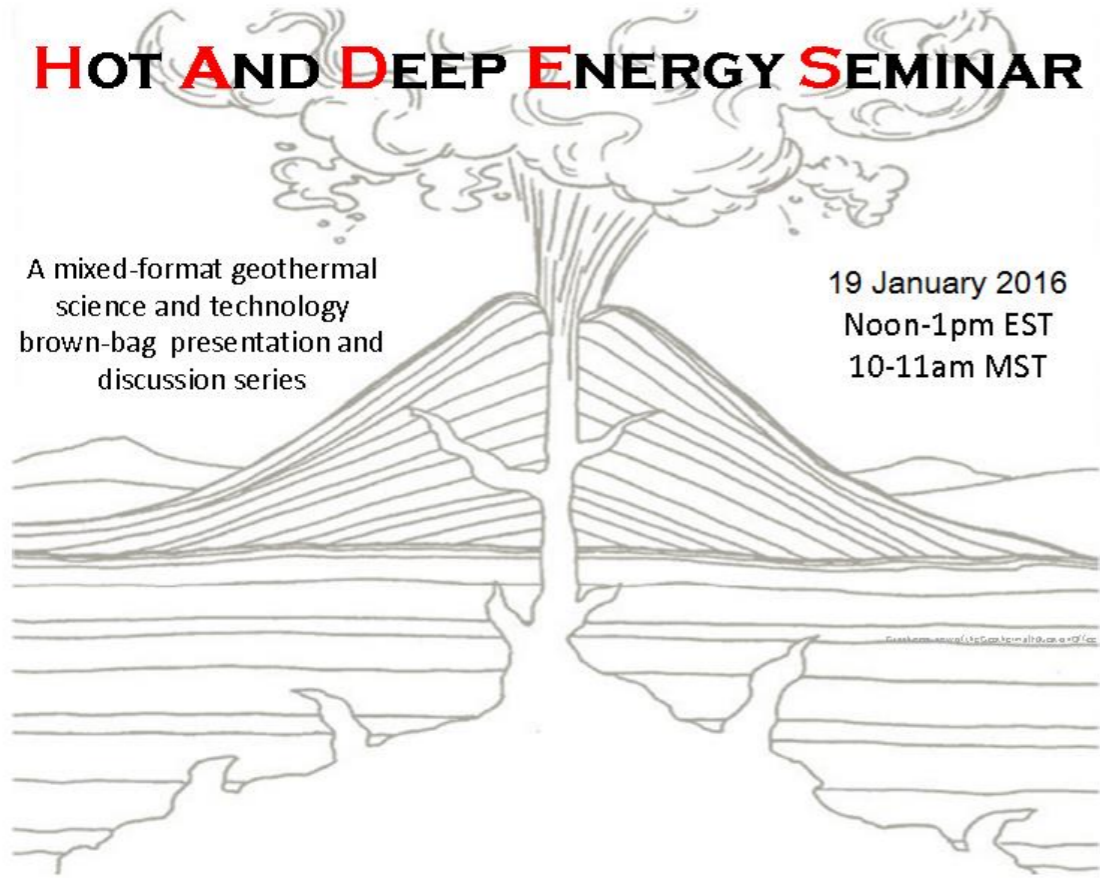


HOT AND DEEP ENERGY SEMINAR

A mixed-format geothermal science and technology brown-bag presentation and discussion series

19 January 2016
Noon-1pm EST
10-11am MST



Introduction: Using Lightning Databases to obtain resistivity information for geothermal exploration.

19 January 2016

H. Roice Nelson, Jr.,
Dr. Jim Siebert,
Les R. Denham



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DOE HADES 1



DML Outline

1. Introduction & Overview
2. Lightning Attributes & Databases
3. Calculating Rock Properties & Volumes
4. Geothermal Opportunities
5. Next Steps



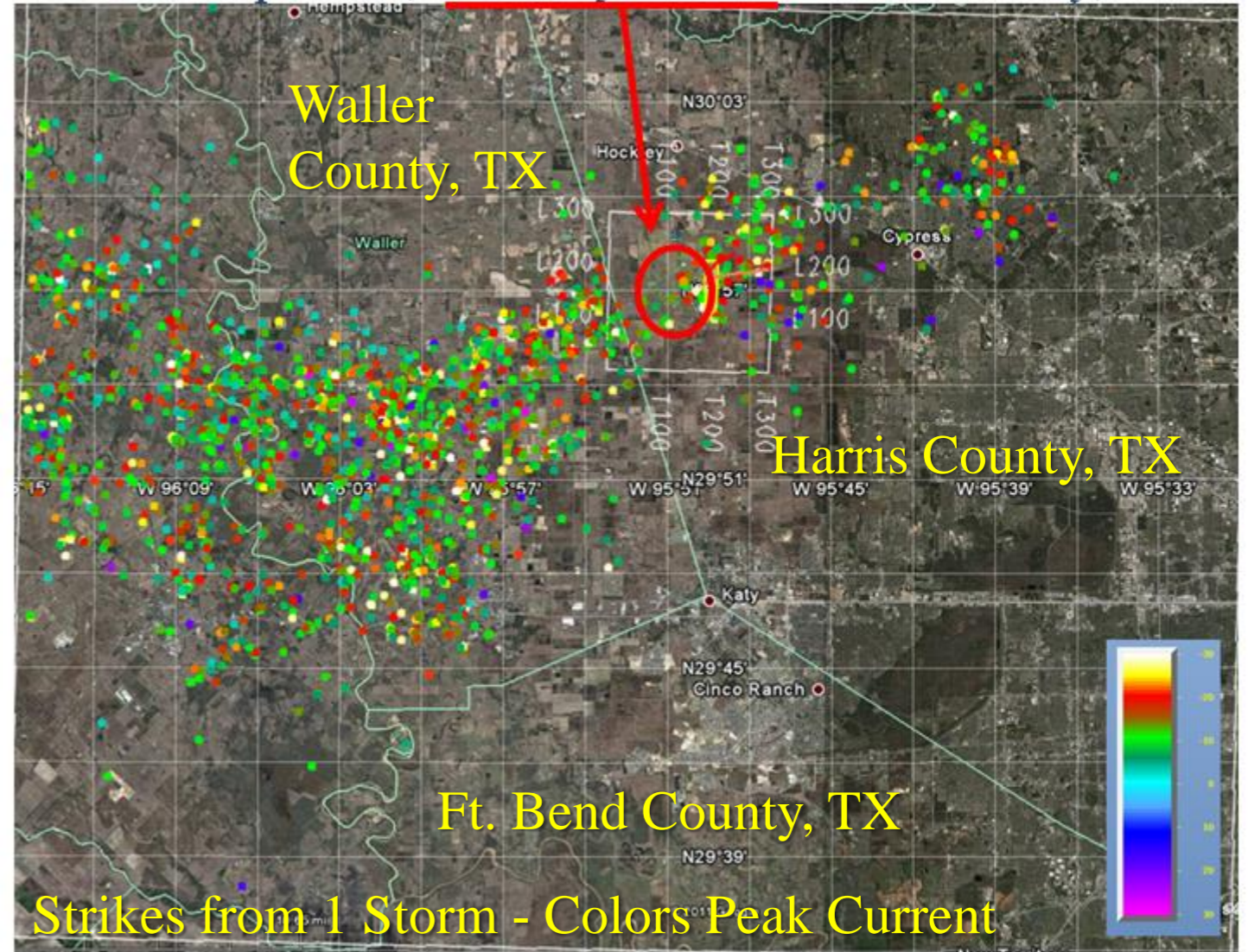


1. Introduction & Overview

27 Sep 2011, Hockley Dome Harris County, TX

DML Started with 2 Questions:

1. Can lightning hit twice at the same place?
2. Does this mean there is oil on my property?



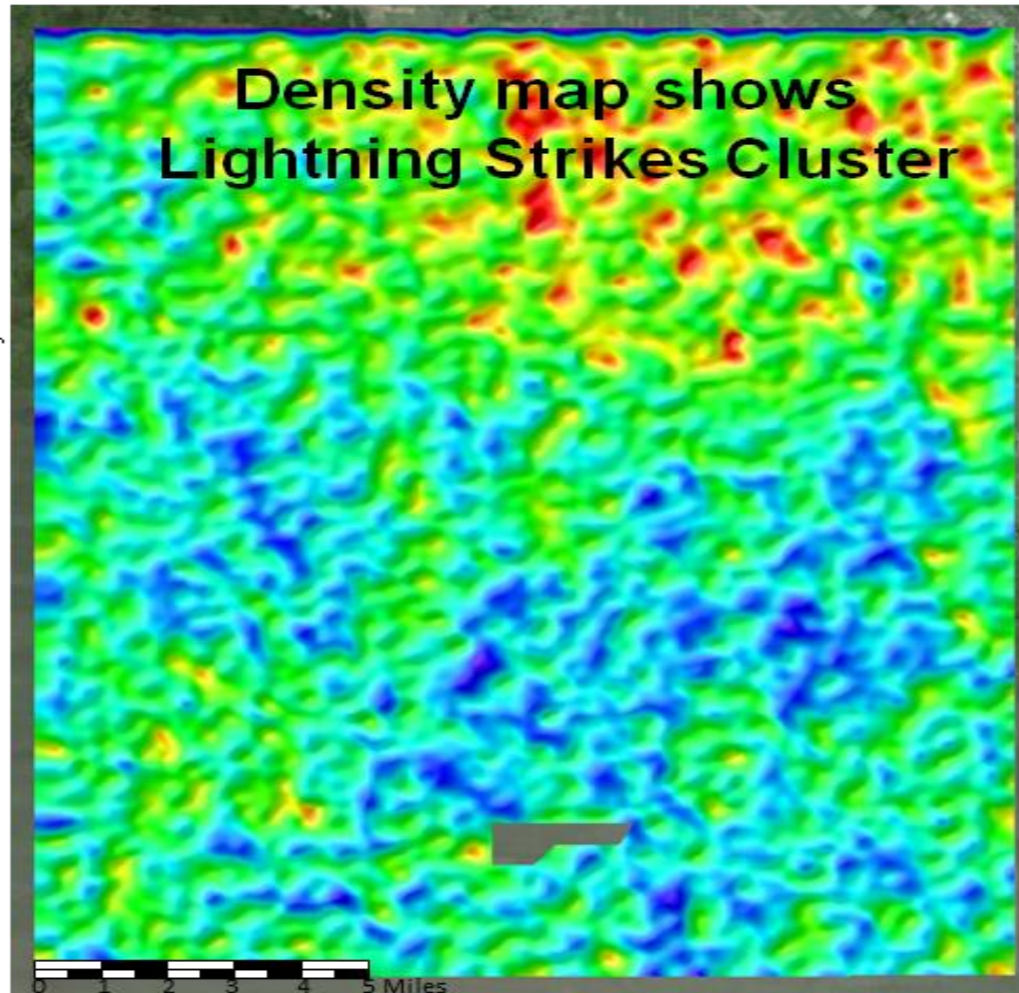
The Answer to Both Questions is Yes



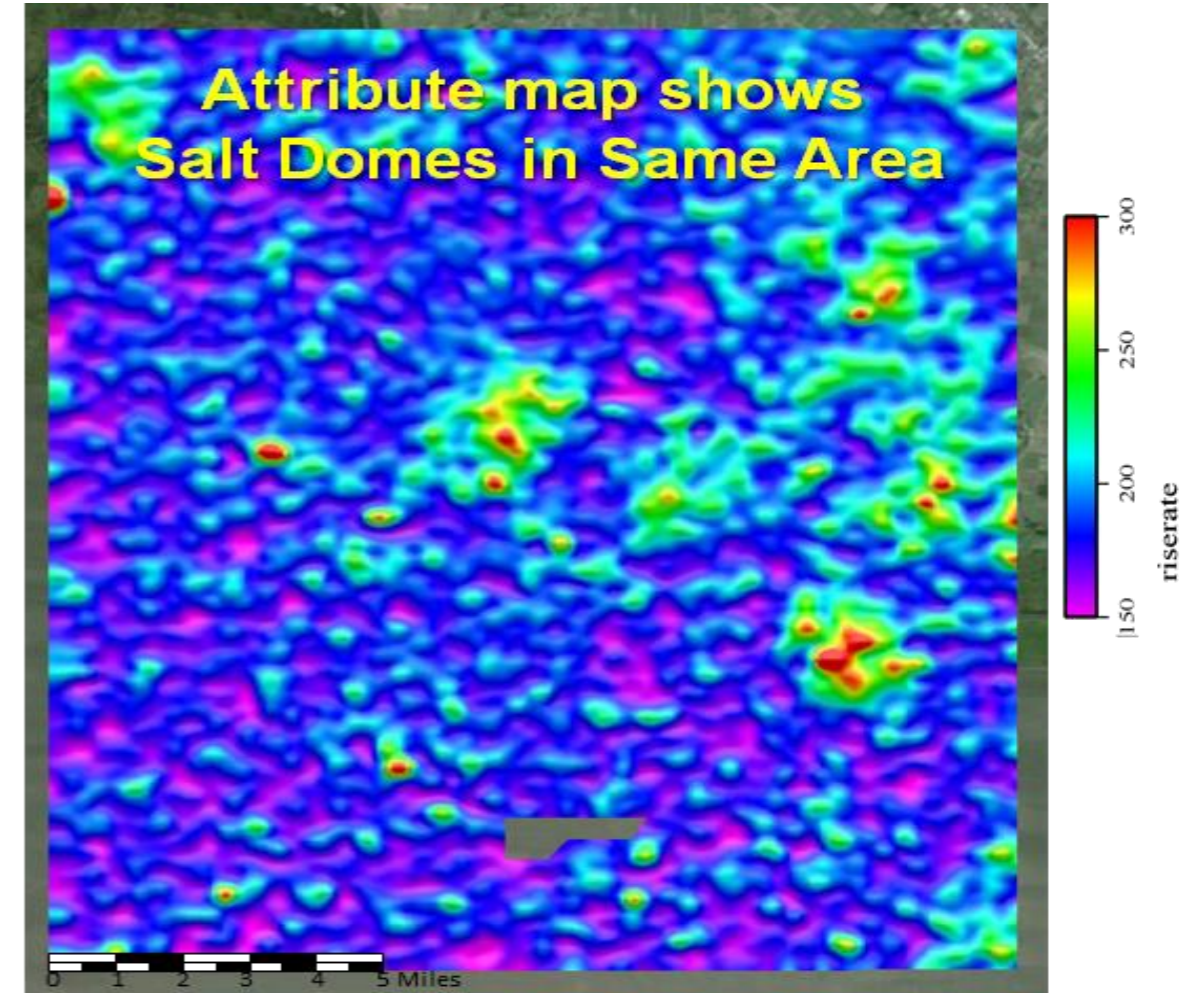
The answer to the first question is “yes,” lightning strikes cluster and the clusters are consistent over time.

The answer the second question is “there is oil here,” as shown by the tanks now at the location of the lightning strikes raising the question.

Enlightning Salt Dome Extent – Iberia Parish, LA



Lightning Density Map



Lightning Rate-of-Rise-Time Map

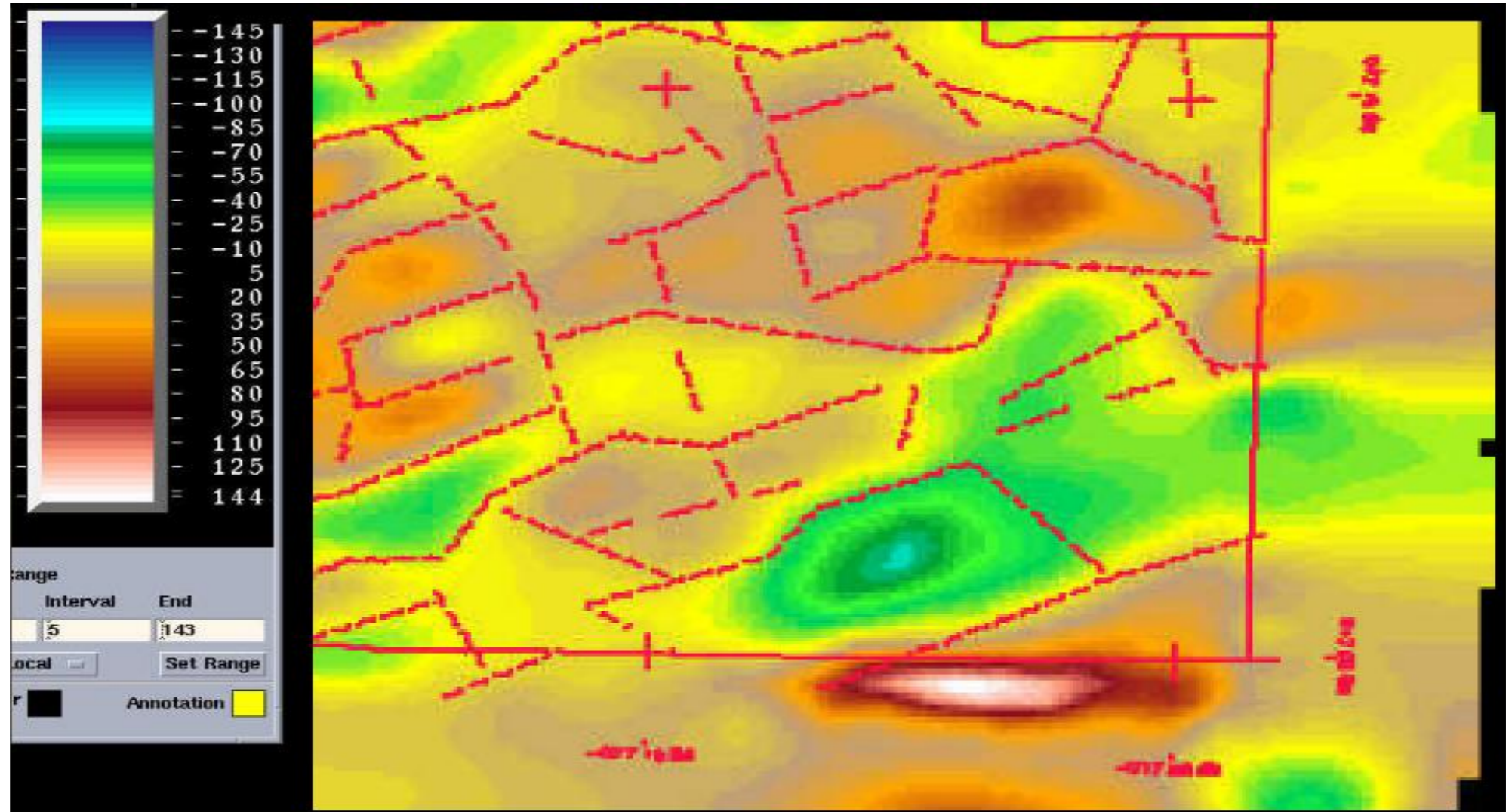
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Enlightening Aeromagnetics – Steuben County, NY



Interpolated NewMag® and Interpretation Overlay

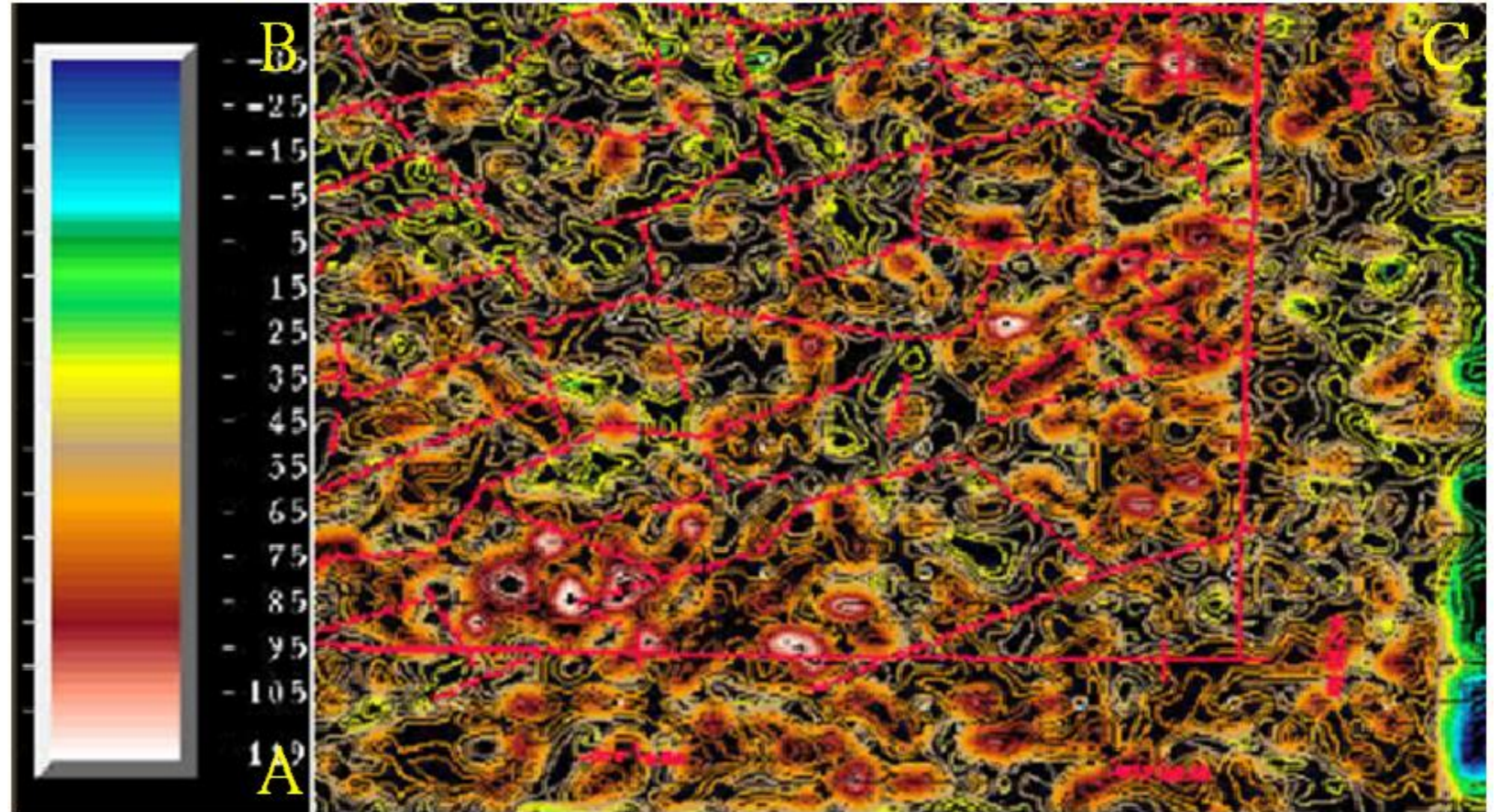
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Enlightening Aeromagnetics – Steuben County, NY



Lightning Density Map and NewMag® Interpretation

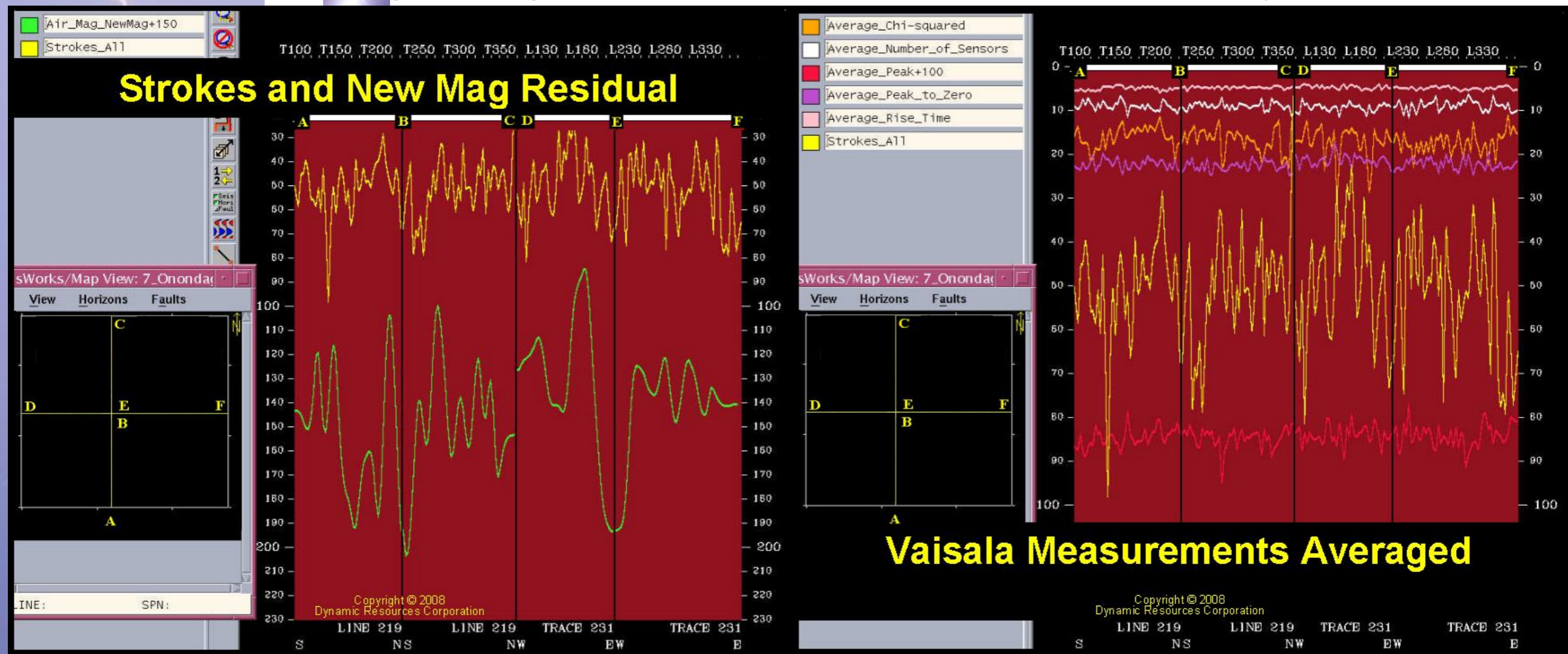
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Enlightning Cross-Sections – Steuben County, NY



19 Jan 2016

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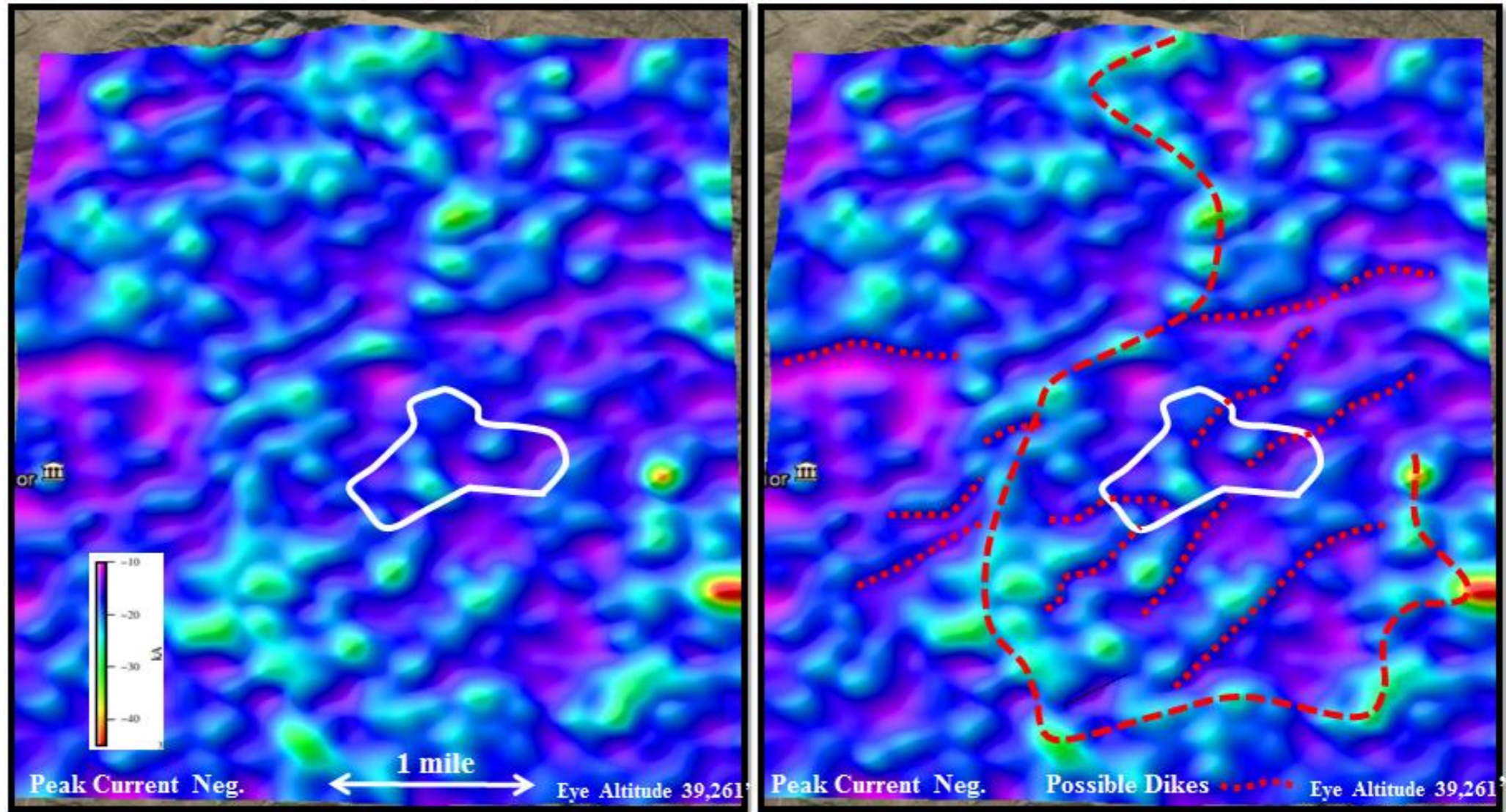
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Lightning Comparison of Air Mag & Lightning Prices

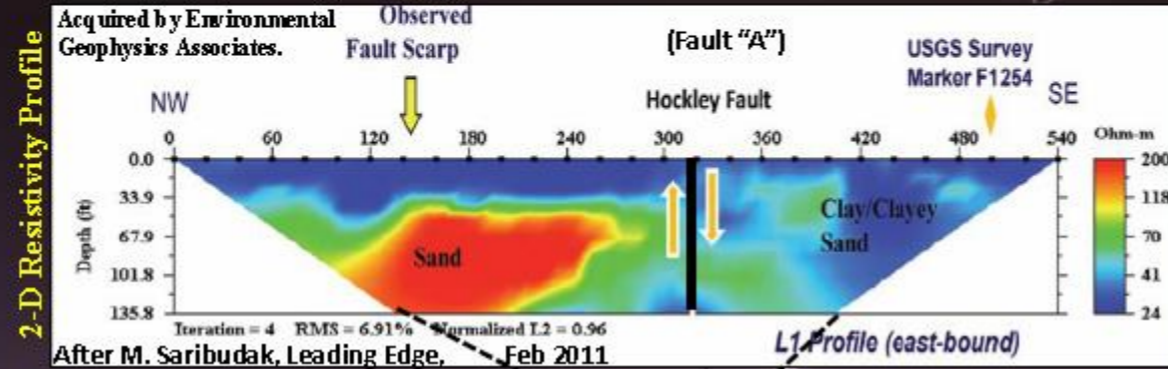
Swath Size		1 km	200 meter	100 meter	50 meter
Aeromagnetic Price	Cost per 1 line km (price)	\$65			
	Cost per 60 line km (factor)	\$3,900			
	Cost per 1,000 line km (min)	\$65,000			
	Cost per 3,600 sq km area (60 km long lines)	\$234,000	\$1,170,000	\$2,340,000	\$4,680,000
Lightning Analysis Price			\$180,000		

Enlightning Mineralization – Resolution Copper, AZ



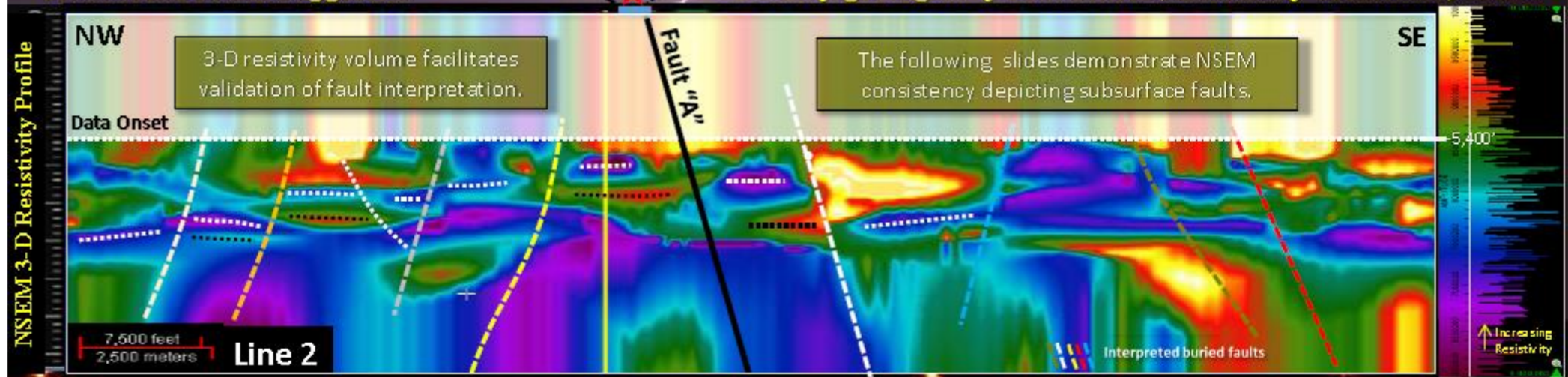
Enlightening EM Surveys – Hockley, TX

NSEM Reveals Additional Faulting 3-D Data Provides Interpretive Checks & Balances



Additional faults suggested.

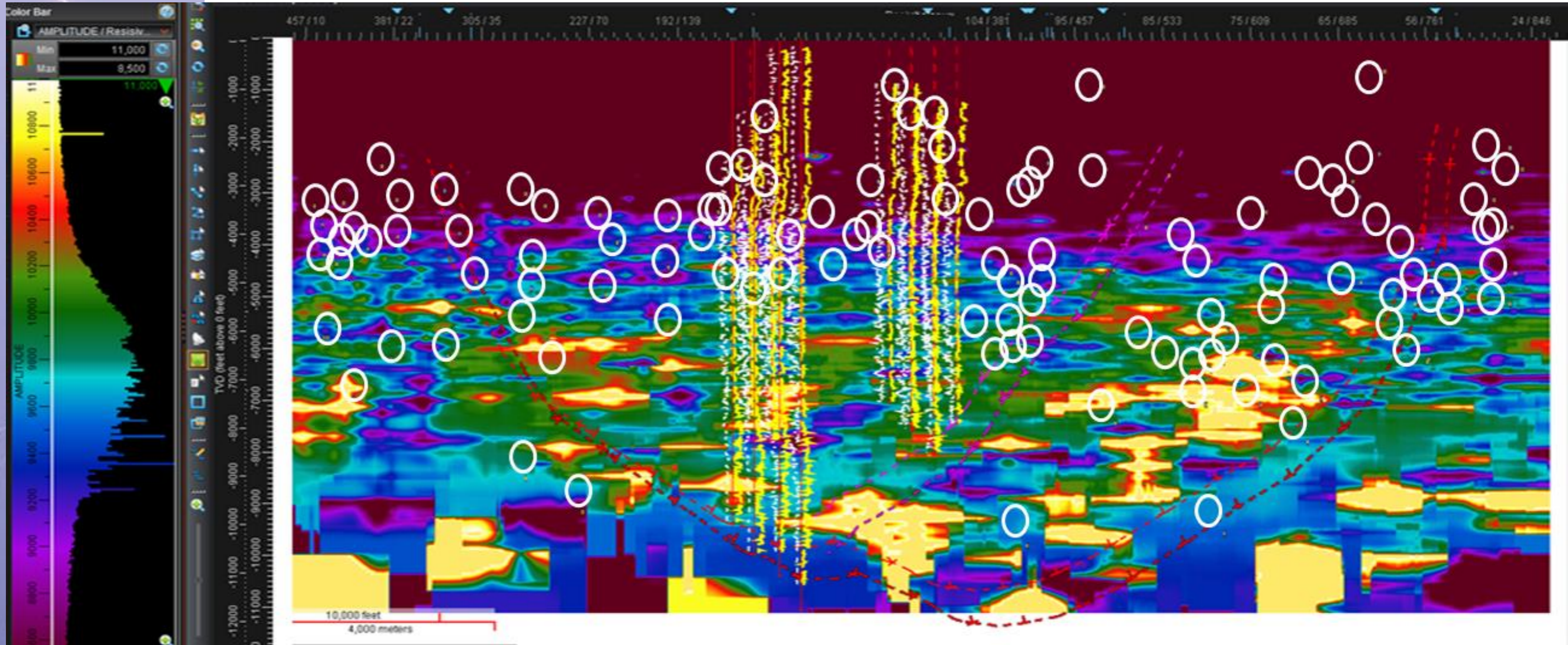
Are they geologically reasonable, internally consistent, valid?



EM Survey ties Lightning Derived Resistivity Cross-Section

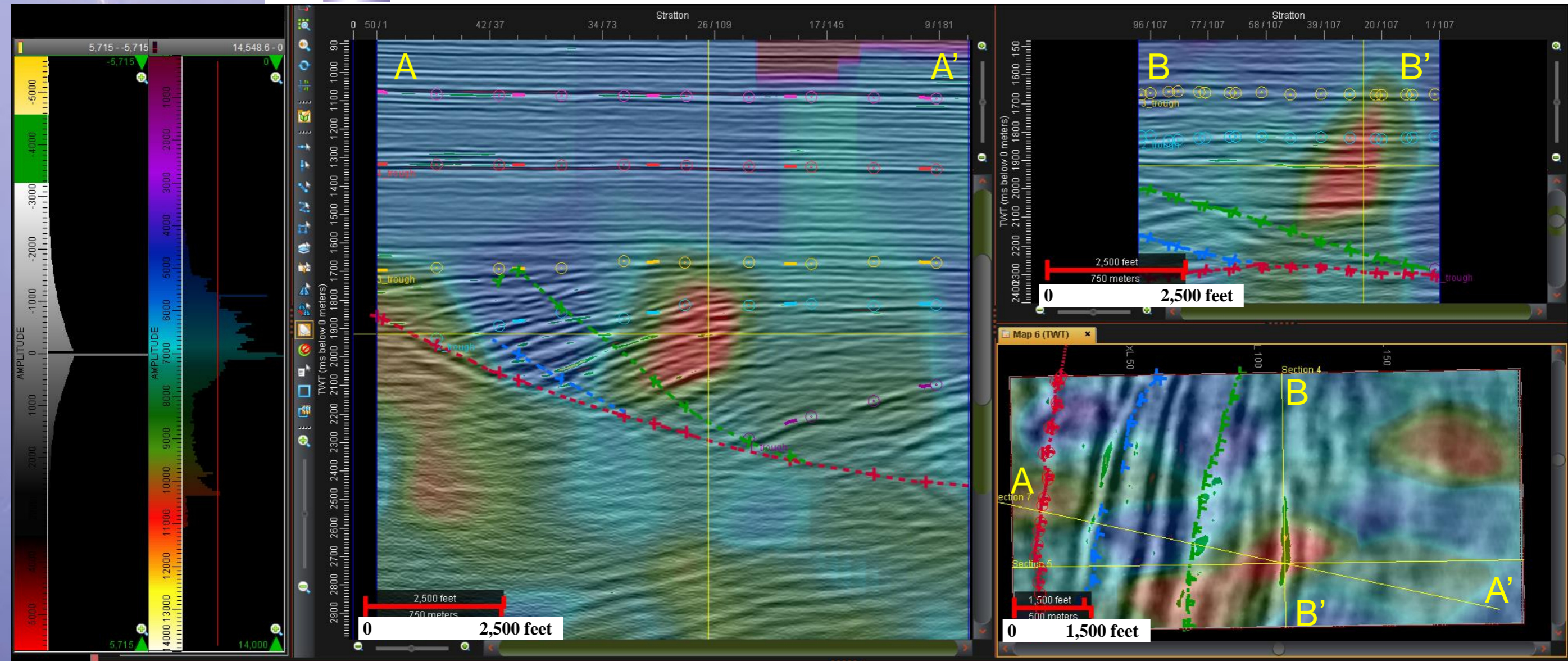


Enlightening Well Interpretation – Goose Point, LA



Lightning Resistivity Cross-Section Faults and Wells

Enlightning Seismic Interpretation – Stratton, TX



19 Jan 2016

Lightning Resistivity Cross-Section over BEG Seismic

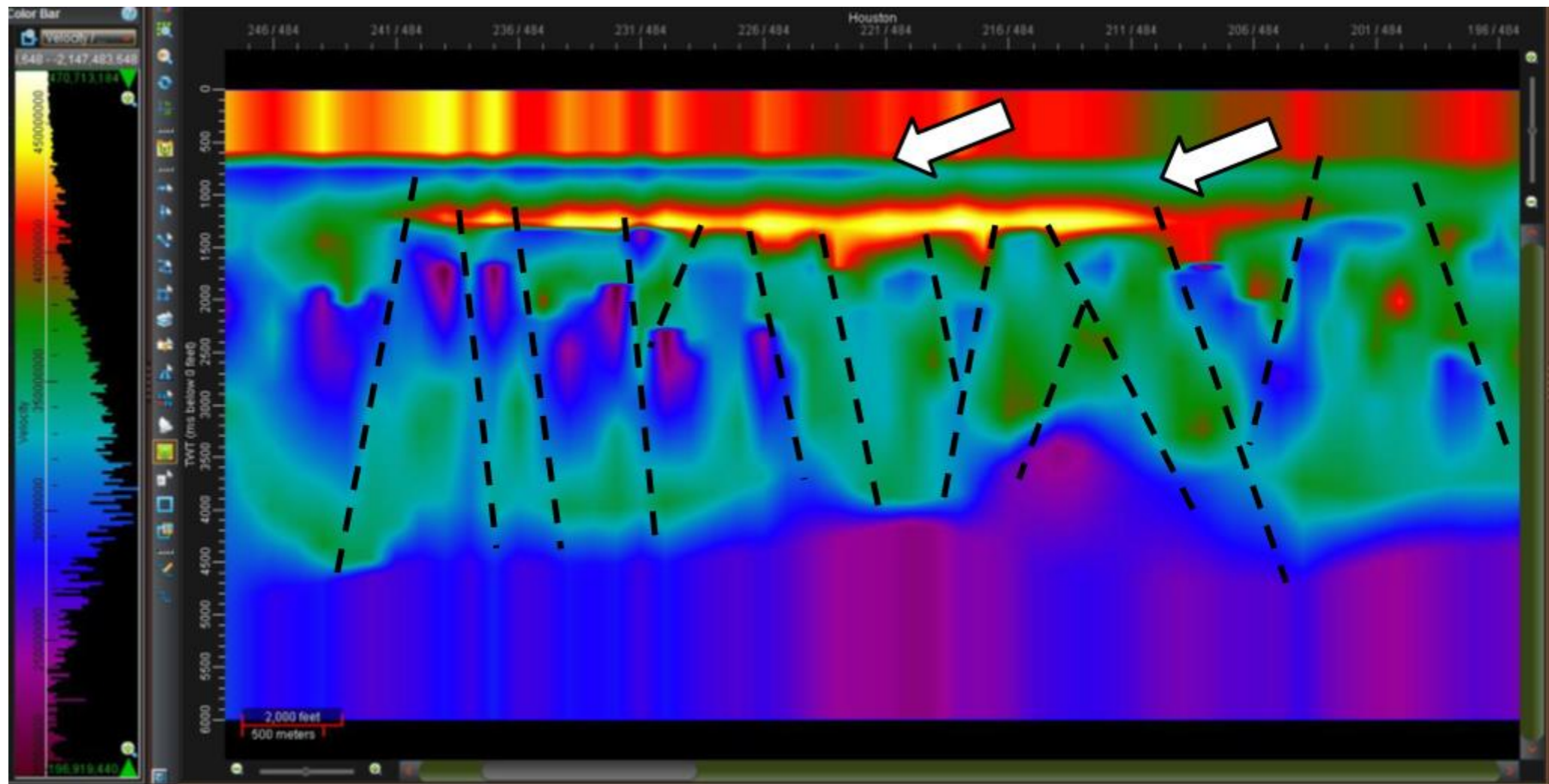
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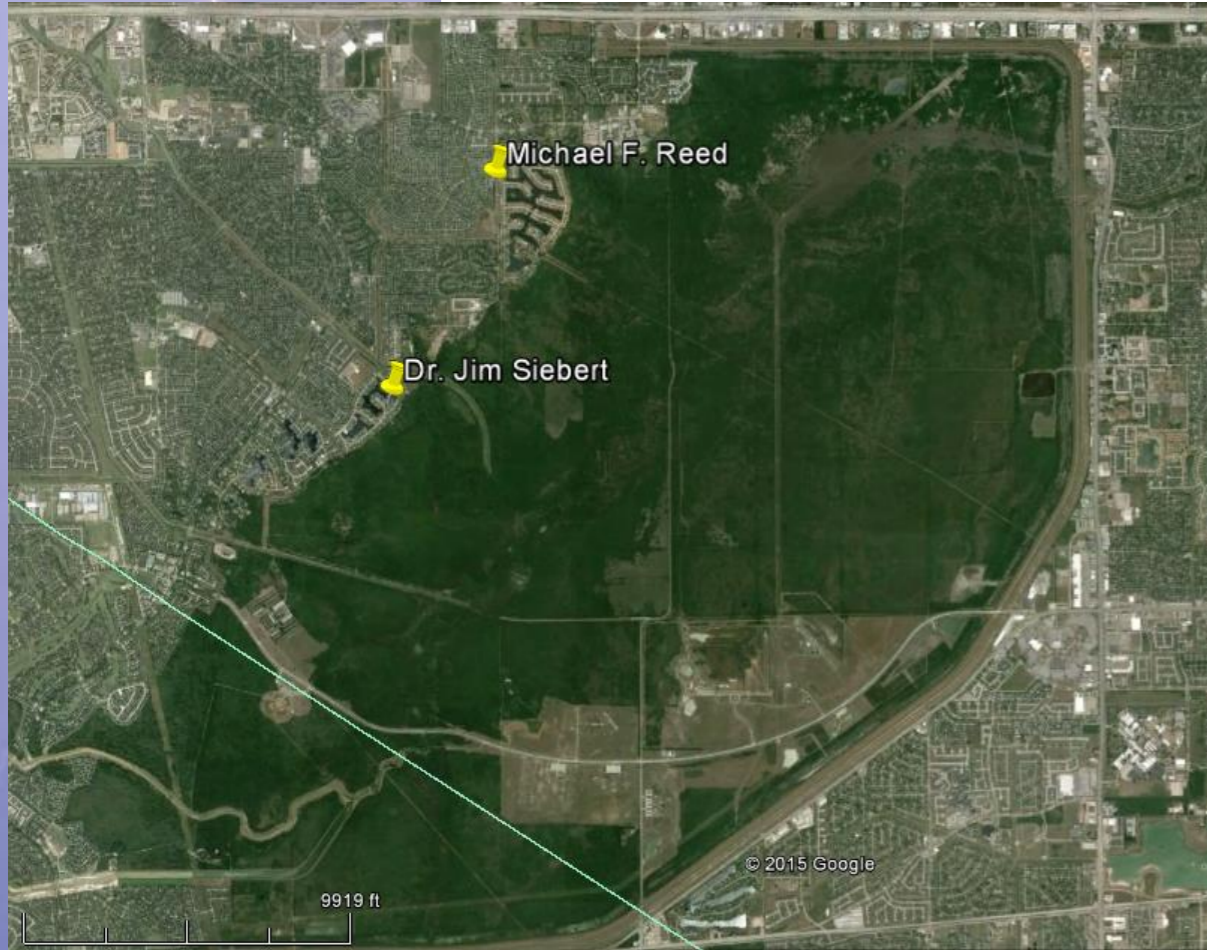


Enlightening Faults and Fluids – Harris County, TX



Lightning interpretation of pinchouts, fluid extent, and faults

2. Lightning Attributes & Databases



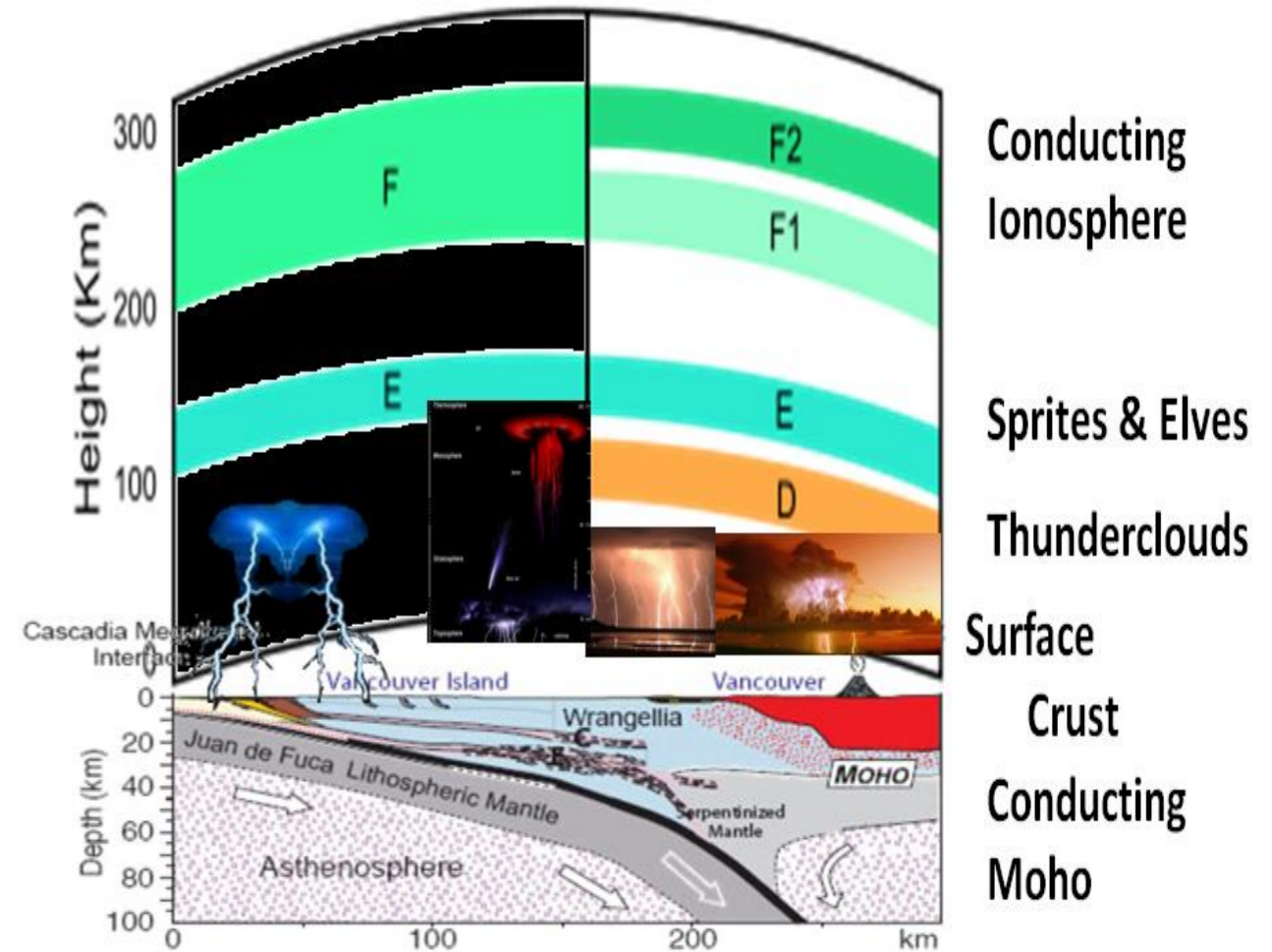
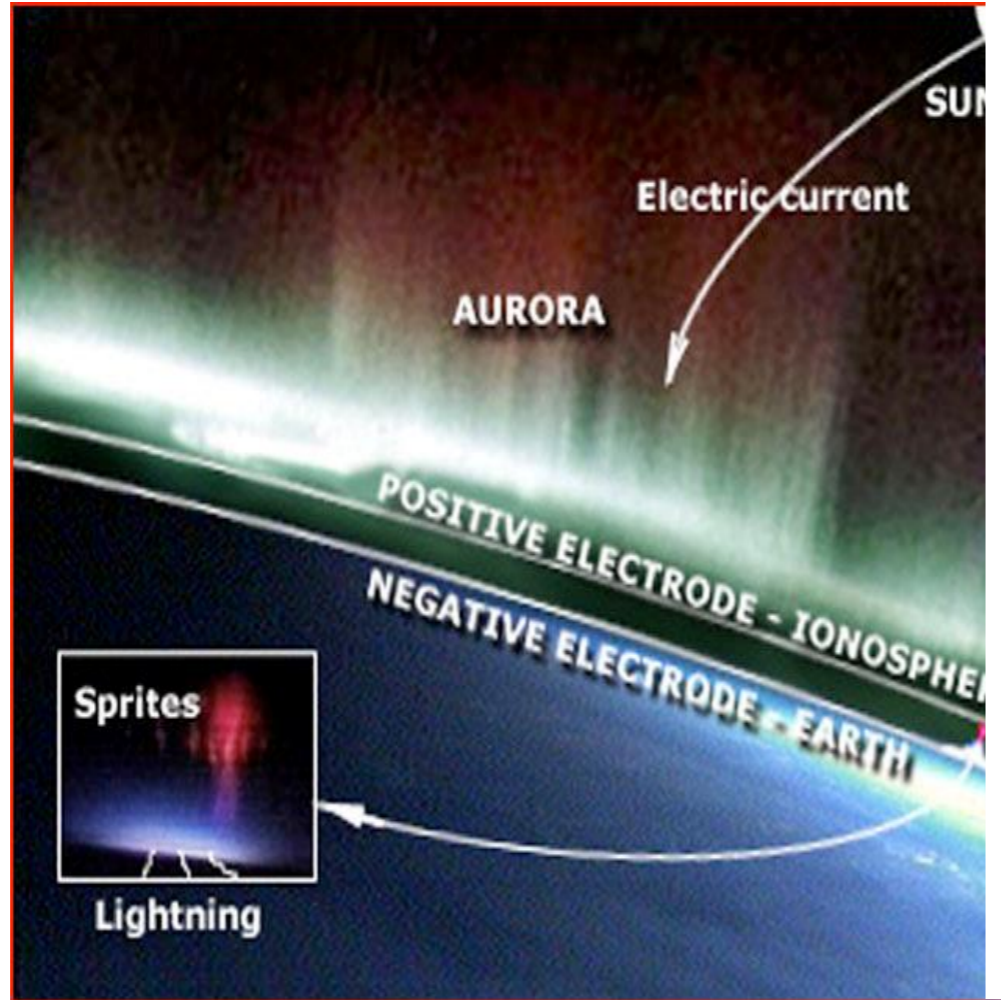
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Electrically, Earth is a Self-Repairing Capacitor



Telluric & Atmospheric Currents make up the Earth's Electrical System

**Up-Going Lightning Strikes
demonstrate the earth is charged**



19 Jan 2016

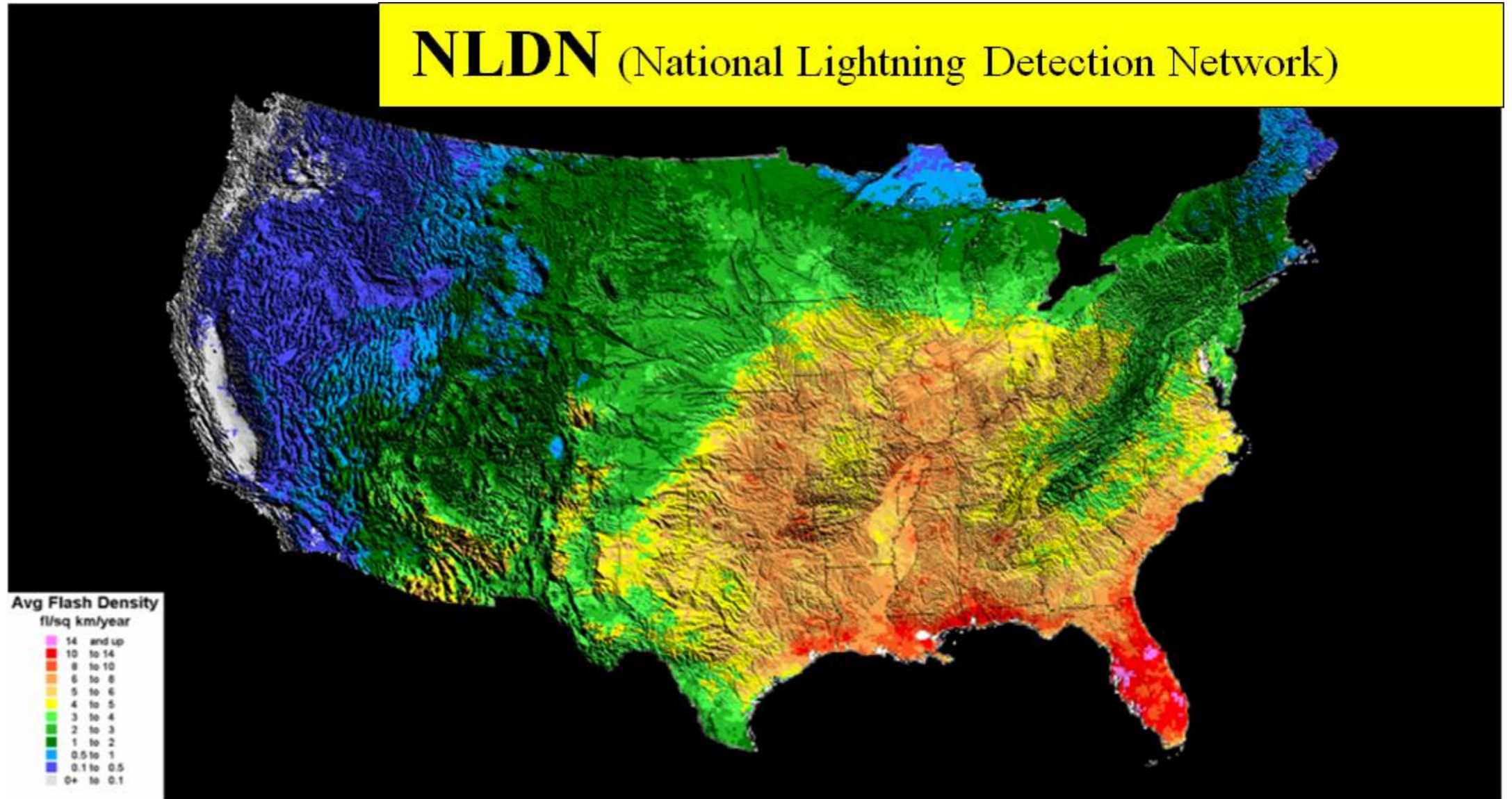
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NLDN & CLDN, 17 years of data collected

NLDN (National Lightning Detection Network)



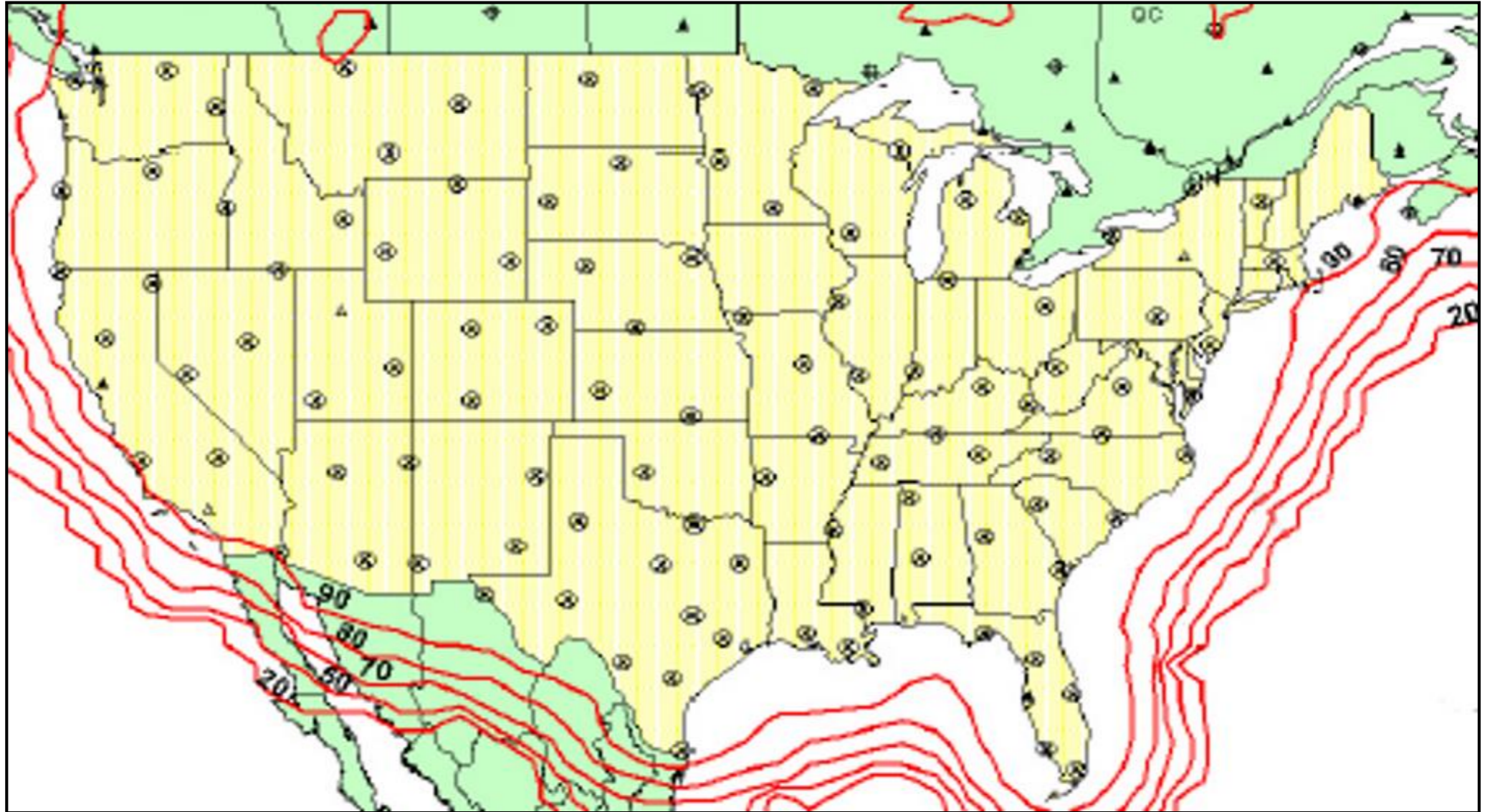
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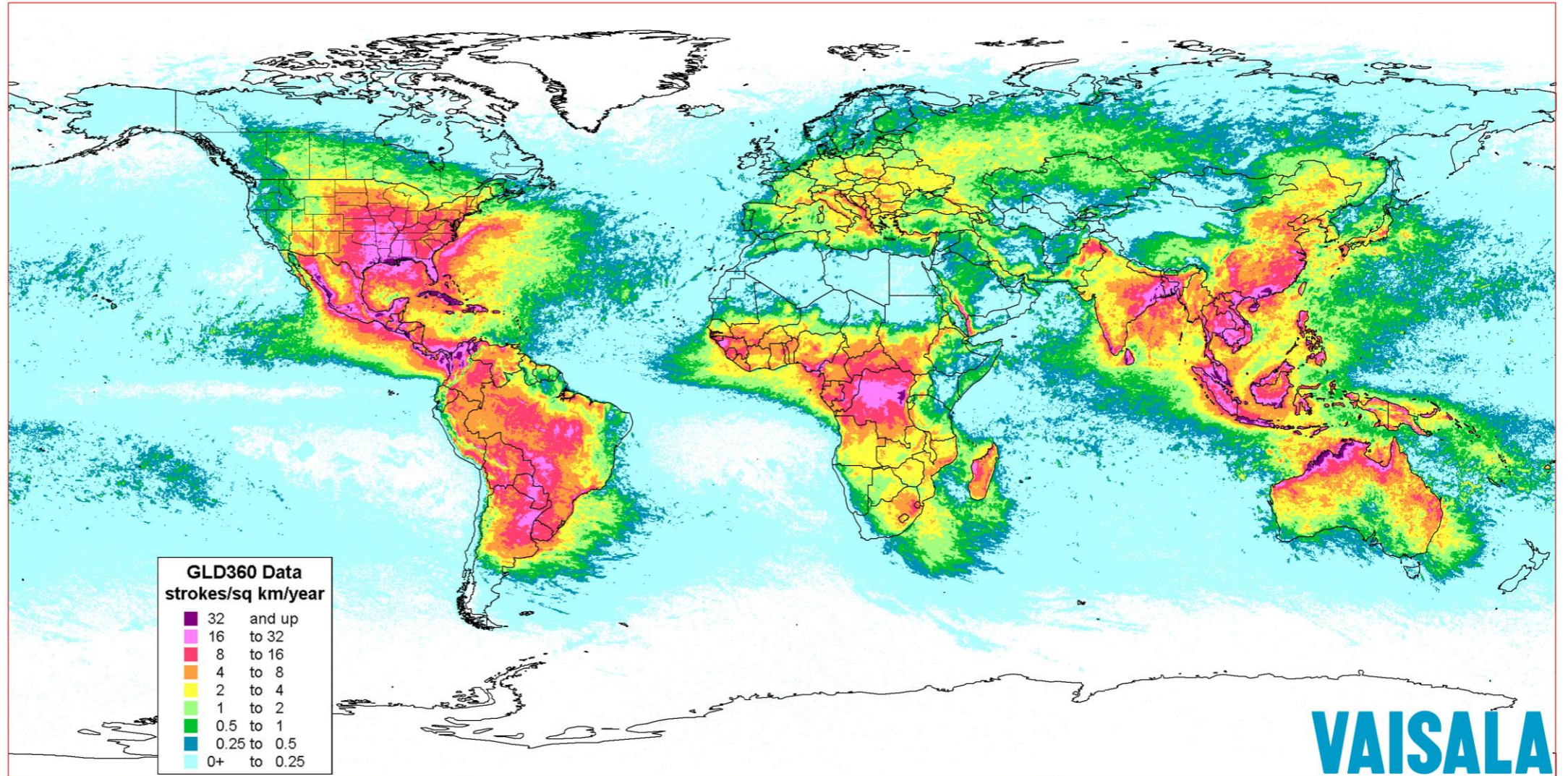
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NLDN Sensor Locations in U.S.



GLD-360 Lightning Density 2011-2015



Stroke Density Map - 20 km grid

May 6, 2011 - May 5, 2015

VAISALA

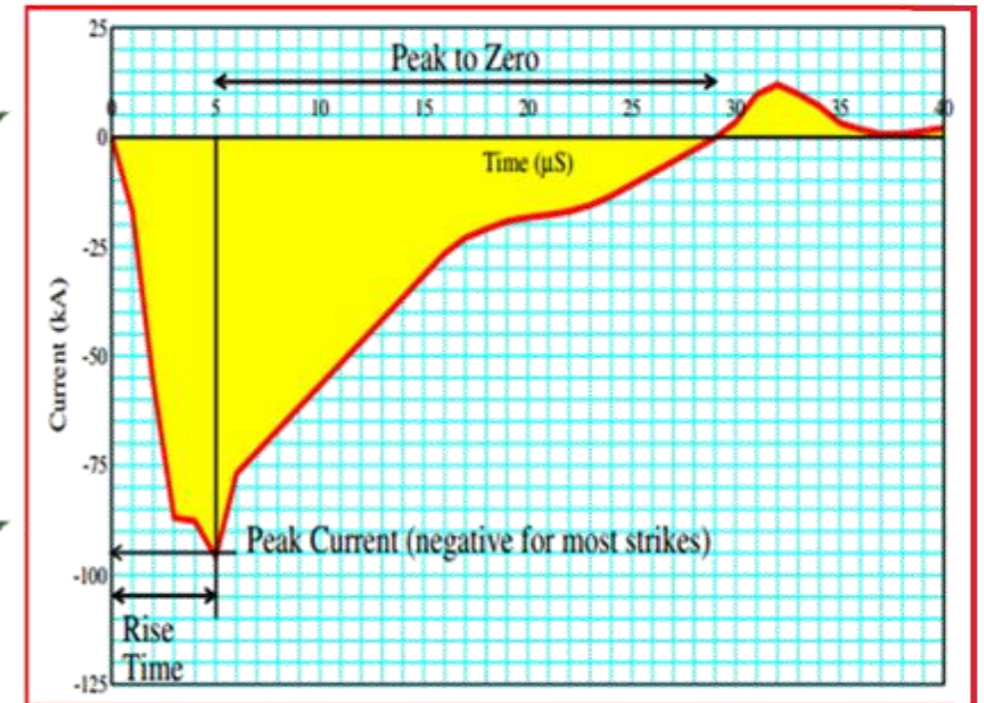
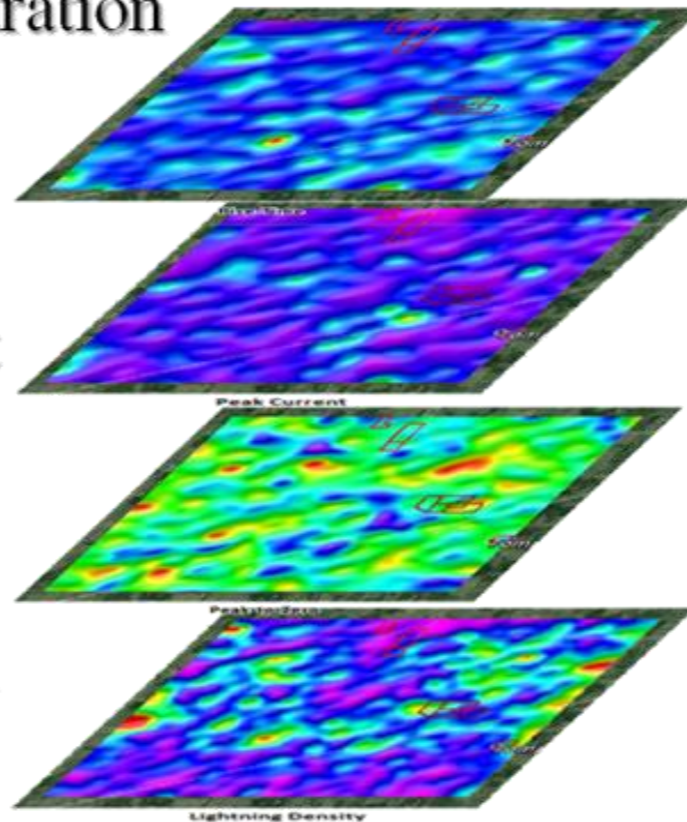
GLD360 data



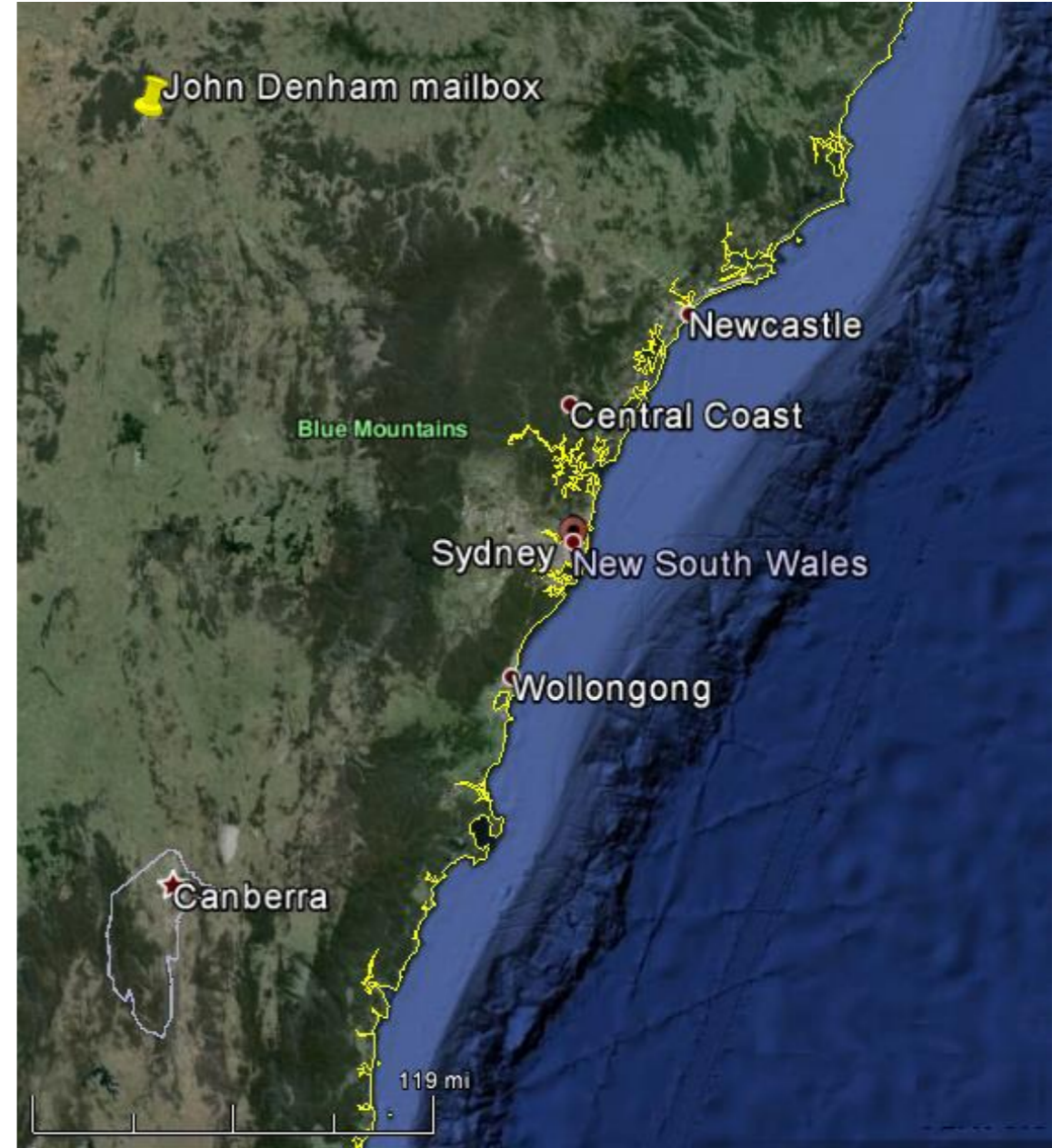


Lightning Strike Measurements

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



3. Calculating Rock Properties and Volumes



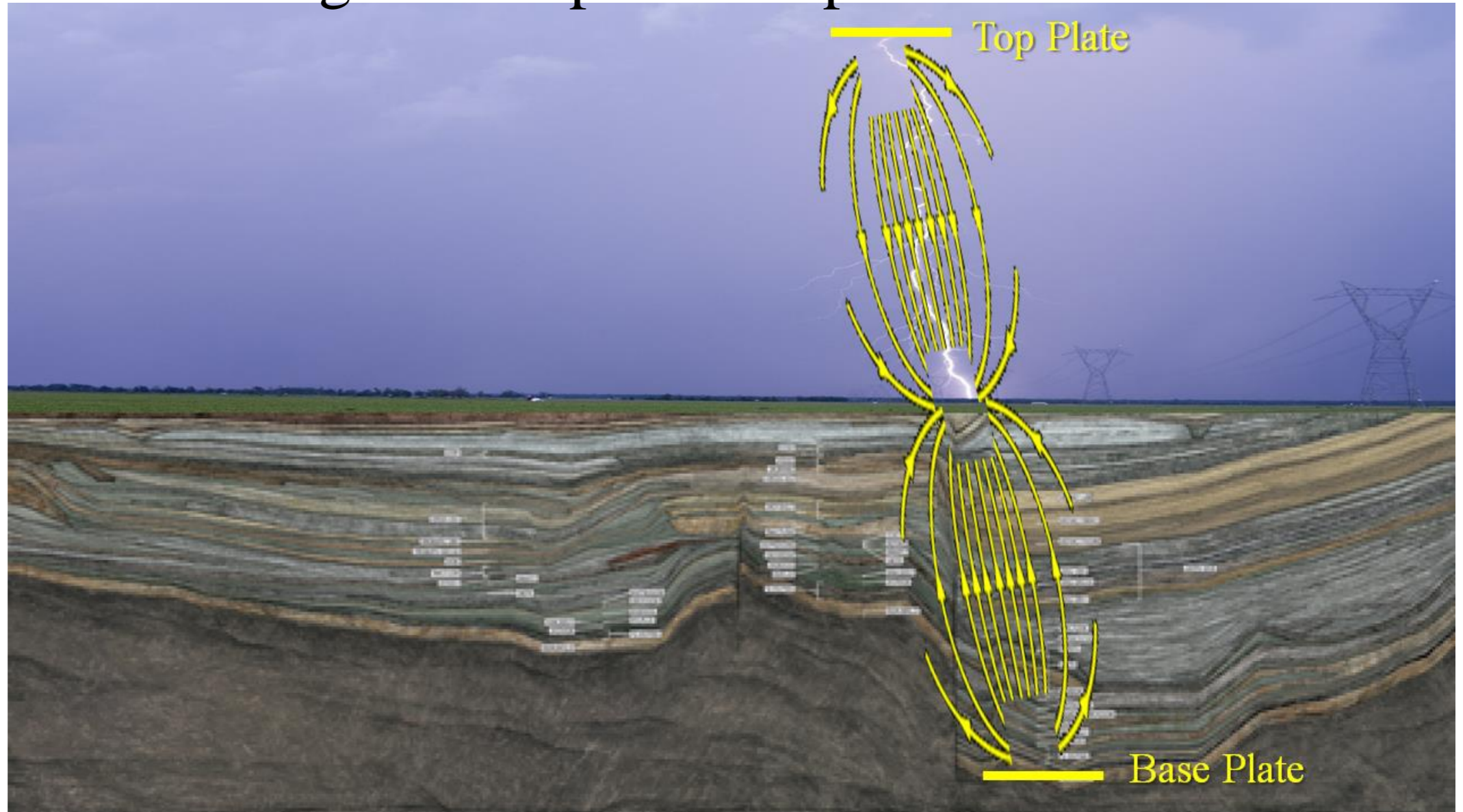
The Atmosphere is an Effective Insulator



The electrical conductivity of air is $0.3-0.8 * 10^{-14} \text{ S.m}^{-1}$ (Siemens per meter).

The effectiveness seen in air's common use separating high voltage transmission lines from the ground, from towers used to support the lines, and from lines carrying different voltages and different phases.

Lightning Occurs when there is Sufficient Charge to Bridge Atmospheric Capacitor



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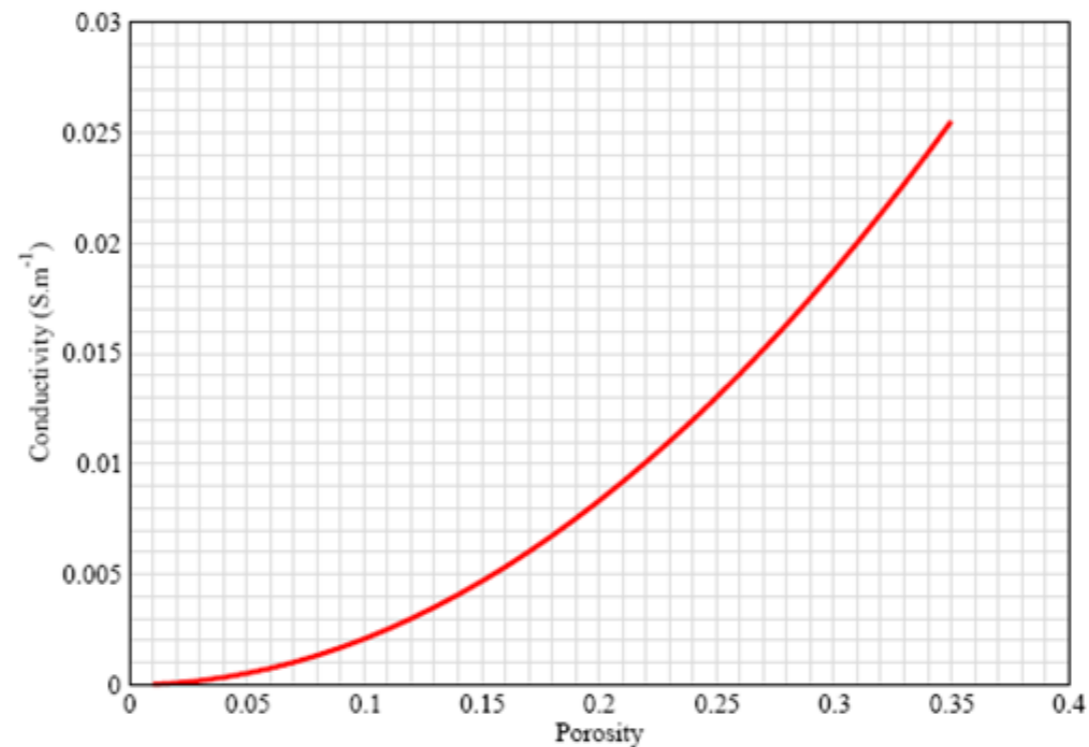
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The earth is much more conductive than air

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



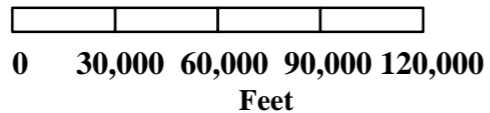
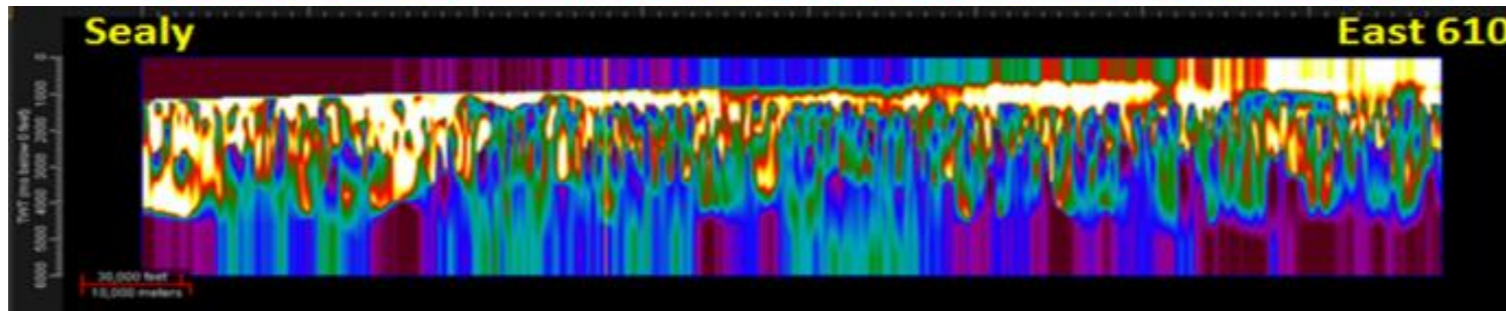
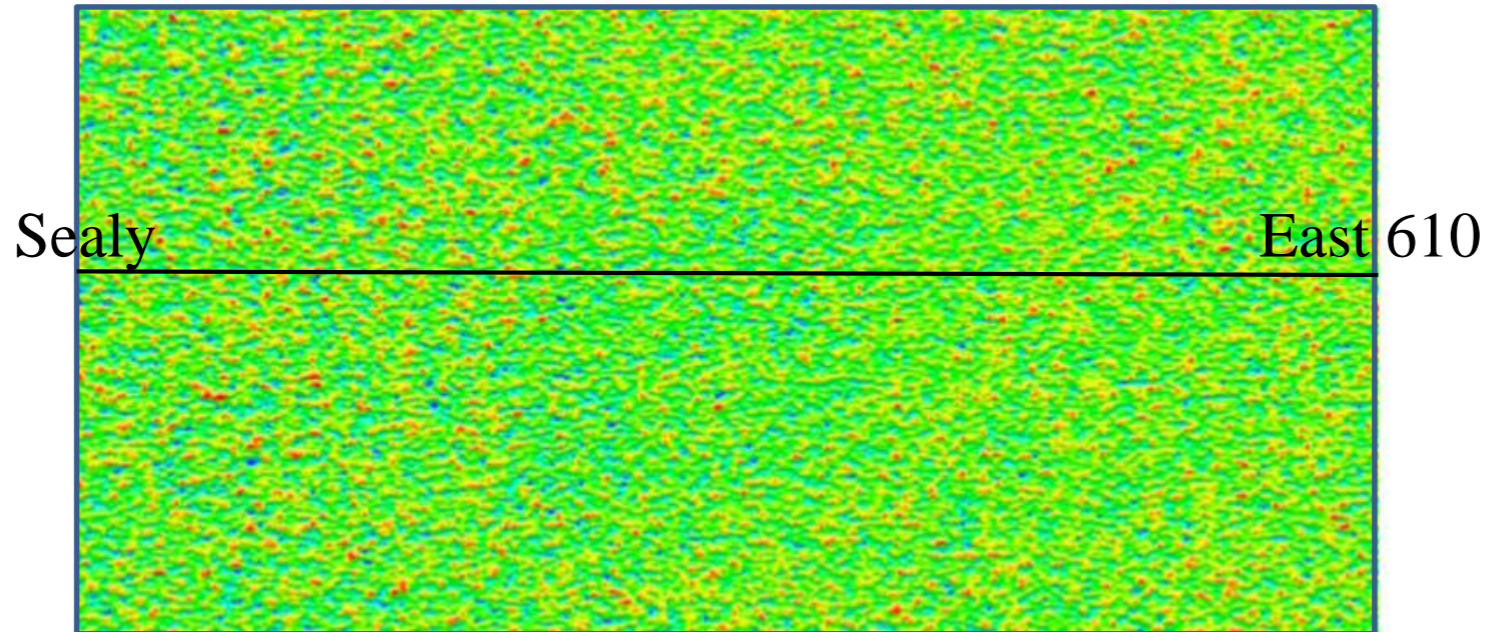
Geothermal temperature increases, further increase conductivity

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

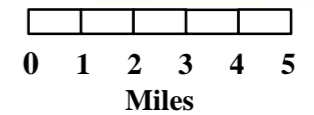
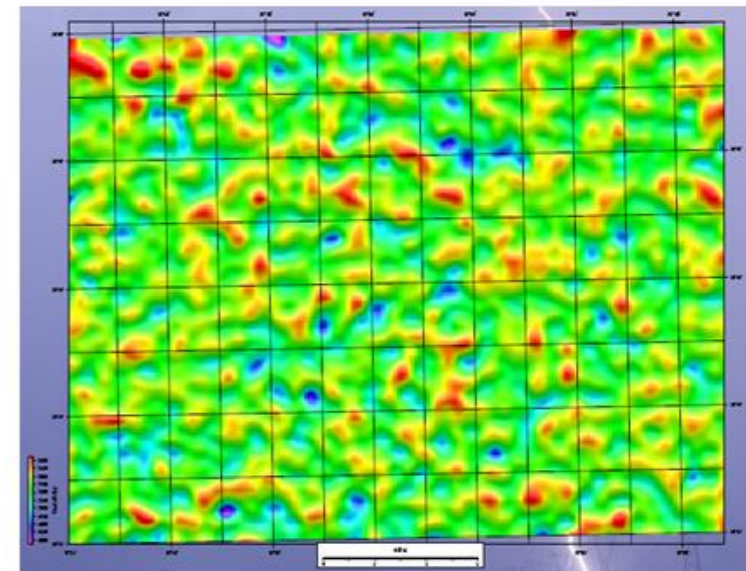


Resistivity Maps

Houston Area



Milam County



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5. Calculating Attribute Volumes

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



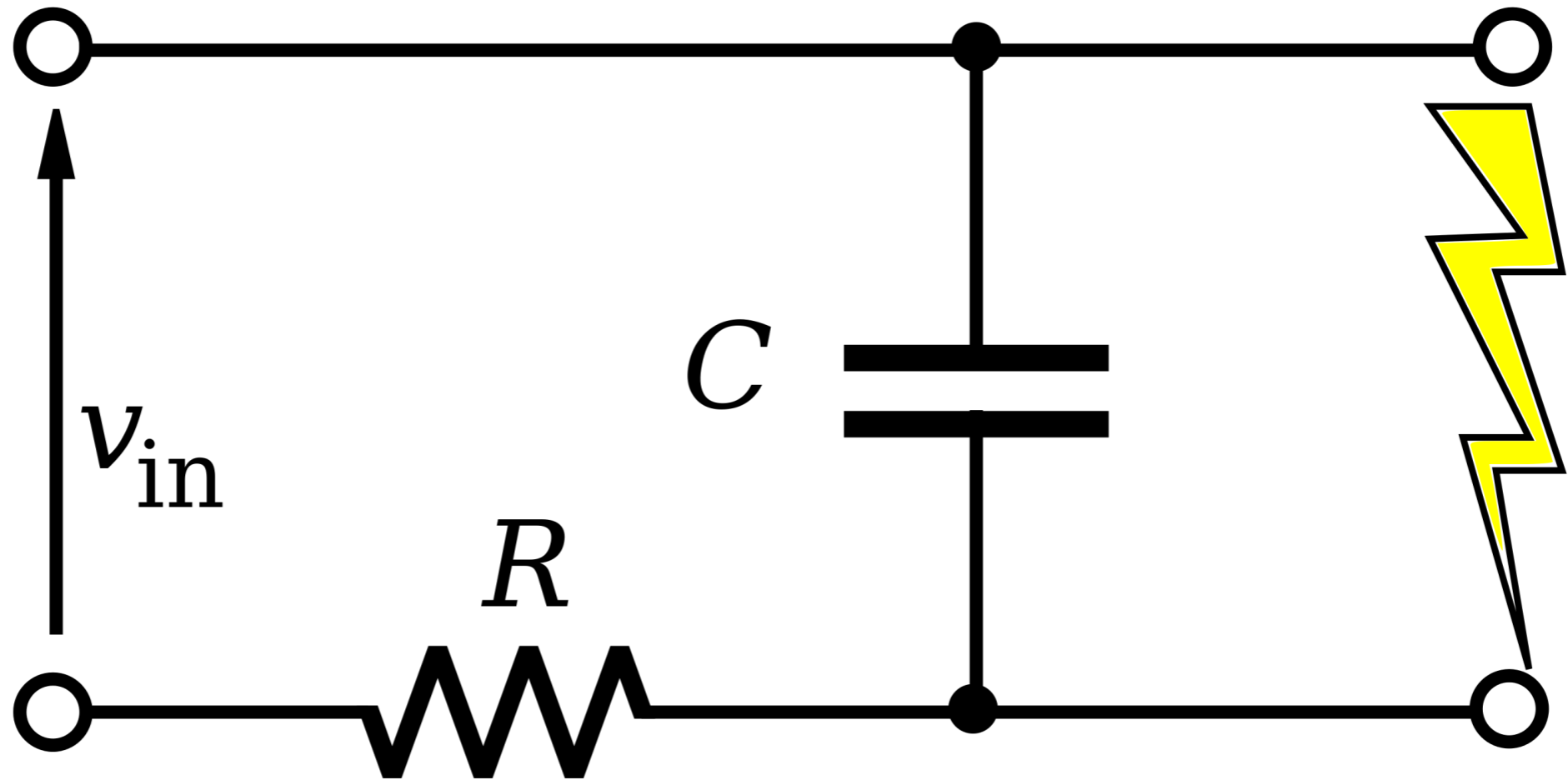
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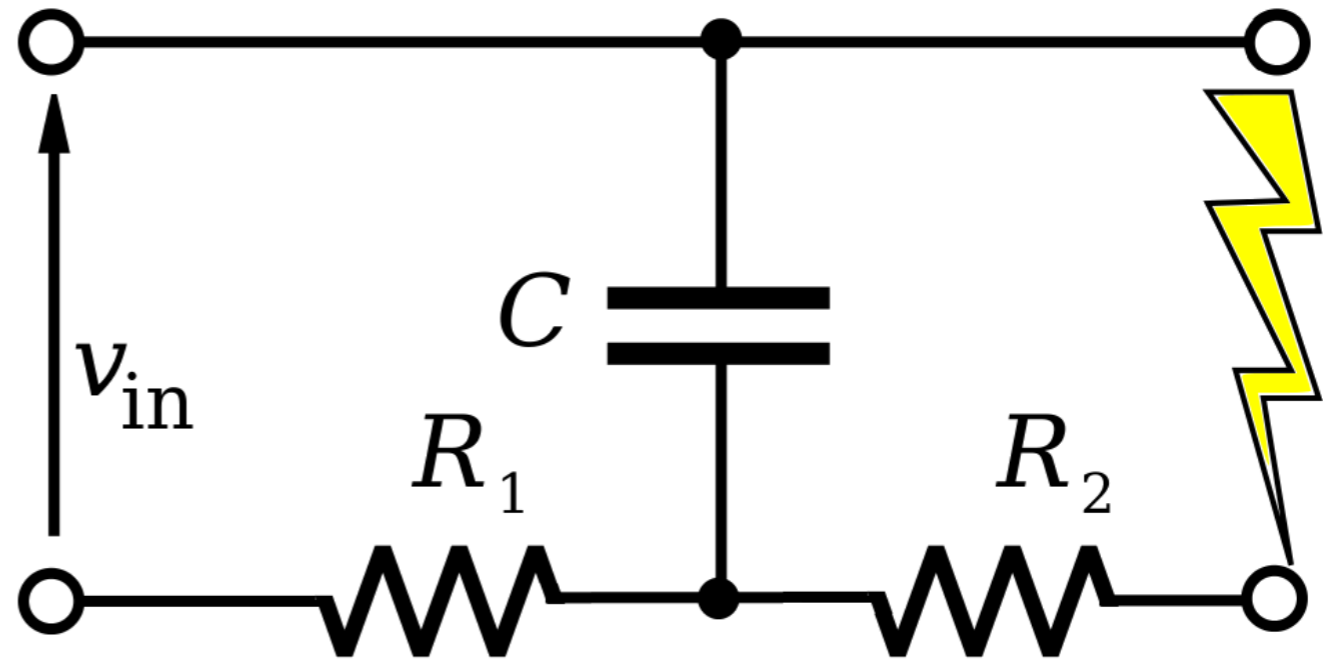
Relaxation Oscillator





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

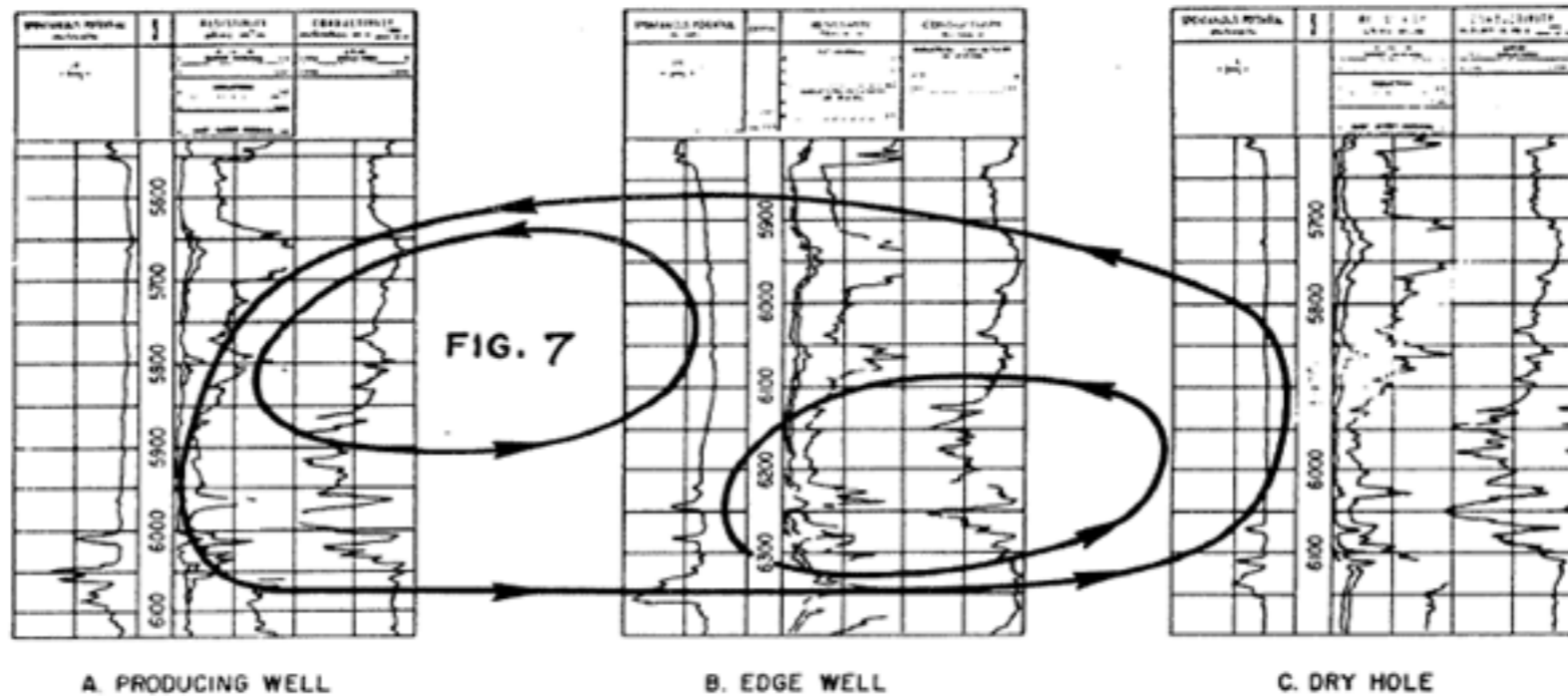


Terralevis (Shallow Earth) Currents

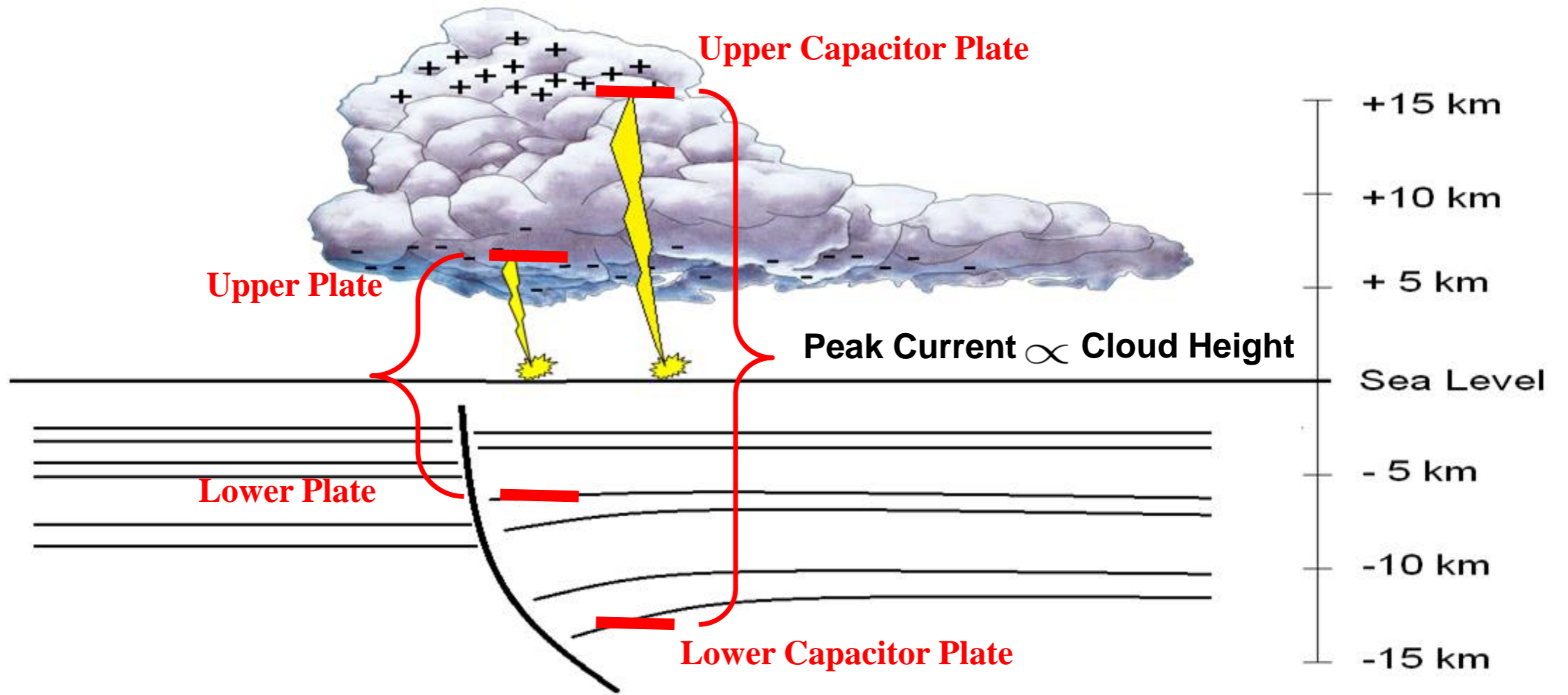
U.S. Patent March 9, 1976 Sheet 4 of 8 3,943,436

[54] LINE INTEGRAL METHOD OF MAGNETO-ELECTRIC EXPLORATION

[76] Inventors: Sylvain J. Pirson; Jacques E. Pirson, both of 8608 Mesa Drive, Austin, Tex. 78759



Millions of Lightning Strikes Millions of Measurements



3. Geothermal Opportunities



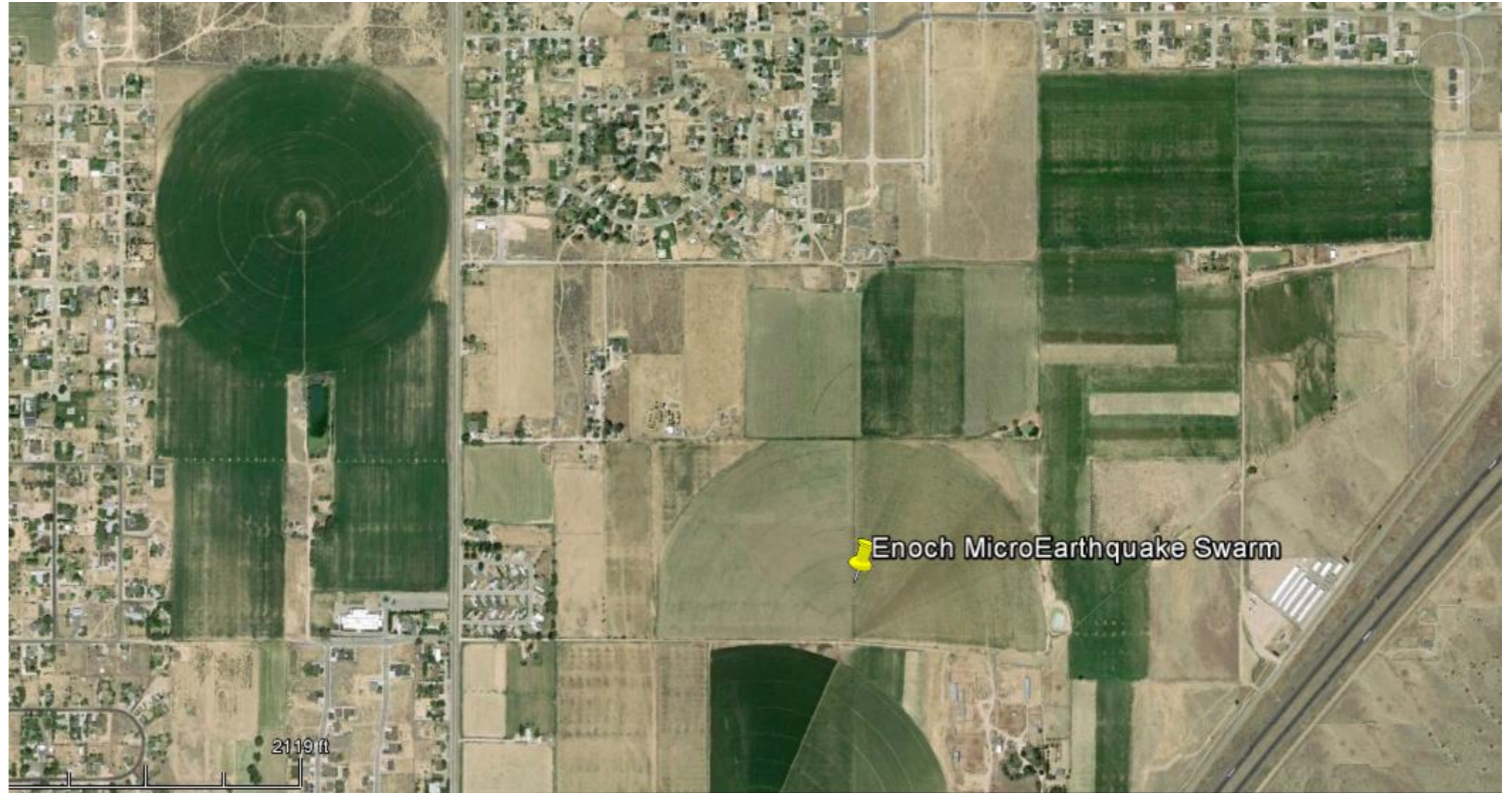
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Lightning Analysis – A New Way for Remote Sensing



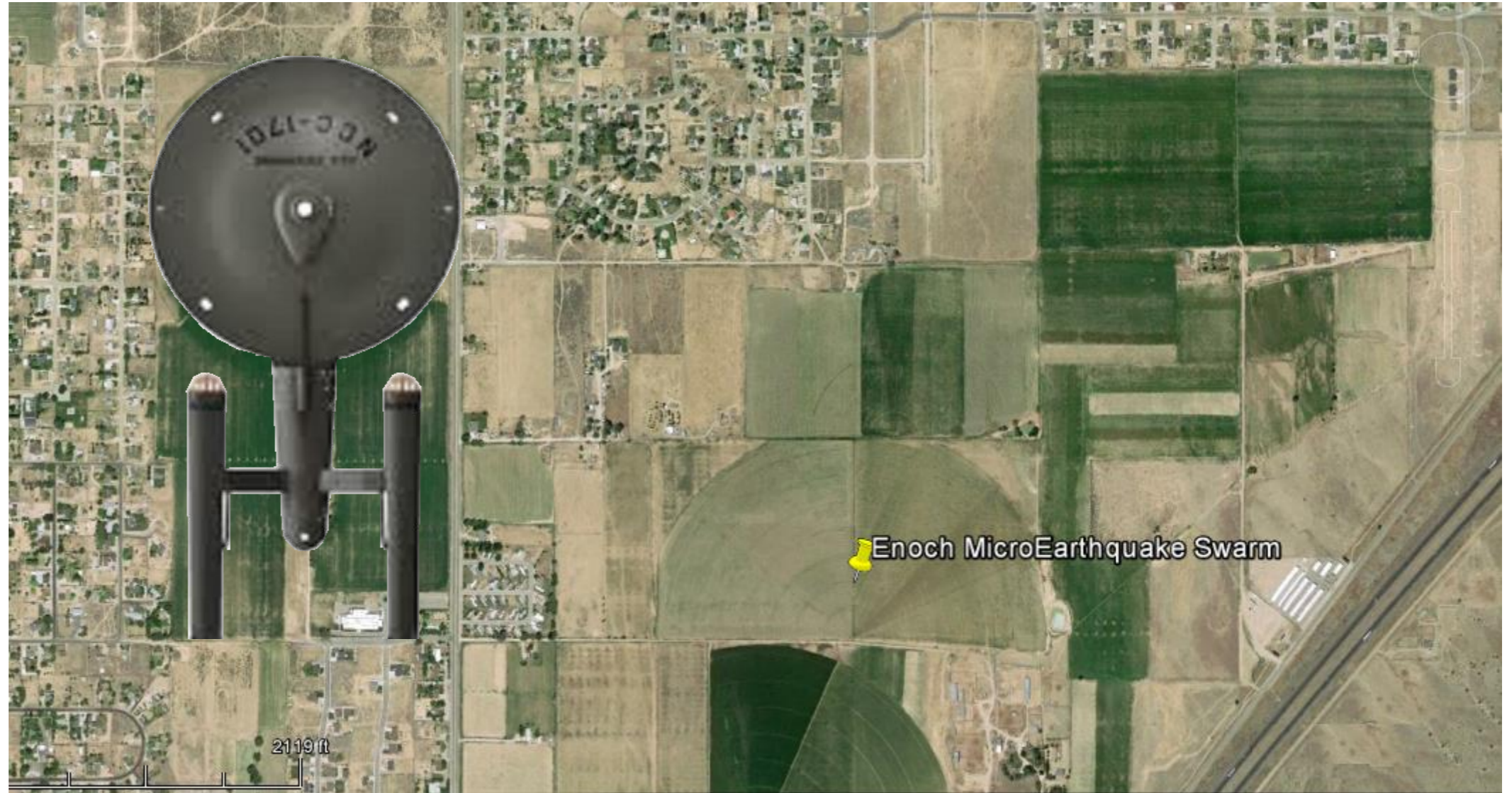
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Lightning Analysis – Remote Sensing



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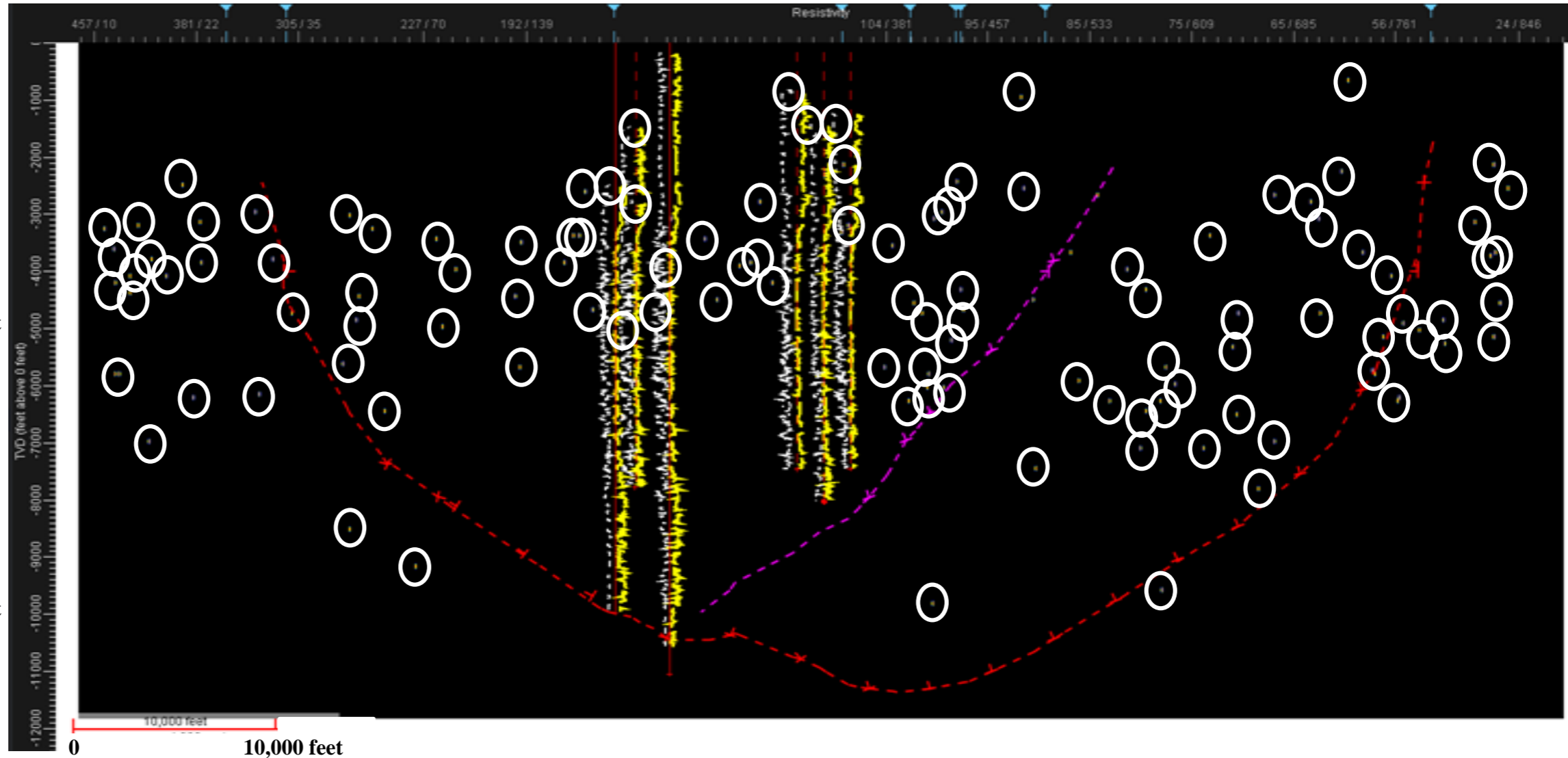


Control for Louisiana Resistivity Volume Interpolation

Surface

5,000 feet

10,000 feet



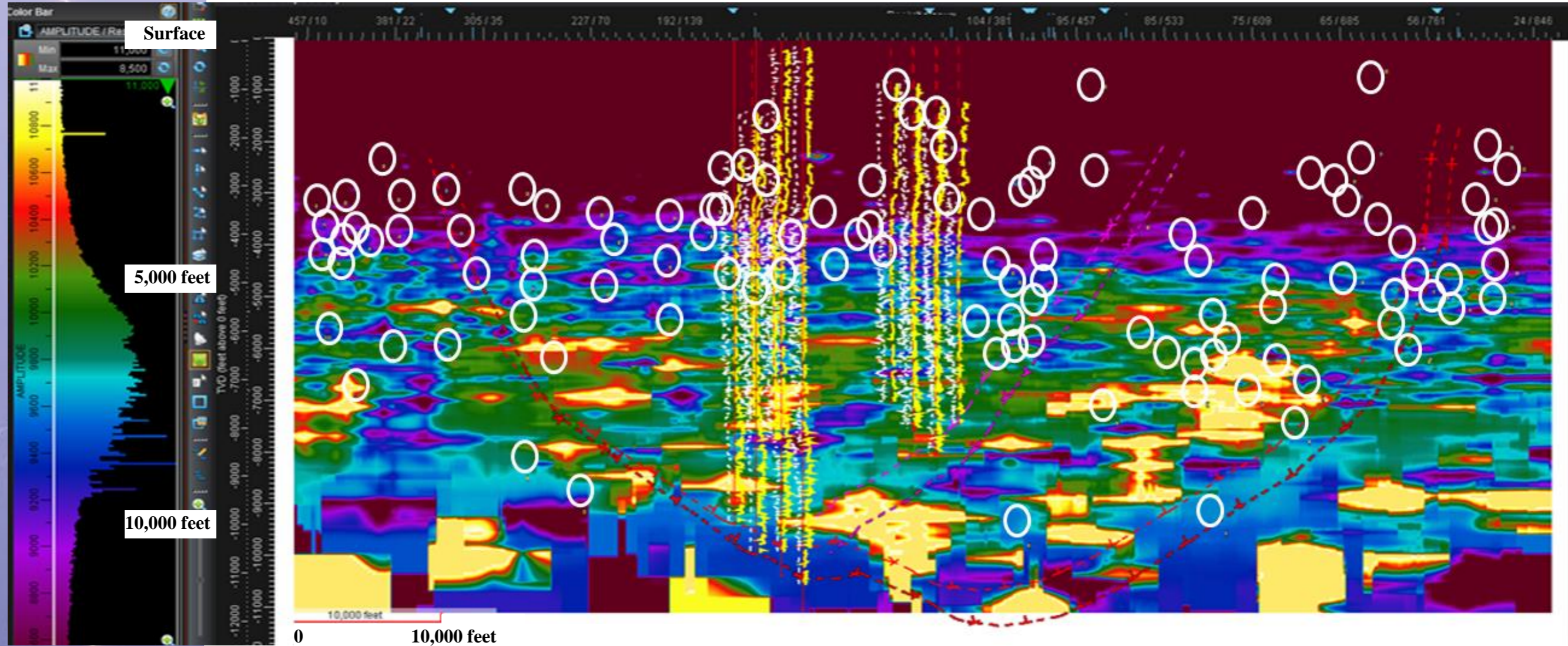
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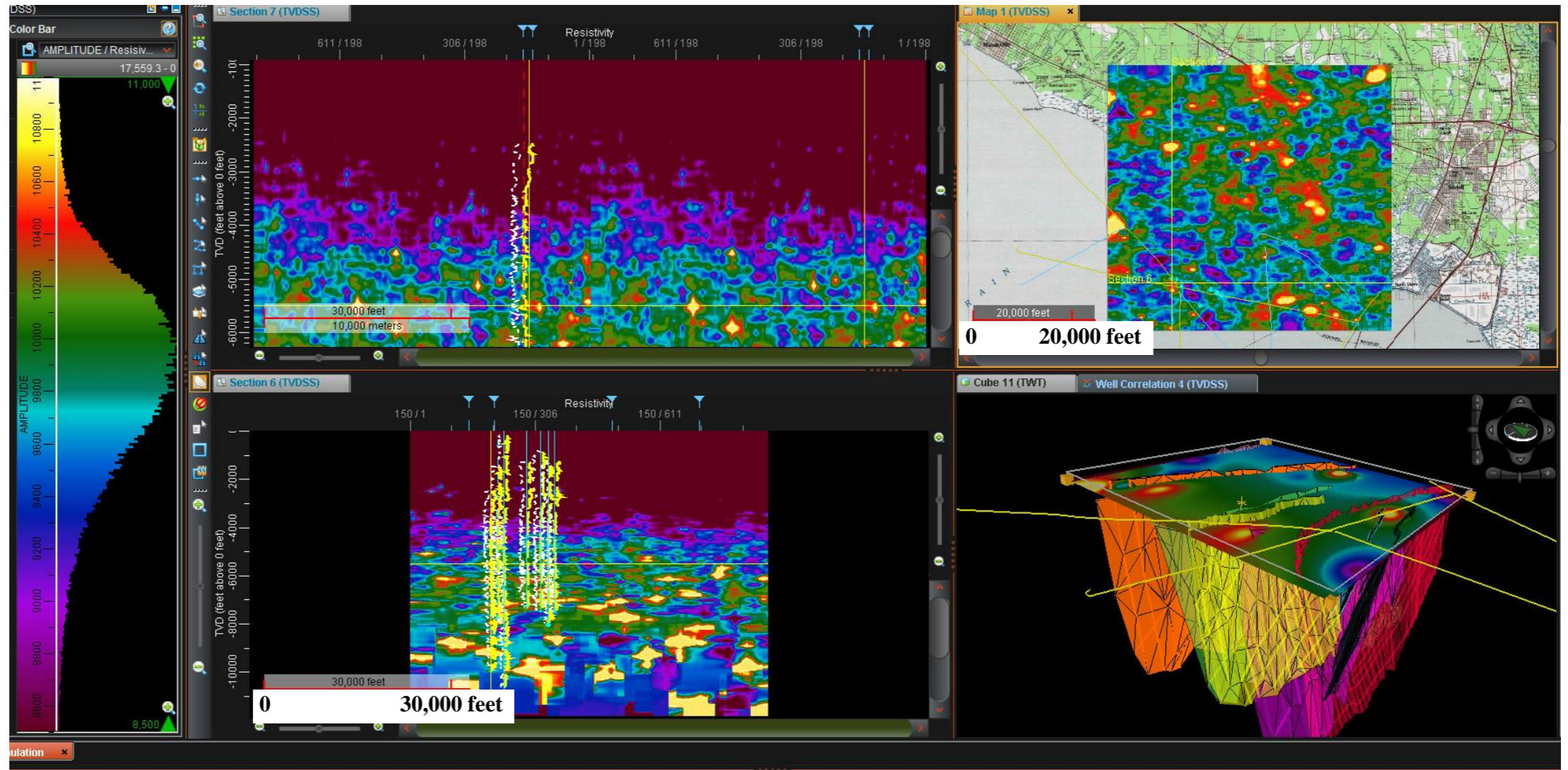
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3-D Resistivity Volume Interpolation on Arbitrary Line through Goose Point, LA Resistivity Volume



3-D Resistivity Volumes matching any 3-D seismic geometry delivered within 2 months



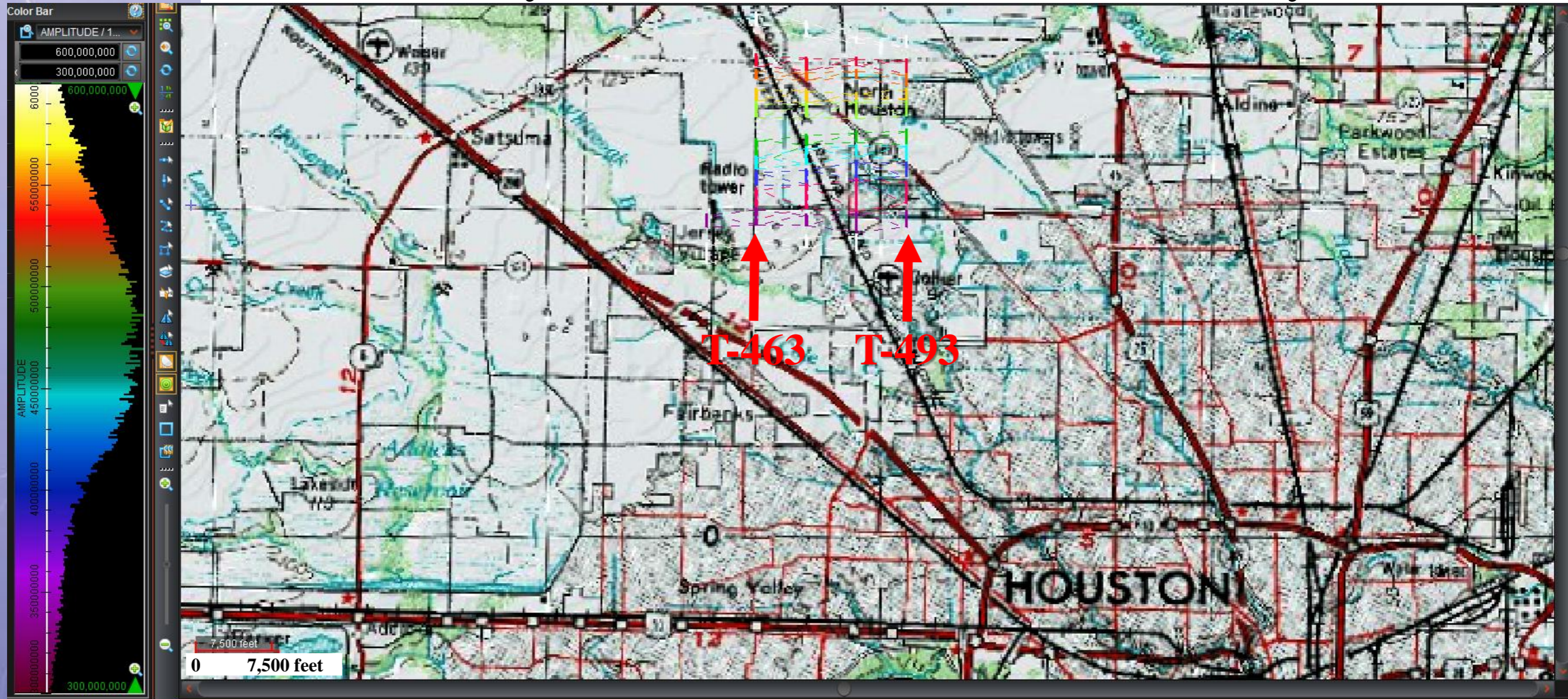
19 Jan 2016

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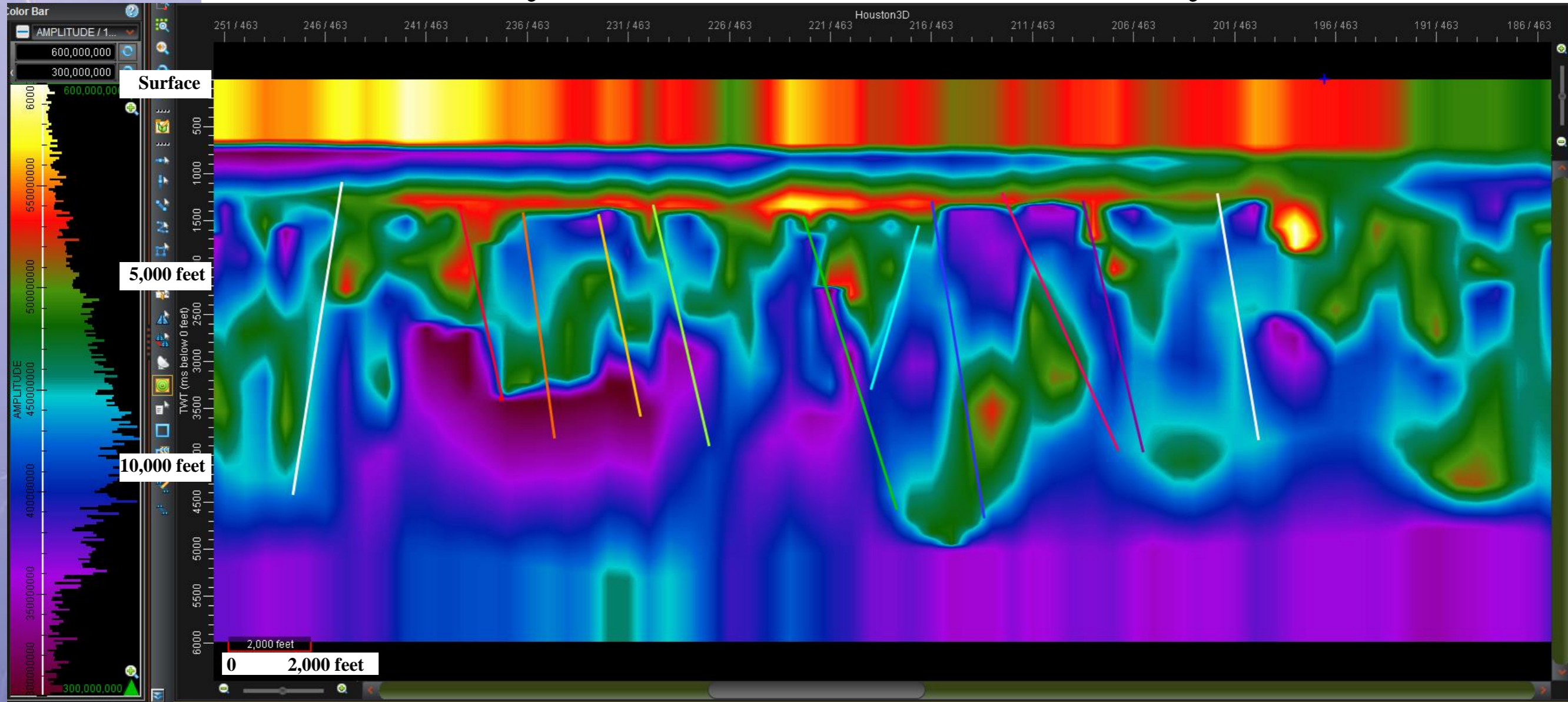
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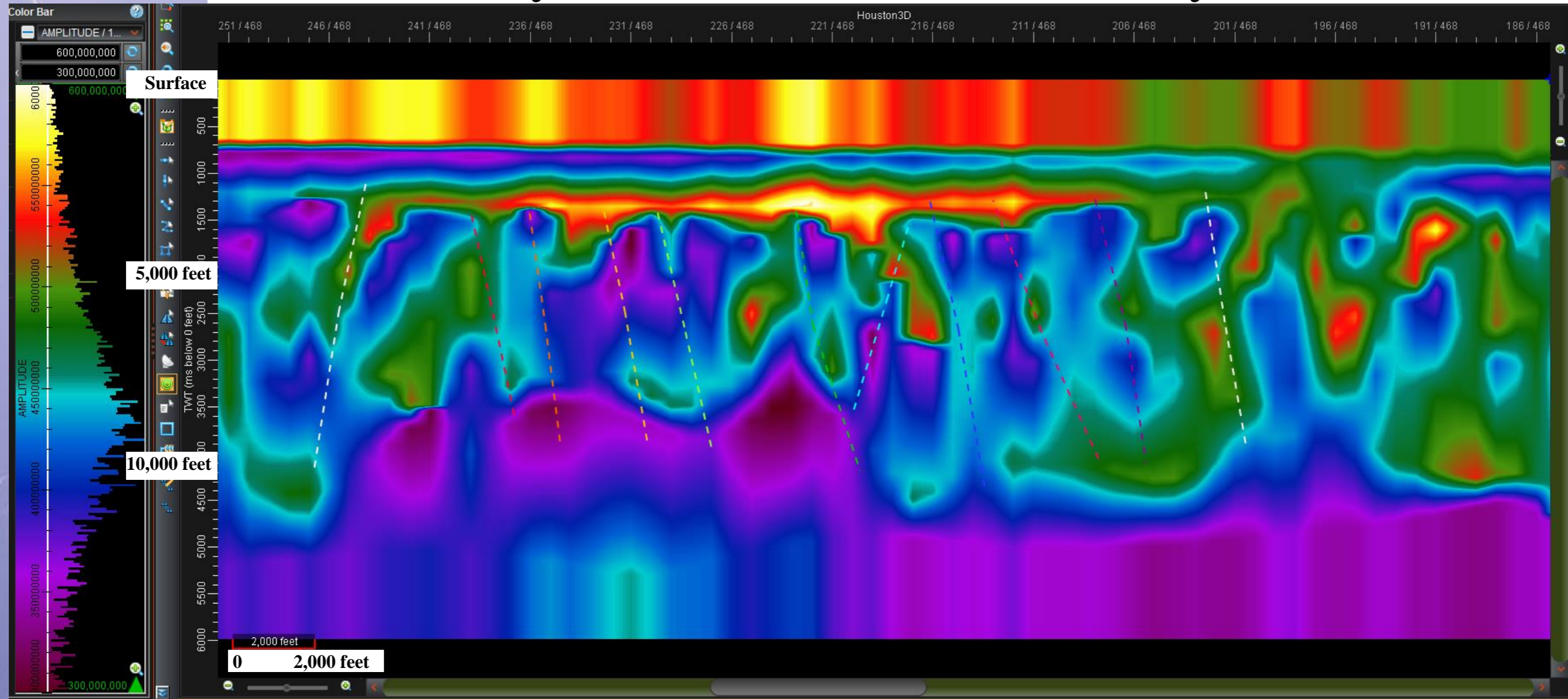
N-S Resistivity Section 463-493 – Harris County, TX



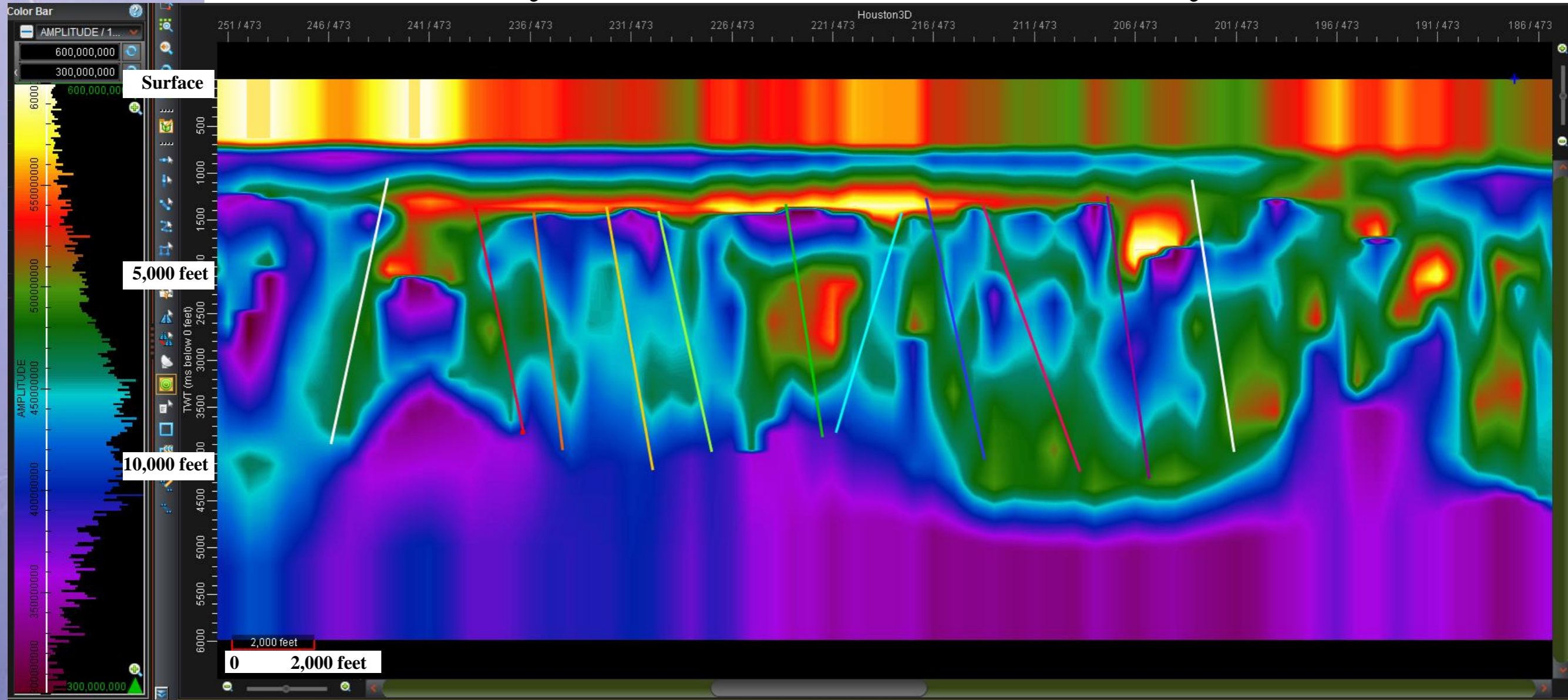
N-S Resistivity Section 463 – Harris County, TX



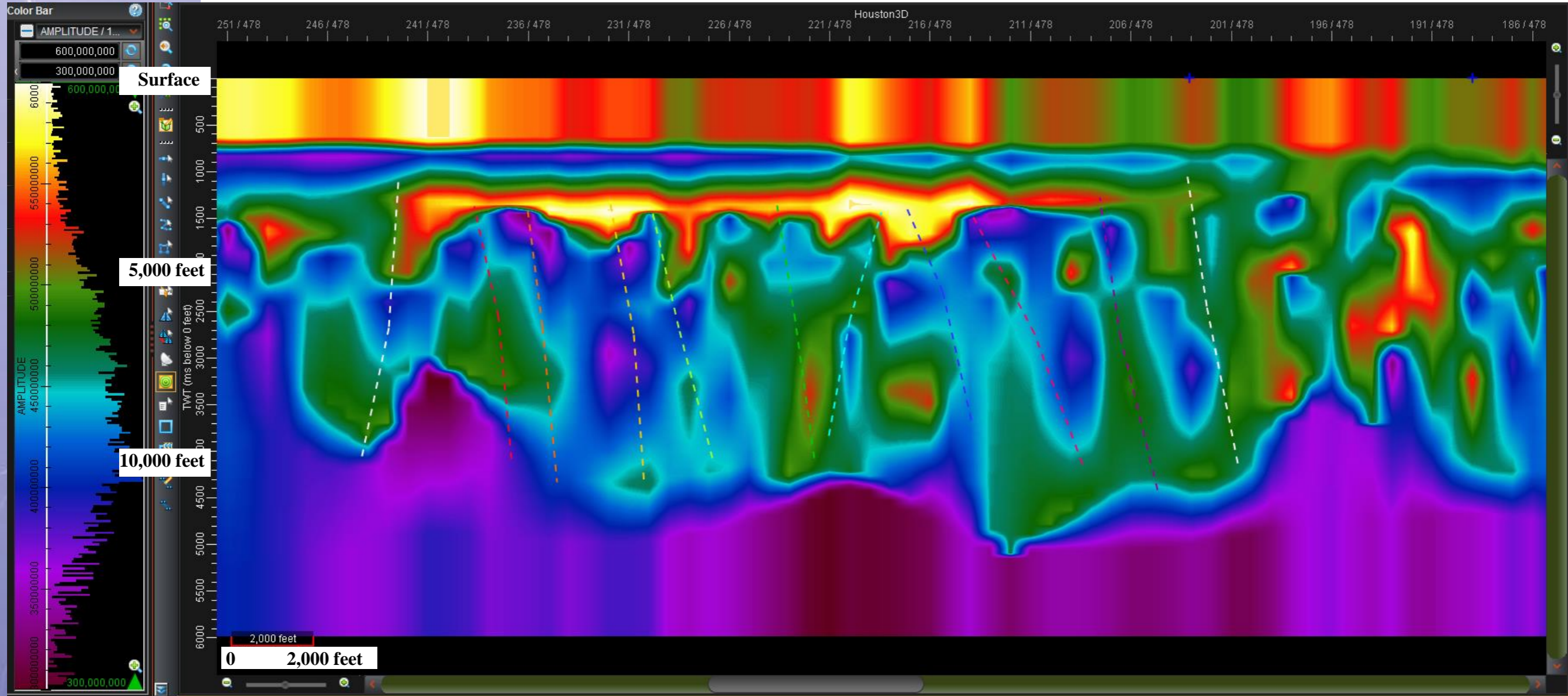
N-S Resistivity Section 468 – Harris County, TX



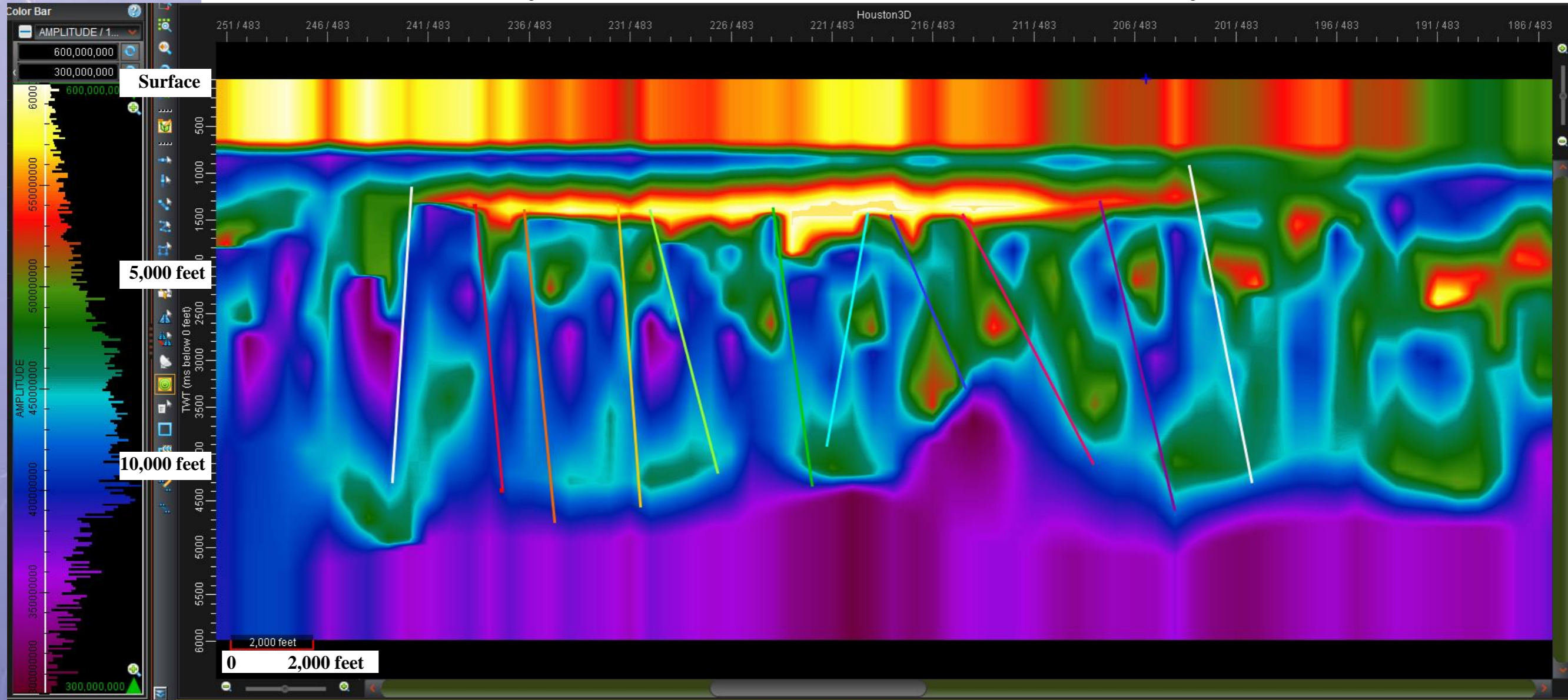
N-S Resistivity Section 473 – Harris County, TX



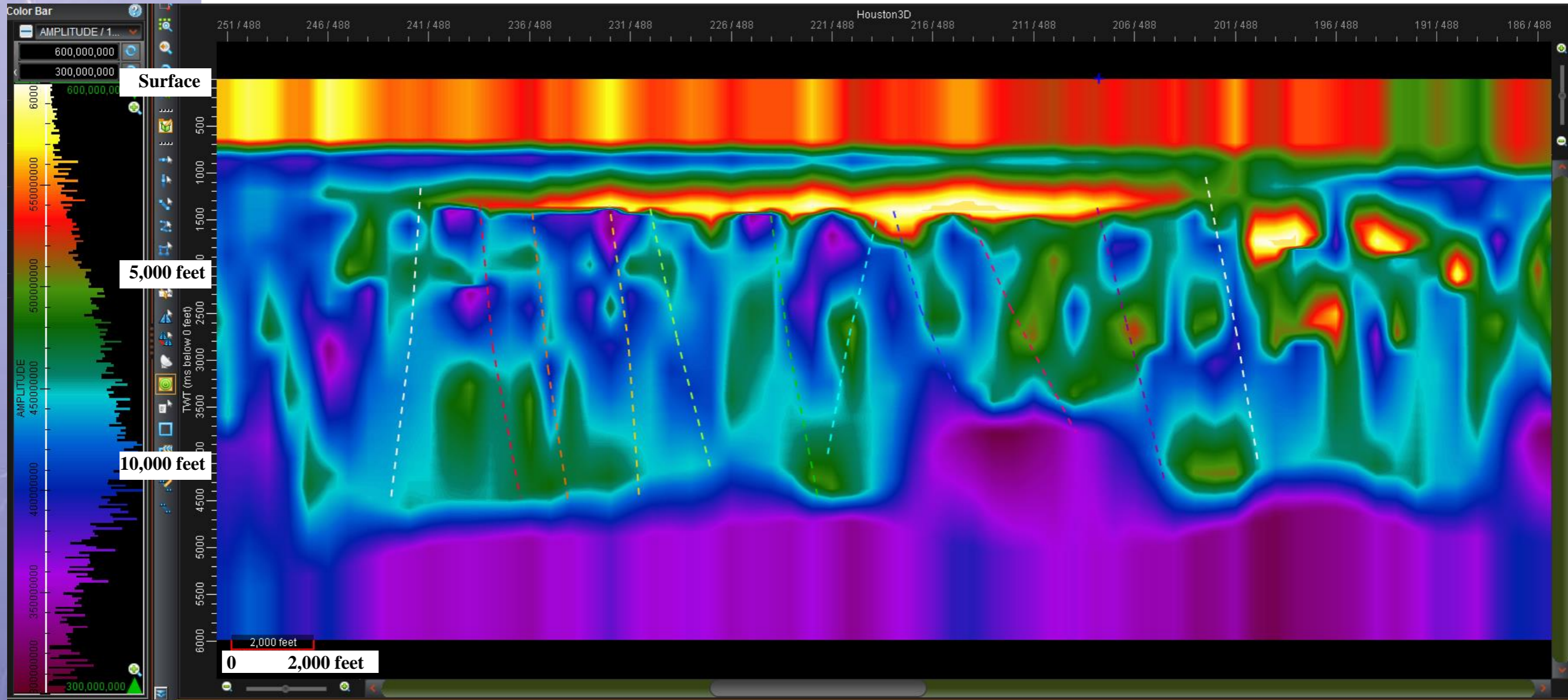
N-S Resistivity Section 478 – Harris County, TX



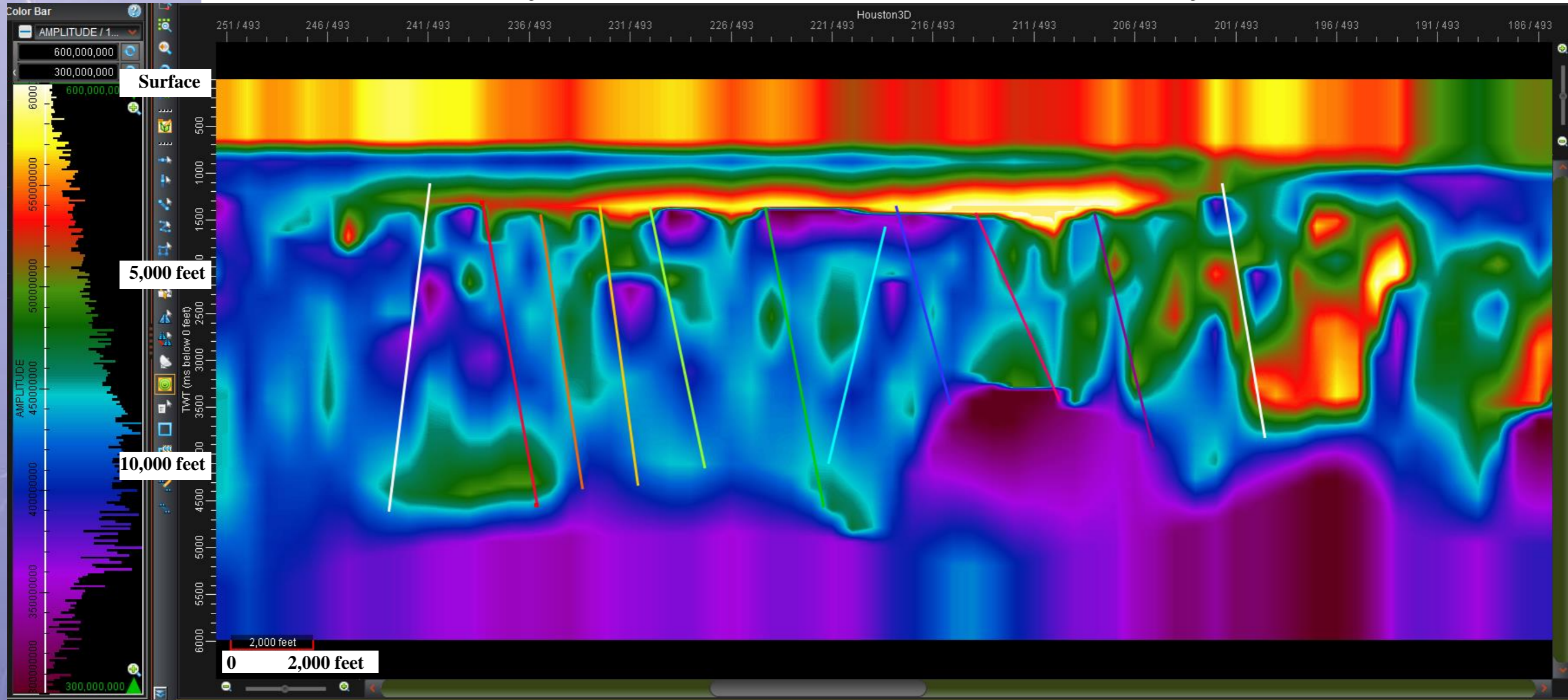
N-S Resistivity Section 483 – Harris County, TX



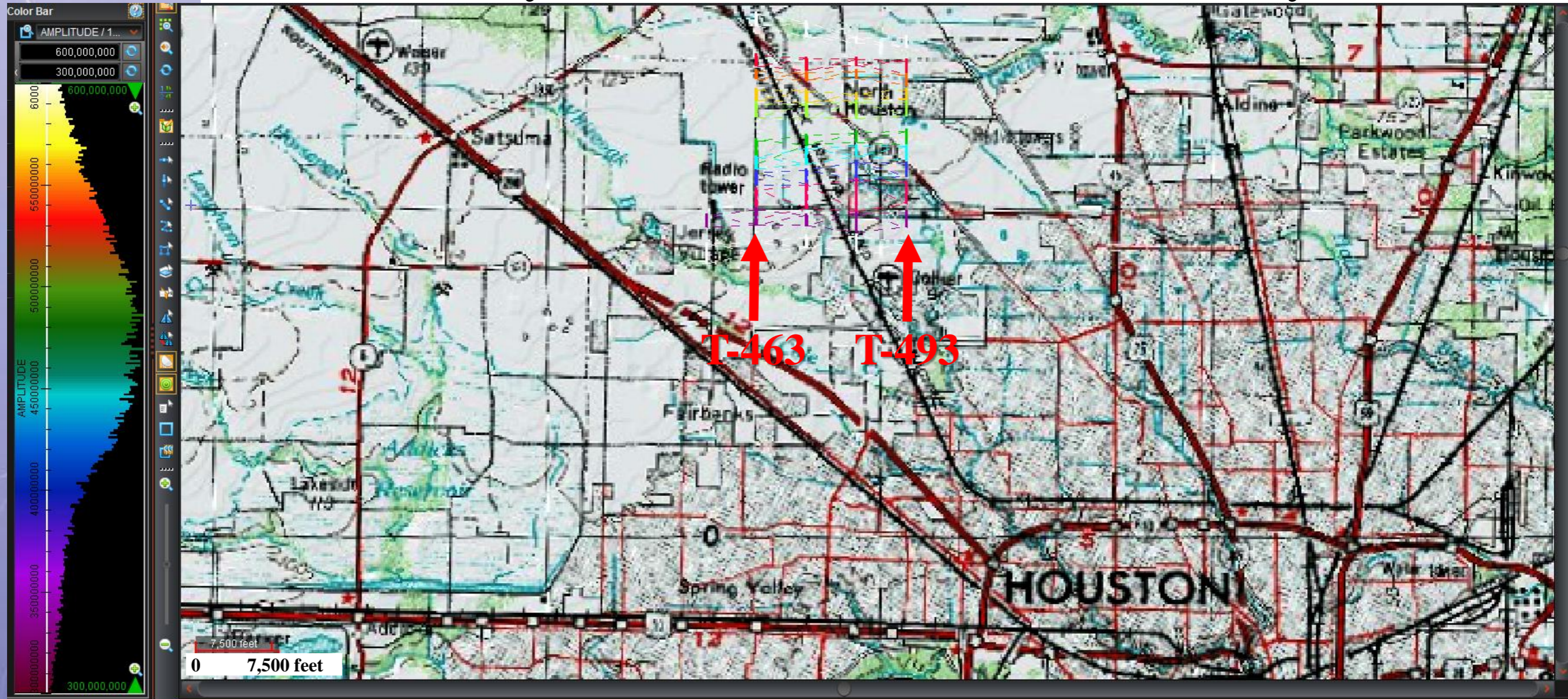
N-S Resistivity Section 488 – Harris County, TX



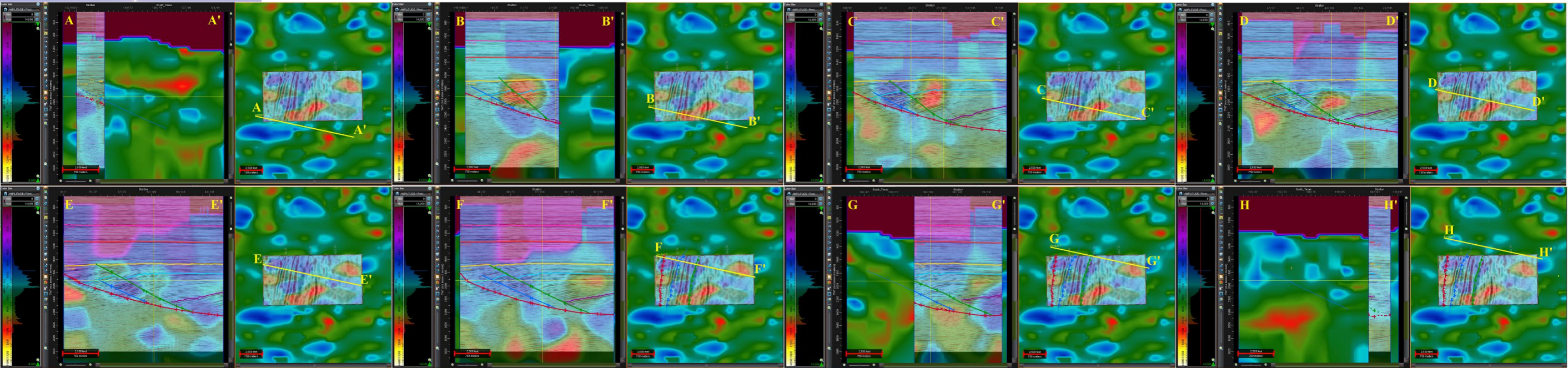
N-S Resistivity Section 493 – Harris County, TX



N-S Resistivity Section 463-493 – Harris County, TX



Lightning Database Analysis Provides A Geological Framework for Exploration



- Analyze large areas quickly: Maps and Volumes within 2 months of order
- Fill the gaps between existing geological and geophysical control
- Identify sweetspots laterally and vertically between 1,000 and 15,000 feet
- Predict rock properties including Resistivity and Permittivity
- Measure and orient Anisotropy

5. Next Steps

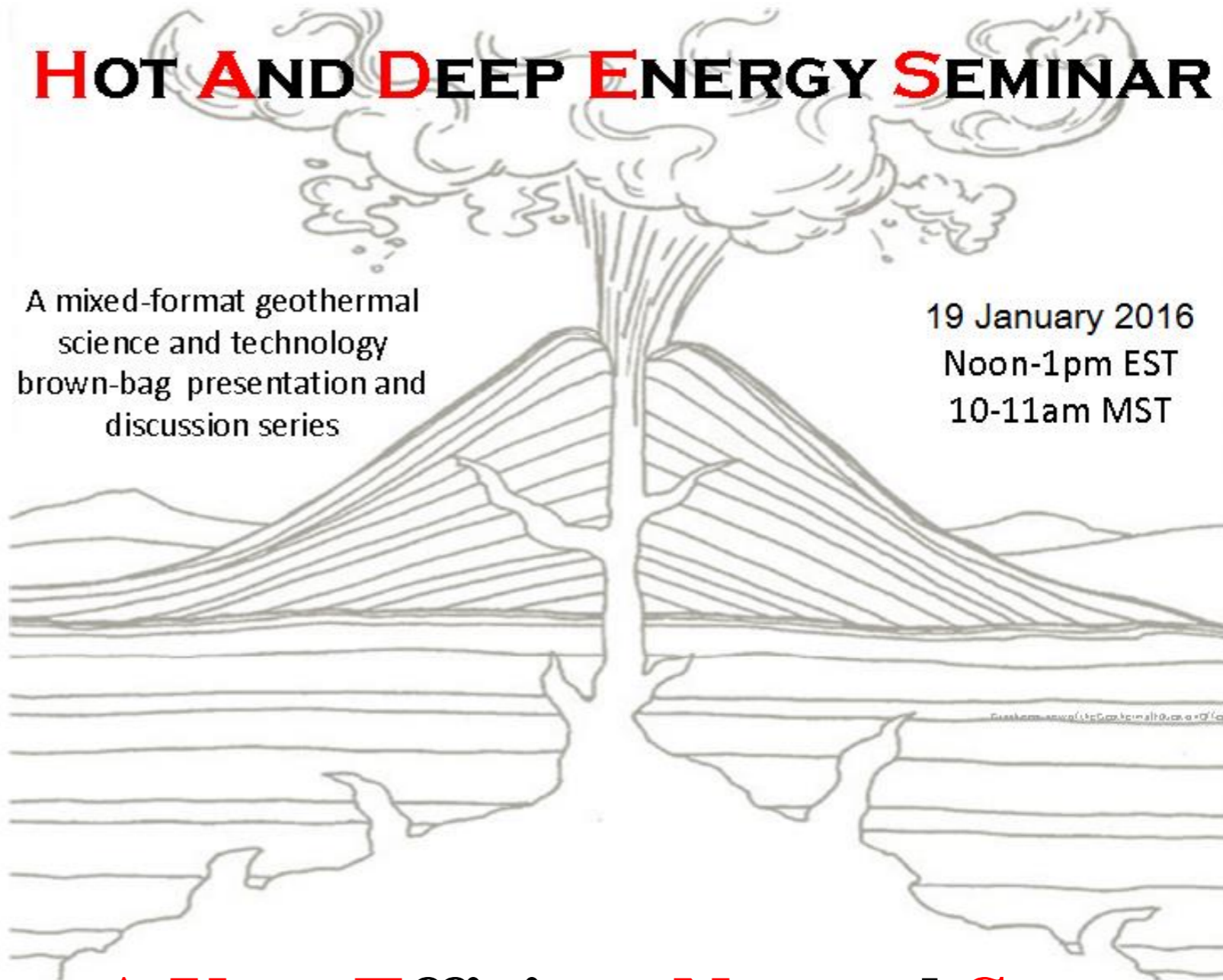
- Review Presentation at:
http://www.dynamicmeasurement.com/160119_DOE-Geothermal
- Review other DML Presentations at:
<http://www.dynamicmeasurement.com/TAMU>
- Additional / More Detailed Webinars
- Calibration / Test Project
- DOE Suggestions

Thank You!

HOT AND DEEP ENERGY SEMINAR

A mixed-format geothermal
science and technology
brown-bag presentation and
discussion series

19 January 2016
Noon-1pm EST
10-11am MST



Hot Energy – A Very Efficient Natural Source

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19 Jan 2016

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