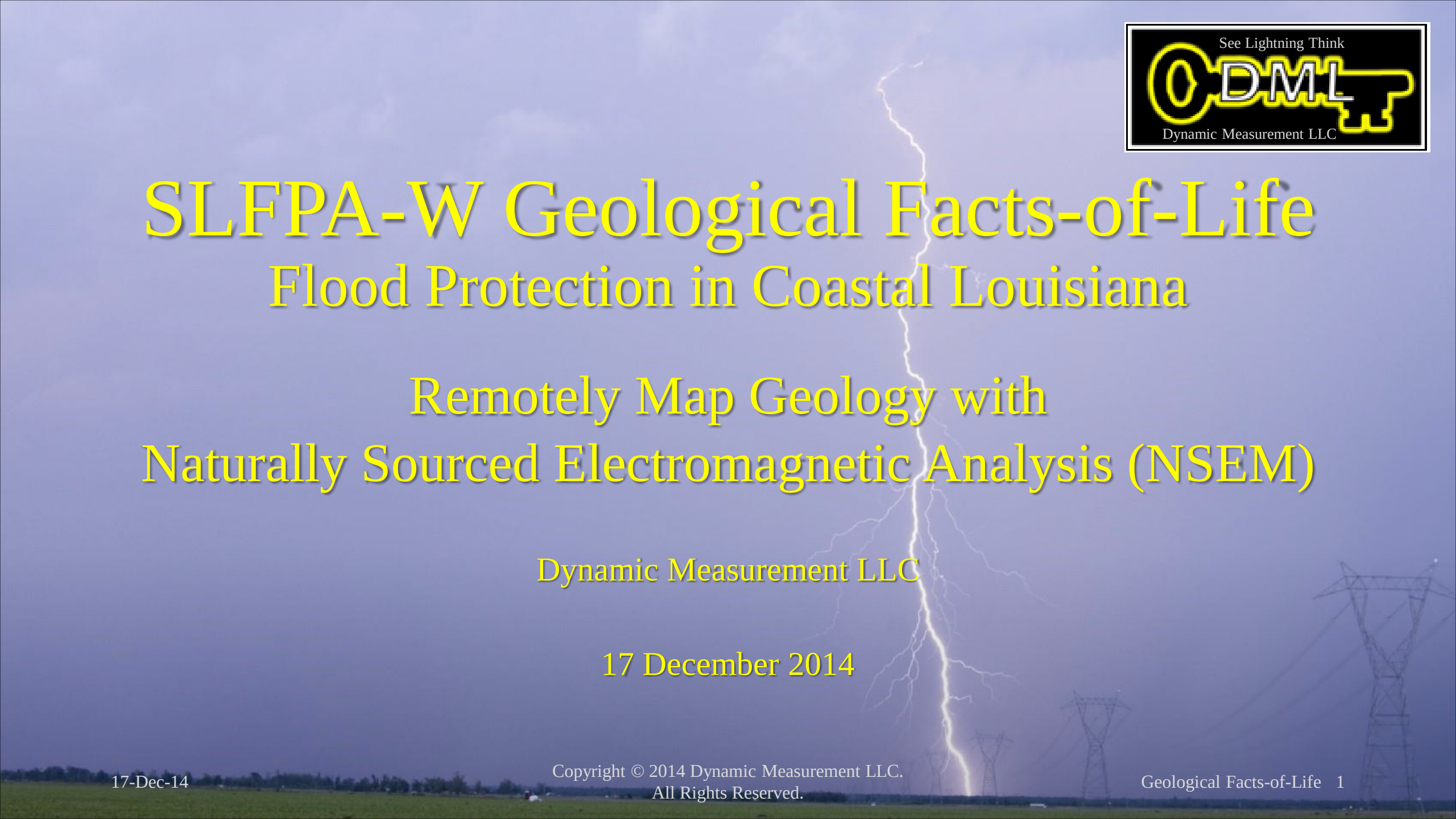


SLFPA-W Geological Facts-of-Life

Flood Protection in Coastal Louisiana

Remotely Map Geology with Naturally Sourced Electromagnetic Analysis (NSEM)

Dynamic Measurement LLC

17 December 2014

Geology is the Foundation of Human Activity

“The land here never sleeps. It’s moving in two directions - vertically and horizontally - all the time. ”

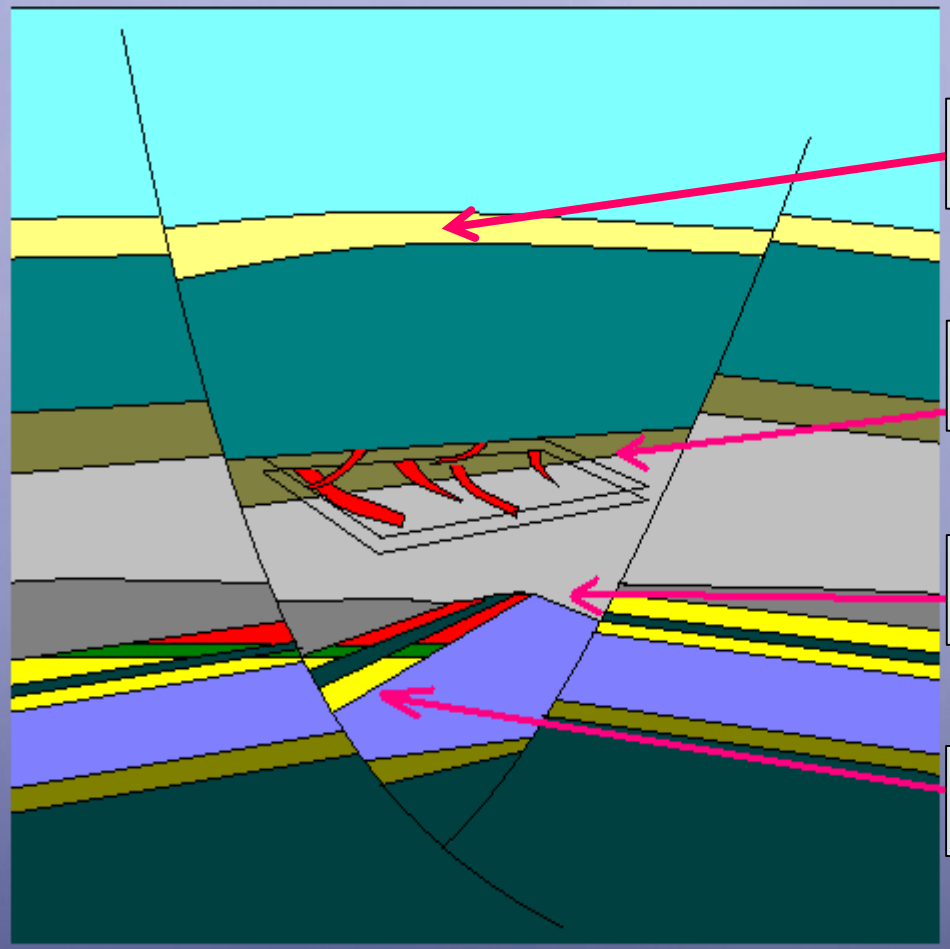
Stephan Estopinal, PE,
President SLFPA-E

When geology moves,
it impacts whatever is at the surface!

Presentation Topic Areas

1. NSEM - A new technology to identify geologic hazards
   - Questions & Answers & Discussion
2. The meteorology behind lightning databases
   - Questions & Answers & Discussion
3. Calculating resistivity volumes from lightning databases
   - Questions & Answers & Discussion
4. Examples of using lightning databases to map geology
   - Questions & Answers & Discussion
5. Goose Point – tectonic driven subsidence lightning case history
   - Questions & Answers & Discussion
6. Mapping & Monitoring geologic movement with evergreen data
   - Questions & Answers & Discussion

Measurement & Monitoring of Geologic Movement



- LIDAR

Peat Deposits

- NSEM (Natural Sourced Electro-Magnetics)

Channels

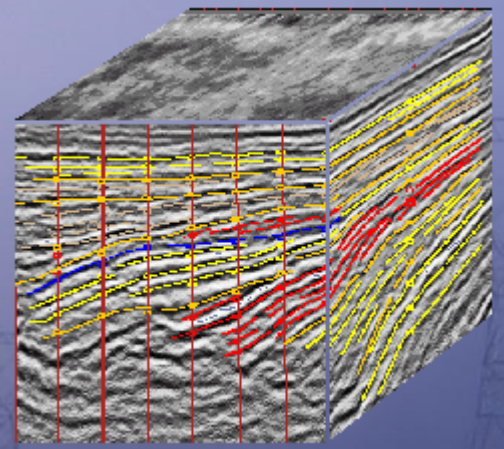
- CSEM (Controlled Source Electro-Magnetics)

Unconformities

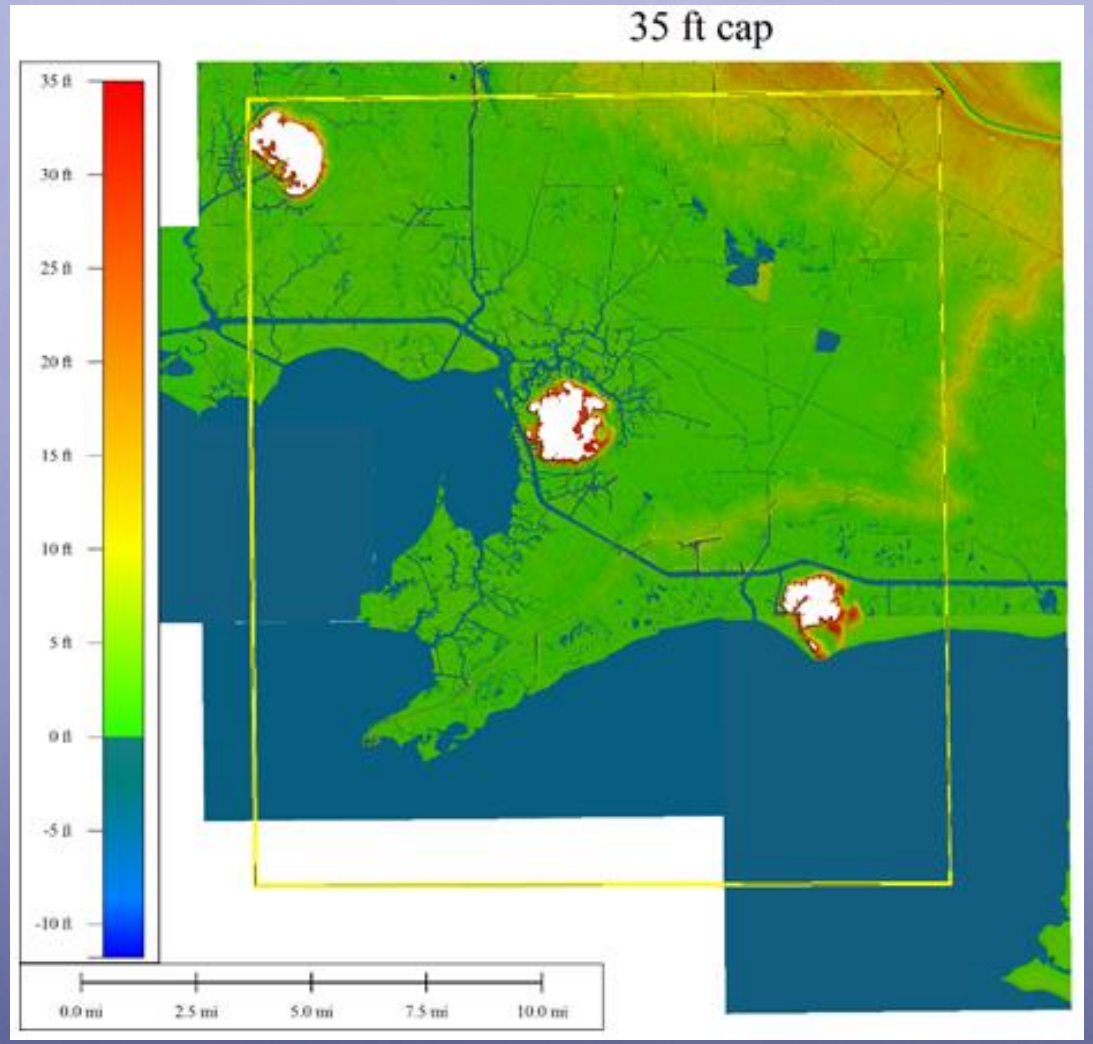
- Electromagnetic Surveys

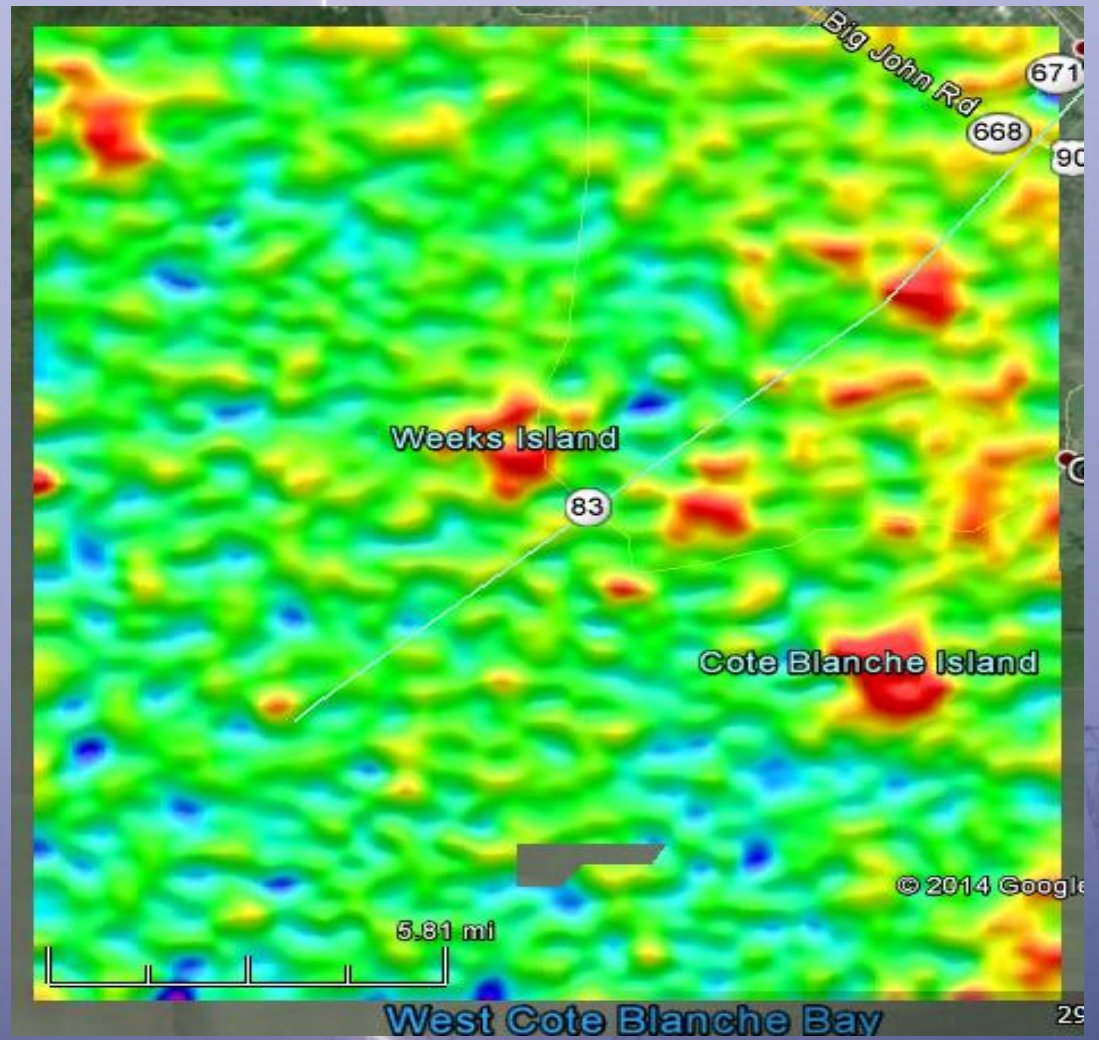
Growth Faults

- 2-D and 3-D Seismic

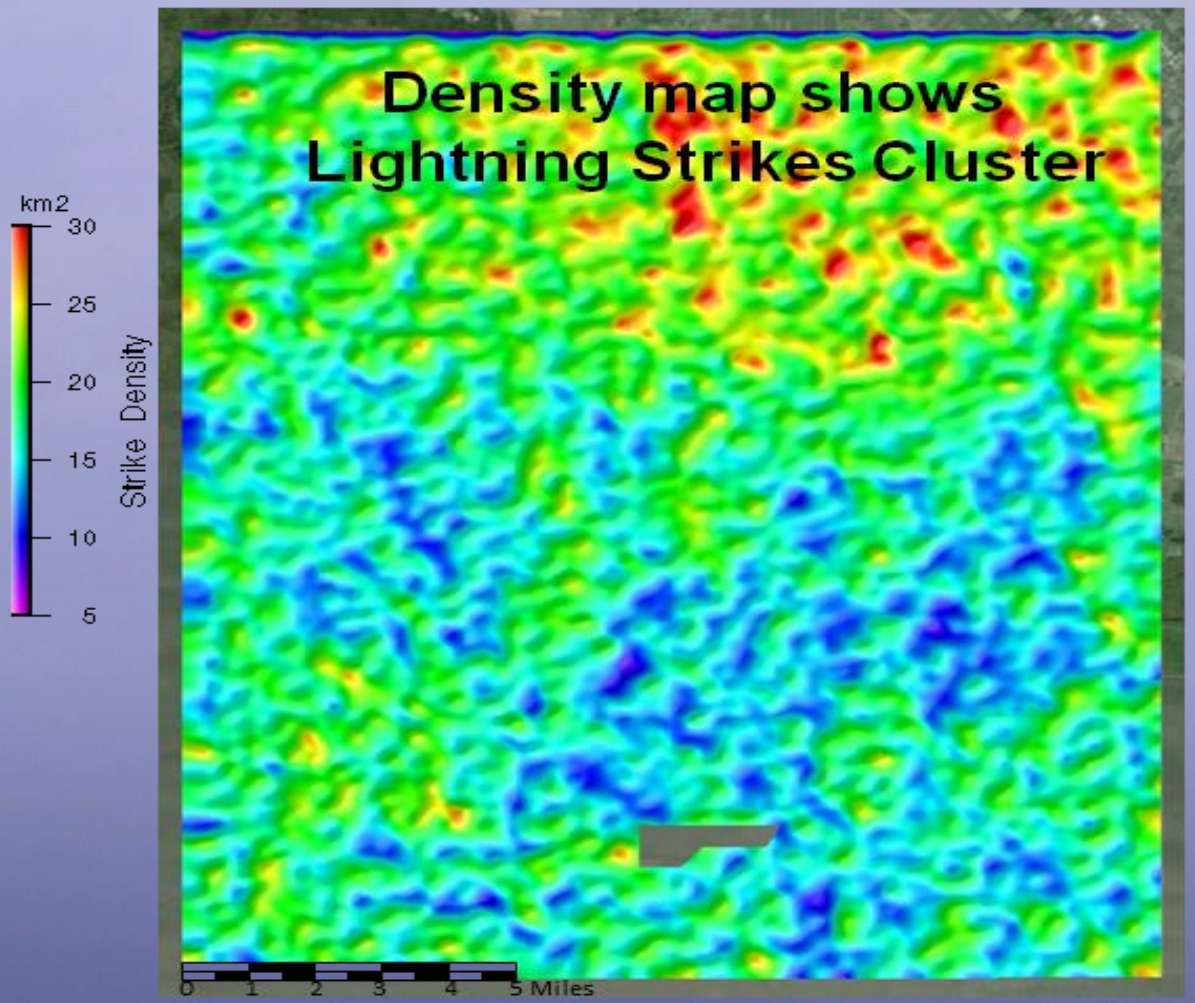


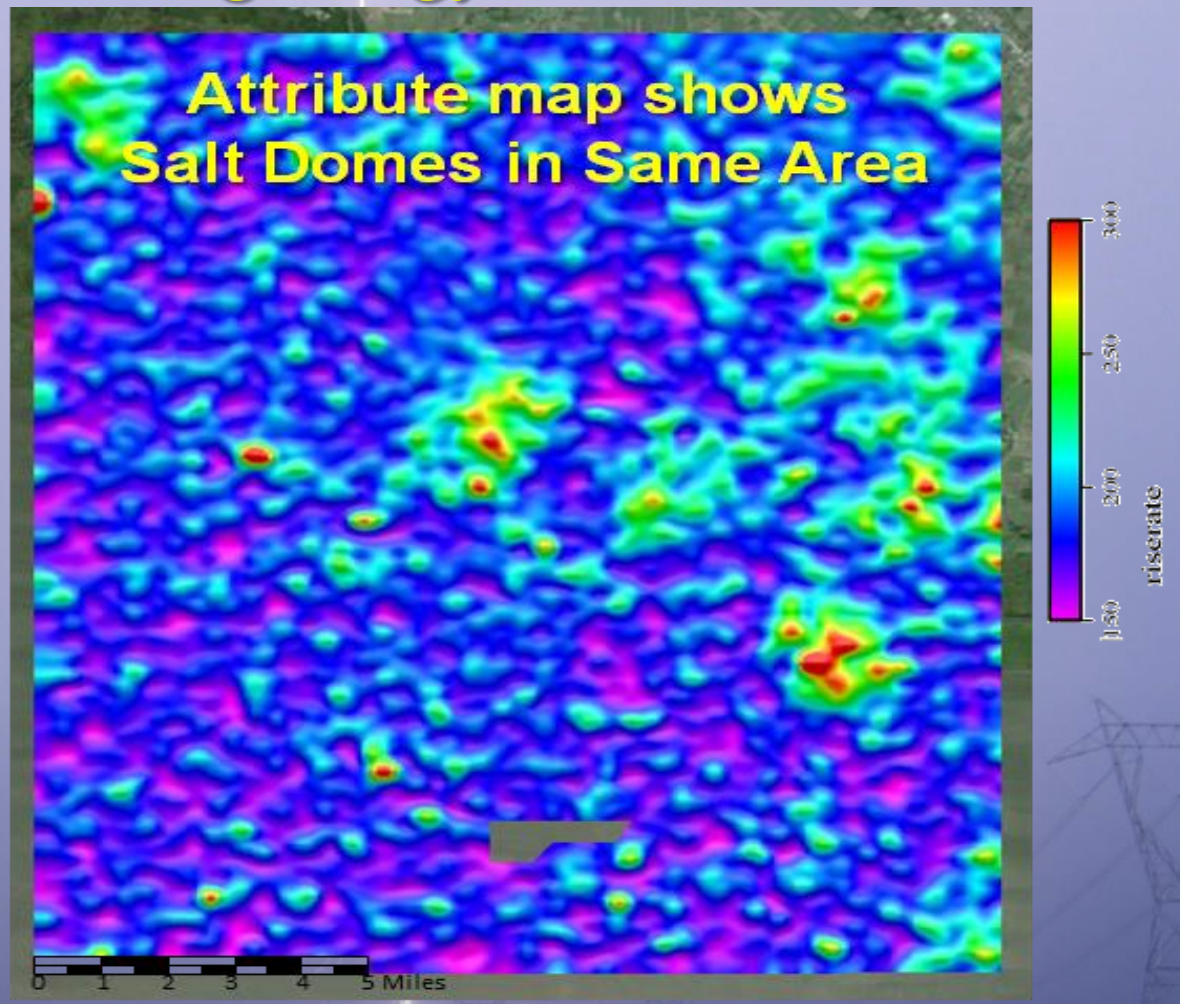
LIDAR Extended with NSEM Analysis





Lightning Data Analysis
demonstrates strikes are tied to geology

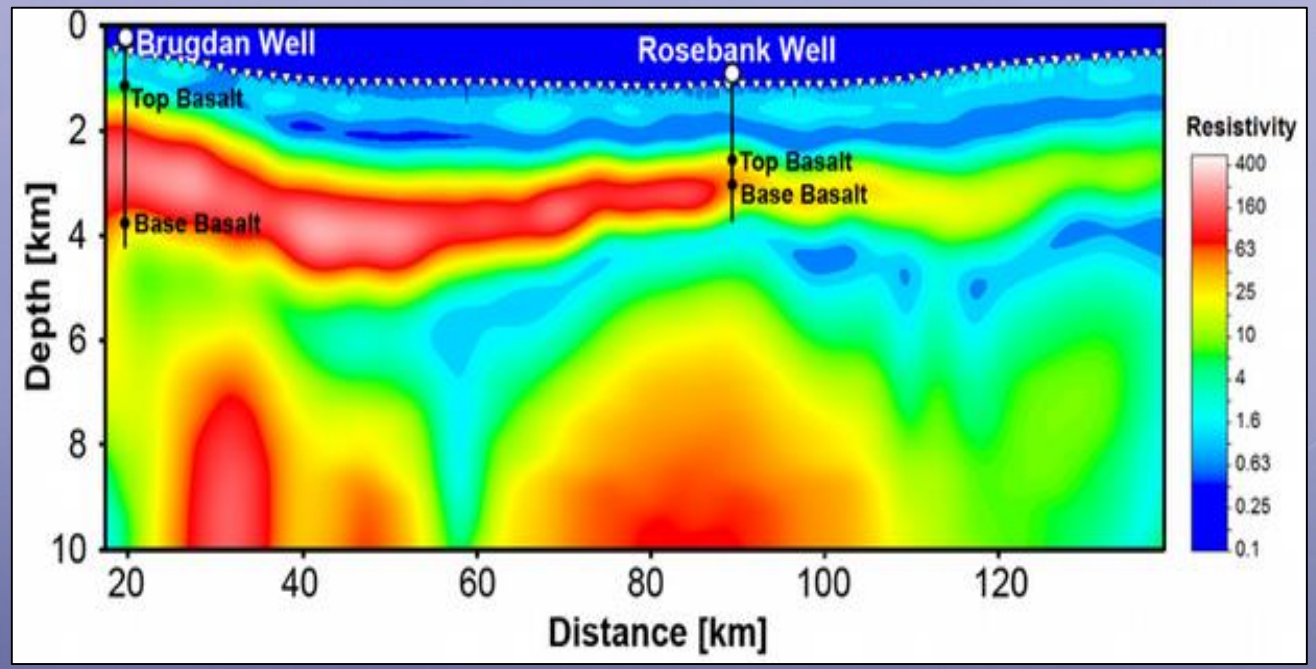




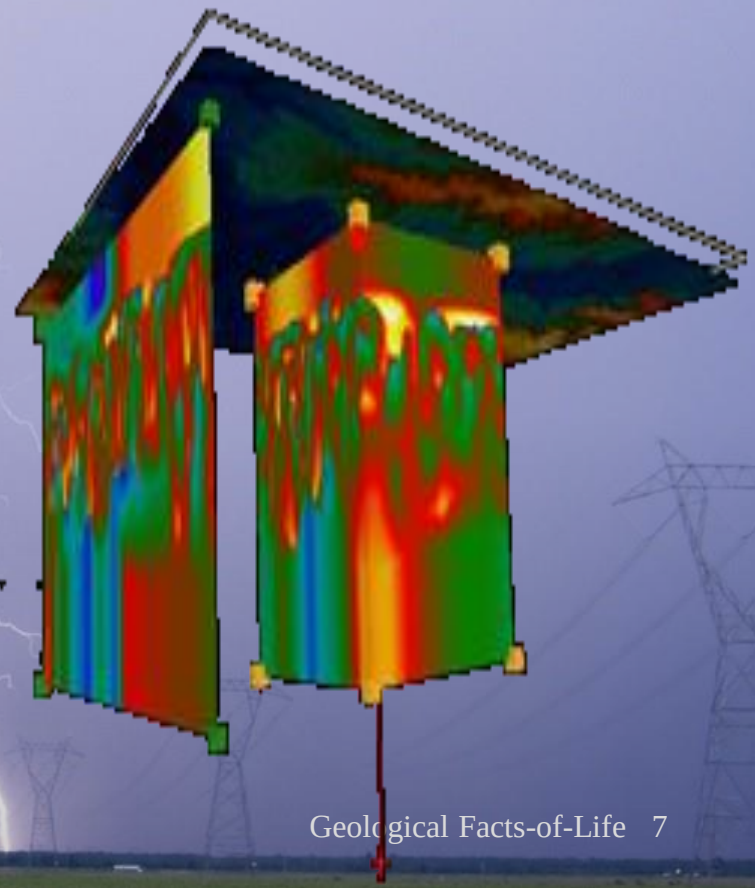
CSEM & NSEM

- Offshore
- > 300 foot water depths
- 1,250-A peak output

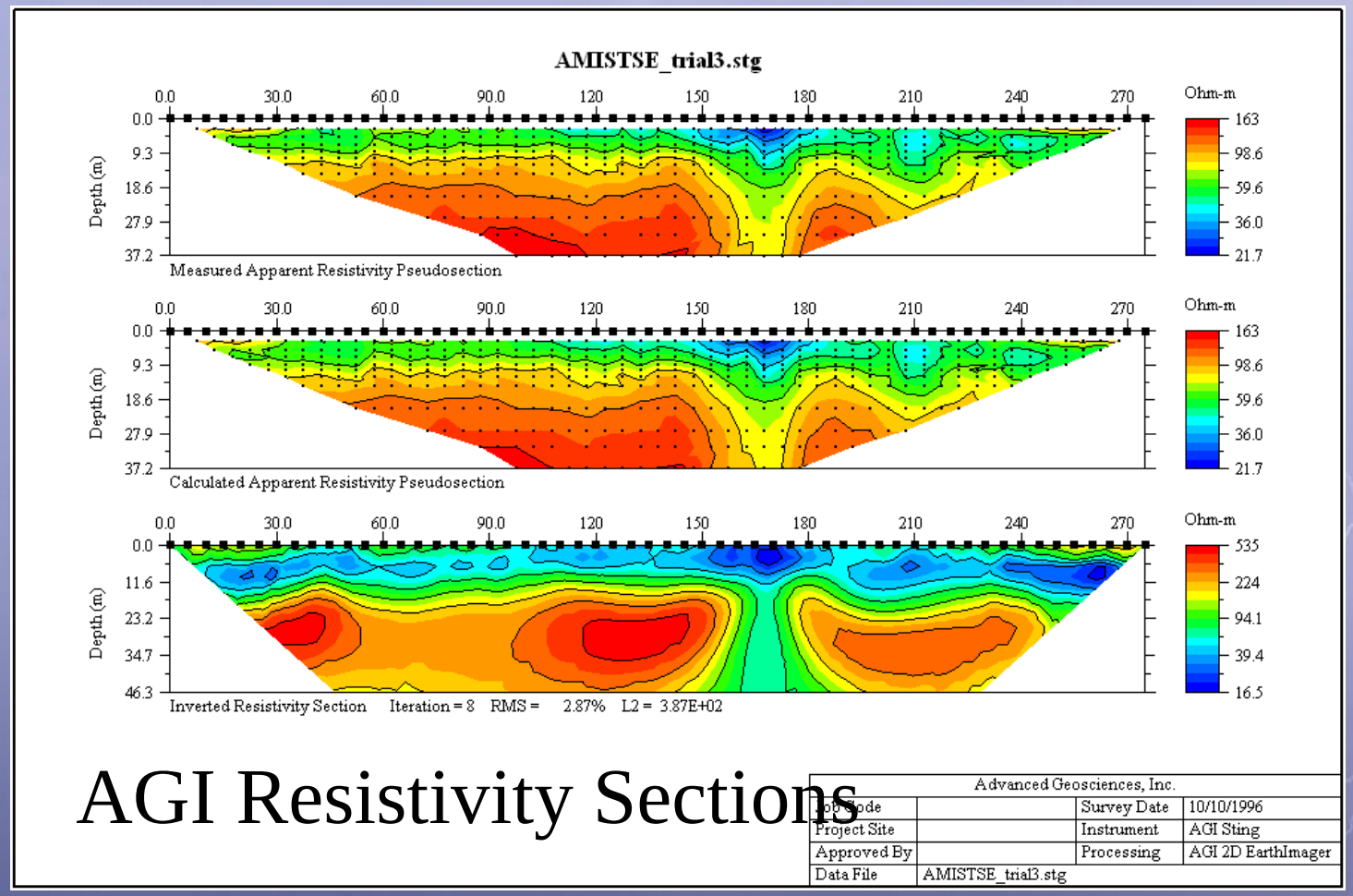
- Onshore
- < 300 foot water depths
- Average 30,000-A per strike



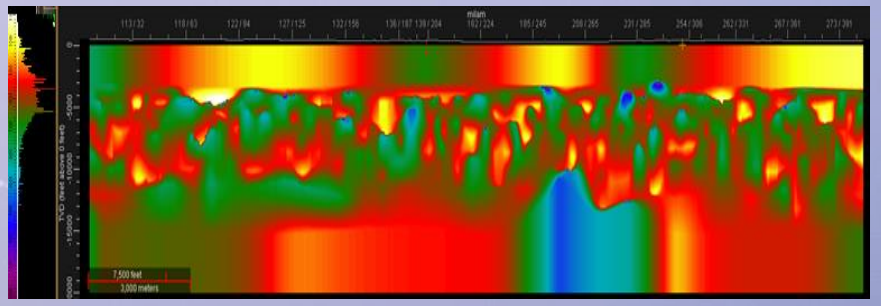
From: http://www.emgs.com/content/870/Structural-imaging



Traditional Electromagnetic Survey vs Lighting Resistivity Analysis



AGI Resistivity Sections



Technical Merit:

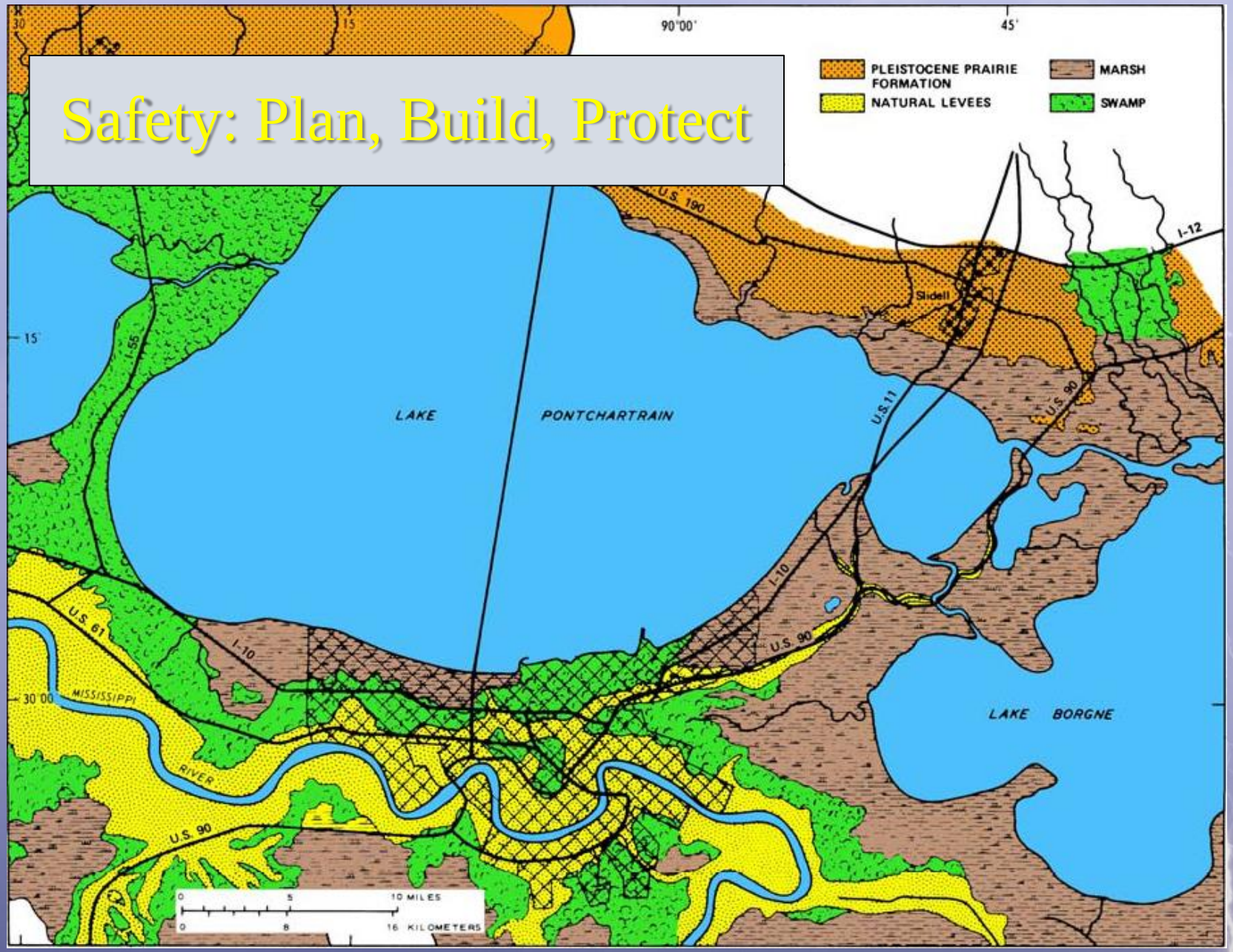
- Sections and Volumes
- Evergreen Data
- 16 year database
- Integrates with other data
- Simple Solution
- Patented, & Patent Pending

Economic Benefit:

- 2 month project turnaround
- Larger Area – Less Expense

1. NSEM –
A new technology to identify geologic hazards

Safety: Plan, Build, Protect



See Lightning Think

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- Picture shows geology and its associated sedimentary geo-hazards
- Distributary and inter-distributary linear events

See Lightning Think

DML

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Regional Tectonic Setting – Geo-hazards

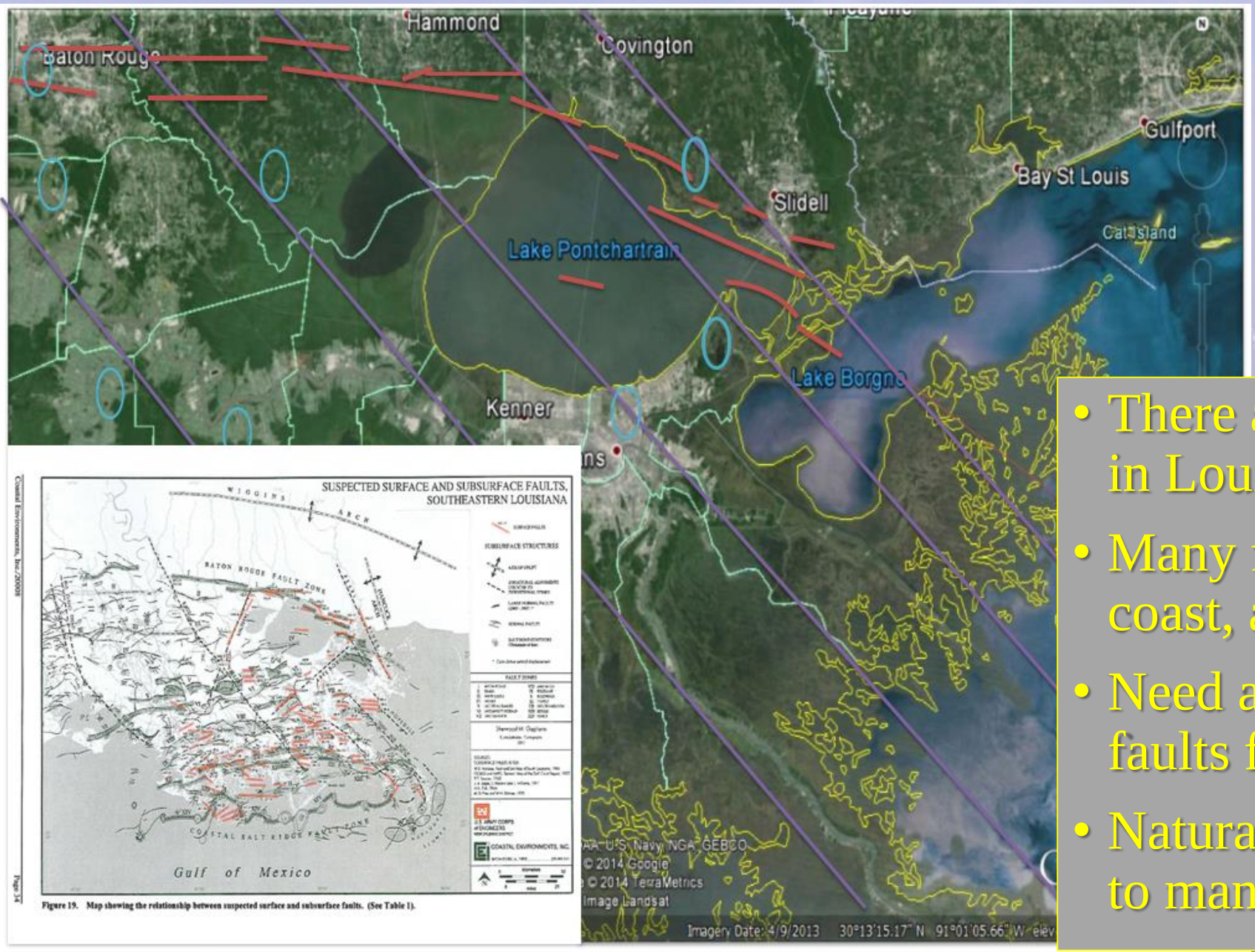
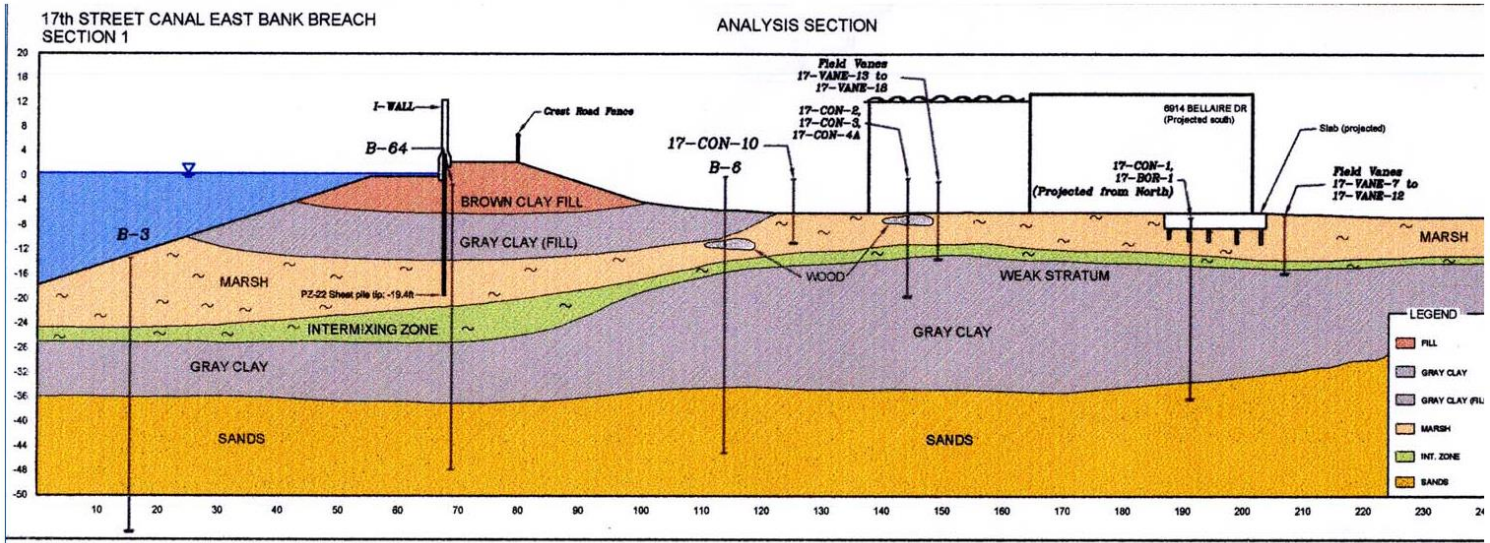
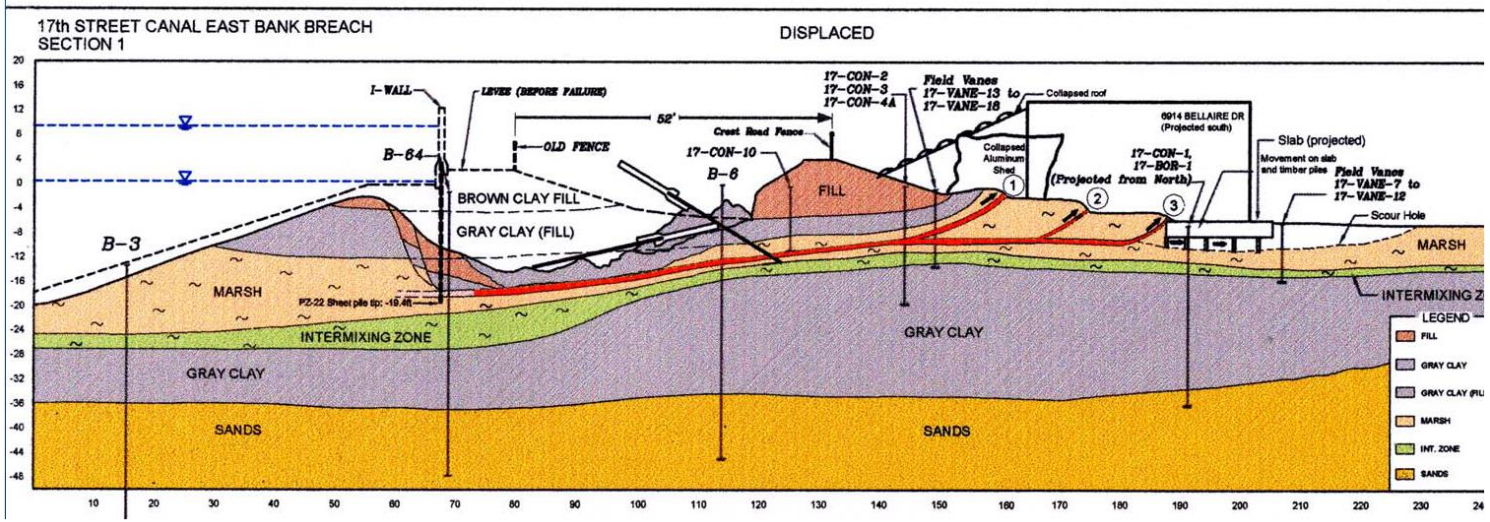


Figure 19. Map showing the relationship between suspected surface and subsurface faults. (See Table 1).

- There are a lot of growth faults in Louisiana (circles are earthquakes).
- Many faults are parallel to coast, as are many of the levees.
- Need awareness of growth faults for planning.
- Natural levees provide stability to man-made levees.





See Lightning Think

ODML

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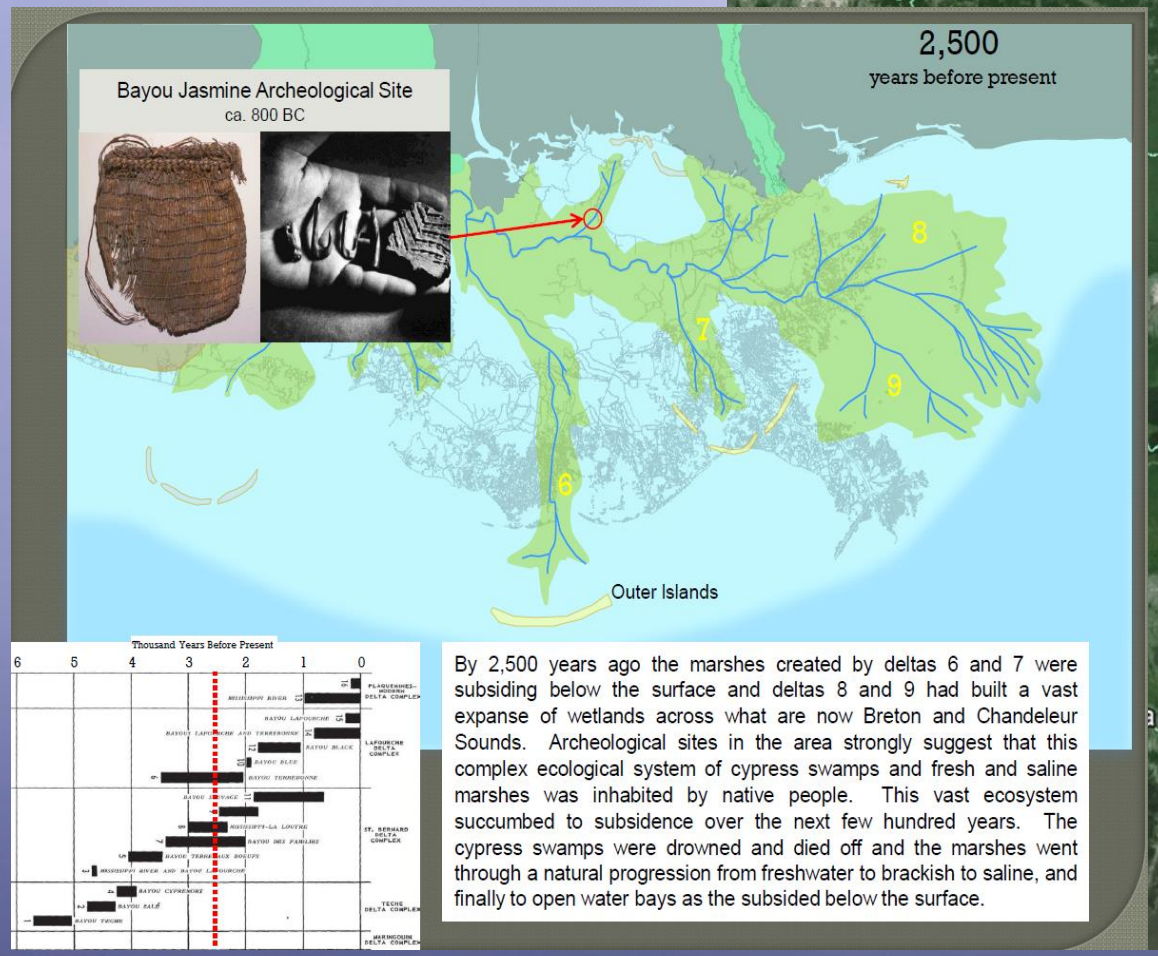
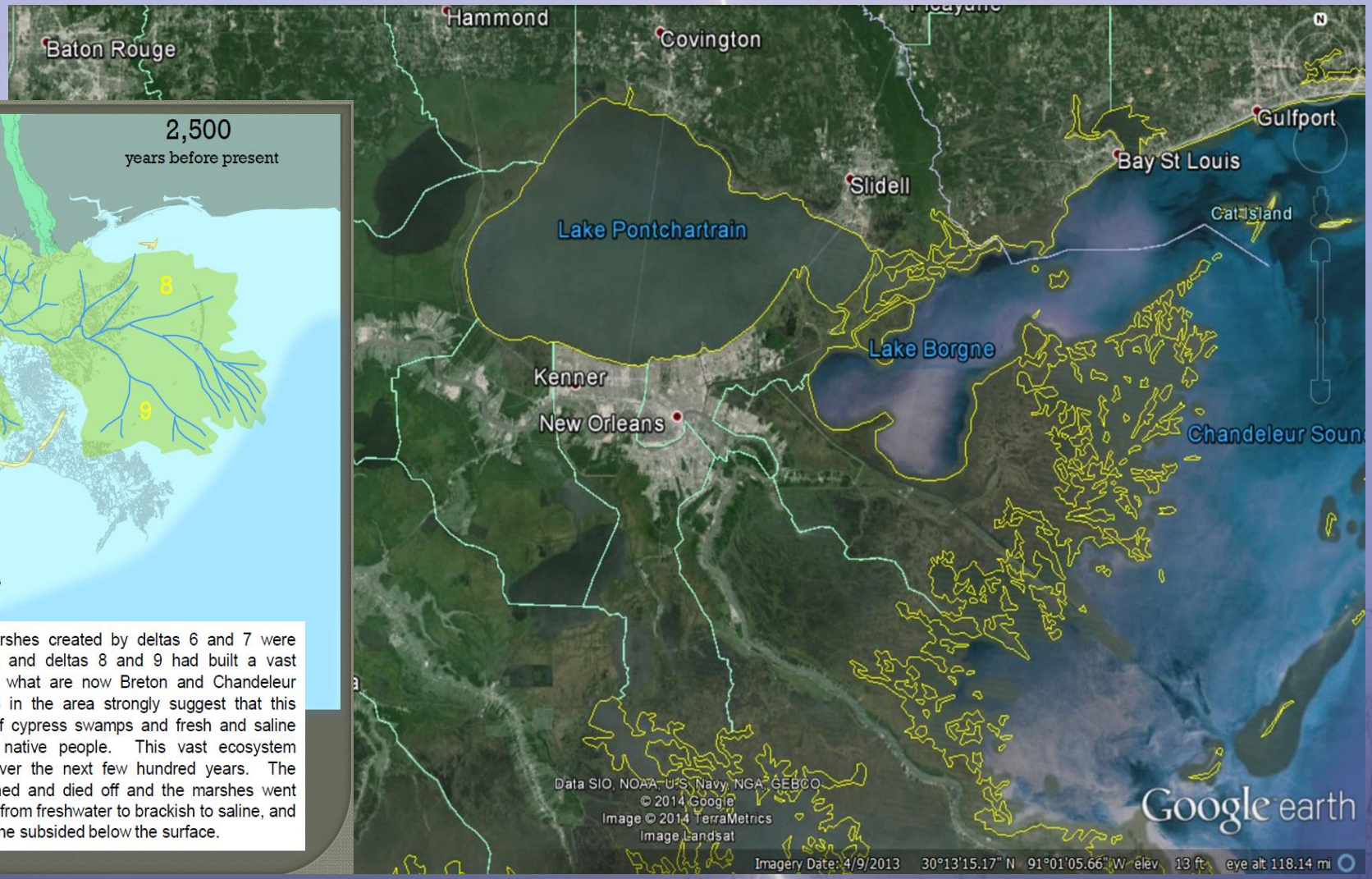
Cross-Section across Flood Wall Failure

Natural Levees date to pre-history



By 2,500 years ago the marshes created by deltas 6 and 7 were subsiding below the surface and deltas 8 and 9 had built a vast expanse of wetlands across what are now Breton and Chandeleur Sounds. Archeological sites in the area strongly suggest that this complex ecological system of cypress swamps and fresh and saline marshes was inhabited by native people. This vast ecosystem succumbed to subsidence over the next few hundred years. The cypress swamps were drowned and died off and the marshes went through a natural progression from freshwater to brackish to saline, and finally to open water bays as the subsided below the surface.



Independent Levee Investigation Team

ILIT 17th Street Canal East Levee- New Orleans, Louisiana **Soil Profile**

New Orleans Levee Systems Hurricane Katrina July 31, 2006

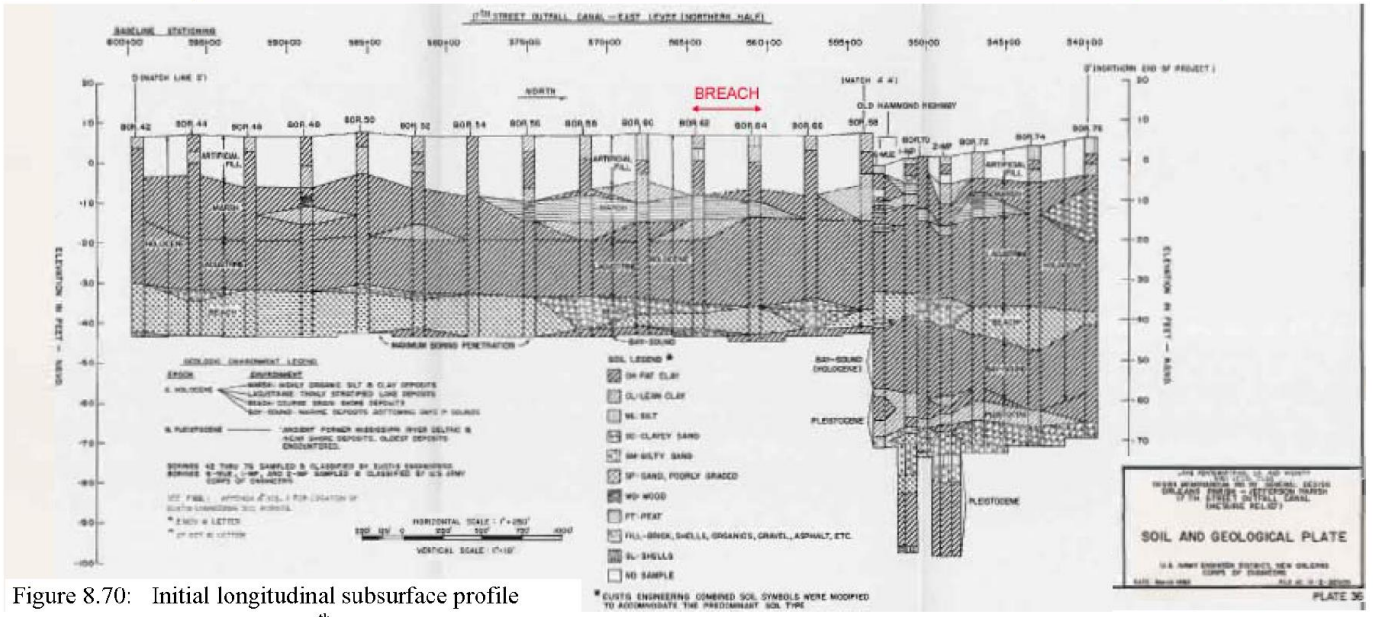


Figure 8.70: Initial longitudinal subsurface profile used for initial design at the 17th Street Canal breach site. 8 - 100 [USACE, DM-20, Vol. 1, 1990]

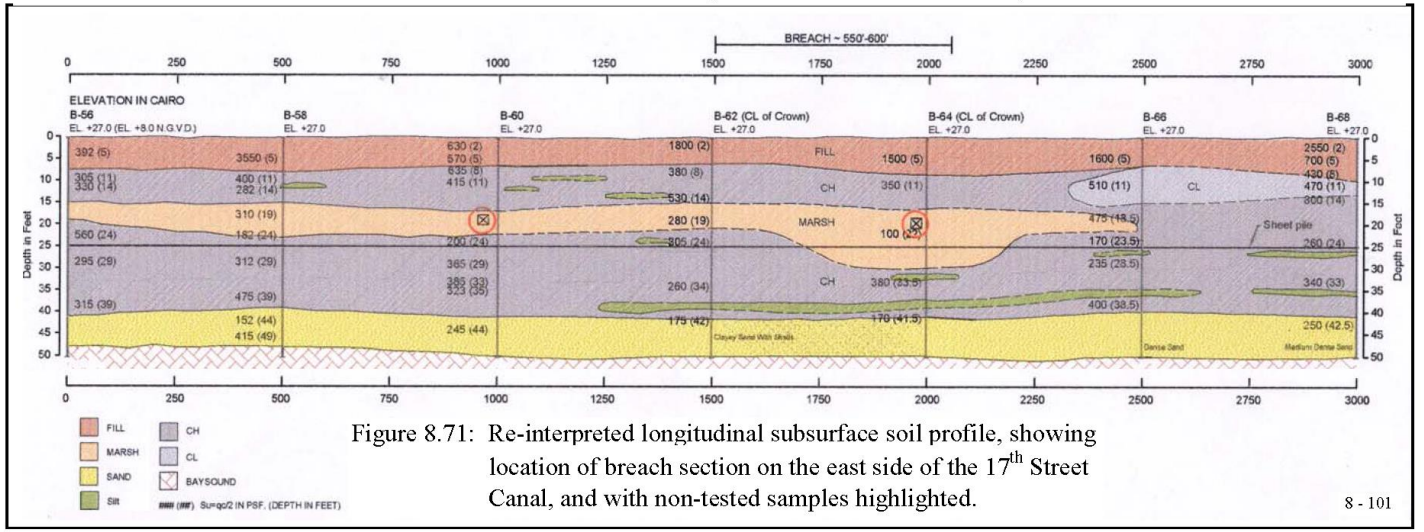
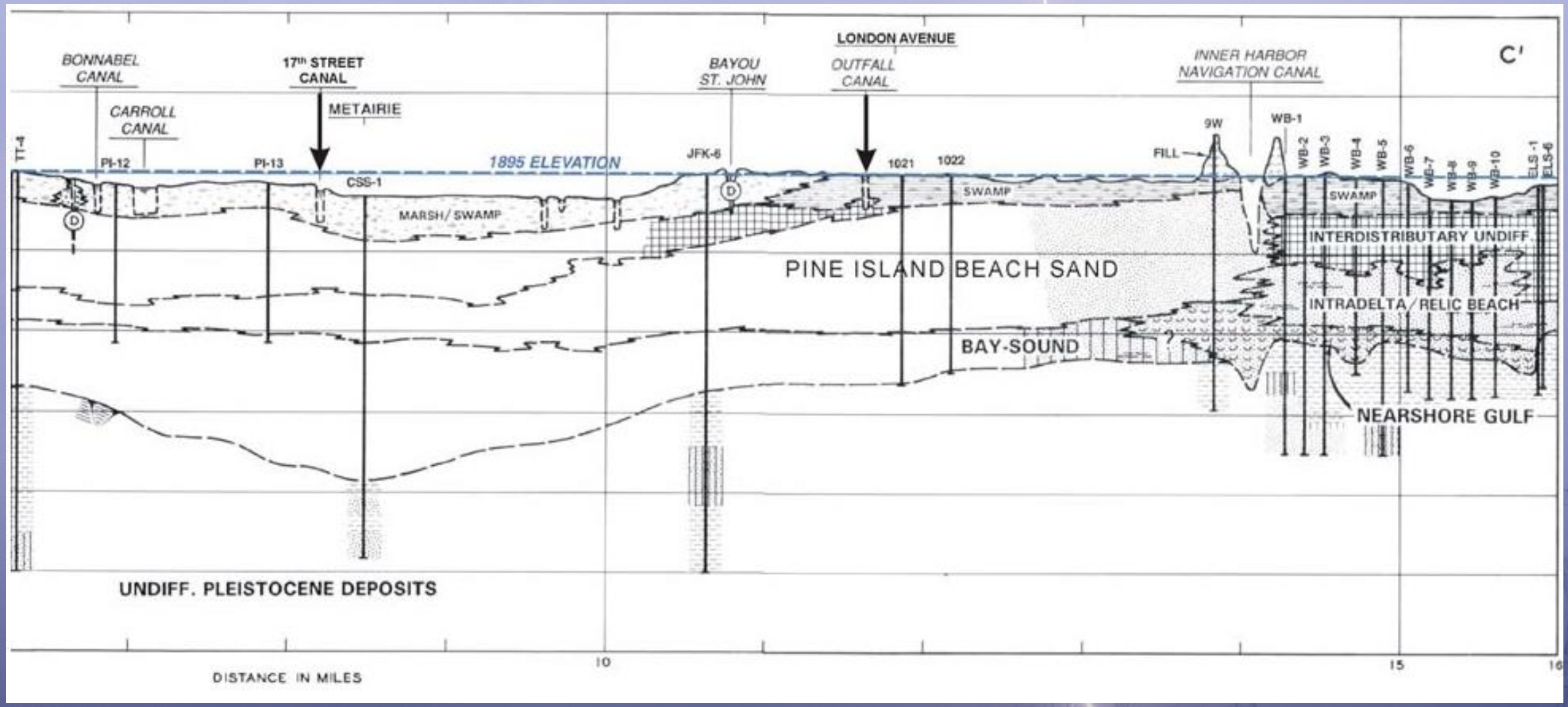


Figure 8.71: Re-interpreted longitudinal subsurface soil profile, showing location of breach section on the east side of the 17th Street Canal, and with non-tested samples highlighted. 8 - 101

See Lightning Think DML Dynamic Measurement LLC

Current Subsurface Monitoring is with the Drill Bit

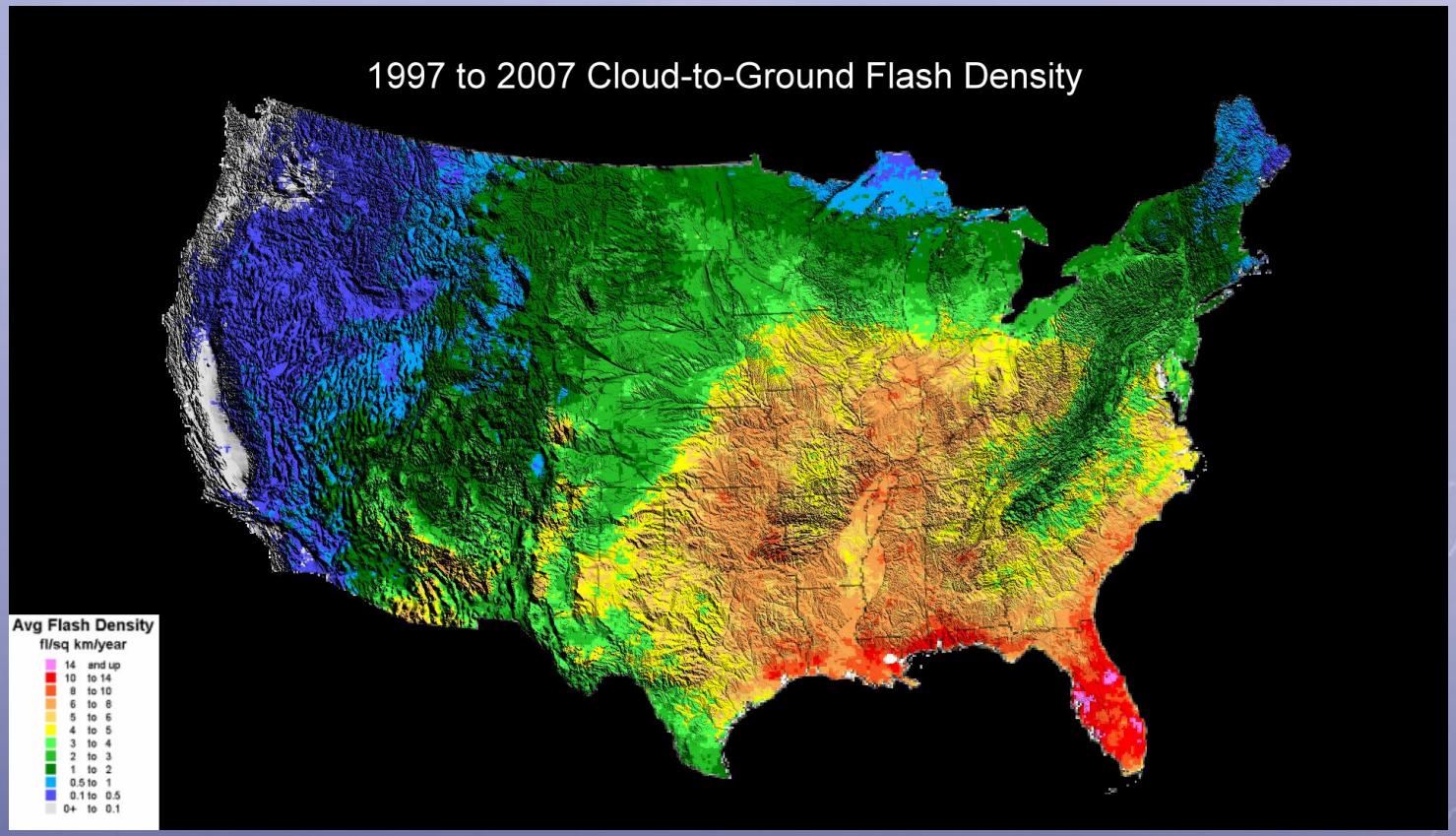
Subsidence Happens in Louisiana



Questions & Answers & Discussion

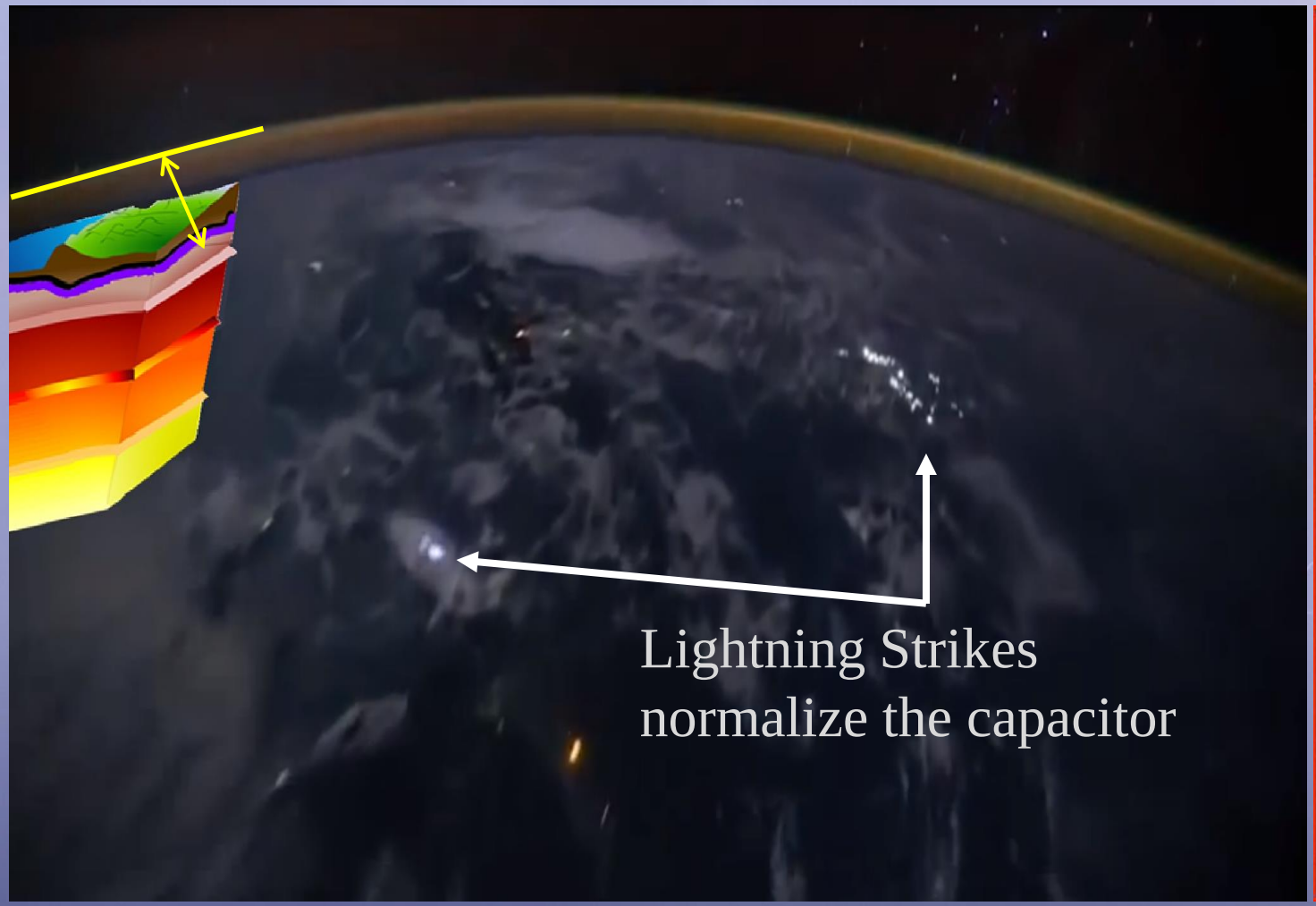
2. The meteorology behind lightning databases

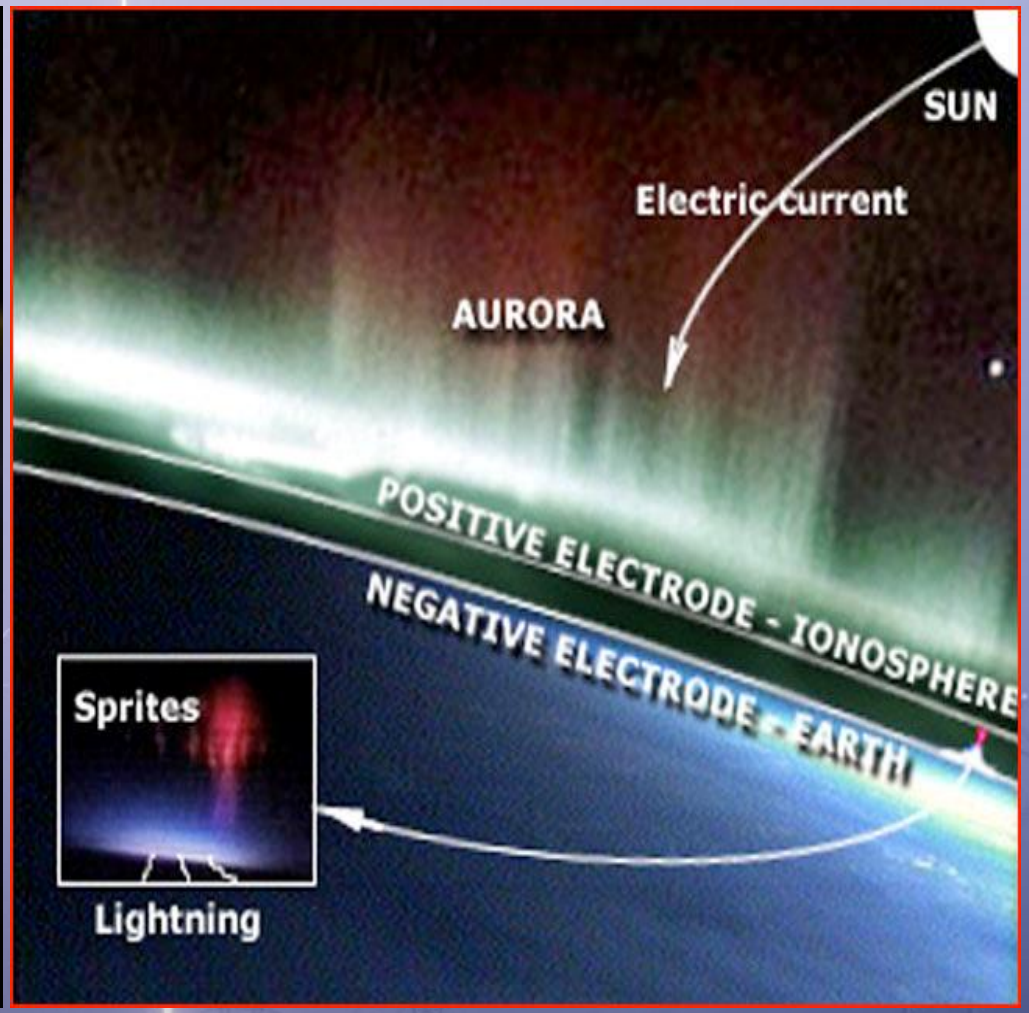
Lightning Maps and Natural Resources



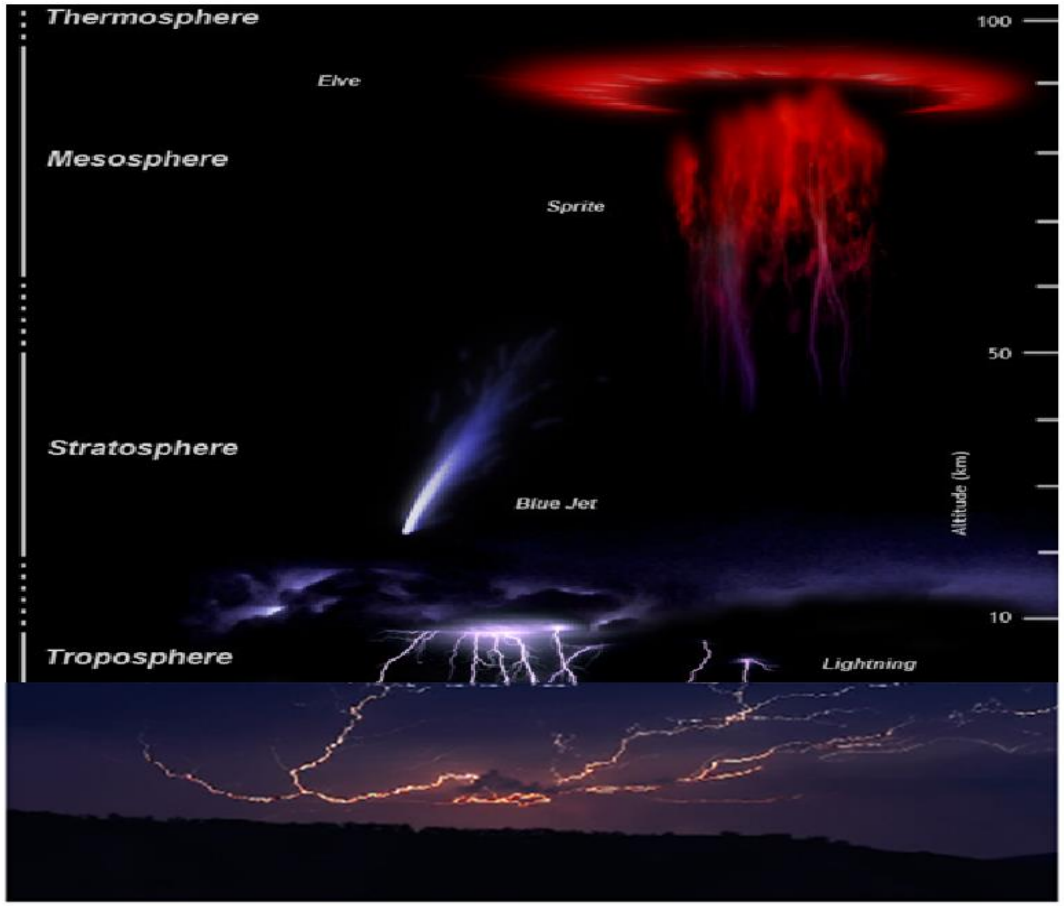
Lightning density regionally controlled by meteorology, and locally controlled by terralevis (shallow earth) currents.

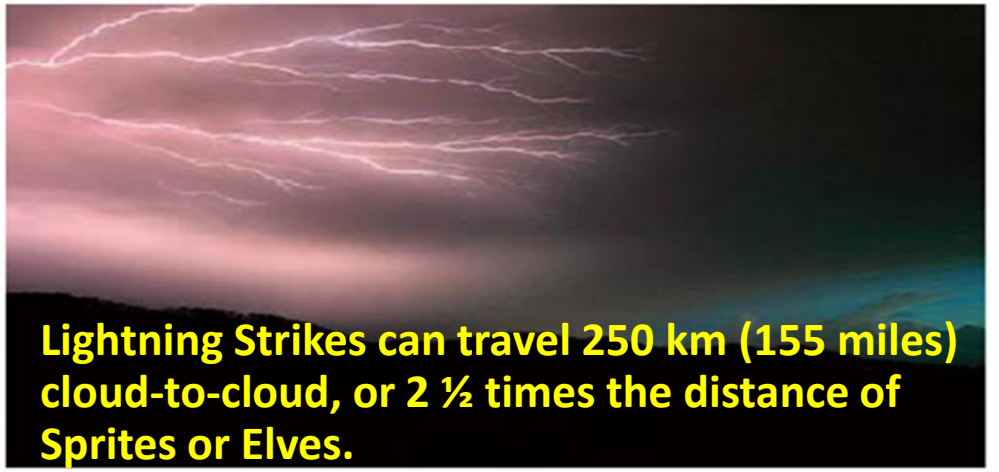
Earth: A Self-Repairing Capacitor





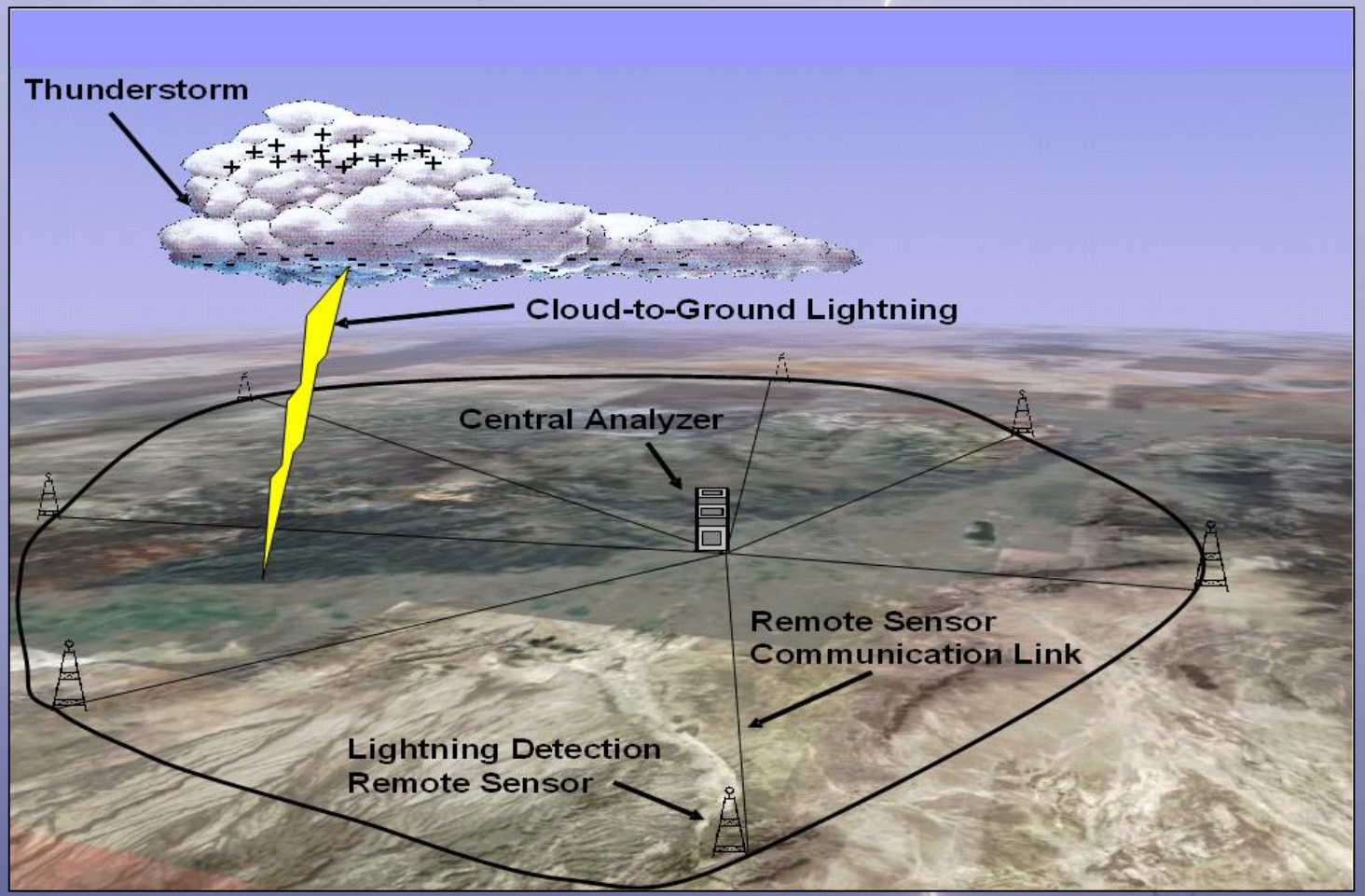
350 million annual Lightning Strikes - a rich database to mine





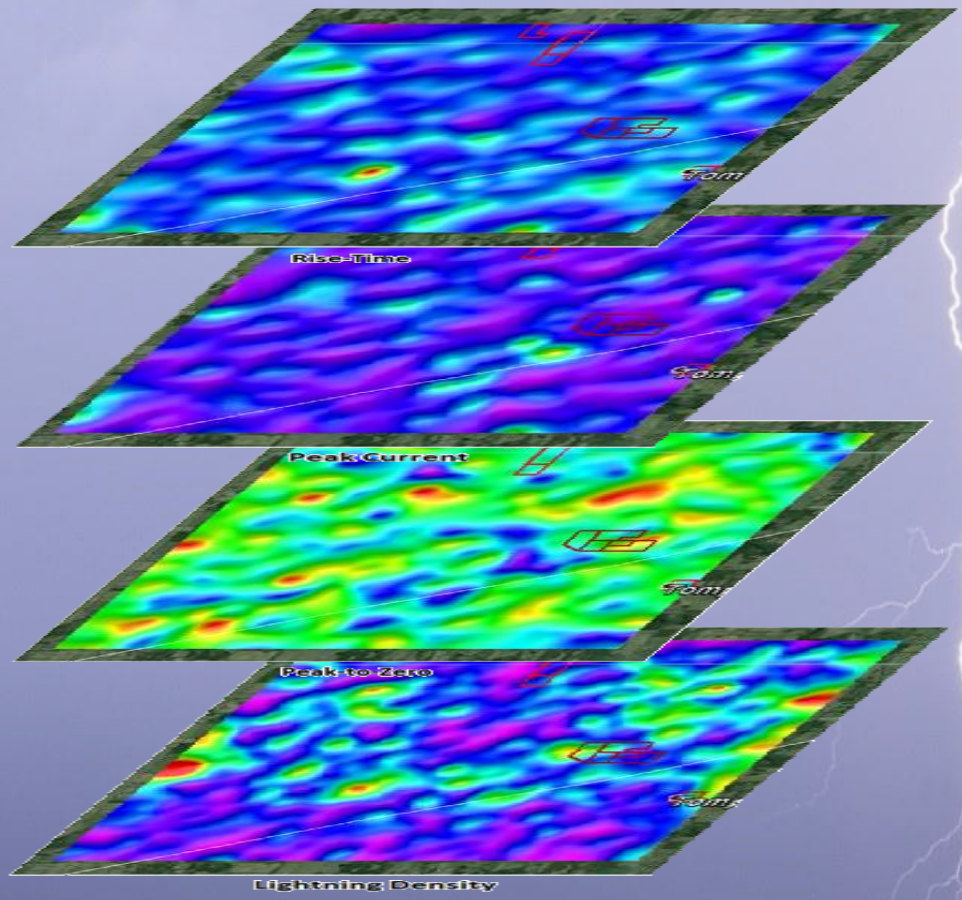
Lightning recorded for early storm warning, safety, **insurance**, and meteorological purposes

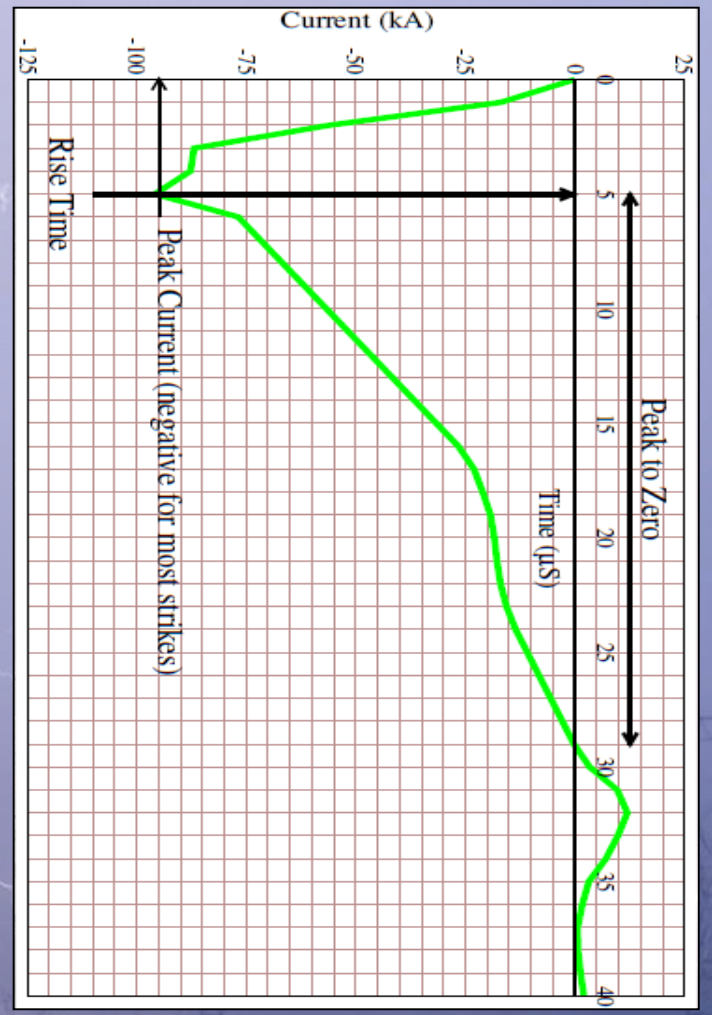
330 Sensors record U.S. lightning strike locations with 100-500 feet (30-150 meter) horizontal resolution



Lightning Strike Measurements

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





Lightning bypasses tall objects to hit geology

Proven and Patented Technology

See Lightning Think
DML
Dynamic Measurement LLC

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)

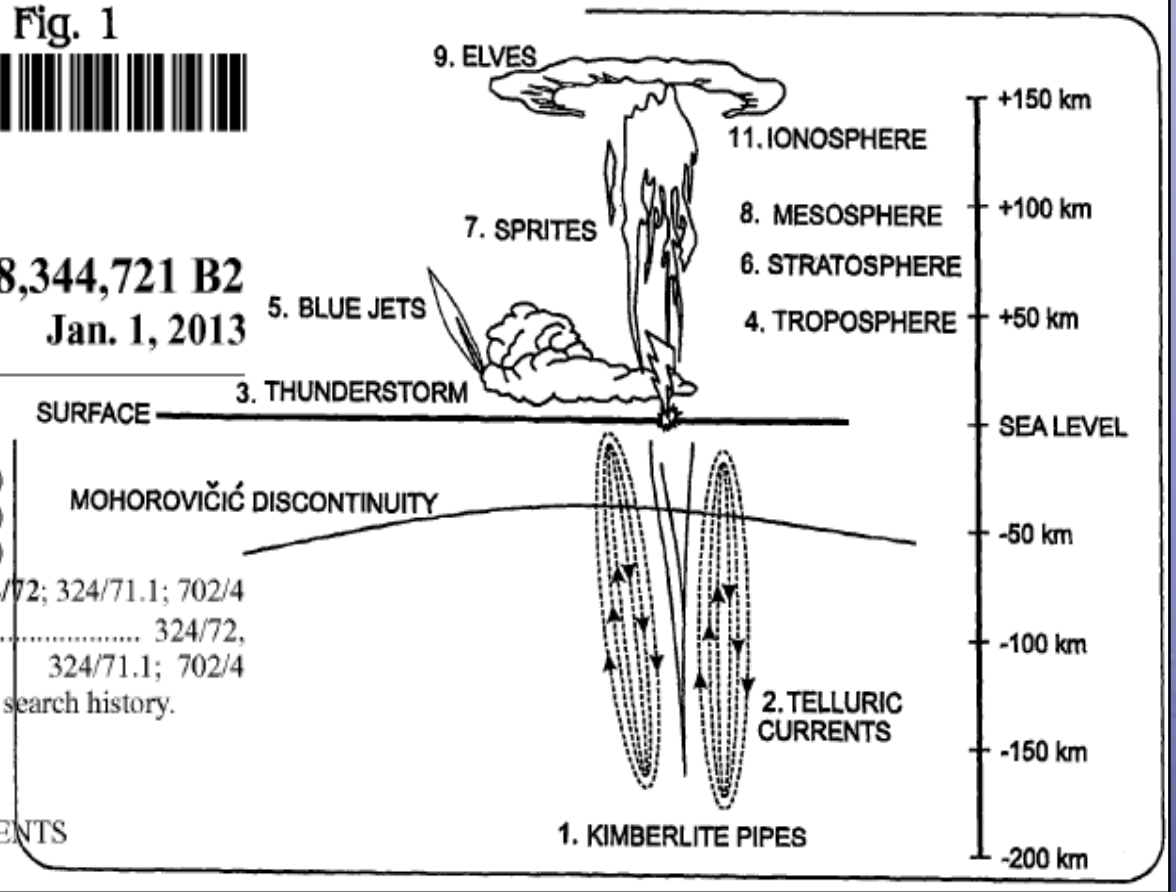
(52) **U.S. Cl.** **324/72**; 324/71.1; 702/4

(58) **Field of Classification Search** 324/72, 324/71.1; 702/4

See application file for complete search history.

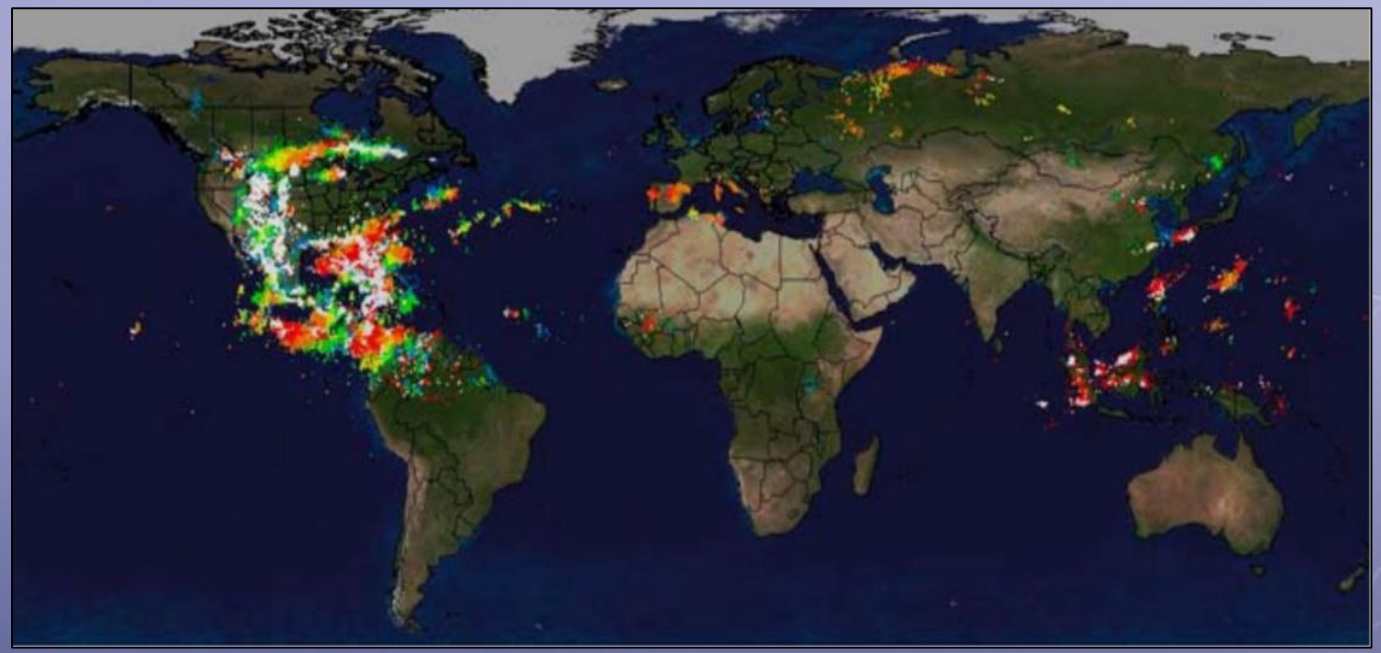
(56) **References Cited**

U.S. PATENT DOCUMENTS



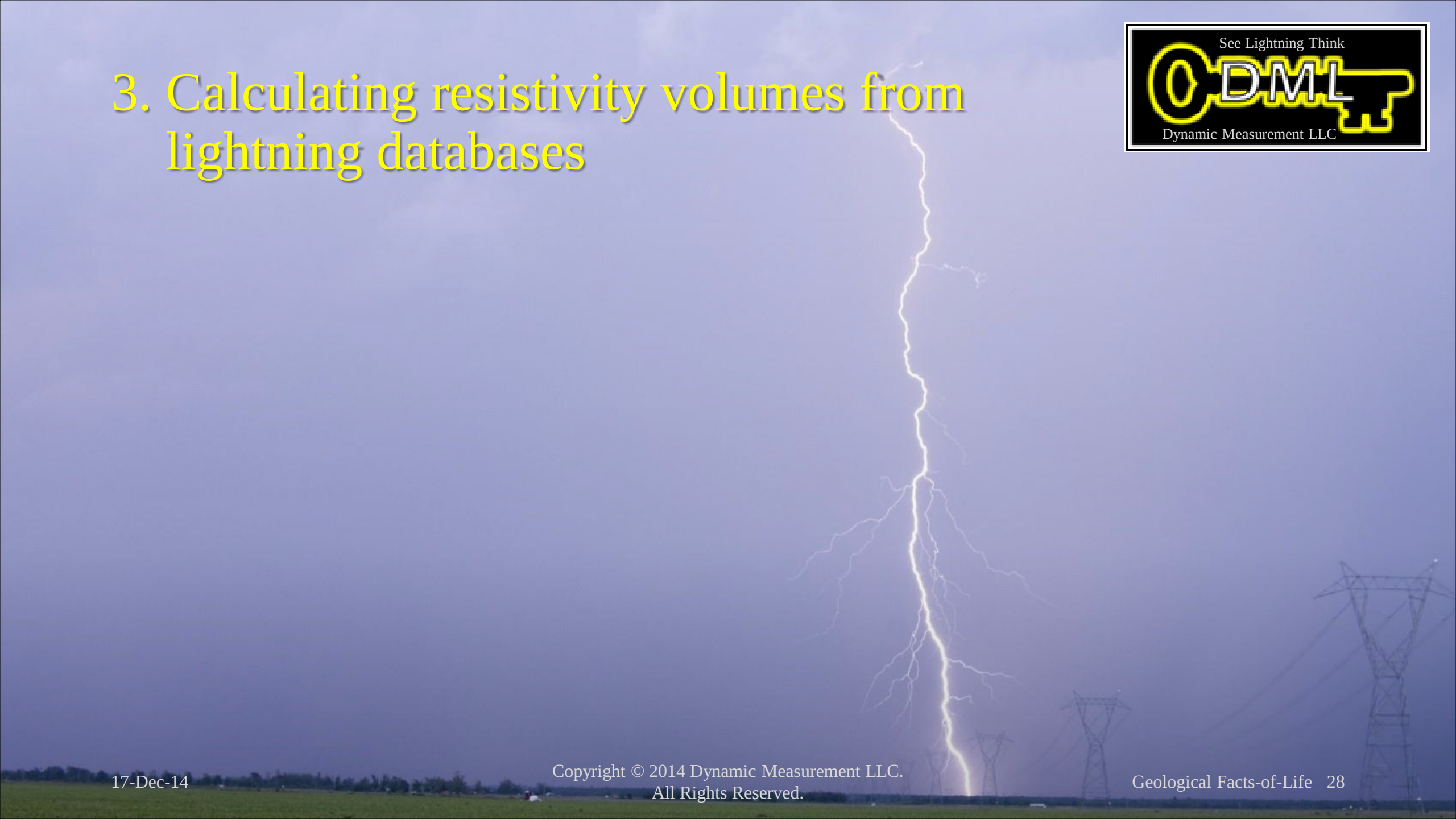
Vaisala Partnership

Exclusive worldwide license with Vaisala of Finland to use their data in the NLDN and GLD-360 for natural resource exploration.



Questions & Answers & Discussion

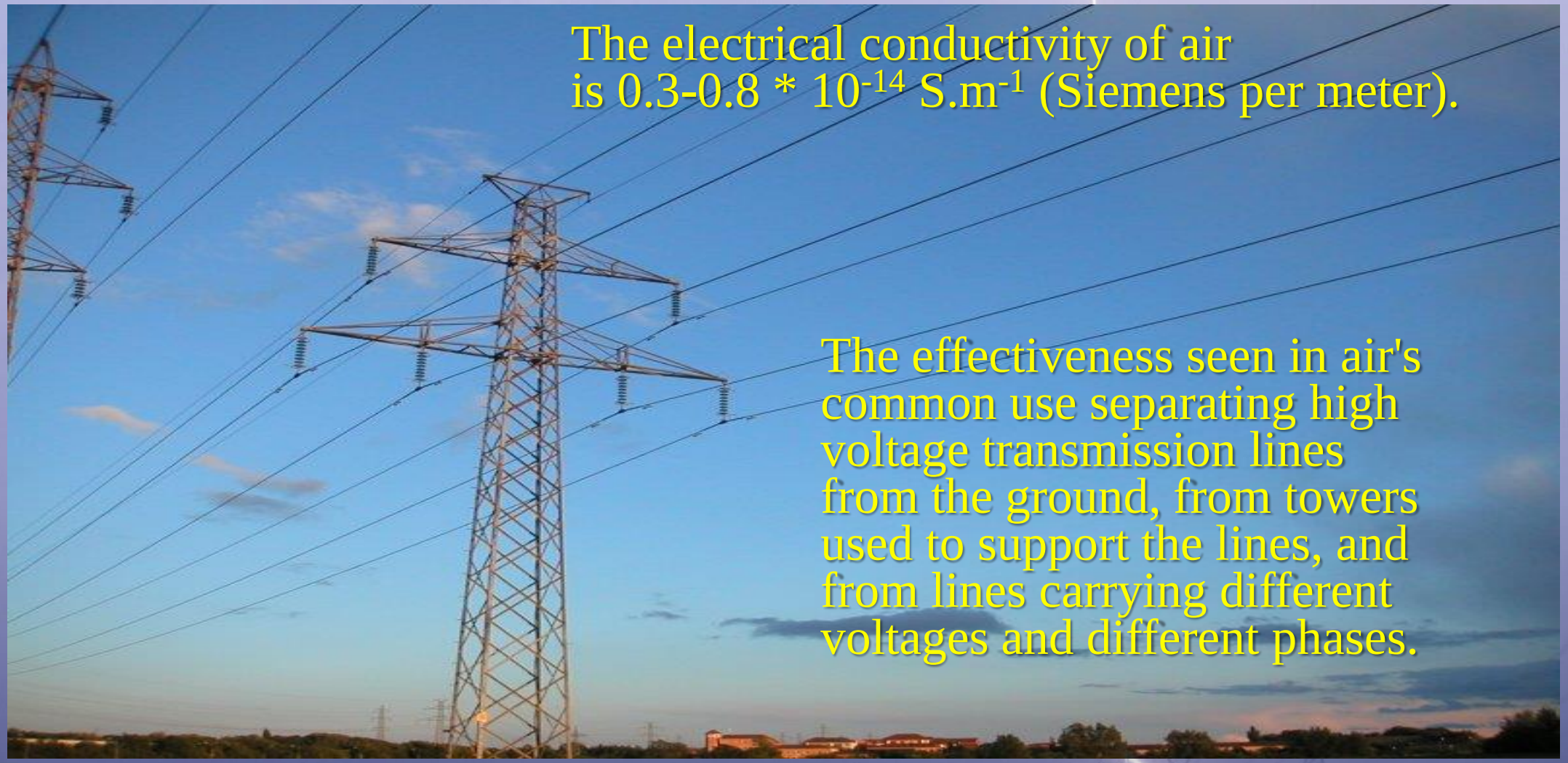
3. Calculating resistivity volumes from lightning databases



Recorded Lightning Data

- Cloud-to-ground lightning can be measured and recorded
- Lightning measurements have been made for more than thirty years
- A continuous record of essentially all cloud-to-ground lightning strokes in the contiguous U.S.A. and Canada has been made for approximately sixteen years.
- A continuous record of cloud-to-ground lightning strokes worldwide has been made for about four years

The atmosphere is an effective insulator

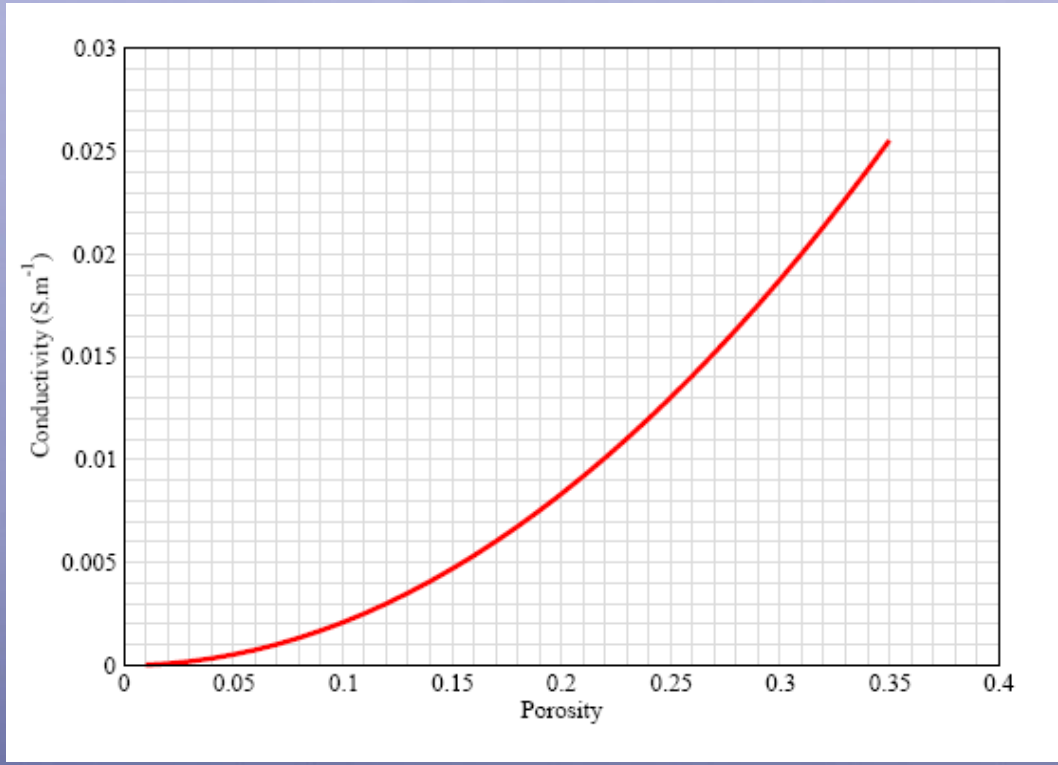


The electrical conductivity of air is 0.3-0.8 * 10^{-14} $S.m^{-1}$ (Siemens per meter).

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.

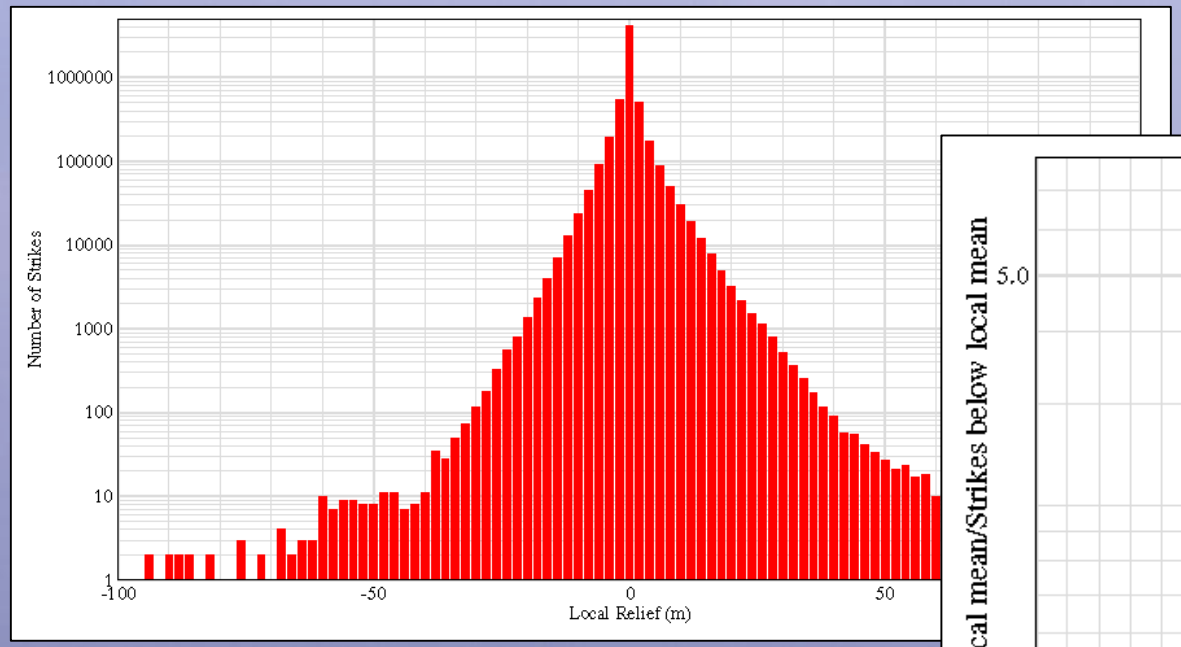
The earth is much more conductive than air

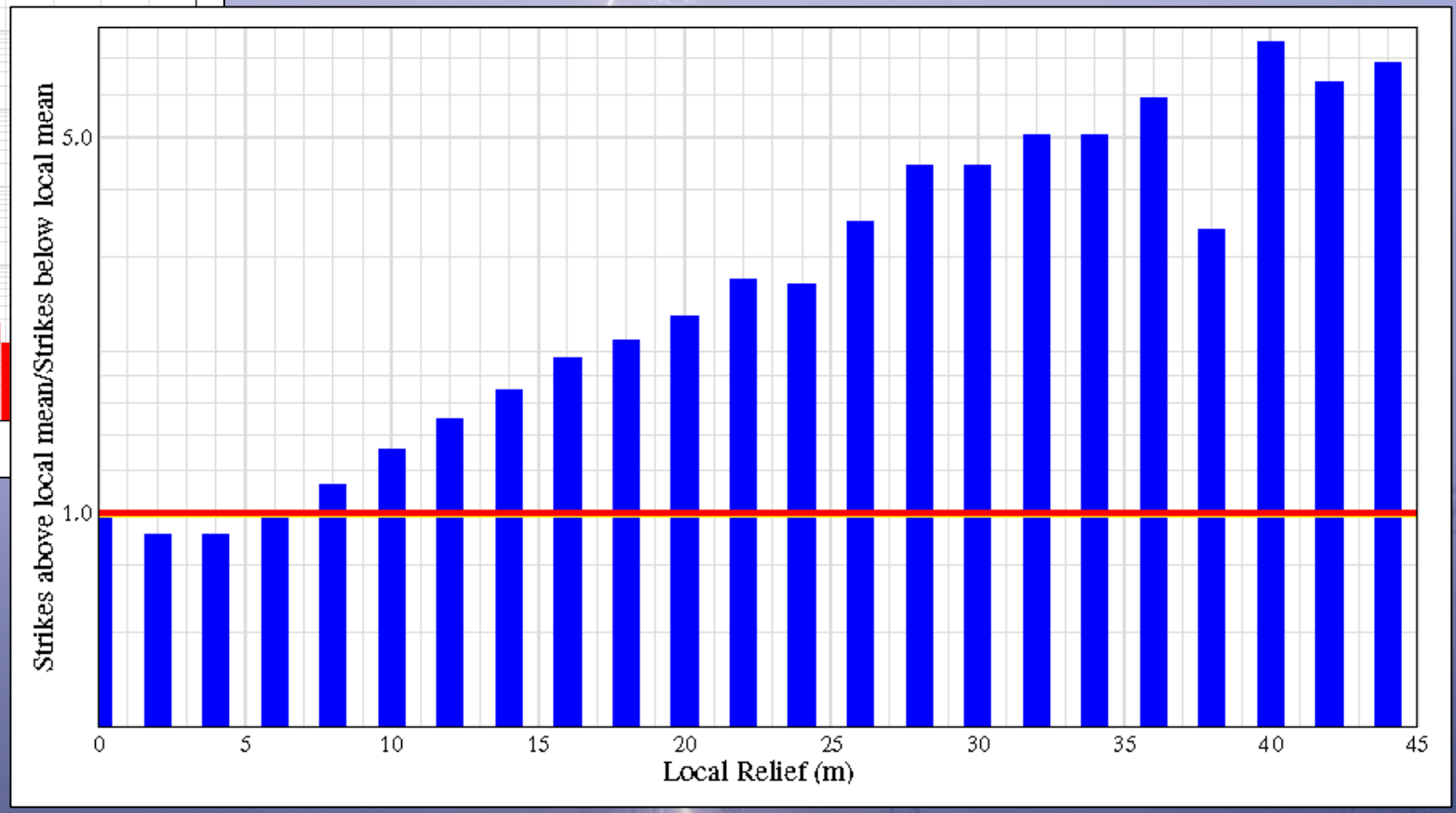
Assuming a typical sedimentary rock has 5% porosity, the electrical conductivity of rocks is $5.0 * 10^{-4}$ $S.m^{-1}$, or about 10^{10} times the conductivity of air.



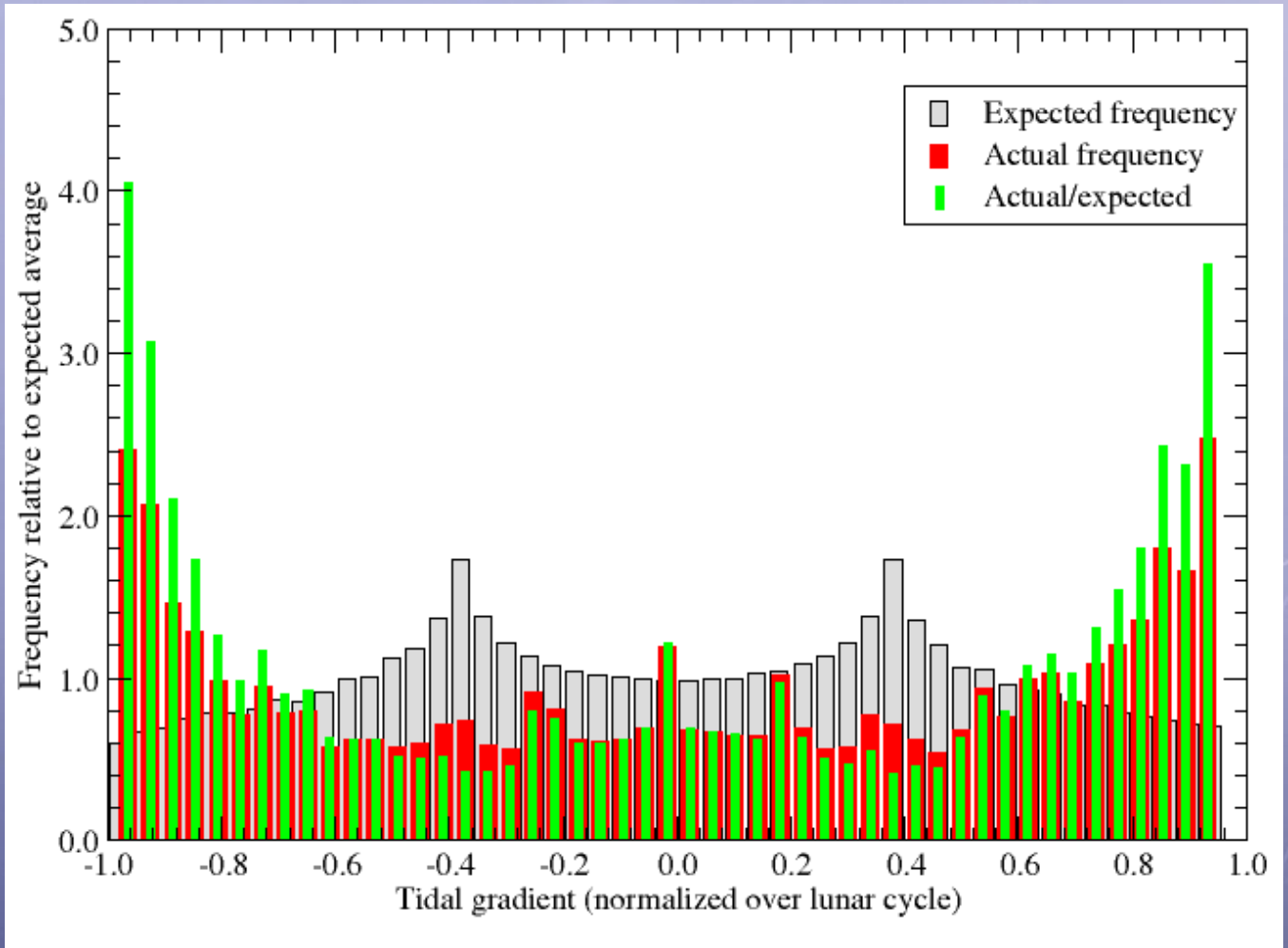
Rock Conductivity Graph computed for a porous rock with 100% brine saturation using Archie's equation

Linear increase in number of lightning strikes with local relief, shows atmosphere's insulating limits





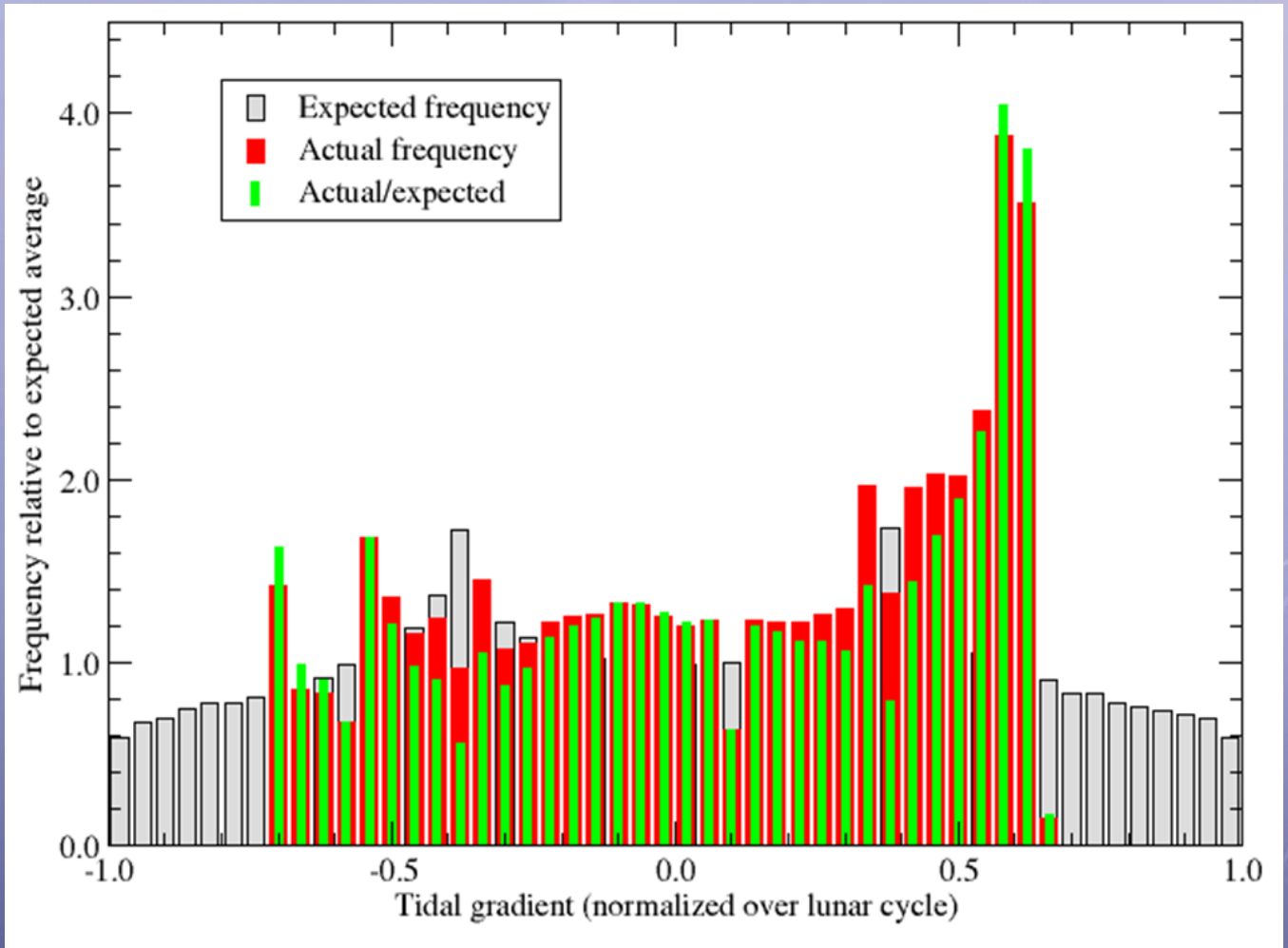
Tidal Gradient North Texas



Similar to several other studies:

- More strikes at both maximum flood and maximum ebb
- Believe it is because tides open or close faults a little bit and increase conductivity

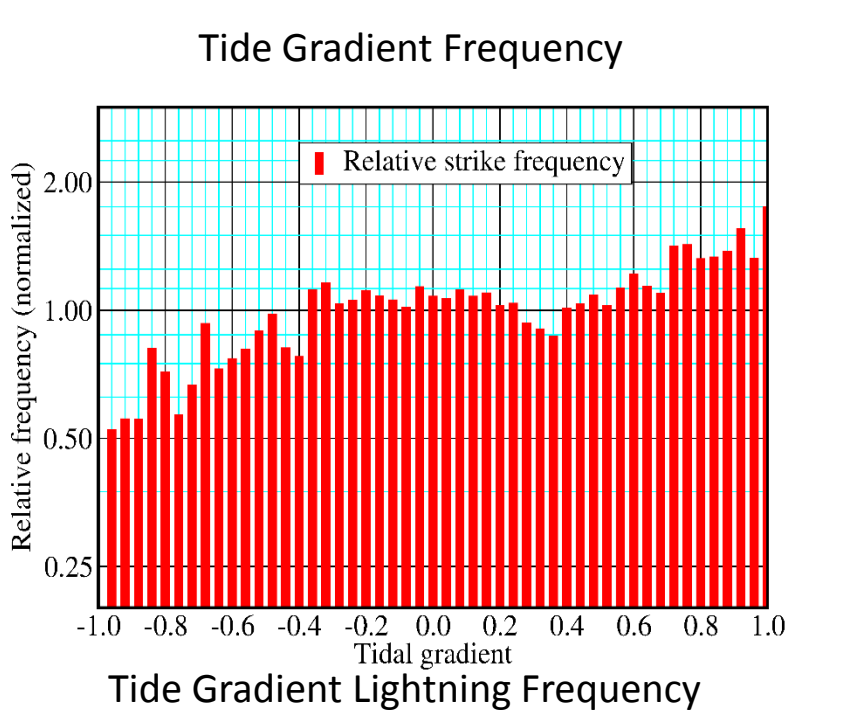
Tidal Gradient in Swampy Area

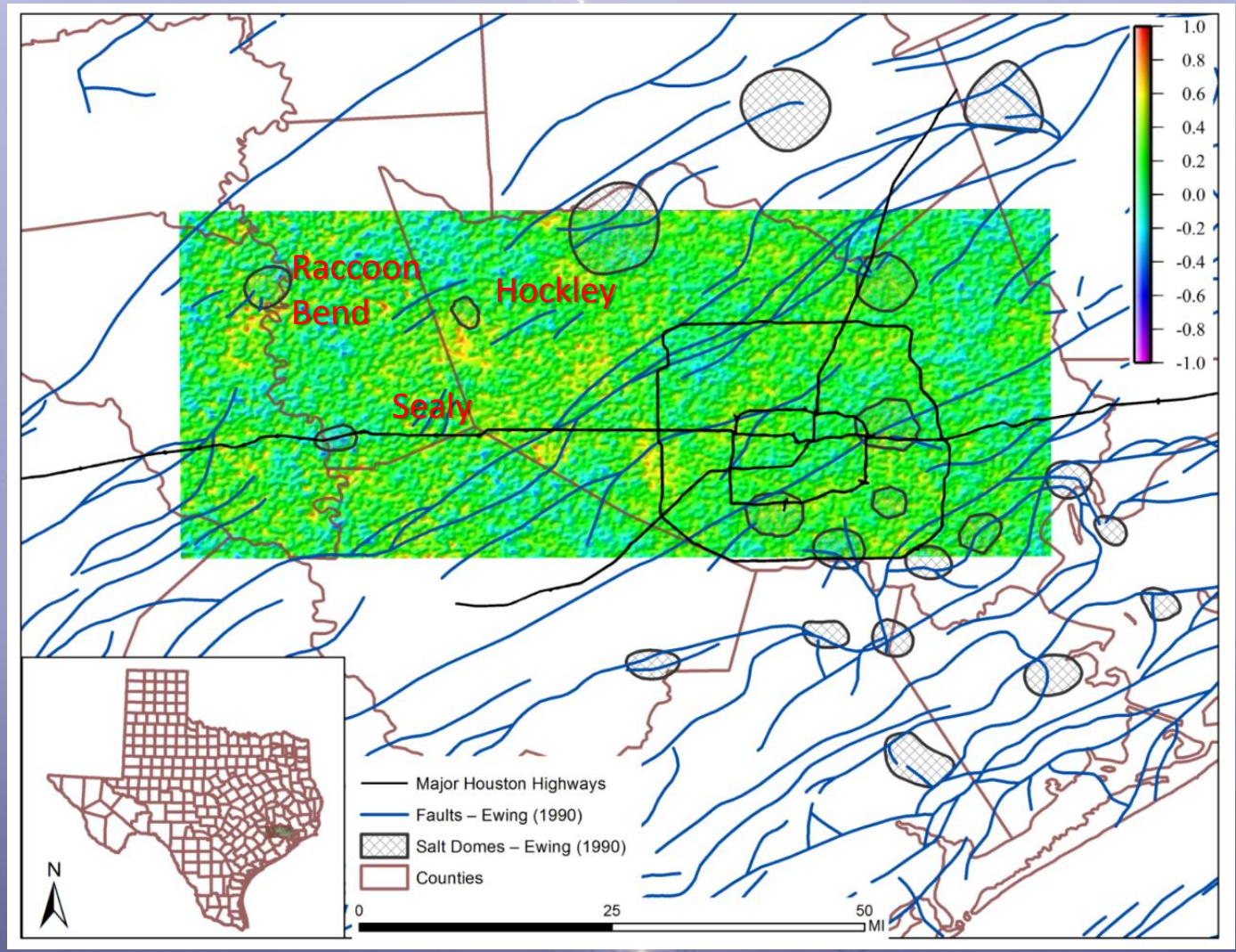


In swamps:

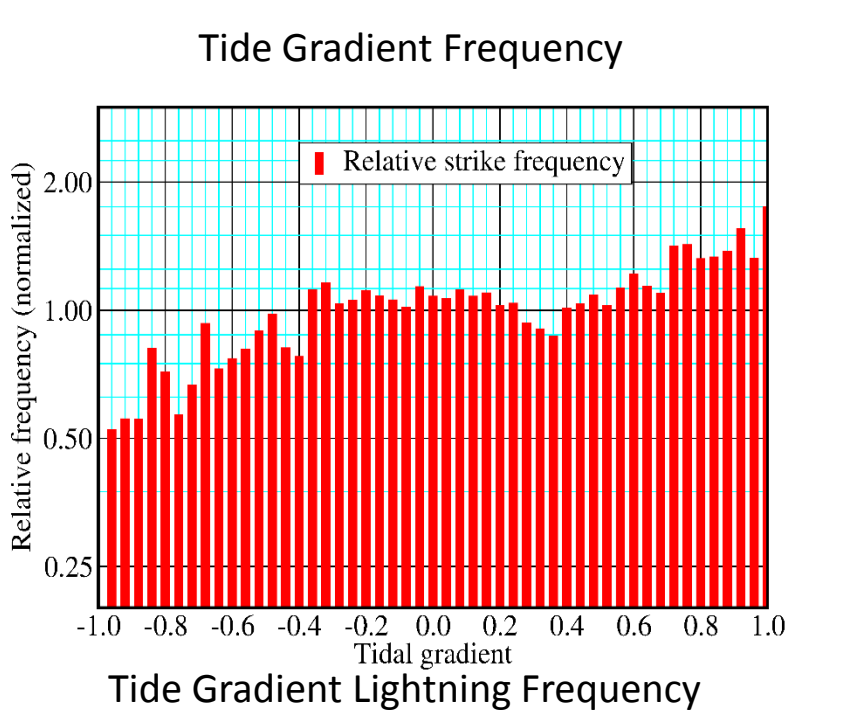
- No strikes at maximum flood or maximum ebb
- Area within a meter of sea level
- Believe tides wash out both biogenic and thermogenic methane
- Most strikes just past half flood

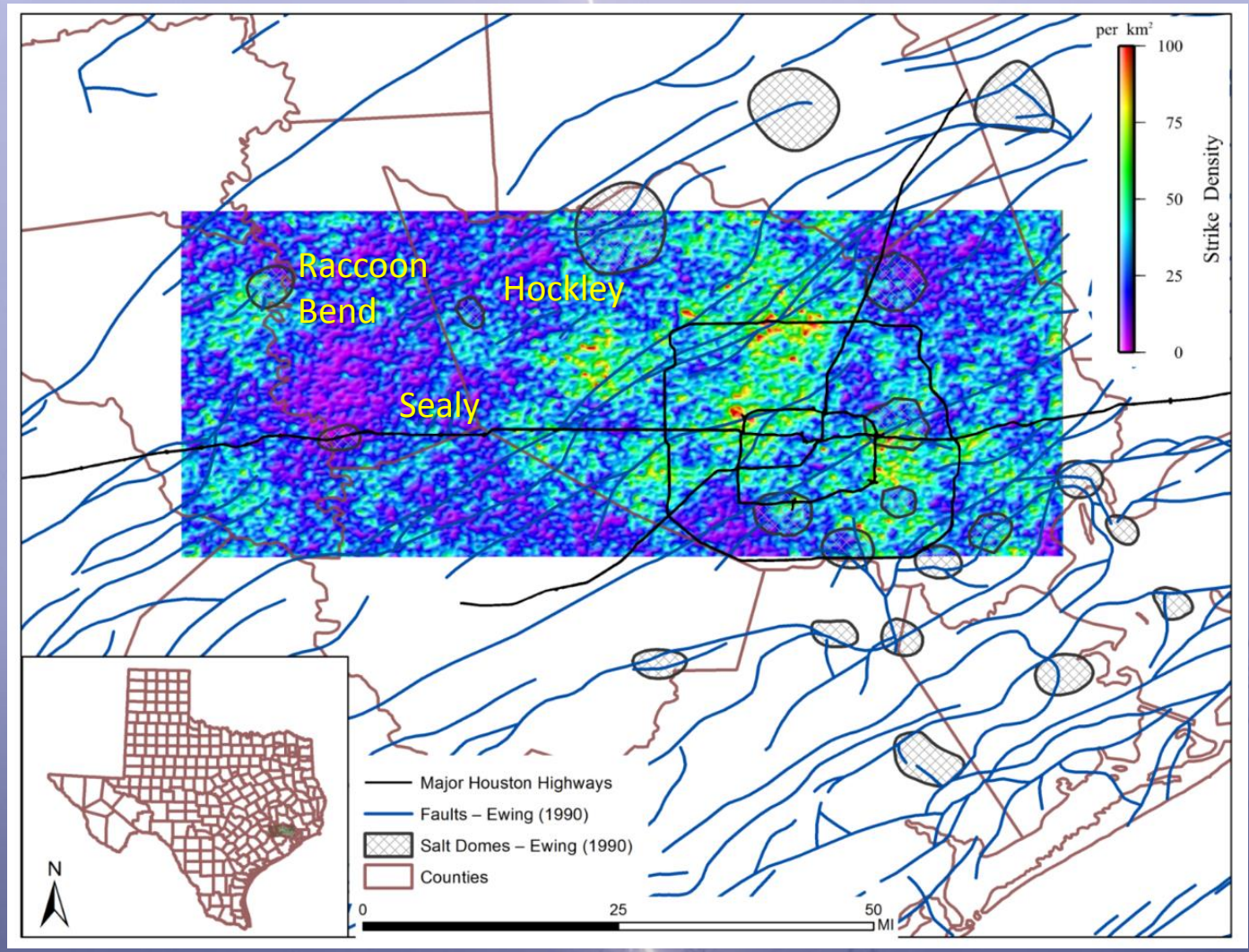
Tidal Gradient when Strikes Occur





Strike Density at High Tidal Gradient





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

Plate 2

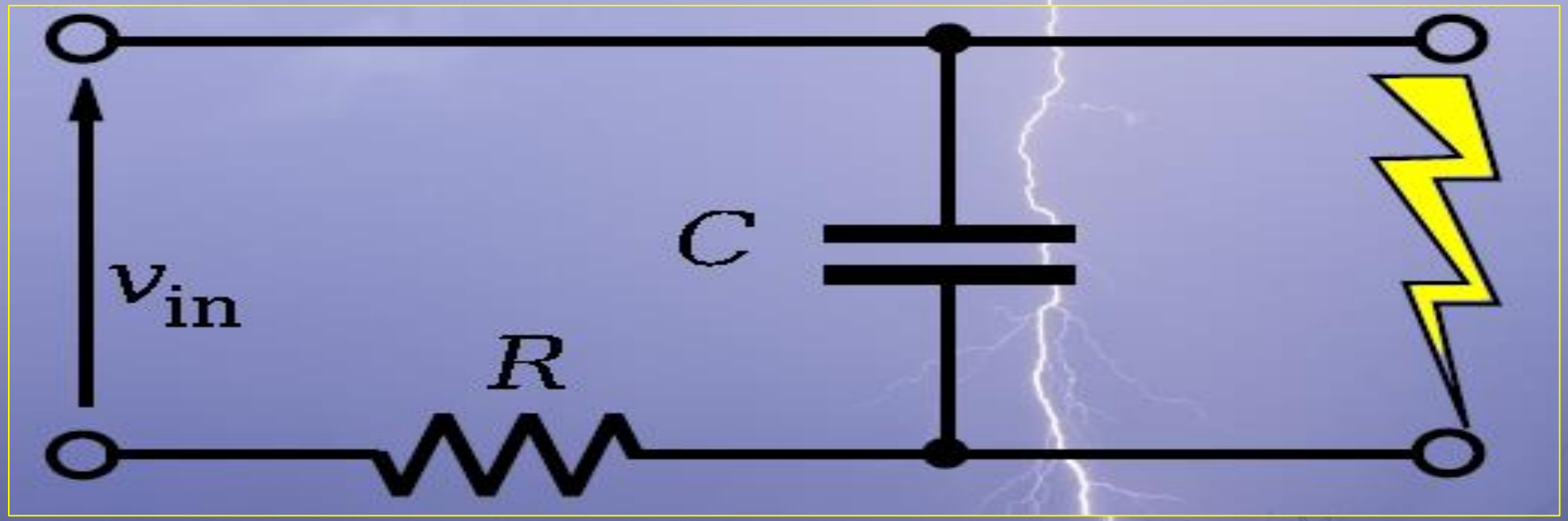
Dielectric

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.

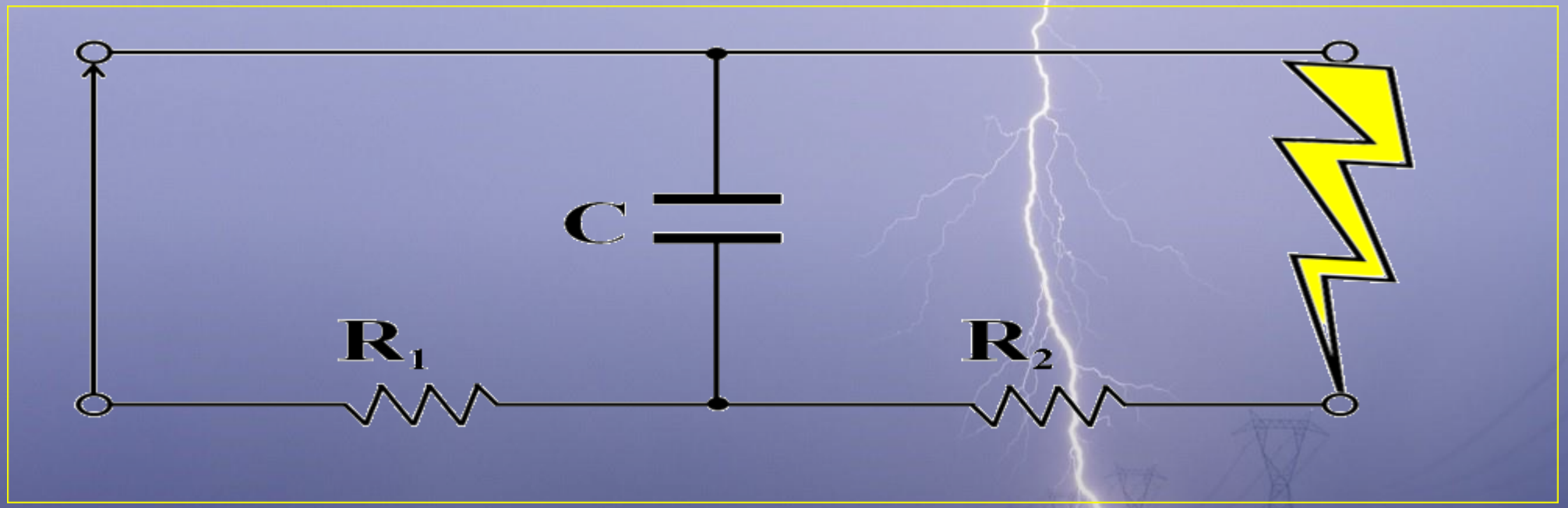
Relaxation Oscillator

- 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



Lightning Physics

- 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

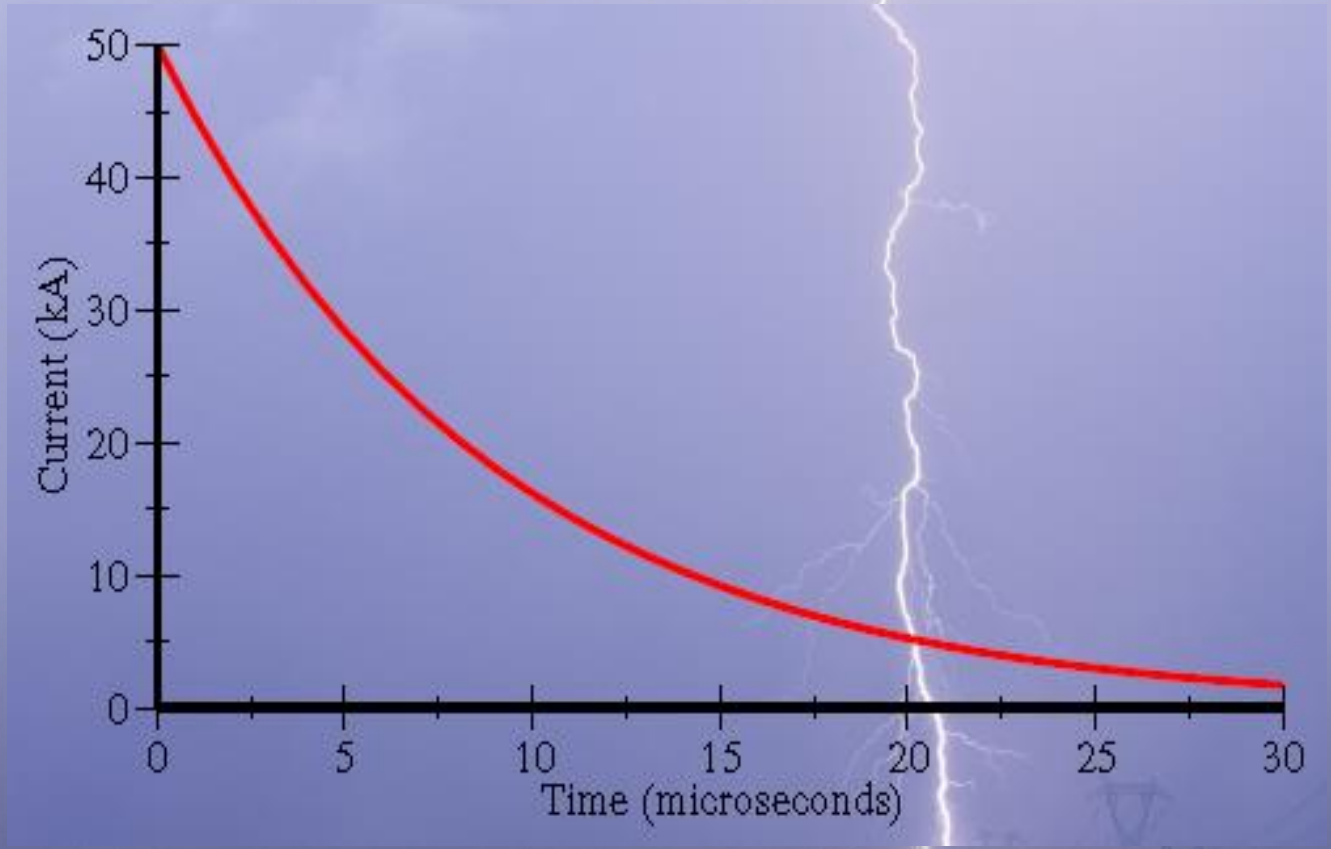


Relaxation Oscillator Physics

- When a relaxation oscillator triggers, the discharge current decays exponentially
- The rate of decay is given by $I_t = I_0 e^{-t/RC}$
- If lightning is similar, can we use the decay to measure resistance?
  - This equation can be rearranged to $ln(\frac{I_t}{I_0}) = -\frac{t}{RC}$ or $R = -\frac{t}{ln(\frac{I_t}{I_0})C}$
  - All we need is the current at two times (I_0 and I_t), and the capacitance (C) to get the resistance R

How do we measure Decay

- Lightning measurements do not give this kind of continuous decay.
- We have two values:
  - Peak current
  - Peak to zero time



The Available Measurements

- Two points on an exponential curve will define the curve

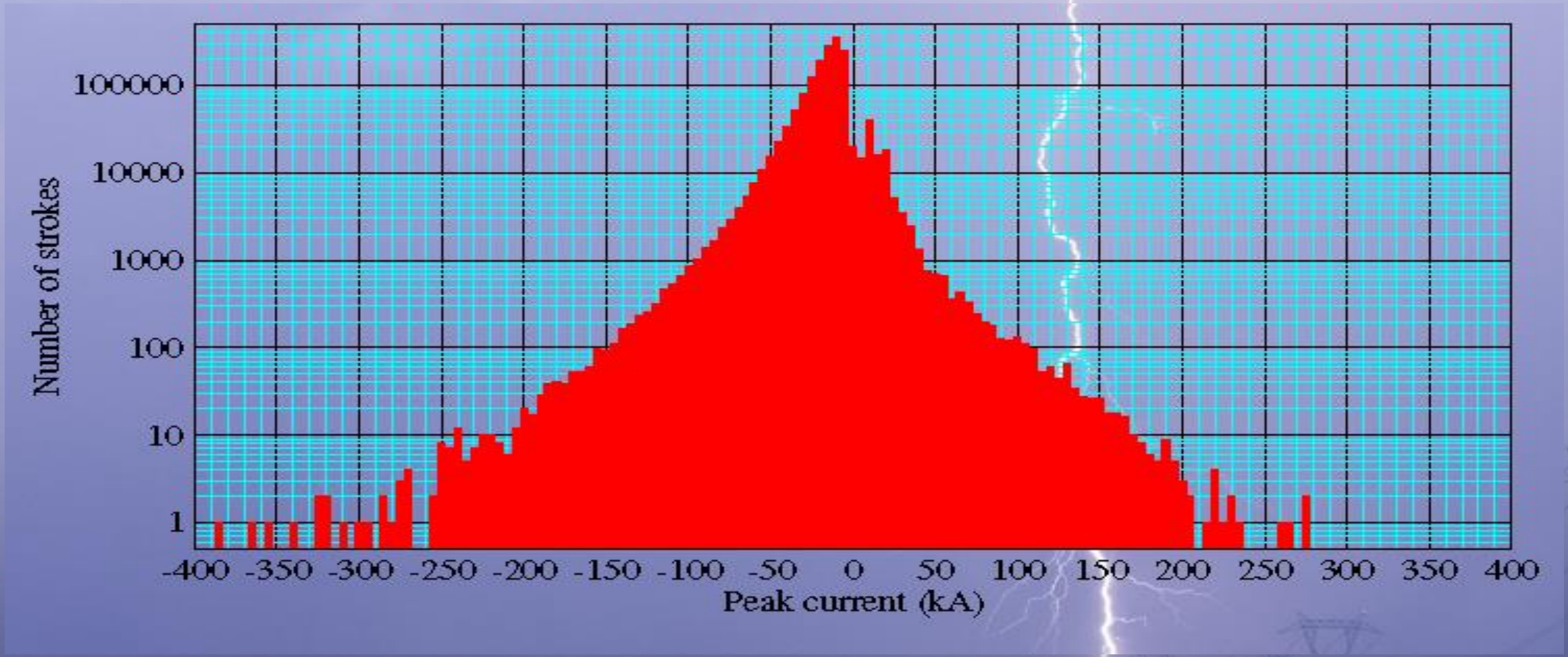
Peak Current:

- The maximum recorded current, when decay starts (I_0)

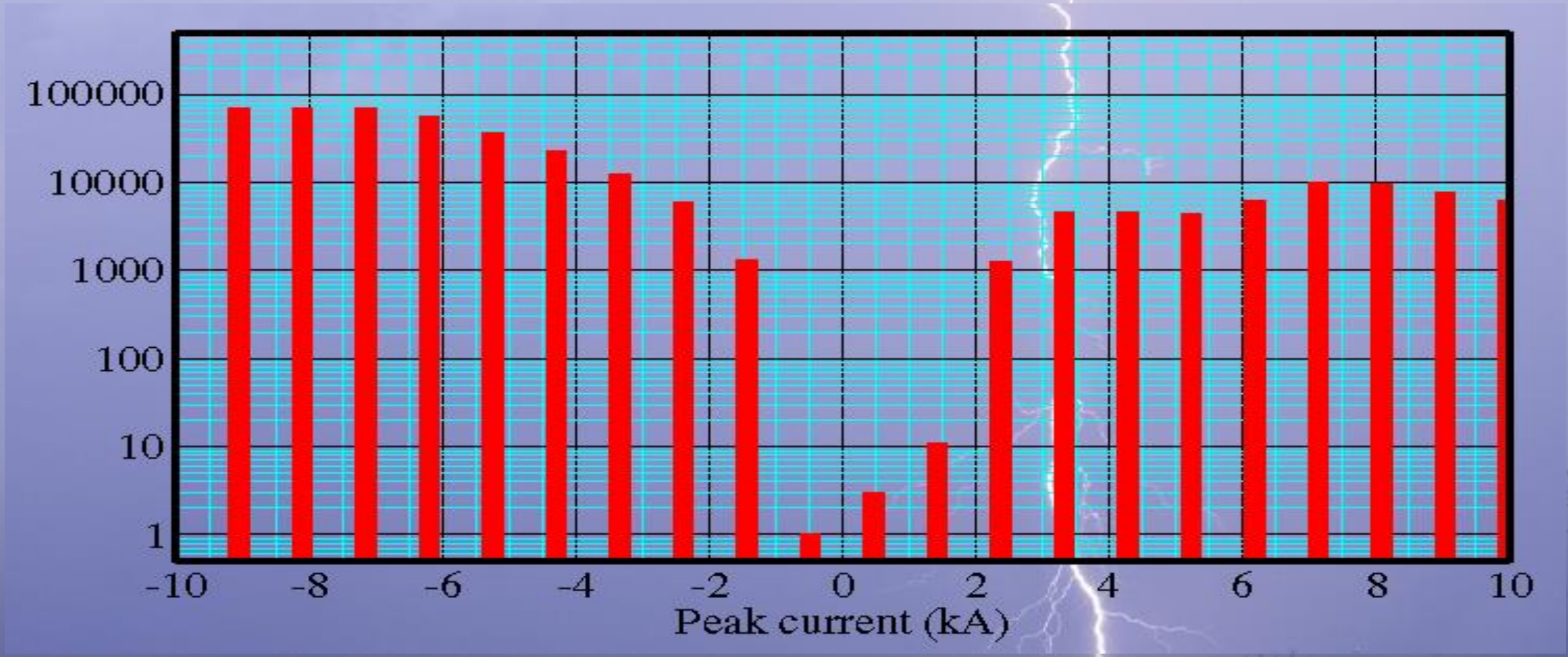
Peak-to-Zero time:

- The elapsed time from the instant of Peak Current until the recorded signal disappears into the background noise.
- This gives us the time *t*.
- But what is the current (I_t)?
- The time for current to decay to a real zero is infinite.
- We need an estimate of the magnitude of the "zero" current (at time *t*) in order to compute resistance.

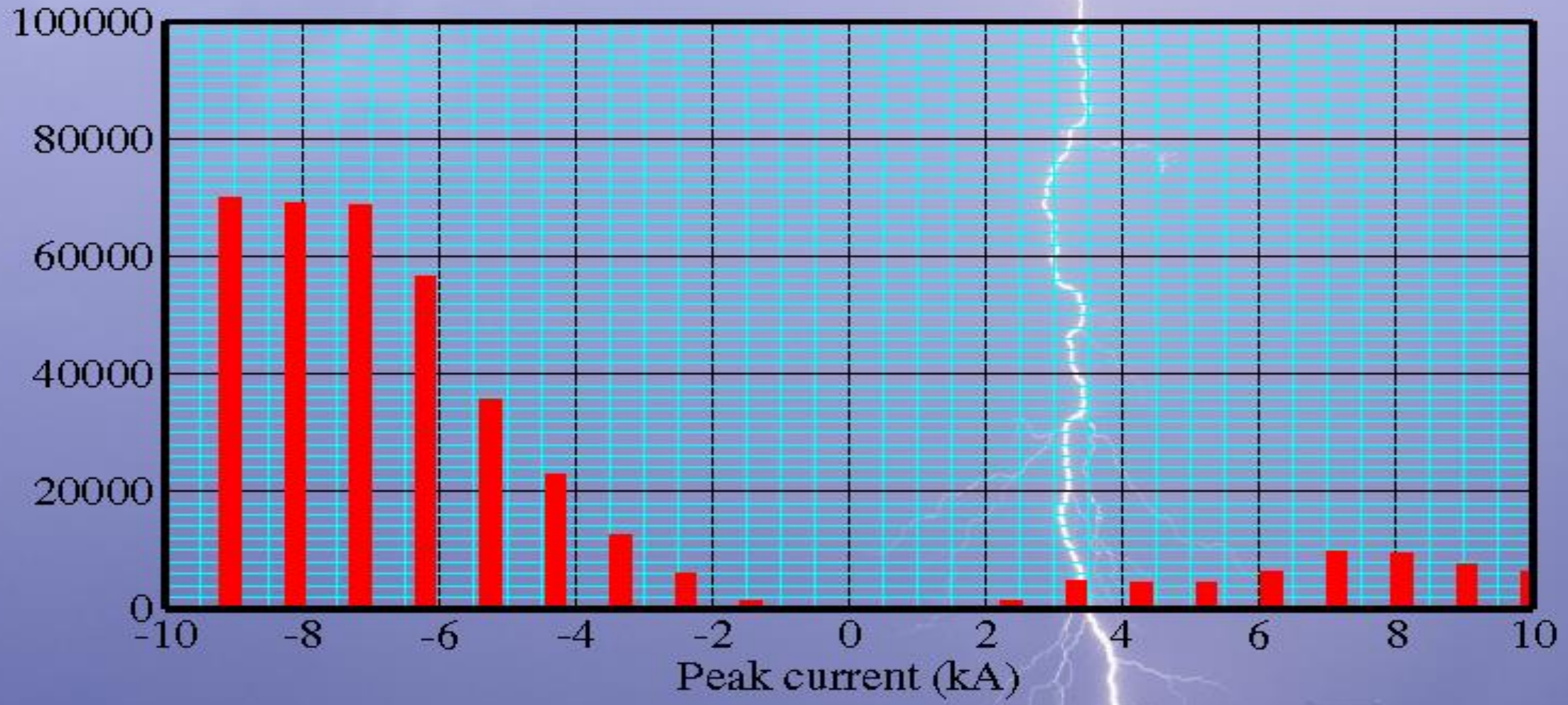
What is "Zero" Current?
Histogram of peak current for 1.6 million strikes



What is Zero Current?



What is Zero Current?



What is Zero Current?

- Total strikes 1.6 million
- 320,000 less than 10 kA absolute peak current
- 30,400 less than 5 kA absolute peak current
- 13,260 less than 4 kA absolute peak current
- 2,579 less than 3 kA absolute peak current
- 15 less than 2 kA absolute peak current
- “Zero” current assumed to be 1 kA

What About Voltage?

- Resistance is equal to voltage/current.
- Our measurements are of current only.
- But the equation gives a solution with capacitance rather than voltage.
- However, how do we find capacitance?
- Capacitance depends on permittivity, plate area, and plate separation.
- While permittivity is approximately constant and known for air, assumptions for area and separation are needed to solve for resistance.

The Assumptions

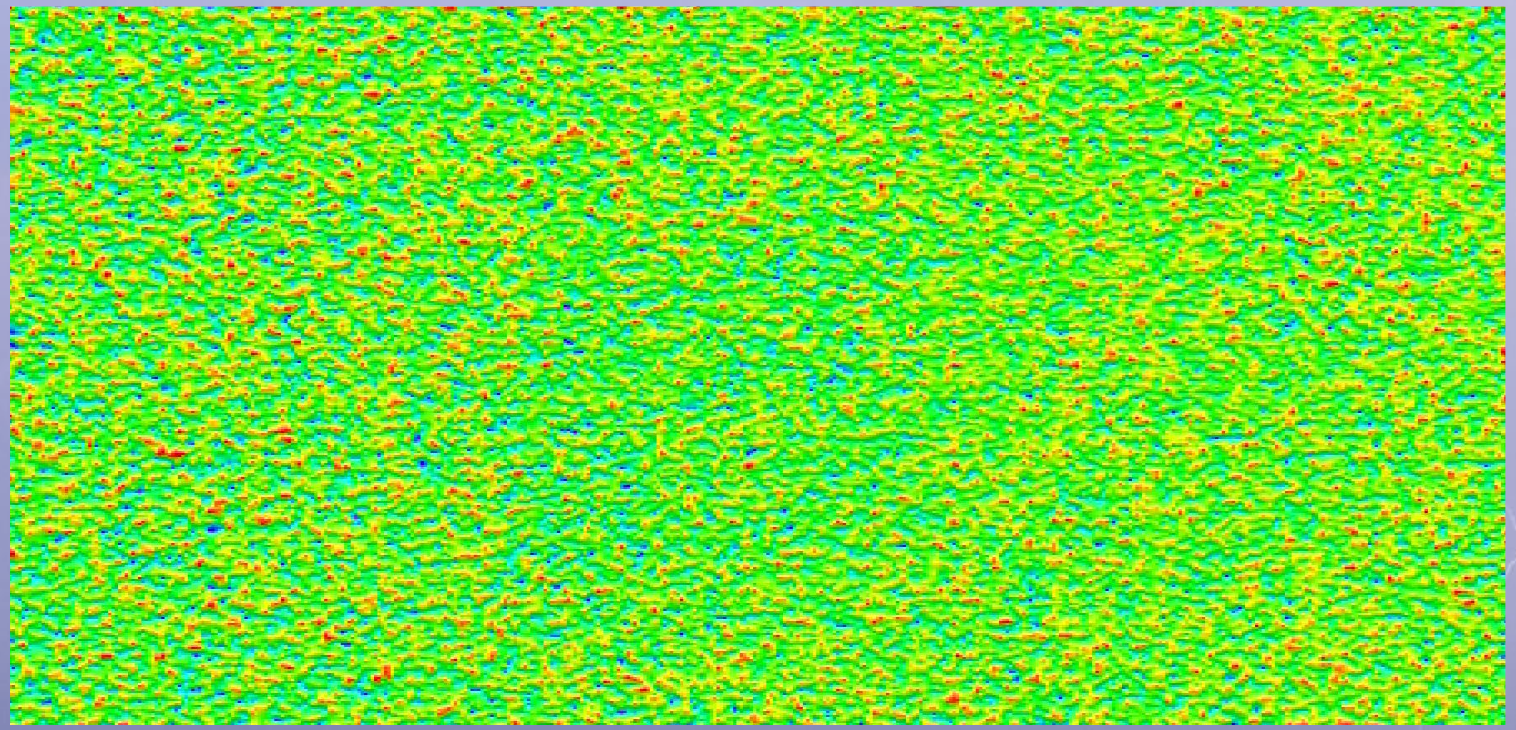
1. Voltage is proportional to peak current (within a local area).
2. Cloud height is proportional to voltage because the dielectric strength of air is more or less constant.
   - This gives plate separation for the atmospheric capacitor
3. The effective capacitor is circular, with a radius proportional to cloud height.
   - This gives plate area for the capacitor
4. With over 100 lightning strikes per square kilometer in the database in many areas, we can stack results to improve signal-to-noise ratio

What is Resistivity?

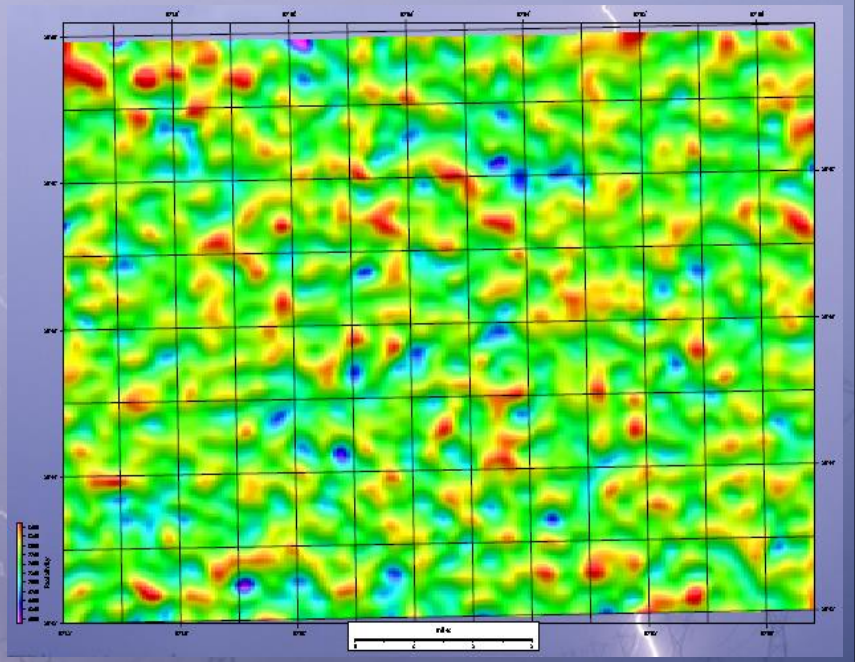
- Resistivity is resistance times cross-sectional area of a conductor, divided by its length; or $\rho = \frac{R \times A}{l}$
- For the lightning energy dissipating in the ground:
  - The area is very small at the strike point, but increases rapidly
  - The length is very short for discharging the charge close to the strike point, but for points near the edge of the effective capacitor, the length is much greater
- For low energy lightning, the resistivity measured is that of rocks close to the surface
- For higher energy lightning, the resistivity measured is an average of resistivities to greater depths.

Resistivity Maps

Houston Area



Milam County



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.

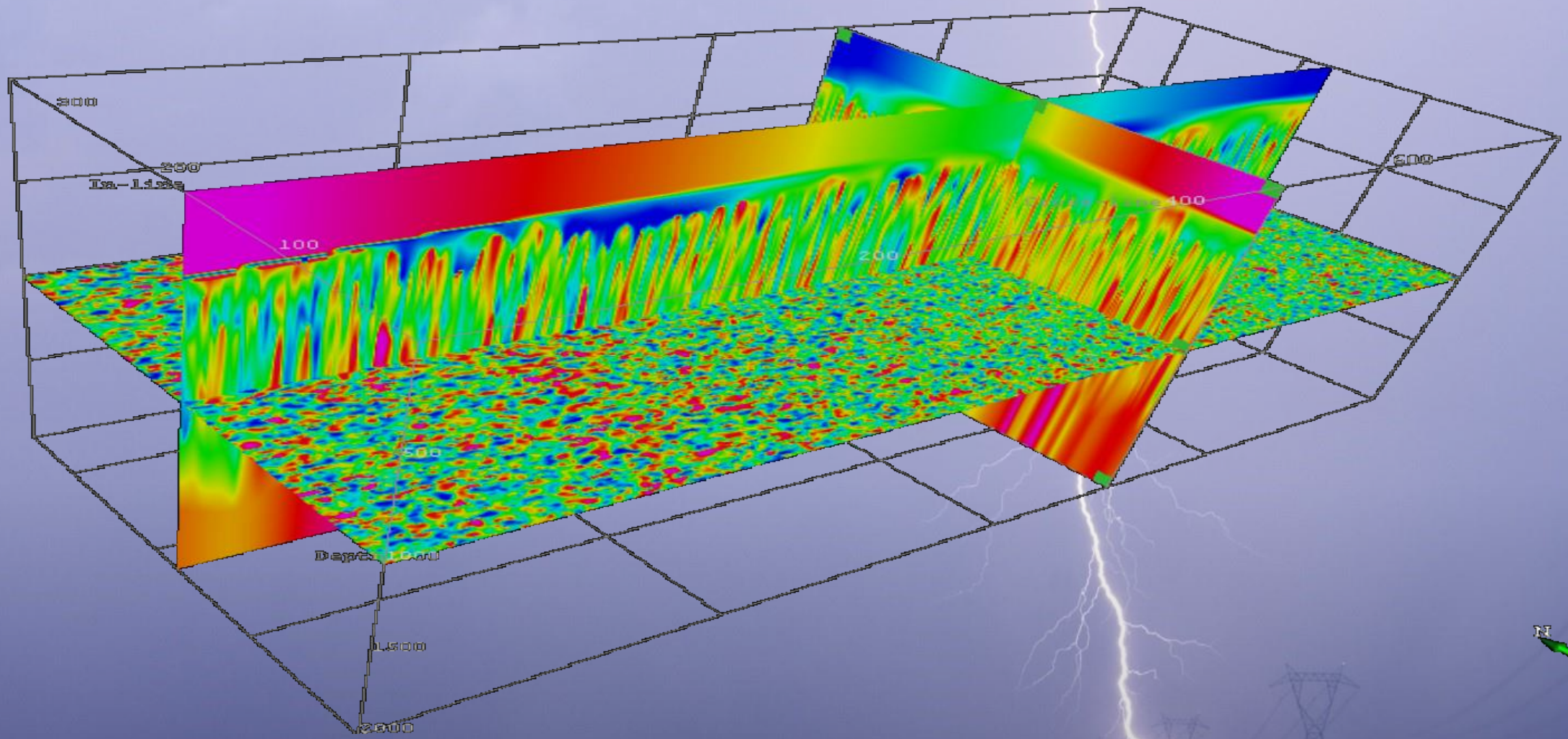
Determining Resistivity and Depth

1. Lightning data is divided into several groups (typically 10) by absolute peak current.
2. Each peak current group is divided into small (typically 0.03-0.04 km^2) cells by latitude and longitude.
   - Not all cells will contain a lightning strike, but some cells will contain more than one lightning strike.
3. For each cell in each group, resistivity and depth values are computed from the lightning data.
4. For each group a smooth surface is fitted to the depth values and to the resistivity values.
   - At any point in the project area, a number of depth/resistivity pairs equal to the number of groups in 1 can be produced by extracting grid values at that point.

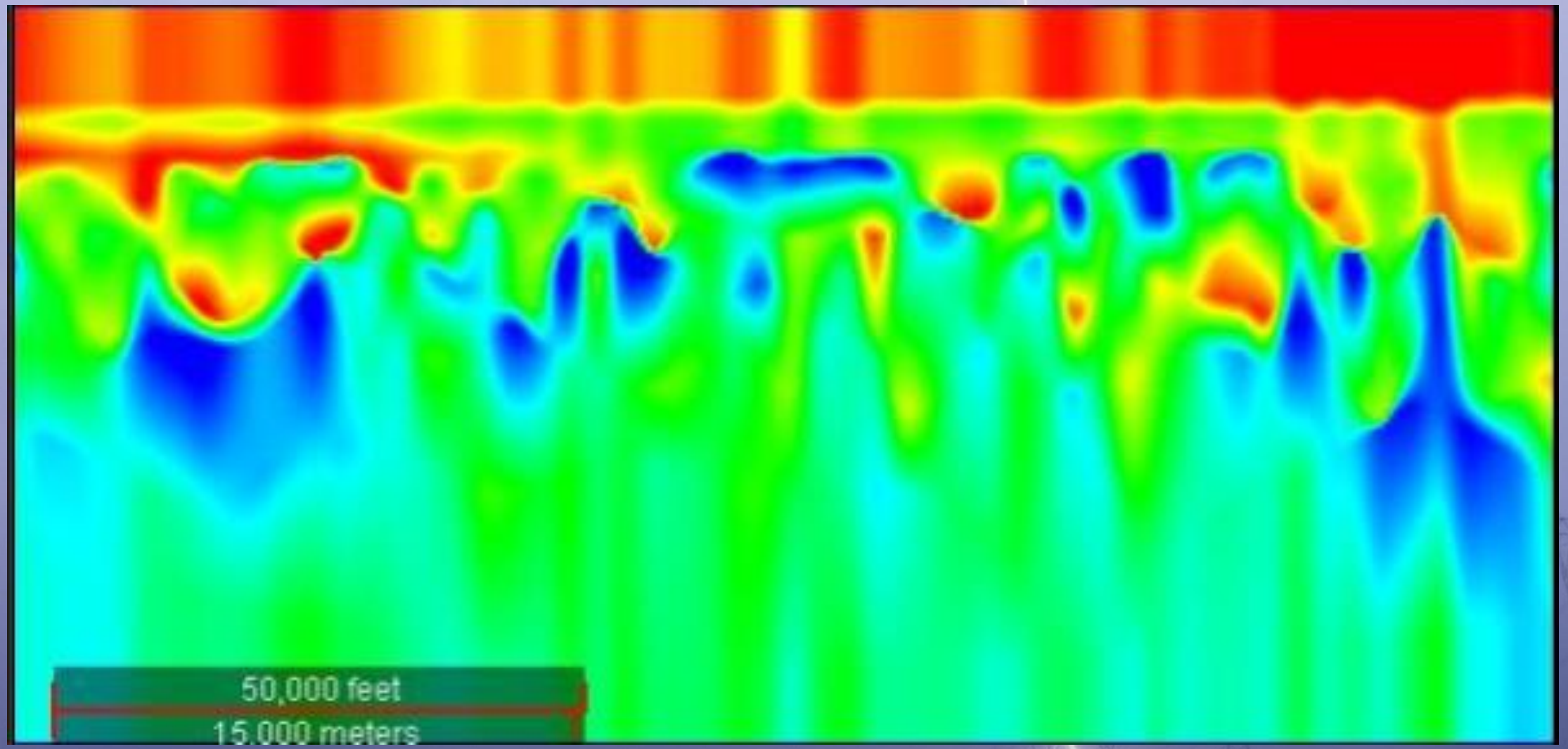
A Resistivity Trace

- 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.

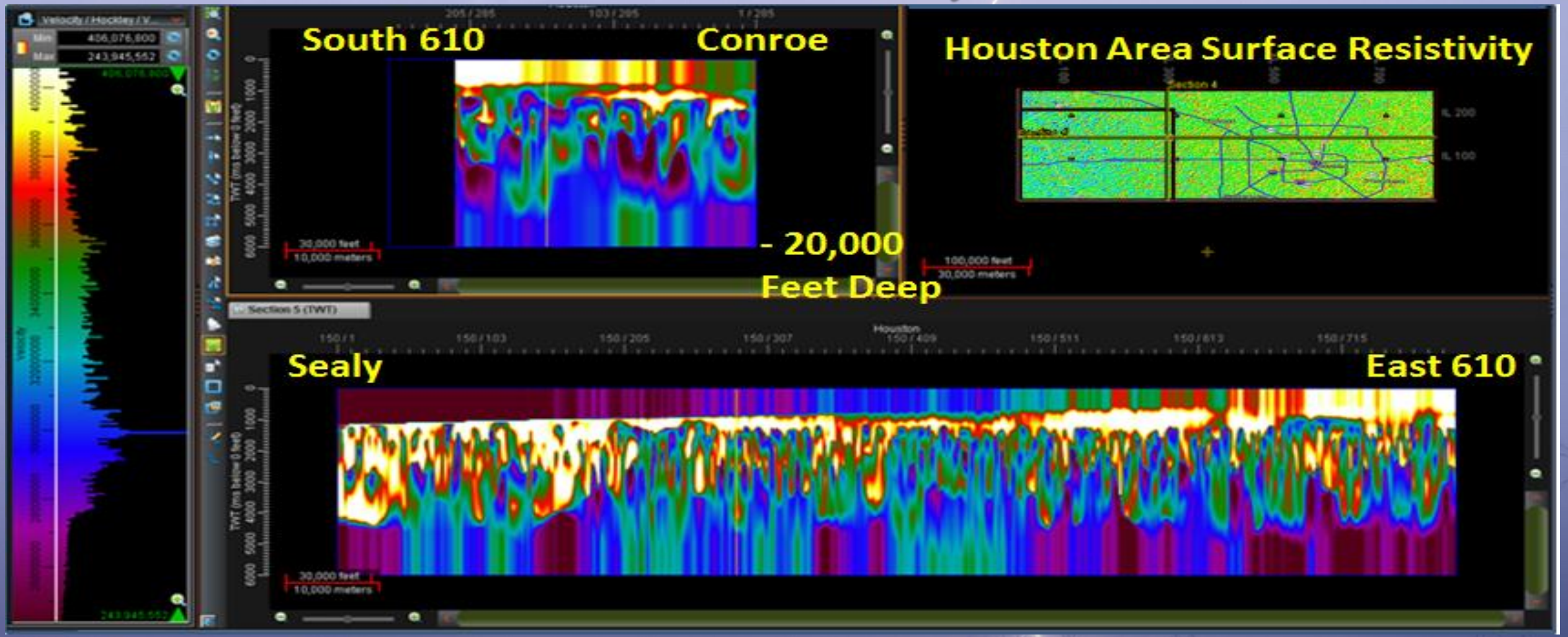
A Resistivity Volume



Resistivity Volume Cross-Section



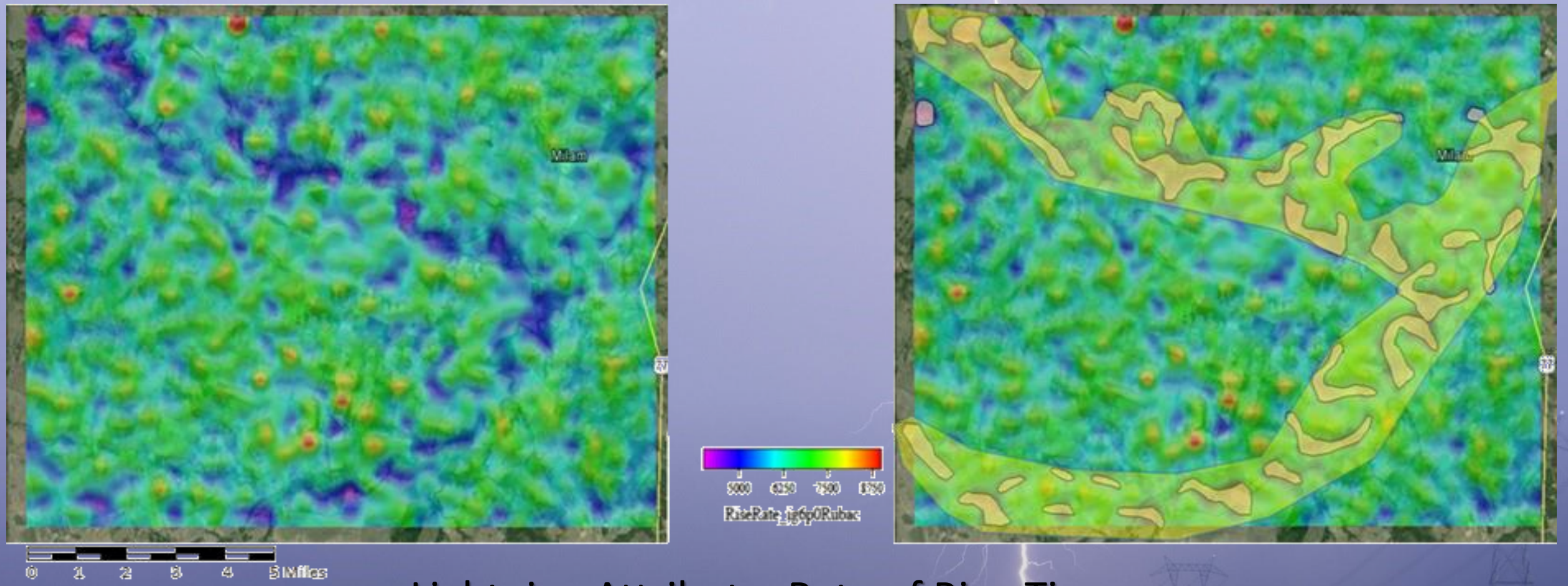
Resistivity Volumes
Define Subsurface Resistivity



Questions & Answers & Discussion

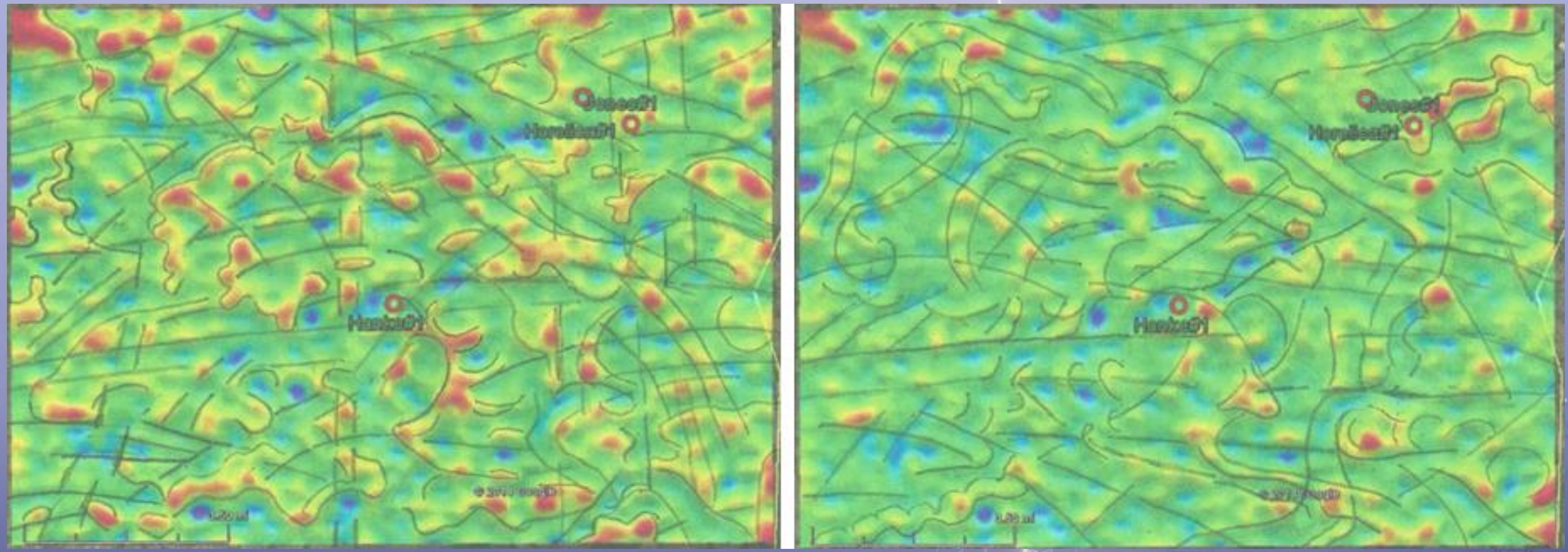
4. Examples of using lightning databases to map geology

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

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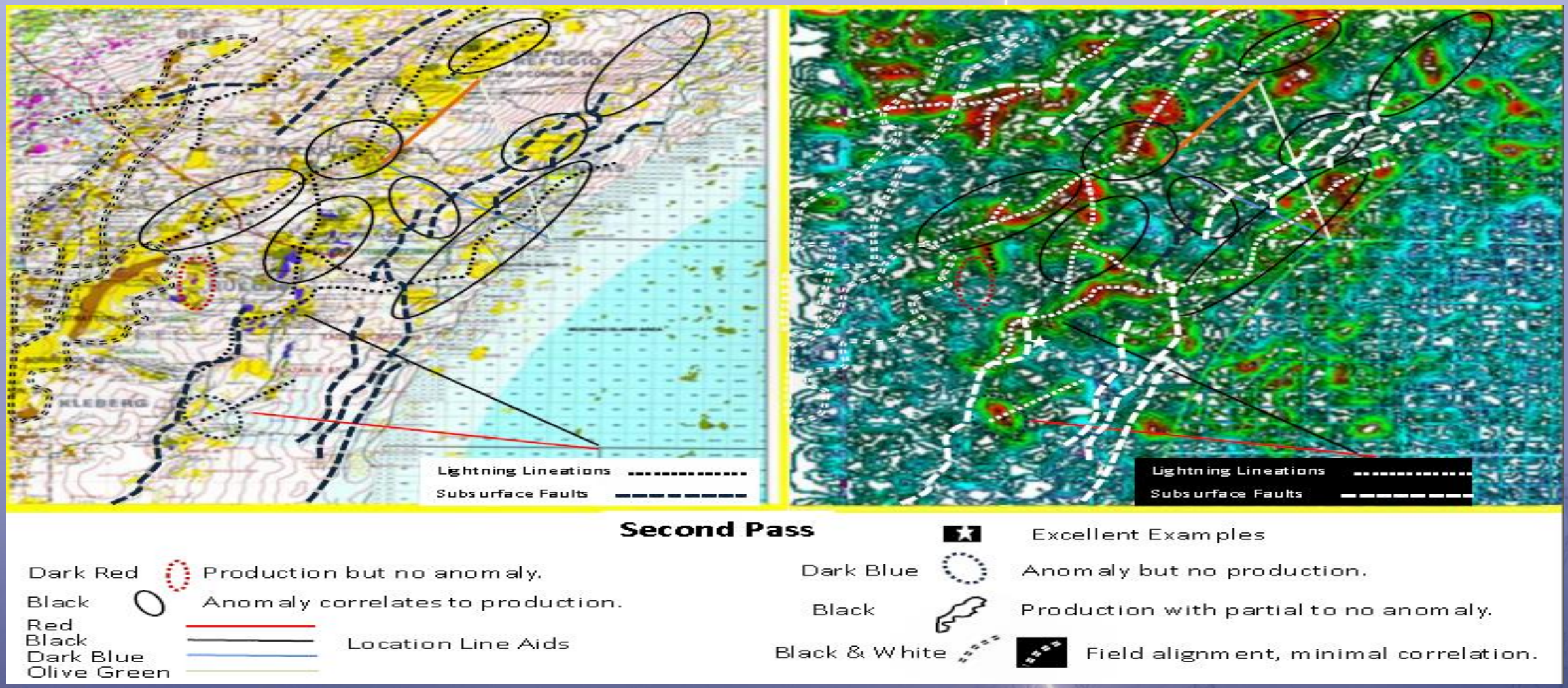
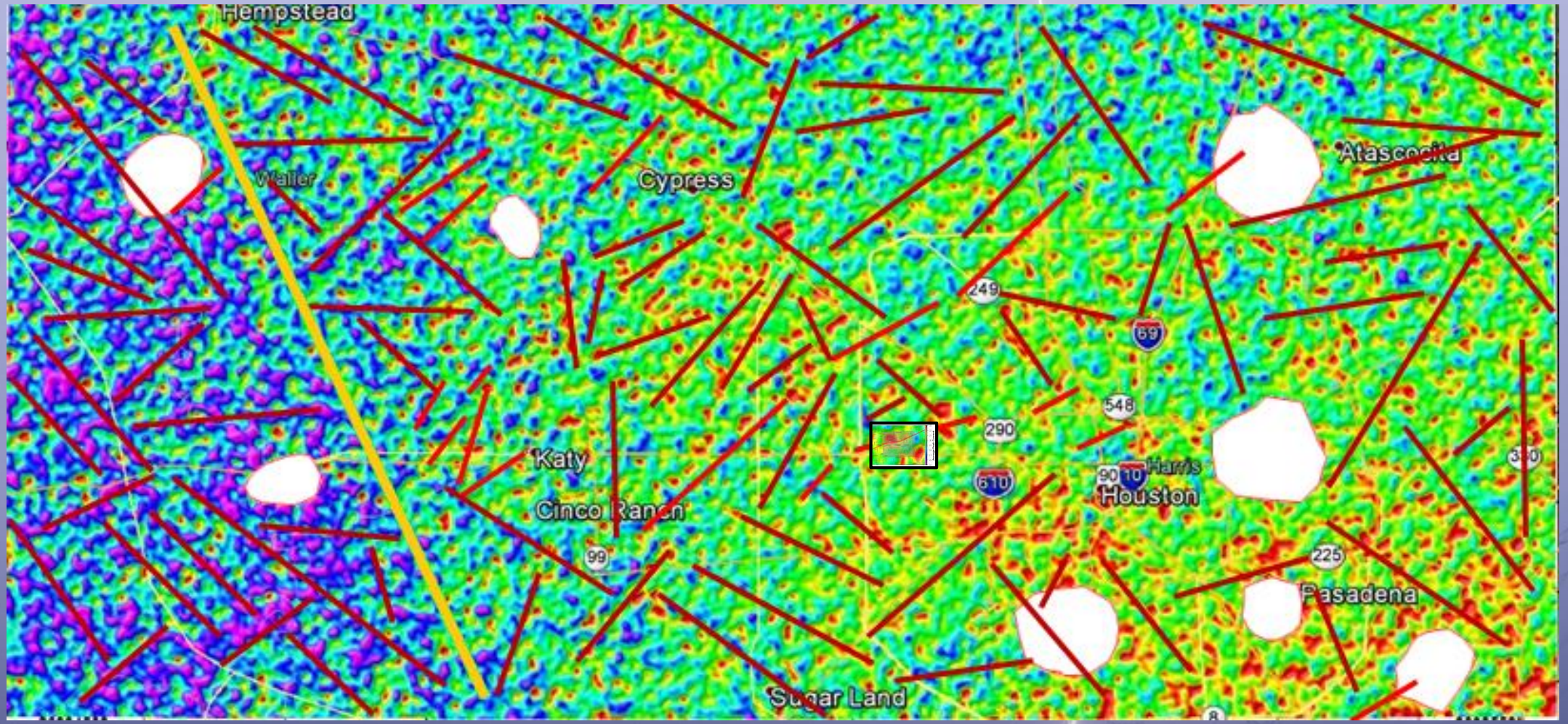
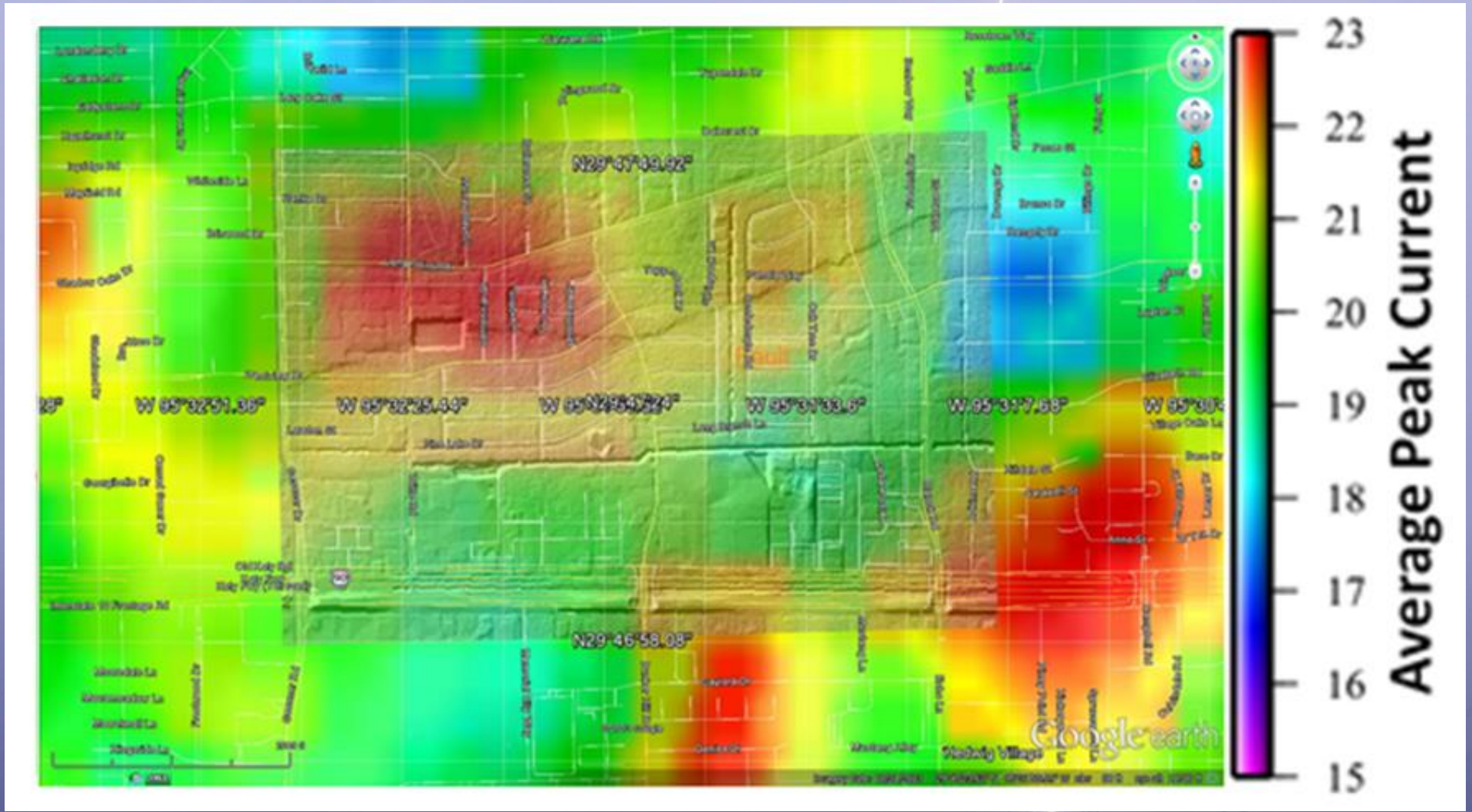


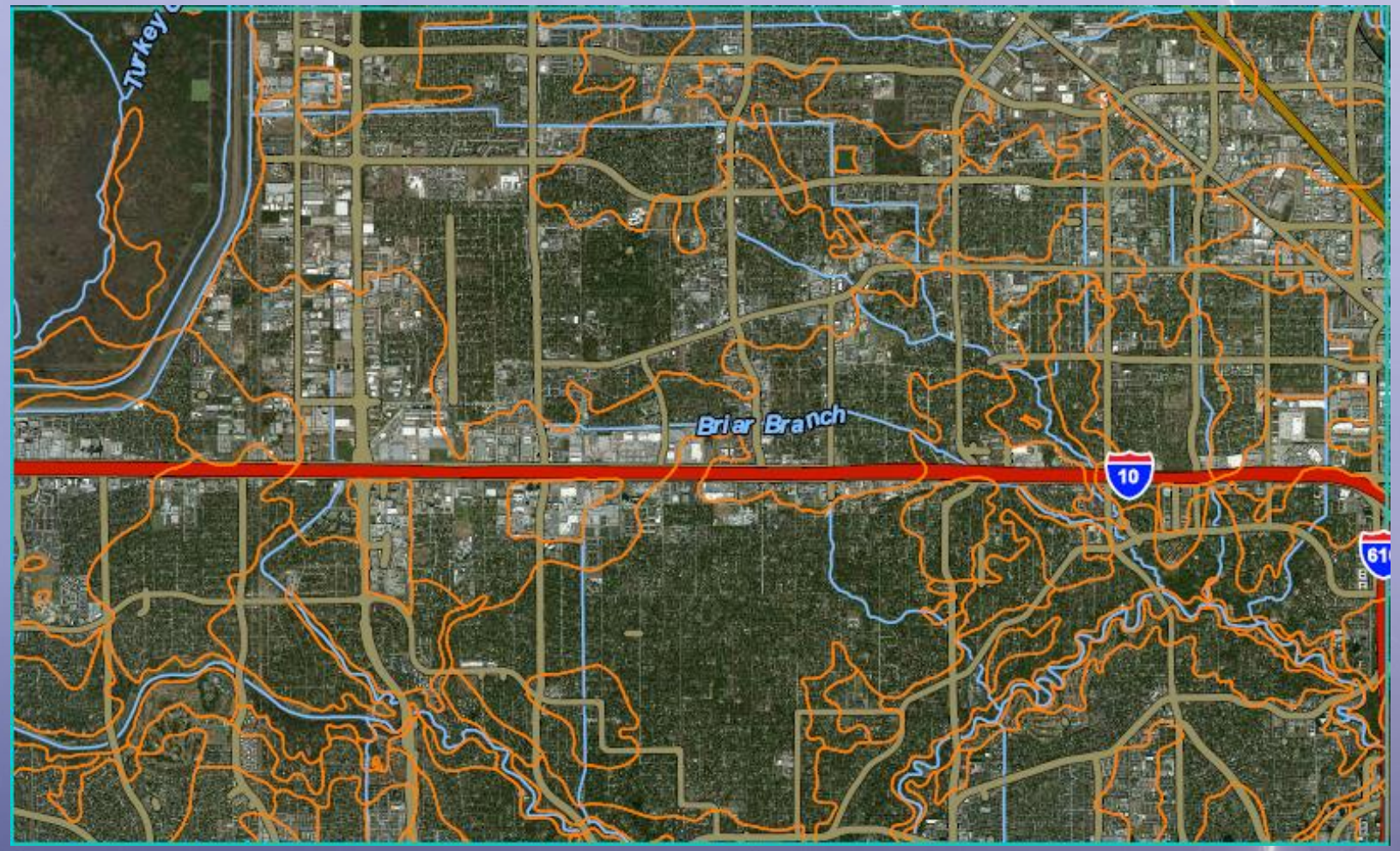
Peak Current from Sealy to East Houston



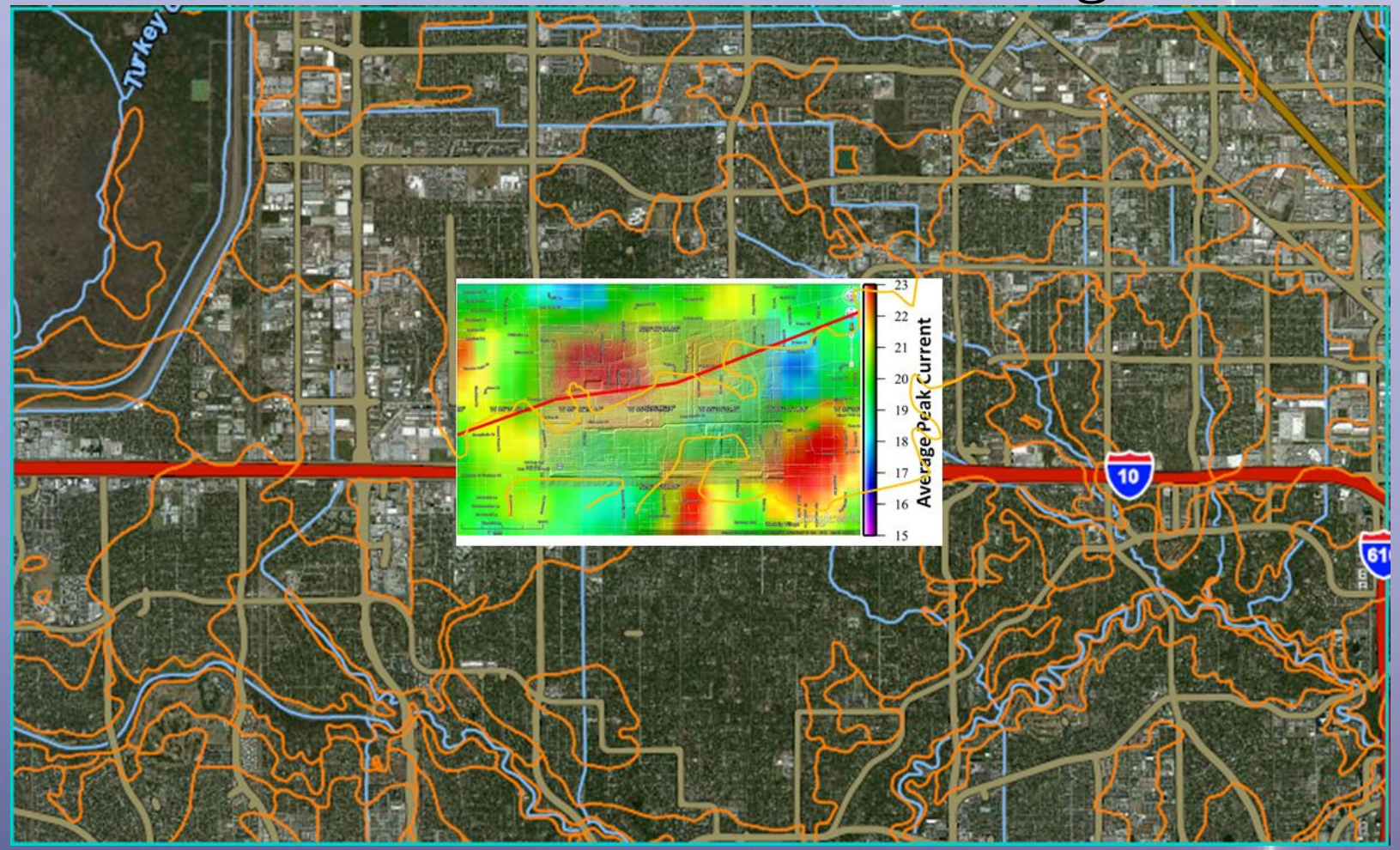
Peak Current Zoom with LIDAR & Long Point Fault



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

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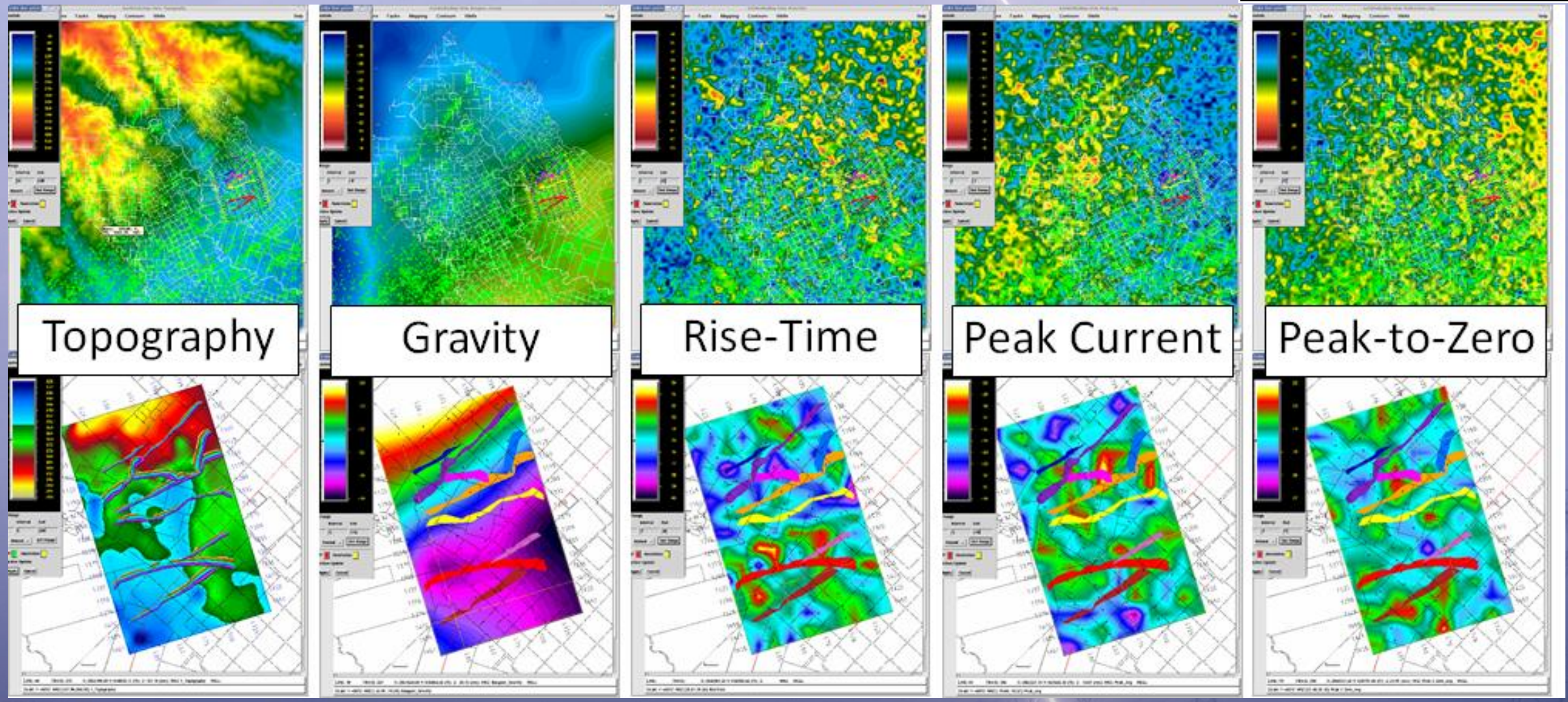
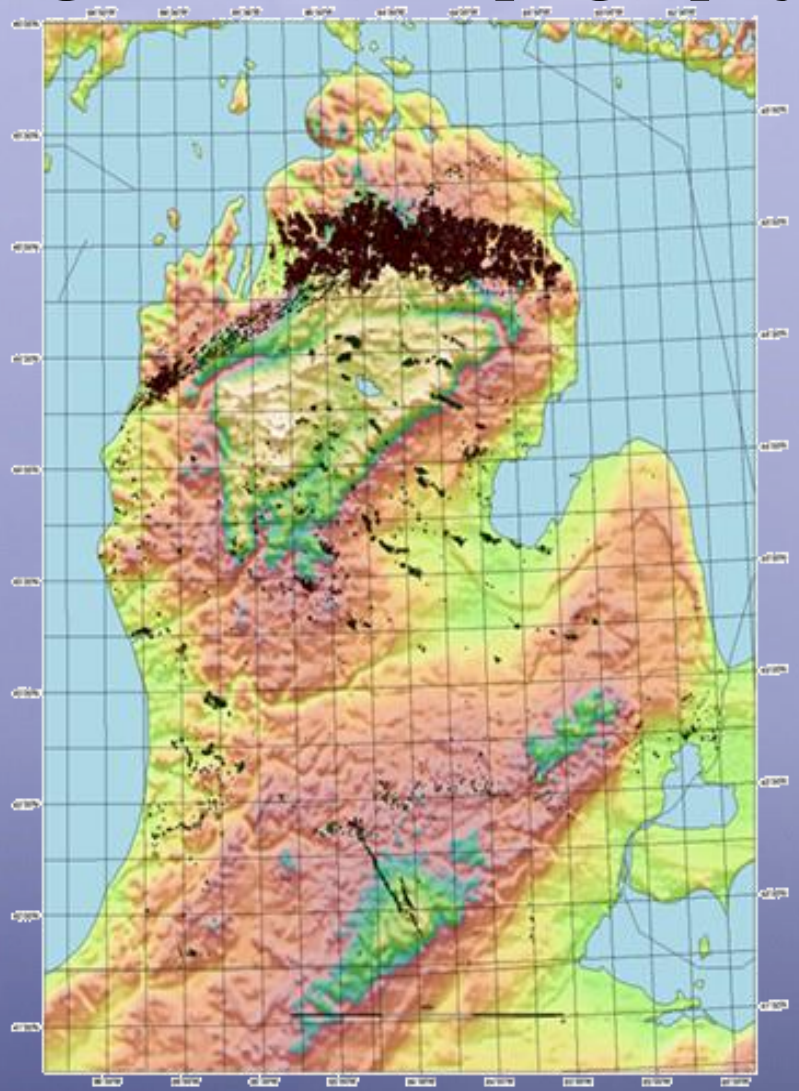
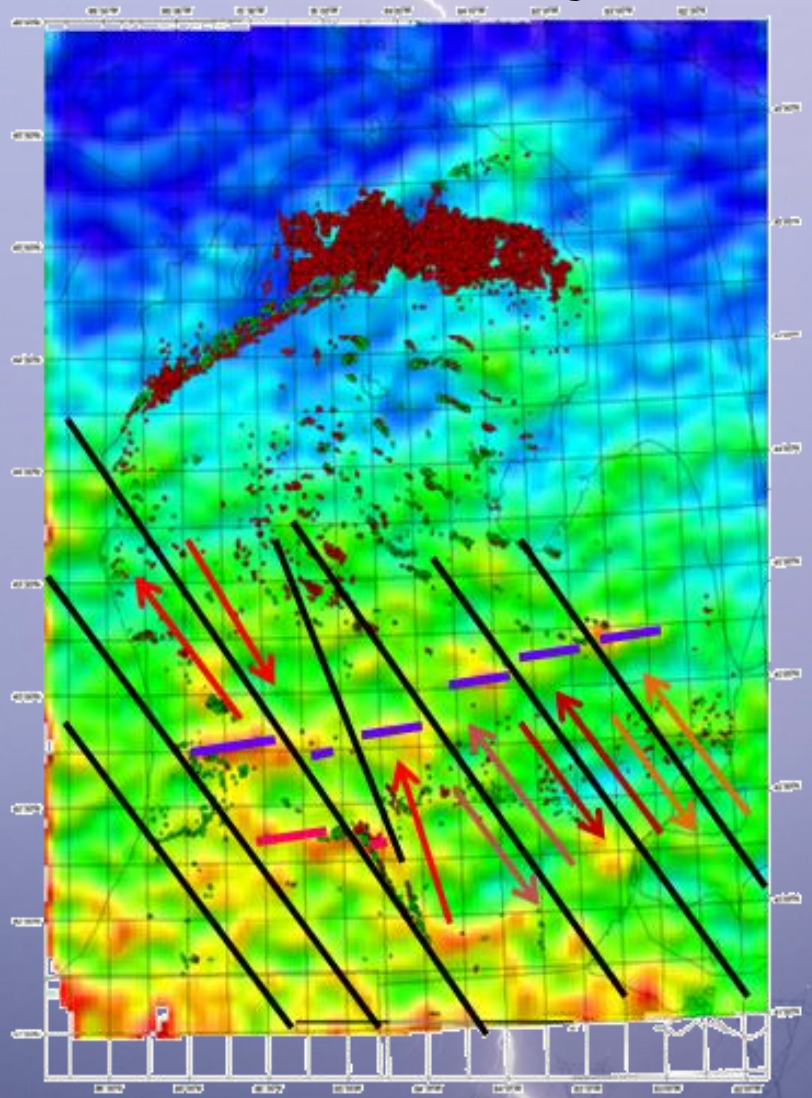
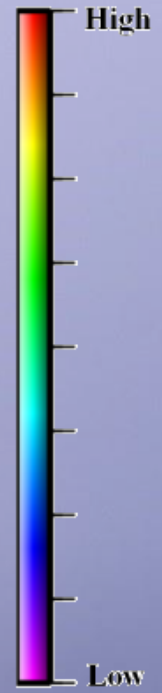


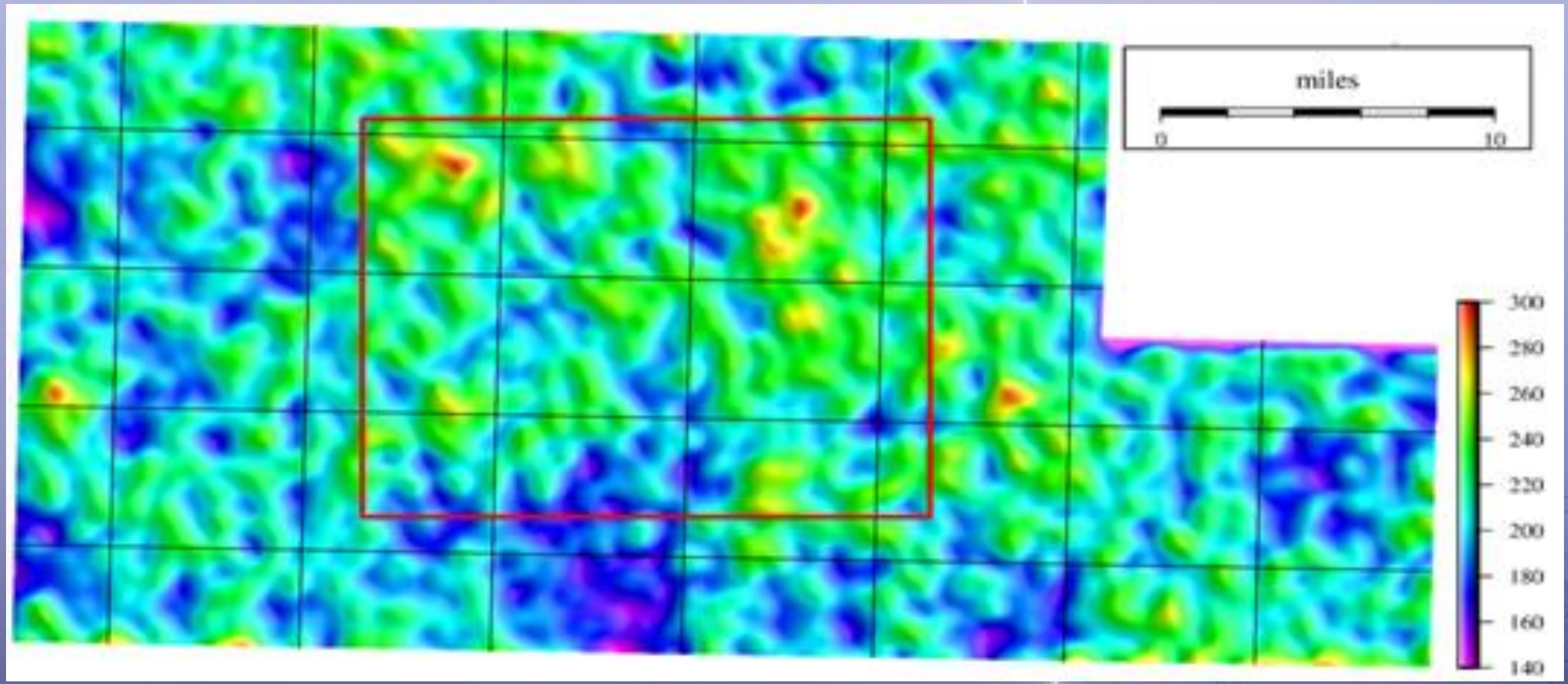
Michigan Basin Topography & Strike Density



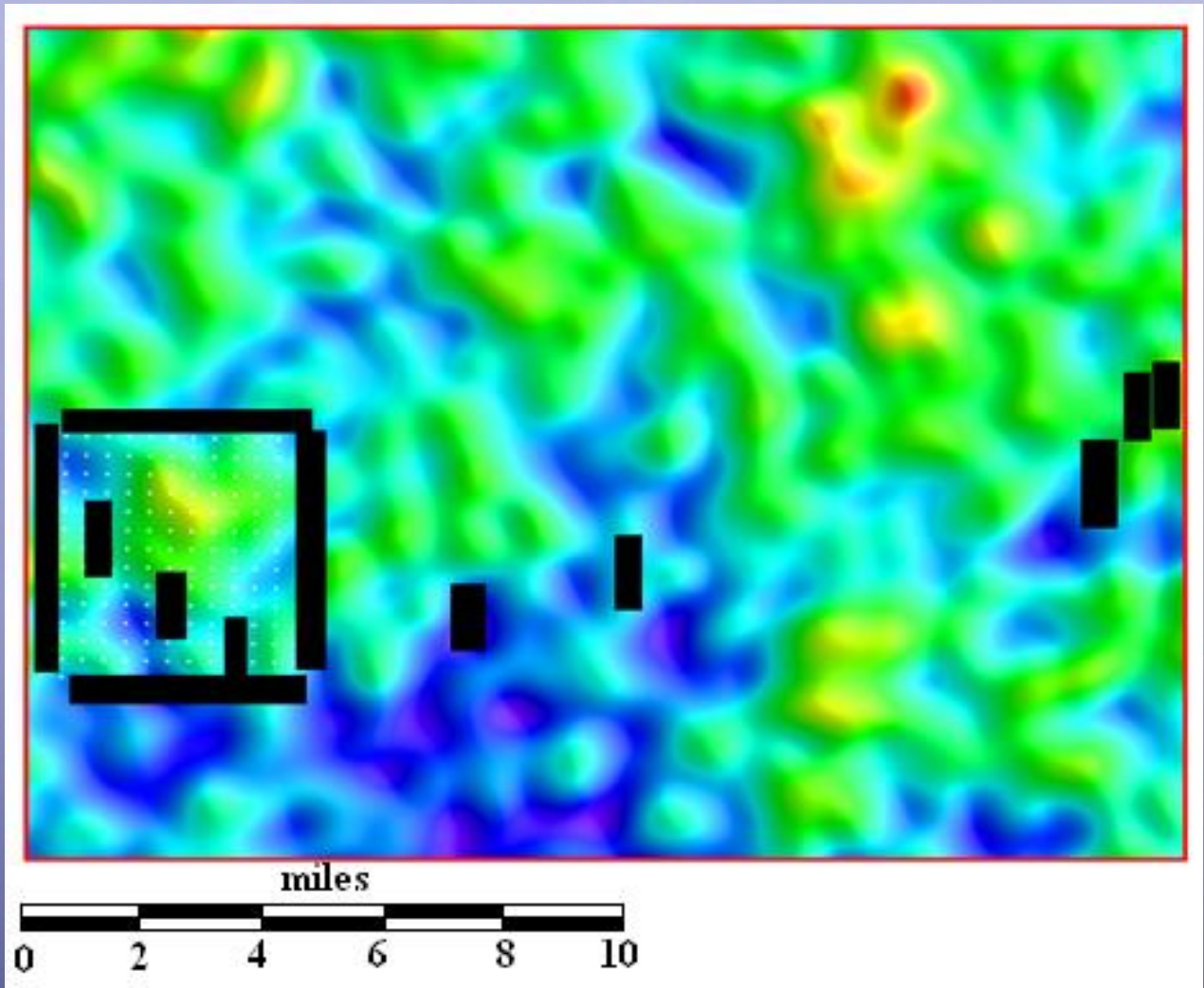


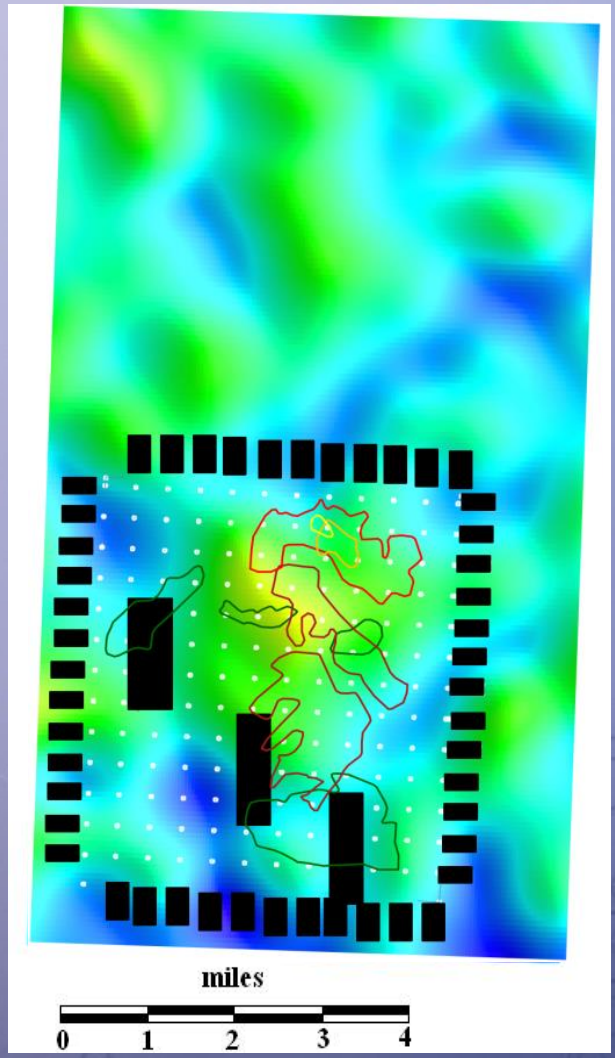


Lightning Analysis Gives Quicker Regional Overview

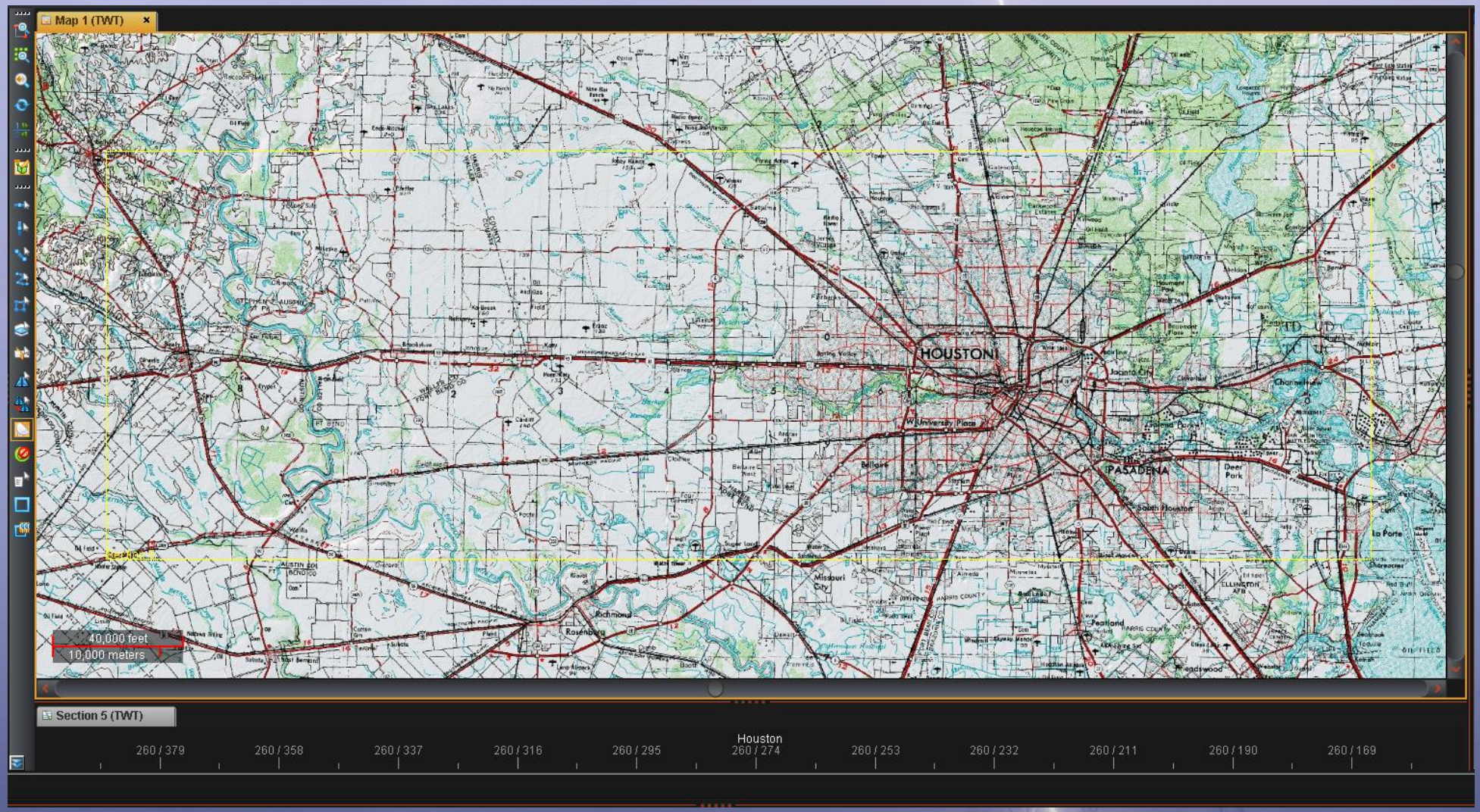


More details at Play Fairway & Prospect Scales

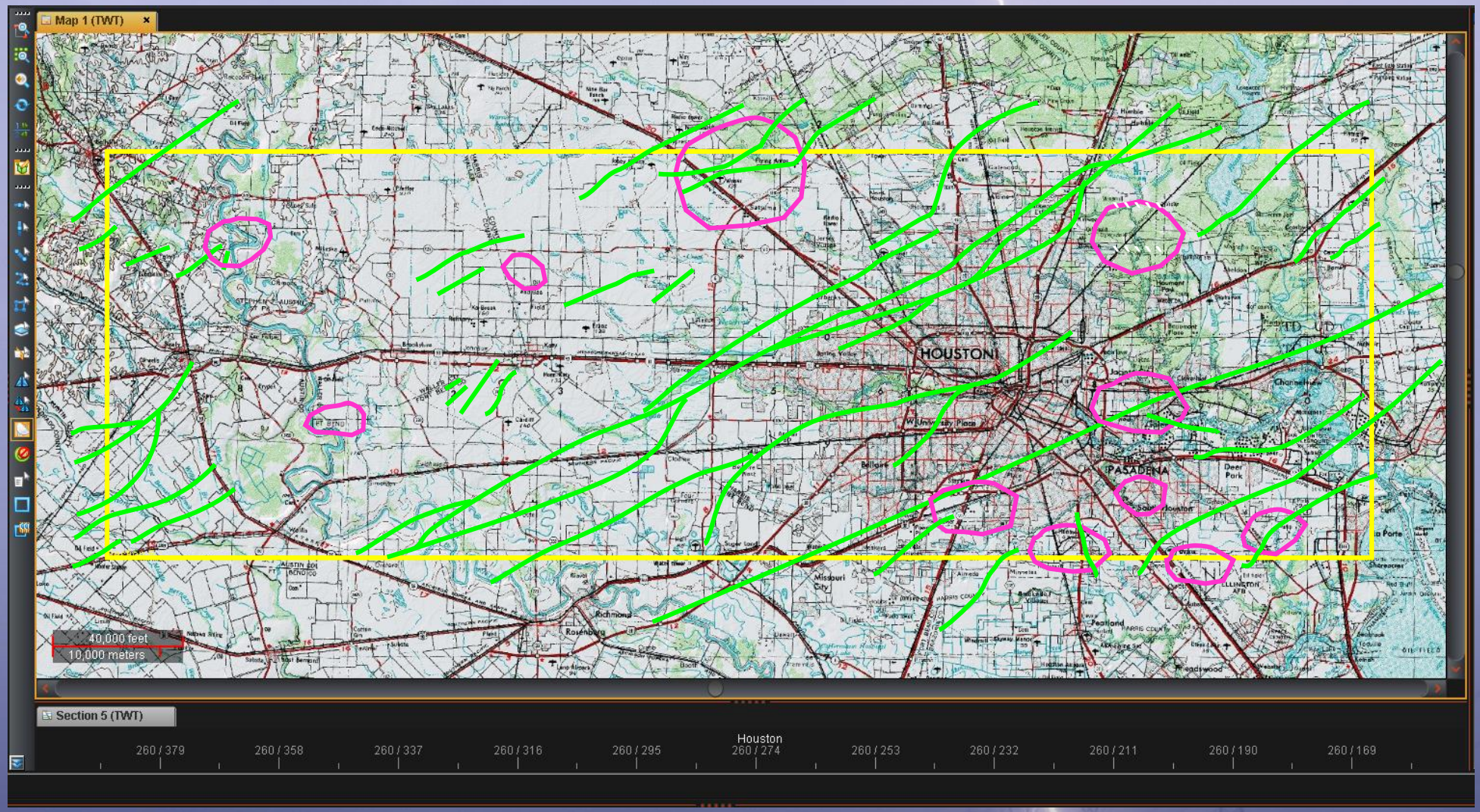




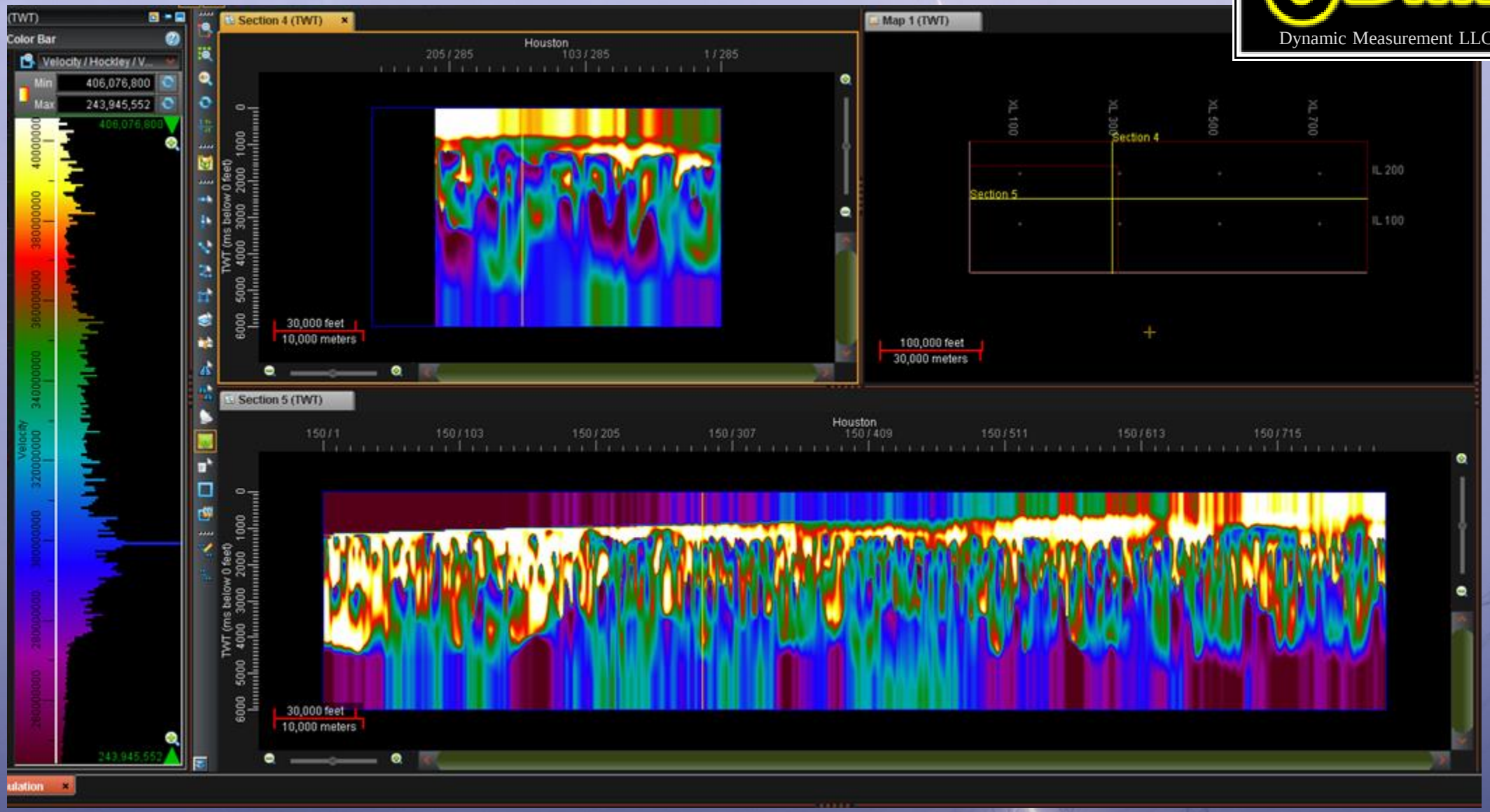
Imagine collecting a 3-D seismic survey here!



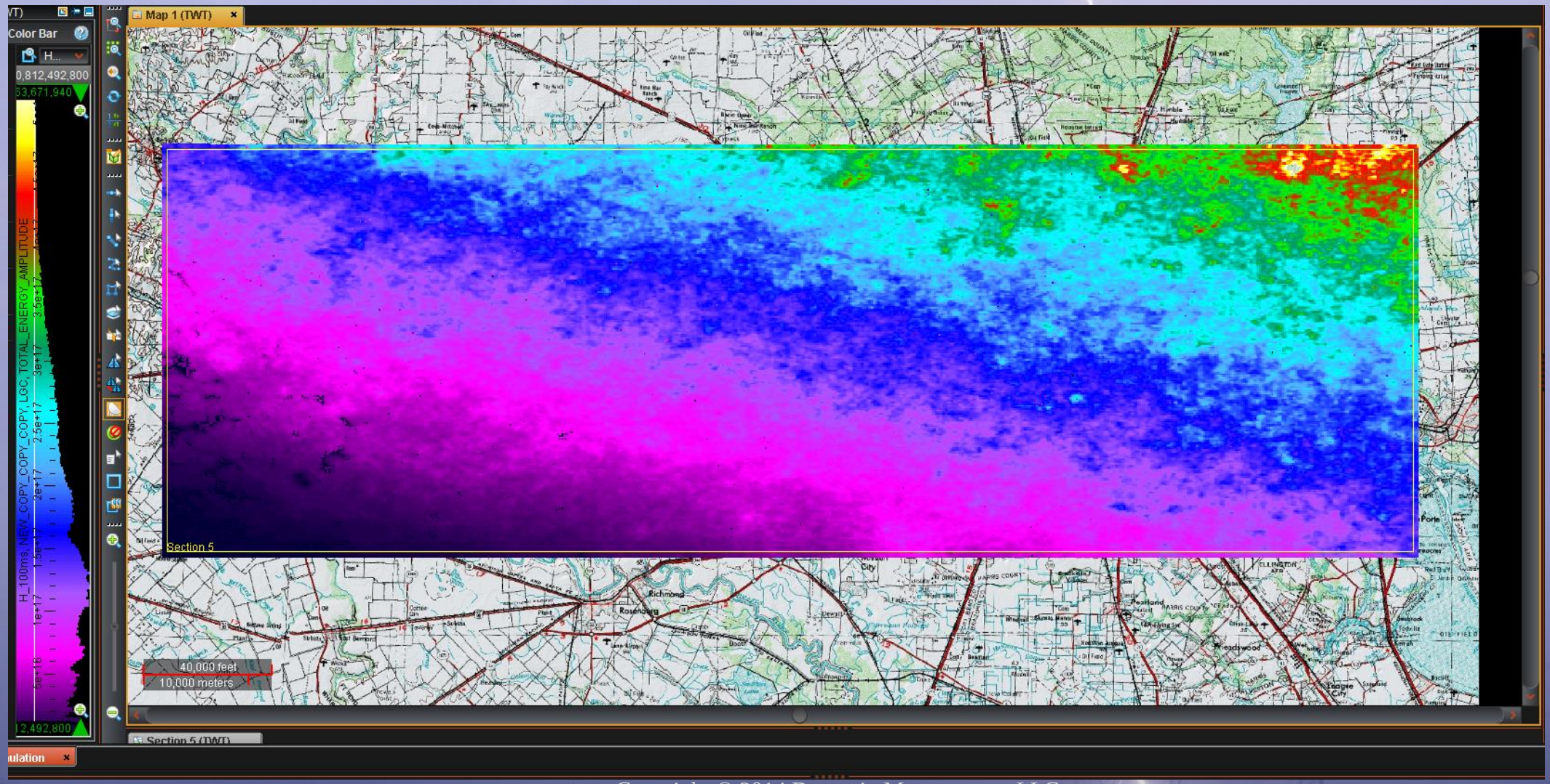
Imagine collecting a 3-D seismic survey here!



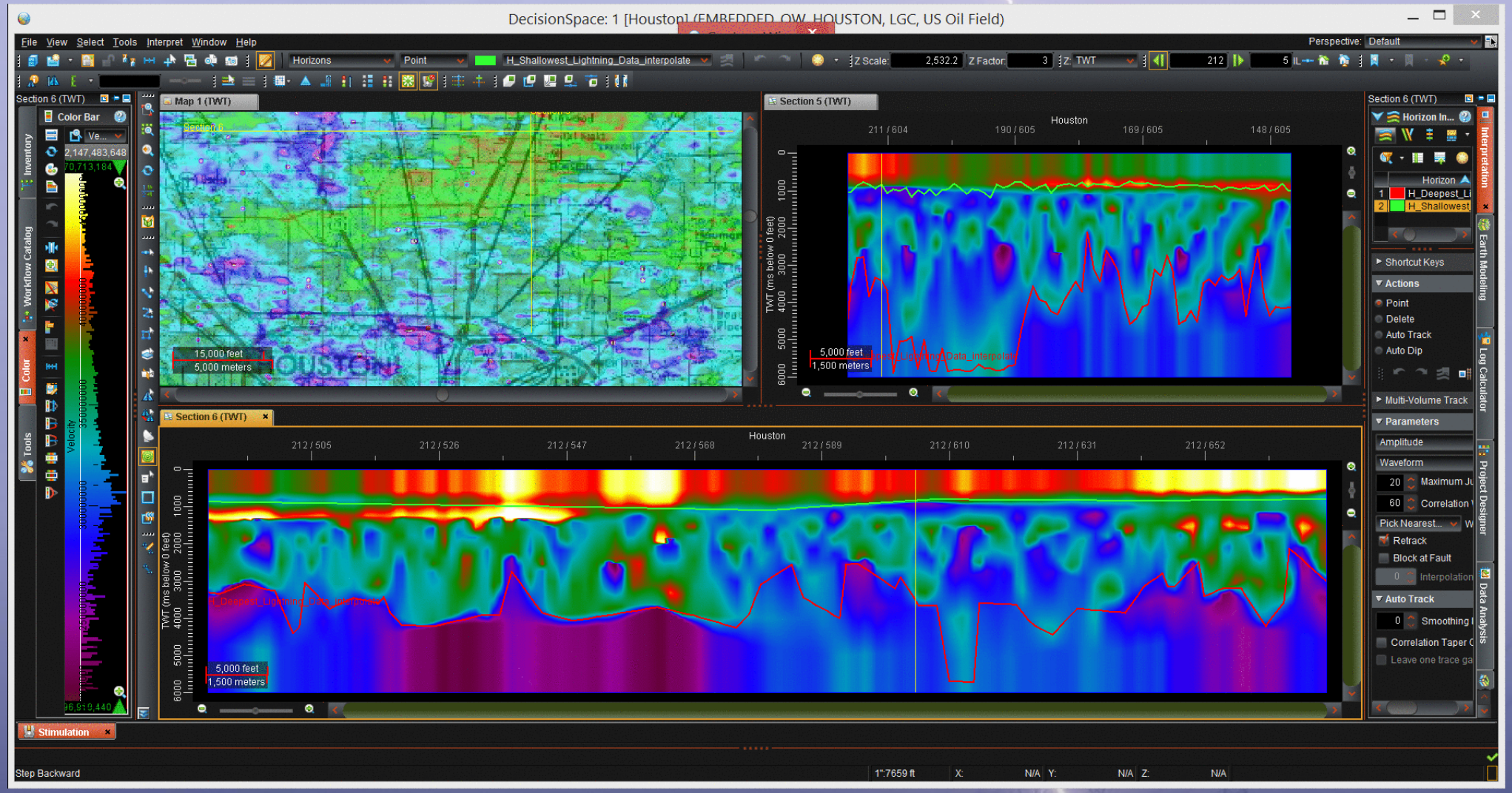
Resistivity Volume Houston Area



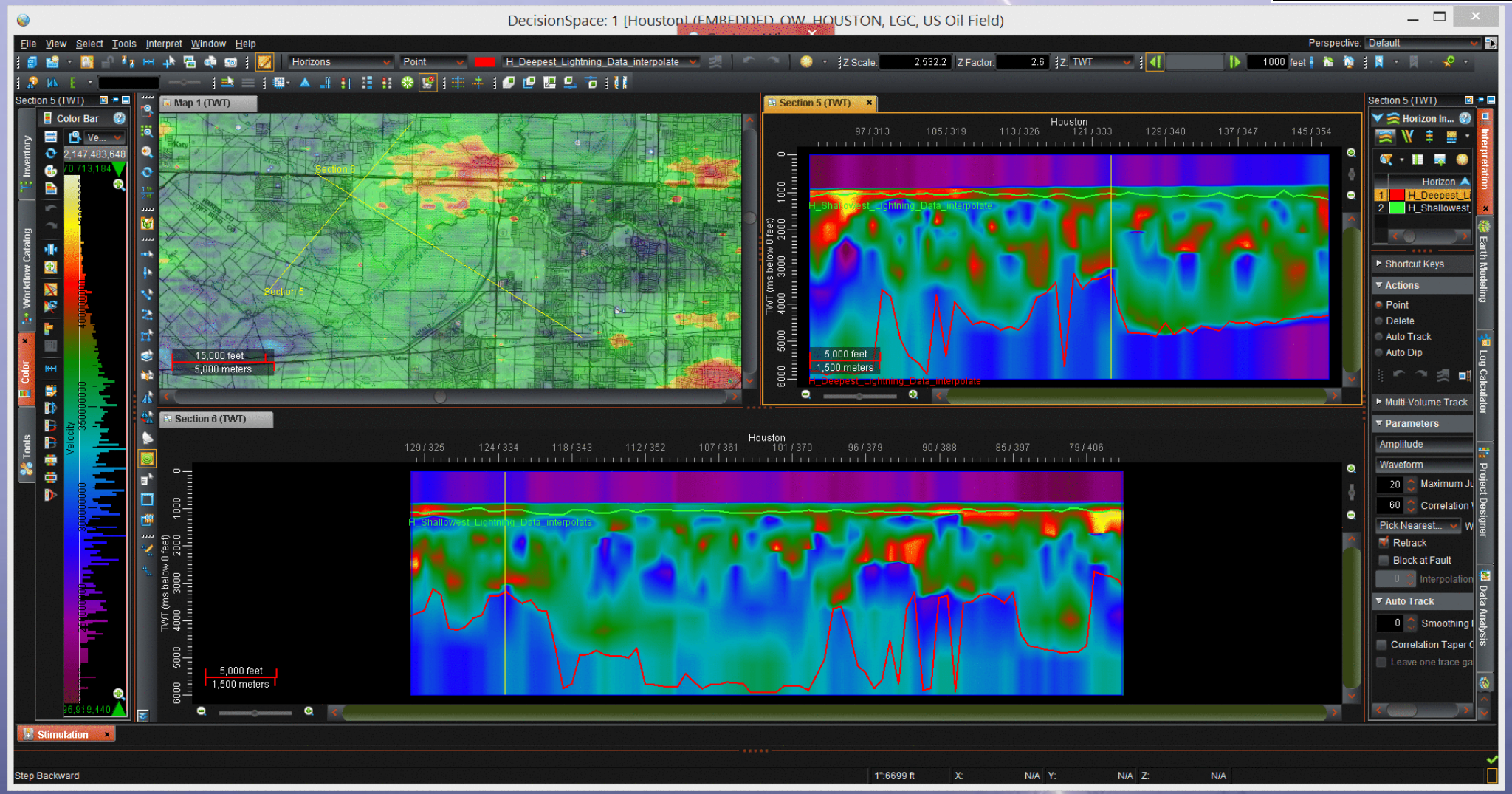
Total Energy 100ms to Shallowest Horizon



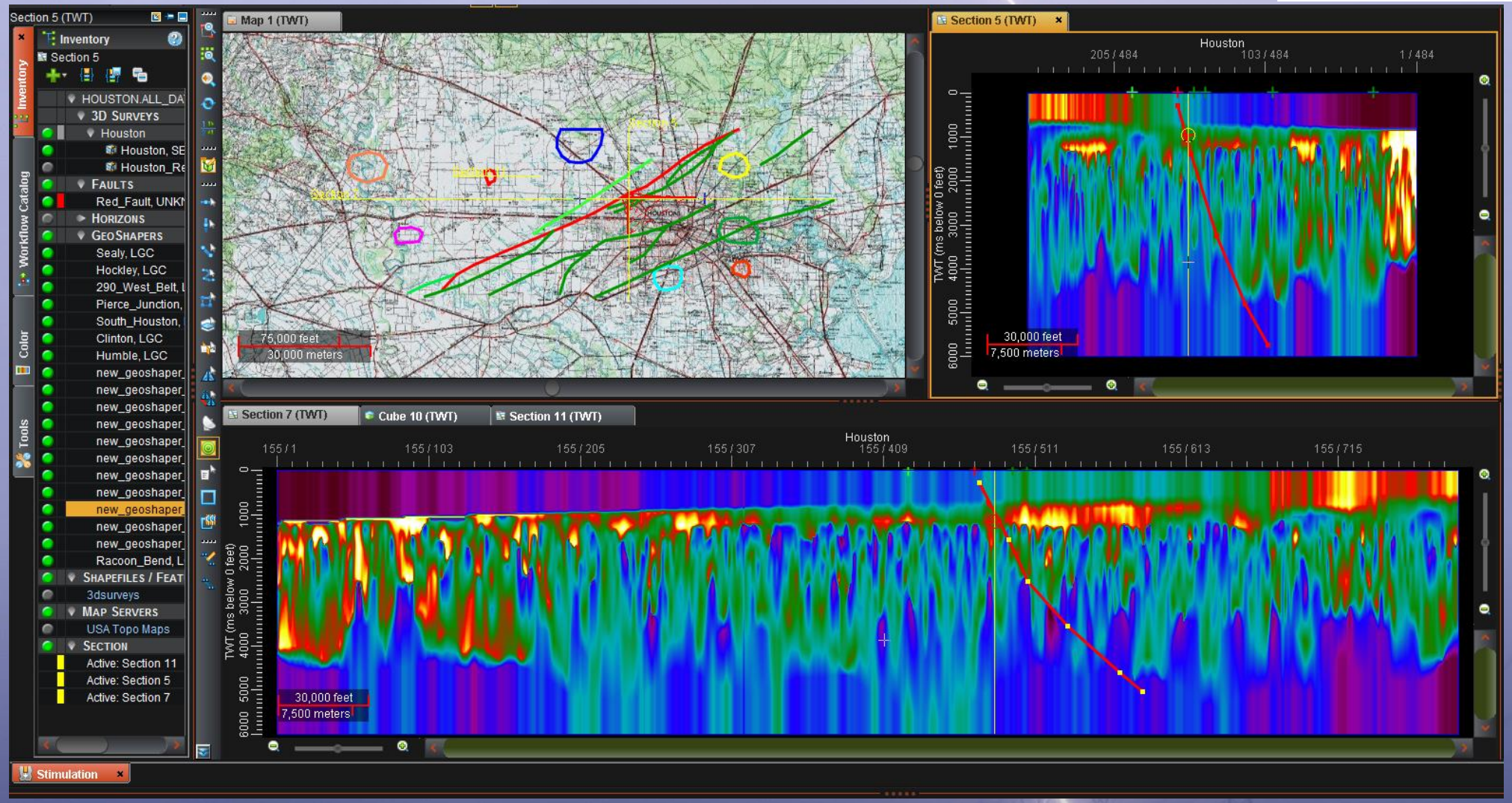
North Houston In-Line Animation



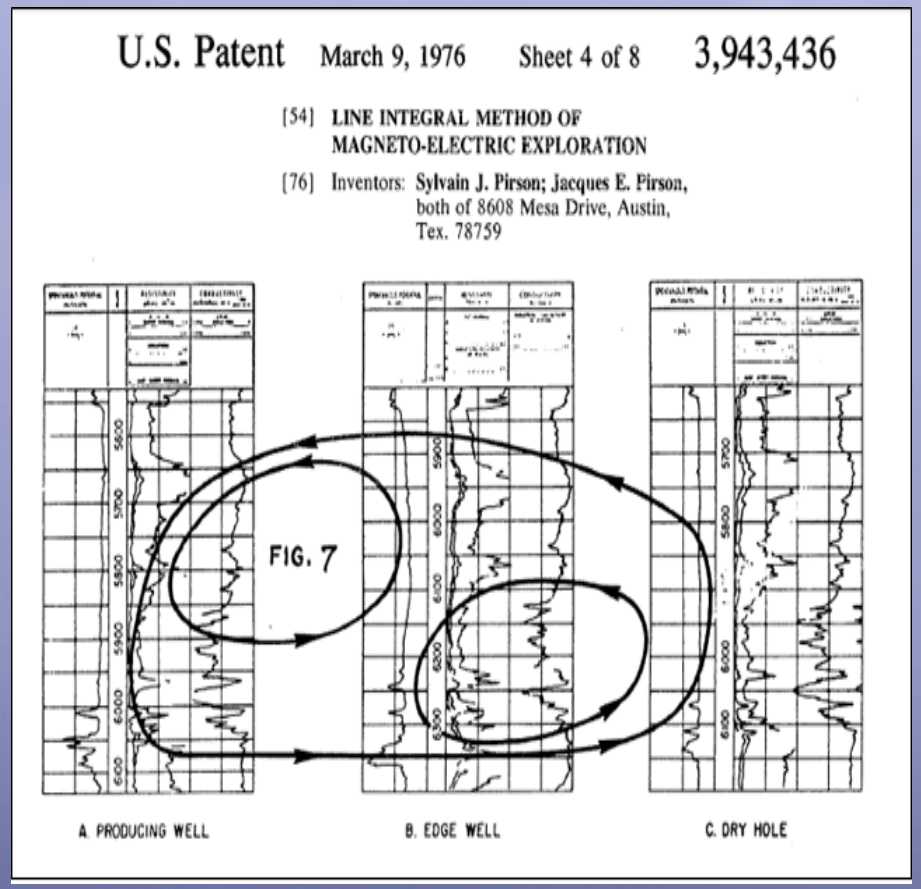
George Bush Park Pipeline Arbitrary Animation



Faults and Salt Domes



Electrical Currents (Telluric and Terralevis)



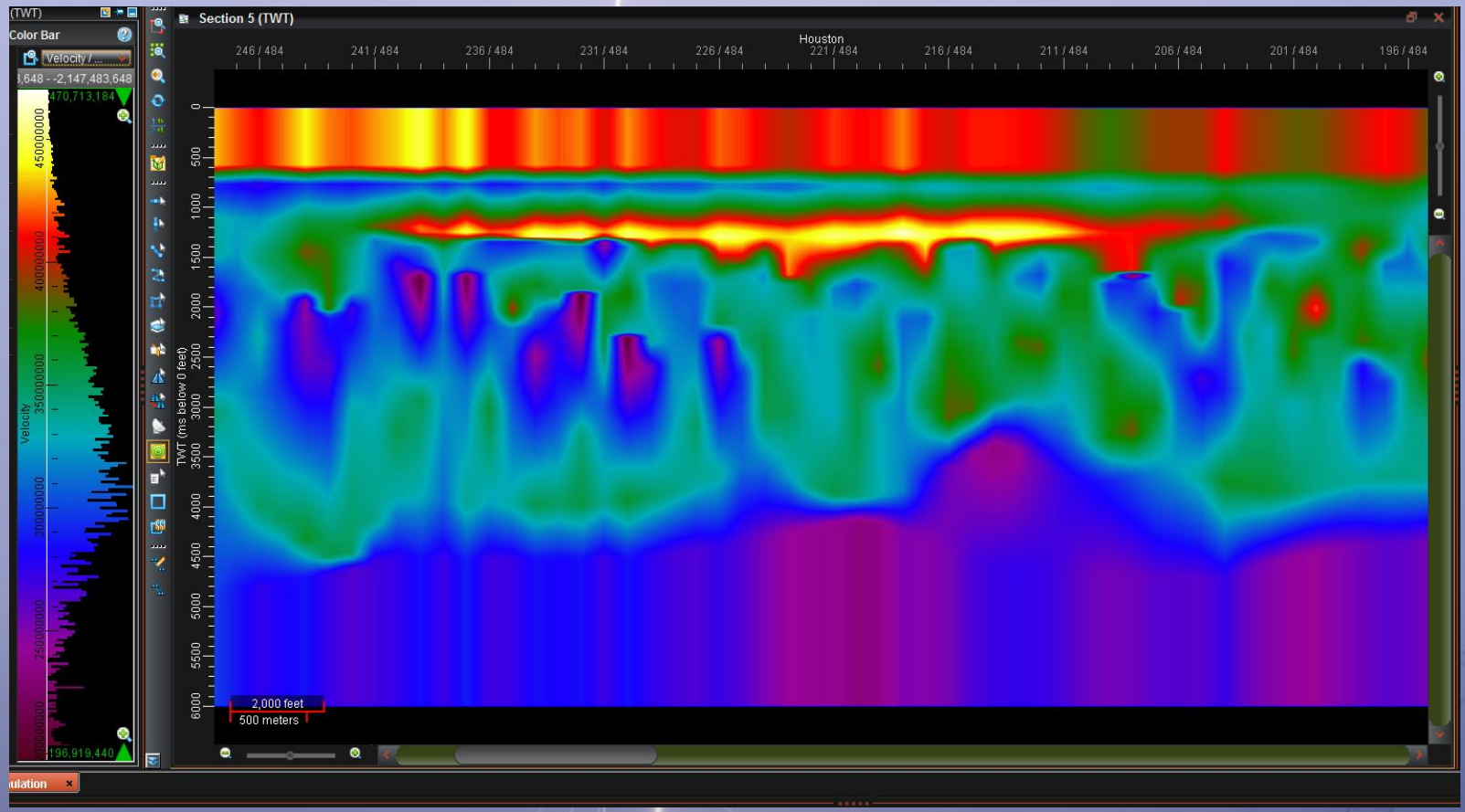
U.S. Patent March 9, 1976 Sheet 4 of 8 3,943,436

[54] LINE INTEGRAL METHOD OF MAGNETO-ELECTRIC EXPLORATION

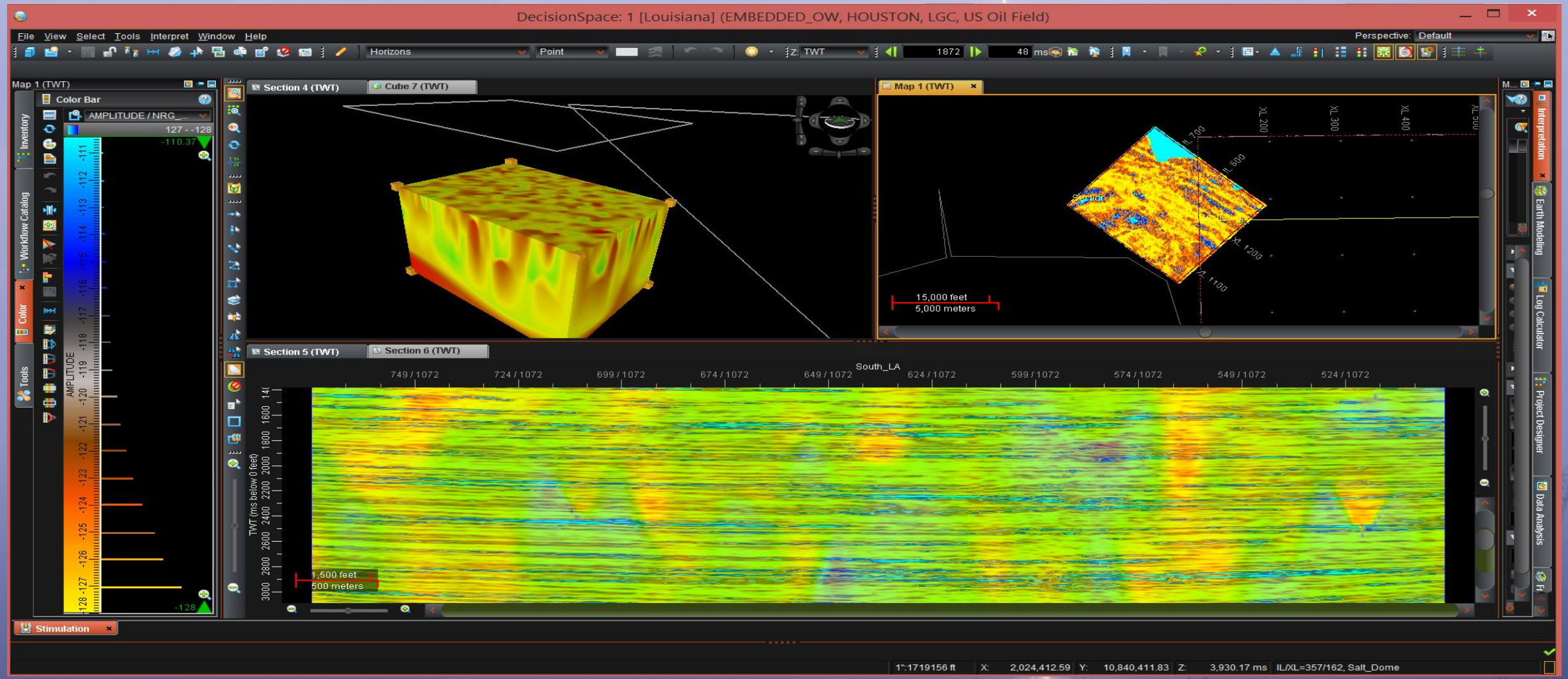
[76] Inventors: Sylvain J. Pirson; Jacques E. Pirson, both of 8608 Mesa Drive, Austin, Tex. 78759

FIG. 7

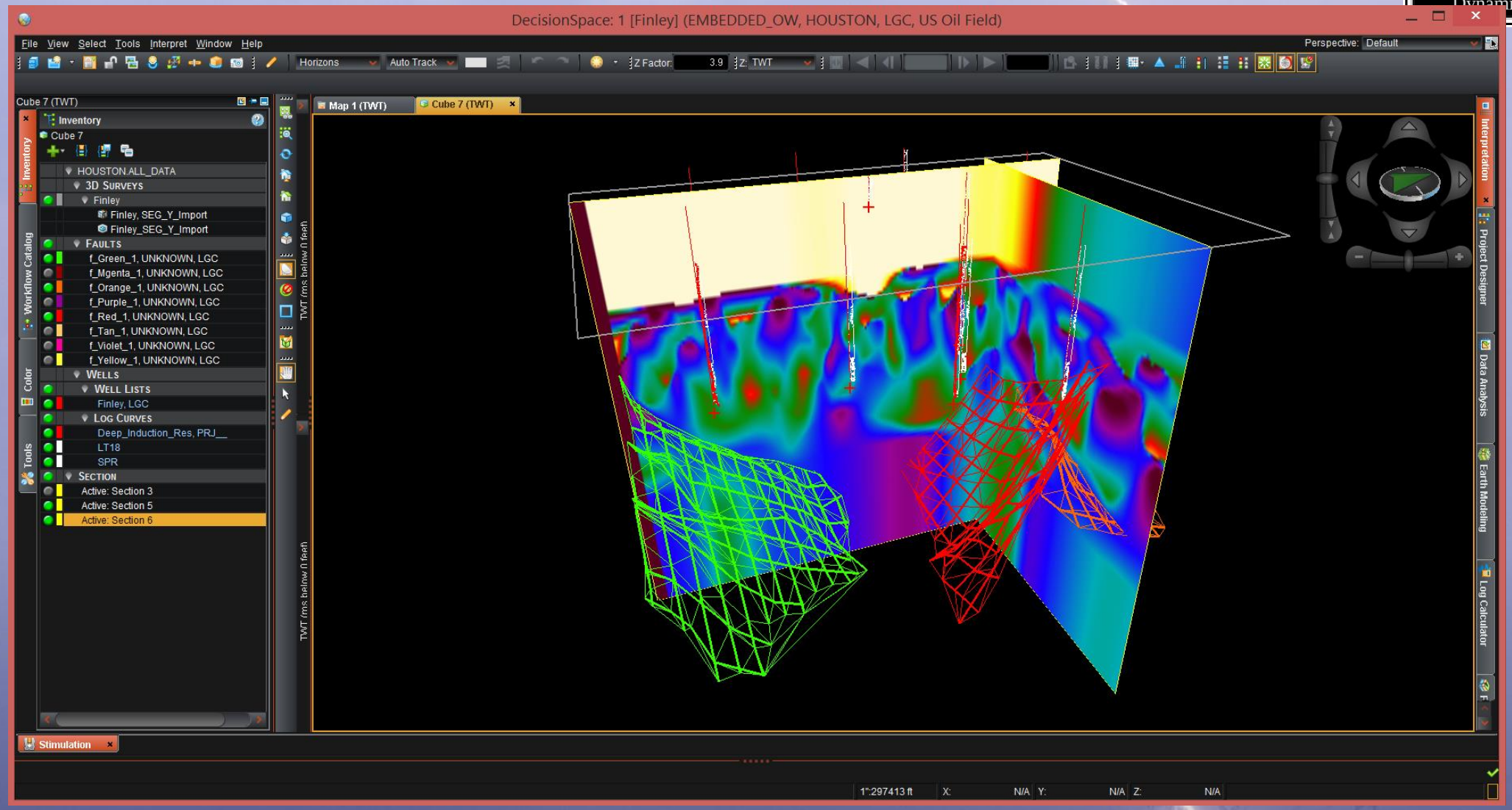
A. PRODUCING WELL B. EDGE WELL C. DRY HOLE



Resistivity Volumes
Complement Velocity Volumes



Texas Resistivity Fault Interpretation - 1



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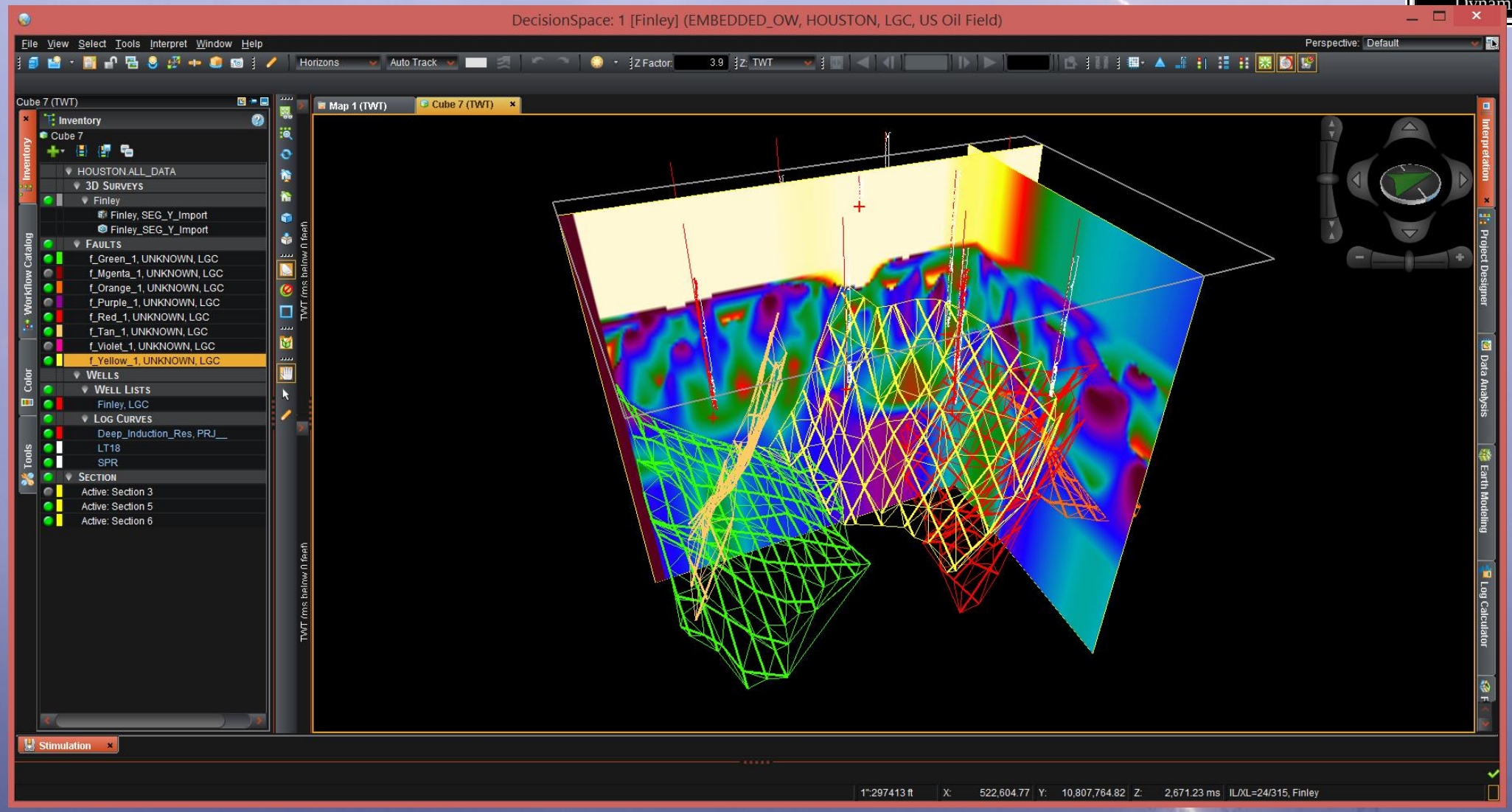
Texas Resistivity Fault Interpretation - 2



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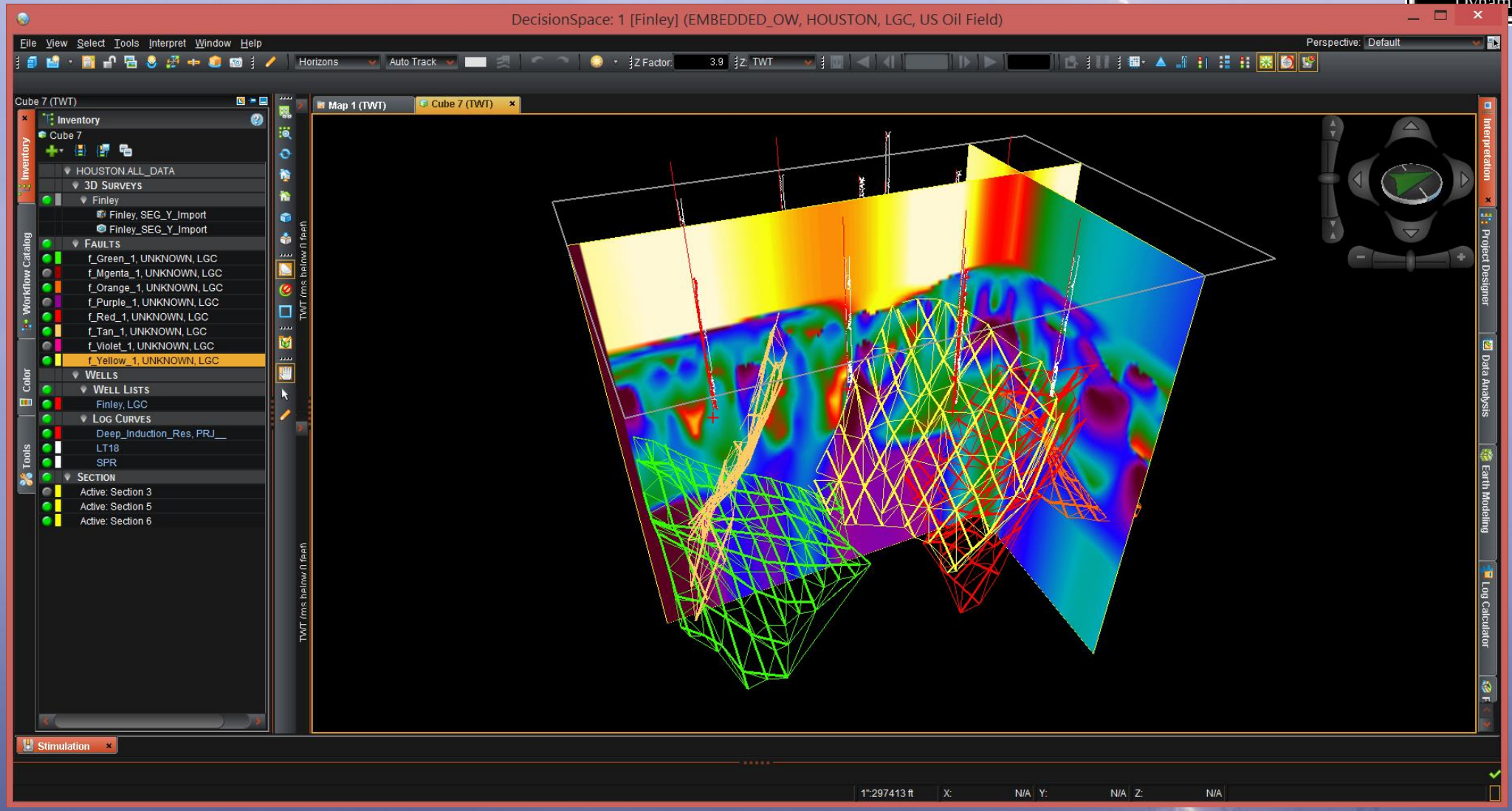
Texas Resistivity Fault Interpretation - 3



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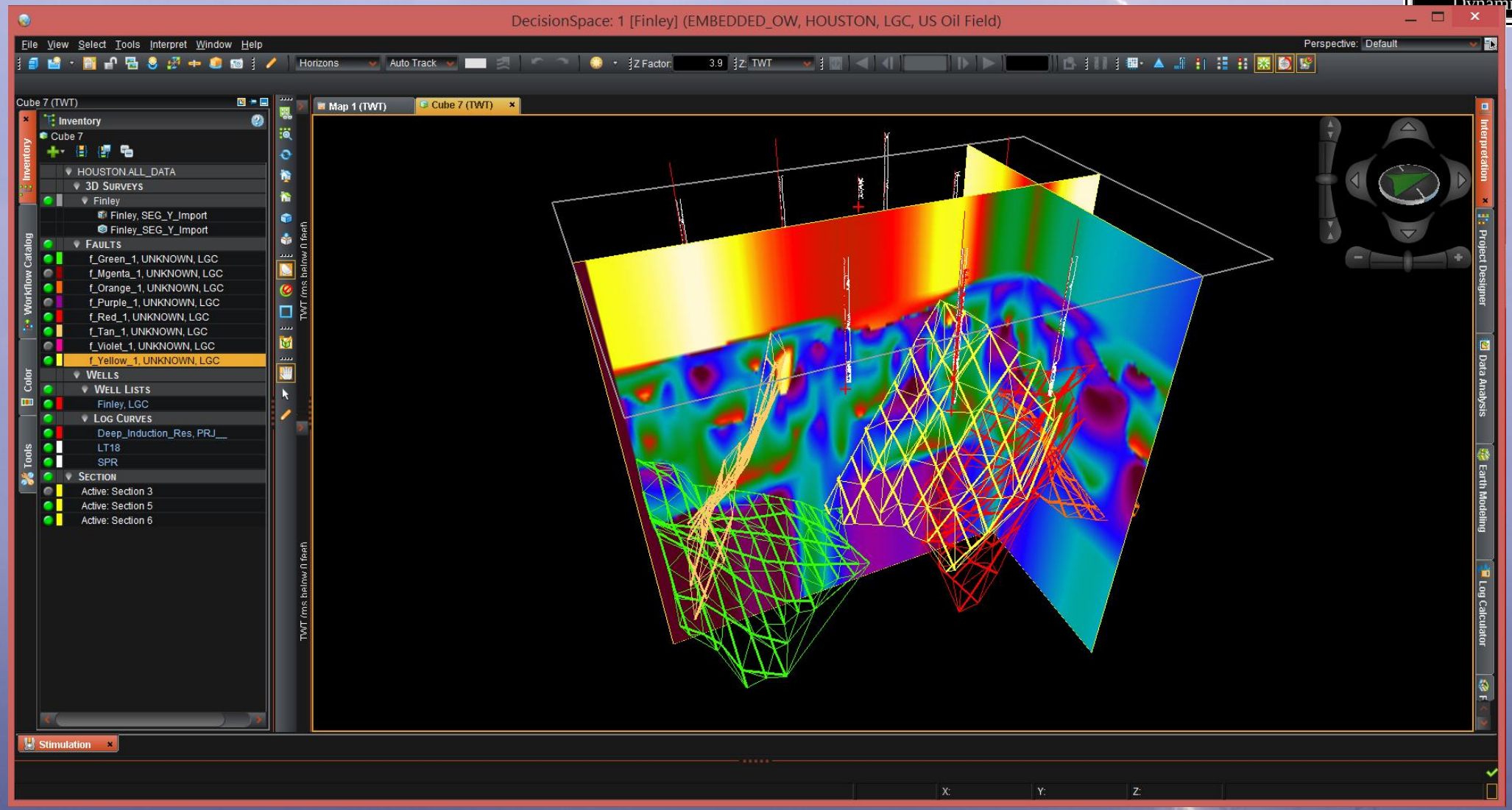
Texas Resistivity Fault Interpretation - 4



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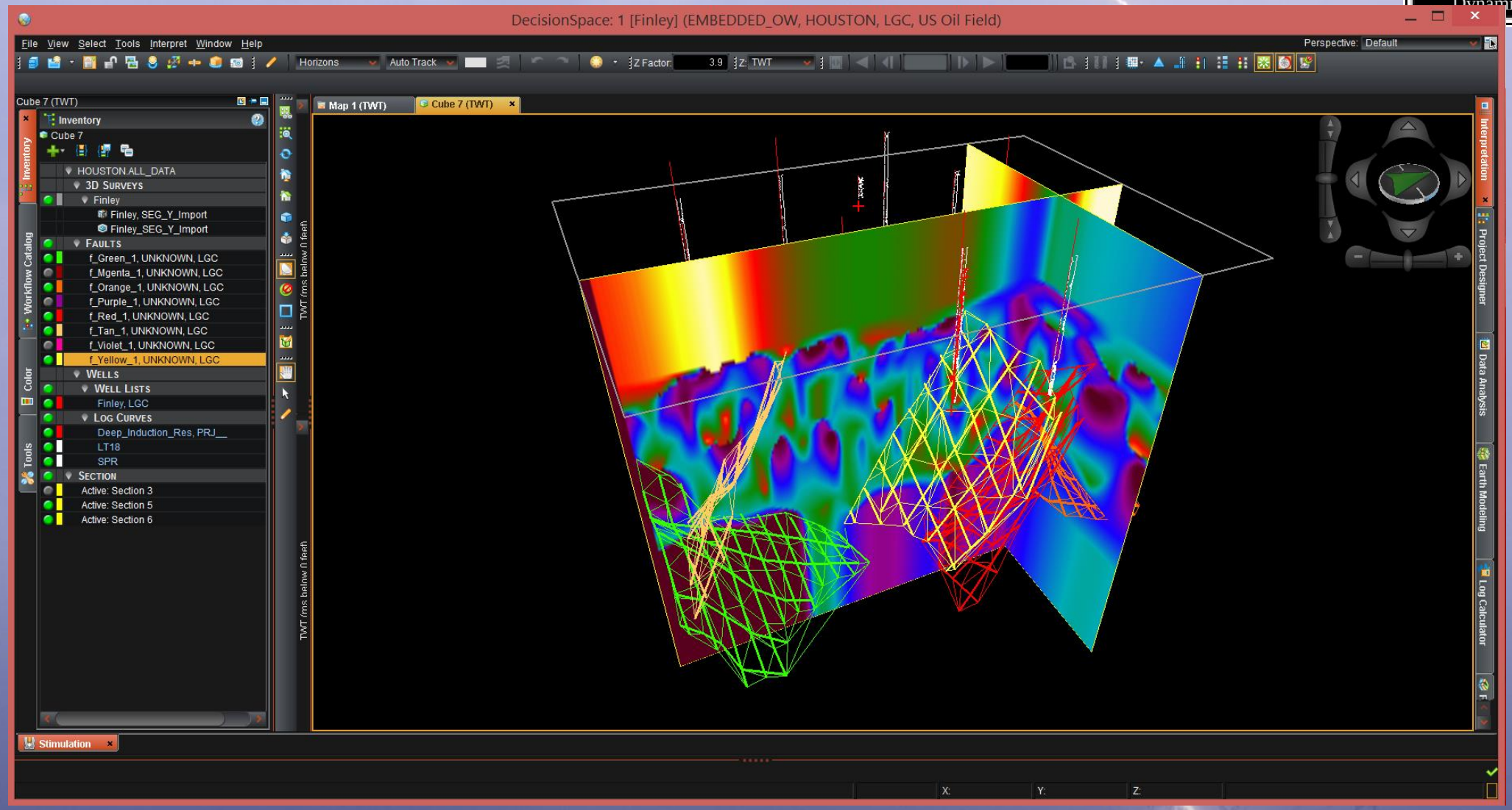
Texas Resistivity Fault Interpretation - 5



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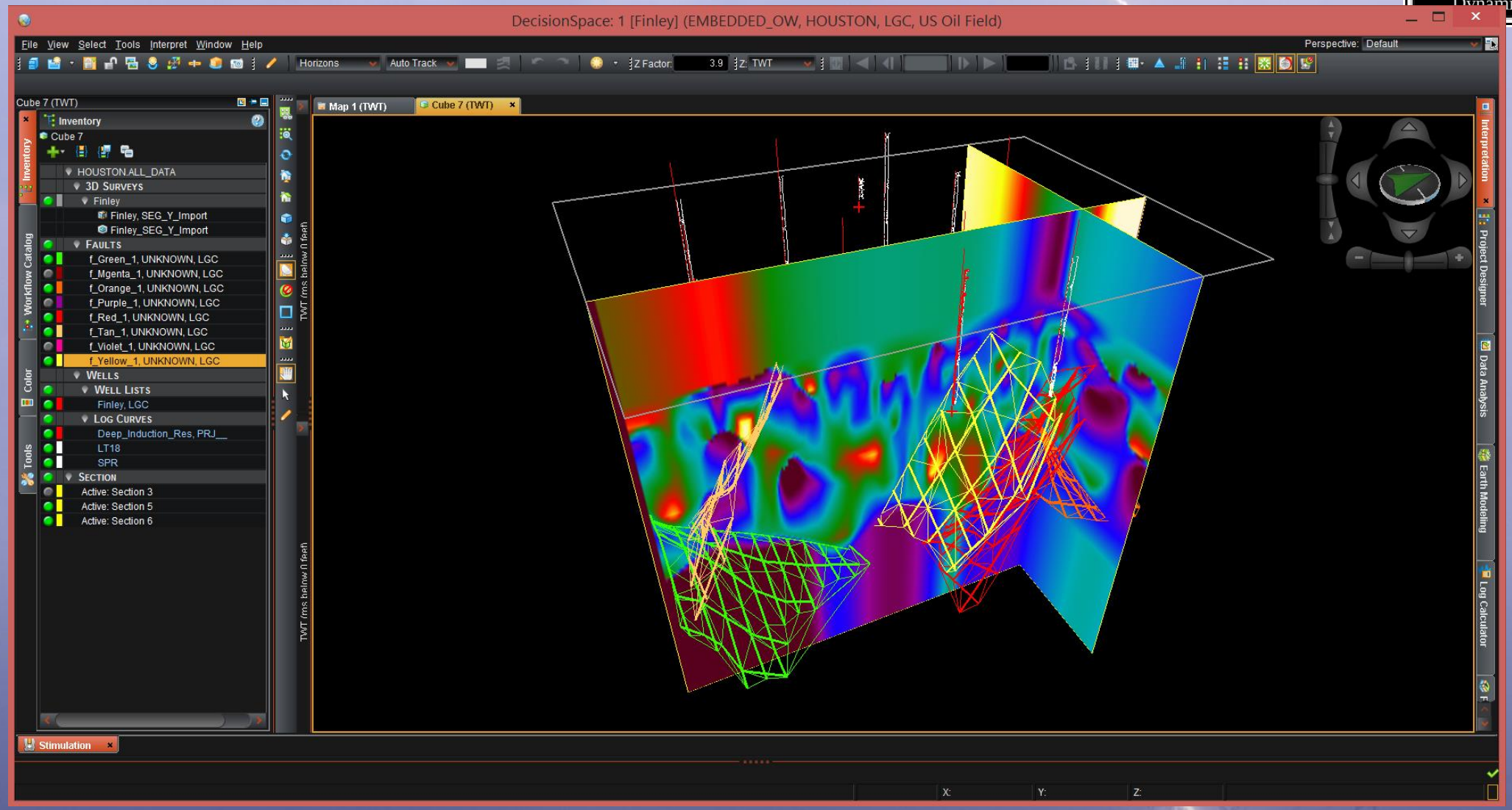
Texas Resistivity Fault Interpretation - 6



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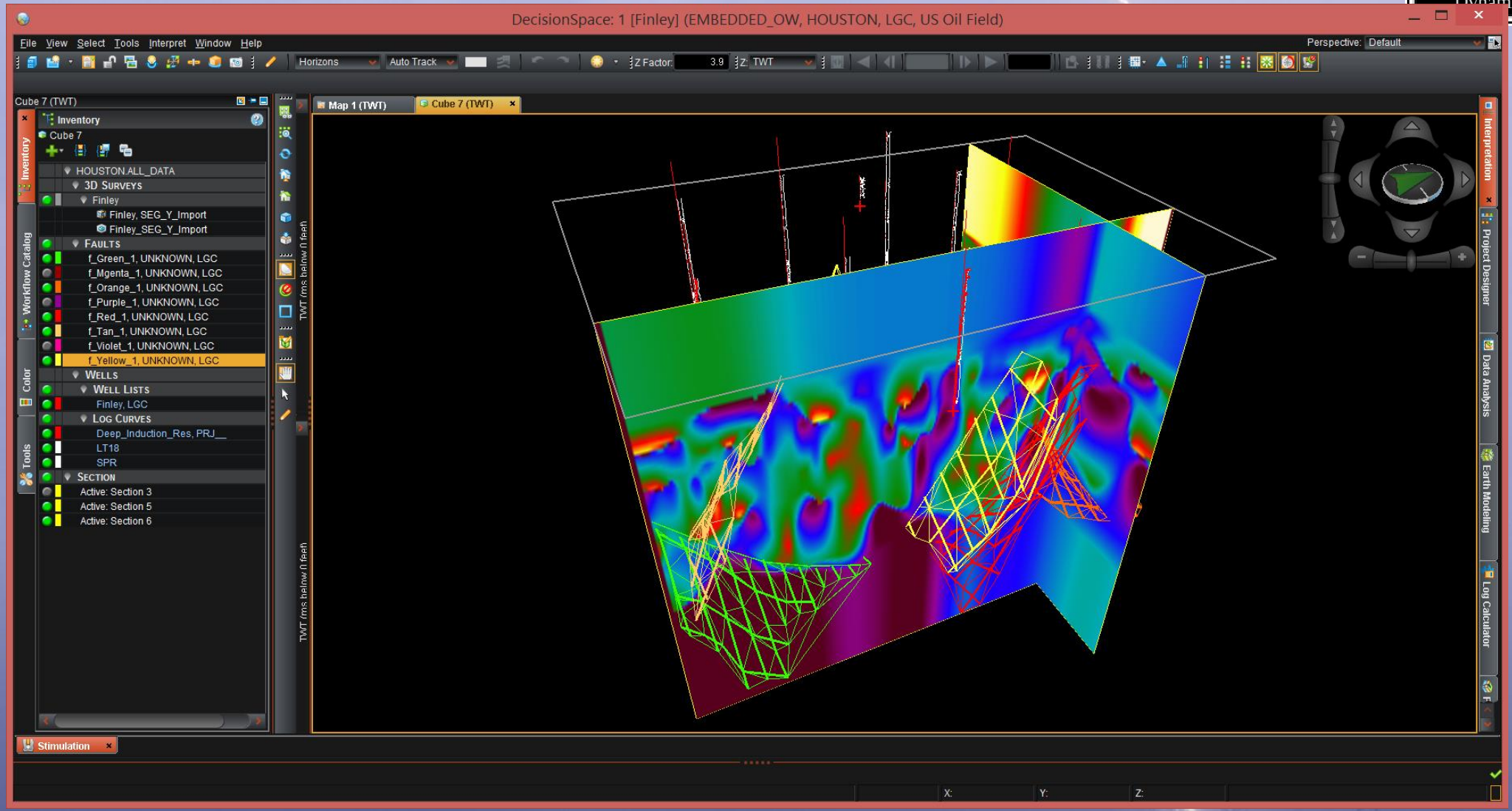
Texas Resistivity Fault Interpretation - 7



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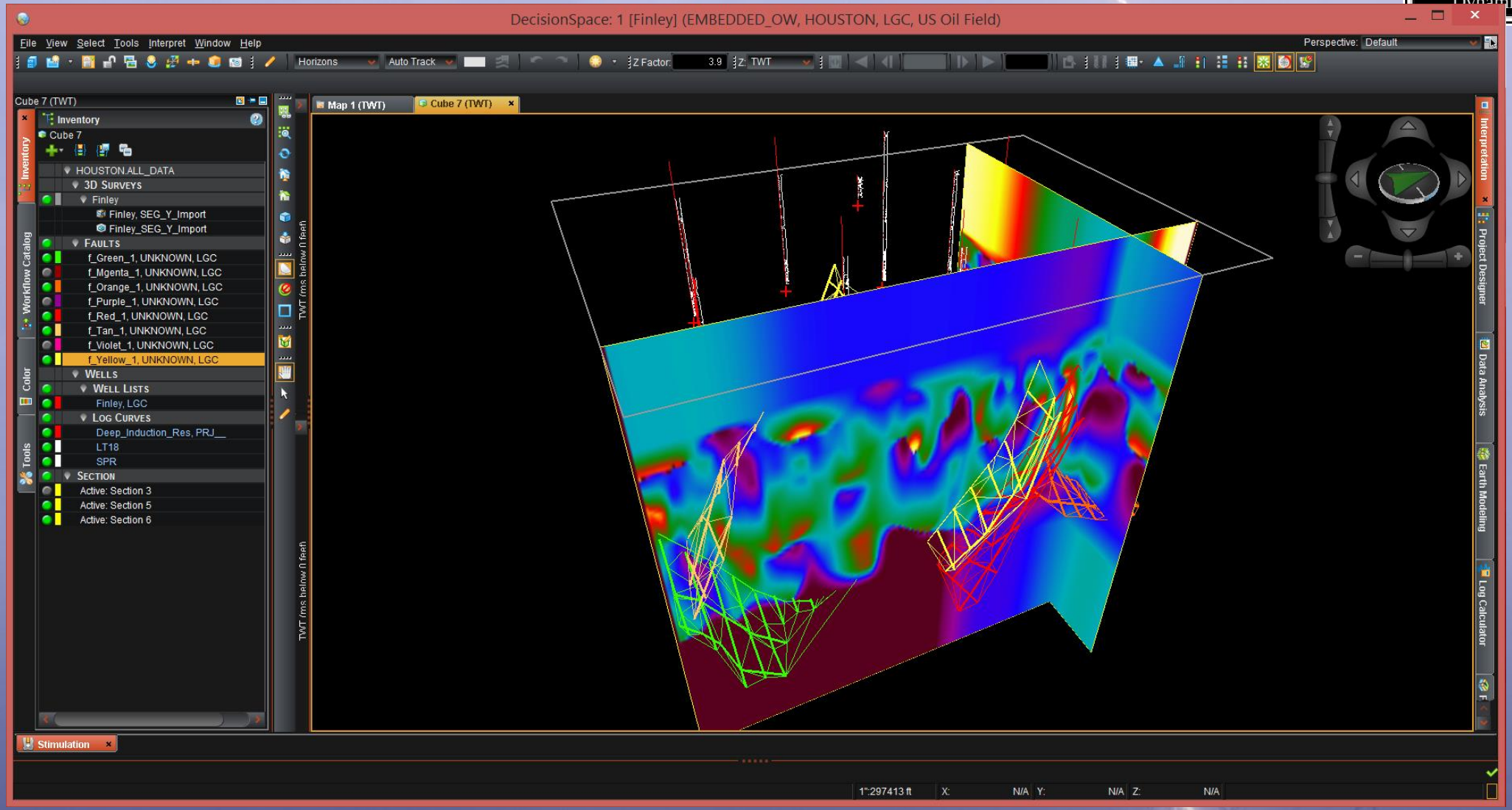
Texas Resistivity Fault Interpretation - 8



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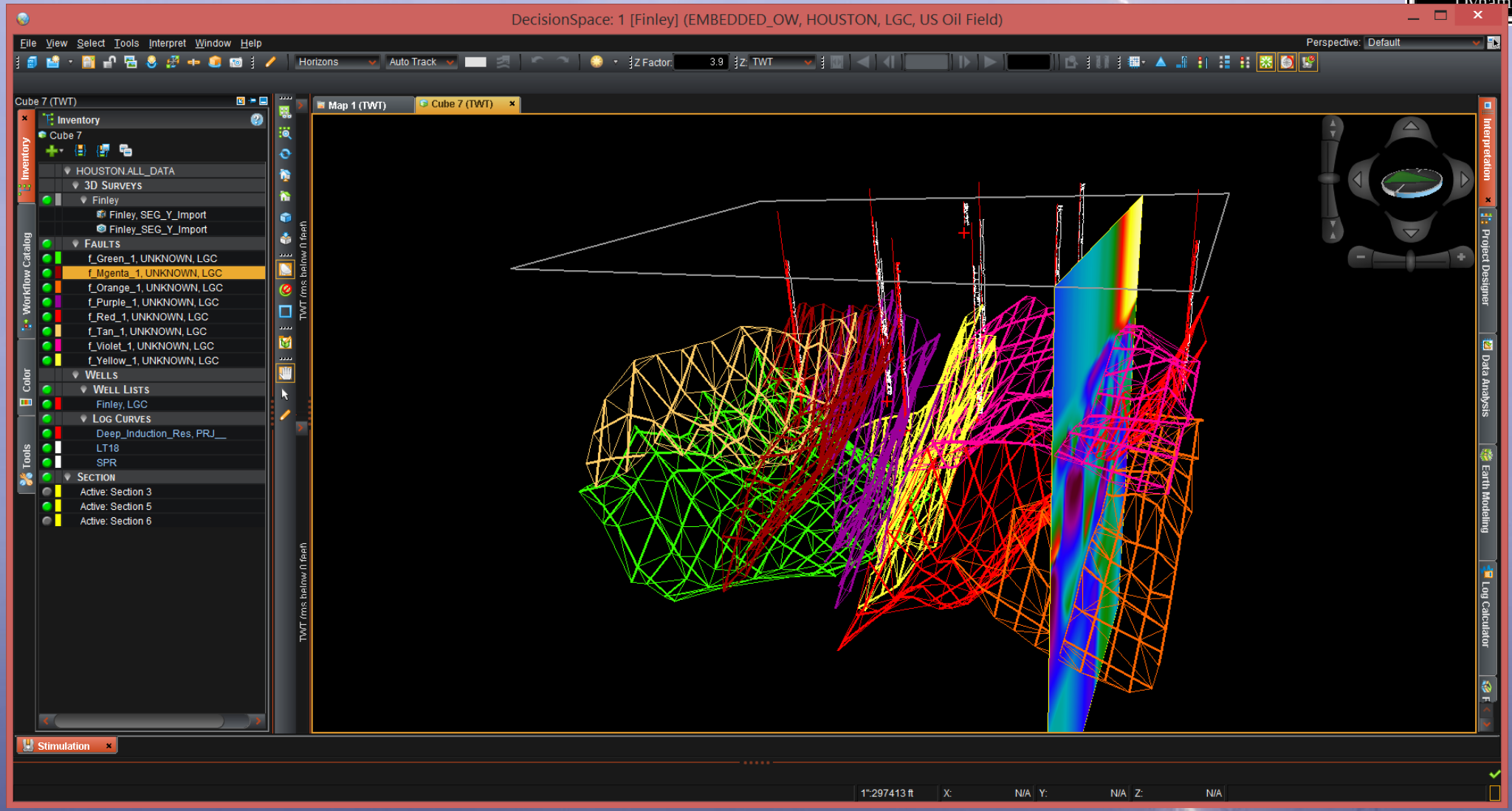
Texas Resistivity Fault Interpretation - 9



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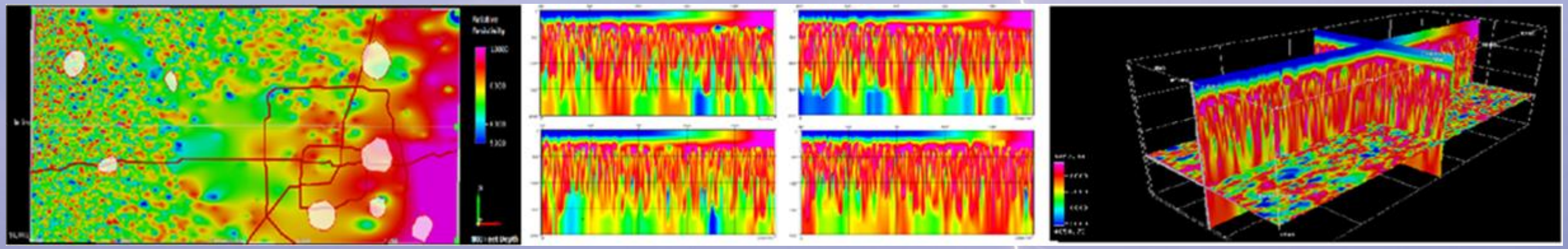
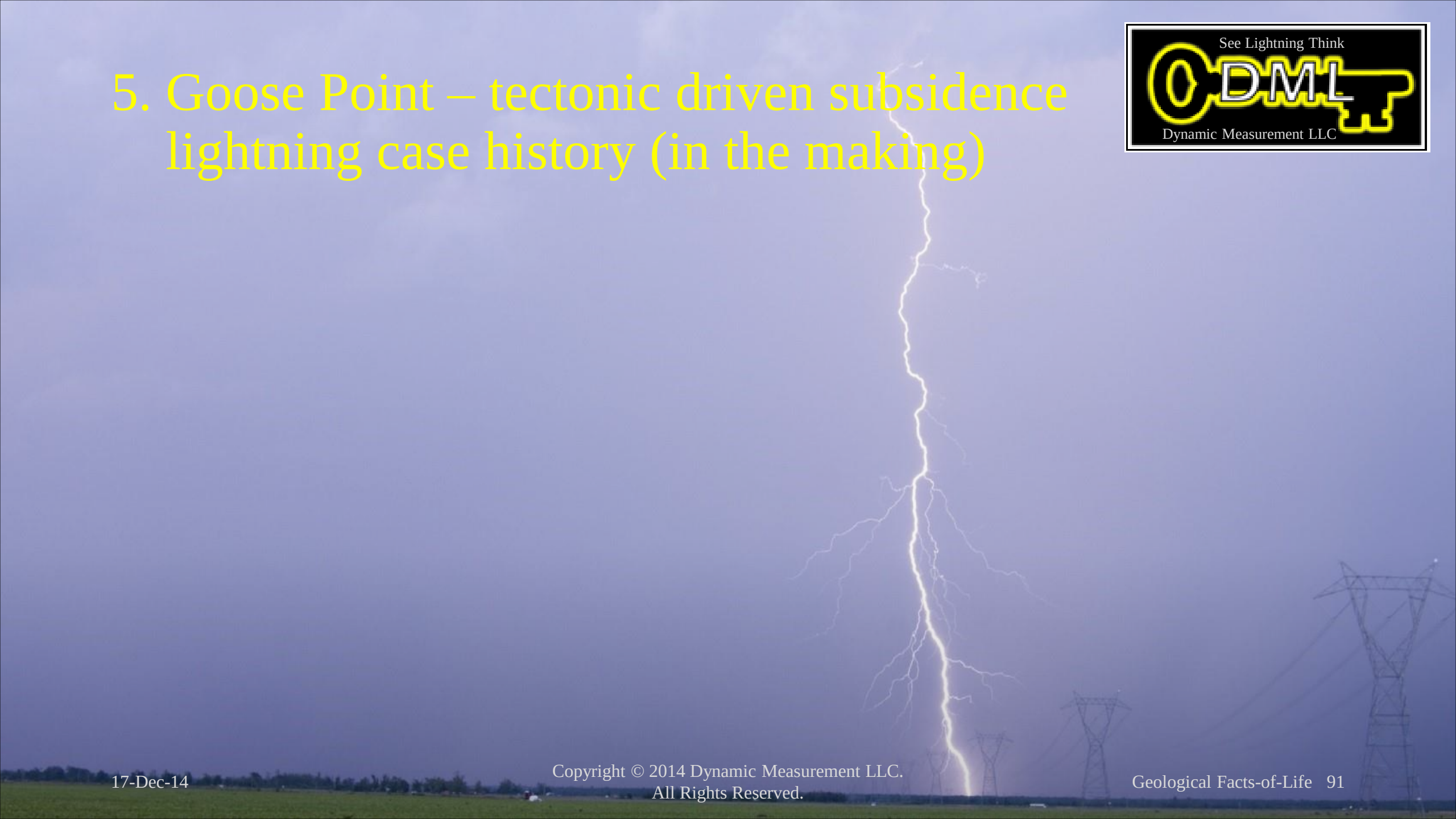
NSEM and Resistivity Volumes are a Technology Breakthrough



- Lightning attribute maps identify lineaments related to faulting
- Lightning resistivity volumes provide an independent view of geology
- Lightning resistivity volumes can be created to match 3-D geometry
- We anticipate a merger of resistivity volumes and lithology predictions

Questions & Answers & Discussion

5. Goose Point – tectonic driven subsidence lightning case history (in the making)



SLFPA-W Levees and Deltas

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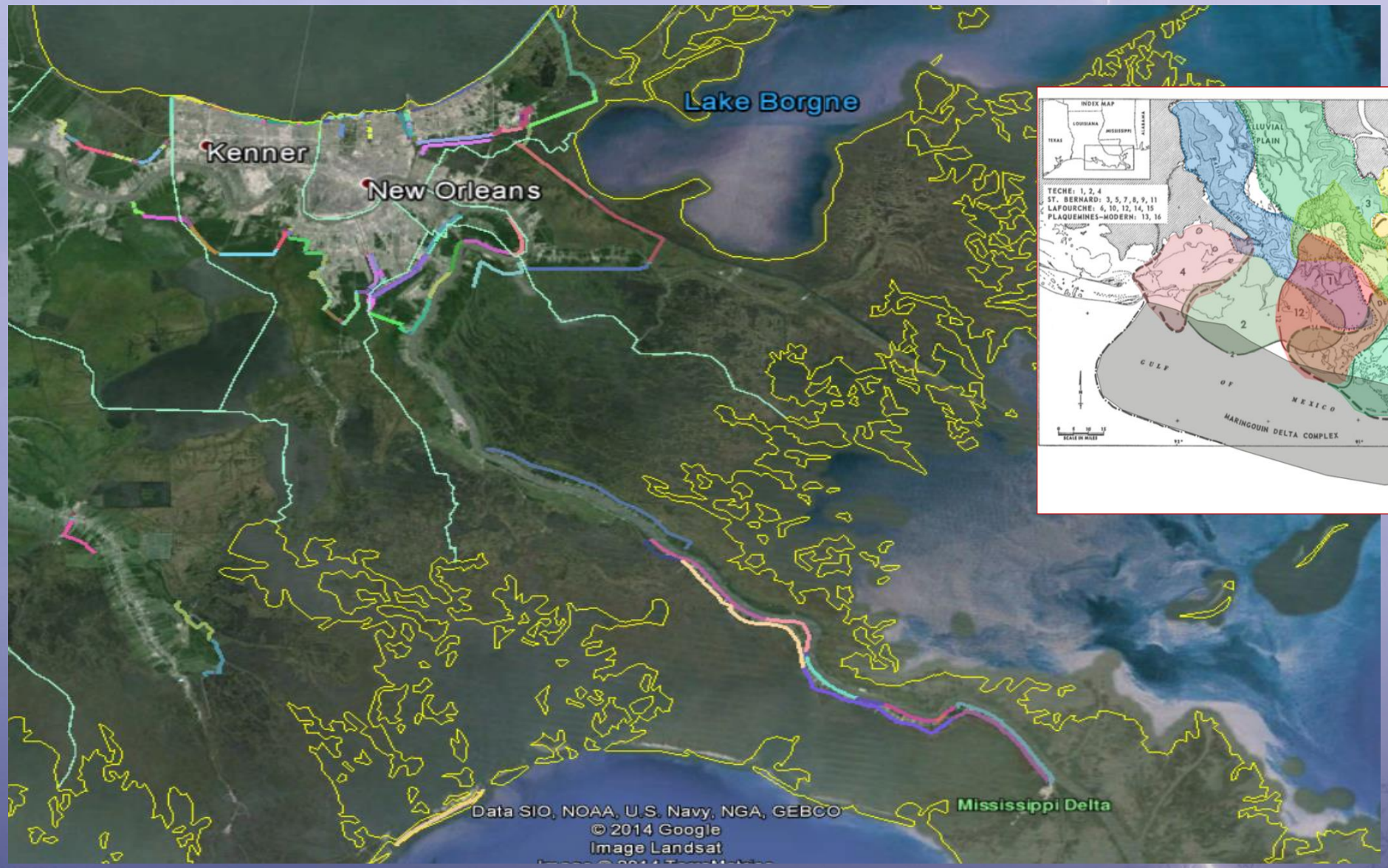
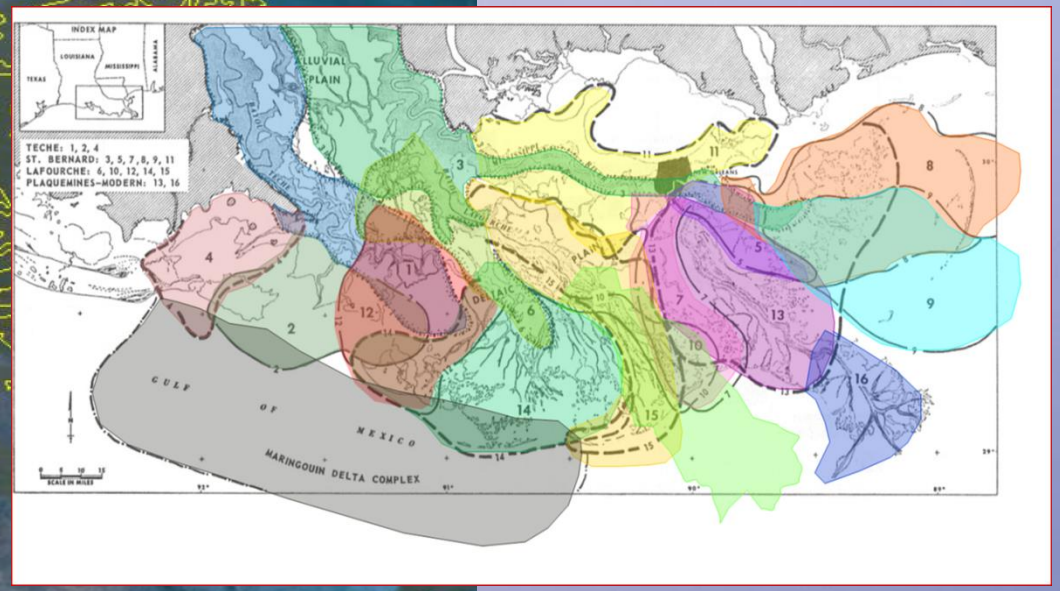
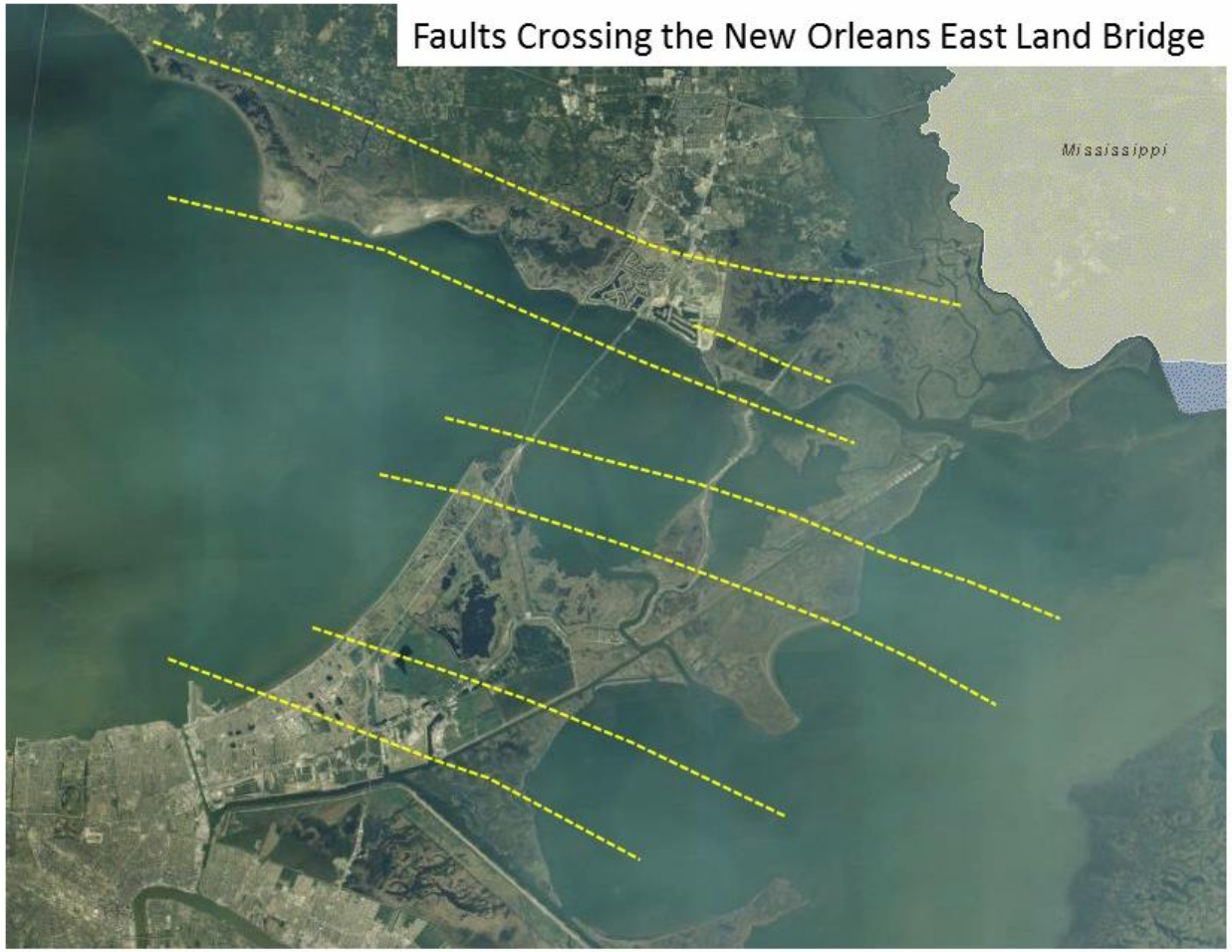




Land Bridge Subsidence and Faulting



Sedimentation Growth Cycles

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Delta Cycle

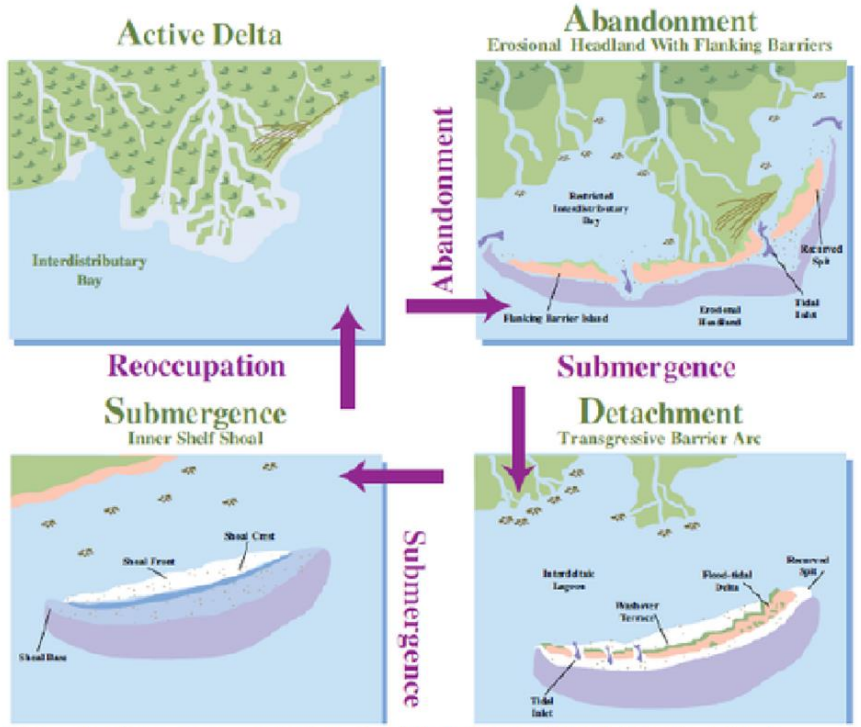
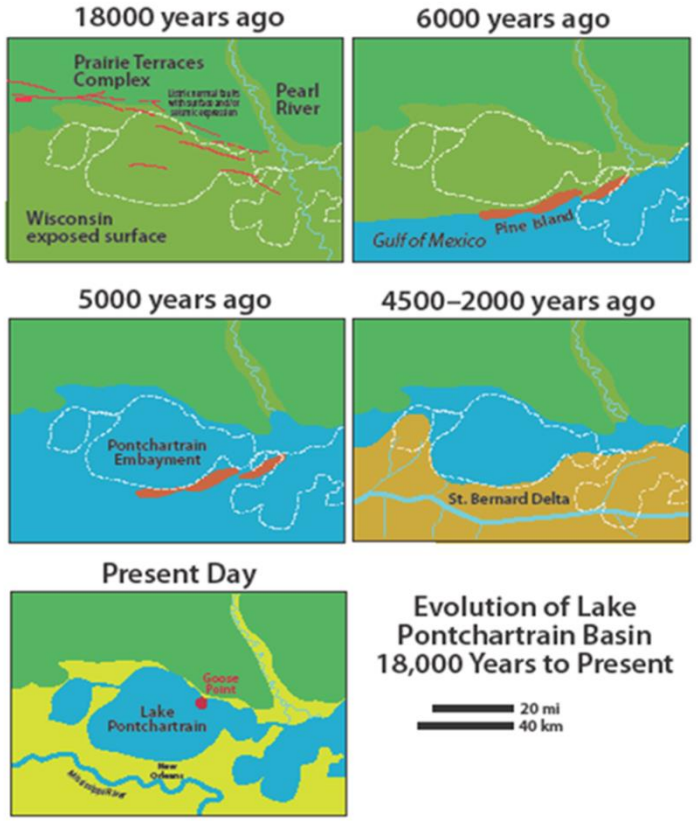


Figure 2. Three stage evolution of a deltaic barrier island. (Barrier Islands Educators Guide: model from Penland and Boyd, 1981.)

Penland, S., Boyd, R., 1981. Shoreline changes on the Louisiana barrier coasts. IEEE Oceans, Marine Technology Society. pp. 209-219.

http://mississippidelta.wmwikis.net/Isles+Dernieres+-+Trinity+Island

Coastal Evolution



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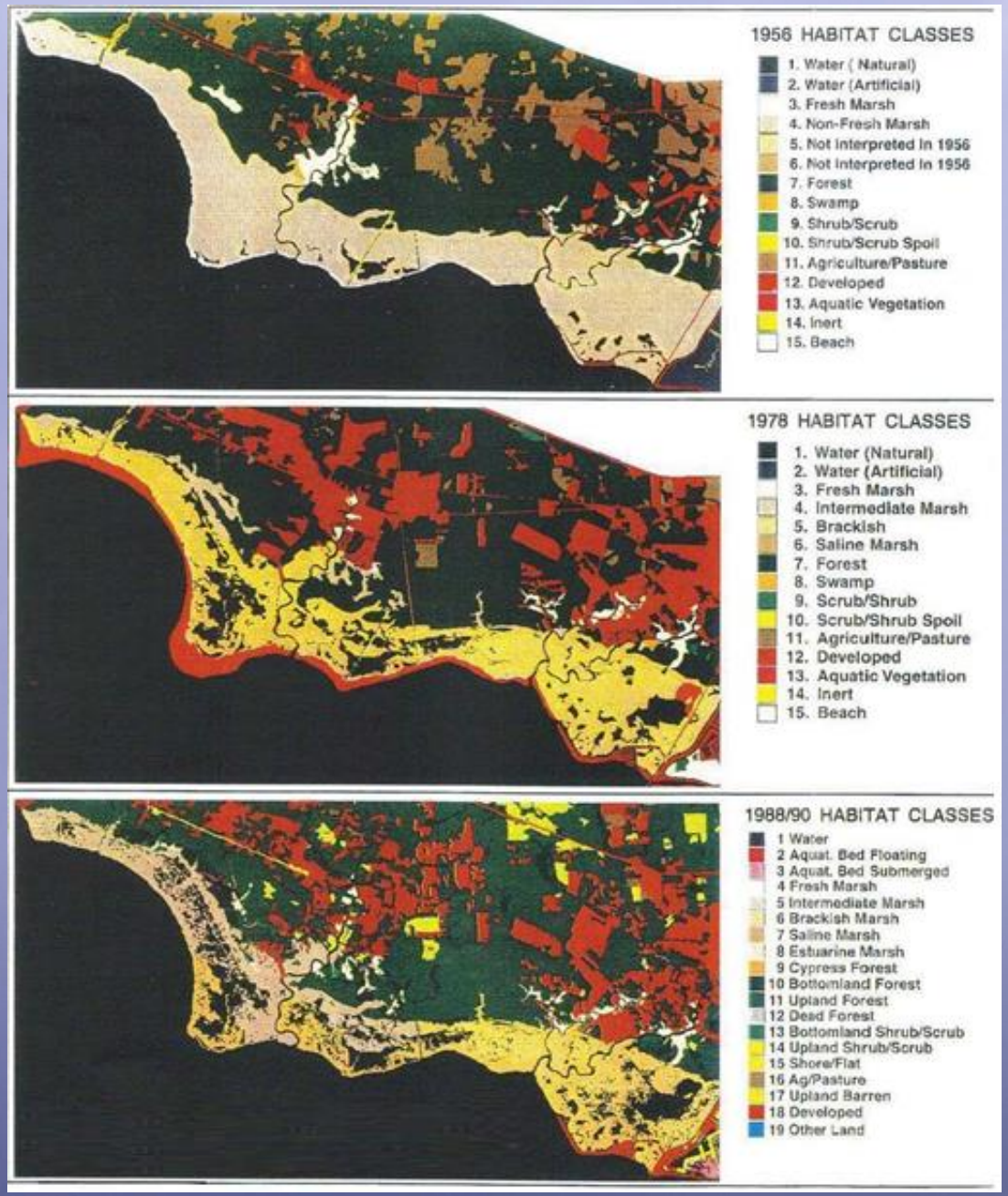
Faults disrupt the surface all across Louisiana



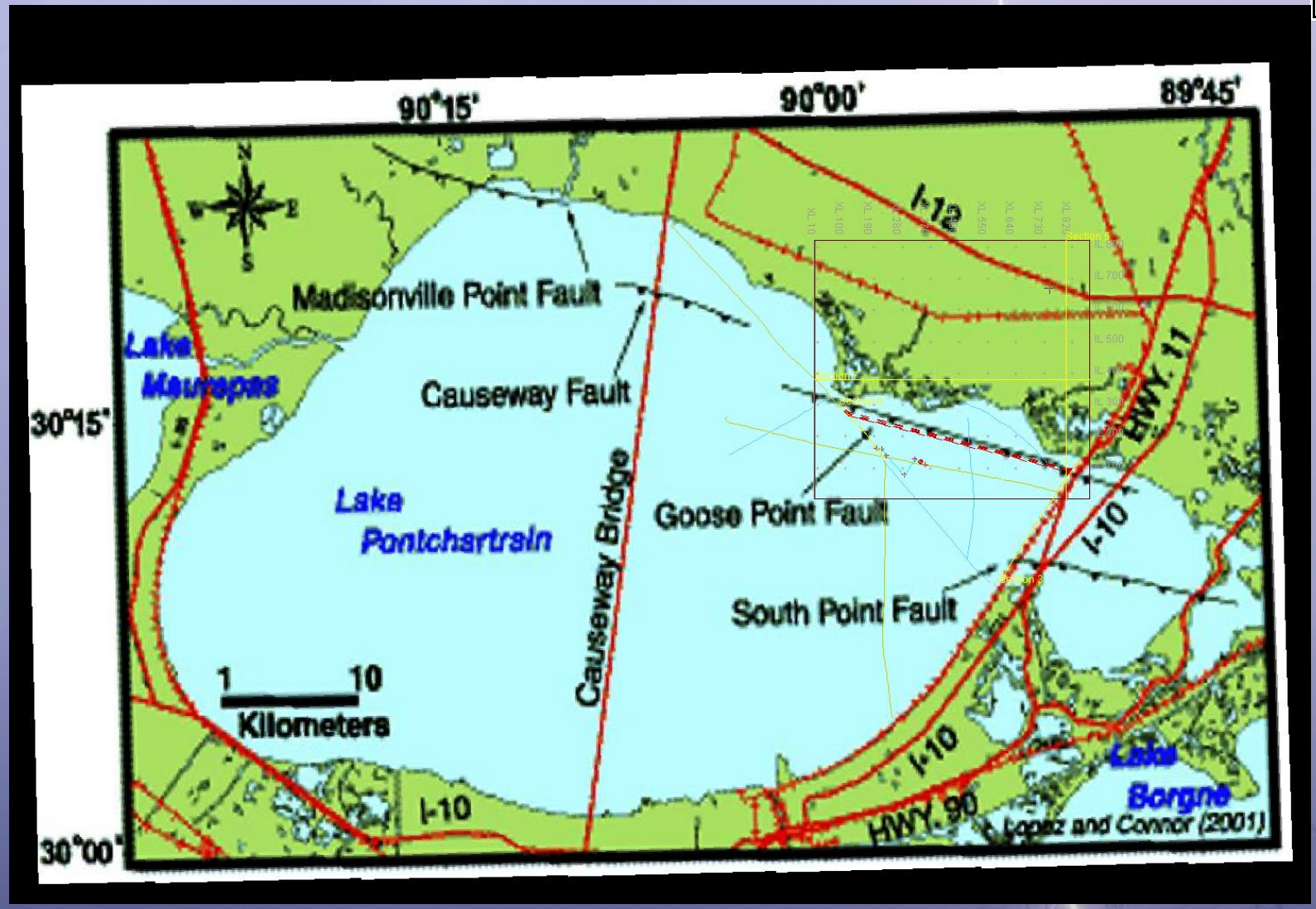
1956

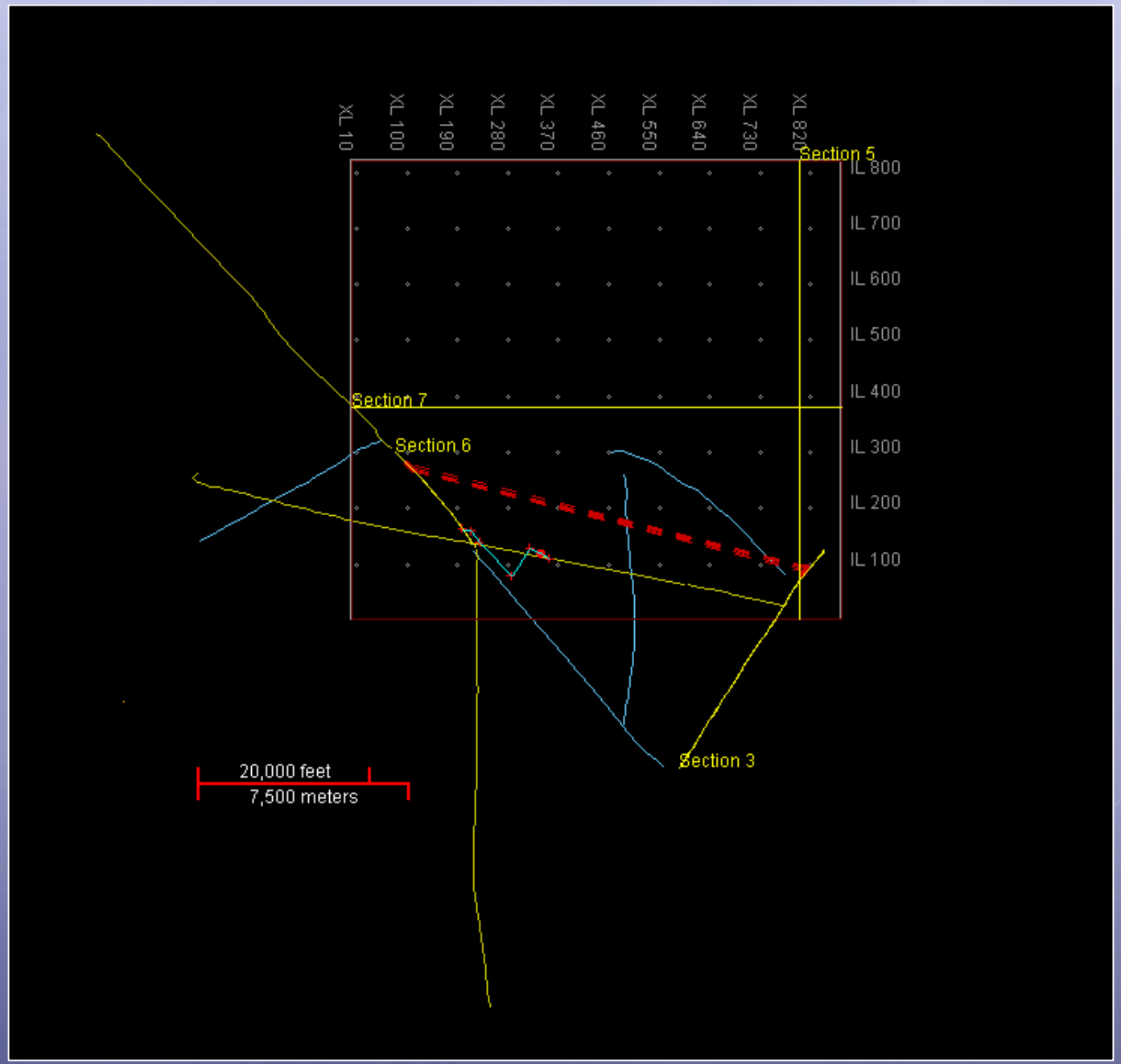
1978

1988-90

Geology changes rapidly enough to be noticed

DML is creating a Goose Point Case History





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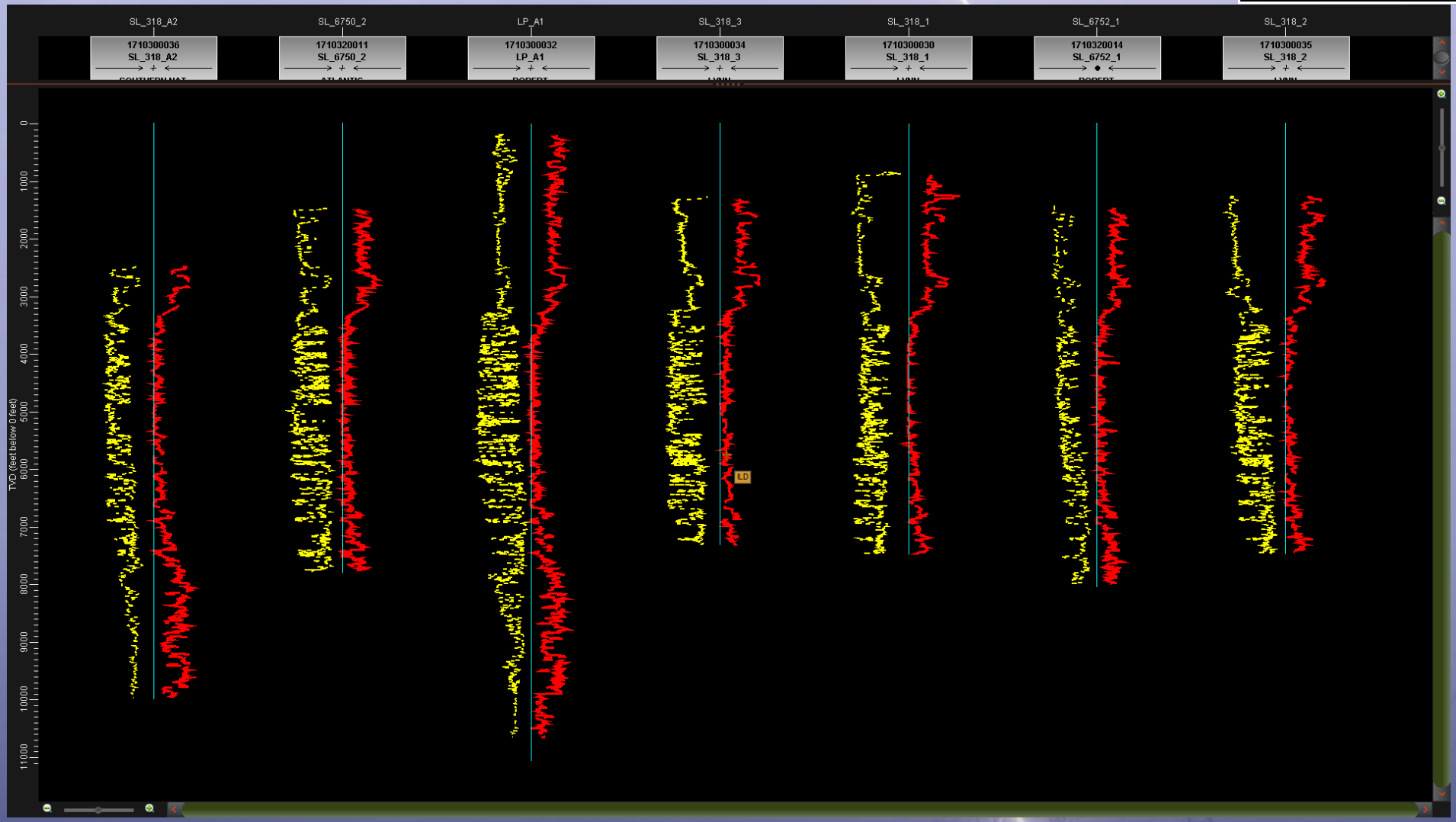
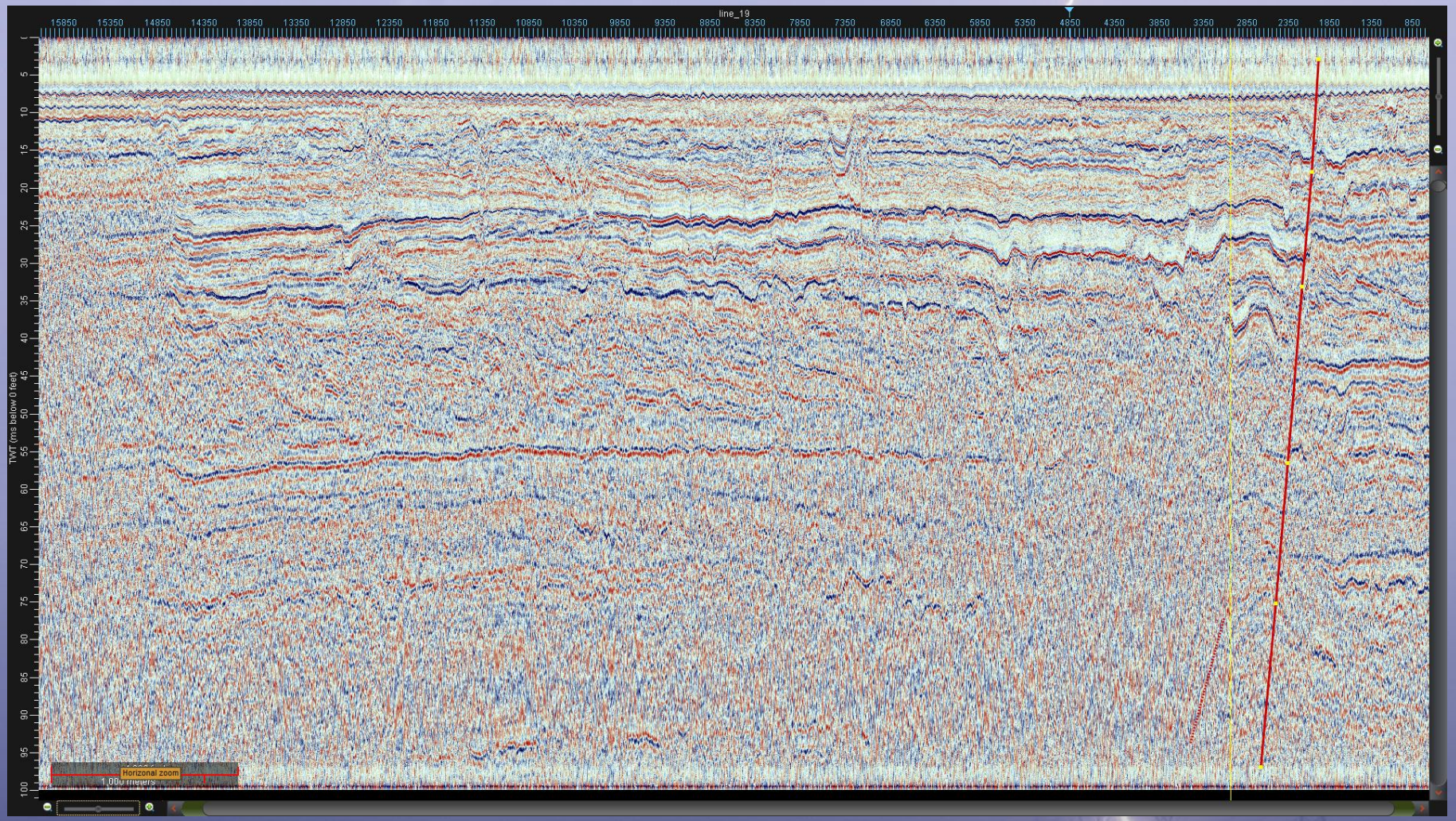
We are building a database

- Wells and Logs
- Sparker Seismic
- Lighting Attributes
- Resistivity Volumes
- All other relevant data

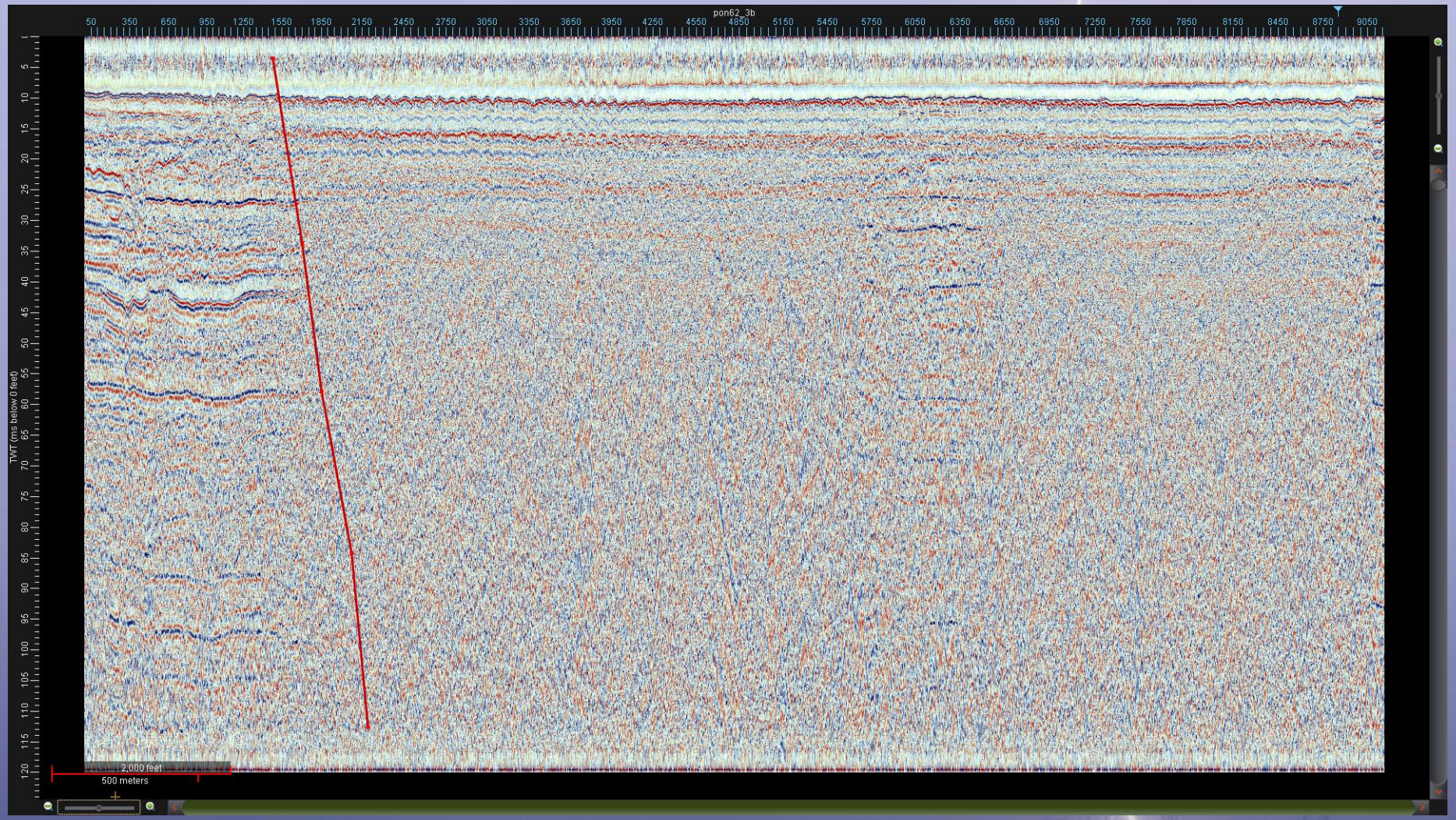
Wells and Logs

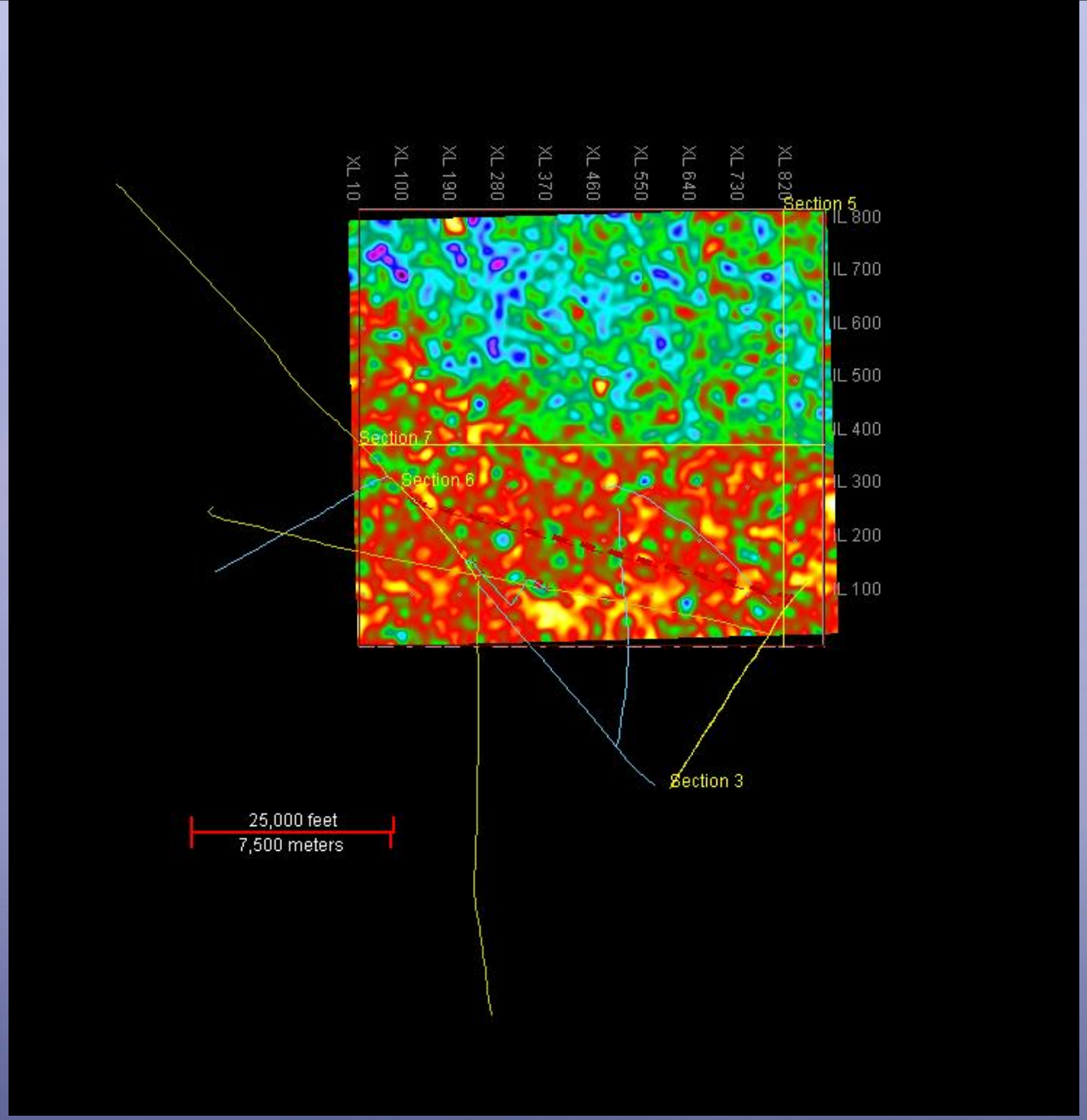


Sparker Line 19



Sparker Line 3b





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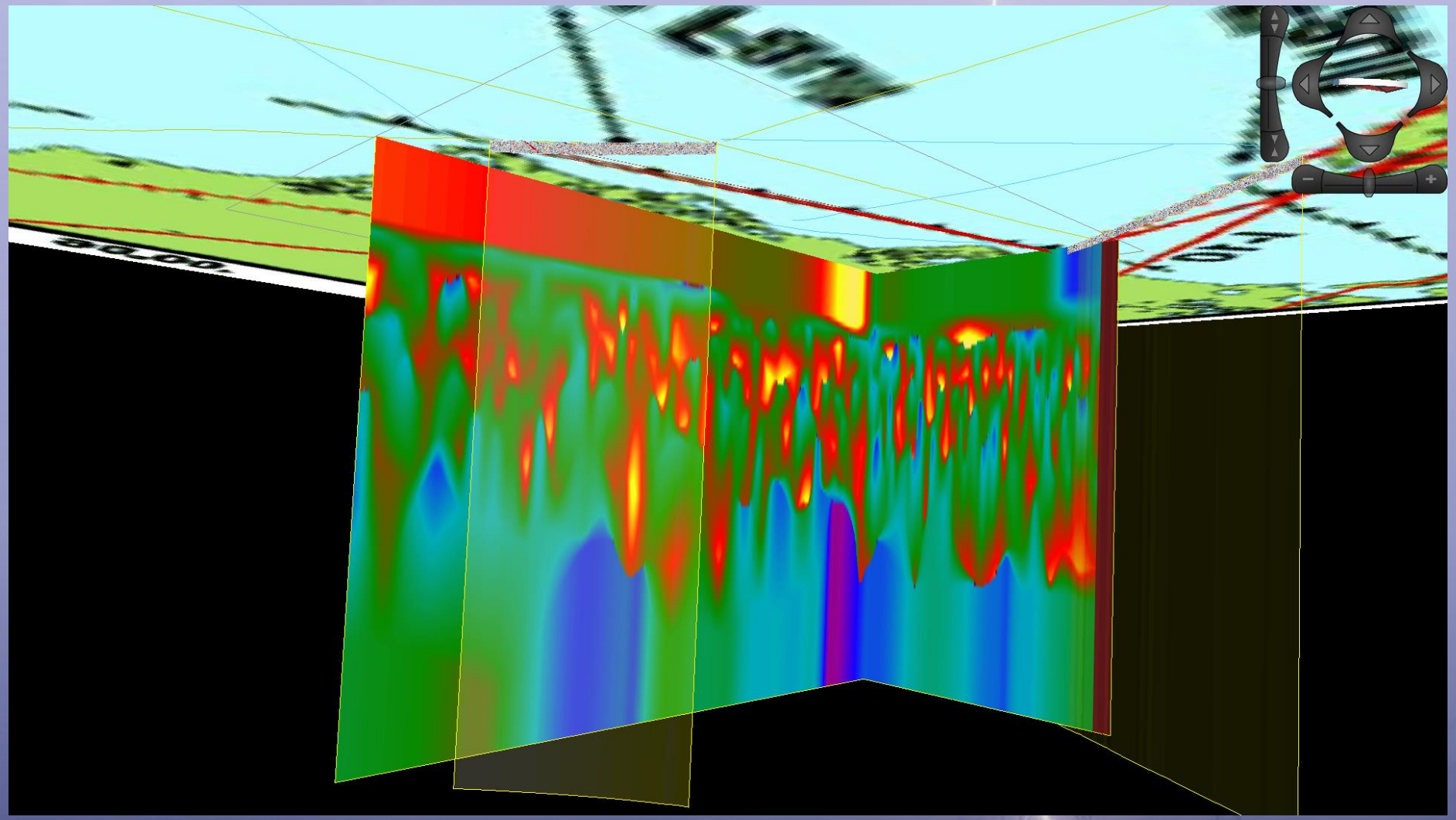
Rate of Rise-Time Lightning Attribute

Resistivity Volume Cross-Sections



We hope the SLFPA-W will seek regular updates on the development of the Goose Point Case History

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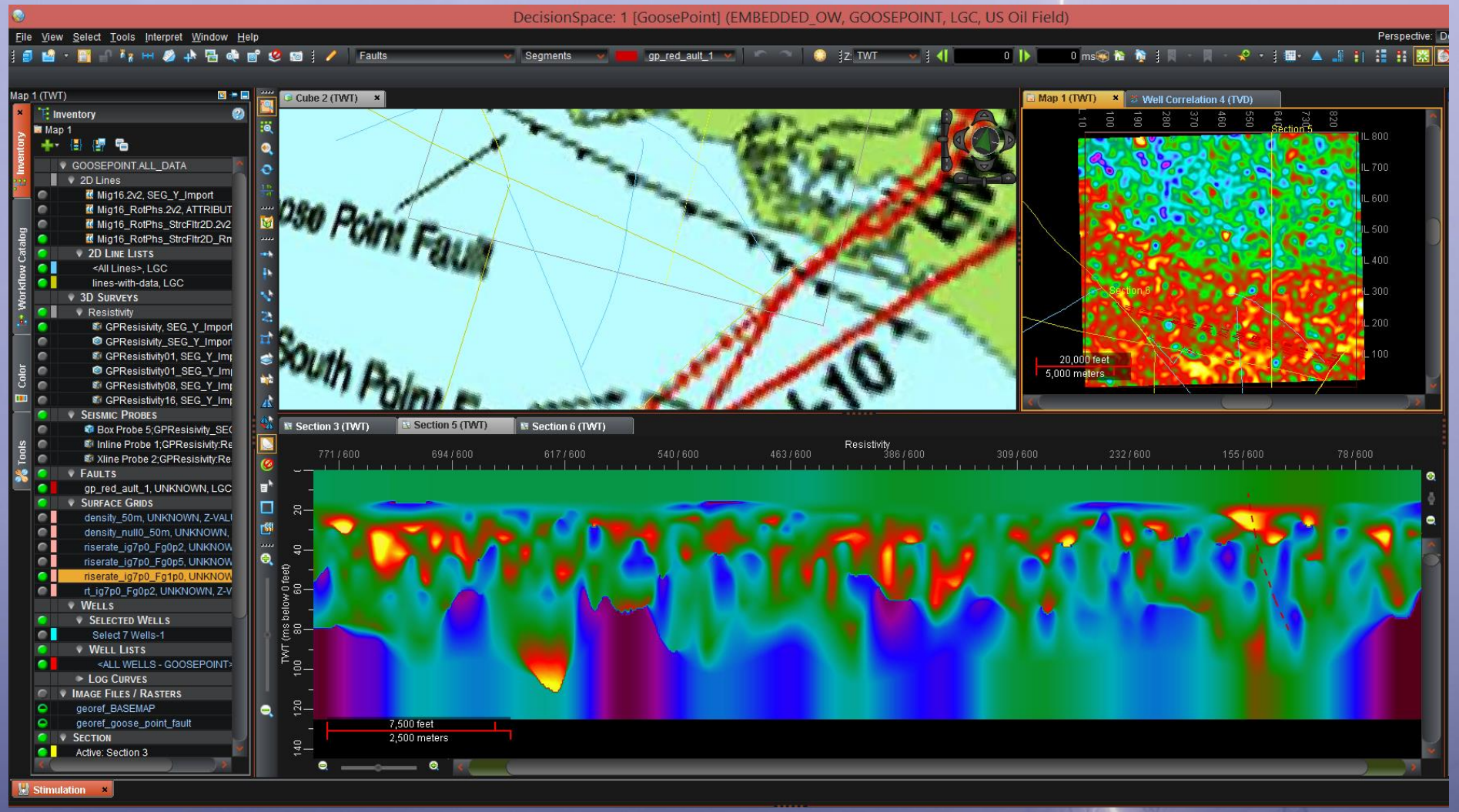

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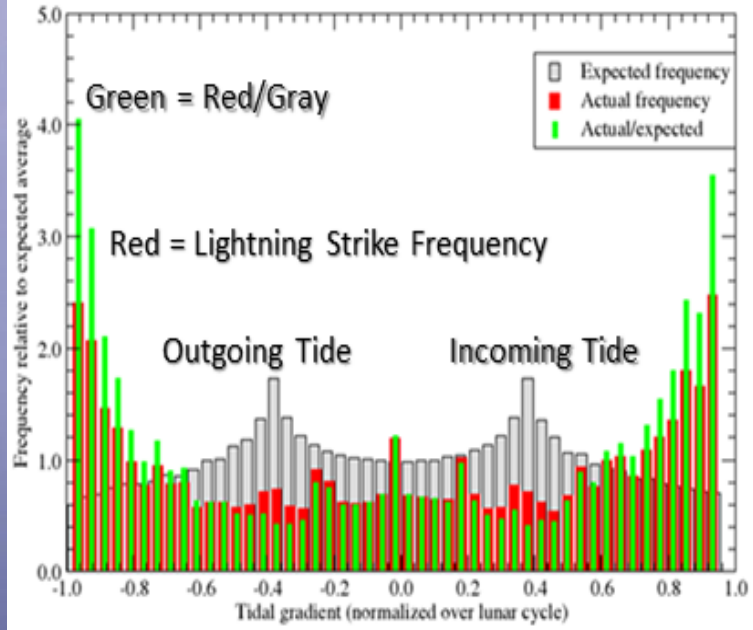
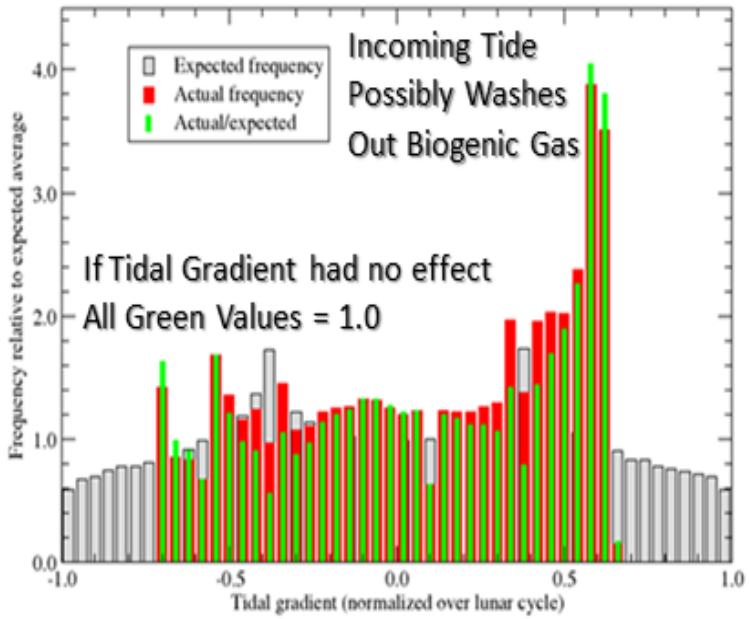
Rate of Change of Lunar/Solar Tides

(Normalized Over Lunar Cycle)

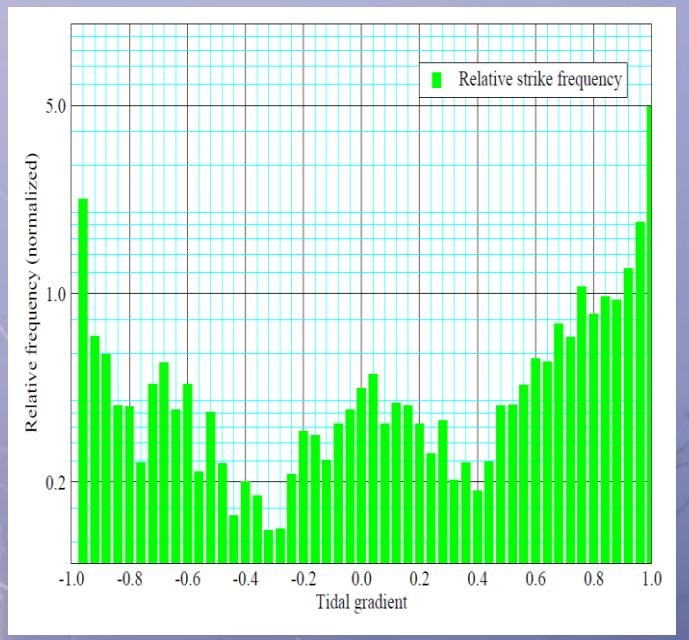
North Texas Example

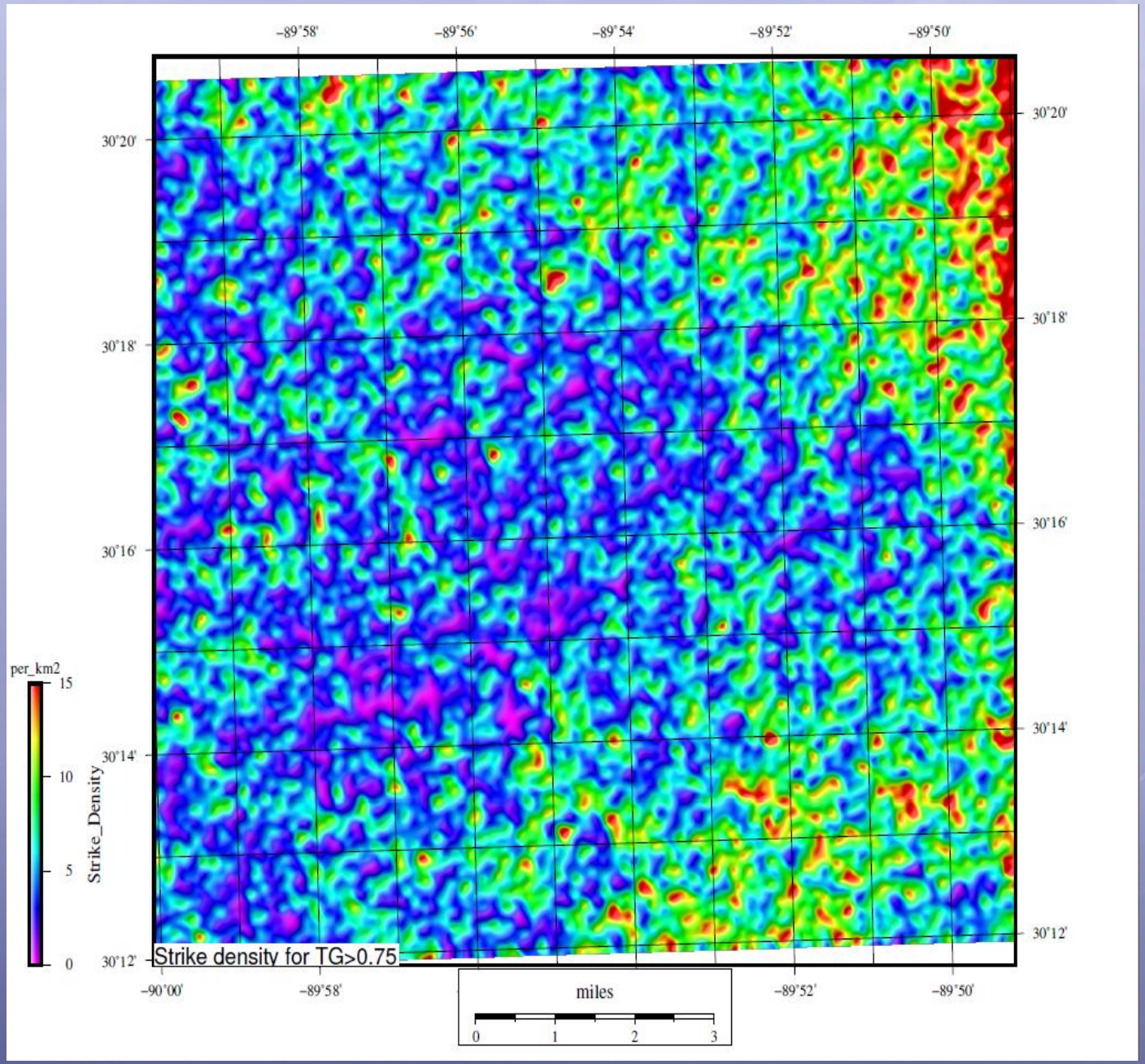


Florida Example



Goose Point Example





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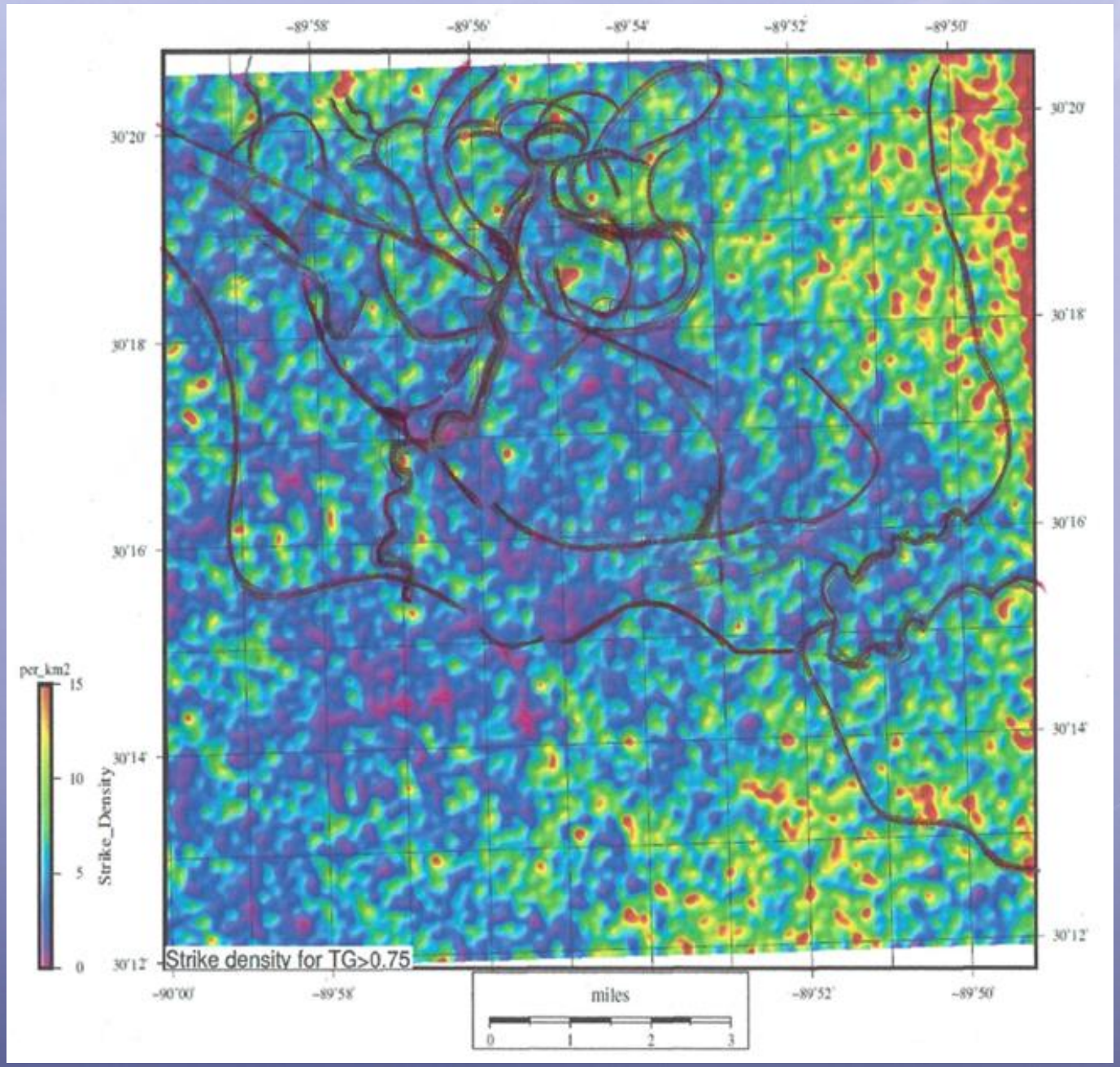
Strike Density at High Tide Gradient



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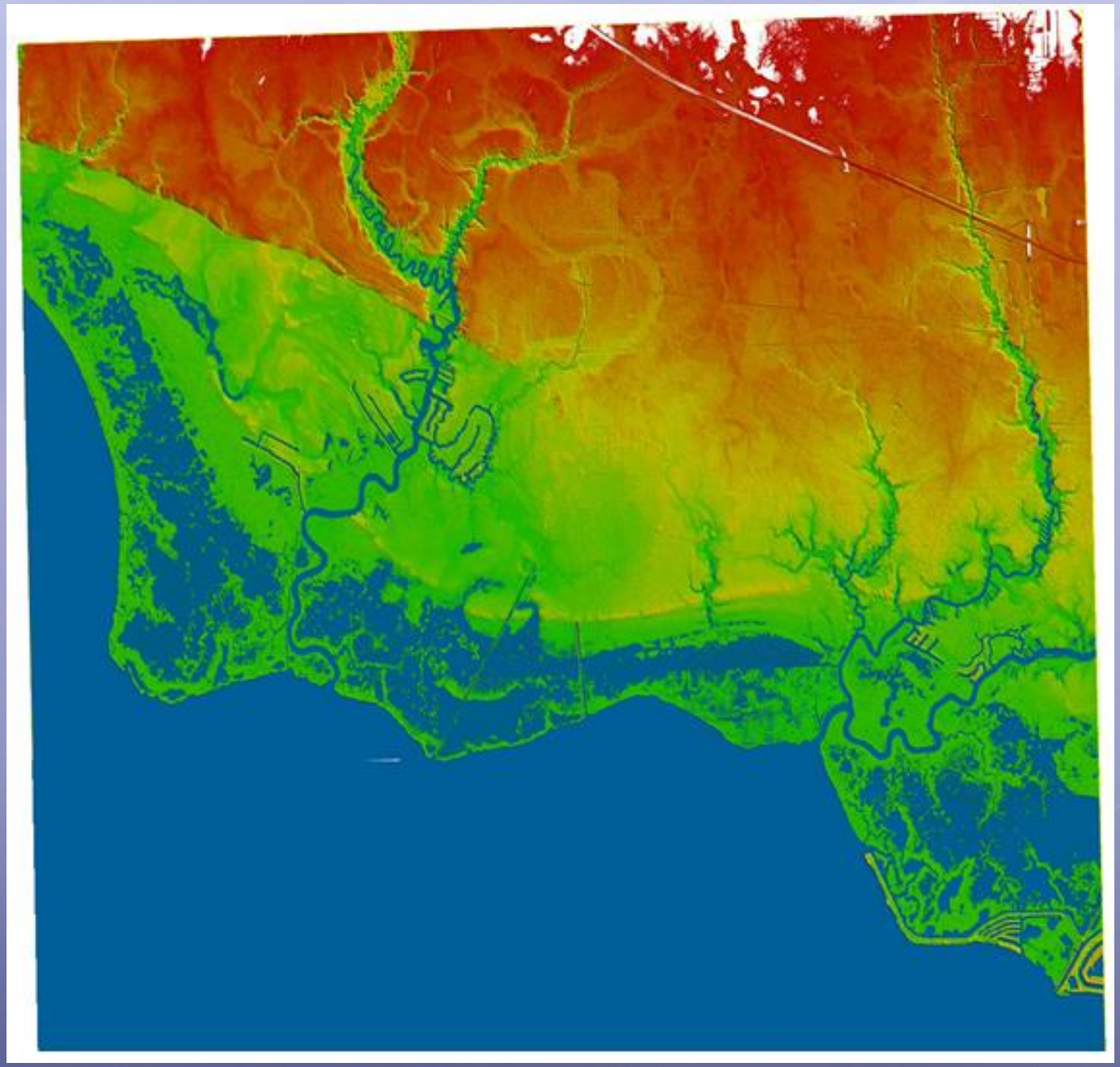
Interpretation of Strike Density at High Tide Gradient



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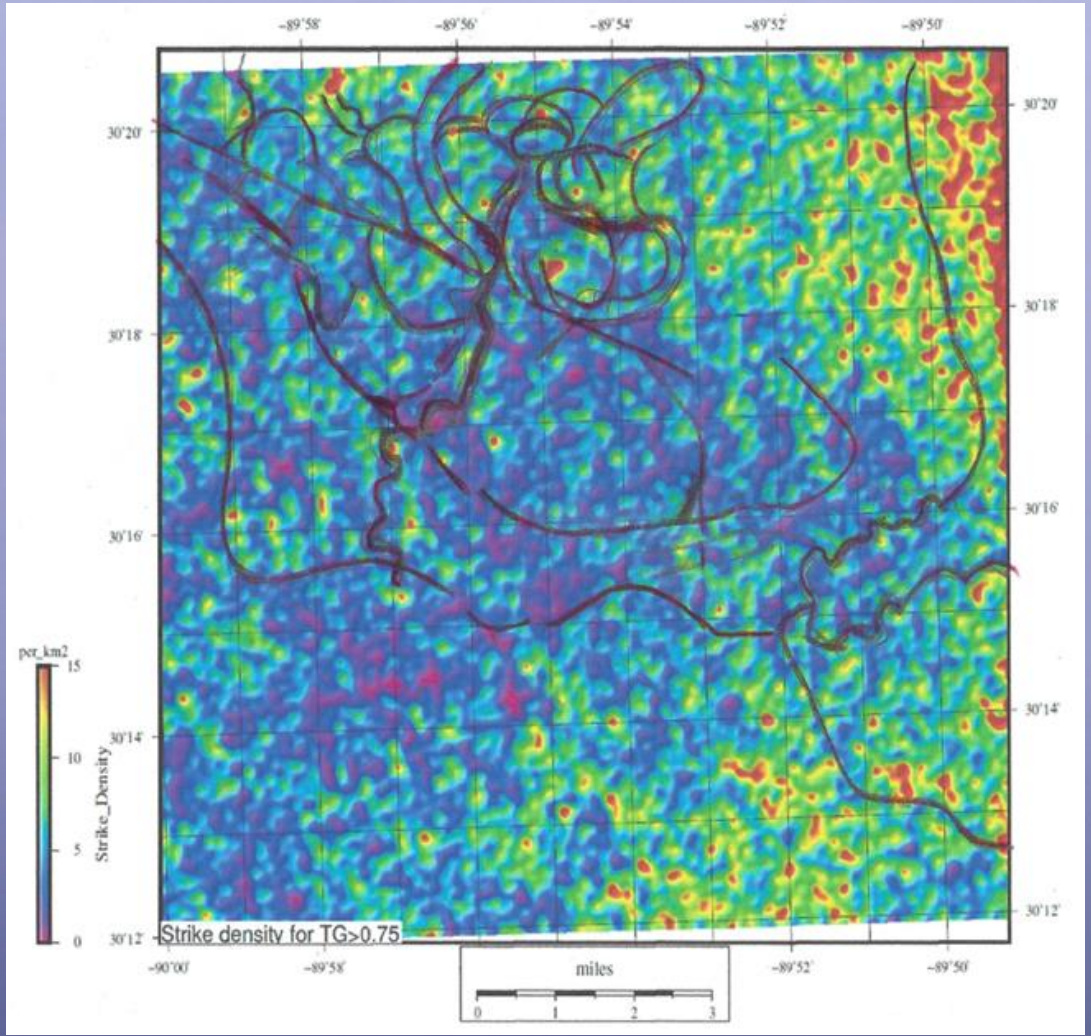
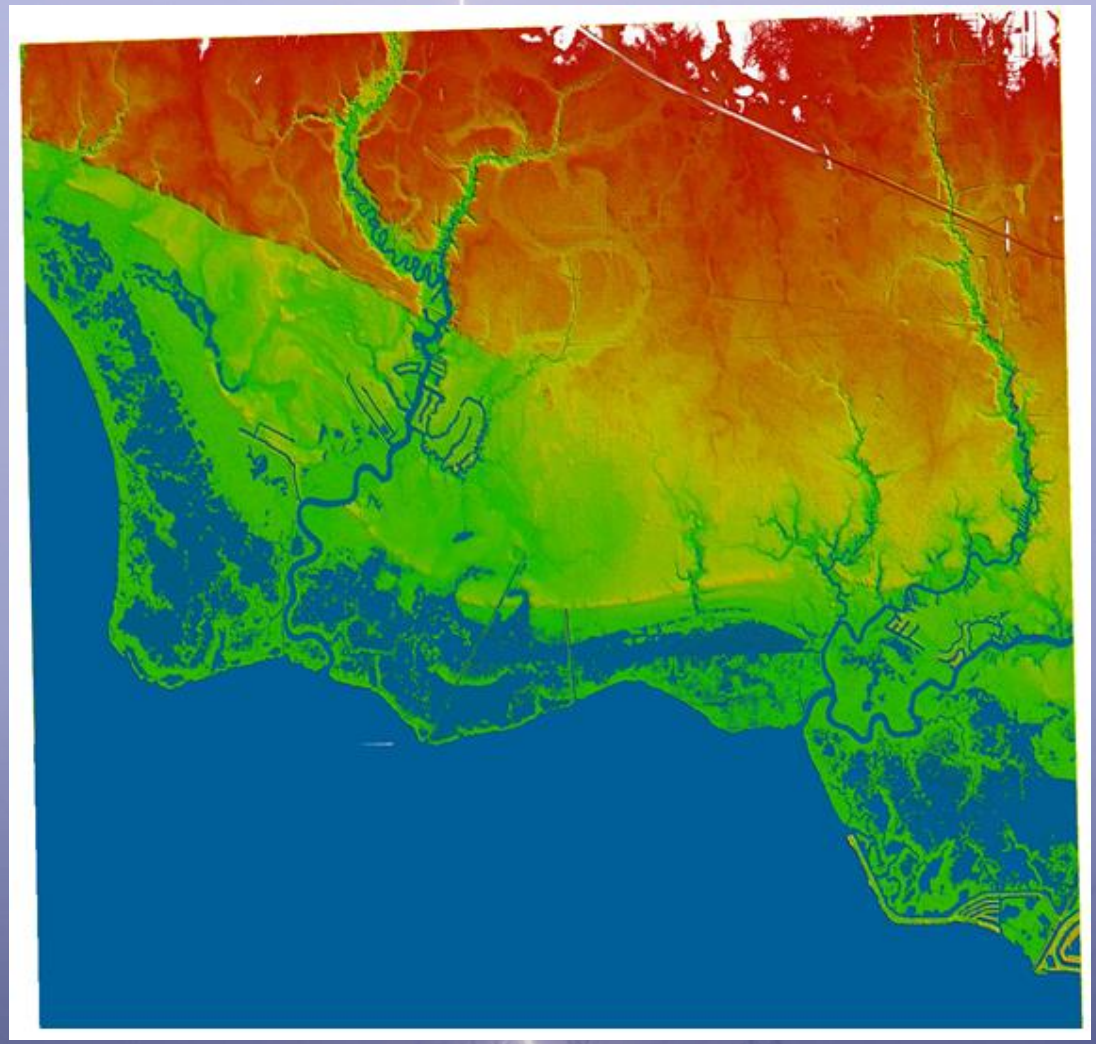
LIDAR over the same area

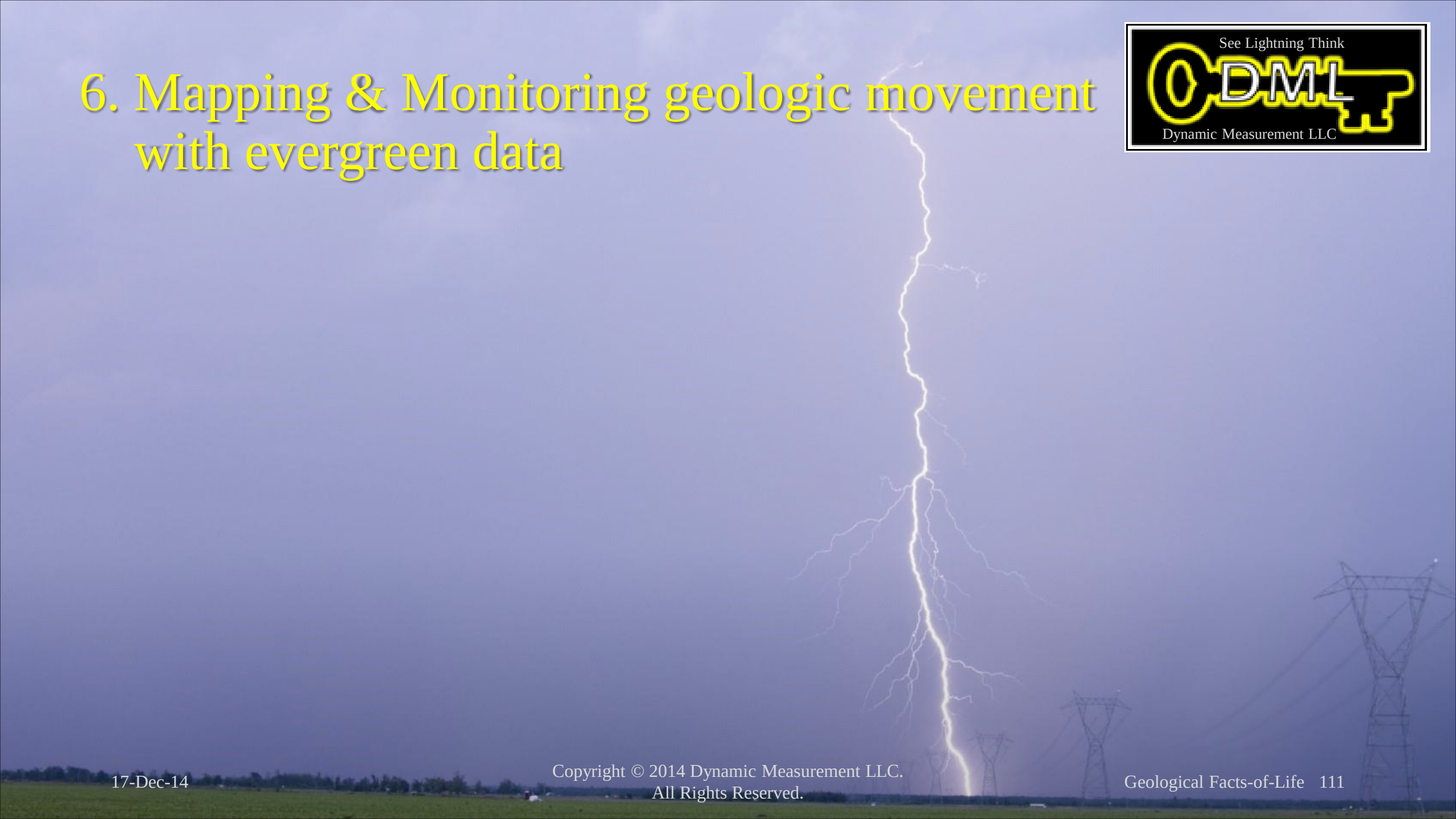
Side-by-Side Comparison





Questions & Answers & Discussion

6. Mapping & Monitoring geologic movement with evergreen data



Planning for Growth and Disasters

- Planning starts with implementing an information based process to manage complexity.
- This information process must be able to:
  - Manipulate data from regional scales to construction's 'nuts & bolts,'
  - Analyze political decisions, and
  - Function as an expert system.
- This starts with understanding the geological foundations of Planning.
- Imagine using "N"-Dimensional languages to analyze all types of data, from satellite images to social patterns, and then integrating the information into designs which optimize interaction between nature and built form.

NSEM provides regularly updated data everywhere starting in 1999

- Land loss and marshes broke up 1956-1978
- 1986 & 1987 fault caused movement on the bridge and the lake changed
- Lightning provides an evergreen data set which provides a base for planning, and when a disaster happens, a base to build solutions on.
- It is important to prepare for the future to help learn from the past
  - Hurricanes
  - Fault Movement
  - Lightning Damage to cement levees (knowing areas of high lightning density allows protecting against strikes in these areas with faraday cages, etc.)

Infinite Grid^{SM} Organization enables capture of historical data, integrated with satellite and lightning data

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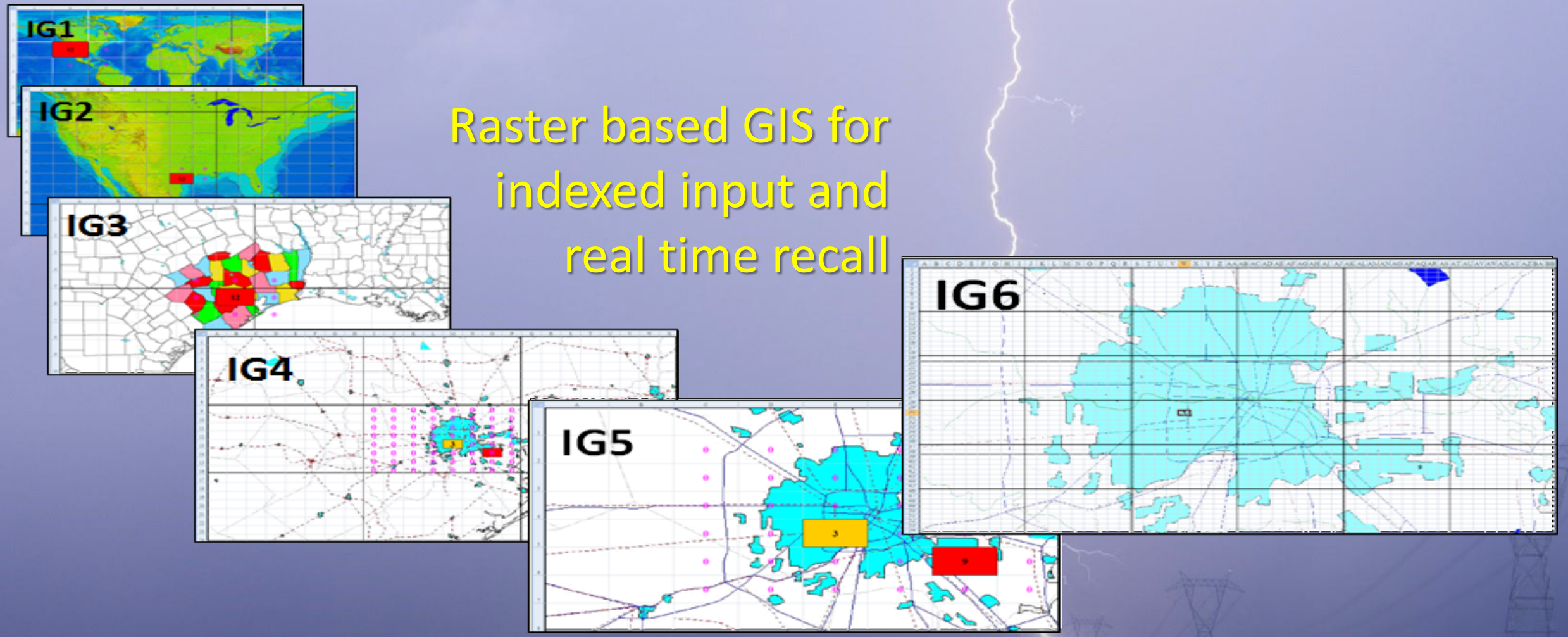
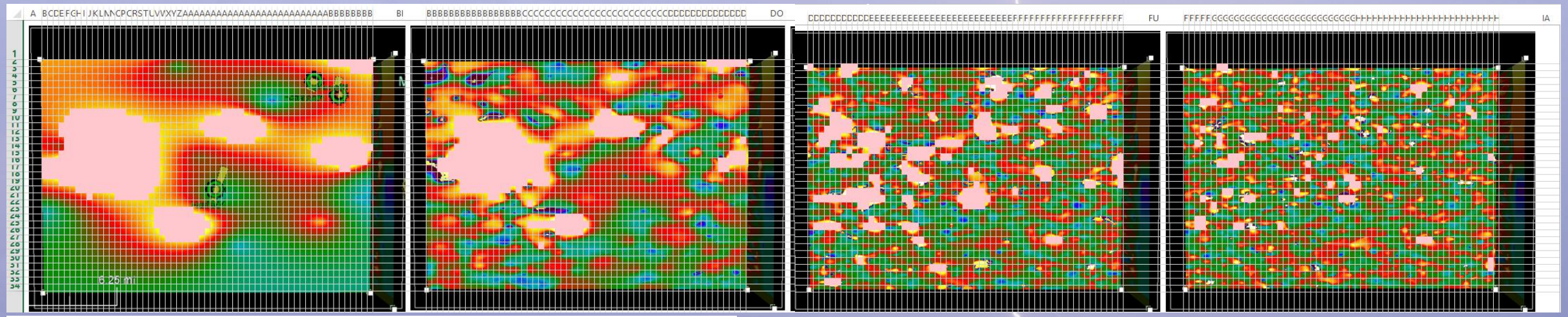
Raster based GIS for indexed input and real time recall



Grid-to-Grid Operations enable GIS prioritization and project focus



	BH	BI	BJ
5		rs1344	fv2:hz33
6		rs1440	c36:bg67
7		rs1632	bj36:dm67
8		rs1824	dp36:ft67
9		rs2016	fv36:hz67
10		rs2208	c69:bg100
11		rs2400	bj69:dm100
12		rs2592	dp69:ft100
13		rs2784	fv69:hz100
14		rs2976	c101:bg132
15		rs3168	b101:dm132
16		rs3360	dp101:ft132
17		rs3552	fv101:hz132
18		rs3744	c133:bg155
19		rs3936	bj133:dm155
20		rs4128	dp133:ft155
21		rs4320	fv133:hz155
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Mapping and Monitoring

- Lightning Data Analysis is a New Geophysical Data Type
- Resistivity Volumes from Lightning Databases are Frameworks
- Geologic Frameworks are critical for stable growth of society
  - Defining exploration plays, and
  - Infrastructure strengths and weaknesses
  - Planning water conservancy, and
  - Managing water abundance
- Lightning Analysis is one of a several remote measurement tools which can be used to test the viability and usefulness of these new planning approaches

Questions & Answers & Discussion

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
   •
5. Goose Point – tectonic driven subsidence lightning case history
   •
6. Mapping & Monitoring geologic movement with evergreen data
   •

See Lightning, Think DML

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  Baton Rogue, LA 70835

Find out more at http://www.dynamicmeasurement.com/TAMU

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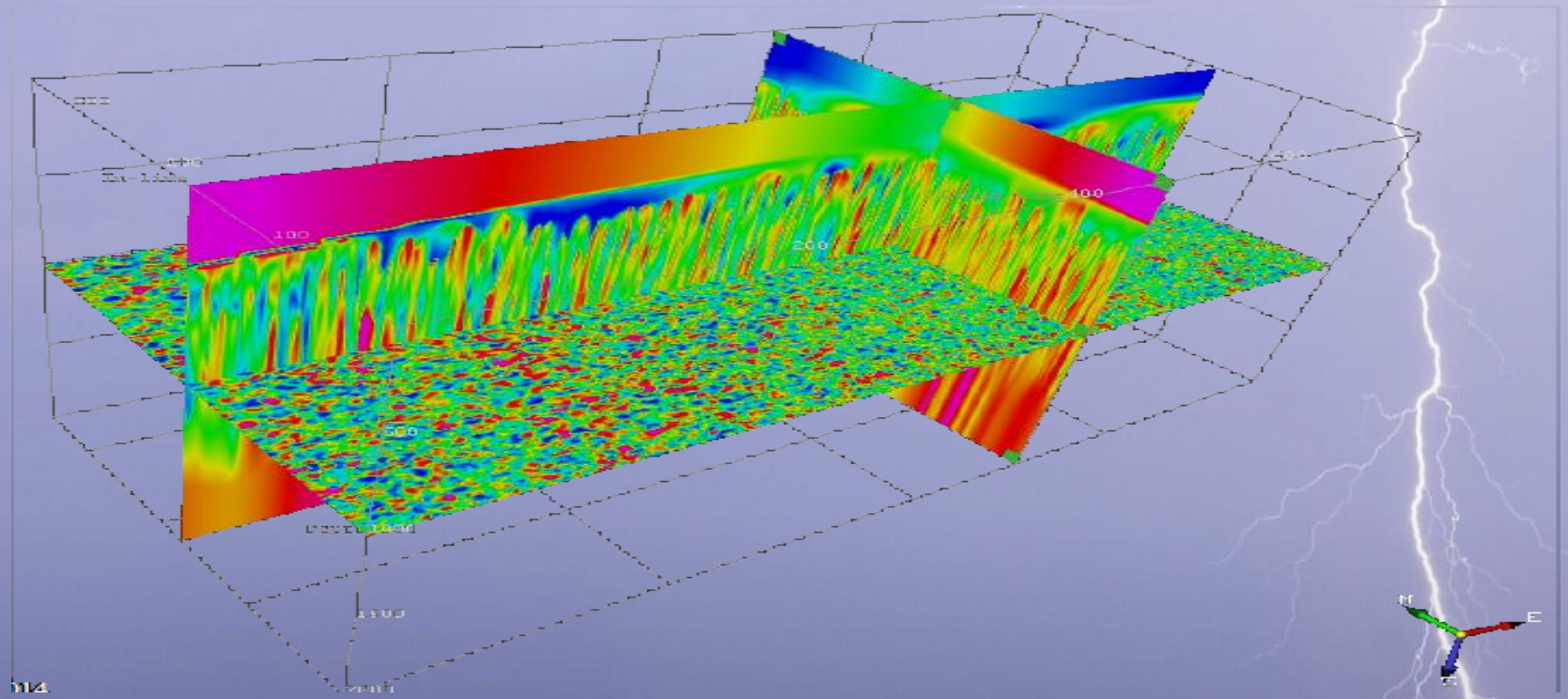
Thank You!



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Think DML!