Great Scott, back to the future with a 1.21 “jigawatt” bolt of lightning!

Scenes from the movie “Back to The Future”

DYNAMIC MEASUREMENT

Lightning Sparks Interest in the Unconventional Mapping of Active Subsurface Faults.

Louis J. Berent
H. Roice Nelson
Dynamic Measurement, LLC

Presentation Objectives

- To point out how lightning is neither random nor predictable and that geology can play a significant role in where and how lightning strikes.
- To demonstrate how lightning-sourced data can be used to map geologic features such as faults.
- To illustrate how lightning-sourced electromagnetic data can be used for reconnaissance mapping & prospecting.

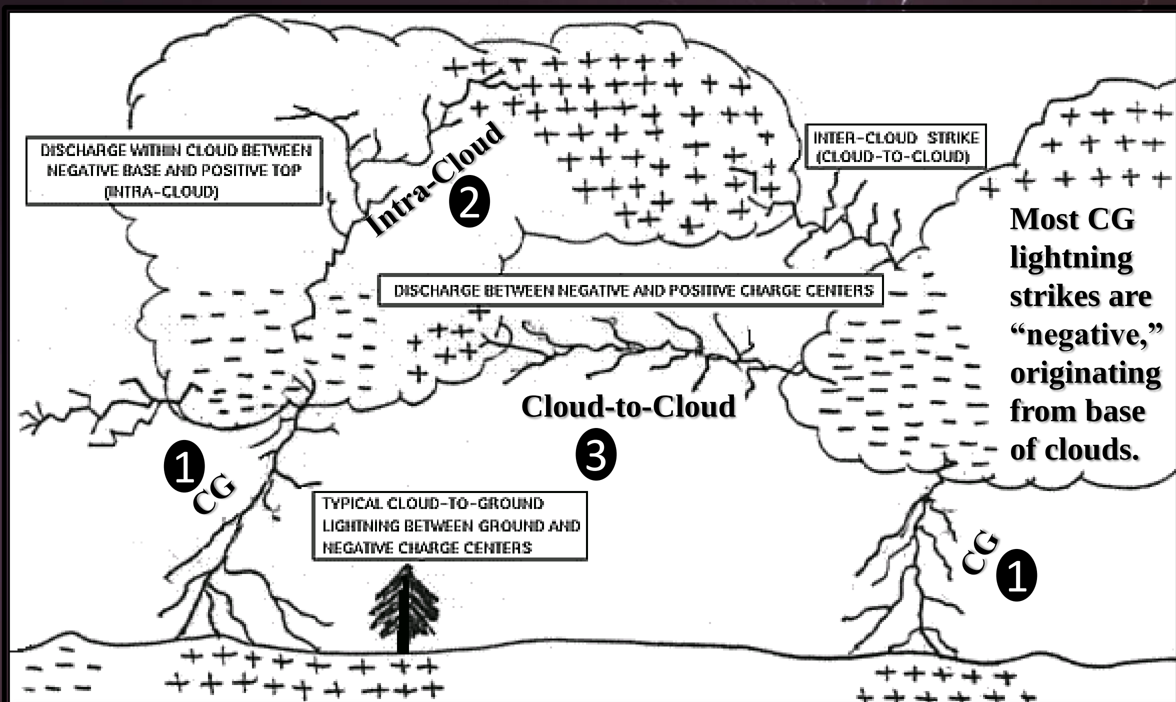
Outline

Lightning, and why it is tracked, stacked & mapped!

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

Using NSEM to interpret geologic features.

Lightning: an atmospheric discharge of electricity that ionizes the air to create highly conductive plasma channels.



1. Cloud-to-Ground (CG) 2. Intra-Cloud 3.

Adapted from: NASA, Global Hydrology Resource Center Website, Lightning & Atmospheric Electricity Research, Description of Lightning Discharge Process (https://lightning.nsstc.nasa.gov/primer/primer2.html).

- Hot moist air rises: freezes to form ice crystals.
- Turbulent winds: ice, hail, water droplet collisions.
- Clouds become polarized:
  + ions carried to top clouds,
  - ions gravitate to base.
- Static charge buildup: when charge strength exceeds insulating property of atmosphere, sudden high-voltage static discharge.

Nature of Lightning
"Step Leaders" & "Streamers"

Intensely charged channels of downward zig-zagging/branching electrons seeking positive ions to discharge built-up static energy.

Rising stream of positive charge attracted to downward seeking electron step leaders when step leaders within 30' to 300'.

Failed Lightning Strikes & Streamers

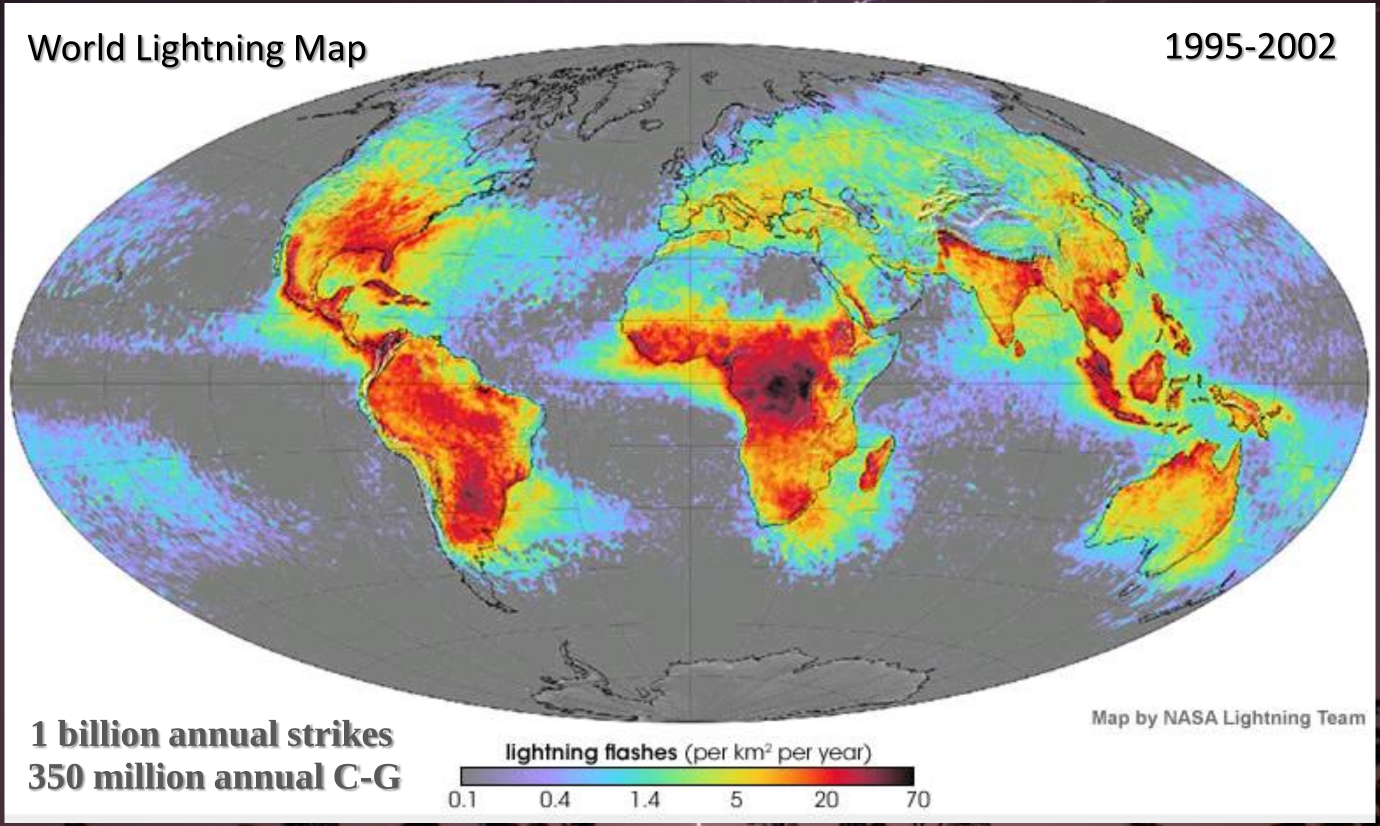
Two streamers launched from tree, but only one connects with step leader to produce a strike.

Streamer launched from telephone pole also does not connect - no strike.

Illustrates competing factors influencing strike location, one of which is geology.

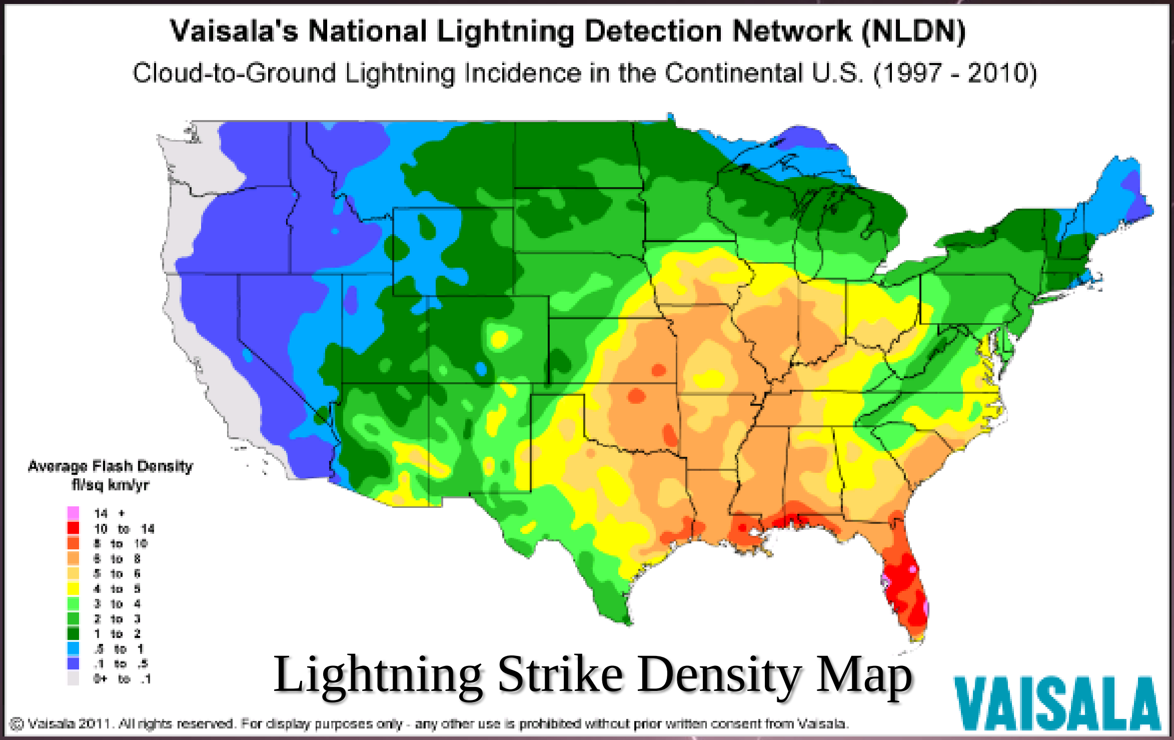
Why is lightning tracked & mapped?

Uneven CG Distribution, But Not Random



- Storm Tracking
- Safety Warnings
- Insurance
- Forest Fire Forecasting
- Hurricane Tracking
- Research & now…
- Natural Resource Exploration!

25 Million Annual U.S. Lightning Strikes
17 Year Database, Rich Database to Mine



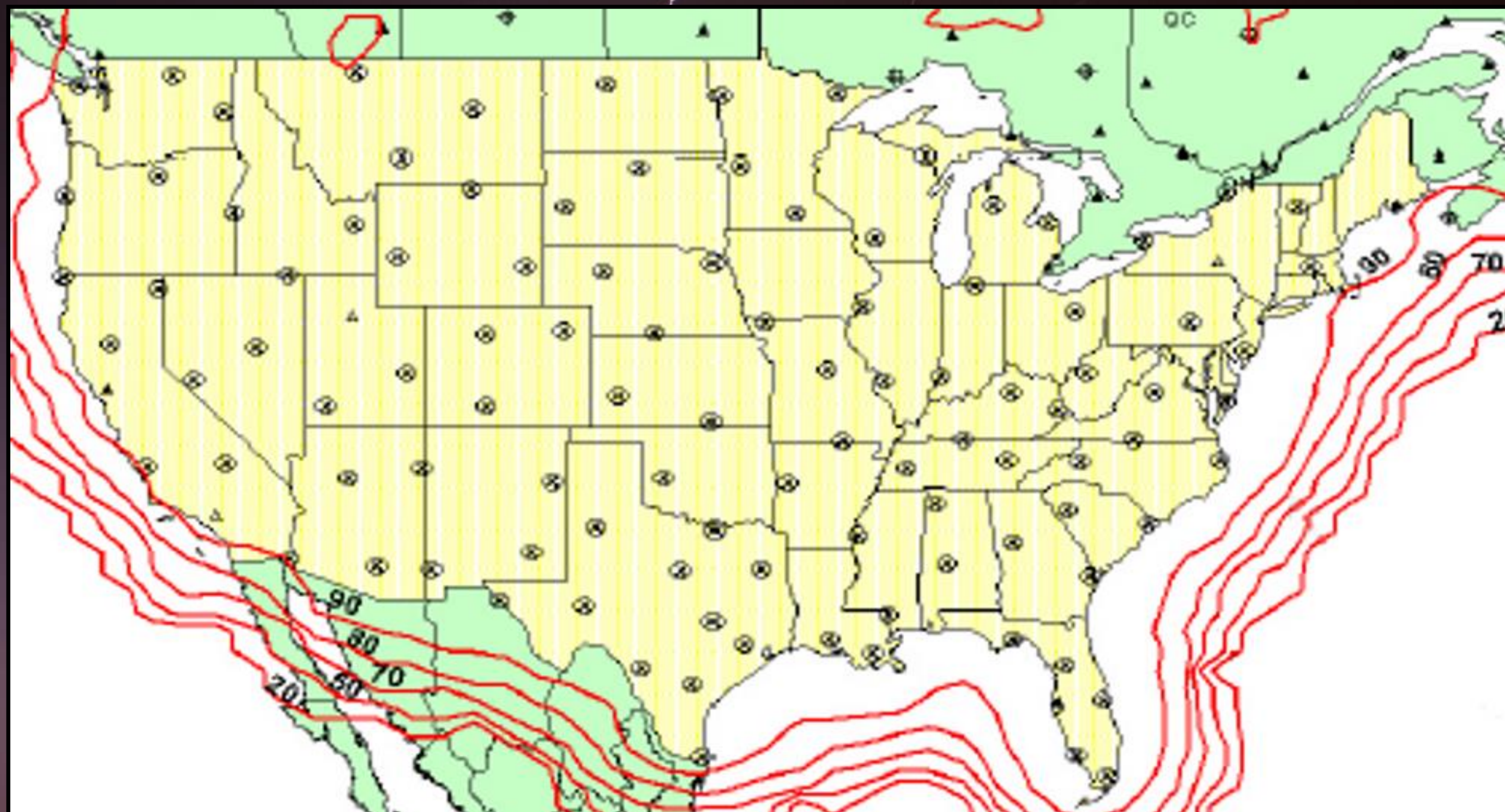
Lightning Strike Density Map

Gulf Coast Database:
200-350 strikes/square mile.

Strike density regionally controlled by meteorology, but locally influenced by geologically-sourced perturbations of the Earth's telluric currents.

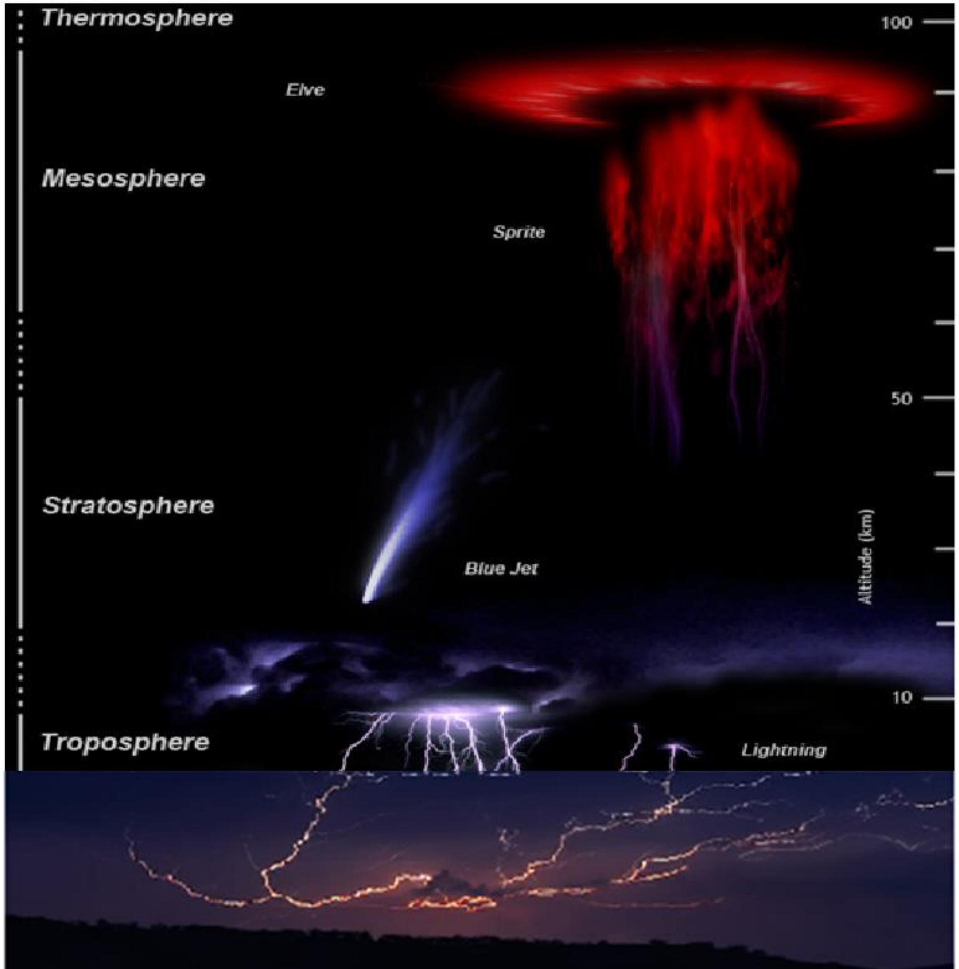
How Lightning Data is Collected

National Lightning Detection Network (NLDN): 115 Sensor Locations in U.S.



Typical lightning strike in Texas picked up by 16 -24 lightning sensors.
Sensors within 600 mi. of strikes contribute to triangulation.
Empirical results show location error from reasonably dense database 35-70’.

Geologically Controlled Telluric Currents
Primary Lightning Influence



Wikimedia Commons

Lightning bypasses tall objects and…

…infrastructure expected to attract lightning.

Lightning Strikes Are Not Random

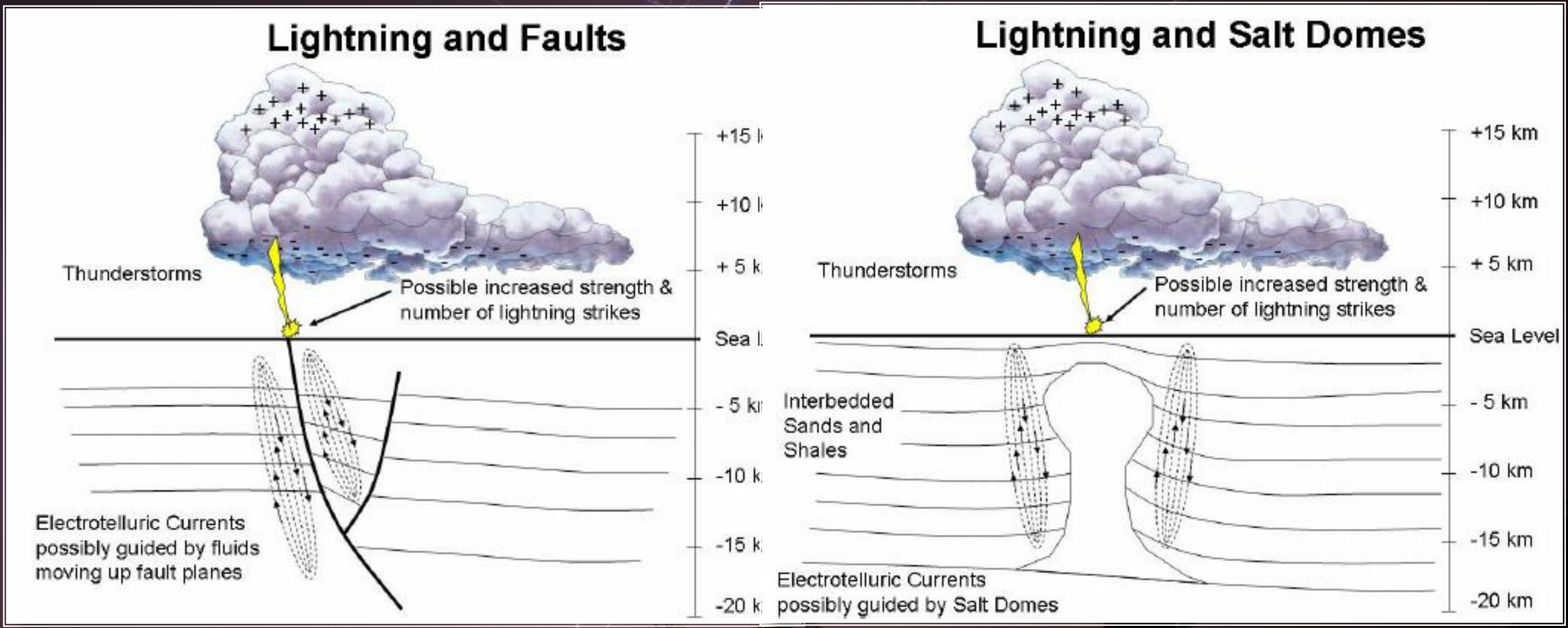
Influenced by Lateral Changes in Rock Properties:

- Faults
- Fracture Swarms
- Salinity
- Pore Fluids
- Porosity
- Permeability
- Mineralization

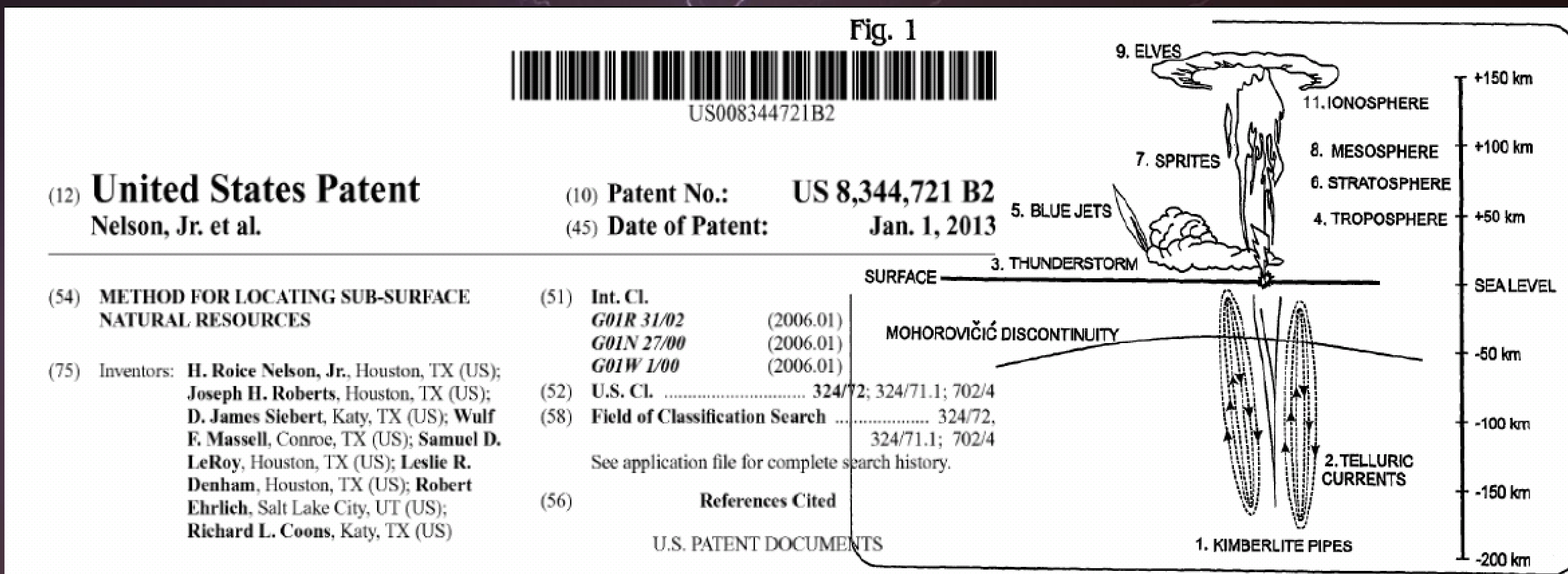
Upward lightning shows electrostatic charge builds up in the ground, as well as in the atmosphere.

Telluric Currents, Lightning & Geology

Earth Currents Modified by Geology ⇨ Prone to Lightning



NATURAL SOURCE ELECTROMAGNETICS (NSEM) - A NEW GEOPHYSICAL DATA TYPE


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.

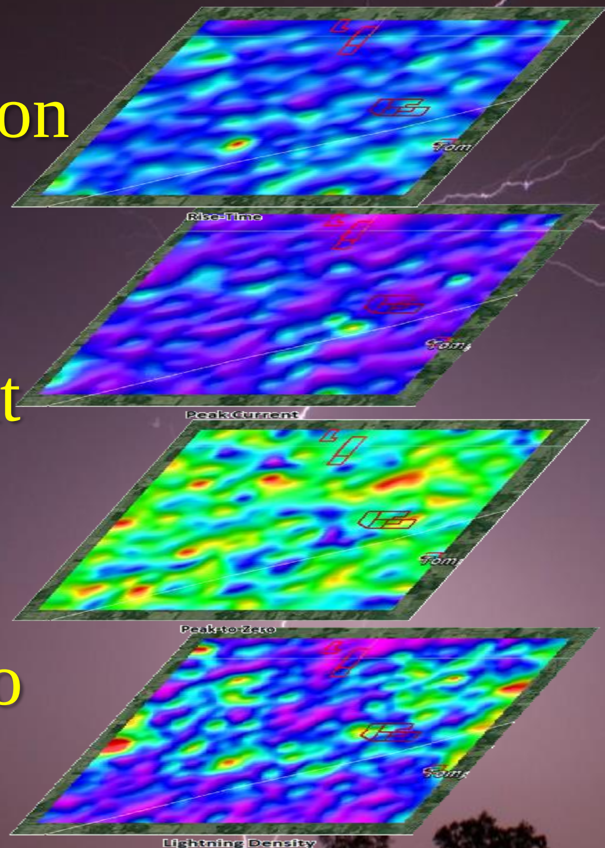
(56) **References Cited**

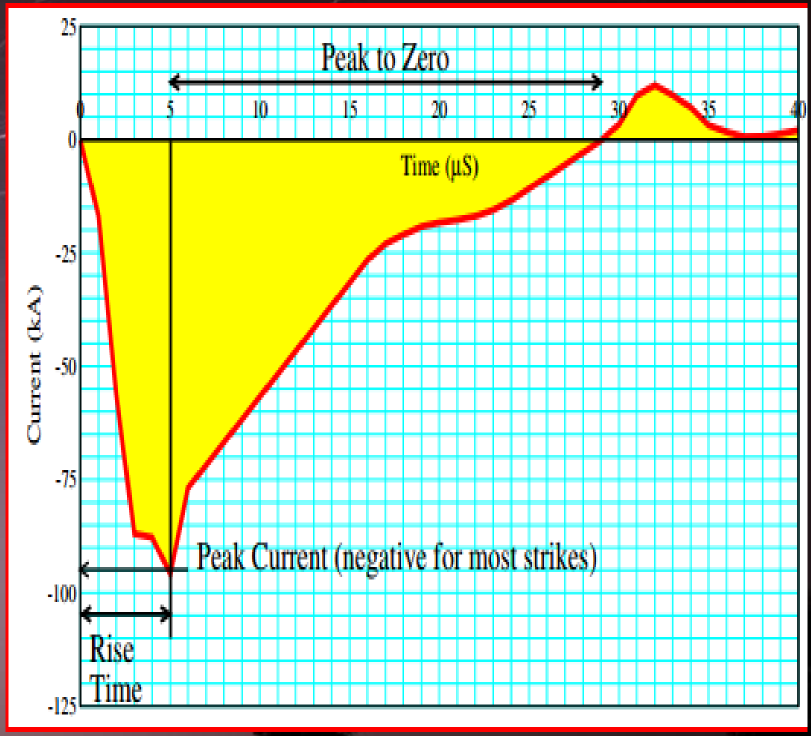
U.S. PATENT DOCUMENTS

Proven & Patented Technology

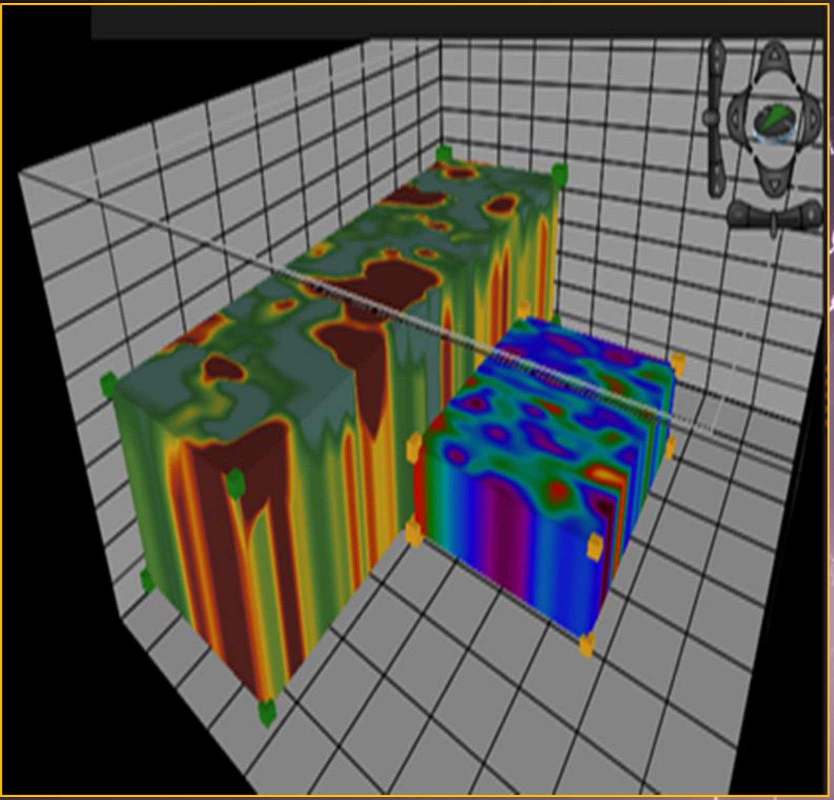
Lightning Attributes & Measurements

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

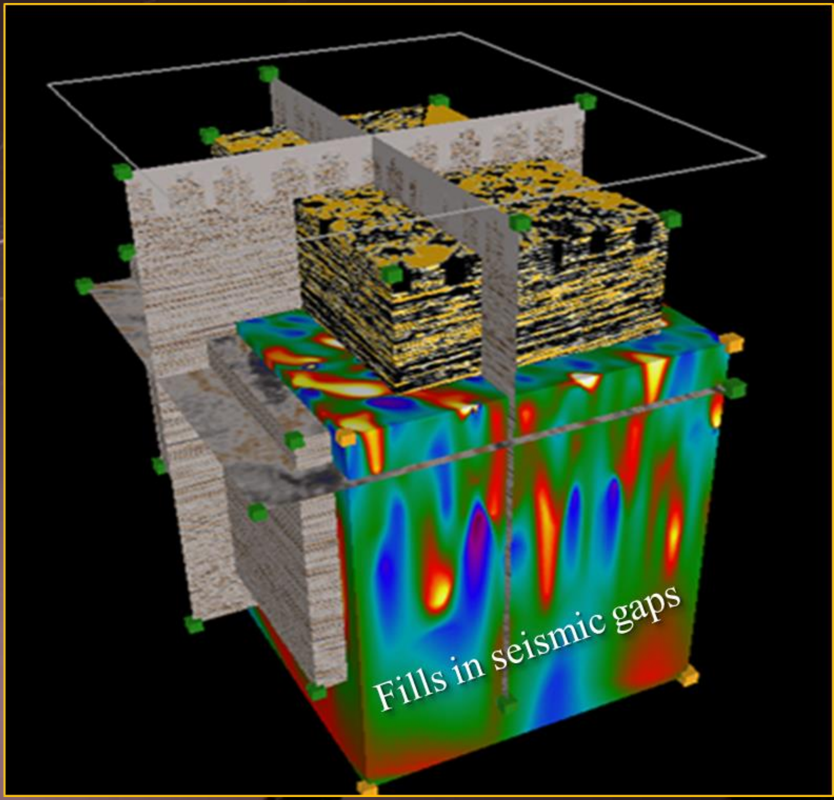




Resistivity & Permittivity Volumes
Easily Integrated with 3-D Seismic & Well Data



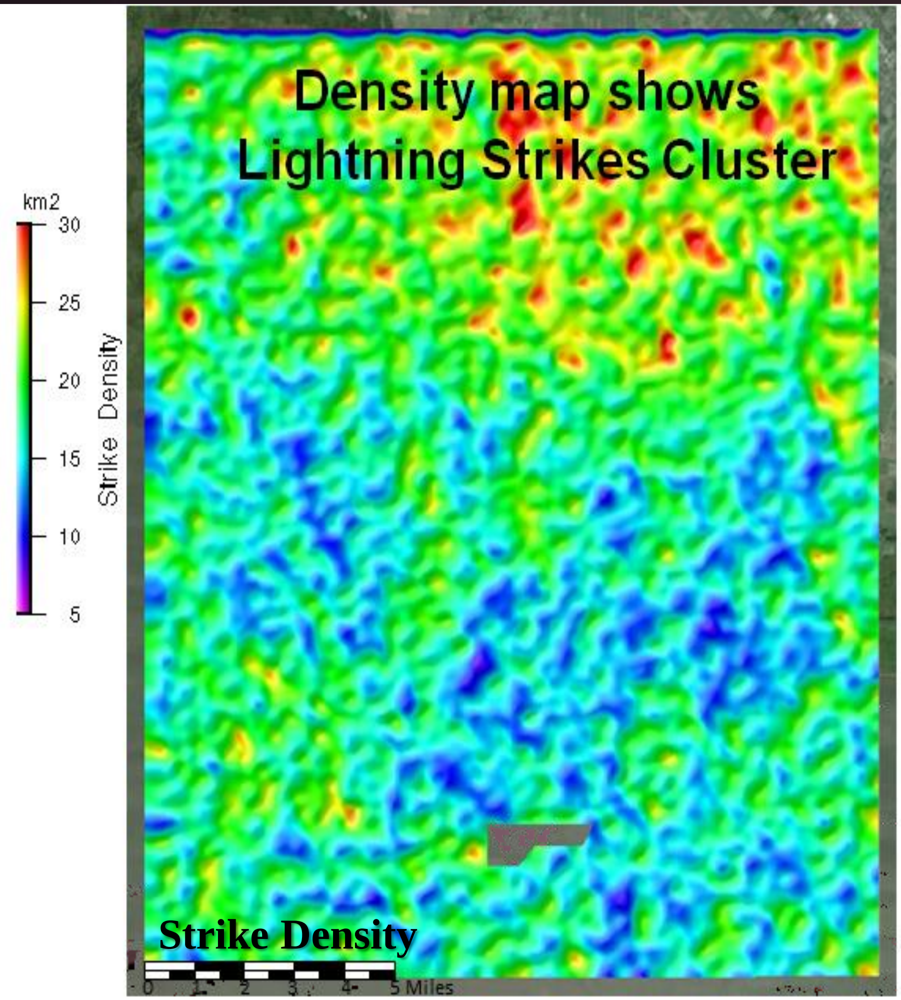
Inlines
Crosslines
Arb Lines
Slices

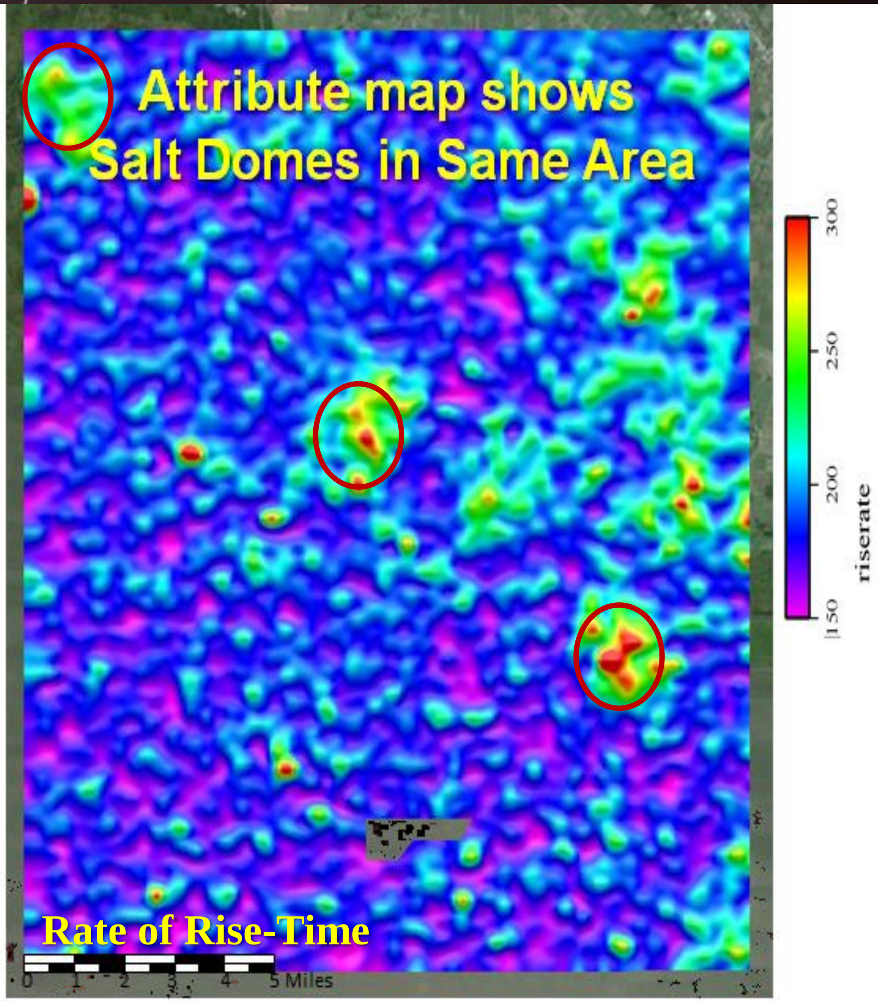


Examples of Geologic Features Identified by NSEM

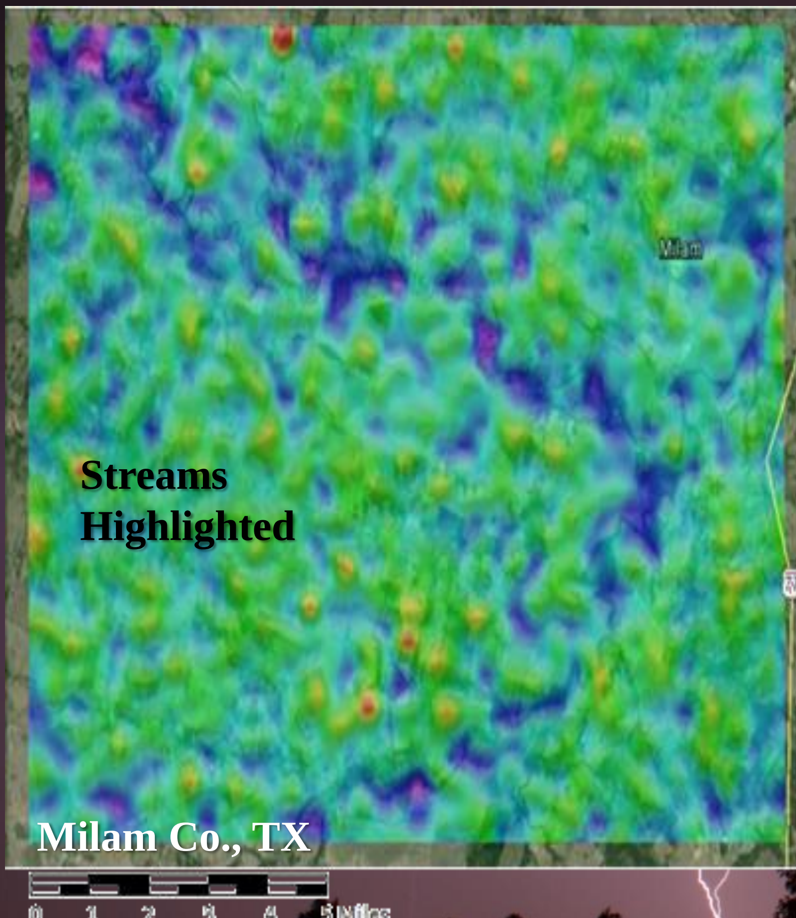
- Iberia Parish, Louisiana
- Milam Co., Texas
- Texas Gulf Coast - Regional
- Colorado Co., Texas - Prospecting
- Hockley Salt Dome, Harris County, Texas
- Houston, Texas
- Pinal Co., Arizona – Rock Properties

NSEM Correlates To Geology:
Iberia Parish, LA Salt Domes

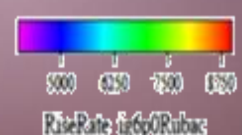


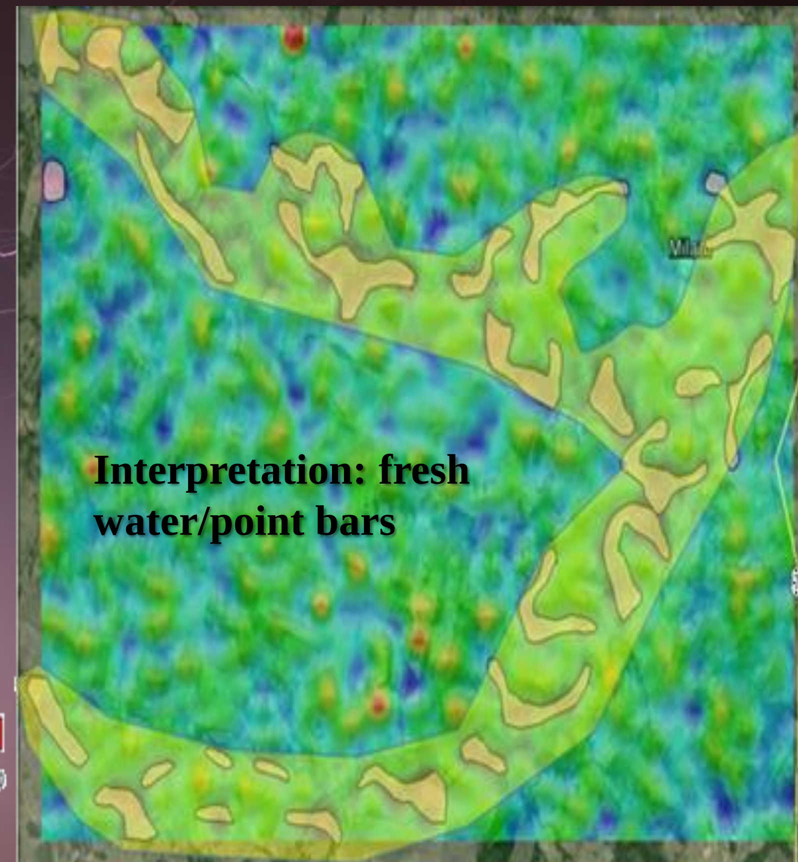


NSEM Correlates To Geology:
Milam Co., TX Fluvial Depositional Patterns



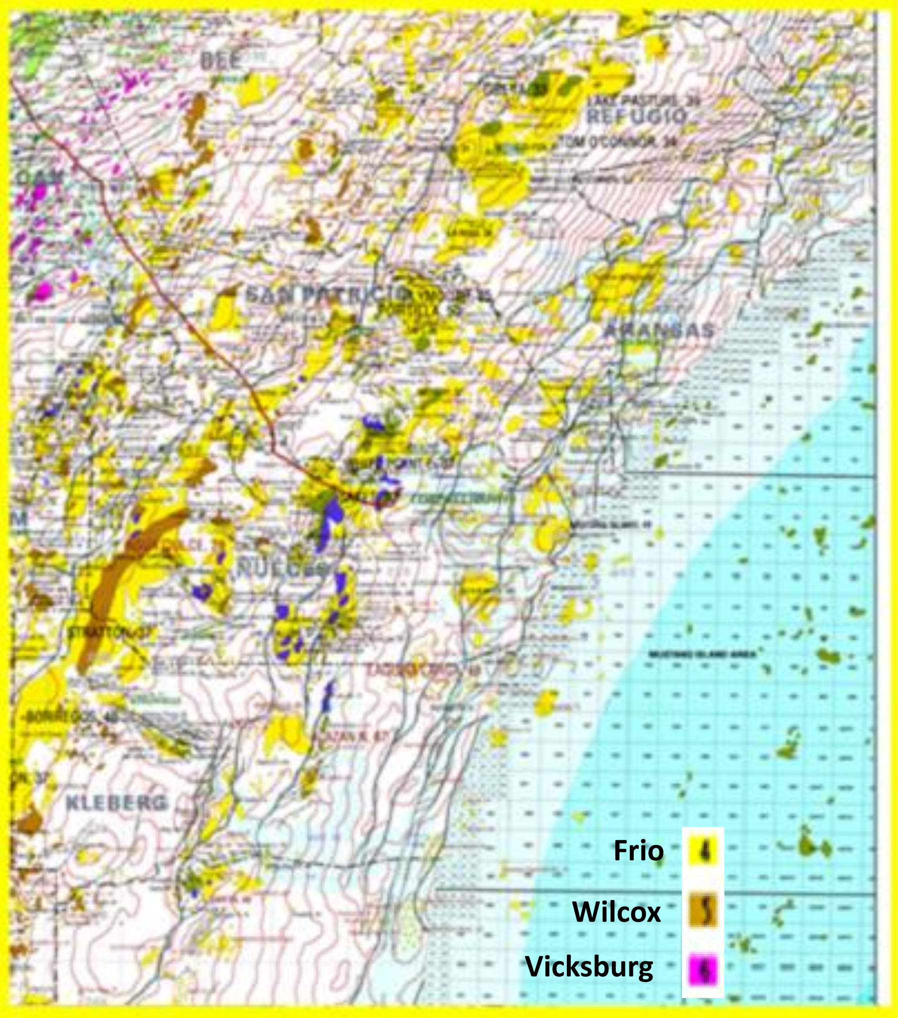
Lightning Attribute Rate of Rise-Time



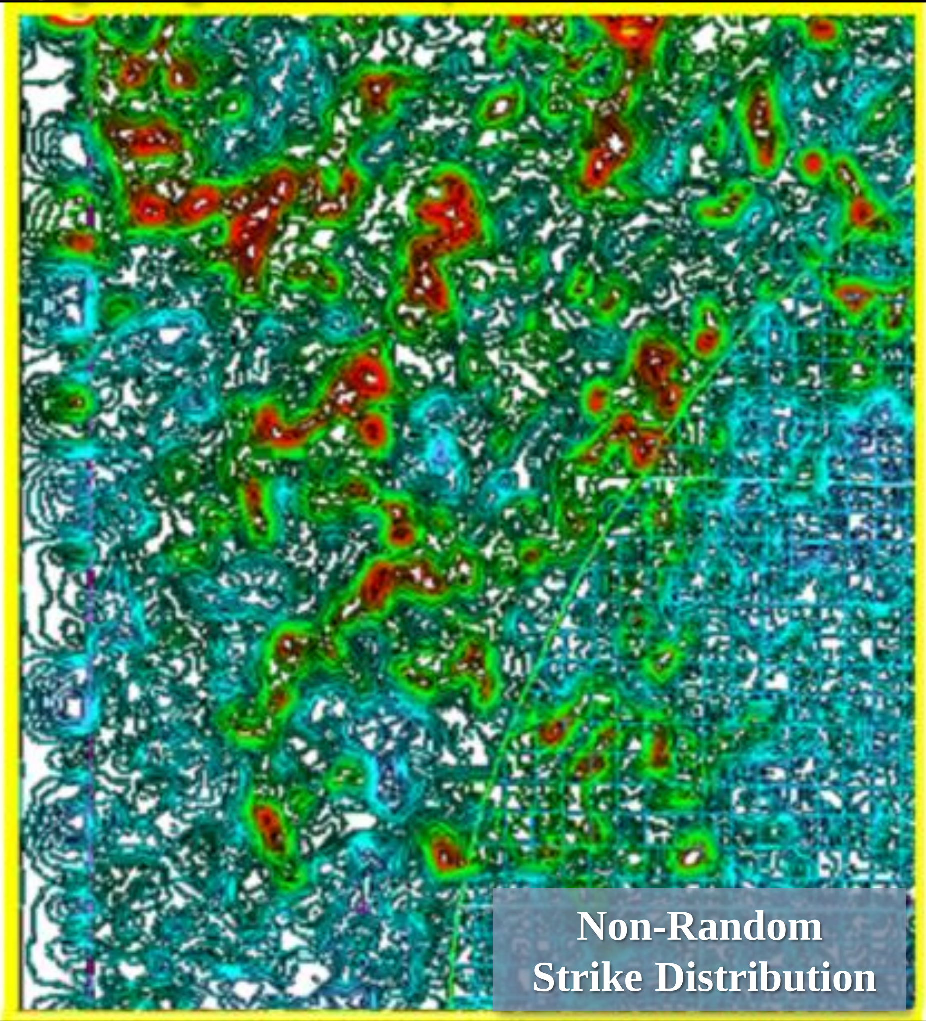


NSEM Correlates To Geology:
Similar TX Gulf Coast Regional Trends

Structure & Field Outlines

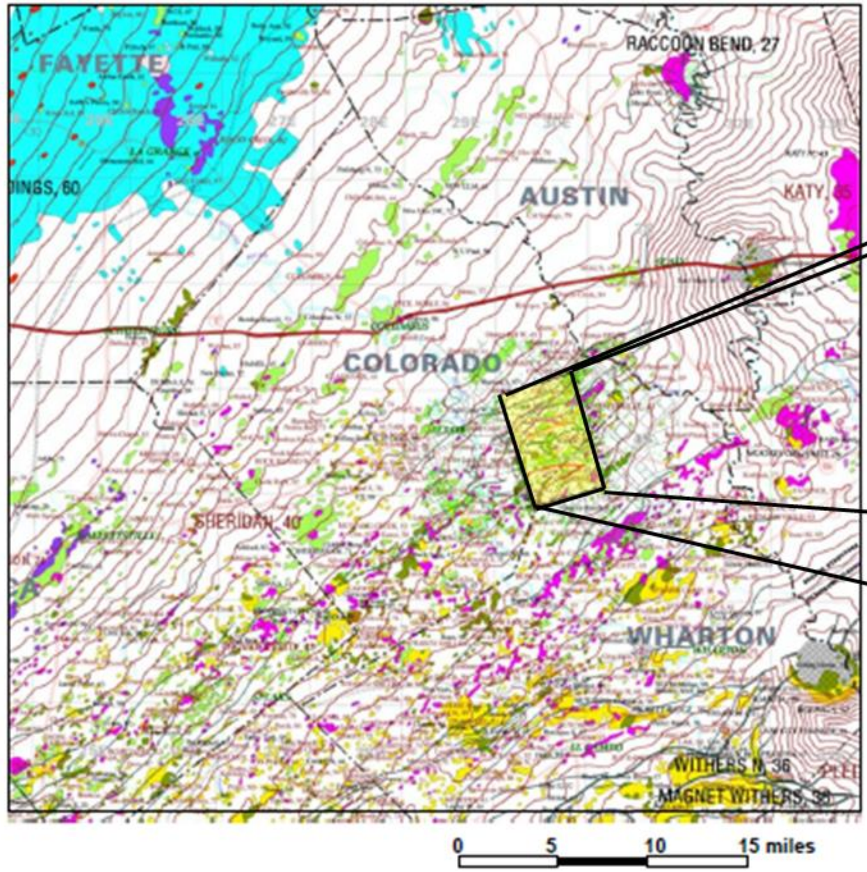


Lightning Strike Density

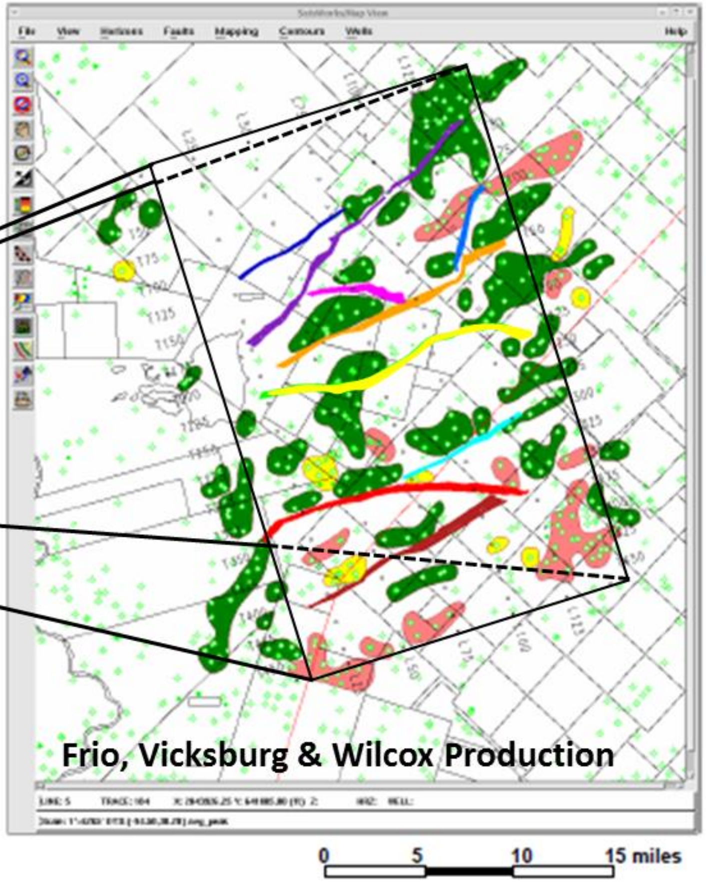


NSEM Correlates To Geology:
Colorado County, TX

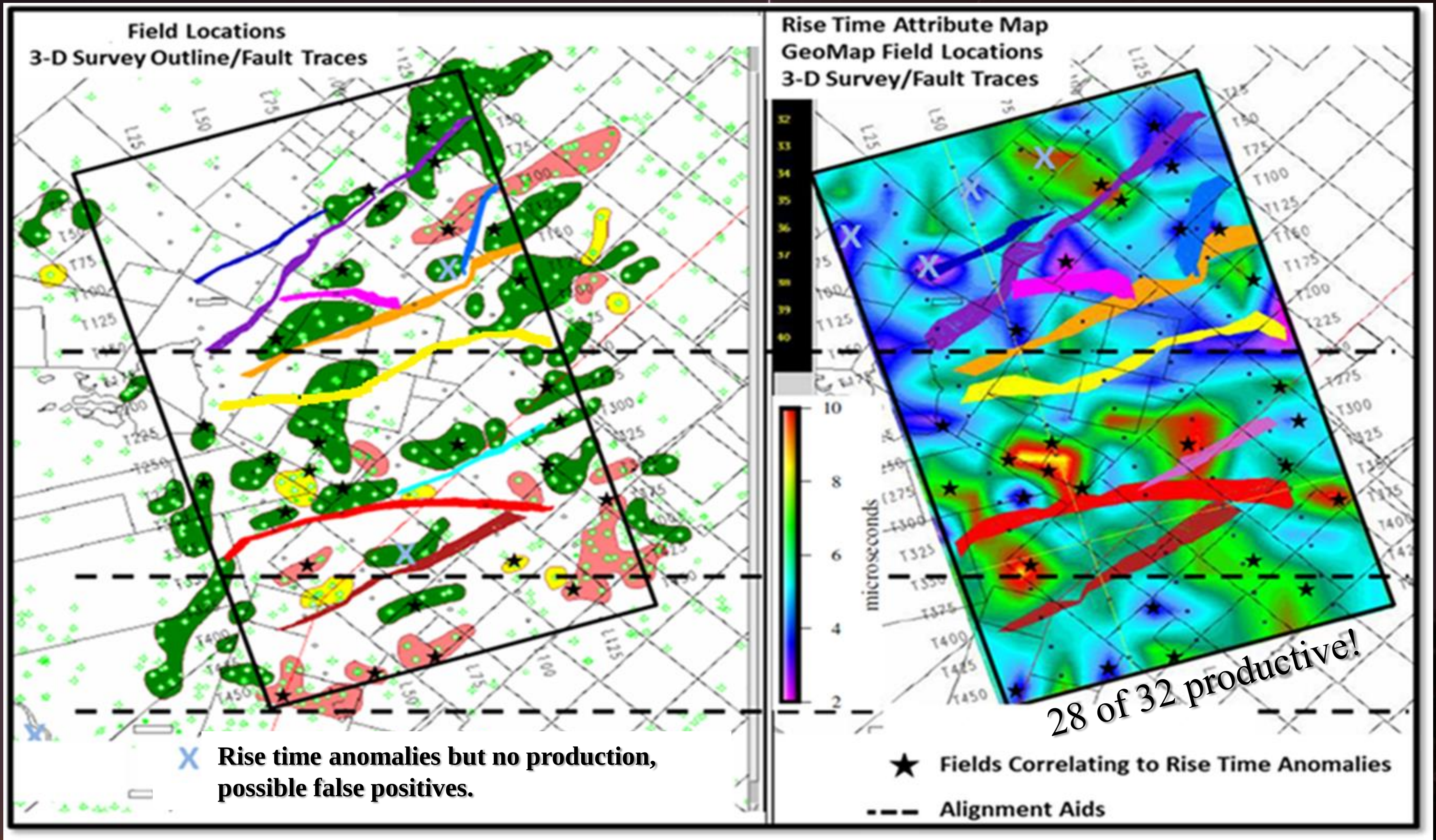
GeoMap



Enlarged



Reconnaissance Mapping
Rise Time Prospect Scale Field Correlations



87% Rise Time anomalies correlated to Frio, Vicksburg or Wilcox production.

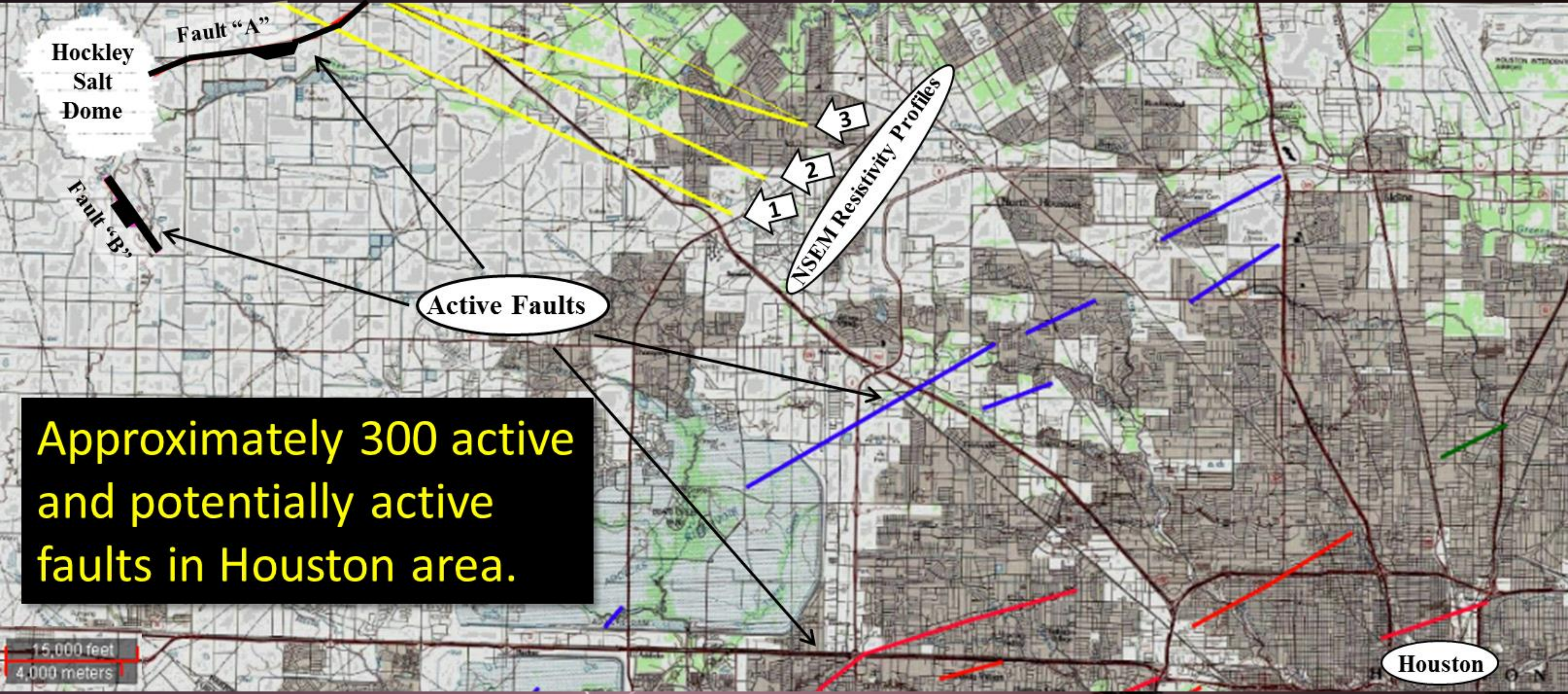
Observations

- Rise-Time attribute map shows non-random patterns.
- NSEM identified 32 leads in study area (☆/x).

Conclusions

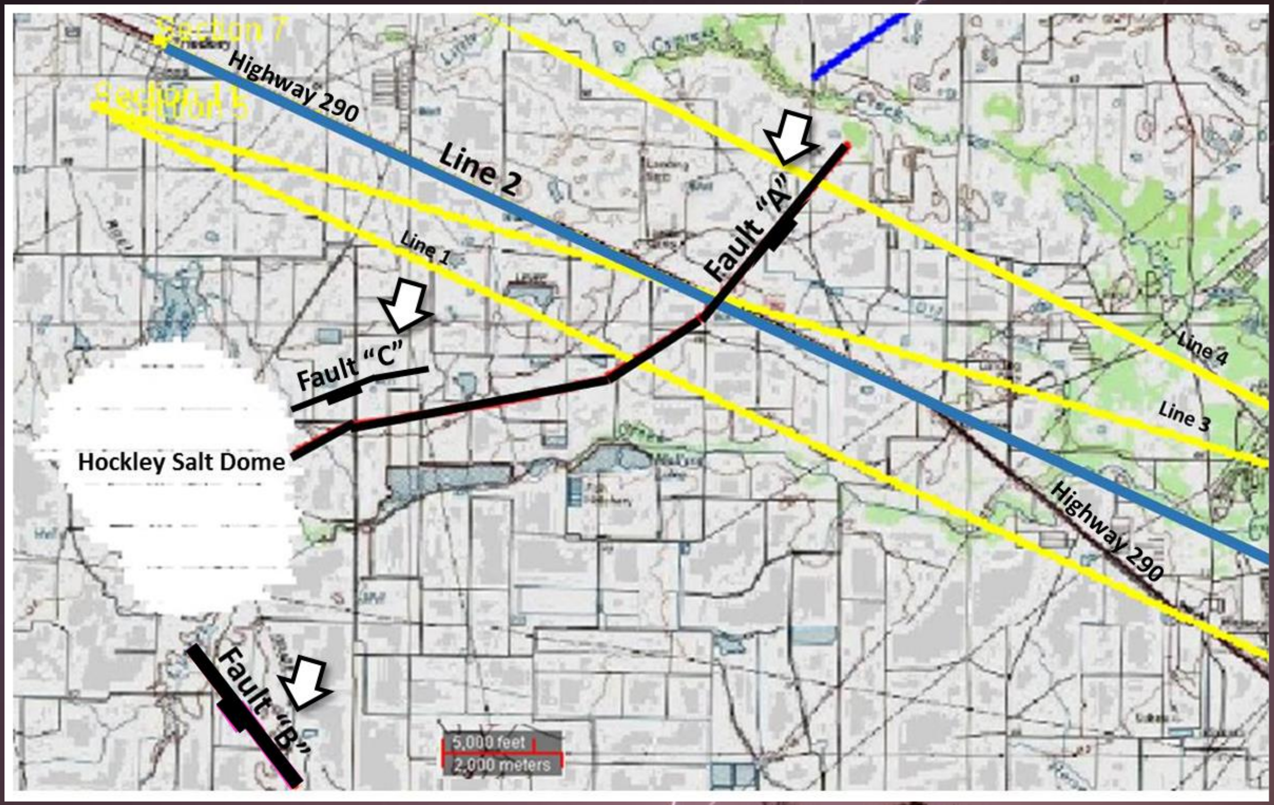
- If these leads were pursued with follow-up seismic data purchase, acquisition and reprocessing, 28-32 drillable prospects would have been generated.
- ★ If NSEM had been utilized for reconnaissance mapping, at least an 87% drilling success rate, if not higher, would have been realized.

Houston/Harris County Area Active Faults



Approximately 300 active and potentially active faults in Houston area.

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

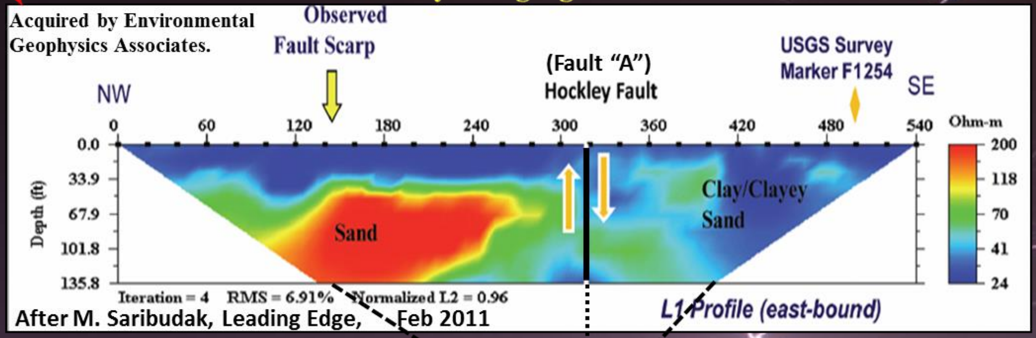


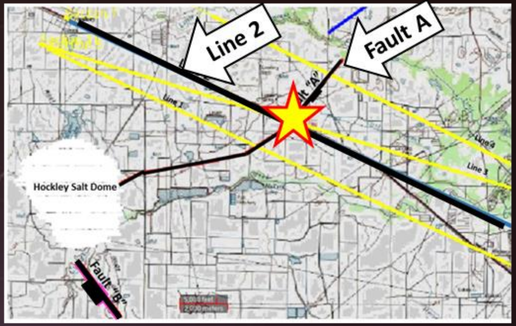
Map shows location of three active faults that have been documented with near-surface geophysical techniques.

The next group of slides will demonstrate how NSEM can identify these faults in the subsurface.

Line 2 Ties Active Fault "A" to Subsurface

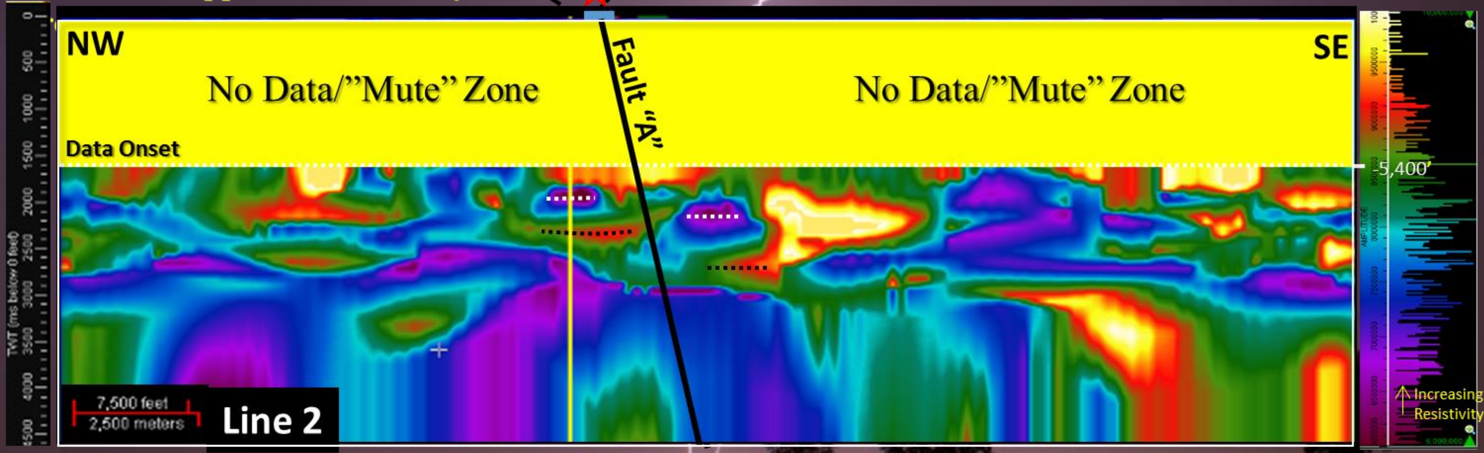
Conventional 2-D Resistivity Imaging Profile





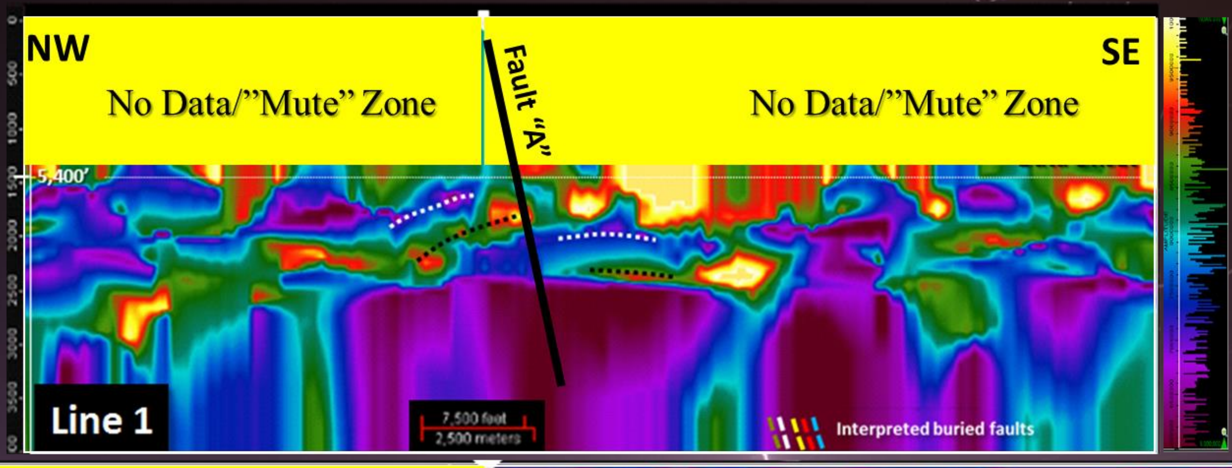
Line 2

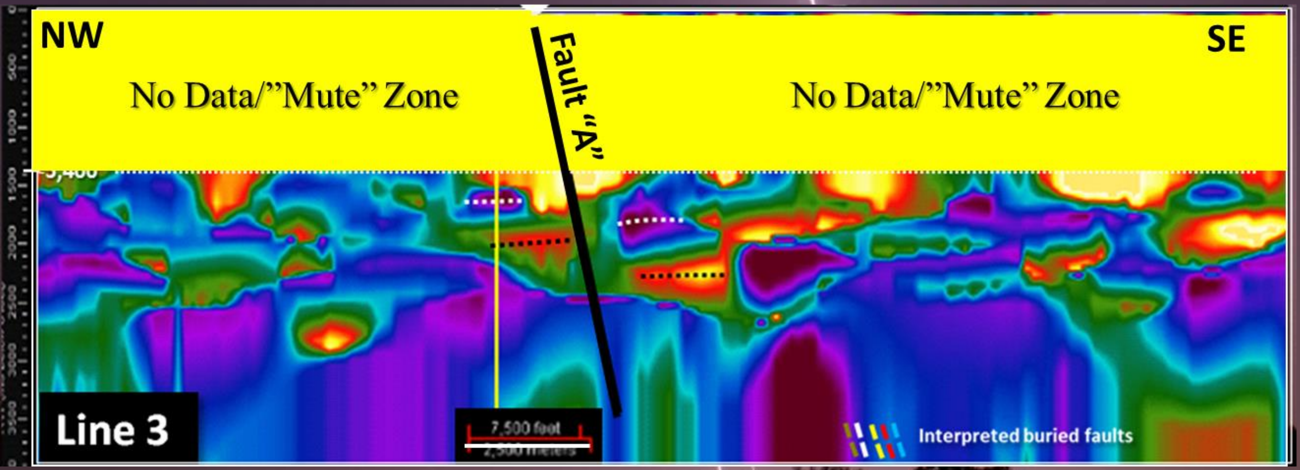
NSEM 3-D Apparent Resistivity



Fault interpretation validated by conventional 2-D resistivity imaging.

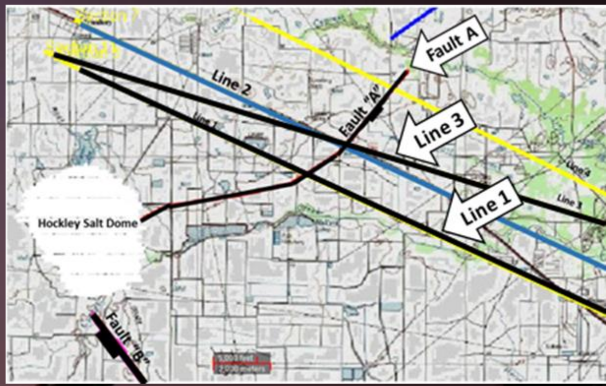
Lines 1 & 3 Also Tie Fault "A" to Subsurface



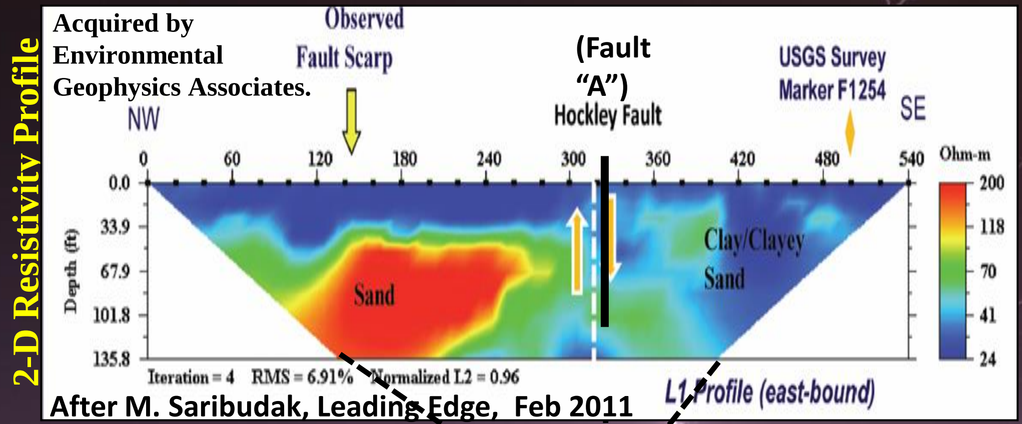


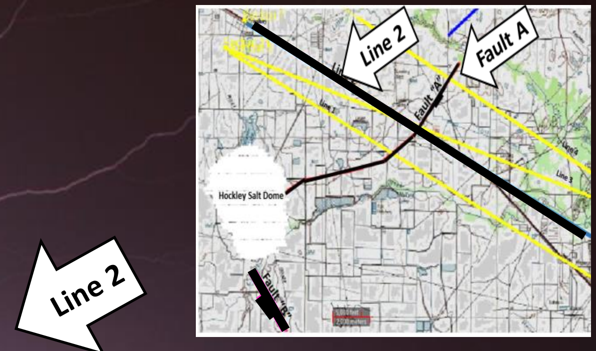
White arrow marks intersection with documented fault trace.

NSEM demonstrates consistency identifying this active fault at depth.

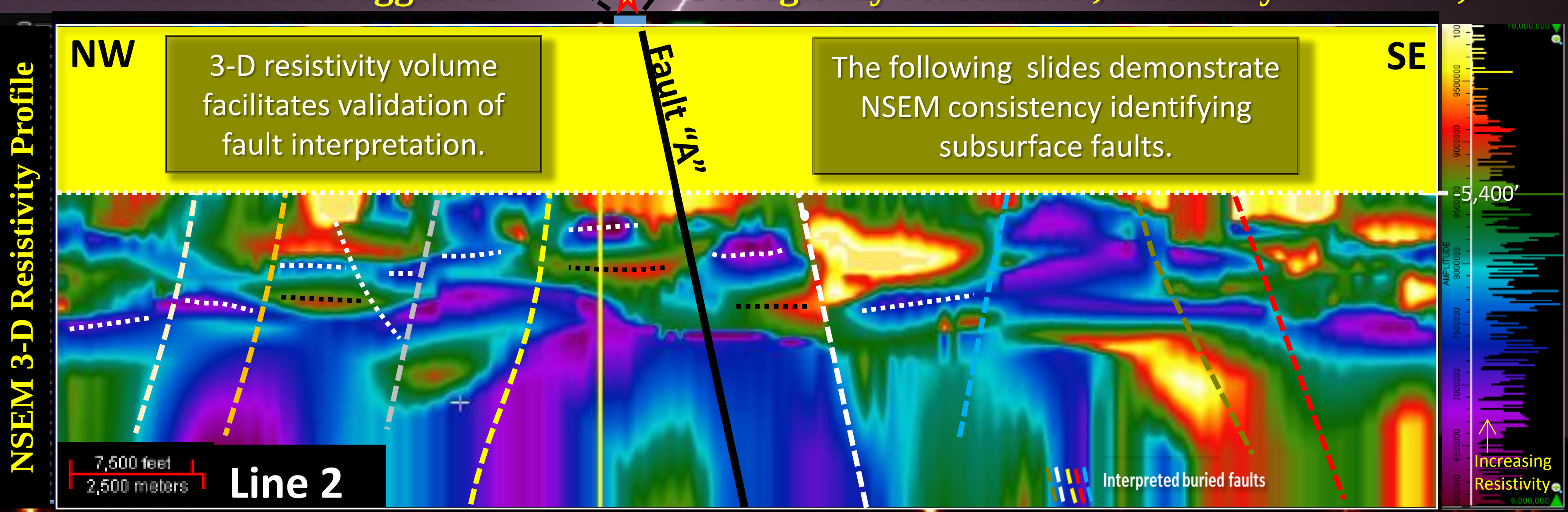


NSEM Line 2 Reveals Additional Faulting
3-D Provides Interpretive Checks & Balances

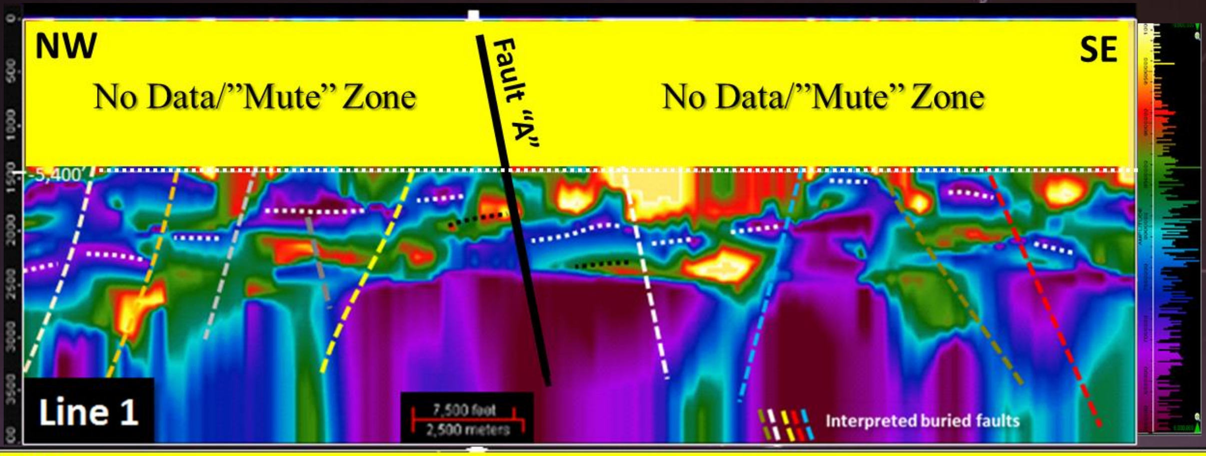


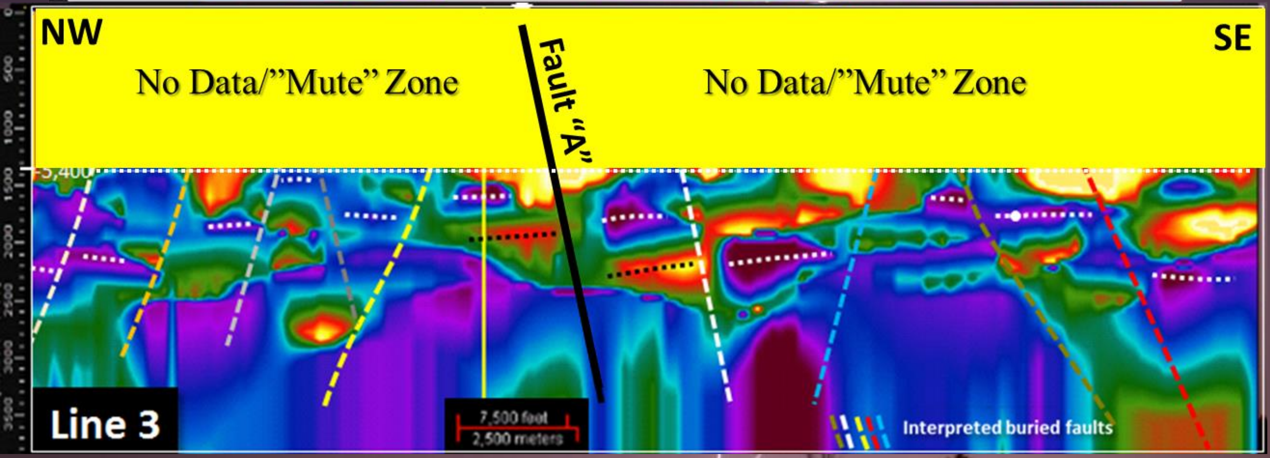


Additional faults suggested. Geologically reasonable , internally consistent, valid?



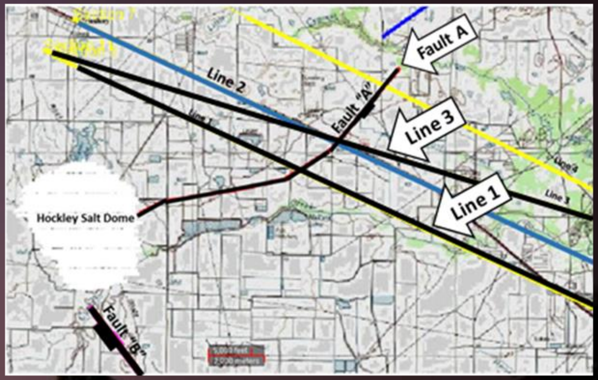
Lines 1 & 3 Also Reveal Additional Faults



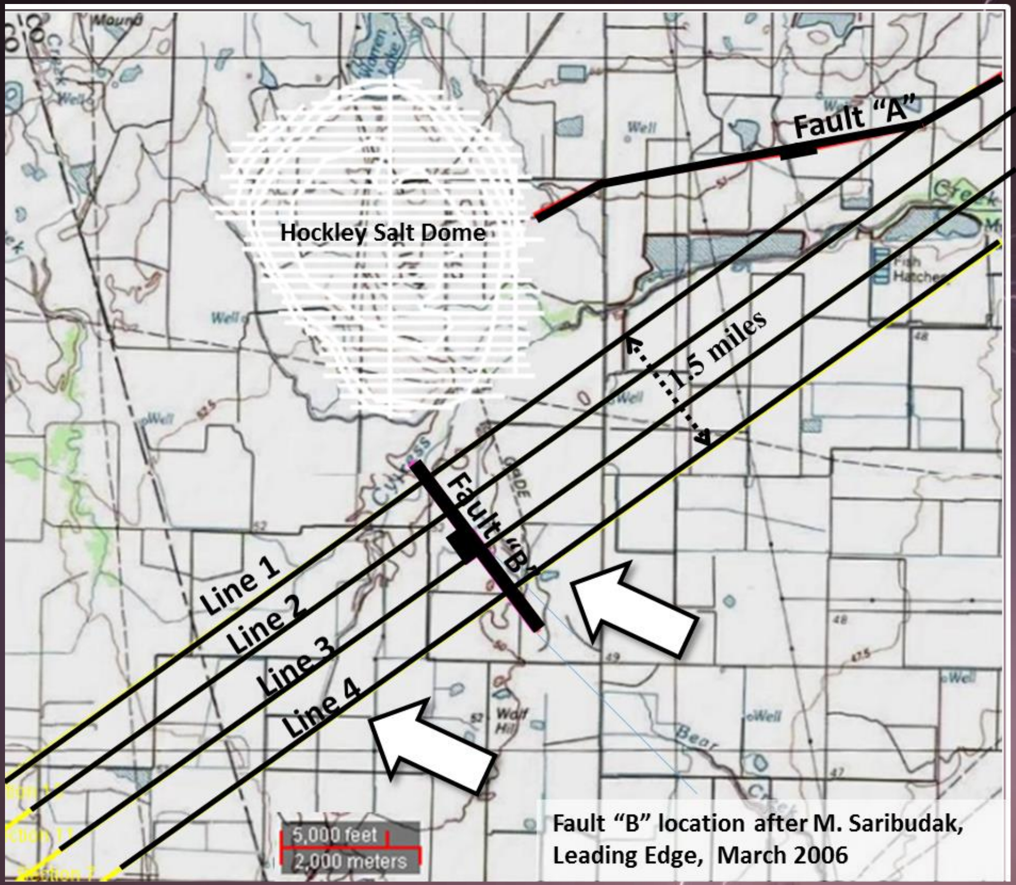


The same 9 color coded faults are identified on all 3 lines.

NSEM demonstrates internal interpretive & structural consistency & ability to map faults at the prospect level.



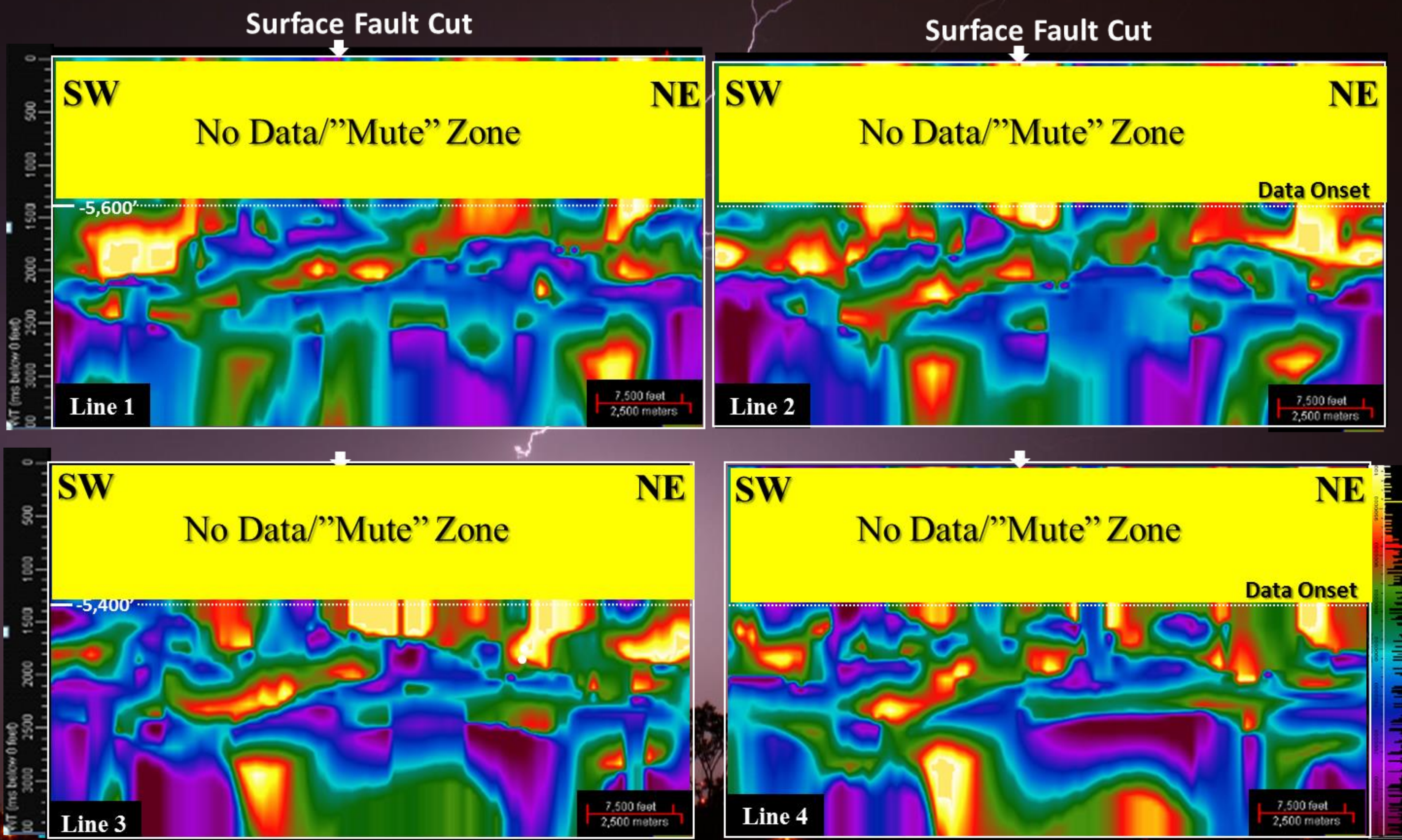
Hockley Radial Fault "B"



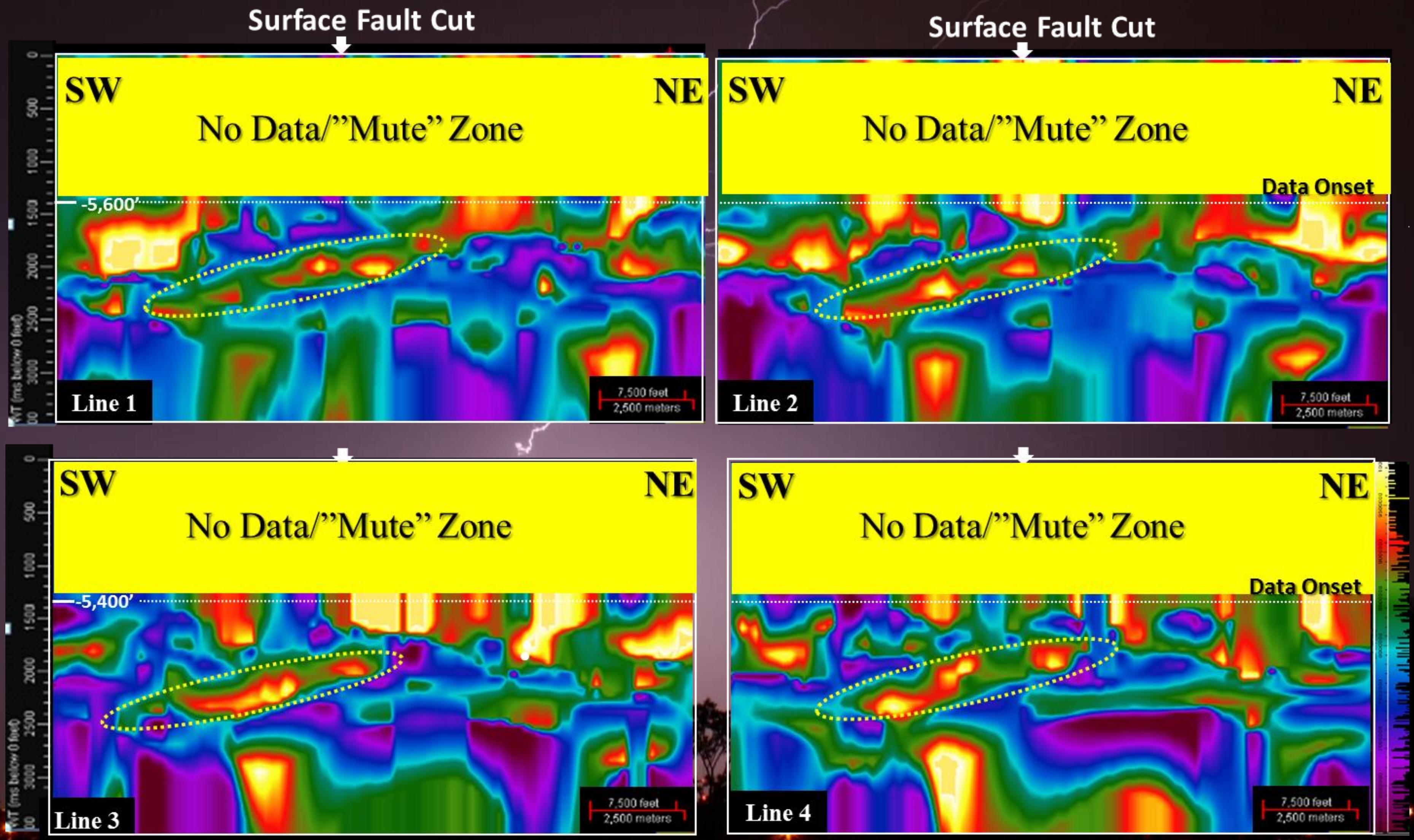
A 1½ mile distance along the Fault "B" trace is sampled with resistivity profiles.

Resistivity Lines 1-4 are displayed on the next slide.

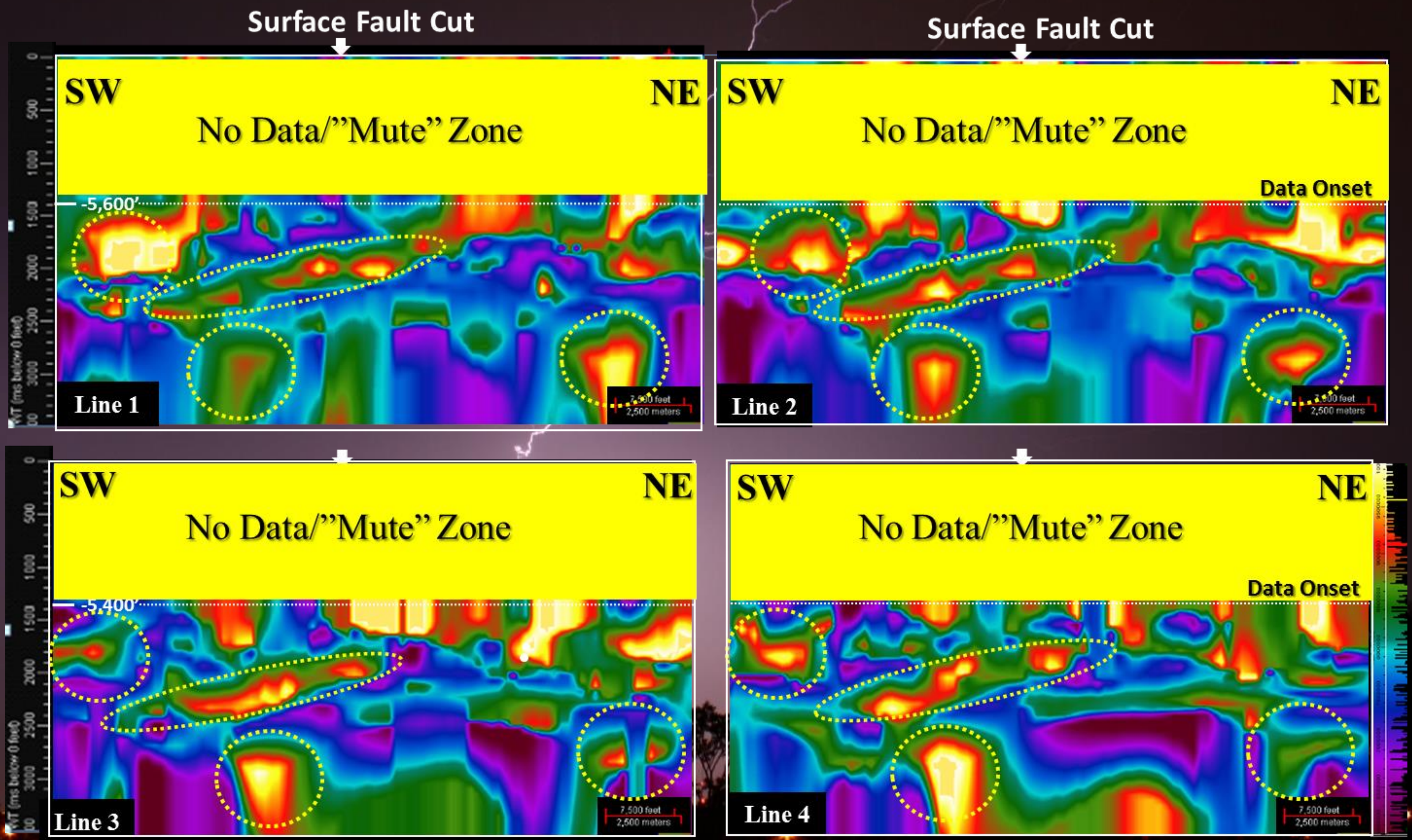
Hockley Radial Fault "B" Lines 1-4



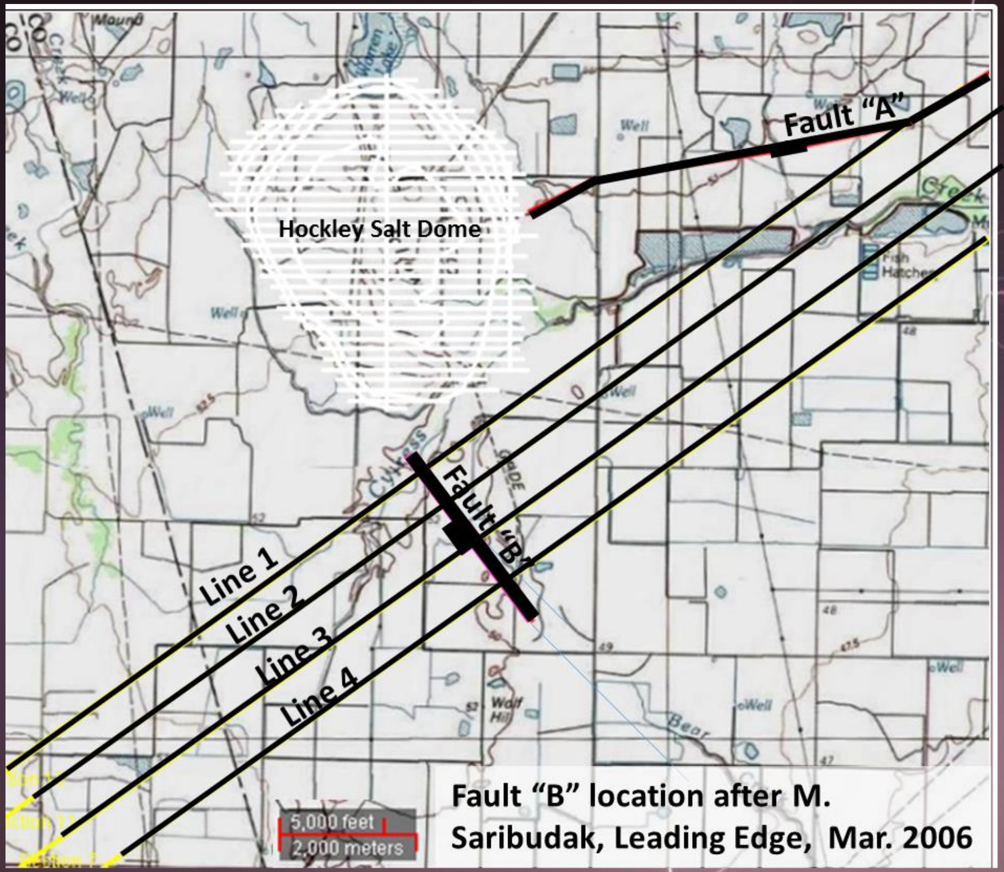
Similar Character Spanning 1.5 Miles



Numerous Features Correlate Line to Line



Hockley Radial Fault "B"

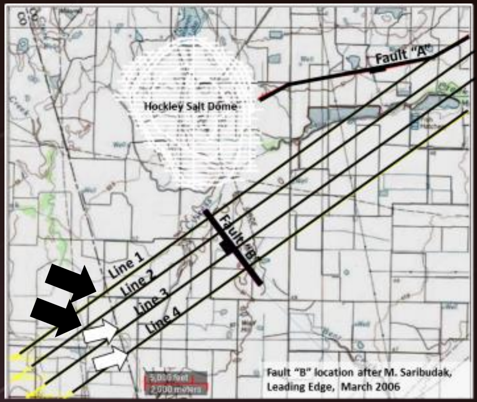


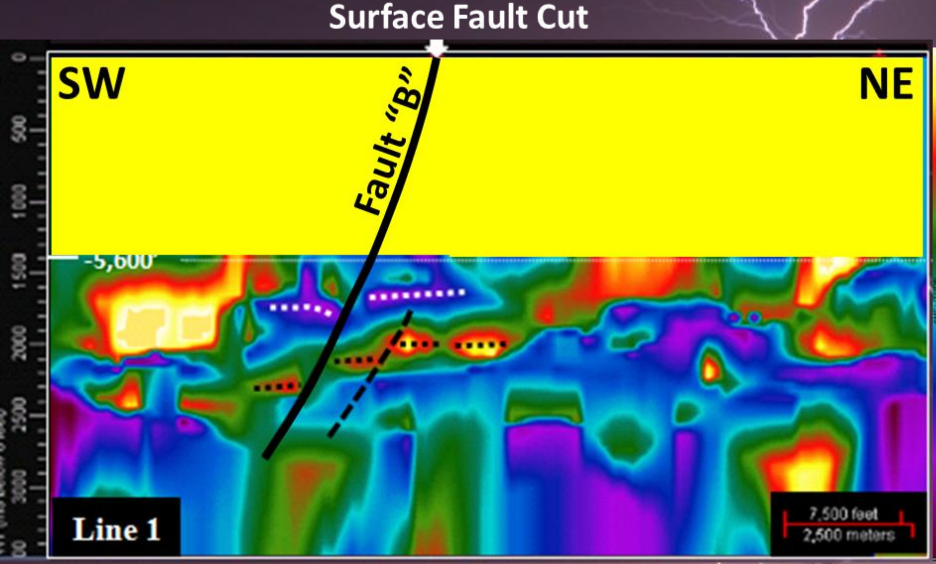
Fault "B" location after M. Saribudak, Leading Edge, Mar. 2006

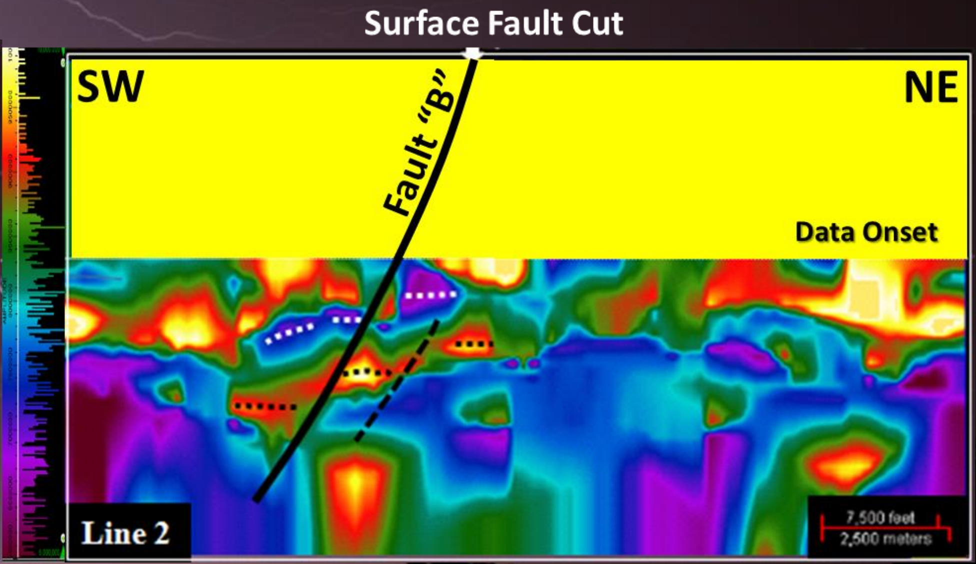
Now let's review these four apparent resistivity lines to determine whether they can identify Fault "B" in the subsurface.

As with Fault "A", trigonometric constraints based on depth, heave, fault surface dip and sense of throw must be satisfied.

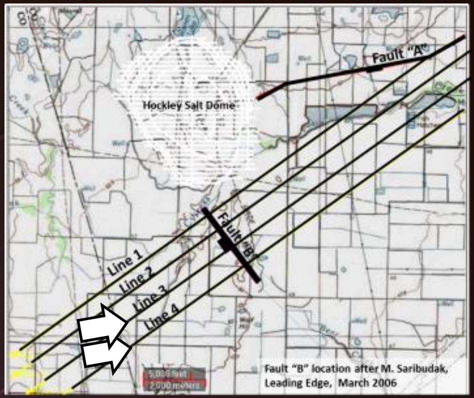
Lines 1 & 2
Consistent Fault Criteria
Both Tie Surface Fault "B"

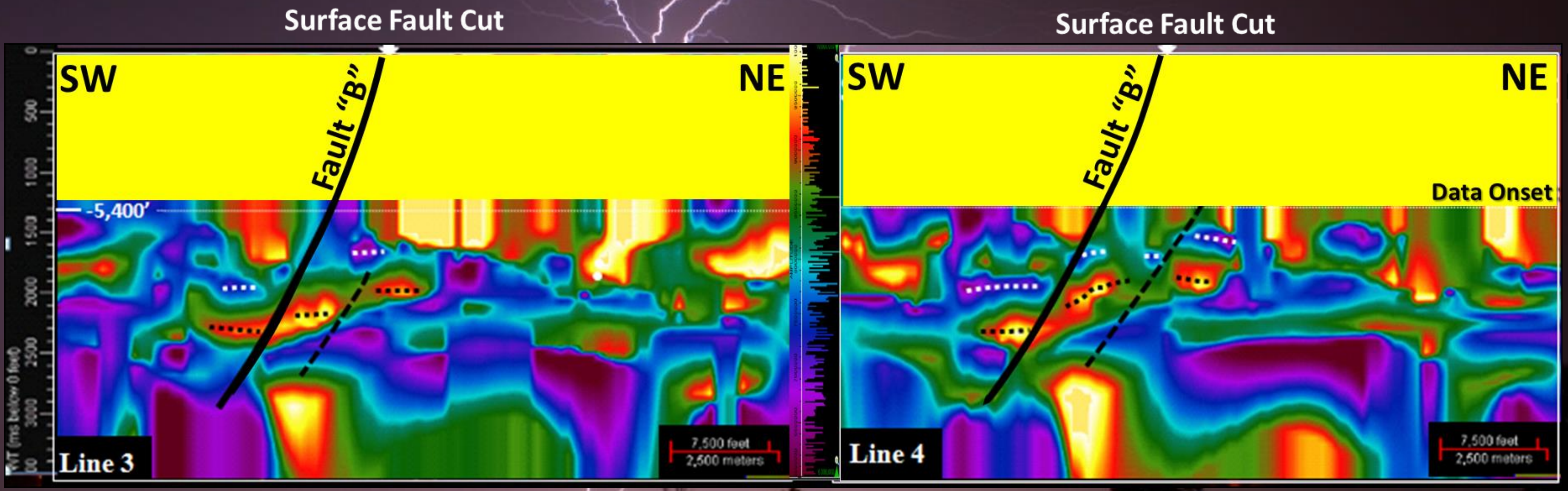




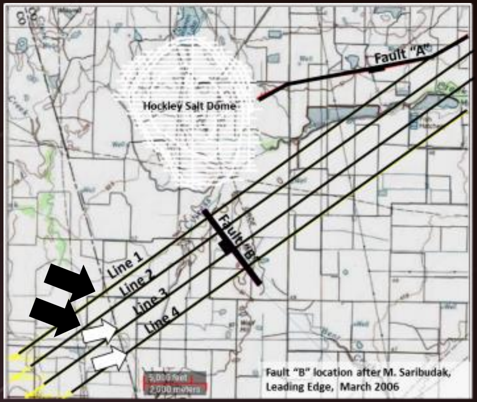


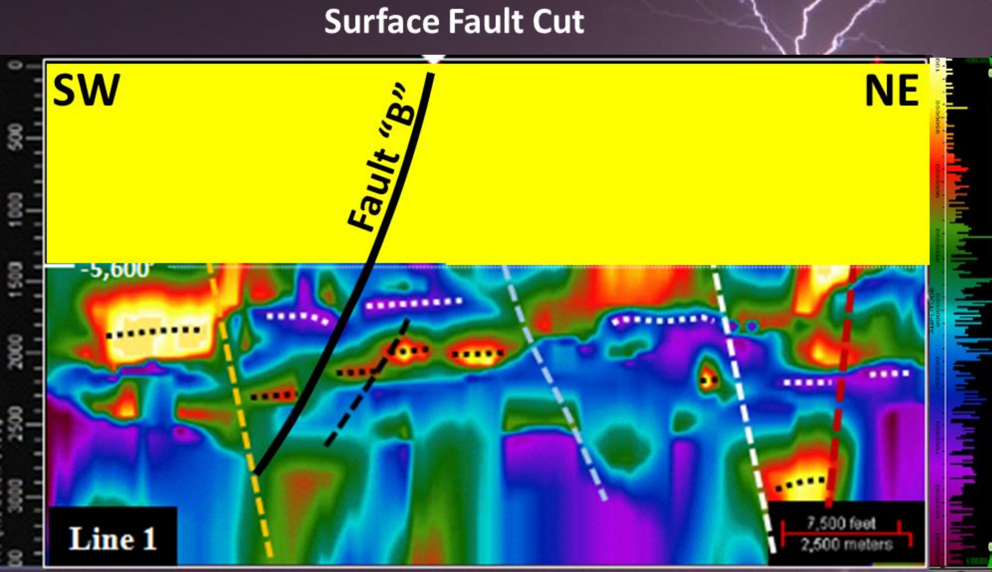
Lines 3 & 4
Consistent Fault Criteria
Both Tie Surface Fault “B”

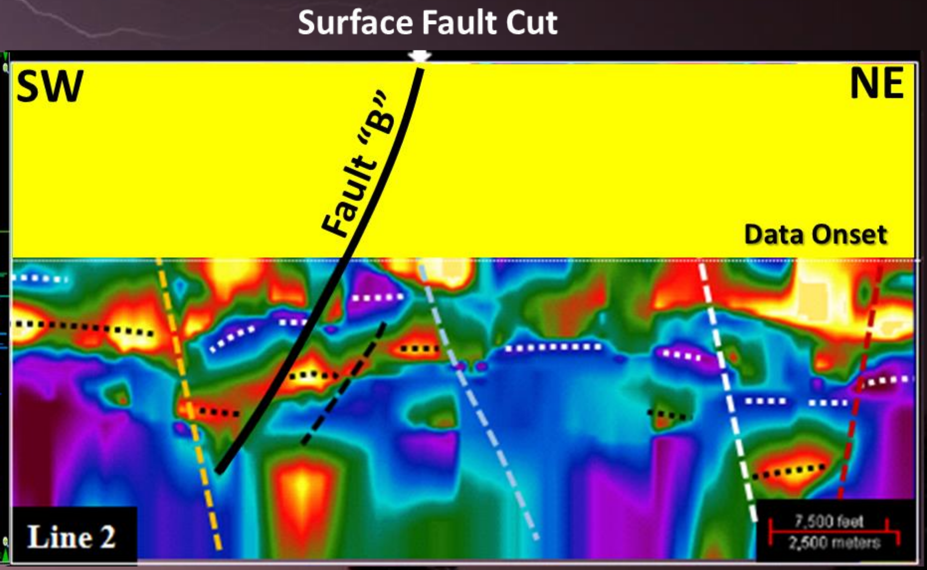




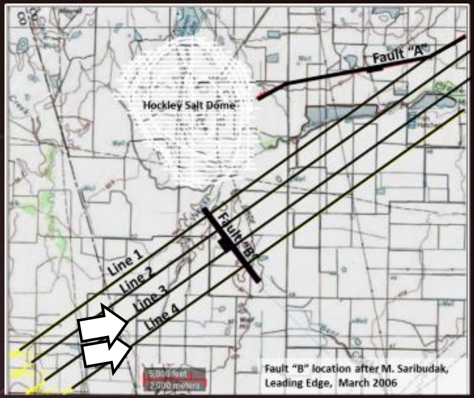
Lines 1 & 2
Additional Faulting?
Consistent Fault Criteria?



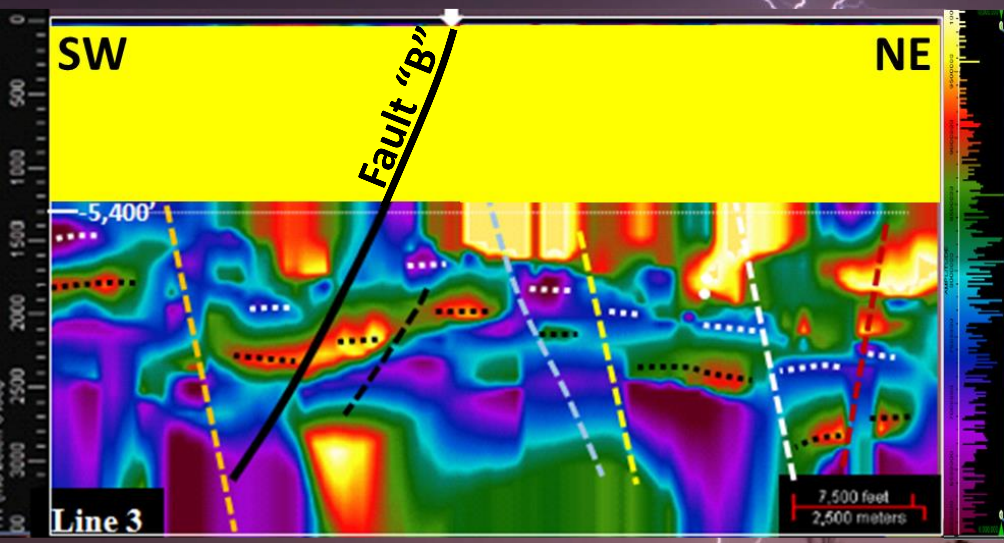




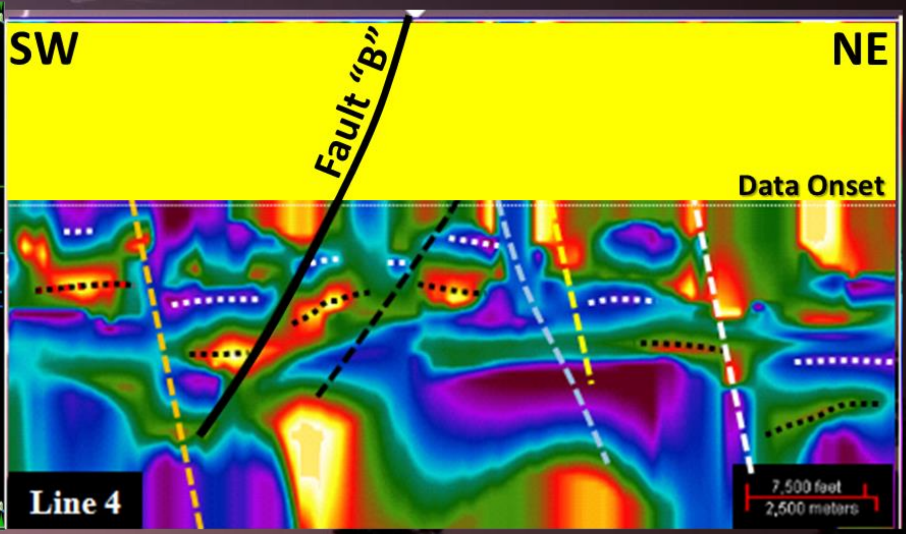
Lines 3 & 4
Additional Faulting Suggested
Consistent Fault Criteria



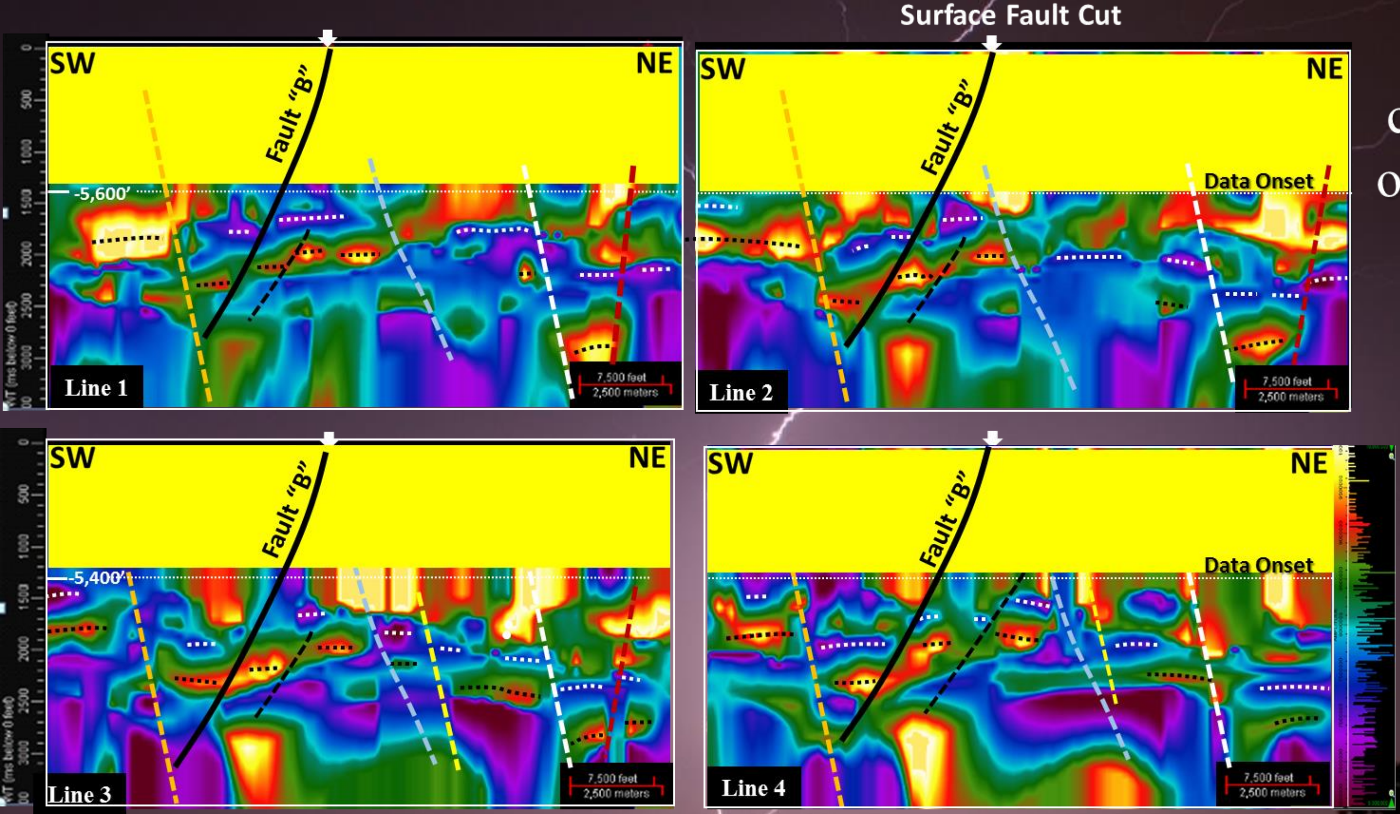
Surface Fault Cut



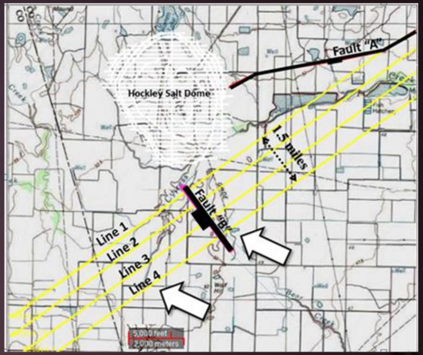
Surface Fault Cut



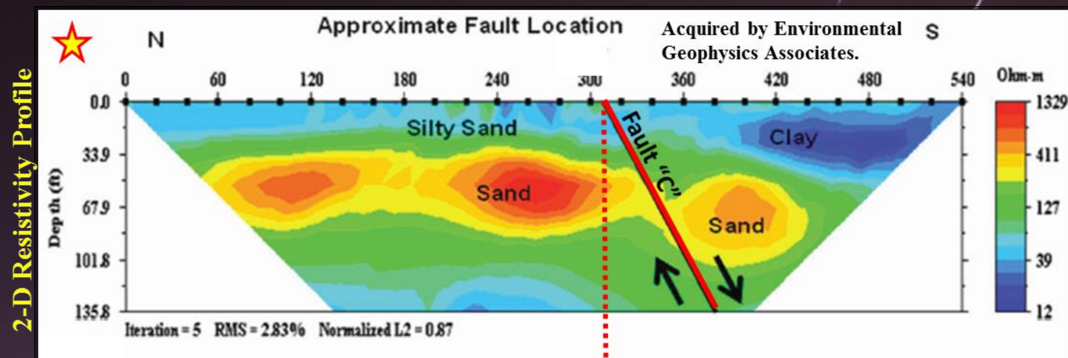
Consistent Fault Criteria On All Profiles!



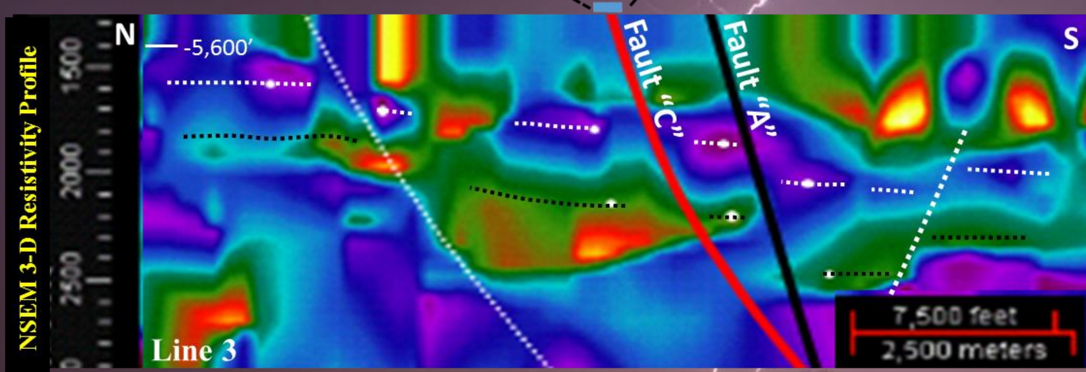
As many as 7 faults consistently identified on 4 resistivity profiles spanning 1.5 miles.



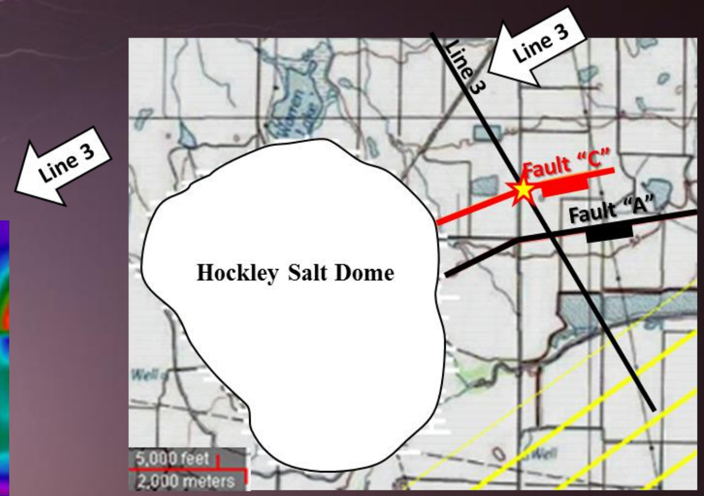
NSEM Ties Fault "C" to Subsurface



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



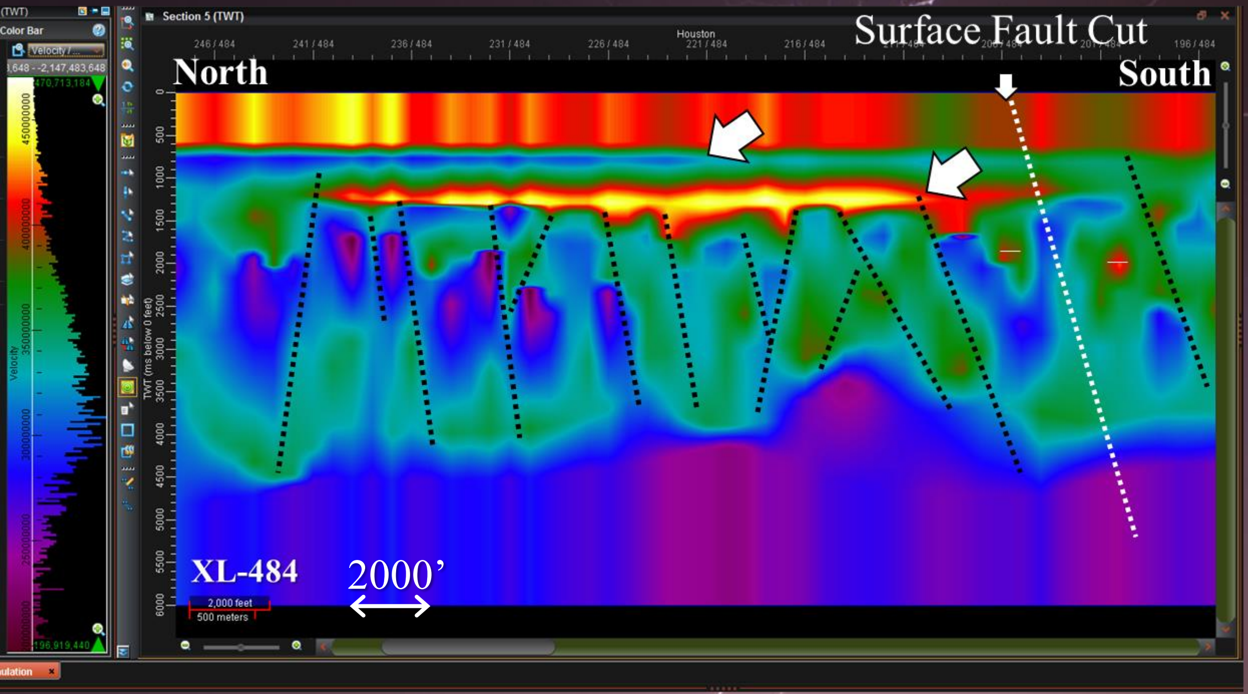
NSEM resistivity profile duplicates 2-D resistivity fault signature & ties Faults "A" and "C".



Hockley Fault Conclusions

- 3-D NSEM resistivity can be interpreted similar to 3-D seismic data to build structural frameworks.
- It can be integrated with & calibrated to other near-surface & potential field geophysical data to expand depth & aerial extent of investigated areas.
- It is scalable & can provide both reconnaissance data for follow-up detailed geophysical evaluation or it can focus on specific faults & previously identified anomalies.

NSEM Identifies Stratigraphy & Faulting in Houston, TX

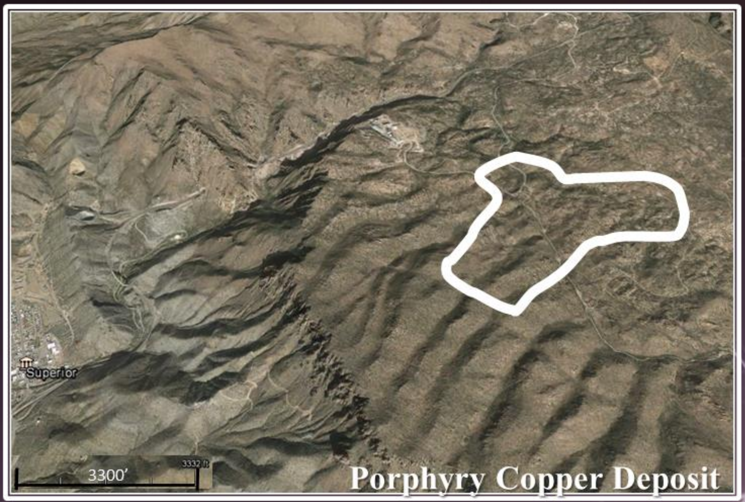


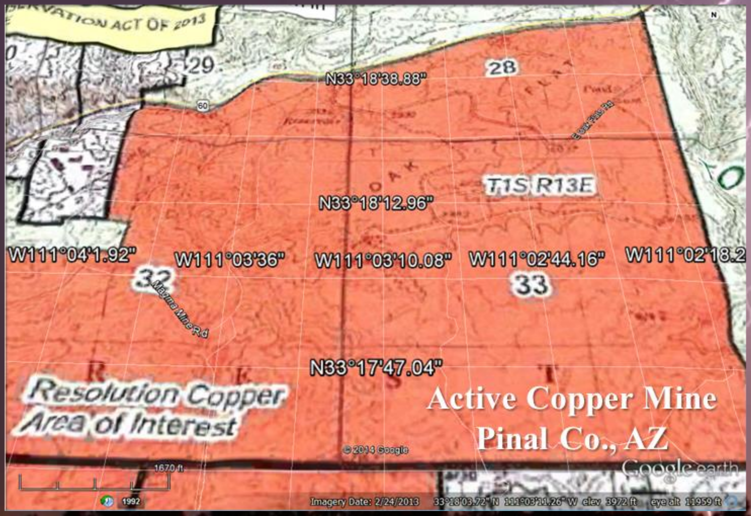
Crossline extracted from 3-D apparent resistivity volume in northwest Houston.

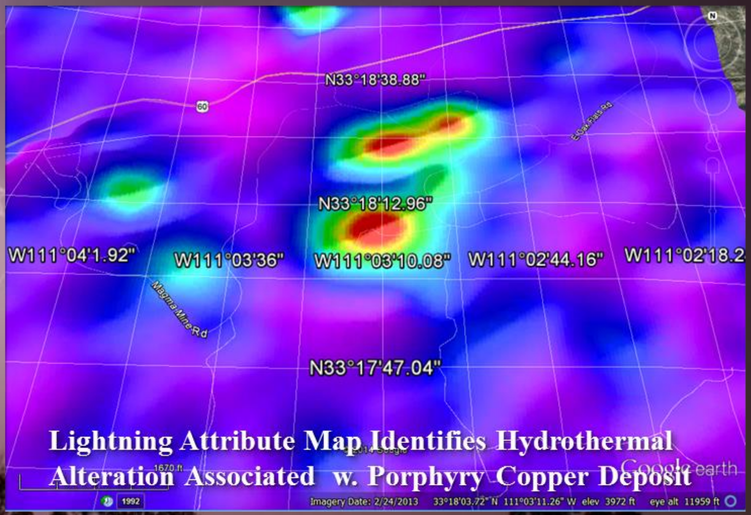
NSEM identifies subsurface structure, stratigraphy & rock properties.

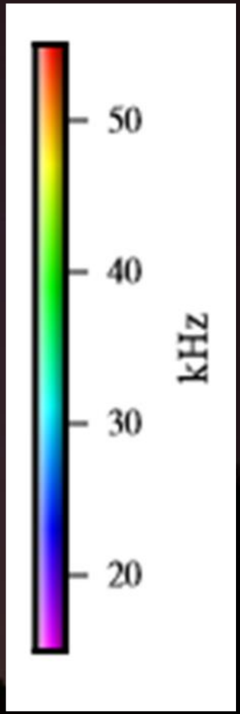
Ties active fault trace.

NSEM Correlates To Rock Properties:
Mineral Exploration



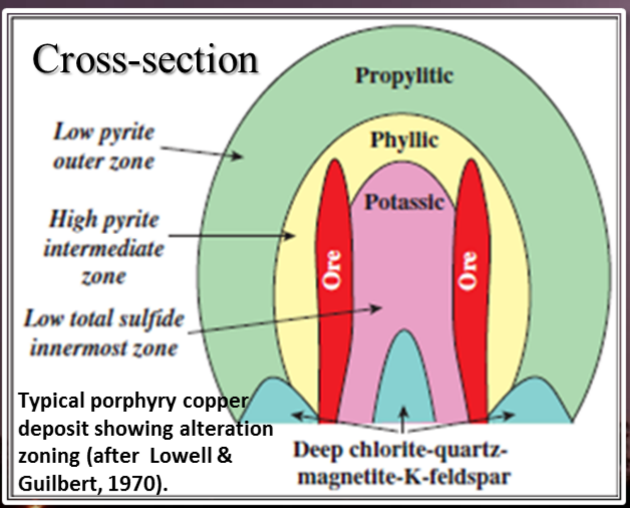




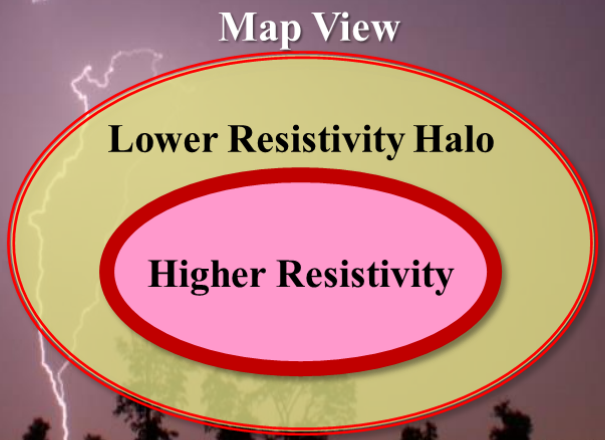


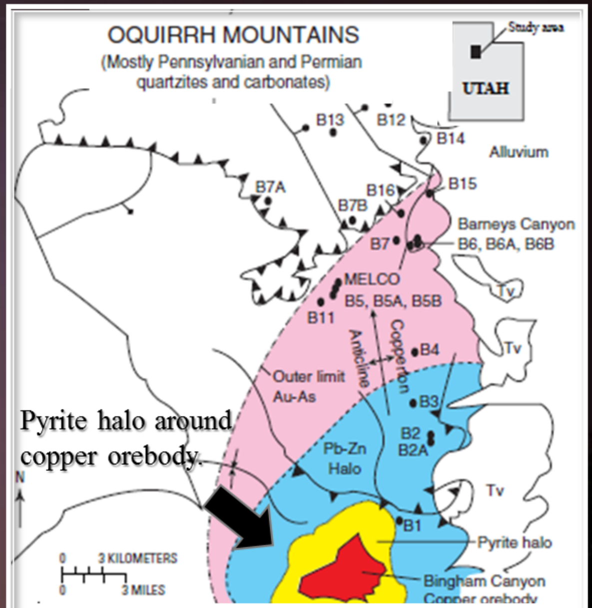
Porphyry Copper Deposit <u>Signature</u>

- Multiple igneous intrusions present.
- Contact metamorphism/alteration halos.
- Inner high resistivity zone partially or completely enclosed by outer conductive zone.



Typical porphyry copper deposit showing alteration zoning (after Lowell & Guilbert, 1970).

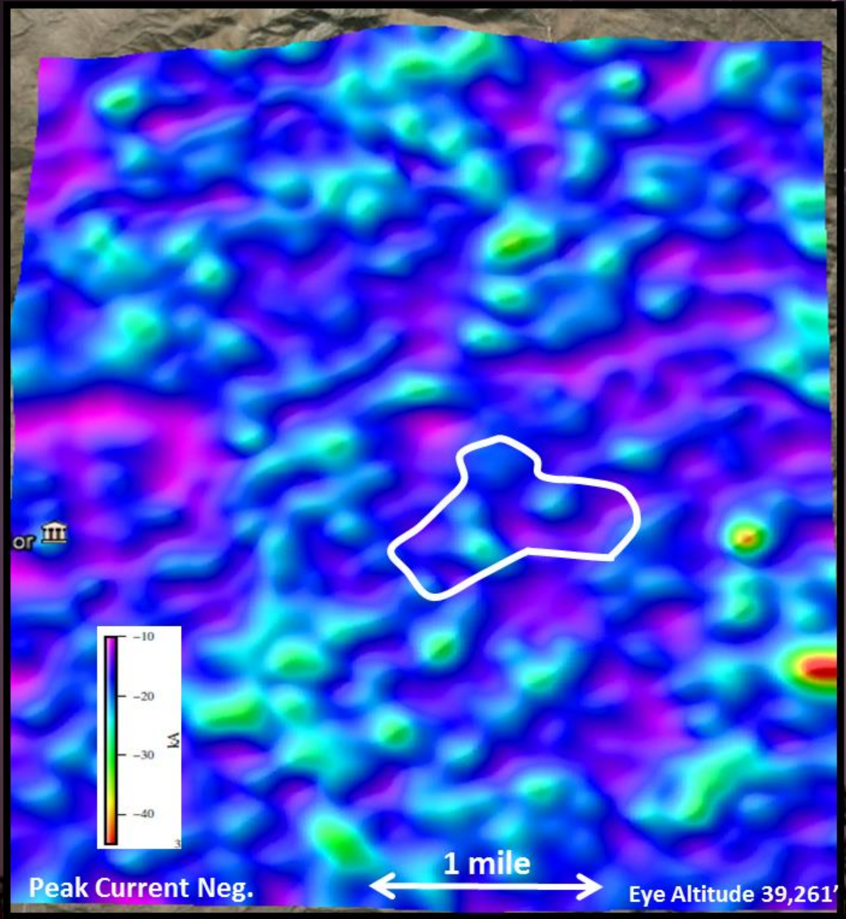


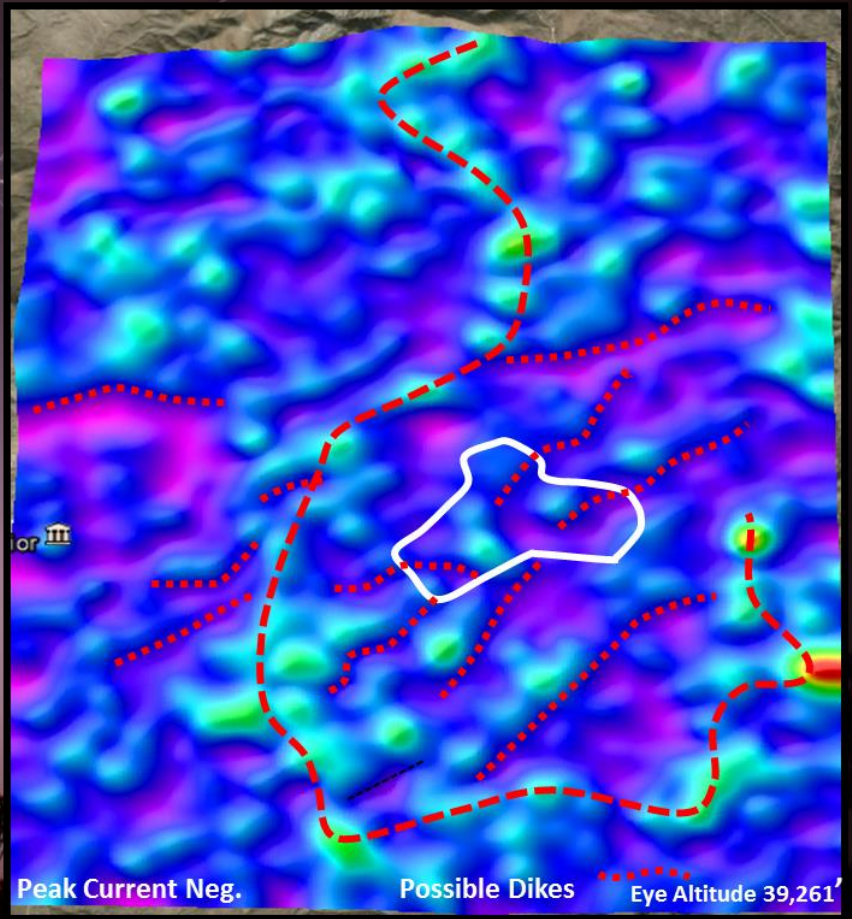


Geochemical zoning around the Bingham Canyon deposit, Utah (modified from Cunningham & others, 2004, their Fig. 1). USGS Report 2010-5070-B, David John, Editor.

Negative Peak Current
Resolution Copper Mine

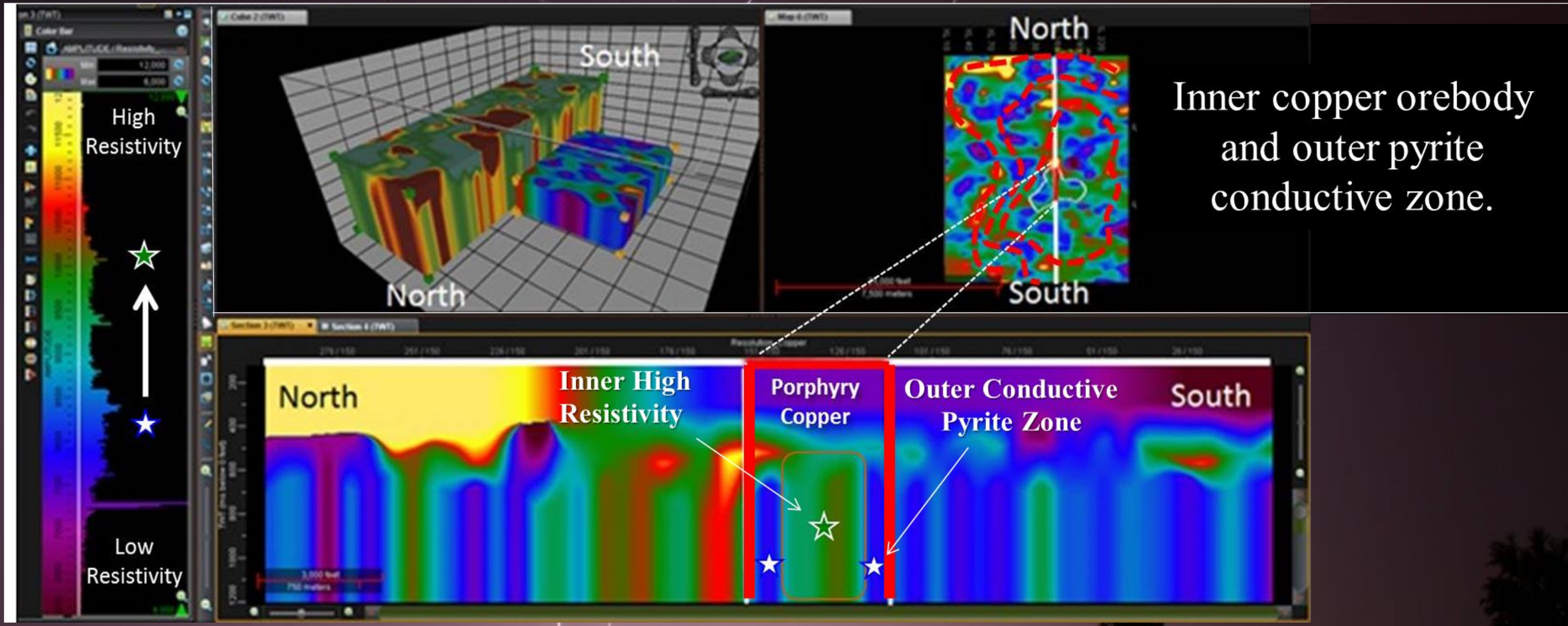
Pyrite halo partially enclosing Cu orebody





Positive Peak Current
Resolution Copper Mine

Resolution Copper Mine Pinal County, AZ



Mineral Exploration Conclusions

- NSEM data has the potential to explore for any mineral commonly found by conventional electrical geophysical prospecting methods.
- ★ NSEM data has the ability to map subsurface rock properties which can be applied to unconventional oil and gas exploration.

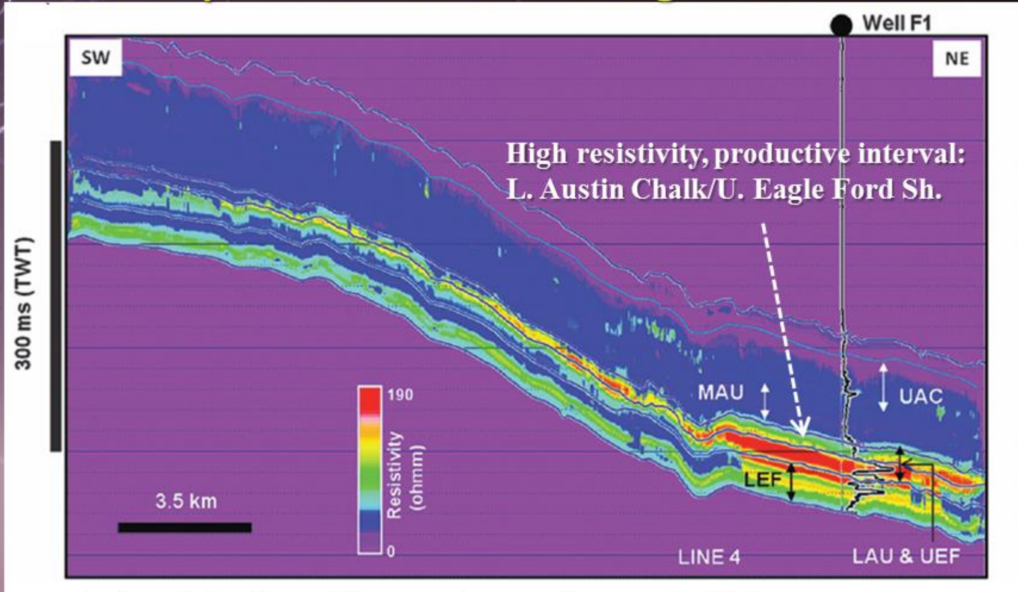
The Same Rock Properties Influencing NSEM May Help Define Unconventional Sweetspots

BEG publication defines Austin Chalk & Eagle Ford Sh. exploration sweetspot model in Maverick Basin.

BEG's South Texas sweetspot model:

- **High Resistivity**
- High Total Organic Carbon
- High Acoustic Impedance
- Low Bulk Volume Water

Resistivity volume transect through Austin Chalk



**After Ogiesoba and Eastwood, see reference cited below.*

*"*Seismic multiattribute analysis for shale gas/oil within Austin Chalk & Eagle Ford Shale in a submarine volcanic terrain, Maverick Basin, South Texas,*" Osareni C. Ogiesoba & Ray Eastwood BEG, Interpretation, Nov. 2013.

NSEM Summary

- NSEM can map regional & individual faults, rock properties and the presence of minerals; it can generate leads, and has demonstrated remarkable potential to identify hydrocarbon accumulations.
- NSEM can be calibrated to, and integrated with, seismic and subsurface geology, potential field and near surface geophysical data.
- NSEM can fill in between or extend existing data and when combined with other data, narrow down feasible interpretations.

Acknowledgments

Thanks to Les Denham of Dynamic Measurement, LLC for his resistivity and permittivity algorithms that helped produce the 3-D apparent resistivity volumes from which these resistivity profiles were extracted.

Questions?

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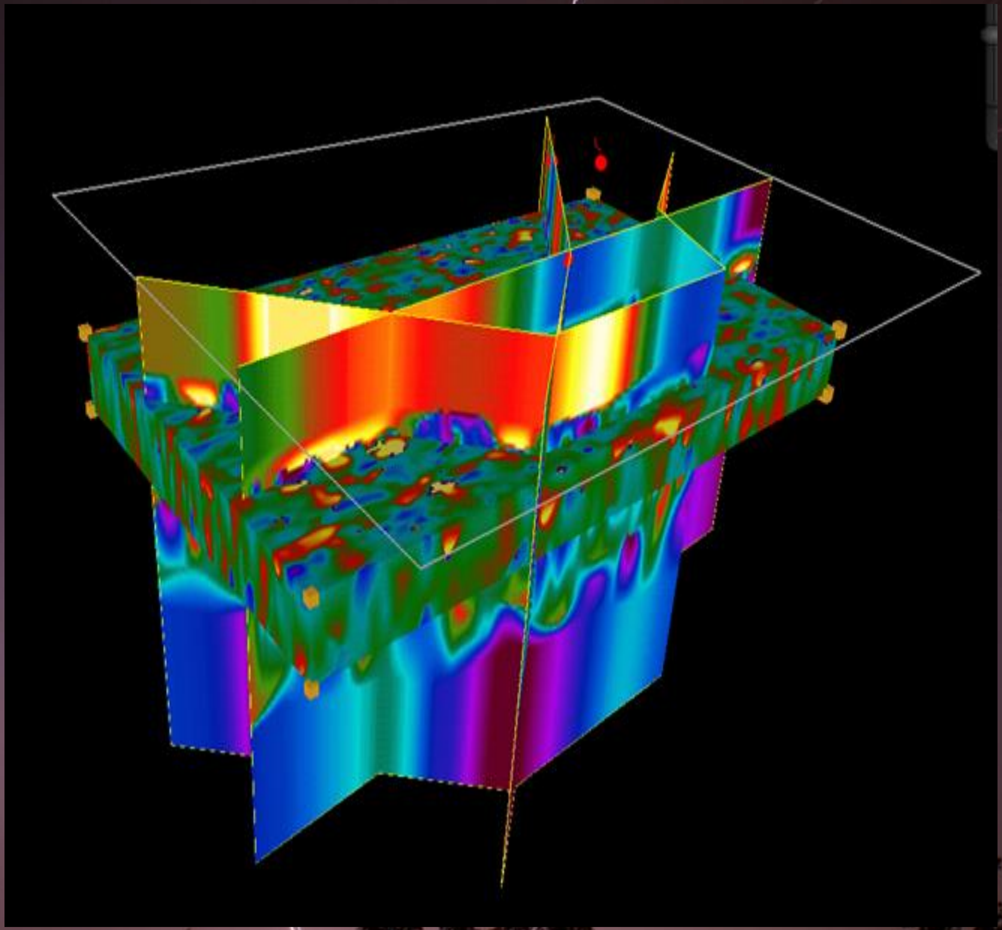
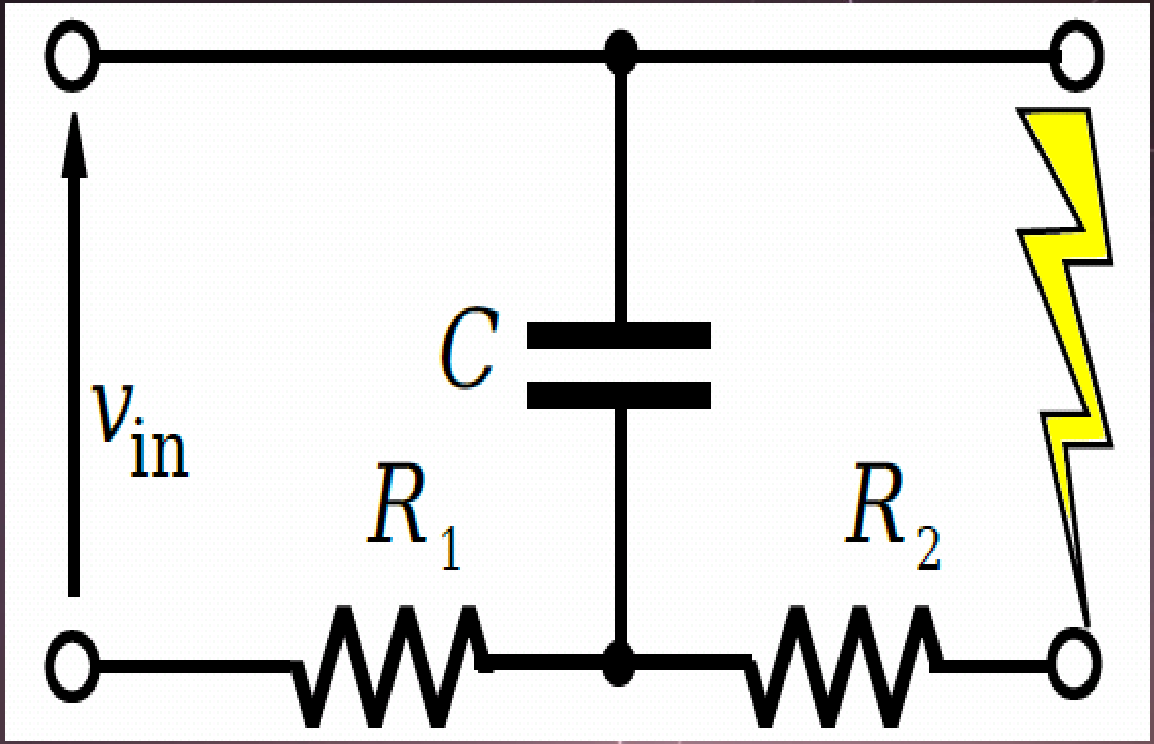
DYNAMIC MEASUREMENT

Appendix



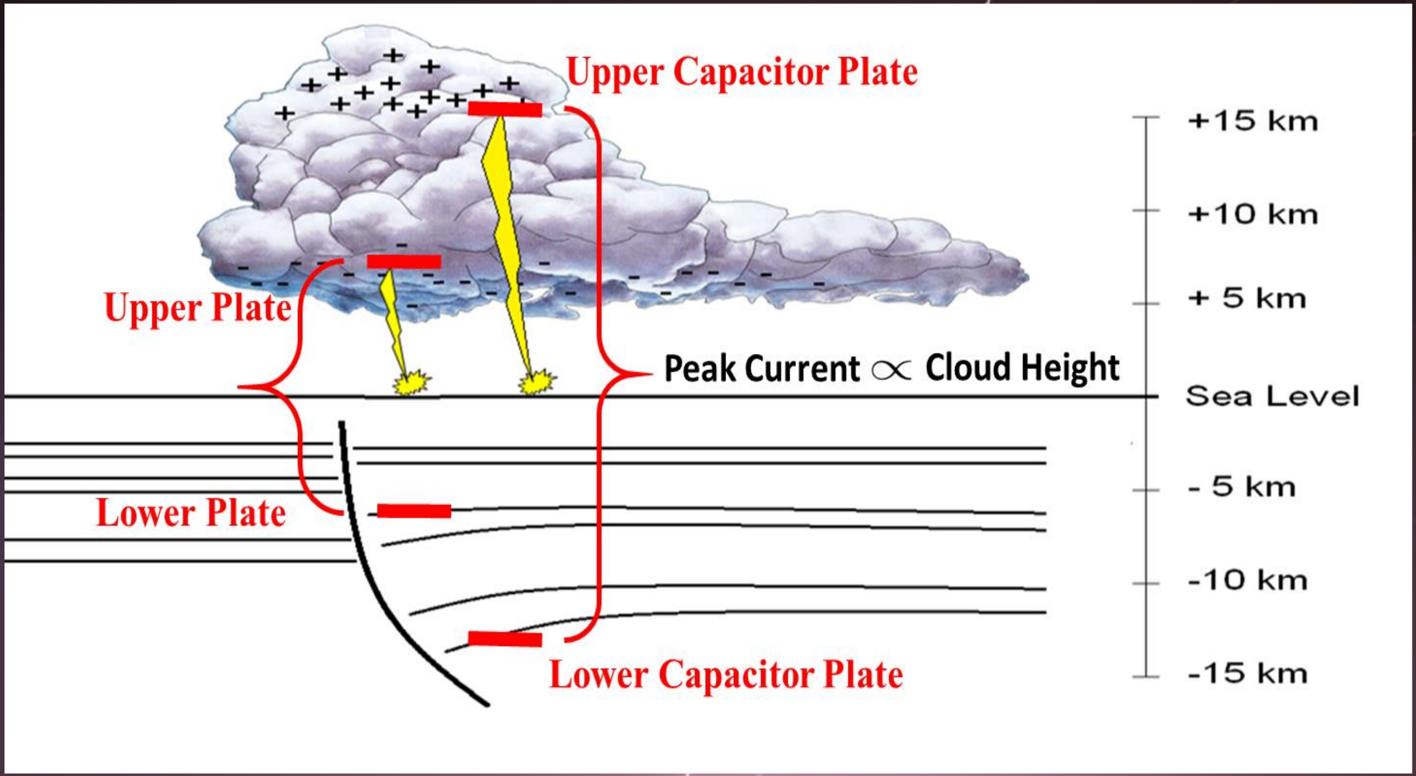
Lightning Physics Analogous to Relaxation Oscillator Physics



Voltage builds across capacitor until an insulating gas ionizes & becomes a conductor.

Similar physics enables generation of 3-D apparent resistivity & permittivity volumes.

Creating Apparent Resistivity Volumes



Millions of lightning strikes grouped by peak current.

Strike data therefore grouped by depth.

Provides basis for generating 3-D apparent resistivity volumes.

3-D Resistivity Volumes

- Data traces uniformly sampled in time/depth with same number samples in each trace as required by 3-D seismic interpretation software.
- For each trace a depth & resistivity grid is generated & sampled.
- Resistivity values interpolated between sampled points w. respect to depth, producing samples at uniform intervals.
- Typical sample interval approximately 160’.
- Typical trace length 125 samples.
- No sample interval/trace length restrictions beyond those imposed by SEG-Y format.

