Lightning Sparks Interest in Unconventional Exploration!

Roice Nelson & Louis Berent

Dynamic Measurement, LLC

Agenda & Outline

Roice Nelson

Welcome & Introduction

Lightning Strikes & Dynamic Measurement – the backstory

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

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

Louis Berent & Roice Nelson

Examples of using NSEM to interpret geologic features.

NSEM Overview.

Current Projects.

LIGHTNING, & WHY IT IS TRACKED, STACKED & MAPPED

See Lightning . . .
DML
. . . think DML & solutions

Can Lightning Hit the Same Place Twice?

Lightning,
An Atmospheric Discharge of Electricity

See Lightning . . .
. . . think DML & solutions

Build-up of static charges.

Turbulent winds: ice, hail, water droplet collisions.

Clouds become polarized: positive ions @ top of clouds, negative ions @ base of clouds.

When charge strength exceeds insulating property of atmosphere, results in sudden high-voltage static discharge.

Nature of Lightning
“Step Leaders” & “Streamers”

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

Streamers: rising stream of protons attracted to the downward seeking electron step leaders; develop when step leaders within 30’ to 300’.

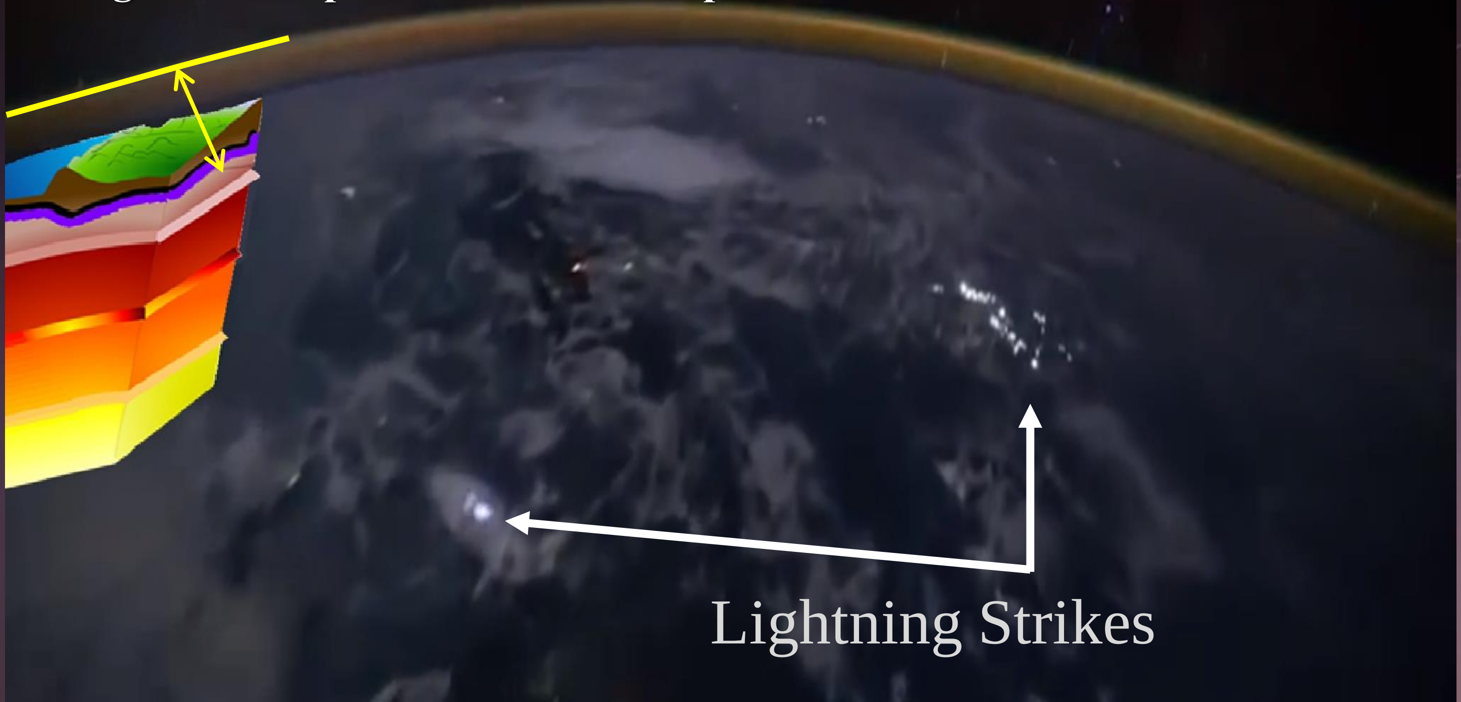
Failed Lightning Strikes & Streamers

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

Note streamer launched from telephone pole also does not connect with a step leader to produce a strike.

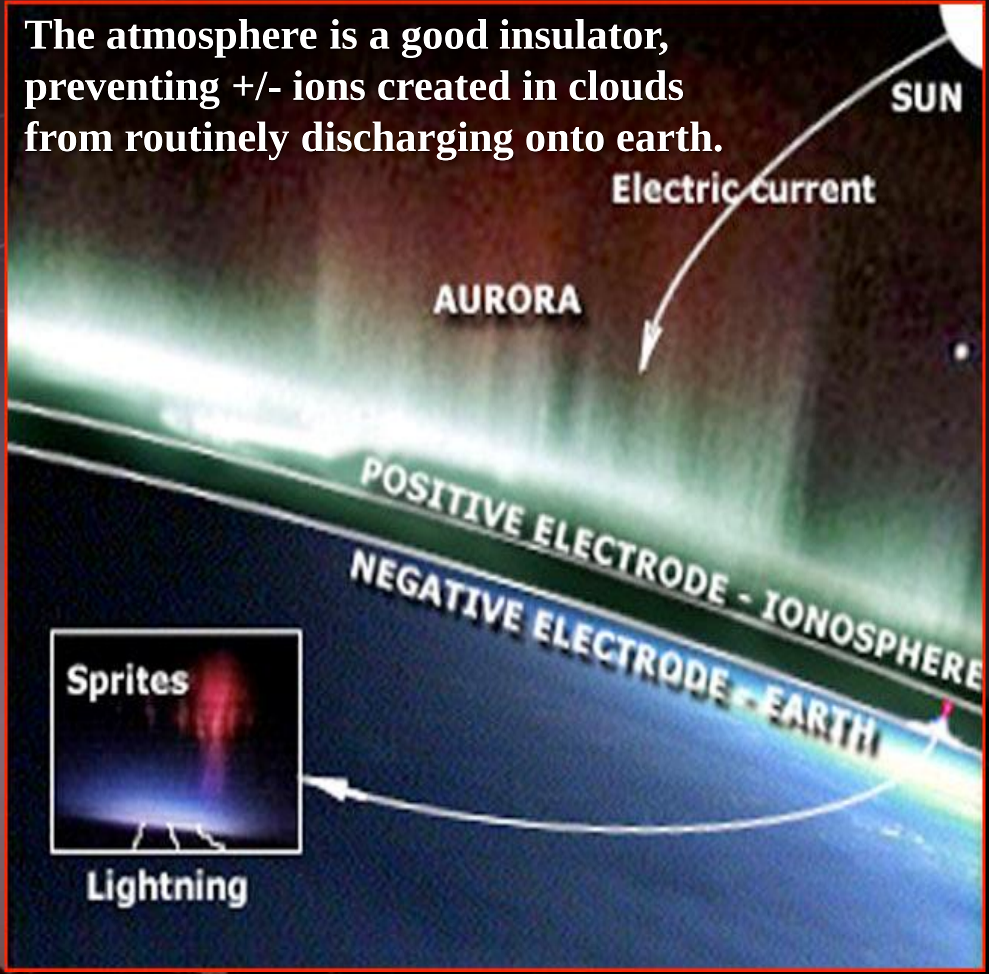
Earth: A Self-Repairing Capacitor

The atmosphere serves as a dialectric between the clouds & earth, each analogous to a capacitor's conductive plate.

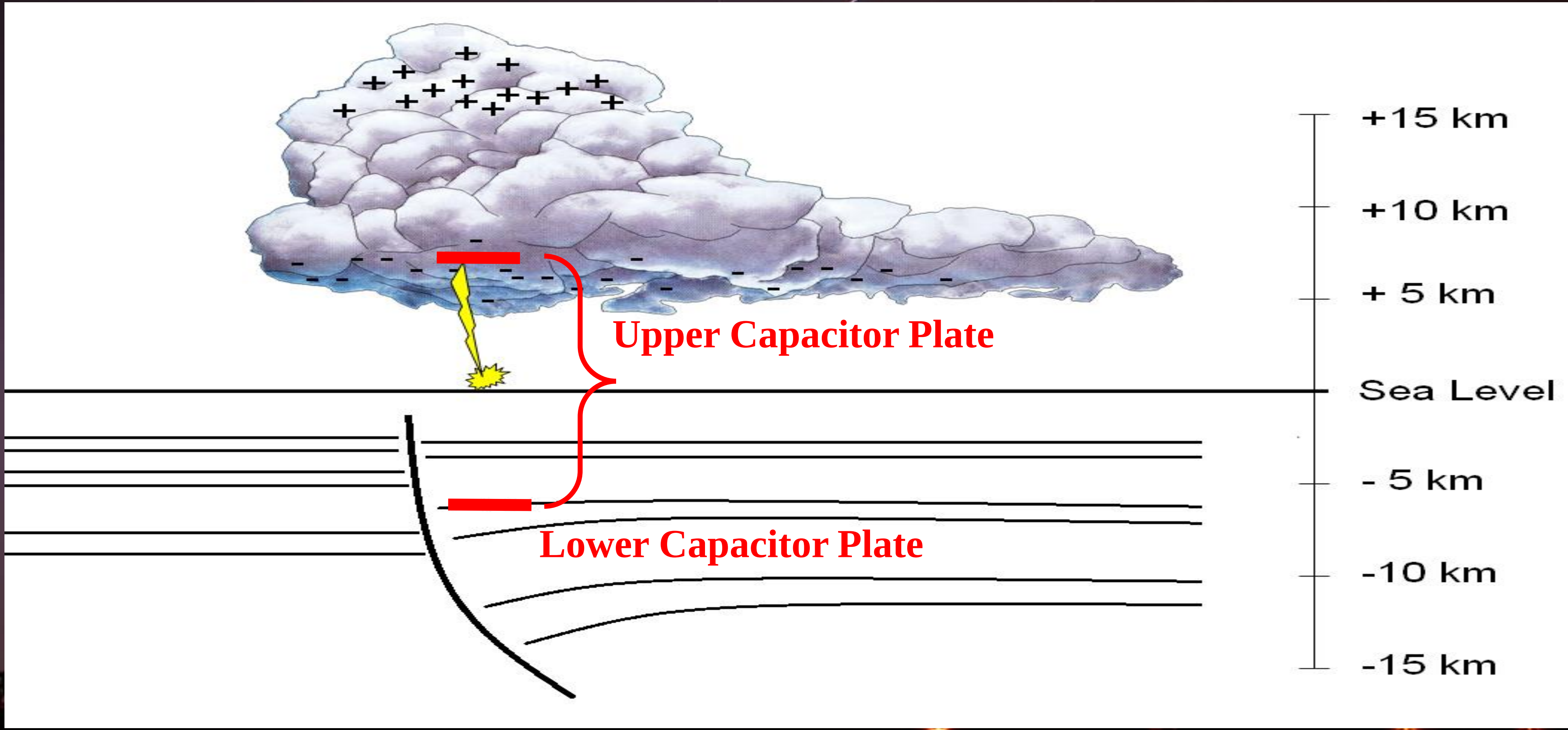


When a cloud charge build-up exceeds the insulating capability of air, electrical energy of the lower atmosphere discharges as lightning, essentially normalizing the earth's capacitor.

The atmosphere is a good insulator, preventing +/- ions created in clouds from routinely discharging onto earth.

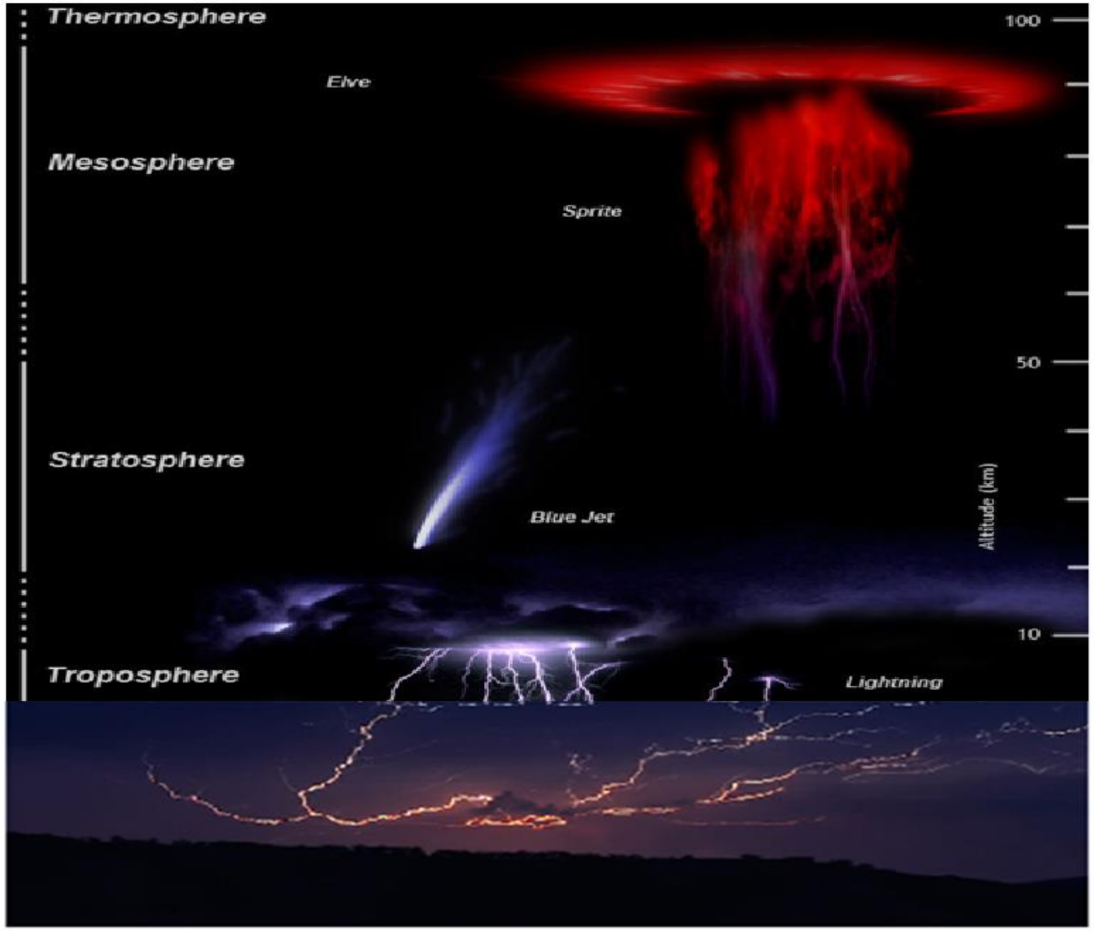


Each Strike Represents a Unique Capacitor
Base of Capacitor is a Function of Cloud Height



Geologically Controlled Telluric Currents
Primary Lightning Influence

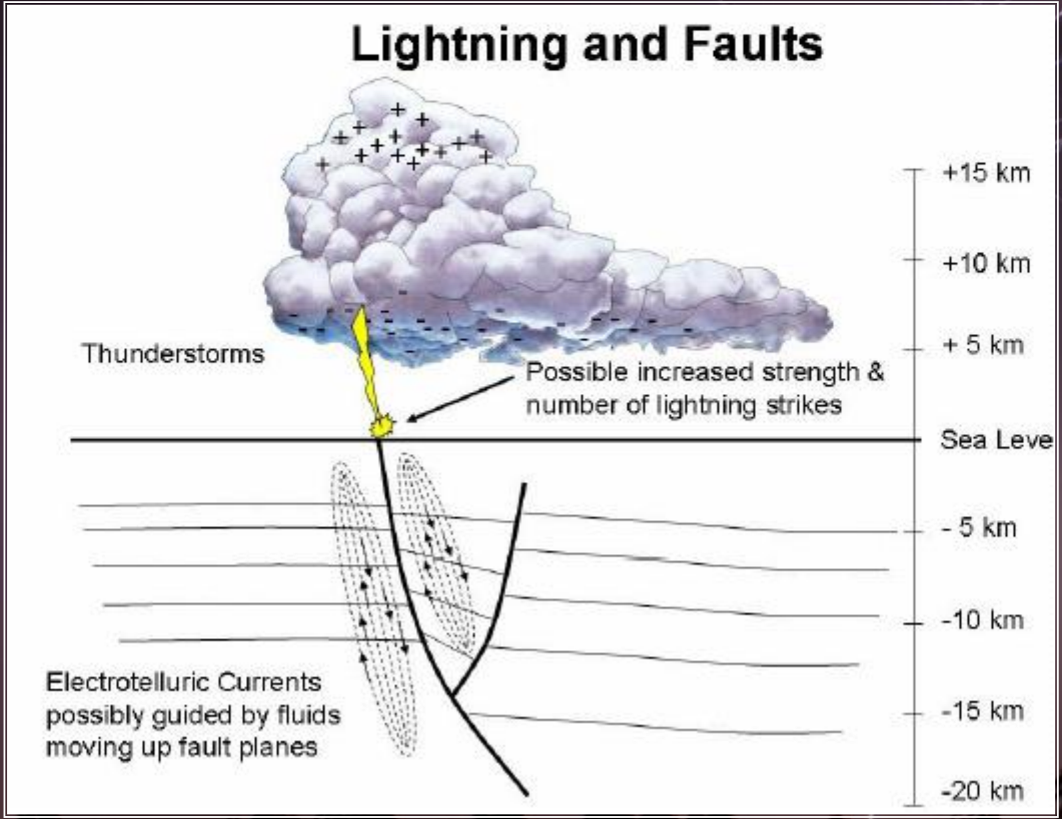
See Lightning . . . DML . . . think DML & solutions

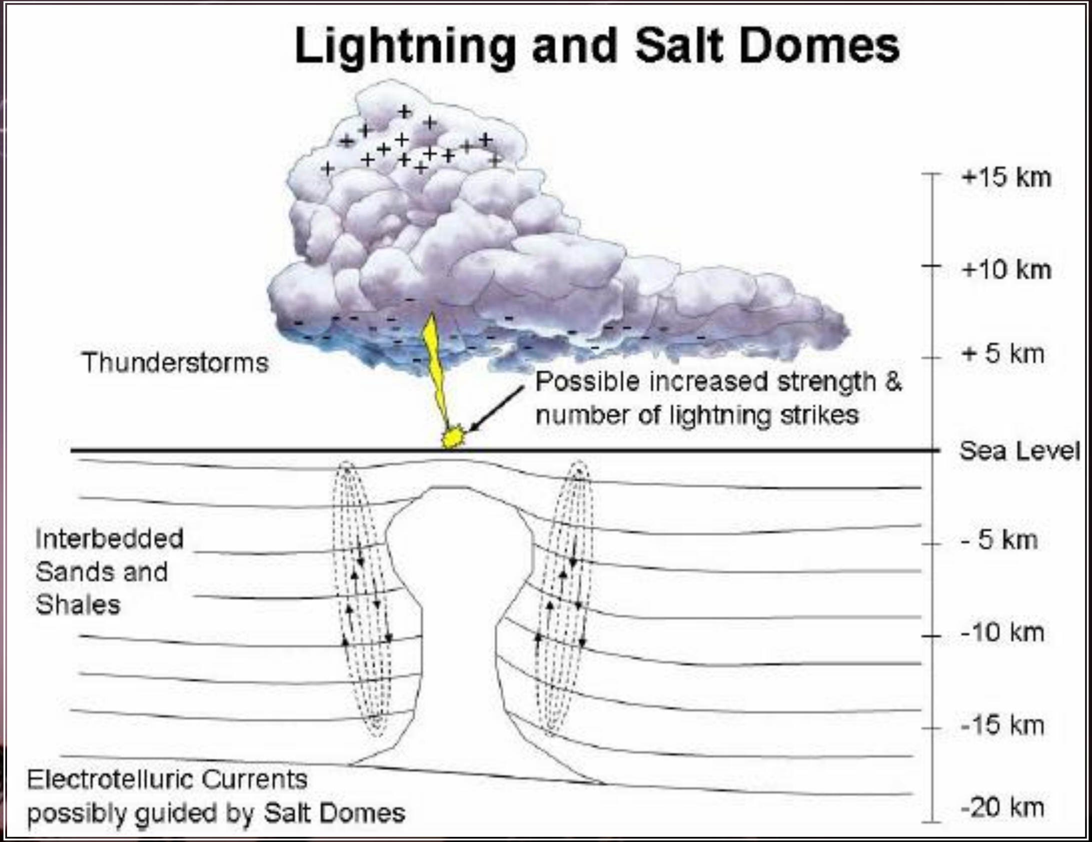


Lightning can travel 155 miles (250 km) from cloud-to-cloud, so why does lightning strike where it does?

Telluric Currents, Lightning & Geology

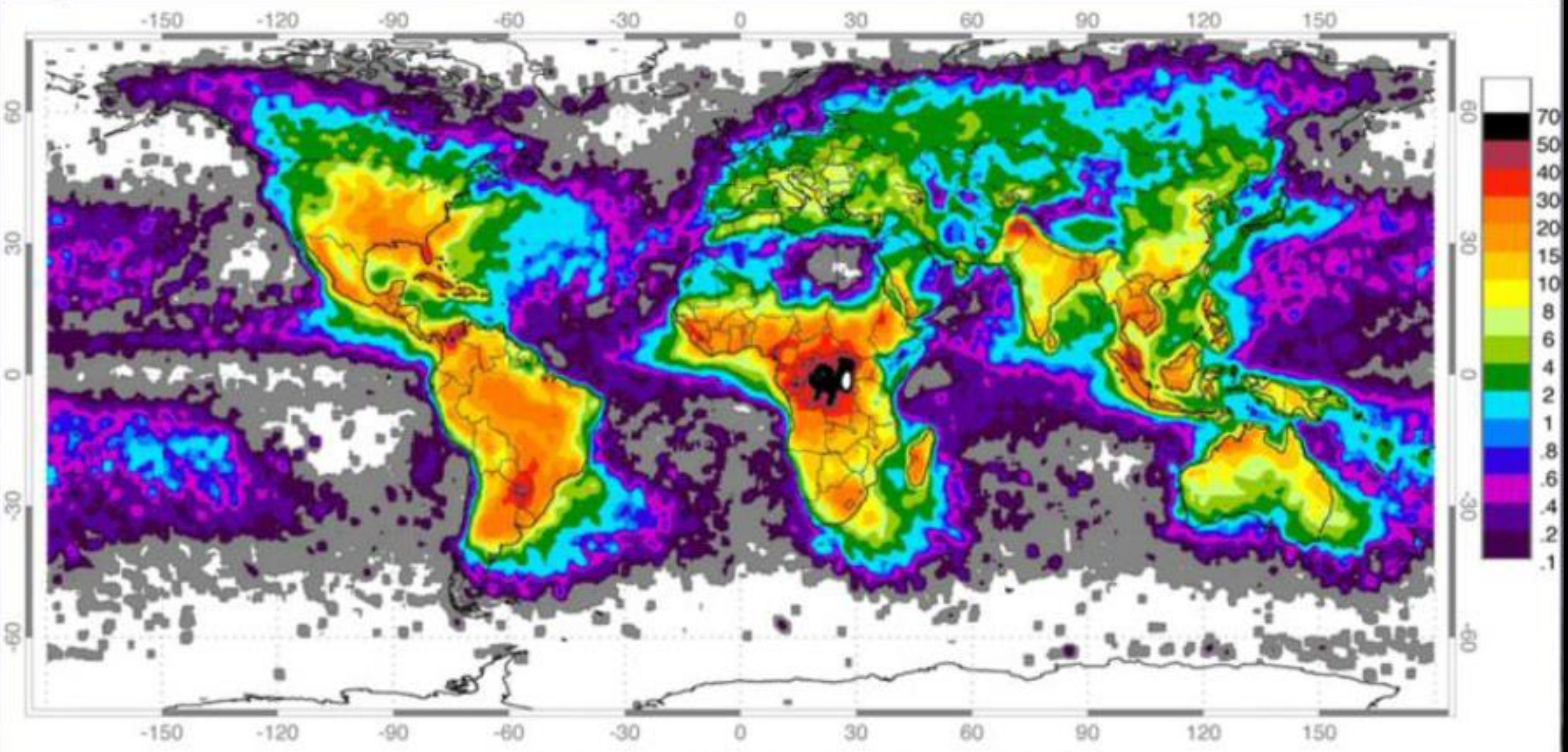
Earth Currents Modified by Geology → Prone to Lightning





350 Million Annual CG Lightning Strikes
Uneven Distribution, But Not Random!

See Lightning . . .
DML
. . . think DML & solutions



1 billion annual strikes

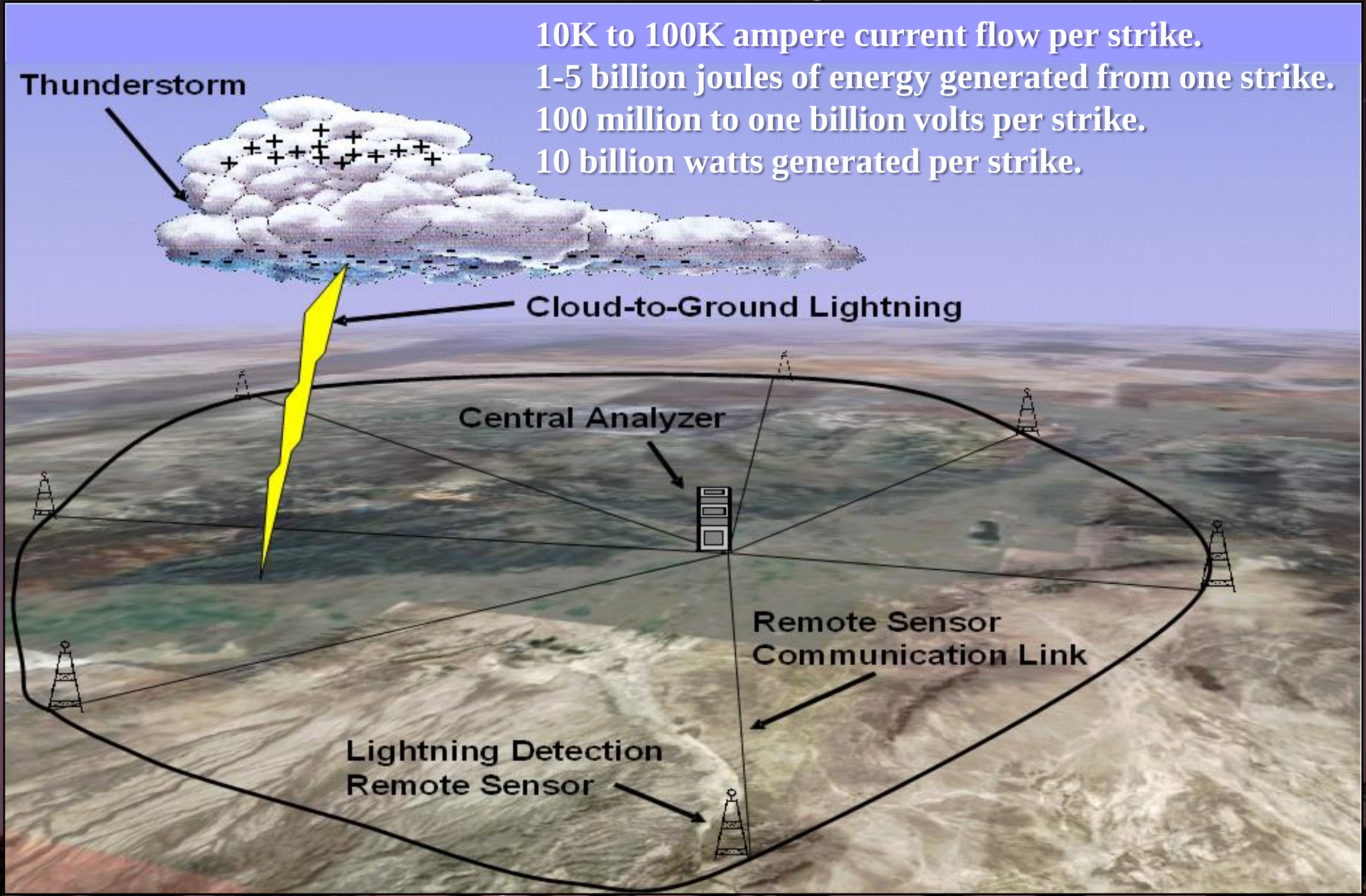
Low Resolution Full Climatology Annual Flash Rate

Global distribution of lightning April 1995-February 2003 from the combined observations of the NASA OTD (4/95-3/00) and LIS (1/98-2/03) instruments.

Why is lightning tracked and mapped?

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

How is Lightning Data Collected?
110 Sensors Record U.S. Lightning Strike Locations



90% of lightning strikes accurate to within 660'.

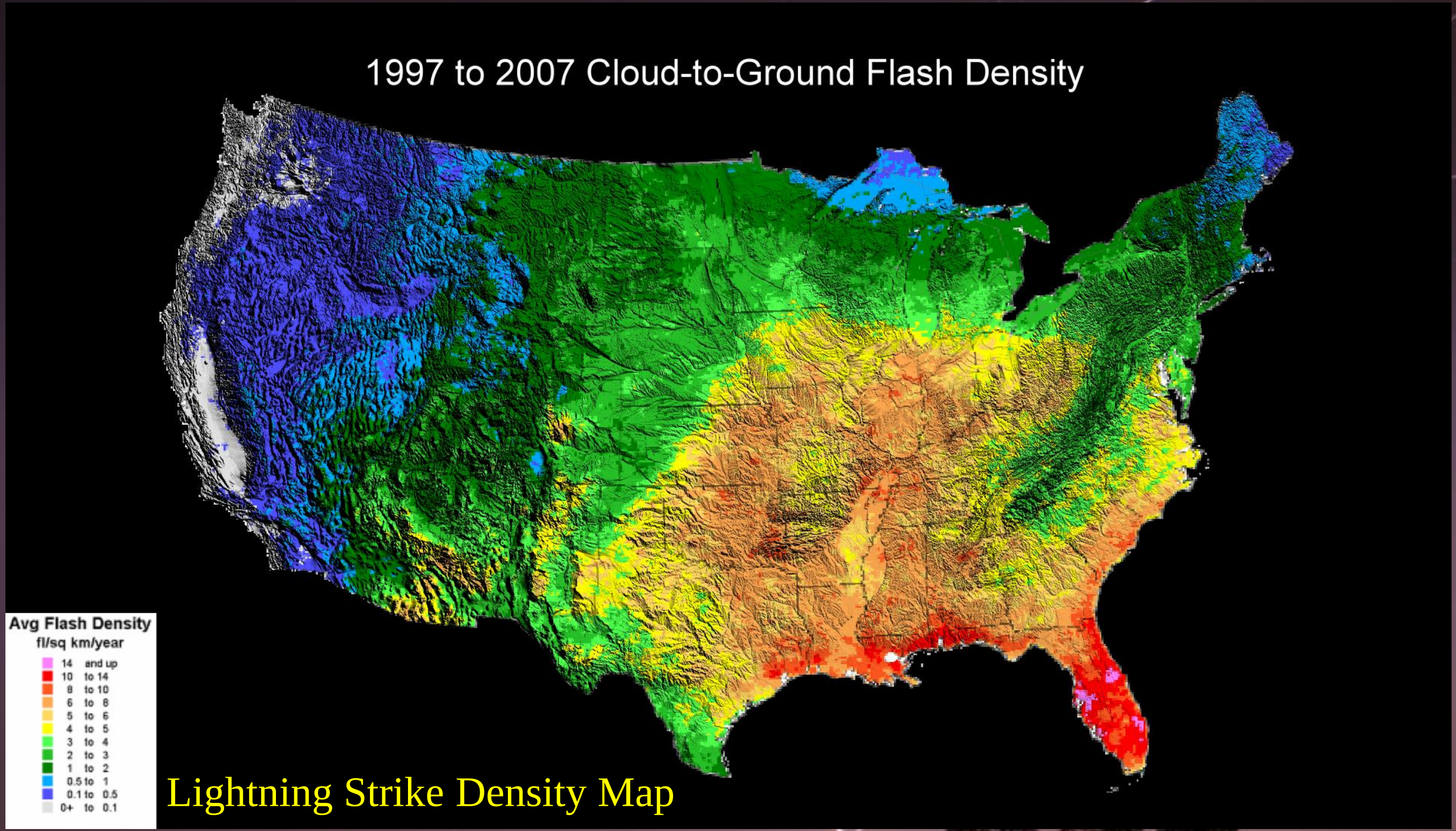
75% of strikes accurate within 400'.

61% of strikes accurate within 260'.

Error in locating any feature from a reasonably dense database is 35-70'.

25 Million Annual U.S. Lightning Strikes

17 Year Database, Rich Database to Mine



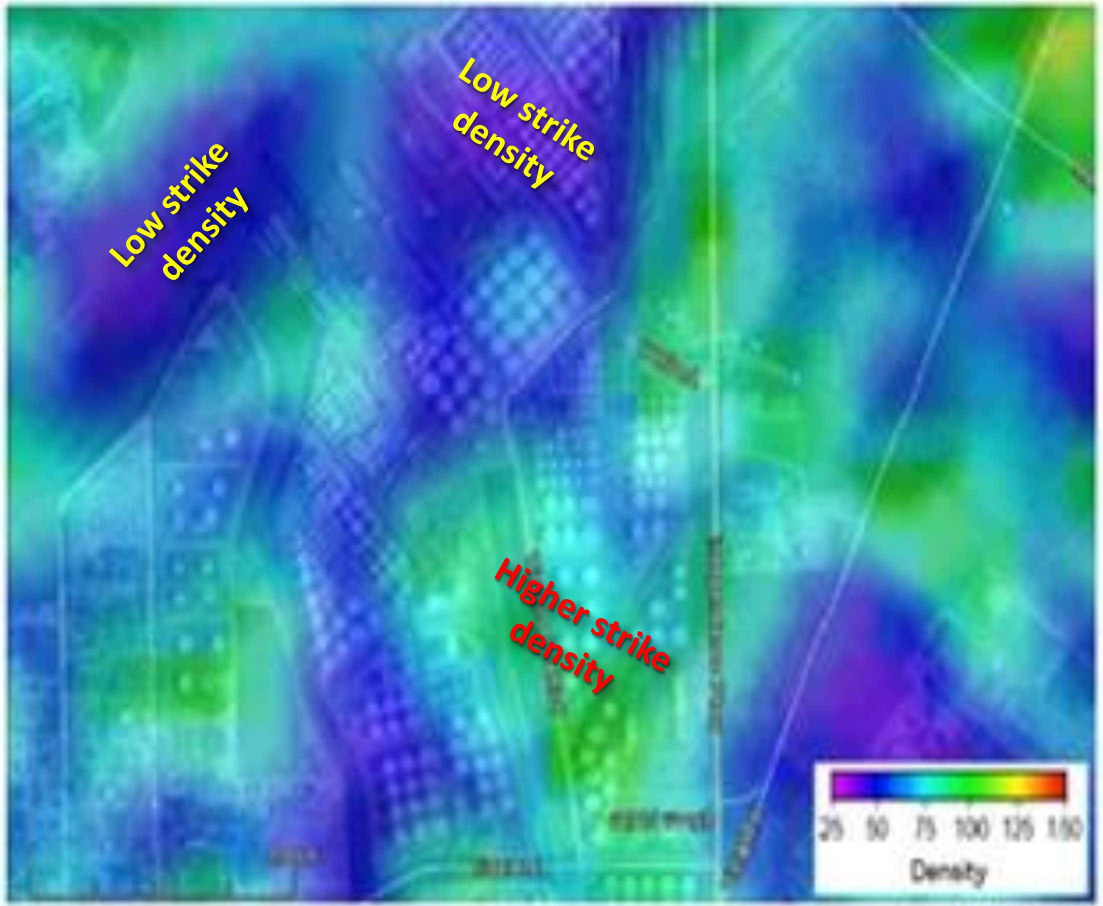
Lightning Strike Density Map

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

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

Does Infrastructure Control Lightning?

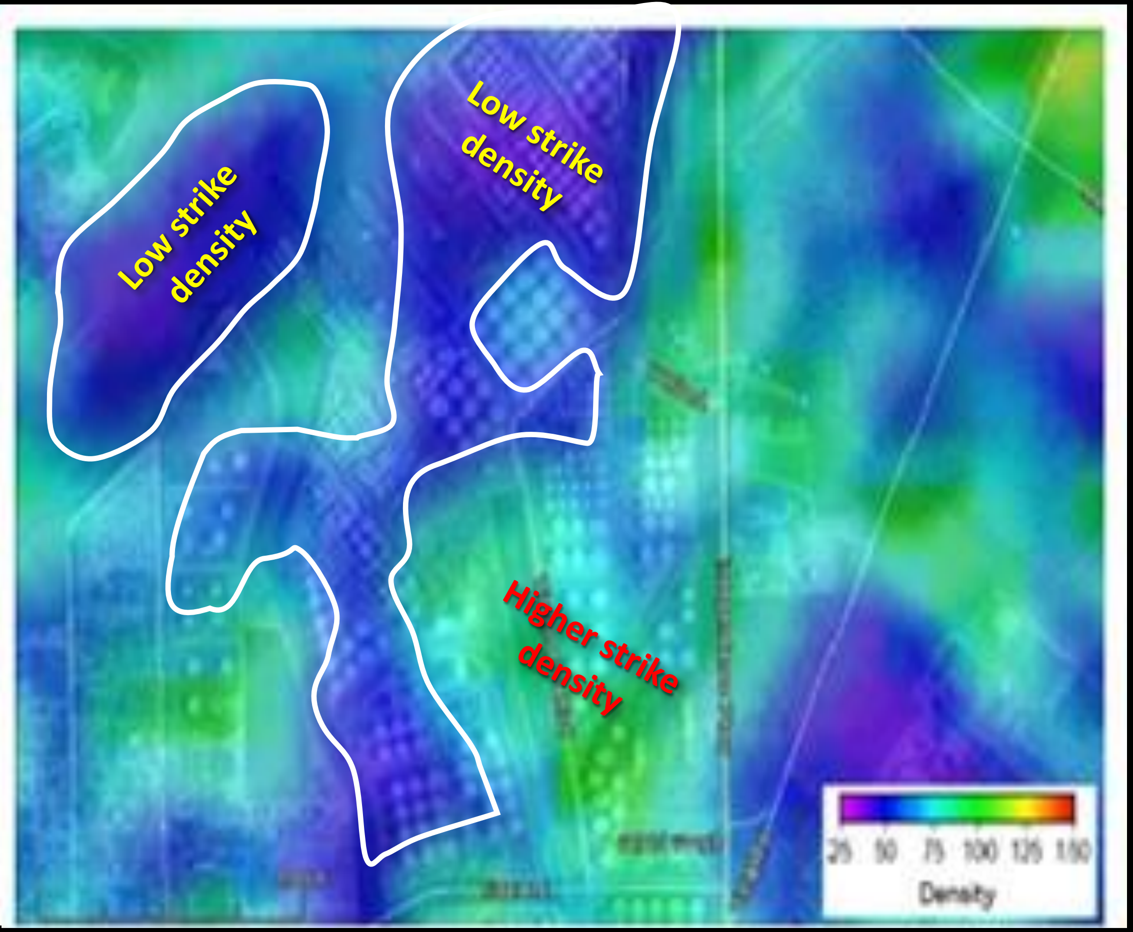
Oil Storage Facility (Tank Farm), Ship Channel, Houston



Strike Density Attribute Map

Approximately 60% of Tank Farm Experienced <u>Low</u> Strike Density

Oil Storage Facility (Tank Farm), Ship Channel, Houston



Strike Density Attribute Map

Lightning bypasses tall objects and…

…infrastructure expected to attract lightning.

See Lightning . . .
DML
. . . think DML & solutions

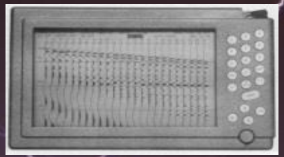
NATURAL SOURCE ELECTROMAGNETICS (NSEM) - A NEW GEOPHYSICAL DATA TYPE

Time-Line of New Geophysical Data Types

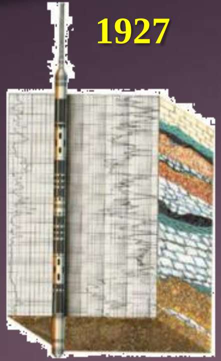
1752

1833

1920s

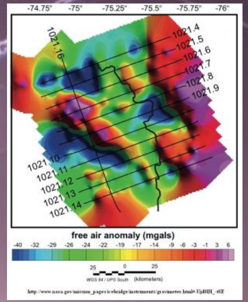


1927

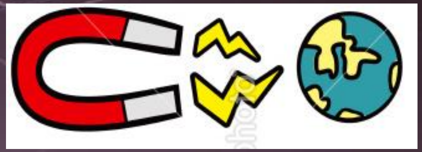


1931

1936

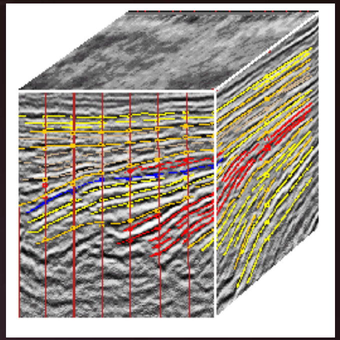


1950s

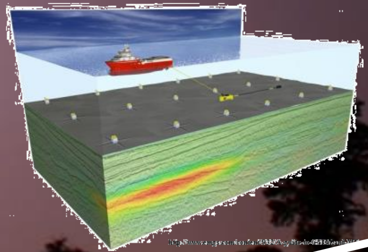


1960s/70s

1974

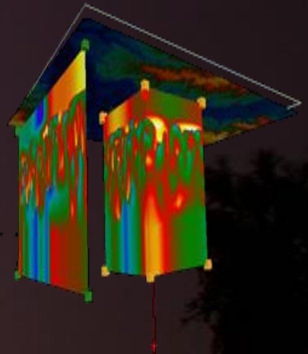


1997



2008

2015



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

Proven & Patented Technology

See Lightning . . . DML . . . think DML & solutions

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)

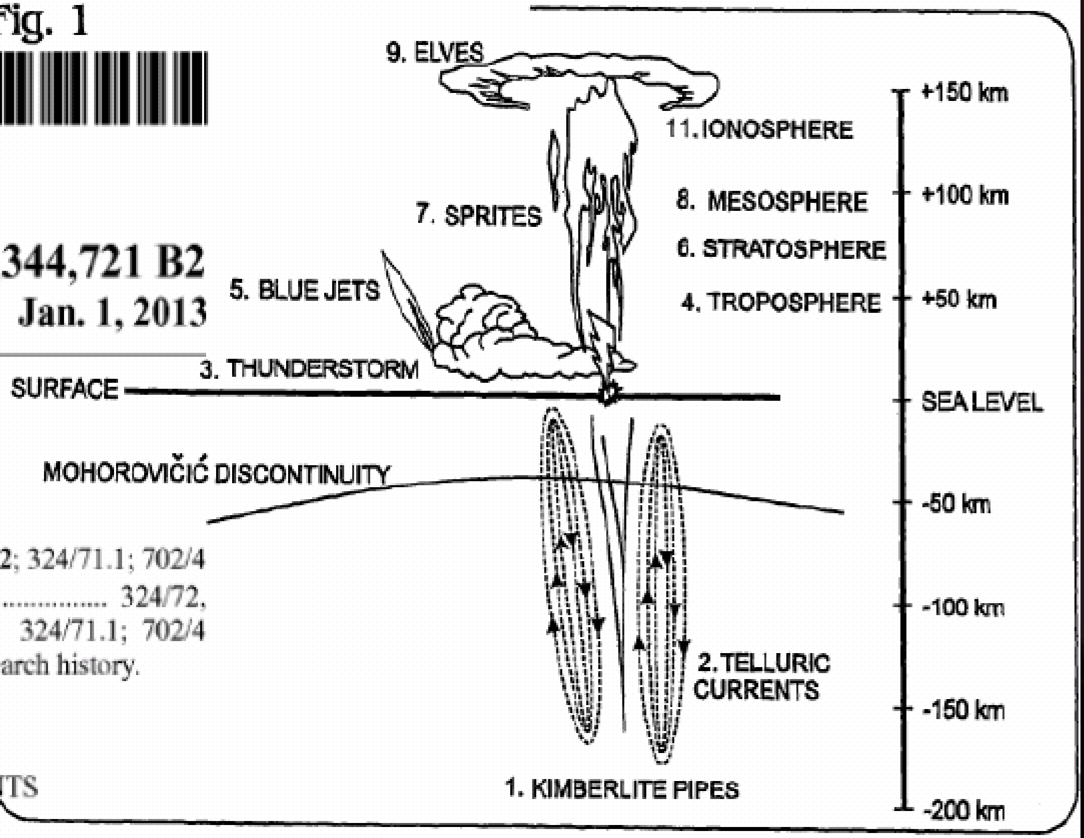
(52) **U.S. Cl.** **324/72**; 324/71.1; 702/4

(58) **Field of Classification Search** 324/72, 324/71.1; 702/4
See application file for complete search history.

(56) **References Cited**

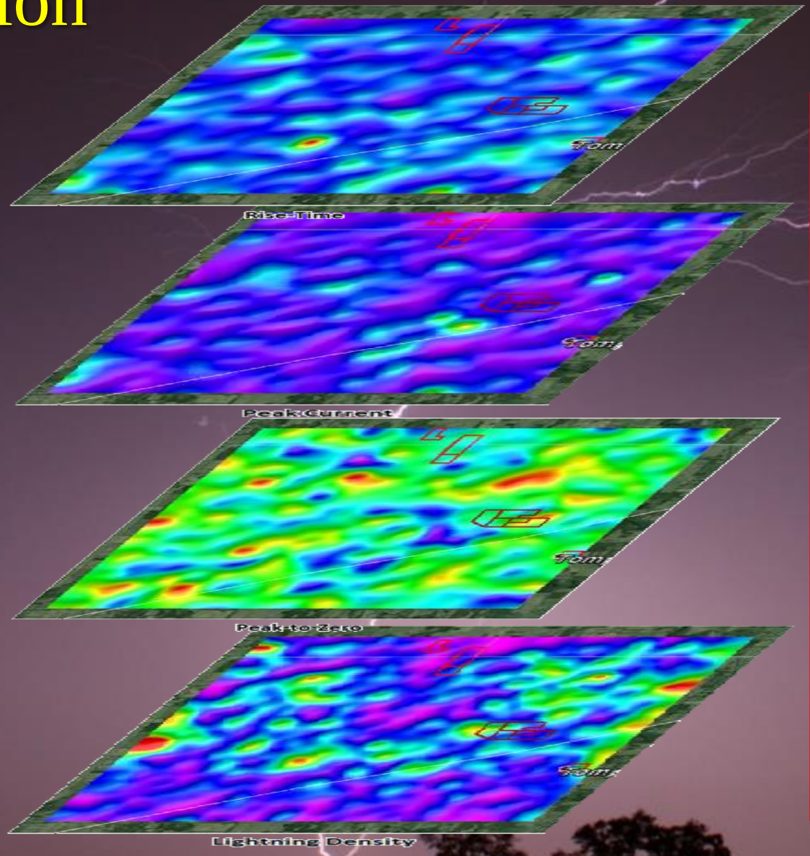
U.S. PATENT DOCUMENTS

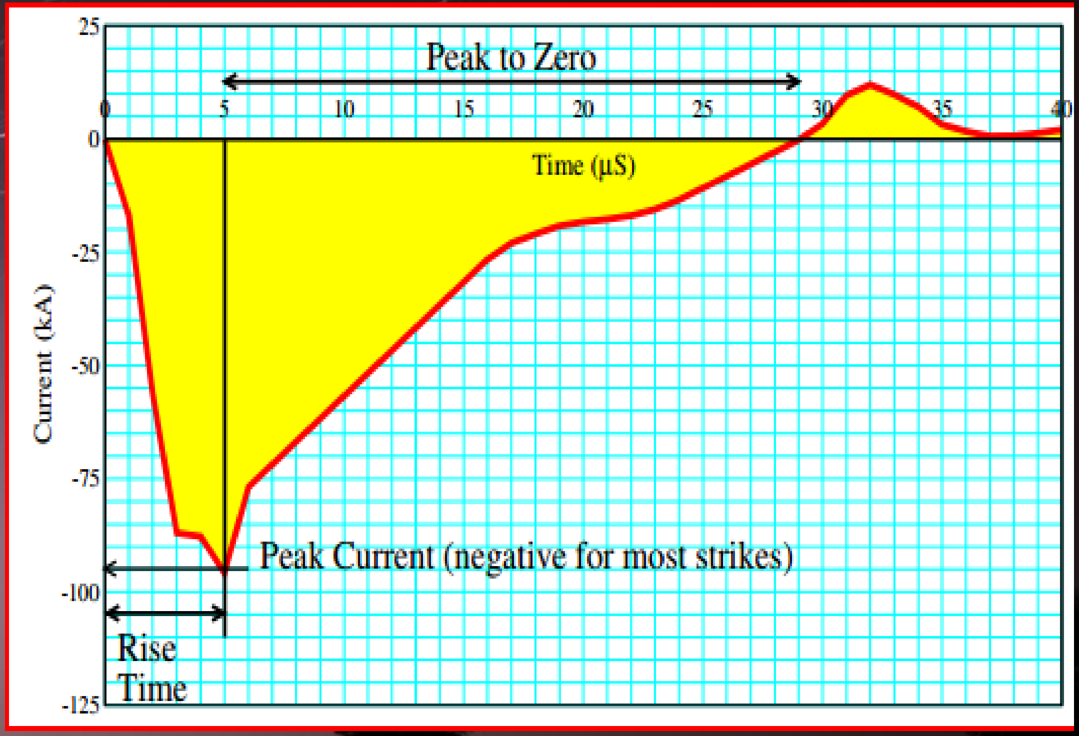
Fig. 1



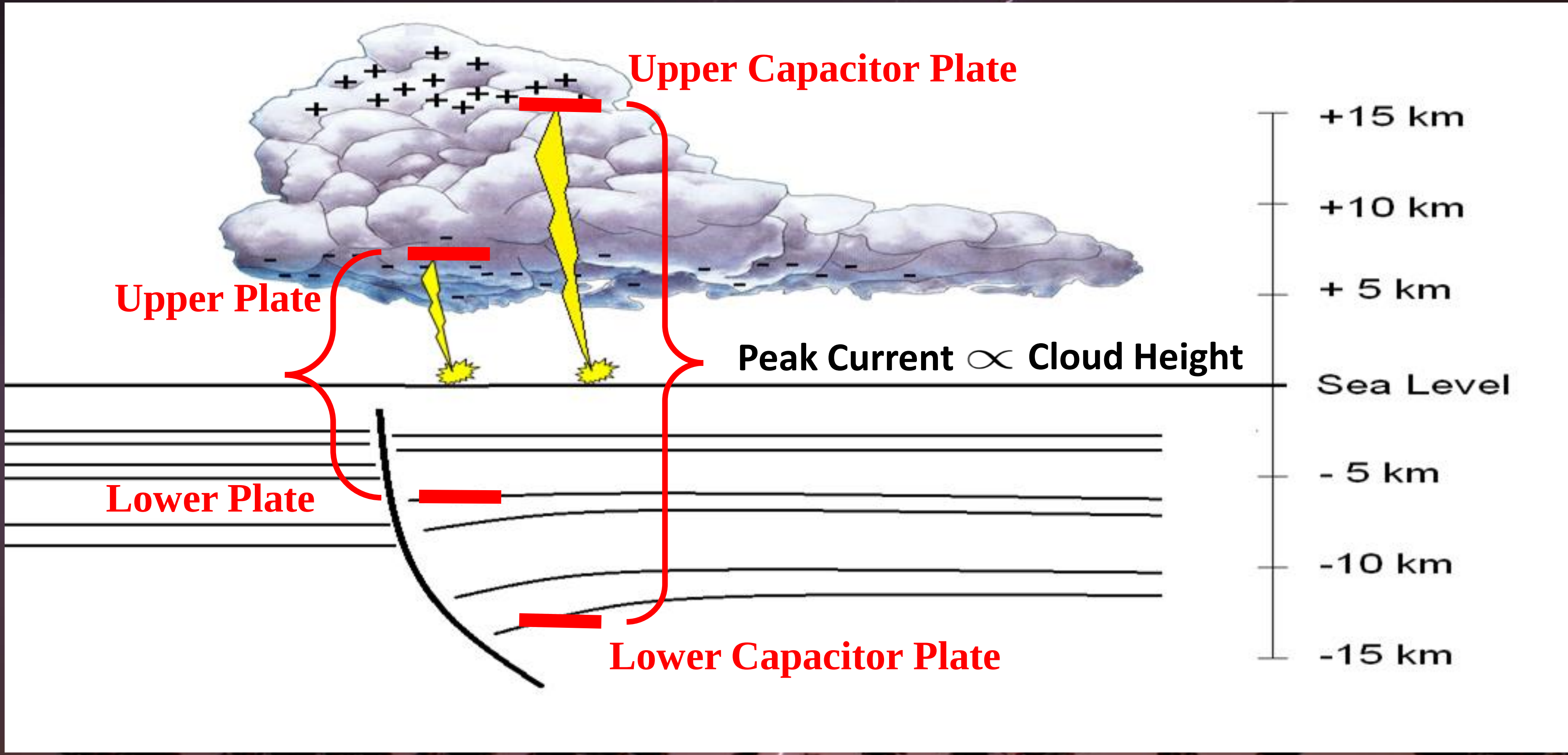
Lightning Strike Measurements

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





Depth of Electrical Energy Penetration - Function of Strike Strength

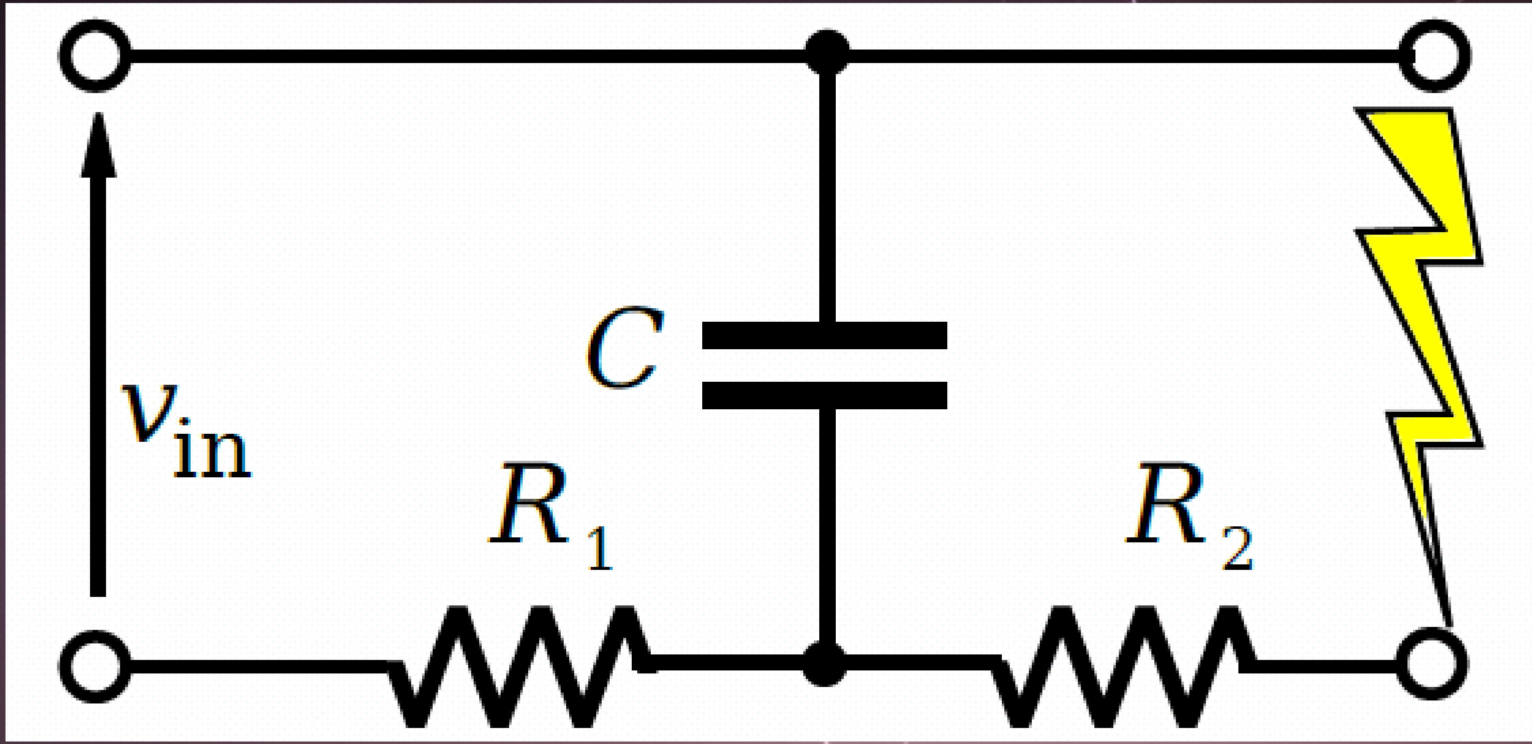


Millions of lightning strikes grouped by peak current.

Strike data therefore grouped by depth.

Provides basis for generating 3-D apparent resistivity volumes.

Lightning Physics Analogous to Relaxation Oscillator Physics



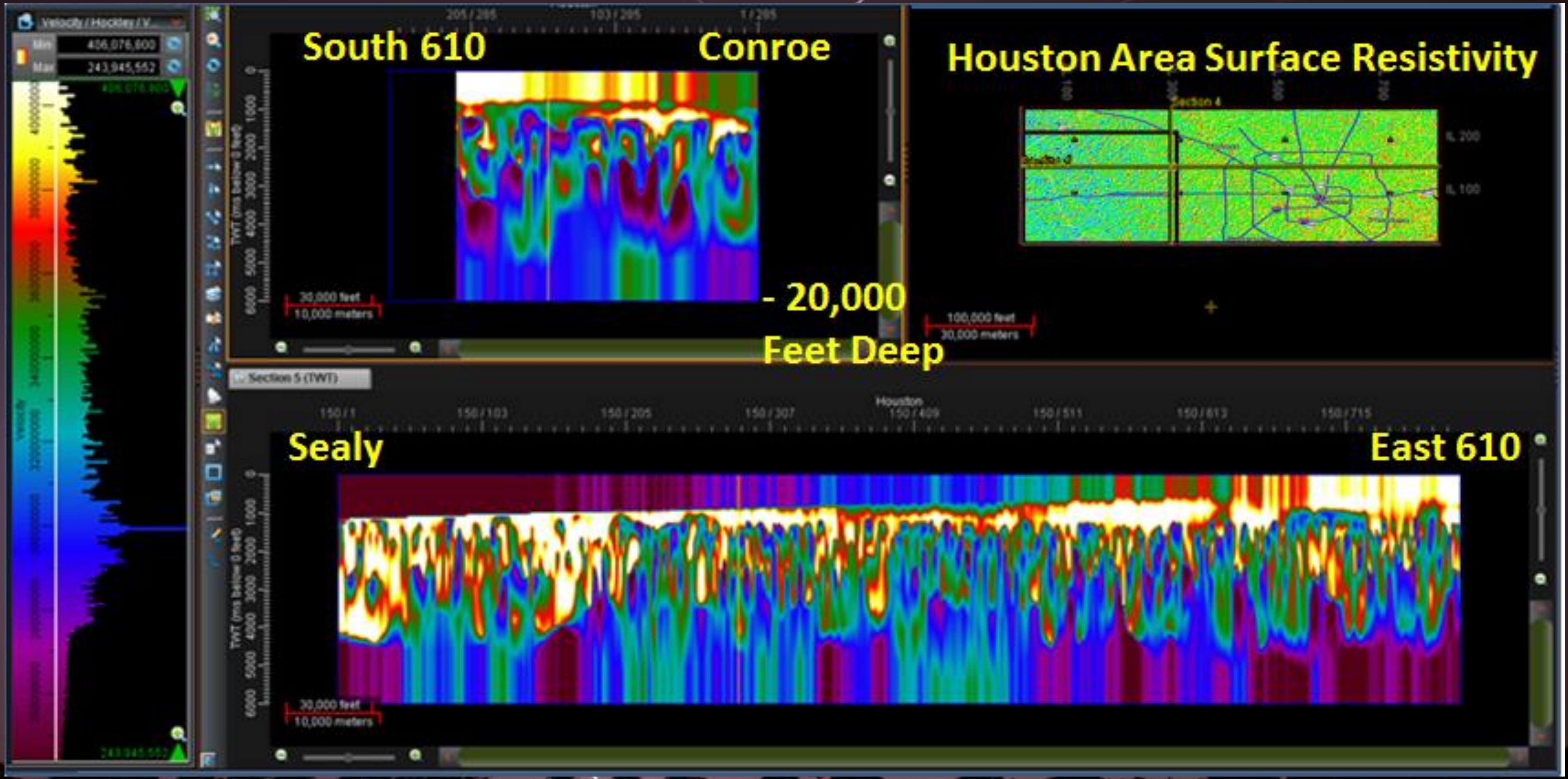
Enables generation of 3-D apparent resistivity and permittivity volumes.

3-D Resistivity & Permittivity Volumes

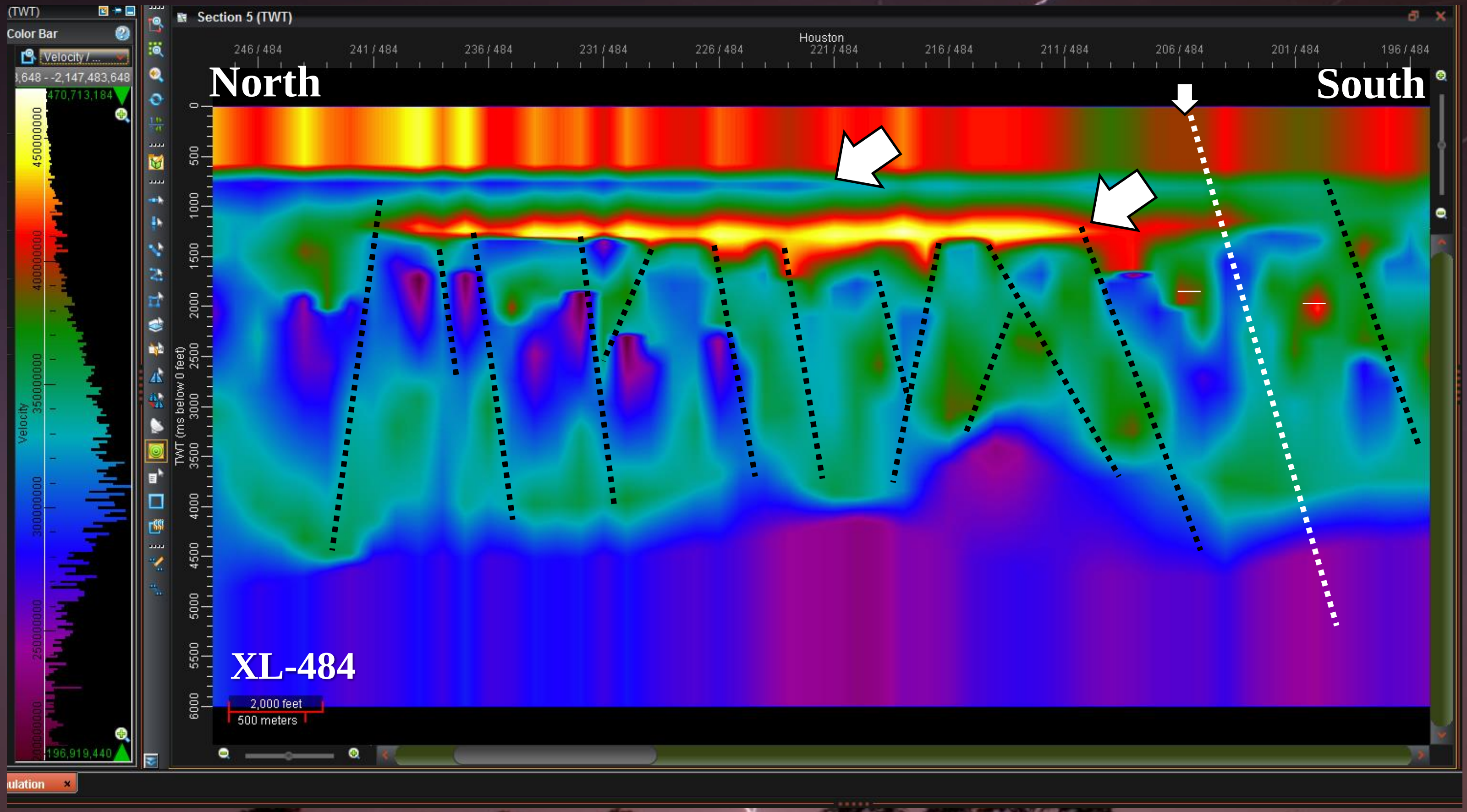
See Lightning . . . DML . . . think DML & solutions

- 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/permittivity grid is generated & sampled.
- Resistivity/permittivity values interpolated between sampled points with 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.

NSEM Correlates To Geology:
Houston, TX Resistivity Cross-Section

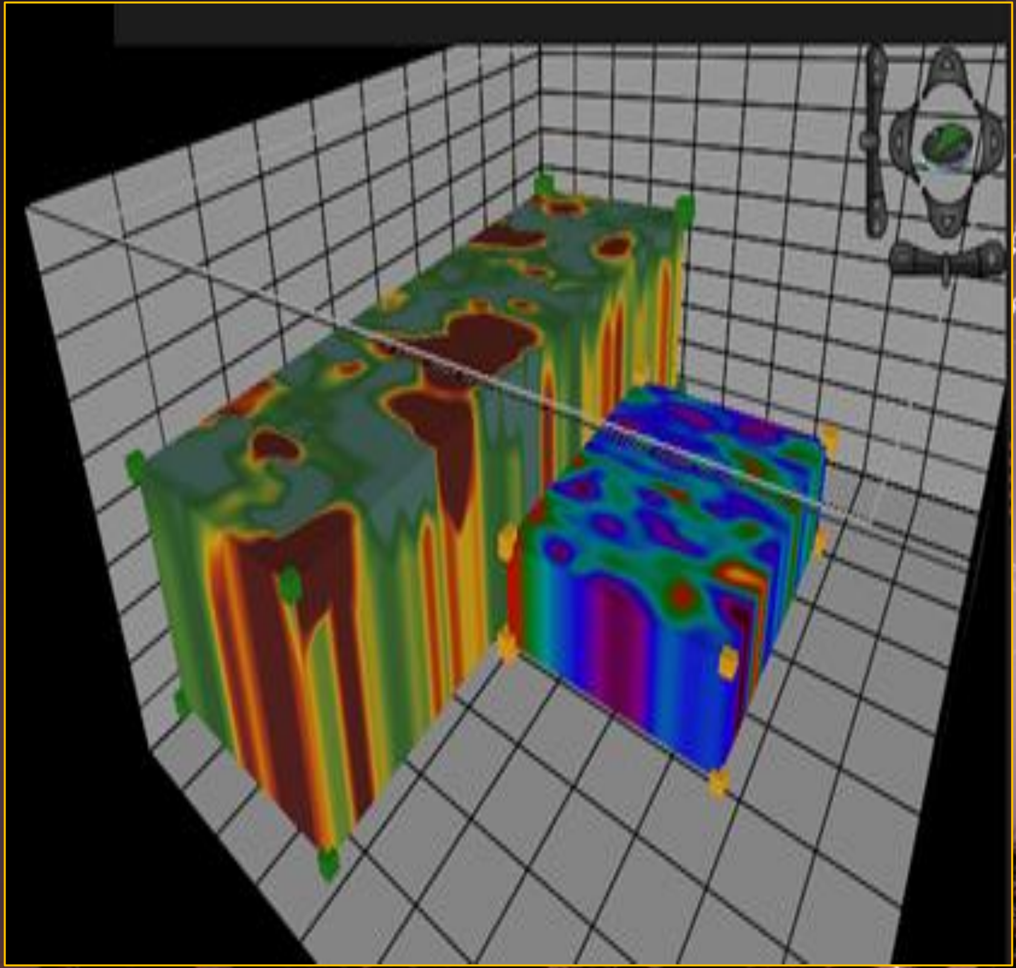


NSEM Identifies Stratigraphy & Faulting
Houston, TX

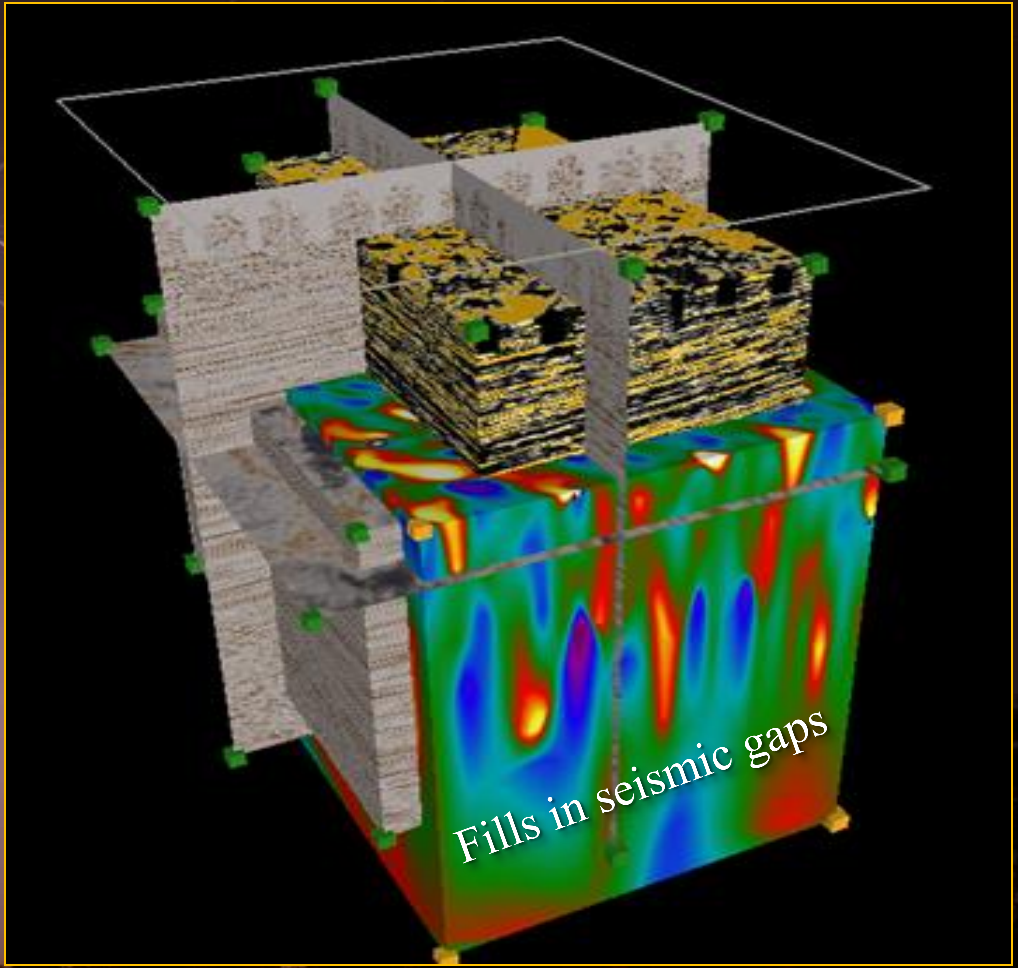


- Crossline extracted from Houston area 3-D resistivity volume.
- NSEM maps subsurface faults, fluid extent & pinchouts.

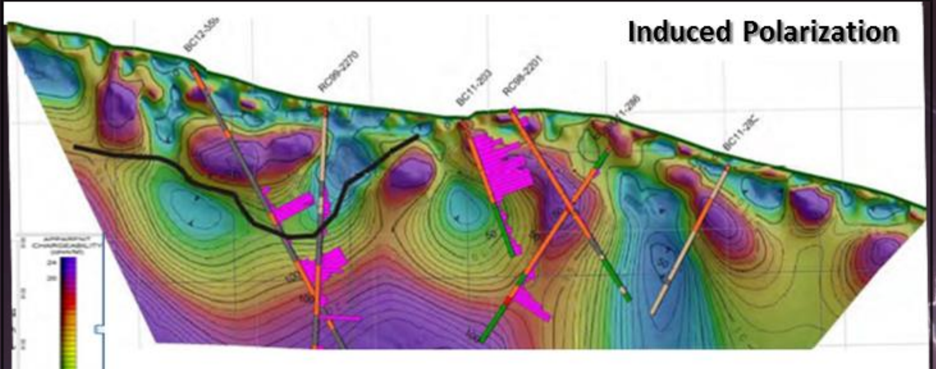
Resistivity & Permittivity Volumes
Easily Integrated with 3-D Seismic & Well Data



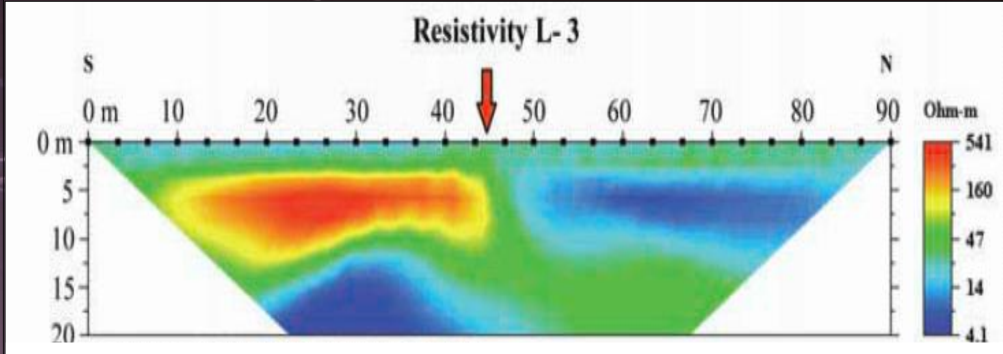
Inlines
Crosslines
Arb Lines
Slices



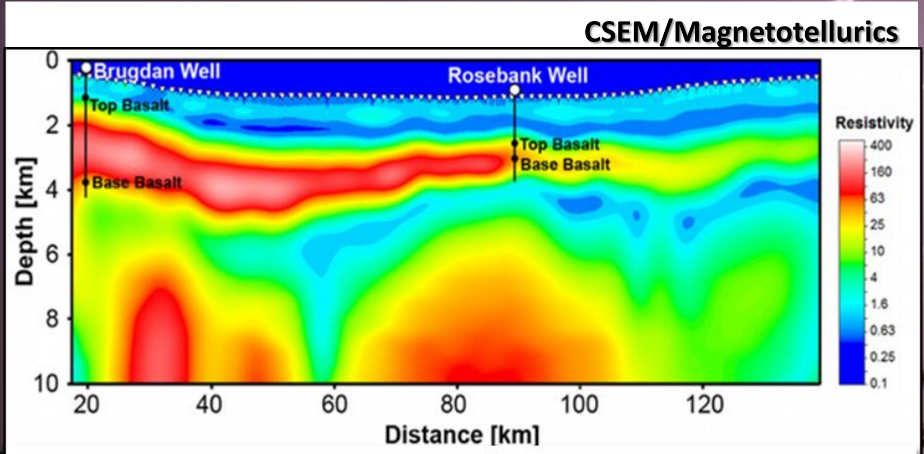
Resistivity & Permittivity Volumes
Easily Integrated w. Near-Surface Geophysical Data



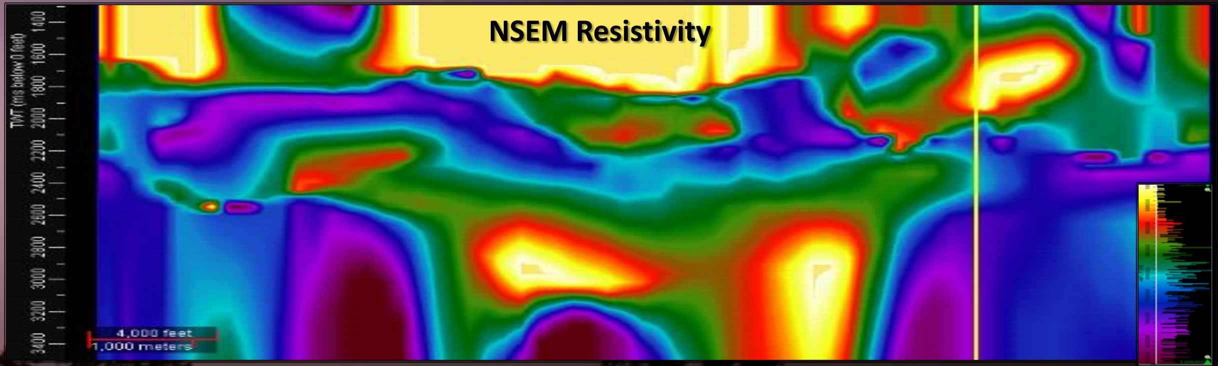
Yukon Geol. Survey, Report MR-11, Case Studies, M. Best, I. Fage and R. Daigle; http://www.geology.gov.yk.ca/pdf/MR-11_web(1).pdf



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



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



Lightning Strikes Are Not Random!

Influenced by Lateral Changes in Rock Properties:

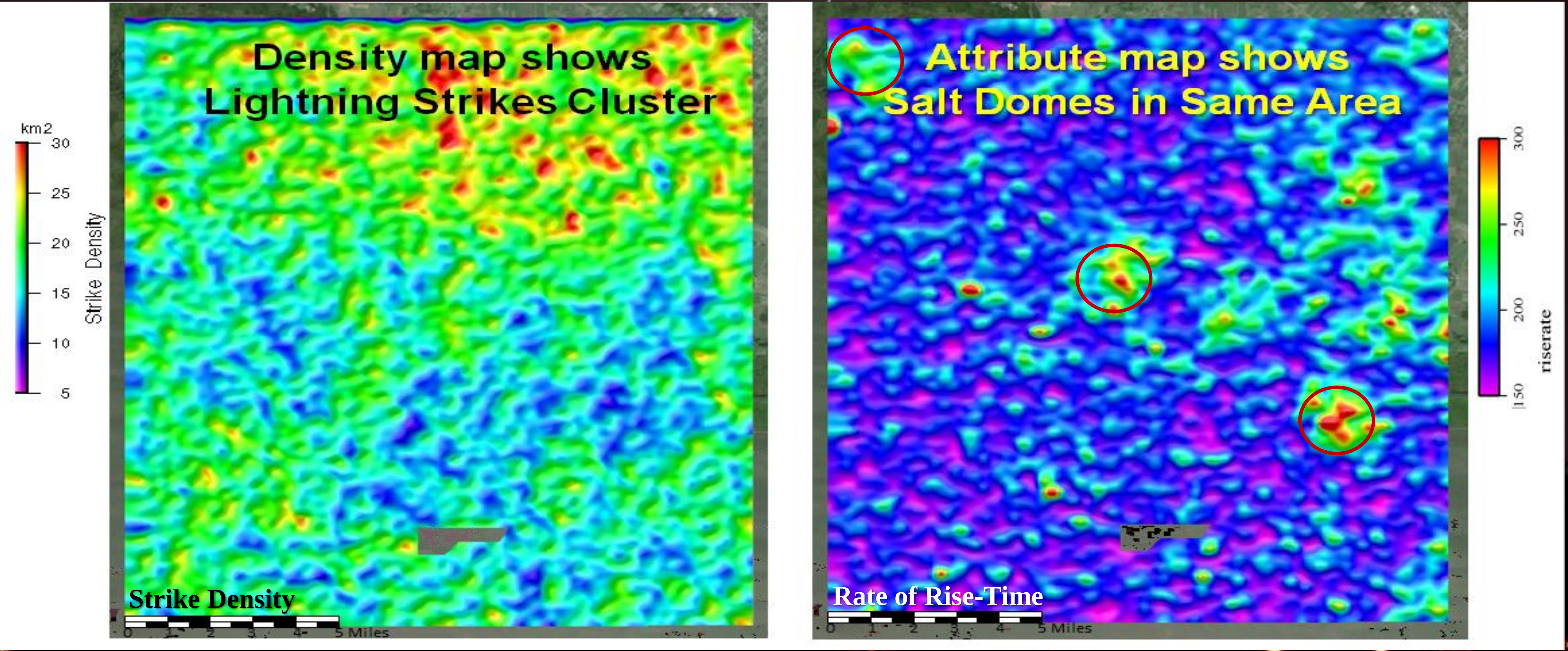
- Faults
- Fracture Swarms
- Salinity
- Pore Fluids
- Porosity
- Permeability
- Mineralization

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

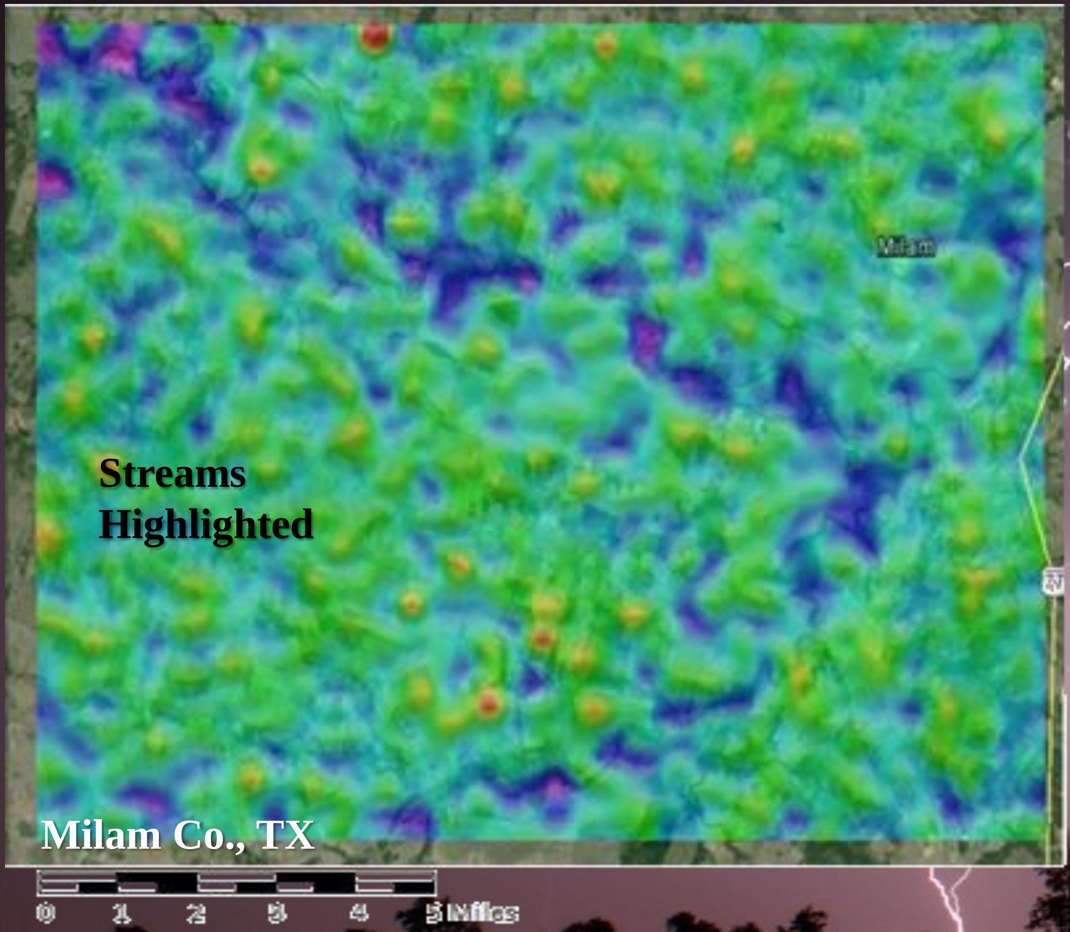
Examples of Using NSEM to Interpret Geologic Features

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

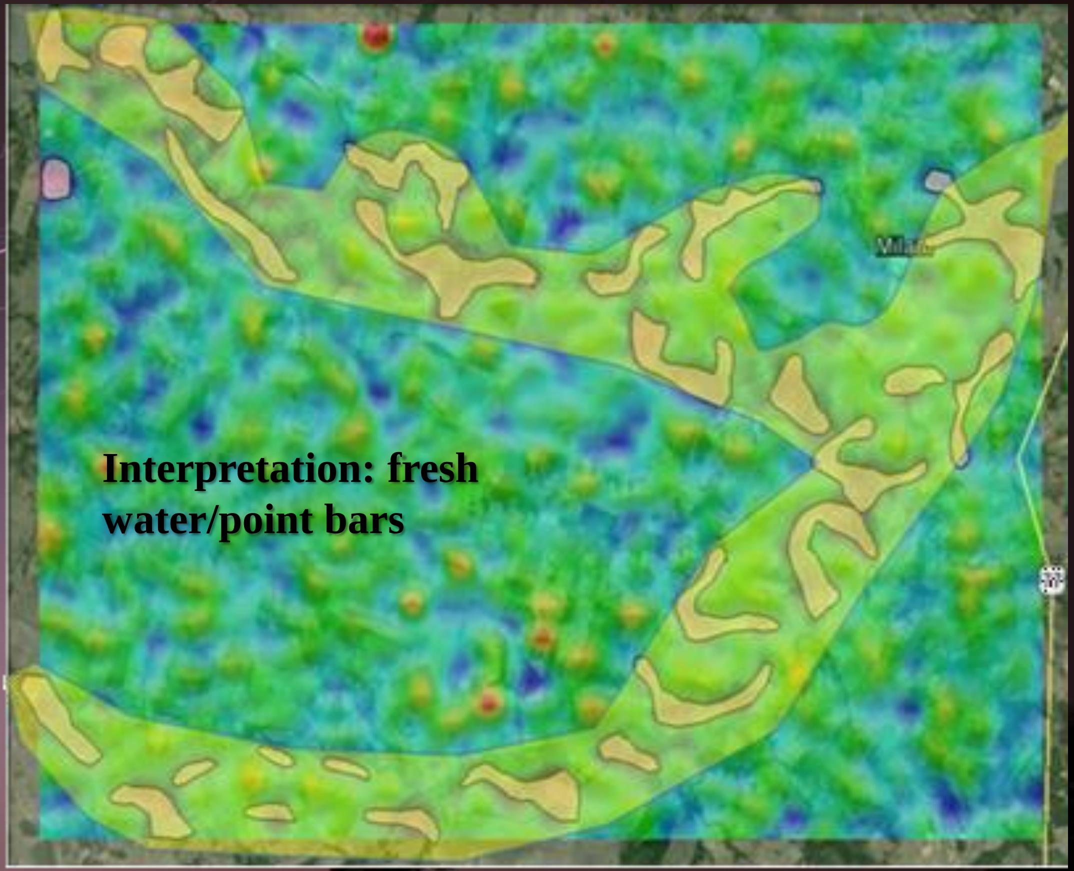
NSEM Correlates To Geology:
Iberia Parish, LA Salt Domes



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

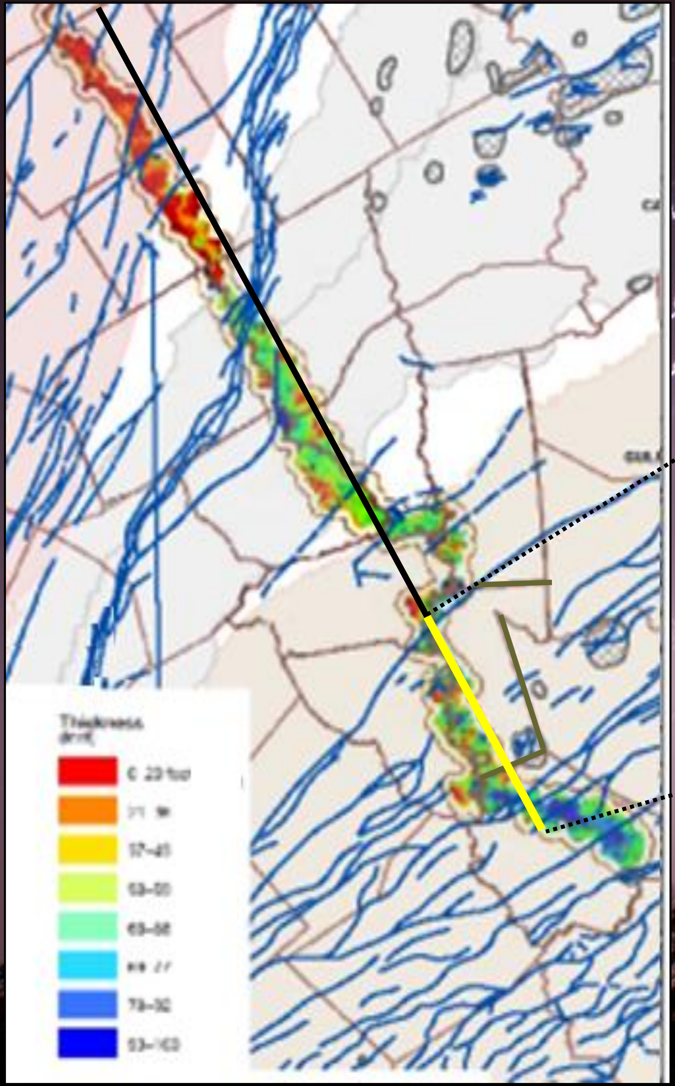


Lightning Attribute
Rate of Rise-Time

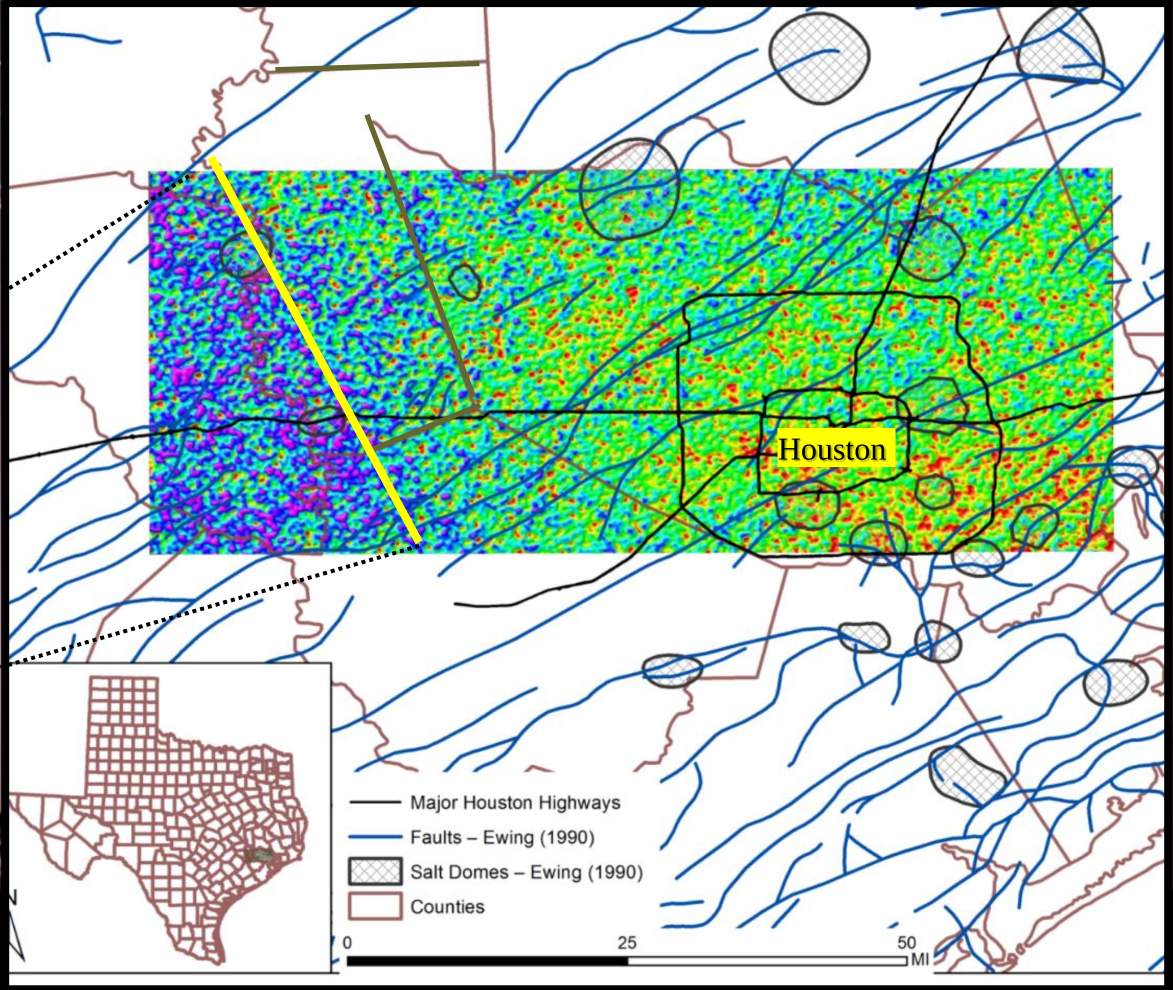


NSEM Correlates To Geology: Alluvium & Cretaceous Transform Fault

Brazos River Alluvium Aquifer



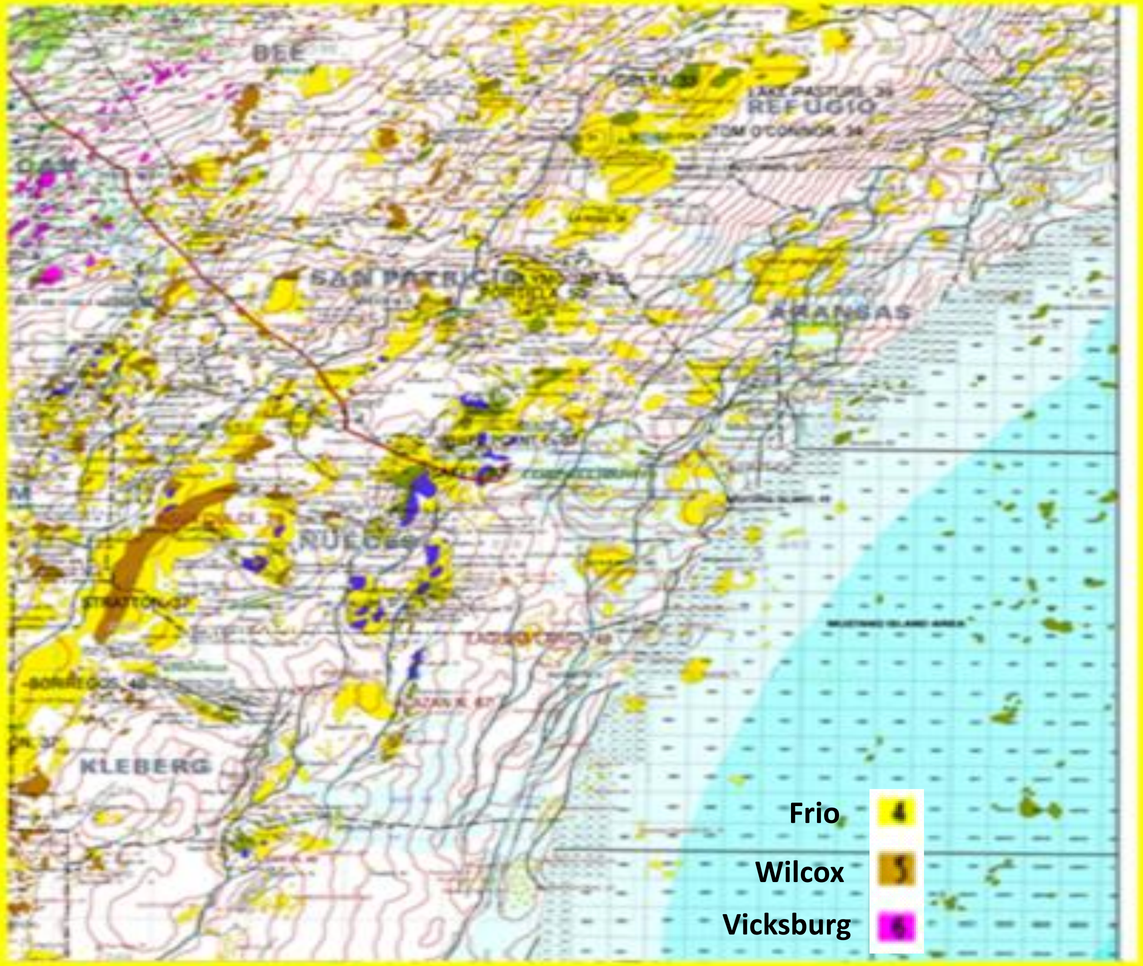
Absolute Peak Current



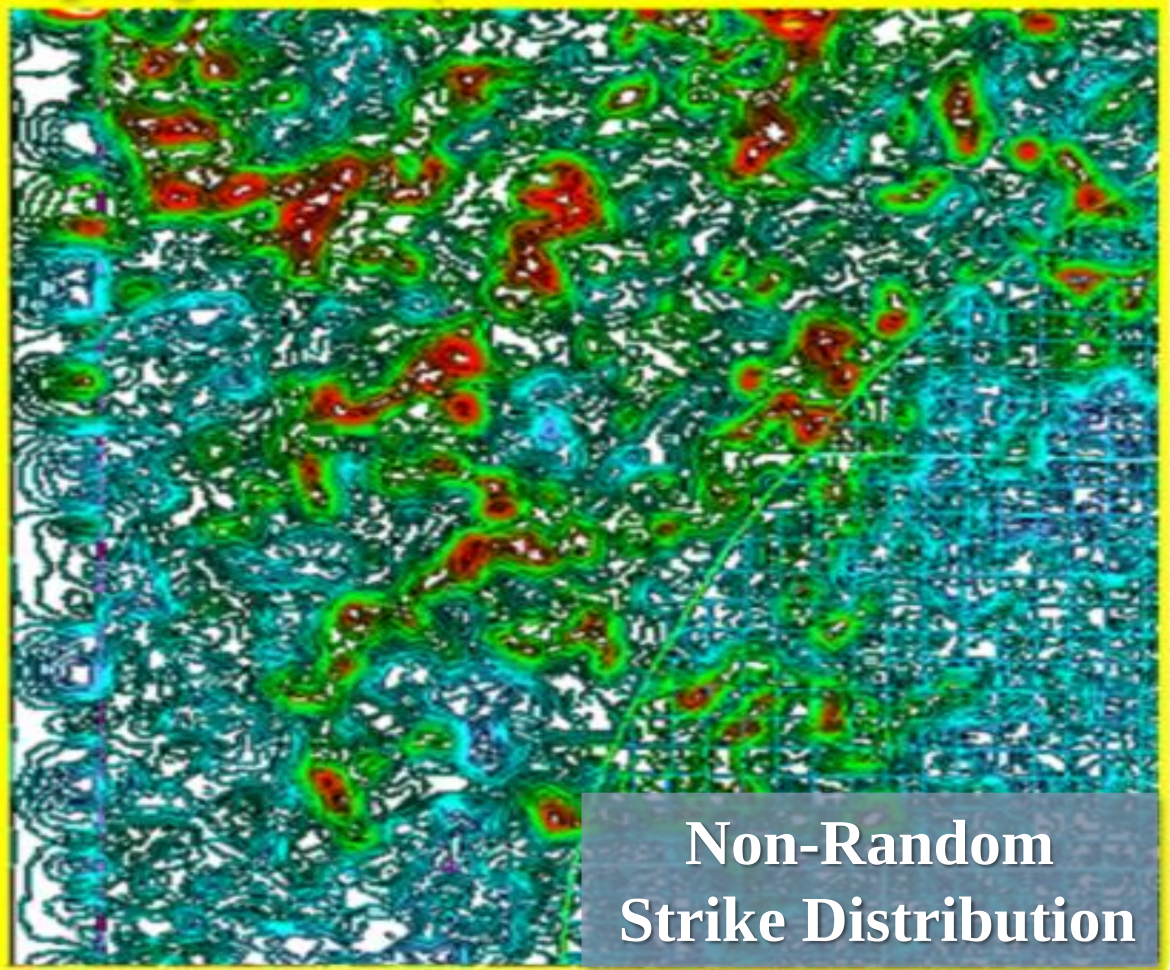
NSEM Correlates To Geology:
Similar Texas Gulf Coast Regional Trends

See Lightning . . .
DML
. . . think DML & solutions

Structure & Field Outlines



Lightning Strike Density



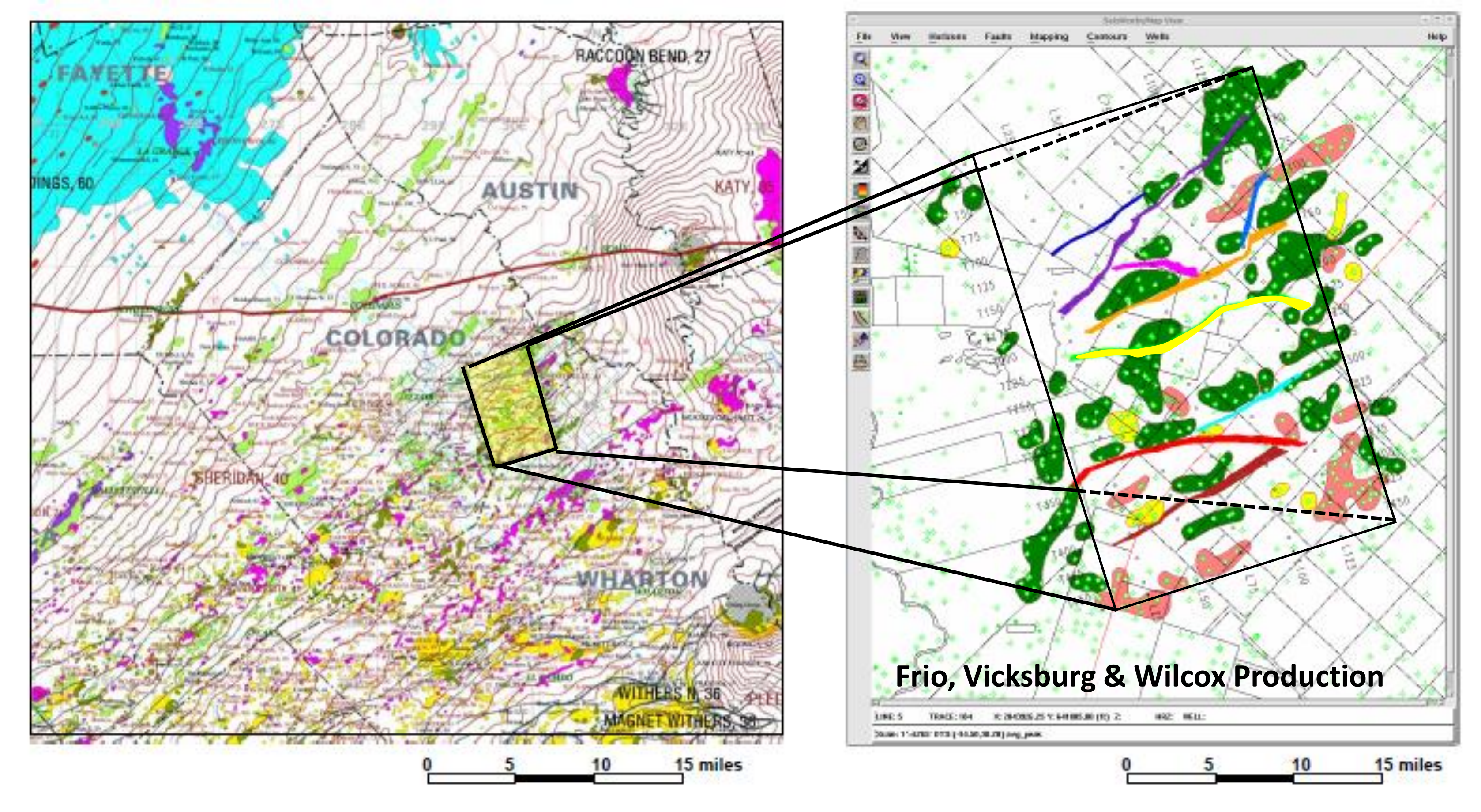
Observations

- Lightning strike locations are not random.
- Show NE/SW lineations similar to field locations.
- Lightning generally strikes parallel to sub-parallel to faults.

Conclusions

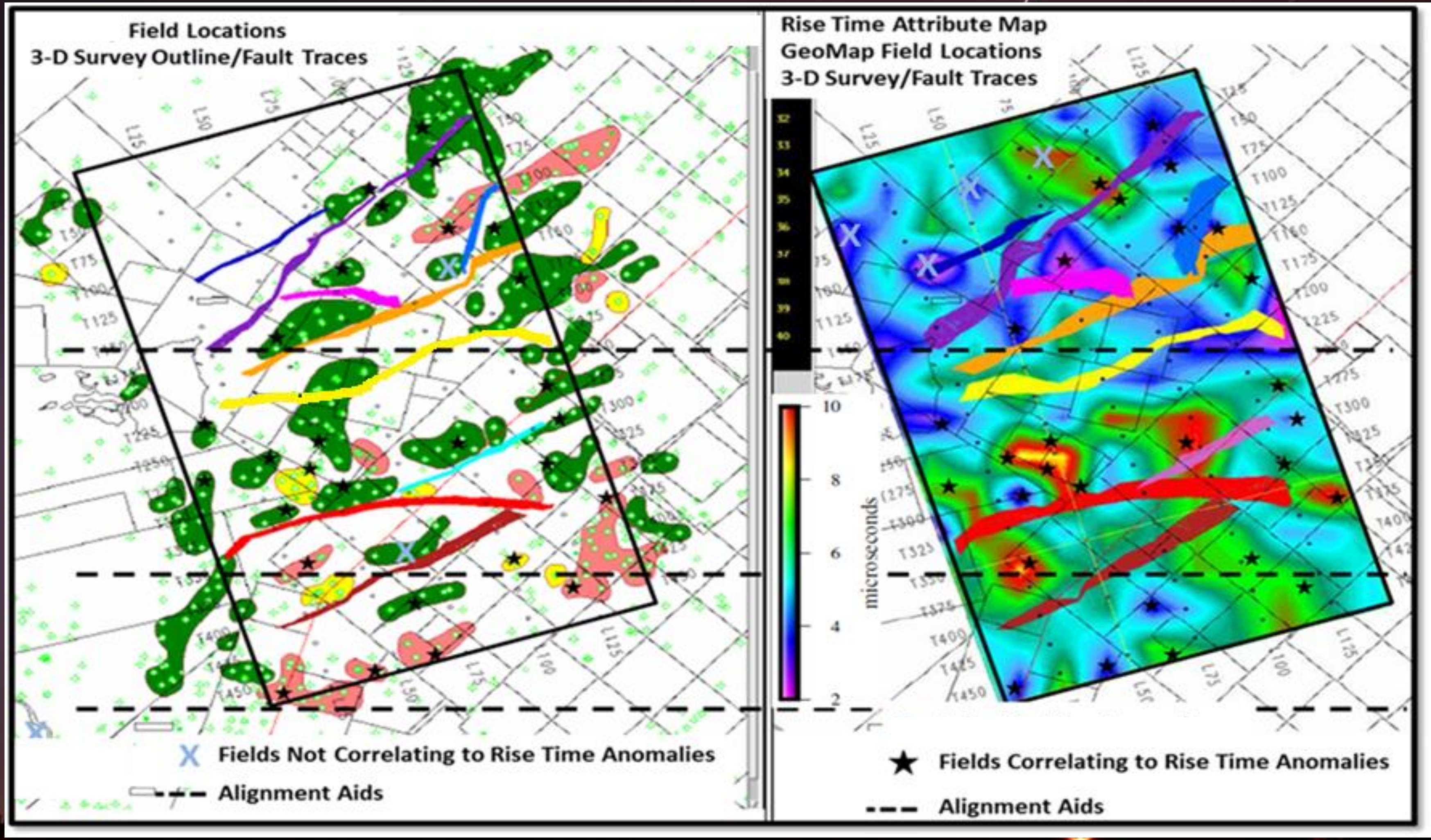
- Local geology can influence where lightning strikes occur.
- Potential to locate hydrocarbons (micro-seepage along faults).
- NSEM has potential to delineate subsurface fault patterns.

NSEM Correlates To Geology:
Colorado County, TX



Effective Reconnaissance Mapping
Rise Time Prospect Scale Field Correlations

See Lightning . . .
DML
. . . think DML & solutions



87% of lightning attribute anomalies (Rise Time) correlate to Frio, Vicksburg or Wilcox production.

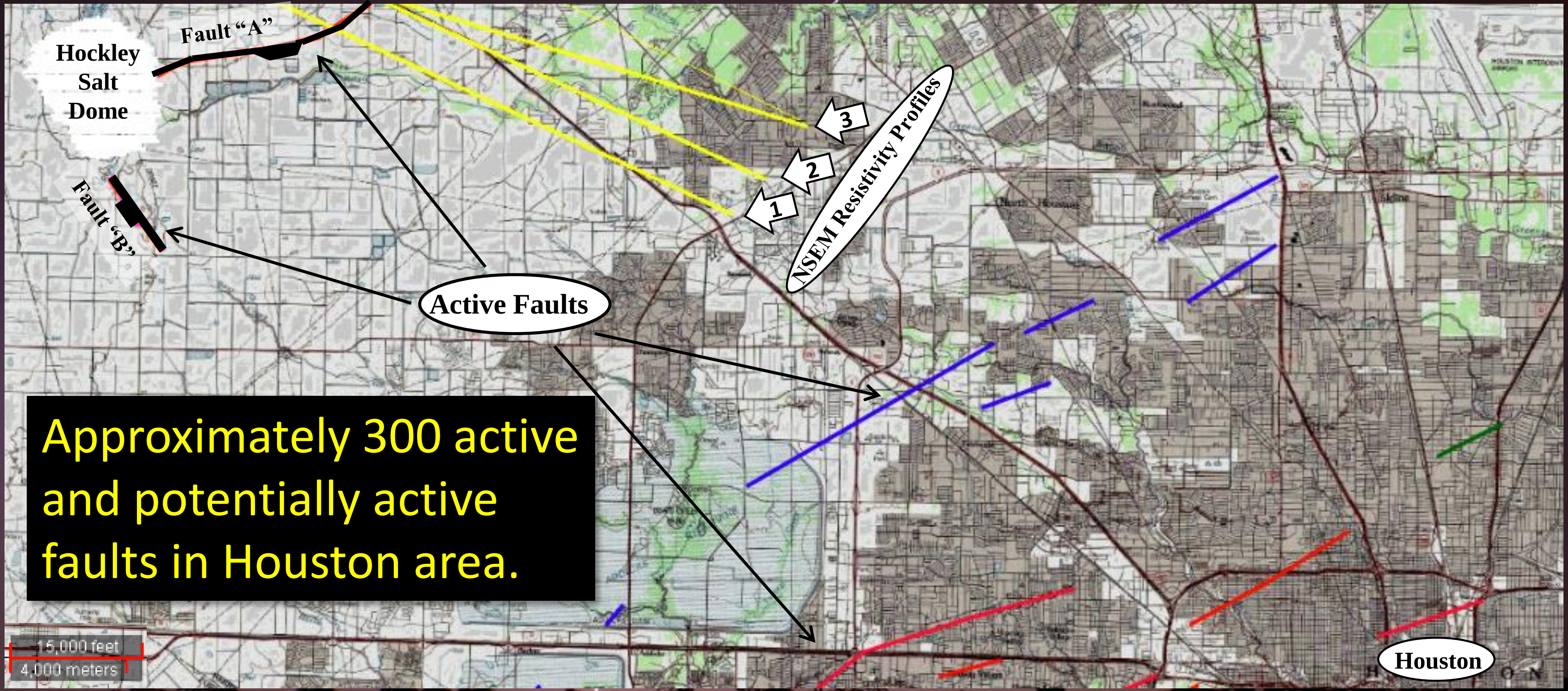
Observations

- Rise-Time lightning attribute shows non-random patterns.
- 26 of 28 fields (93%) correlate to Rise-Time anomalies.

Conclusions

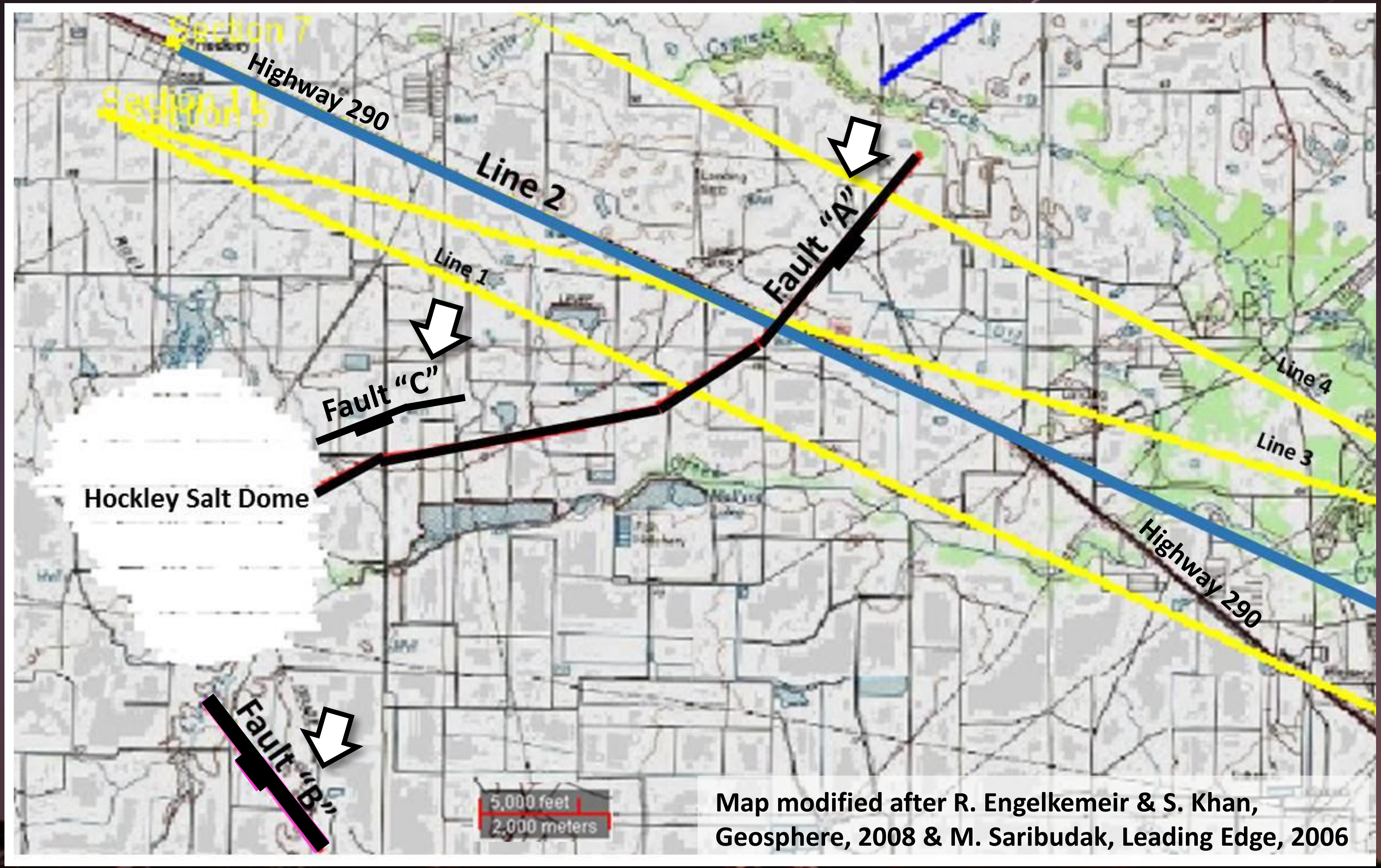
- NSEM identified 32 leads in study area.
- Reconnaissance mapping would have justified seismic data follow-up resulting in the generation of 28 prospects.
- ★ NSEM reconnaissance mapping would have resulted in an 87% drilling success rate.

NSEM Correlates to Geology:
Houston/Harris County Area Active Faults



Approximately 300 active and potentially active faults in Houston area.

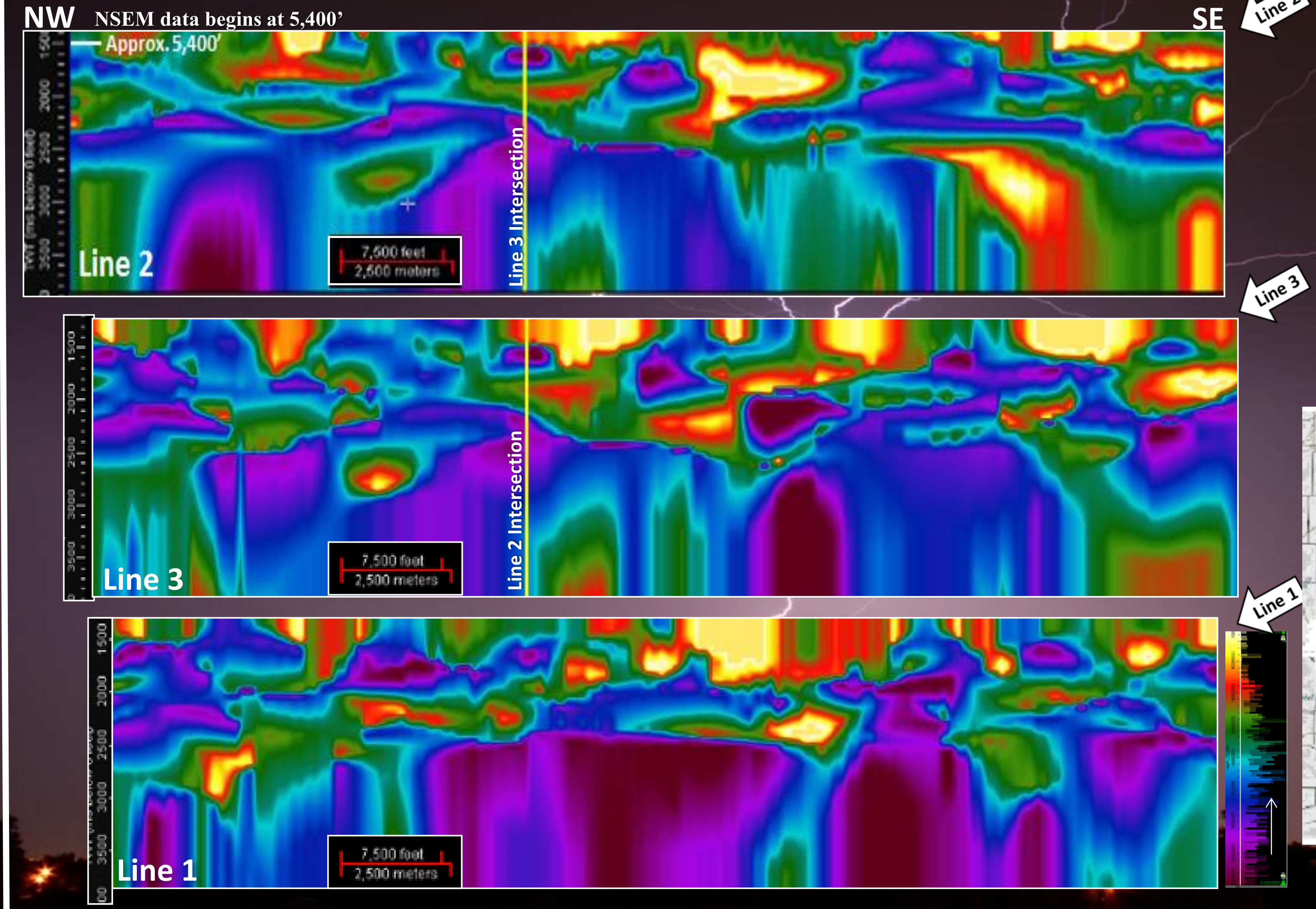
NSEM Correlates To Geology:
Active Faults, Harris Co., TX



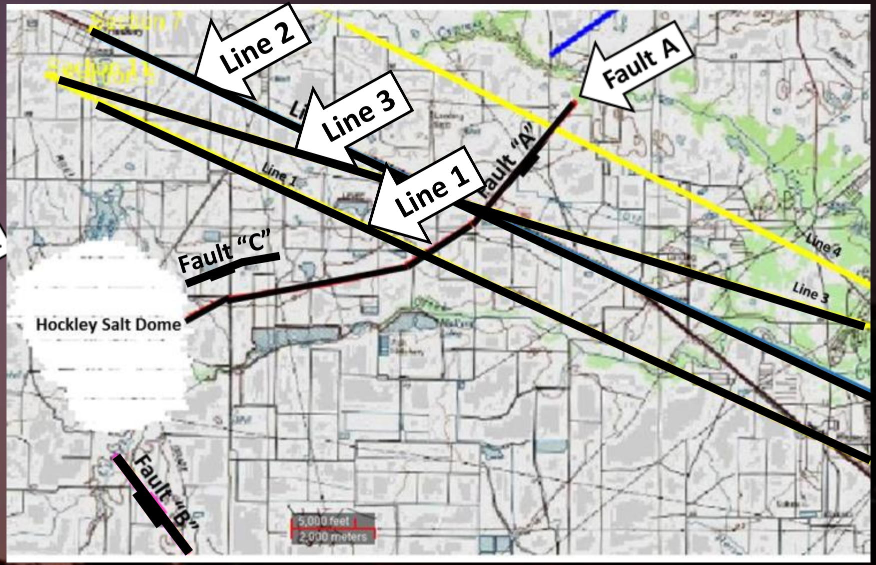
Map shows location of three active faults that have been documented with near-surface geophysical techniques.

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

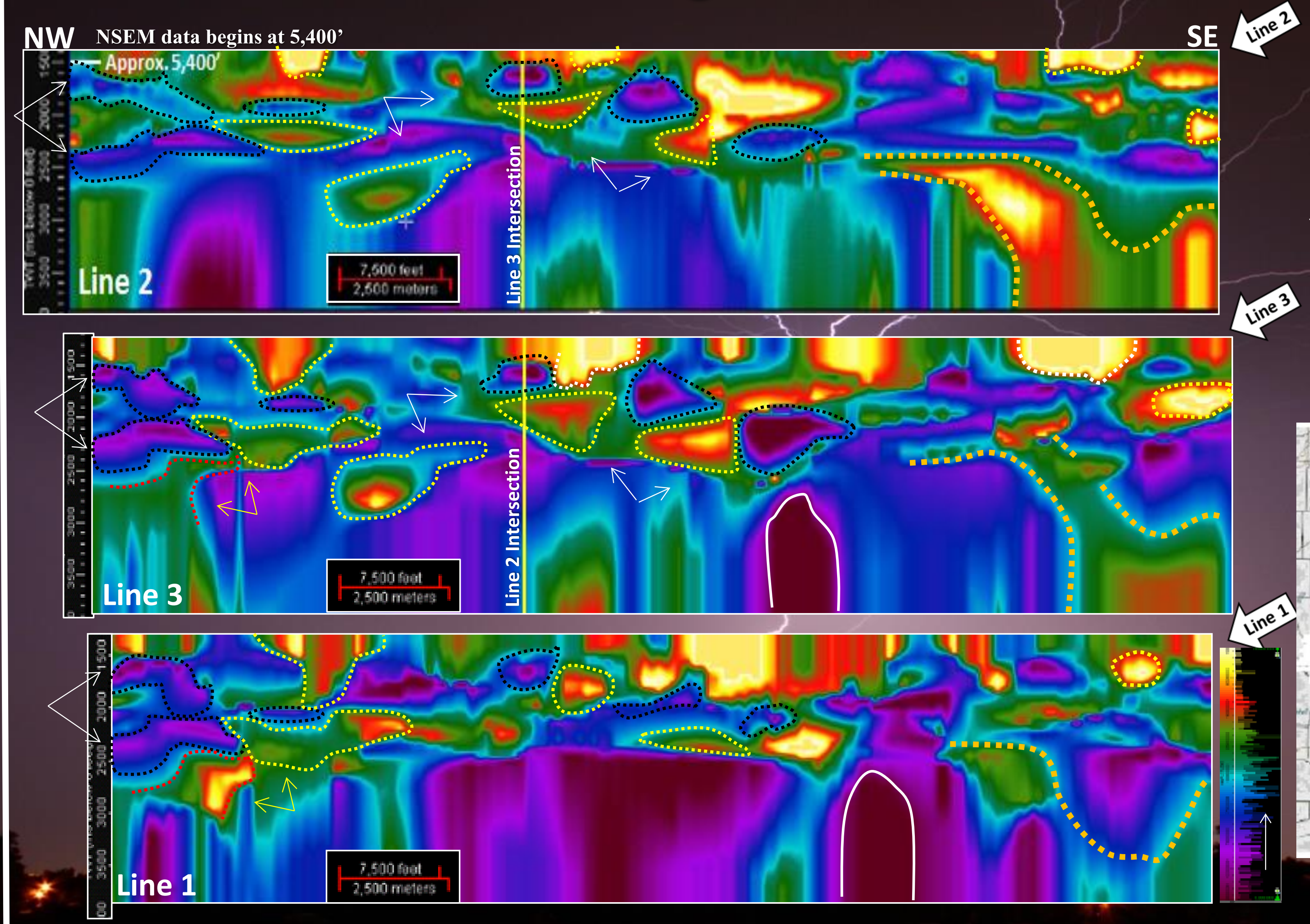
NSEM Resistivity Profile Comparisons



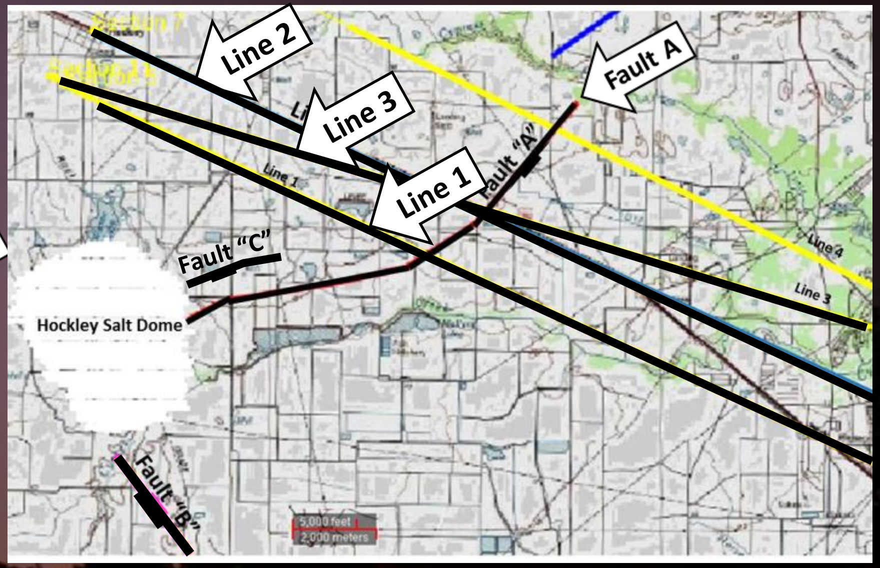
Similar resistivity patterns from line to line would be required to identify consistent fault patterns.



Pattern Recognition

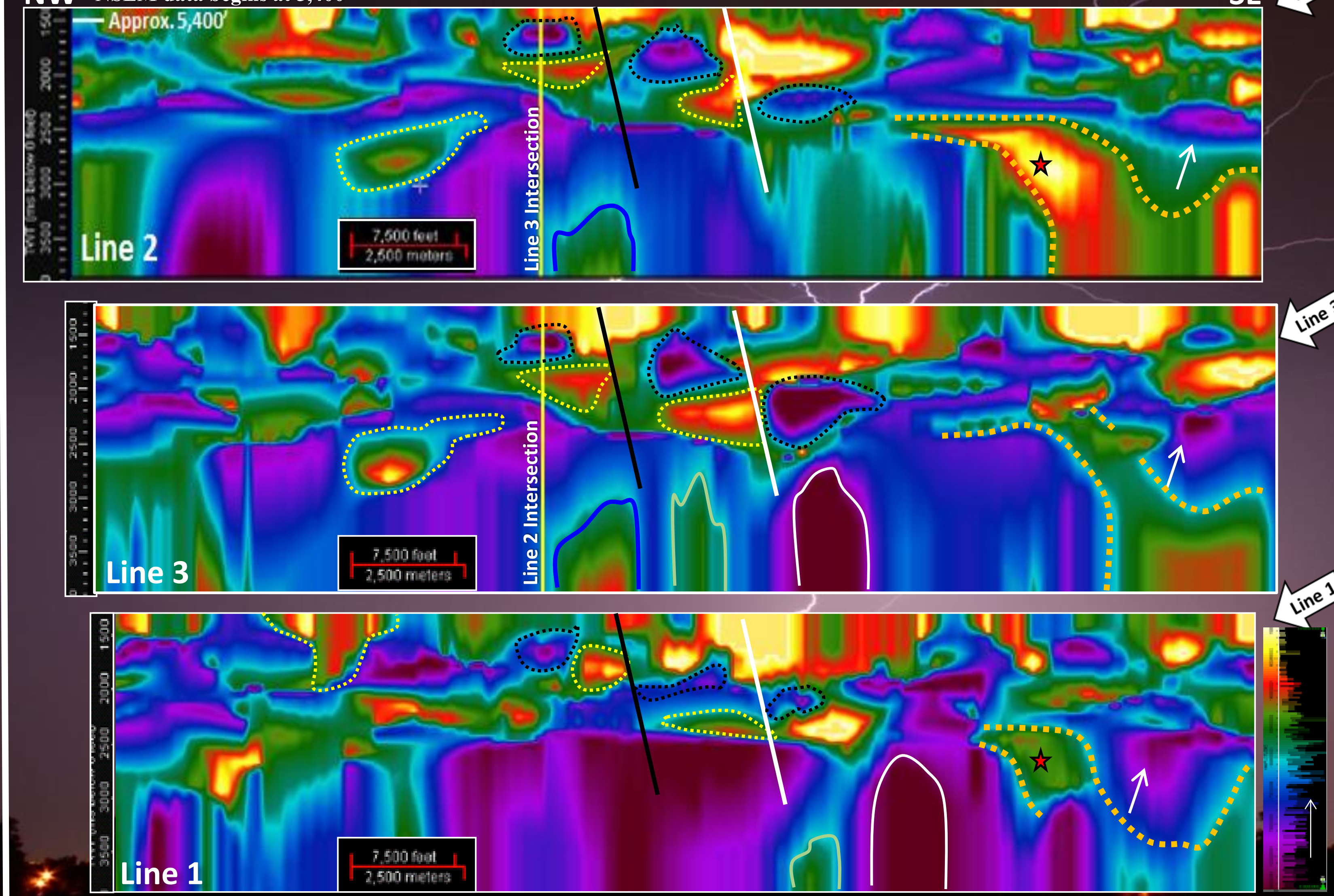


Note similar patterns adjacent to the intersection of lines 2 and 3 and where lines 1 and 3 converge to the northwest.



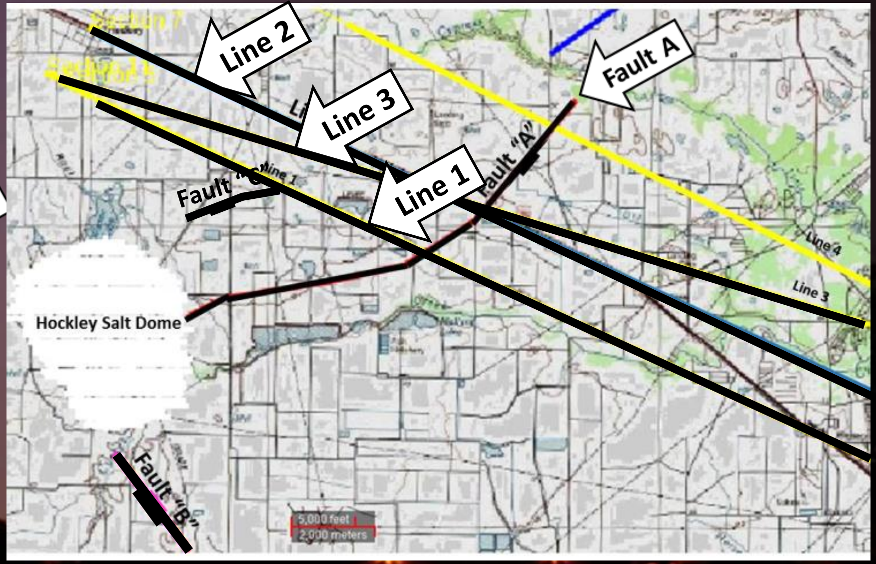
Resistivity Discontinuities & Offsets

NW NSEM data begins at 5,400' SE



Breaks in resistivity and offsets would suggest faulting.

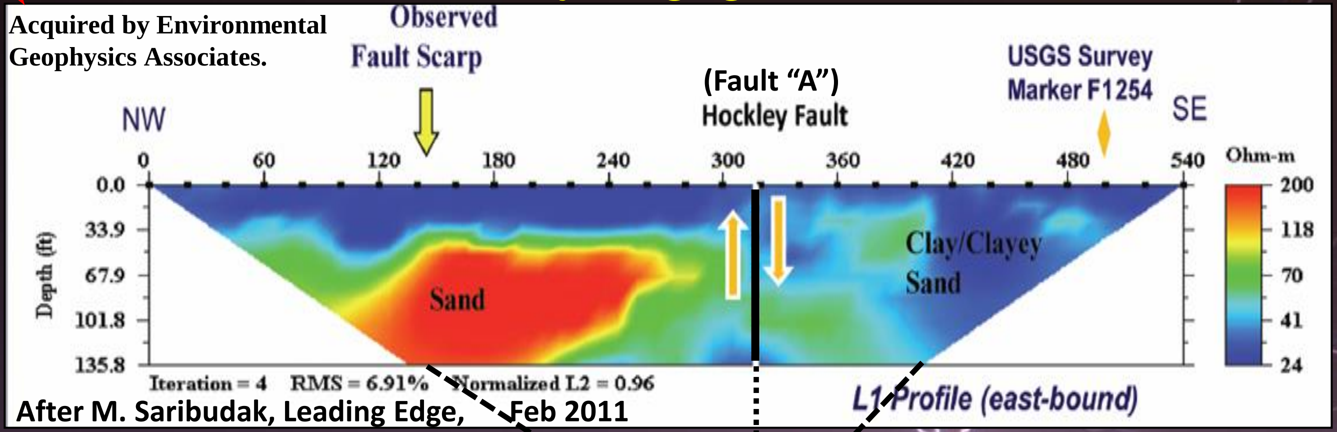
Can documented surface faults validate NSEM-derived subsurface faults?

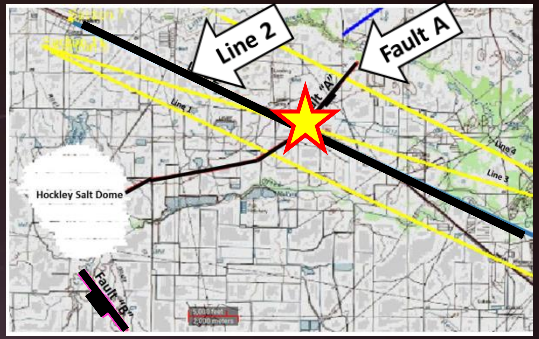


Line 2 Ties Active Fault "A" to Subsurface

See Lightning . . .
DML
. . . think DML & solutions

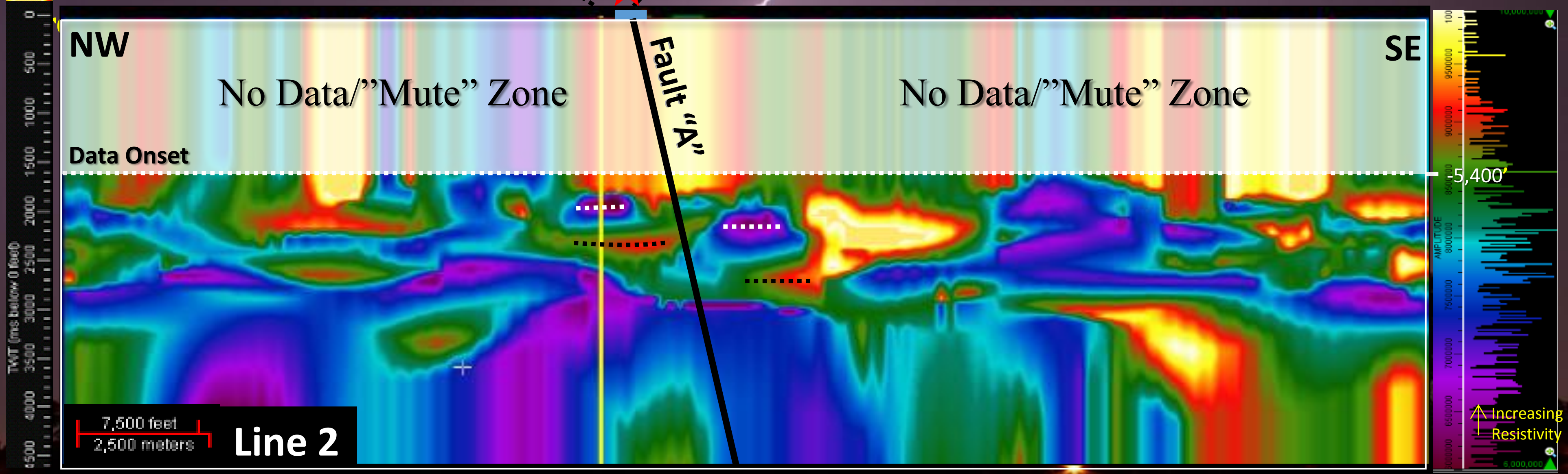
★ Conventional 2-D Resistivity Imaging Profile





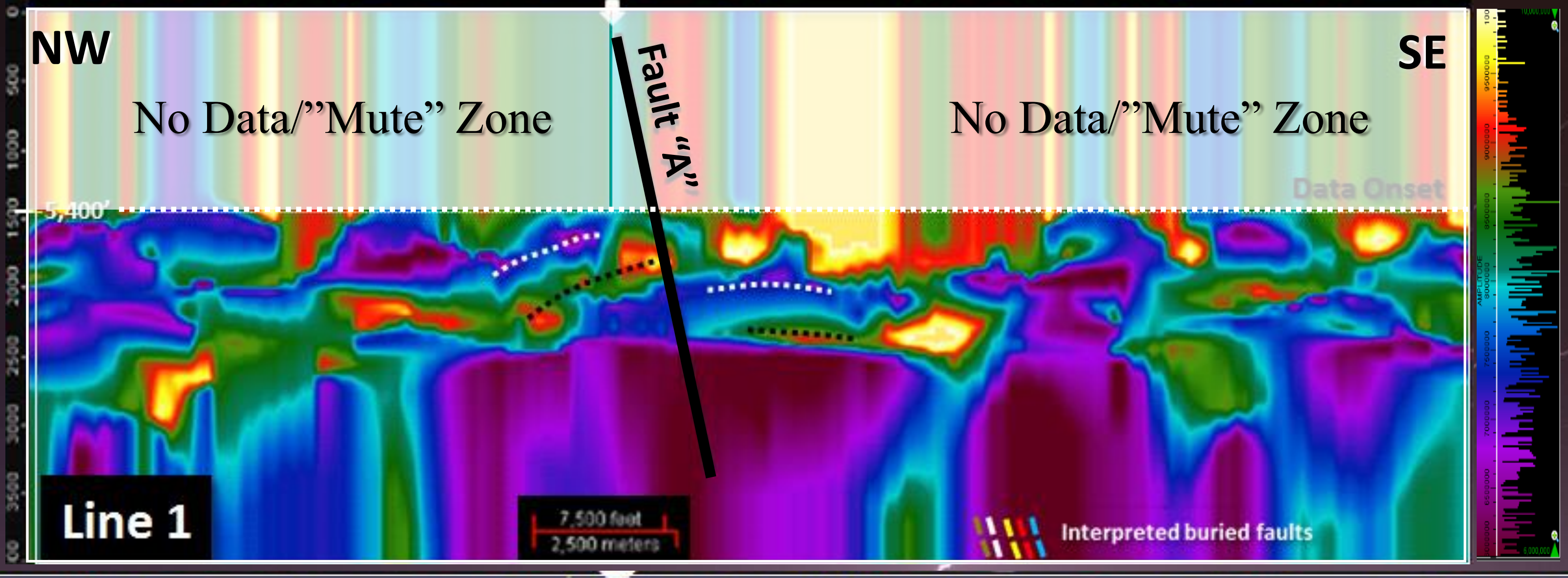
Line 2

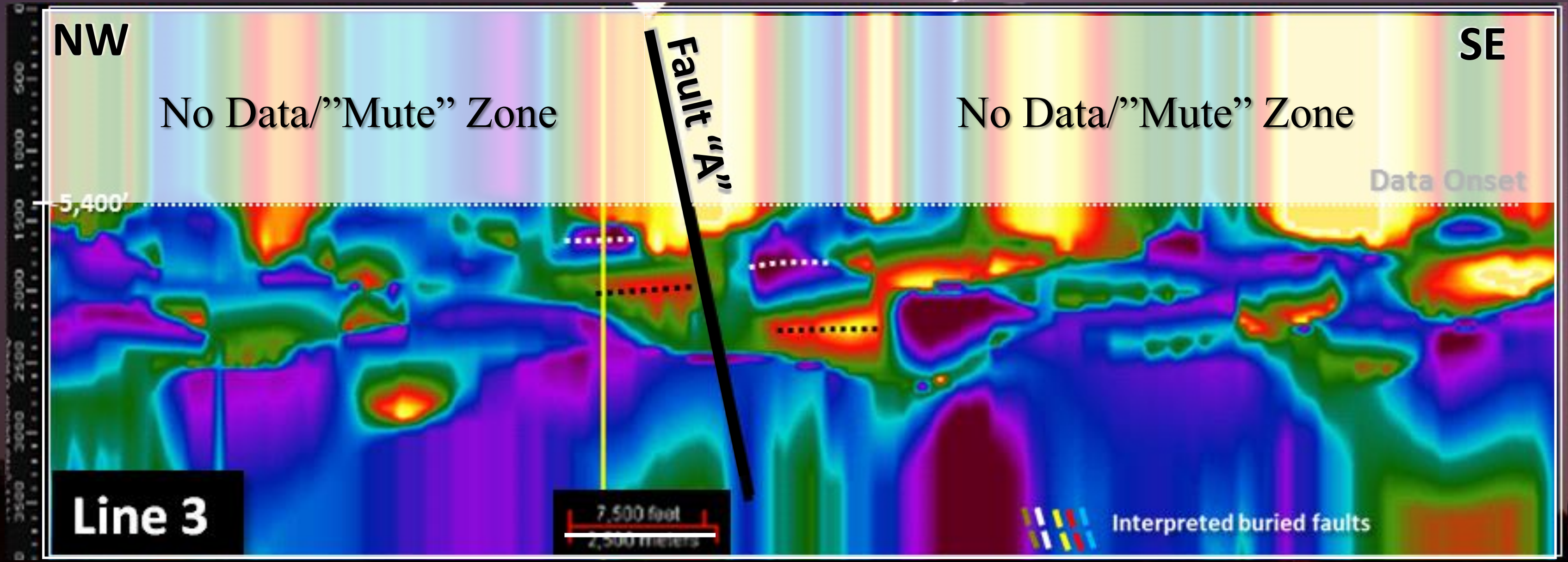
NSEM 3-D Apparent Resistivity



Fault interpretation validated by conventional 2-D resistivity imaging.

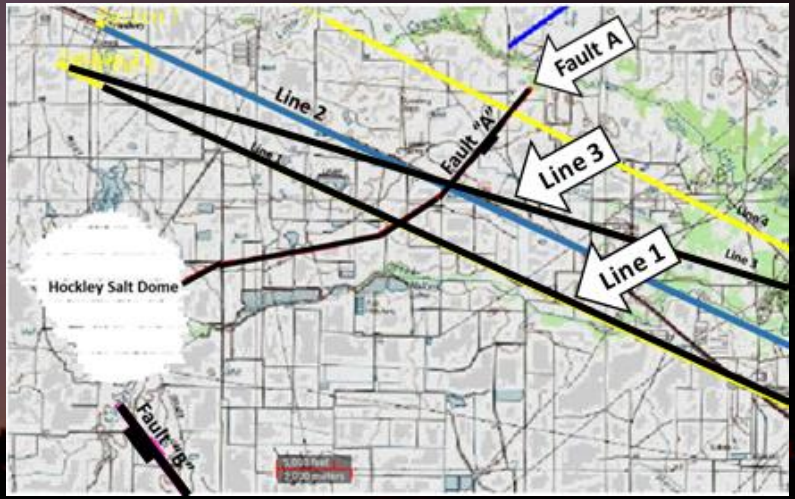
Lines 1 & 3 Also Tie Fault "A" to Subsurface





White arrow marks intersection with documented fault trace.

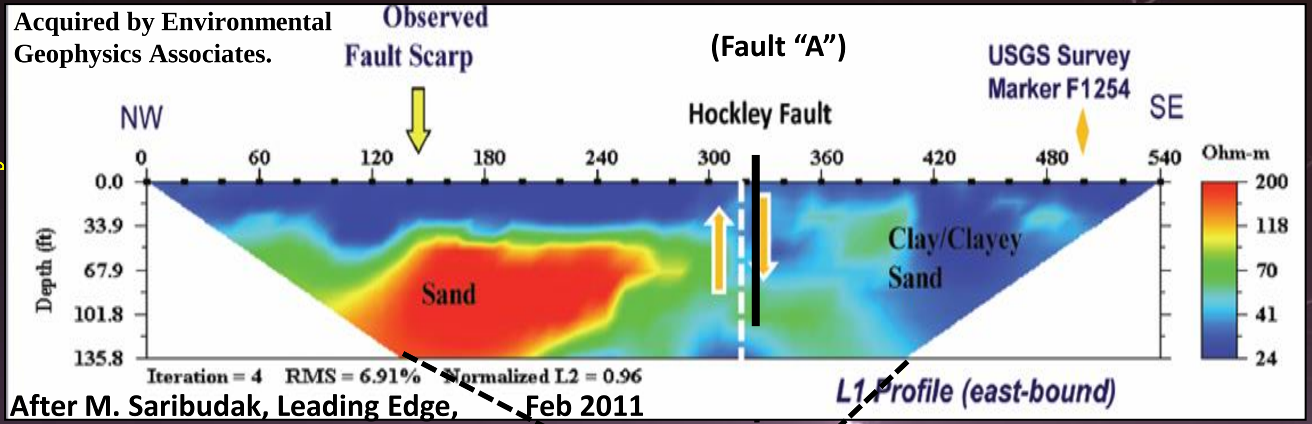
NSEM demonstrates consistency identifying this active fault at depth.

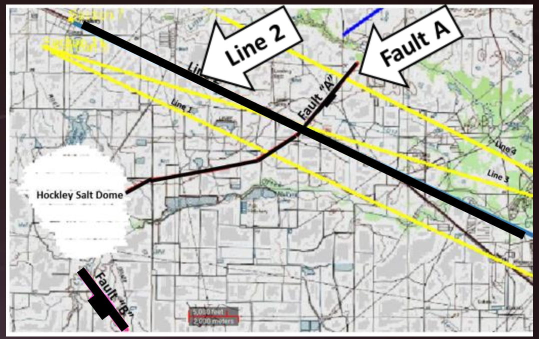


NSEM Line 2 Reveals Additional Faulting

3-D Data Provides Interpretive Checks & Balances

2-D Resistivity Profile



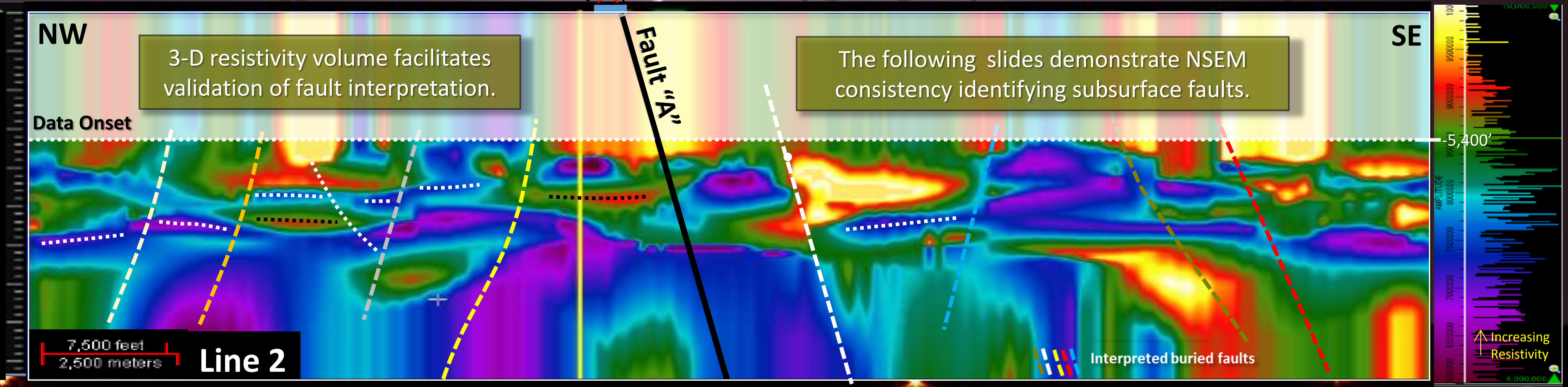


Line 2

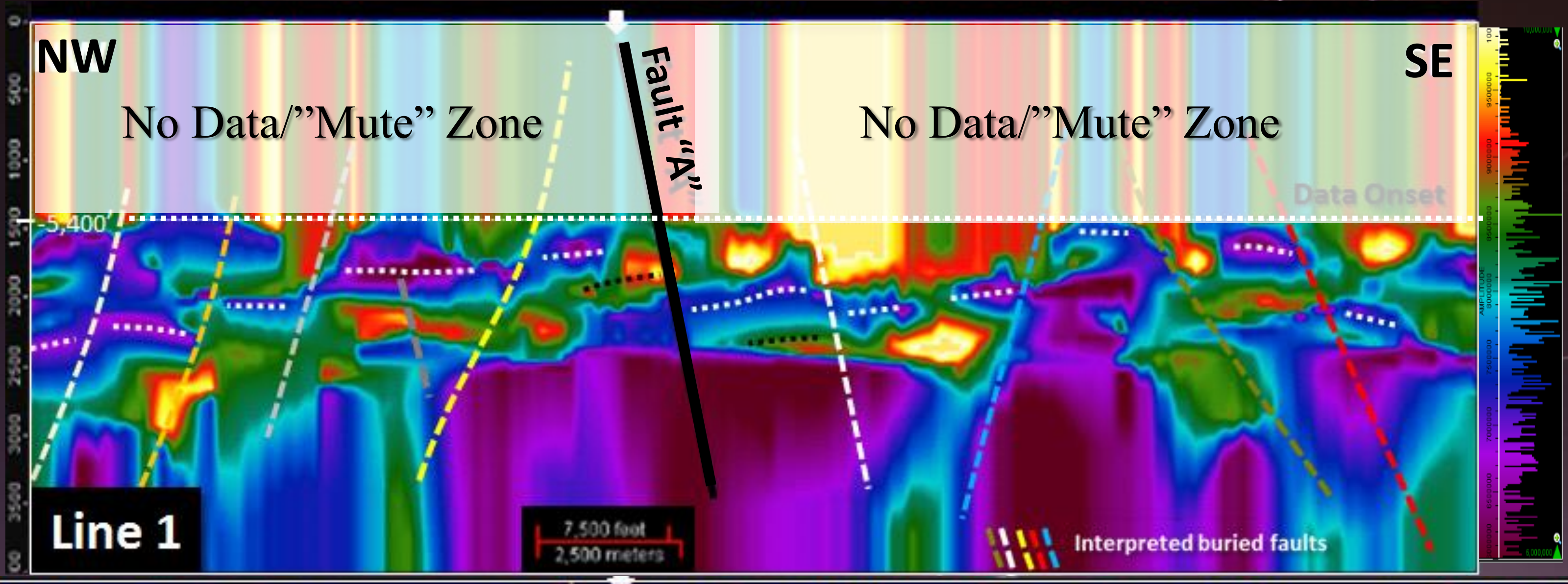
Additional faults suggested.

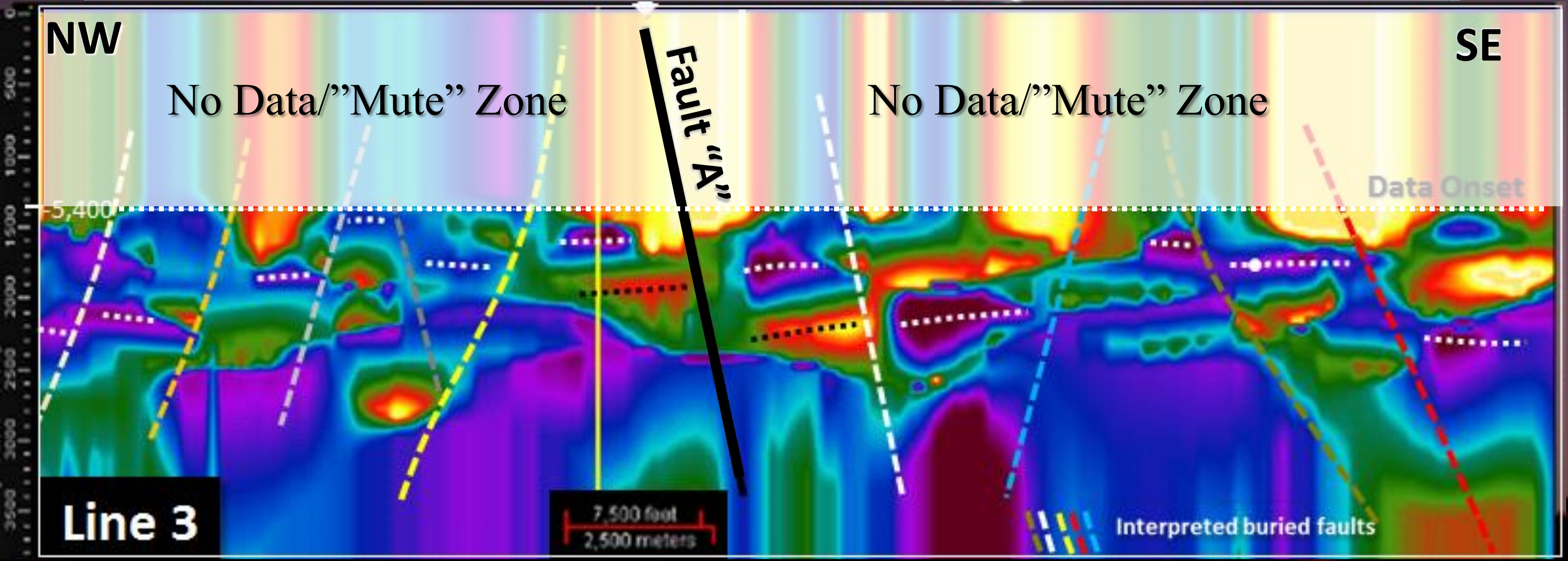
Are they geologically reasonable , internally consistent, valid?

NSEM 3-D Resistivity Profile



Lines 1 & 3 Also Reveal Additional Faults

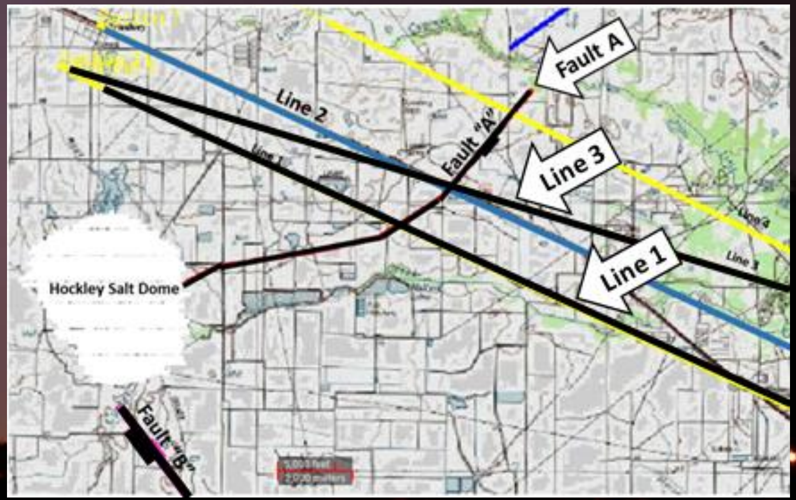




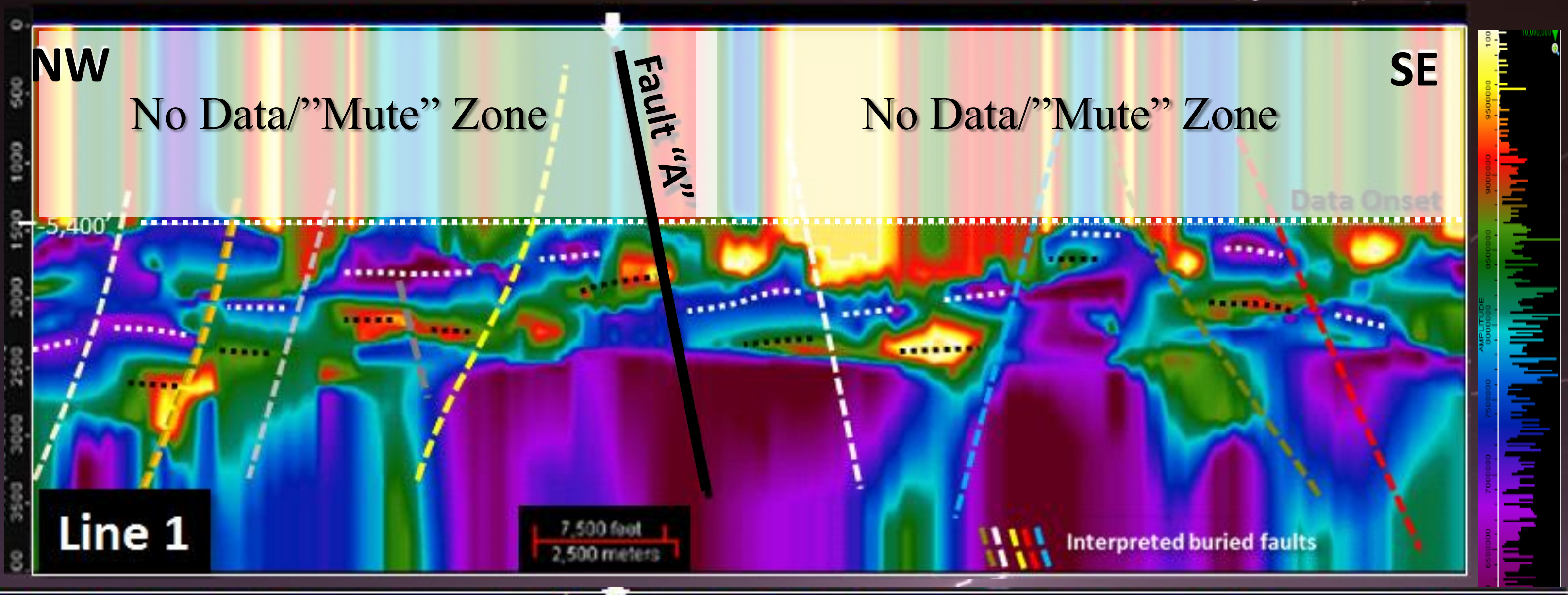
See Lightning . . . DML . . . think DML & solutions

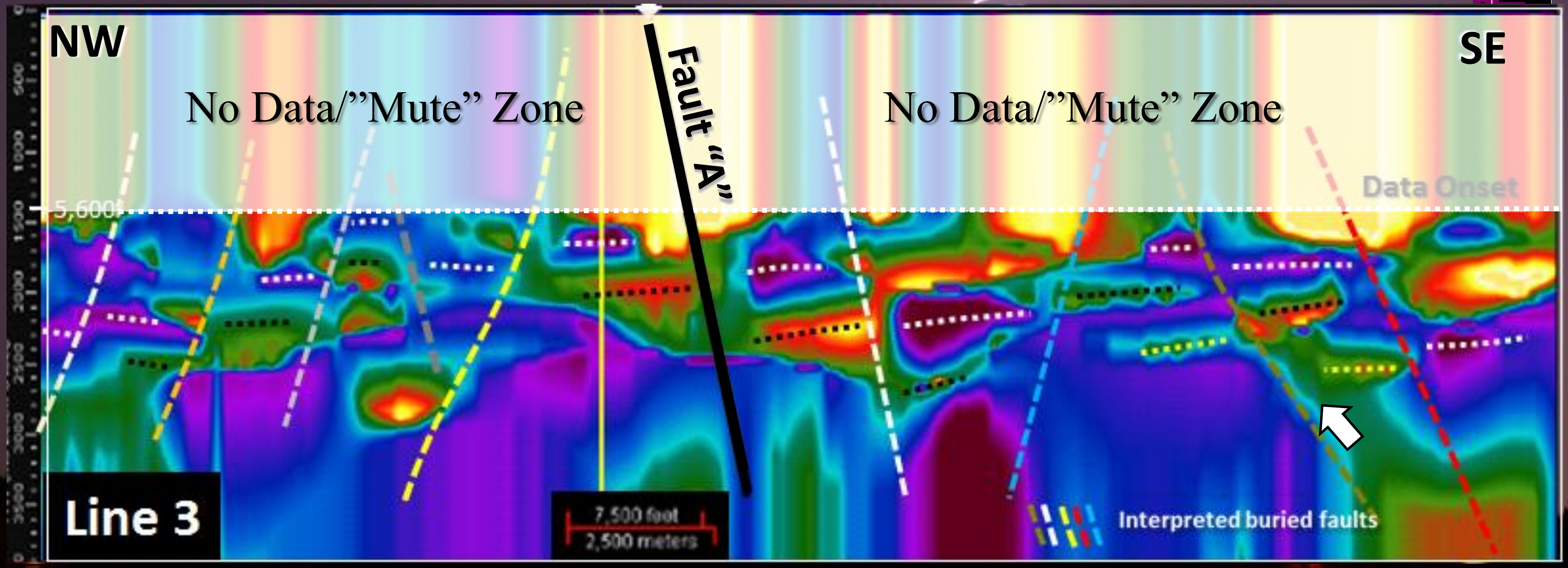
The same 9 color coded faults are identified on all 3 lines.

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



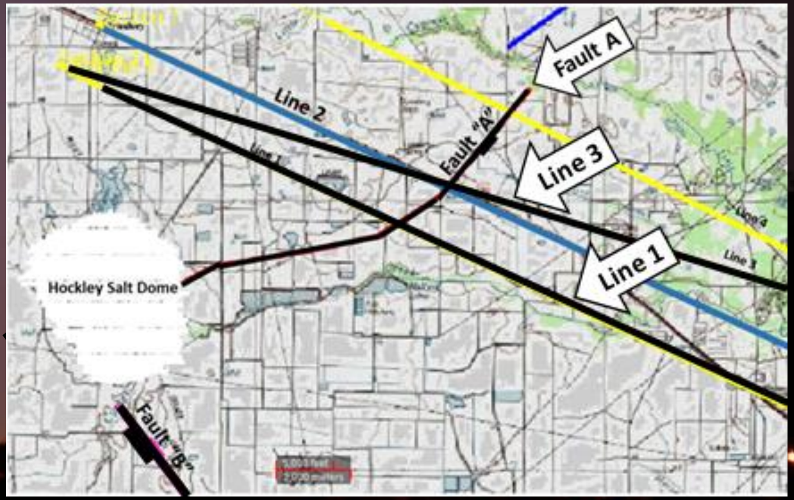
NSEM Builds Reliable Structural Framework





Of 20 faults displayed on these profiles, 19 defined by two resistivity layer offsets; one by three (see white arrow line 3).

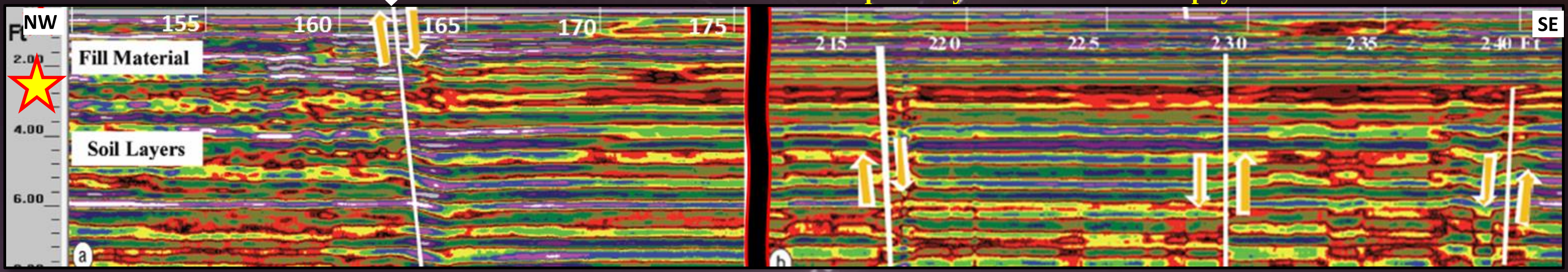
3-D NSEM enables structural & fault plane mapping.

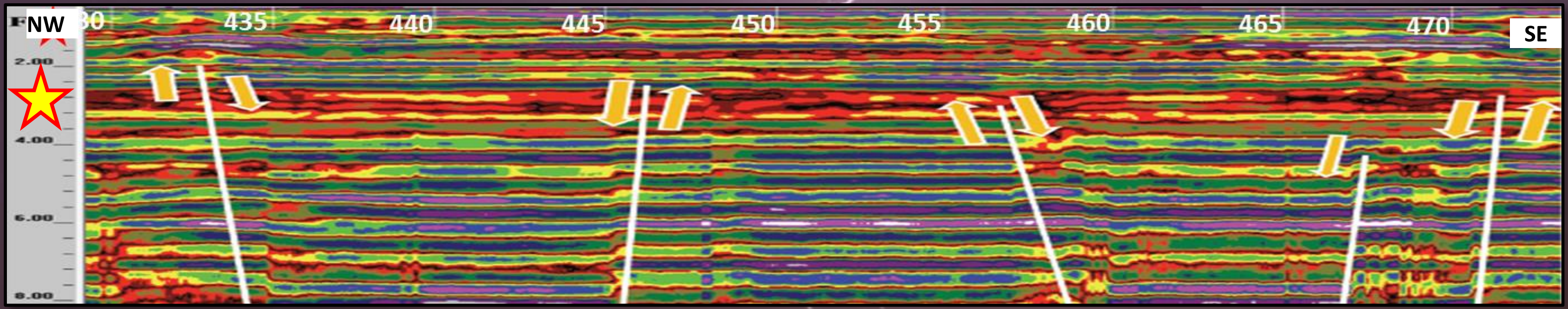


Ground Penetrating Radar
Shallow Micro-Faulting Adjacent to Fault “A”

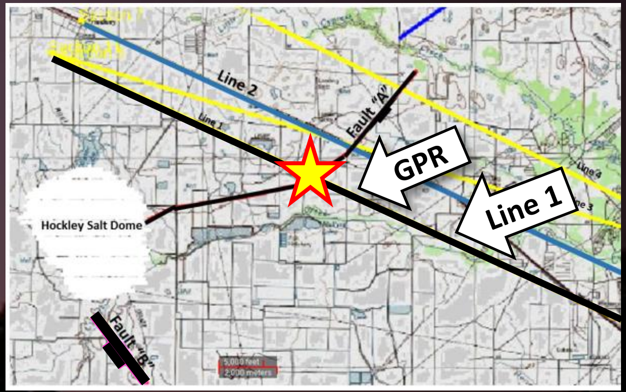
Hockley Fault (Flt. “A”)

GPR acquired by Environmental Geophysics Associates





Modified after M. Saribudak, Leading Edge, Feb 2011

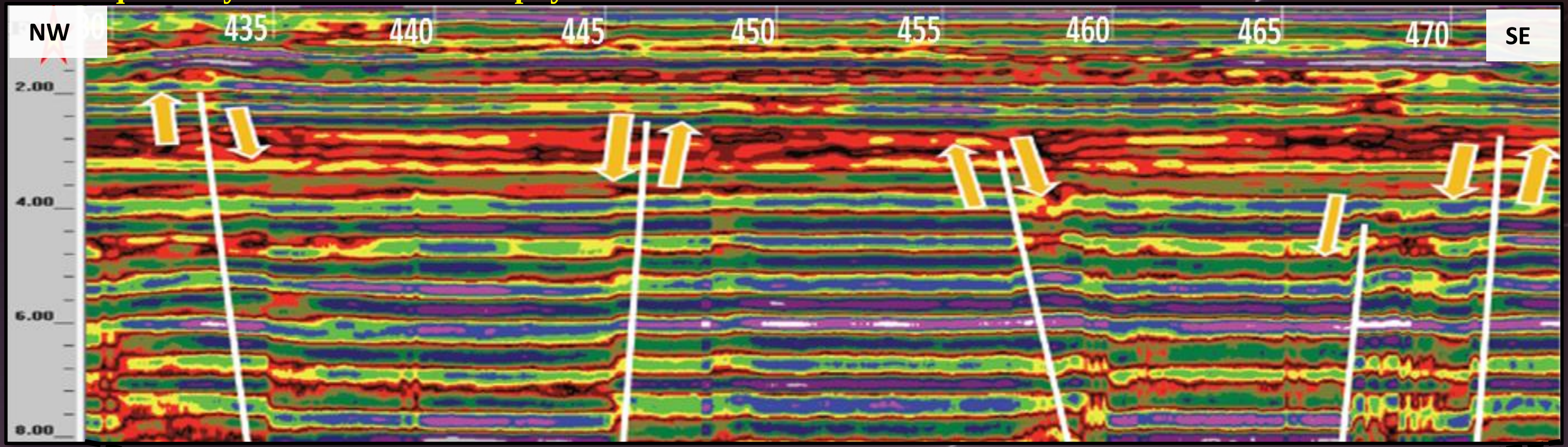


GPR & NSEM

Similar Micro/Macro Structural Styles

GPR acquired by Environmental Geophysics Associates

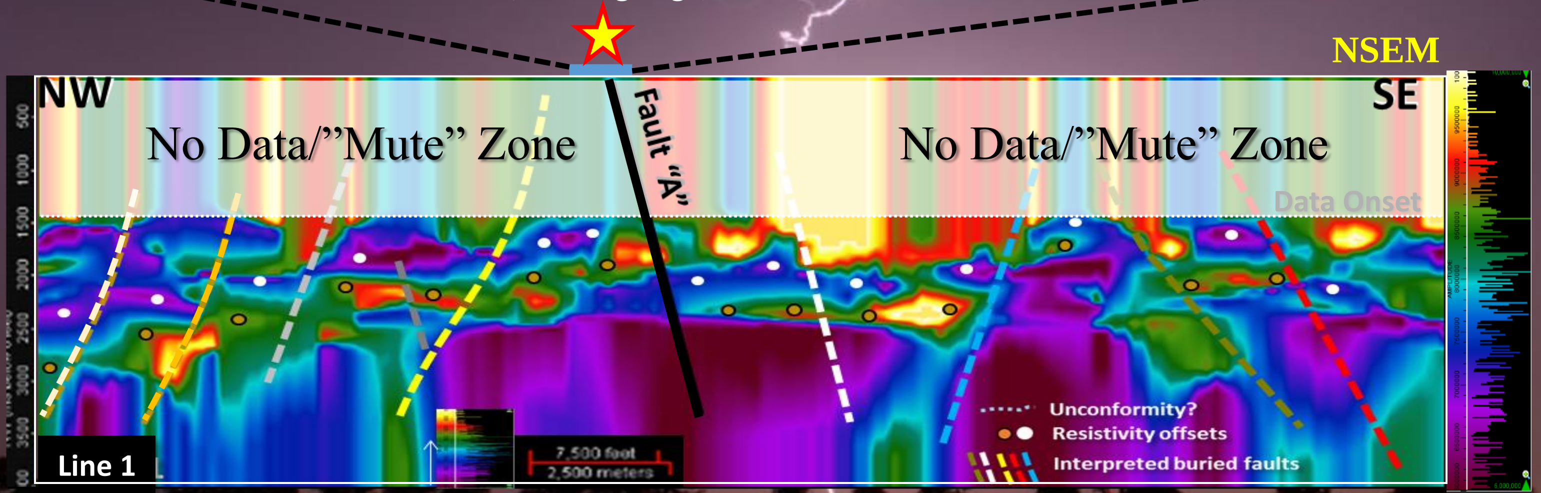
GPR

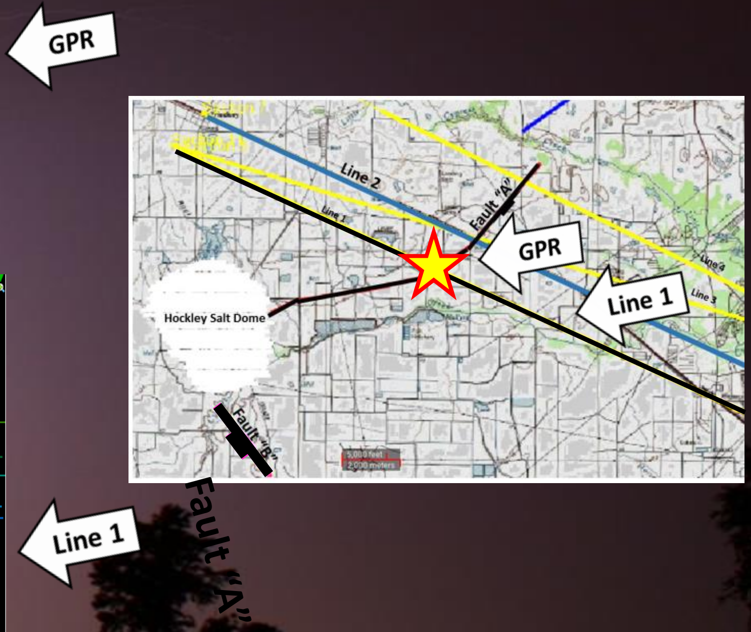


After M. Saribudak, Leading Edge, Feb 2011

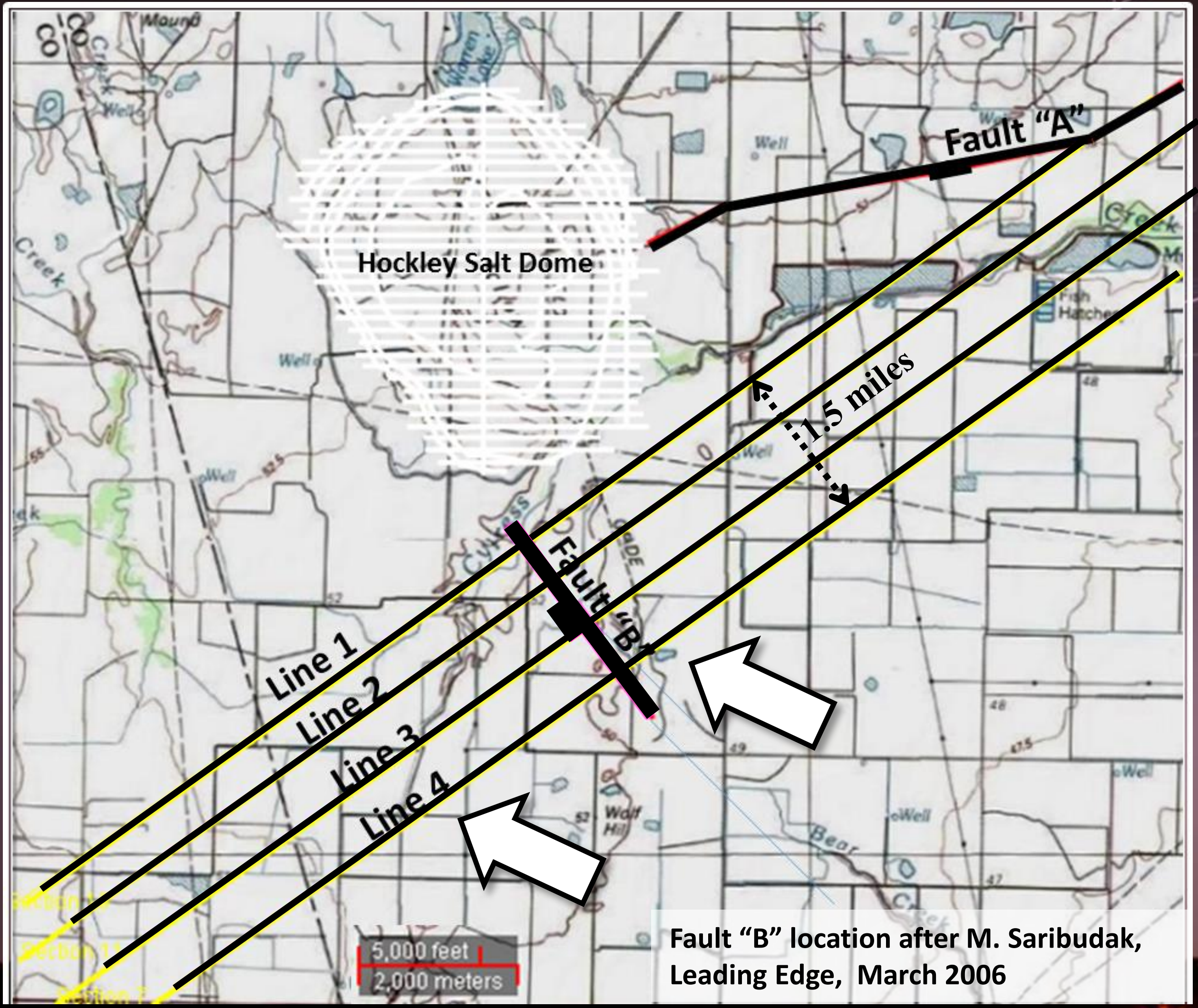
Horsts, grabens & half-graben structures identified.

NSEM





Hockley Radial Fault "B"



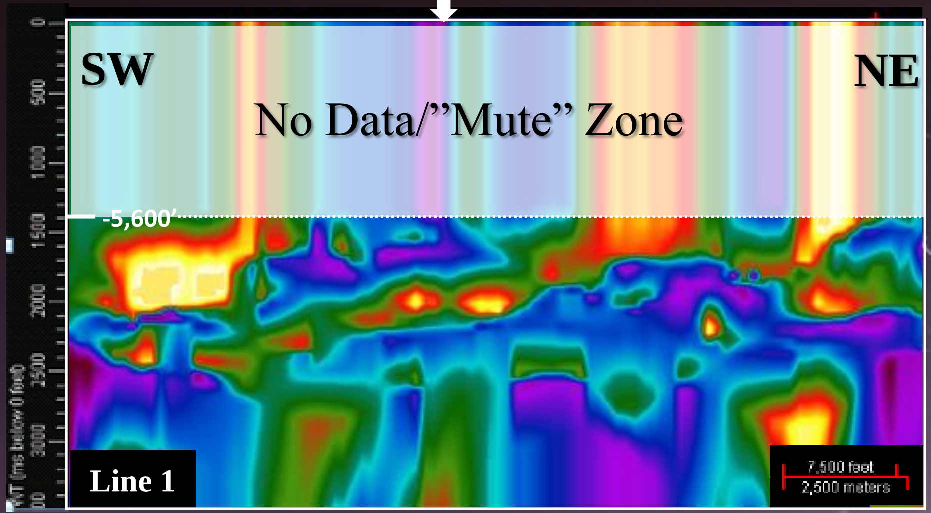
Fault "B" location after M. Saribudak, Leading Edge, March 2006

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

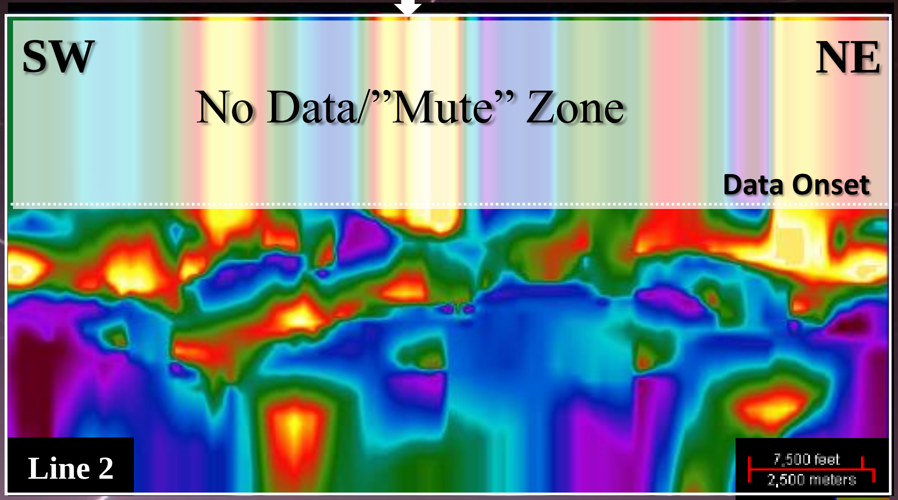
Resistivity Lines 1-4 are displayed on the next slide.

Hockley Radial Fault "B" Lines 1-4

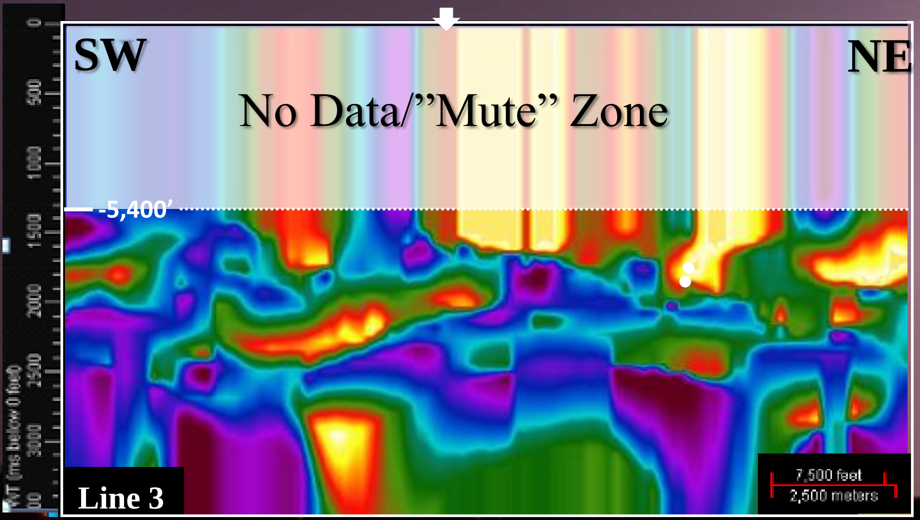
Surface Fault Cut

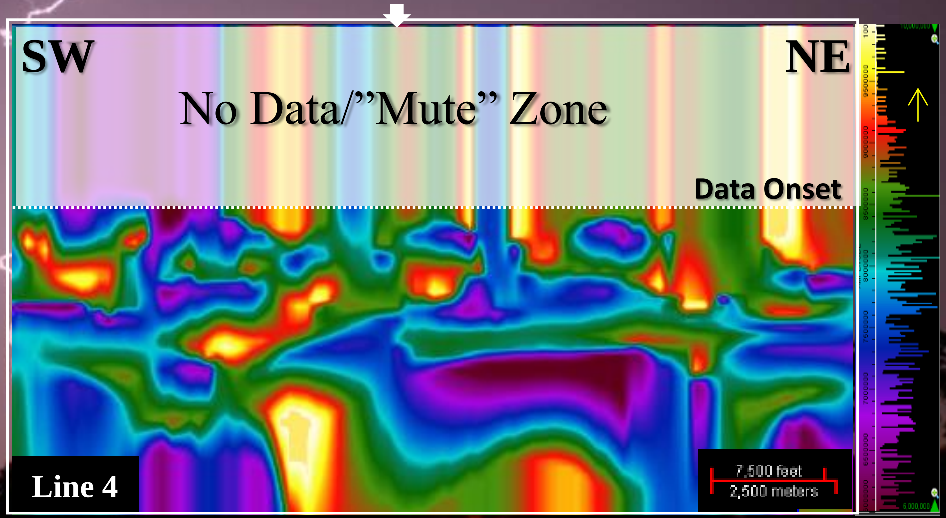


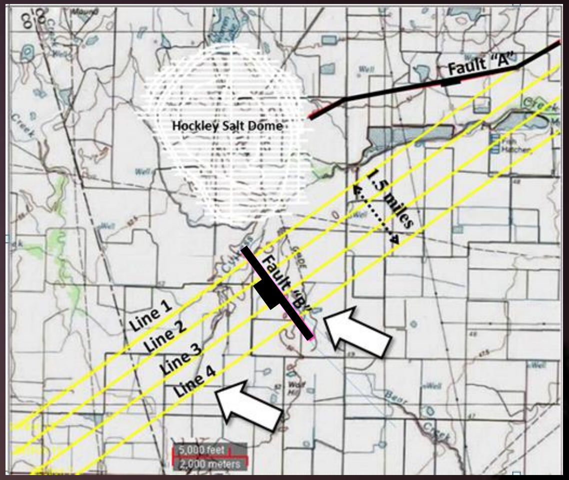
Surface Fault Cut



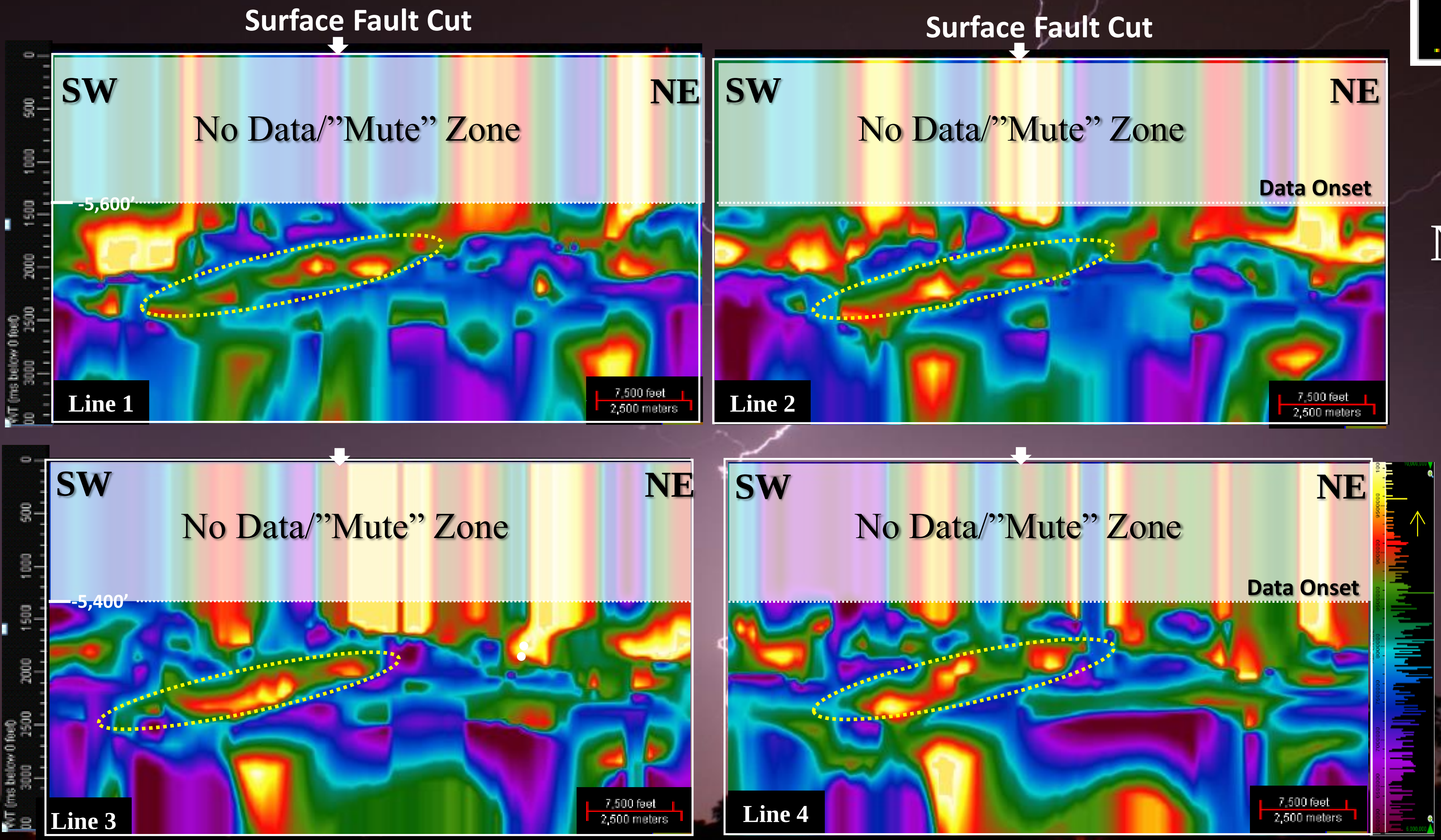
Lines ½ mile apart.
Note similar character.



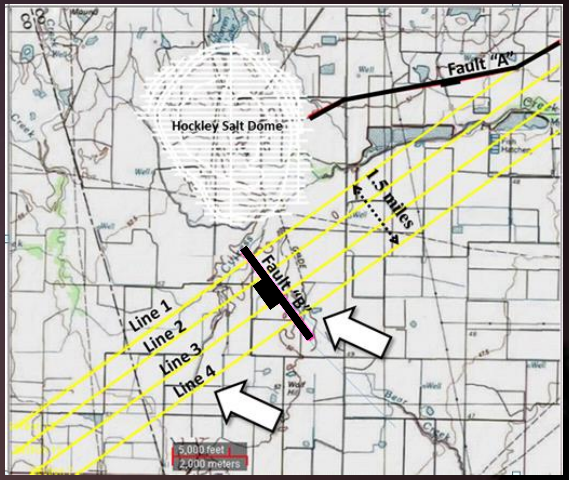




Similar Character Spanning 1.5 Miles



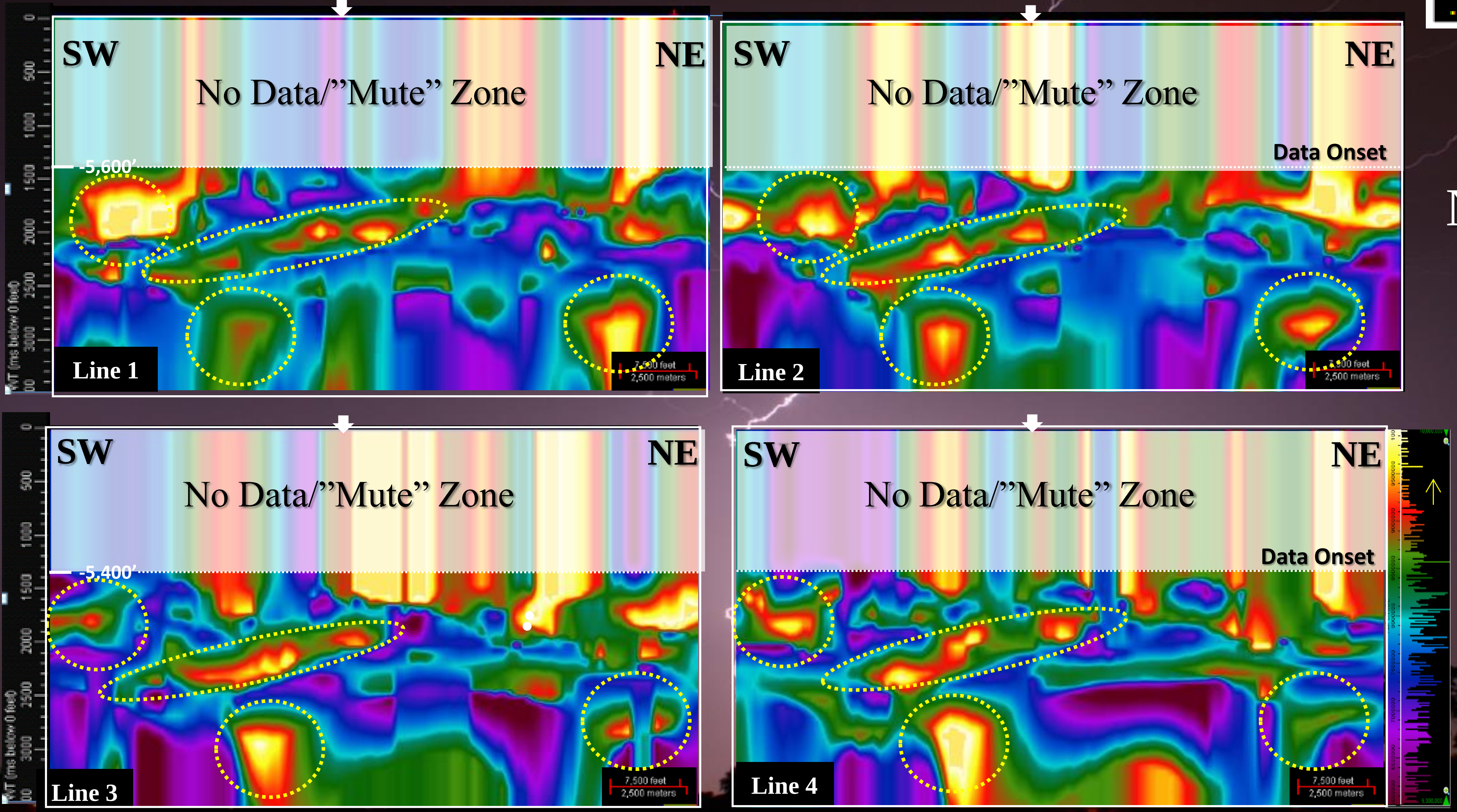
Lines ½ mile apart.
Note similar character.



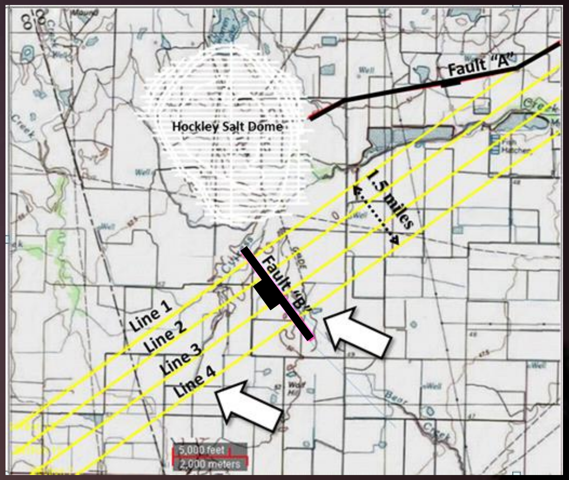
Numerous Features Correlate Line to Line

Surface Fault Cut

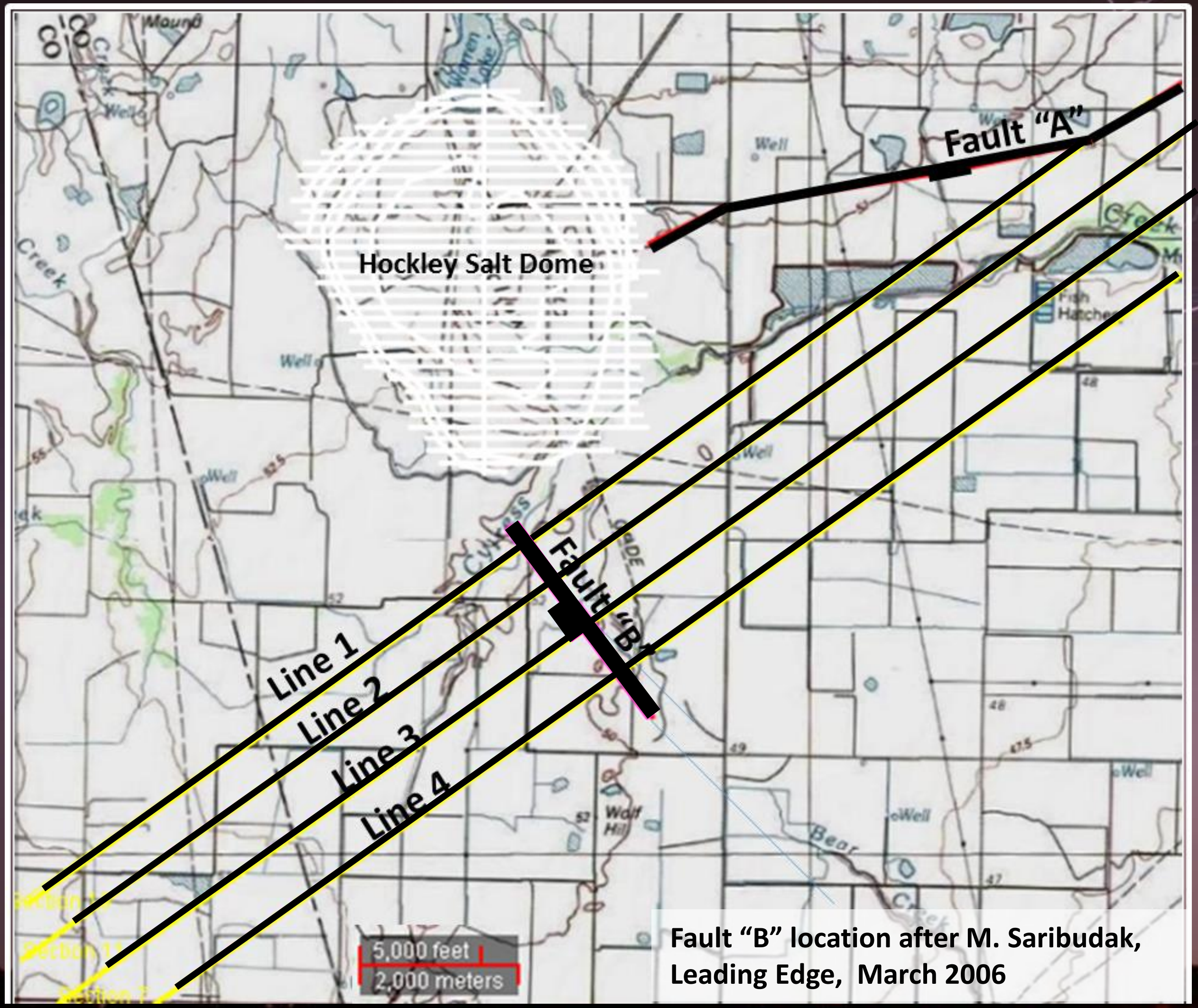
Surface Fault Cut



Lines ½ mile apart.
Note similar character.



Hockley Radial Fault "B"

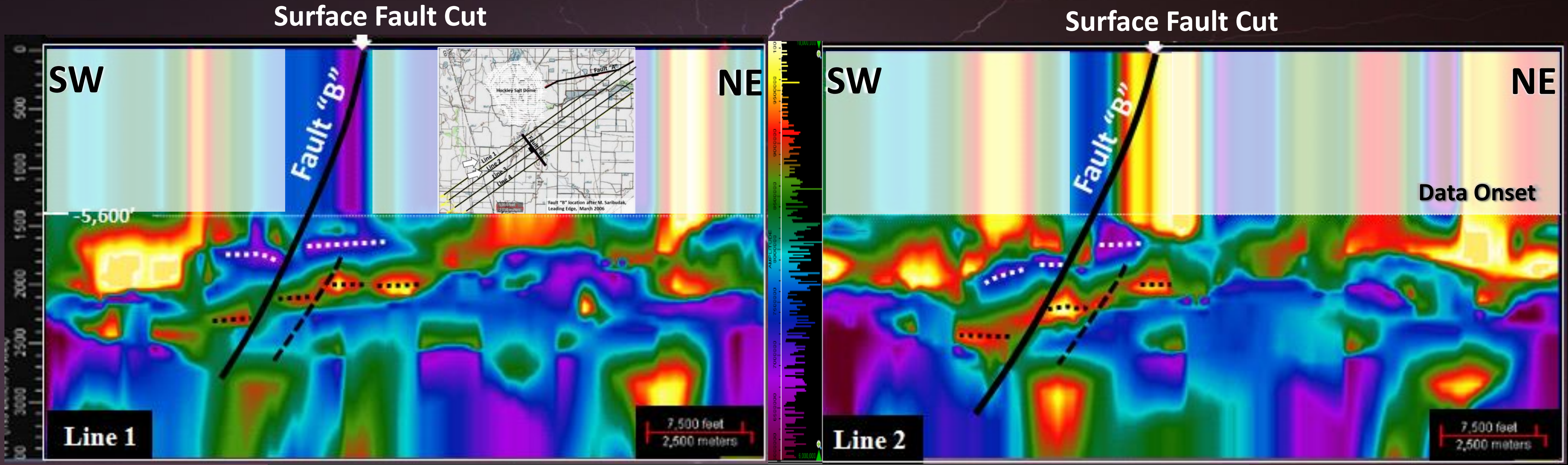


Fault "B" location after M. Saribudak, Leading Edge, March 2006

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

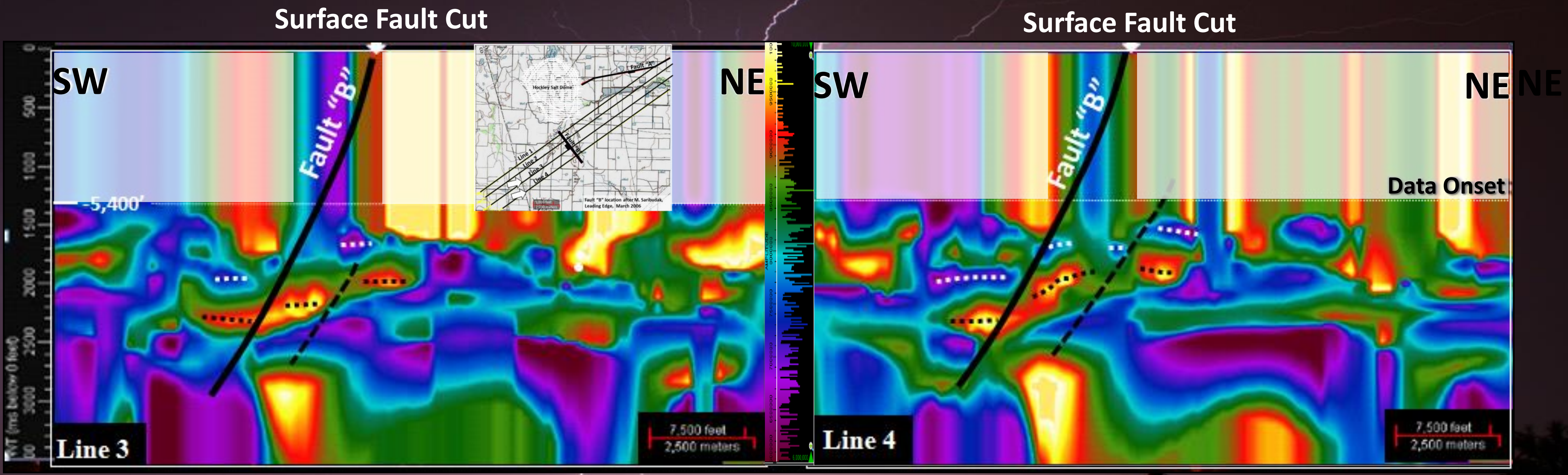
As with Fault "A", trigonometric constraints based on depth, heave, fault surface dip and sense of throw must be satisfied.

NSEM Ties Surface Fault "B" to Subsurface



Lines 1 & 2 show consistent subsurface fault criteria.

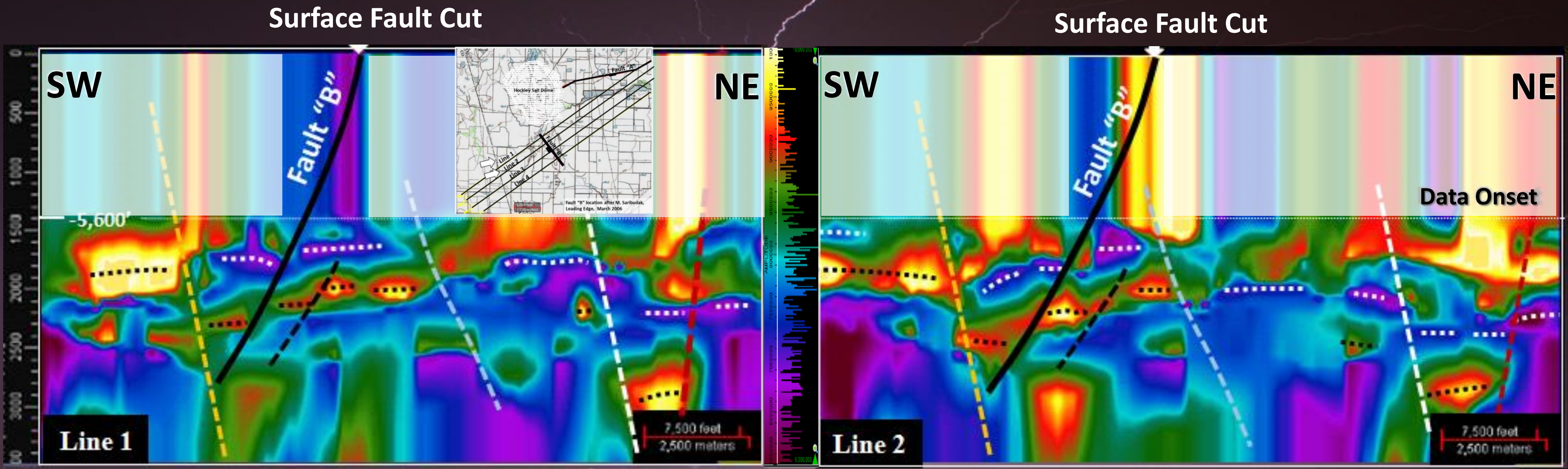
NSEM Ties Surface Fault "B" to Subsurface



Lines 3 & 4 show similar consistent subsurface fault criteria.

NSEM Shows Additional Faulting
Lines 1 & 2

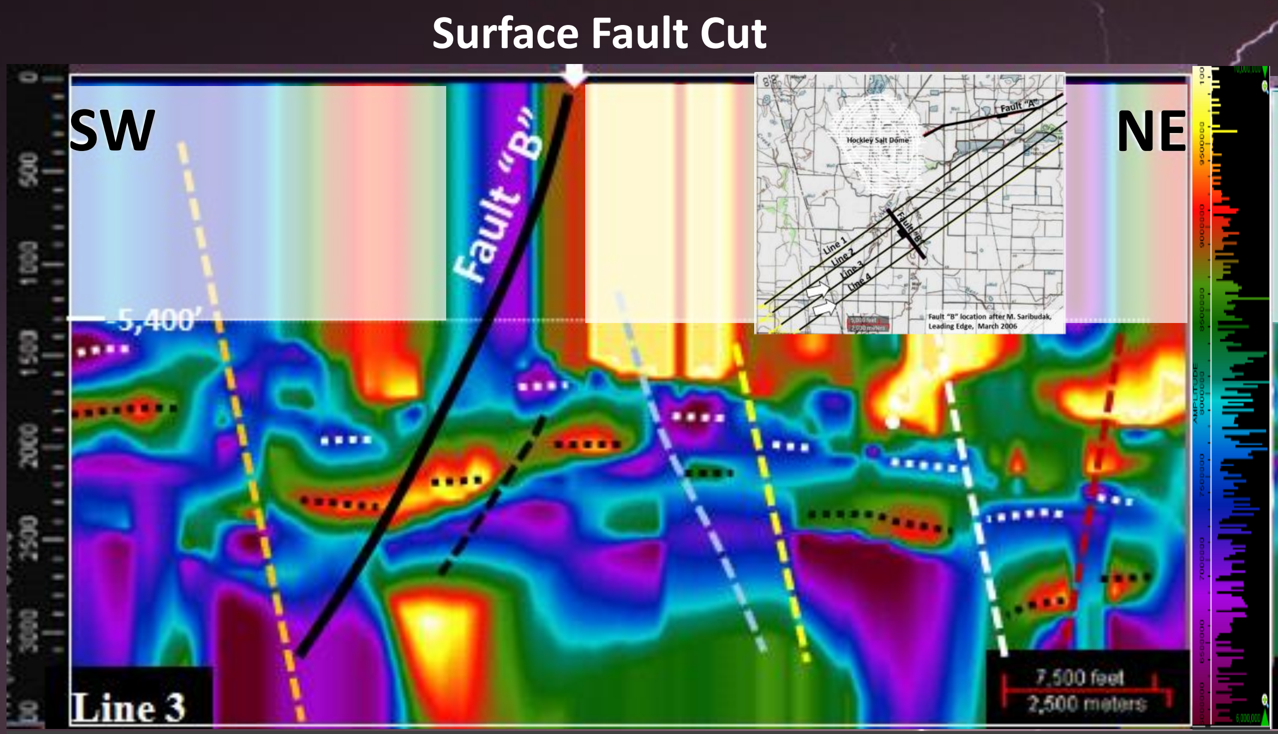
See Lightning . . .
DML
. . . think DML & solutions

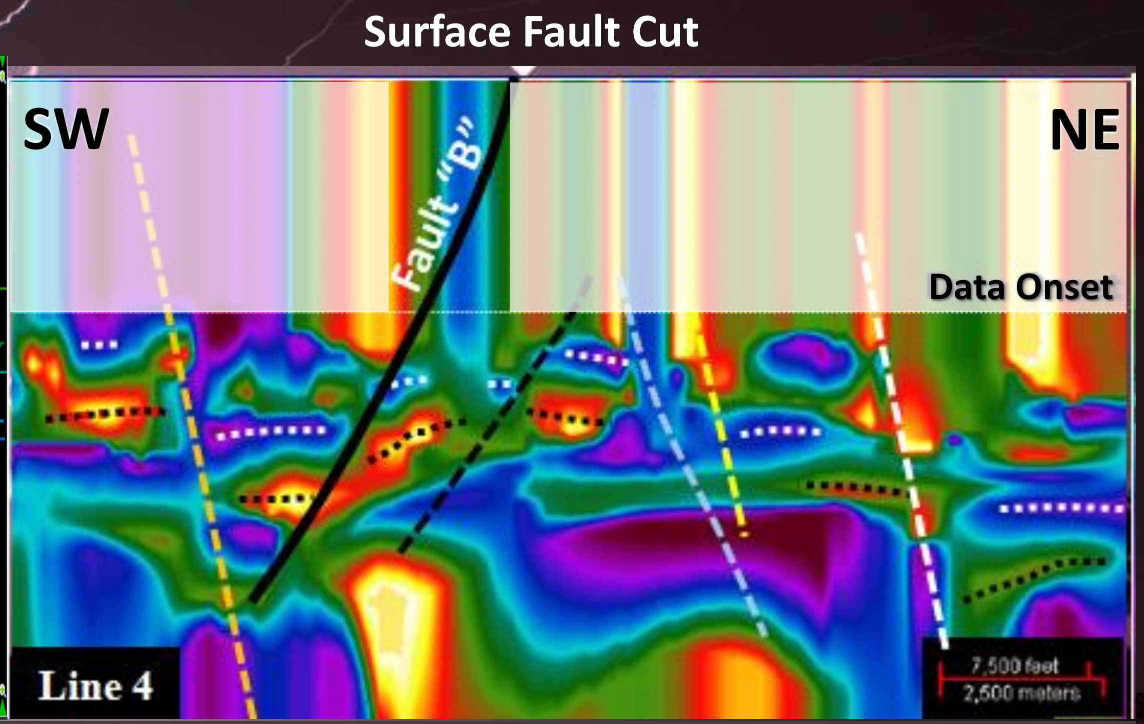


Six geologically reasonable faults consistently interpreted on both lines.

NSEM Shows Additional Faulting Lines 3 & 4

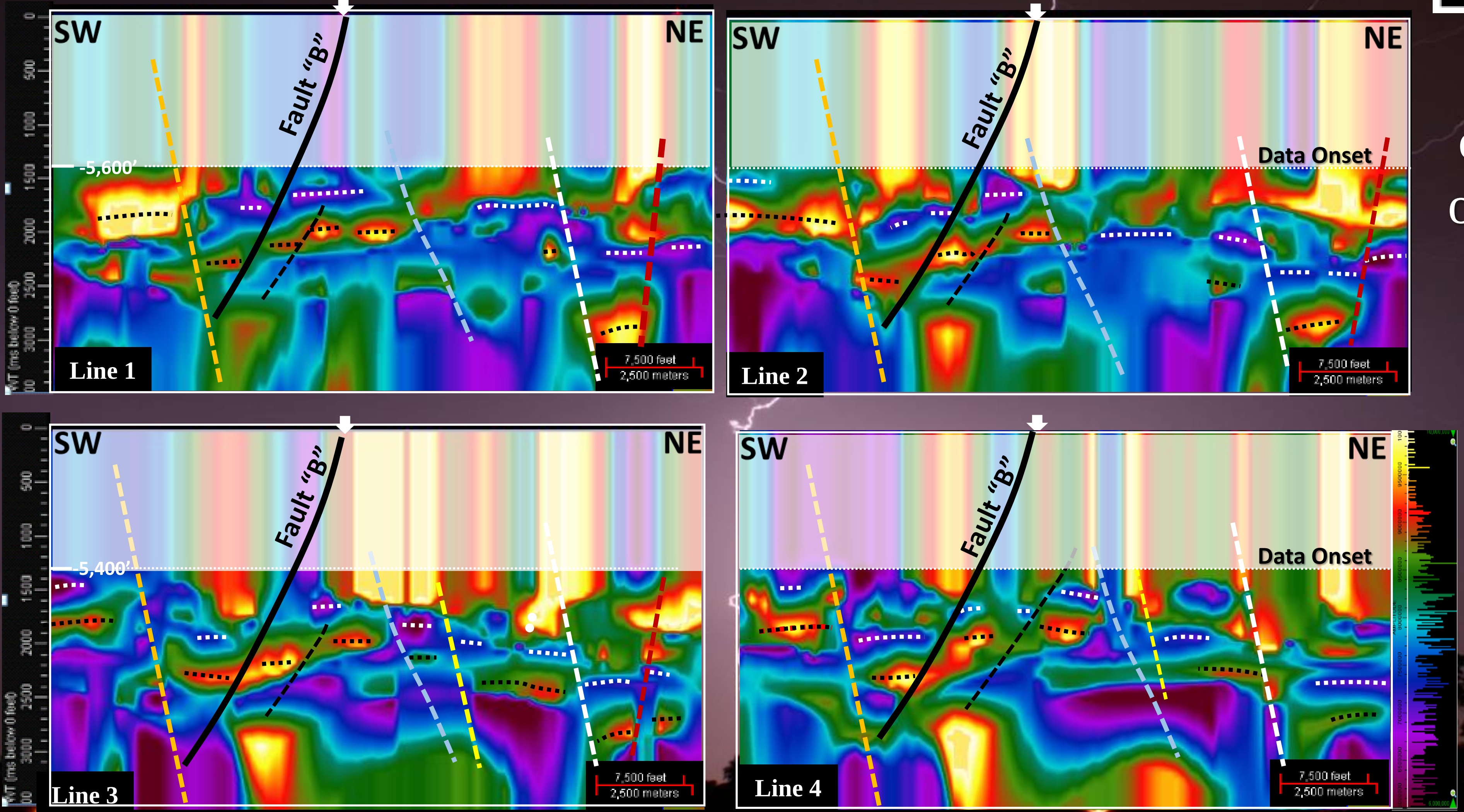
See Lightning . . . DML . . . think DML & solutions



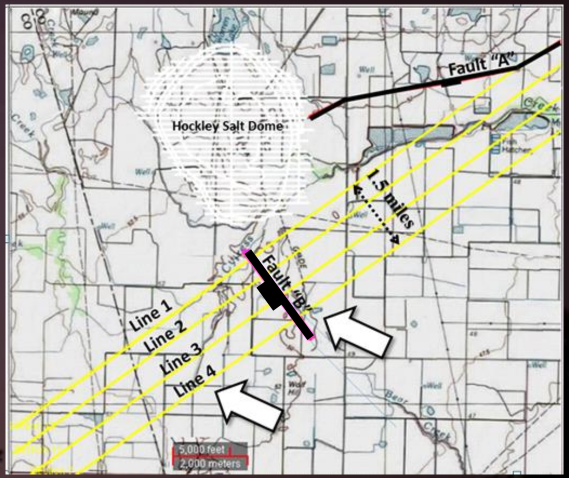


The same fault patterns on the previous slide can be interpreted on these lines.

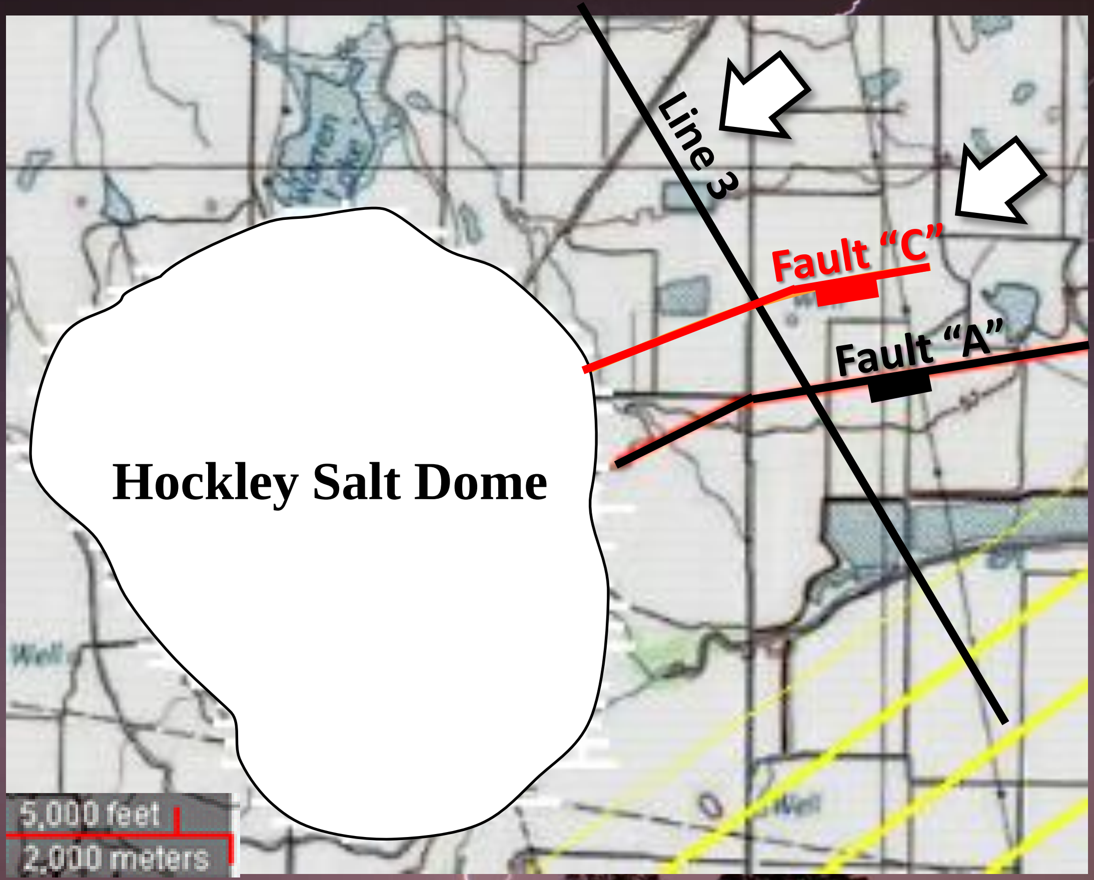
NSEM Shows Consistent Interpretation



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

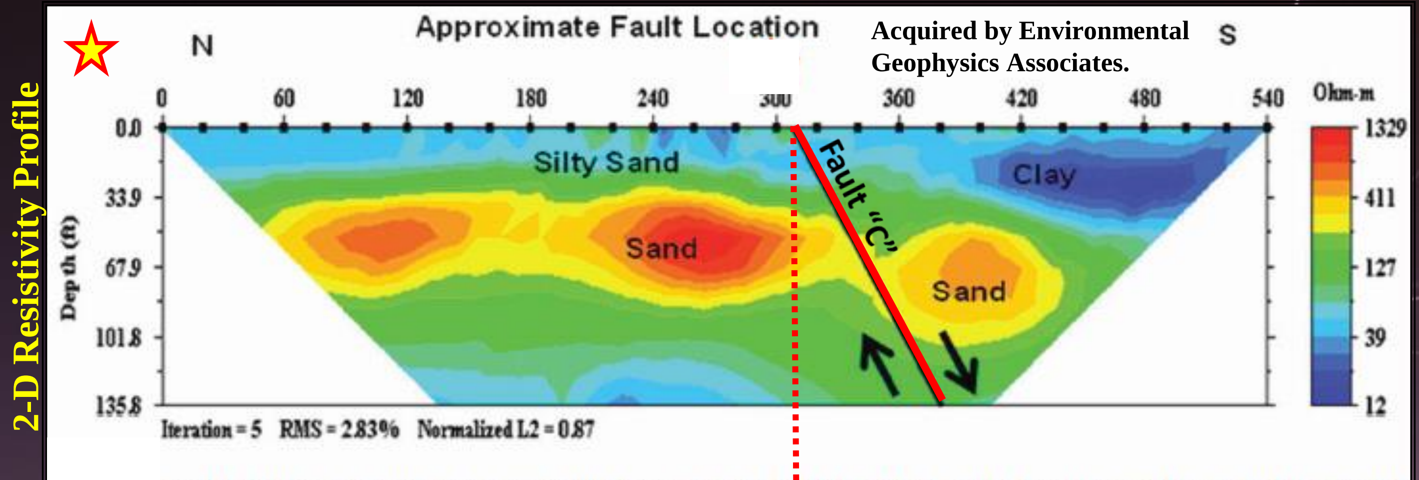


Hockley Radial Fault "C"



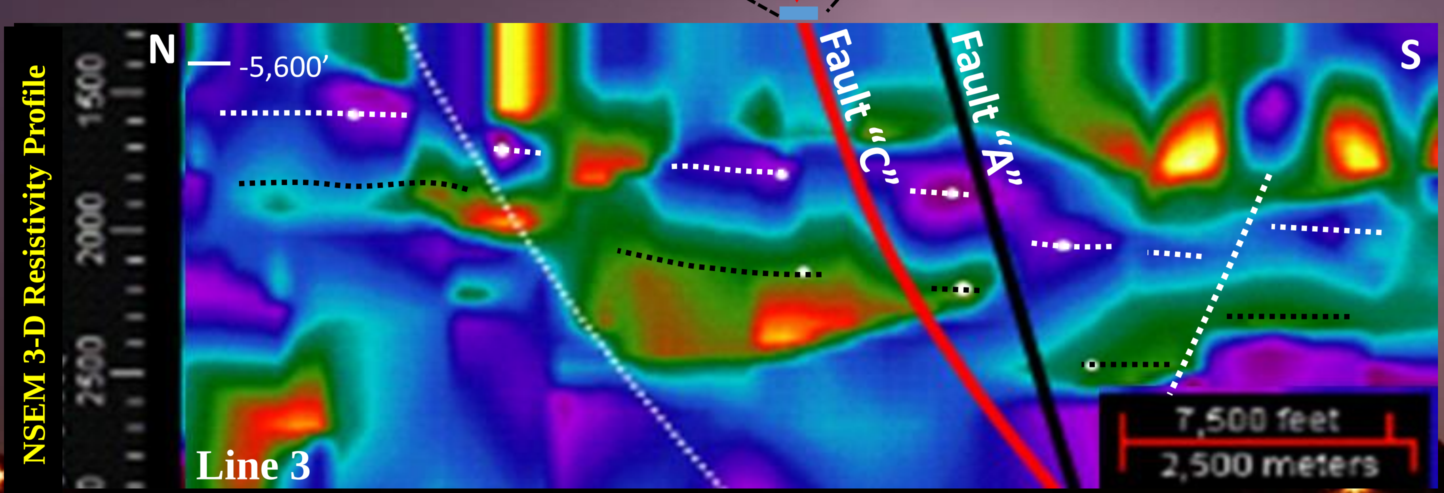
Apparent resistivity profile "Line 3" displayed next.

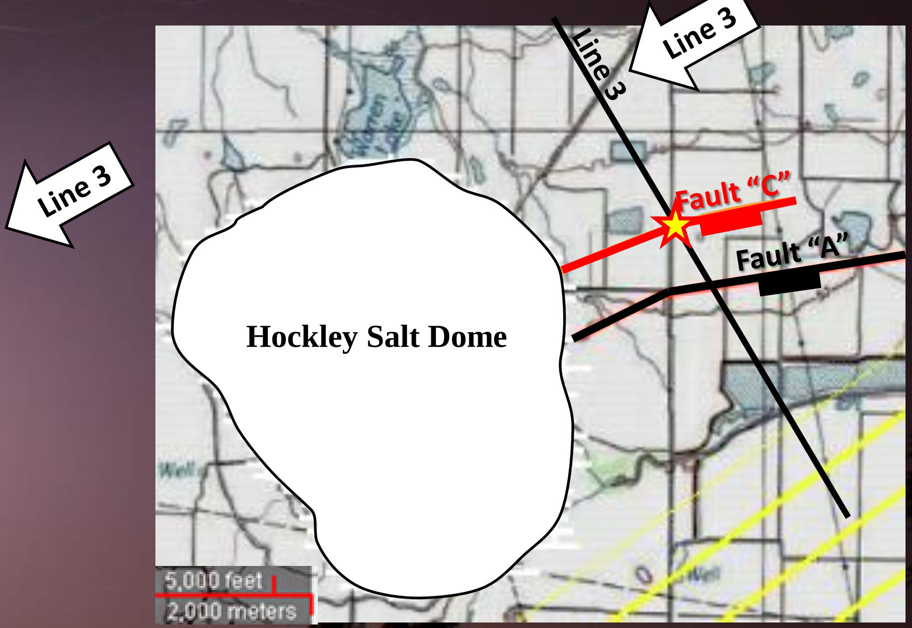
NSEM Ties Fault "C" to Subsurface



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".





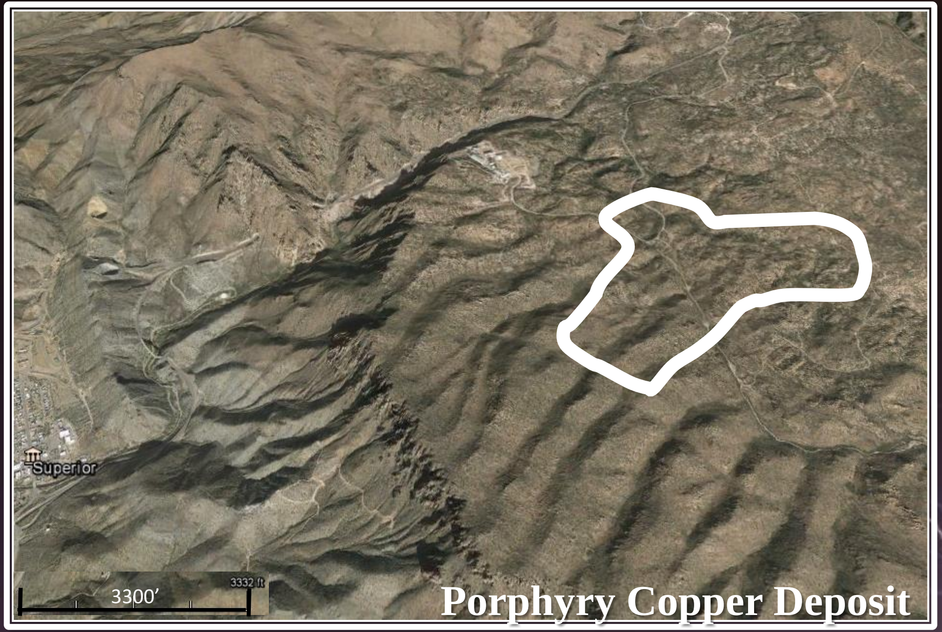
Observations

- 3-D NSEM resistivity data was able to tie surface faults and extend fault interpretations to deeper than 5,600’.
- 3-D NSEM fault criteria was credible and at least as good as conventional 2-D resistivity imaging.
- In most cases NSEM fault criteria was based on the offset of two resistivity layers.

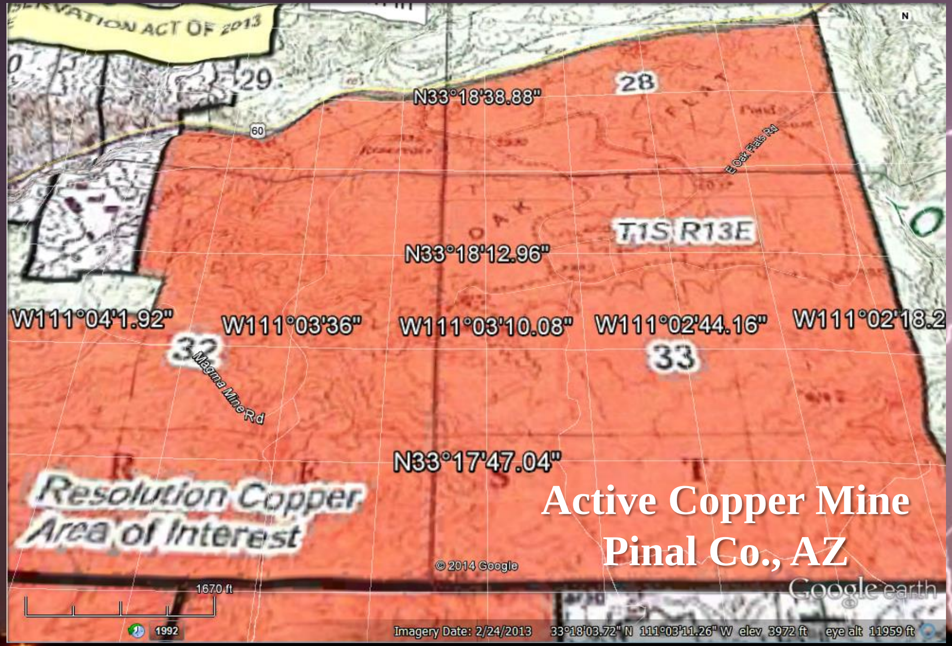
Hockley Fault Conclusions

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

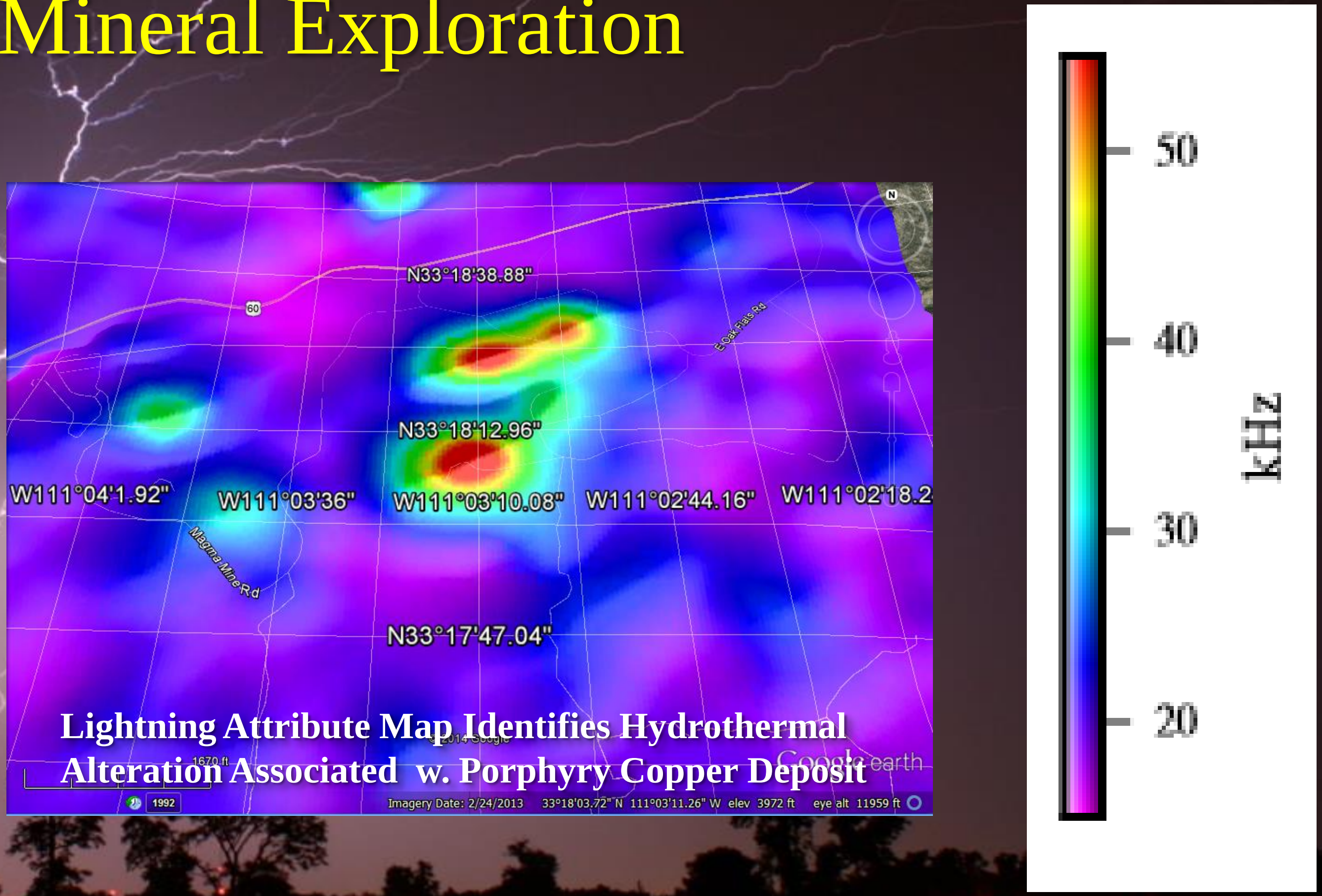
NSEM Correlates To Rock Properties: Mineral Exploration



Porphyry Copper Deposit



Active Copper Mine
Pinal Co., AZ



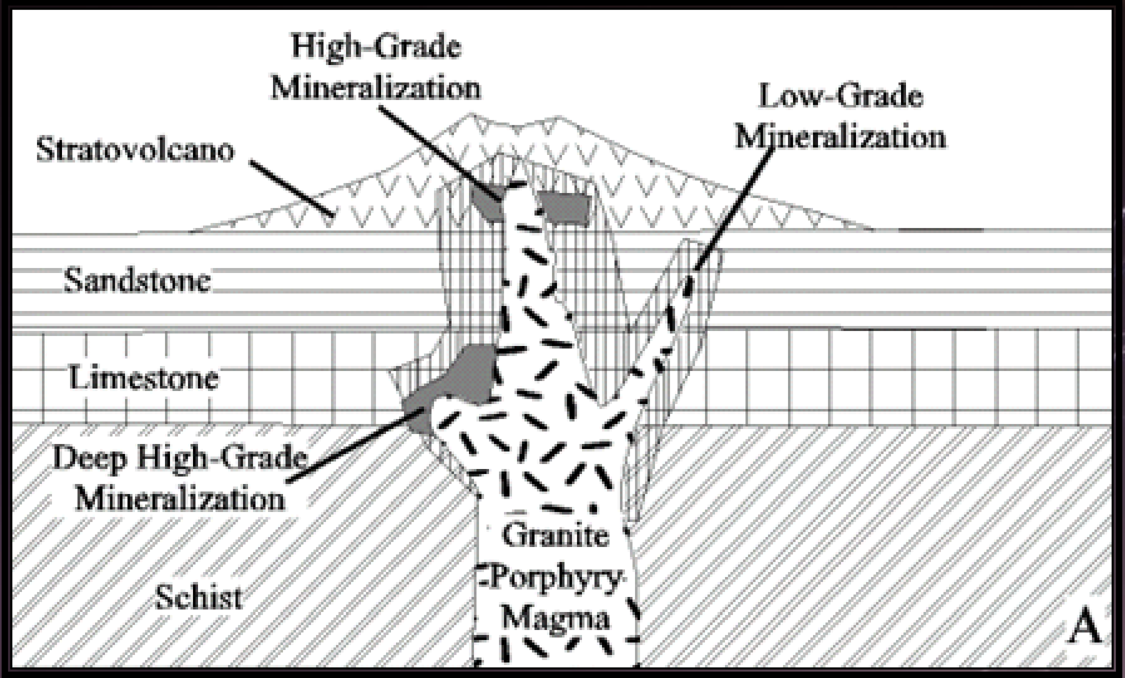
Lightning Attribute Map Identifies Hydrothermal Alteration Associated w. Porphyry Copper Deposit

Mapping of Porphyry Copper Deposits

NSEM - a patent pending, successfully blind-tested, rock property mapping tool.

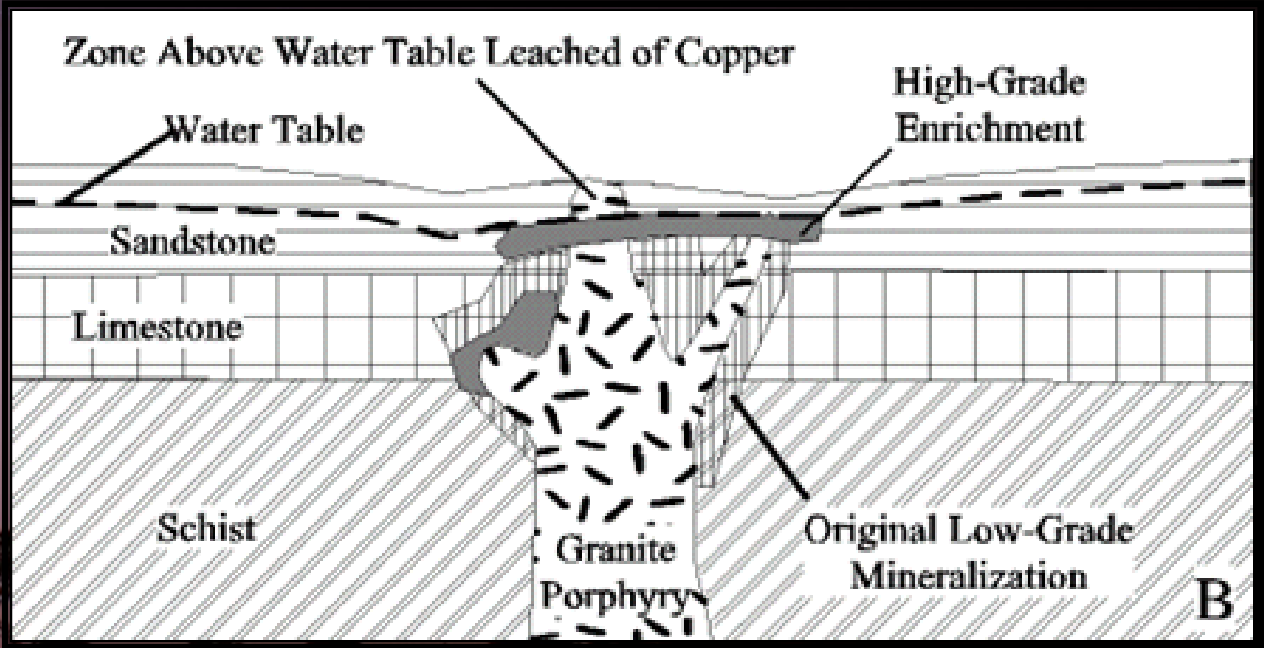
Following a brief description of the general geology of porphyry copper deposits & the near-surface geophysical exploration technique used to identify these deposits, a case study is presented.

Formation of a Porphyry Copper Deposit



- Magma chamber feeds upward intrusion of molten rock into shallow sedimentary rocks.
- Magma & associated hot mineral-rich fluids come in contact with host rocks & generate chemical/mineral changes creating low-grade copper mineralization.

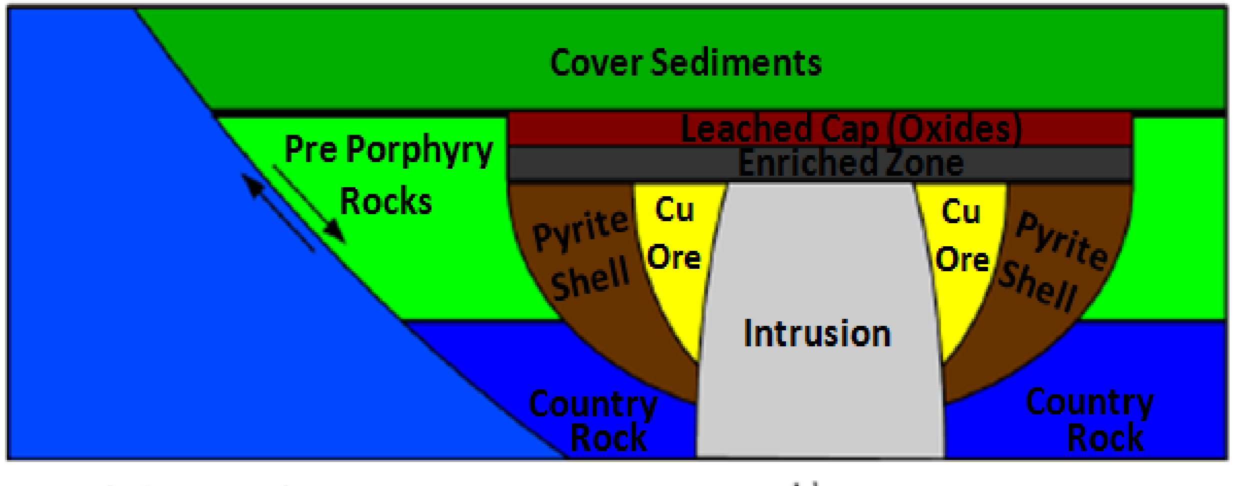
- Erosion strips away overburden subjecting low-grade mineralized areas to weathering.
- Rainwater leaches Cu and redeposits it below at the water table, creating concentrations of high-grade Cu deposits.



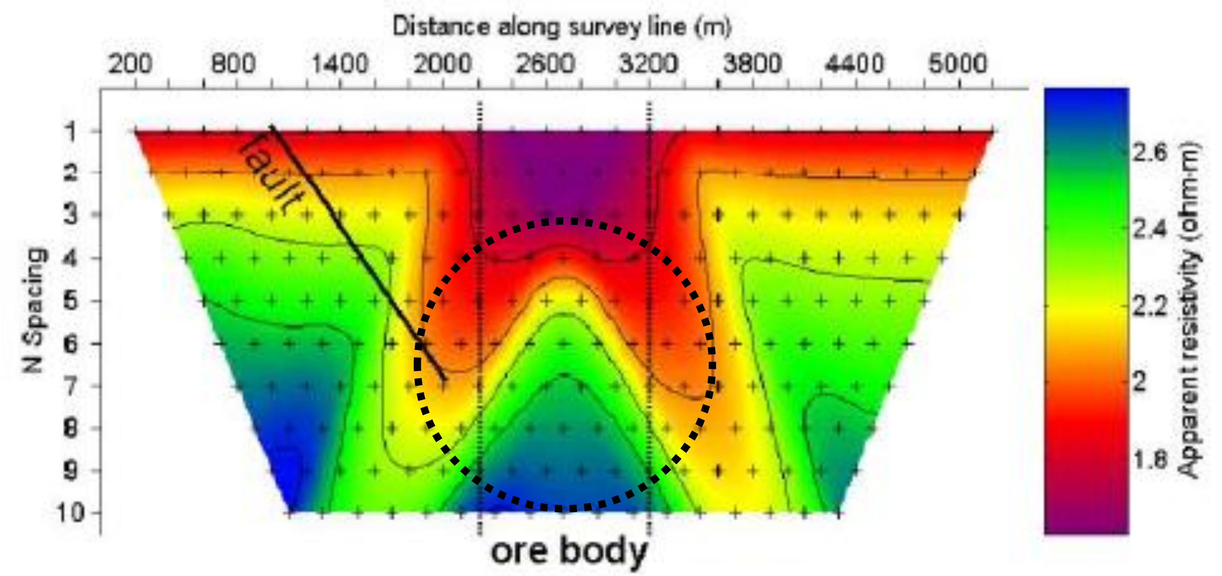
Simplified Porphyry Copper Deposit Model

Typical Mineral Zones of a Porphyry Deposit

Conductivity anomaly surrounds more resistive ore body in center.

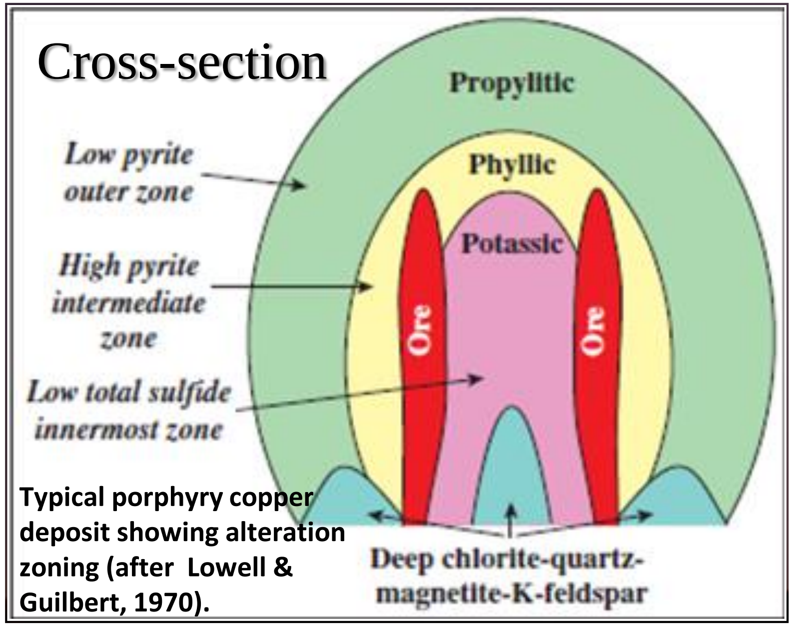


(after Emond, Zhdanov & Petersen, 1970)



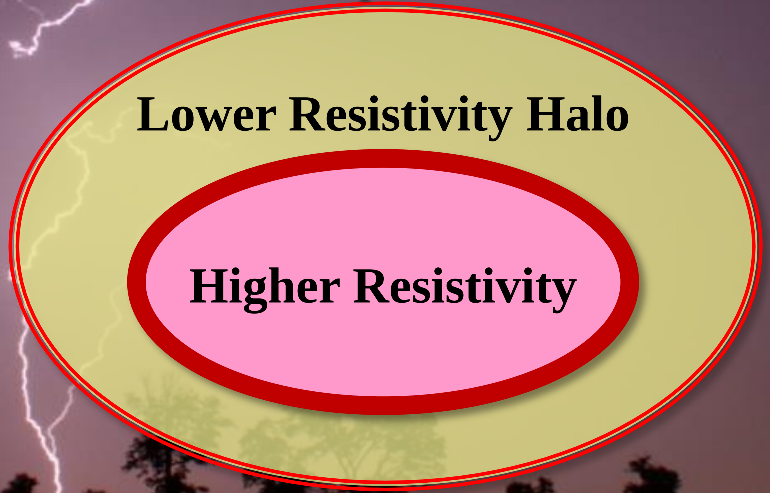
Porphyry Copper Deposit Signature

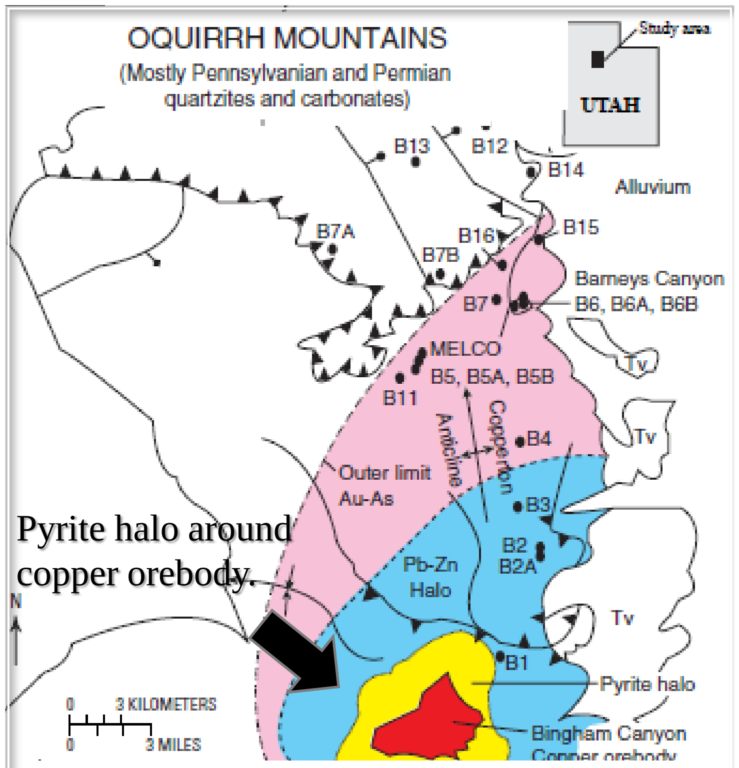
- Multiple igneous intrusions present.
- Contact metamorphism/alteration halos.
- Inner high resistivity zone partially or completely enclosed by outer conductive zone.



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

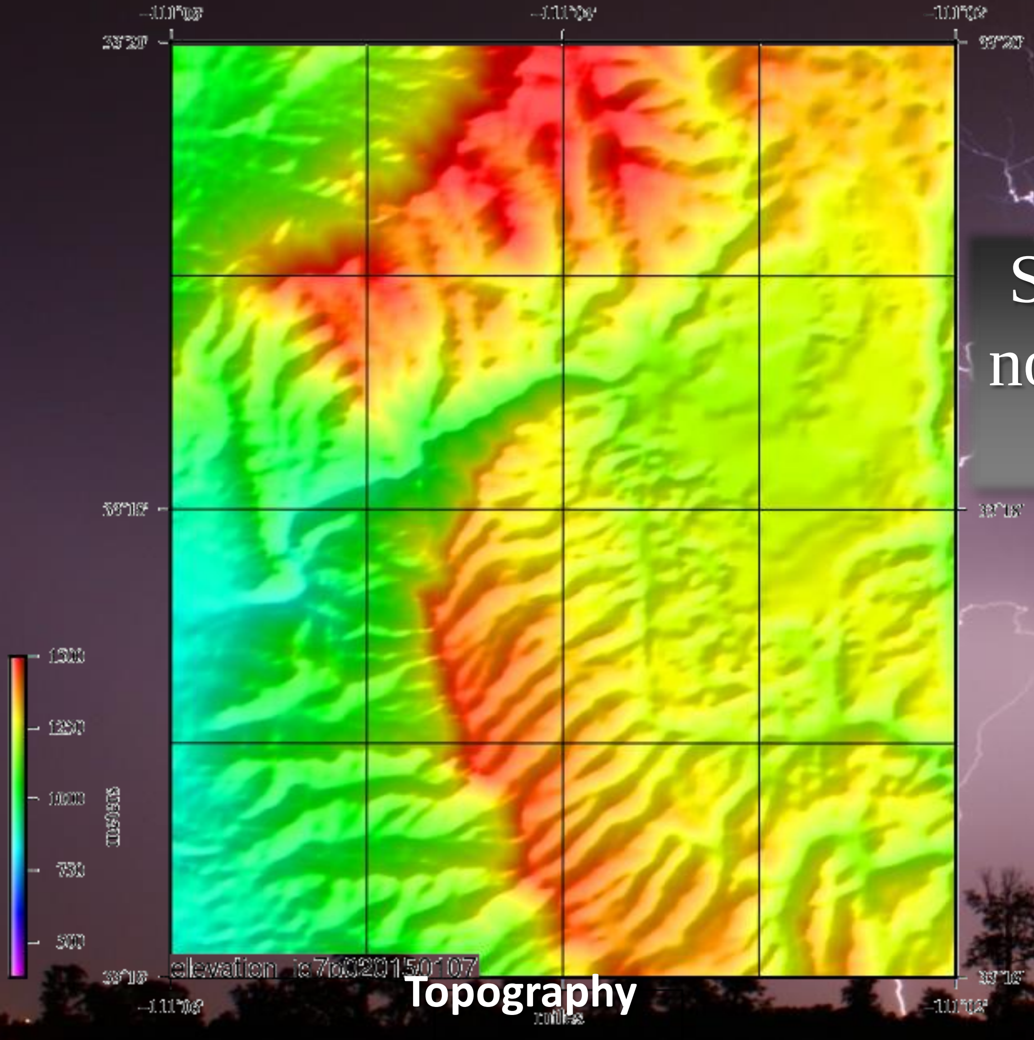
Map View





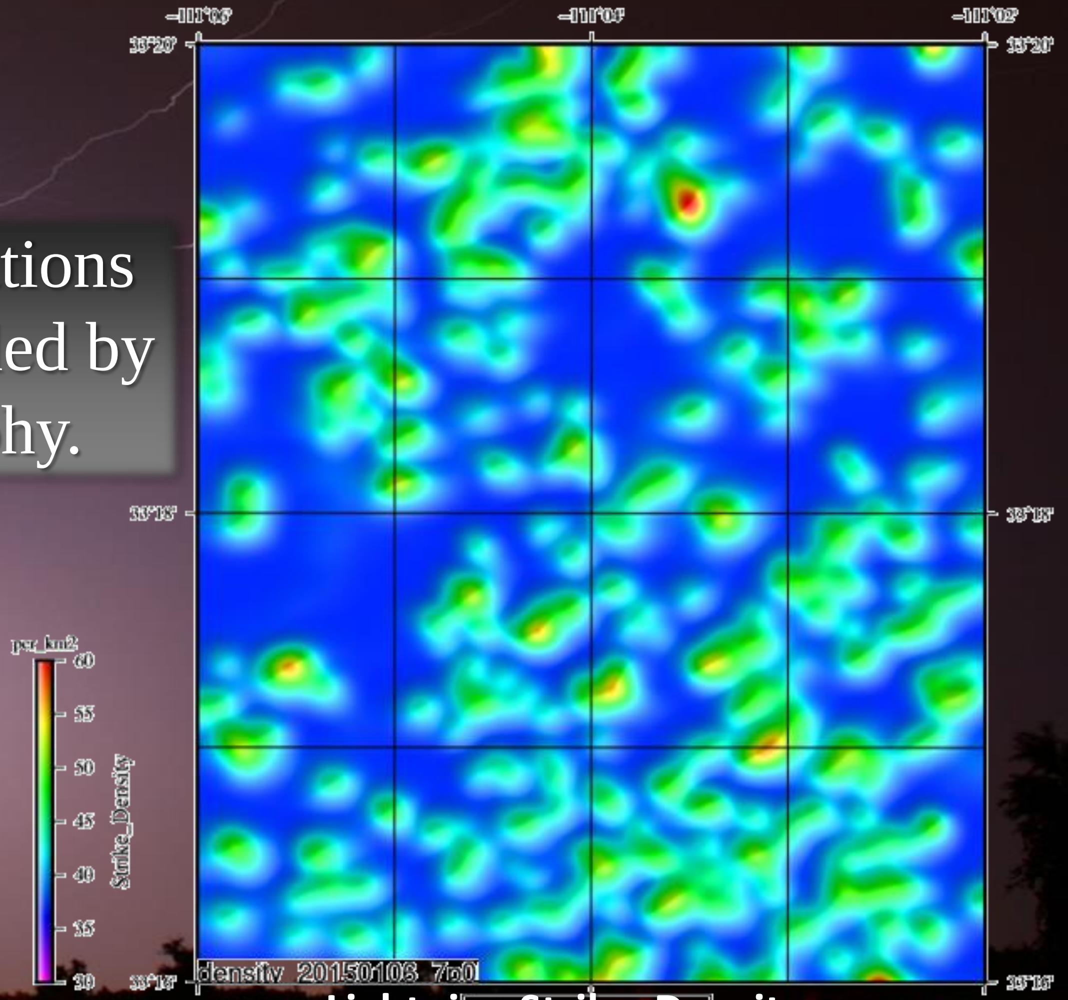
Geochemical zoning around the Bingham Canyon deposit, Utah (modified from Cunningham & others, 2004, their Fig. 1). USGS Report 2010-5070-B , David John, Editor.

Case Study: Resolution Copper Mine
Pinal Co., AZ



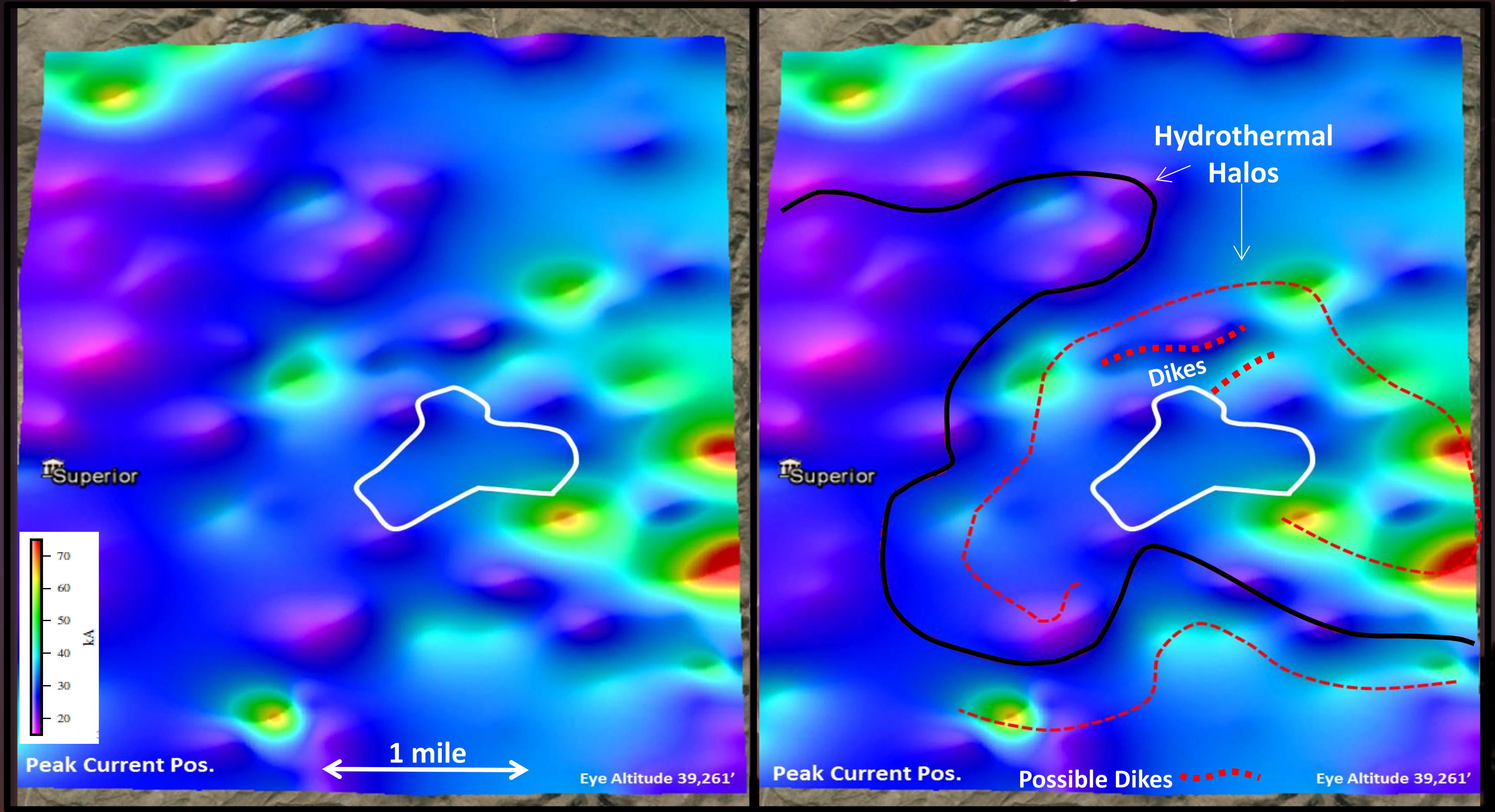
Topography

Strike locations not controlled by topography.



Lightning Strike Density

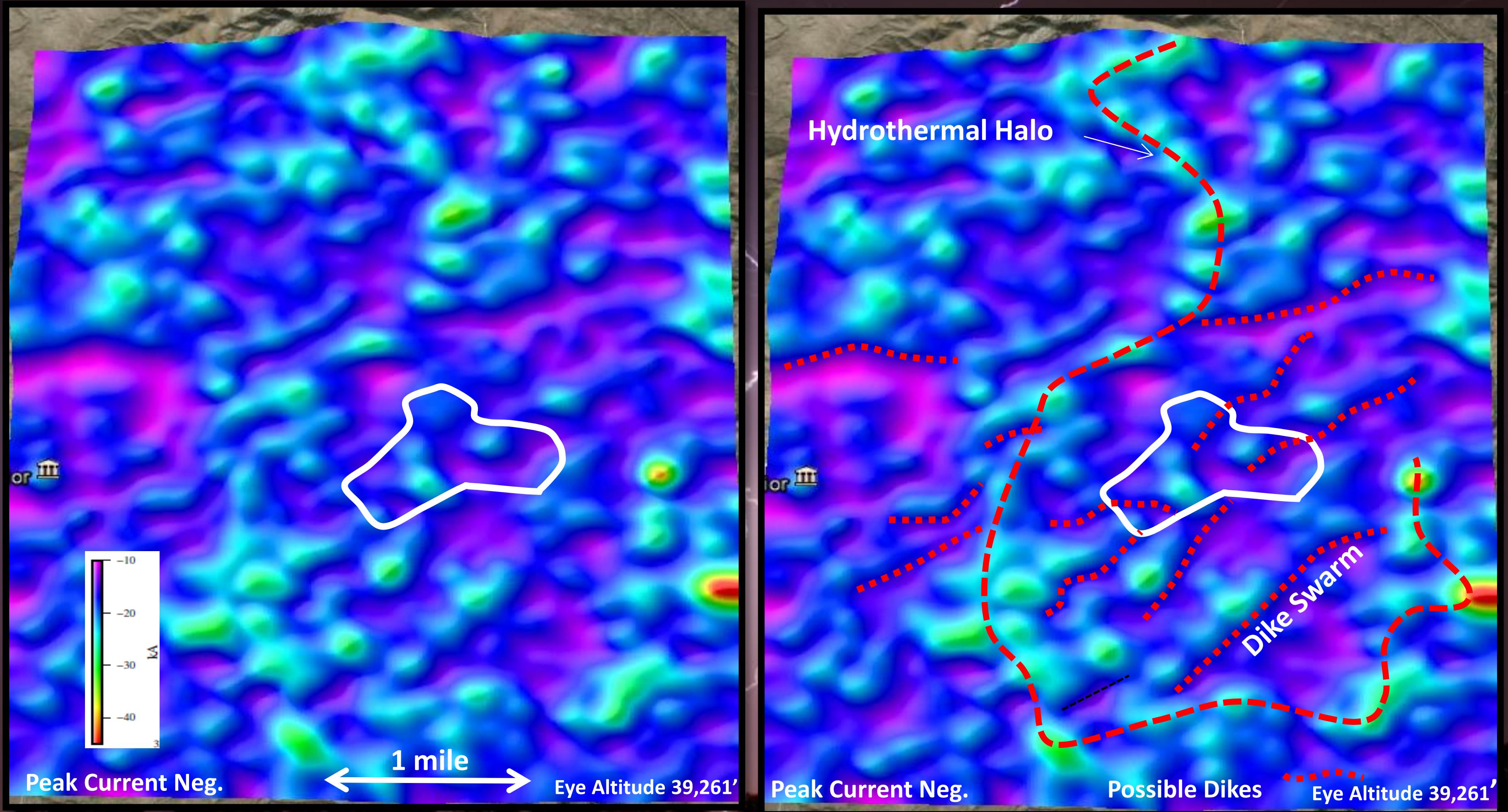
Positive Peak Current
Resolution Copper Mine



Geology Influences Peak Current

Hydrothermal Alteration & Dike Interpretation

Negative Peak Current
Resolution Copper Mine



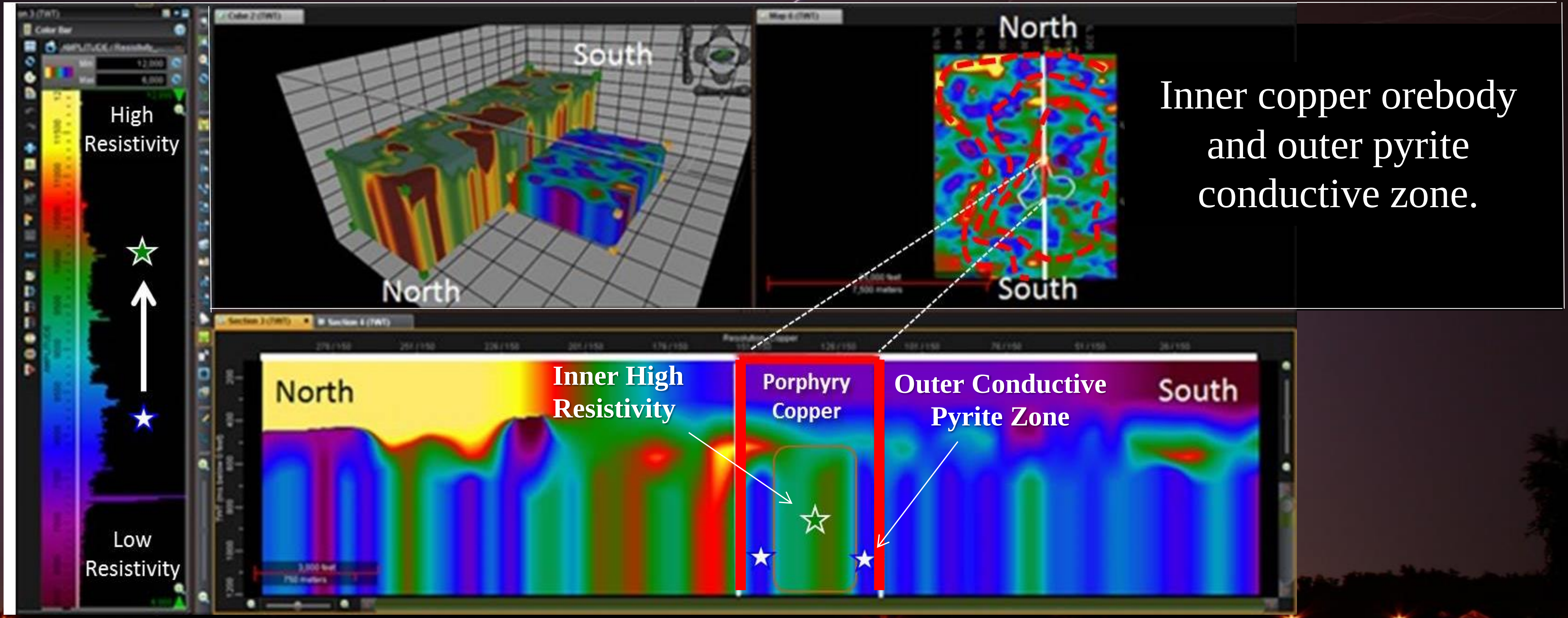
Lightning attribute pattern unrelated to topography.

Pyrite halo partially enclosing copper orebody.

Presence of dikes, indicative of porphyry copper.

3-D Resistivity Profile Through Mine
Reveals Porphyry Copper Signature

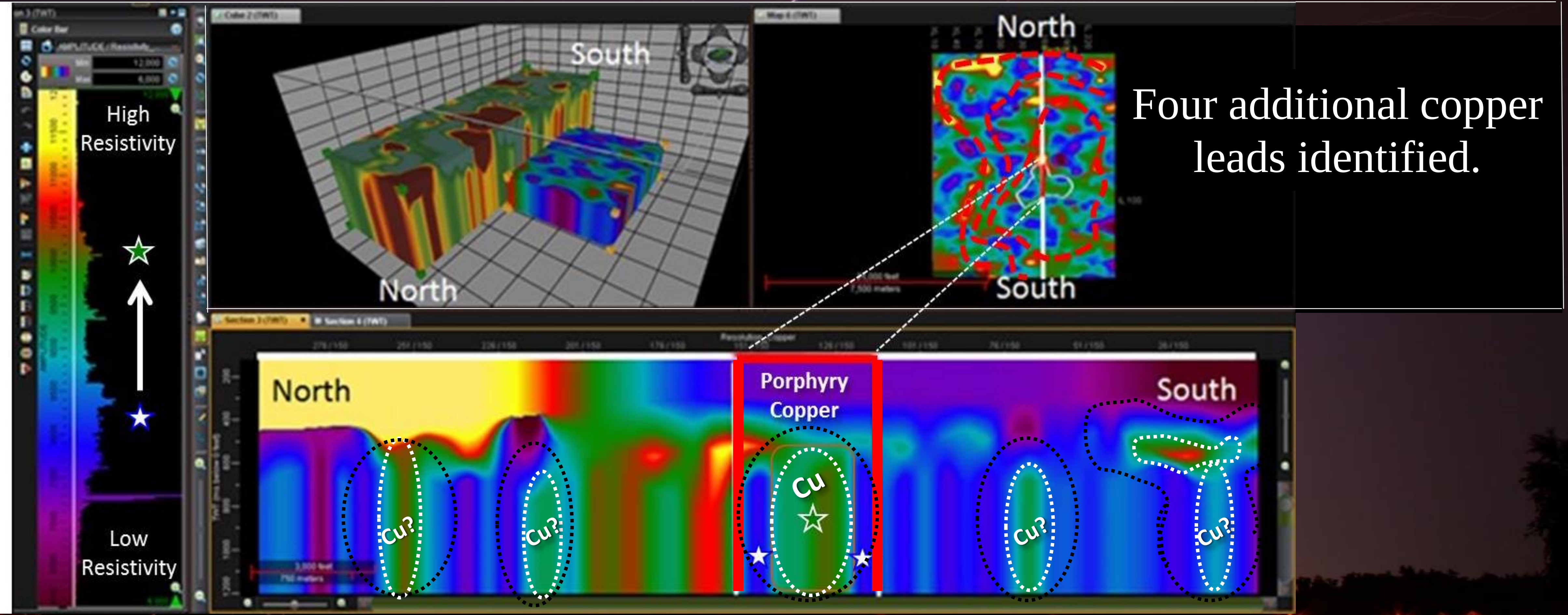
Resolution Copper Mine Pinal County, AZ



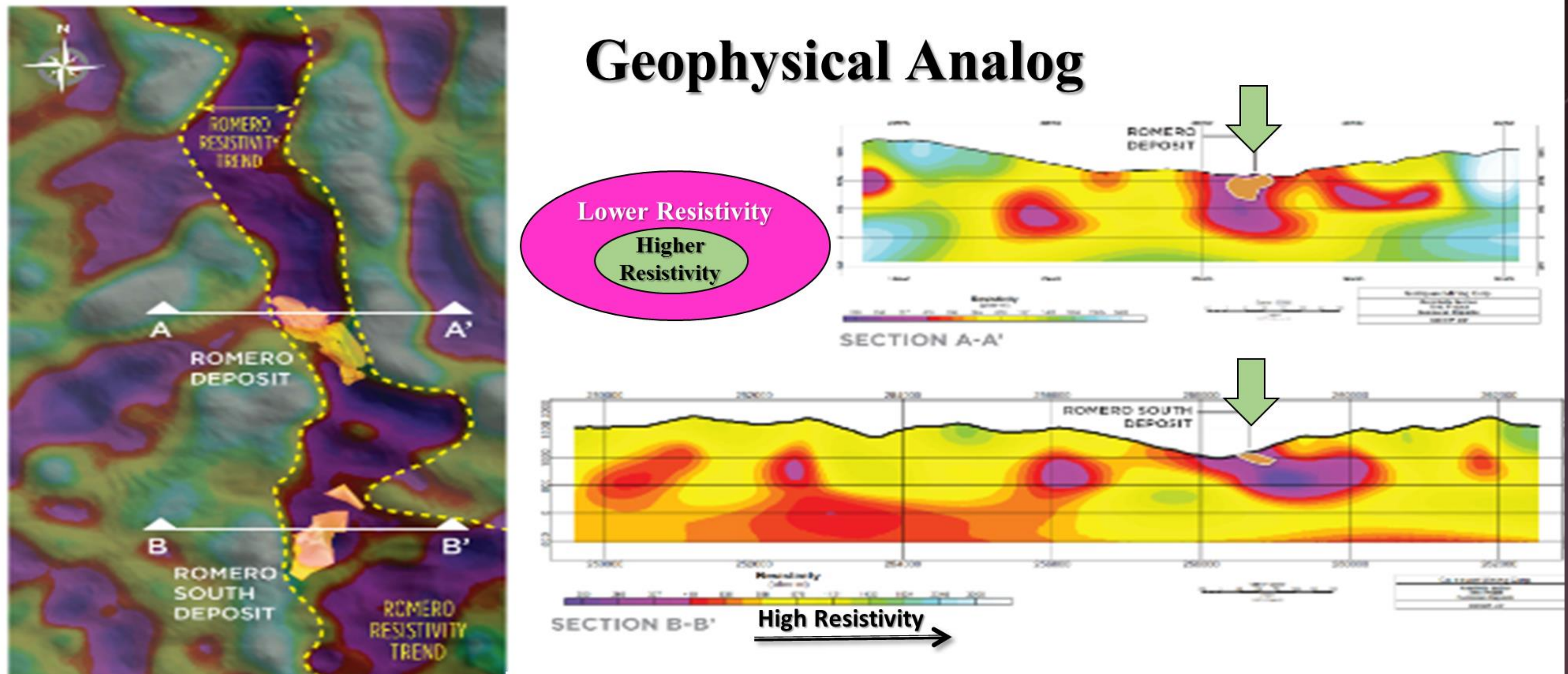
Inner copper orebody and outer pyrite conductive zone.

Mapping Rock Properties with Lightning

Resolution Copper Mine Pinal County, AZ



Copper Deposit Analog
Romero Resistivity Trend, Dominican Republic



After Geotech 2014 ZTEM Survey for Goldquest (www.goldquest.com) , Seismic Resistivity Signature of Romero Au/Cu Resistivity Trend, Dominican Republic, http://www.marketwire.com/library/MwGo/2014/4/14/11G014504/Images/GQC-2014-ZTEMSurvey-ResistivitySignature(April1520-1141602677010.jpg

Traditional resistivity profiling shows same Cu signature as NSEM.

Note same inner high resistivity core that is surrounded by a lower resistivity halo.

Observations

- Annular lightning attribute clusters suggest lateral resistivity changes caused by igneous intrusion & hydrothermal alteration.
- Linear trends of positive & negative peak current believed to be guided by igneous dikes/sills emplaced during igneous intrusion.
- 3-D NSEM resistivity data shows same electromagnetic signature used by mining industry to map porphyry copper deposits.

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 <u>rock properties</u> which can be applied to unconventional oil and gas exploration.

The Same Rock Properties Influencing NSEM May Help Define Unconventional Sweetspots

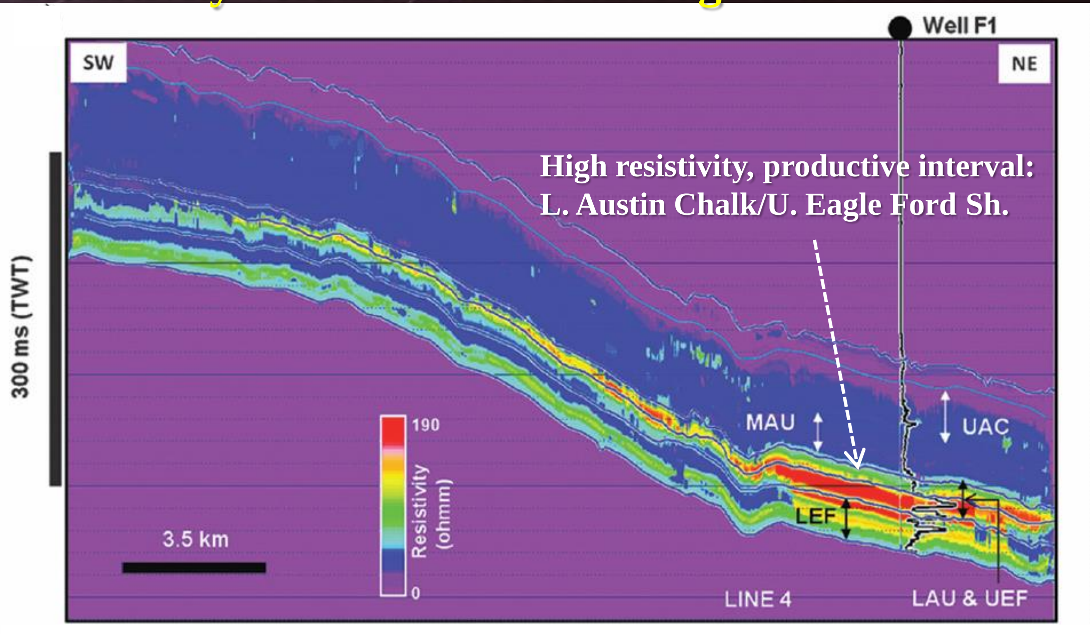
See Lightning . . . DML . . . think DML & solutions

BEG: Lower Austin Chalk/Eagle Ford Sh.
Maverick Basin, S. TX

Combination of the Following:

- High Resistivity
- High Total Organic Carbon
- High Acoustic Impedance (brittleness)
- Low Bulk Volume Water

Resistivity volume transect through Austin Chalk.



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

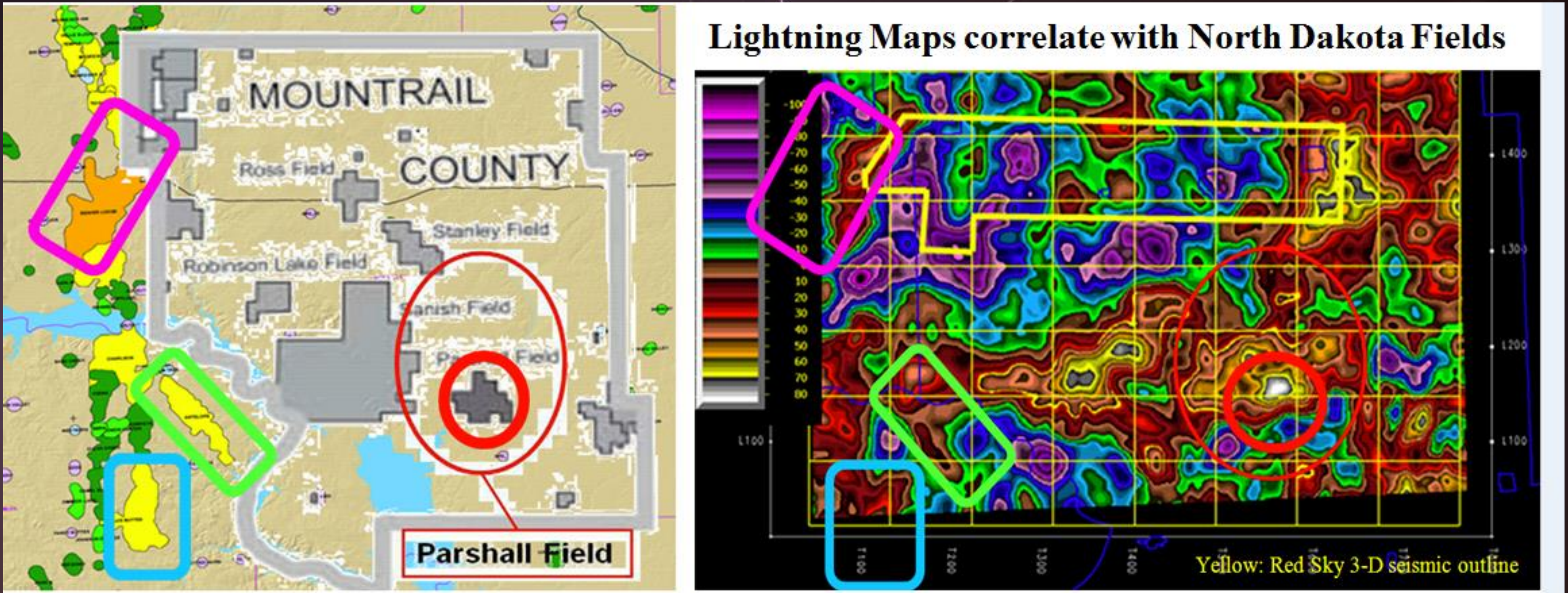
**"Seismic multiattribute analysis for shale gas/oil within the Austin Chalk and Eagle Ford Shale in a submarine volcanic terrain, Maverick Basin, South Texas,"* Osareni C. Ogiesoba and Ray Eastwood BEG, Interpretation, Nov. 2013.

NSEM Applications to Whiting Petroleum

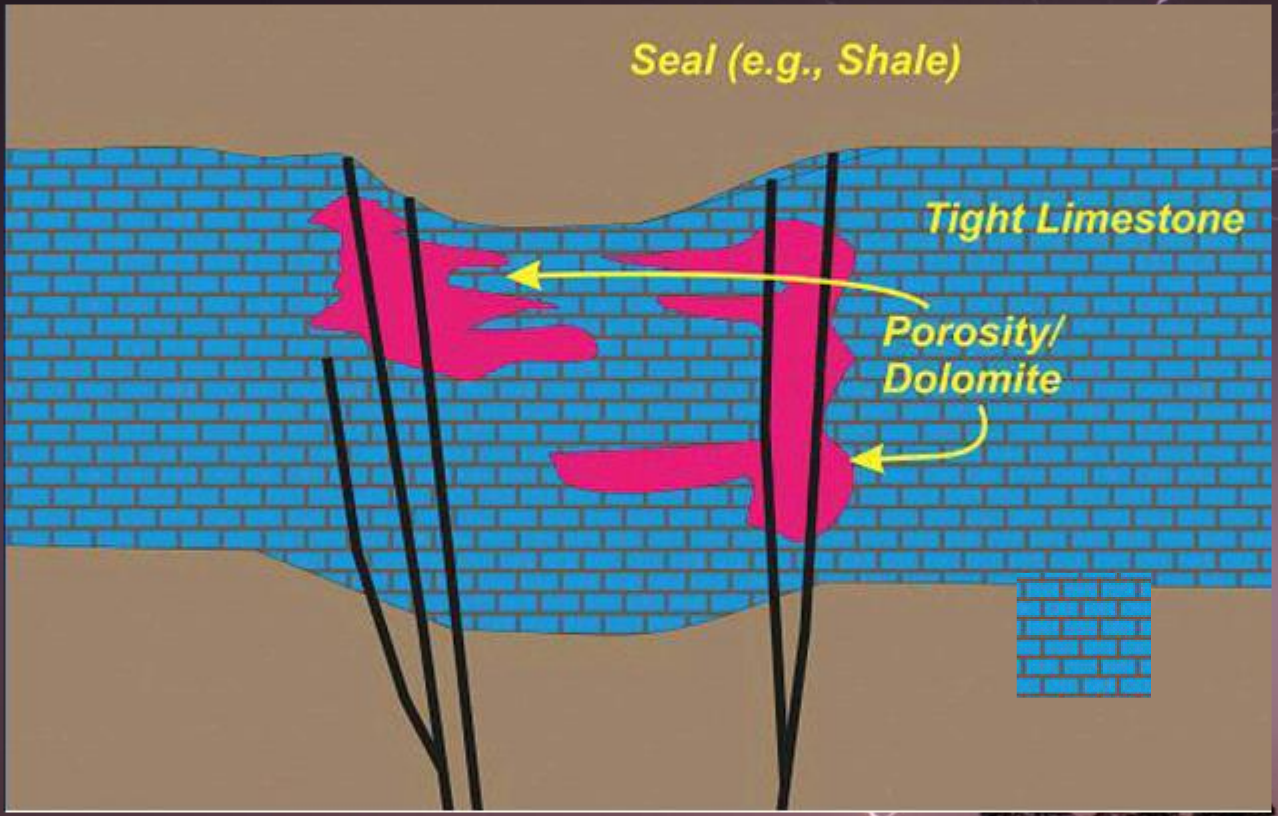
Exploration & Enhanced Oil Recovery Operations

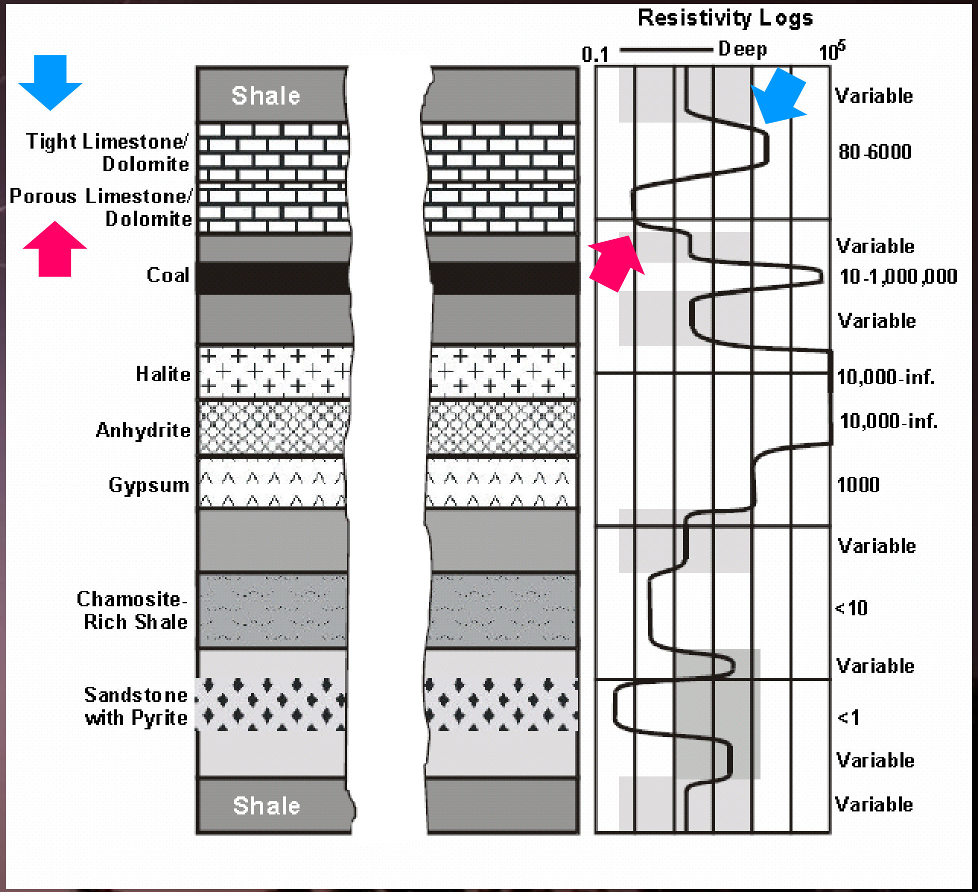
- North Dakota Field Correlations
- Hydrothermal Dolomites
- Monitoring CO_2 Injection

Lightning Strike Density Anomalies
Correlate to Bakken/Three Forks Fields
Williston Basin, North Dakota



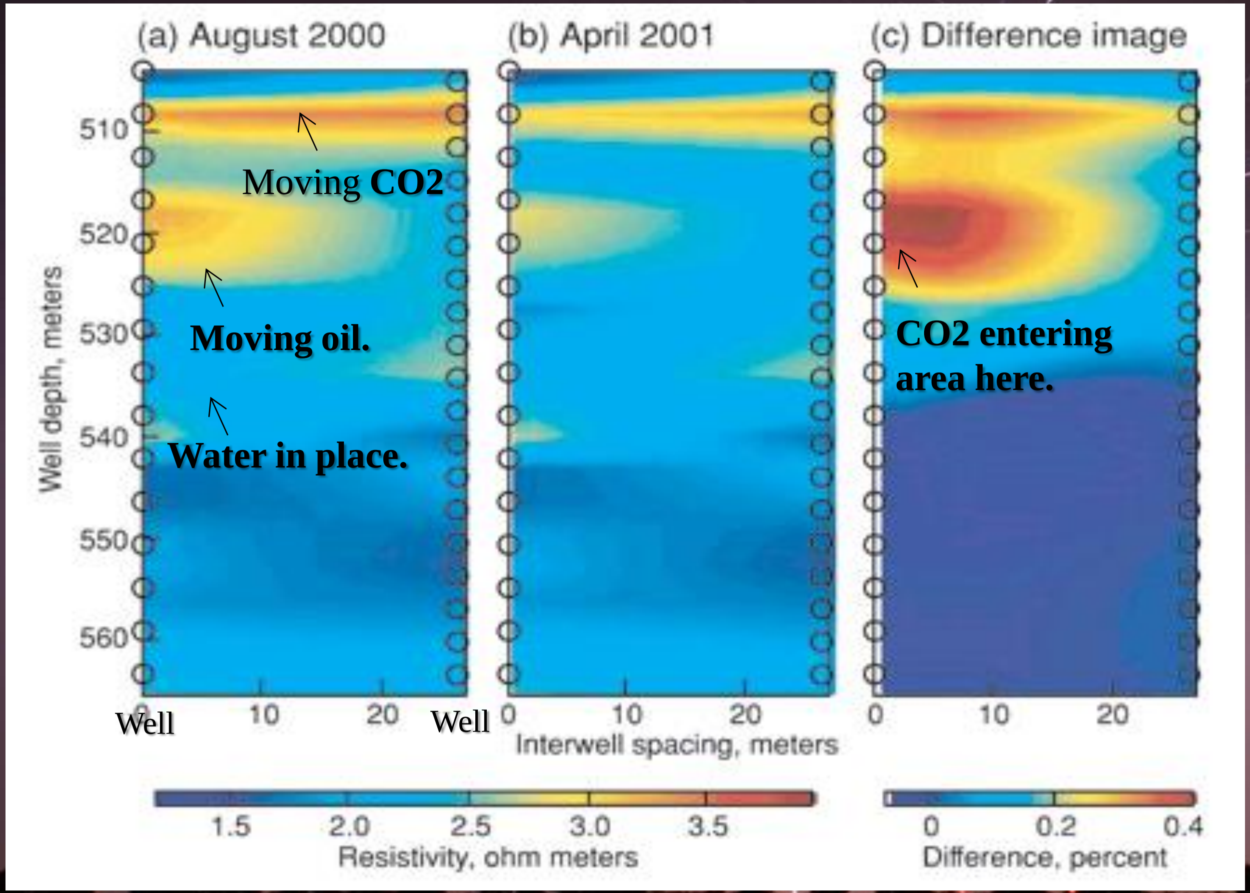
Hydrothermal Dolomites
Large Resistivity Contrasts ➡ NSEM Anomalies





CO_2 Enhanced Oil Recovery Operations
Monitoring Operations with Electrical Methods

Crosswell Electromagnetic Imaging



Electrical methods such as Crosswell Electromagnetic Imaging & Electrical Resistivity Tomography are useful for monitoring the migration of CO_2 in the subsurface.

DML can generate multi-year time lapse maps and potentially support EOR operations.

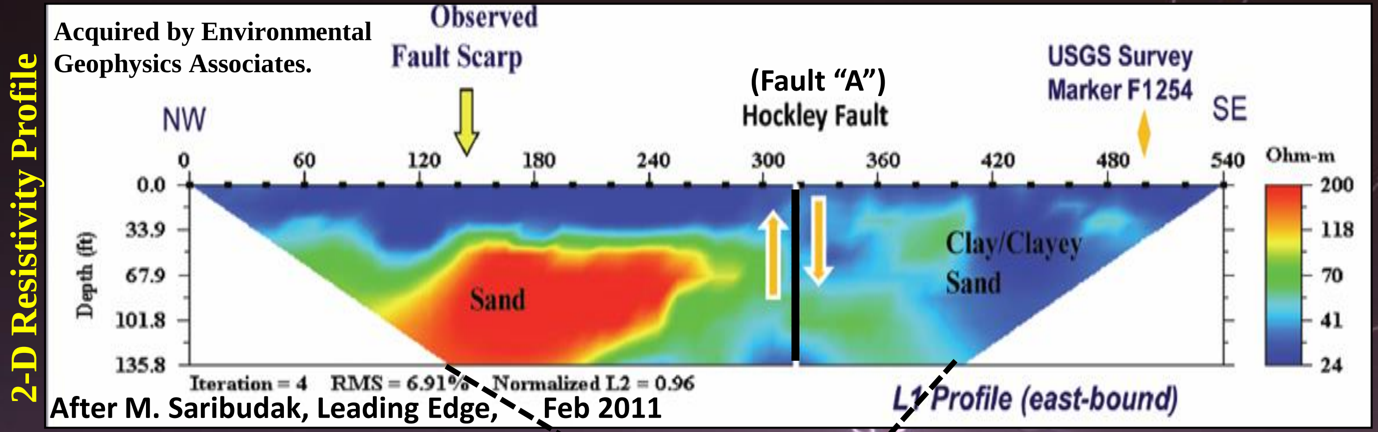
Current DML R&D Projects

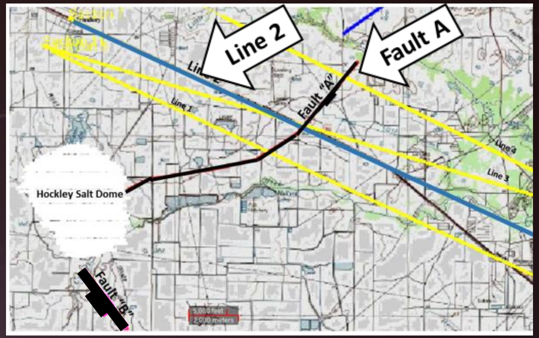
- Sequence Stratigraphy – Hockley, Texas
- 3-D Seismic Calibration Project – South Texas
- Mapping Active Faults - North Houston

Hockley, Texas

- Recent evaluation suggests NSEM may have resolution to identify & map erosional & depositional features.
- Comprehensive interpretation of entire 3-D resistivity volume in progress to properly distinguish between structural & stratigraphic features.

Sequence Stratigraphy

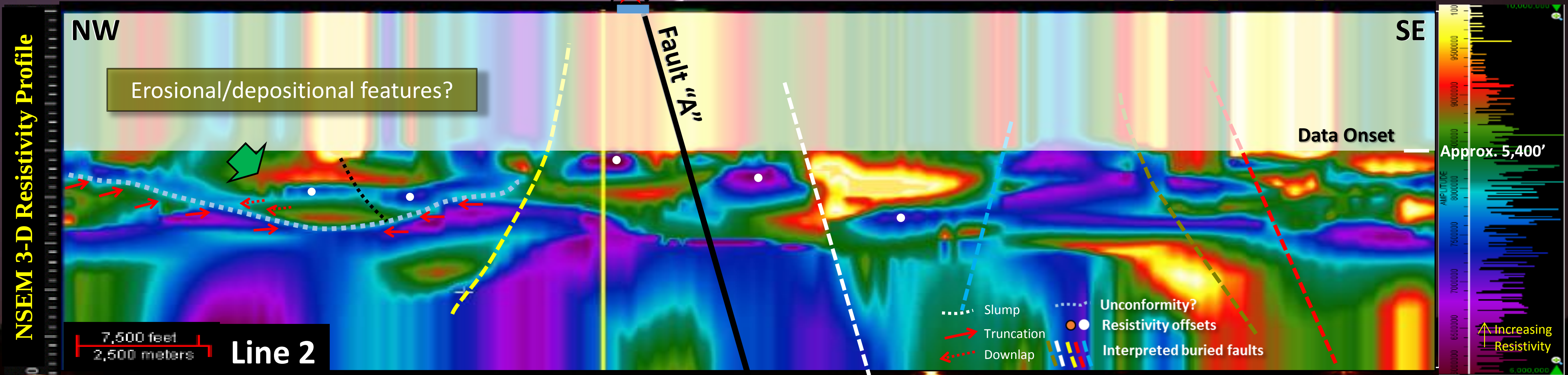




Line 2

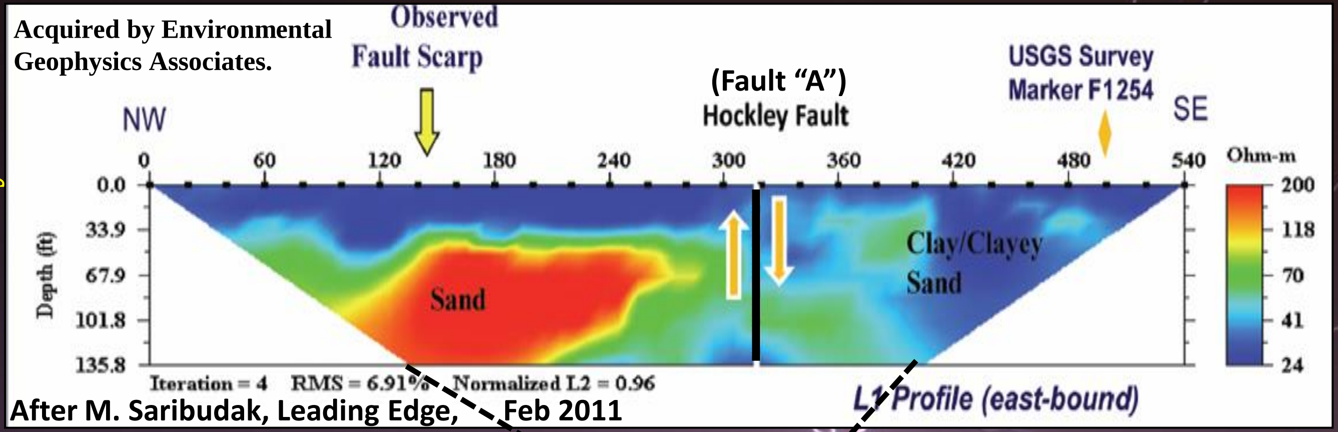
Alternate stratigraphic interpretation.

Potential identification of stratigraphic traps?

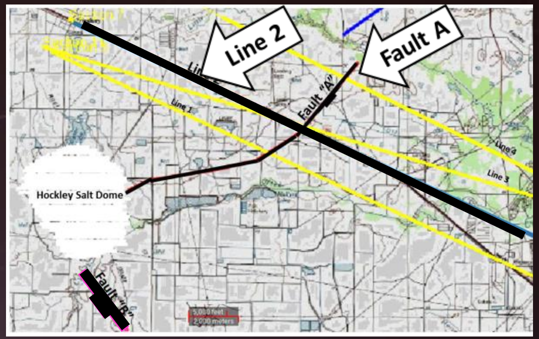


Sequence Stratigraphy

2-D Resistivity Profile



After M. Saribudak, Leading Edge, Feb 2011

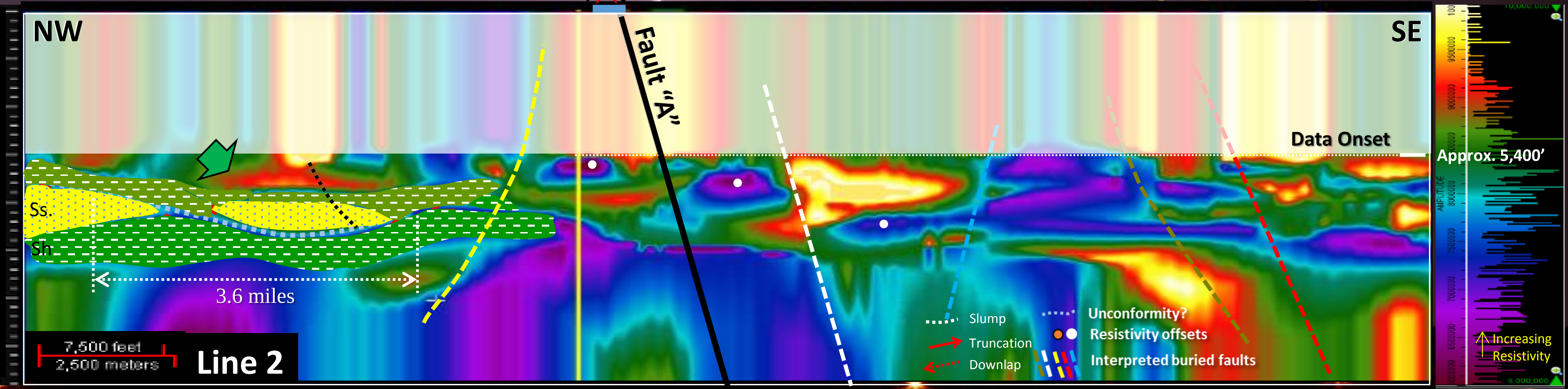


Line 2

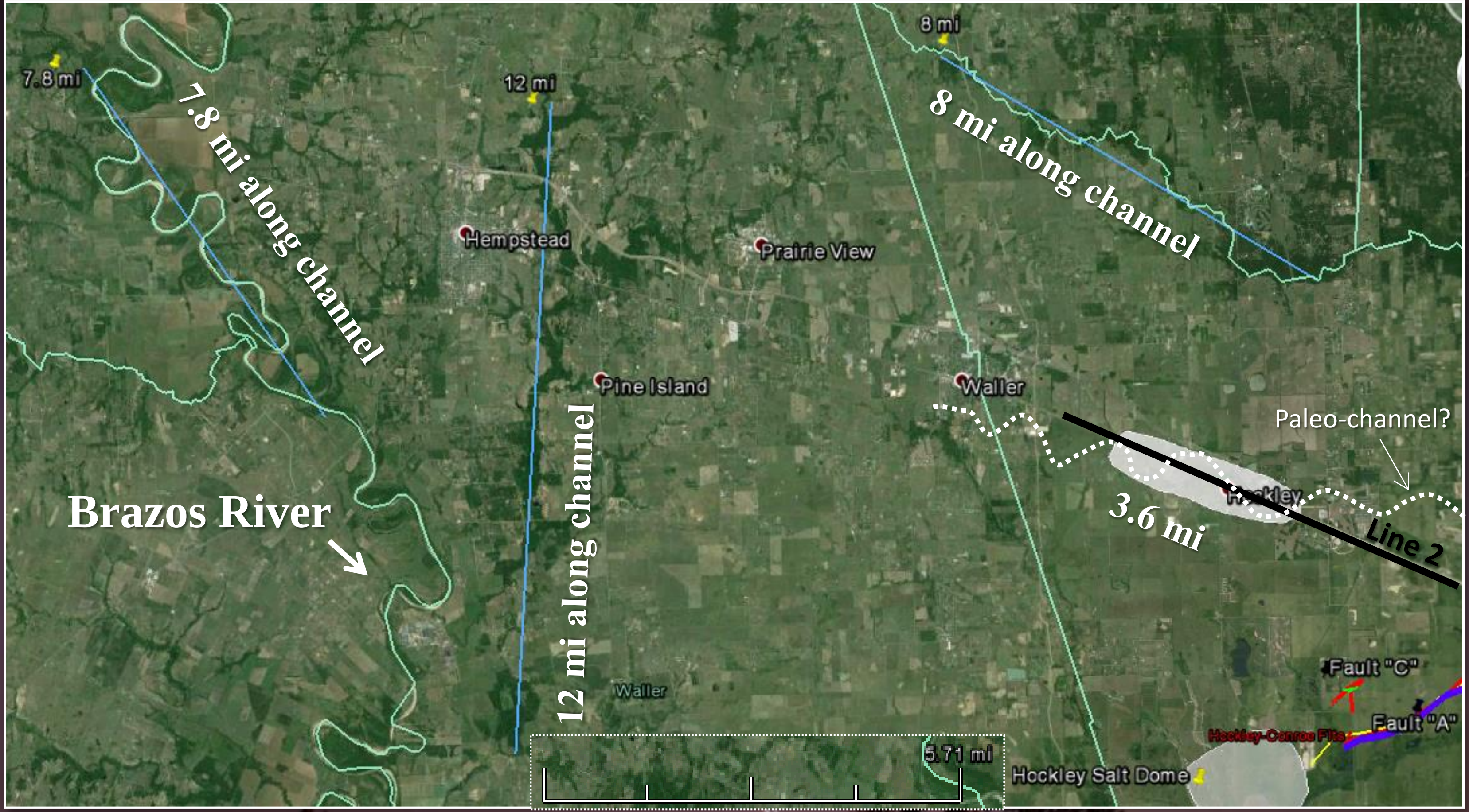
Strike line parallel to channel.

Potential identification of stratigraphic traps?

NSEM 3-D Resistivity Profile



Fluvial Analogues



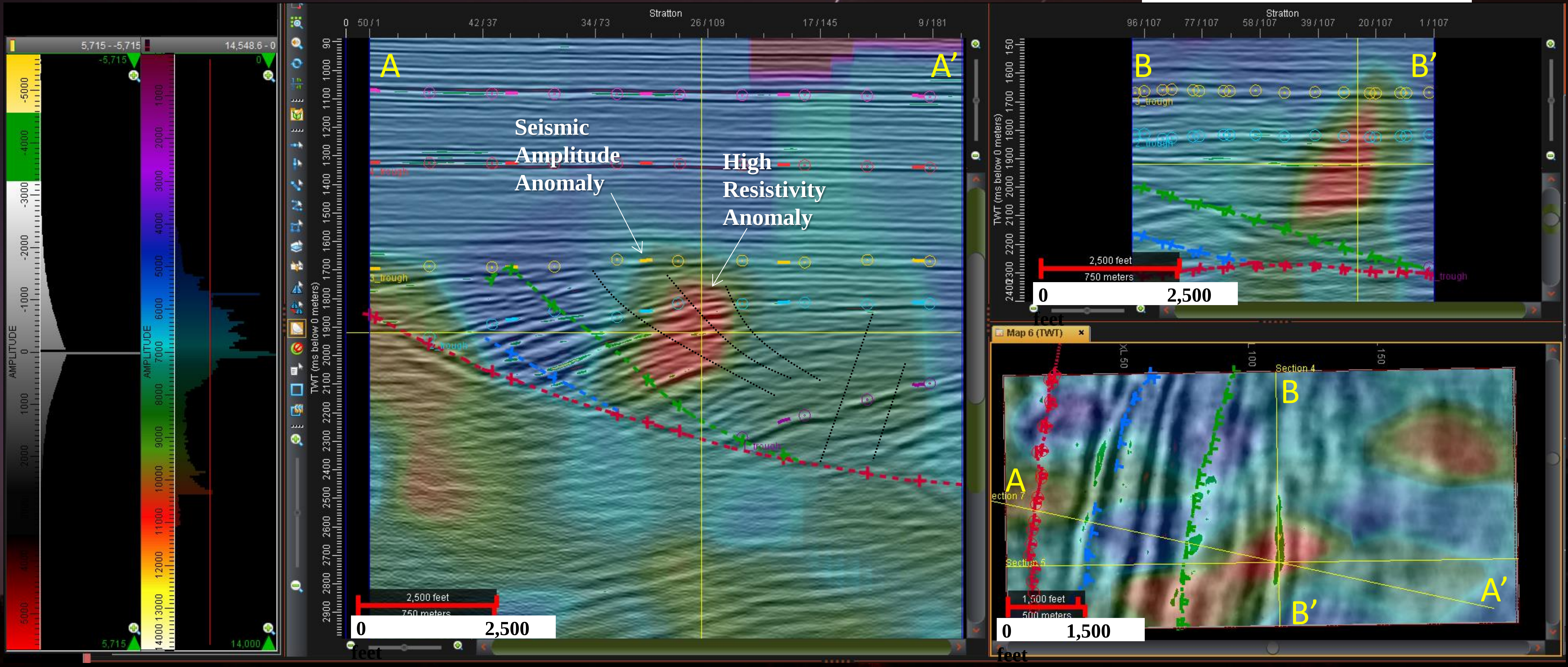
Possible analogues provided by nearby Brazos River and other meandering fluvial systems.

Line 2 possibly parallel to paleo-channel, encountering 3.6 miles of coalescing point bars within meander belt.

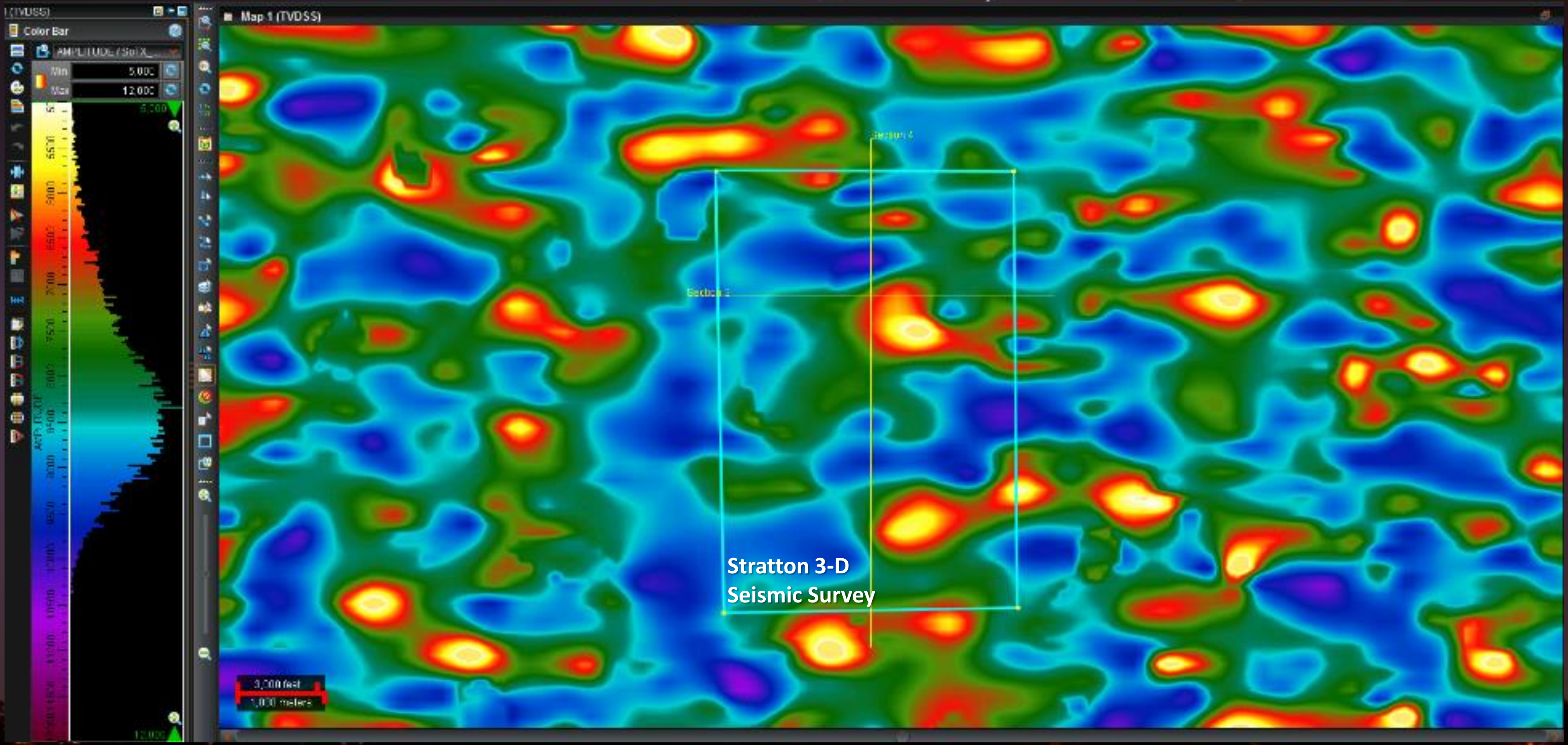
South Texas

- Hydrocarbon Indicator?
- Resistivity Slices
- Mapping Faults & Rock Properties

Resistivity Cross-Section over BEG Seismic



Resistivity Slice, South Texas
Interpretation in Progress

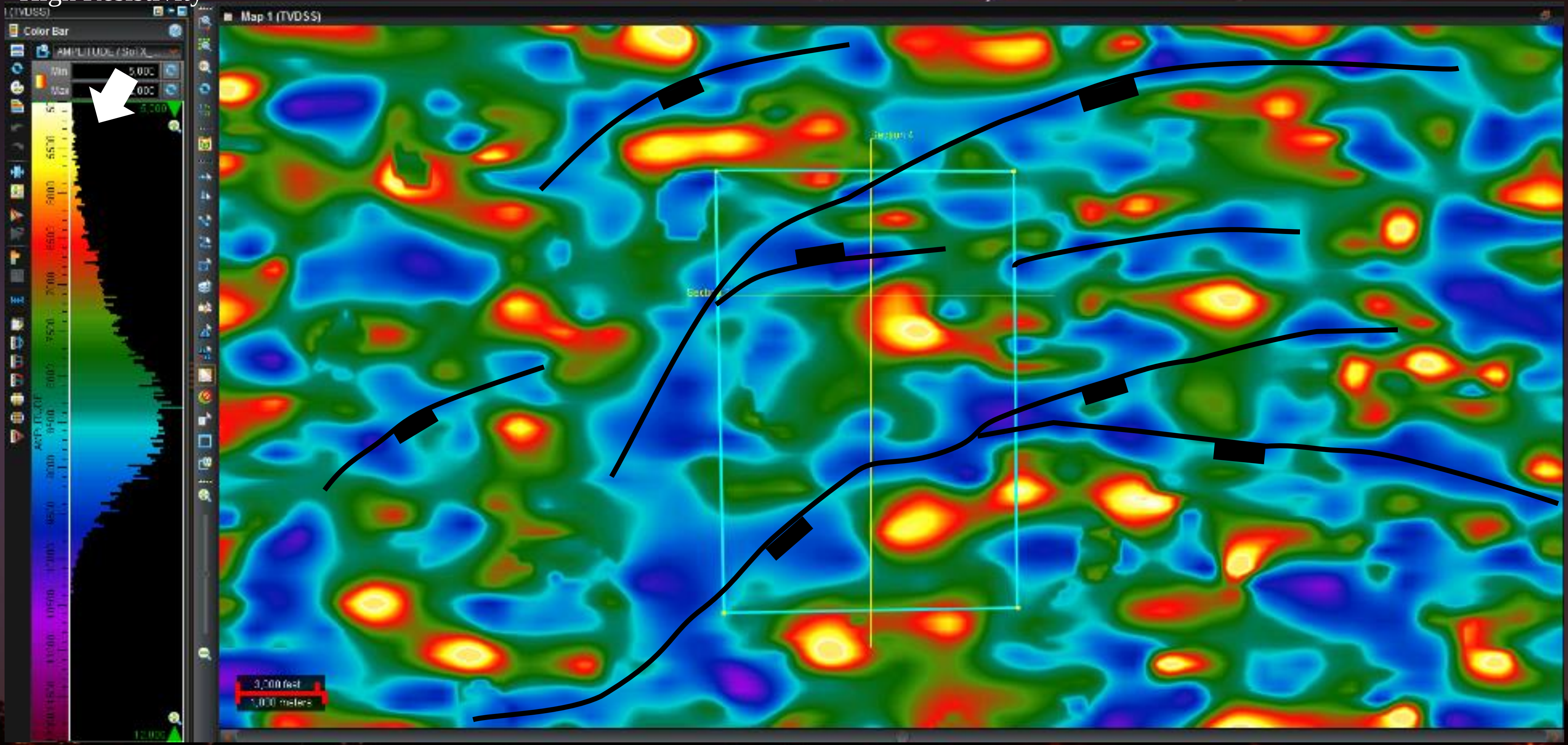


Apparent resistivity shows non-random patterns.

Laterally varying electrical properties of sedimentary rocks, and their associated fault surfaces, influence NSEM.

Another Interpretive Tool: Potential to Map Faults

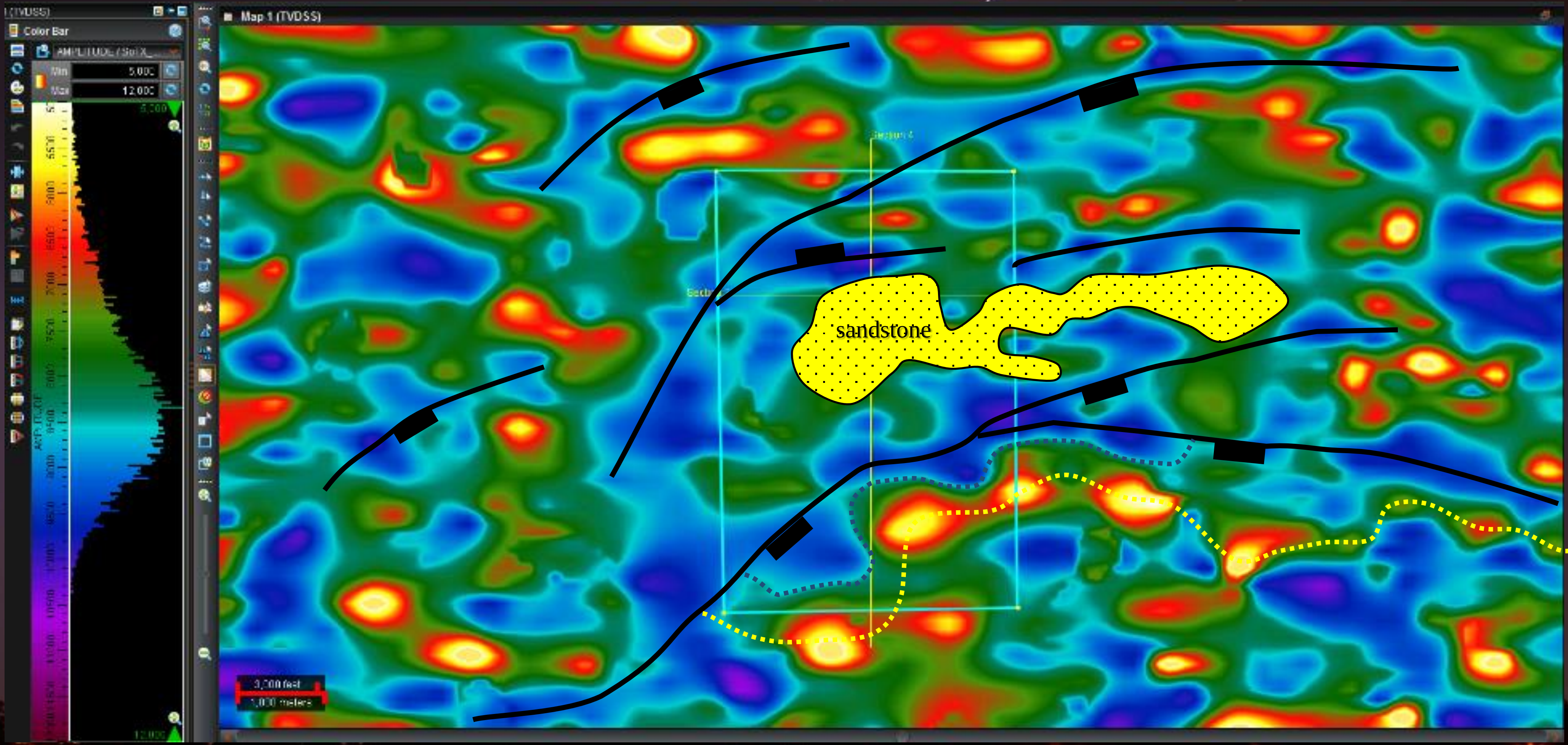
High Resistivity



Low Resistivity

Distribution of high & low resistivity lineaments suggest geological influence on lightning & the presence of faults.

Another Interpretive Tool: Potential to Map Rock Properties/Hydrocarbons



High resistivities associated with sandstones, i.e. potential reservoir quality rock.

NSEM resistivity slice analogous to subcrop showing distribution of reservoir quality formation.

North Houston

- Mapping Subsurface Faults
- Calibrating to active Addicks Fault System

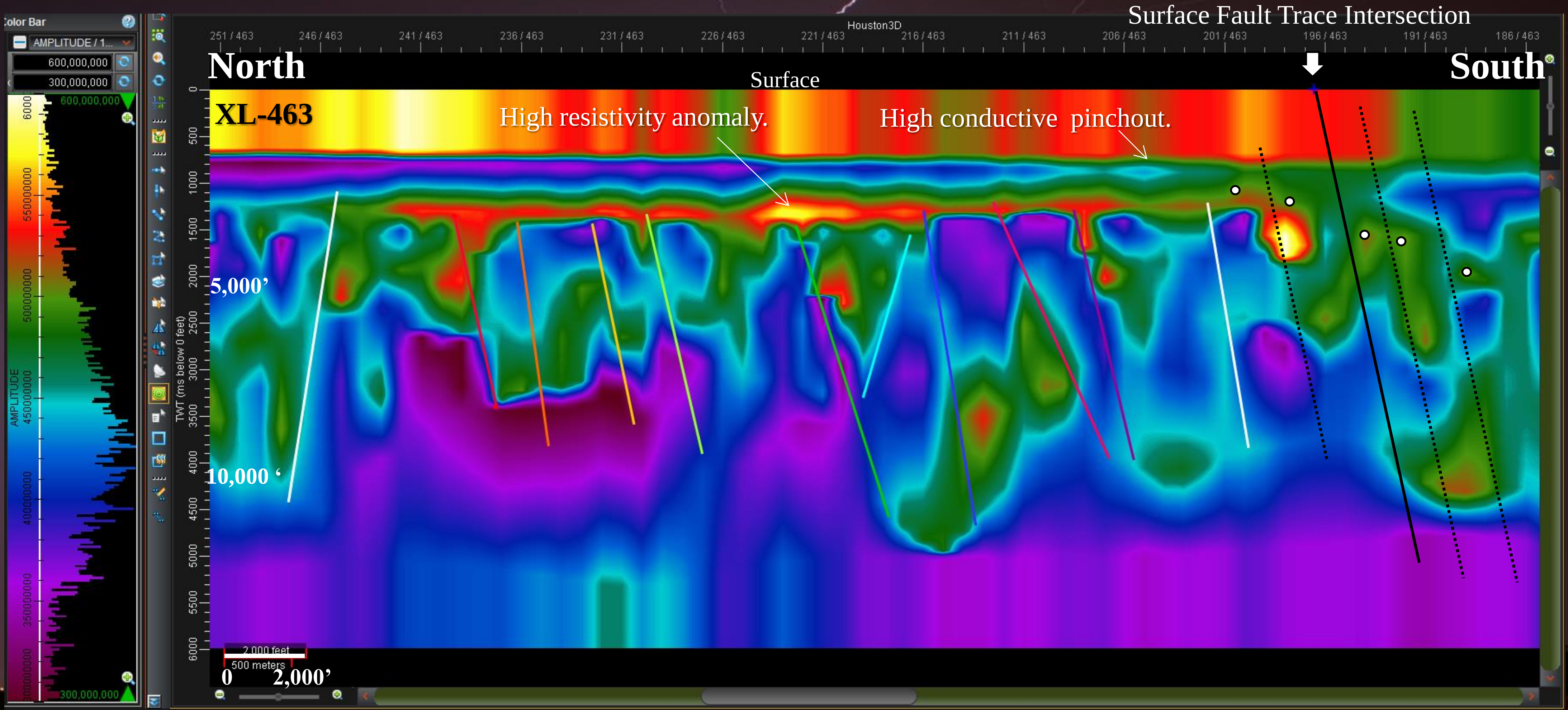
Active & Subsurface Fault Mapping In Progress
North Houston, Harris County, TX

See Lightning . . .
DML
. . . think DML & solutions

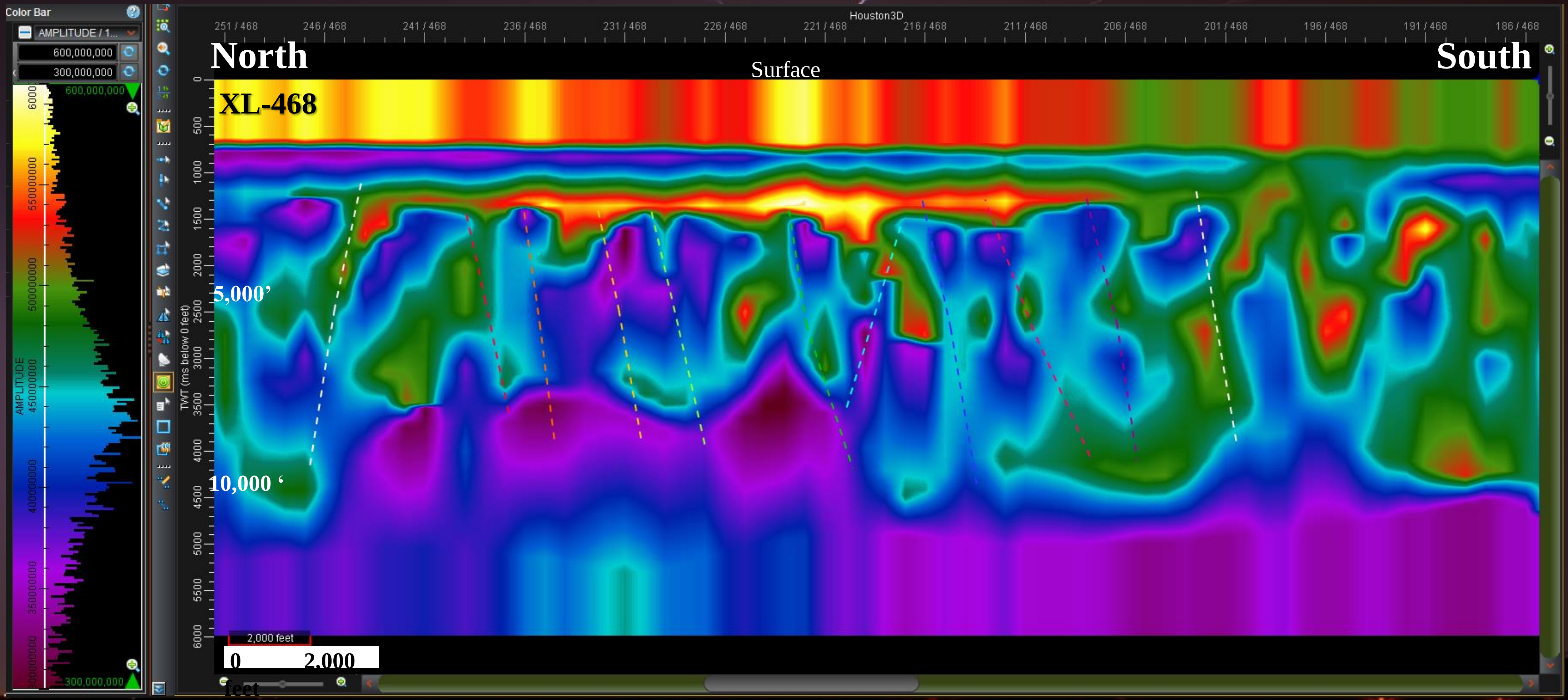
Location Map

NSEM Reveals Structure & Stratigraphy

Potential Faults, Pinchouts & Resistivity Anomaly



3-D Fault Analysis Capability
Triangulated Fault Segments & Fault Plane Maps

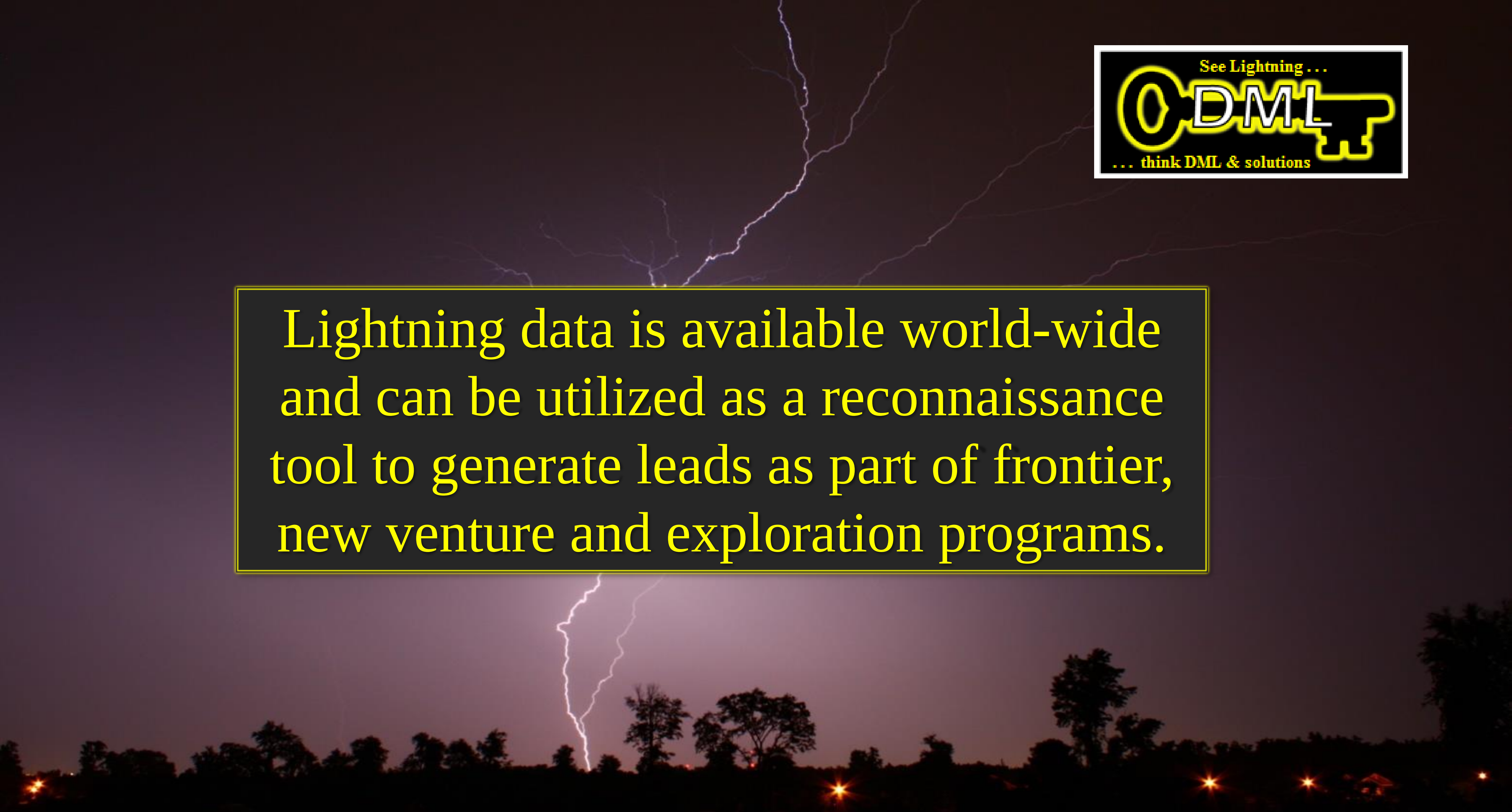


NSEM OVERVIEW

- NSEM can map regional & individual faults, rock properties & the presence of minerals; it can generate leads, & has demonstrated remarkable potential to identify hydrocarbon accumulations.

- NSEM can be calibrated to, & integrated with, seismic & subsurface geology, potential field & near surface geophysical data.

- NSEM can fill in between or extend existing data & when combined with other data, narrow down feasible interpretations.



Lightning data is available world-wide and can be utilized as a reconnaissance tool to generate leads as part of frontier, new venture and exploration programs.

DML's Technology is being Recognized

See Lightning . . .
DML
. . . think DML & solutions

GULF COAST ASSOCIATION OF GEOLOGICAL SOCIETIES

www.gcags.org

Dear Kathleen,

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

• • •

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

"Best Paper" 2 yrs. running!
2014/2015

Recent Presentations:

Annual SW AAPG Conv., Wichita. Falls, TX
Annual AAPG Convention, Denver, CO
WTGS Fall Symposium, Midland, TX
Annual SEG Convention, New Orleans, LA
Annual GCAGS Convention, Houston, TX
2nd Annual Hydro Geo Workshop, Boerne, TX
Landmark Innovation & Forum, Houston, TX
Miss. River Comm./Corps Engineers, Baton Rouge, LA
AGU/SEG Potential Field/EM Workshop, Keystone, CO
New Orleans Geological Society Luncheon
Lafayette SIPES Luncheon
South Texas Geological Society Luncheon, San Antonio
Geoph Soc. Houston Potential Fields SIG Dinner Meeting
SW Louisiana Geophysical Society Luncheon, Lafayette
Baton Rouge Geological Society Luncheon

Two Papers & Posters Accepted for 2016

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.

Appreciation to Roice Nelson of Dynamic Measurement, LLC for his assistance extracting the resistivity profiles displayed in this presentation and for the slides borrowed from his image inventory.

Dynamic Measurement, LLC.

See Lightning . . . DML . . . think DML & solutions

For questions regarding:

- Proprietary/Speculative Data Sales
- Project Design/Management
- Seismic, Subsurface, NSEM Data Integration
- Seismic Structural/Stratigraphic Interpretation
- Lead & Prospect Generation
- Exploitation Mapping/Drill-Site Delineation
- Detailed Fault Analyses

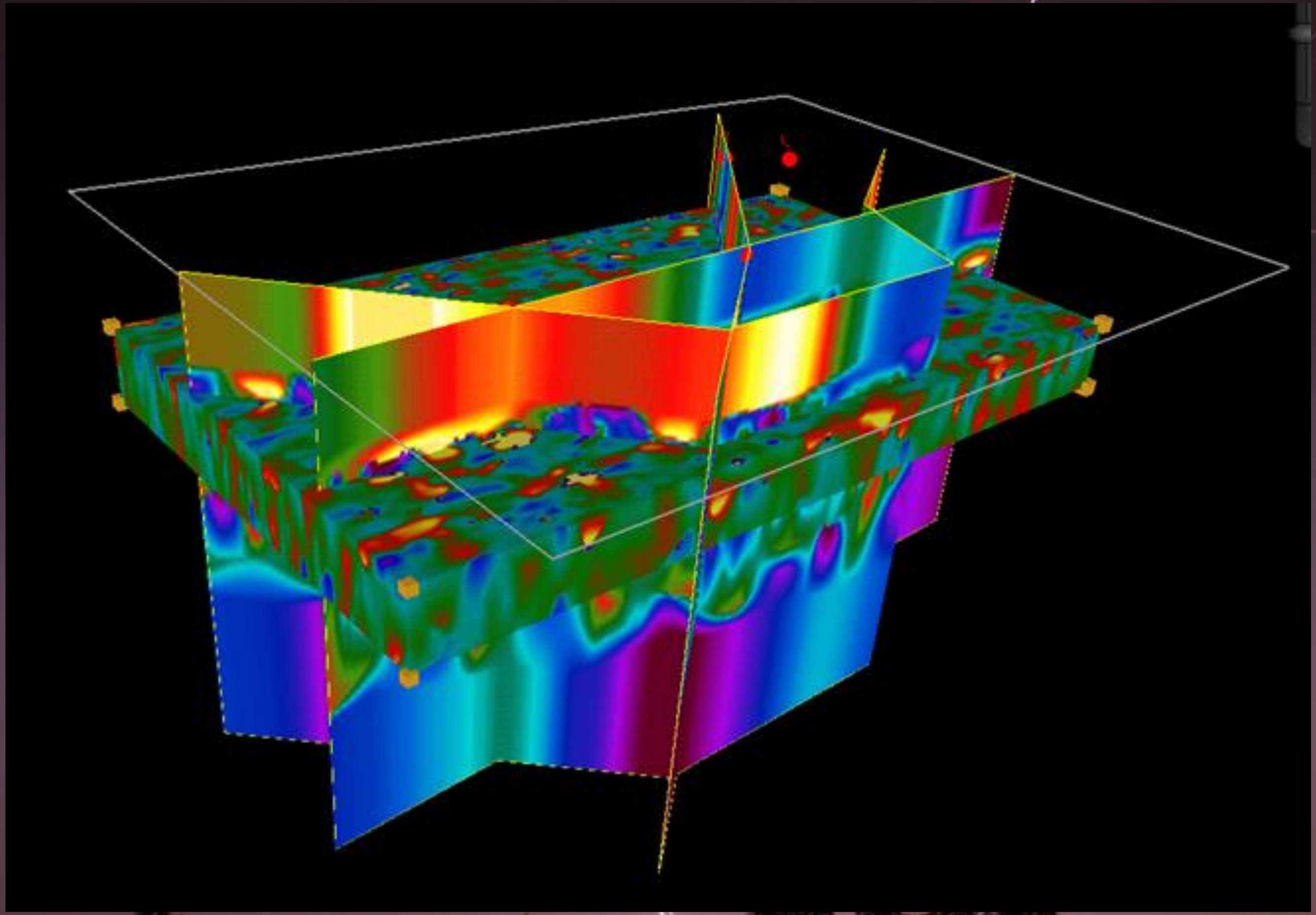
Contact:

Louis Berent
P.O. Box 690388
Houston, TX 77269

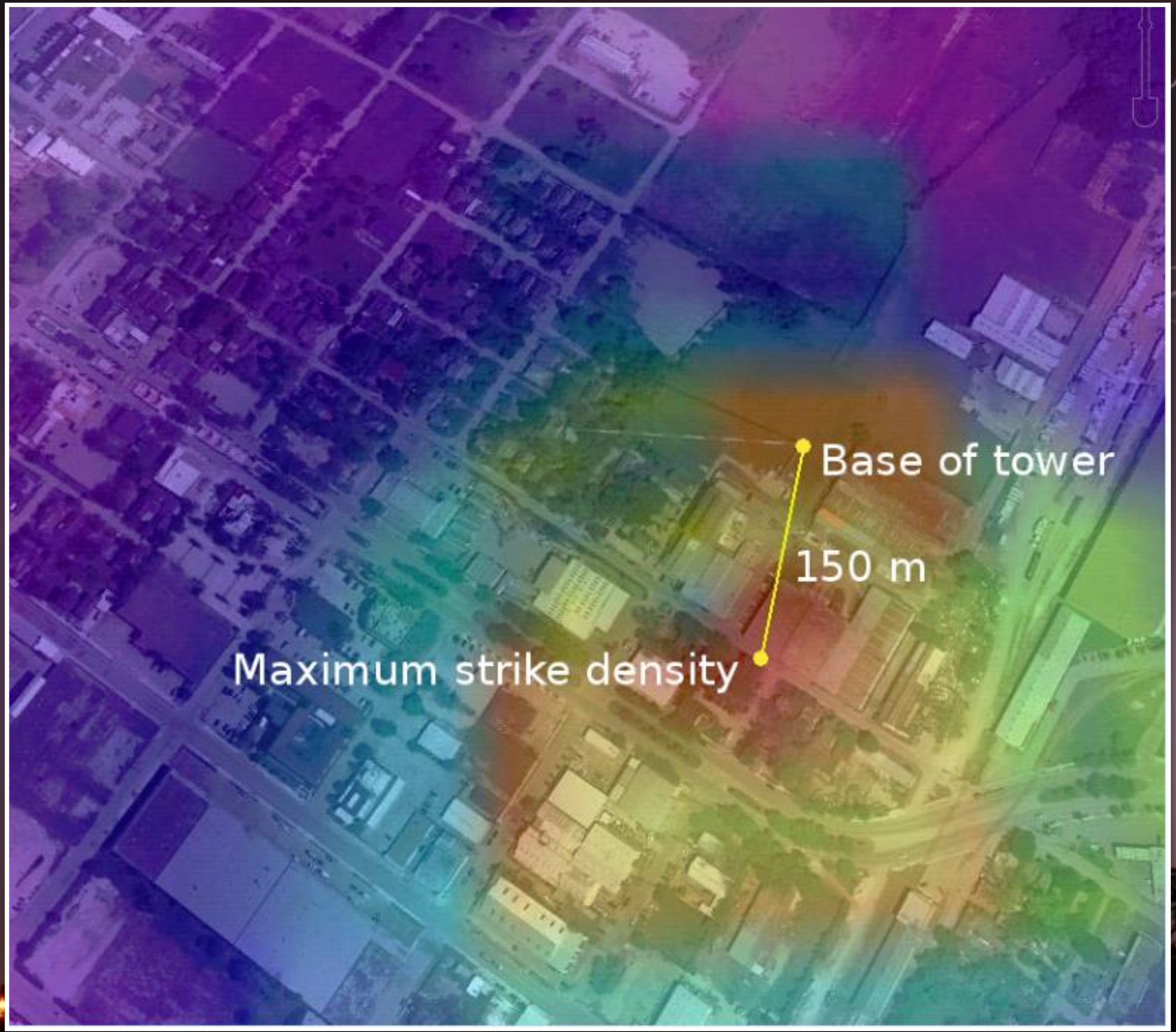
Office: 281 370-5296
Cell: 832 352-3795
ljberent@dynamicmeasurement.com

Roice Nelson
2155 West 700 South #31
Cedar City, Utah 84720
roice@dynamicmeasurement.com

Appendix



Accuracy Locating Lightning Strikes



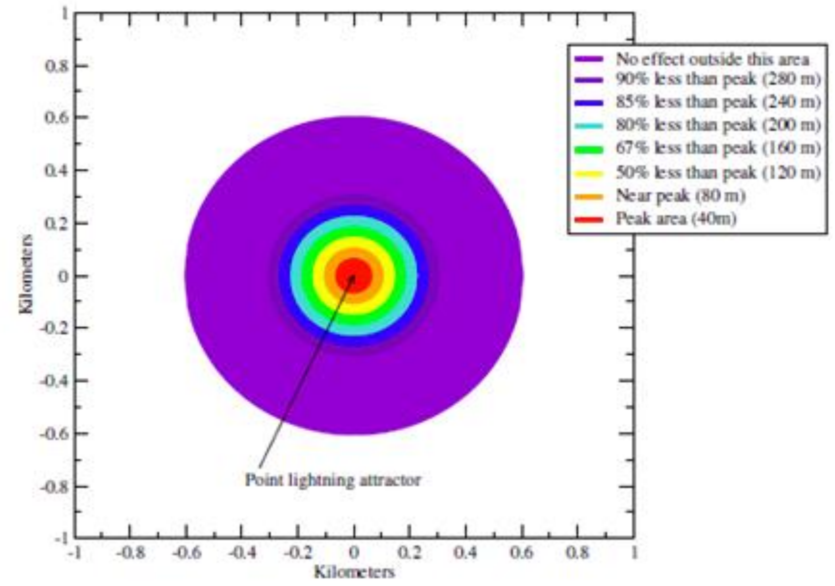
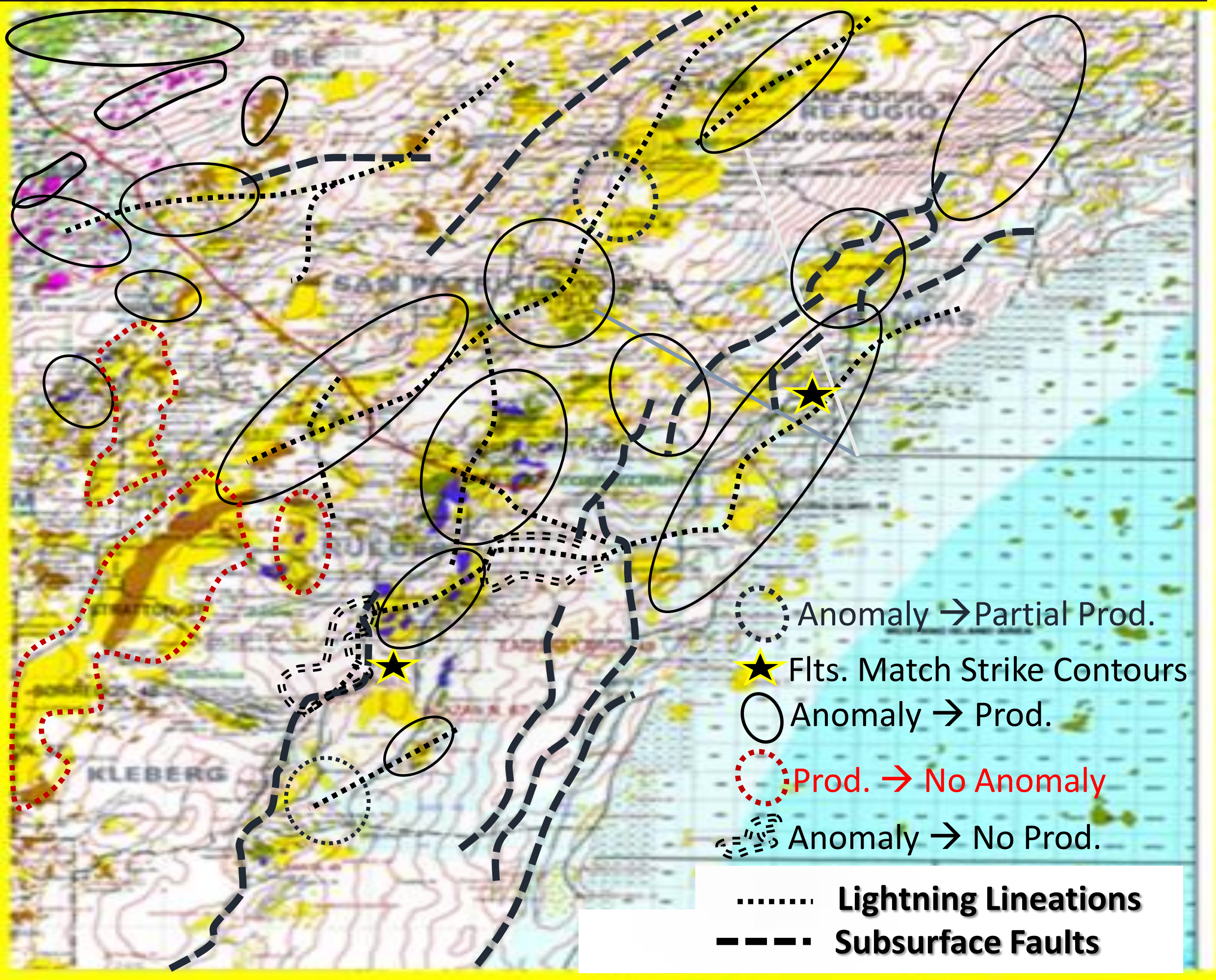


Figure 3: Summary of strike location variation

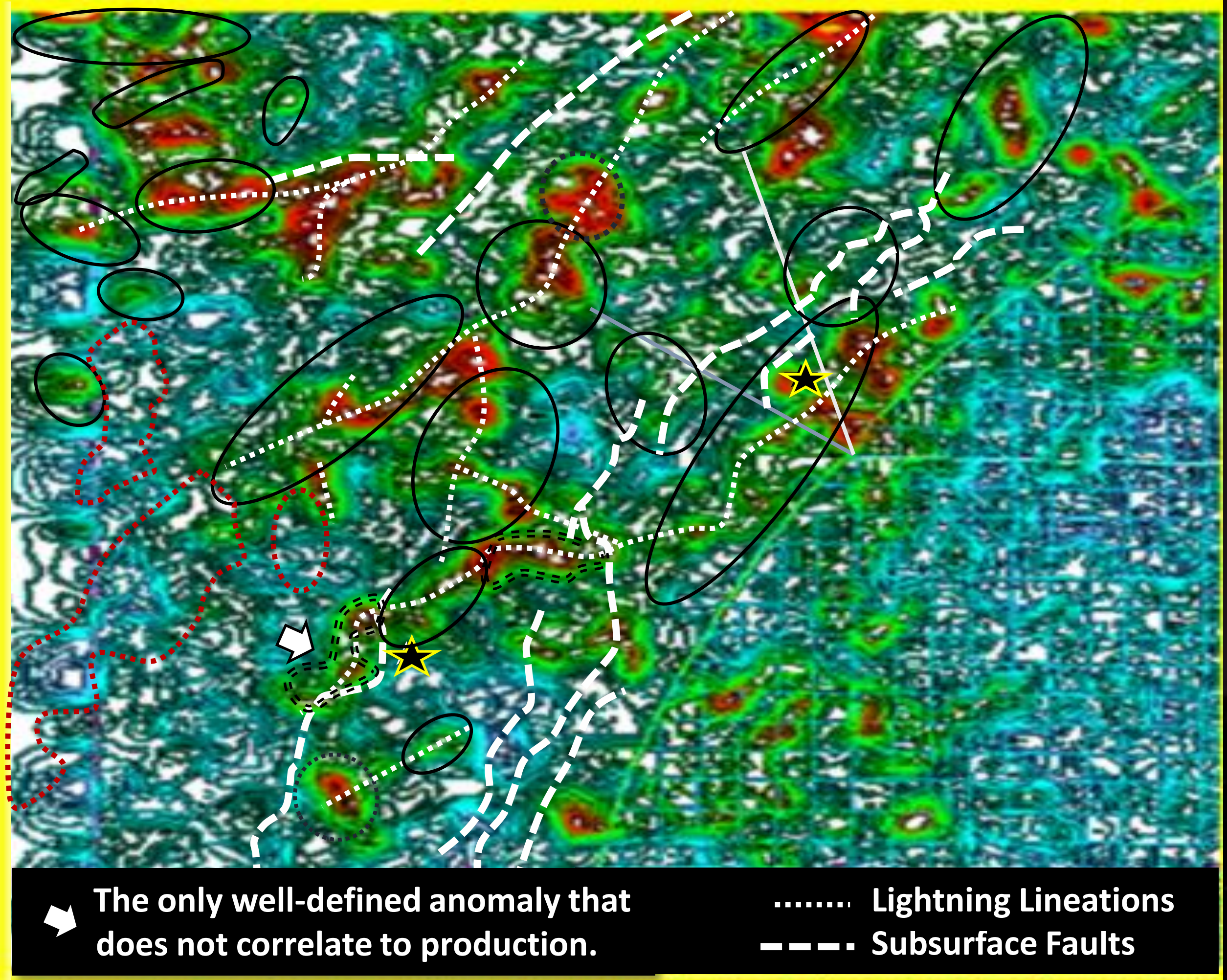
- The error in location for 90% of strikes is less than 200 m.
- The error in location for 75% of strikes is less than 120 m.
- The error in the location of 61% of strikes is less than 80 m.
- The error in the location of a feature interpreted from a reasonably dense database of strikes is 10-20 m.

NSEM Correlates To Geology:
Fault Patterns and Hydrocarbon Accumulations

Structure & Field Outlines

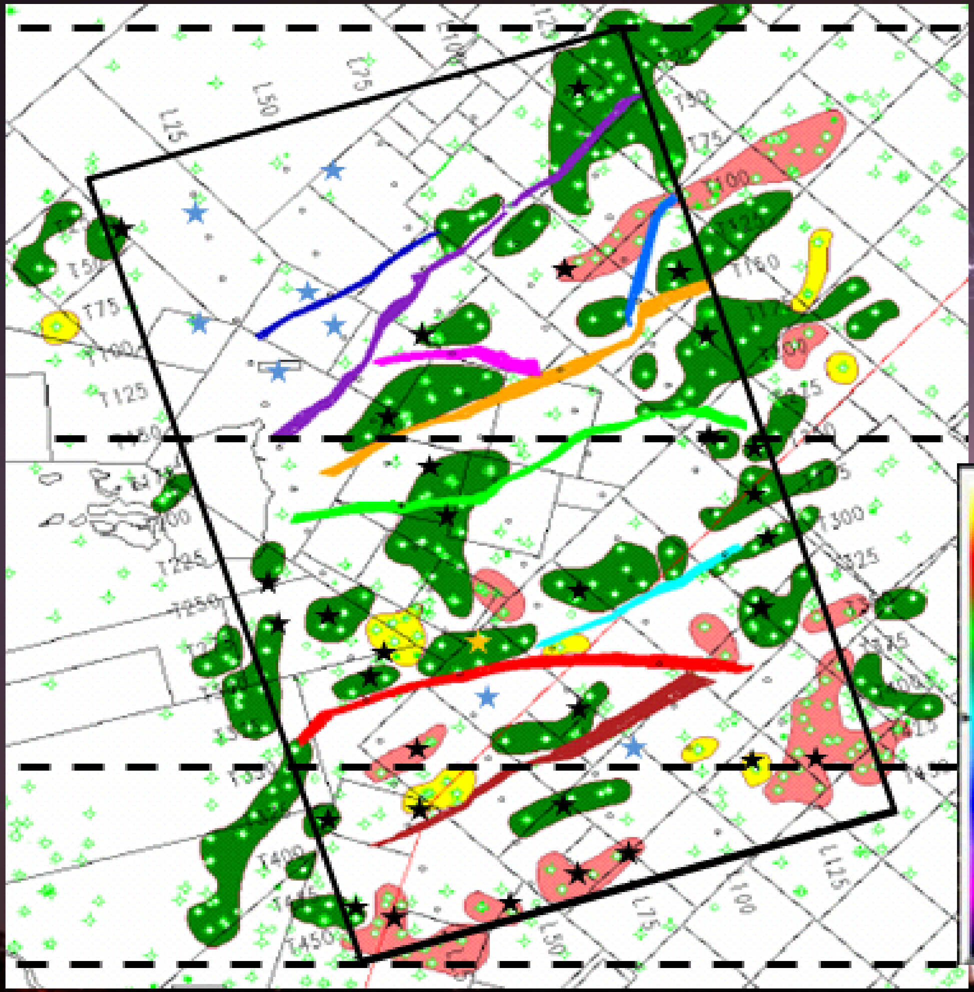


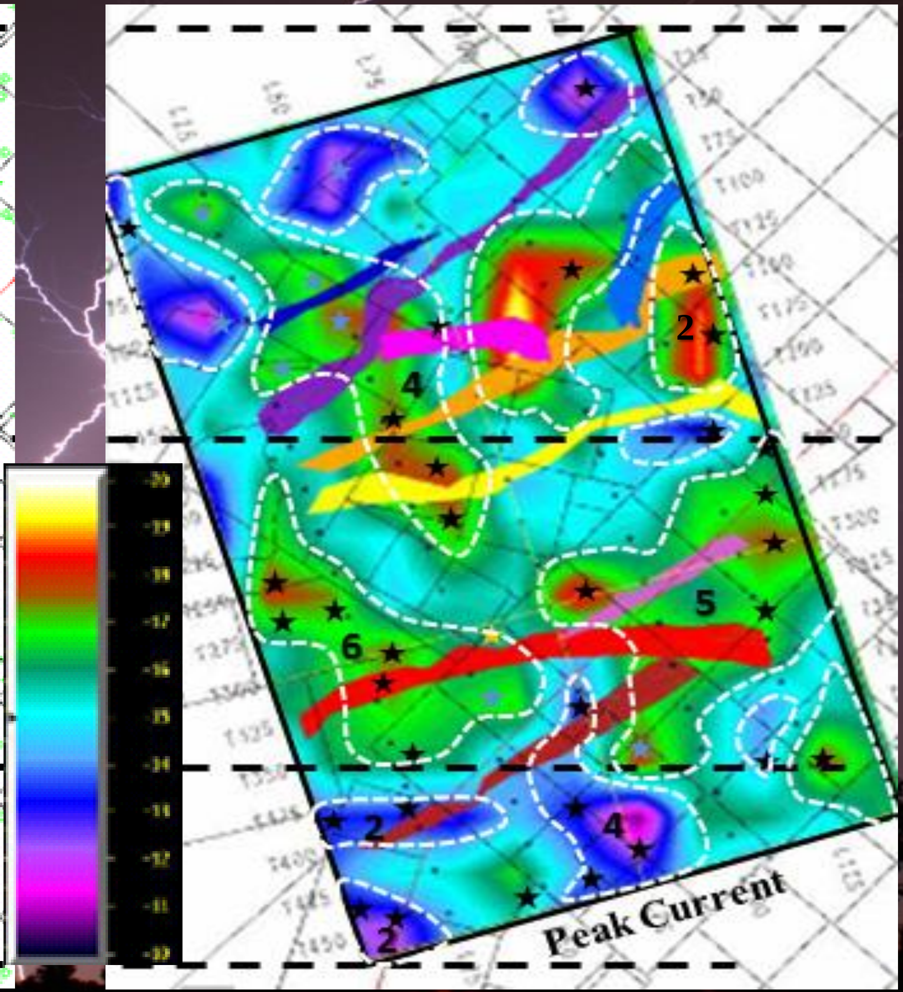
Lightning Strike Density



Interpretation of Peak Current Clusters: Duplicates Rise Time Reconnaissance Mapping

See Lightning . . . DML . . . think DML & solutions



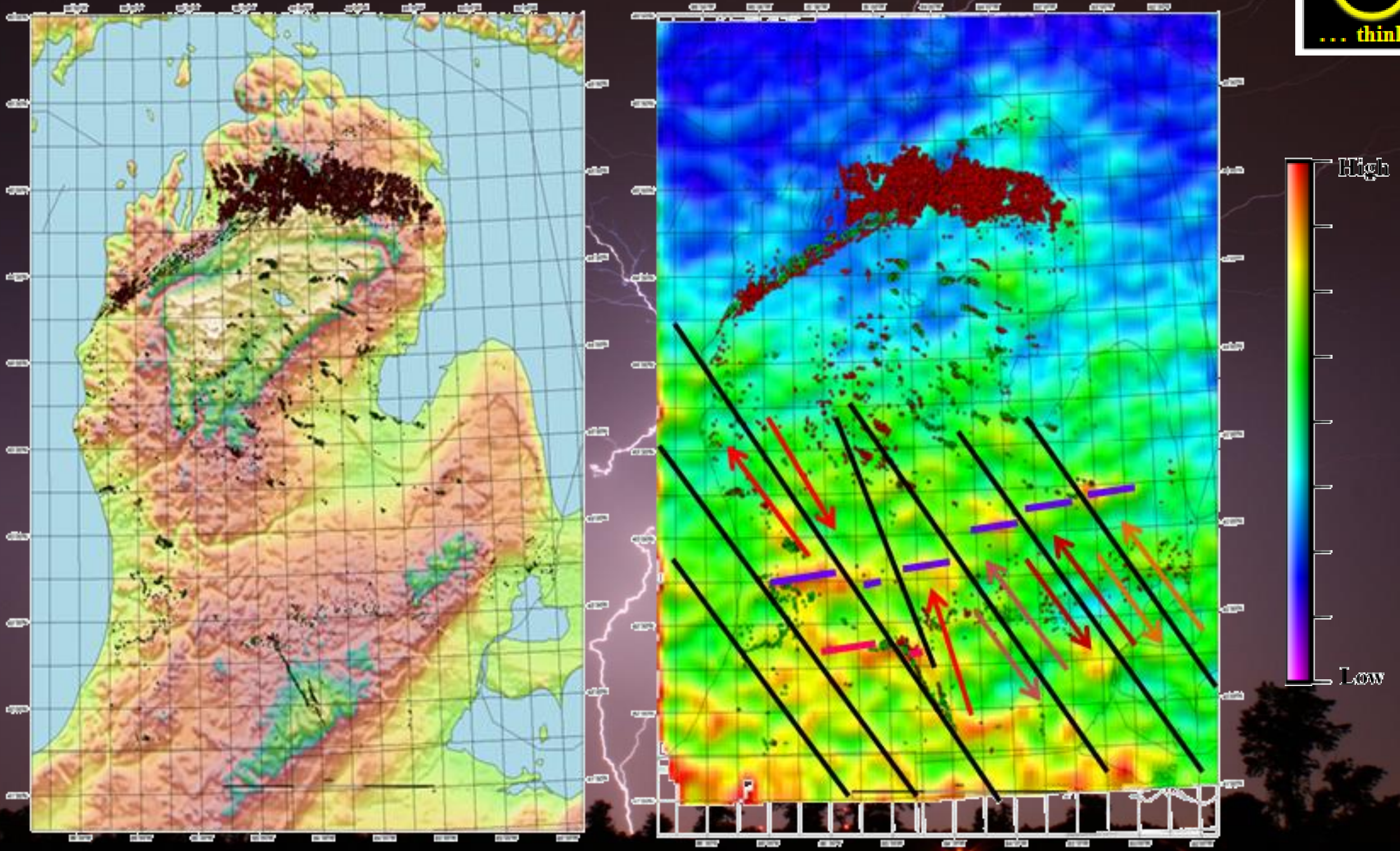


In this slightly different interpretive technique, 81% of lightning Peak Current clusters correlated to Frio, Vicksburg or Wilcox production, again illustrating how NSEM can be used for reconnaissance mapping.

★ Field correlations.
★ Missed Production
★ False positives
-- Alignment markers.

42 anomalies
34 correlate to production.
8 false positives

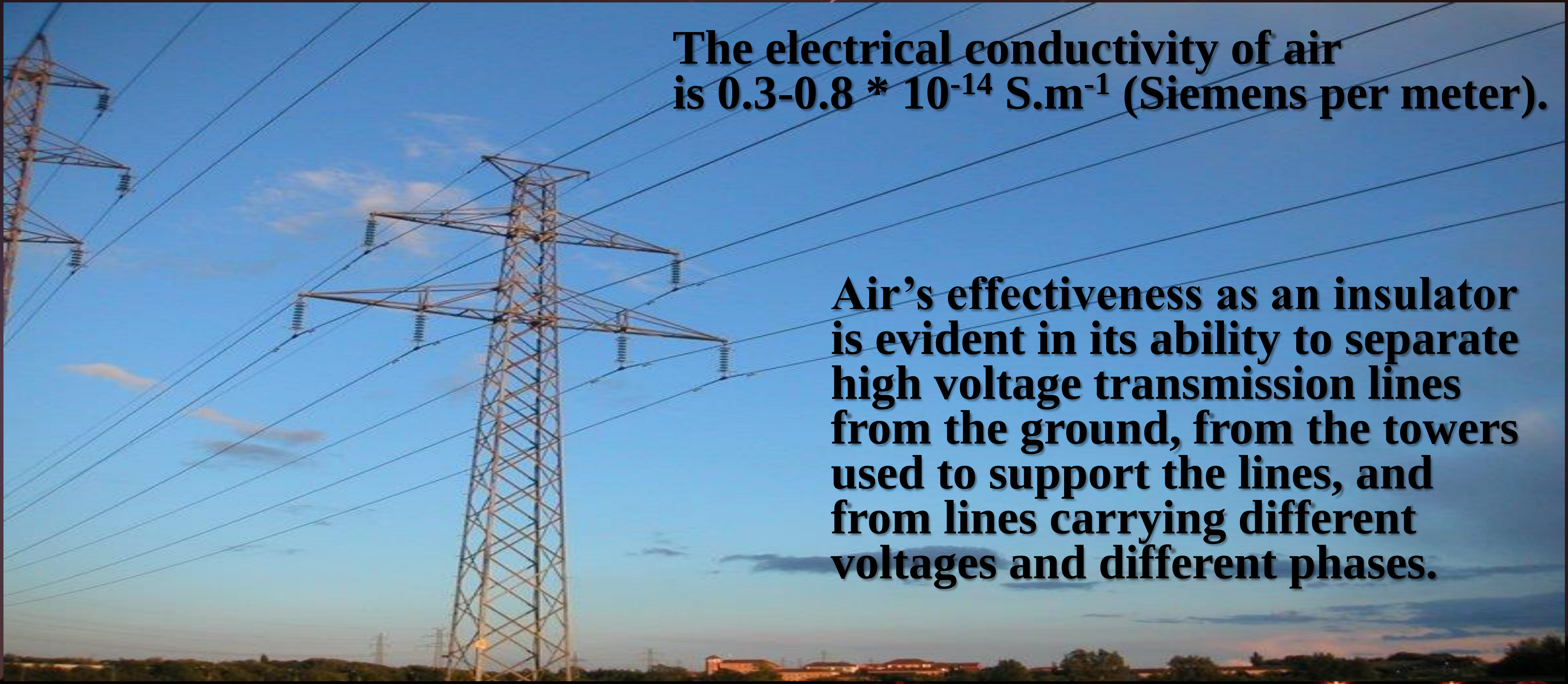
Michigan Basin Topography & Strike Density



Strike-slip Faulting

The Earth as a Capacitor ,
Generating & Displaying 3-D Resistivity Volumes

The Atmosphere is an Effective Insulator



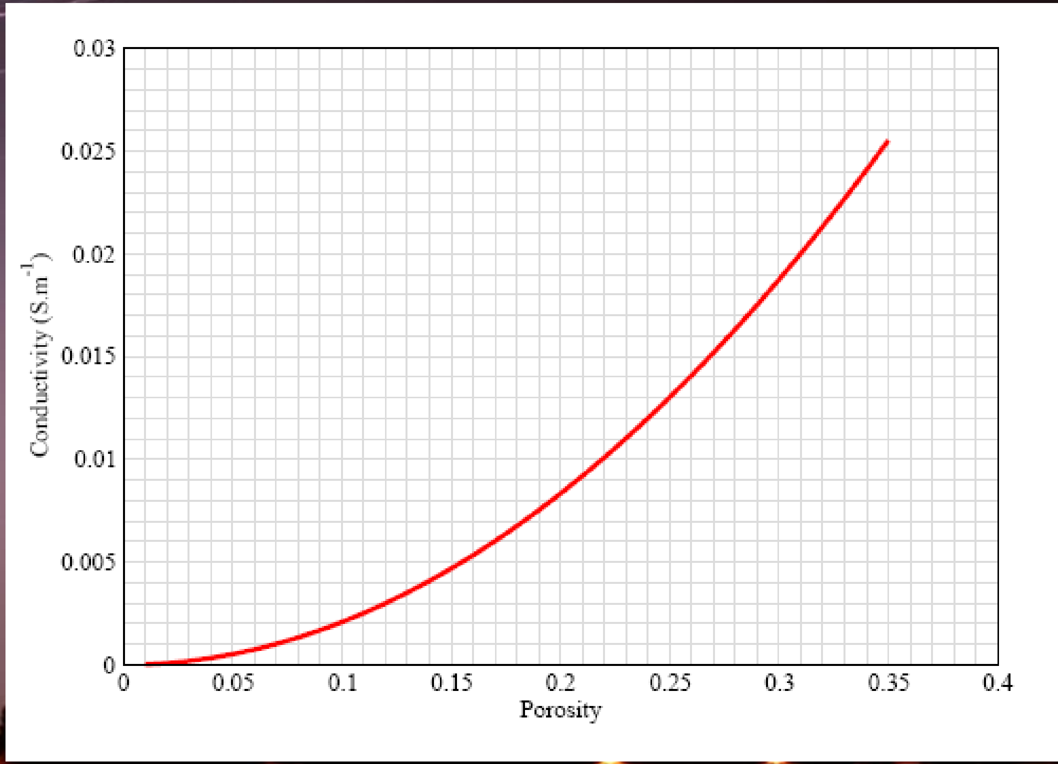
The electrical conductivity of air is 0.3-0.8 * 10^{-14} S.m^{-1} (Siemens per meter).

Air's effectiveness as an insulator is evident in its ability to separate high voltage transmission lines from the ground, from the towers used to support the lines, and from lines carrying different voltages and different phases.

Discussion of Electrical Conductivity

The earth is much more conductive than air, which is why air acts as a dialectric.

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



Assuming 5% porosity, a typical sedimentary rock's electrical conductivity is 5.0 $* 10^{-4}$ S.m^{-1} or about <u>10^{10} times the conductivity of air.</u>

The Atmospheric Capacitor

Upper Plate

- 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.

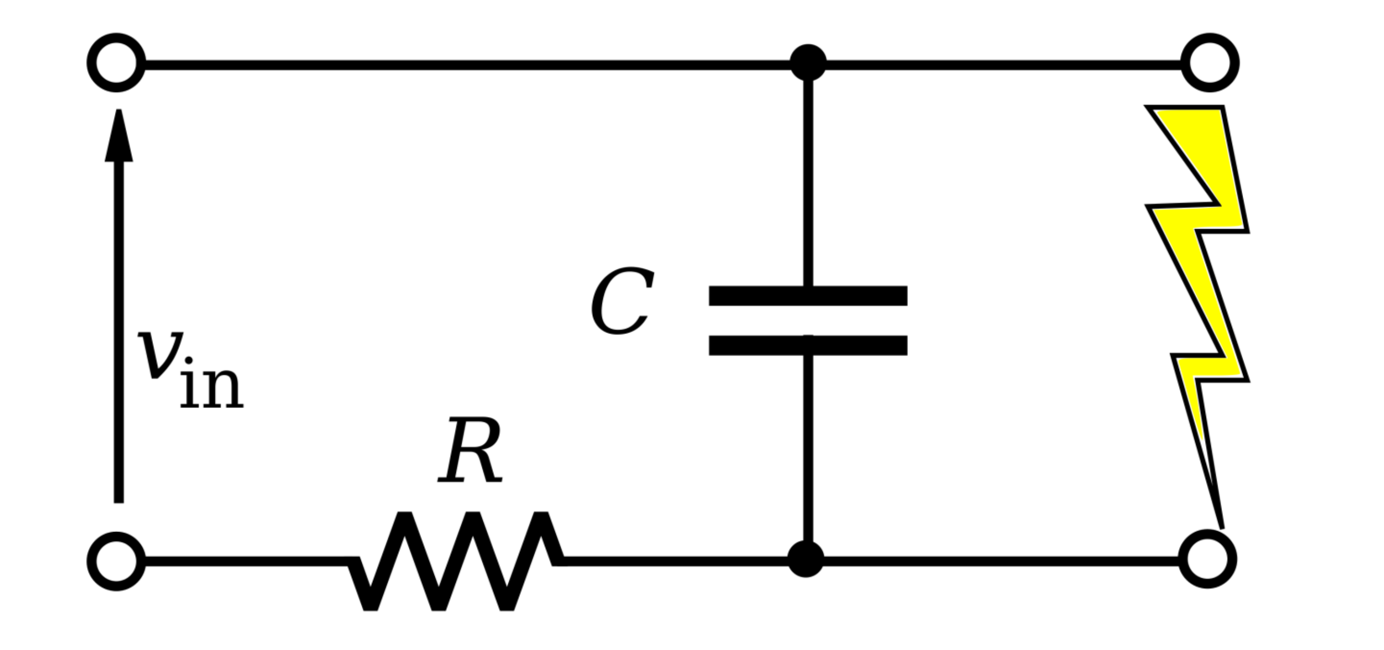
Dielectric

Lower Plate

Lightning: Dielectric Breakdown

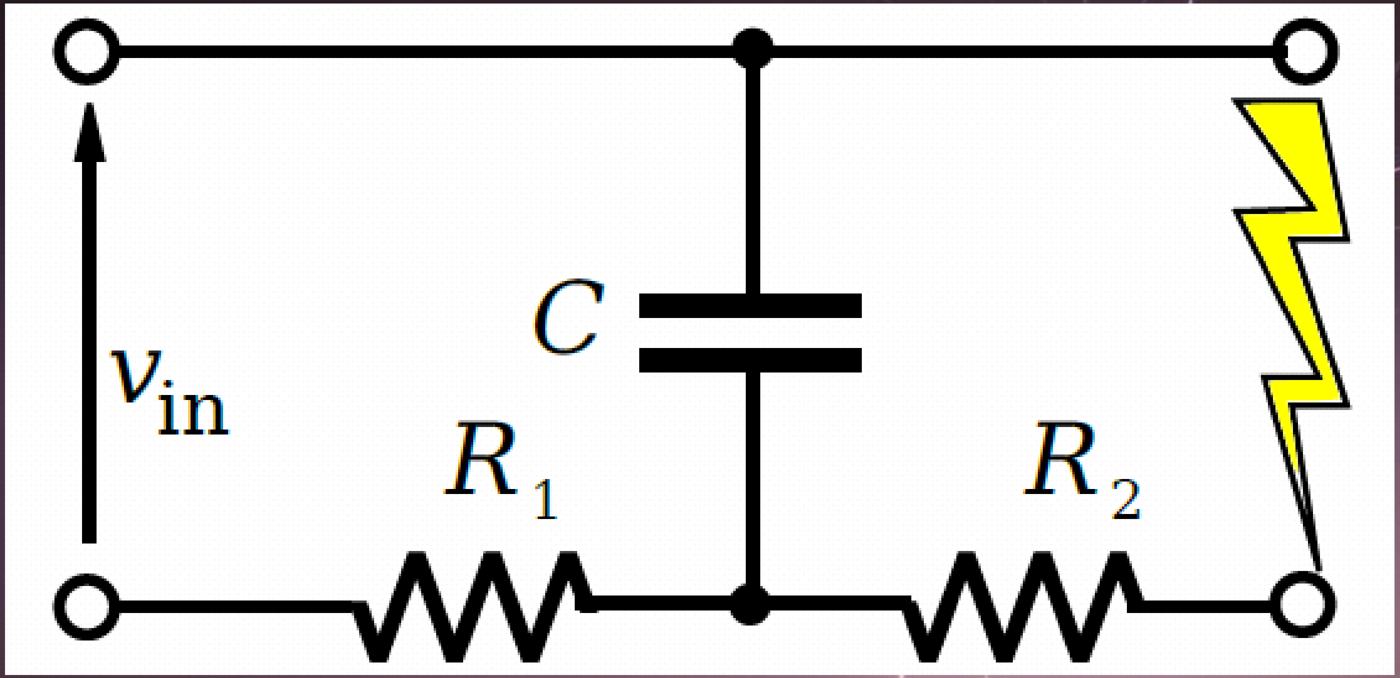
- Lightning occurs when the voltage across the atmospheric capacitor exceeds the dielectric strength of the air.
- Resistance in the atmosphere is very low once the path is ionized.
- Resistance in the subsurface is approximately constant over long periods of time.

Relaxation Oscillator
(Nonlinear Electronic Oscillator)



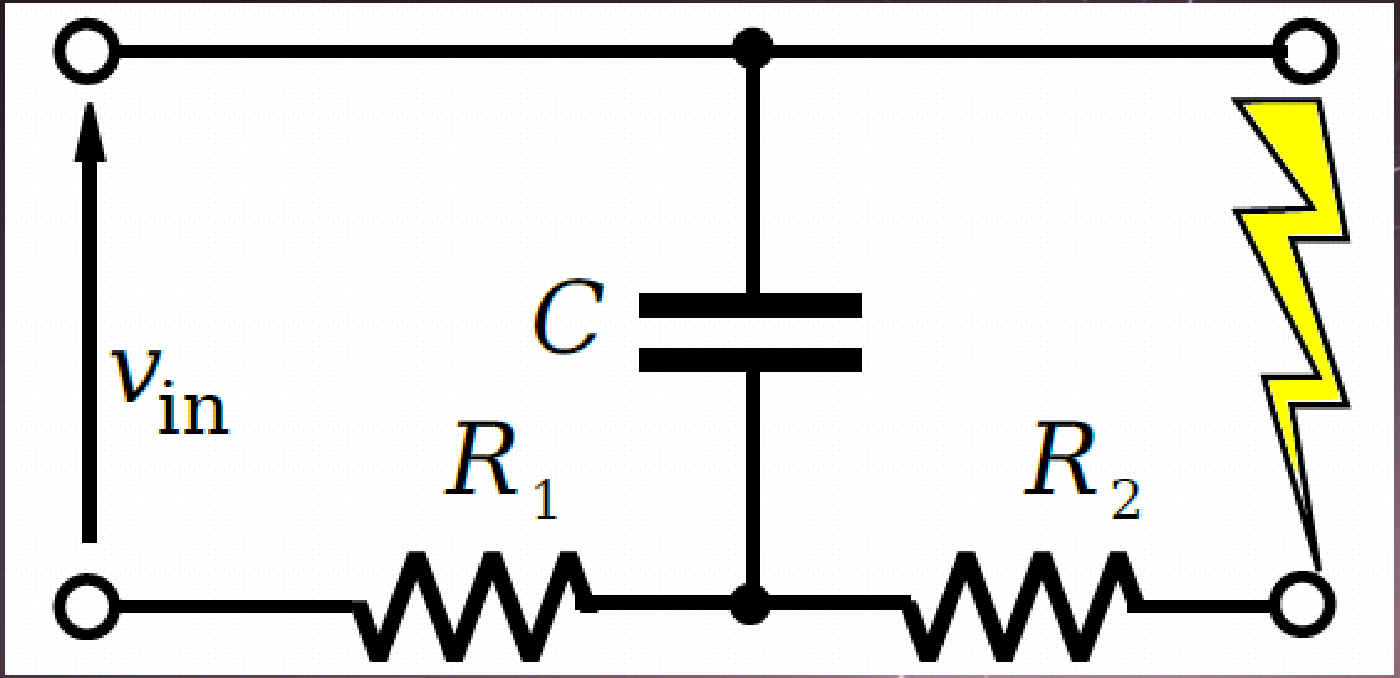
- Outputs repetitive non-sinusoidal signal.
- Circuit for relaxation oscillator has one resistor.

Lightning Physics Analogous to Relaxation Oscillator Physics



- The physics of a lightning discharge is similar to the physics of a neon-tube relaxation oscillator.
- In each case, voltage builds across a capacitor until an insulating gas ionizes & becomes a conductor.

Lightning Physics Analogous to Relaxation Oscillator Physics



- Lightning capacitor has an additional resistance, R2, limiting current associated with lightning.
- R2 is resistance between lightning strike point & bottom plate of capacitor.
- This relationship is the theoretical basis for generating 3-D apparent resistivity/permittivity volumes.