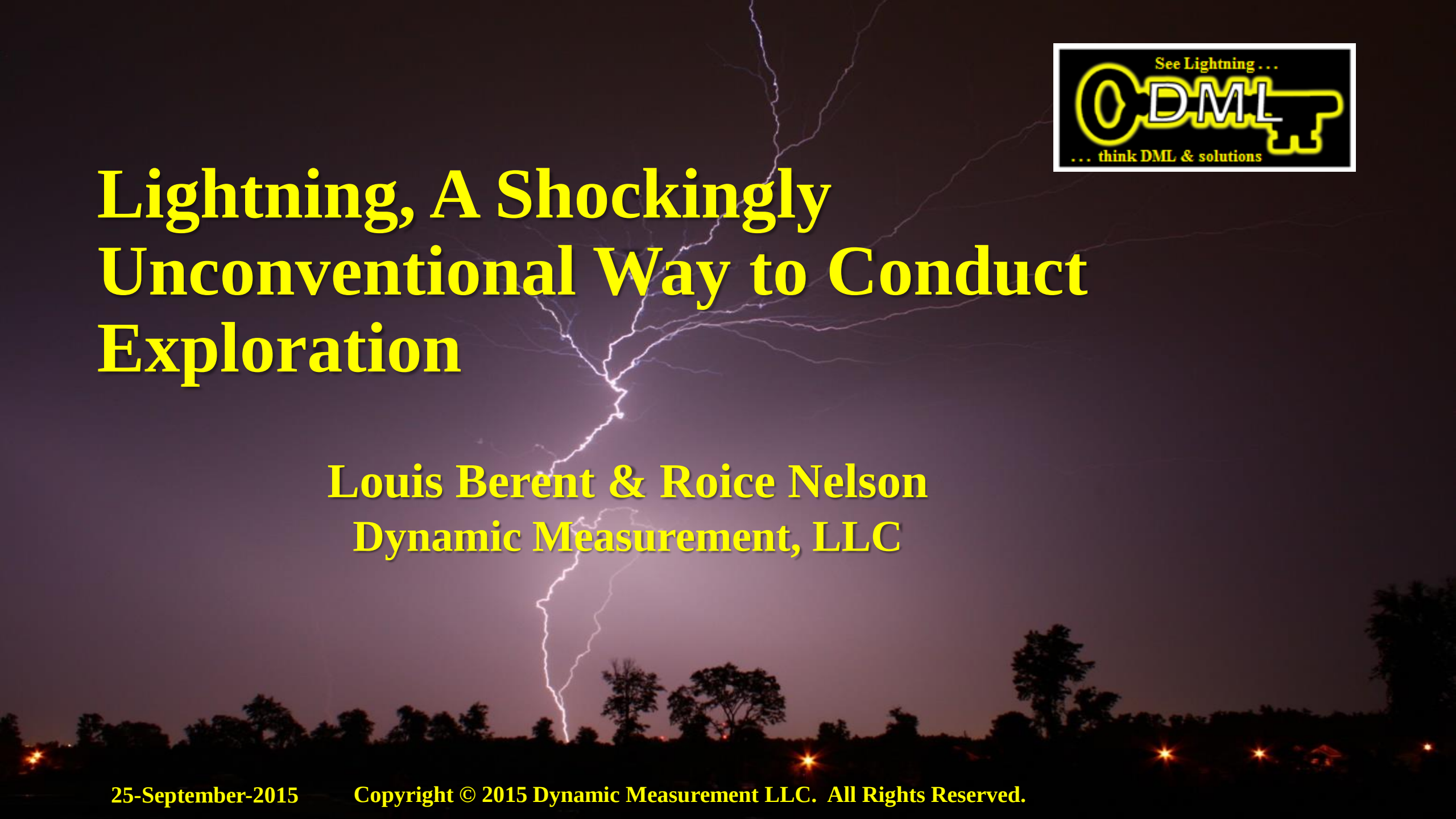


Lightning, A Shockingly Unconventional Way to Conduct Exploration

Louis Berent & Roice Nelson
Dynamic Measurement, LLC

25-September-2015

Outline

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

Natural Sourced Electromagnetism (NSEM) – a new geophysical data type.

Examples of using NSEM to interpret geologic features.

NSEM overview.

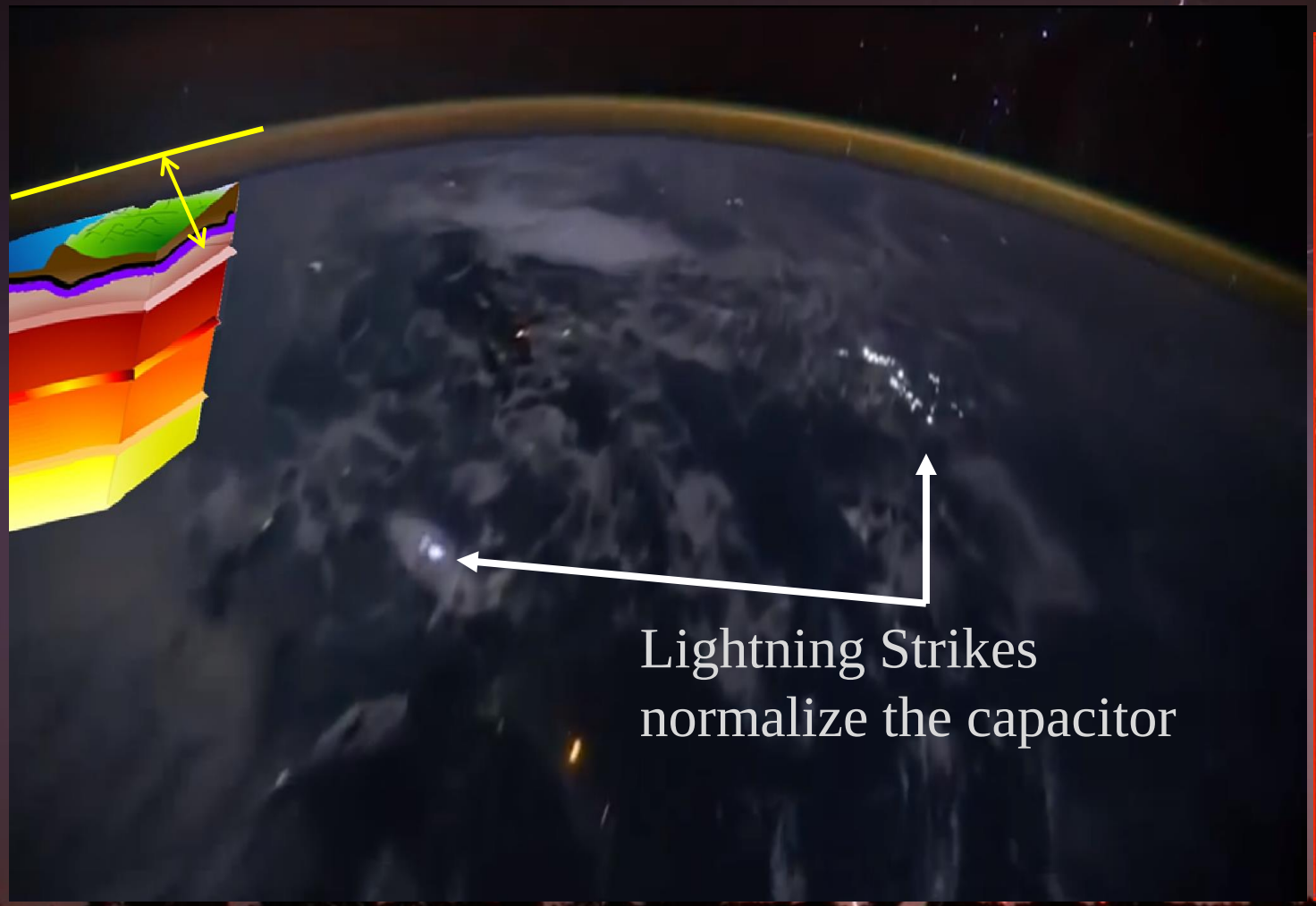
LIGHTNING, & WHY IT IS TRACKED, STACKED & MAPPED

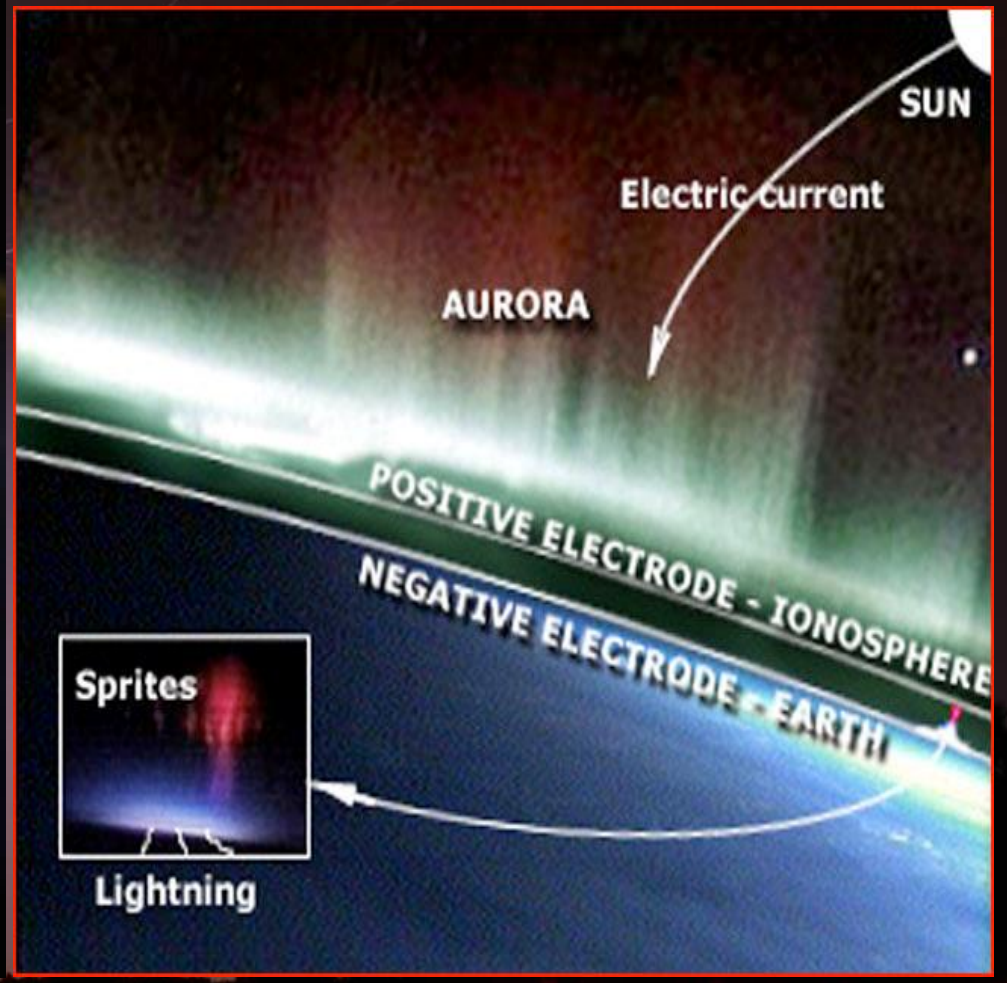
25-September-2015

Can Lightning Hit the Same Place Twice?

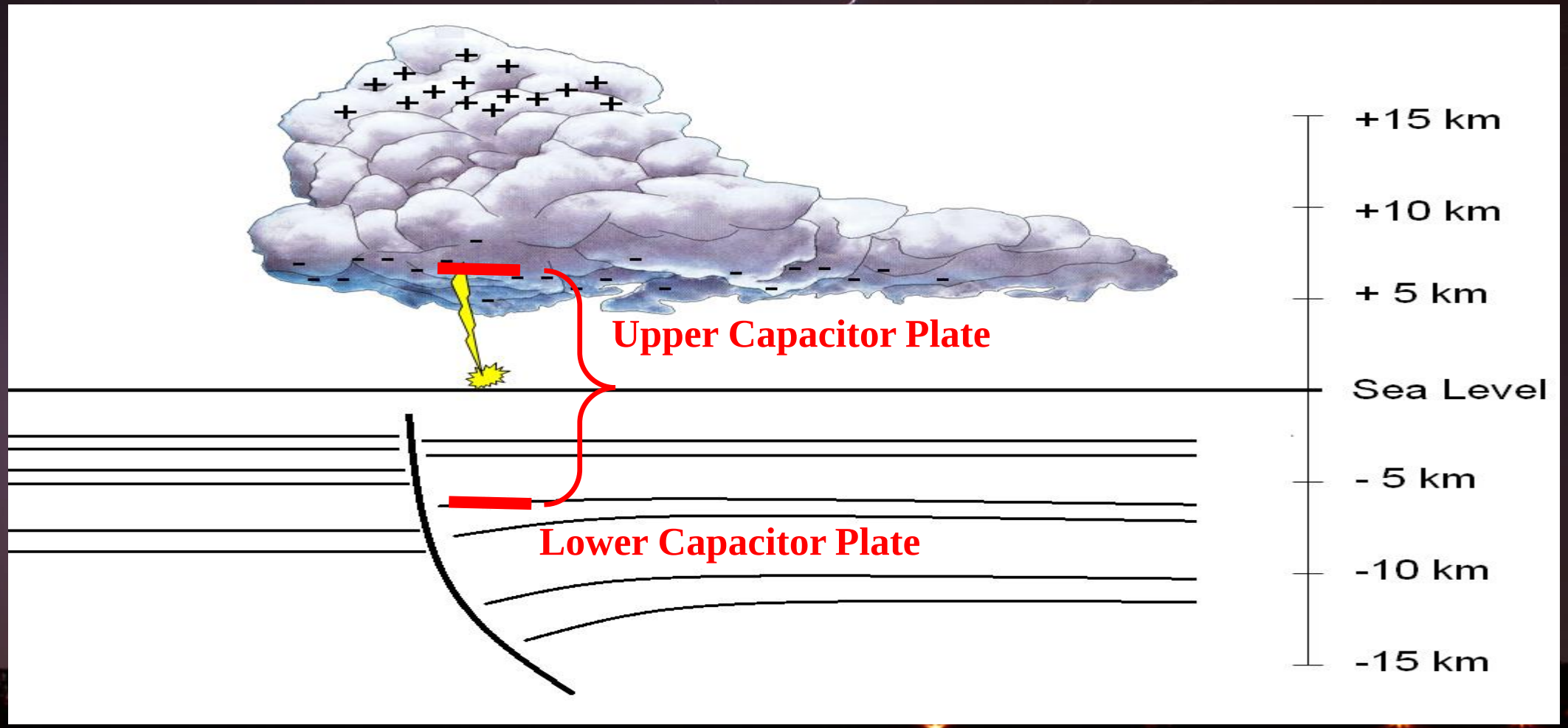
25-September-2015

Earth: A Self-Repairing Capacitor

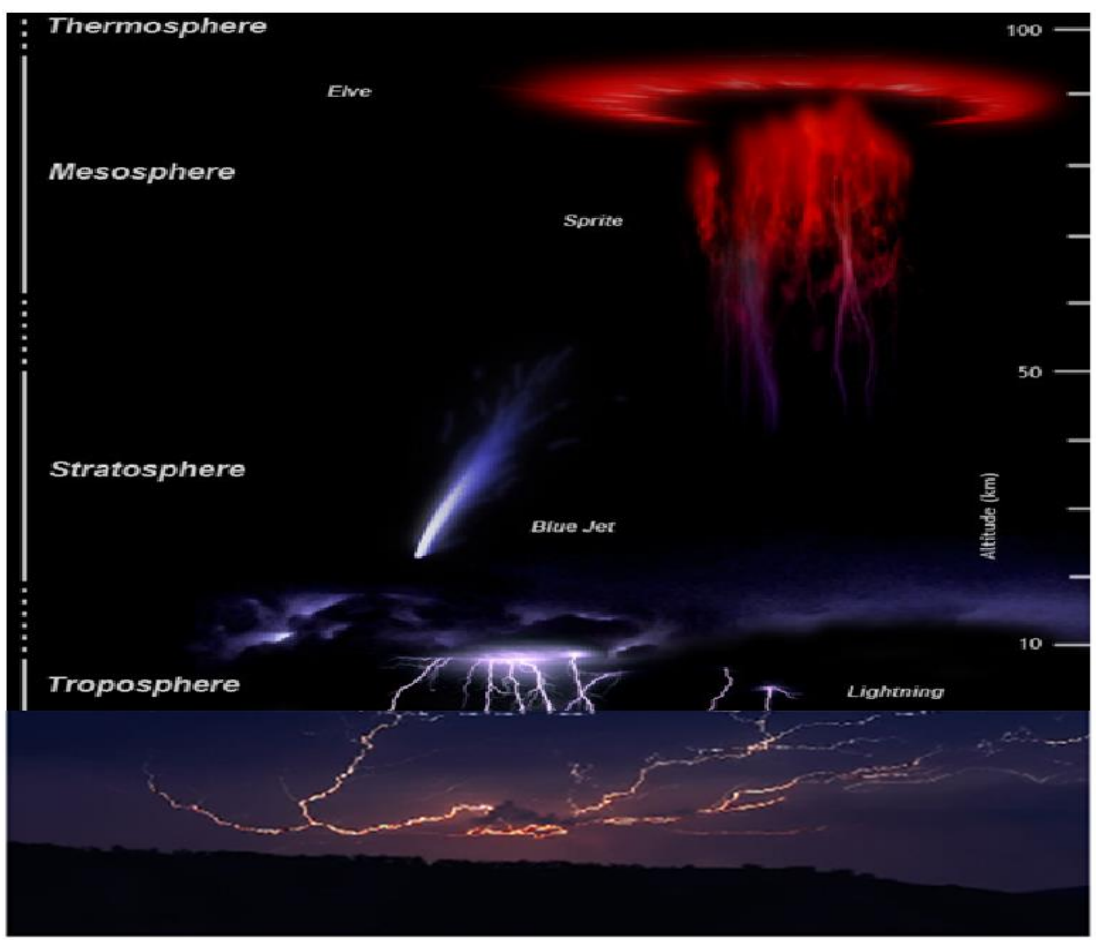


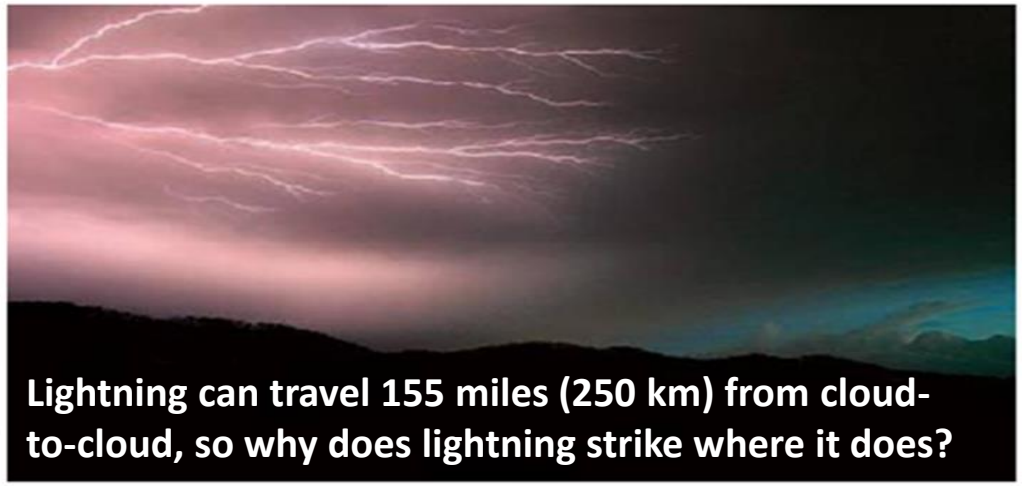


Each Strike Represents a Unique Capacitor



Geologically Controlled Telluric Currents
Primary Lightning Influence



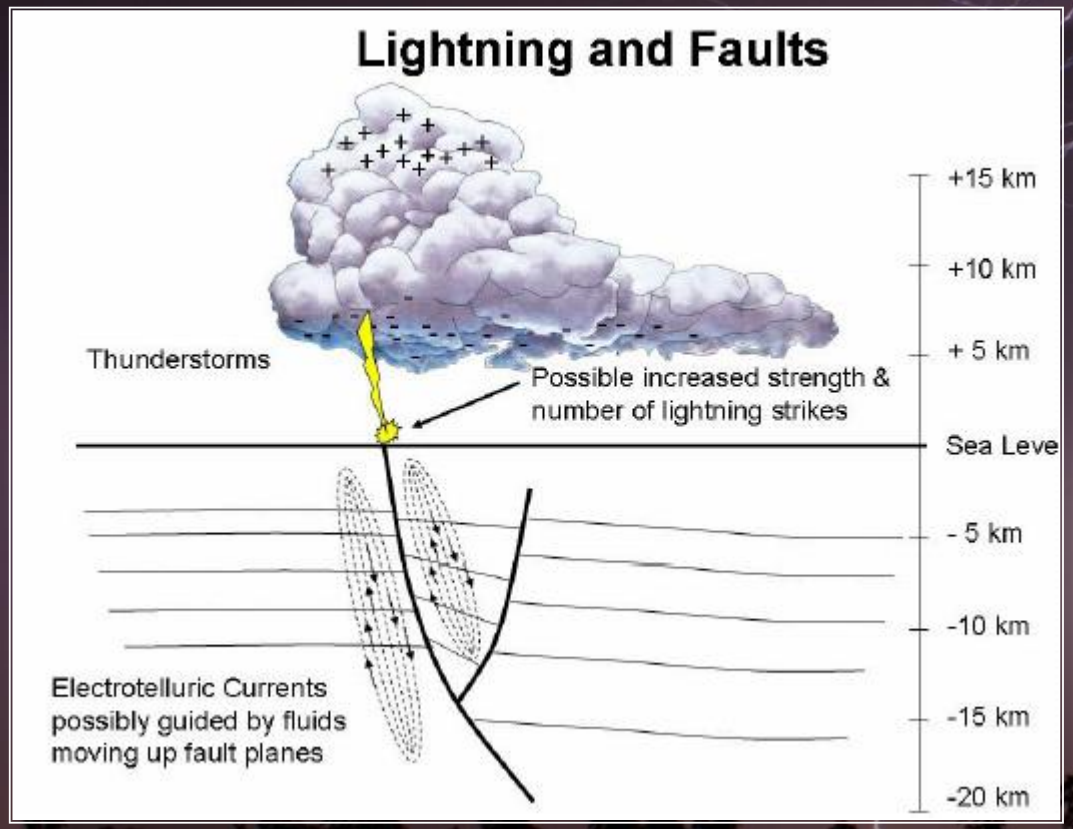


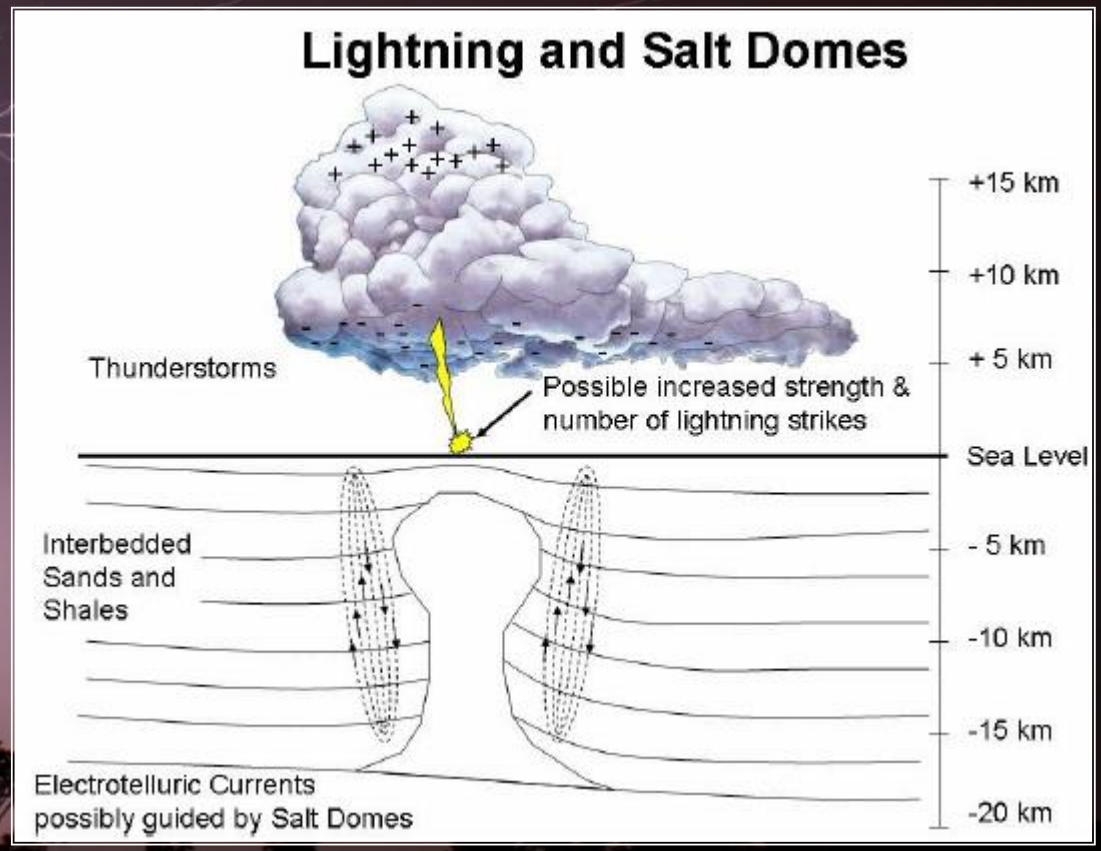
Lightning can travel 155 miles (250 km) from cloud-to-cloud, so why does lightning strike where it does?

Strike locations primarily controlled by earth's electromagnetic currents.

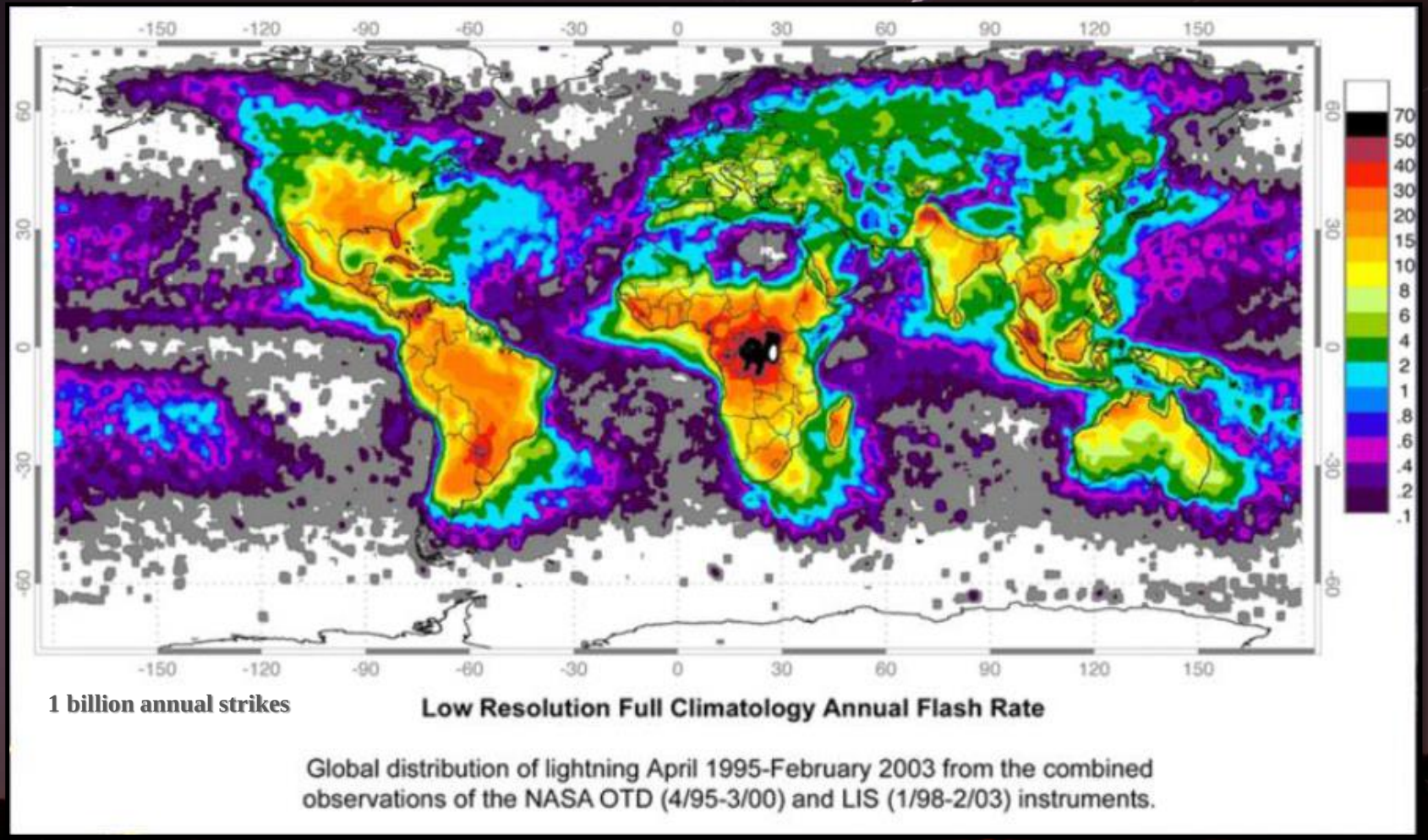
Telluric Currents, Lightning & Geology

Earth Currents Modified by Geology ➡ Prone to Lightning





350 Million Annual CG Lightning Strikes
Uneven Distribution

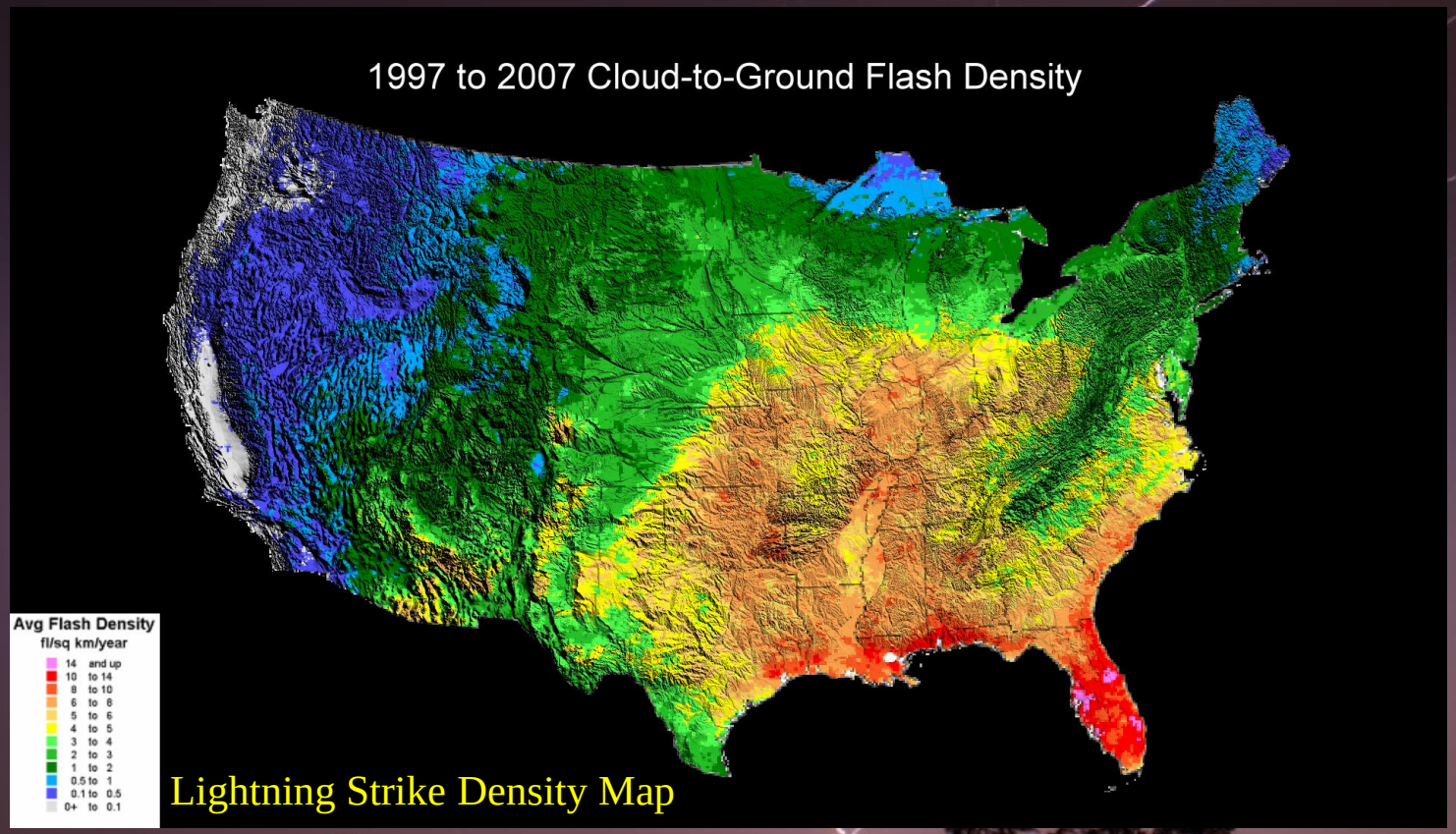


Global distribution of lightning April 1995-February 2003 from the combined observations of the NASA OTD (4/95-3/00) and LIS (1/98-2/03) instruments.

Why is lightning recorded?

Early Storm Warning - Safety - Insurance - Meteorology

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

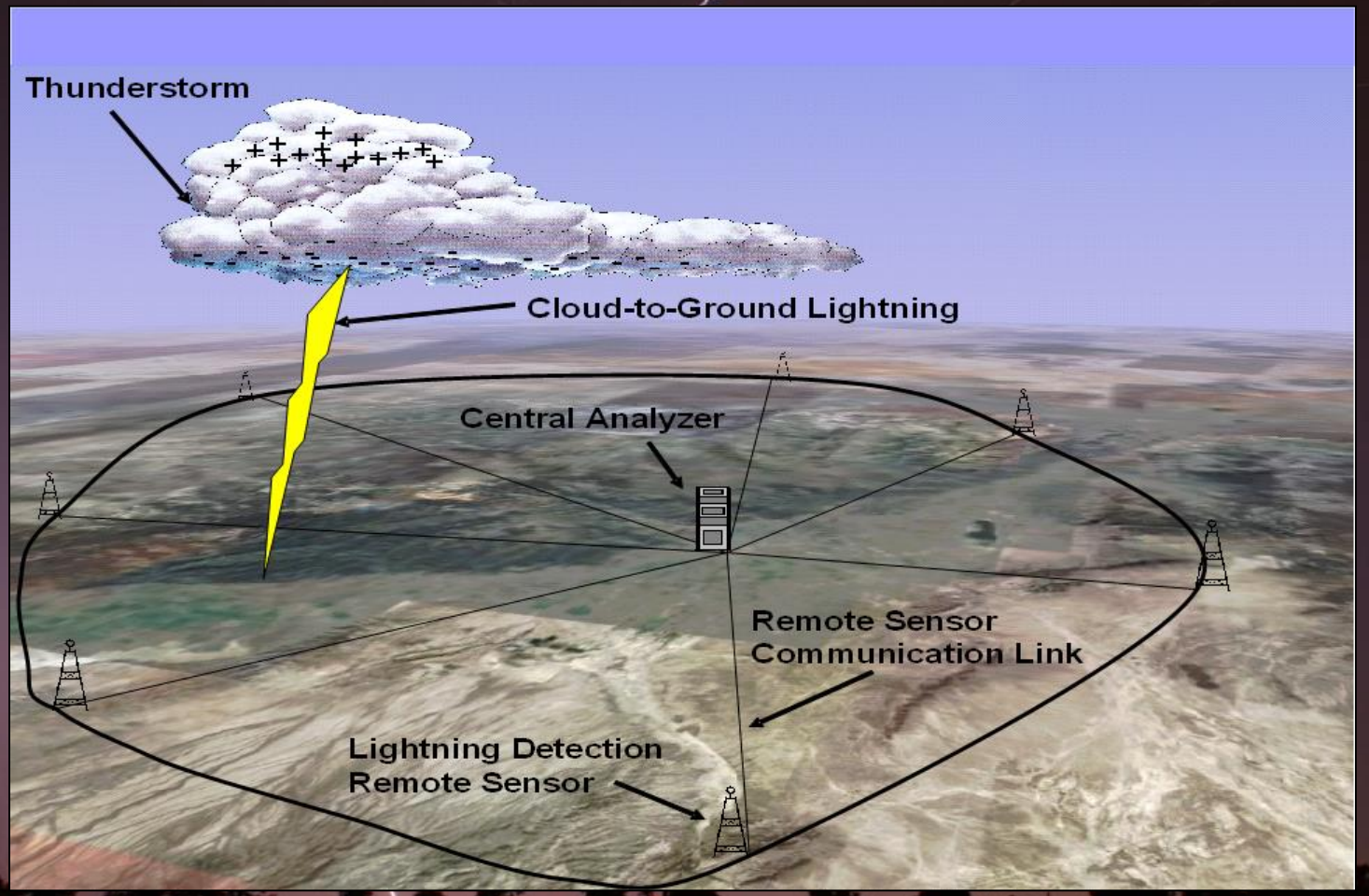


Lightning Strike Density Map

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

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

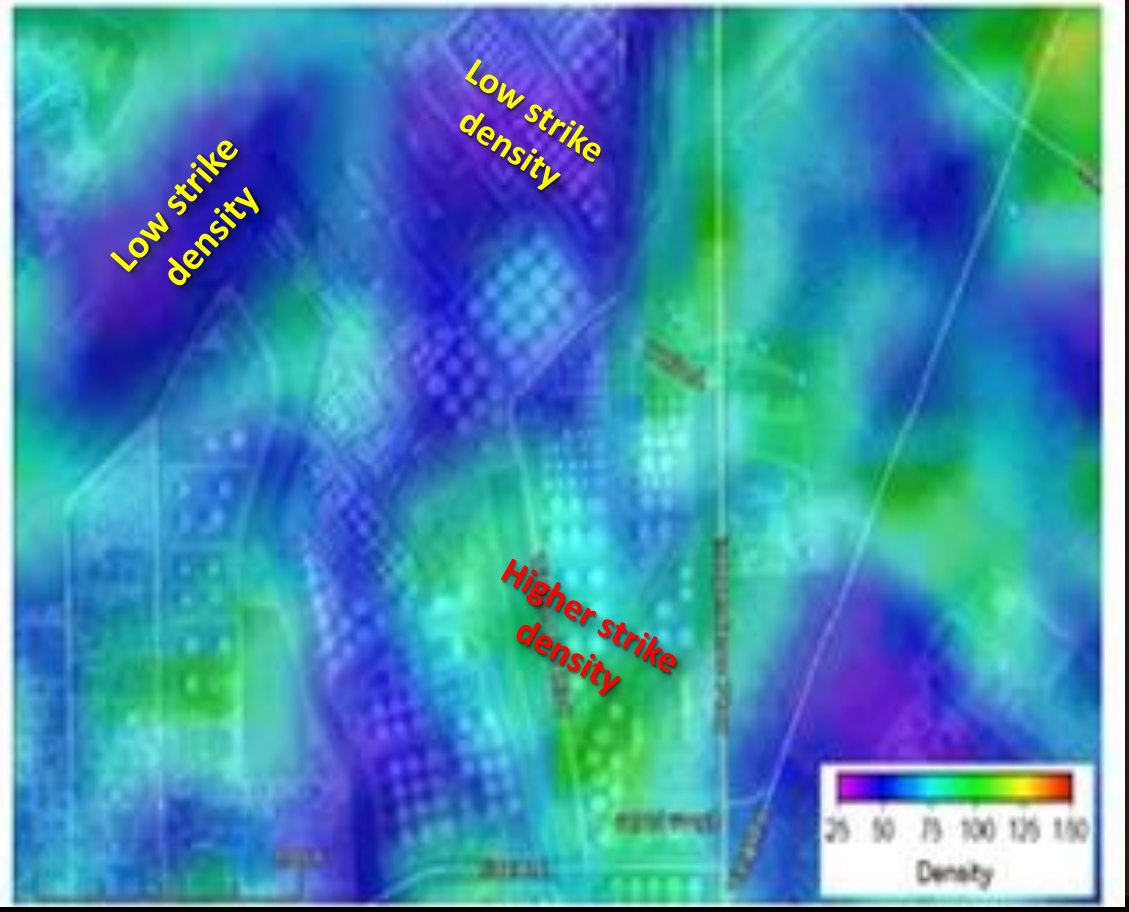
How is Lightning Data Collected?
150 Sensors Record U.S. Lightning Strike Locations



Horizontal Resolution 650’- 980’ (200-300 meters)

Does Infrastructure Control Lightning?

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

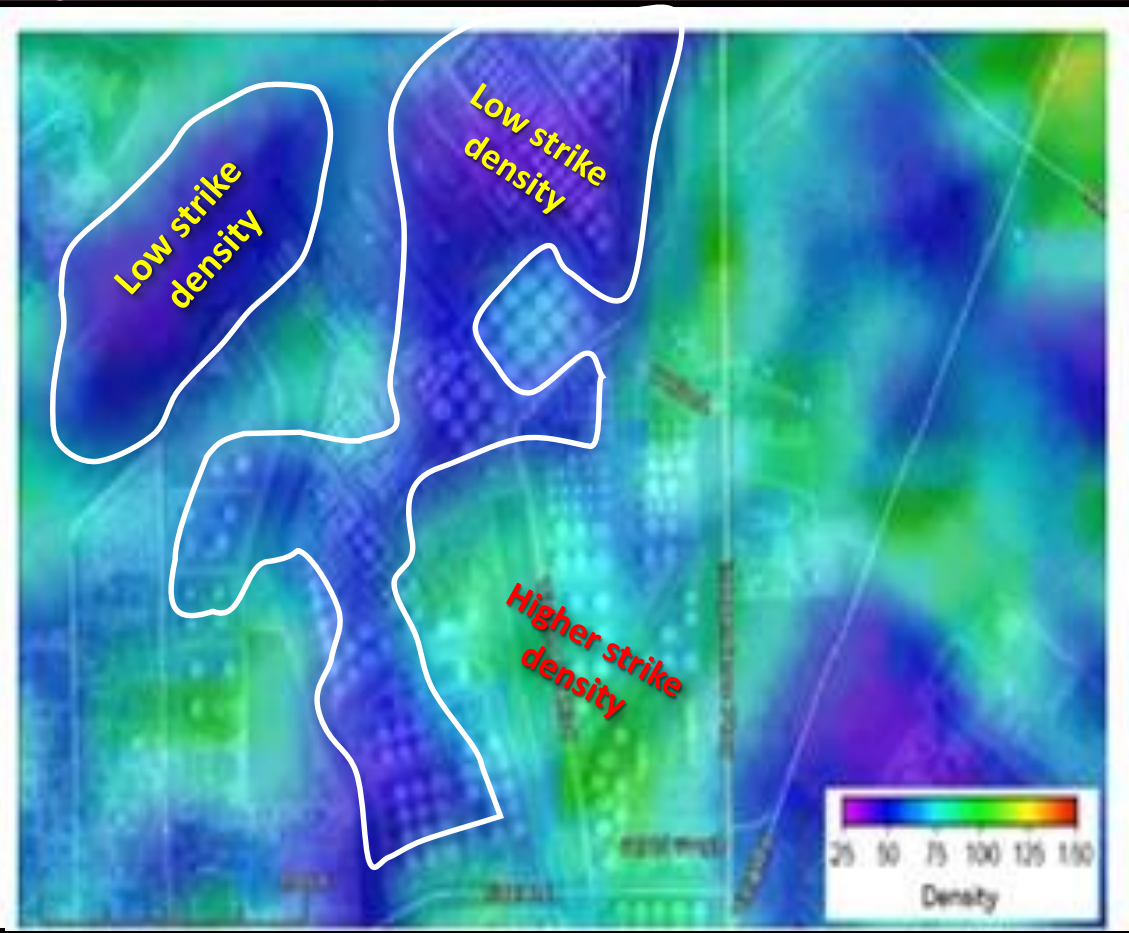


Strike Density Attribute Map

25-September-2015

Approximately 60% of Tank Farm Experienced Low Strike Density

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



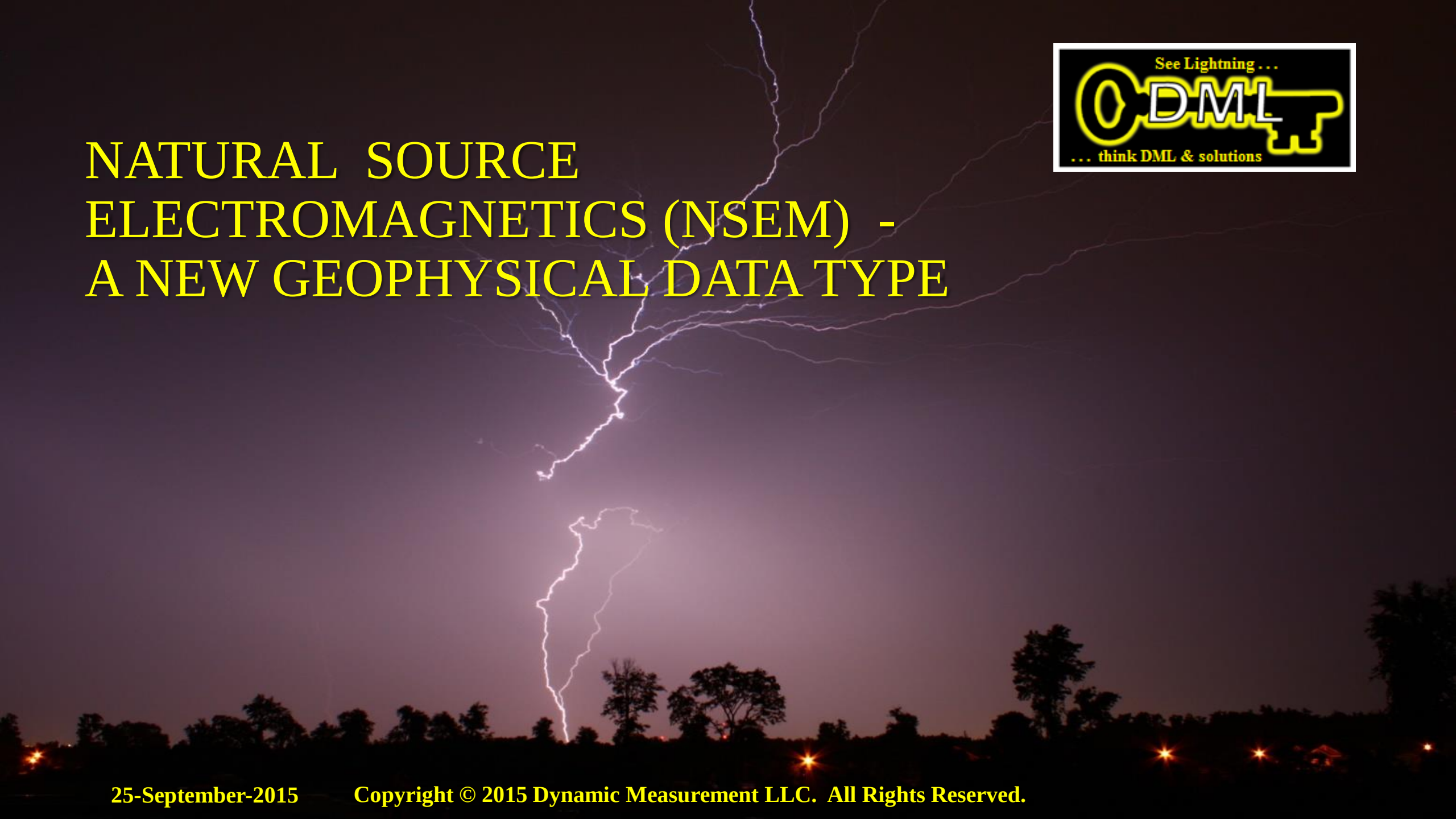
Strike Density Attribute Map

25-September-2015

Lightning bypasses tall objects and…

…infrastructure expected to attract lightning.

25-September-2015



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

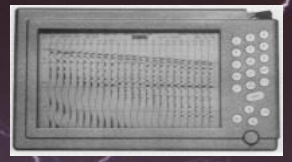
25-September-2015

Time-Line of New Geophysical Data Types

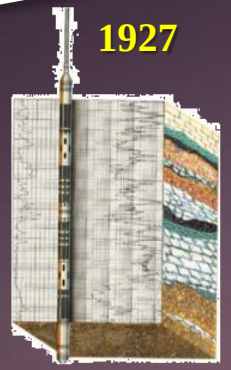
1752

1833

1920s

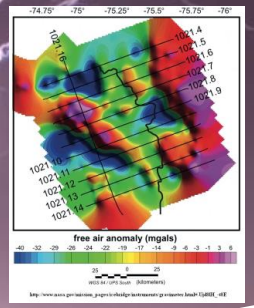


1927

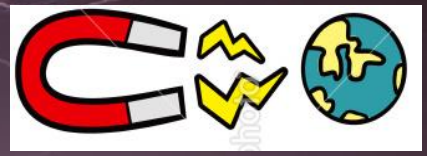


1931

1936

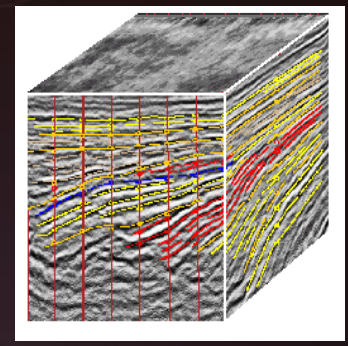


1950s

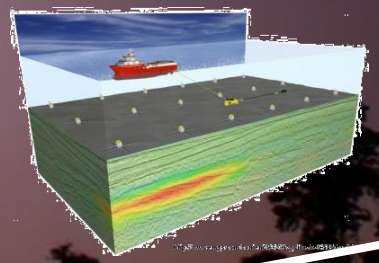


1960s/70s

1974

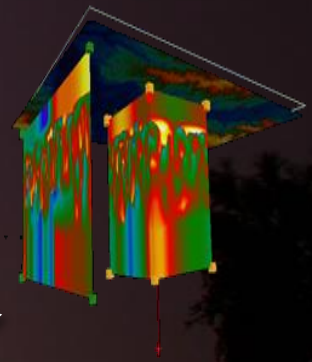


1997



2008

2015



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

25-September-2015

Proven & Patented Technology

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)

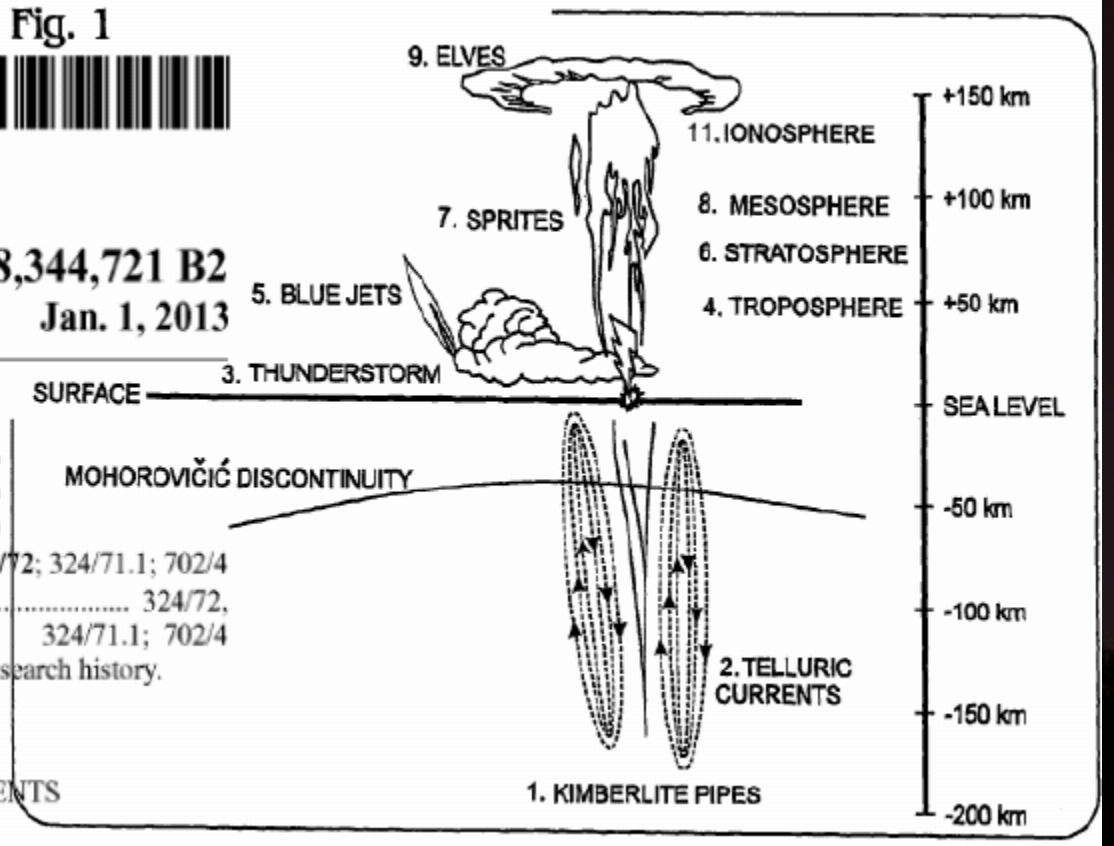
(52) **U.S. Cl.** **324/72**; 324/71.1; 702/4

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

See application file for complete search history.

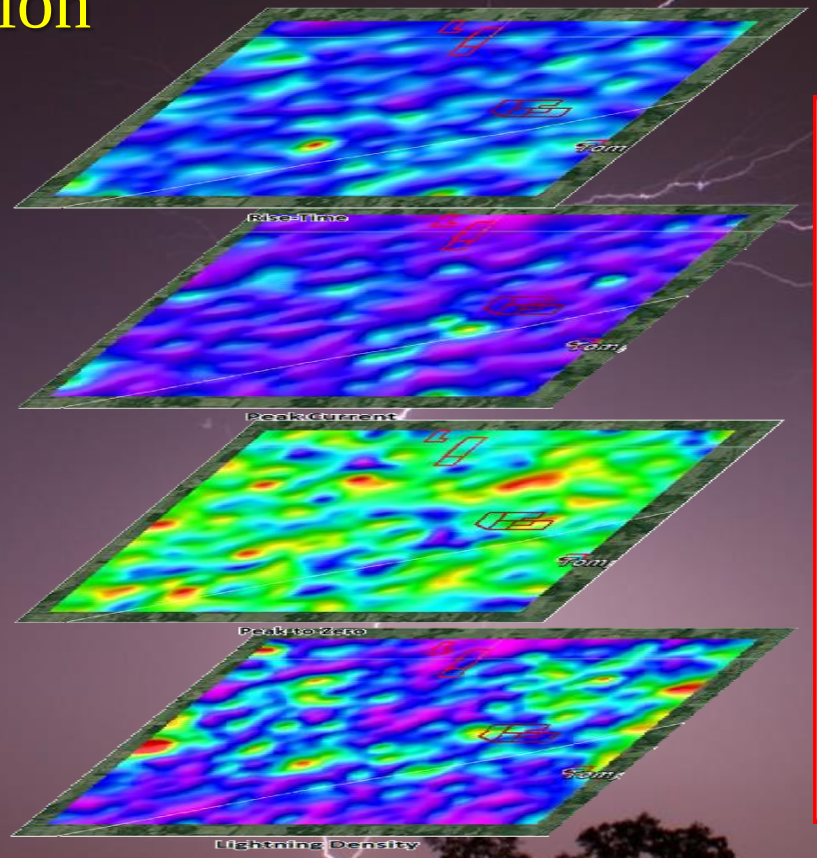
(56) **References Cited**

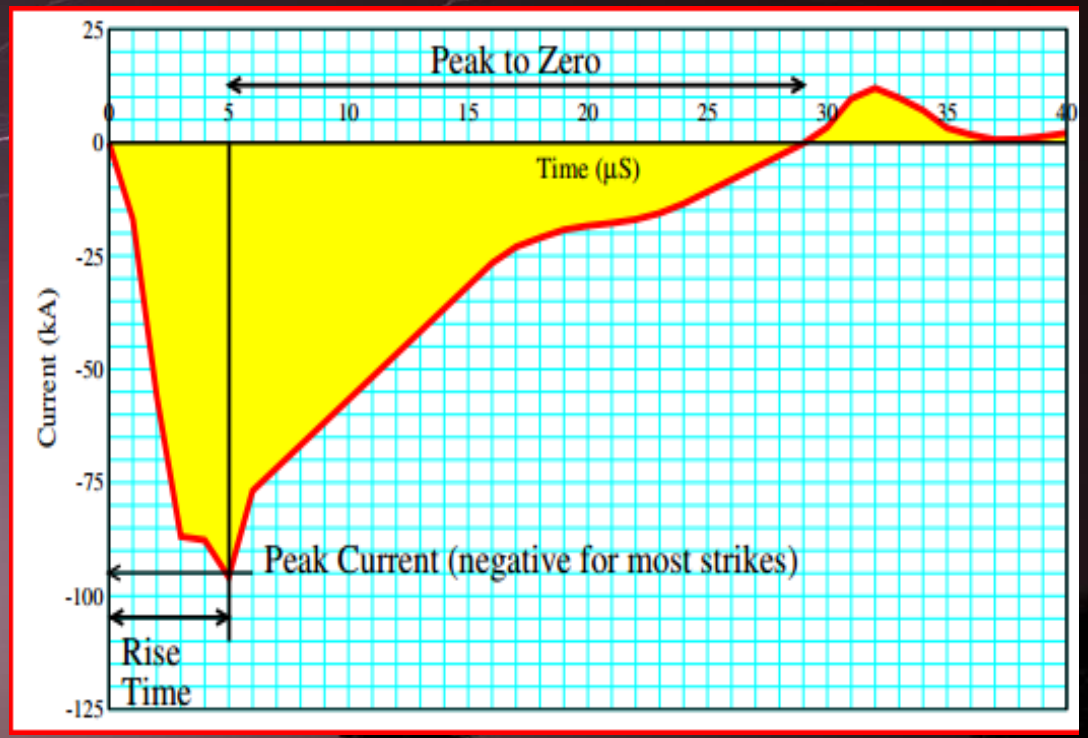
U.S. PATENT DOCUMENTS



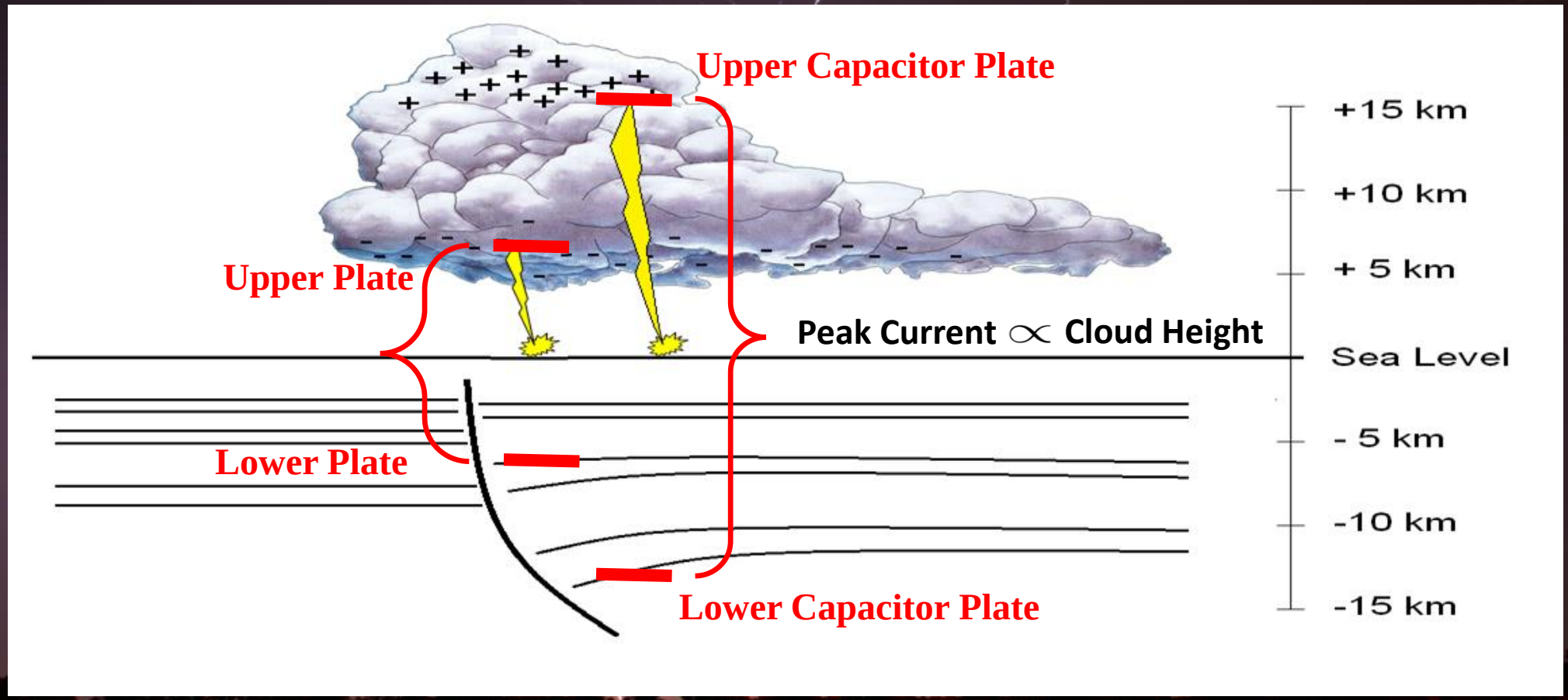
Lightning Strike Measurements

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

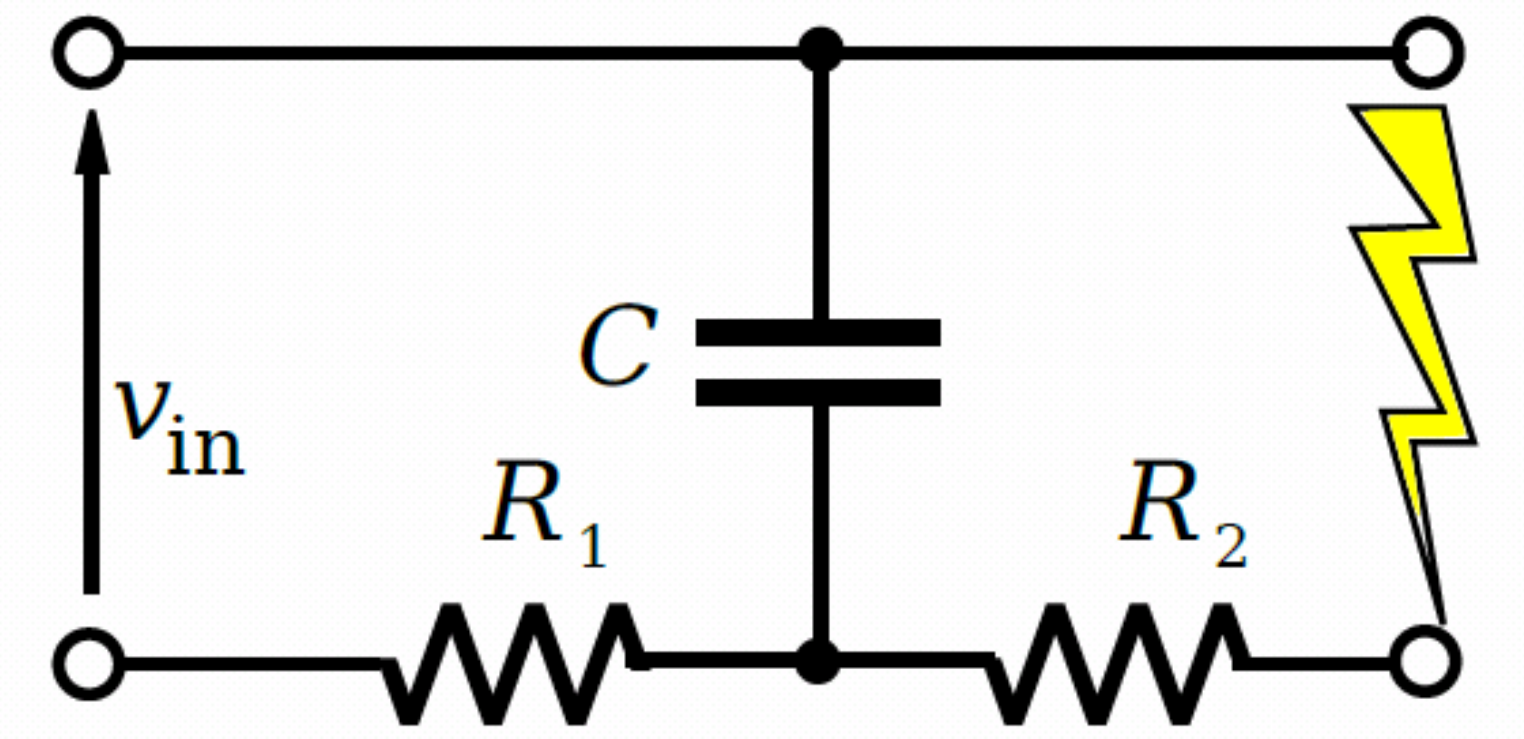




Millions of Lightning Strikes
Millions of Measurements

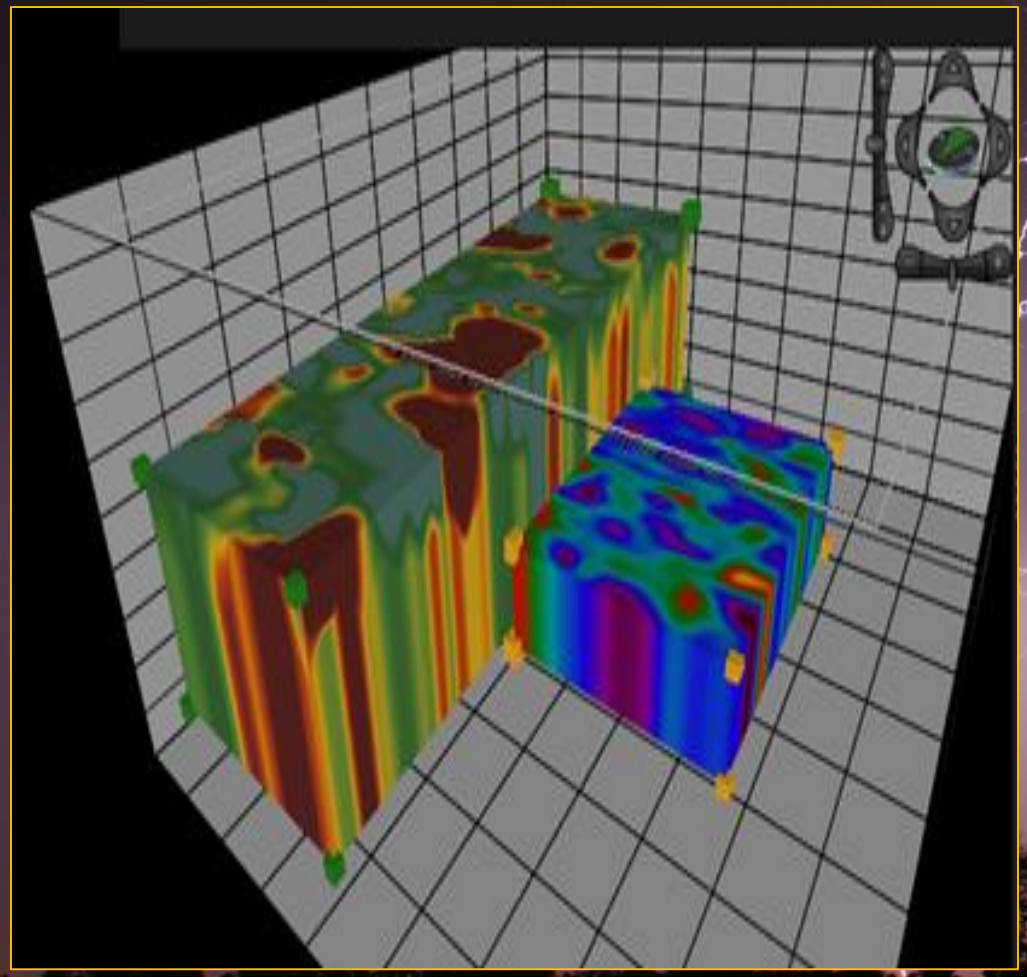


Lightning Physics Analogous to Relaxation Oscillator Physics

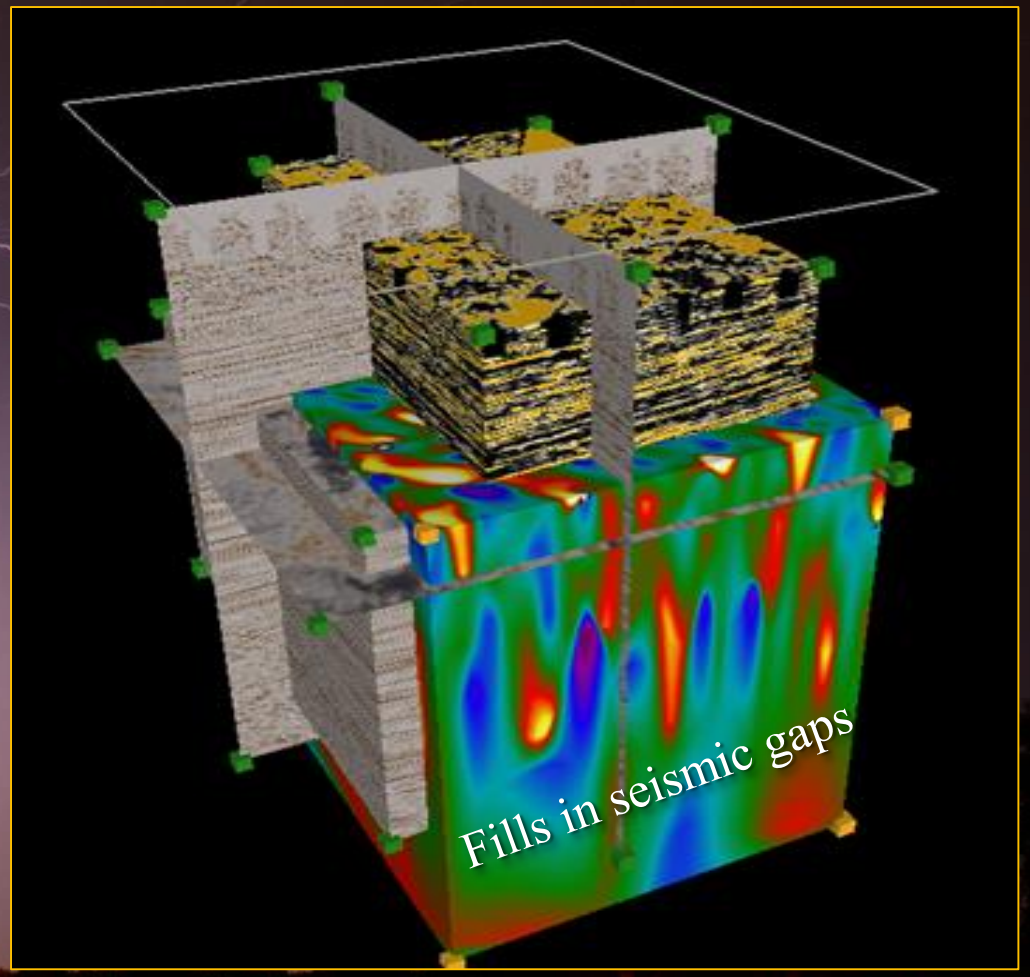


Enables generation of 3-D apparent resistivity and permittivity volumes.

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

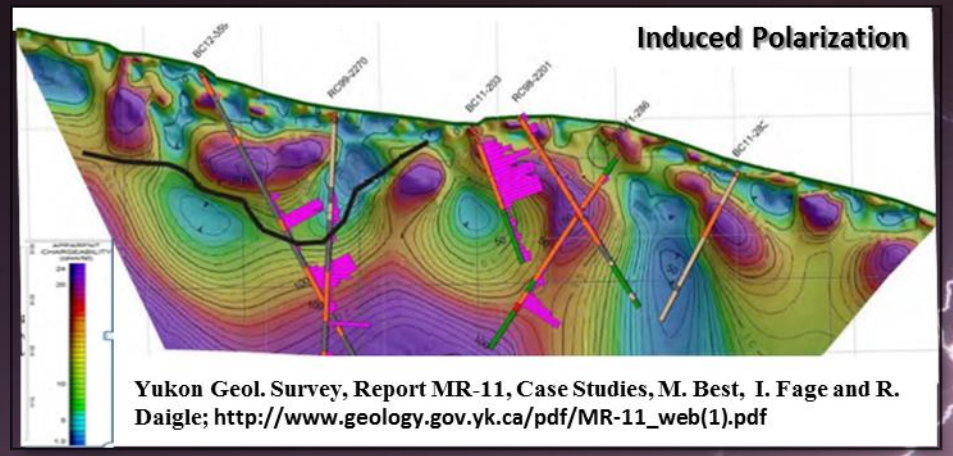


Inlines
Crosslines
Arb Lines
Slices

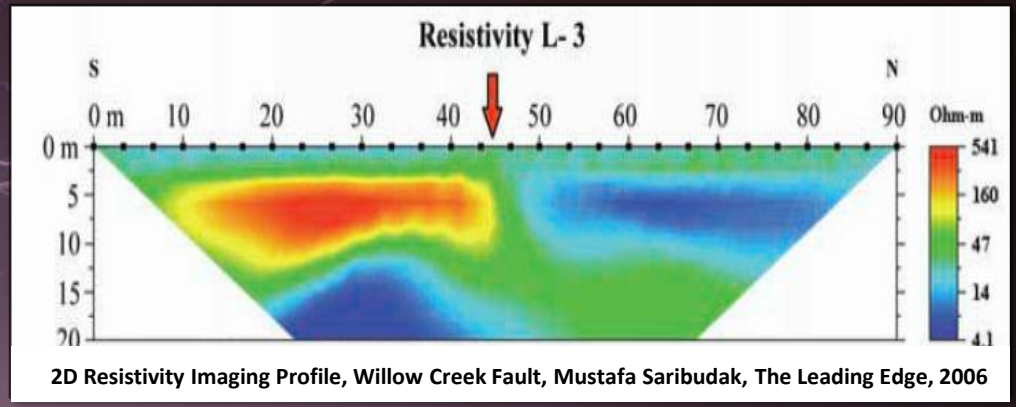


25-September-2015

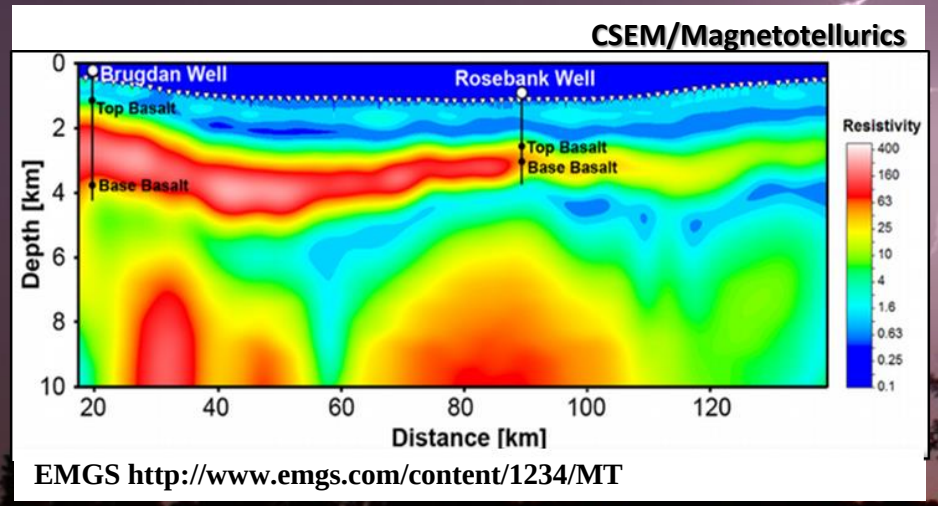
Resistivity & Permittivity Volumes Easily Integrated with Near-Surface Geophysical Data



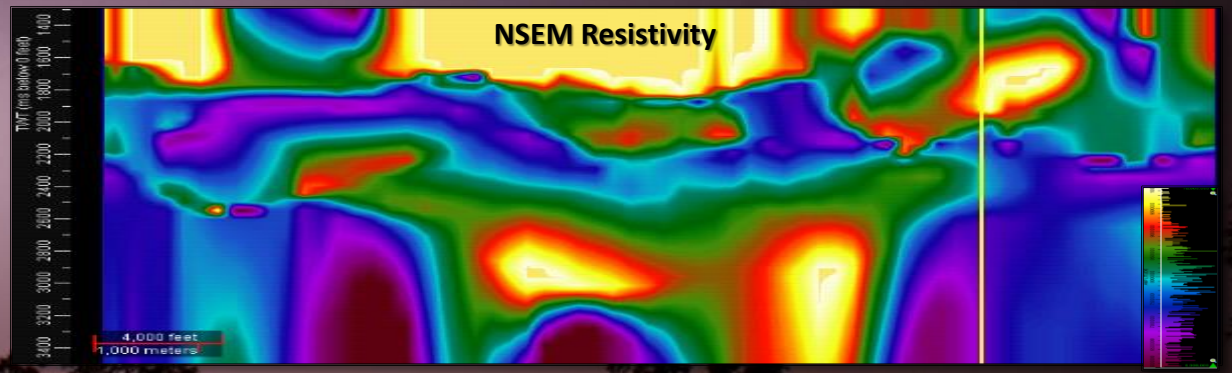
Yukon Geol. Survey, Report MR-11, Case Studies, M. Best, I. Fage and R. Daigle; http://www.geology.gov.yk.ca/pdf/MR-11_web(1).pdf



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



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



Lightning Strikes Are Not Random!

Influenced by Lateral Changes in Rock Properties:

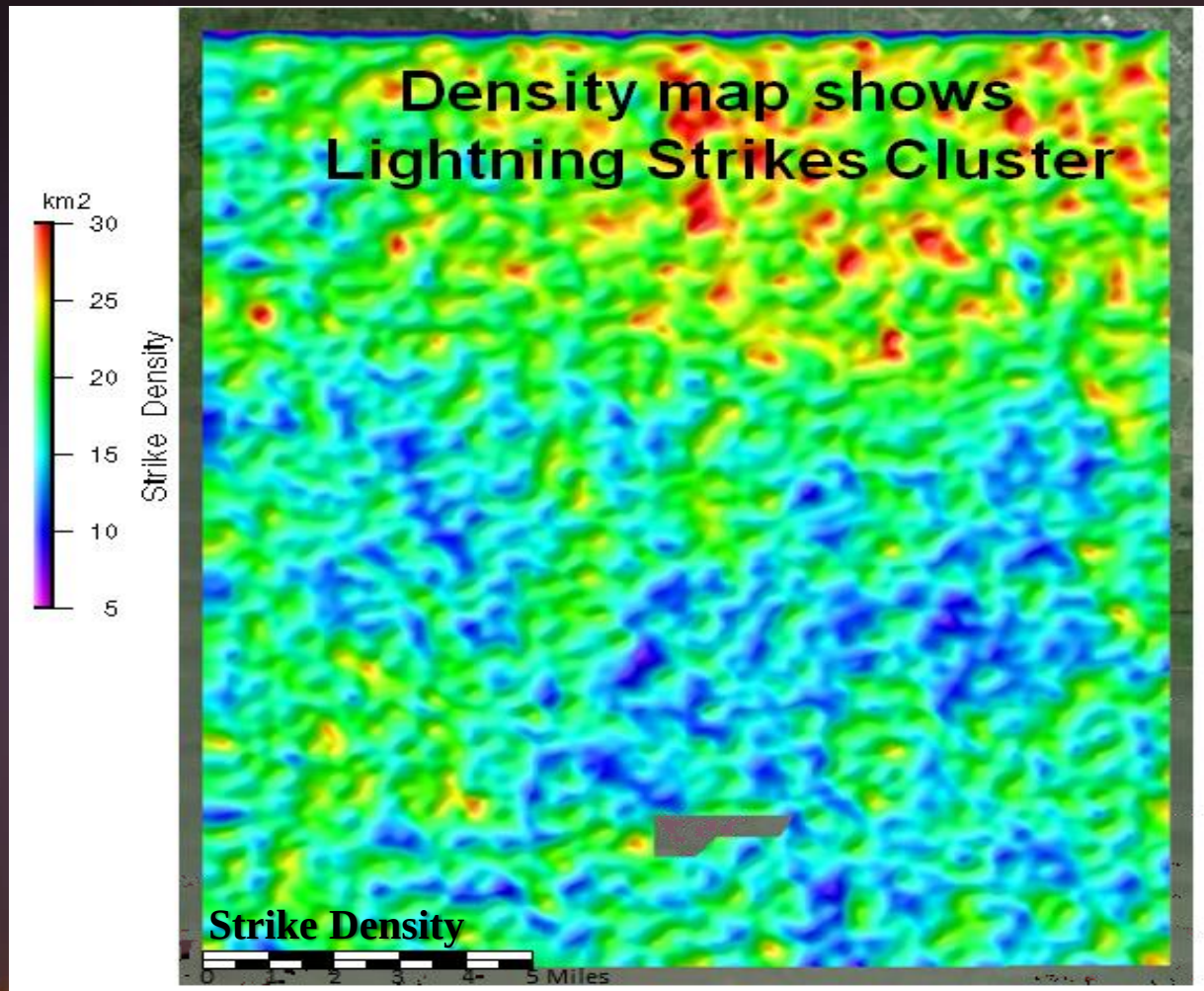
- Faults
- Fracture Swarms
- Salinity
- Pore Fluids
- Porosity
- Permeability
- Mineralization

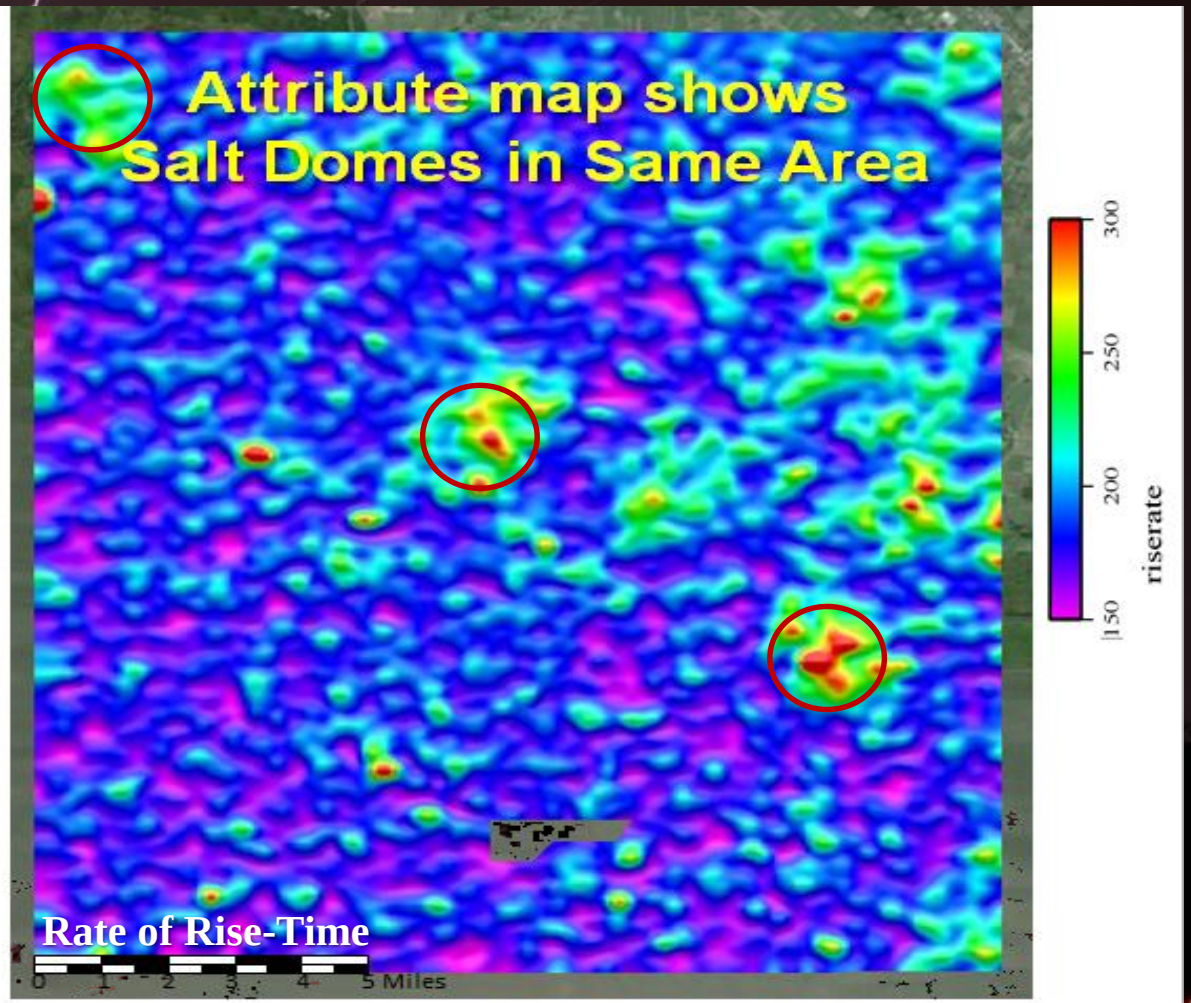
Upward lightning shows electrostatic charge builds up in the ground, as well as in the atmosphere.

Examples of Using NSEM to Interpret Geologic Features

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

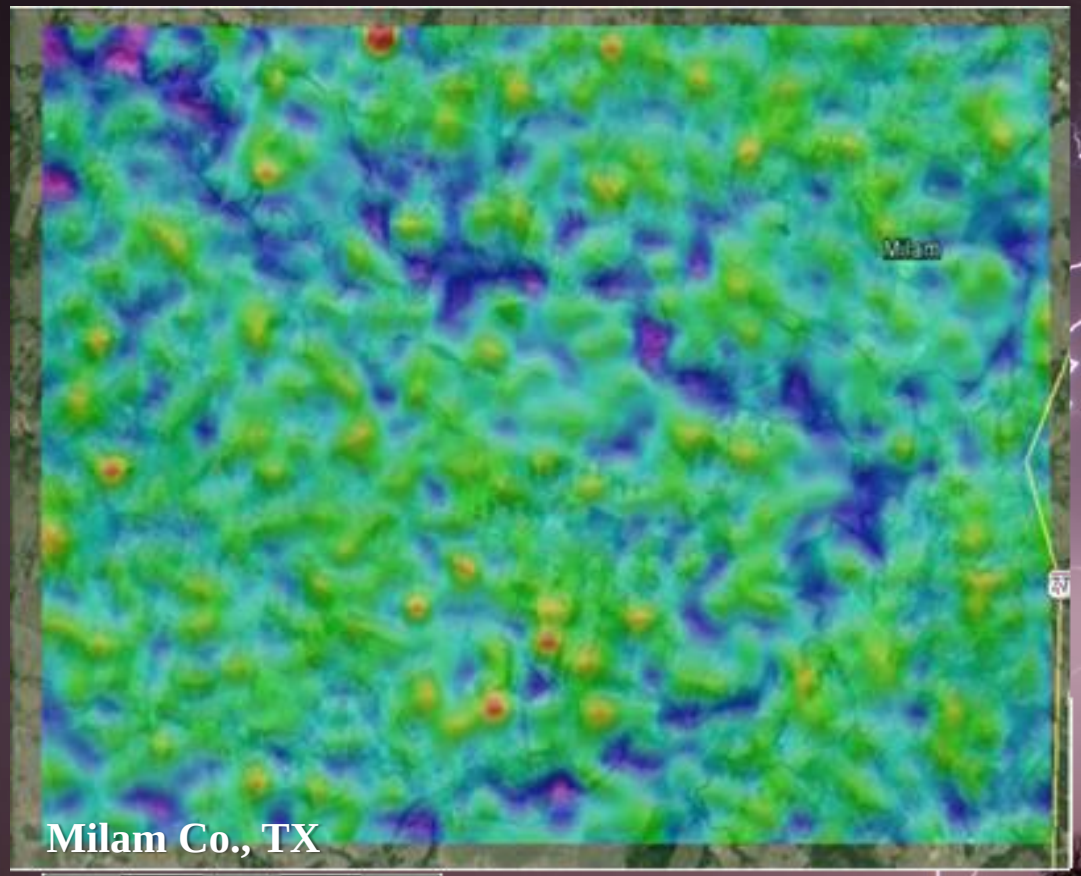
NSEM Correlates To Geology:
Iberia Parish, LA Salt Domes



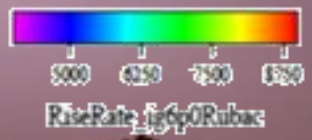


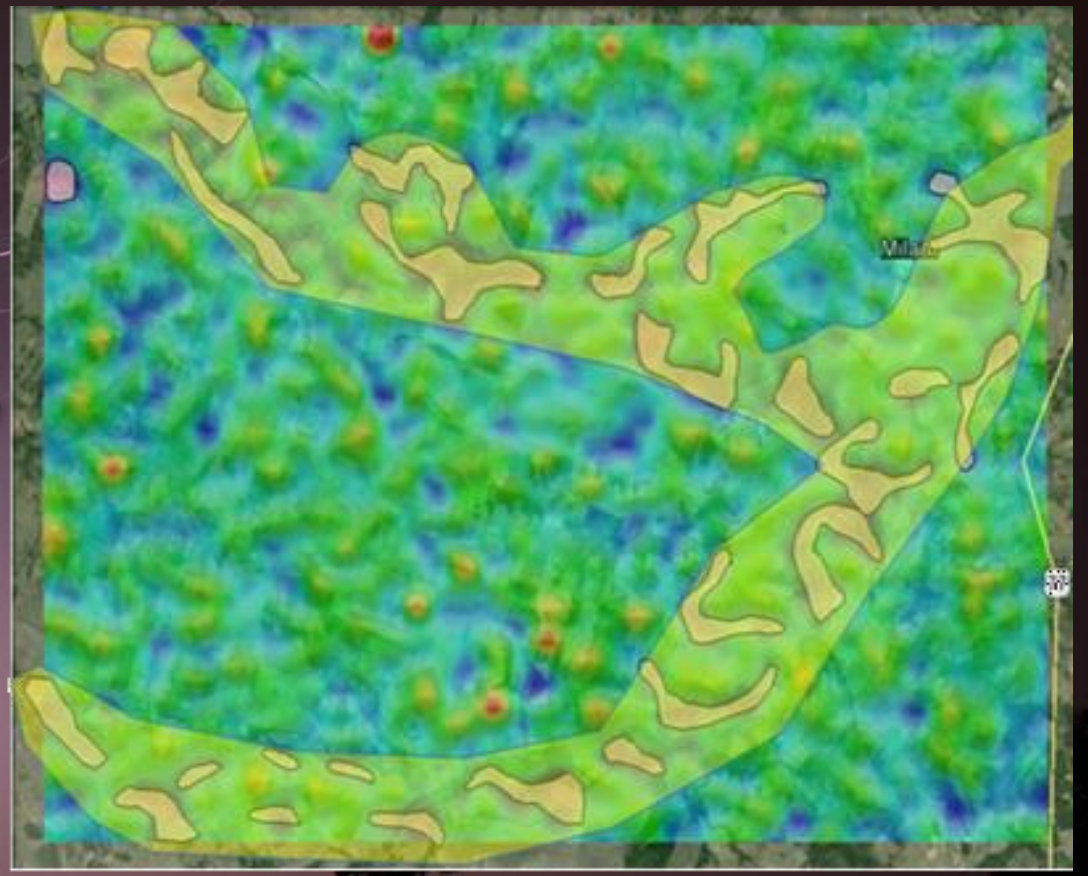
25-September-2015

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



Lightning Attribute
Rate of Rise-Time

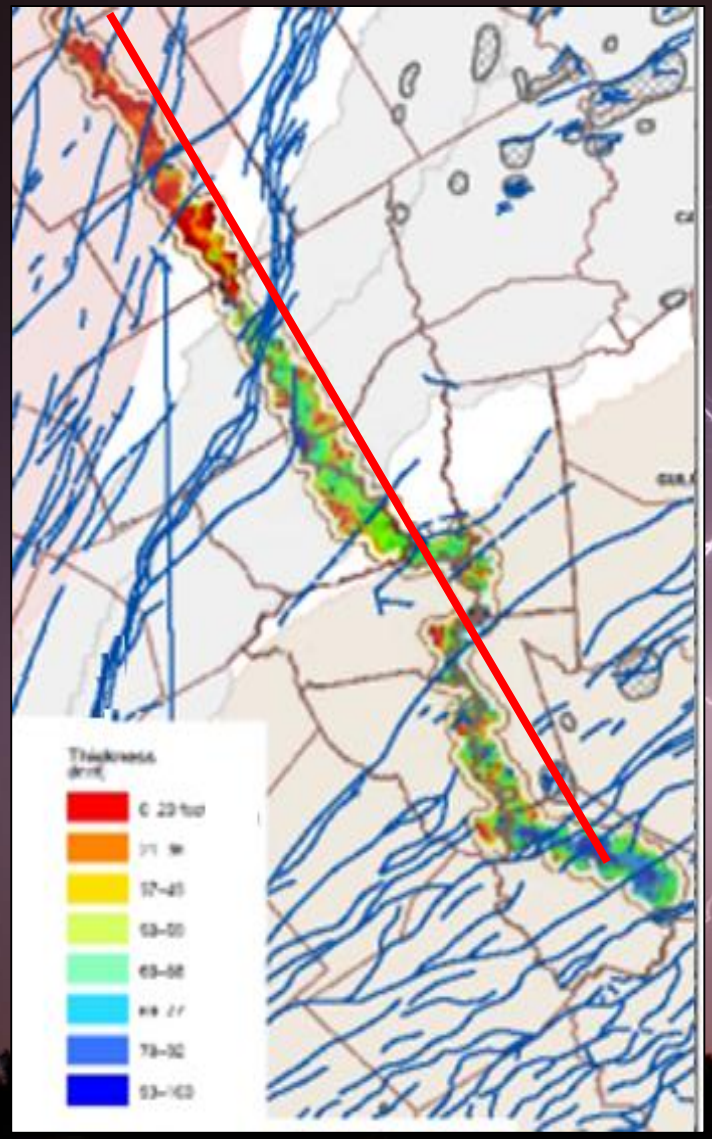




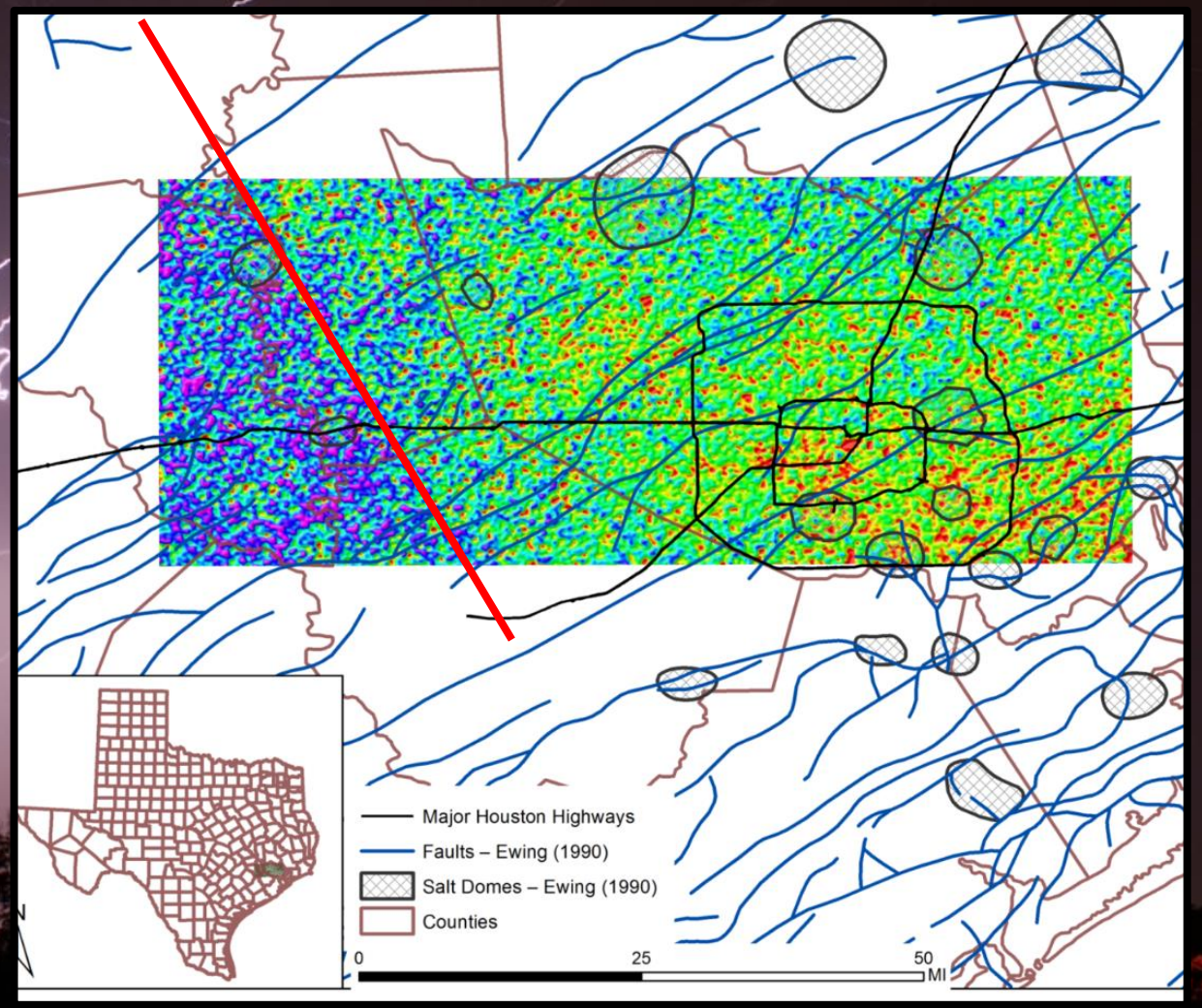
25-September-2015

NSEM Correlates To Geology:

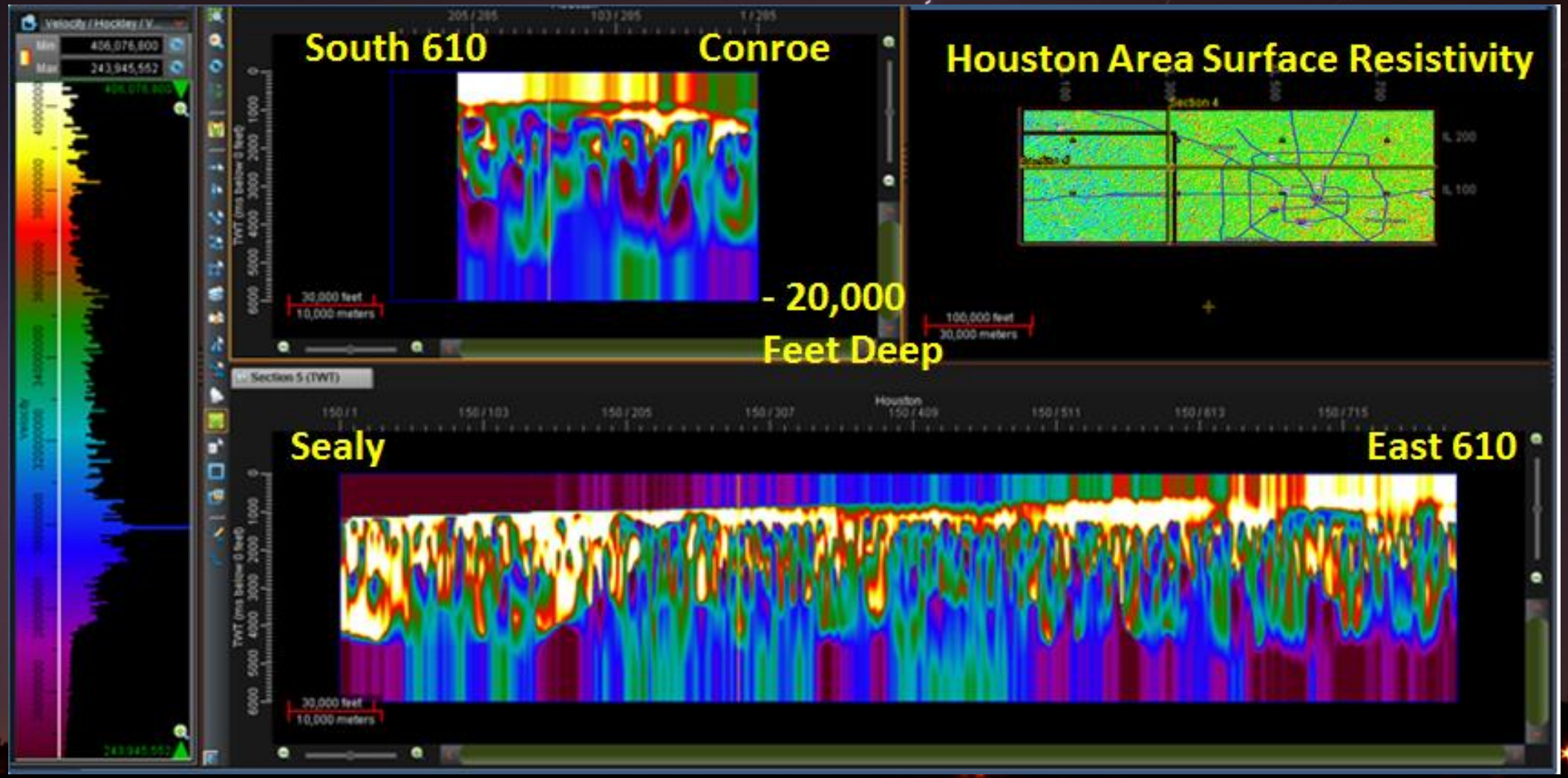
Brazos River Alluvium Aquifer



Absolute Pk-Current



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

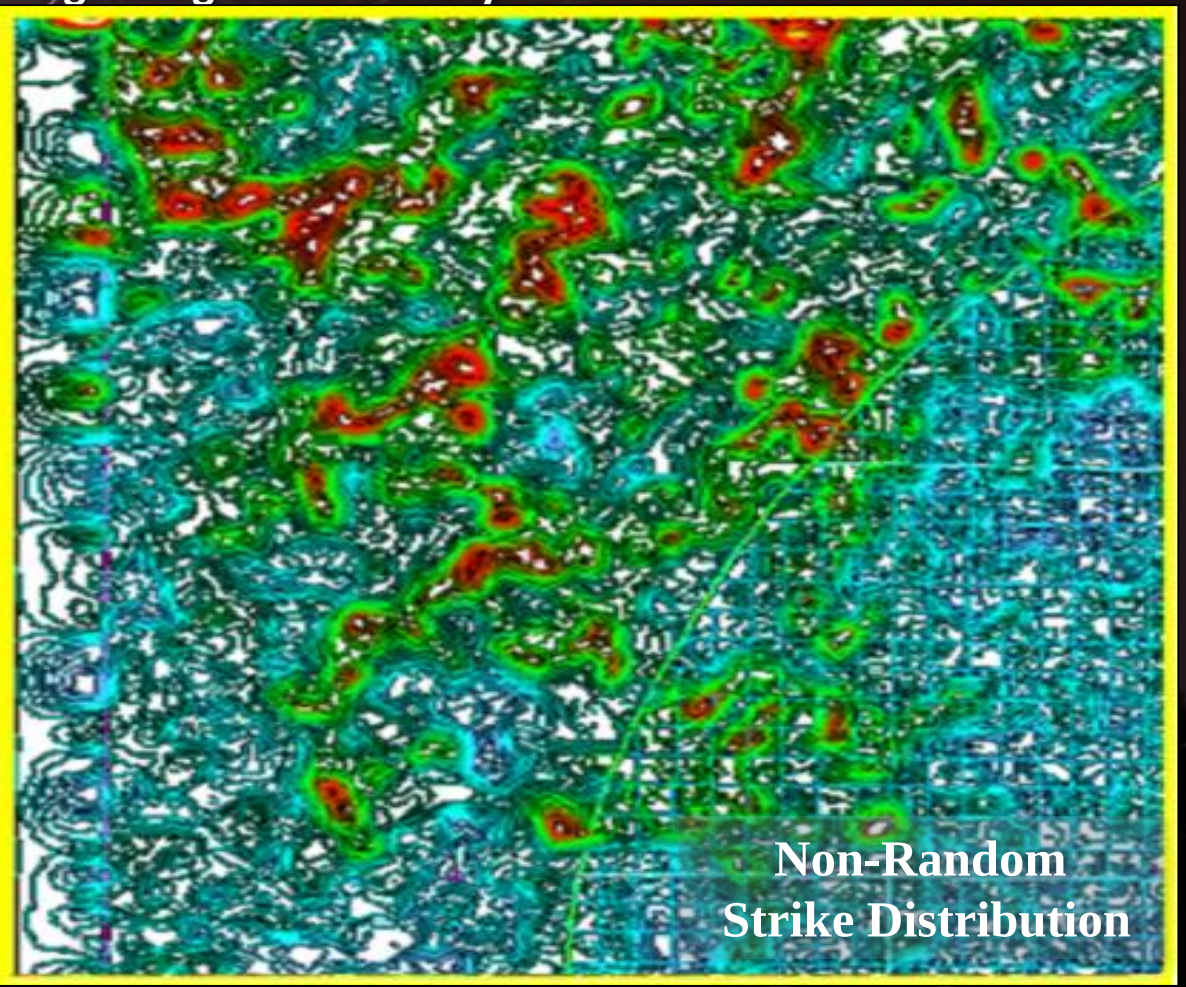


NSEM Correlates To Geology:
Texas Gulf Coast Regional Correlation

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

Structure & Field Outlines

Lightning Strike Density



25-September-2015

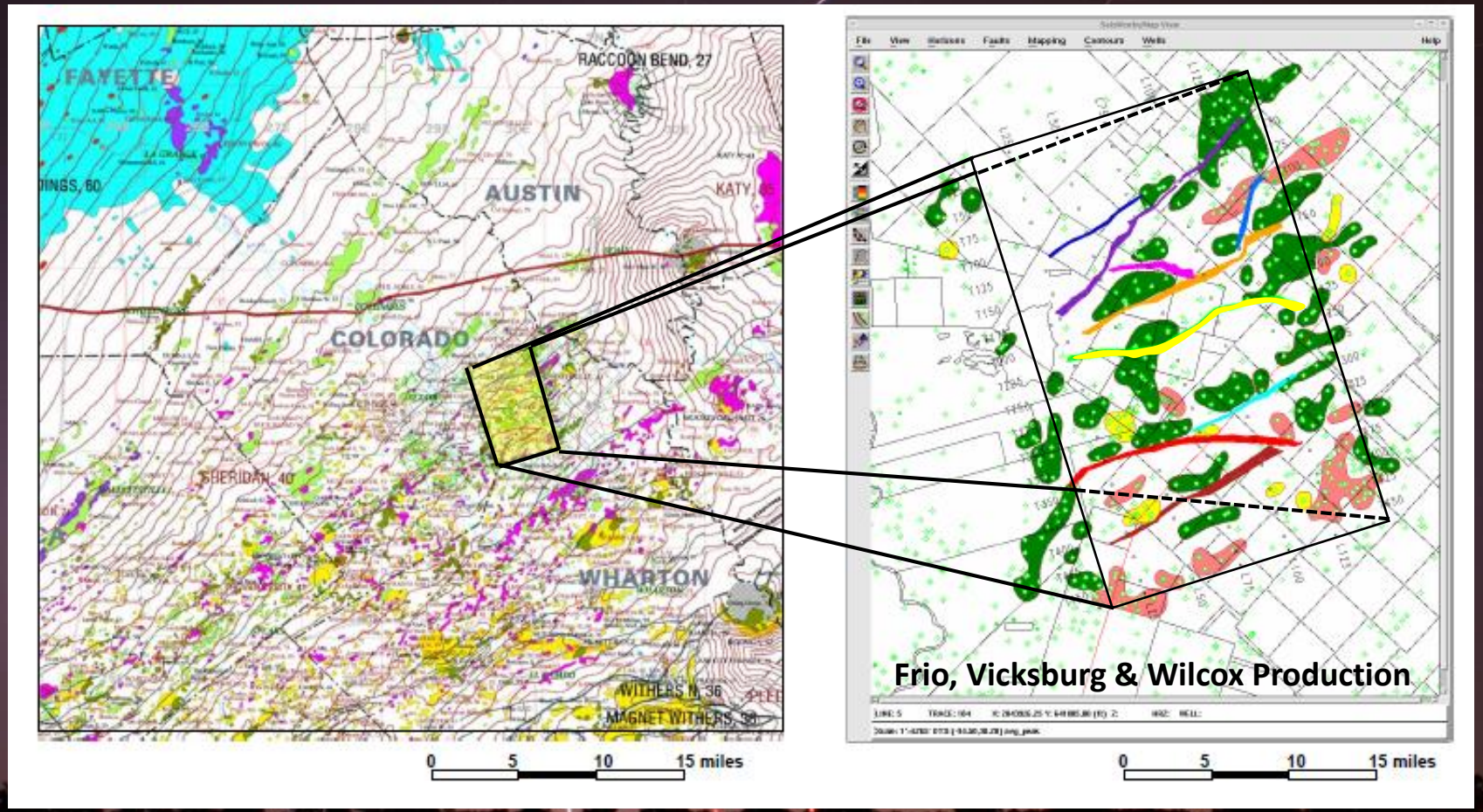
Observations

- Lightning strikes are non-random.
- Lightning strikes generally correlate to field locations.
- Faults do not appear to cut across lightning lineaments, generally striking parallel/sub-parallel to lightning features.

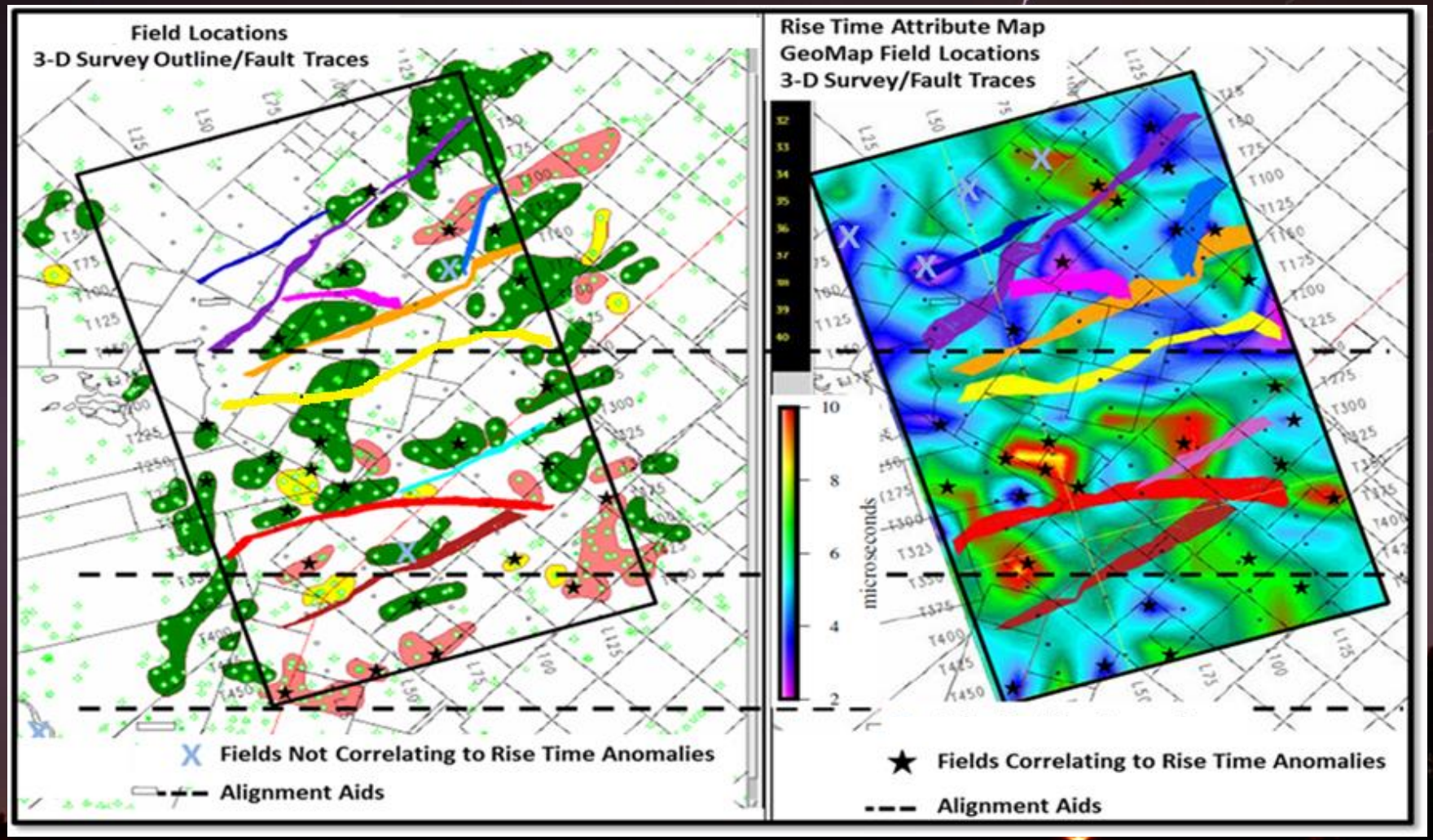
Conclusions

- Local geology influences where lightning strikes occur.
- NSEM has potential to locate hydrocarbons.
- NSEM has potential to delineate subsurface fault patterns.

NSEM Correlates To Geology:
Colorado County, TX



Effective Reconnaissance Mapping
Prospect Scale Field Correlations



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

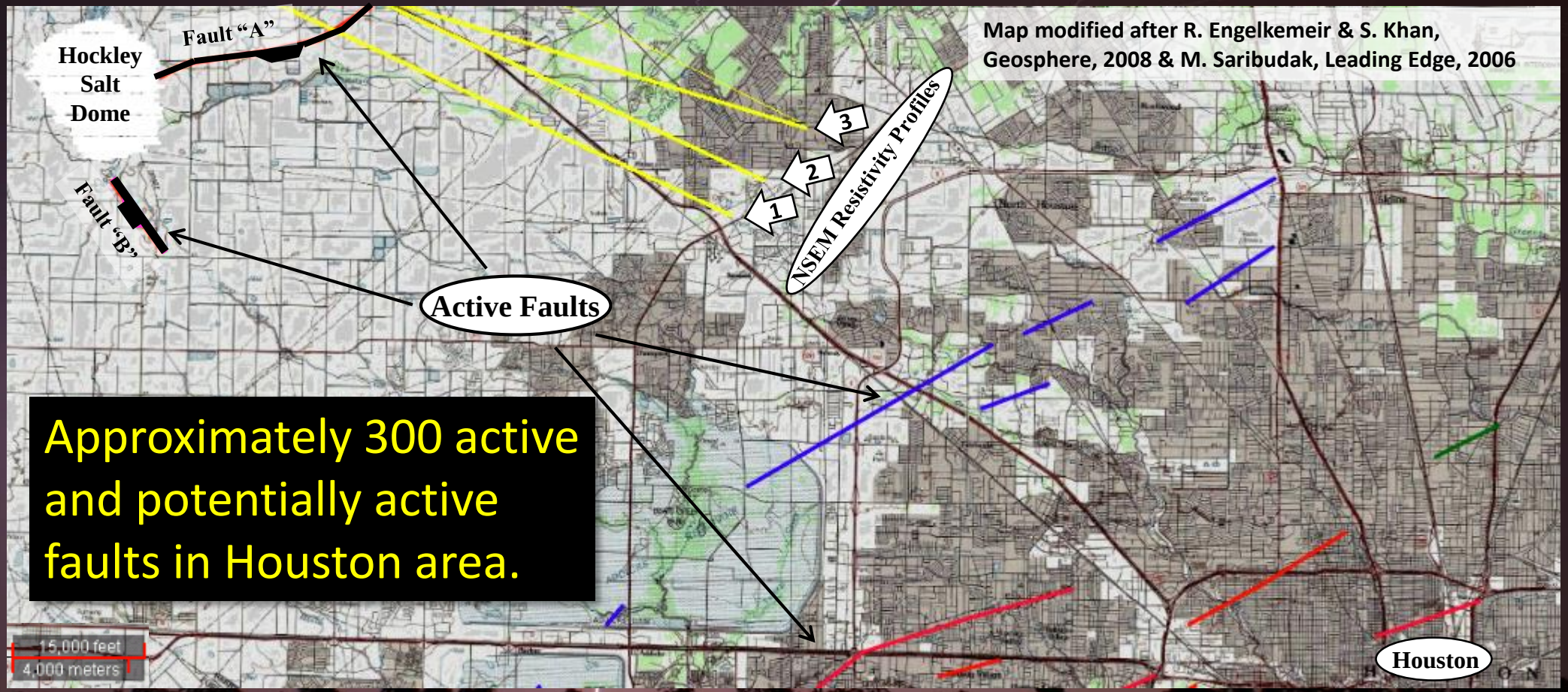
Observations

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

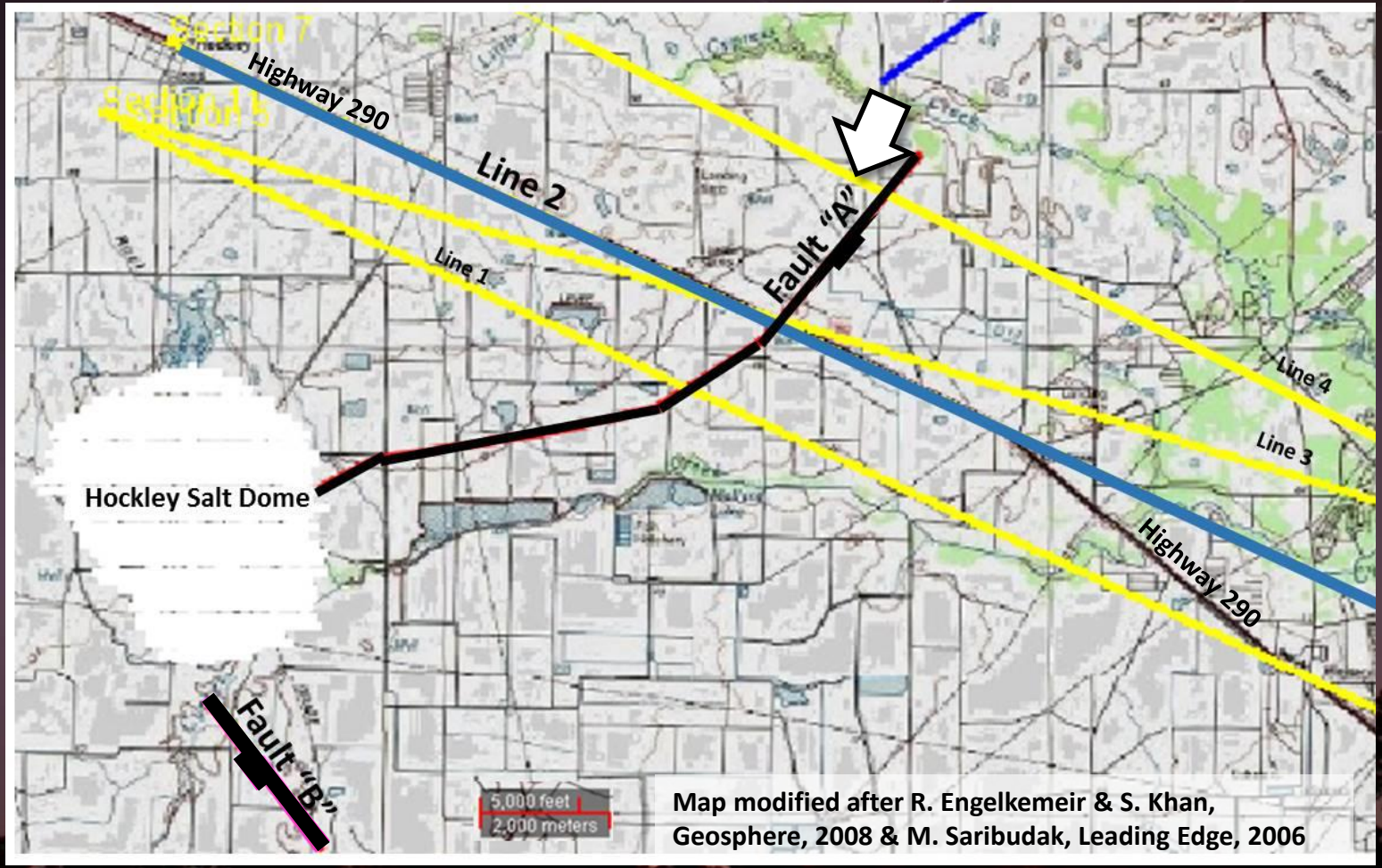
Conclusions

- 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% success rate.

Houston/Harris County Area Active Faults



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



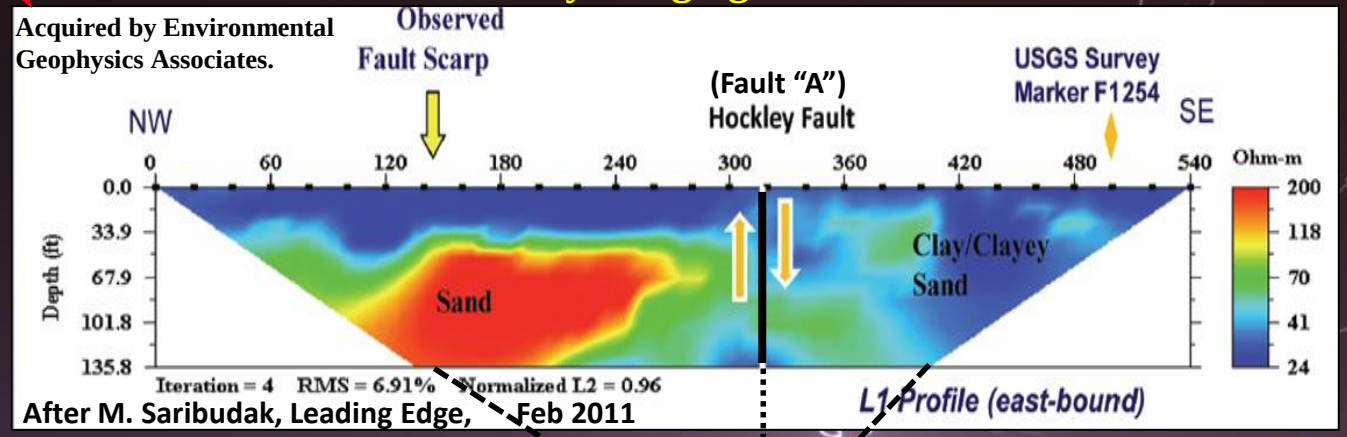
Hockley Radial Fault "A"

Resistivity profile "Line 2" displayed in next slide.

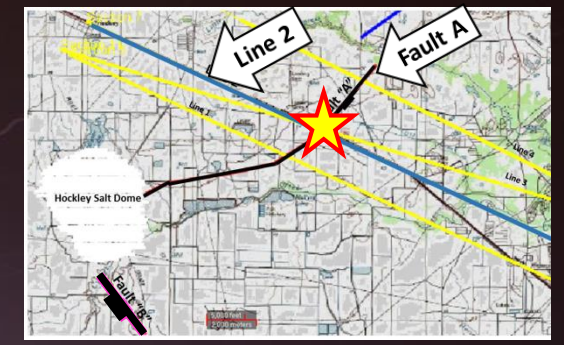
Line 2 Ties Fault "A" to Subsurface

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

Conventional 2-D Resistivity Imaging Profile

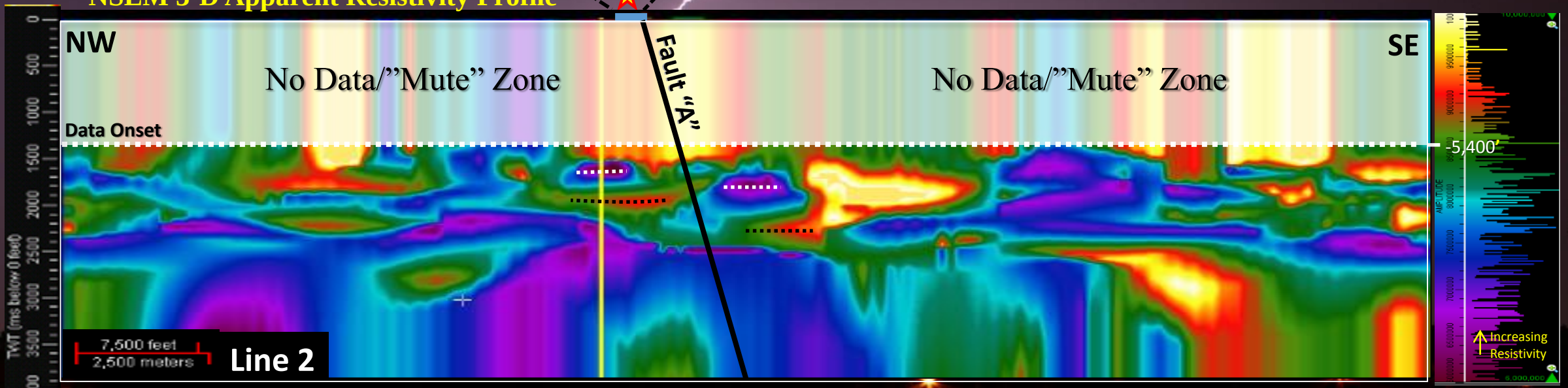


After M. Saribudak, Leading Edge, Feb 2011



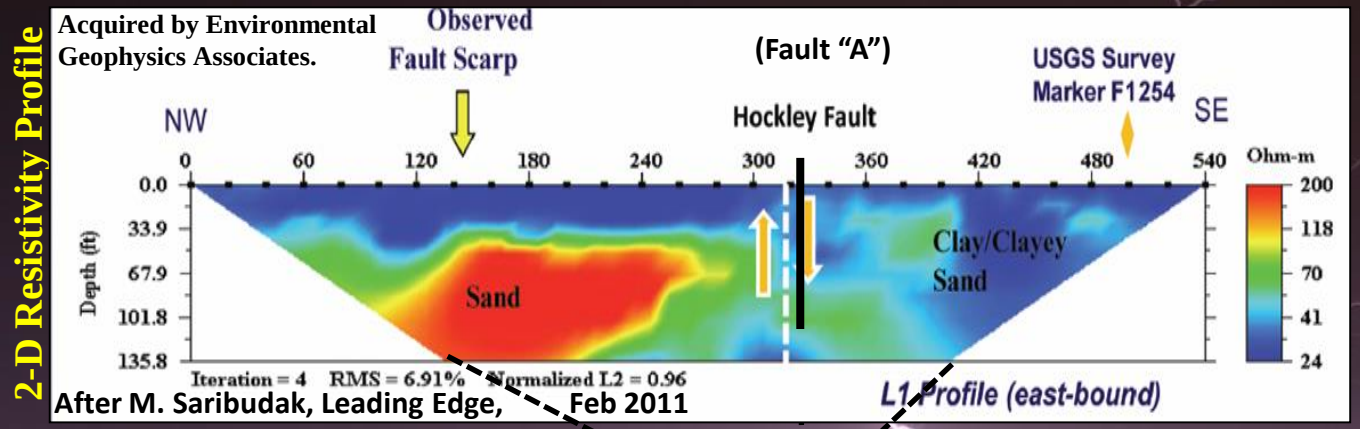
Line 2

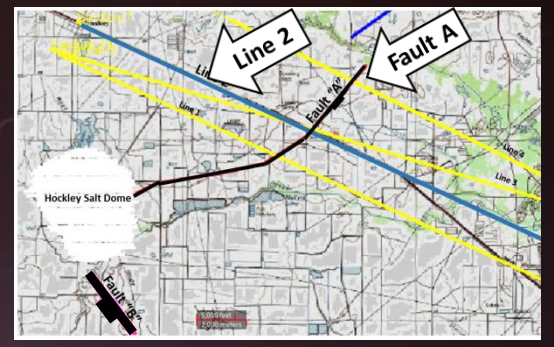
NSEM 3-D Apparent Resistivity Profile



NSEM Reveals Additional Faulting

3-D Data Provides Interpretive Checks & Balances

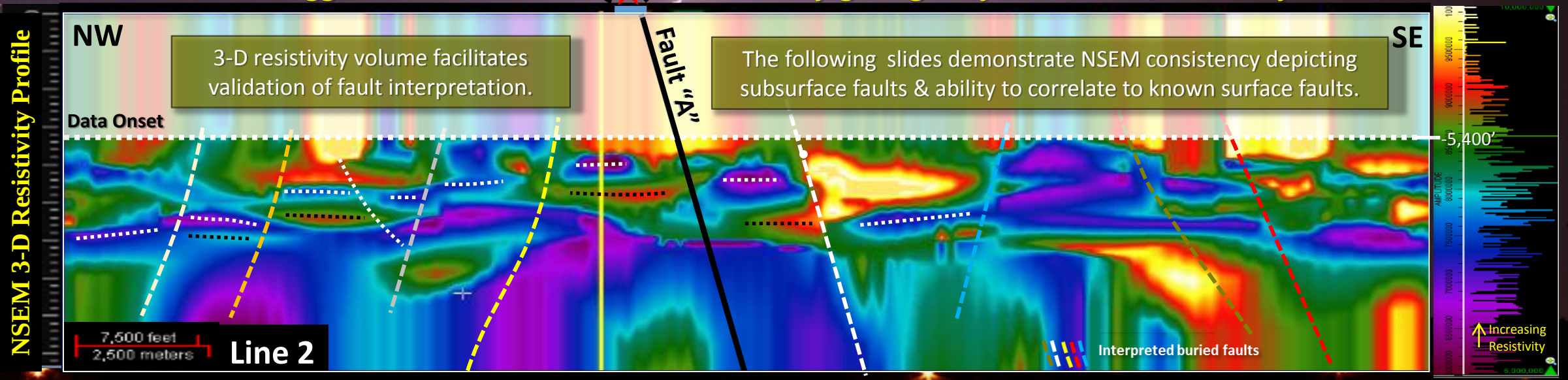




Line 2

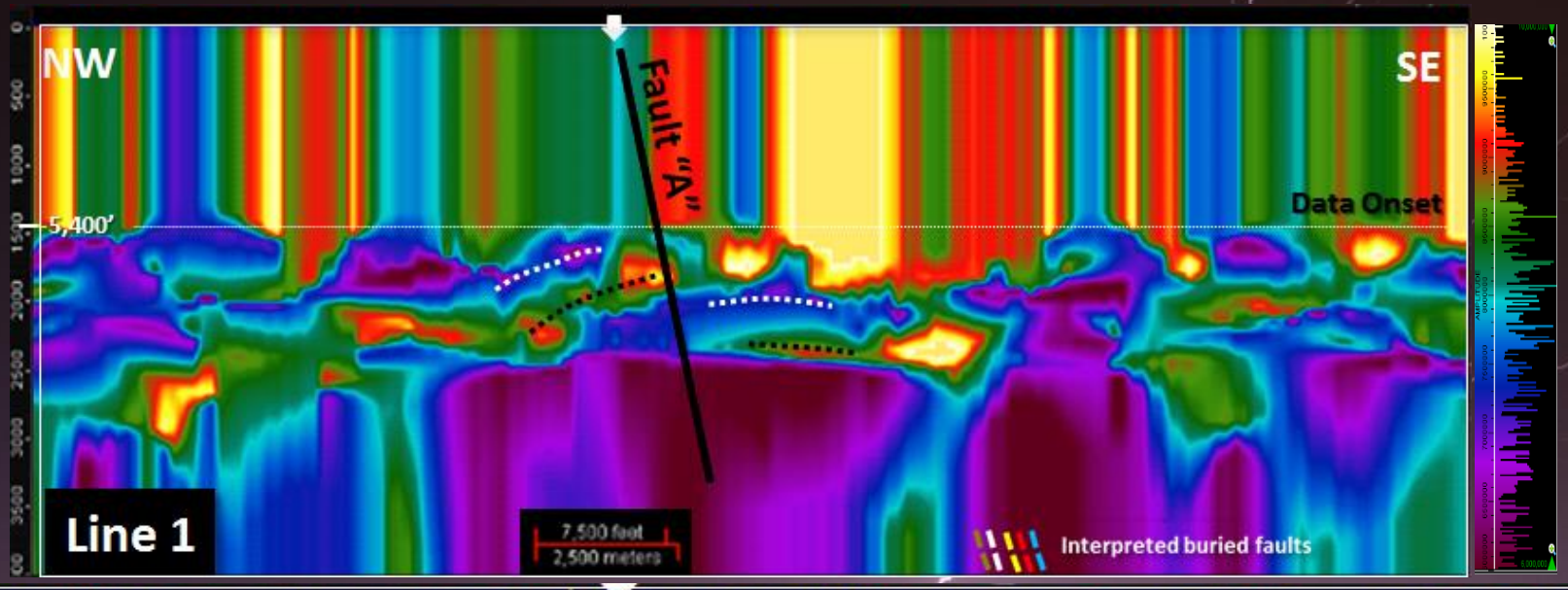
Additional faults suggested.

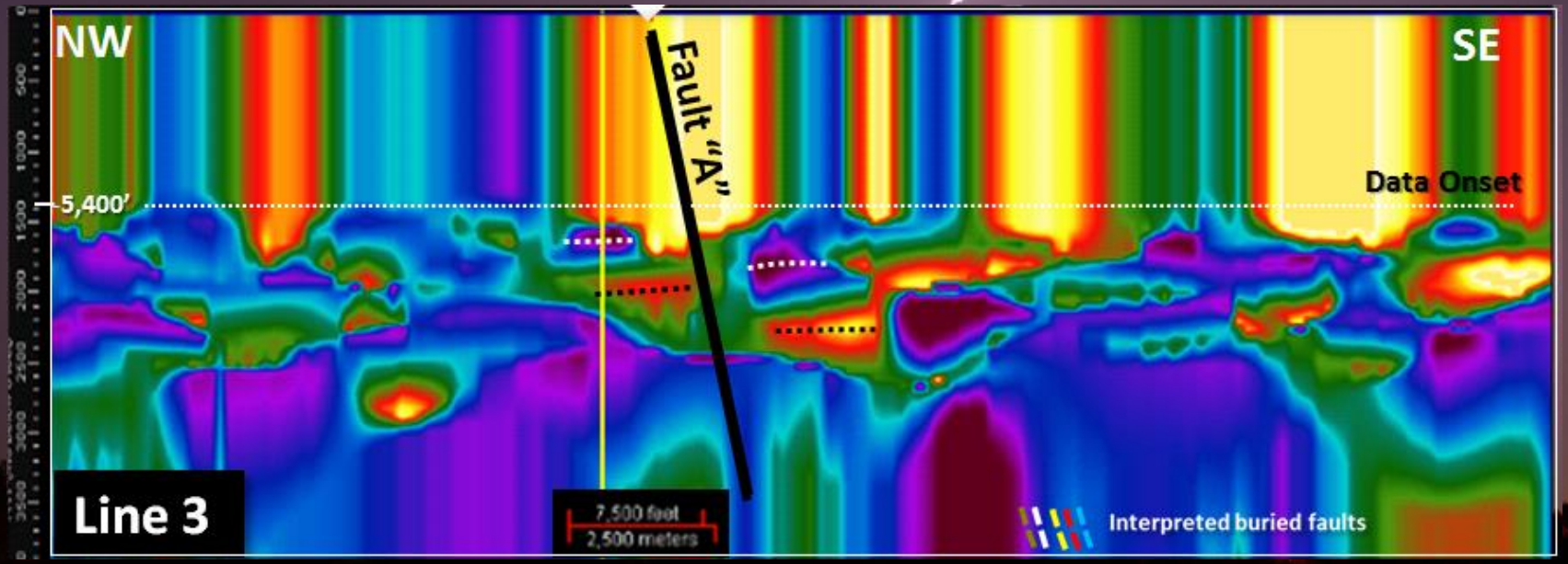
Are they geologically reasonable, internally consistent, valid?



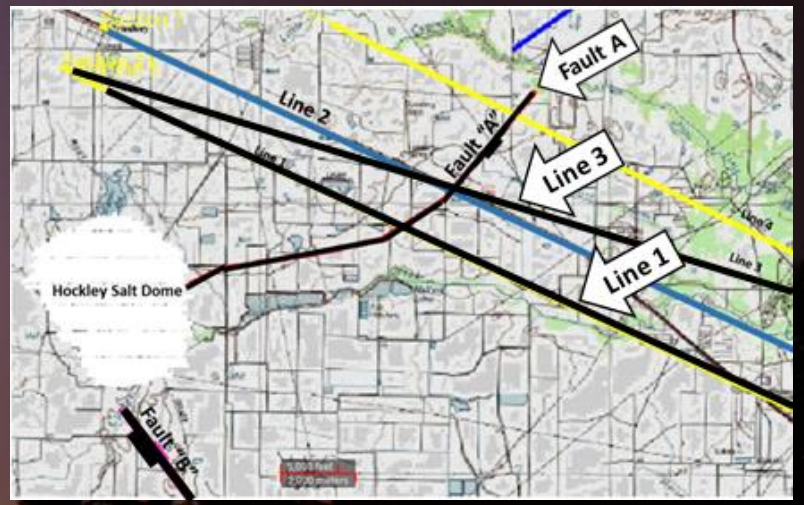
25-September-2015

Lines 1 & 3 Tie Fault "A" to Subsurface

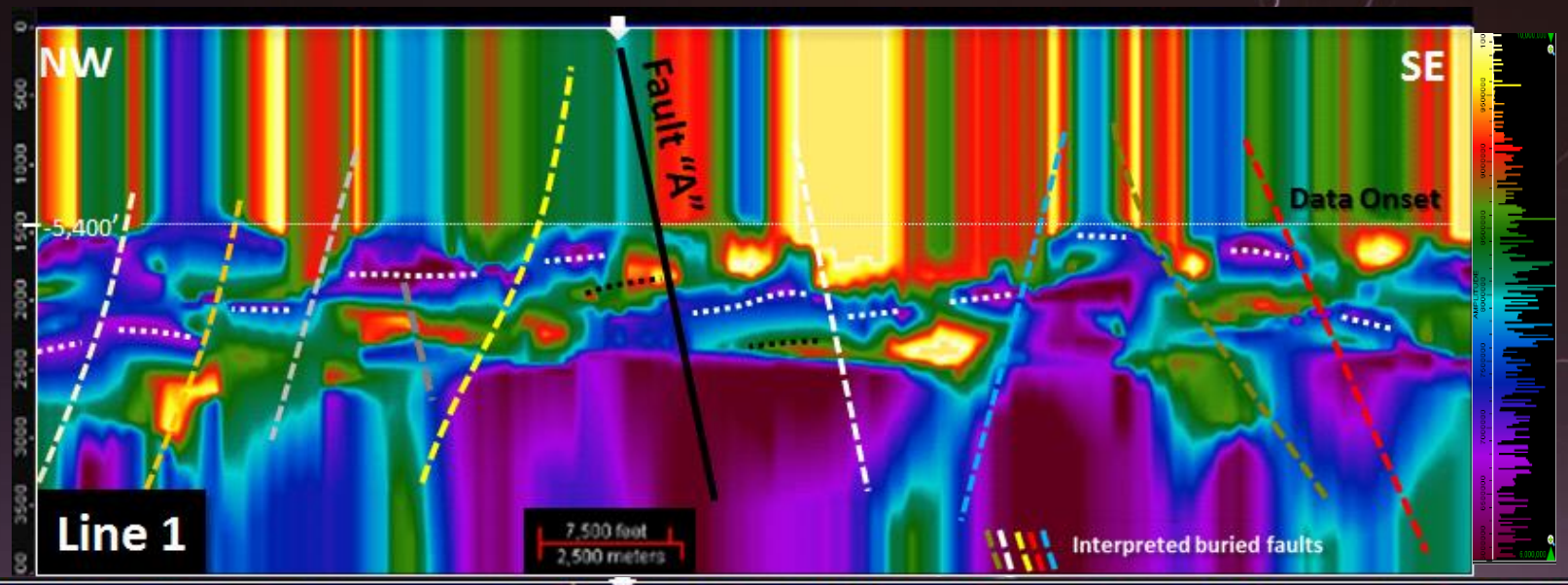


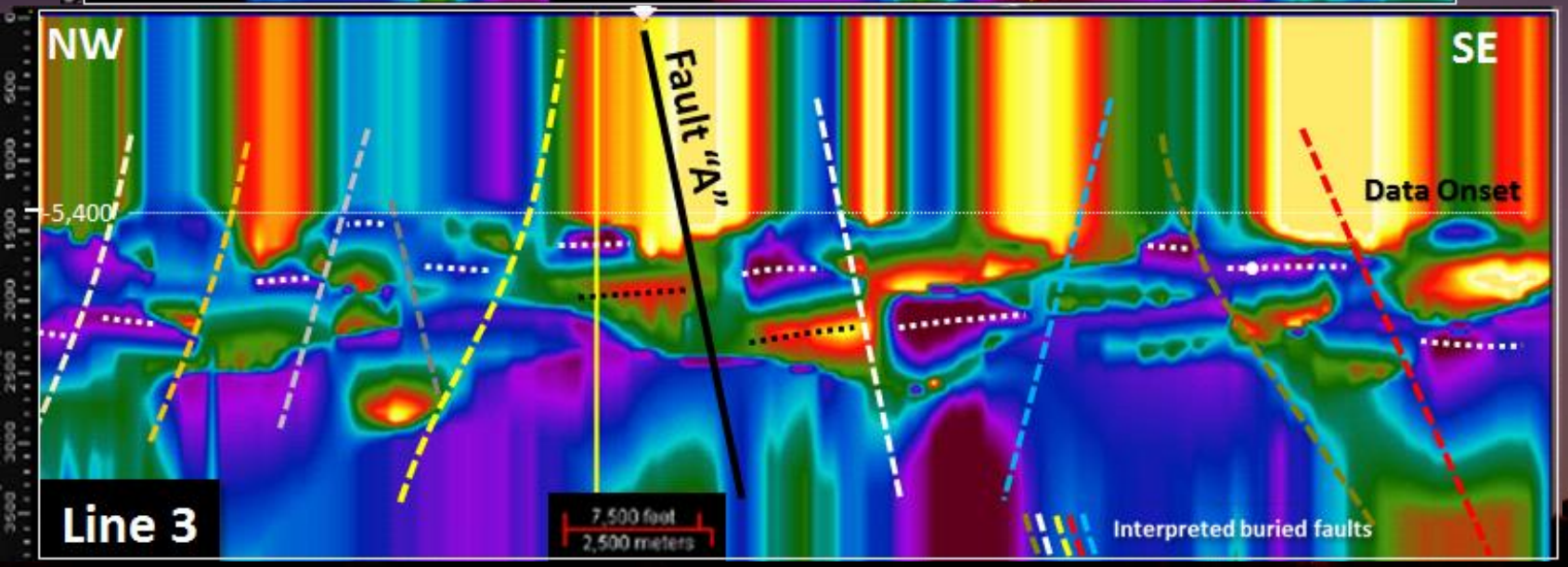


NSEM demonstrates consistency identifying Fault "A'.

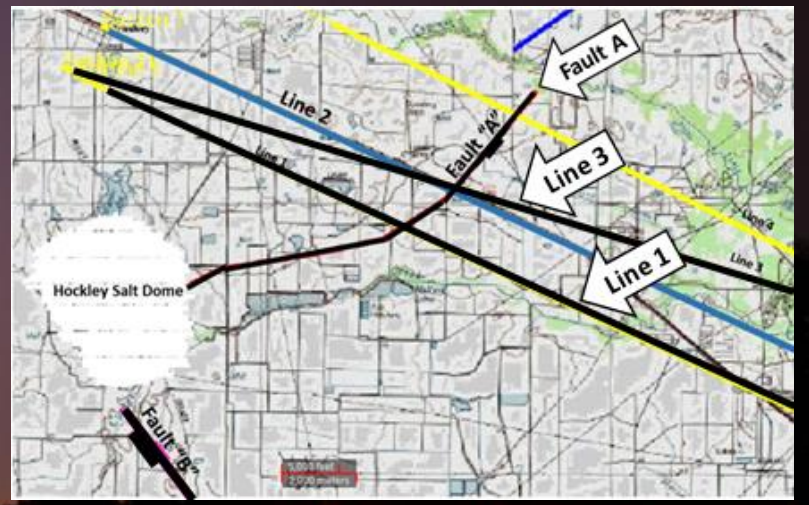


Lines 1 & 3 Also Reveal Additional Faults



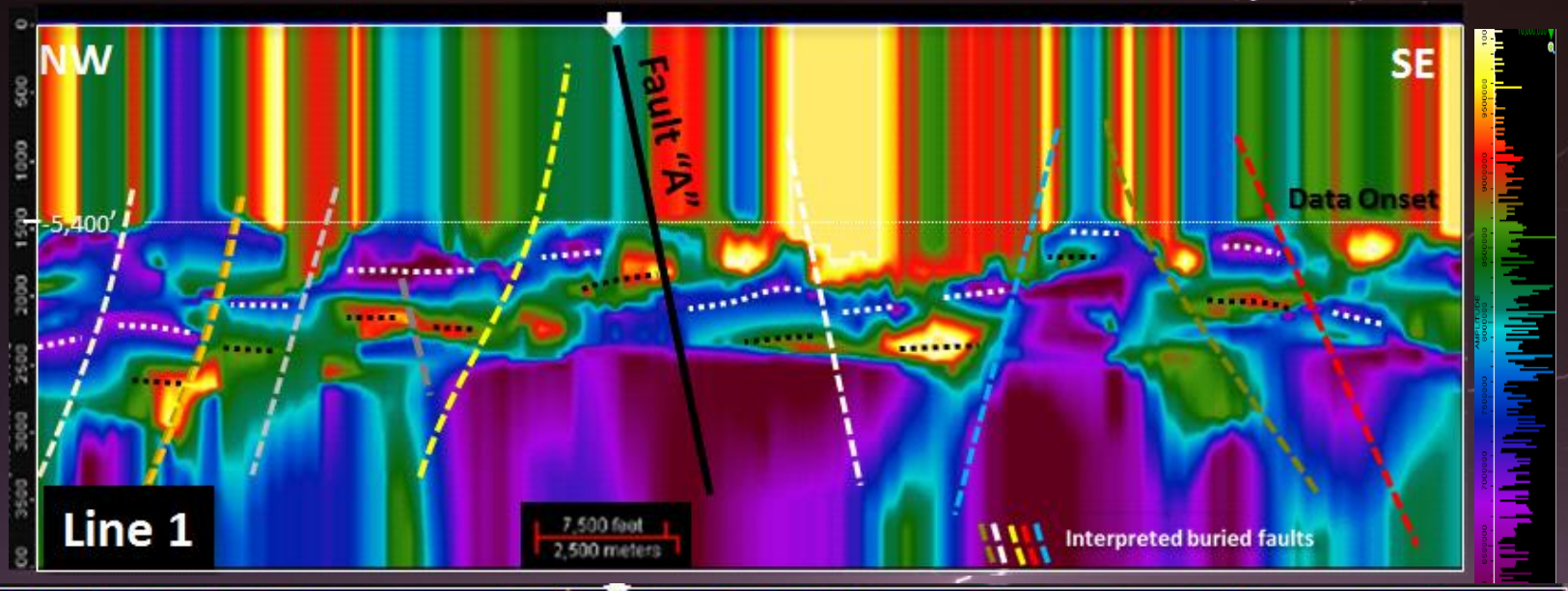


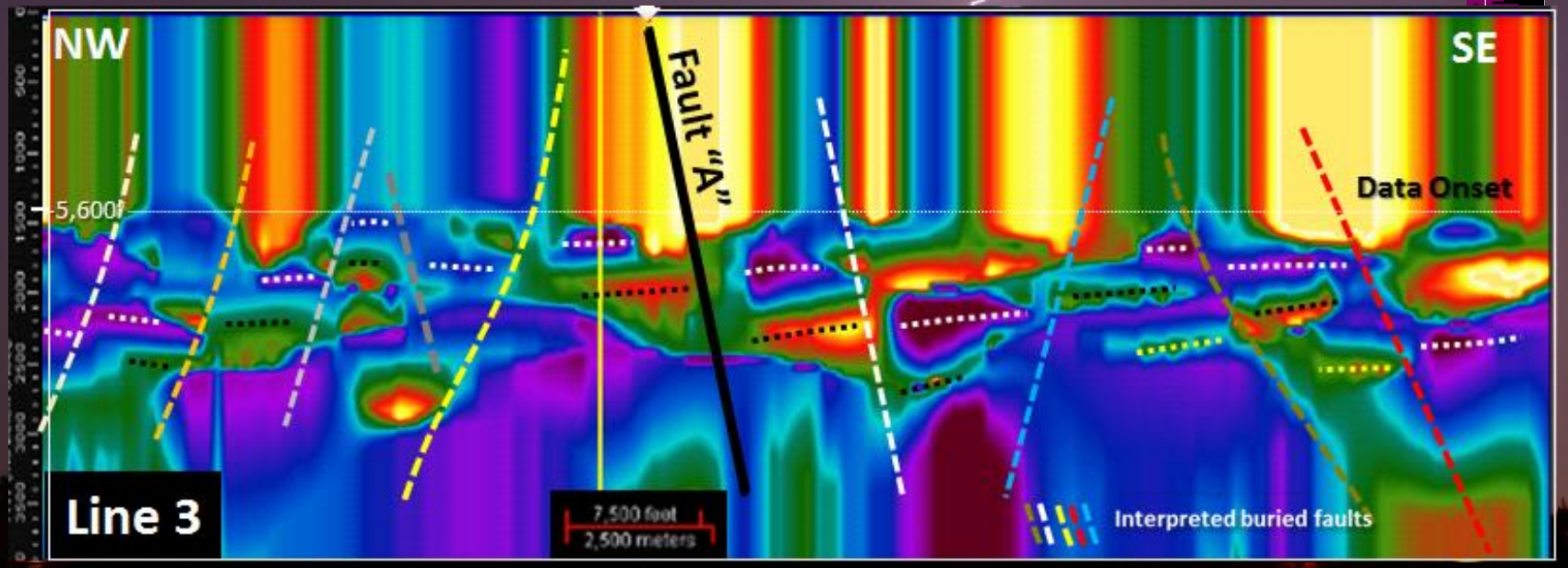
NSEM demonstrates internal consistency mapping nine faults on multiple profiles.



25-September-2015

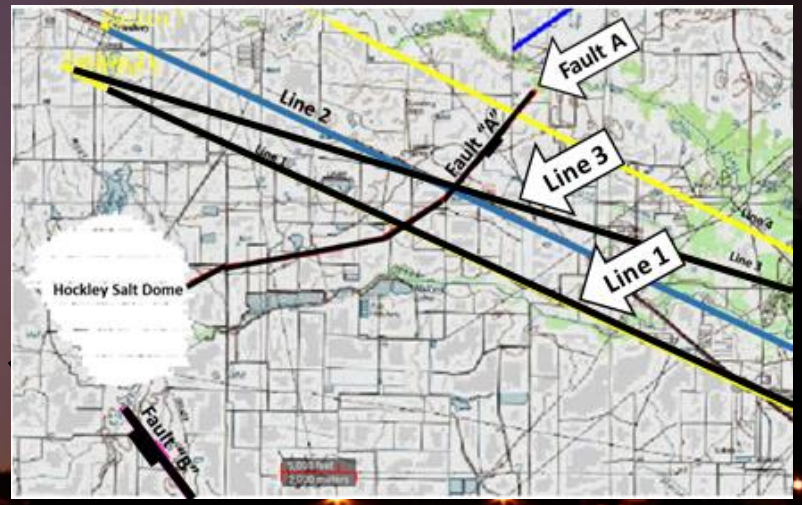
NSEM Builds Reliable Structural Framework





Dotted lines highlight as many as 3 resistivity offsets.

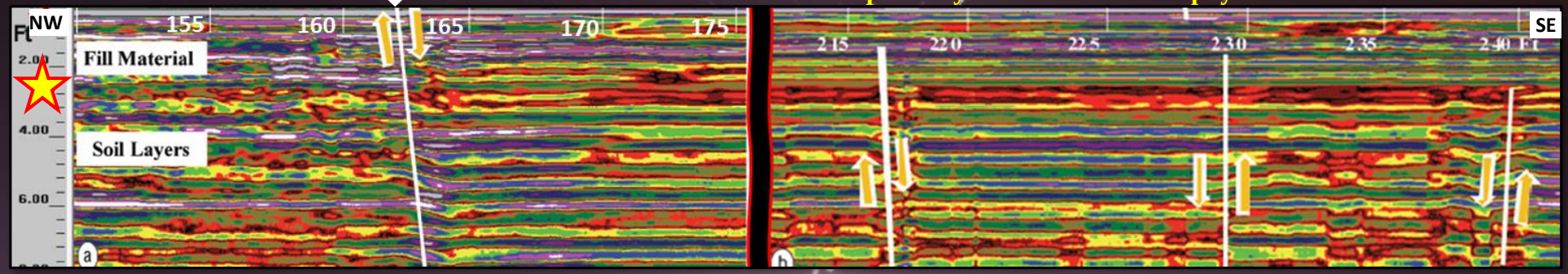
3-D NSEM enables structural and fault plane mapping.

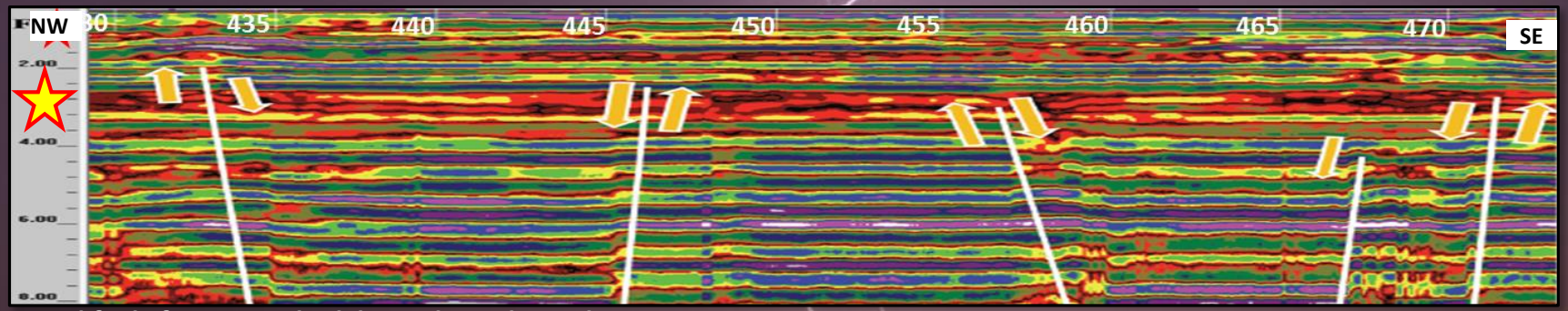


Ground Penetrating Radar
Shallow Micro-Faulting Adjacent to Fault "A"

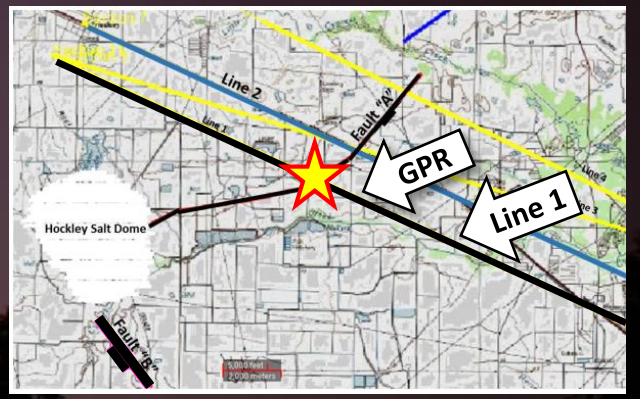
Hockley Fault (Flt. "A")

GPR acquired by Environmental Geophysics Associates



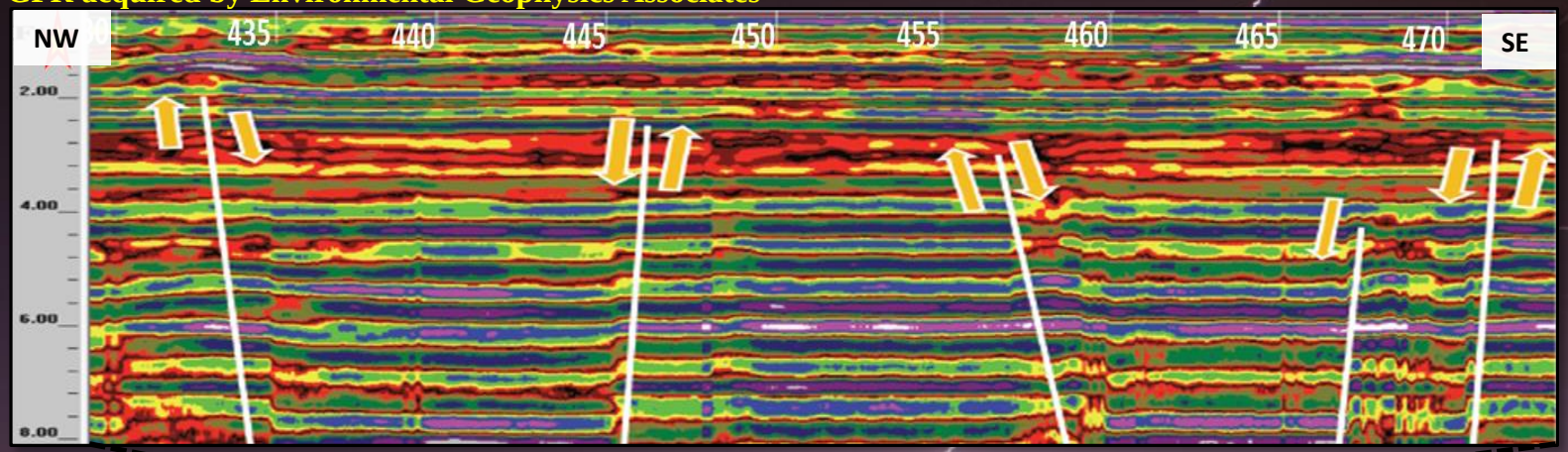


Modified after M. Saribudak, Leading Edge, Feb 2011

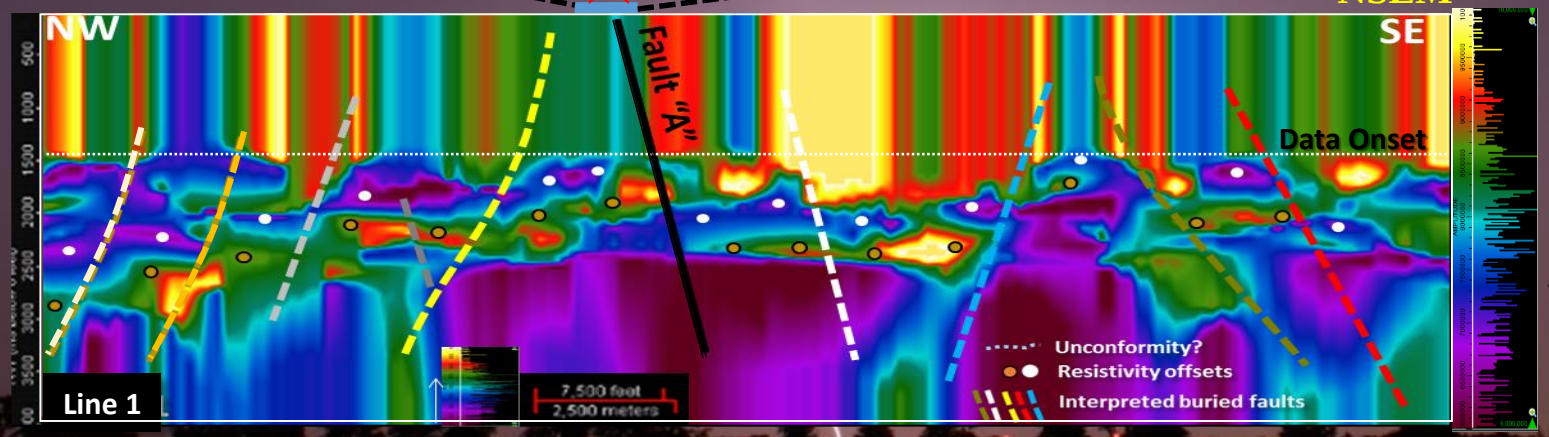


GPR & NSEM
Similar Micro/Macro Structural Styles

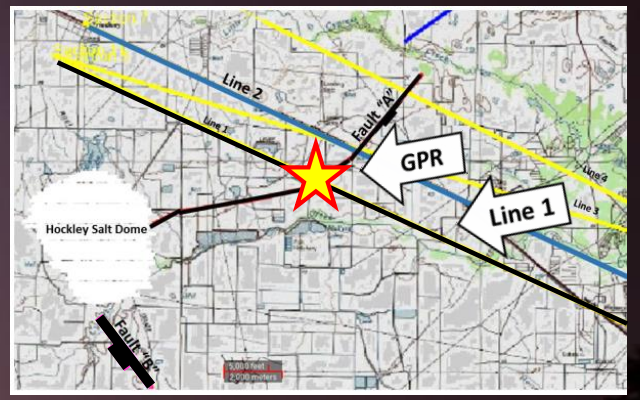
GPR acquired by Environmental Geophysics Associates



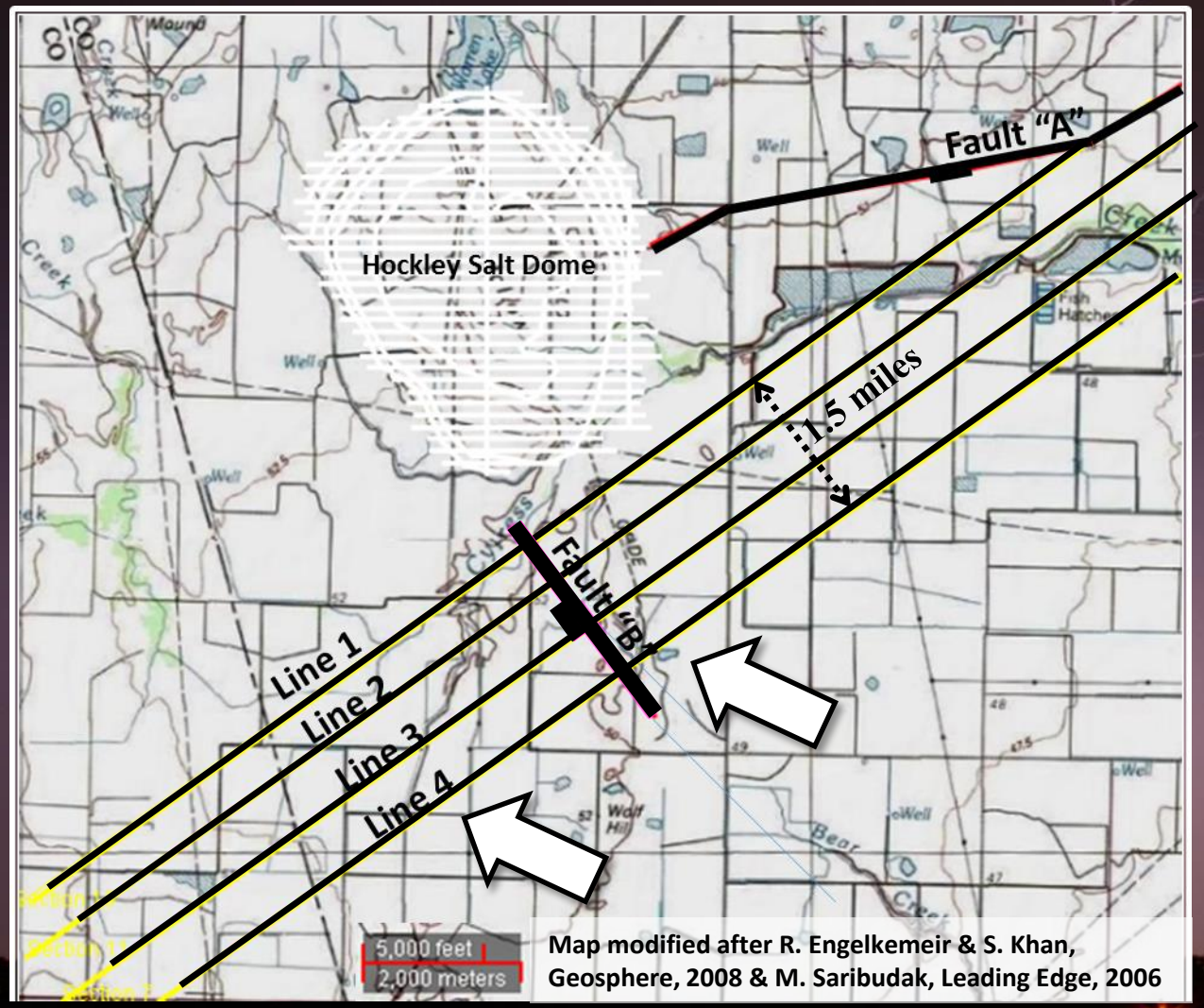
After M. Saribudak, Leading Edge, Feb 2011



Horsts, grabens & half-graben structures identified.



Hockley Radial Fault "B"

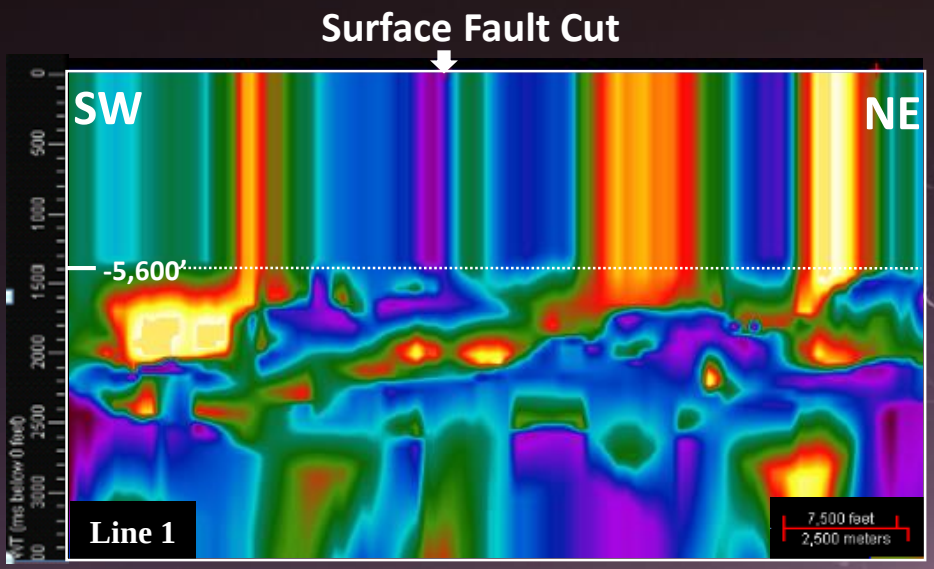


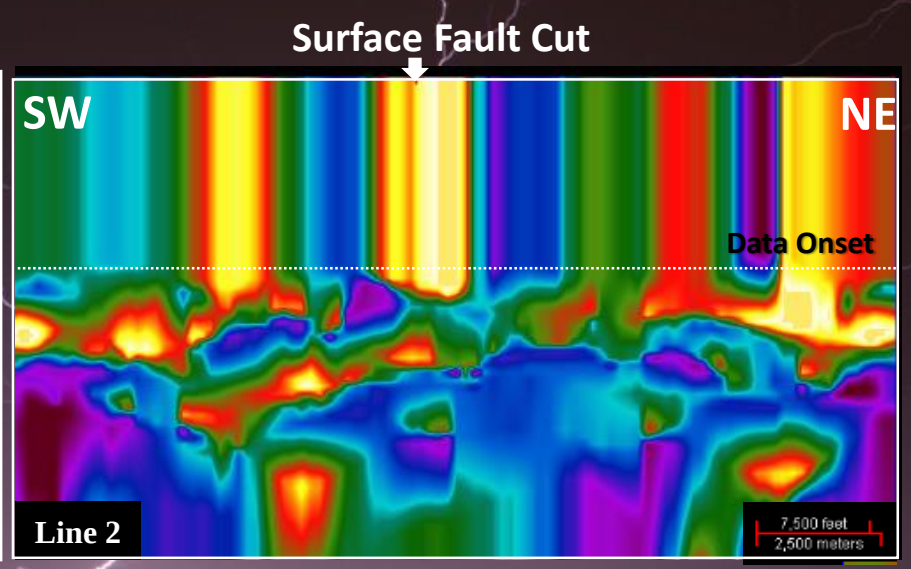
Map modified after R. Engelkemeir & S. Khan, Geosphere, 2008 & M. Saribudak, Leading Edge, 2006

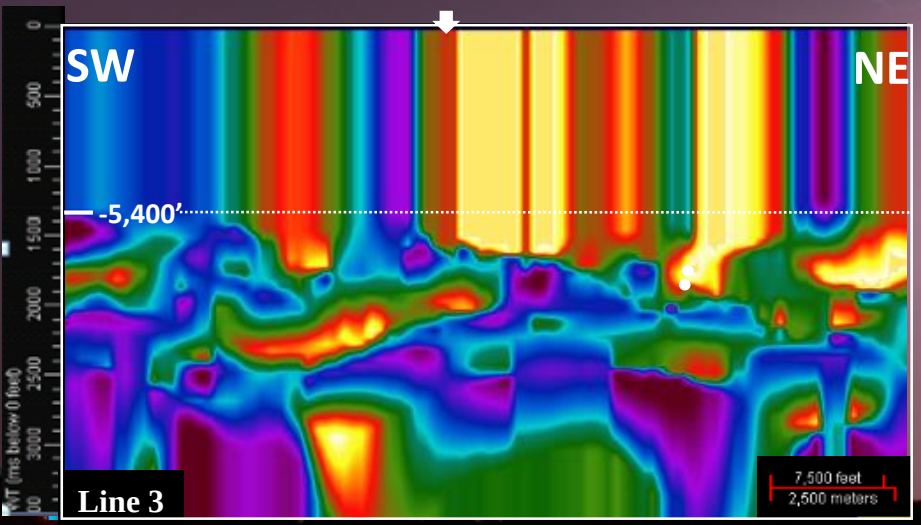
A 1½ mile distance along the Fault "B" trace is sampled with resistivity profiles.

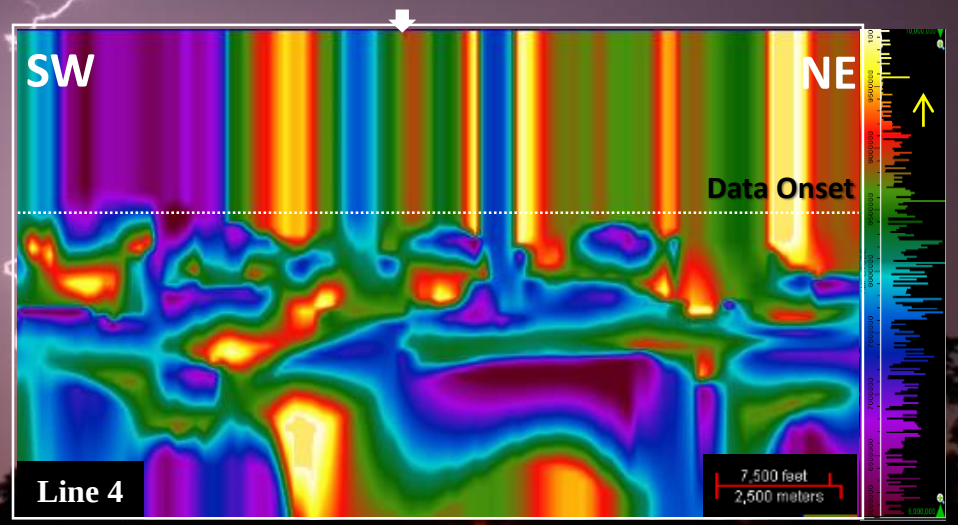
Resistivity Lines 1-4 are displayed on next slide.

Hockley Radial Fault "B" Lines 1-4

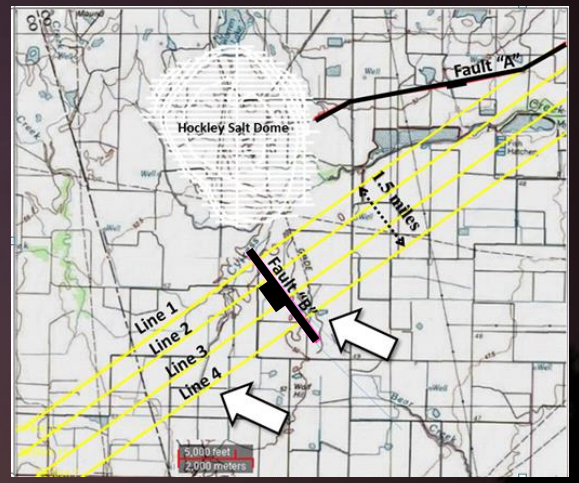




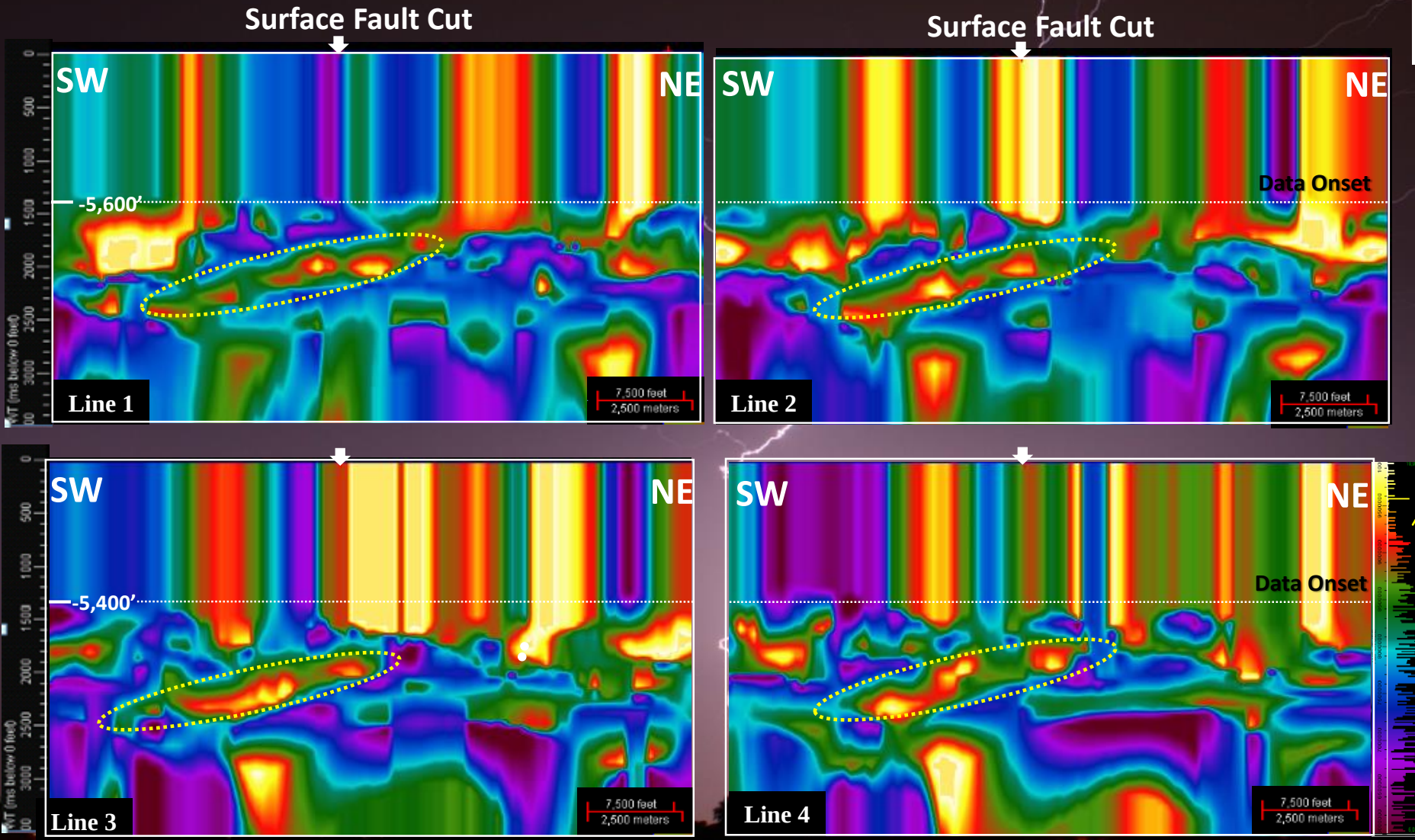




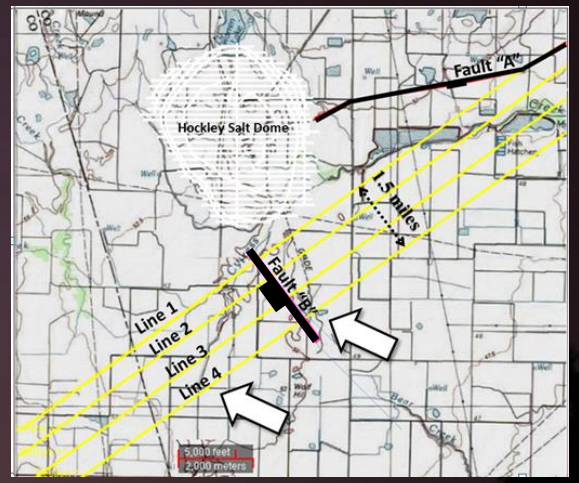
Lines ½ mile apart.
Note similar character.



Similar Character Spanning 1.5 Miles

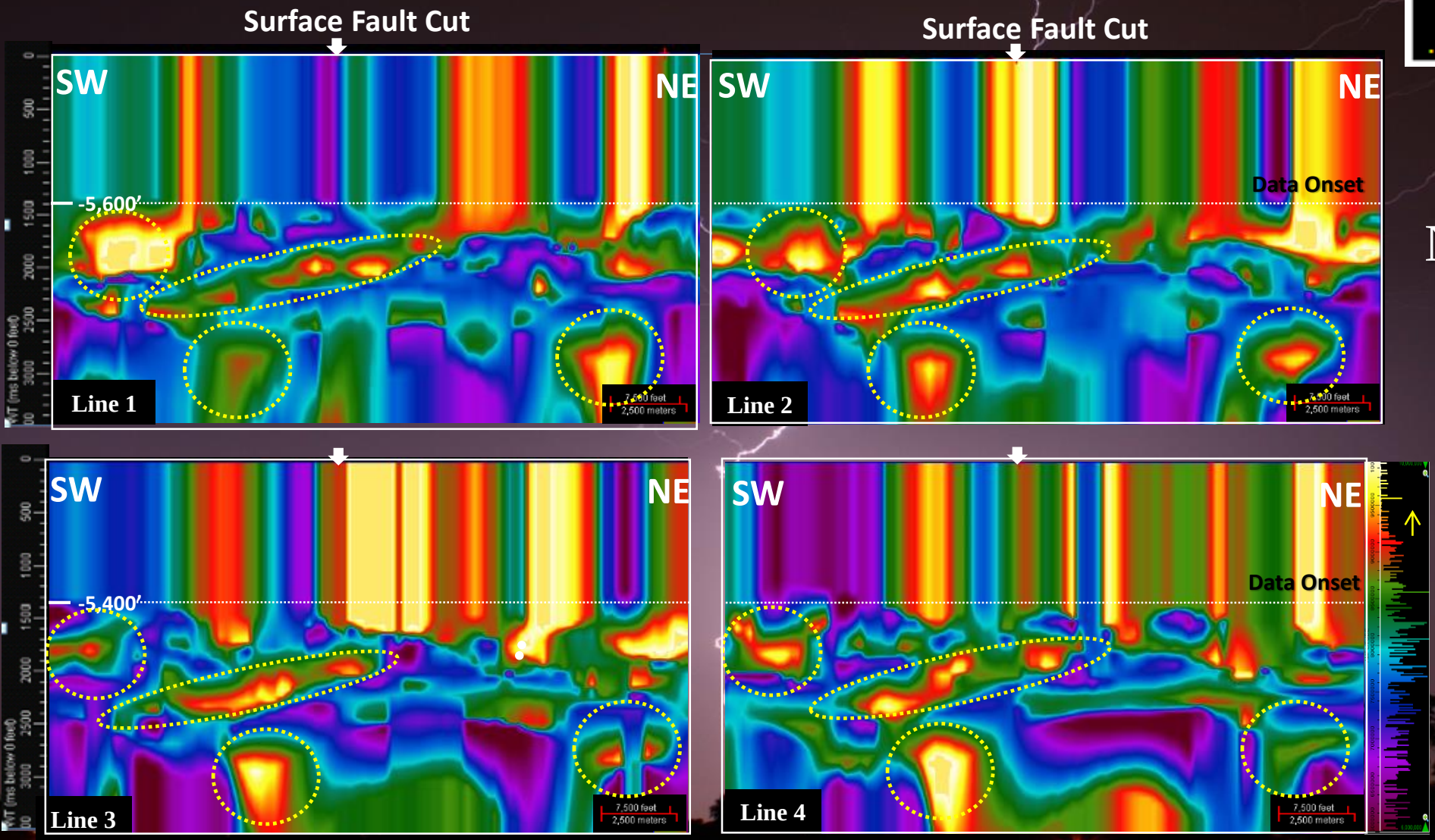


Lines ½ mile apart.
Note similar character.

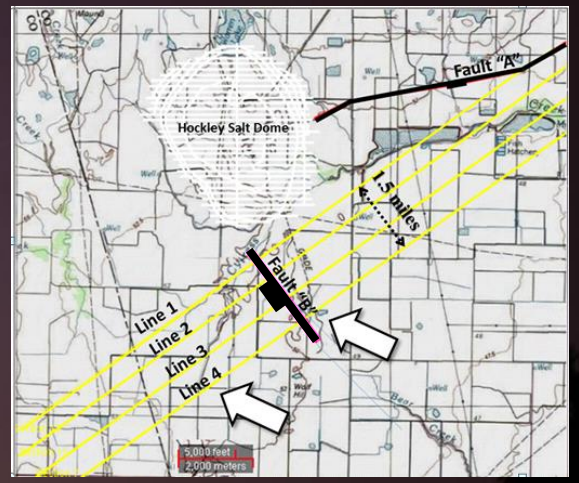


25-September-2015

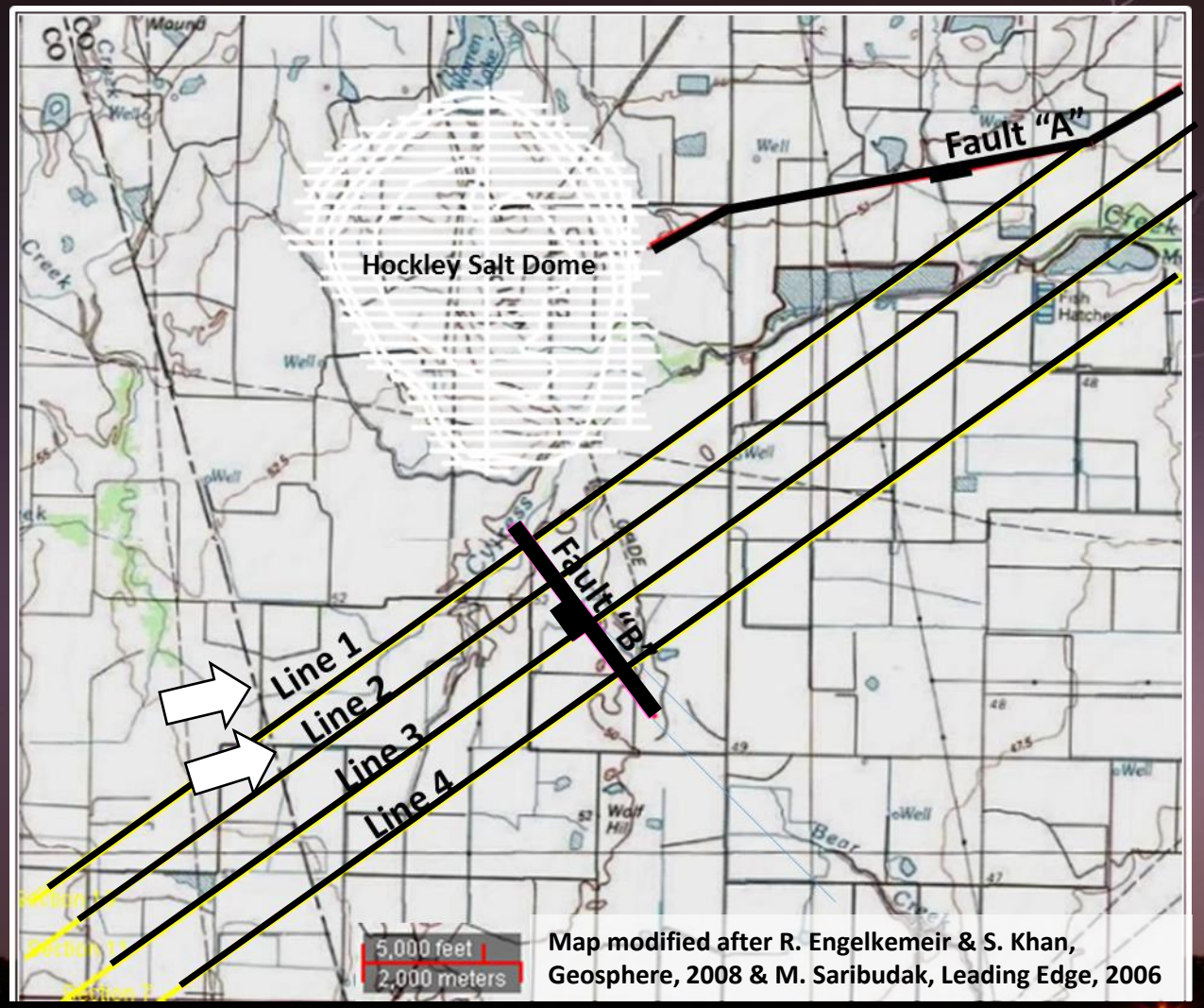
Numerous Features Correlate Line to Line



Lines ½ mile apart.
Note similar character.



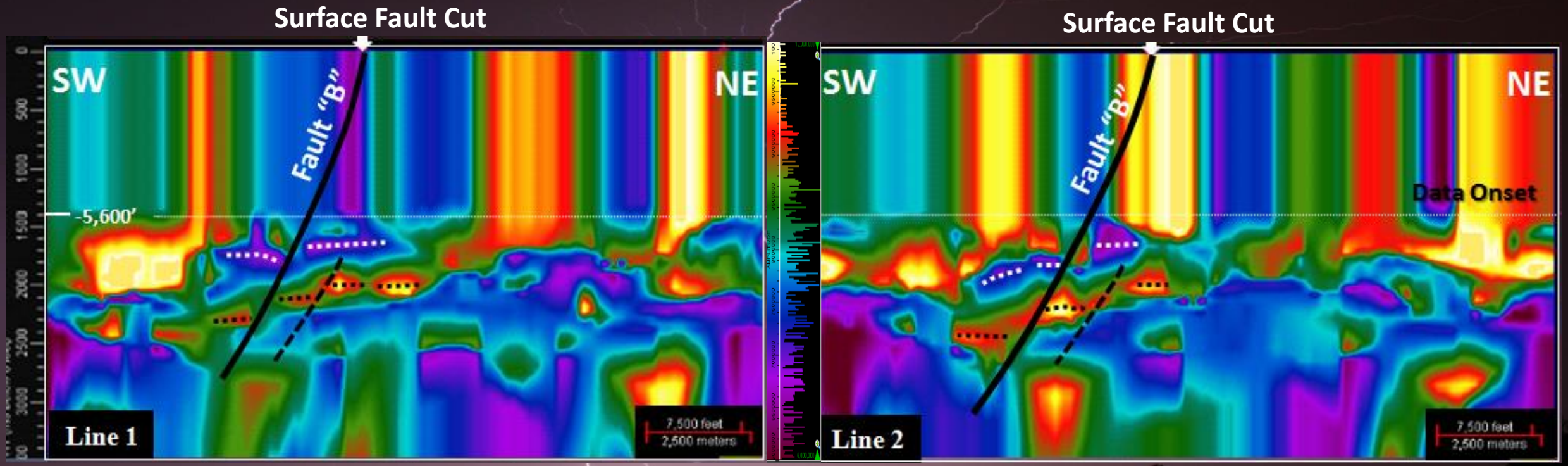
Hockley Radial Fault "B"



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

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

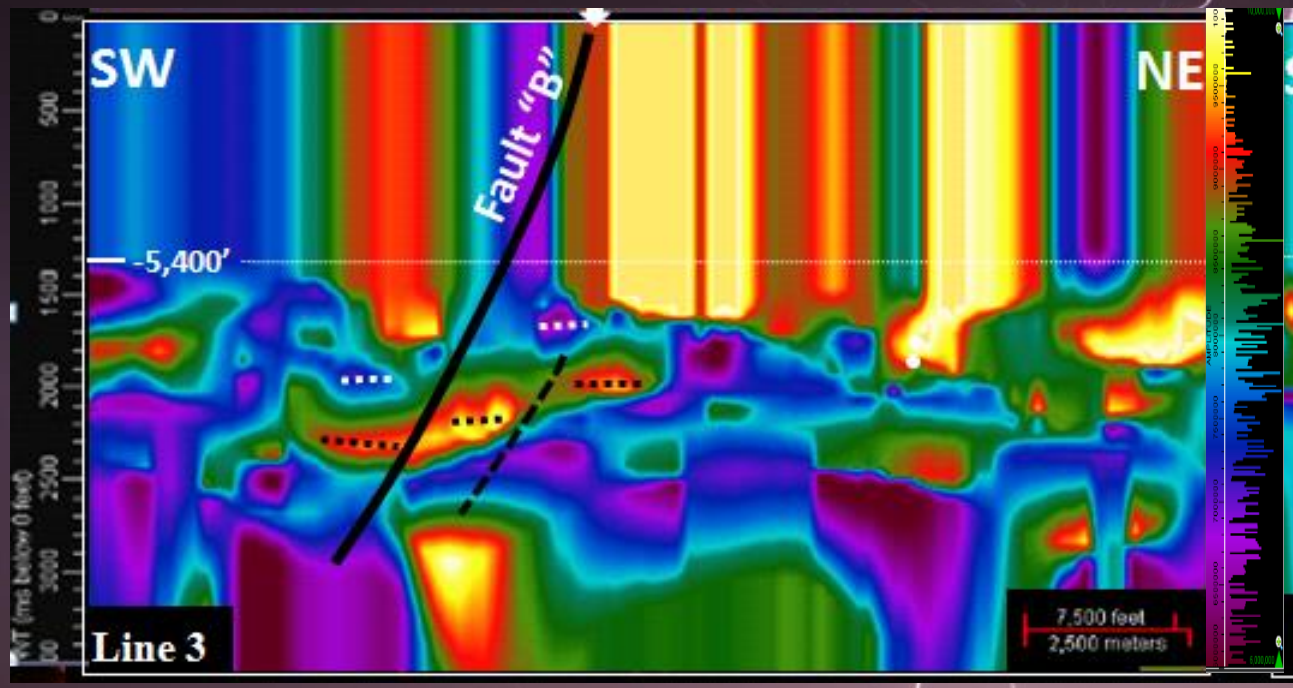
NSEM Ties Surface Fault "B" to Subsurface



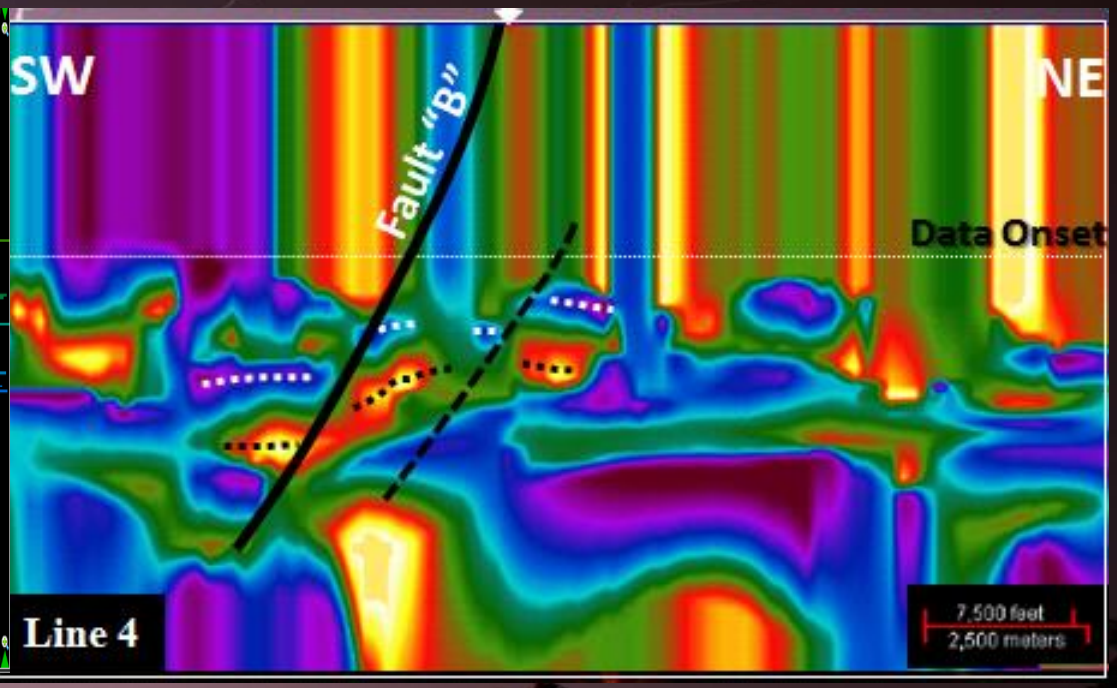
Lines 1 & 2 show consistent subsurface fault criteria.

NSEM Ties Surface Fault "B" to Subsurface

Surface Fault Cut

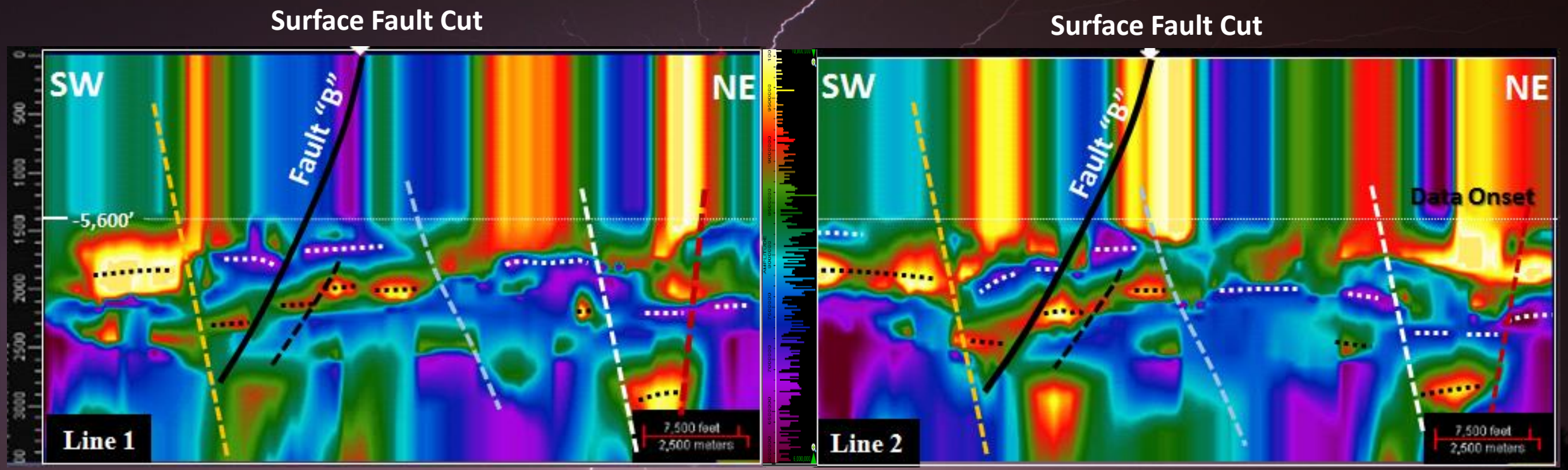


Surface Fault Cut



Lines 3 & 4 show similar consistent subsurface fault criteria.

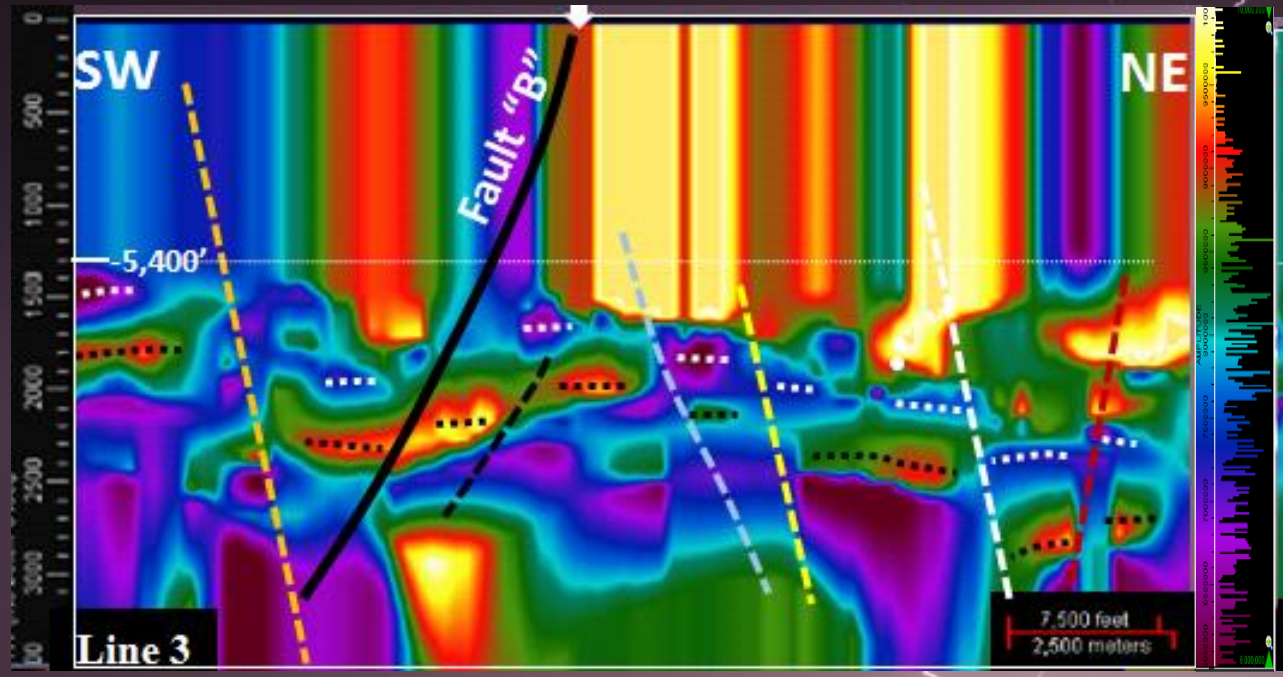
NSEM Shows Additional Faulting
Lines 1 & 2



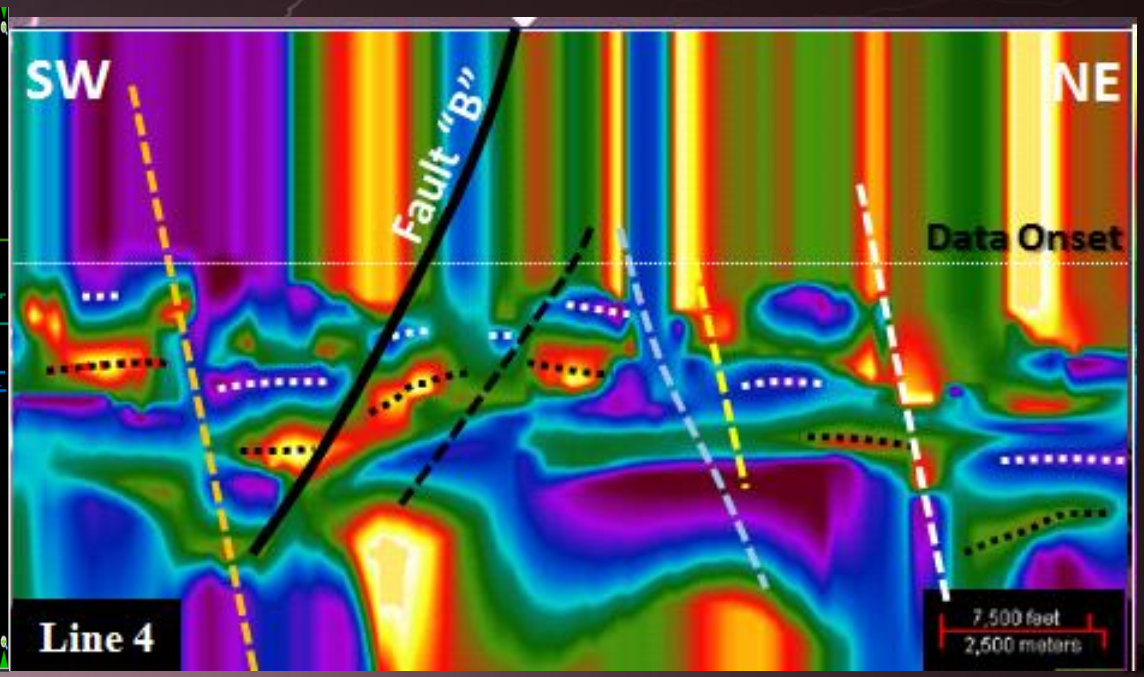
Six geologically reasonable faults consistently interpreted on both lines.

NSEM Shows Additional Faulting
Lines 3 & 4

Surface Fault Cut

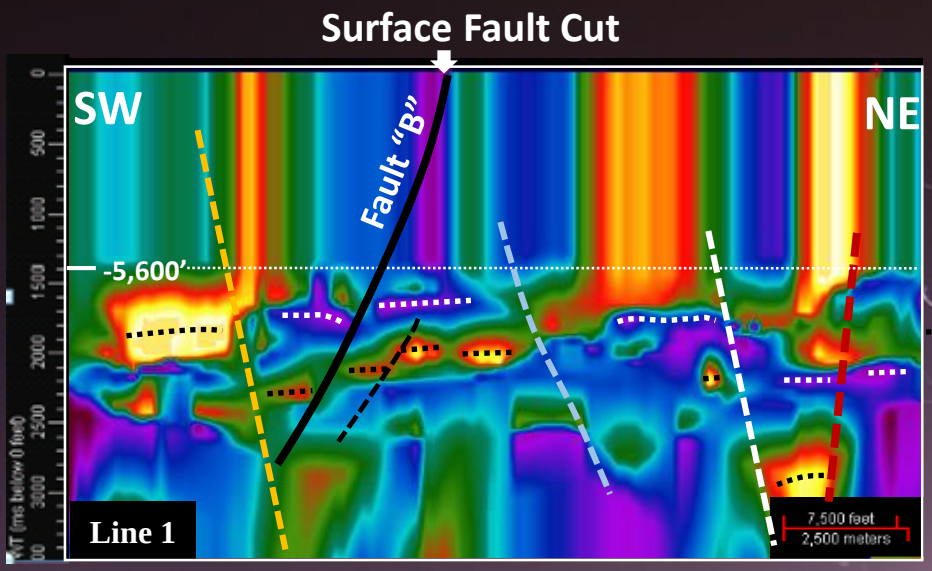


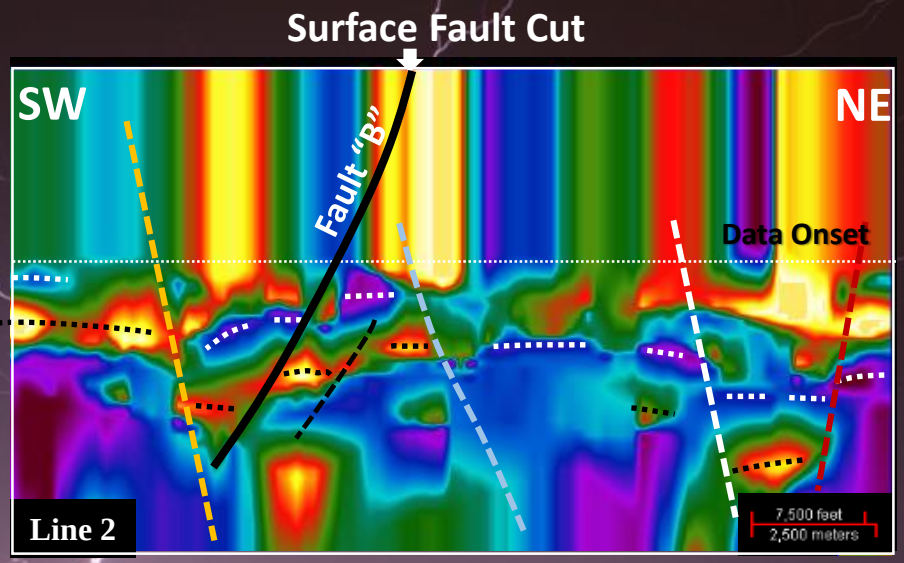
Surface Fault Cut

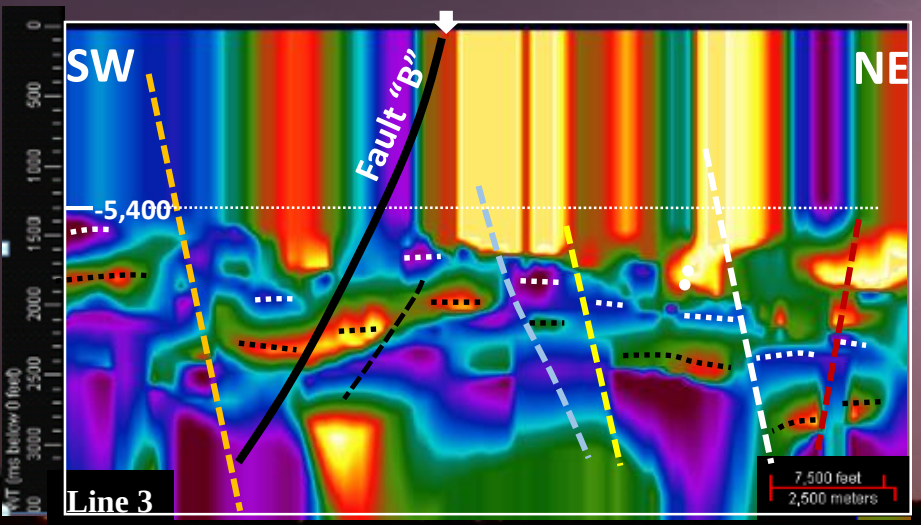


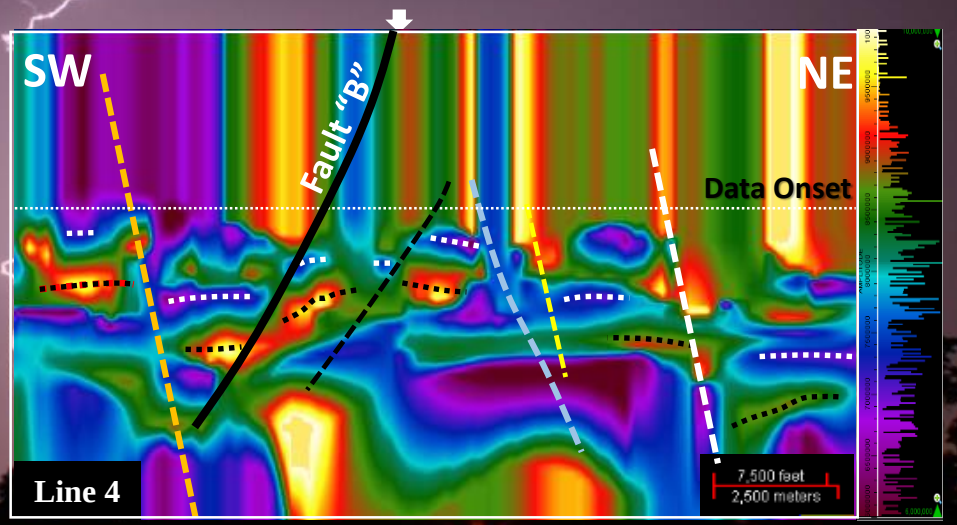
The same fault patterns on lines 1 & 2 can be interpreted on lines 3 & 4 above

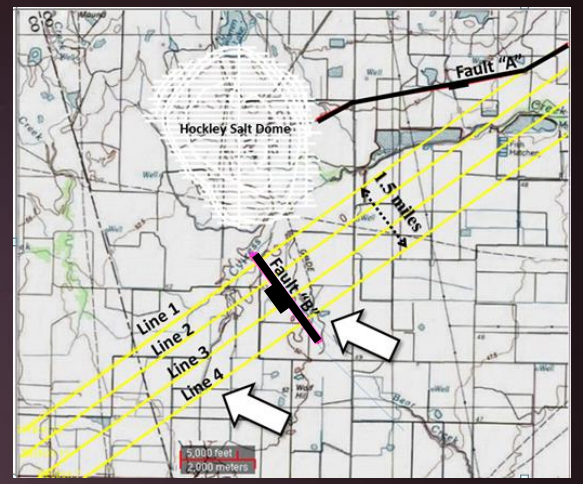
NSEM Shows Consistent Interpretation



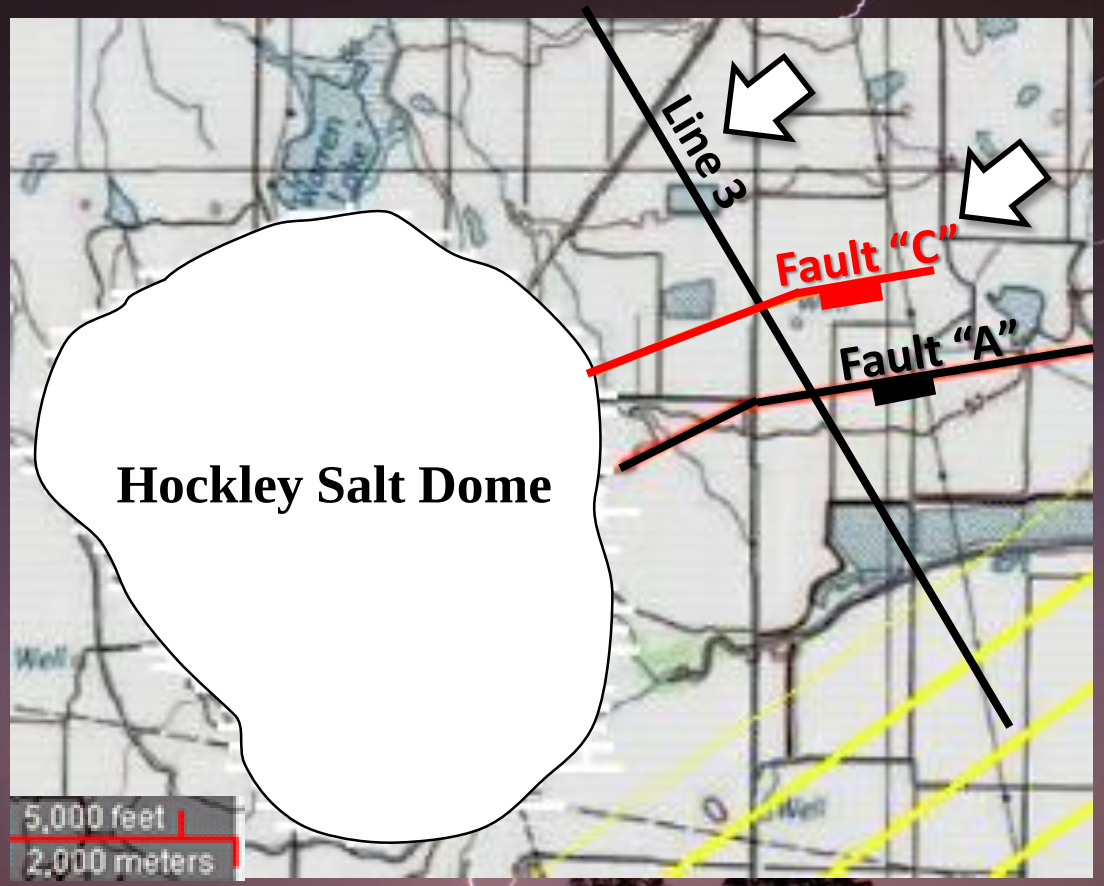






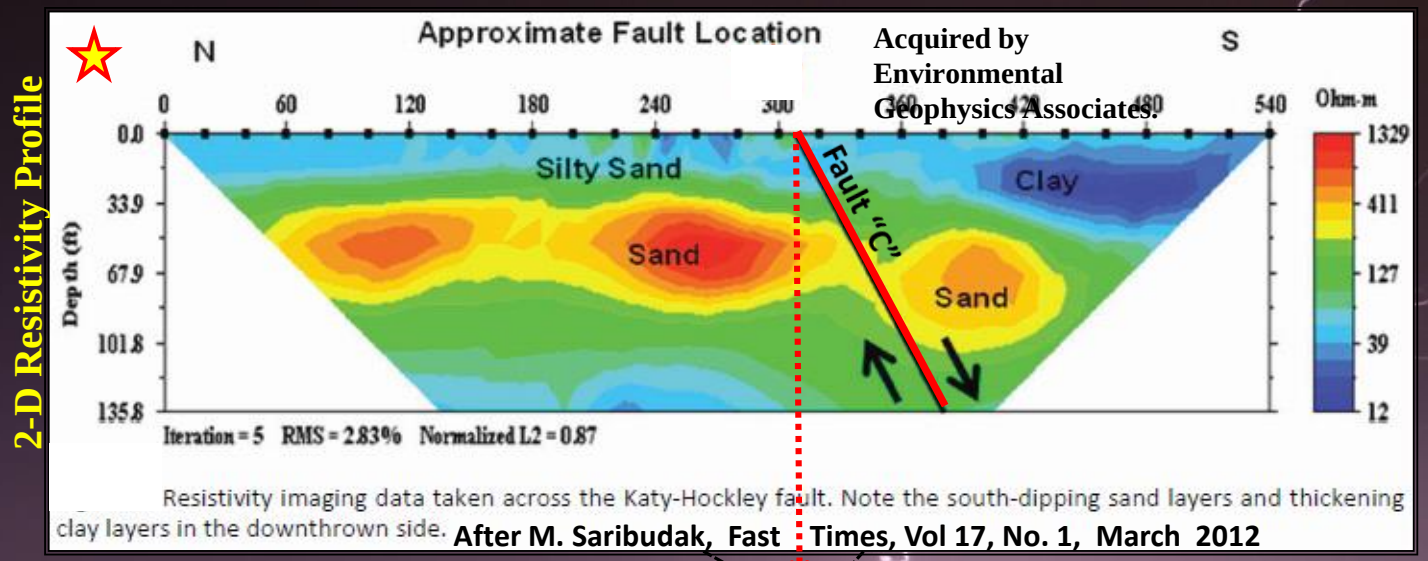


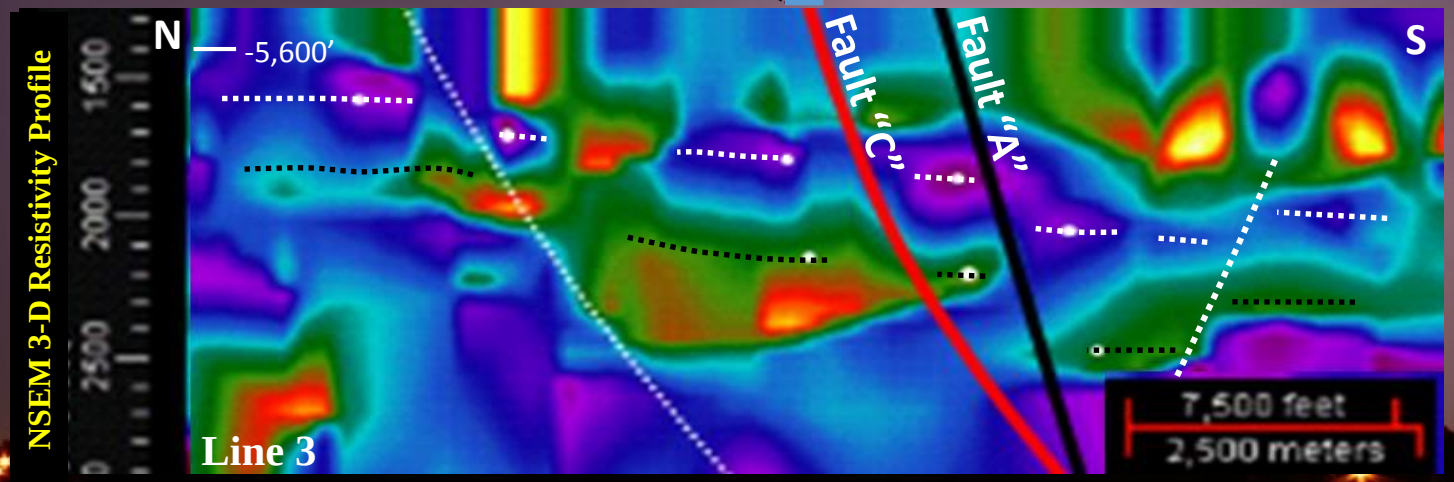
Hockley Radial Fault "C"



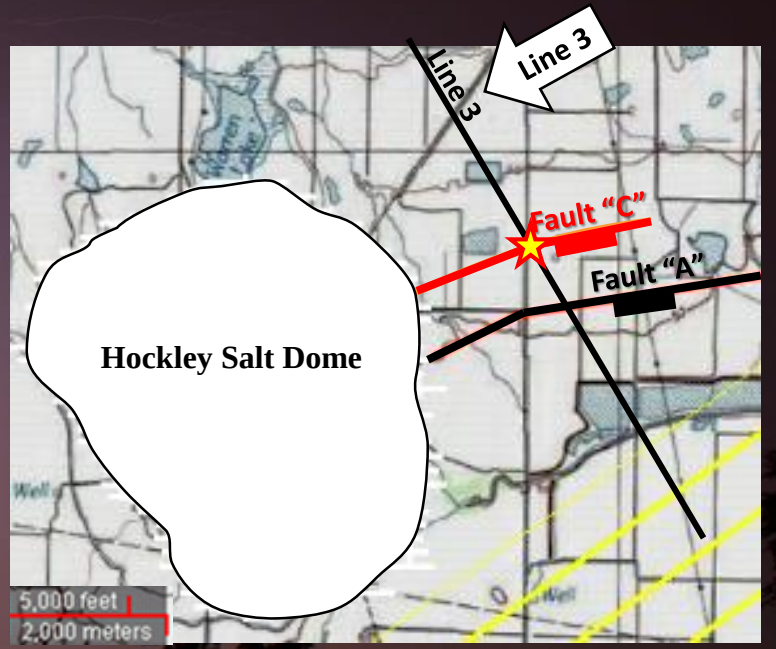
Apparent resistivity profile "Line 3" displayed next.

NSEM Ties Fault "C" to Subsurface





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



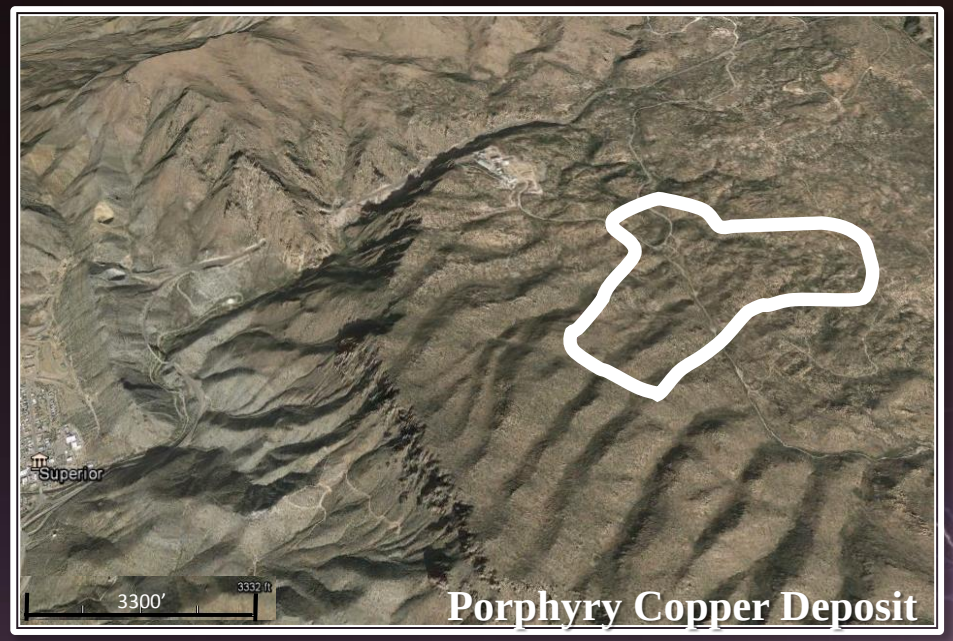
Observations

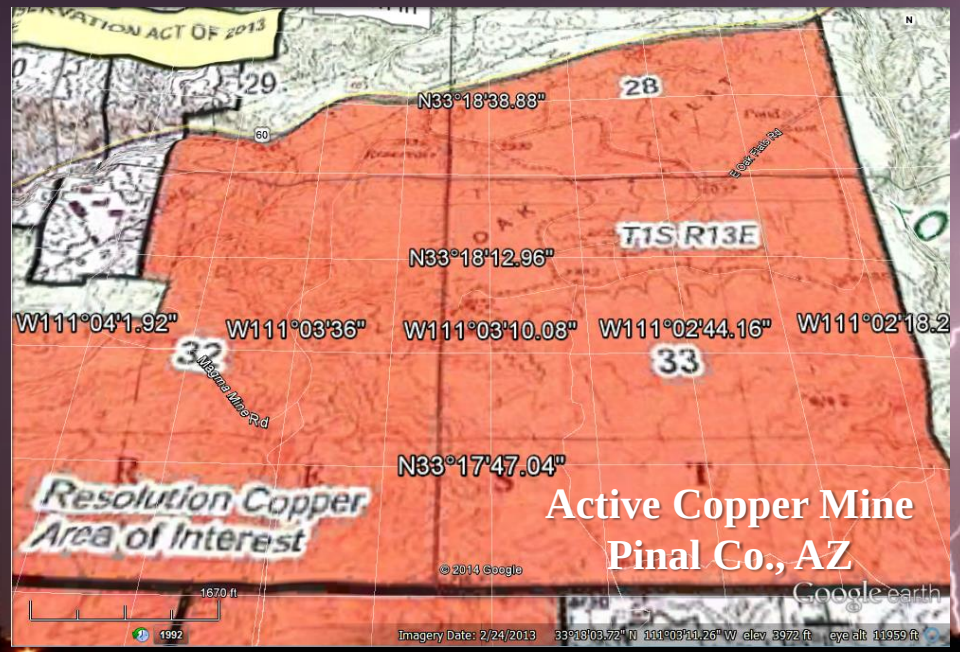
- 3-D NSEM resistivity data was able to tie surface faults and extend fault interpretations to deeper than 5,400’.
- 3-D NSEM fault criteria was credible and at least as good as conventional 2-D resistivity imaging.
- In some cases NSEM could identify two to three resistivity layers offset across the faults.

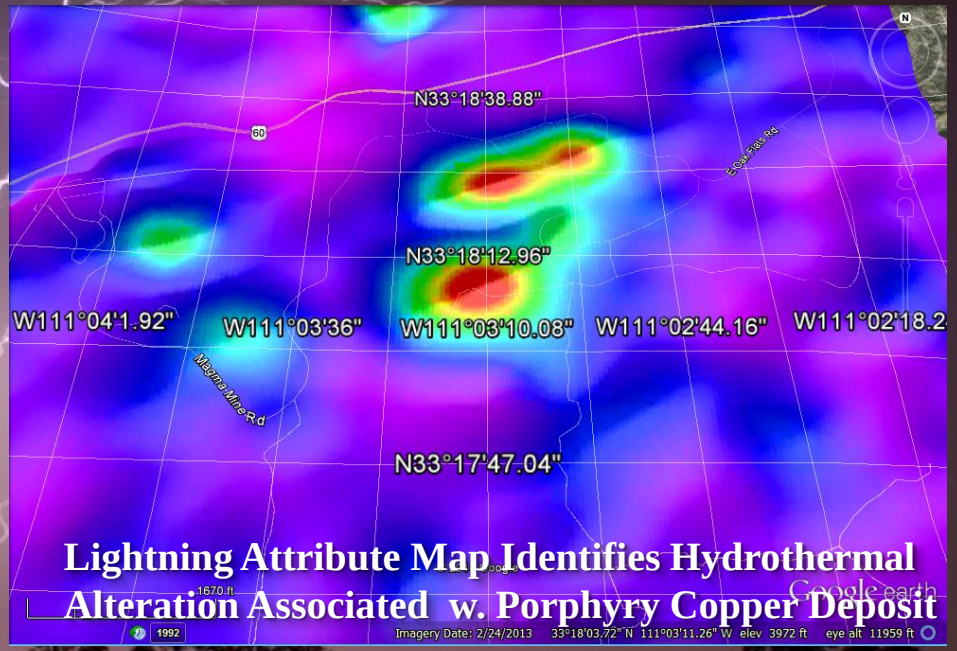
Hockley Fault Conclusions

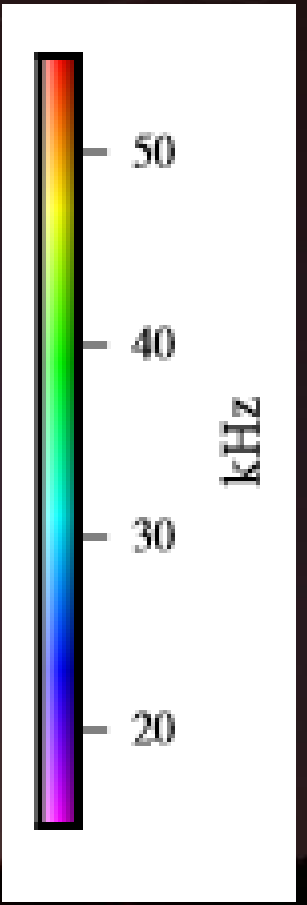
- 3-D NSEM resistivity can be interpreted similar to 3-D seismic data to identify potential subsurface structural weakness.
- 3-D NSEM resistivity can be integrated with & calibrated to other near-surface geophysical data to expand the depth & aerial extent of investigated areas.
- NSEM is scalable & can provide both reconnaissance data for follow-up detailed geophysical & engineering evaluation or it can focus on specific areas, confirming potential geo-hazards.

NSEM Correlates To Rock Properties: Mineral Exploration



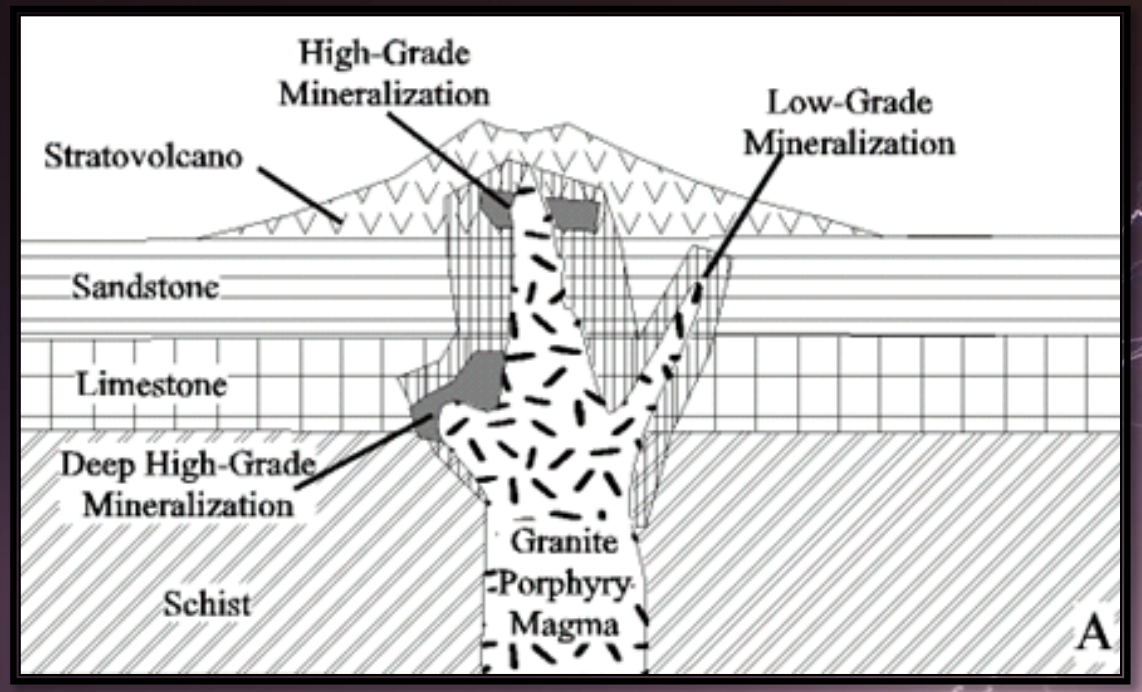






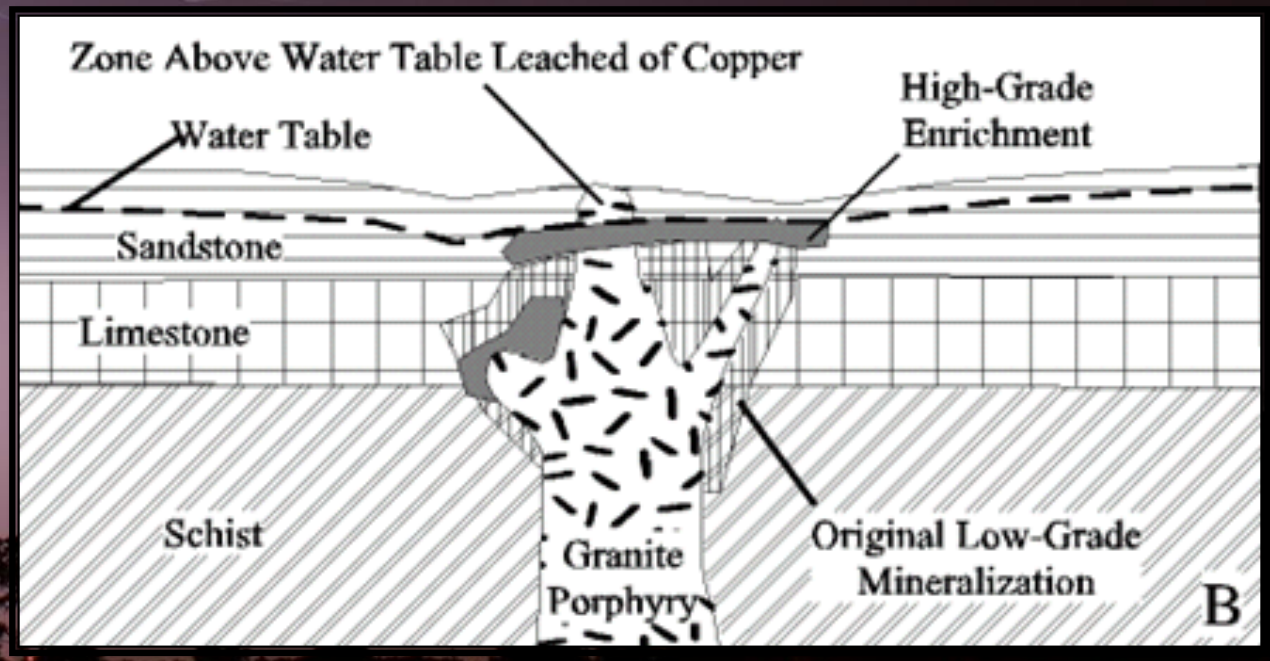
25-September-2015

Formation of a Porphyry Copper Deposit



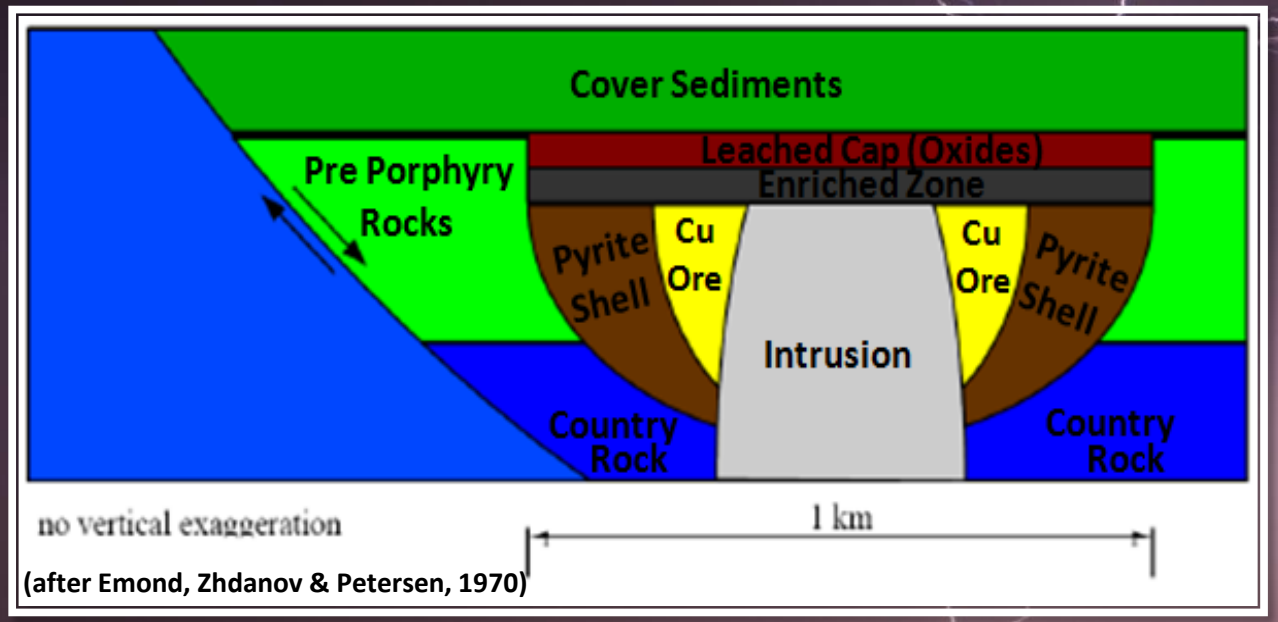
- Magma chamber feeds upward intrusion of molten rock into shallow sedimentary rocks.
- Magma & associated hot mineral-rich fluids come in contact with host rocks & generate chemical/mineral changes creating low-grade copper mineralization.

- 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.



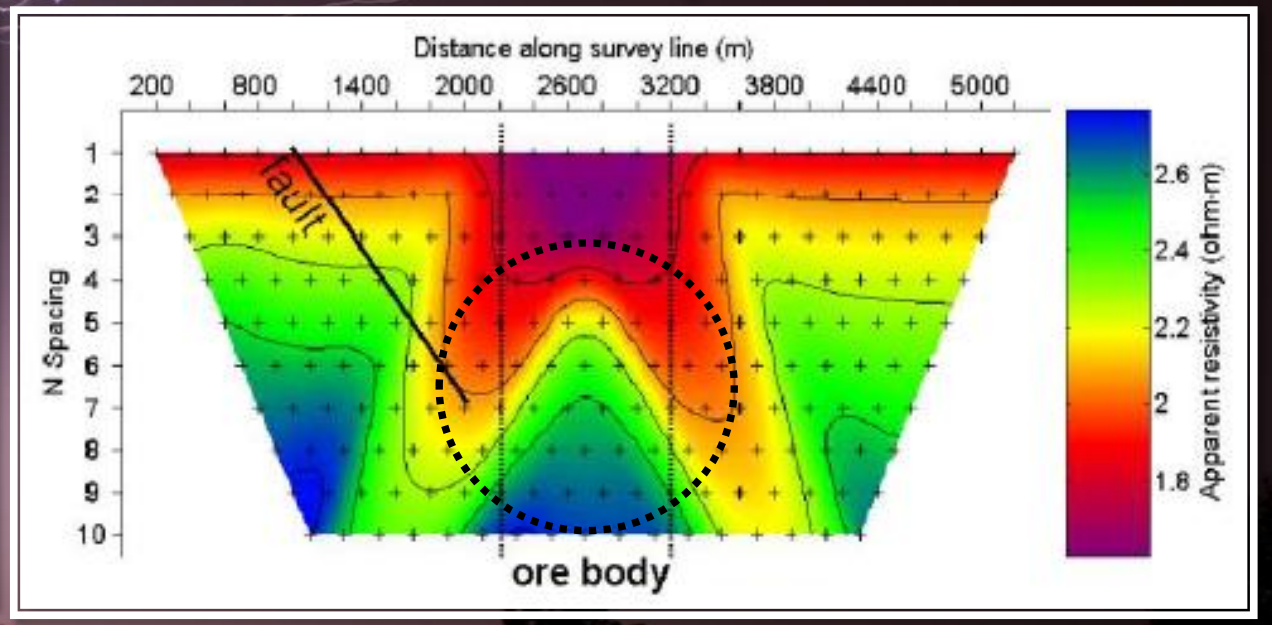
Simplified Porphyry Copper Deposit Model

Typical Mineral Zones of a Porphyry Deposit



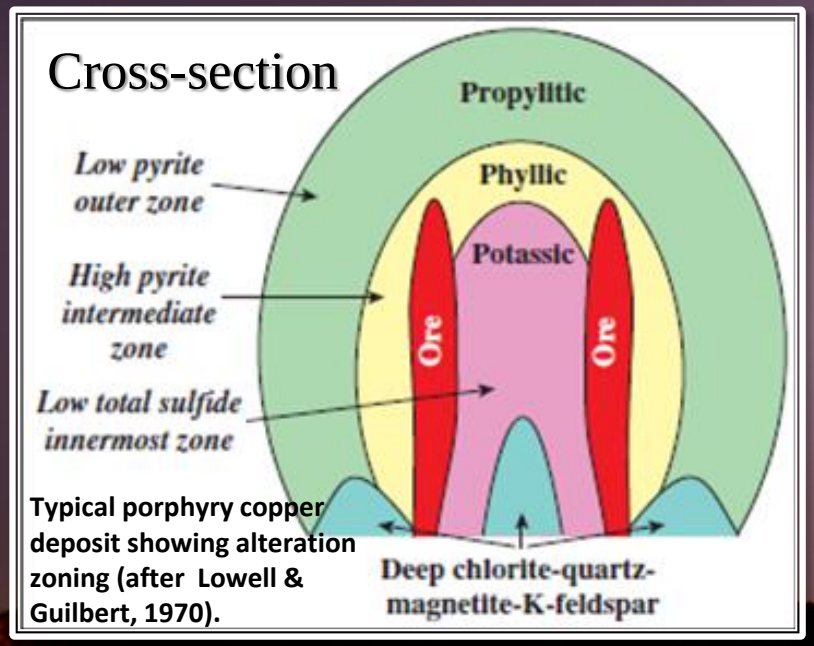
(after Emond, Zhdanov & Petersen, 1970)

Conductivity anomaly surrounds more resistive ore body in center.

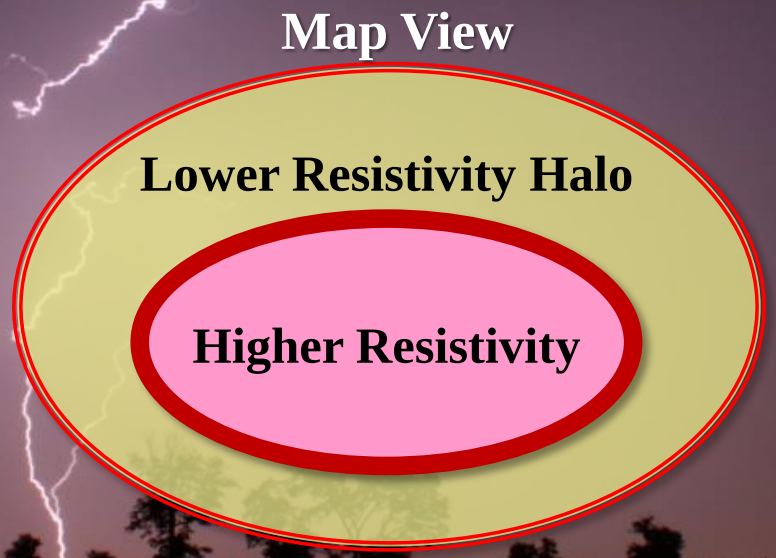


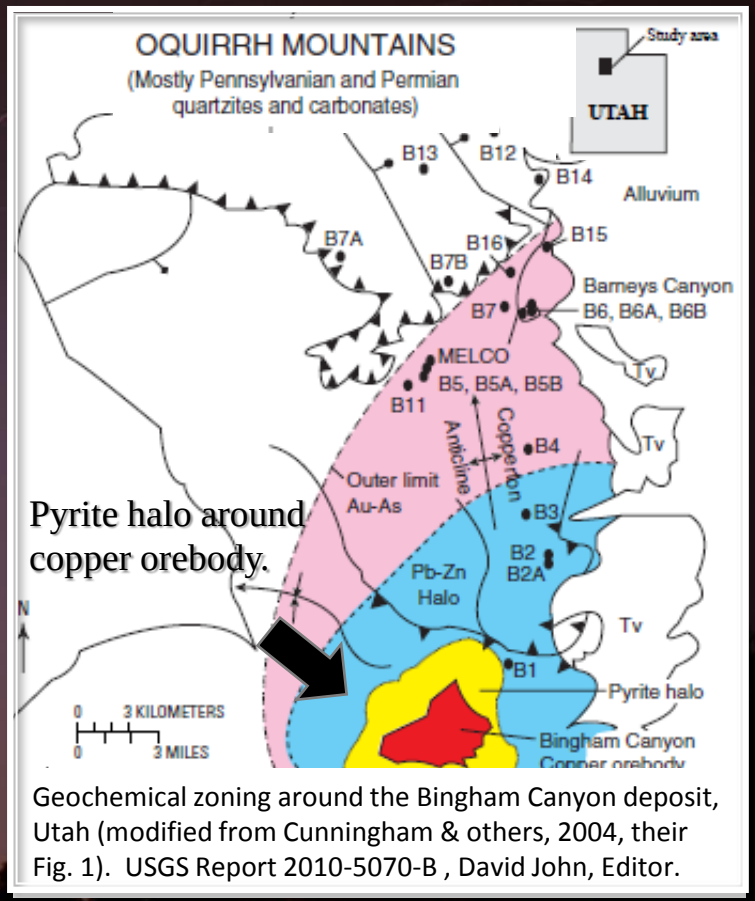
Porphyry Copper Deposit Signature

- 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).

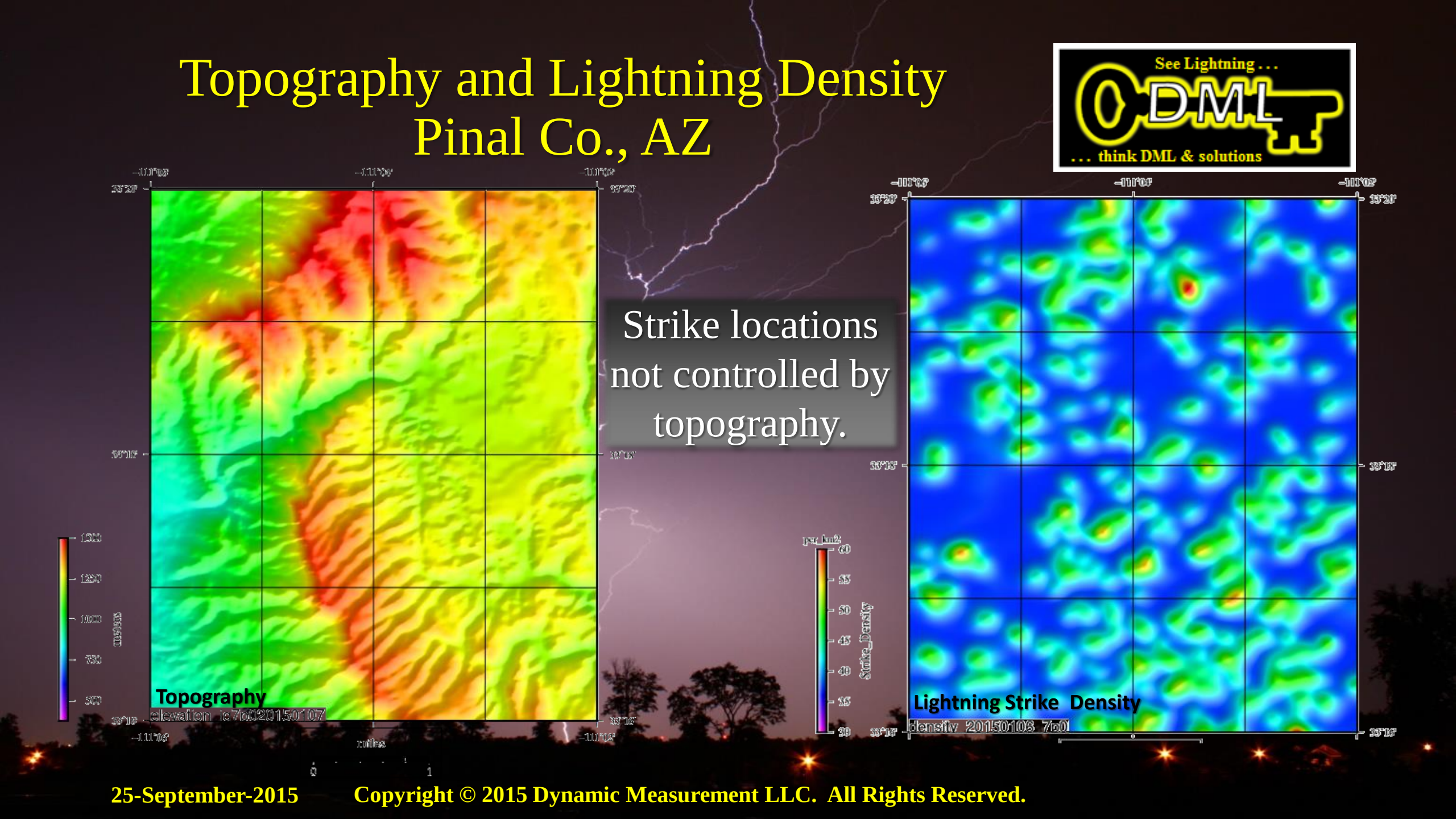




Pyrite halo around copper orebody.

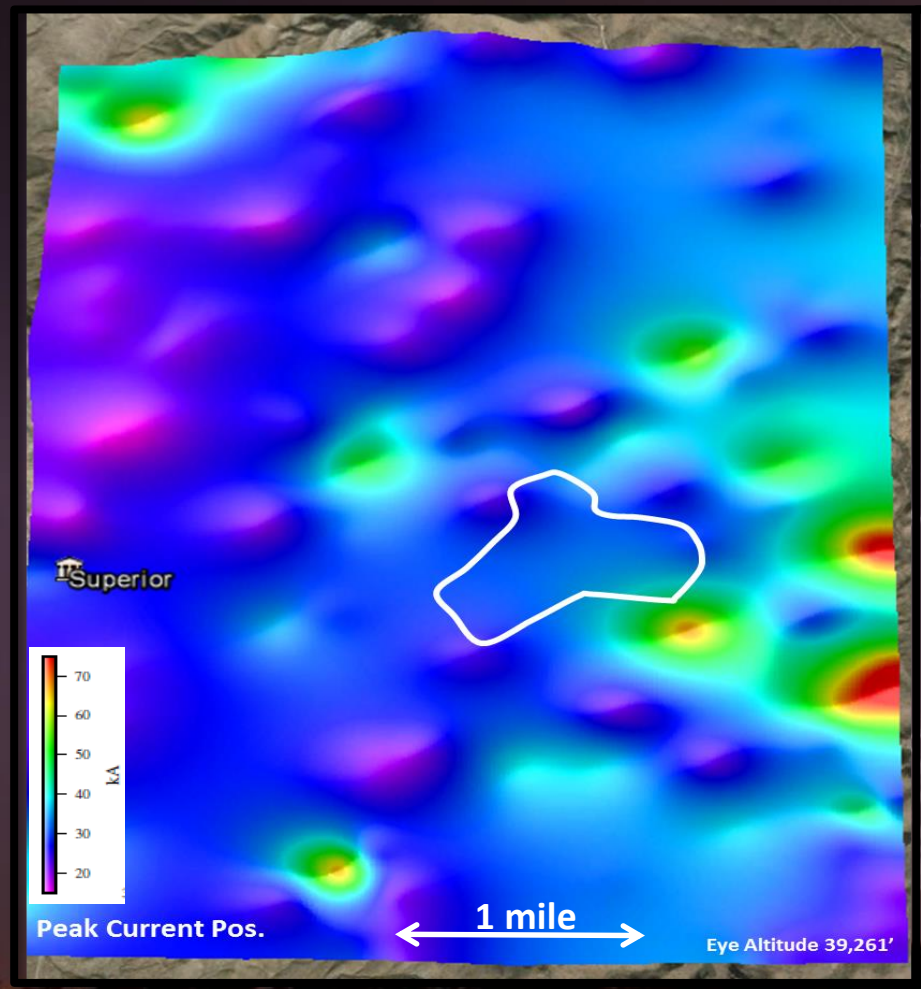
Geochemical zoning around the Bingham Canyon deposit, Utah (modified from Cunningham & others, 2004, their Fig. 1). USGS Report 2010-5070-B , David John, Editor.

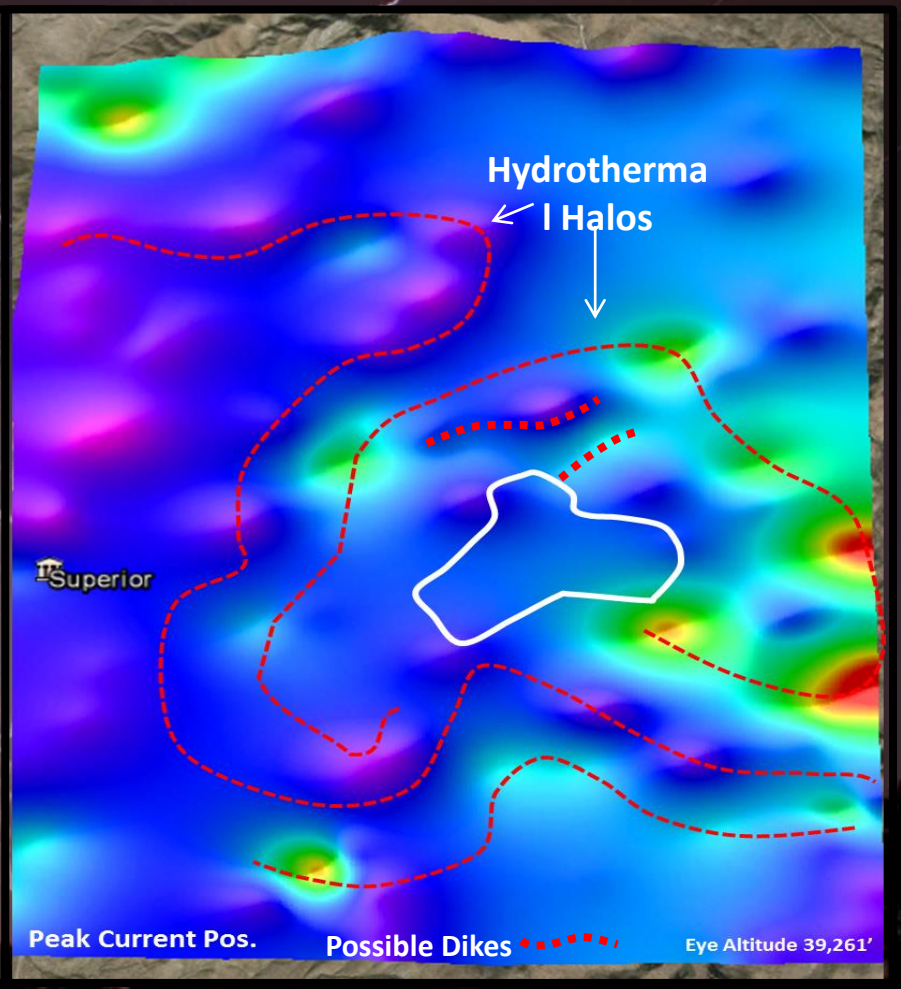
Topography and Lightning Density
Pinal Co., AZ



25-September-2015

Positive Peak Current
Resolution Copper Mine

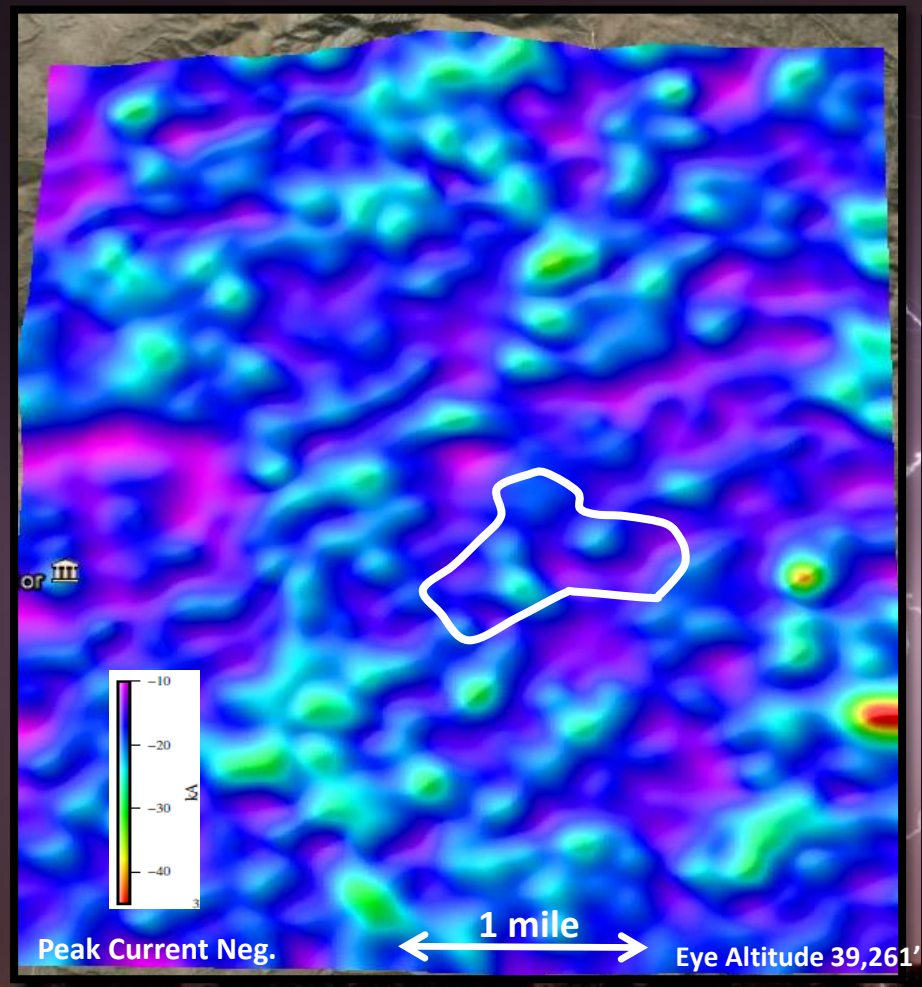


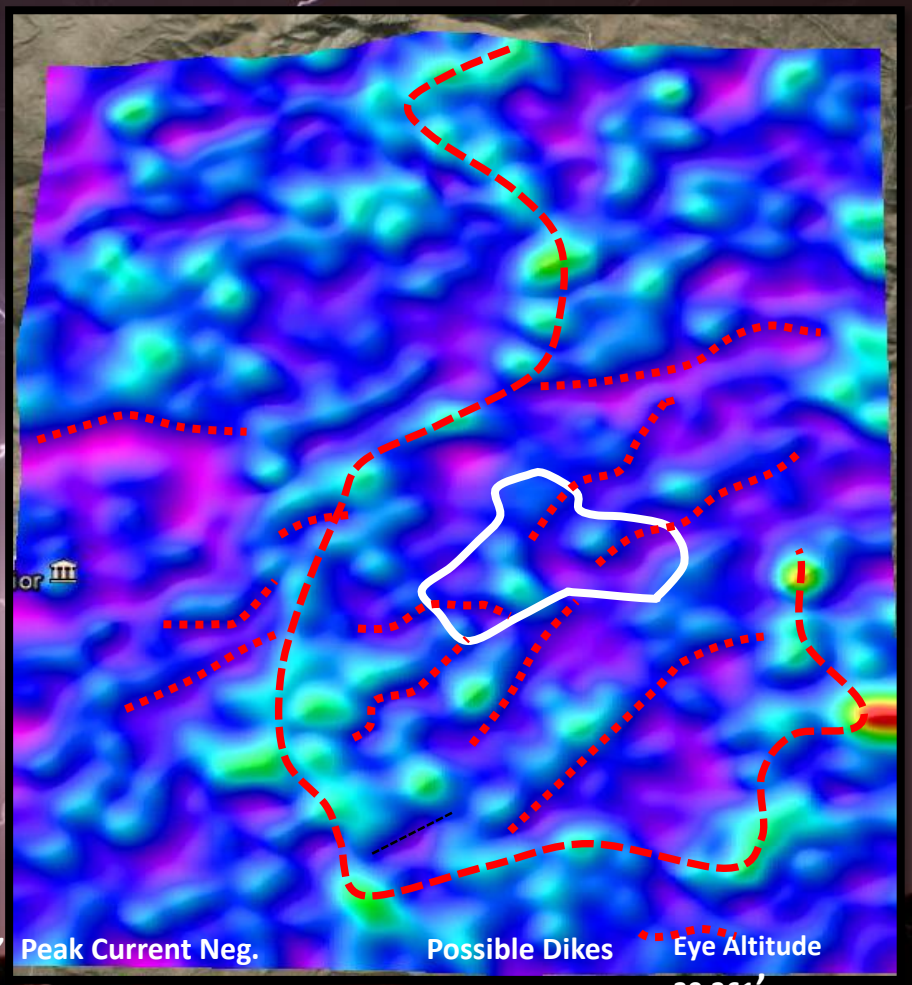


Hydrothermal Alteration
& Dike Interpretation

25-September-2015

Negative Peak Current
Resolution Copper Mine



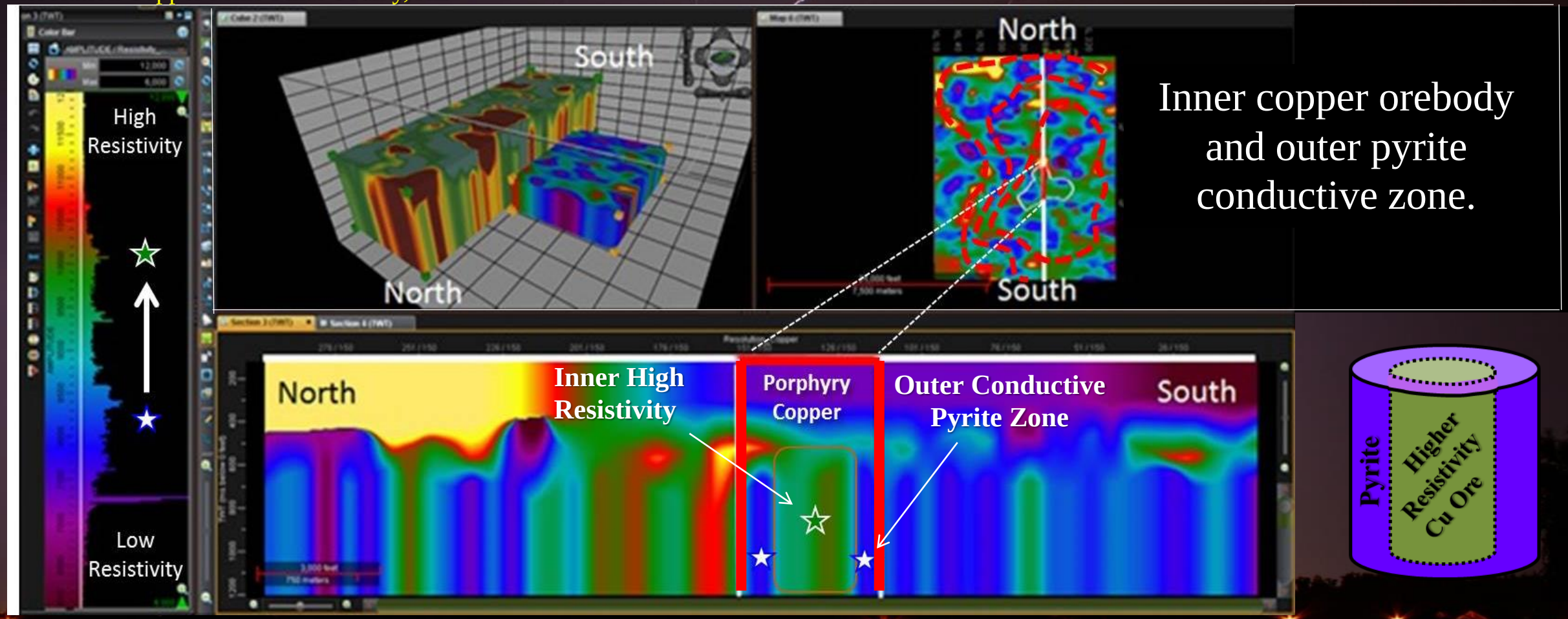


Shows pyrite halo partially enclosing copper orebody.

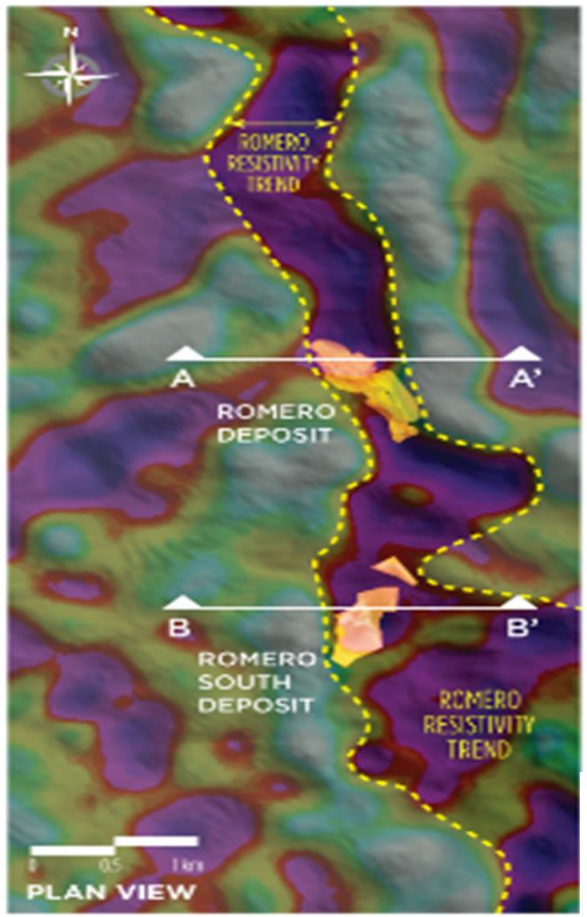
Presence of dikes indicative of Cu.

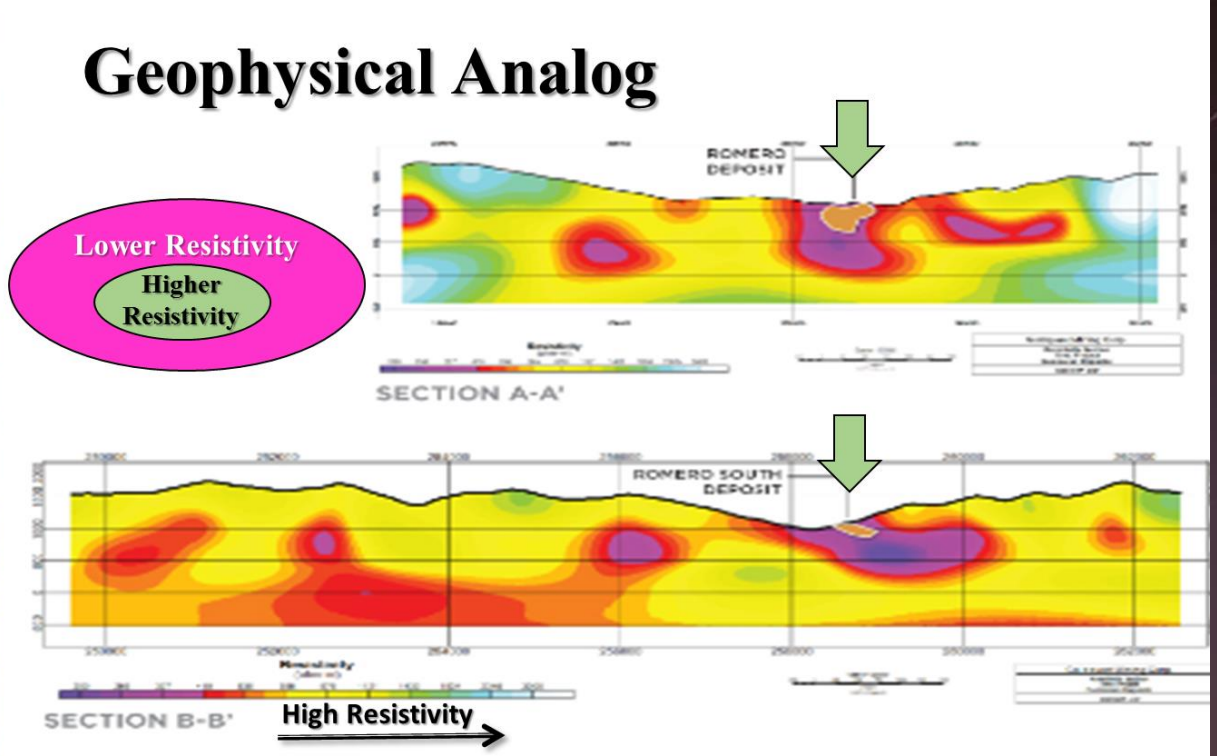
3-D Resistivity Profile Through Mine
Reveals Porphyry Copper Signature

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 surrounded by 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.

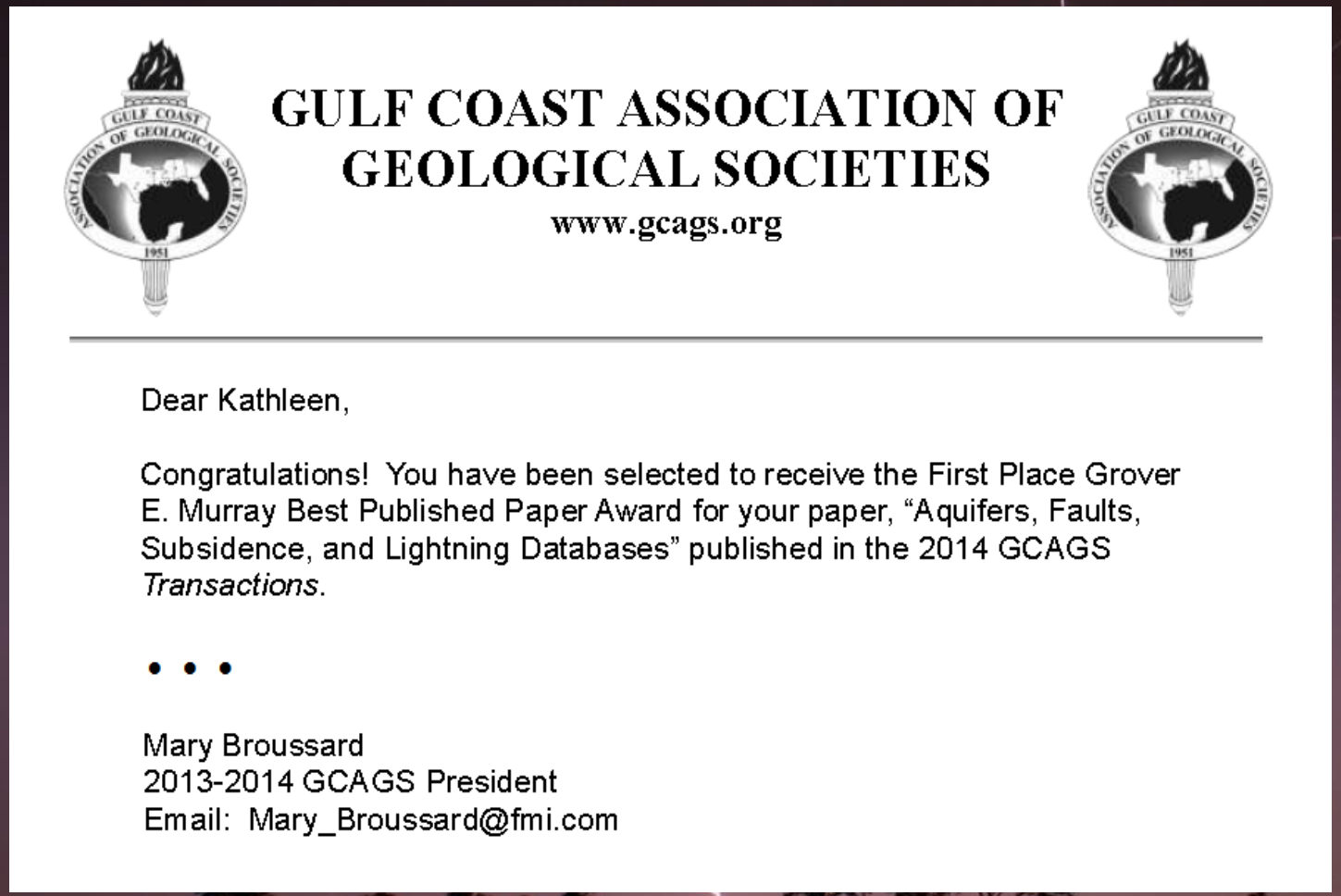
Mineral Exploration Conclusions

- 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 rock properties which can be applied to unconventional oil and gas exploration as well as water & geotechnical investigations.

NSEM OVERVIEW

- NSEM can map: regional & individual faults; the presence of minerals & hydrocarbon traps; rock properties; & has demonstrated remarkable potential to identify hydrocarbon accumulations.
- NSEM can also map subsurface salinity variations & contaminant plumes.
- NSEM can be calibrated to, & integrated with, seismic & subsurface geology, potential field and near surface geophysical data.
- NSEM can fill in between or extend existing data.
- NSEM cost 1% of 3-D seismic, approximately 20% of traditional near-surface geophysical techniques & can be acquired, processed & interpreted within 6-8 weeks.

DML's Technology is being Recognized



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

See updates at:

GCAGS Houston
SEG New Orleans
WTGS Midland

Acknowledgments

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

An additional thanks to Kathy Hagger of Dynamic Measurement for the use of her Brazos River Alluvium Aquifer slide.

Appreciation is also expressed to Mustafa Saribudak of Environmental Geophysics Associates, for his geophysical investigations of the active faults in the Hockley & Tomball areas, several of which were used to help validate NSEM's ability to identify subsurface faults.

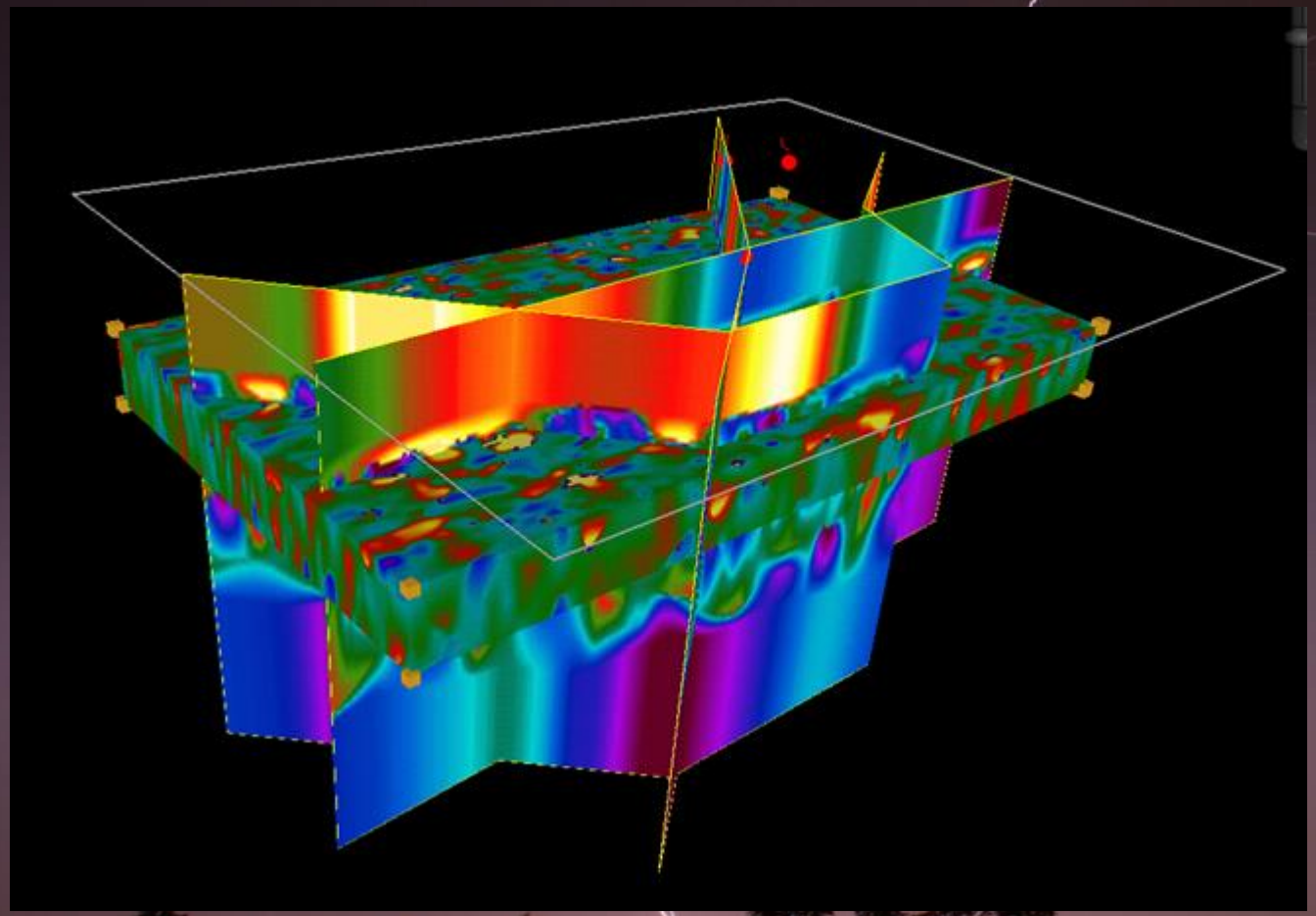
Lightning, A Shockingly Unconventional Way to Conduct Exploration

Louis J. Berent
P.O. Box 690388
Houston, TX 77269
Office: 281 370-5296
Cell: 832 352-3795
ljberent@dynamicmeasurement.com

H. Roice Nelson, Jr.
2155 West 700 South #31
Cedar City, UT 84720
Cell: 713.542.2207
Fax: 435.267.2668
roice@dynamicmeasurement.com

25-September-2015

Appendix



References

Engelkemeir, Richard M., Khan, Shuhab D., Lidar mapping of Faults in Houston, TX, USA, Geosphere, Feb 2008.

Khan, Shuhab D. et al., A geophysical investigation of the active Hockley Fault System near Houston, TX, Geophysics, Jul-Aug 2013.

Noble, J.E. et al., Estimated depth to the water table & estimated rate of recharge in outcrops of the Chicot & Evangeline aquifers near Houston, TX., 1996.

Saribudak, Mustafa, Integrated geophysical studies over an active growth fault in Houston, The Leading Edge, March 2006.

Saribudak, Mustafa, Geophysical mapping of the Hockley growth fault in northwest Houston, TX and recent surface observations, The Leading Edge, Feb 2011.

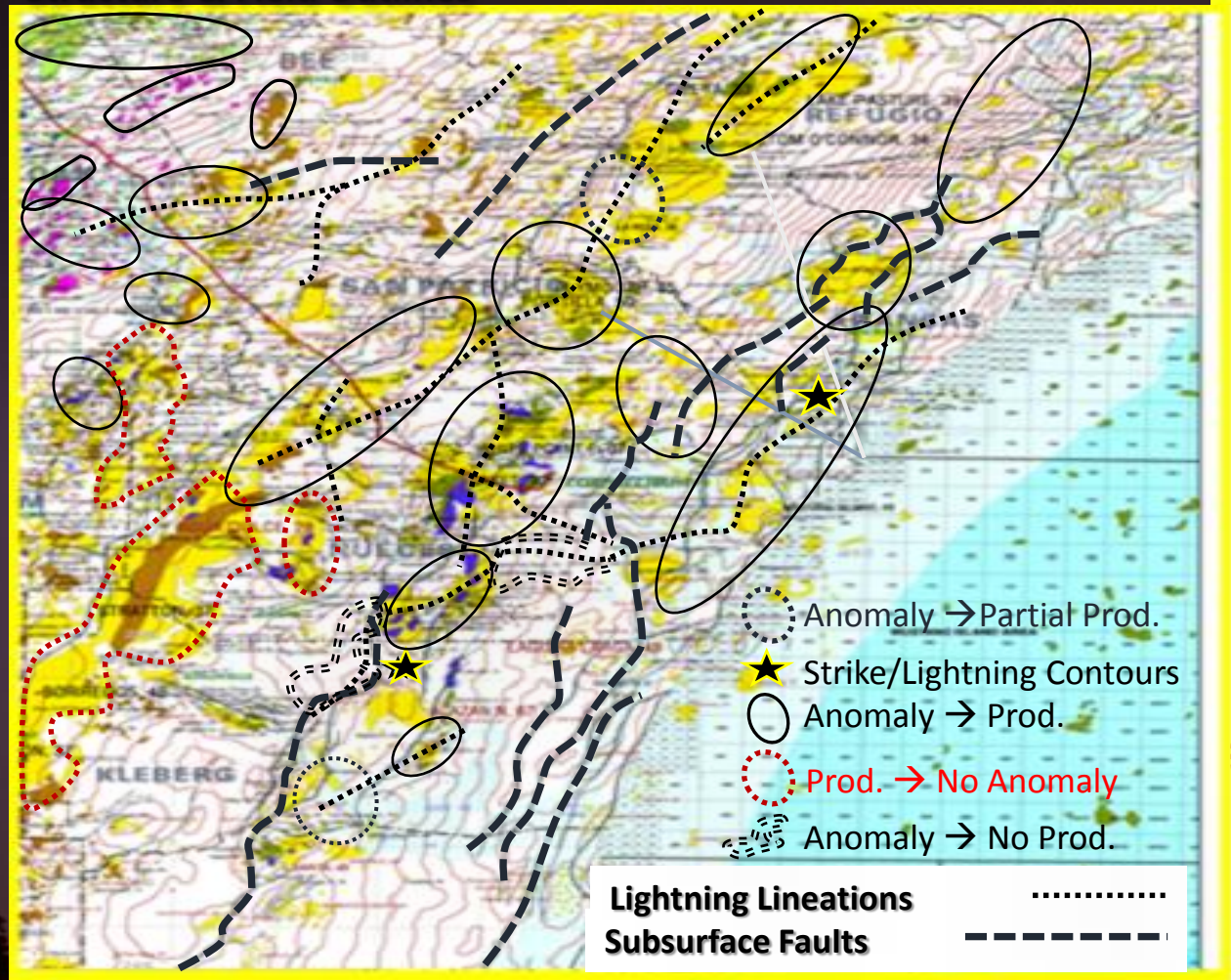
Saribudak, Mustafa, 2-D Resistivity Imaging Investigation of Long Point, Katy-Hockley, Tomball & Pearland Faults, Houston, TX., Houston Geological Society Bulletin, Nov 2011.

Saribudak, Mustafa, 2D Resistivity Imaging Investigation of Long Point, Katy-Hockley, Tomball and Pearland Faults, Houston, TX., Fast Times, Mar 2012.

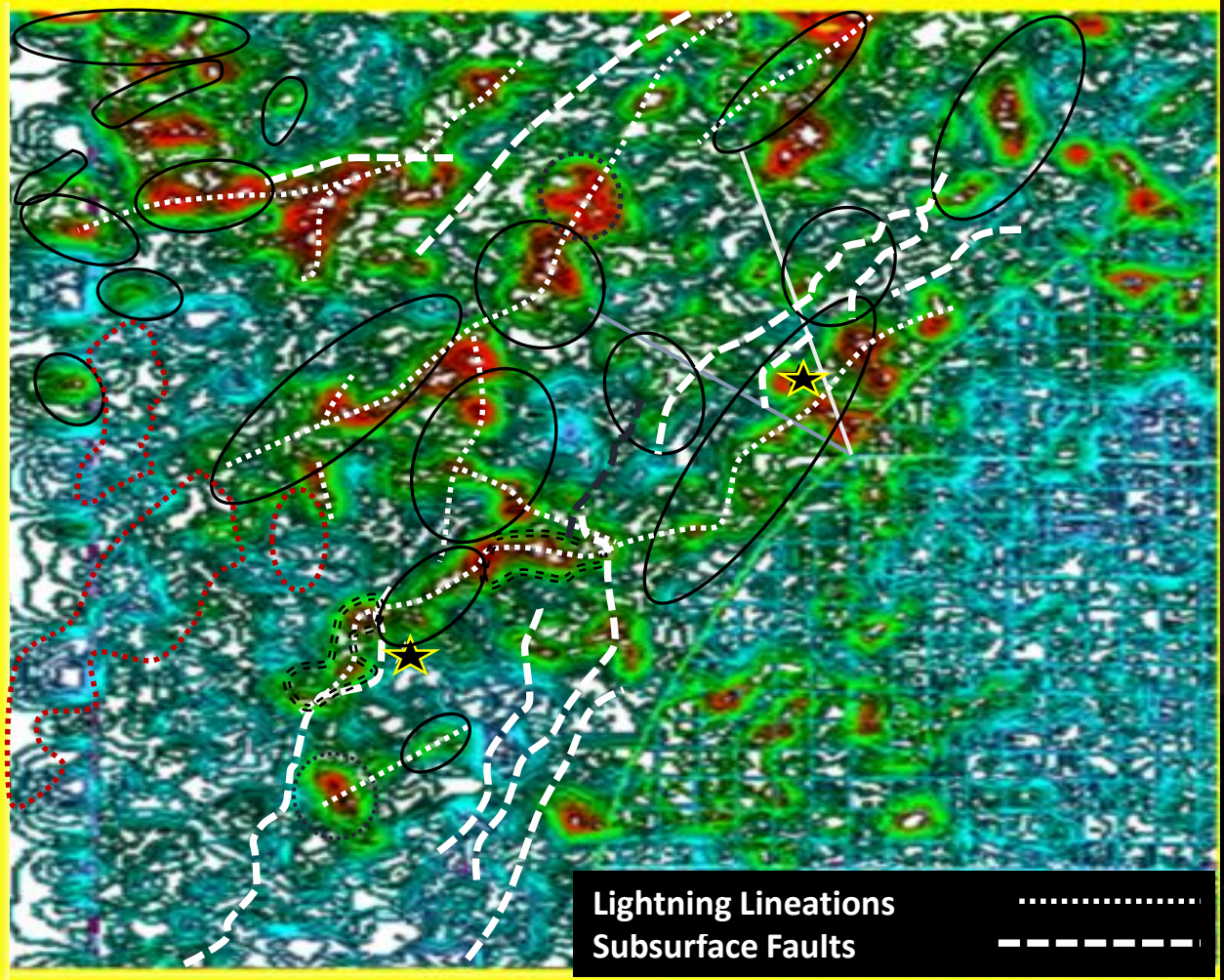
NSEM Correlates To Geology:
Fault Patterns and Hydrocarbon Accumulations

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

Structure & Field Outlines

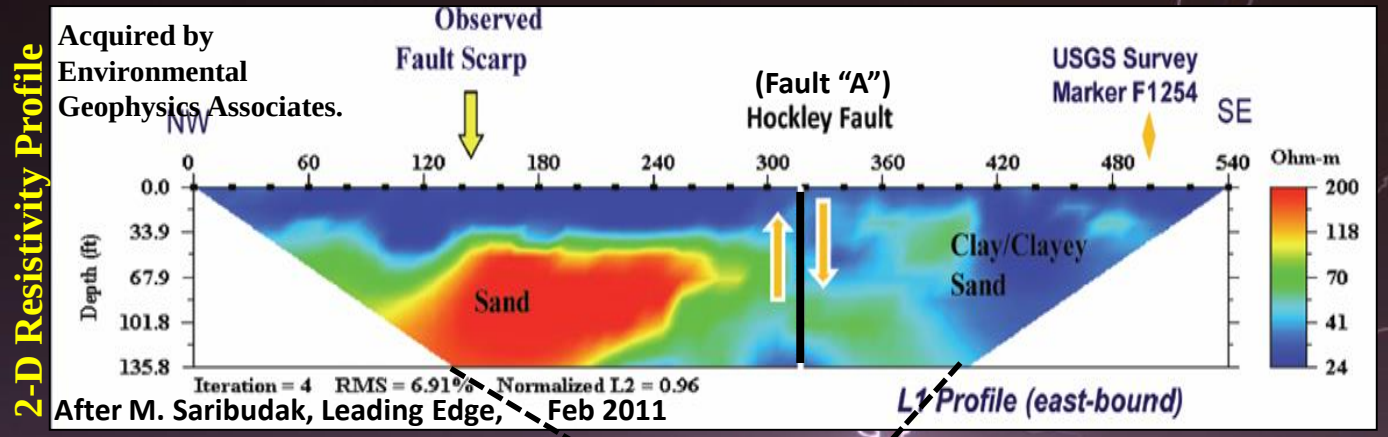


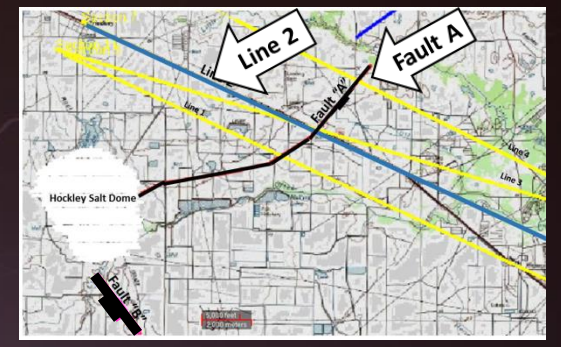
Lightning Strike Density



25-September-2015

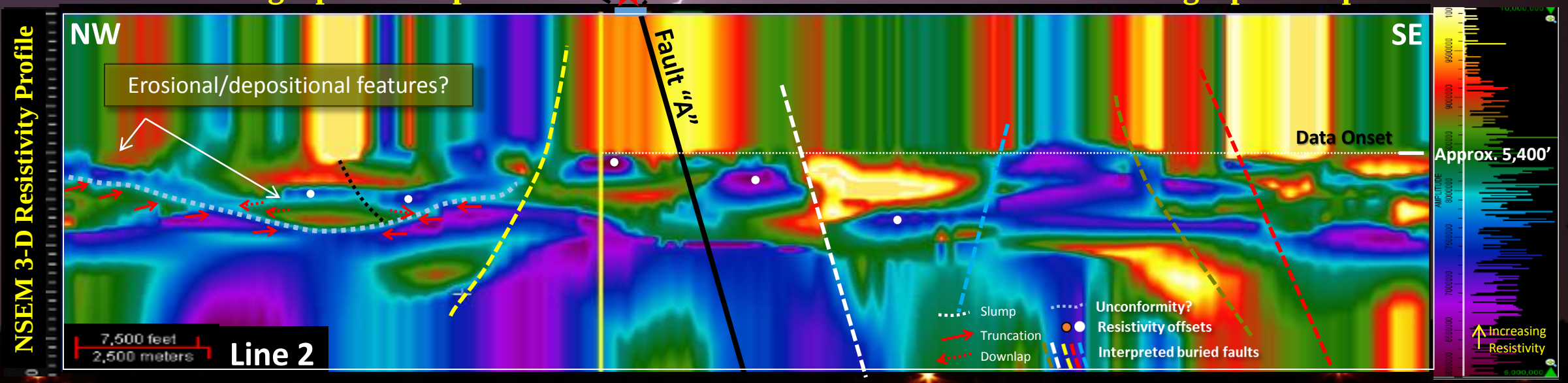
Sequence Stratigraphy?





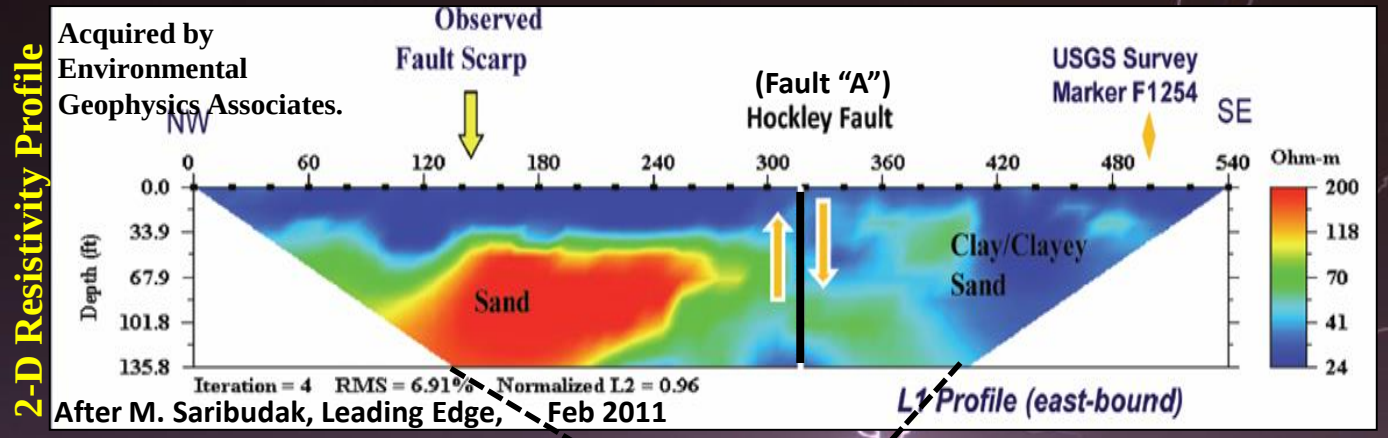
Line 2

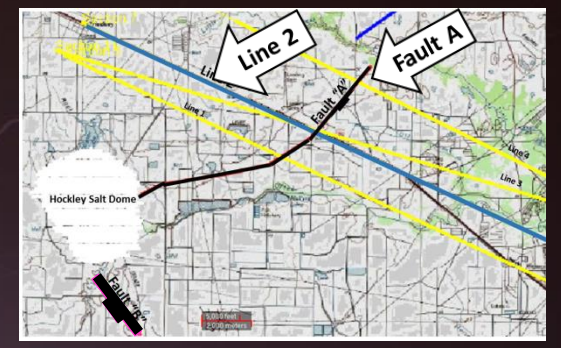
Alternate stratigraphic interpretation. **Potential identification of stratigraphic traps?**



25-September-2015

Sequence Stratigraphy?

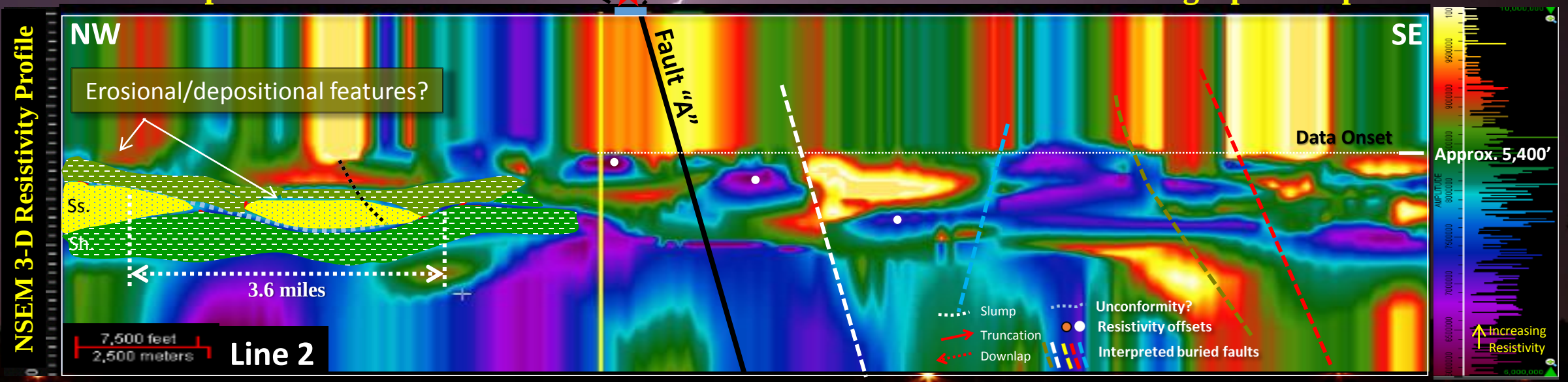




Line 2

Strike line parallel to channel.

Potential identification of stratigraphic traps?



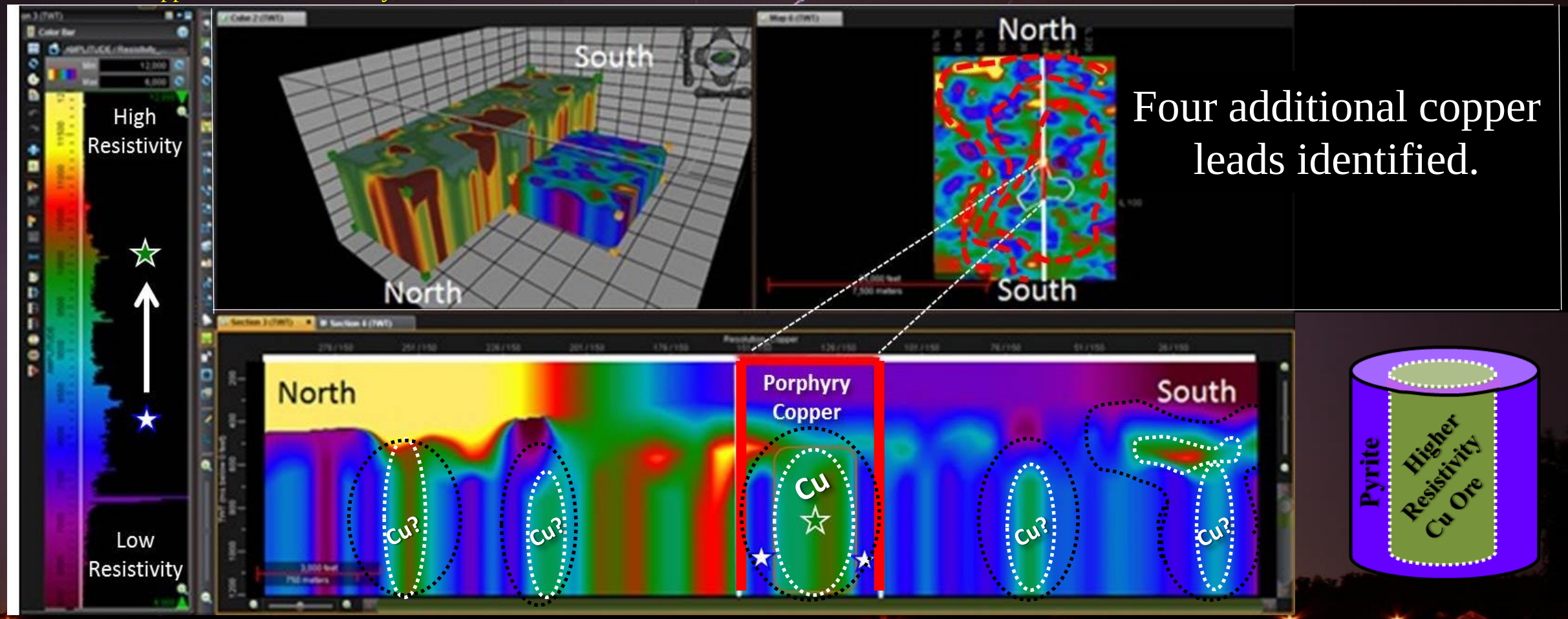
Fluvial Analogues

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.

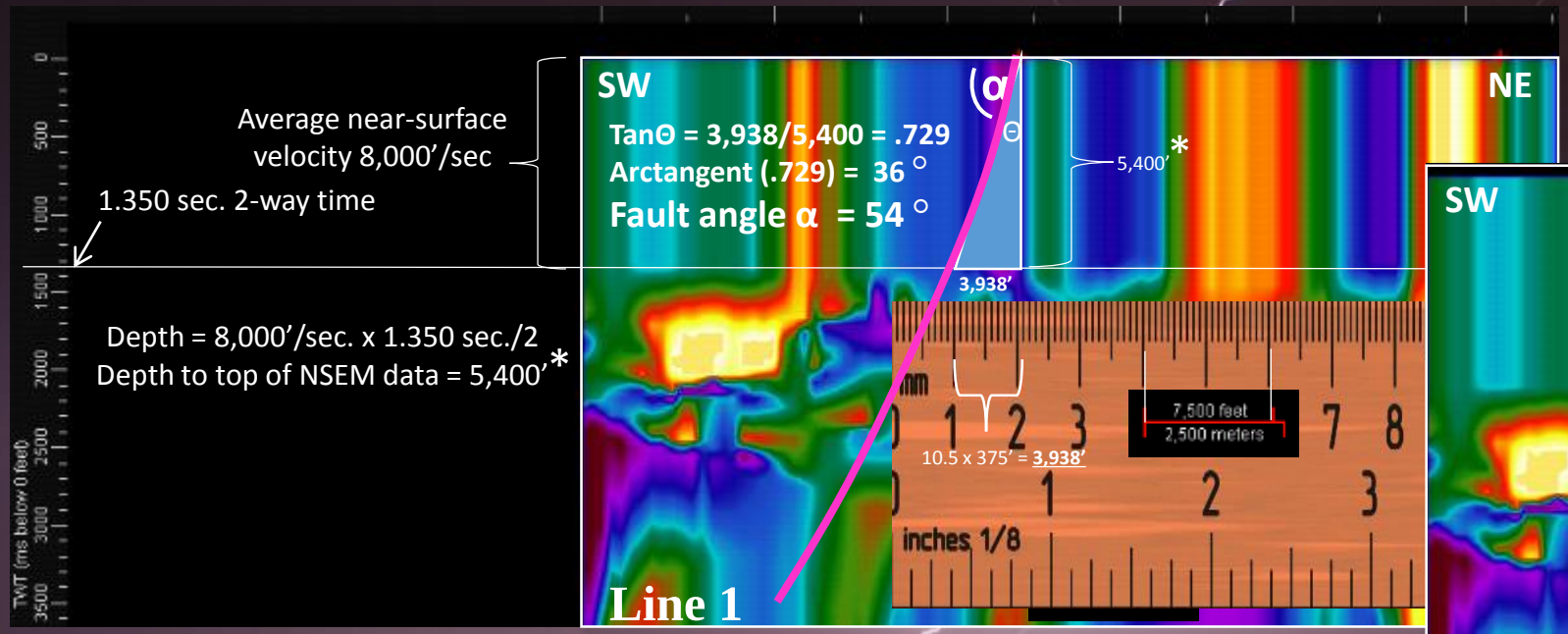
Mapping Rock Properties with Lightning

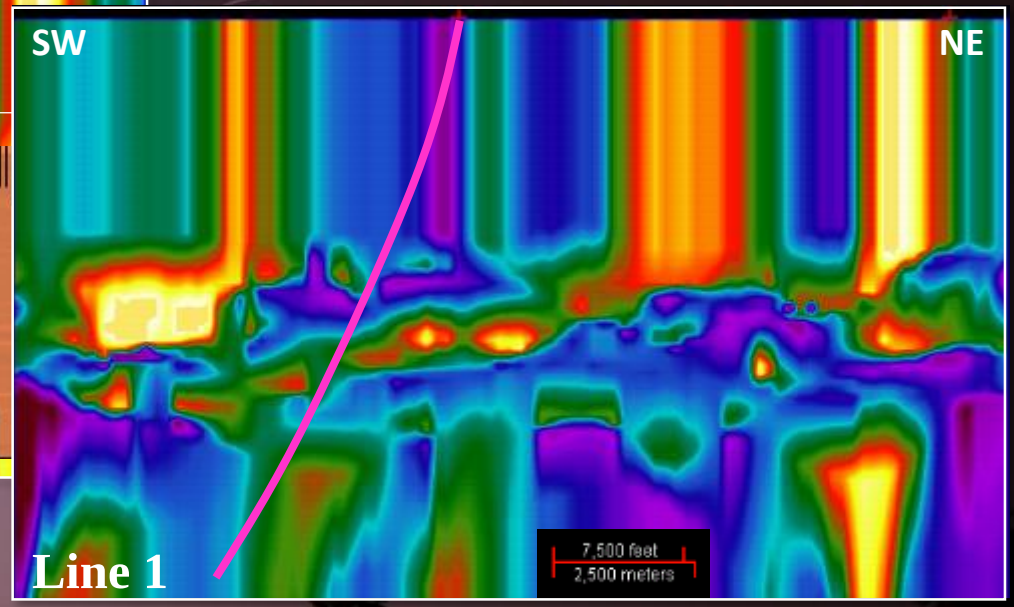
Resolution Copper Mine Pinal County, AZ



Four additional copper leads identified.

Fault Plane/Heave Constraints
Katy-Hockley Fault: 54 ° @ 5,400’
(*assuming 8000’/sec velocity)





* @ 4000’/sec
TanΘ = 3,938/2,700 = 1.46
Arctangent (.972) = 56 °
Fault angle α = 34 °
Note: probably too low an angle for such a shallow depth even though fault is listric. Need independent depth profile for these faults.

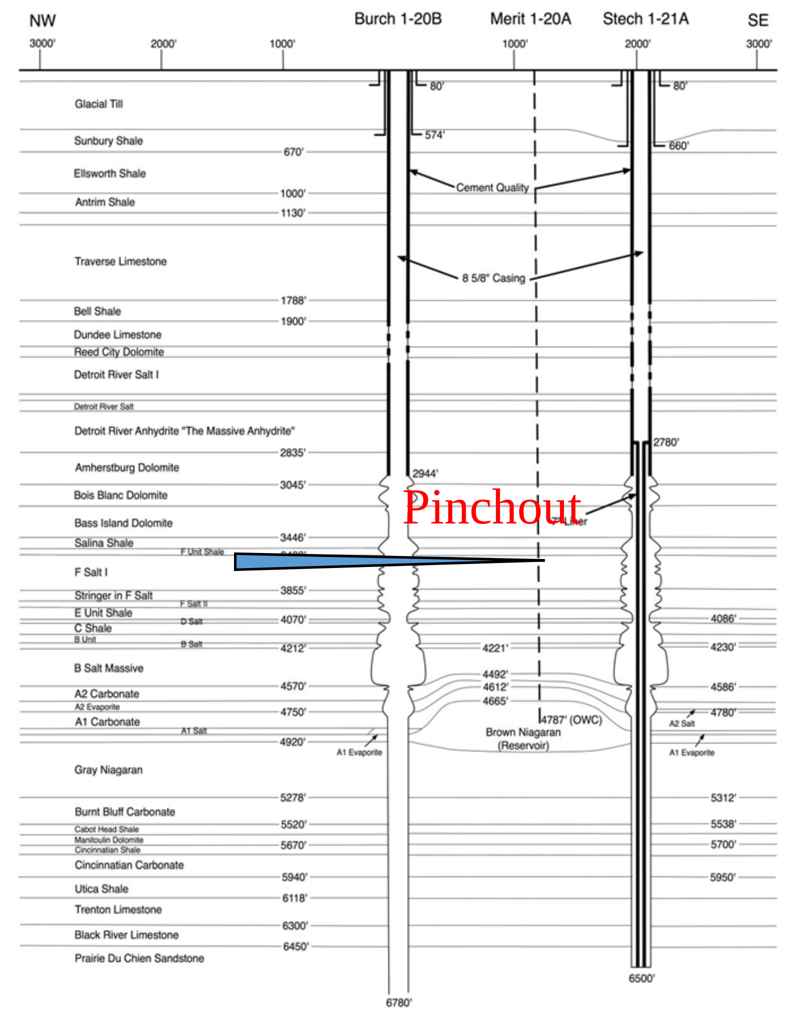
* @ 6000’/sec
TanΘ = 3,938/4,050 = .972
Arctangent (.972) = 44 °
Fault angle α = 46 °
Note: again, likely too low an angle at this depth.

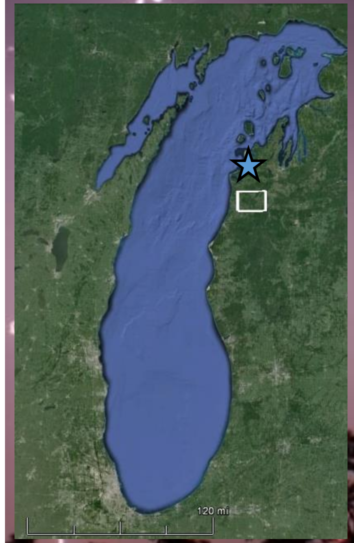
Michigan Technology University
Cross Well Tomography

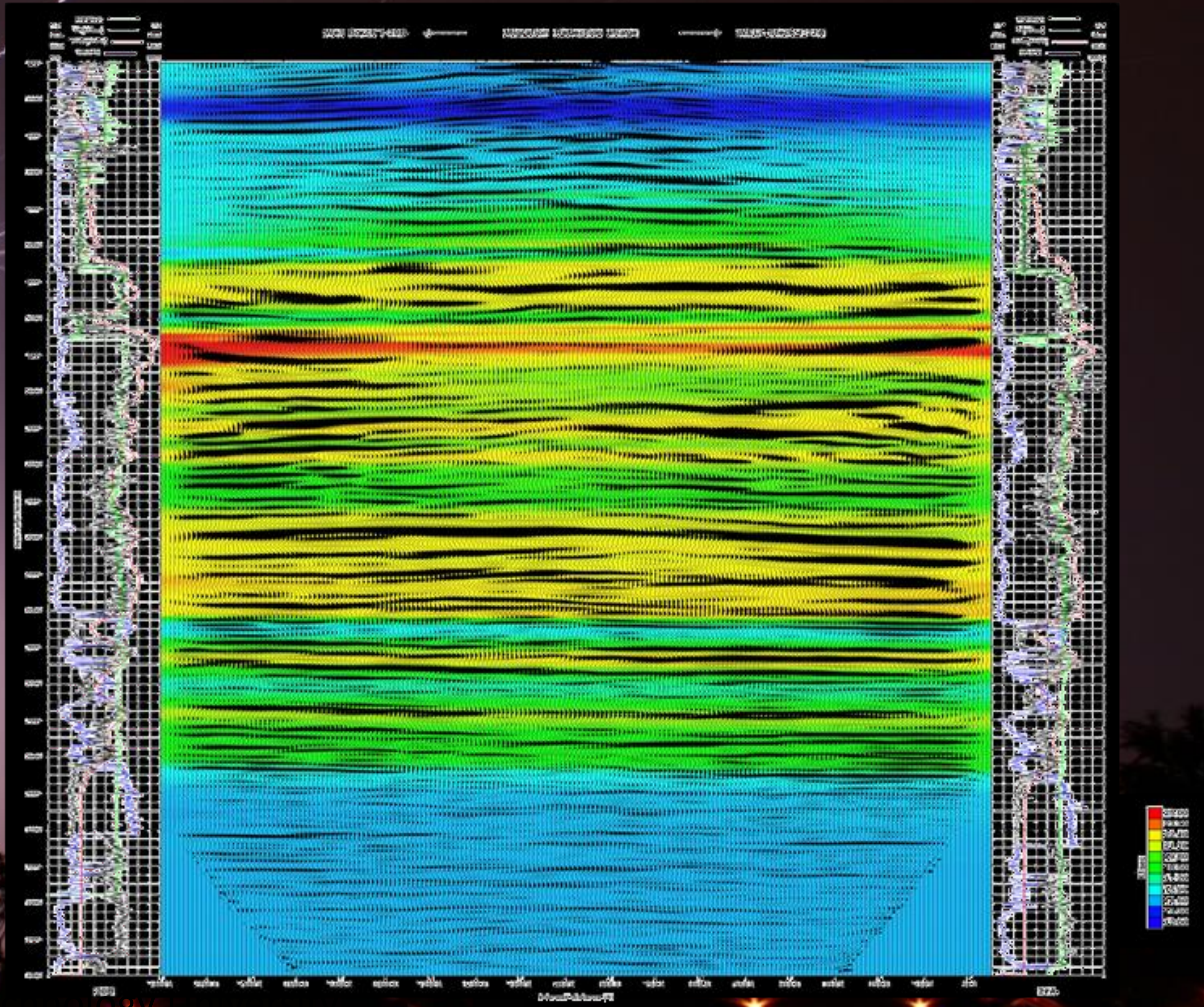
Depth and Amplitude Calibration

25-September-2015

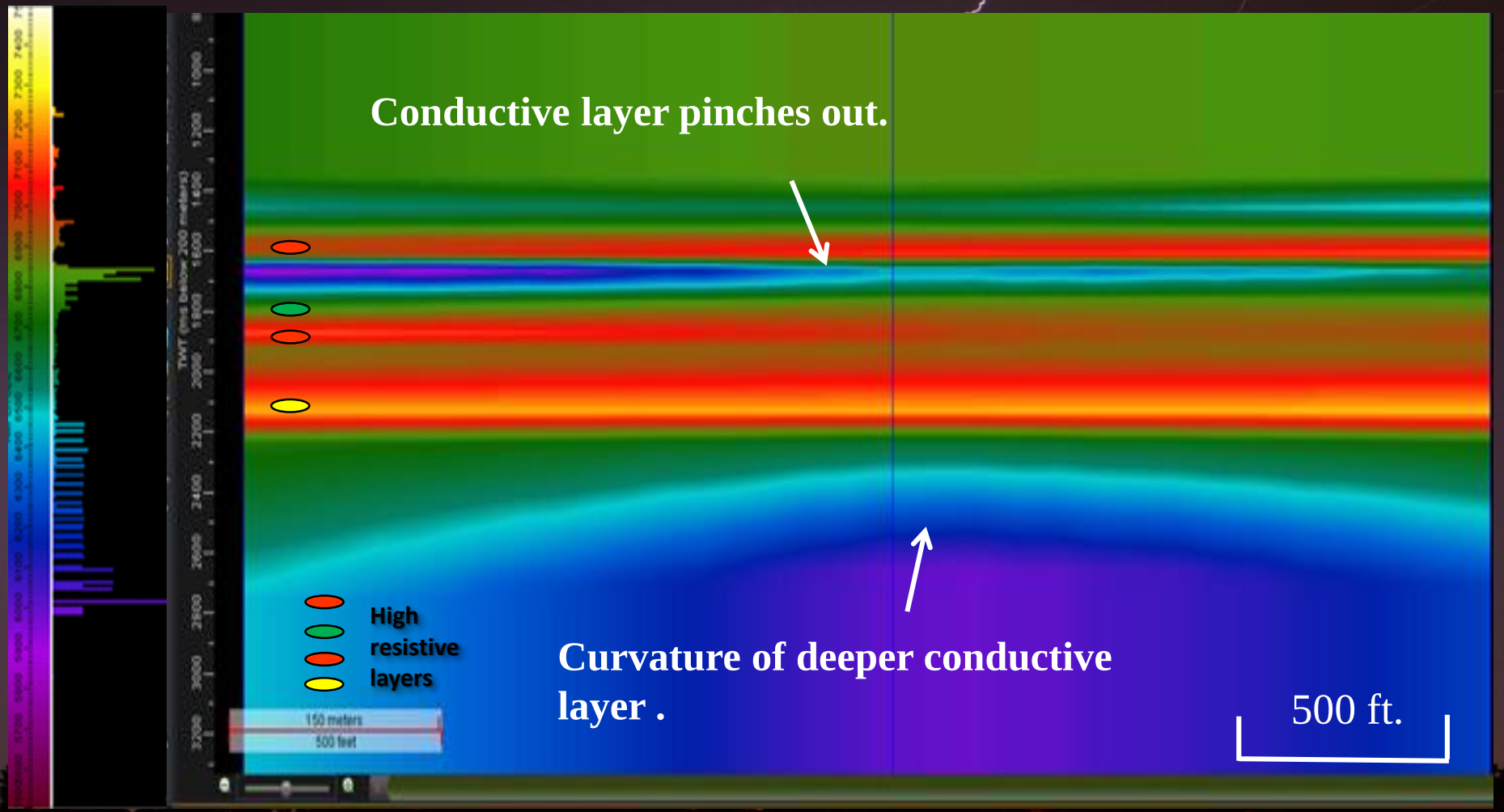
MTU Test Site with Cross-Well Tomography

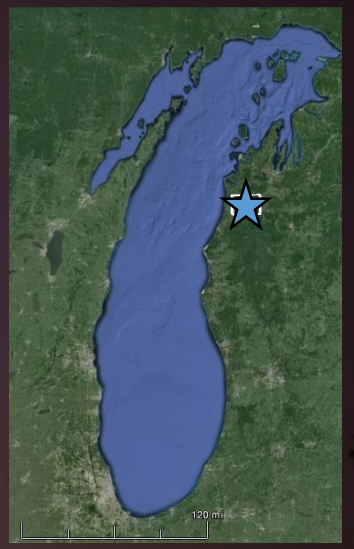






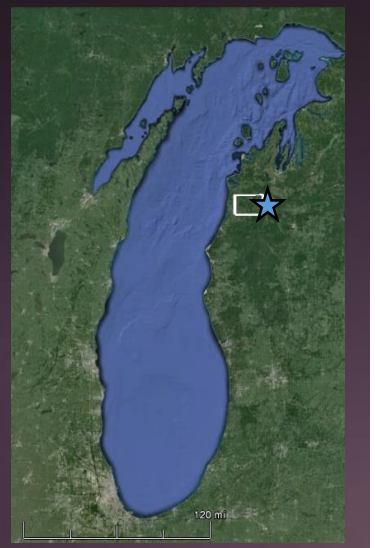
Resistivity Section Between MTU Test Site Wells

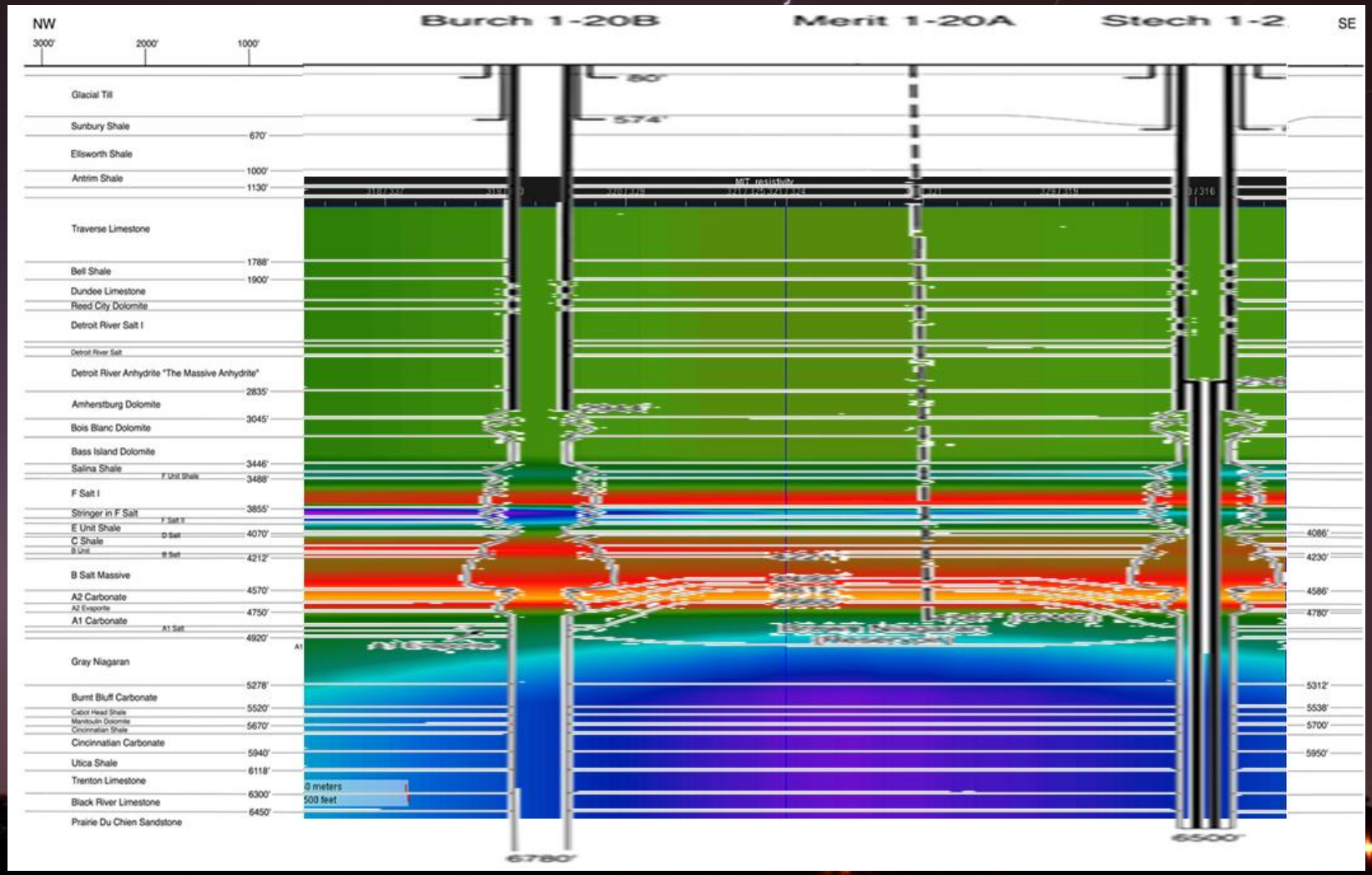


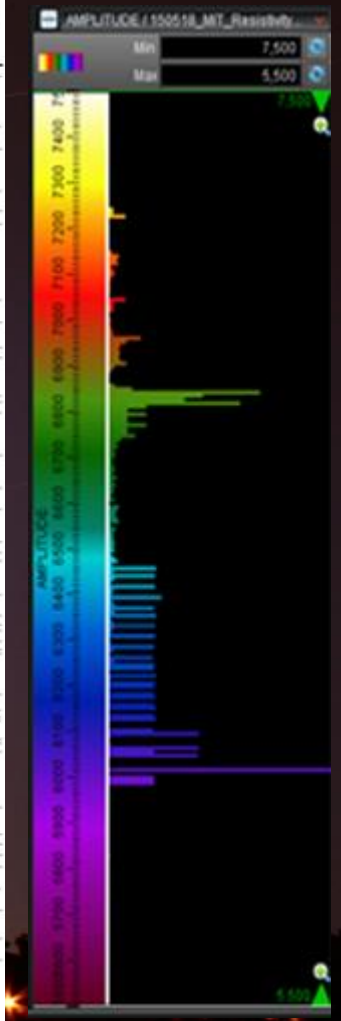


1
2
3

MTU Test Site Wells Overlaid on Resistivity Section







25-September-2015