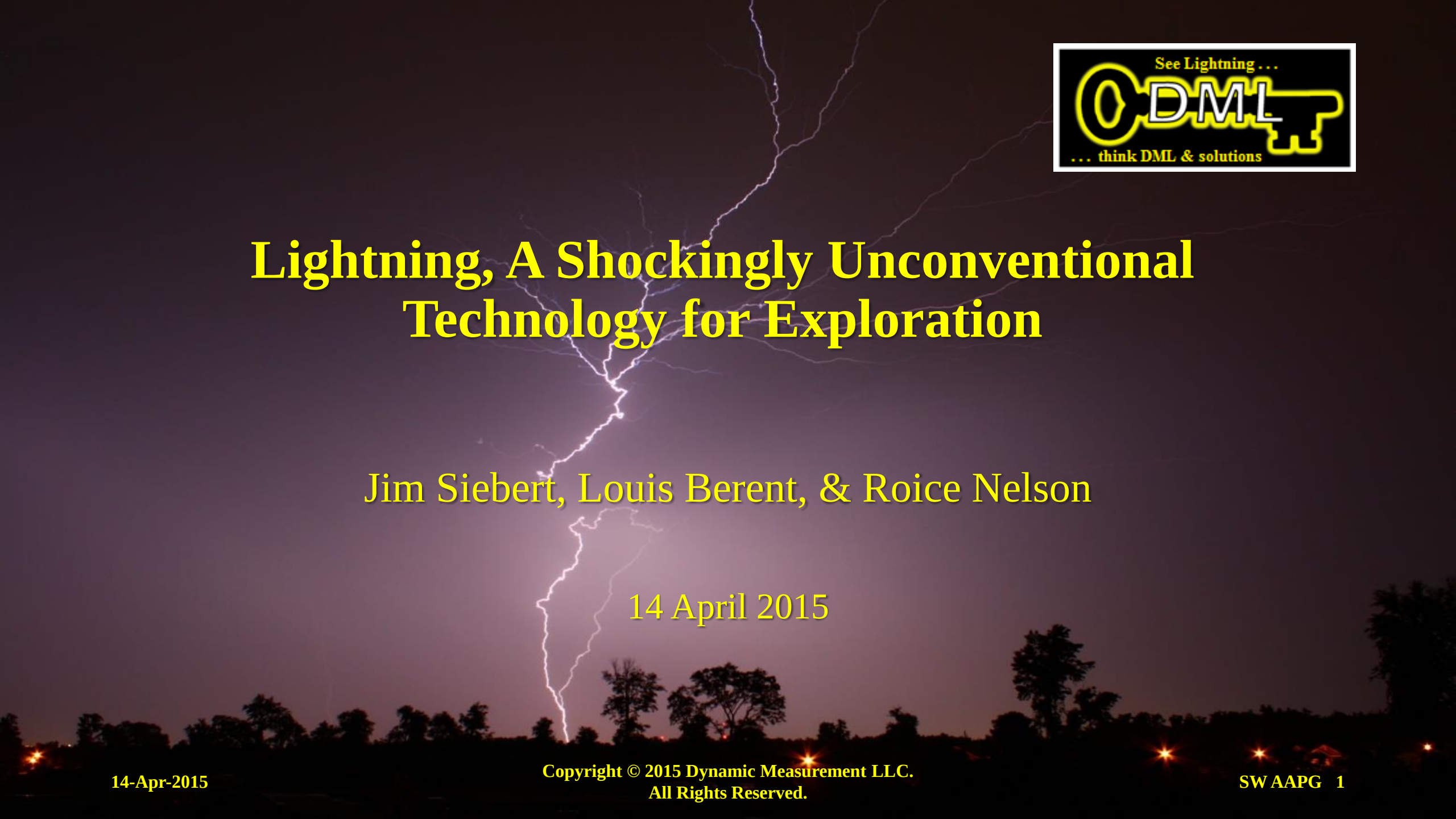


Lightning, A Shockingly Unconventional Technology for Exploration

Jim Siebert, Louis Berent, & Roice Nelson

14 April 2015

Outline

NSEM - A new geophysical data type

The meteorology behind lightning databases

Examples of using lightning data to interpret geologic features

Natural Source Electro-Magnetics (NSEM)

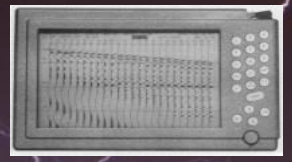
A NEW GEOPHYSICAL DATA TYPE

Time-Line of New Geophysical Data Types

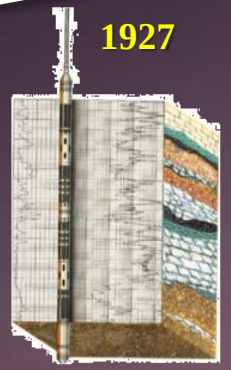
1752

1833

1920s

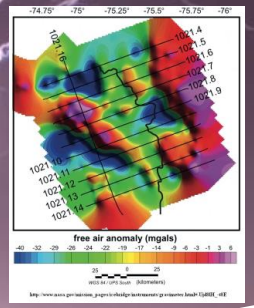


1927

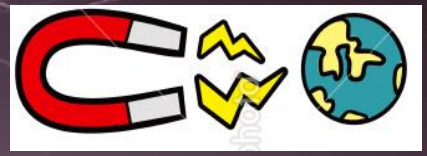


1931

1936

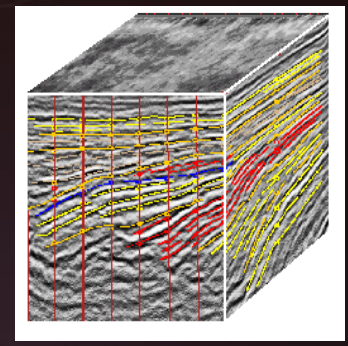


1950s

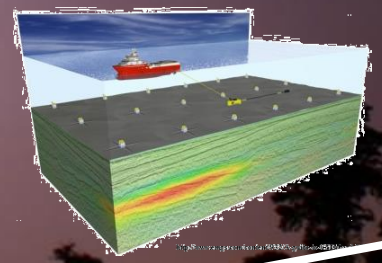


1960s/70s

1974

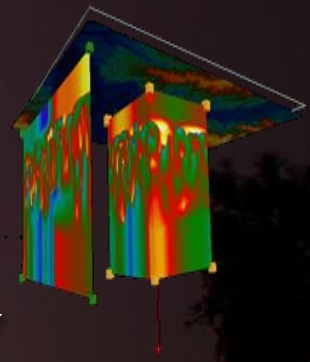


1997



2008

2015



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

Proven & Patented Technology

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)

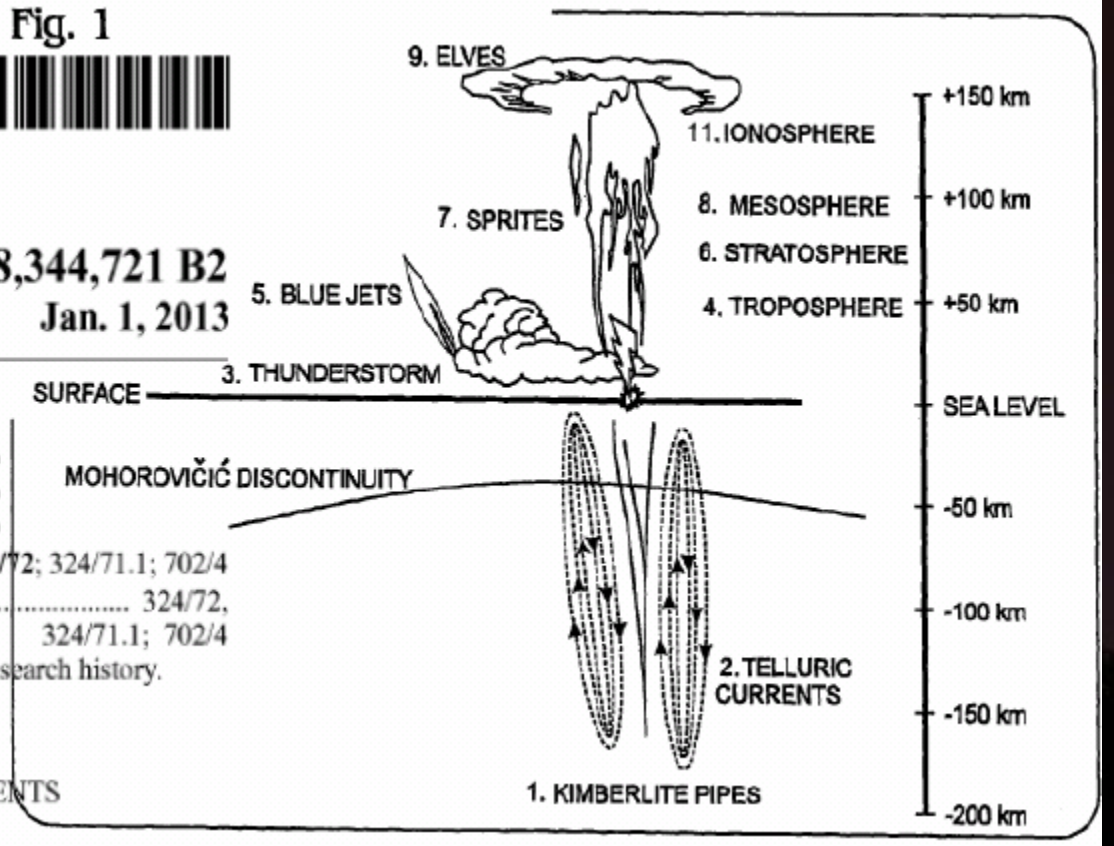
(52) **U.S. Cl.** **324/72**; 324/71.1; 702/4

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

See application file for complete search history.

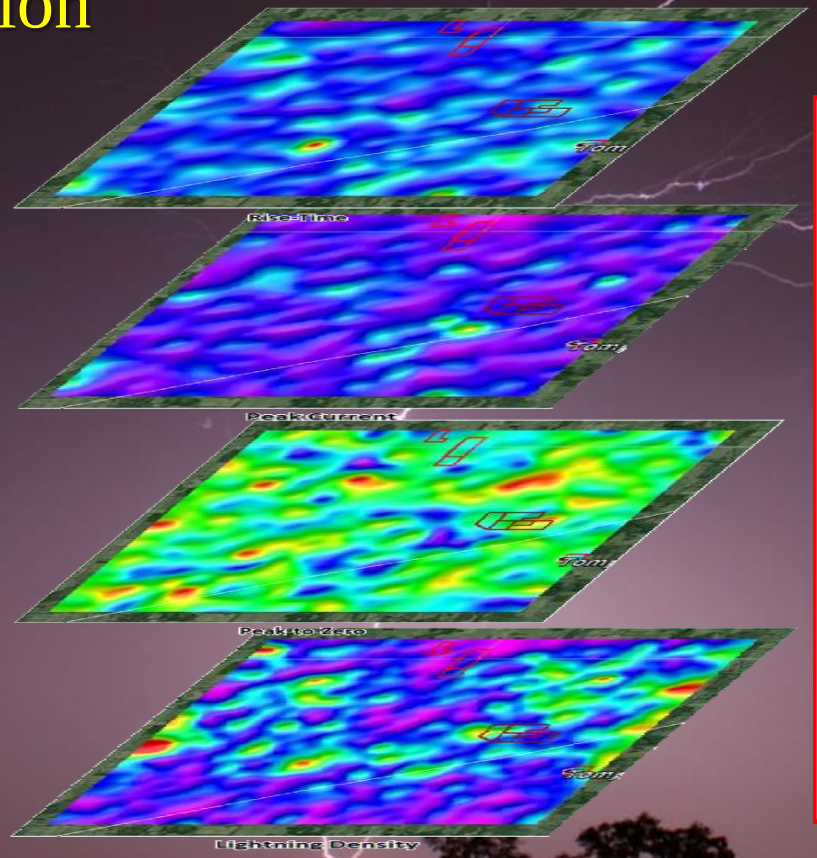
(56) **References Cited**

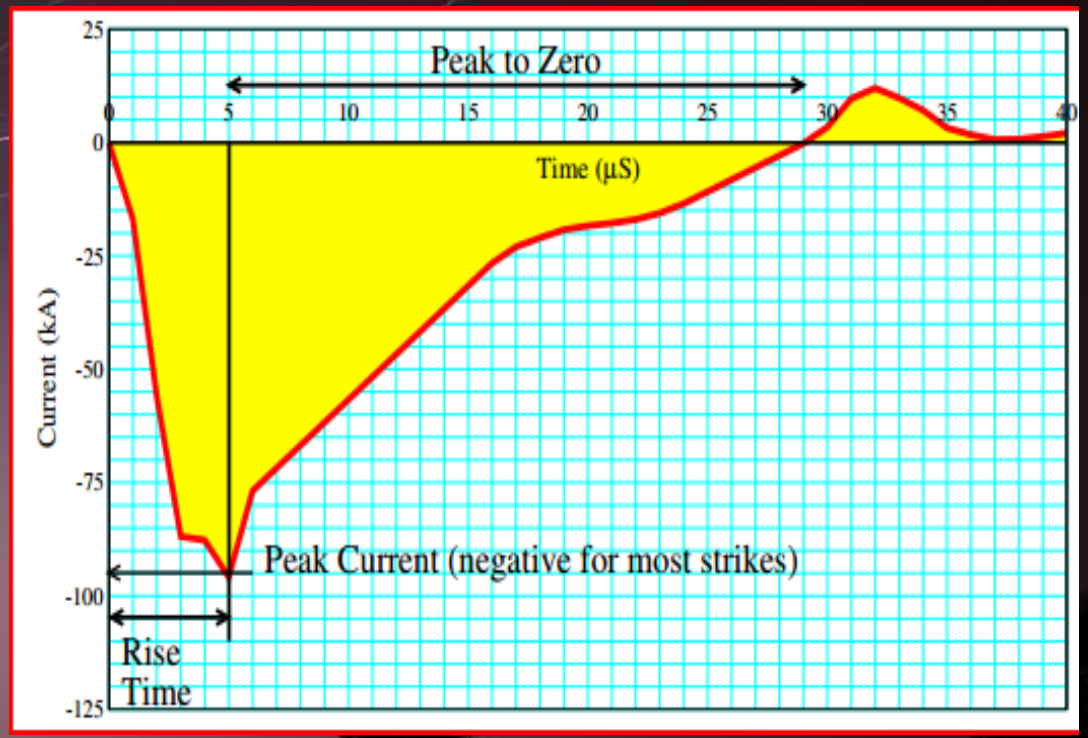
U.S. PATENT DOCUMENTS



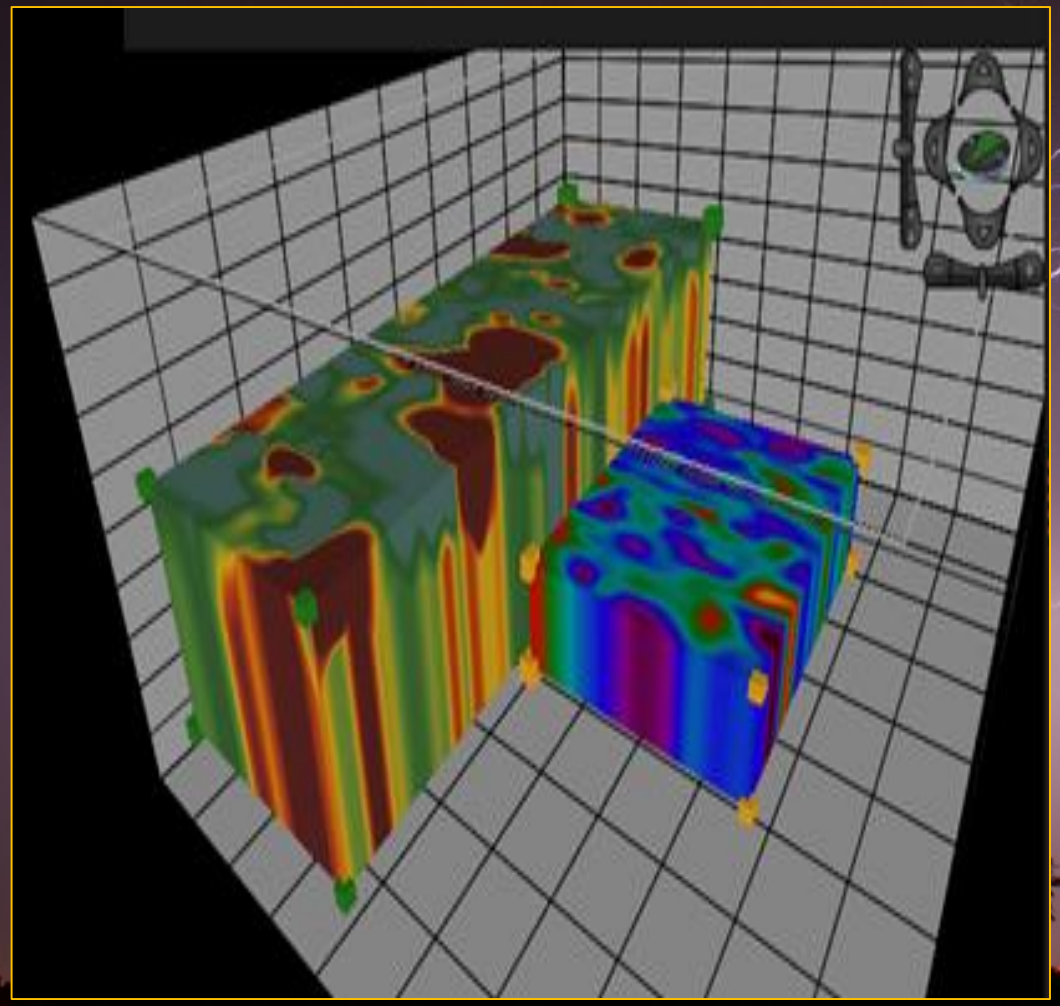
Lightning Strike Measurements

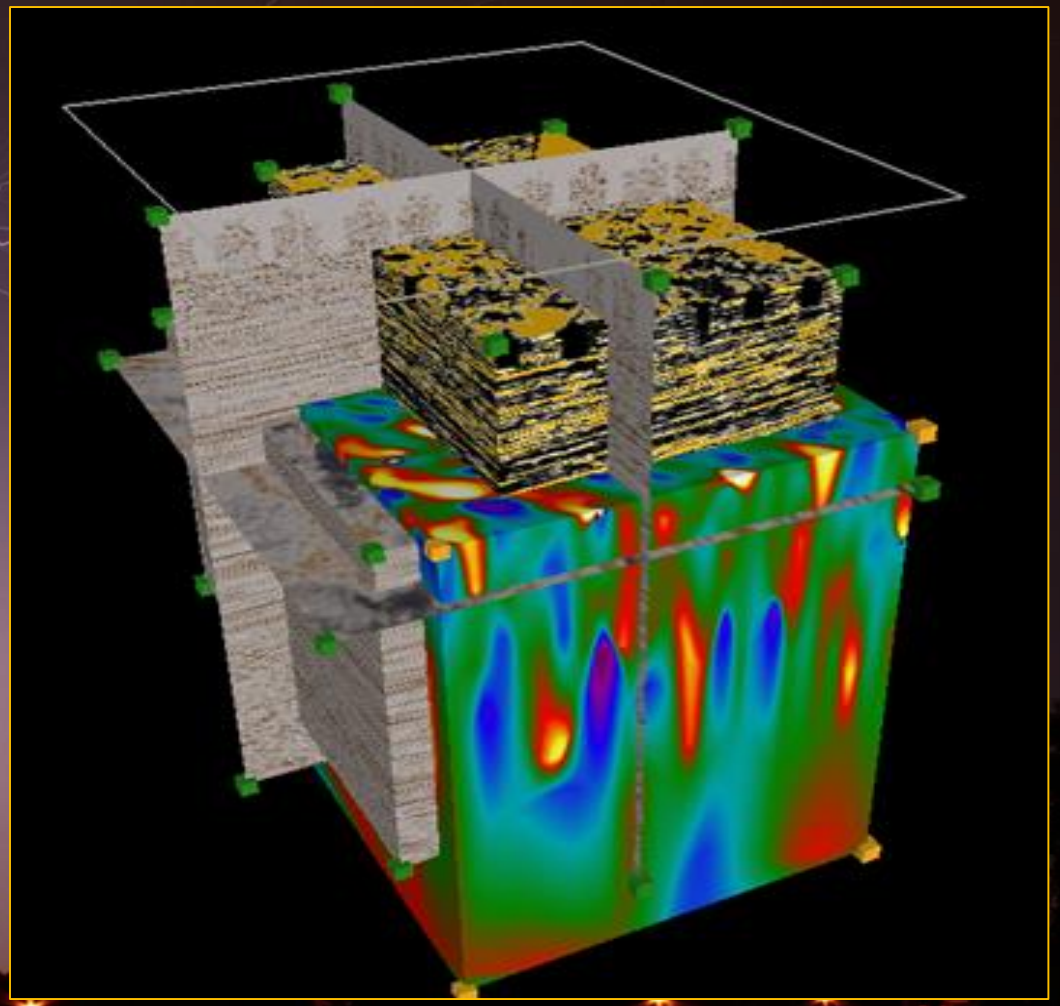
- Location
- Time and Duration
- Rise Time
- Peak Current
- Polarity
- Peak-to-Zero
- Density



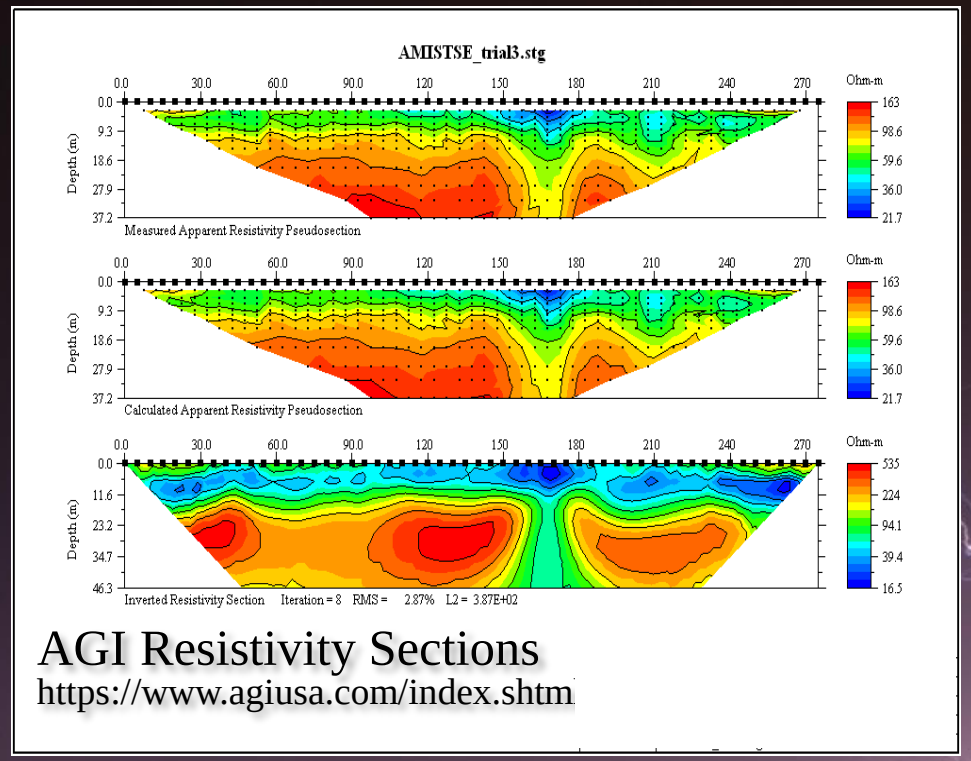


Resistivity & Permittivity Volumes
Easily Integrated with 3-D Seismic & Well Data

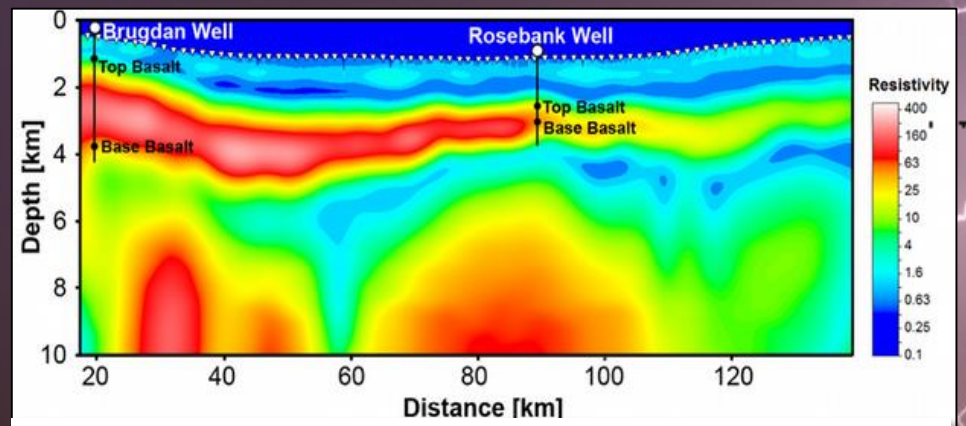




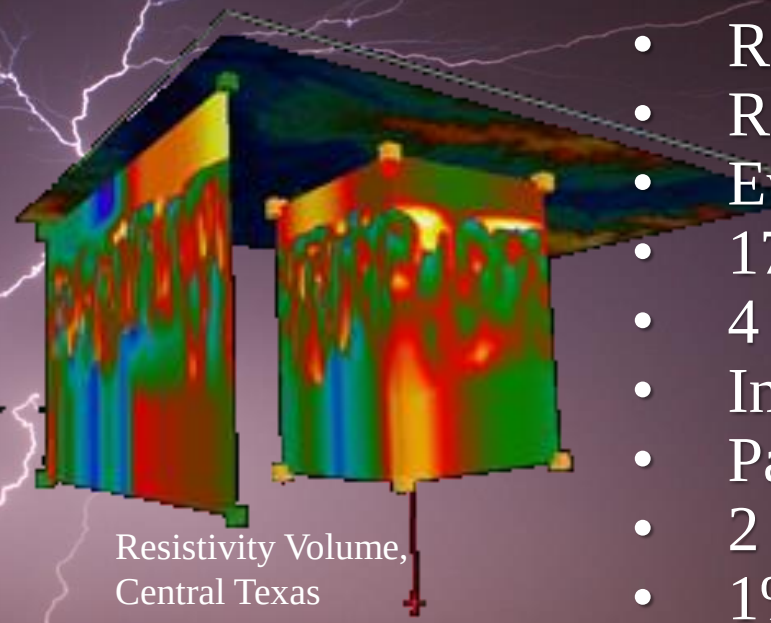
Existing Technology & Lightning Technology



AGI Resistivity Sections
https://www.agiusa.com/index.shtm



CSEM Survey from: EMGS
http://www.emgs.com/content/870/Structural-imaging

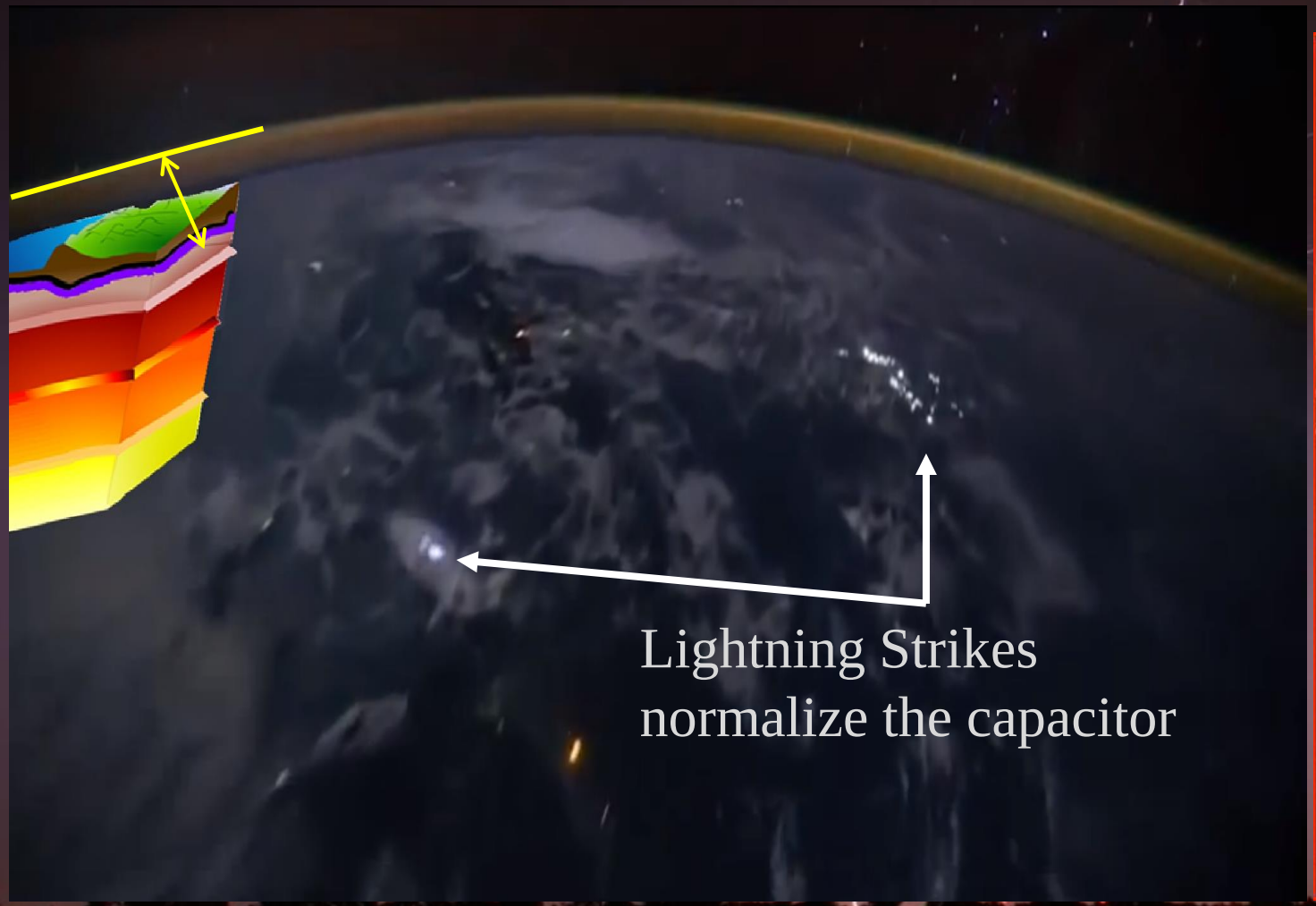


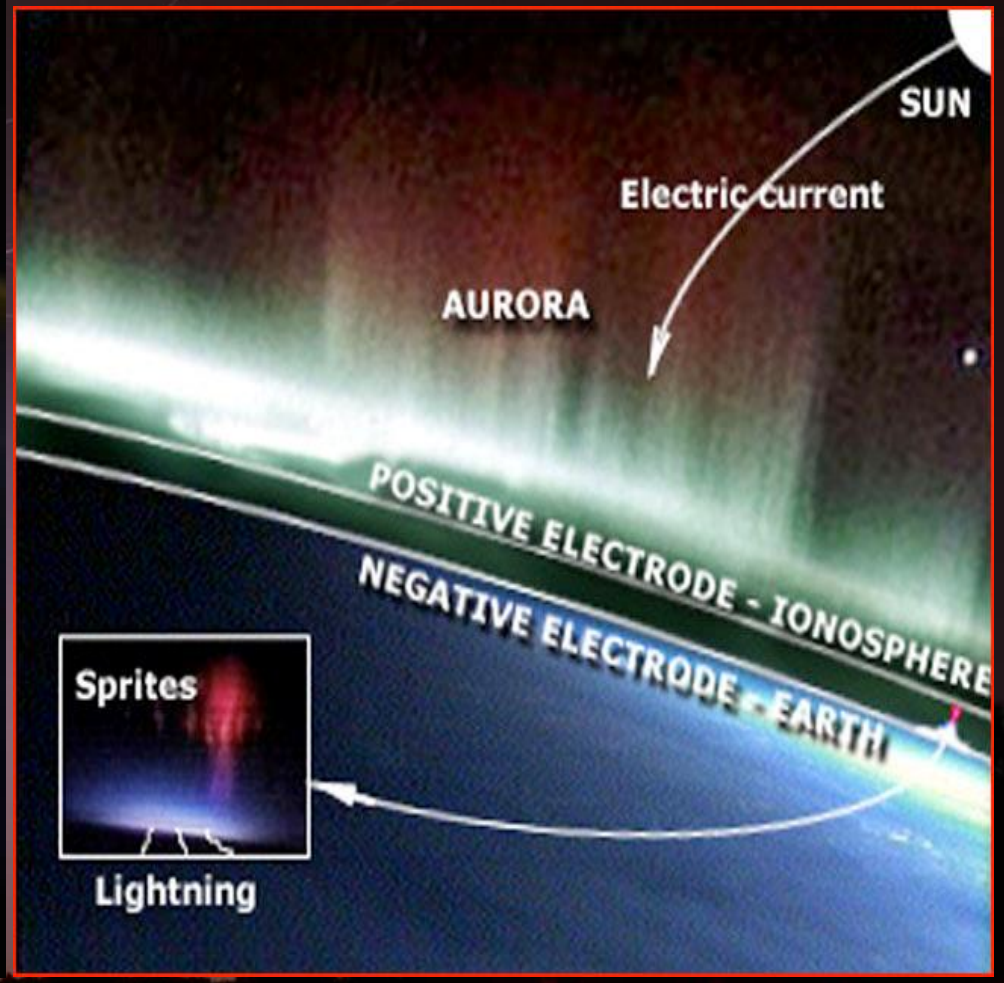
Resistivity Volume,
Central Texas

- Attribute Maps
- Resistivity Volumes
- Resistivity X-Sections & Slices
- Evergreen Data
- 17 Year Database US & Canada
- 4 Year Database Worldwide
- Integrates with G&G Data
- Patented, & Patent Pending
- 2 month project turnaround
- 1% cost of 3-D Seismic

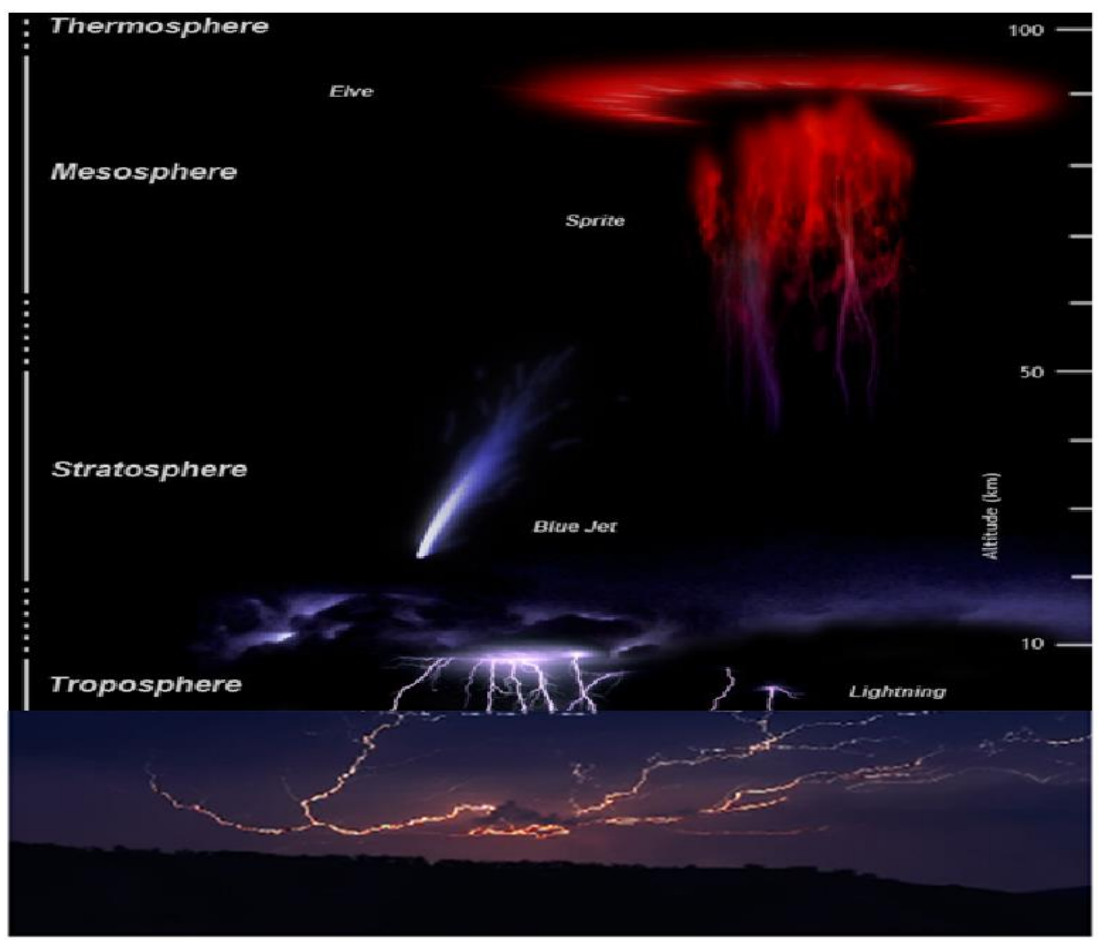
THE METEOROLOGY BEHIND LIGHTNING DATABASES

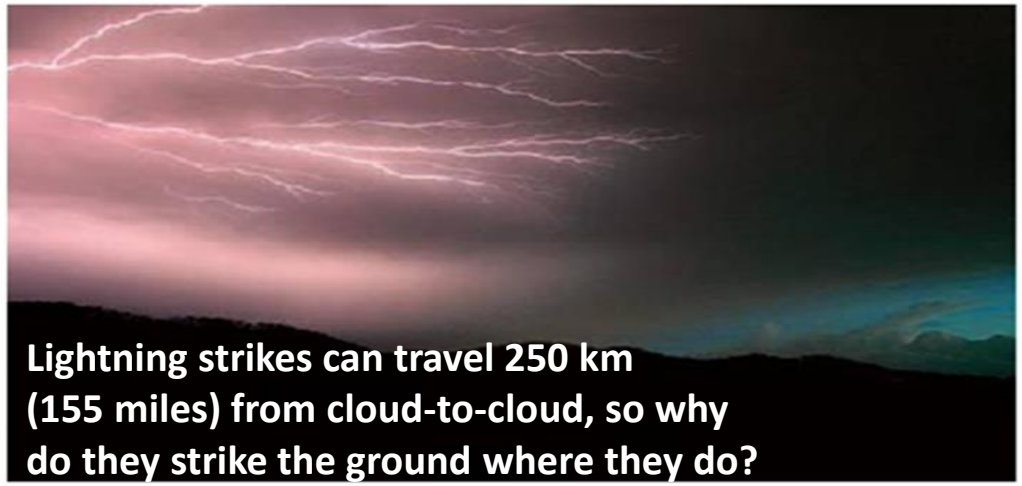
Earth: A Self-Repairing Capacitor



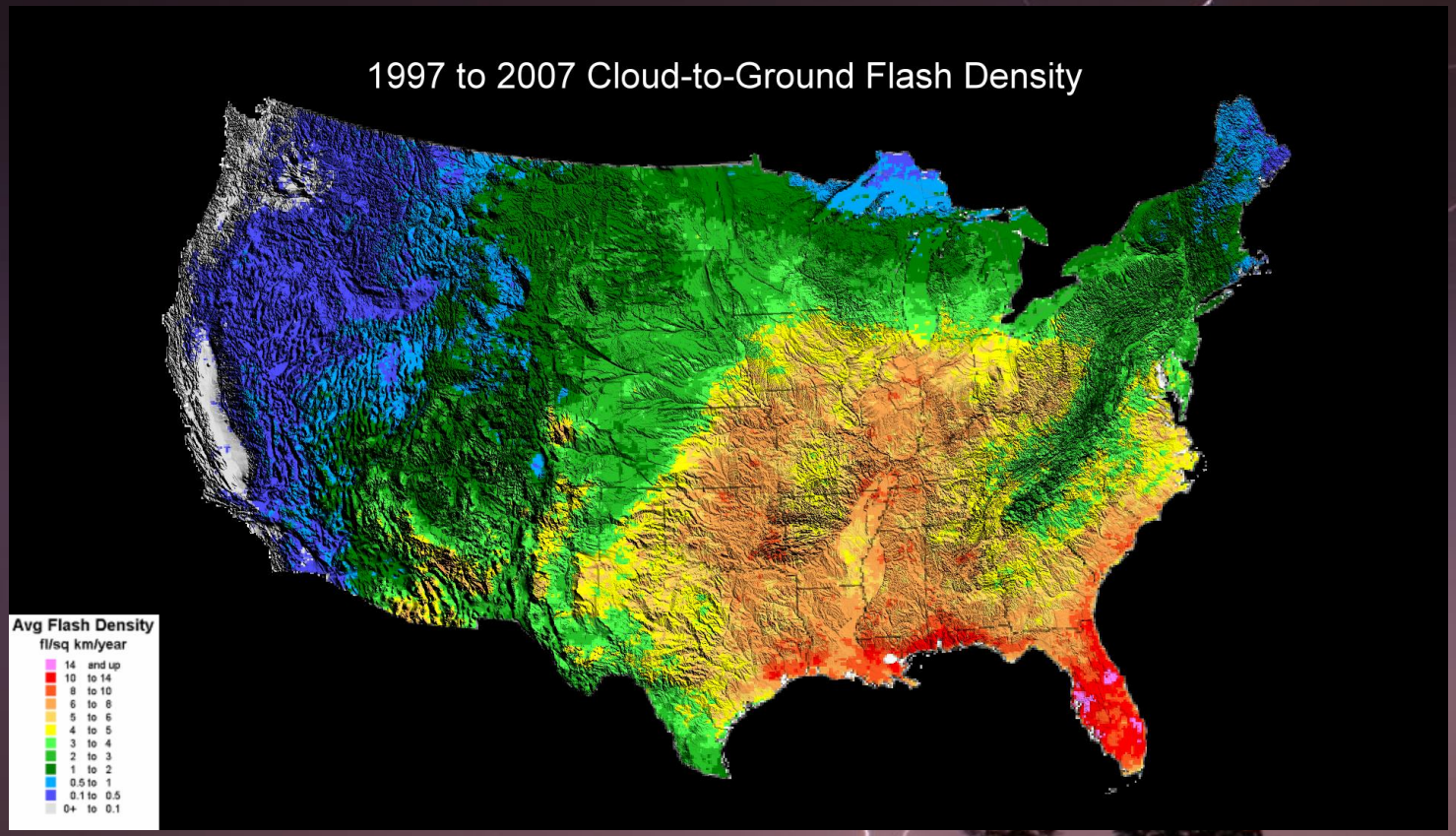


350 Million Annual Lightning Strikes - A Rich Database to Mine





Lightning Maps and Natural Resources

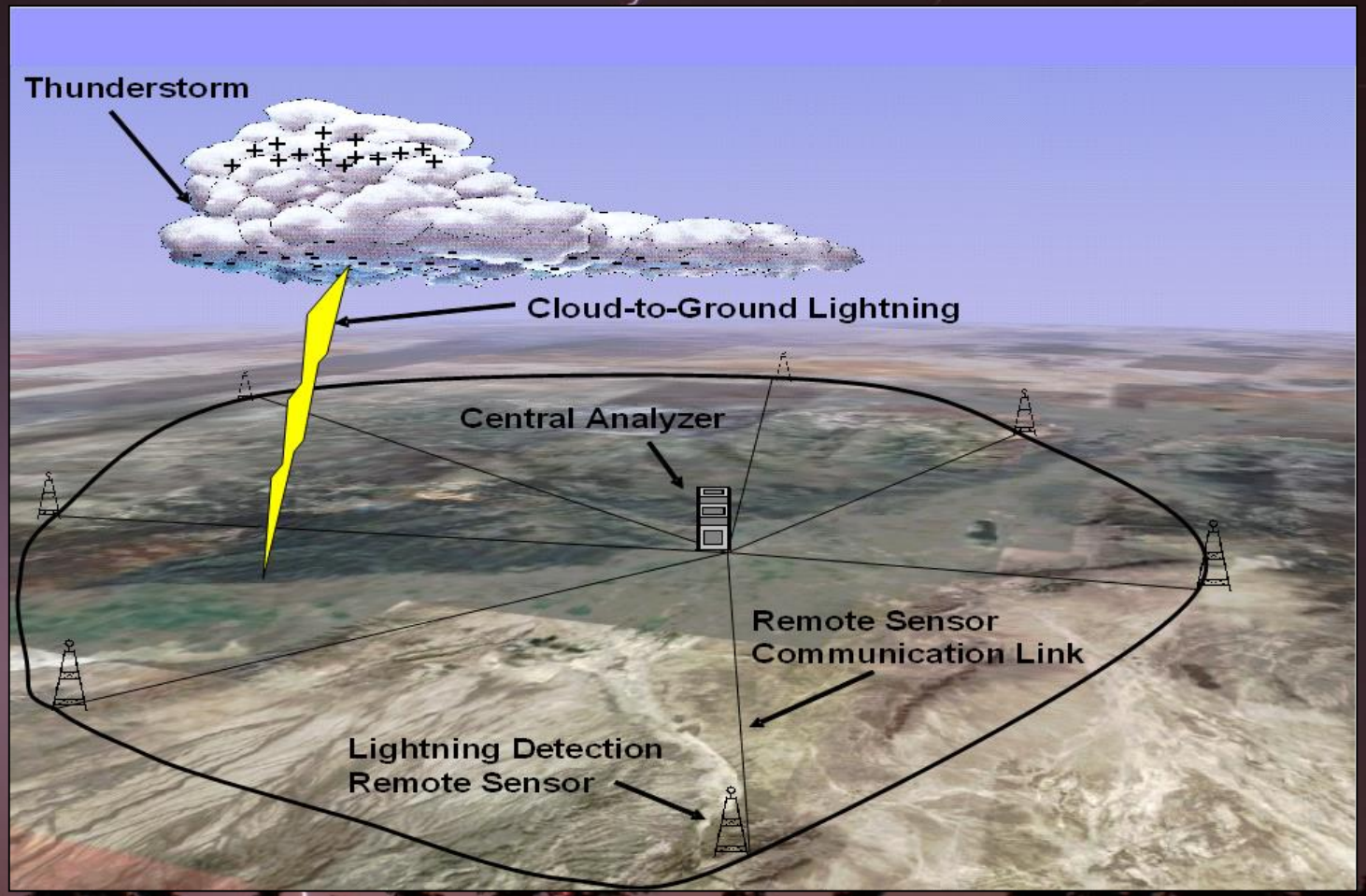


Lightning strike density regionally controlled by meteorology, and locally controlled by terralevis (shallow earth) currents.

Why is lightning recorded?

Early Storm Warning - Safety - Insurance - Meteorology

330 Sensors Record U.S. Lightning Strike Locations
Horizontal Resolution: 650-980’ (200-300 meter)



Lightning Bypasses Tall Objects

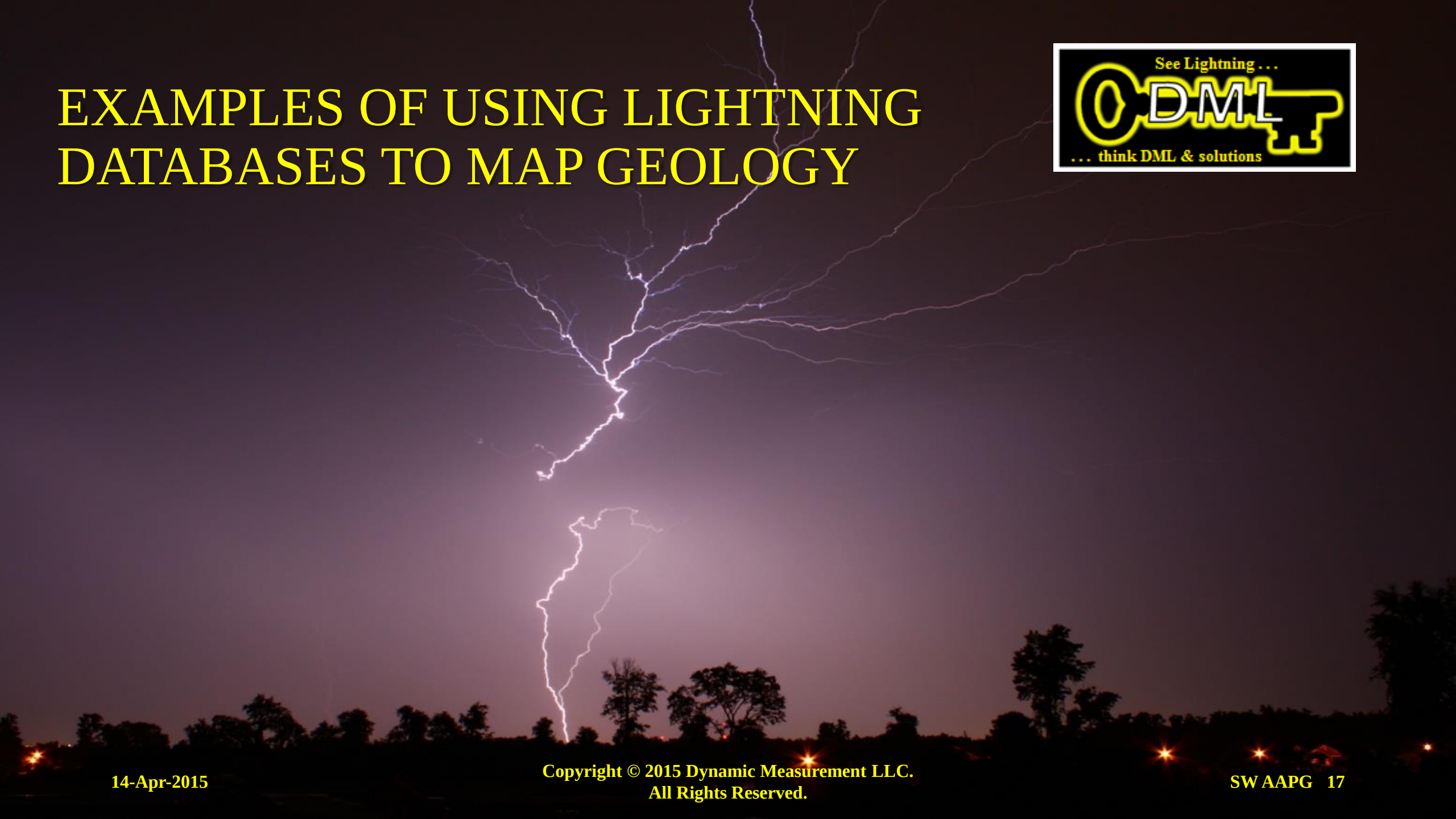
Lightning Strikes Are Not Random!

Influenced by Lateral Changes in Rock Properties:

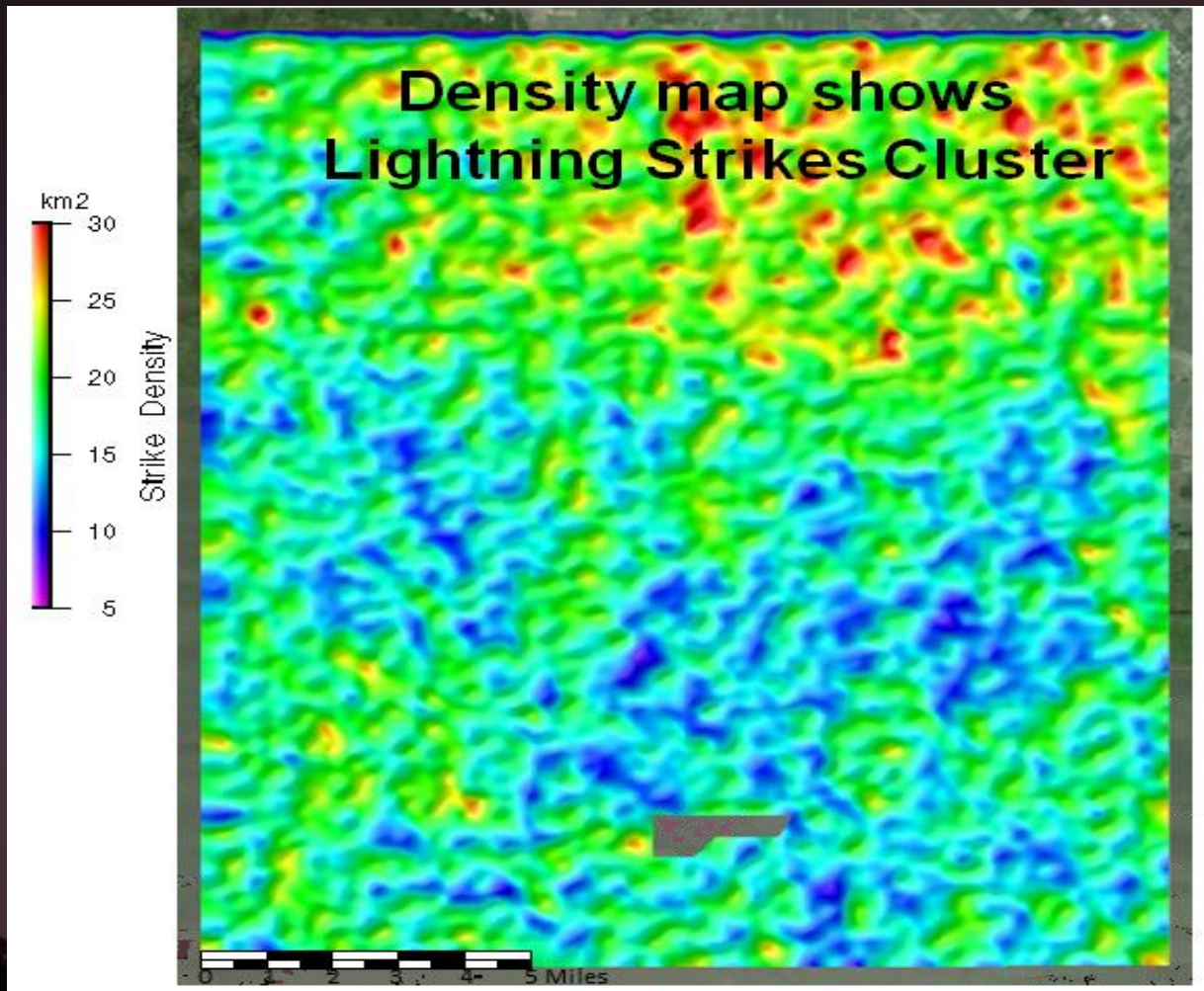
- Faults
- Fracture Swarms
- Anisotropy
- Pore Fluids and Salinity
- Porosity changes
- Permeability changes
- Mineralization

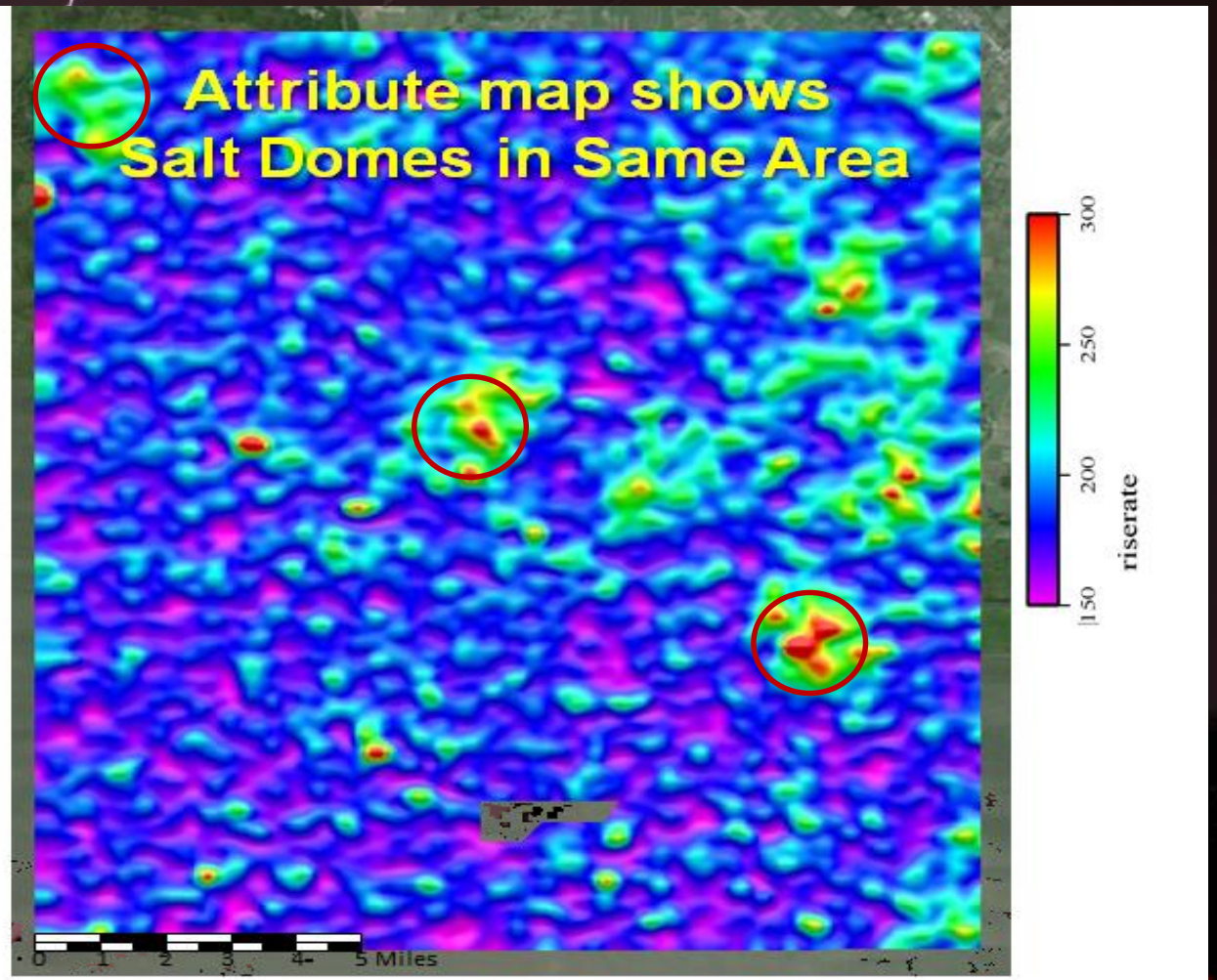
Upward lightning to left shows electrostatic charge builds up in the ground, as well as in the atmosphere.

EXAMPLES OF USING LIGHTNING DATABASES TO MAP GEOLOGY

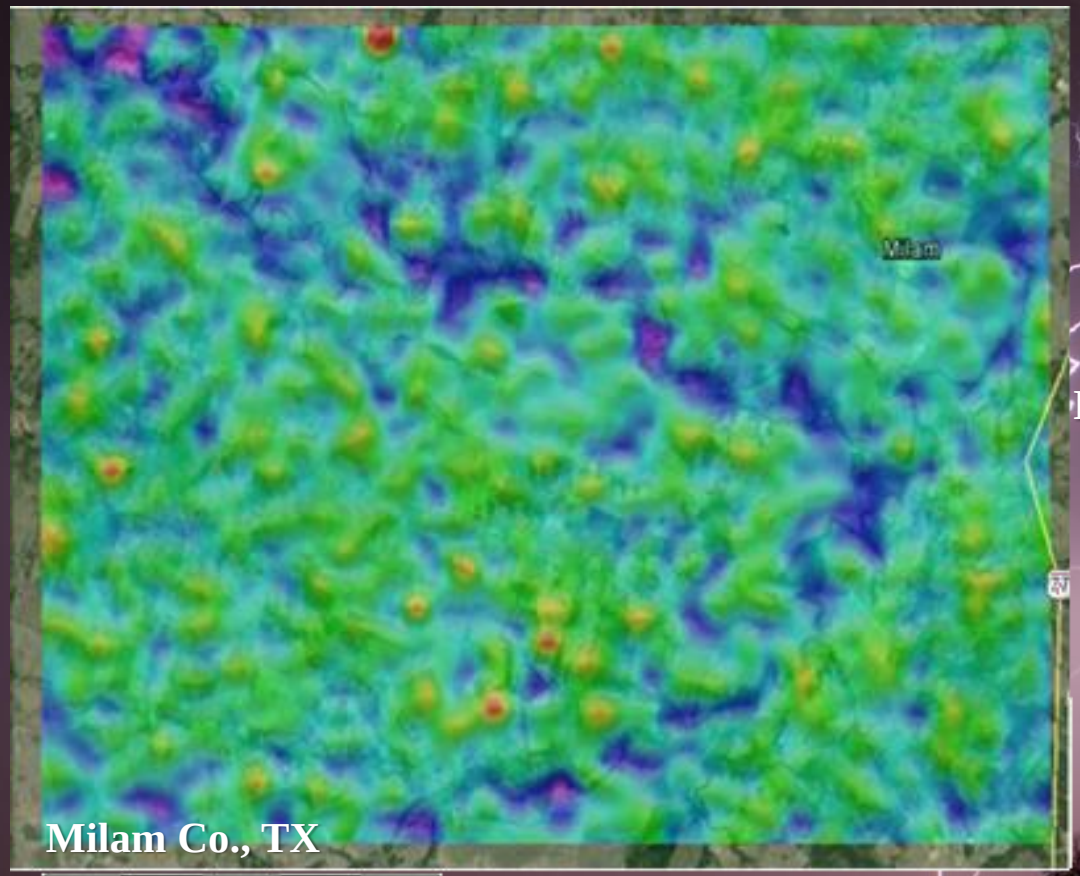


Lightning Data Correlates To Geology:
Salt Domes

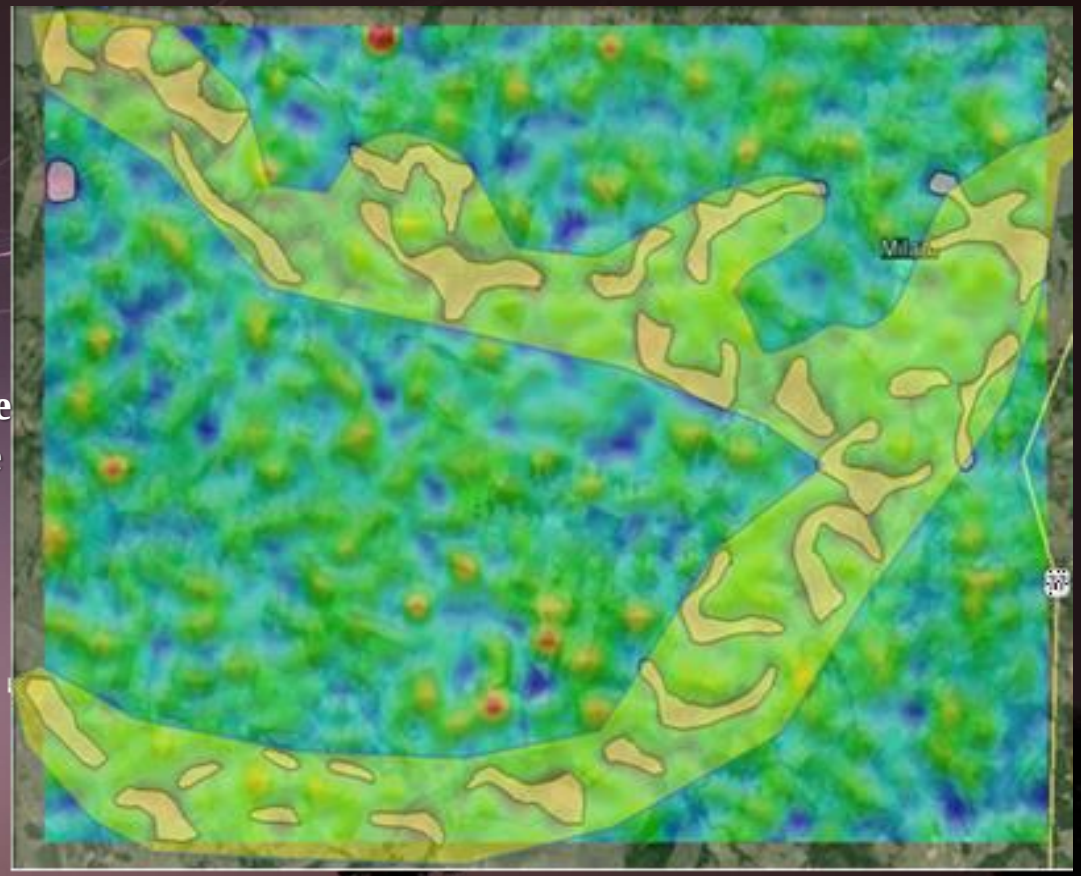




Lightning Data Correlates To Geology:
Fluvial Depositional Patterns

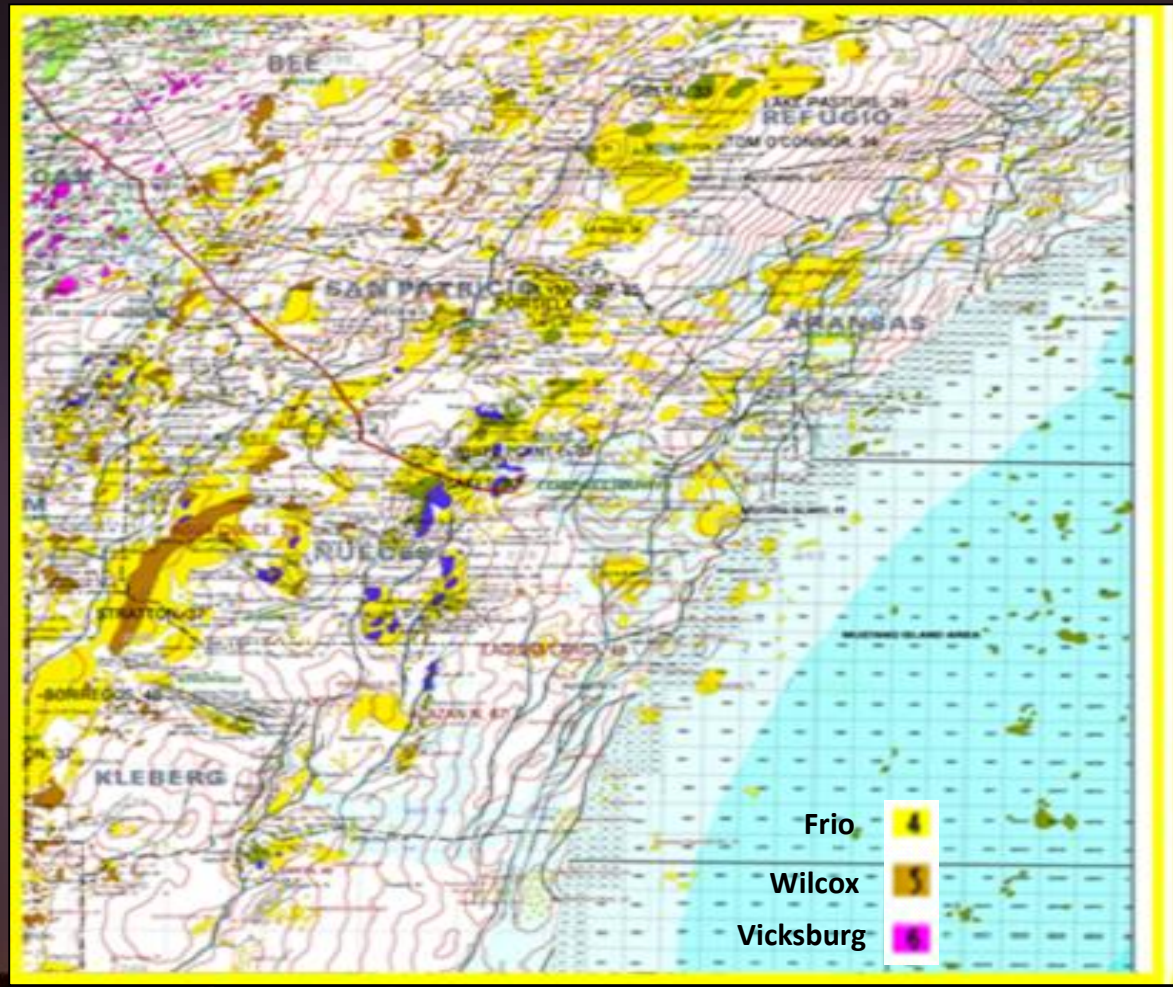


Lightning Attribute
Rate of Rise-Time

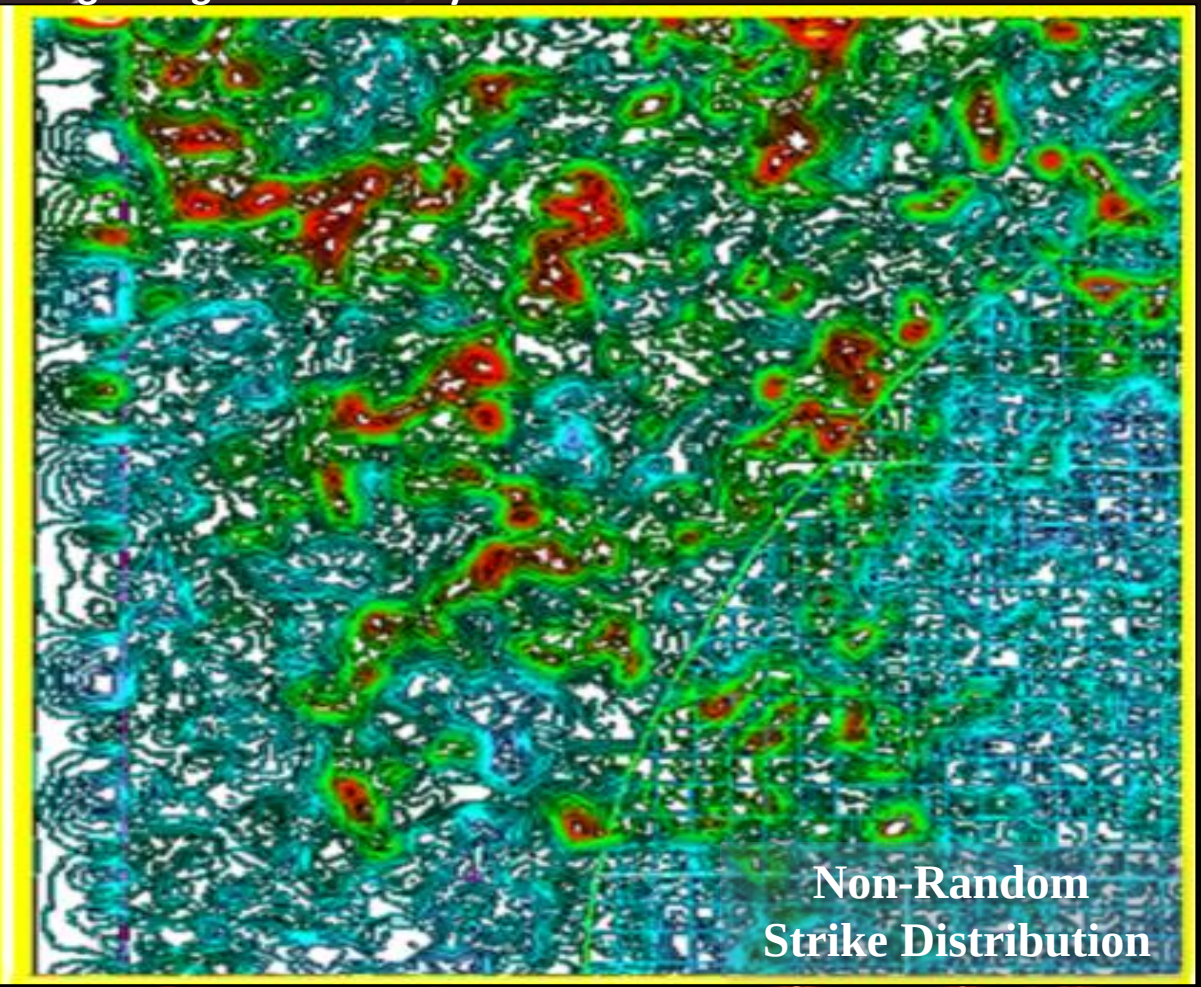


Lightning Data Correlates To Geology:
Texas Gulf Coast Regional Correlation

Structure & Field Outlines



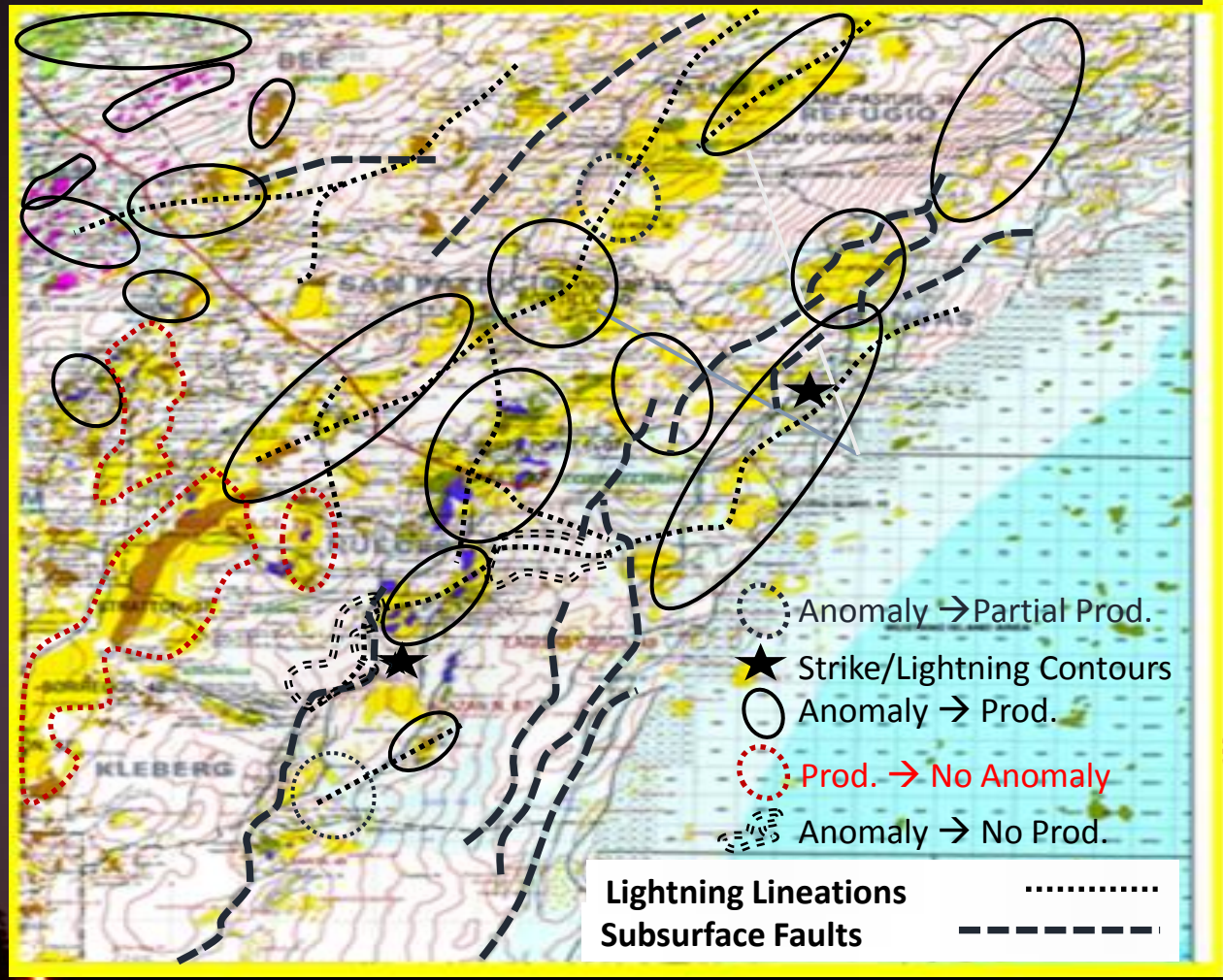
Lightning Strike Density



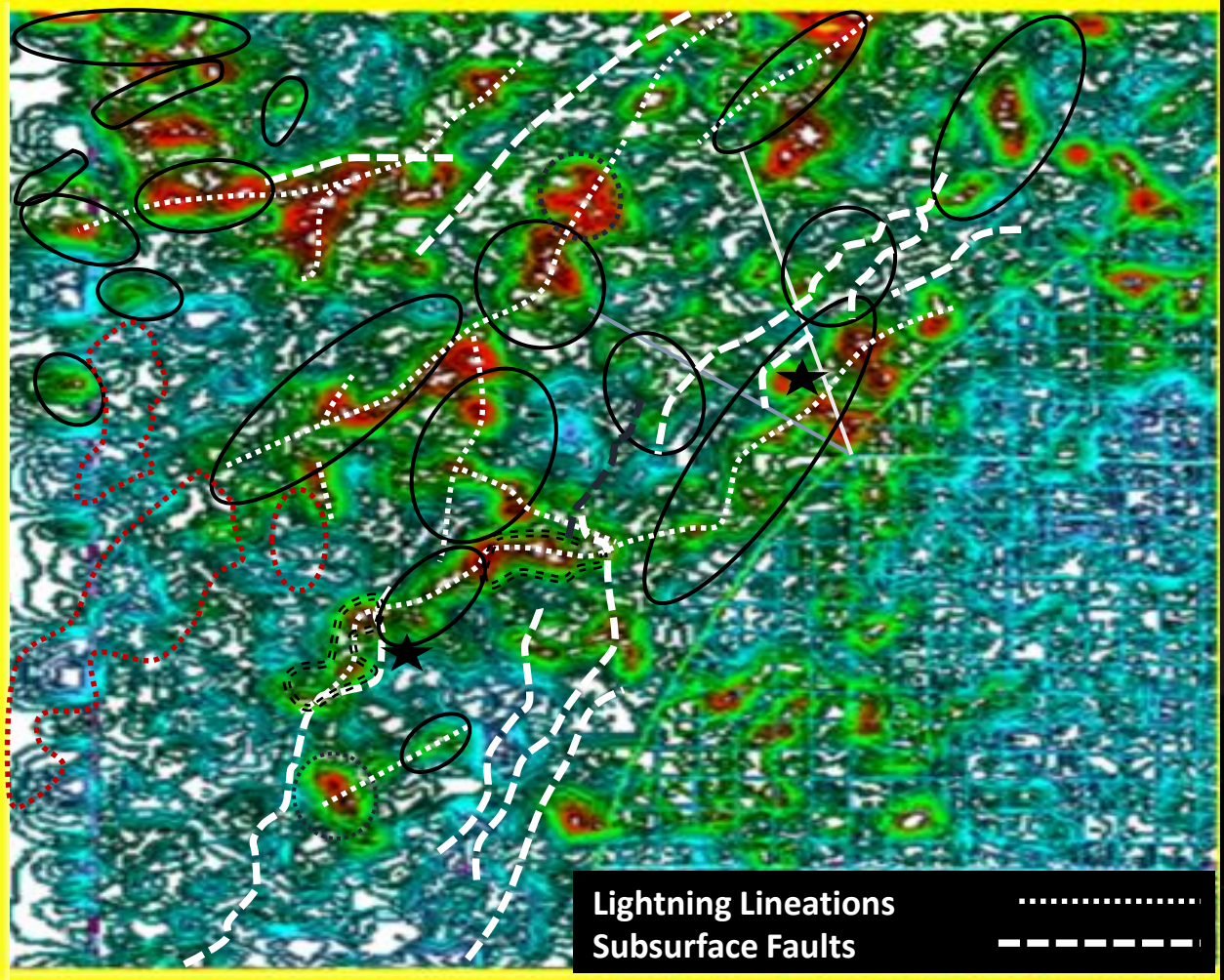
Lightning Data Correlates To Geology:
Fault Patterns and Hydrocarbon Accumulations

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

Structure & Field Outlines



Lightning Strike Density



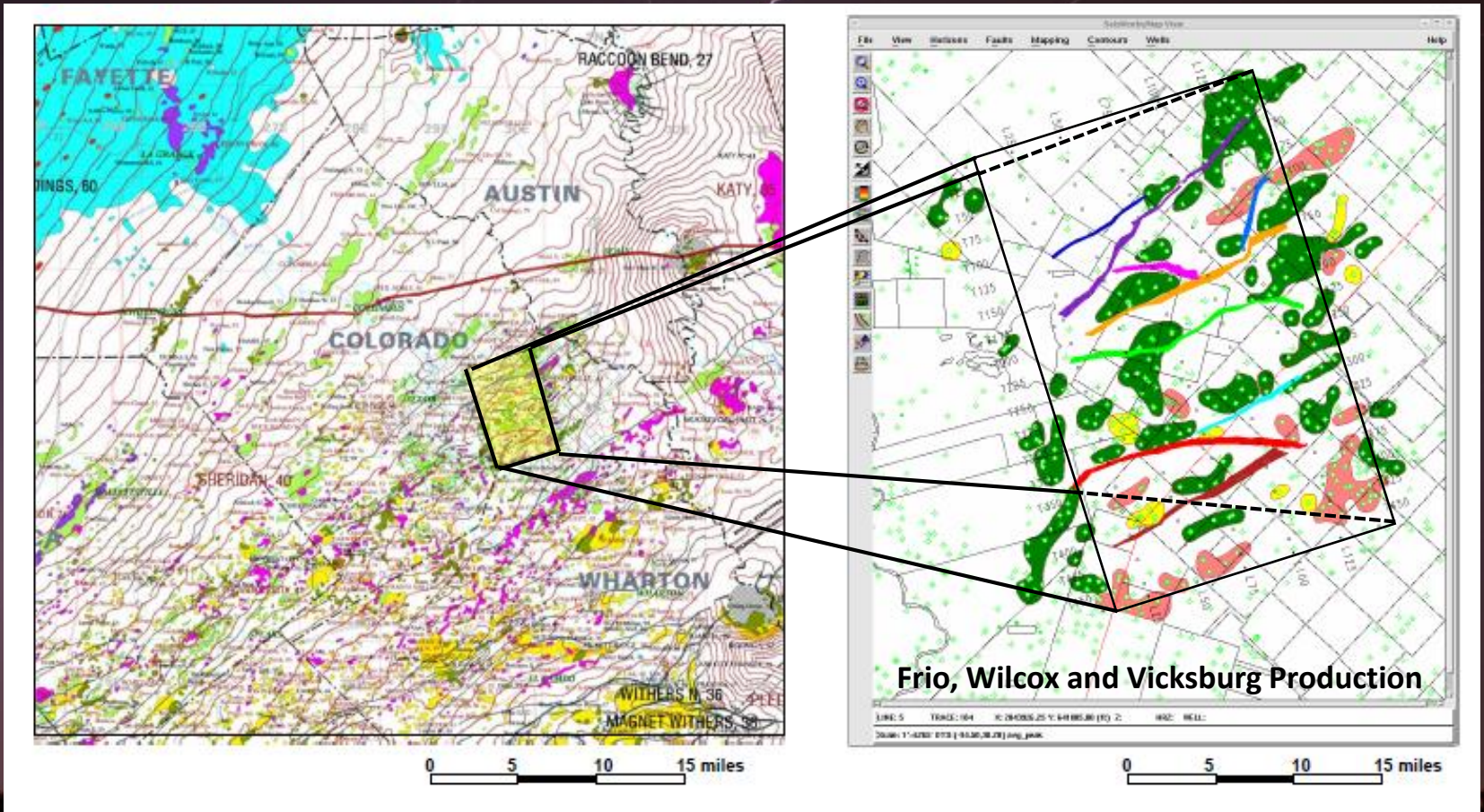
Observations

- Lightning strikes 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.
- Two faults show abrupt change in strike direction that closely match lightning contour patterns.

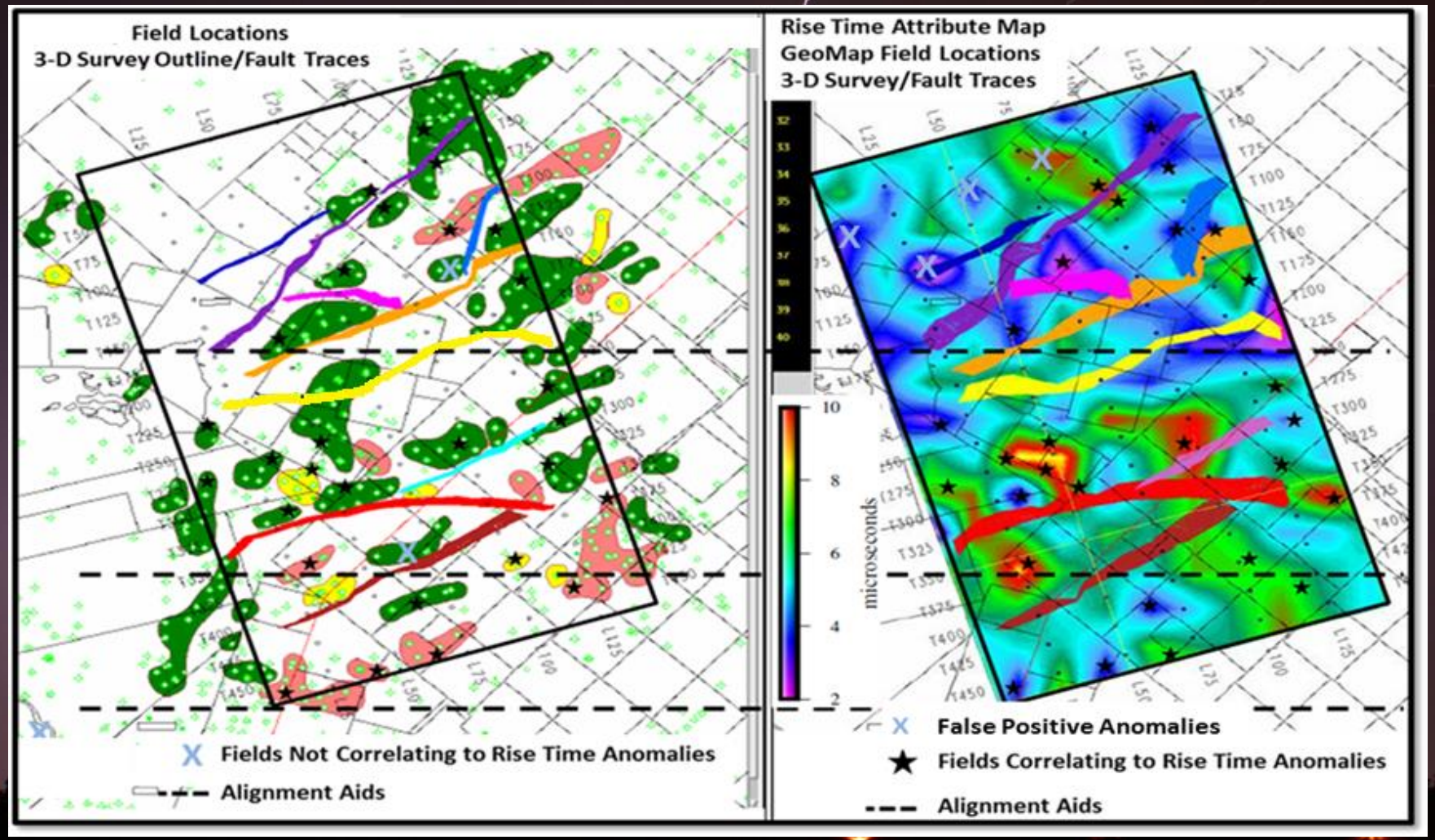
Texas Gulf Coast Conclusions

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

Regional Structure Map & Field Locations
Colorado County, TX



Lightning Data Correlates To Geology:
Effective Reconnaissance Mapping



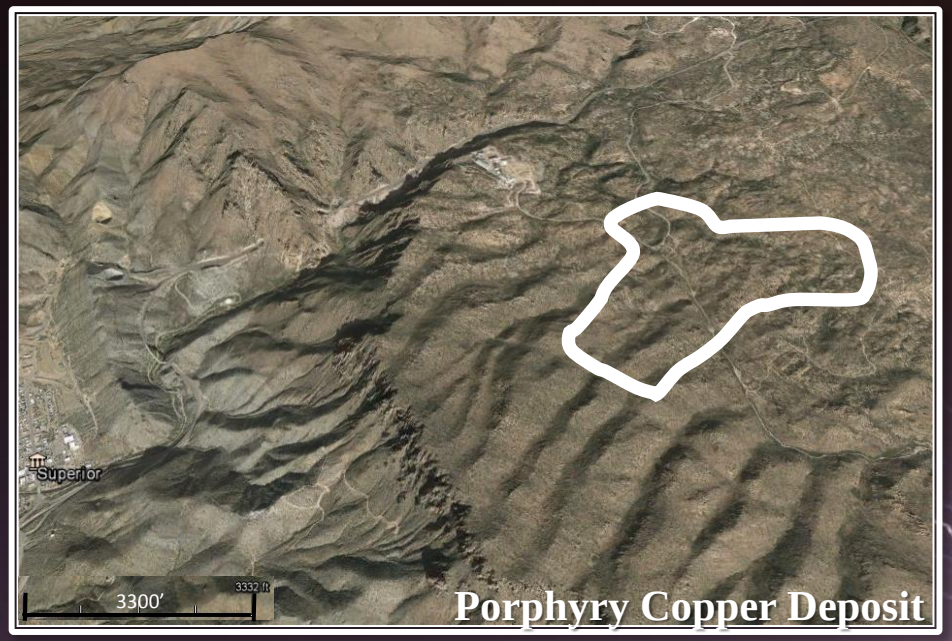
Observations

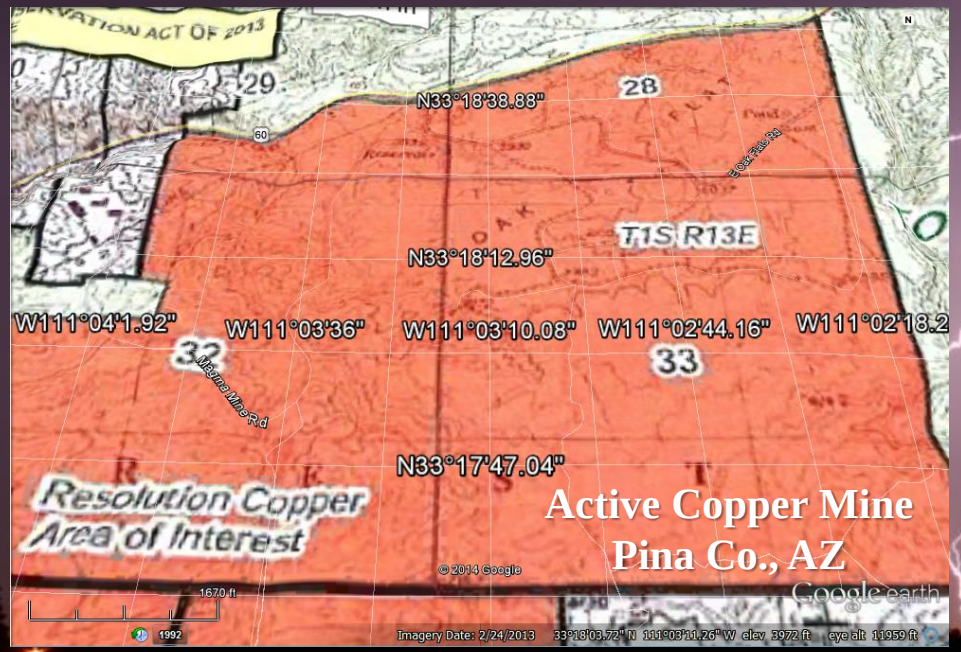
- Rise-Time lightning attribute shows non-random patterns.
- E/W trending yellow and orange faults generally separate the northern low Rise-Times from the southern high Rise-Times.
- 26 of 28 fields (93%) correlate to Rise-Time anomalies.
- Although 4 strong Rise-Time anomalies do not correlate to production, 28 of 32 (87%) of them do correlate to fields.

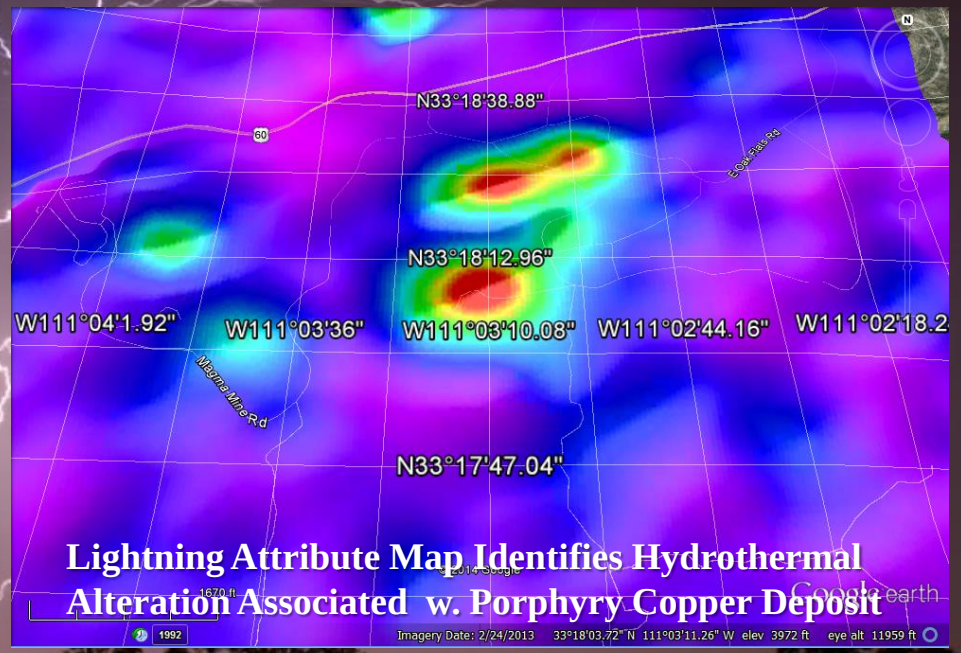
Colorado Co., Texas Conclusions

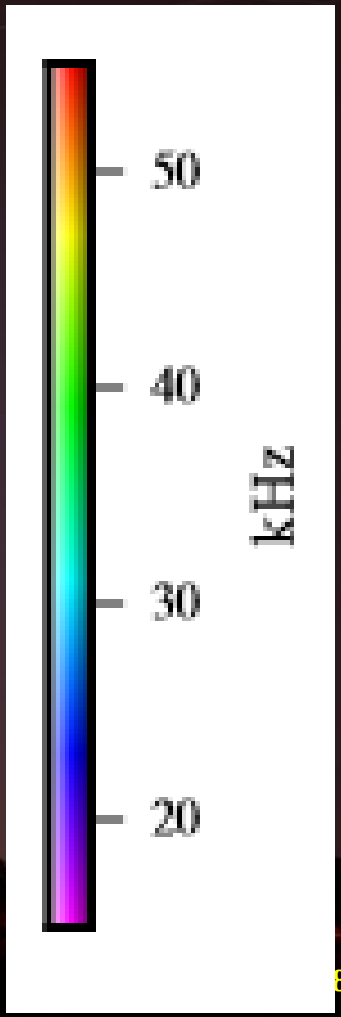
- NSEM identified 32 leads in study area.
- NSEM reconnaissance mapping would have justified purchase &/or acquisition of seismic data resulting in 28 prospects generated.
- NSEM reconnaissance mapping would have resulted in an 87% drilling success rate.

Lightning Data Correlates To Geology: Mineral Exploration





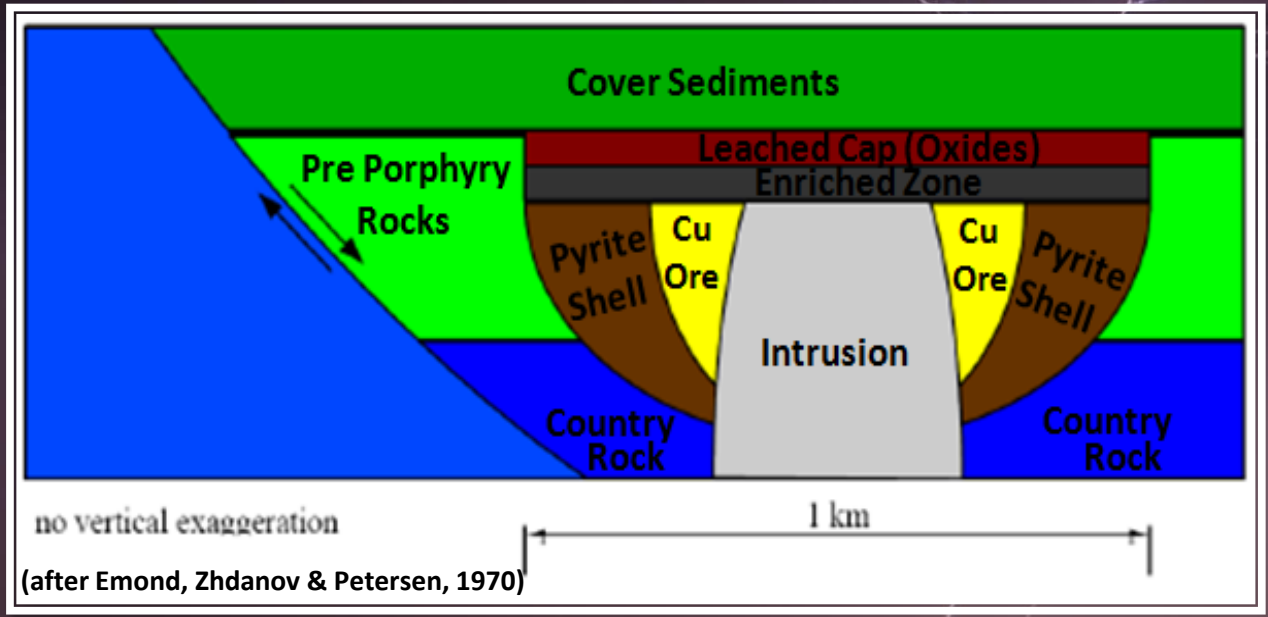




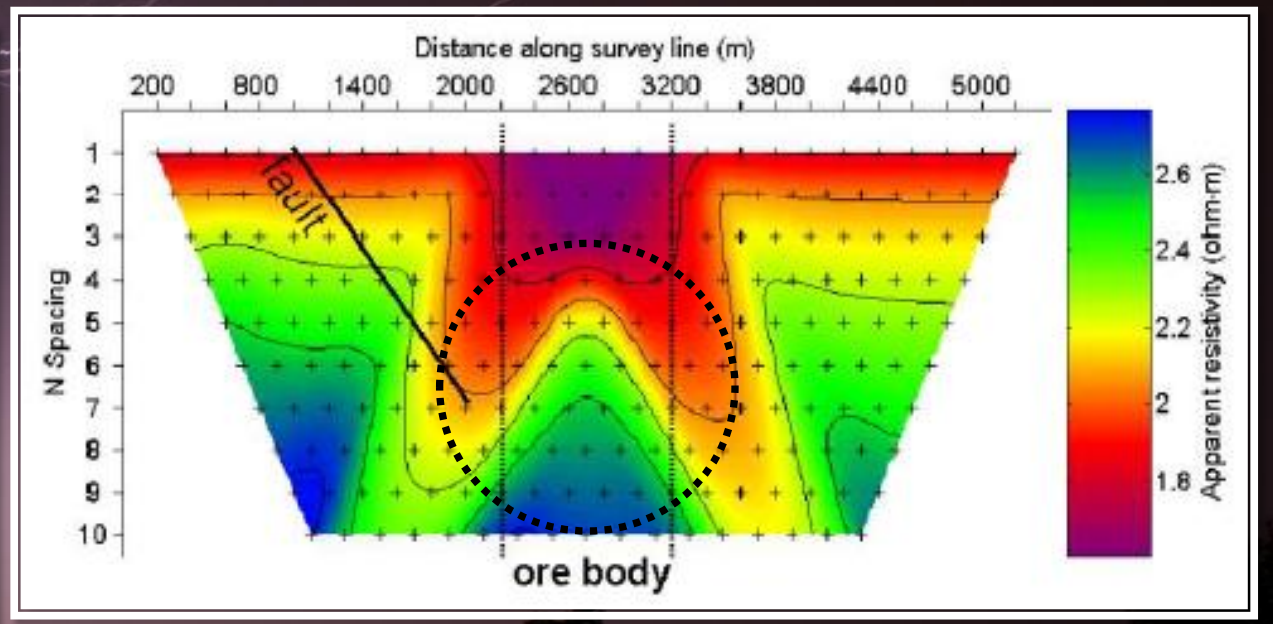
14-Apr-2015

Simplified Porphyry Copper Deposit Model

Typical Mineral Zones of a Porphyry Deposit



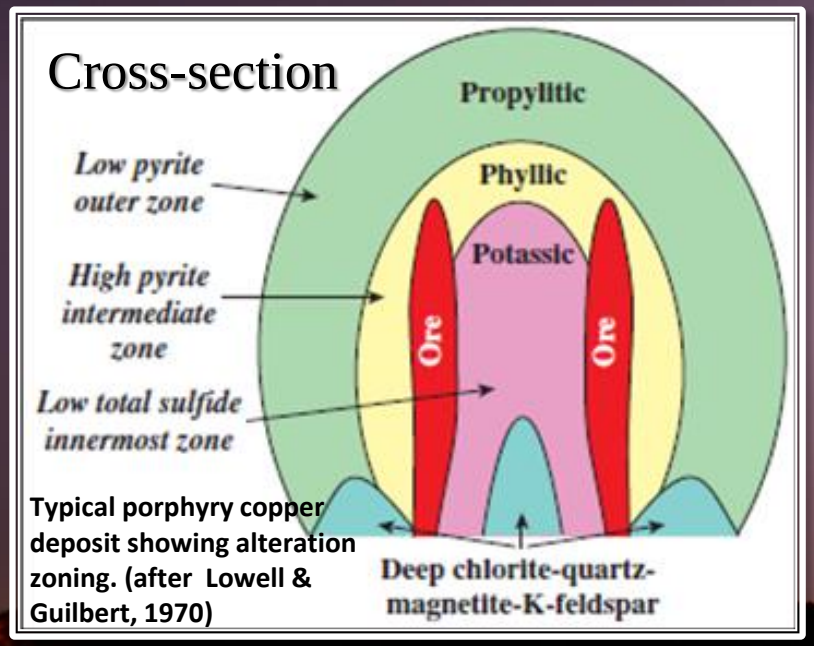
(after Emond, Zhdanov & Petersen, 1970)



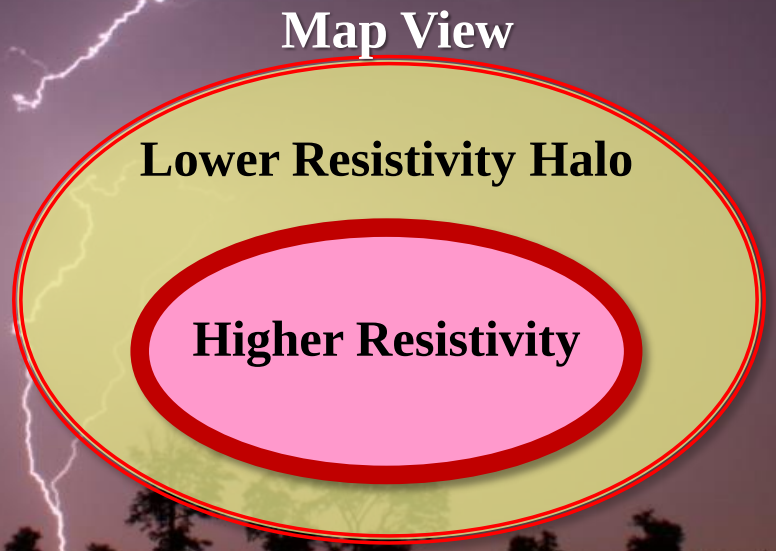
Conductivity anomaly surrounds more resistive ore body in center.

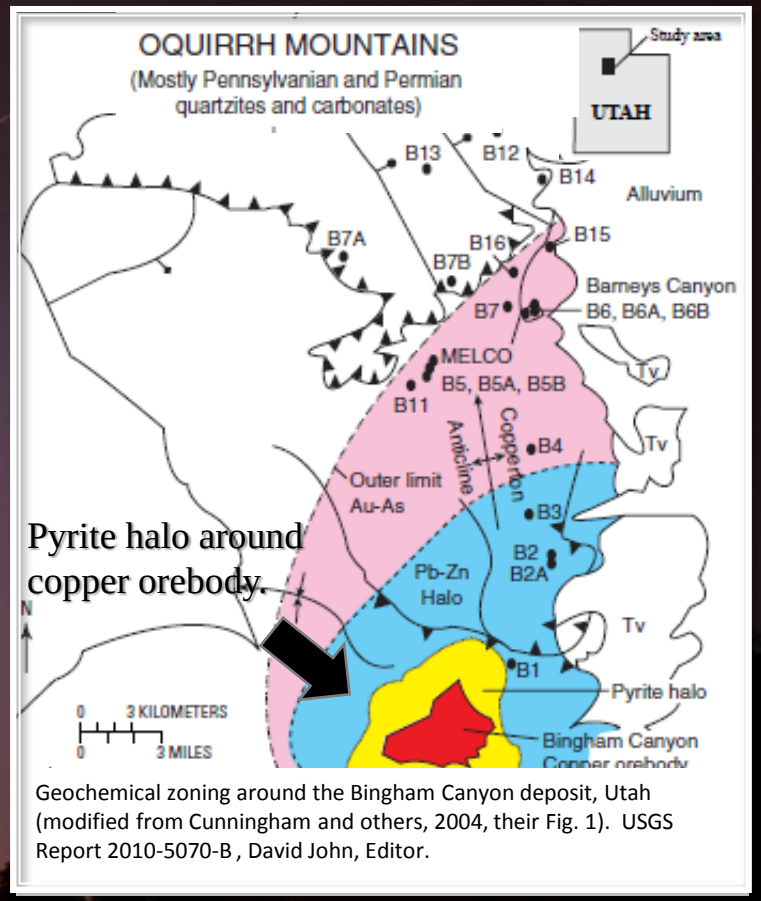
Porphyry Copper Deposit Signature

- 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)

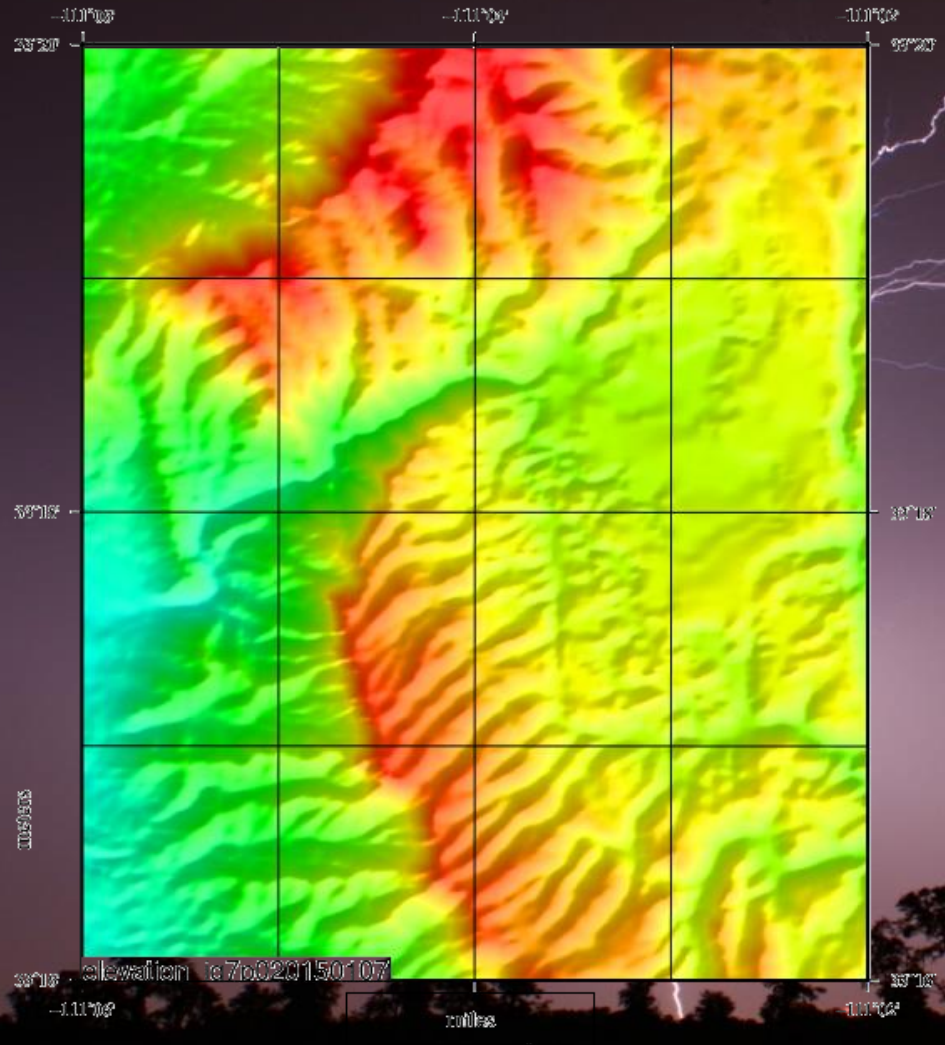


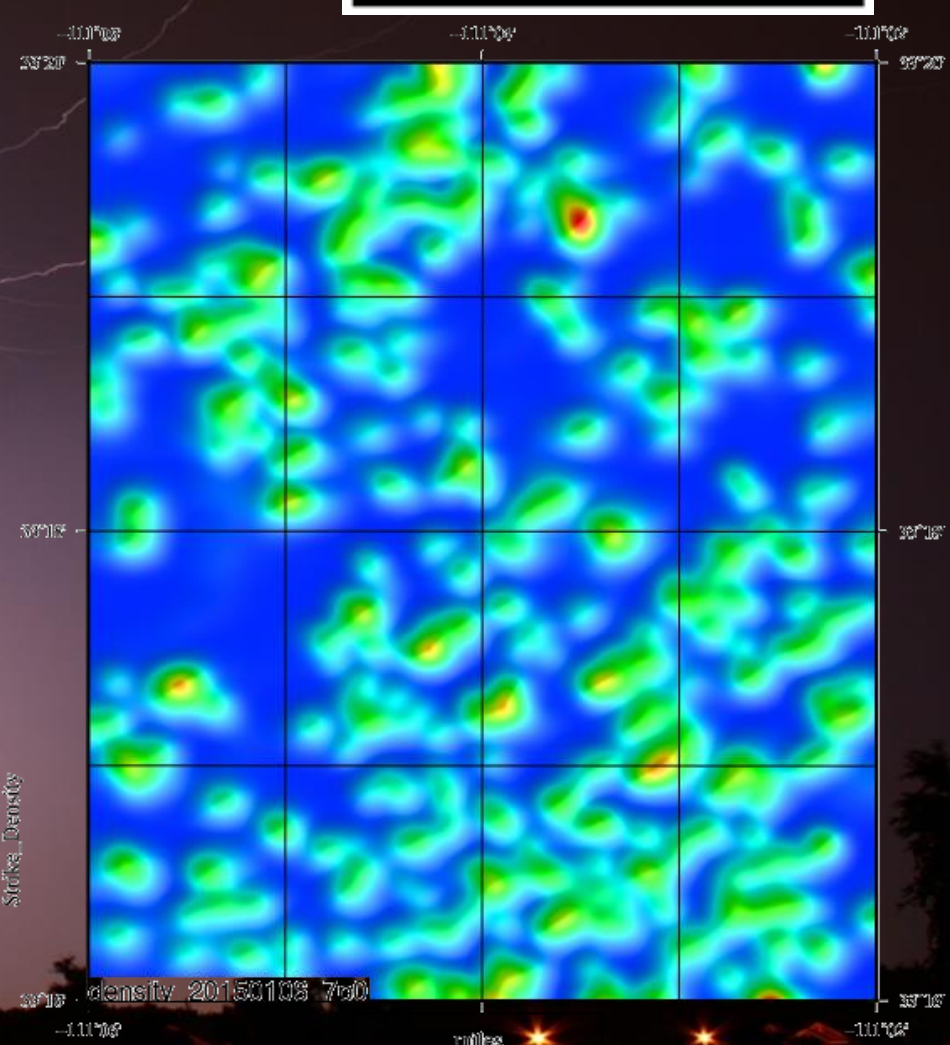


Pyrite halo around copper orebody.

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

Topography and Lightning Density
Pina Co., AZ

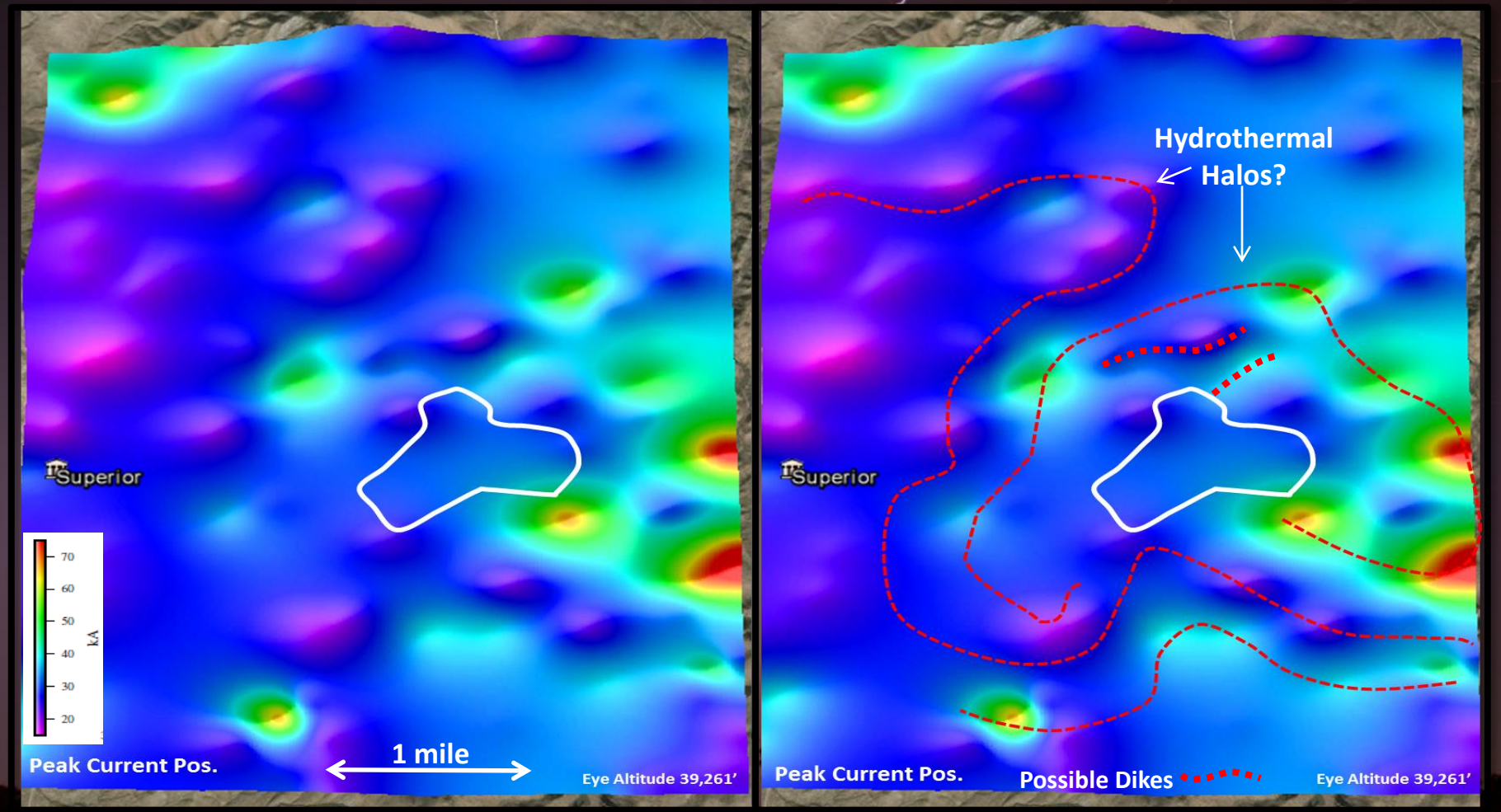




Positive Peak Current

Resolution Copper Mine

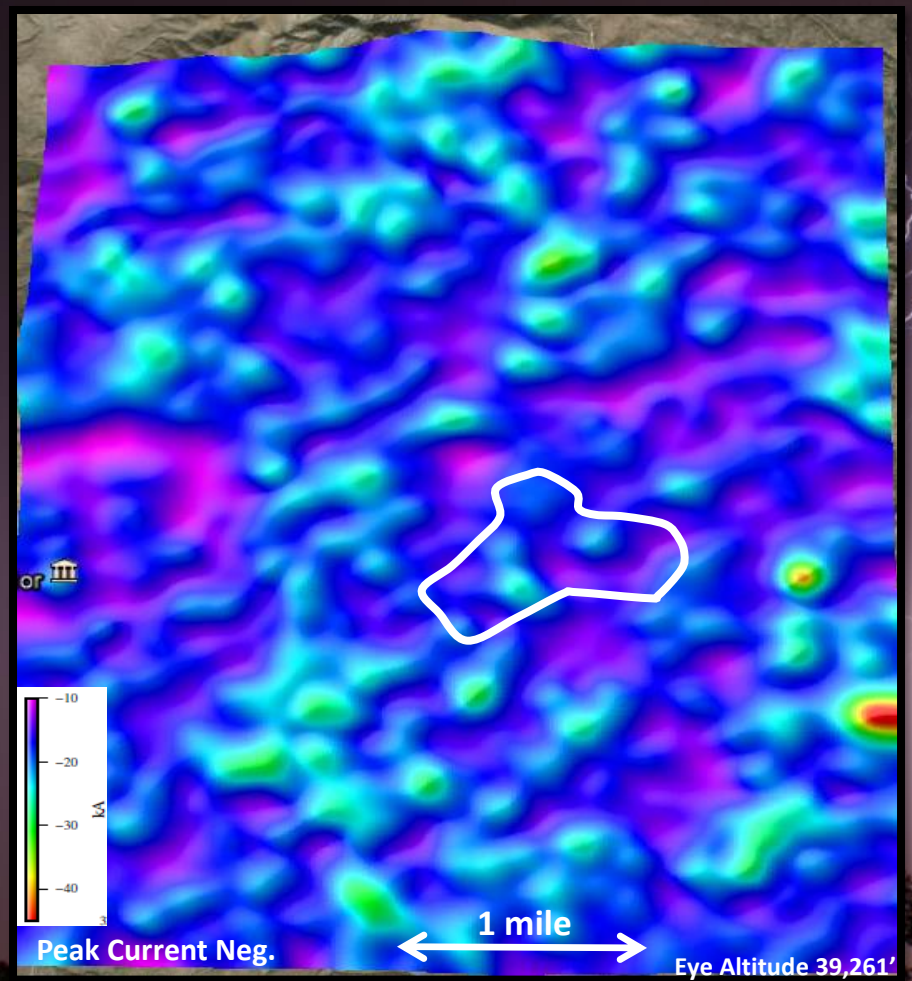
Hydrothermal Alteration & Dike Interpretation

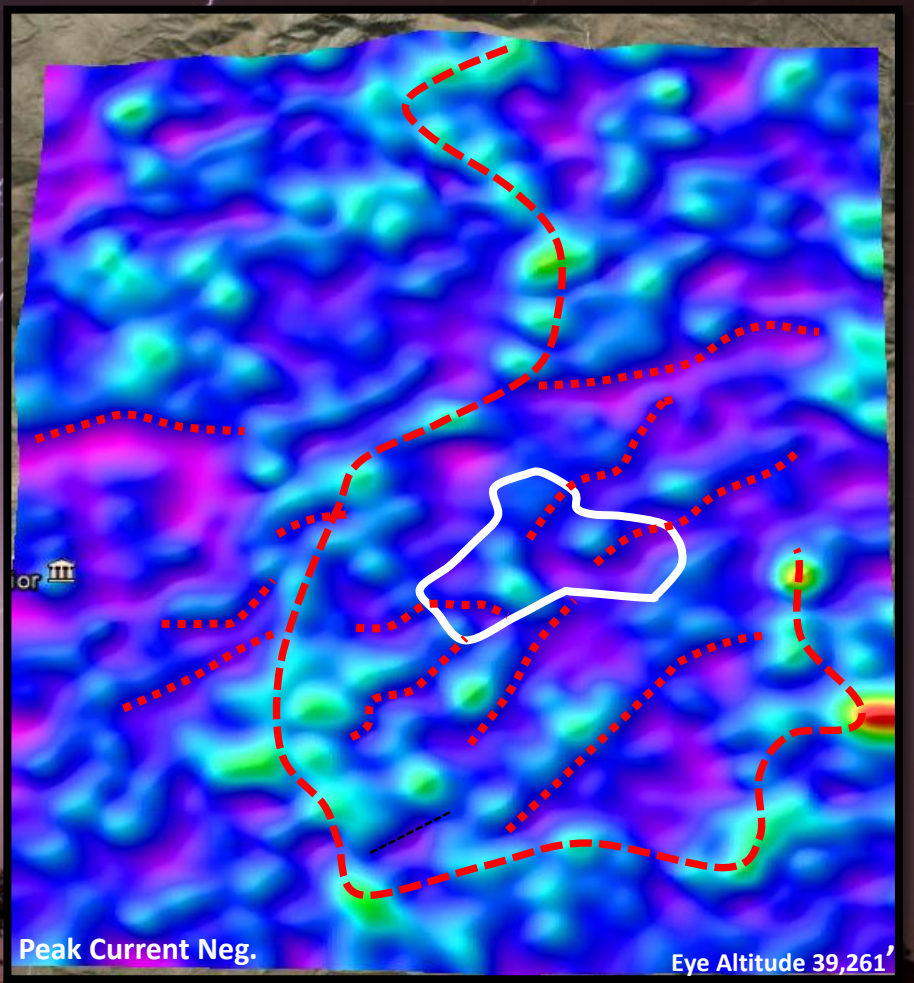


Negative Peak Current

Resolution Copper Mine

Hydrothermal Alteration & Dike Swarm Interpretation

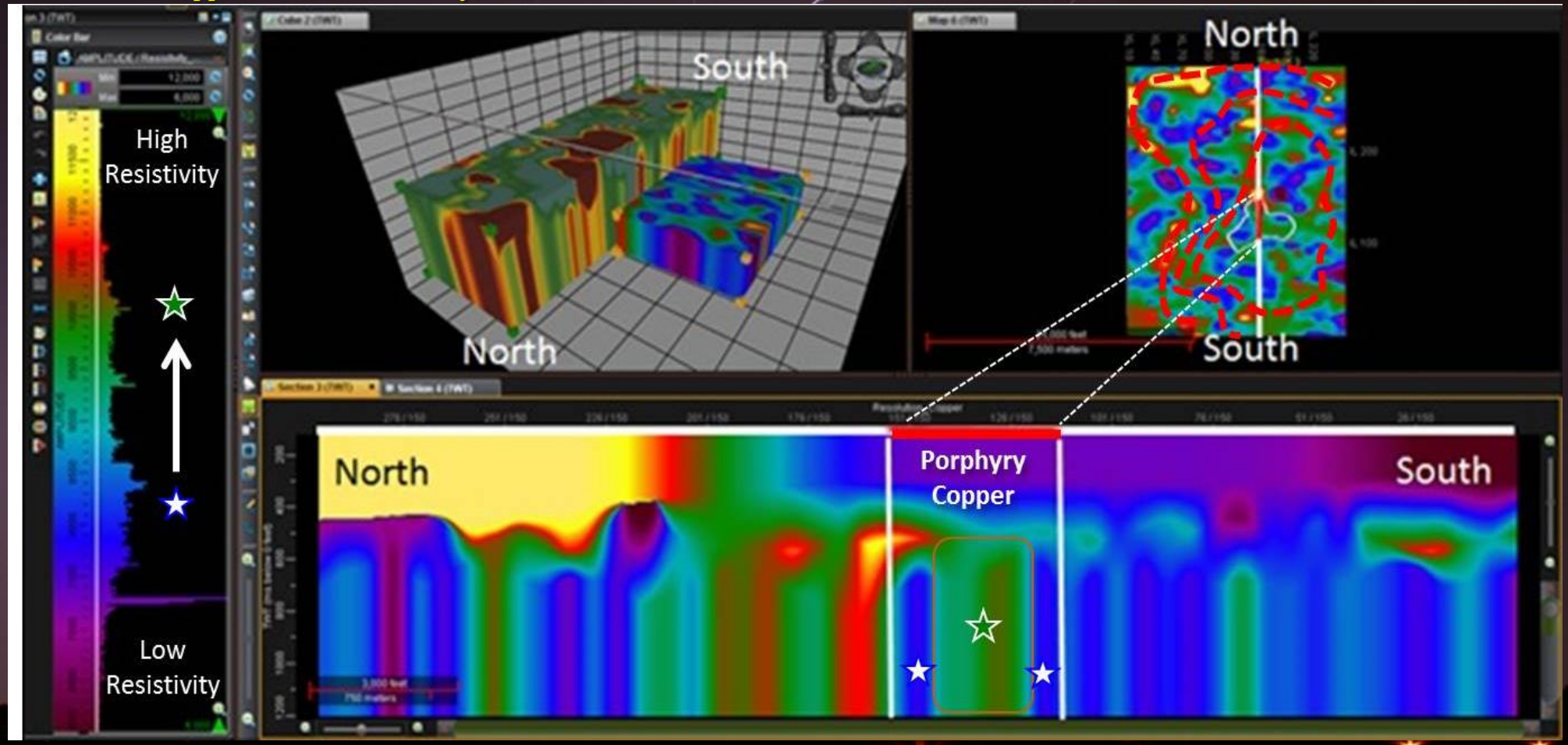




3-D Resistivity Volume

Resistivity Profile Shows Porphyry Copper Signature
Inner High Resistivity & Outer Conductive Zone

Resolution Copper Mine Pinal County, AZ



Pina Co., Arizona Conclusions

- 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.
- Resistivity profile shows same electromagnetic signature used by mining industry to map porphyry copper deposits.

Facts

- NSEM data can identify regional fault trends & may ultimately be capable of mapping prospect scale faults.
- NSEM has shown remarkable potential to identify hydrocarbon accumulations.
- NSEM's ability to identify hydrothermal alteration zones demonstrates potential to map rock properties.

NSEM Overview

- NSEM can be calibrated to, & integrated with, potential field, seismic & subsurface data.
- NSEM can fill in between or extend beyond 3-D surveys & can supplement 2-D seismic data.
- NSEM cost 1/100th the cost of 3-D seismic & can be acquired, processed and interpreted within 6-8 weeks.
- Lightning data is available world-wide & can be utilized for reconnaissance mapping for frontier, new venture & exploration.

What we have covered:

NSEM - A new geophysical data type

The meteorology behind lightning databases

Examples of using lightning data to interpret geologic features

DML's Technology is being Recognized

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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*.

• • •

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2013-2014 GCAGS President
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See updates at:

AAPG Denver
GCAGS Houston
SEG New Orleans
WTGS Midland

See Lightning, Think DML

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