An Unconventional Tool for Unconventional Exploration

Authors: Louis J. Berent[1], H. Roice Nelson[2]; 1. Berent Geophysical Consulting, 2. Dynamic Measurement, LLC

- **The power of lightning has been harnessed for mapping structure, stratigraphy & rock properties.**
- **Natural-Sourced Electromagnetics (NSEM) has been proven effective for petroleum & mineral resource exploration. It's quick, inexpensive & versatile.**
- **Applications include reconnaissance & detailed fault mapping, delineating hydrocarbon accumulations & mapping porphyry copper deposits.**

ABSTRACT

TITLE: An Unconventional Exploration Tool for Unconventional Exploration

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INSTITUTIONS: 1. Berent Geophysical Consulting, 2. Dynamic Measurement, LLC, Houston, TX, United States

The surface of the Earth in the U.S. is struck by lightning approximately 25 x 106 times each year. A typical thunderstorm in South Texas could deliver 5-10,000 cloud-to-ground lightning strikes. Each time lightning strikes in the U.S. the time, location, type of strike & the electrical properties & attributes associated with each strike is recorded & entered into a massive database. Until recently, the primary purpose of this private database was to provide insurance companies with lightning reports to verify their customer's lightning damage claims. That changed several years ago when a meteorologist, geophysicist & a frightened duck hunter who was almost struck by lightning, walked into a bar to discuss whether lightning ever struck twice in the same place.

Thus, a new geophysical data type was born, Natural Source Electromagnetics (NSEM). Lightning can & does strike repeatedly in the same place more than once & the location of these cloud-to-ground bolts of lightning are not necessarily attracted to infrastructure, trees or topography. This poster will discuss how lightning strike locations, the type of lightning strikes & the electrical attributes associated with each strike can be influenced by lateral inhomogeneity caused by faults, fractures, mineralization, pore-fluids, & salinity variations.

NSEM has been employed by the petroleum & mining industry for use as a geophysical exploration tool. To date, applications to conventional petroleum exploration have been limited to identifying & mapping subsurface faults & stratigraphic traps, while one validated case study revealed how NSEM would have delivered an 87% drilling success rate had it been utilized as a reconnaissance tool to generate leads.

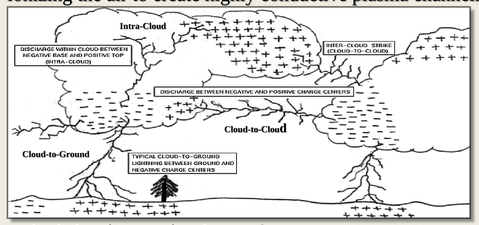
A validated case study demonstrates NSEM's ability to duplicate the patented resistivity signature used by the mining industry to locate porphyry copper deposits. NSEM attribute maps delineated hydrothermal alteration zones & in doing so, distinguished between the electrical rock properties of copper & its pyrite halo.

NSEM's resolution & ability to produce apparent resistivity maps & apparent resistivity time/depth slices, provides the unconventional exploration community with an independent dataset that can be easily tied to seismic/subsurface data. NSEM can thus help map sweet spots across unconventional fairways. An exploration model developed by the BEG will be used to demonstrate NSEM's potential contribution to mapping sweet spots in the Maverick Basin.

POSTER OUTLINE

- **Lightning, what is it and why it is tracked, stacked & mapped!**
- **Natural Source Electromagnetics (NSEM) – a new geophysical data type.**
- **Example of using NSEM to map active faults.**
- **Conclusions.**

LIGHTNING: an atmospheric discharge of electricity, ionizing the air to create highly conductive plasma channels.



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

NATURE OF LIGHTNING

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

Streamers: rising stream of positive charge attracted to downward seeking electron step leaders when step leaders are within 30' - 300'.

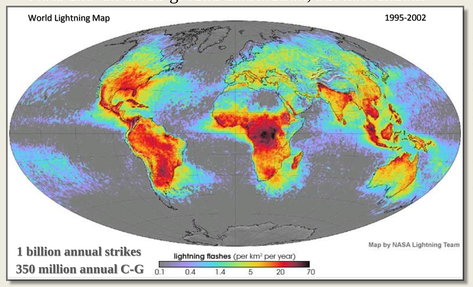
FAILED LIGHTNING STRIKES & STREAMERS

Note streamer launched from telephone pole also does not connect with a step leader to produce a strike. Illustrates competing factors influencing strike location, one of which is geology.

PRIMARY LIGHTNING INFLUENCE - GEOLOGICALLY CONTROLLED TELLURIC CURRENTS

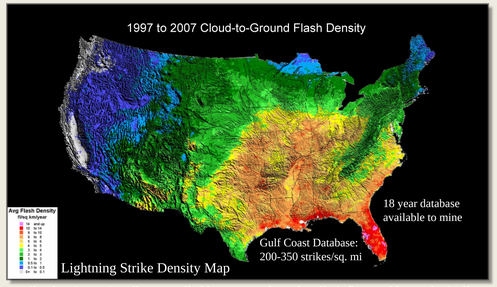
WHY IS LIGHTNING TRACKED & MAPPED?

Note uneven cloud-ground distribution, but not random.



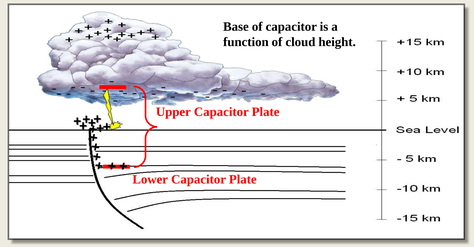
- **Storm tracking**
- **Safety warnings**
- **Insurance**
- **Forest fire forecasting**
- **Hurricane tracking**
- **Research & now…natural resource exploration!**

25 MILLION ANNUAL U.S. LIGHTNING STRIKES



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

EACH STRIKE REPRESENTS A UNIQUE CAPACITOR



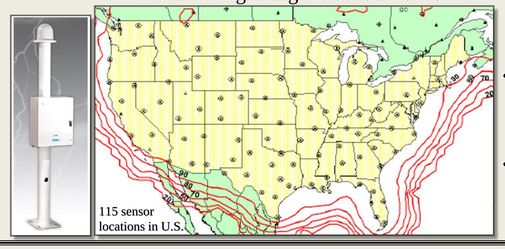
The top or base of the cloud (the originating point for positive or negative lightning strikes respectively), represents the top of the Earth capacitor. The base capacitor depth utilized to derive apparent resistivity volumes is derived from "Peak Current."

"Peak Current", one of the lightning attributes collected worldwide, is the maximum current associated with any given lightning strike.

Lightning is believed to be influenced by geology to a depth proportional to cloud height, as derived from the "Peak Current" lightning attribute.

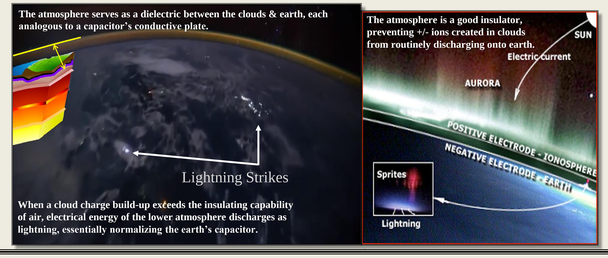
COLLECTION of LIGHTNING DATA

National Lightning Detection Network



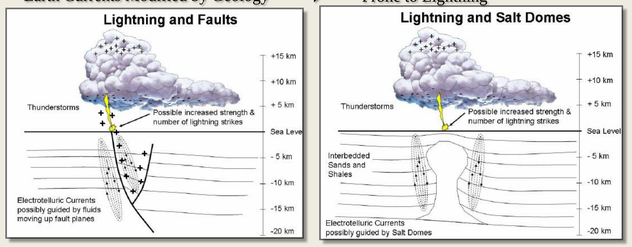
- **Typical Texas lightning strike recorded by 16 -24 sensors.**
- **Sensors within 600 mi. of strikes contribute to triangulation.**
- **Empirical results show location error from reasonably dense database 35-70'.**

EARTH: A SELF-REPAIRING CAPACITOR



TELLURIC CURRENTS: LIGHTNING & GEOLOGY

Earth Currents Modified by Geology ⇨ Prone to Lightning



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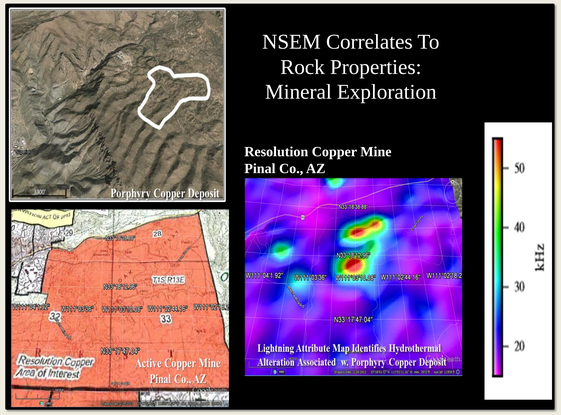
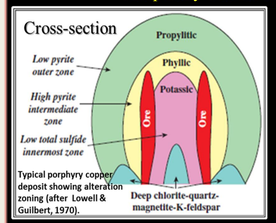


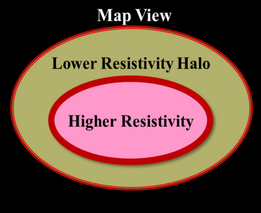
NSEM Correlates To Rock Properties: Mineral Exploration

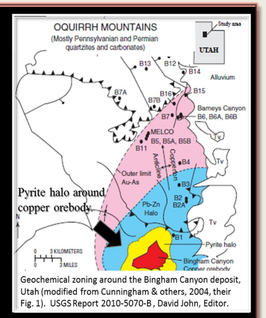
Resolution Copper Mine Pinal Co., AZ

Porphyry Copper Exploration Signature

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



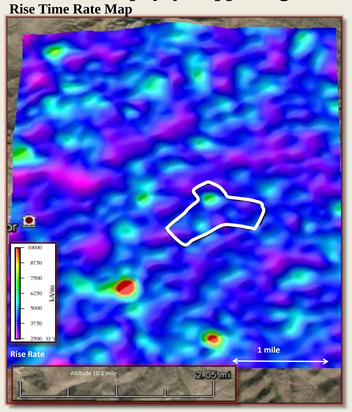




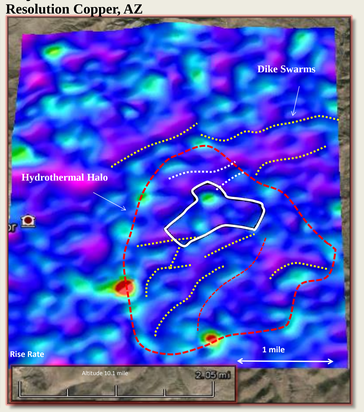
Geochemical zoning around the Bingham Canyon deposit, Utah (modified from Cunningham & others, 2004, their Fig. 1). USGS Report 2010-5070-B , David John, Editor.

Porphyry Copper Signature: Pyrite Halo & Intrusions

Rise Time Rate Map

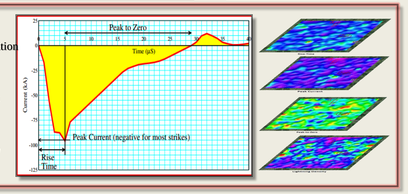


Resolution Copper, AZ



LIGHTNING MEASUREMENTS ⇨ ATTRIBUTE MAPS

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



Lightning attribute maps are generated & interpreted similar to seismic attributes. These attribute maps have been used to identify regional & sub-regional fault patterns, hydrocarbon accumulations, salt domes, near-surface point bar deposits & porphyry copper deposits. The basis for these correlations is that lightning strike locations, the type of lightning strikes & the electrical attributes associated with each strike can be influenced by lateral inhomogeneity caused by faults, fractures, mineralization, pore fluids & salinity variations.

U.S. & Canadian Patents
Porphyry Copper Electromagnetic Signature

US 20090251146A1

(19) **United States**

(12) **Patent Application Publication**
Morrison et al.

(10) **Pub. No.: US 2009/0251146 A1**

(43) **Pub. Date: Oct. 8, 2009**

(54) **DETECTION OF PORPHYRY COPPER DEPOSIT USING NATURAL ELECTROMAGNETIC FIELDS**

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(21) Appl. No.: **12/062,795**

(22) Filed: **Apr. 4, 2008**

Publication Classification

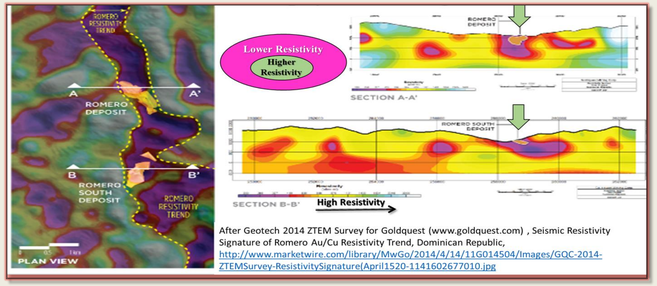
(51) **Int. Cl.**
G01V 3/76 (2006.01)

(52) **U.S. Cl.** **324/330**

(57) **ABSTRACT**

A method for identifying a possible porphyry copper deposit which includes flying an airborne sensor over a survey area measuring natural electromagnetic fields in the survey area, and then determining, in dependence on the measured natural electromagnetic fields, if one or more sub-areas in the survey area have a resistivity pattern that corresponds to a predetermined resistivity signature for a porphyry copper deposit. The predetermined resistivity signature includes a higher resistivity inner region at least partially surrounded by a lower resistivity outer region

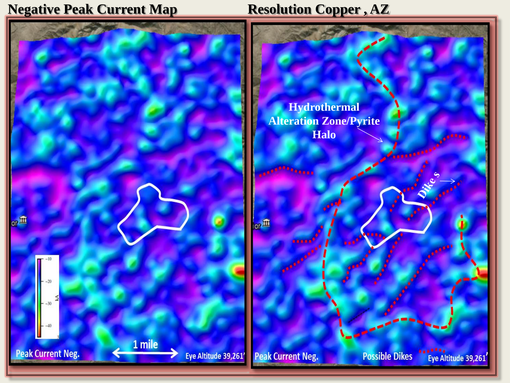
Resistivity Profile Signature, Dominican Republic Analog



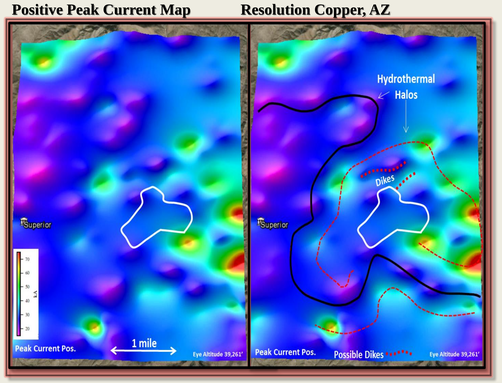
After Geotech 2014 ZTEM Survey for Goldquest (www.goldquest.com) , Seismic Resistivity Signature of Romero Au/Cu Resistivity Trend, Dominican Republic, http://www.marketwire.com/library/MwGo/2014/4/14/11G014504/Images/GQC-2014-ZTEMSurvey-ResistivitySignature(April1520-1141602677010.jpg

Exploration Signature Replicated With Two Additional Lightning Attributes

Negative Peak Current Map **Resolution Copper , AZ**

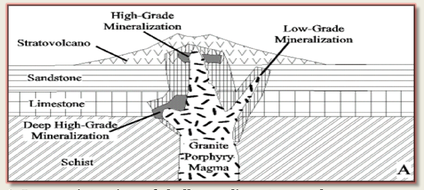


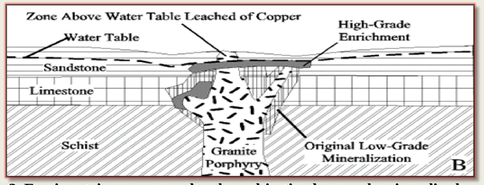
Positive Peak Current Map **Resolution Copper, AZ**



Note positive and negative lightning peak current contour-like anomalies partially enclosing copper orebody at Resolution Copper Mine. Patterns consistent with hydrothermal alteration zones associated with pyrite halos. Linear features correspond to igneous intrusions, typically associated with porphyry copper deposits.

Formation of Porphyry Copper Deposits





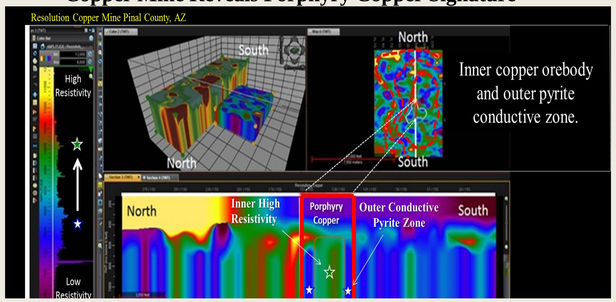
1. Igneous intrusion of shallow sedimentary rocks.

2. Magma and associated hot mineral-rich fluids come in contact with host rocks and generate chemical/mineral changes creating low-grade copper mineralization.

3. Erosion strips away overburden subjecting low-grade mineralized areas to weathering.

4. Rainwater leaches Copper and redeposits it below at the water table, creating concentrations of high-grade Cu deposits.

3-D Apparent Resistivity Profile Through Resolution Copper Mine Reveals Porphyry Copper Signature



Application to Mineral Exploration

- **NSEM has the potential to explore for any mineral commonly found by conventional electrical geophysical prospecting techniques.**
- **NSEM can map subsurface electrical rock properties, structure & stratigraphy, also applicable to unconventional resource exploration.**

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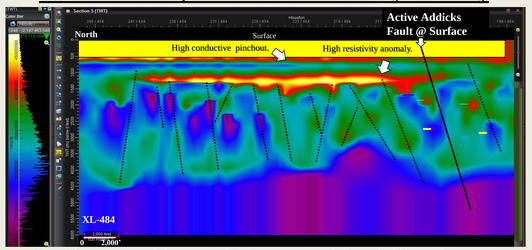
Seismic Stratigraphy and Prospect Generation - North Houston

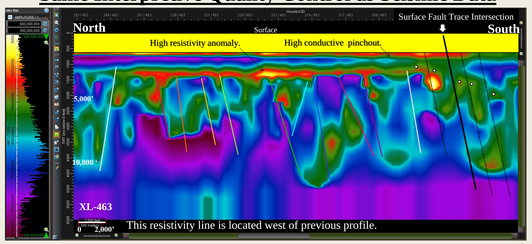
- Mapping subsurface faults.
- Calibrating to known active fault systems.
- Mapping resistivity anomalies
- Prospect generation!

NSEM Reveals Structure & Stratigraphy
Potential Faults, Pinchouts & Resistivity Anomaly

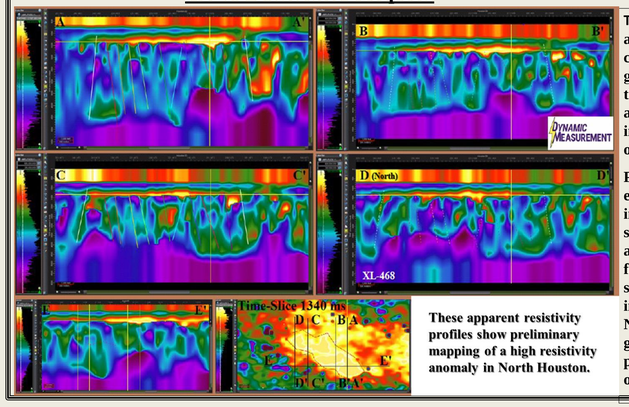


- Crossline extracted from north Houston area 3-D resistivity volume.
- Solid black fault ties documented active fault in north Houston.
- Demonstrates ability to map structural & stratigraphic traps, electrical rock properties, lateral variations in fluid content & hydrocarbon accumulations.

Triangulated Fault Segments & Fault Plane Maps:
Same Interpretive Quality Control as Seismic Data



NSEM Generates Prospects



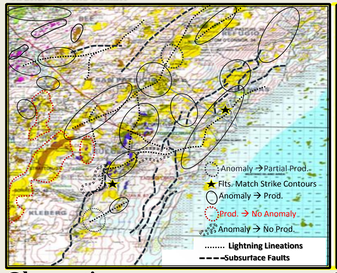
This shallow high apparent resistivity anomaly-based prospect, likely containing gas, was discreetly generated in a large city w/o "boots on the ground," surface or mineral owner authorization or delays related to infrastructure, government regulation or permit fees.

Preliminary analyses of the NSEM electrical rock property volume indicates the presence of a stratigraphic trap based on the apparent high resistivity pinchout in four directions. Additional geologic support for this prospect and the inherent support for the validity of NSEM as an unconventional geophysical exploration tool, is provided by consistent fault patterns observed on all cross-lines.

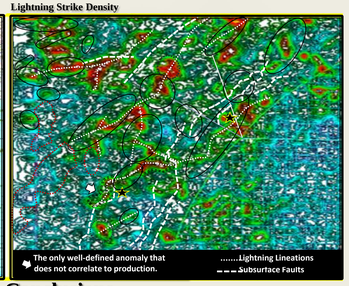
These apparent resistivity profiles show preliminary mapping of a high resistivity anomaly in North Houston.

NSEM Correlates To Geology:
Fault Patterns and Hydrocarbon Accumulations

Structure & Field Outlines



Lightning Strike Density



Observations

- Lightning strike locations are not random.
- Show NE/SW lineations similar to field locations.
- Faults generally strike parallel to sub-parallel to lightning features; 2 curved faults (★) coincide with strike density contours.

Conclusions

- Local geology can influence where lightning strikes occur.
- These and other findings show NSEM has the capability to identify hydrocarbons, likely related to micro-seepage along faults and localized modifications of telluric currents. resulting local perturbation of telluric currents .
- NSEM has potential to delineate subsurface fault patterns.

The Same Rock Properties Influencing NSEM
May Help Define Unconventional Sweetspots

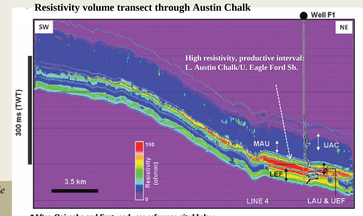
*BEG publication defines Lower Austin Chalk & Eagle Ford Shale exploration sweetspot model in Maverick Basin.

BEG's South Texas sweetspot model:

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

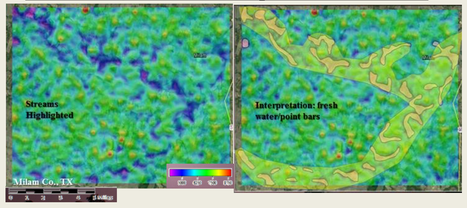
*"Seismic multiattribute analysis for shale gas/oil within Austin Chalk & Eagle Ford Shale in a submarine volcanic terrain, Maverick Basin, South Texas," Osareni C. Ogiesoba & Ray Eastwood BEG, Interpretation, Nov. 2013.

Resistivity volume transect through Austin Chalk

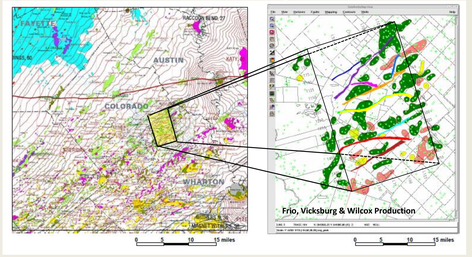


*After Ogiesoba and Eastwood, see reference cited below.

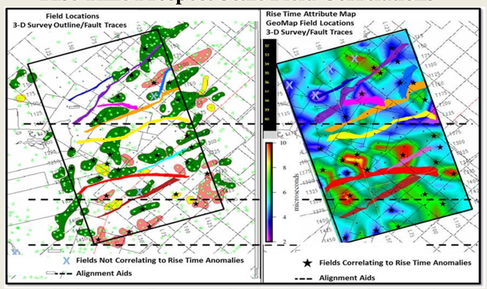
NSEM Correlates To Geology:
Milam Co., TX Fluvial Depositional Patterns



NSEM Correlates To Geology:
Colorado County, TX



Effective Reconnaissance Mapping
Rise Time Prospect Scale Field Correlations



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

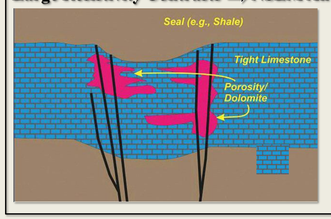
Observations

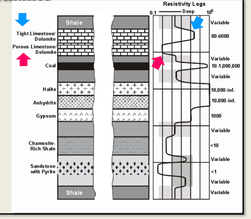
- Rise-Time lightning attribute shows non-random patterns.
- 26 of 28 fields (93%) correlate to Rise-Time anomalies.

Conclusions

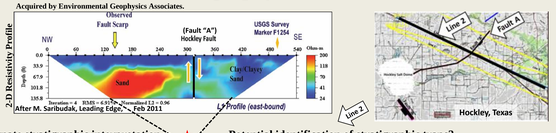
- NSEM identified 32 leads in study area.
- Reconnaissance mapping would have justified seismic data follow-up resulting in the generation of 28 prospects.
- ☆ NSEM reconnaissance mapping would have resulted in an 87% drilling success rate.

Hydrothermal Dolomites
Large Resistivity Contrasts ➡ NSEM Anomalies



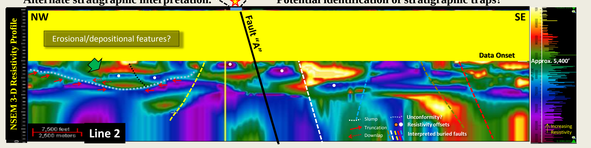


Sequence Stratigraphy

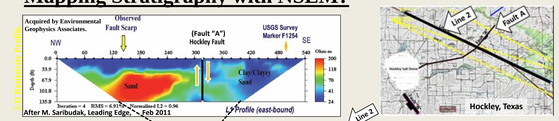


Alternate stratigraphic interpretation.

Potential identification of stratigraphic traps?

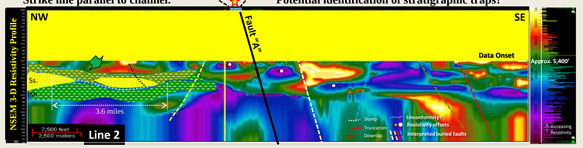


Mapping Stratigraphy with NSEM?



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.

Unconventional Exploration Conclusions

- NSEM can provide apparent resistivity maps of unconventional reservoirs in depth & 2-way time for calibration to logs & seismic data.
- NSEM apparent resistivity inlines, crosslines & arbitrary lines can tie well data & be displayed, interpreted & integrated with well logs & seismic data.
- NSEM can be used as a reconnaissance mapping tool to high-grade resistivity sweet spots for subsequent in-depth evaluation.
- NSEM can be employed in other basins in search for Austin Chalk & Eagle Ford Shale sweet spots.
- NSEM can be similarly utilized in search for sweet spots in any unconventional trend relying on resistivity as a key predictive tool.

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