Harnessing Lightning in the Hunt for Hydrocarbons

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: Harnessing Lightning in the Hunt for Hydrocarbons.

AUTHORS: Louis J. Berent[1], H. Roice Nelson[2]

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

Lightning occurs everywhere & its energy is now being used by the petroleum & mining industries to find natural resources. This naturally-sourced electromagnetic energy, comprised of billions of worldwide cloud to earth electrical discharges, produces millions of usable attribute data that can be tracked, stacked & mapped for use as a geophysical exploration tool.

Natural Sourced Electromagnetics (NSEM) is a patented emerging technology that offers the petroleum & mineral exploration industries a green & relatively quick, scalable & inexpensive mapping tool. Although lightning is guided by meteorological conditions, the precise location of strikes & their individual attributes appear to be influenced by lateral inhomogeneity caused by faults, fractures, mineralization, pore-fluids & salinity variations. Empirical results suggest faults may facilitate the upward flow of positive & negative currents that can in turn influence lightning, in much the same way that faults are believed to facilitate micro-seepage of hydrocarbons to the surface.

Examination of worldwide lightning data shows lightning strikes are not uniformly distributed. An analysis of 16 years of recorded North American lightning data also reveals non-random strike patterns. After the raw lightning data is stacked & mapped much like multi-fold seismic data, lightning strike density & geologically diagnostic lightning attribute maps show interesting & at times remarkable correlations to surface & subsurface geology.

3-D apparent resistivity volumes can be generated from lightning data & displayed in the same fashion as 3-D seismic data, with all wells, curves & synthetic seismograms posted & correlated in the usual manner. Lines, traces, arbitrary lines & apparent resistivity slices can then be extracted, calibrated, interpreted & integrated with available seismic & subsurface data to expand interpreted areas beyond the bounds of existing conventional data.

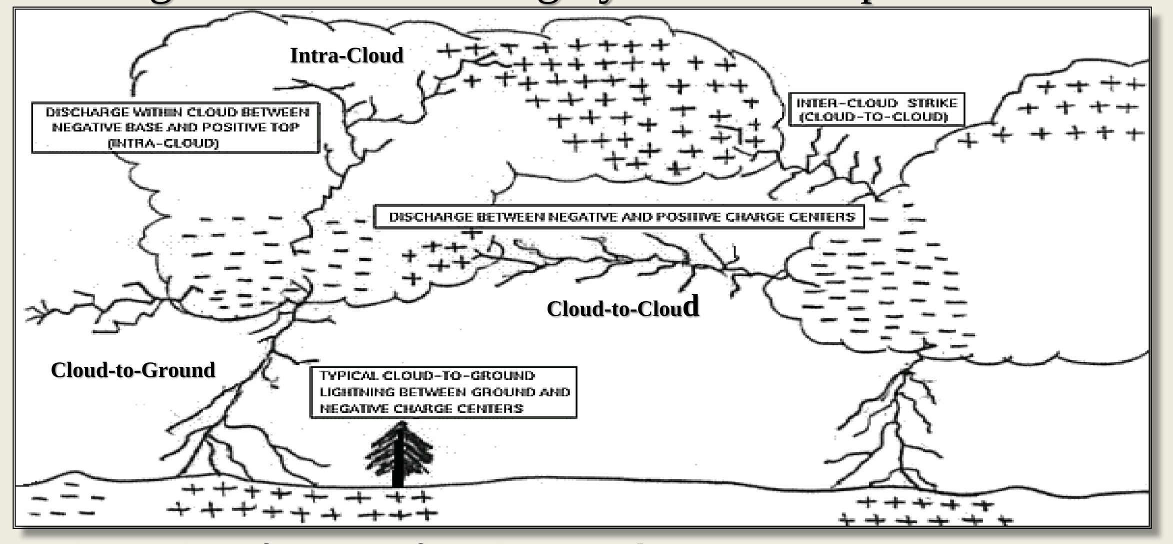
The case studies presented will reveal how lineations, lightning-sourced data clusters & offsets appear to correlate to geologic features, electrical rock properties & hydrocarbon accumulations. One such example will demonstrate how several well-documented active surface faults in the vicinity of two salt domes could be identified in the subsurface.

In addition to mapping faults, NSEM maps electrical rock properties which can be used to distinguish lithology, & if calibrated to well logs, identify favorable hydrocarbon-bearing intervals.

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.

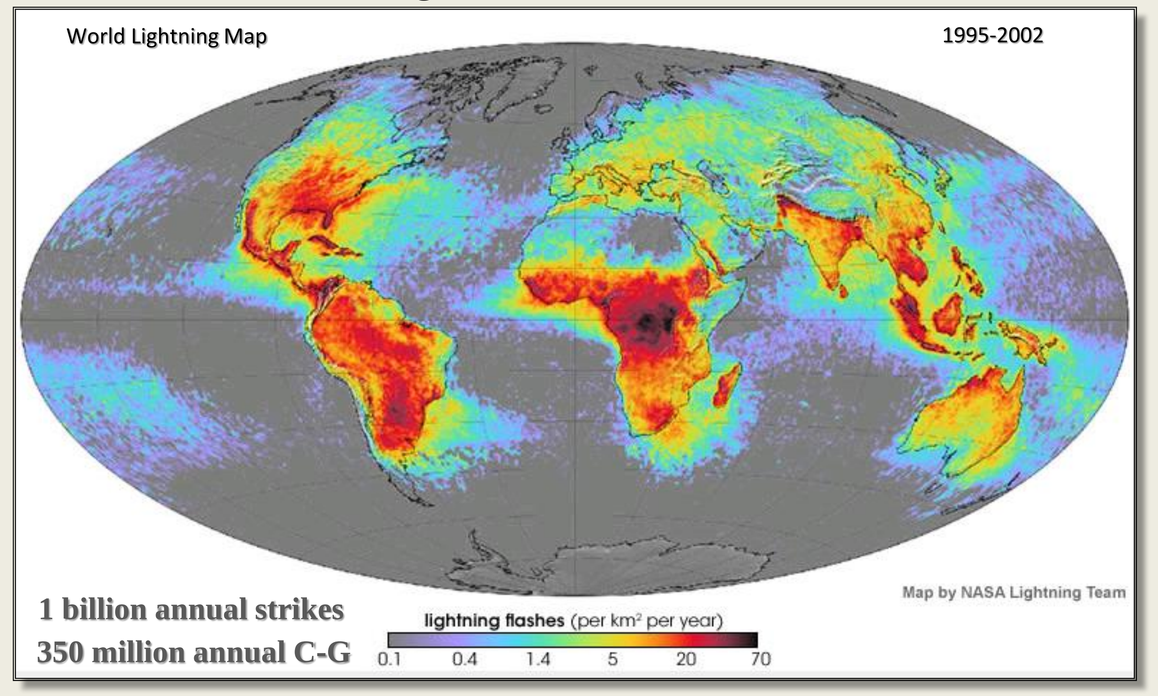
NATURE OF LIGHTNING

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'.

WHY IS LIGHTNING TRACKED & MAPPED?

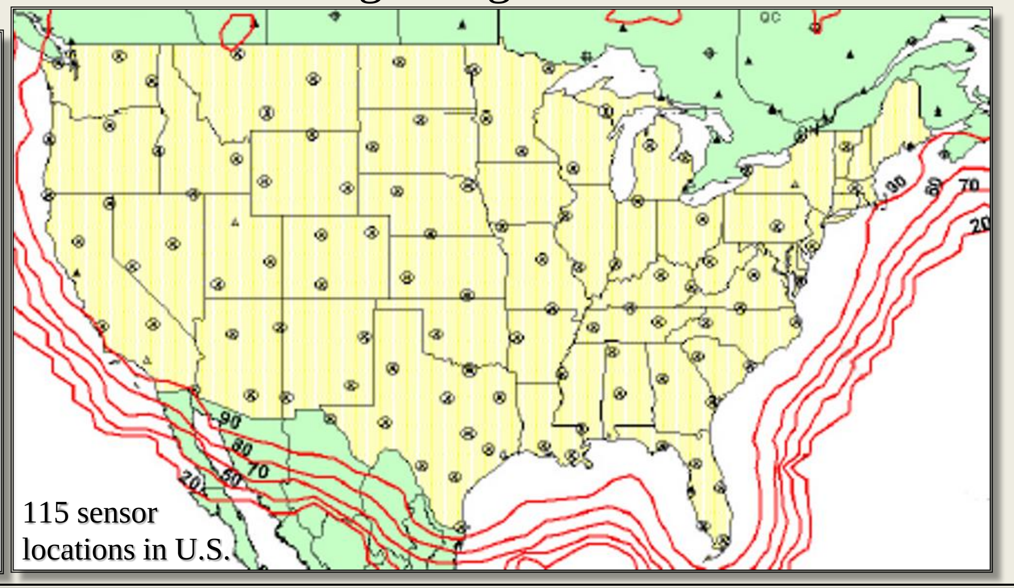
Note uneven cloud-ground distribution, but not random.



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

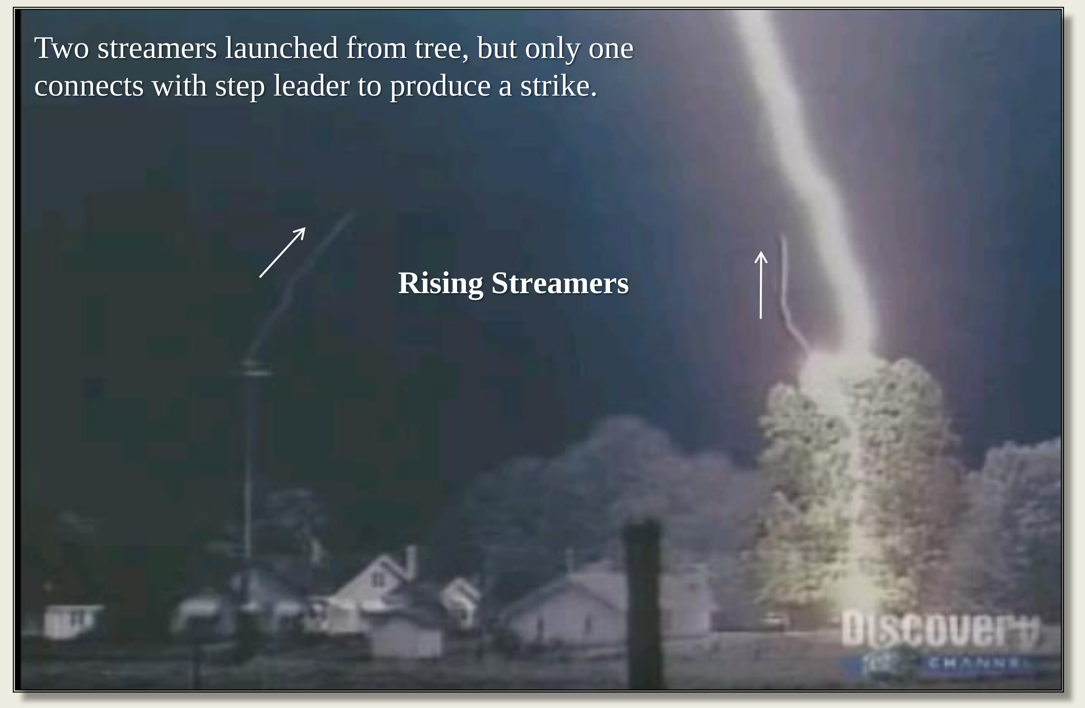
COLLECTION of LIGHTNING DATA

National Lightning Detection Network



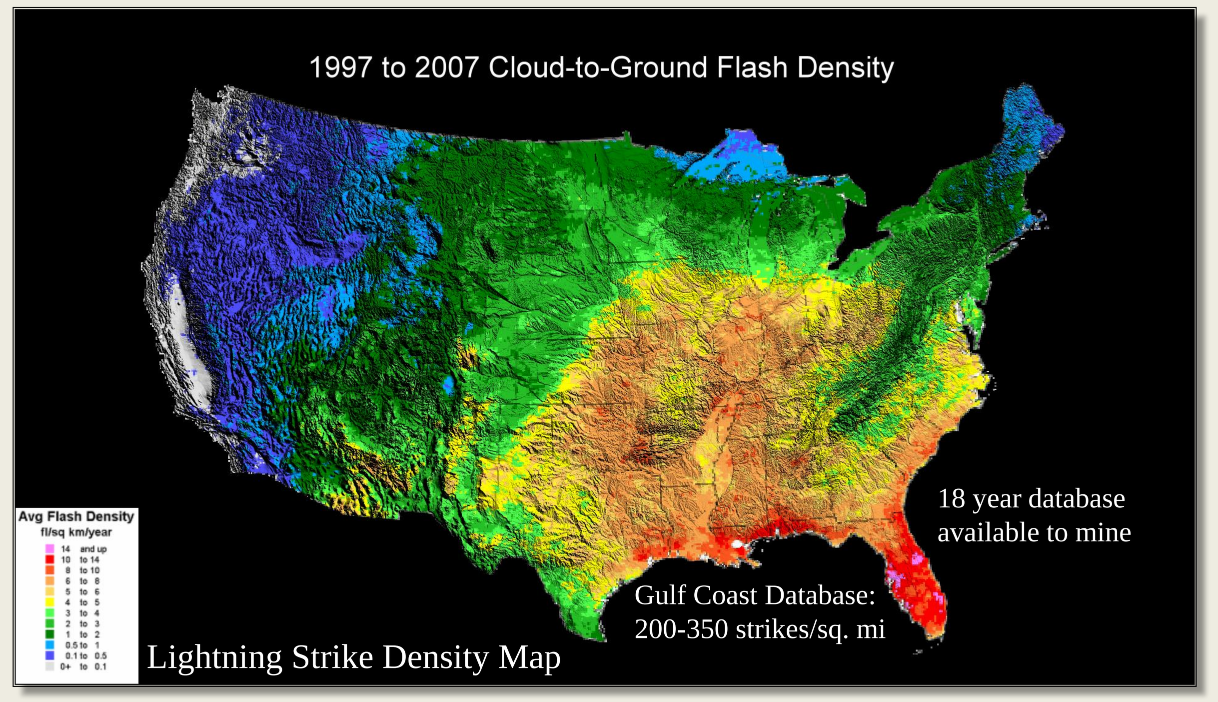
- **Typical Texas lightning strike recorded by 16 -24 sensors.**
- **Sensors within 600 mi. of strikes contribute to triangulation.**
- **Empirical results show location error from reasonably dense database 35-70'.**

FAILED LIGHTNING STRIKES & STREAMERS



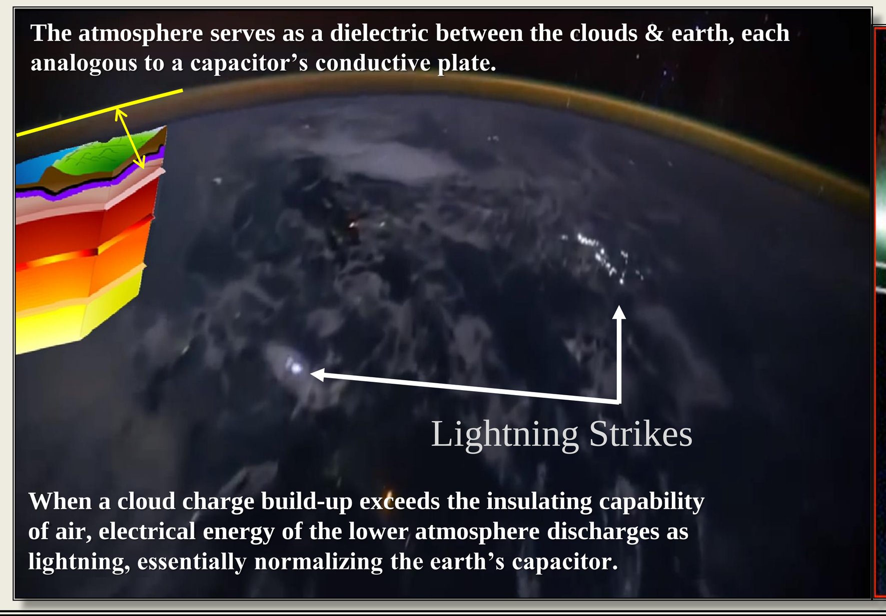
Note streamer launched from telephone pole also does not connect with a step leader to produce a strike. Illustrates competing factors influencing strike location, one of which is geology.

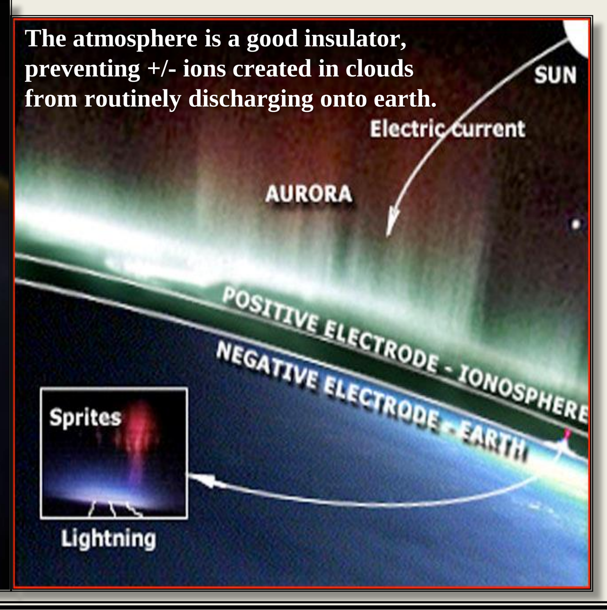
25 MILLION ANNUAL U.S. LIGHTNING STRIKES



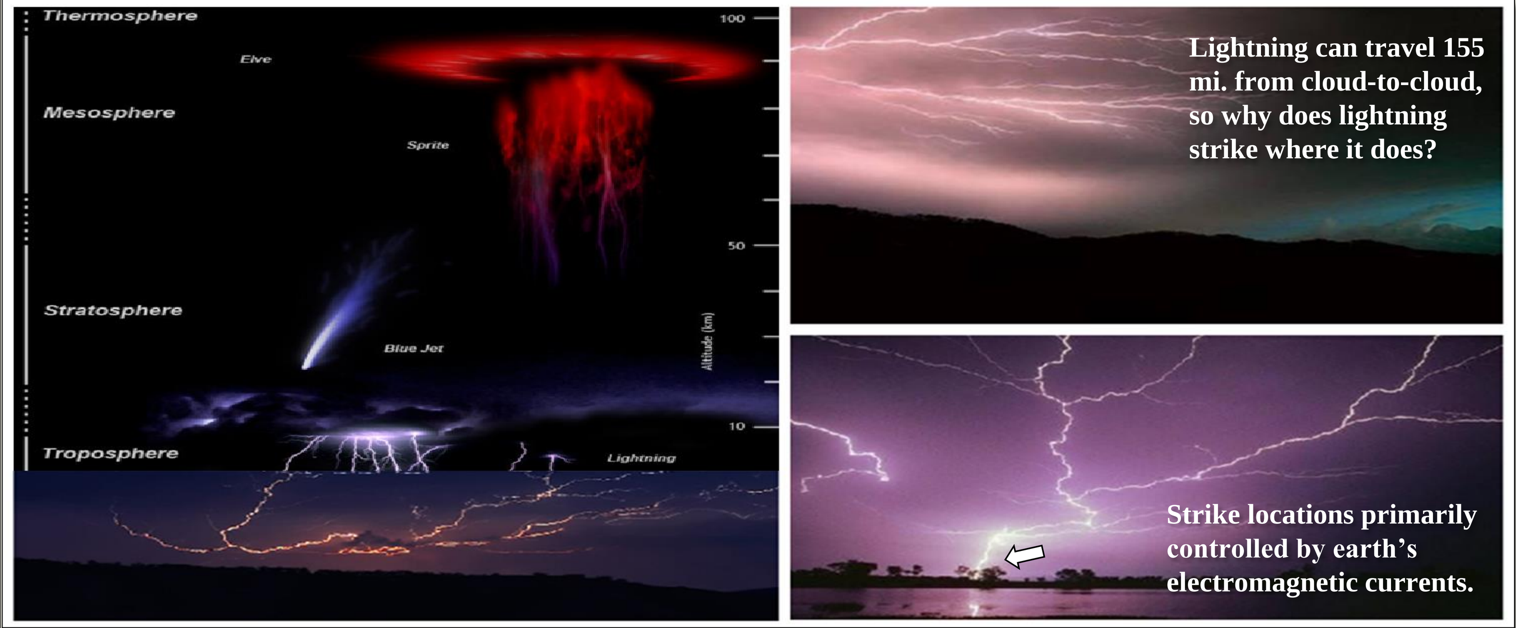
Strike density regionally controlled by meteorology, locally influenced by geologically-sourced perturbations of the Earth's telluric currents ("Terralevis" currents).

EARTH: A SELF-REPAIRING CAPACITOR

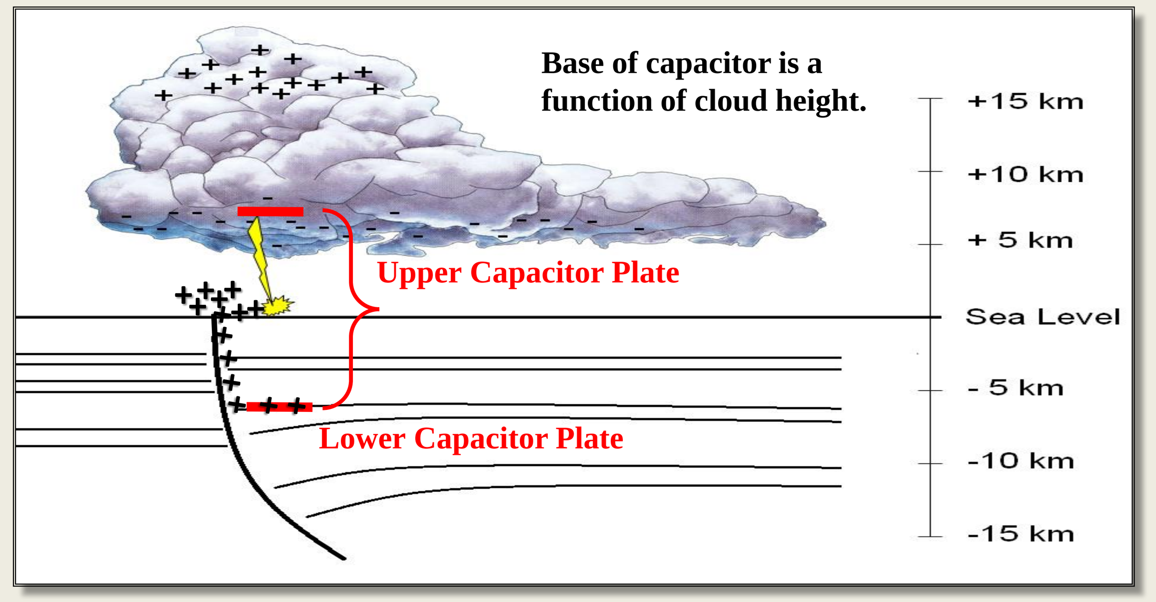




PRIMARY LIGHTNING INFLUENCE - GEOLOGICALLY CONTROLLED TELLURIC CURRENTS



EACH STRIKE REPRESENTS A UNIQUE CAPACITOR



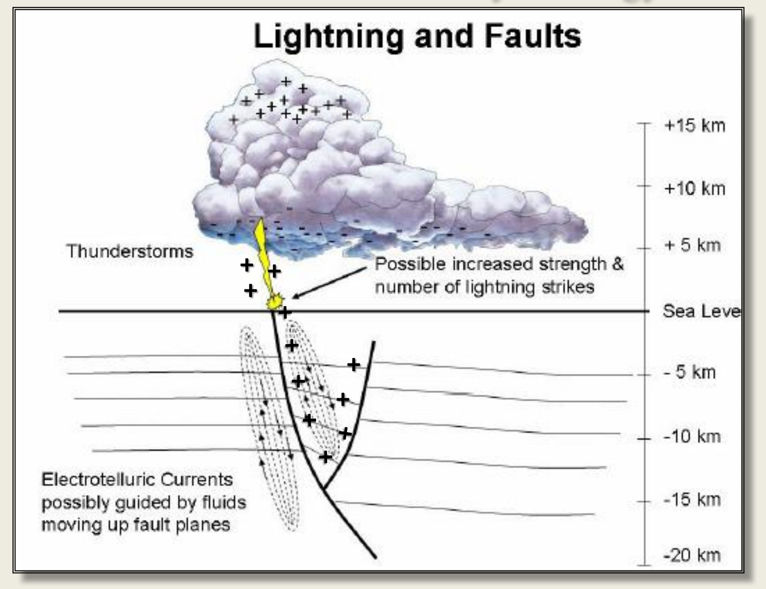
"Peak Current", one of the lightning attributes collected worldwide, is the maximum current associated with any given lightning strike.

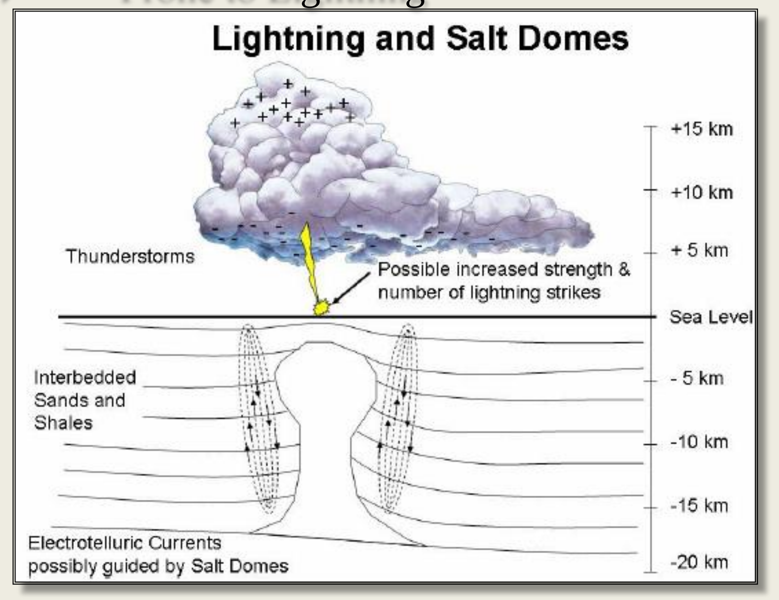
Lightning is believed to be influenced by geology to a depth proportional to cloud height, as derived from the "Peak Current" lightning attribute.

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."

TELLURIC CURRENTS: LIGHTNING & GEOLOGY

Earth Currents Modified by Geology → Prone to Lightning



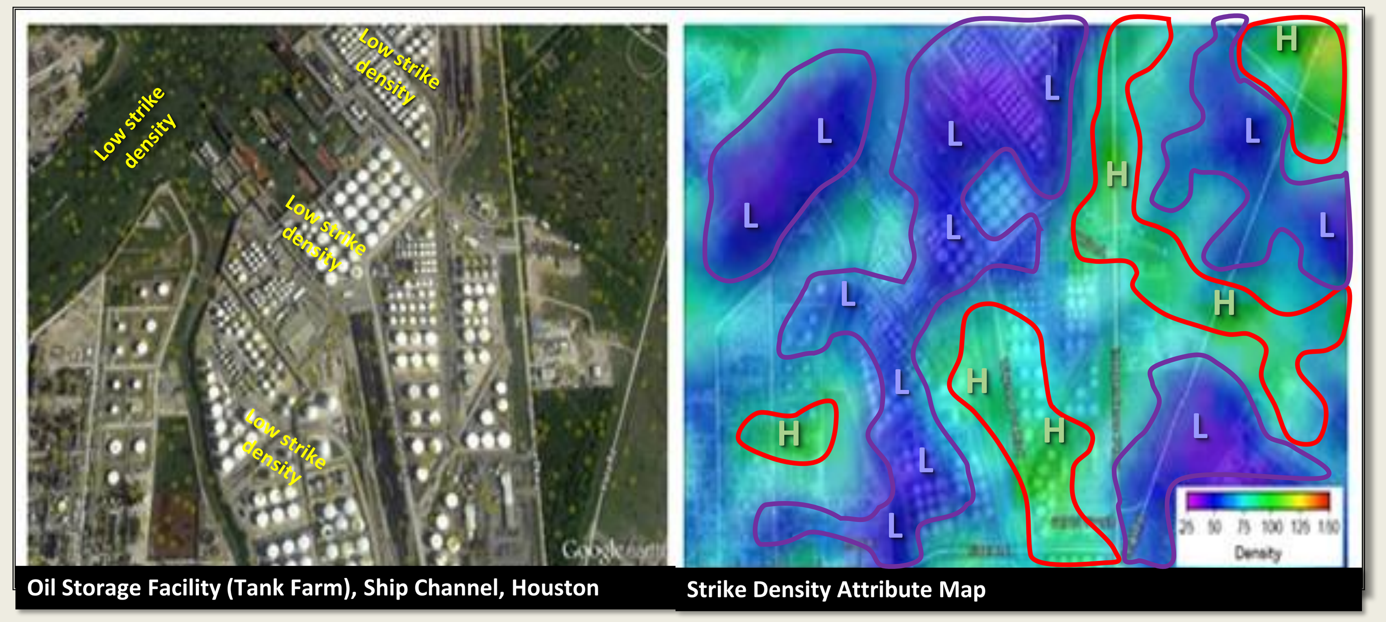


Louis Berent, Berent Geophysical Consulting, Houston, TX
ljberent@dynamicmeasurement.com, 281 370-5296

Harnessing Lightning in the Hunt for Hydrocarbons

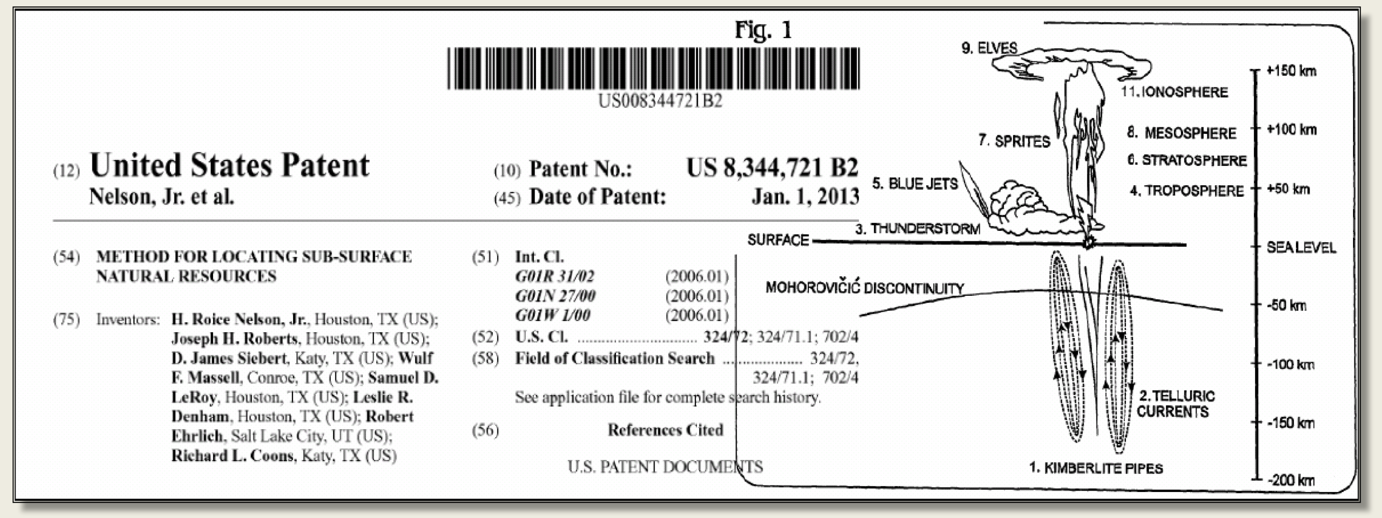
DOES INFRASTRUCTURE CONTROL LIGHTNING?

APPROXIMATELY 60% of TANK FARM EXPERIENCED LOW STRIKE DENSITY



LIGHTNING BYPASSES TALL OBJECTS AND INFRASTRUCTURE EXPECTED TO ATTRACT LIGHTNING

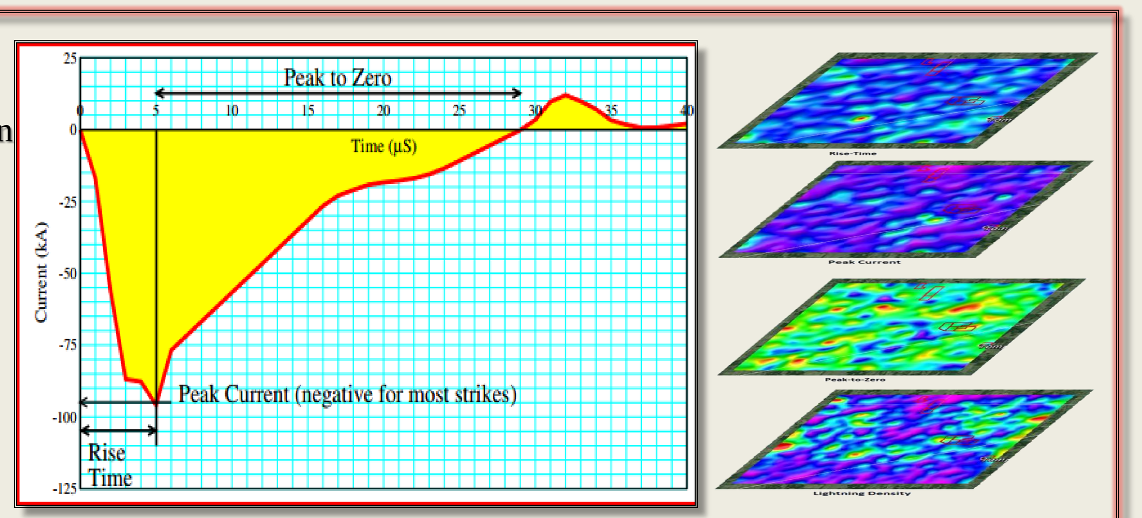
NATURAL SOURCE ELECTROMAGNETICS (NSEM) - A NEW GEOPHYSICAL DATA TYPE



PROVEN & PATENTED TECHNOLOGY FOR LOCATING SUBSURFACE NATURAL RESOURCES

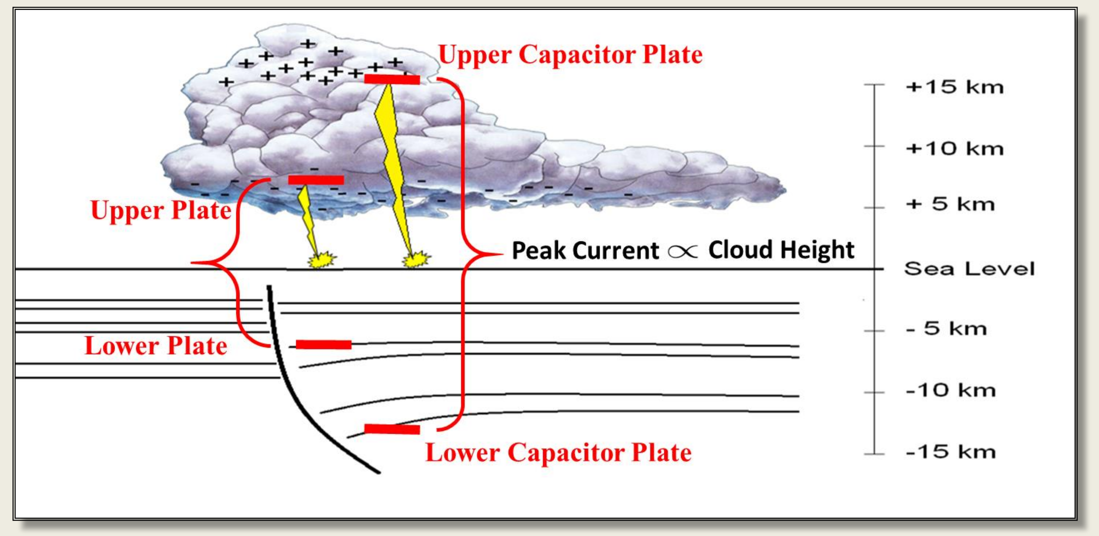
LIGHTNING STRIKE MEASUREMENTS ⇨ ATTRIBUTE MAPS

- 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.

THE BASIS FOR CALCULATING 3-D APPARENT RESISTIVITY AND ATTRIBUTE VOLUMES



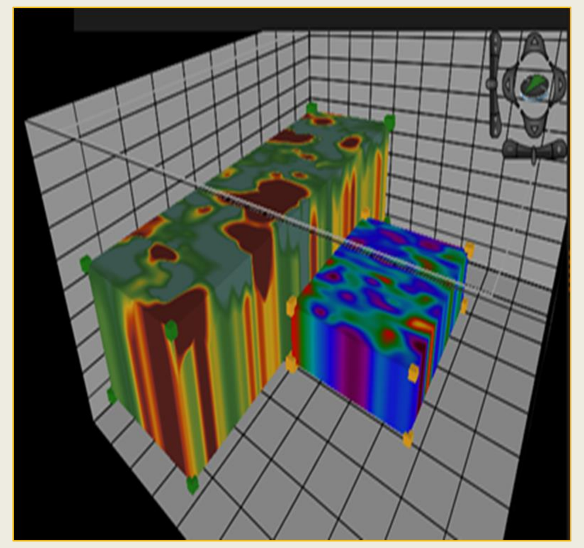
Millions of lightning strikes grouped by peak current.

Strike data therefore grouped by depth.

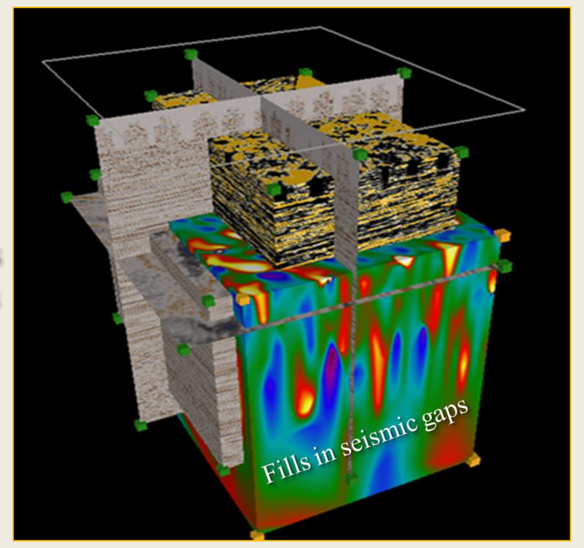
Provides basis for generating 3-D apparent resistivity volumes.

Based on the Earth's capacitor model, this illustration depicts how subsurface variation in electrical rock properties can interact with & perturb telluric currents. The depths of electrical interaction & hence its affect on lightning is proportional to the strength of each lightning strike. Peak current is measured & from this attribute cloud height (the top of the capacitor) is calculated. The data is "stacked", sorted by peak current (depth), interpolated & used to generate 3-D attribute volumes.

3-D DATA VOLUMES DERIVED FROM LIGHTNING

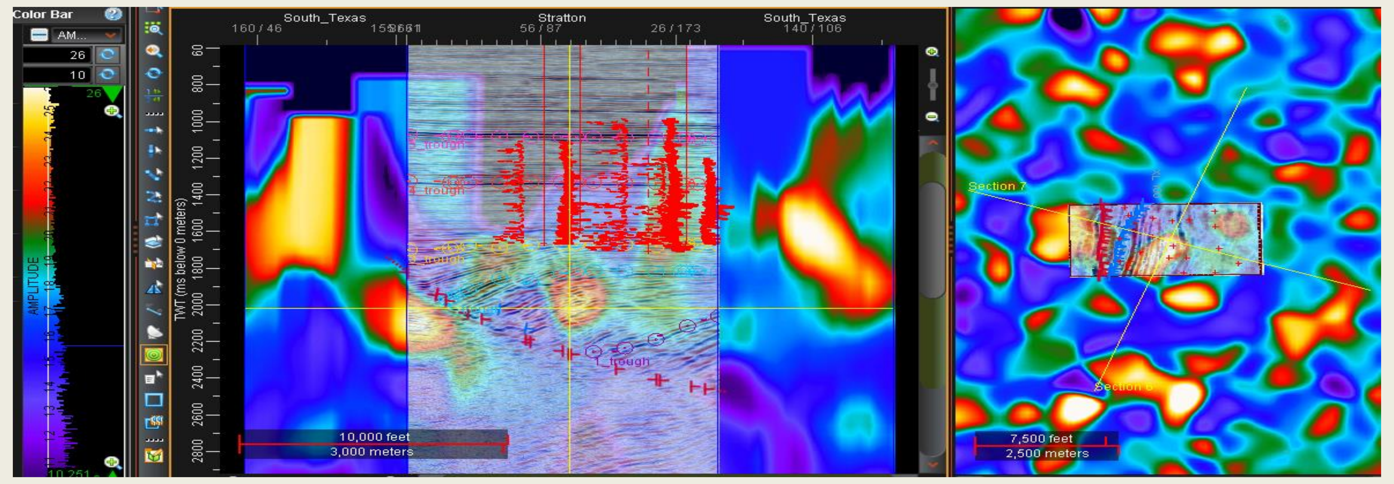


Inlines
Crosslines
Arb Lines
Slices



Resistivity, permittivity and all measured and calculated lightning attributes can be used to generate 3-D data volumes, all of which are easily integrated with 3-D Seismic & well data.

SEISMIC, SUBSURFACE, NSEM DATA INTEGRATION



Seismic overlay on apparent resistivity profile with seismic and resistivity time slices to right. interpreters can display well logs, synthetic seismograms, seismic & resistivity profiles along any line, trace or arbitrary line direction for data integration and interpretation.

ROCK STRESS ELECTROMAGNETIC SIGNAL THEORY

The next series of images represent the culmination of theoretical, field & laboratory work of Dr. Friedemann Freund, who has formulated and written extensively about his Rock Stress Electromagnetic Signal Theory.

Dr. Freund's findings provide independent support for Dynamic Measurement's empirical field results and theoretical argument linking geology to lightning strike patterns and lightning attributes.

Dr. Freund is affiliated with the NASA Ames Research Center, the Carl Sagan Center and the SETI Institute, located in Mountain View, CA and the Department of Physics at San Jose State University, San Jose, CA.

Dr. Freund's theory will now be applied to the field of Natural Source Electromagnetics.

STRESS-INDUCED CURRENTS IN THE LABORATORY

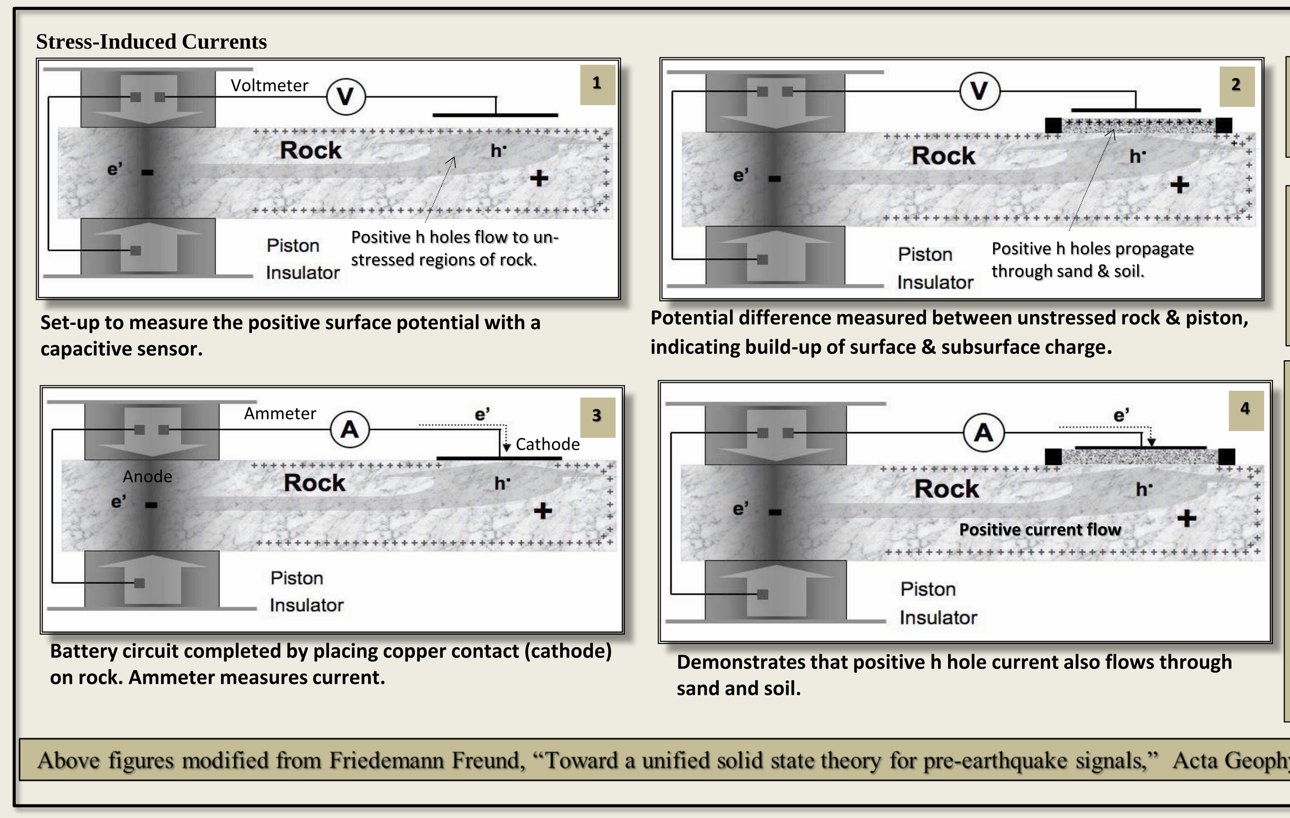
Although silicate minerals are primarily insulators, most can behave as semiconductors because they contain dormant electronic charge carriers, i.e. electricity that can be activated by stress.

When rocks are subjected to stress, first positive and then negative charge carrying currents are produced (positive or "h holes" and electrons respectively).

These stress-induced currents flow toward the unstressed region of rock samples and from the interior to the rock's exterior, ultimately ionizing the air.

Thus, faulted areas offer a plentiful supply of dormant charge carriers that when triggered by the attraction of overhead storm clouds, can provide the necessary current flow, in the form of "streamers," to attract opposite charged step-leaders.

STRESS PRODUCES A ROCK BATTERY IN THE LAB



Stress produces positive charge carrying currents in the lab.

Subsurface stress associated with faulting can likewise produce positive charge carrying currents.

"Loading simulates tectonic stresses causing existing dislocations to move & new ones to be generated in response to shear forces acting on mineral grains."

"Dislocations activate h charge carriers alongside electrons" (Freund, 2002; Freund et al., 2006).

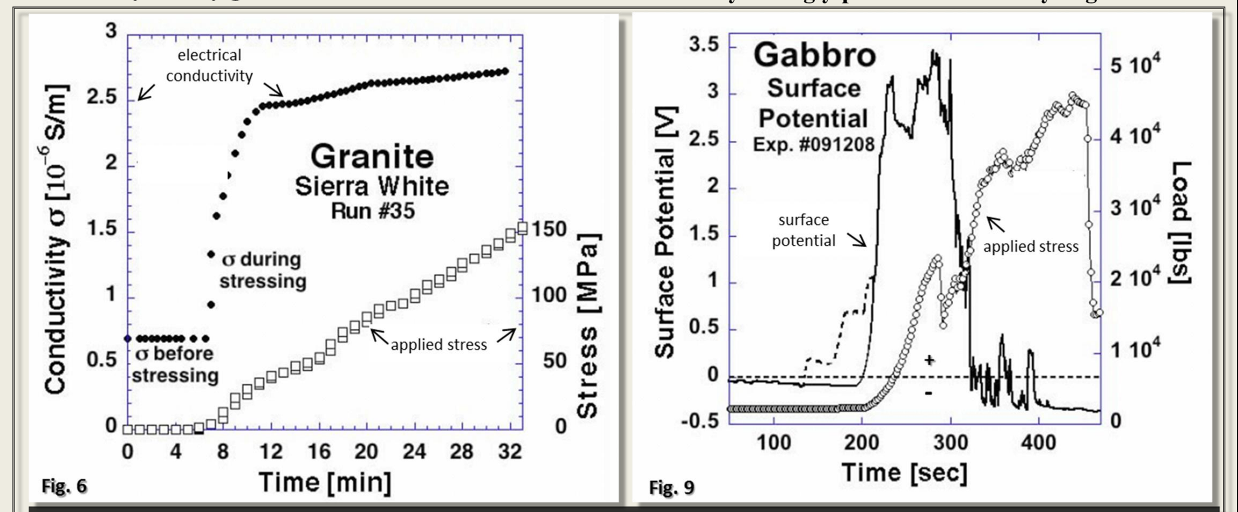
Above figures modified from Friedemann Freund, "Toward a unified solid state theory for pre-earthquake signals," Acta Geophysica 58(5):719-766 · Oct 2010.

STRESS-INDUCED CHANGES OF ELECTRICAL ROCK PROPERTIES IN GRANITE & GABBRO

- Creation of dormant charge carriers.
- Localized electrical currents generated.
- Provides reservoir of positive and negatively charged particles.
- Streamers capable of influencing lightning.

Conductivity of dry granite increases with uniaxial stress.

Surface potential of gabbro increases with stress, initially strongly positive then weakly negative.



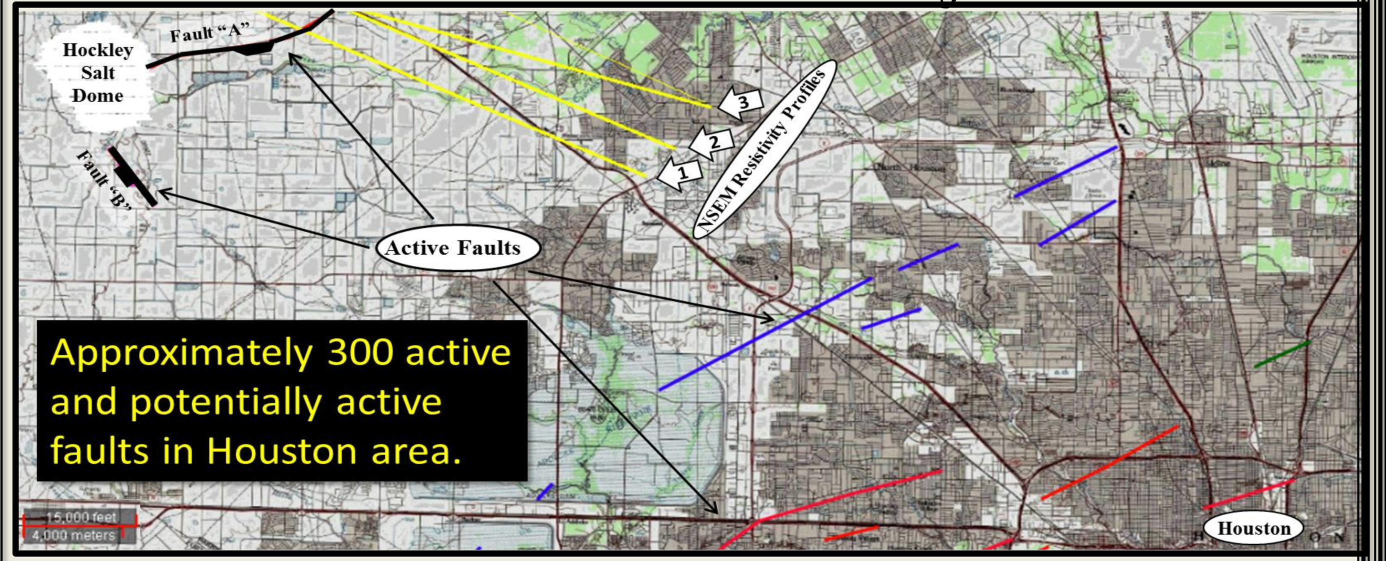
Above figures modified from F. Freund, "Toward a unified solid state theory for pre-earthquake Signals," Acta Geophysica - October 2010, DOI: 10.2478/s11600-009-0066-x . * From F. Freund's rock stress-EM signal theory.

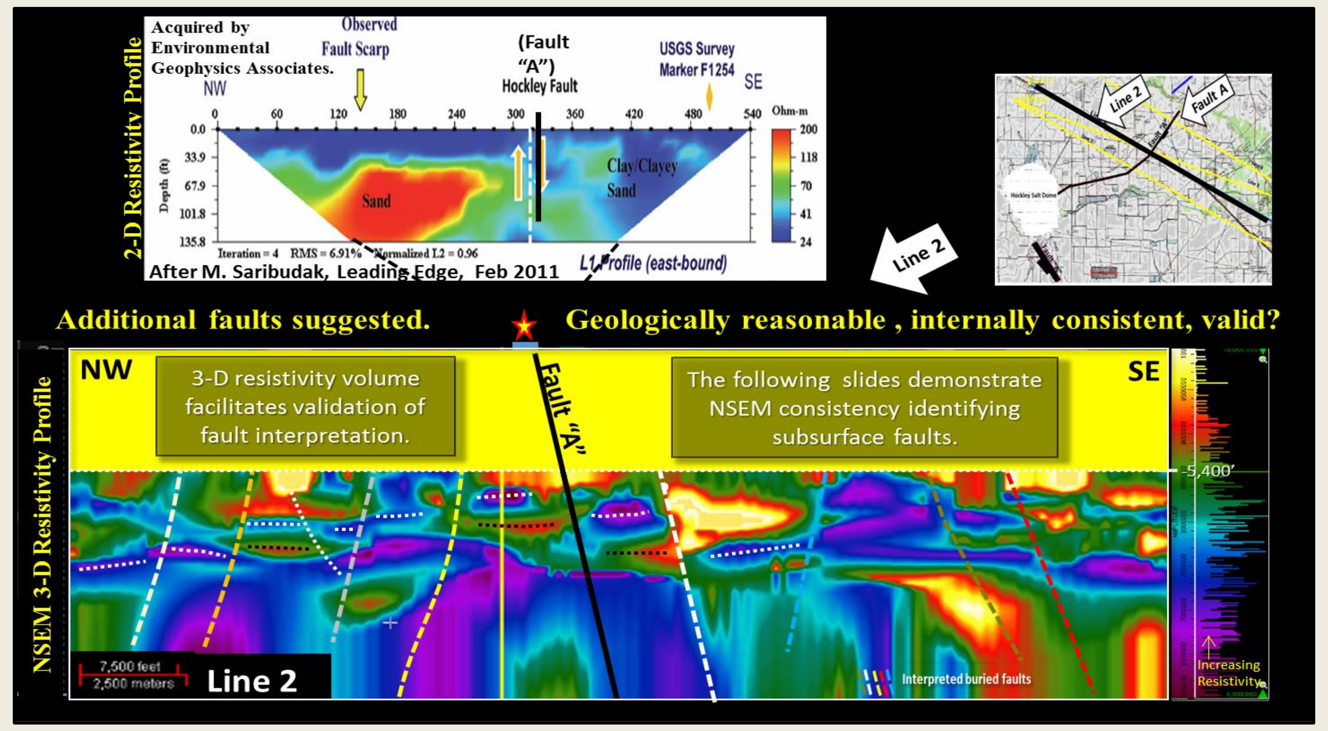
Recent studies by F. Freund suggest that stress-induced increases in conductivity & the generation of positive & negative currents & surface potential, are not solely influenced by improved grain-to-grain contacts.

It is likely that changes in electrical rock properties are caused by an increase in the number of electrons, negative ions & positive hole charge carriers produced when rock volumes are stressed.

Louis Berent, Berent Geophysical Consulting, Houston, TX
lberent@dynamicmeasurement.com, 281 370-5296

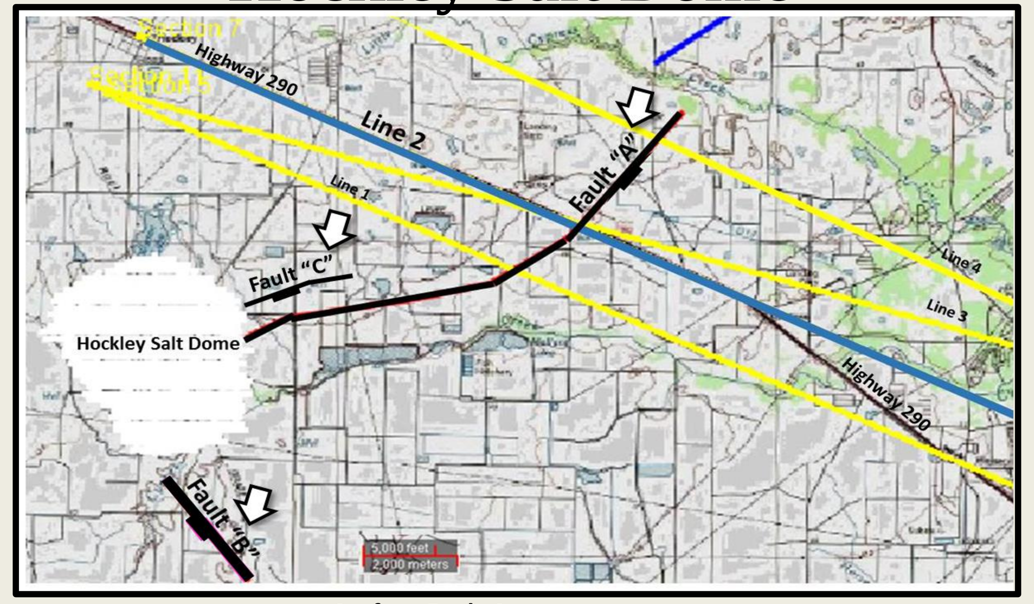
1 Active Faults Houston/Harris County Area

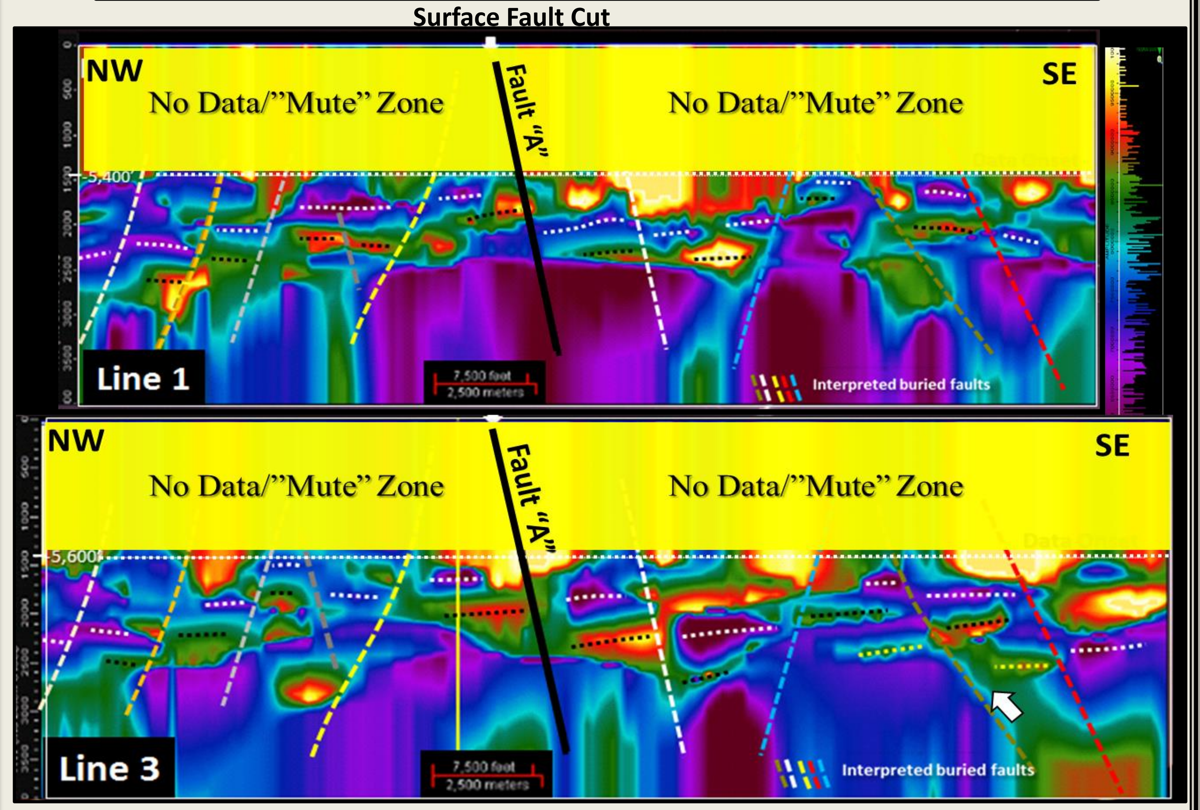




Subsurface fault interpretation of Fault "A" on NSEM apparent resistivity (lower image) is validated by tie to surface fault trace on 2-D resistivity imaging (white arrow, upper image). Resistivity profile provided by Mustafa Saribudak of EGA.

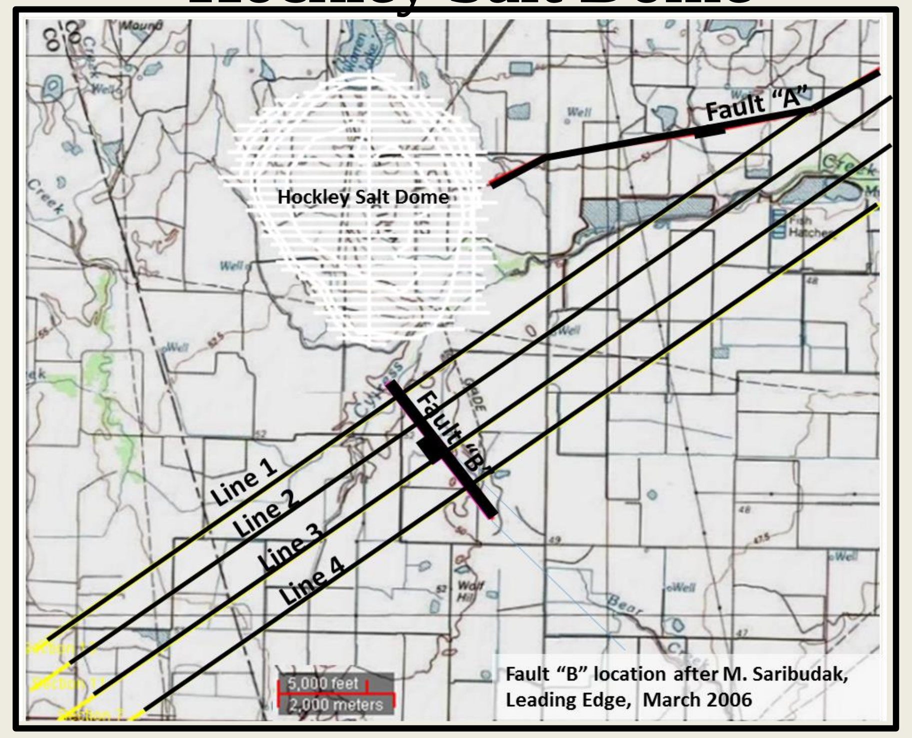
2 Radial Fault "A" Hockley Salt Dome

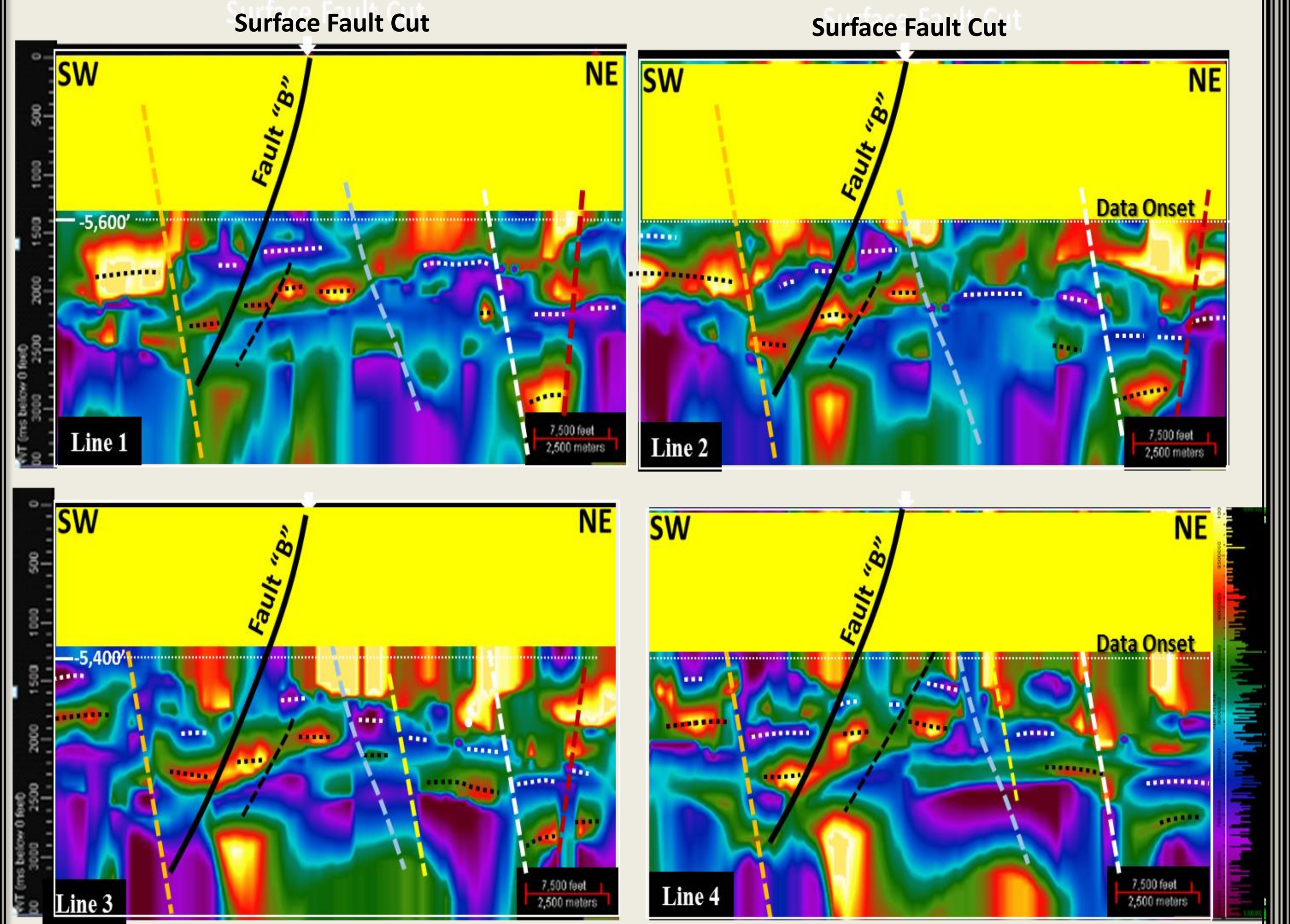




Hockley Fault "A" identified in subsurface on two arbitrary NSEM apparent resistivity profiles. Both fault interpretations validated via tie to surface fault trace.

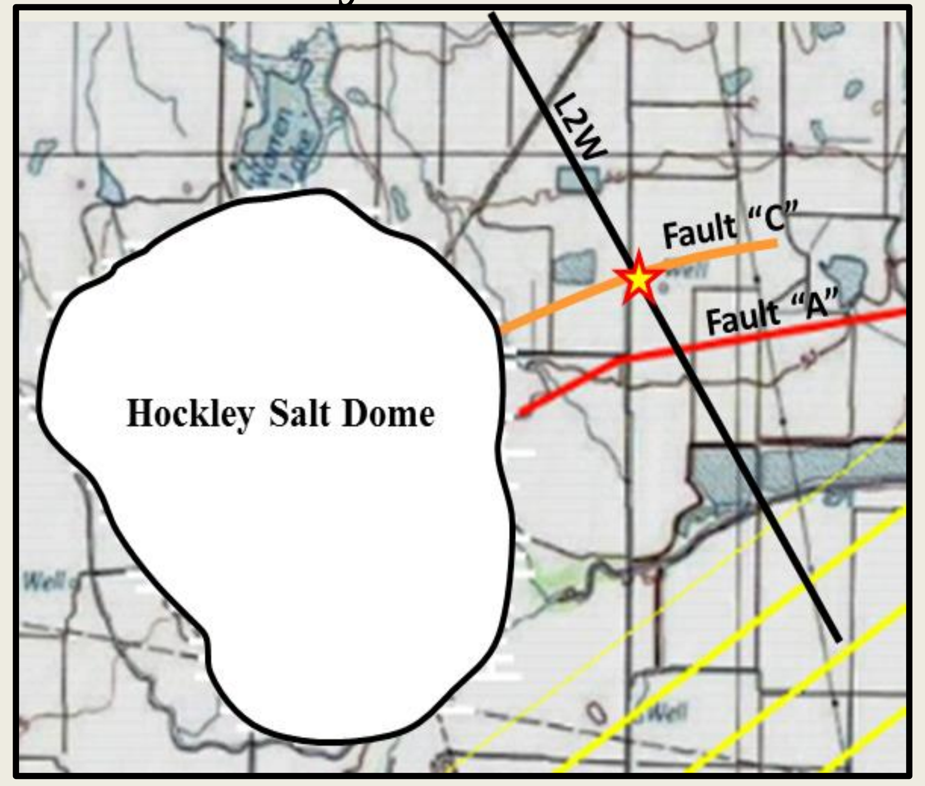
3 Radial Fault "B" Hockley Salt Dome

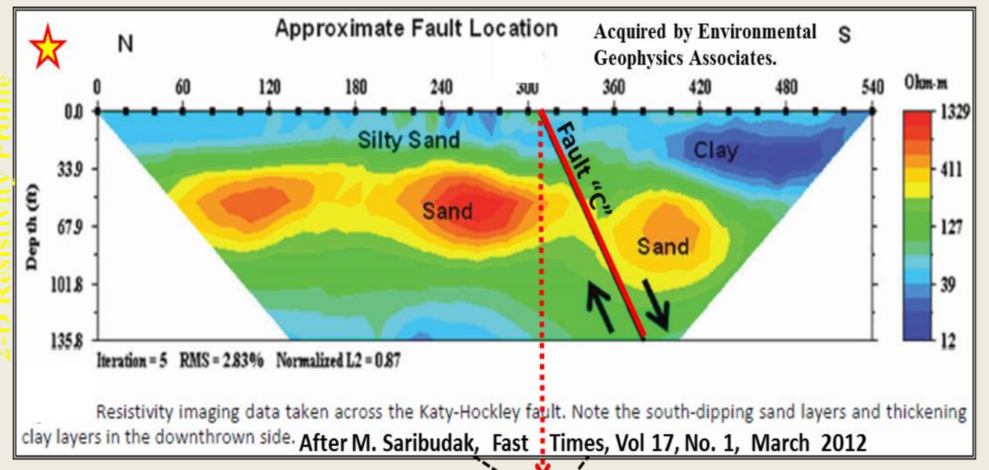


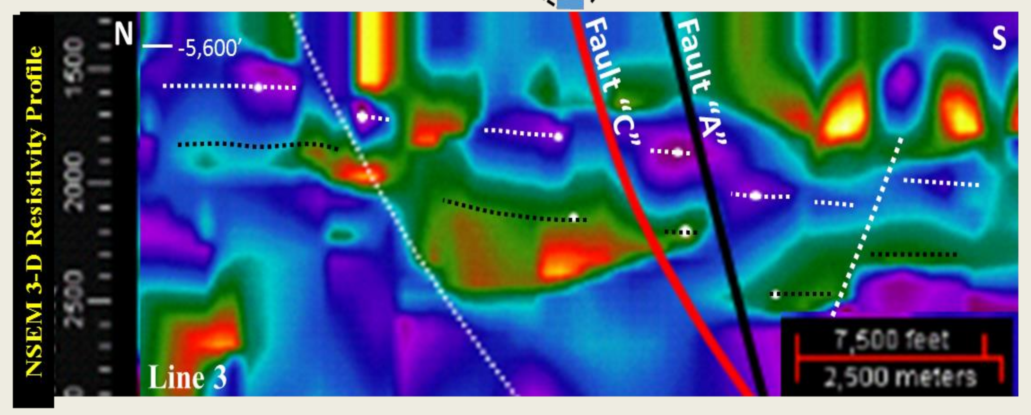


All four NSEM profiles reveal presence of active Fault "B" validated at surface.

4 Radial Fault "C" Hockley Salt Dome

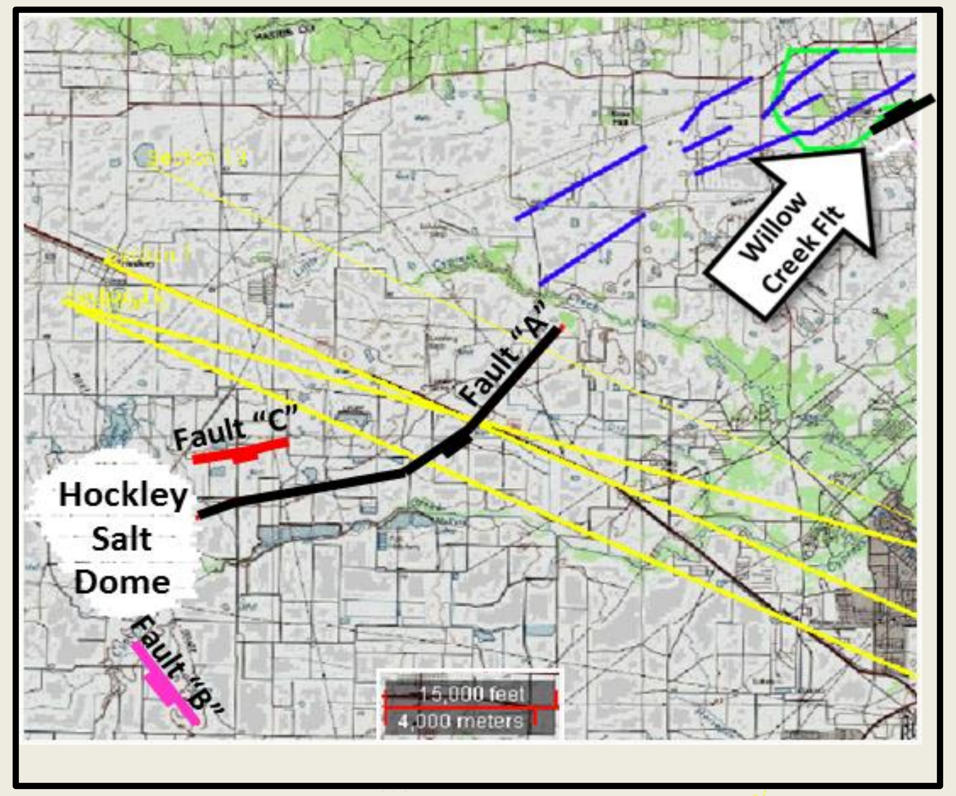


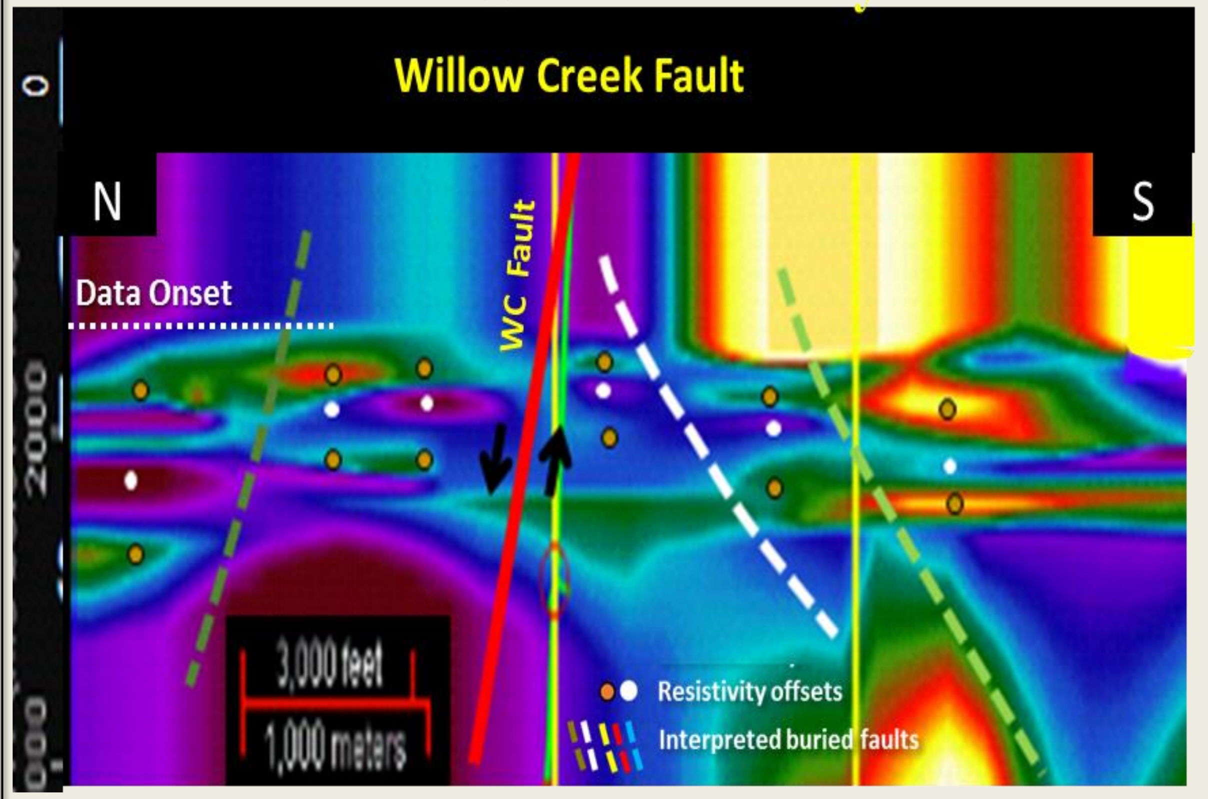




This NSEM profile shows both Faults "A" & "C".

5 Willow Creek Fault Northwest Houston





Another active fault in NW Houston (FM 249, south of Tomball) was clearly identified with NSEM resistivity.

Panels 1-2: The same nine color-coded faults can be identified on all three lines . NSEM demonstrates internal interpretive & structural consistency & an ability to map faults at the prospect level. Of the twenty faults displayed on these three profiles, nineteen are defined by two resistivity layer offsets & one fault is defined by three (see white arrow line 3). 3-D NSEM enables structural & fault plane mapping for comprehensive interpretive quality control, similar to seismic interpretation.

Panel 3: shows consistent fault criteria on all four profiles._As many as seven faults could be consistently identified on four resistivity profiles spanning 1.5 miles.

Panels 4-5: NSEM apparent resistivity profiles identify two additional active faults that are confirmed by near-surface geophysics. The NSEM resistivity profile intersecting radial Fault "C" also intersects Fault "A" shown in panels 1 & 2 and confirms NSEM's ability to reliably identify faults. Both panels , along with the first three, show how NSEM could be used to map subsurface structure.

Observations

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

Hockley Fault Conclusions

- 3-D NSEM resistivity can be interpreted similar to 3-D seismic data to build structural frameworks.
- It can be integrated with & calibrated to other near-surface & potential field geophysical data to expand the depth & aerial extent of investigated areas.
- NSEM is scalable – providing reconnaissance data in support of exploration or it can focus on specific faults & electrical rock properties in support of development drilling projects.