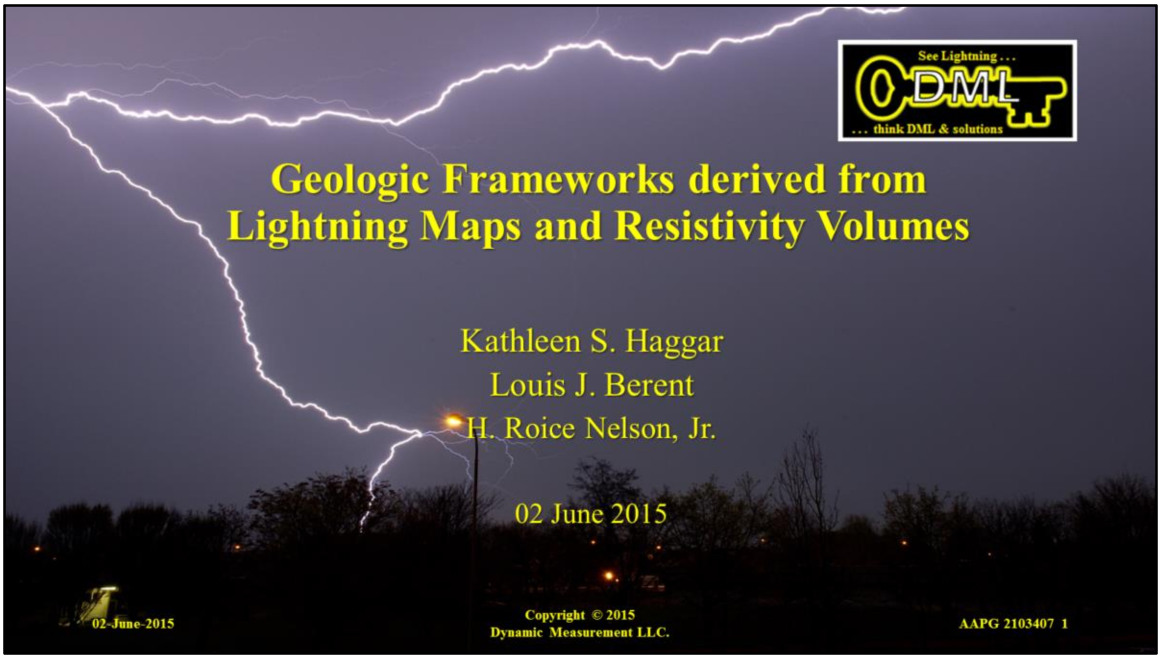
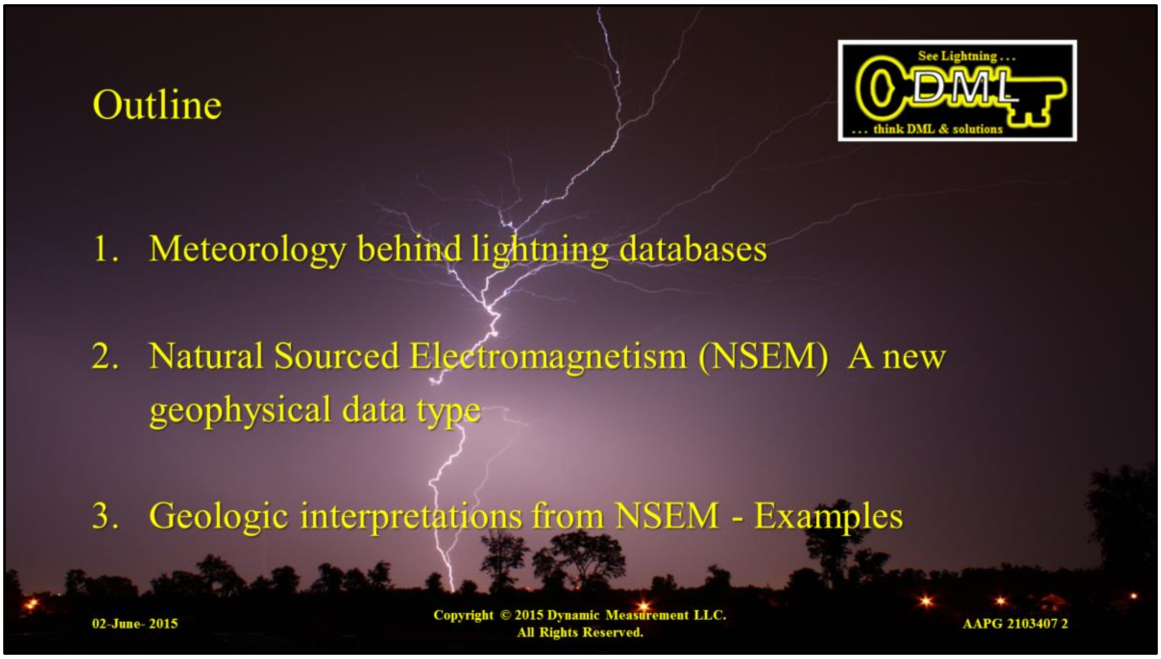
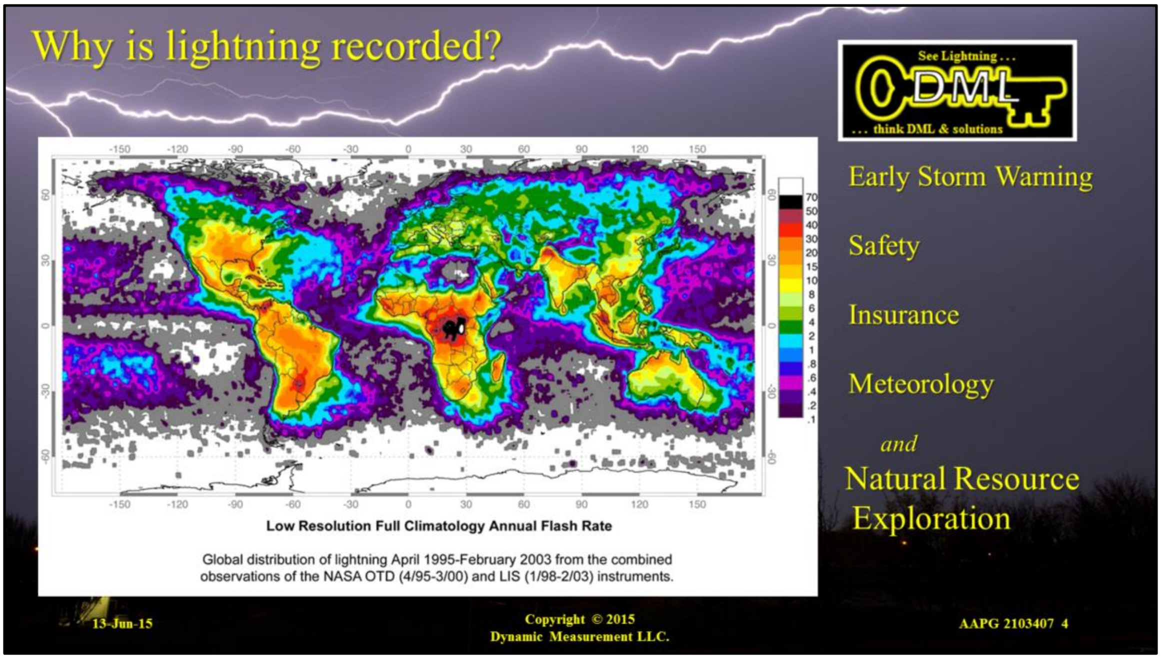


The DML team who contributed to the production of this paper includes the authors as well as Dr. Jim Seibert, Les Denham and Tom Sherman. We hope you enjoy this shockingly different lightning presentation!



Our outline is simple.
We will briefly cover -
The Meteorology behind the lightning database,
Natural Sourced Electromagnetism (NSEM) as a new geophysical data type,
and Geologic interpretations from 4 different areas.

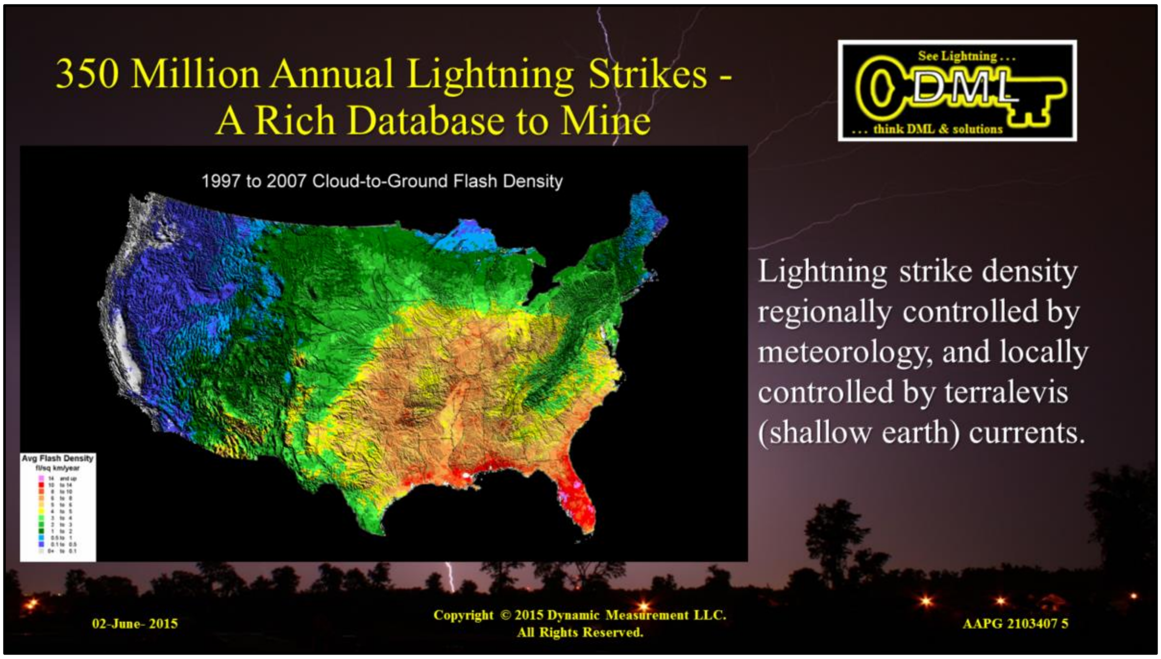
First, Meteorology.



Lightning occurs virtually everywhere. 2003 NASA global lightning map. If you are Astrophobic – frightened by lightning and thunder, consider visiting the poles and the deep oceans. Consider Travel Insurance if your itinerary includes : Johannesburg, South Africa where 500 people a year are killed by lightning, Darwin, Australia, Central Florida, Teresina, Brazil, Kifuka, Democratic Republic of Congo, Catatumbo River, Venezuela, or avoid them.

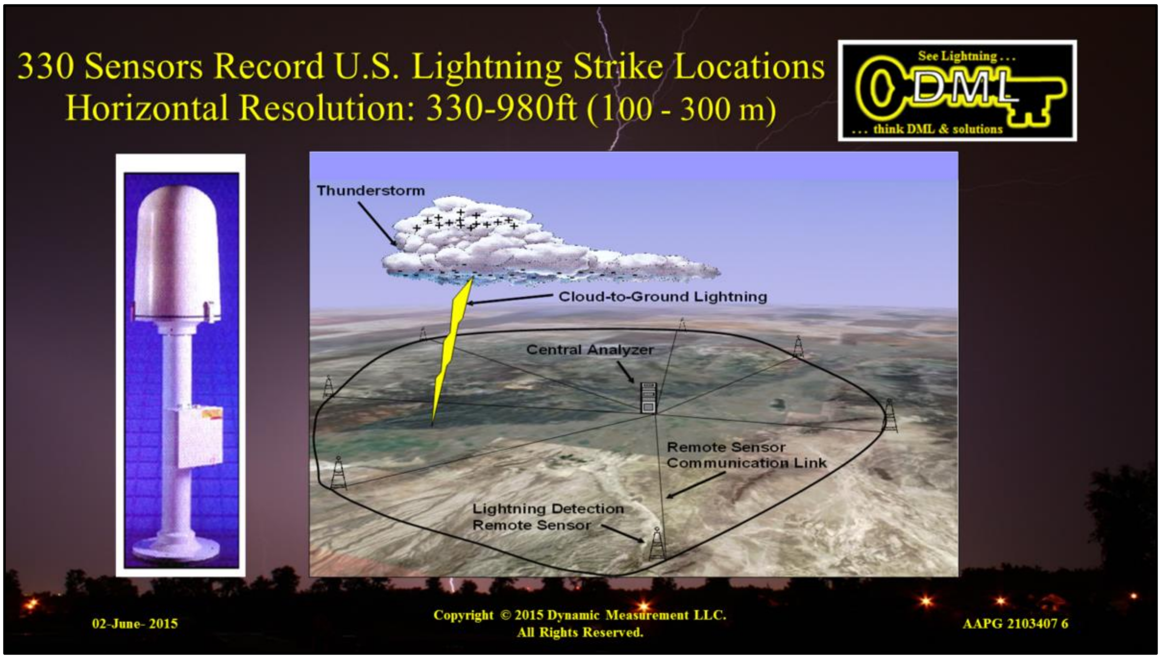
Lightning is recorded for; early storm warning, safety, insurance, meteorology, and now for natural resource exploration.

http://www.heraldsun.com.au/travel/travel-news/lightning-strikes-worlds-biggest-hot-spots/story-fnjjv9zn-1227135552965

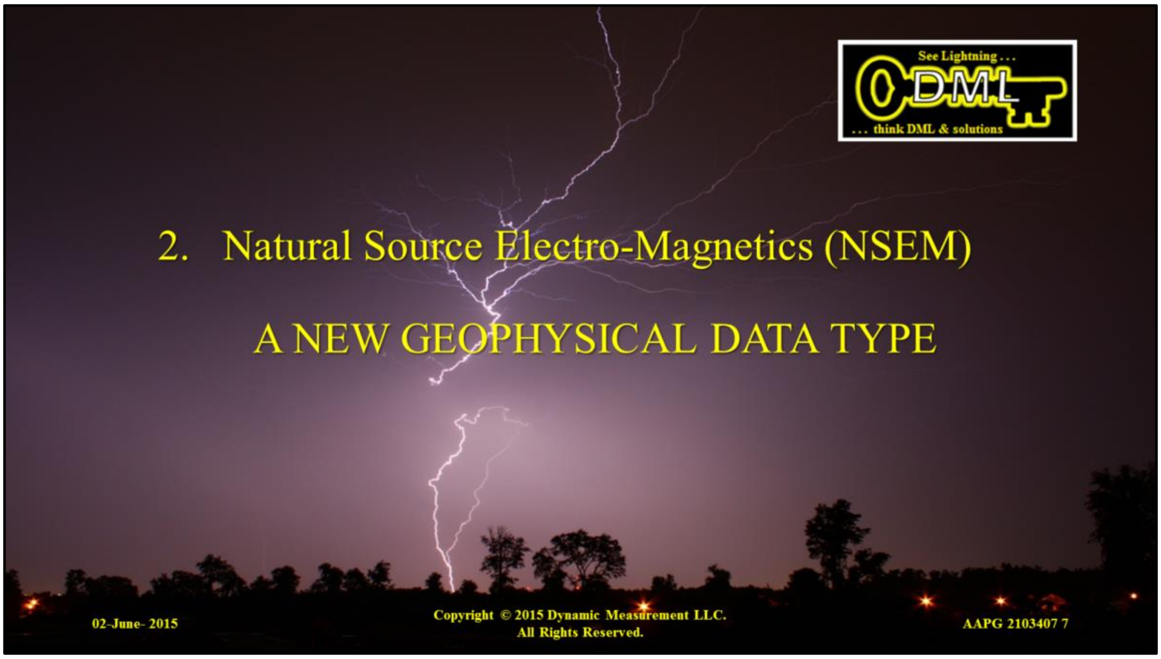


This map shows just 10 years of data from 1997-2007. (An updated map is being provided courtesy of Vaisala, owners and operators of the National Lightning Detection Network.)
Places with a lot of rainfall generally see a good deal of lightning.
Red areas of the map have considerable lightning strikes where gray and blue areas see very few. Weather patterns are regional but where the lightning strikes in local areas is controlled by the geology and the shallow earth currents, terra levis currents.

In the US there is currently 17 years of data available and 4 years in Canada. In areas with no land based sensors, lightning data analysis is limited to; Peak Current, Strike Density, Location and Timing. As data continues to arrive and as instrumentation technology continues to improve, we expect the future to hold many new discoveries.

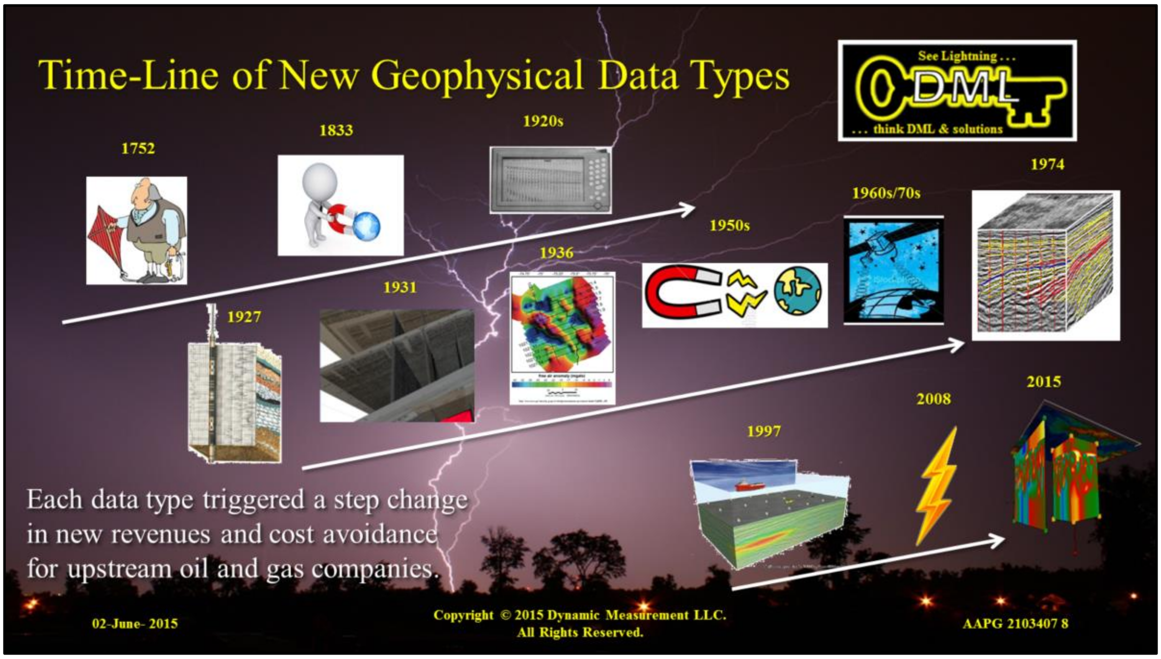


There are several lightning networks in the US. Depending on the technology they deploy, the number of lightning detectors vary between 100 and more than 300 to image lightning strikes. The sensor numbers reflect the ability of the technology deployed by the acquisition companies to record strike data over a given region.

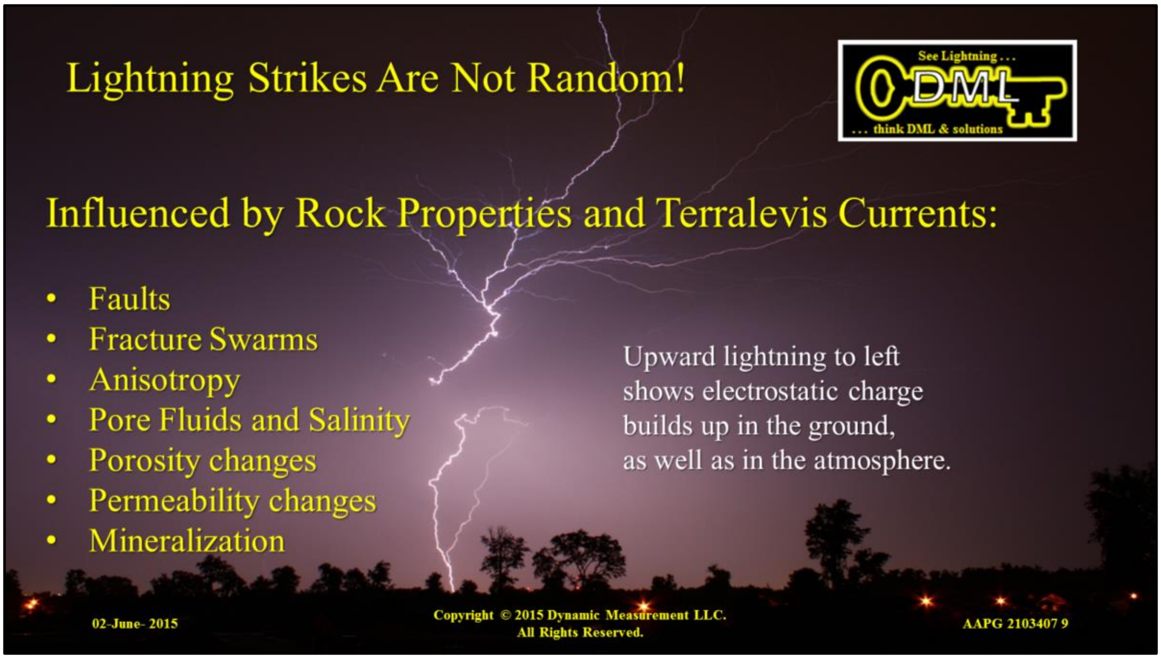


Topic 2.

NSEM as a new Geophysical Data Type.

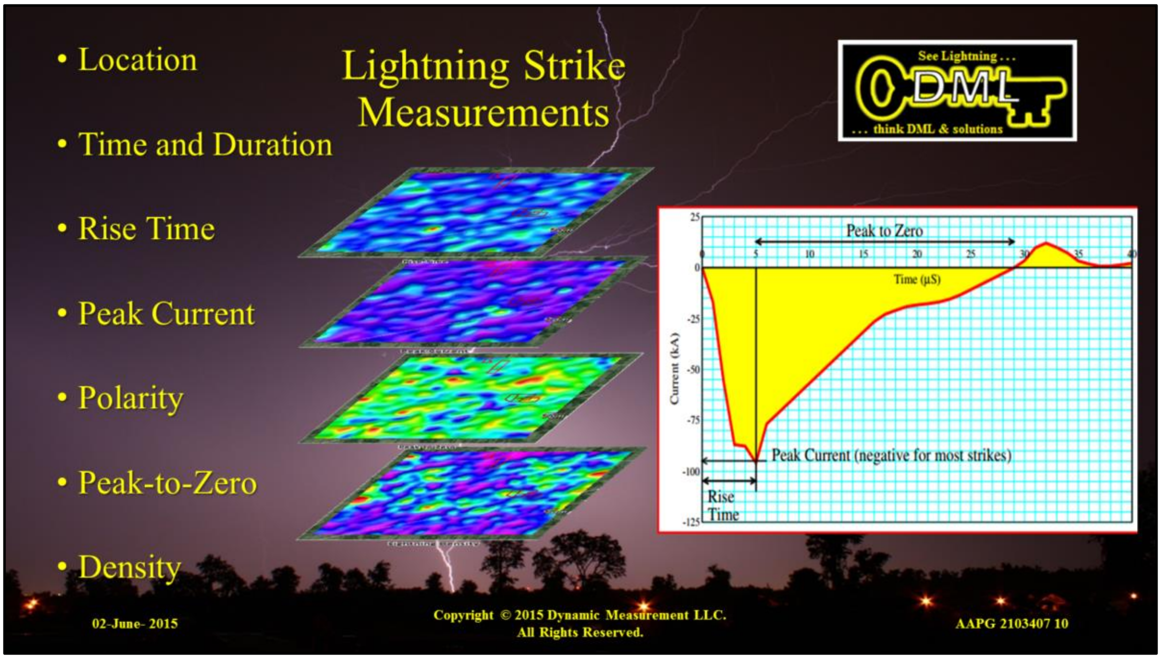


New discoveries tend to inspire and enable new discoveries. Each of these new data types has created a new generation of tools available to exploration and production. Cost reduction and lower risk are also part of the package of each of these milestone technologies. Over a 250 year span, we've gone from Benjamin Franklin's discovery that lightning was electricity to using lightning data to explore for natural resources. (Three corner Ben Franklin hats were worn by all of the DML folks at the AAPG 2015 – Research Pavilion in the Exhibition Hall. This was Dynamic Measurement's first booth.) Some of the discoveries above are commonplace and taken for granted now, such as electric logs, work stations, and 3-D seismic. Controlled source electromagnetism entered the industry in 1997. In 2008, Lightning as a new geophysical data type was born, delivered by Dynamic Measurement, LLC.

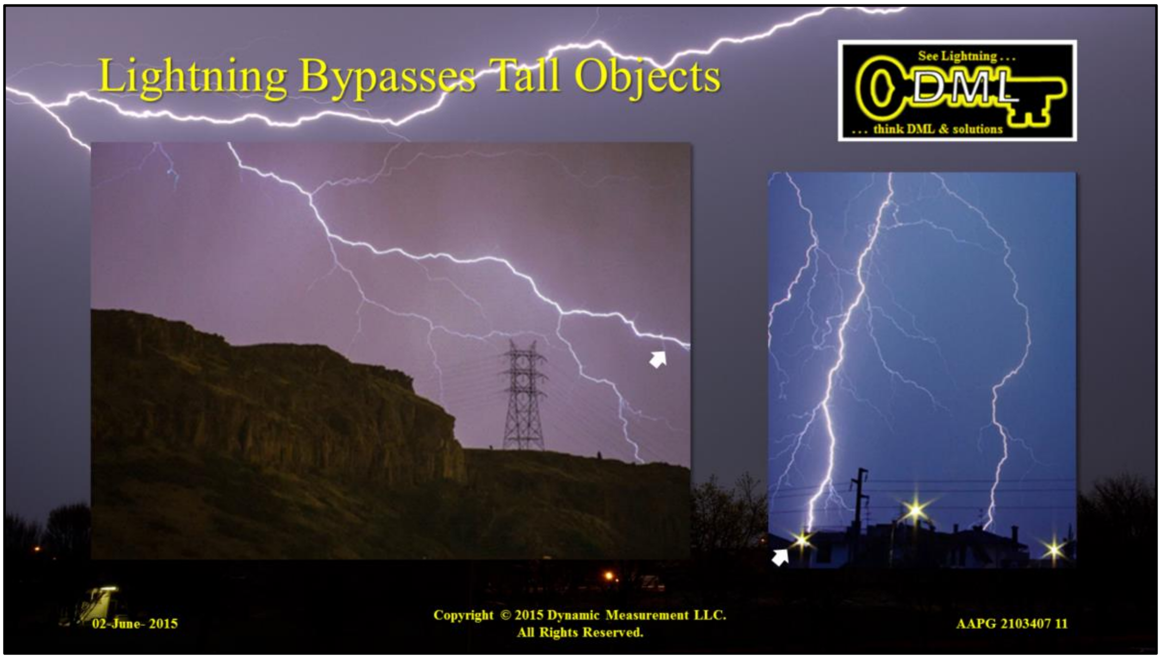


In the past 7 years, we have discovered that lighting strikes are not random. Over time they are observed to cluster over features controlled by the geology. Rock properties, faults and fractures are seen as the reasons for the clusters.

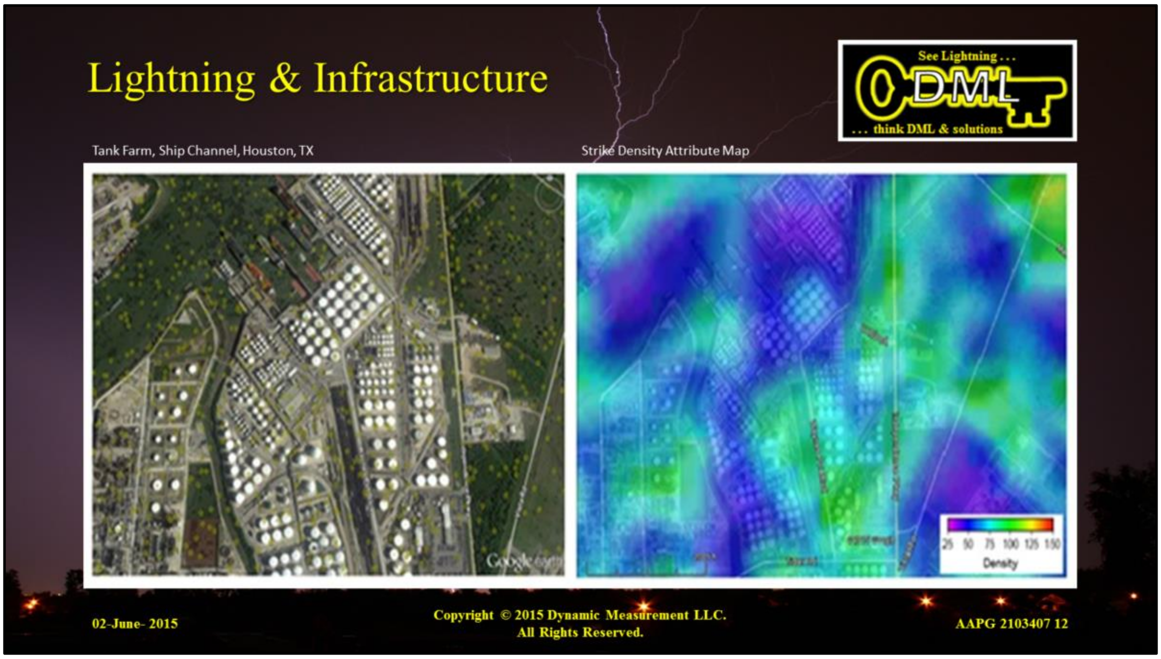
"Up lightning" is a relatively common occurrence in Norman Oklahoma. In this instance the earth also generates a leader. However, this is a very rare form of lightning elsewhere.



Lightning strike detectors in the US and Canada measure: Location, Time and Duration, Rise Time, Peak Current, Polarity, Peak to Zero, and Strike Density.
The graph on the right shows the waveform of a lightning strike with respect to time in microseconds and Current in Kilo Amps. Rise Time, Peak Current, Peak to Zero and Strike Density are useful attributes that have been recognized in this dataset for mapping specific segments of the data much like seismic attributes.



We've all heard that lightning strikes tall objects, however, here we see lightning bypassing a tall hill and a transmission line to strike elsewhere in the valley.



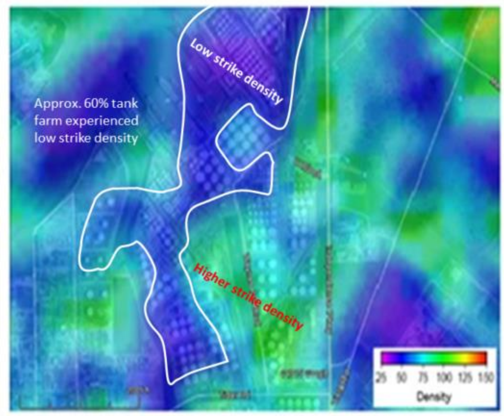
You have already heard that lightning strikes cluster due to geology – here is an example an oil refinery tank farm along the Ship Channel, Houston, TX.
Large areas are blanketed by large metal tanks. However, the lightning strike density is not a blanket.

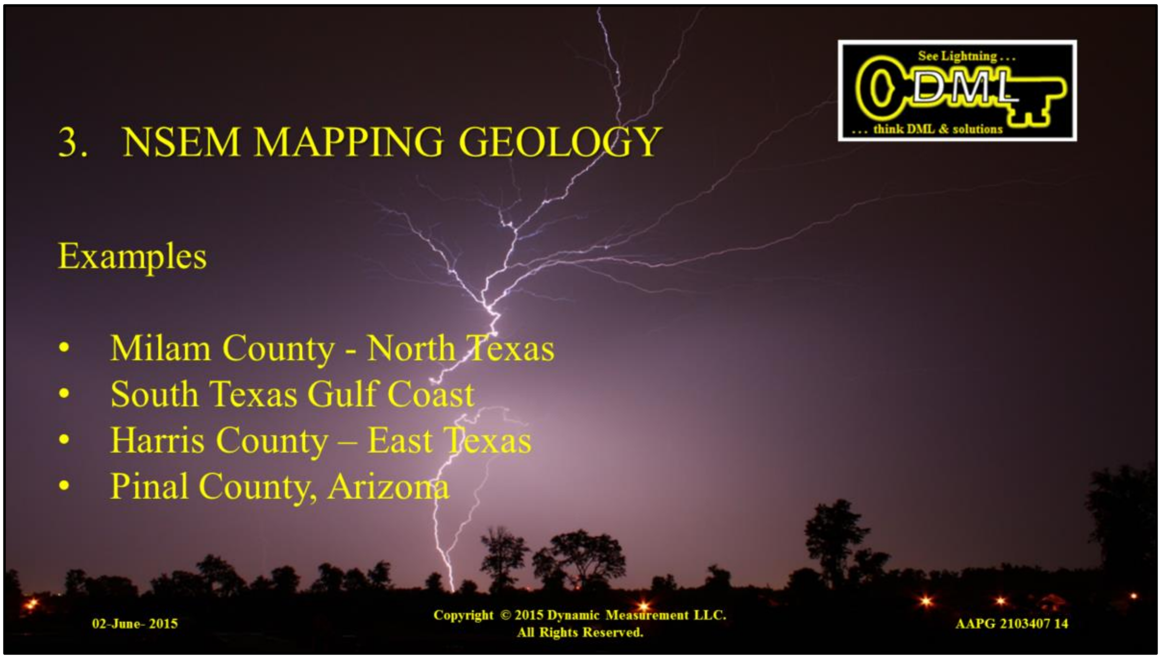
Lightning & Infrastructure

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

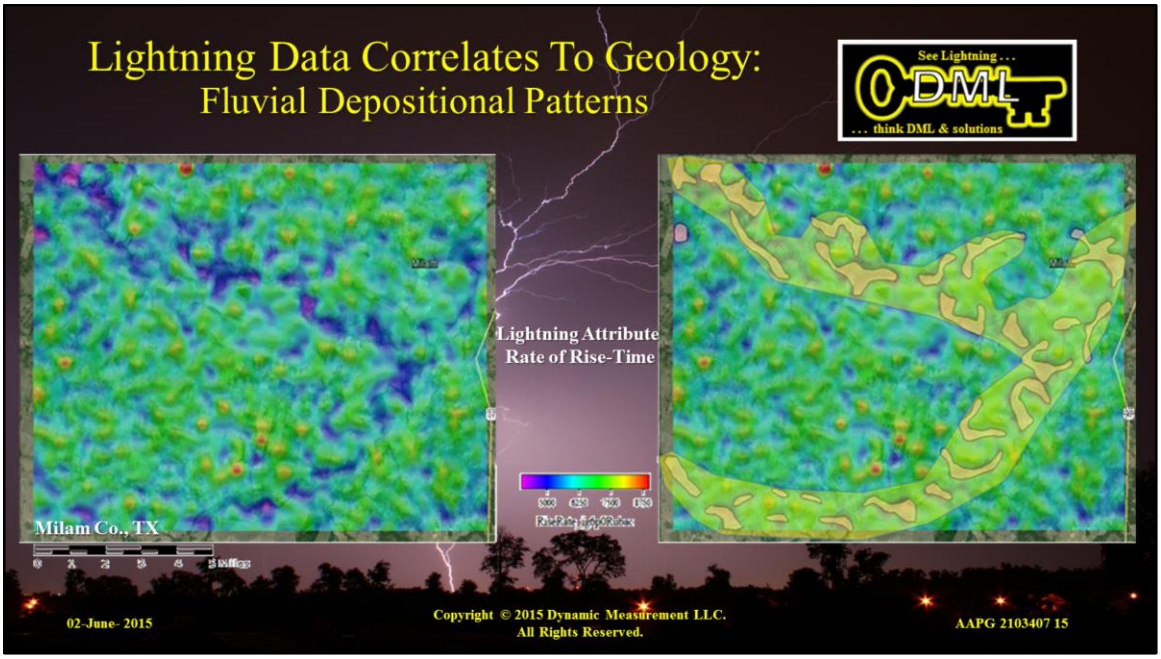
Tank Farm, Ship Channel, Houston, TX

Strike Density Attribute Map

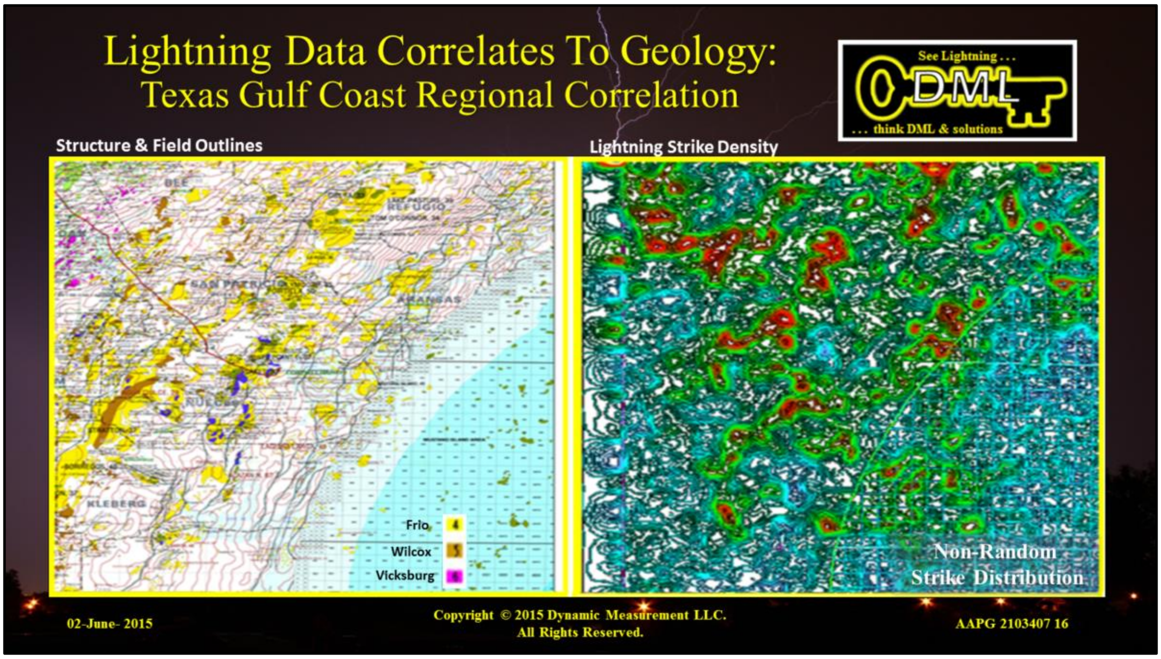




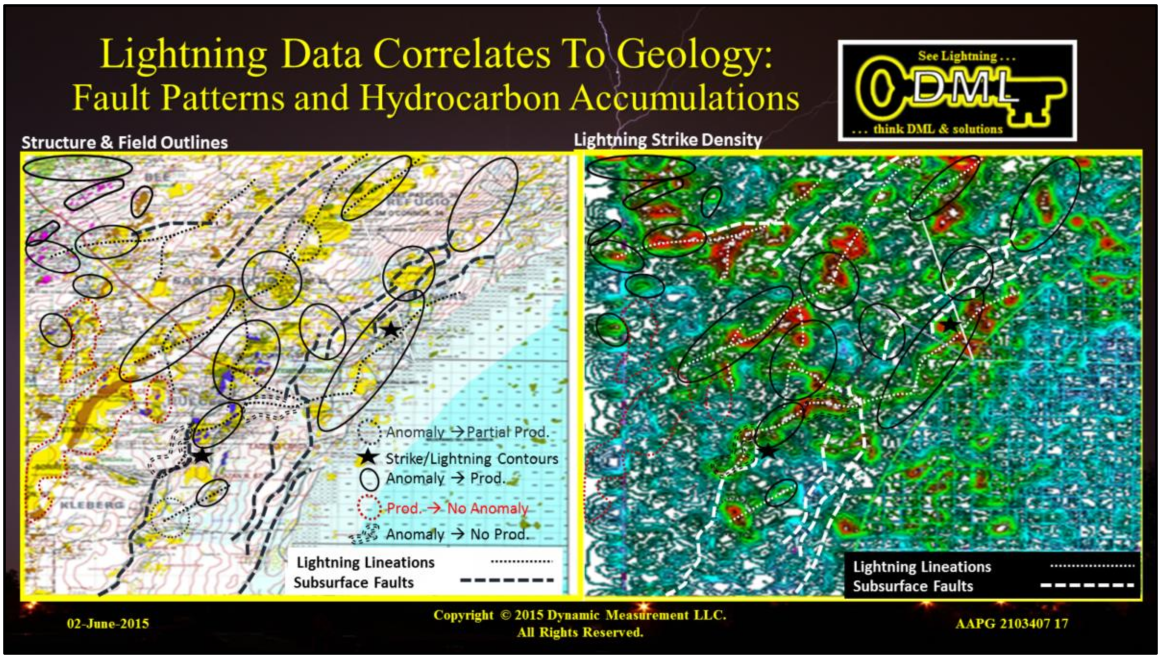
Here are 4 examples of how Natural Sourced Electromagnetism is used to explore for natural resources and image faults.
We'll see a stream and its features imaged in North TX, identify field trends along the South TX GOM, image a fault, and define a copper porphyry in Arizona.



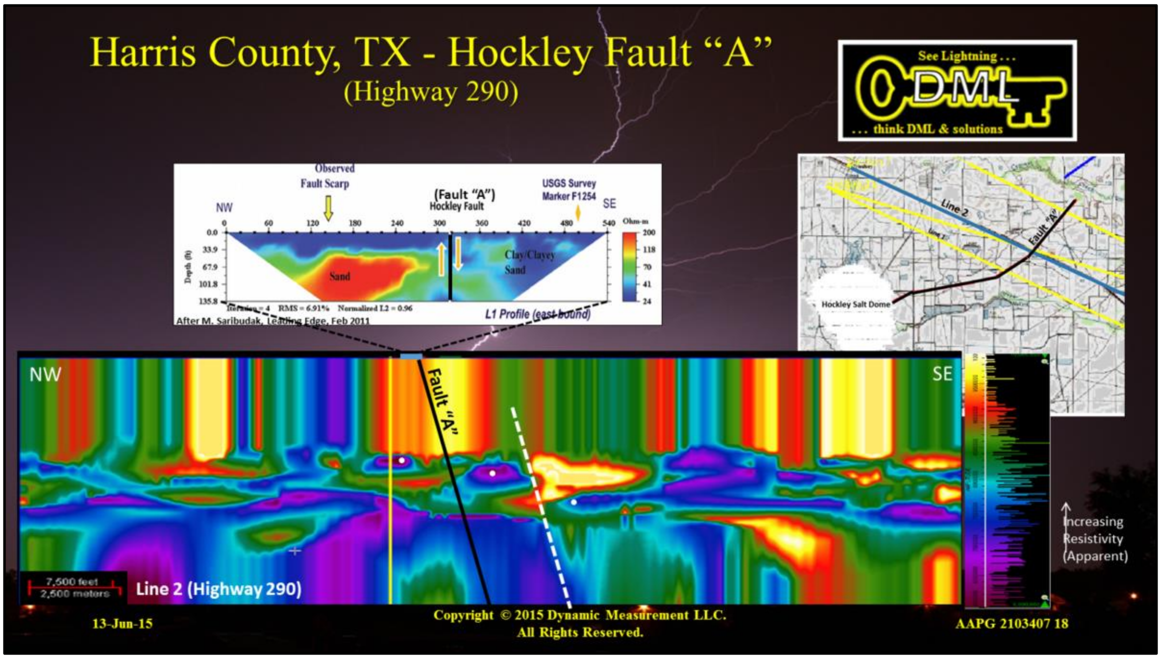
Example 1.
Rate of Rise Time attribute is shown in this example form Milam, Co, TX. We see on the left the un-interpreted Rate-of-Rise-Time attribute. The scale is in microseconds per kilo Amp.
The red areas are high rise times and the blue are low. Note the blue area resembles a stream - it actually is a stream. The image to the right is an interpreted map on the same attribute.
We have interpreted individual stream features such as bars in the channel. This pattern corresponds to the surface/near surface geology of the area.



Example 2.
The map on the left is a Geo-Map which shows producing trends along the south Texas Gulf Coast - from Refugio to Kleberg County. The Frio production is in the yellow bands. Wilcox is in tan and Vicksburg is in pink. Faults also run coast parallel largely between the bands of production but in some areas they are coincident with production.
The map on the right shows Strike Density. The reds are areas of high Strike Density and the blue areas are low Strike Density. Note the similarity in the production trends and the lightning Strike Density lineaments.

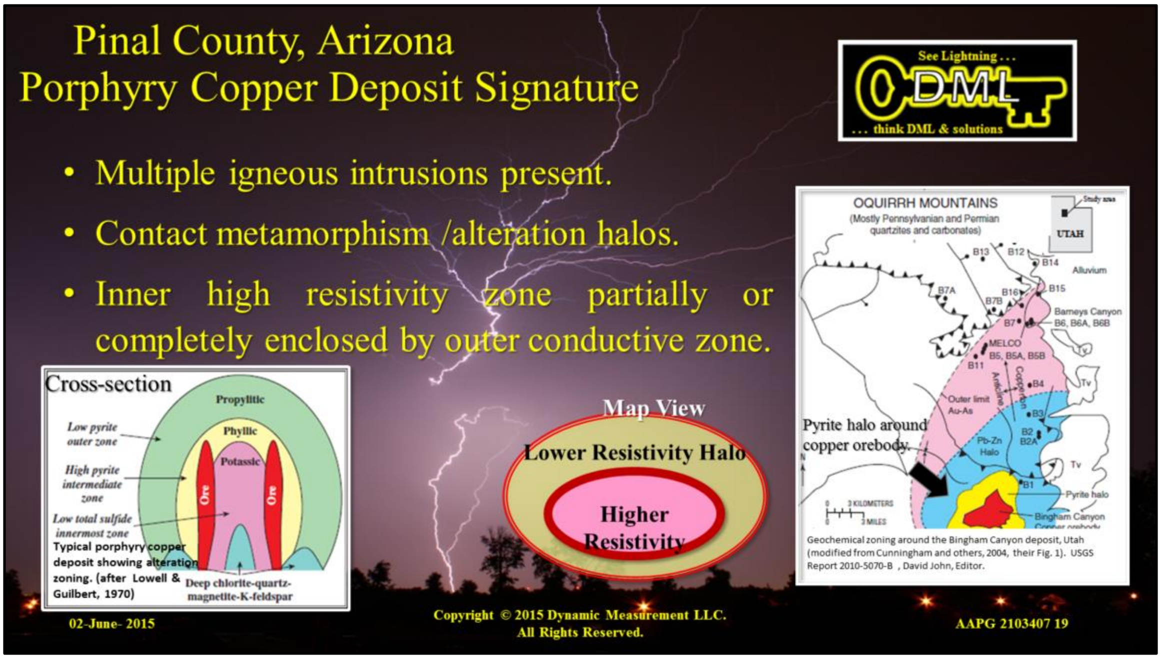


Here are the identical 2 maps. In this panel we have added some circles and ovals around specific features to facilitate direct visual comparison. The lightning lineaments are shown as
black dots on the left and white dots on the right. The faults are dashed lines with the same colors code.
Note that the lightning strike patterns extend onto the shelf. The lightning strike patterns correspond well with known fields and production.



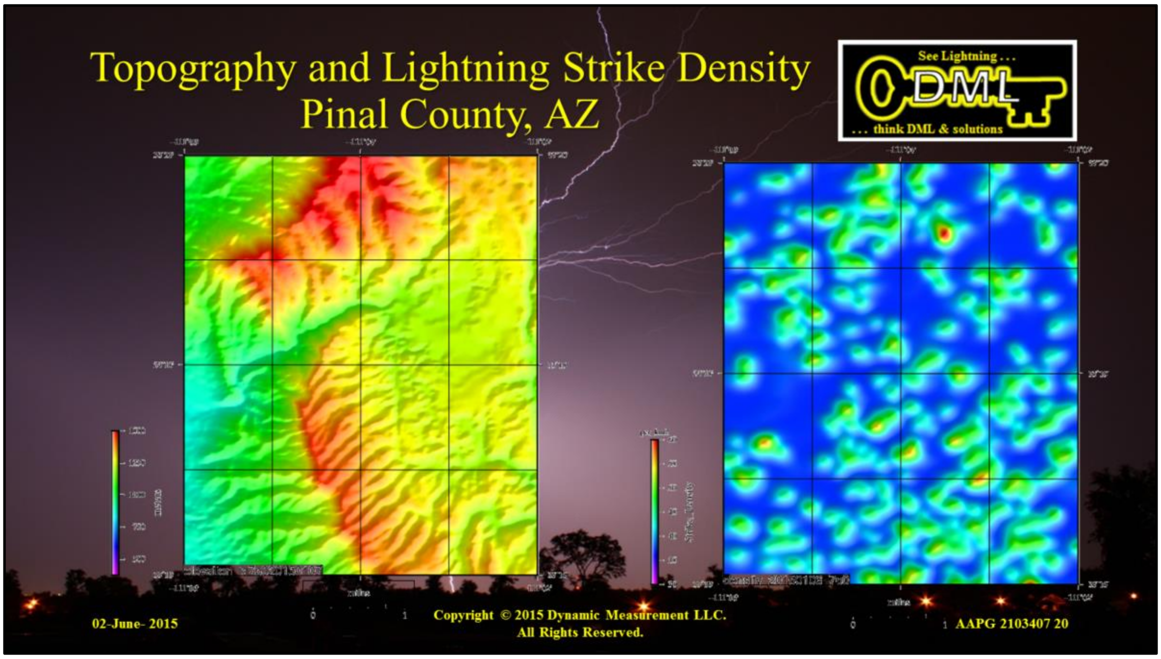
Example 3.
The Hockley salt dome is located to the west of Houston and east of Sealy, TX. This is a shallow salt dome that was actively mined in the 1800's. Faults radiate out from the dome, a pattern that is typical of diapiric structures. One of the faults, Fault A, shown as a black line, extends out from the dome to the east and northeast and is down to the south.
The 2 colorful displays are resistivity profiles. The top profile was imaged across Fault A by conventional means, a line of resistivity sensors was placed on the ground across the fault, a current was induced, and the response was recorded and interpreted. Note that the color scale shows the highest resistivity recorded is in red and the lowest is in blue on both profiles. Also, there is a high resistivity concentration up-thrown to the fault and a low resistivity response imaged on the downthrown side. These patterns are typical of sands and shales respectively.
The conventional resistivity profile only covers a distance of approximately 540 meters. The blue bar at the top of the large resistivity panel below is to scale and provides a surface tie point for the interpretation of the longer resistivity panel that is from the blue line in the index map. The yellow lines on the base map correspond to additional profiles that were not included here.

The resistivity profile below shows a pattern that mirrors the smaller profile with offsetting patterns of high to low resistivity across the fault – the dashed black lines show approximately same distance on NSEM resistivity profile. Once recognized, additional patterns can be interpreted as faults along the line of section. White dashes show another possible fault offset of resistivity layers to the southeast.

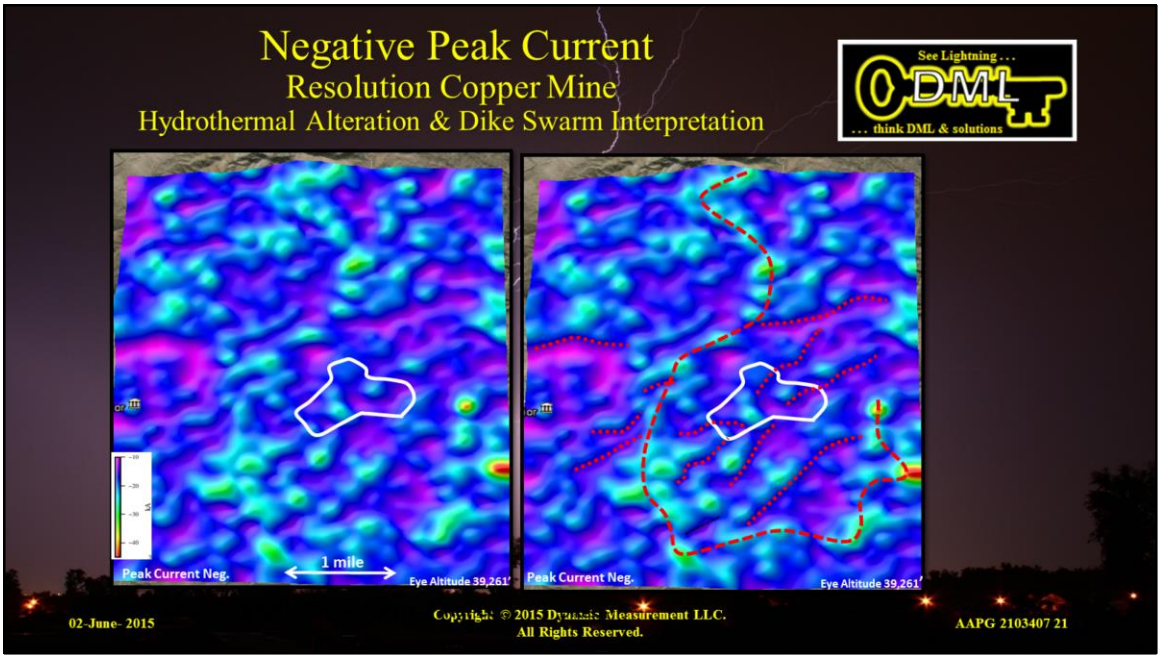


Example 4.

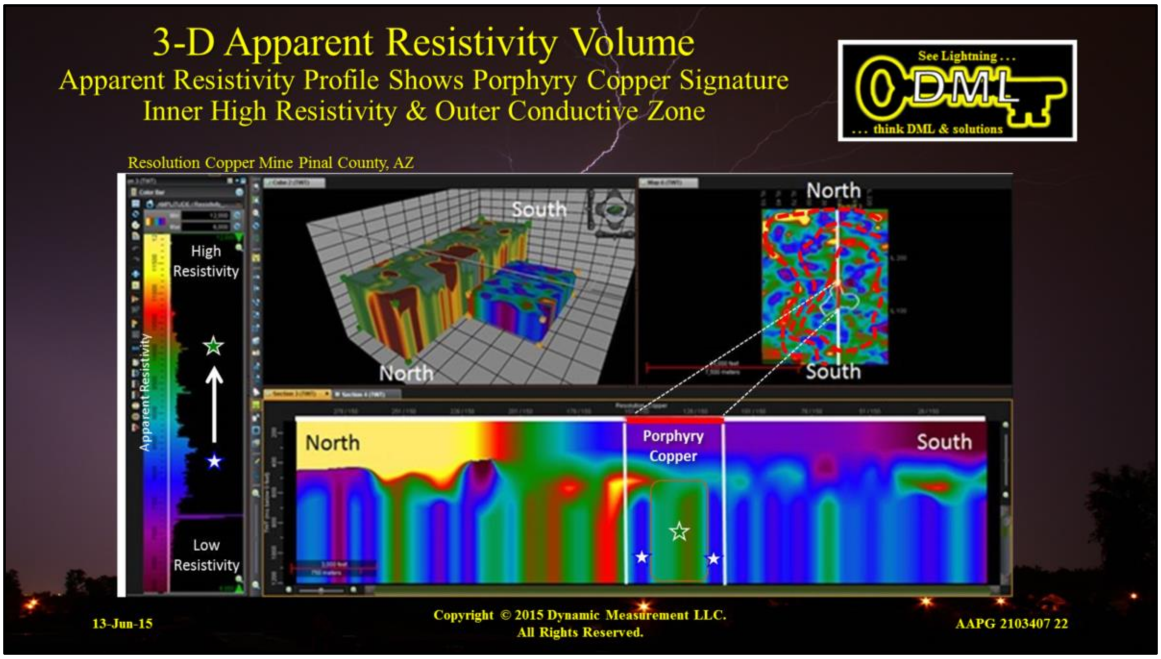
Lastly we look at the NSEM signature of a copper porphyry deposit in Pinal County, AZ. This slide gives a little background on copper porphyries.
Copper porphyries are associated with igneous intrusions that carry mineralized fluids up from depth. Copper orebodies are found near the igneous intrusion.
The heat of the intrusion causes contact metamorphism in bands out from the intrusion. The map on the right shows alteration halos associated with a copper deposit in Idaho, a particularly good published example; alteration halos were identified by geochemical means. The same halo pattern of pyrite surrounding the copper ore body found in Idaho also occurs in our Arizona study area. The illustration in the center shows the resistivity halo that is found with copper porphyry deposits. High resistivity is associated with the copper porphyry and a lower resistivity halo is associated with the pyrite mineralization zone that surrounds it.



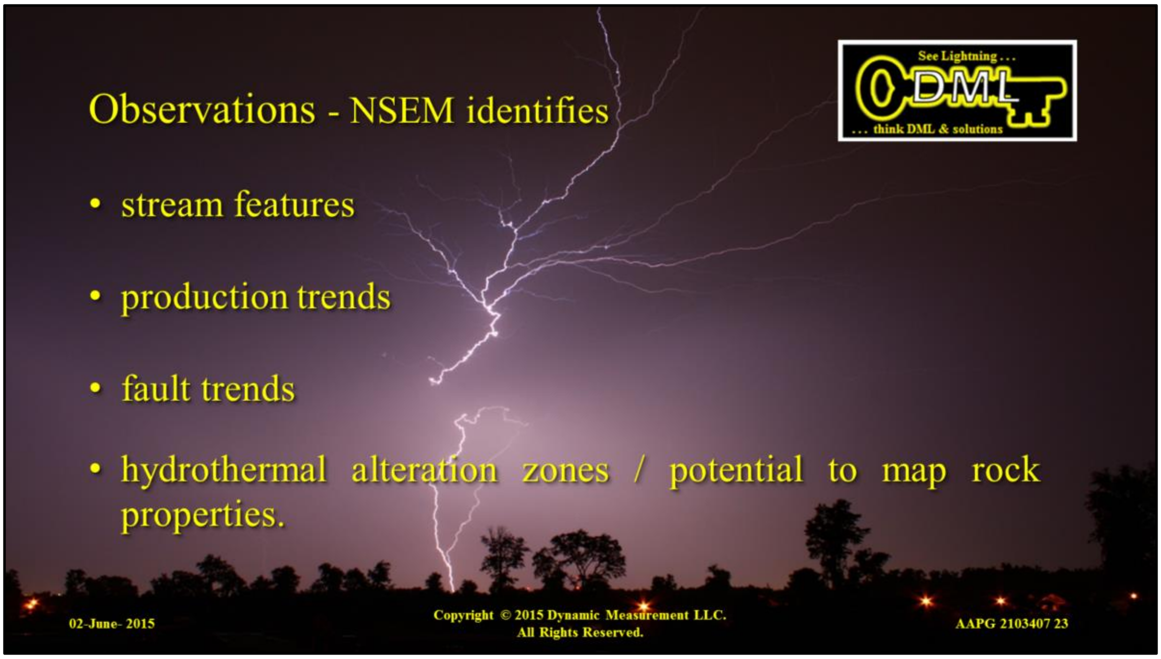
In the Arizona study area, the map on the right shows topography with the reds being high hills and ridges and the greens and light blues corresponding to the valley areas. The map on the right shows the Strike Density attribute over the study area. While there is some similarity, the patterns are not identical. The scale shows high strike densities in red and the low strike density areas in blue.



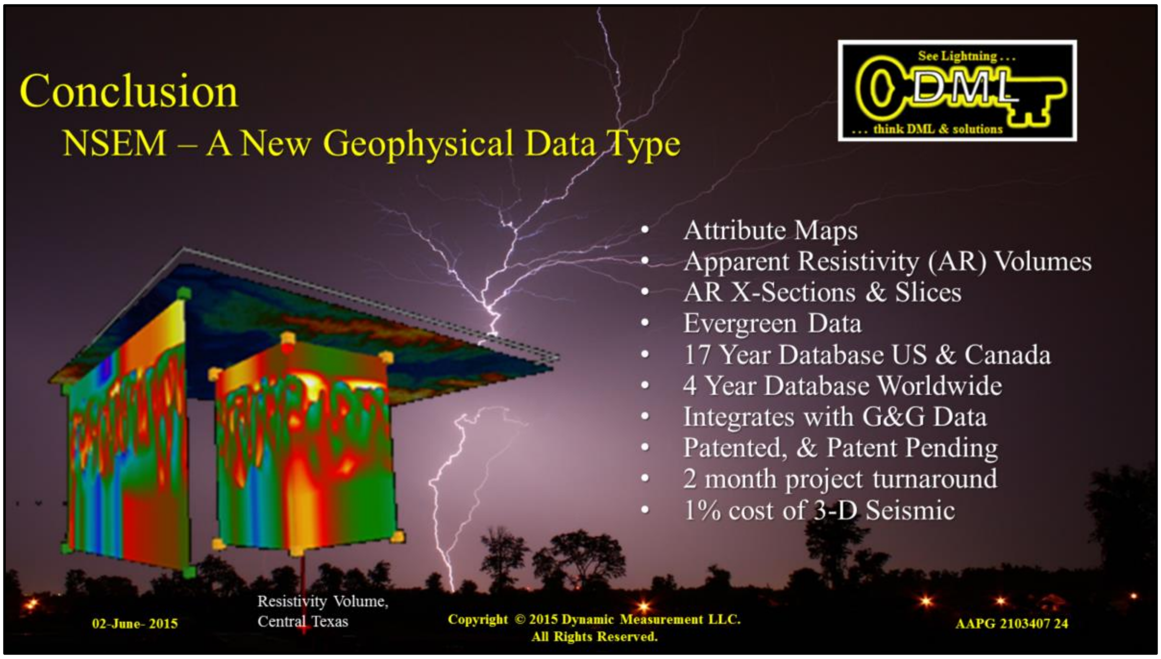
The study area overlays the Resolution Copper Mine. A different attribute, Negative Peak Current, is displayed in both maps over the study area. The scale is identical in both images and shows high Negative Peak Current values in red and low Negative Peak Current in blue. Both maps show the outline of the copper porphyry in white. Note the sinuous pattern of small green shapes that surround this feature. This red dashed line corresponds to the pyrite alteration zone halo. The dotted lines are interpreted as dikes. Dike swarms are typically associated with copper deposits.



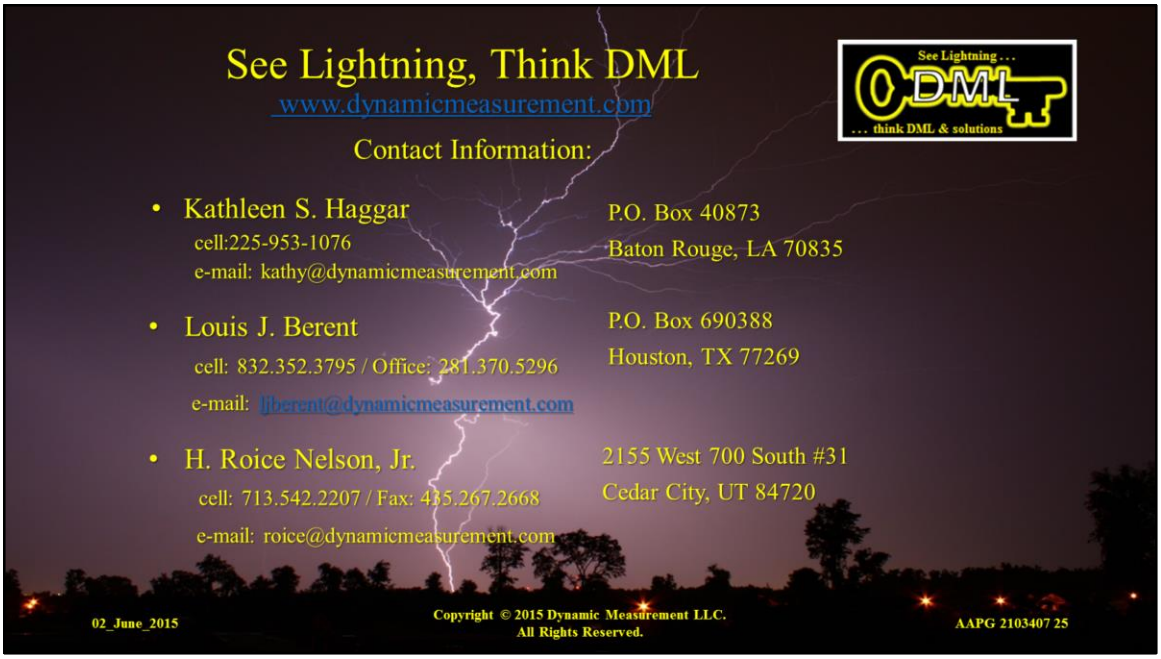
Now we look at a north south resistivity profile through the copper porphyry deposit. Here we see the anticipated copper porphyry response in the resistivity profile – higher resistivity surrounded by low resistivity. The resistivity slice view above also shows the banding fom the alteration halo minerals. These displays were generated on Landmark Decisionspace™.



These 4 NSEM examples illustrated how various attributes can highlight different features, observable at or near the surface; stream features, production trends, faults, and hydrothermal alteration zones. These attributes provide valuable reconnaissance information for O&G and mineral exploration, and potentially for analysis of streams/stream features. Resistivity profiles and slices derived from resistivity volumes locate fault planes and show mineral deposit signatures. We have shown the potential of this new geophysical tool to map rock properties.



In conclusion, NSEM is a new geophysical data type that consists of Attributes and Apparent Resistivity Volumes/slices and profiles. This data base is evergreen and continuously growing. 17 years of data are available in the US and 4 years in Canada. Worldwide, there is useful Attribute data from the last 4 years. You have seen that this data integrates well with Geological and Geophysical data. This technology is patented and patent pending. Typically, due to the digital nature of this data, clients experience a 2 month project turn around. At present, this data is provided at about 1% of the cost of 3-D seismic.



The Dynamic Measurement website is
http://www.dynamicmeasurement.com

You can find all of our public presentation available at
http://www.dynamicmeasurement.com/TAMU

The authors can be reached via the information above. Comments and questions are welcome!

Thank You for your interest in NSEM, our new geophysical data type based on Natural Sourced Electromagnetism / lighting data! We know that you will now see lightning in a whole new light.

And this is only the beginning! Please follow us on LinkedIn for the latest developments and see our presentations at http://www.dynamicmeasurement.com//TAMU