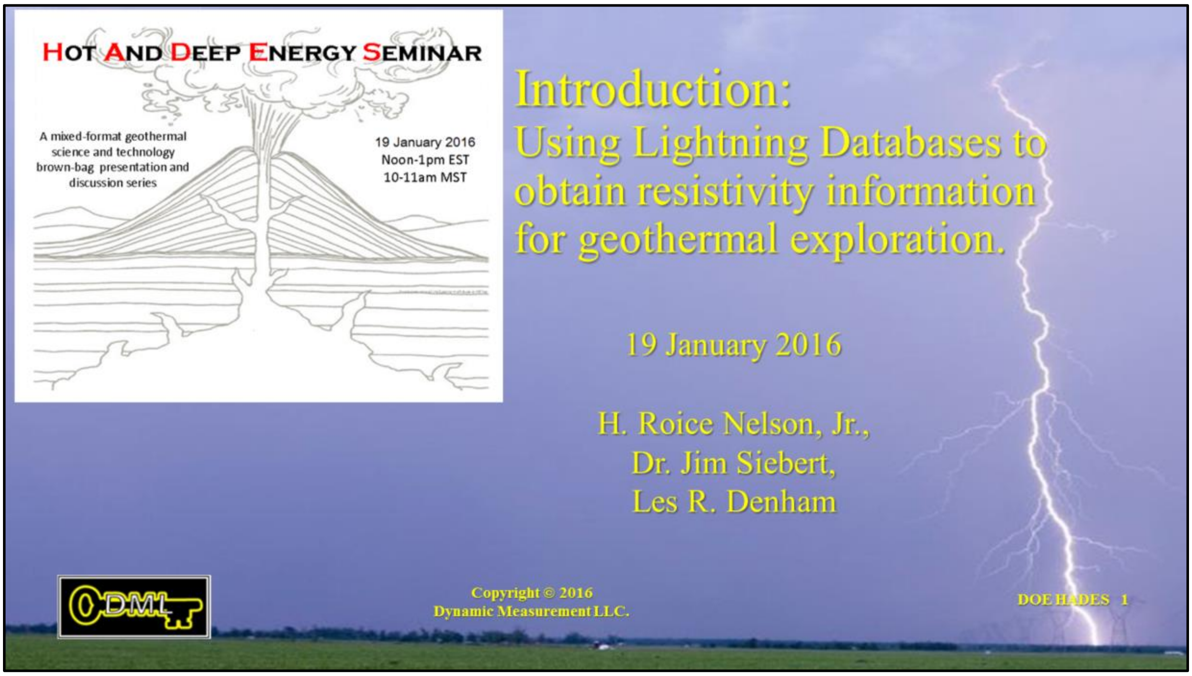


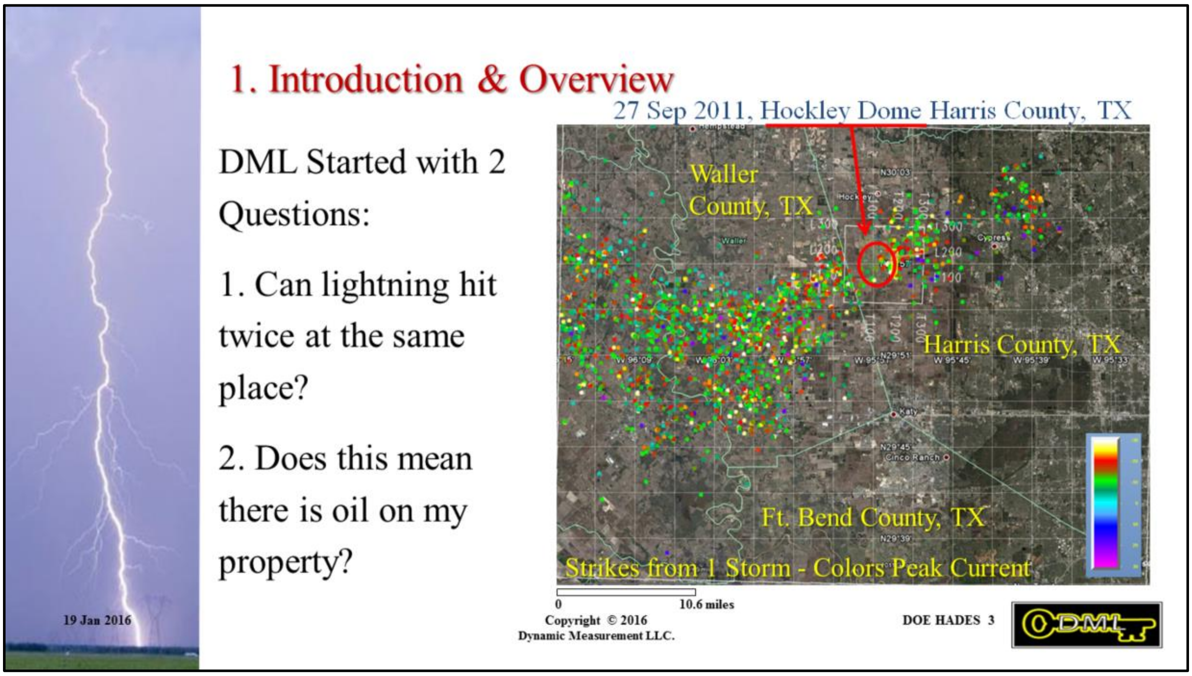
Laura Garchar (Fellow)
Science and Technology Policy Fellow
Geothermal Technologies Office
laura.garchar@ee.doe.gov

Laura Garchar invited DML to present to the HADES Lunch 'N Learn on 19 January 2016. Dr. Jim Siebert, DML Co-Founder and Chief Meteorologist at Fox News, is recovering from foot surgery and was not able to join us. Les Denham, DML Co-Founder and Geophysicist Extraordinaire was on a Linux system and he could hear us, but he could not be heard and so Roice Nelson gave the presentation. Roice introduced himself as being best known as a founder of Landmark Graphics Corporation, which built the first stand-alone seismic interpretation workstations for oil and gas exploration.

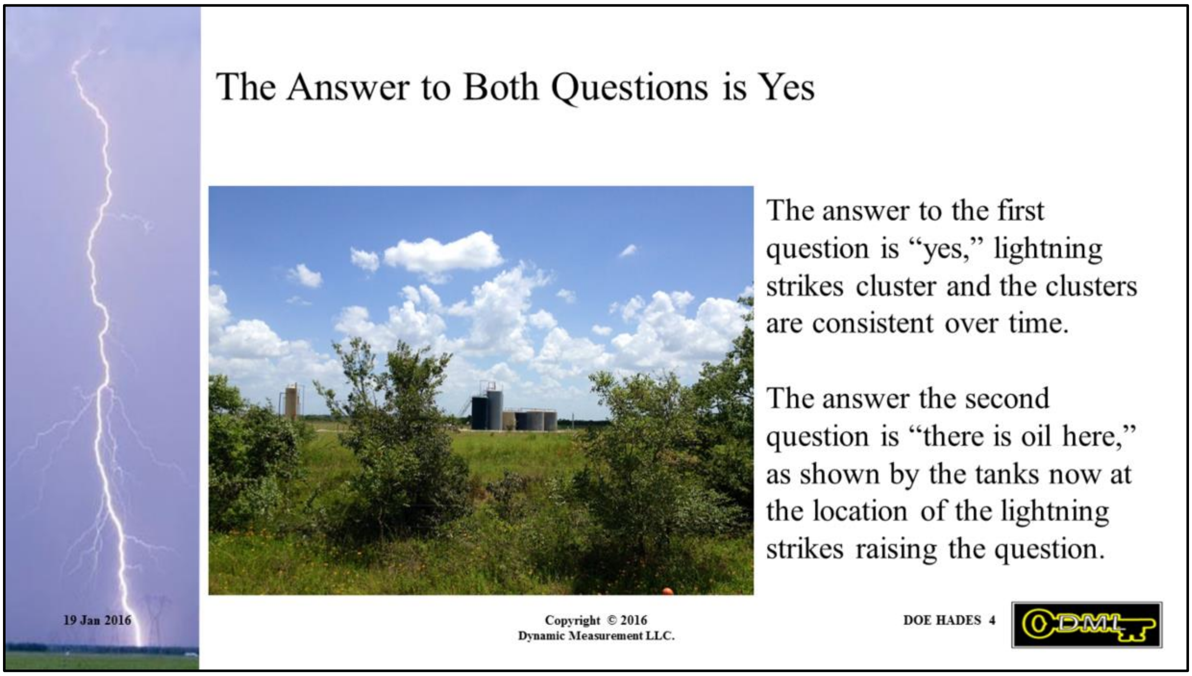
DML Outline

1. Introduction & Overview
2. Lightning Attributes & Databases
3. Calculating Rock Properties & Volumes
4. Geothermal Opportunities
5. Next Steps

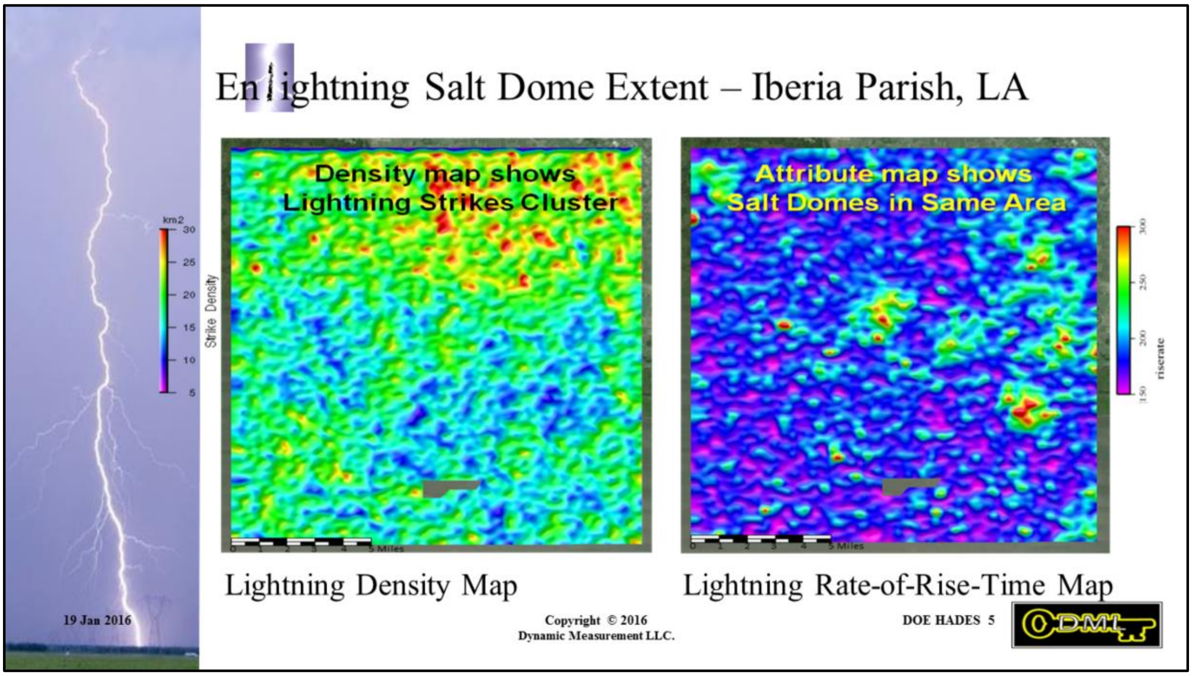
The topics to be covered are as outlined here.



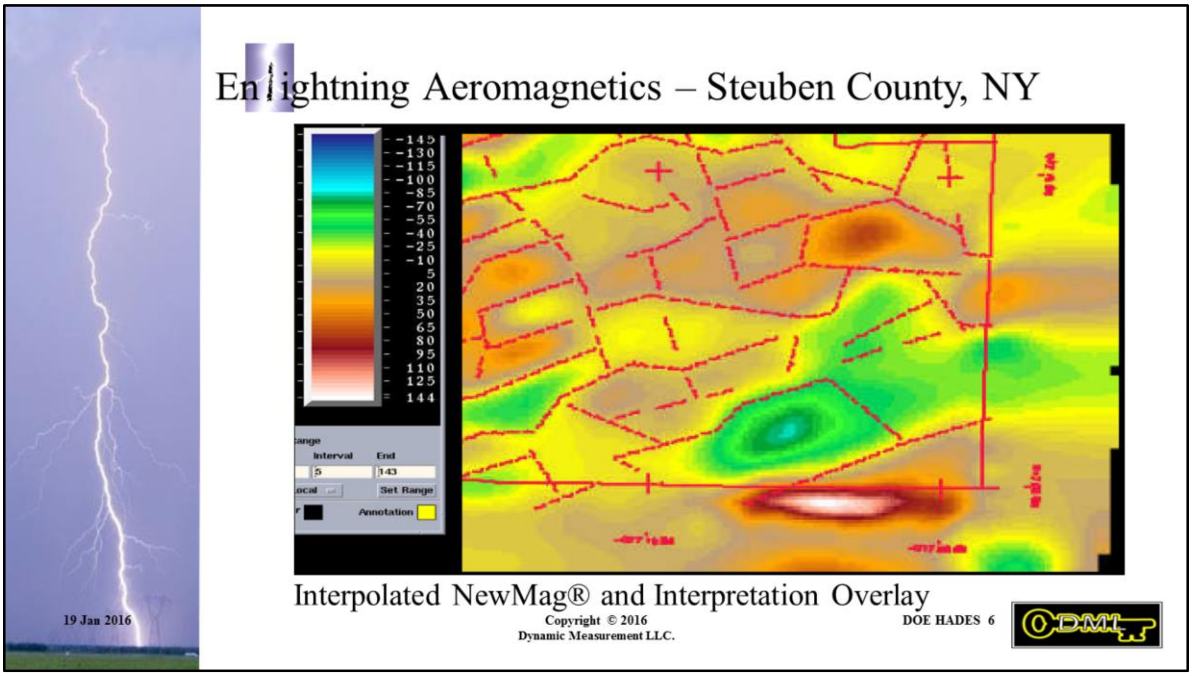
The possibility of using lightning databases to interpret geology started with two questions in 2006. Joe Roberts, a commercial Real Estate agent in West Houston, had spent several years negotiating for mineral rights under some property he bought on the east flank of the Hockley Salt Dome. He was hunting ducks and a storm came up. There was a lightning strike just in front of his truck which scared him enough he remembered it. The next year he was back at the same place hunting ducks another storm came up and struck the same place. He drove to Roice Nelson's place and asked, "Can lightning can strike twice in the same place?" And if so, "Does it mean there is oil on his property?" Then on September 27th, 2011 he was out at his property again, and there were lightning strikes all around him and his truck. He was sure he was going to be killed. The map above shows the lightning strikes associated with this one storm. The colors of the strike location are Peak Current. This map was DML's first on-site confirmation the lightning databases accurately reflect what happens when a storm comes through.



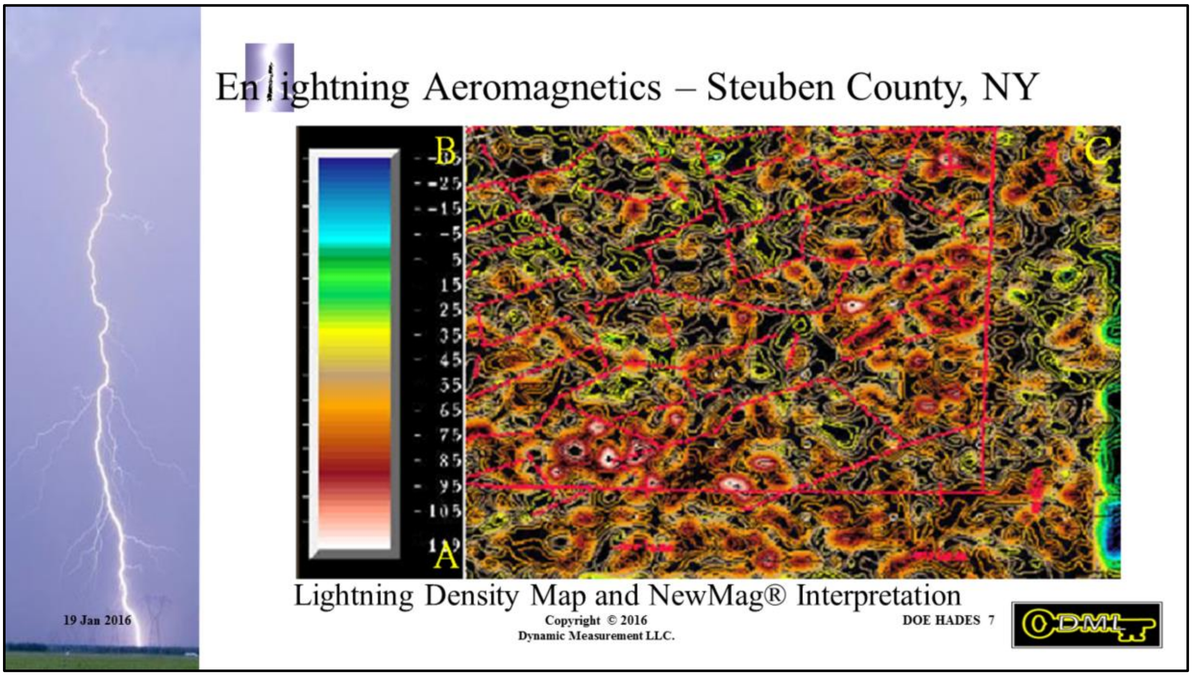
The answer to both questions is "Yes." DML has found lightning strikes cluster and these clusters are somewhat consistent over time. In terms of "is there oil under my property?", the photo of the newly placed oil tanks above show there is production where the concept was first recognized. The next 10 slides highlight some of the things we have learned since 2008, when we first started working with this new geophysical data type. Note, DML has presentations backing up each of these 10 slides, which go into more detail and provide context for the results presented introducing this new way to map geology.



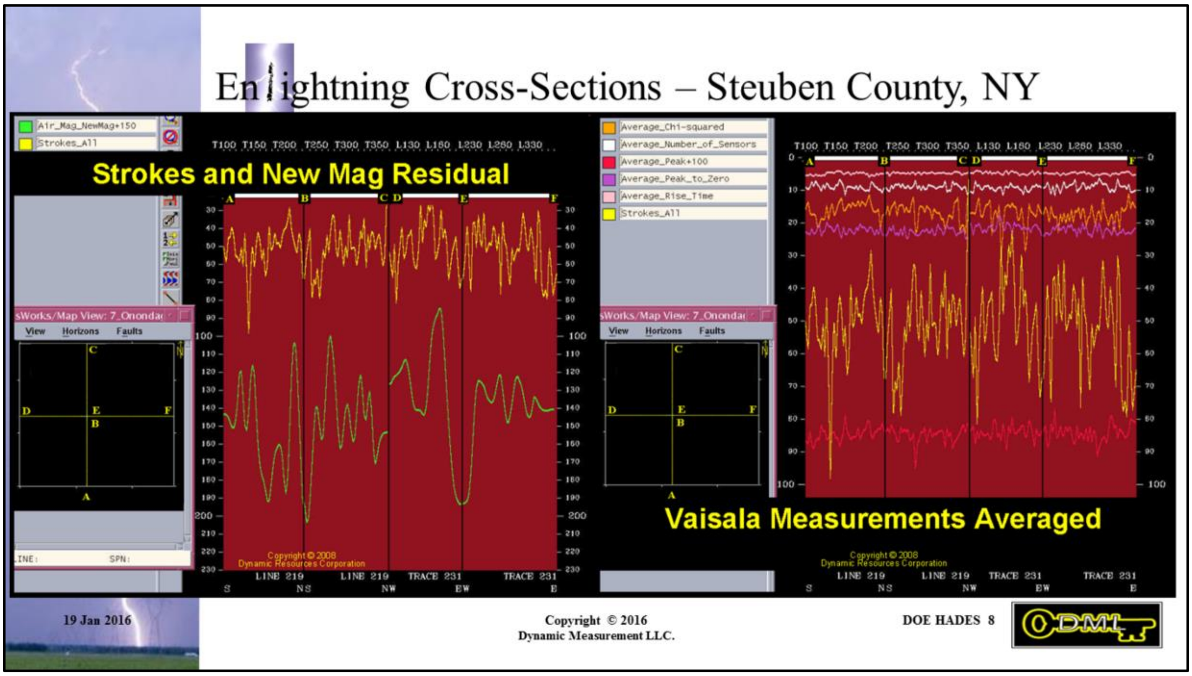
The map on the left shows lightning density in Iberia Parish, Louisiana. Reds are the highest strike density with 30 strikes per grid cell. The blues are the lowest strike density at 10 strike per grid cell. This same type of lightning density clustering has been found from Arizona to Florida, and from Michigan to South Texas. Zooming in on lightning density maps, lineaments have been shown to be related to fault trends, pinchouts, and subsurface geology. The map on the right shows one of many lightning attribute maps for the same area: Rate of Rise-Time. Note the three circular areas, far northwest corner, center, and on trend on the east side. These circular anomalies are the locations of large salt domes in this area.



This is a residual aeromagnetic map, NewMag®, covering part of Steuben County, New York. The red overlay is an interpretation of the residual air mag data showing the location of basement concordant faulting. I anticipate Air mag is one of the tools DOE is using to map basement faults as part of the process to identify potential geothermal deposits.



This image shows the air mag interpretation of basement faulting overlain on a lightning density map in the same part of Steuben County, New York. This was the first project DML did back in 2008 and the strongest lightning density areas are the dark red surrounding white contours. Note the strongest lightning concentrations are at basement fault intersections. Also note there seems to be a consistency of lightning density within different basement fault blocks. DML expects this is because subsurface earth currents, known as telluric or terralevis currents, are the primary control for lightning strike locations. Different fault blocks appear to be charged differently. Note map corner locations A, B, and C.



This image shows cross-sections from A to B to C and beyond. On the left image the yellow curve is strike density and the green curve is NewMag® from Applied Geophysics in Salt Lake City, Utah. The image on the right shows the key lightning attributes from the Vaisala database along these same cross-sections, including Rise-Time, Peak Current, and Peak-to-Zero time. Again, this was one of the first two projects DML did, and we have since been able to convert the vertical axis from measurement space to depth.

Enlightning Comparison of Air Mag & Lightning Prices

	Swath Size	1 km	200 meter	100 meter	50 meter
Aeromagnetic Price	Cost per 1 line km (price)	$65			
	Cost per 60 line km (factor)	$3,900			
	Cost per 1,000 line km (min)	$65,000			
	Cost per 3,600 sq km area (60 km long lines)	$234,000	$1,170,000	$2,340,000	$4,680,000
	Lightning Analysis Price		**$180,000**		

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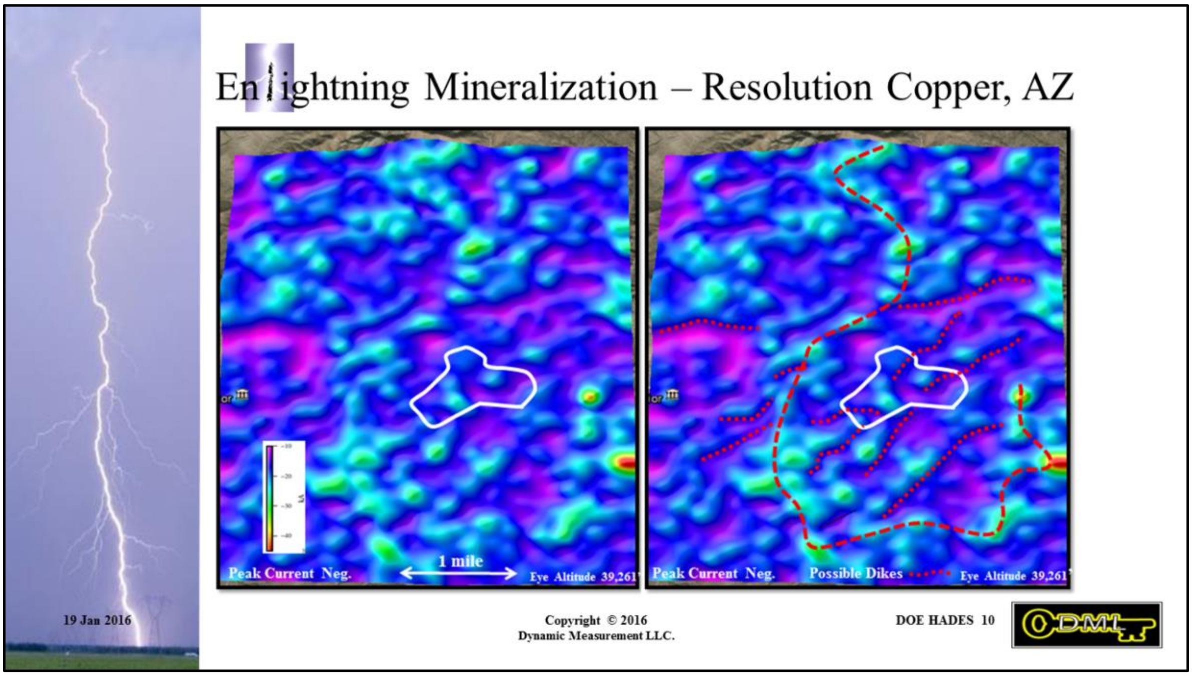
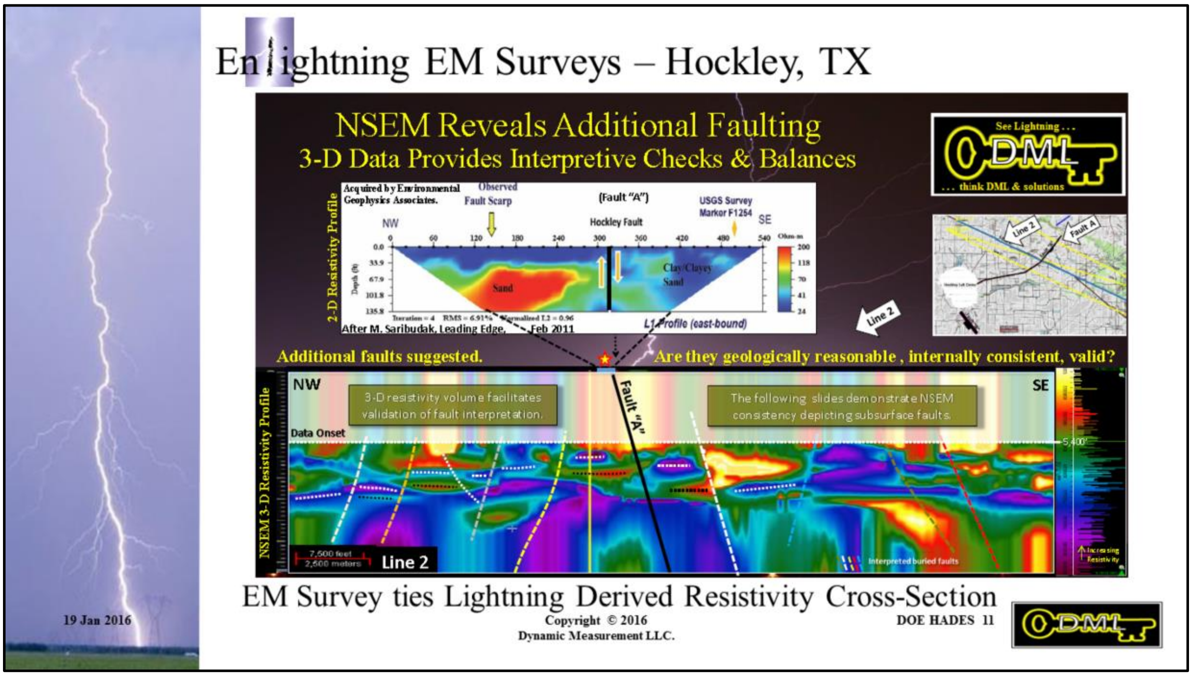
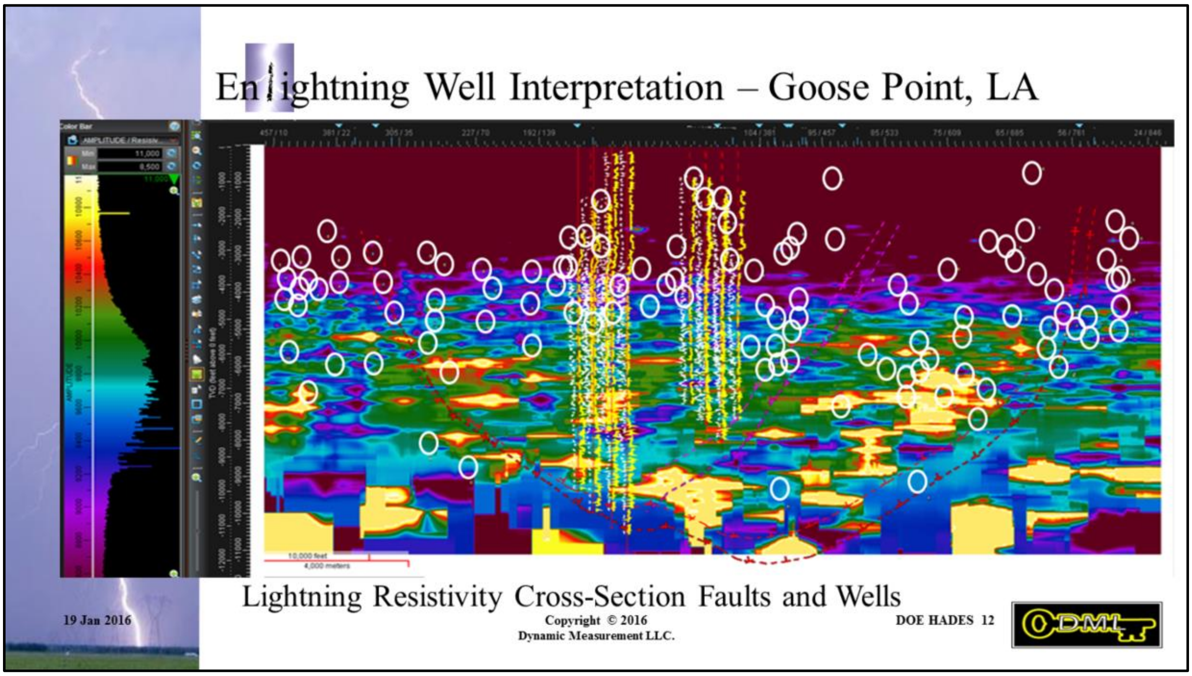
Any exploration data costs money, and the previous three slides emphasize the relationship between lightning data and aeromagnetic data. This slide demonstrates the cost of a lightning analysis is an order of magnitude less than the cost of an aeromagnetic survey, and of course this means a lightning analysis is around 2 orders of magnitude less cost than a 3-D seismic survey. Remember, a lightning analysis is not a silver bullet, rather it is a new geophysical data type, providing a different view of subsurface geology, and is best utilized integrated with and in conjunction with other exploration data types.



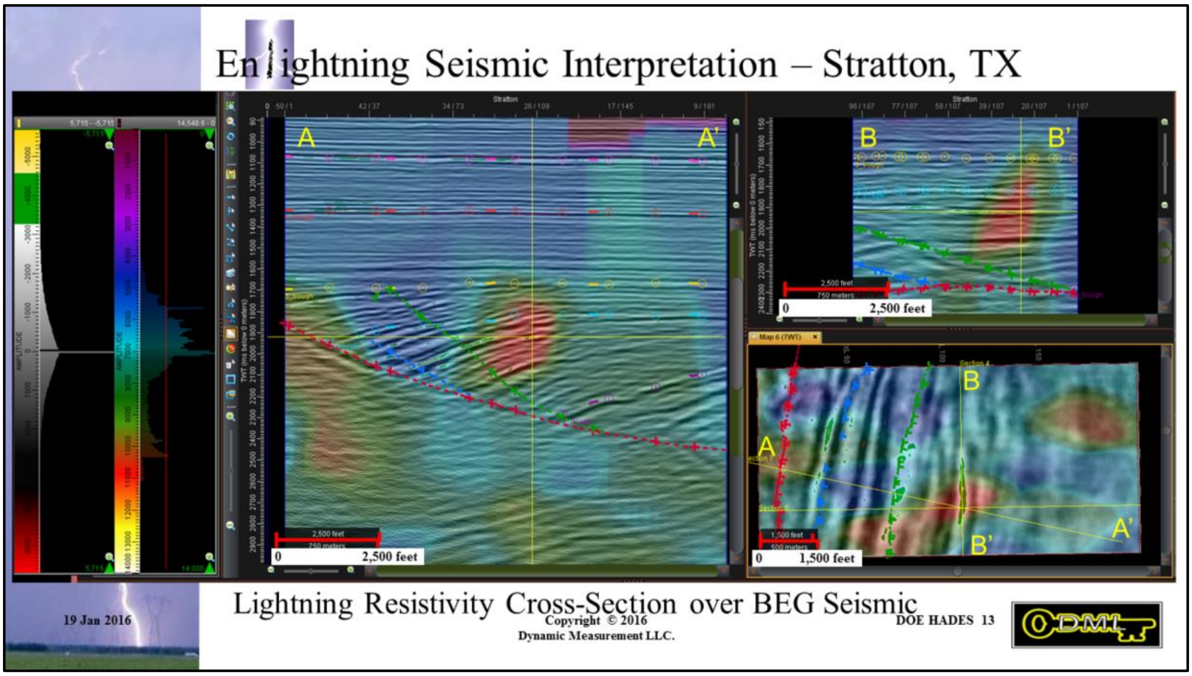
This example is from the Resolution Copper Mine near Superior, Arizona. Here, in this desert, there are about 2 lightning strikes per square kilometer per year, or about 30 lightning strikes per square kilometer over 15 years of lightning data. Note the interpreted red mineralization halo surrounding the copper porphyry mine location. The smaller dashed red lines are possible volcanic sills through the area. Note in the Mojave Desert of California there are an average of 0.5 lightning strikes per square kilometer per year. This is still 9 lightning strikes per square kilometer over the 18 years of data currently in the evergreen database. In Texas and Louisiana there can be 14+ lightning strikes per square kilometer per year, which means over 18 years you have an average of up to 250 strikes per square kilometer per year.



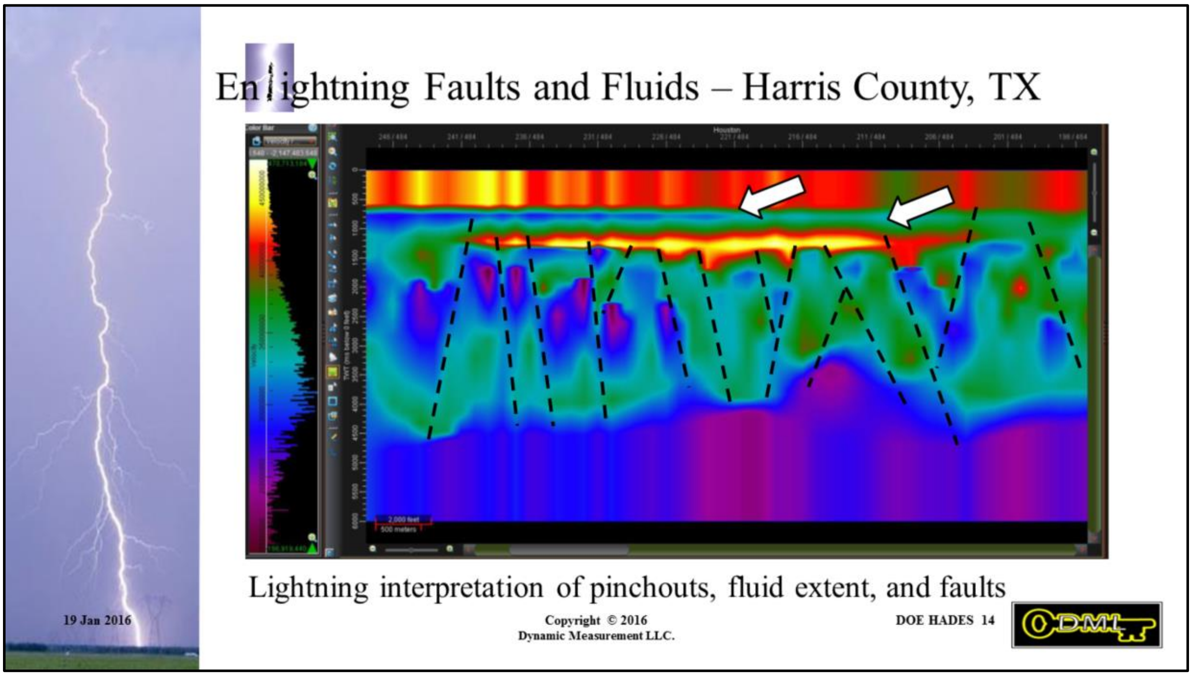
This is an example from Hockley, Texas where there is a known fault that comes to the surface. This fault was imaged with a standard EM Resistivity survey, shown in the top cross-section. You can see the strong resistivity contrast on either side of the fault, with higher resistivity on the left (west) side of the section. The results on a cross-section generated from the lightning database shows the same results. Note all of the additional faults interpreted on this cross-section. These anomalies and the fault interpretations are consistent and can be followed from line to line across the area. Again note we have entire presentations showing the development of each of these interpretation results.



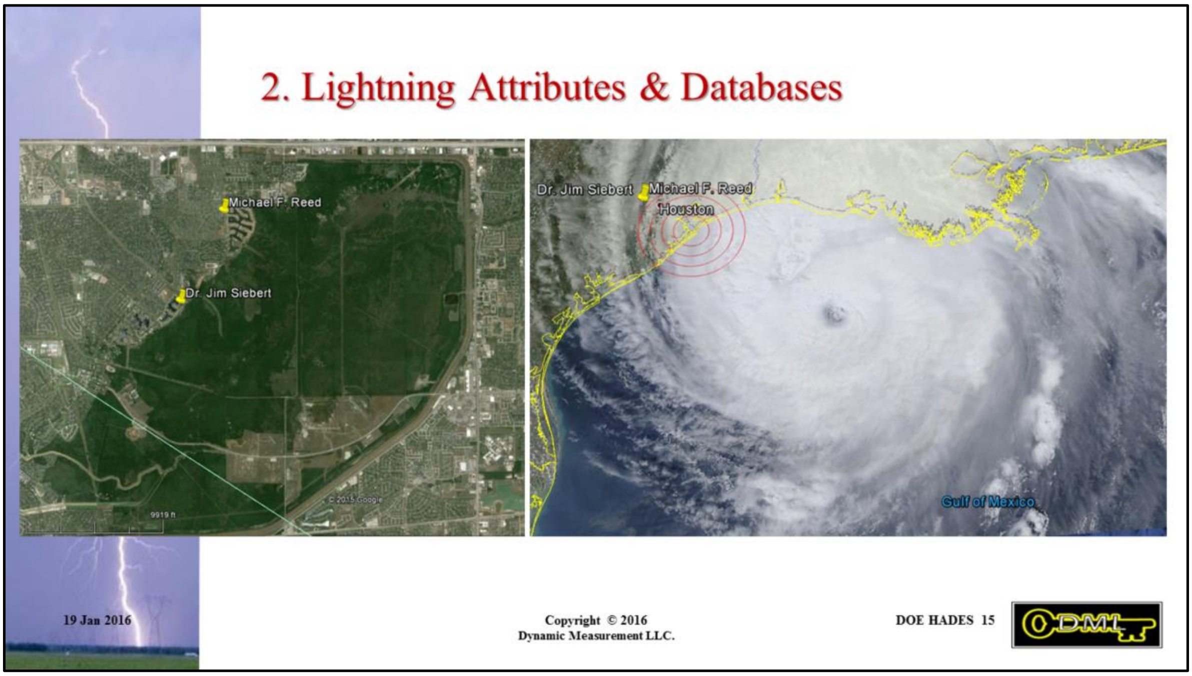
This example is from Goose Point on the north shore of Lake Ponchartrain, Louisiana. The circles show the control for the interpolated resistivity along this arbitrary cross-section.. The deepest well is 11,200 feet (forth from the left) and the shallowest well is at 7,200 feet (forth from the right). Notice the higher resistivity anomalies on the downthrown side of the large regional fault. Lightning analysis helped to tie down the location of this fault. The GCAGS (Gulf Coast Association of Geological Societies) gave DML Geologist Kathy Hagger best paper for the second year in a row based on the paper behind this image. GCAGS has awarded best paper to the same author twice before.



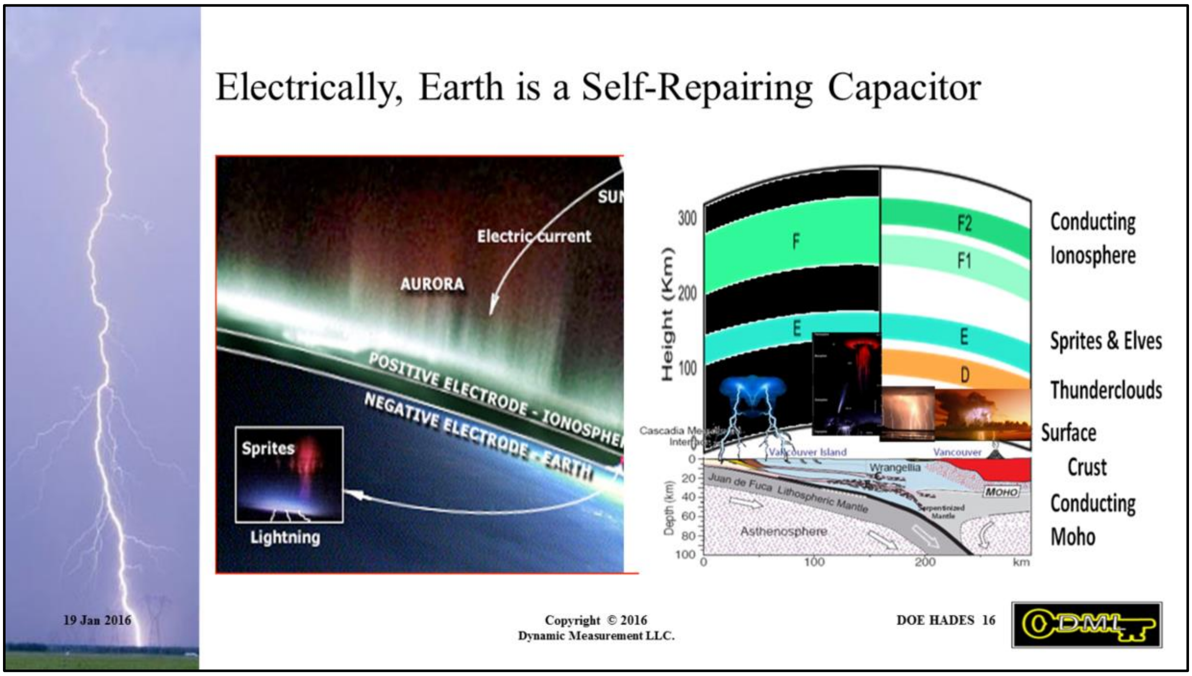
This example is from South Texas, close to Corpus Christi. Here a 3-D seismic survey, available from the BEG (Bureau of Economic Geology), was overlain with semi-transparent sections from a resistivity volume interpolated to the same line and trace spacing as the seismic. The higher resistivity red area in the center of cross-section A-A' is in the middle of the Vicksburg formation right where you would expect significant production. The strongest negative seismic amplitudes, colored green, are also exactly where this resistivity anomaly is. These negative seismic amplitude anomalies have proven to identify hydrocarbon accumulations in other 3-D seismic surveys I have worked in this area.



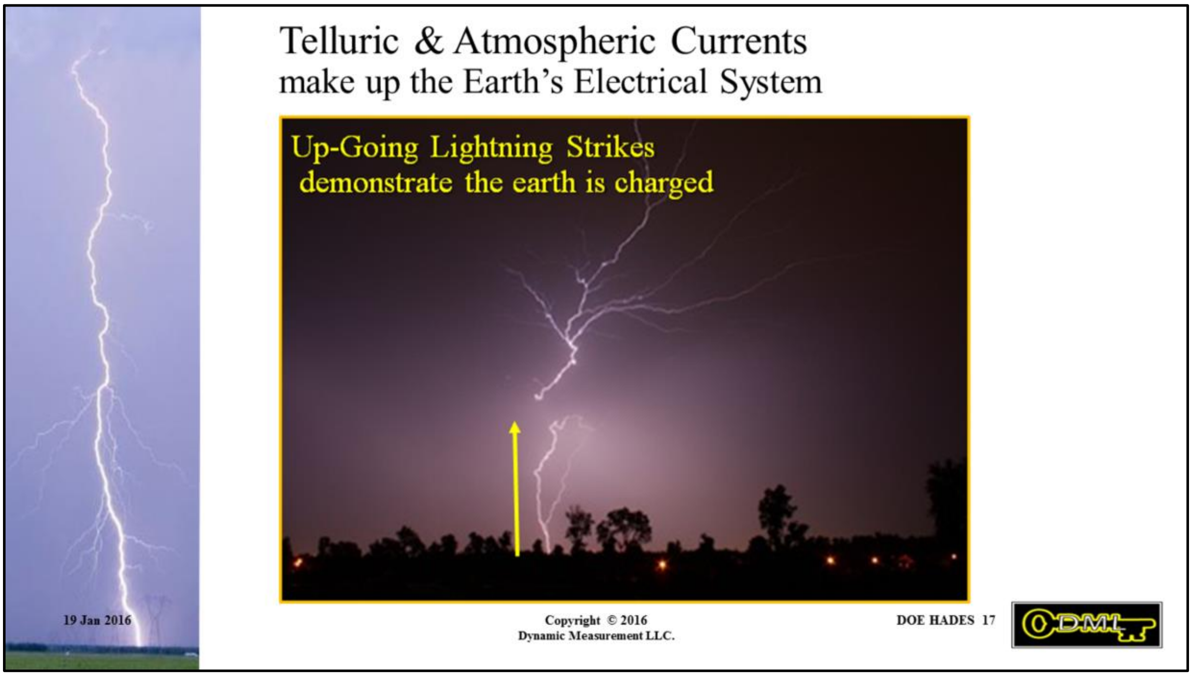
The last example is from the Houston, Texas area, just to the northwest of downtown Houston. Notice the shallow vertical striping at the top and the bottom of the section. This is interpolation of the first and last valid values. I will explain our assumptions in more detail later. As an introduction we assume the height of the lightning stroke source is related to the depth of the telluric electrical currents controlling the strike location. Notice the higher blue conductivity pinchout just underneath the red and yellow vertical stripping. The red/yellow higher resistivity lens is possibly a gas charged aquifer. Also the interpreted faults underneath the anomaly look very geological and they are consistent line to line as I will show at the end of the is presentation.



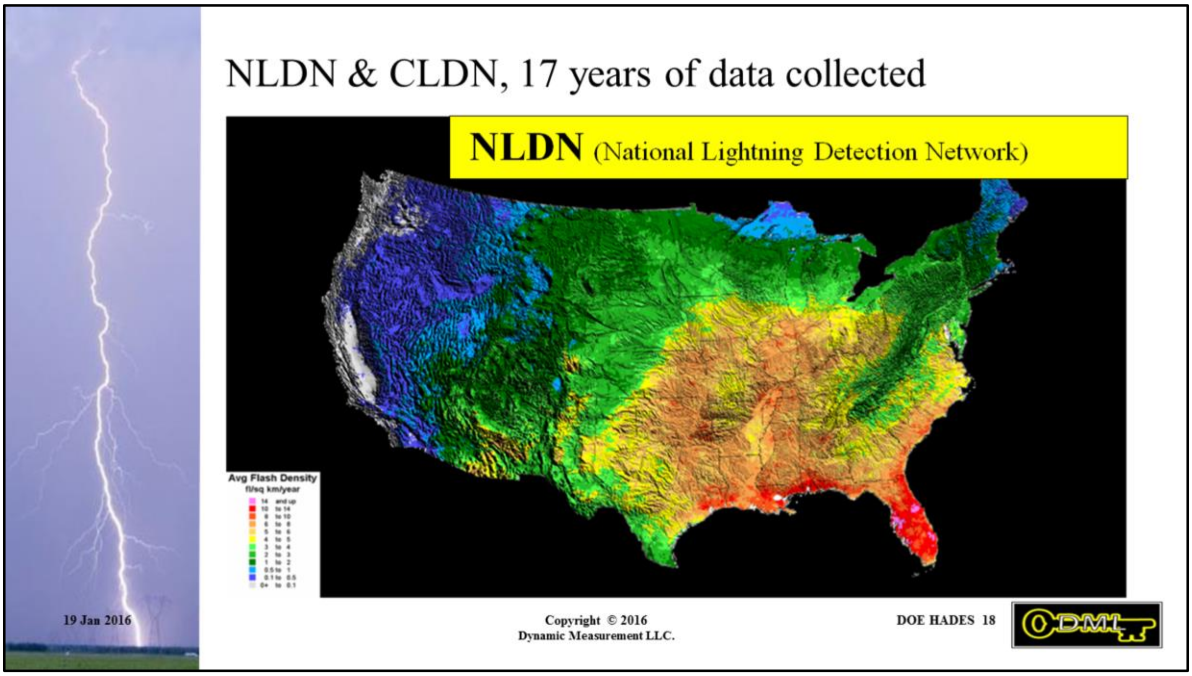
Dr. Jim Siebert, DML Co-Founder and Chief Meteorologist at Fox News Houston was going to present this portion of the presentation, which is why these two images were included, as his introduction.



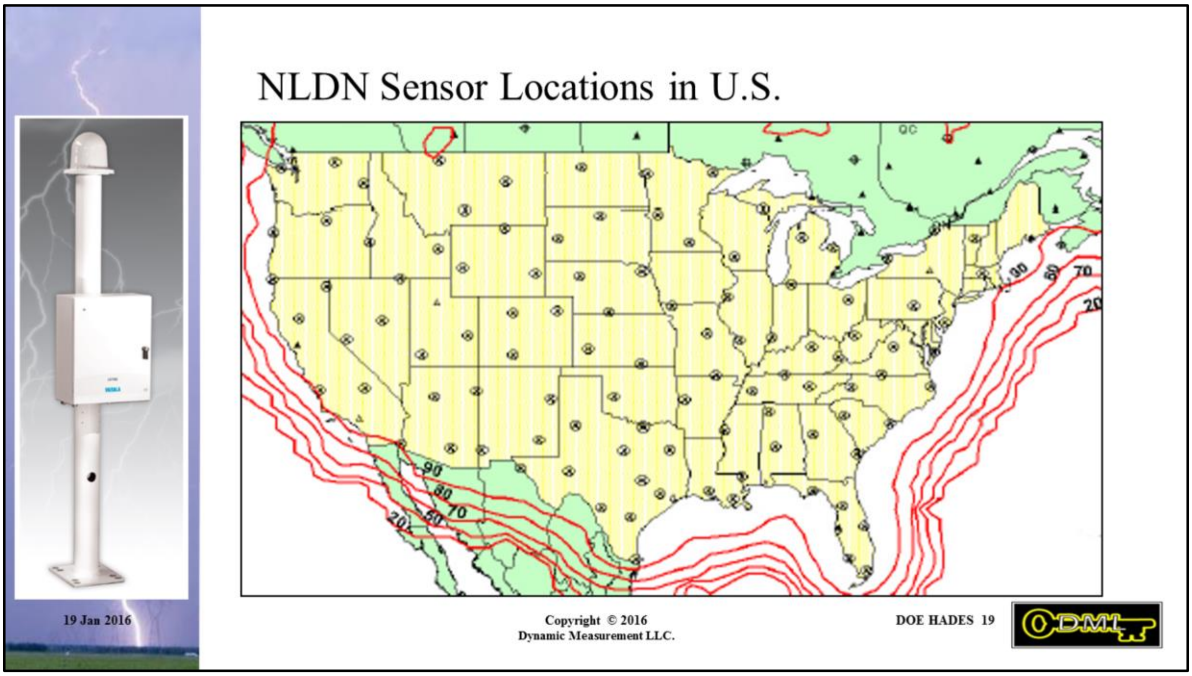
The earth's electrical system consists of the ionosphere, lightning strikes, and subsurface telluric currents. Like all electrical systems, all components are tied together. Cosmic rays from the sun charge the ionosphere. Energy from the ionosphere goes into the earth charging telluric currents via the Aurora Borealis and the Aurora Australis, and the atmosperhic-telluric capacitor is kept in balance with lightning strikes.



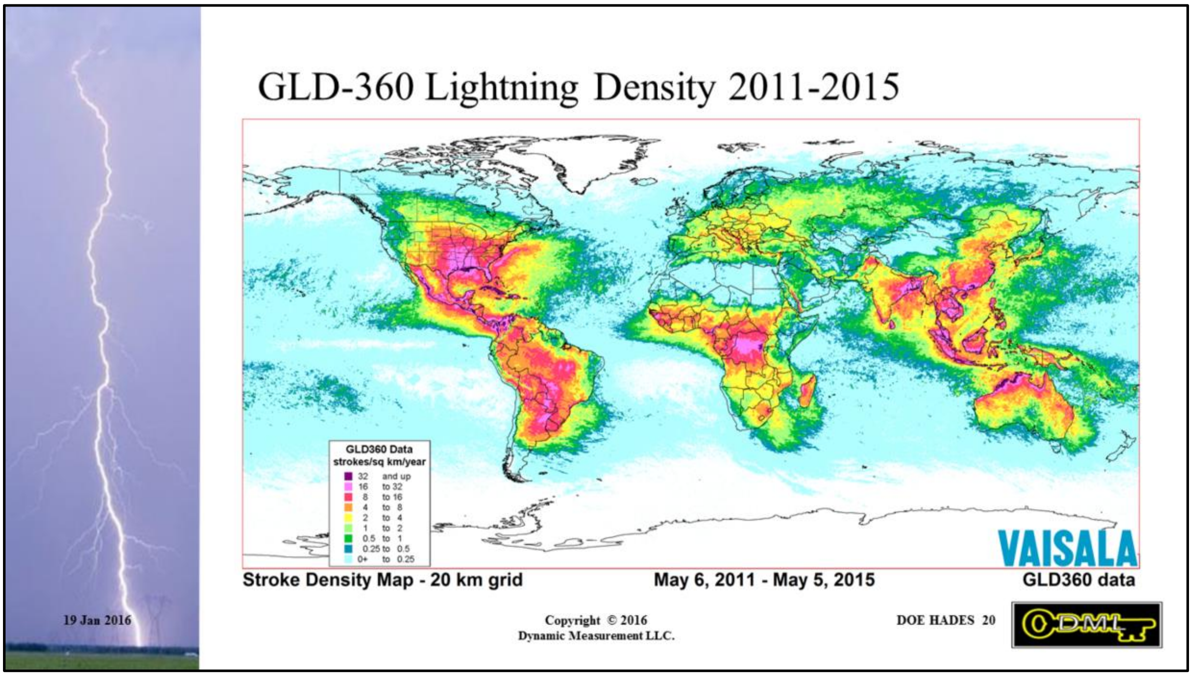
This image shows lightning going up from the ground, showing the earth can be charged enough to send an up-going lightning strike. With each lightning strike, once the leaders come down from the cloud and reaches the ground, it creates an ionized channel with virtually zero resistance. Lightning can travels 250 kilometers cloud to cloud before it goes to ground. It goes to ground primarily due to shallow earth currents. Topography (mountains), infrastructure (radio towers, etc.), and vegetation (oak and elm and pine trees) have an impact on lightning strike locations, but are not the primary control on strike location.



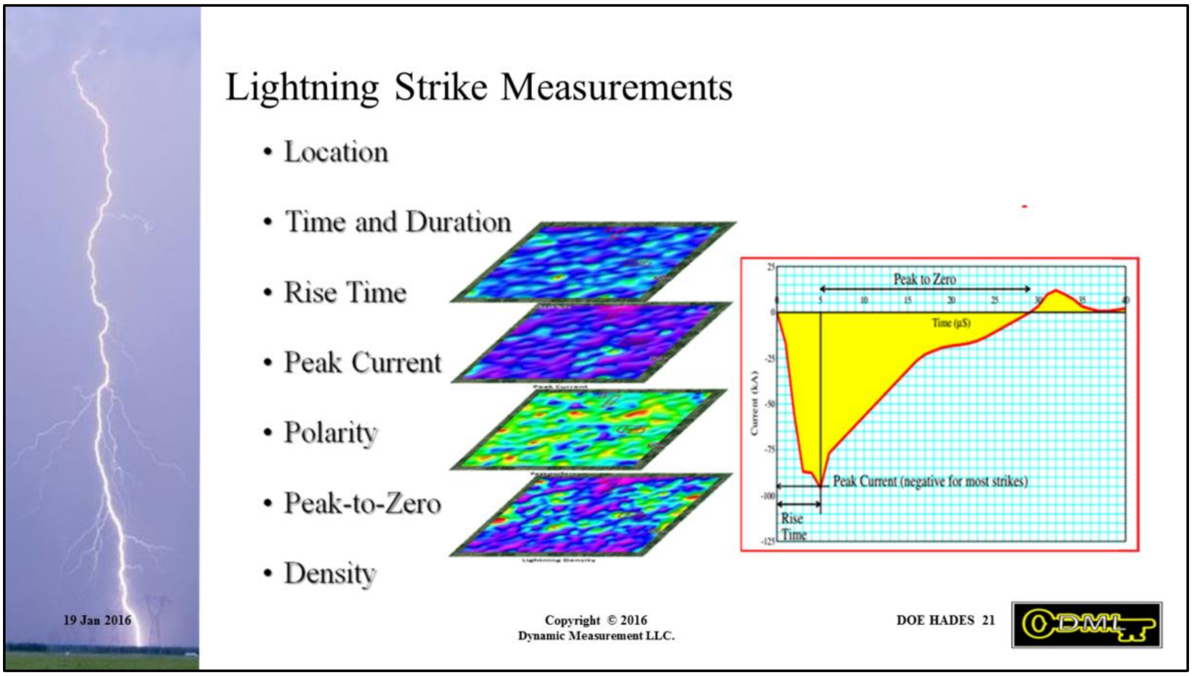
In North America lightning strikes are monitored by the National Lightning Detection Network (NLDN) and the Canadian Lightning Detection Network (CLDN). The CLDN is owned by the Crown and is maintained by Vaisala, a Helsinki lightning instrumentation company. Vaisala also owns and maintains the NLDN. The NLDN is primarily selling data to insurance companies monitoring claims for lightning damage, meteorologists who show lightning strikes locations on the evening weather reports, and for safety warnings to places like airports and golf courses. DML is opening a new business area for Vaisala, and has an exclusive to sublicense and use their data for geologic application like exploring for natural resources.



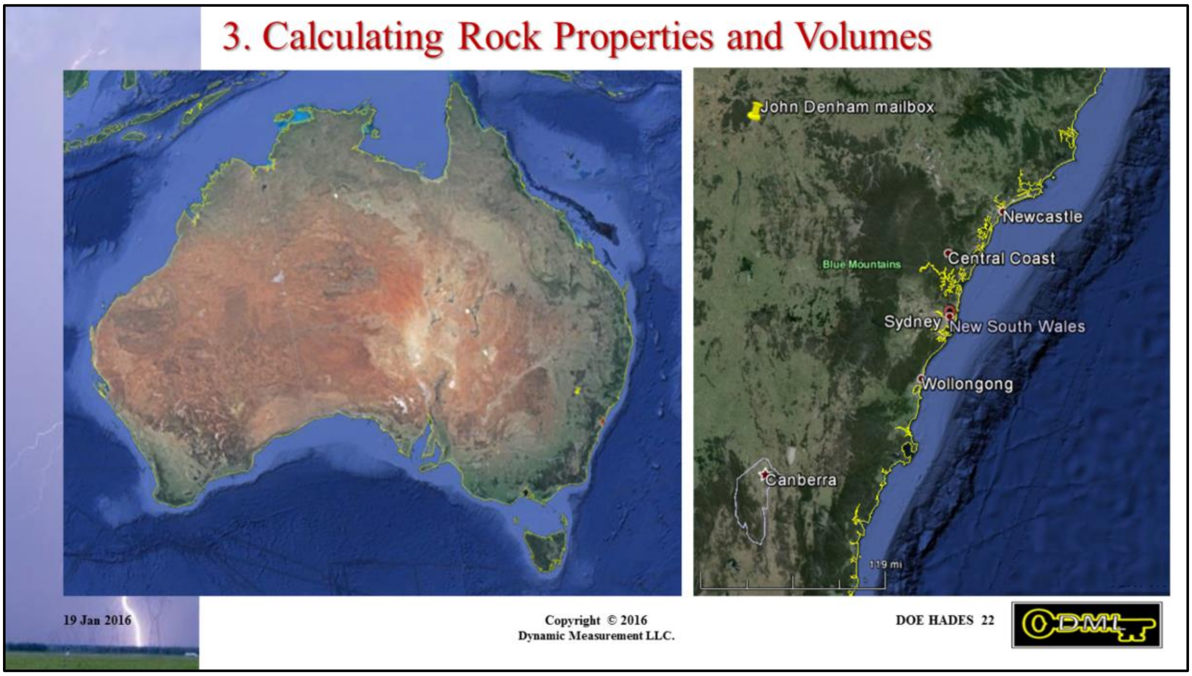
The NLDN consists of 115 lightning detectors. Each detector is about 6 feet tall as shown to the left. A typical lightning strike in Texas is picked up on between 16 and 24 lightning sensors. This means sensors within about 600 miles of the strike contribute to triangulation of the strike location, and the associated recorded lightning attributes. The electromagnetic pulse emanating from lightning striking the ground is traveling at close to the speed of light, and times are measured to the nearest microsecond, explaining the 100 meter location accuracy and fidelity of data in the NLDN.



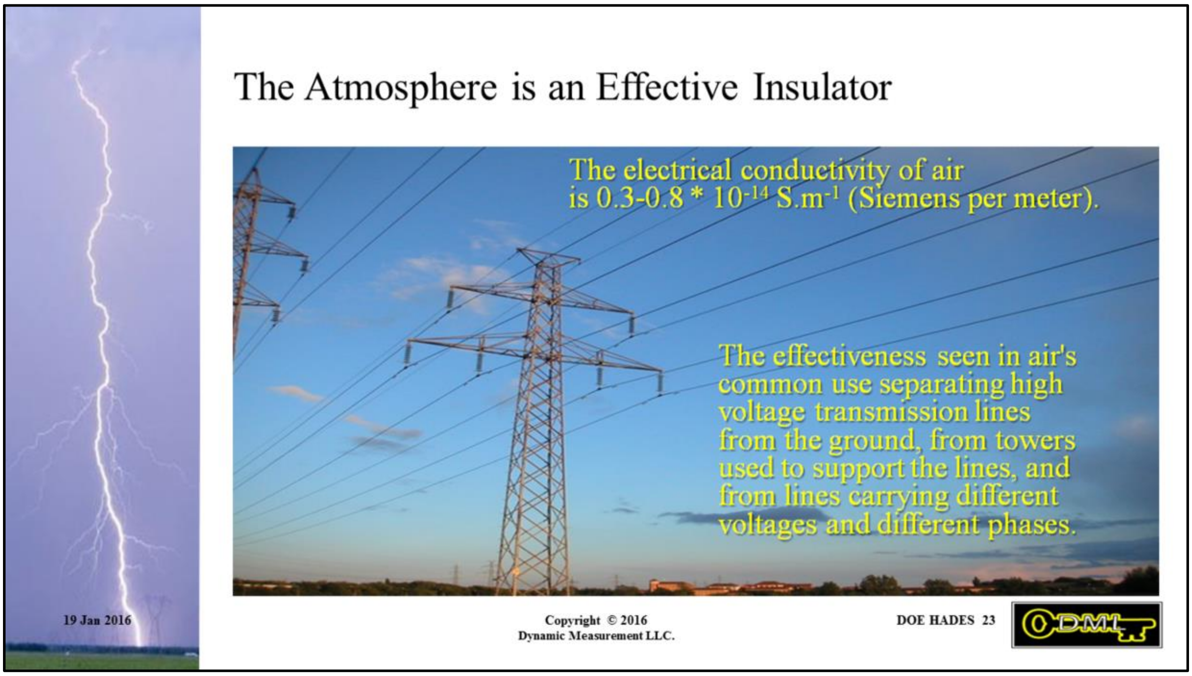
Since DML started working with the Vaisala lightning database, a new technology has been developed by Vaisala which provides lightning stroke time and location information worldwide. The location accuracy is about an order of magnitude less than the NLDN data because the sensors are much further apart and because the sensors use VLF (Very Low Frequency) measurement techniques. DML has demonstrated there is a good tie between GLD-360 and NLDN data with the Resolution Copper project in Arizona.



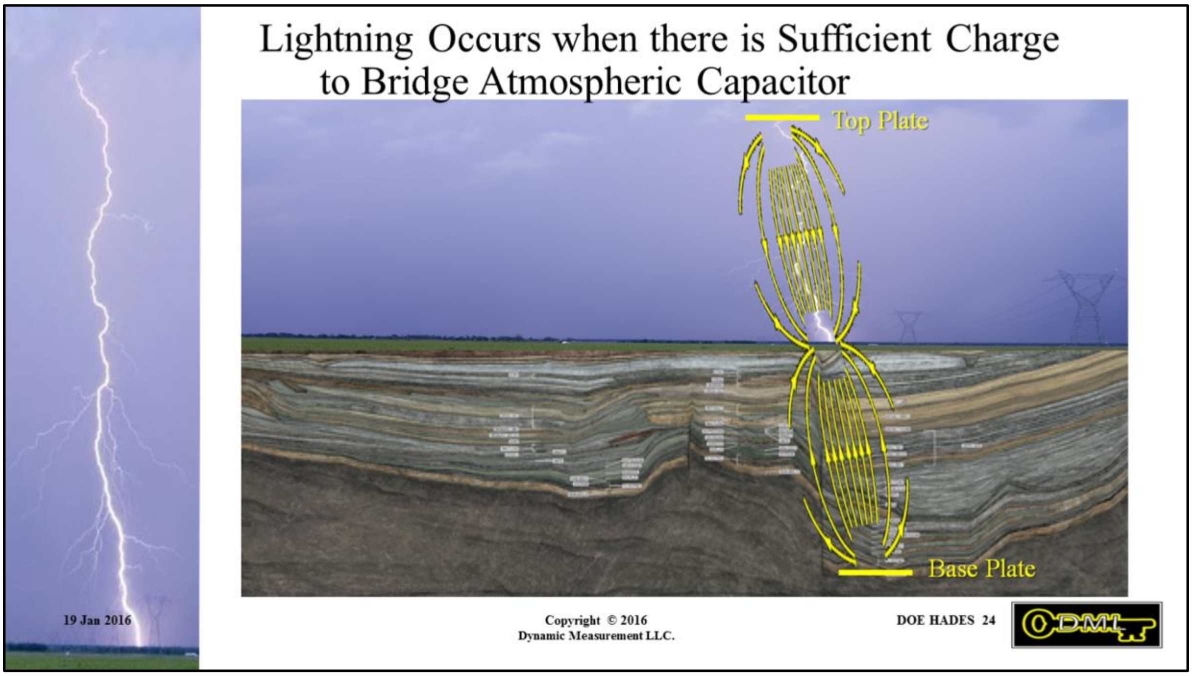
These are the key lightning attributes available from the lightning NLDN database. Lightning strike locations are calculated with about 100 meter accuracy. However, DML has demonstrated geologic lineaments like faults and stratigraphic pinchouts can have a horizontal accuracy of 5-20 meters. This is the same order of location accuracy as a 3-D seismic survey. The time the lightning strike occurs is measured to the nearest microsecond, which is a key requirement for integrating the same lightning stroke information recorded on multiple sensors. The duration of the lightning strike consists of the Rise-Time plus the Peak-to-Zero time. Rise-Time measures the time from energy exceeding background electrical noise to the Peak Current. Peak-to-Zero time measures the time from Peak Current back to the background electrical noise. Peak Current is measured in Kilo-Amps and can have negative or positive polarity. About 90% of lightning strikes are negative polarity and originate with negative charge build-up at the base of clouds. Knowing the location of each strike, DML bins the strikes and sums the number of strikes in bins to come up with lightning strike density.



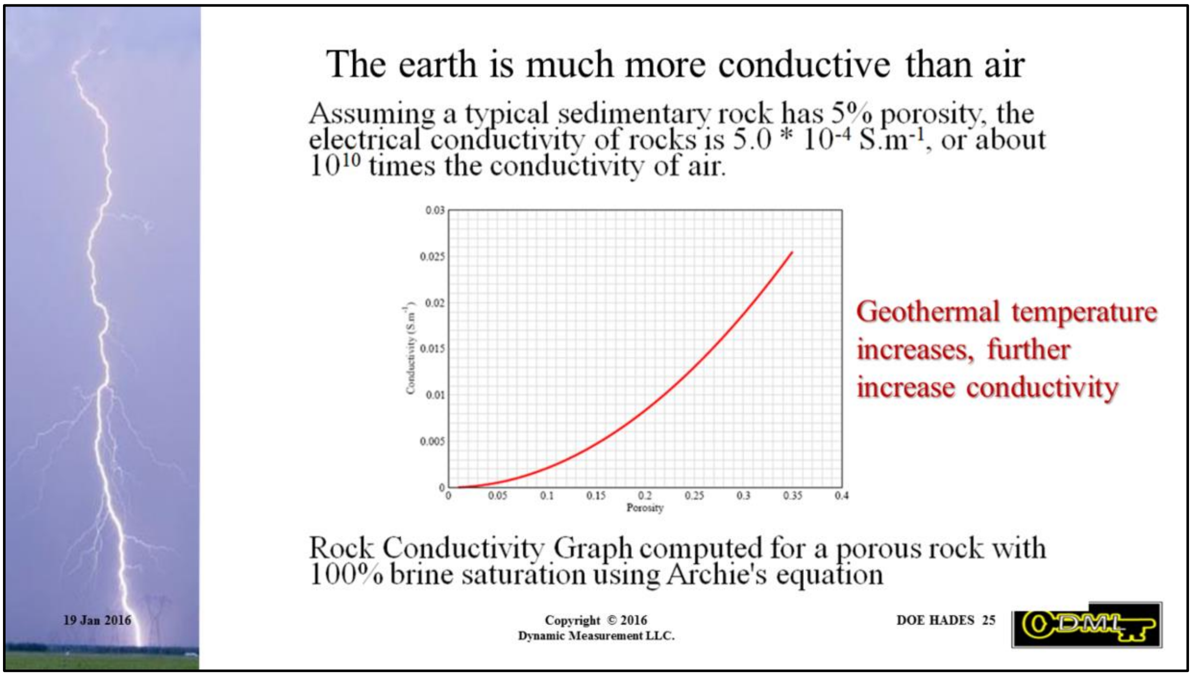
Algorithm development and processing of lightning databases is coordinated by Les Denham, an Australian Geophysicist with about 60 years experience. Les has worked all across the world, including in Antarctica and Greenland, with most of his time spent doing seismic interpretation. Les was going to give this part of the presentation, and it turns out we could not hear him, so Roice gave the entire presentation.



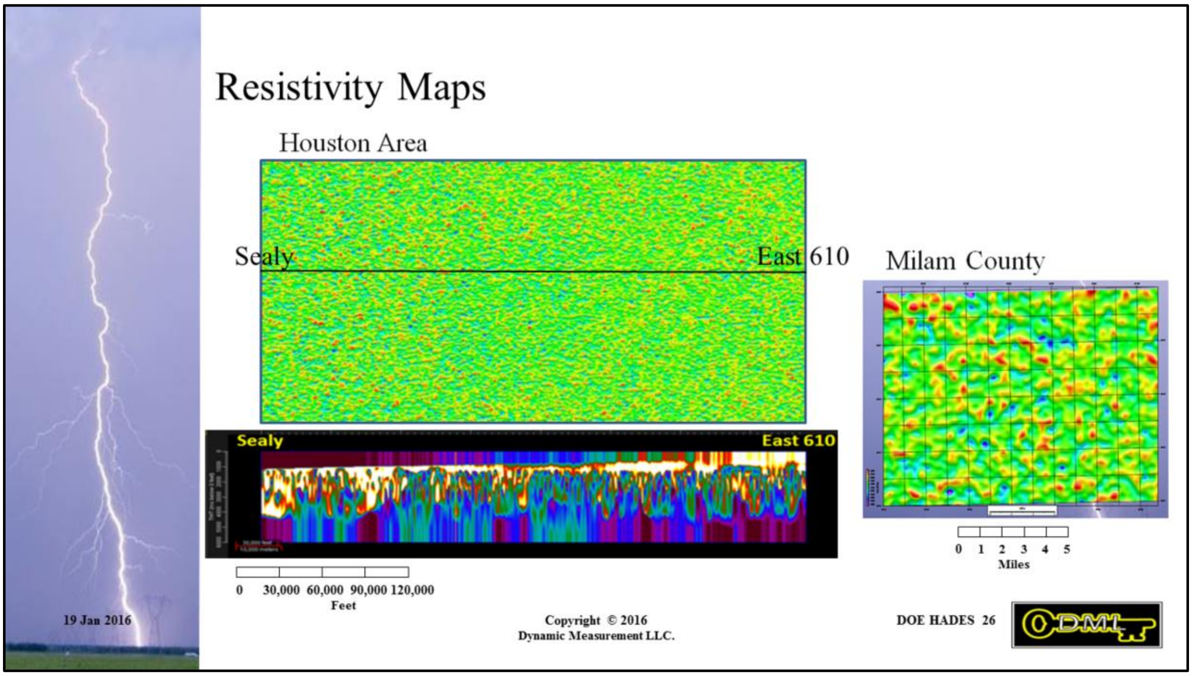
We know the atmosphere is a very effective insulator, as is shown by how high power transmission lines do not spark across the gap (unless you throw bailing wire across the transmission line, which I assure you from personal experience causes a very big spark). In terms of electrical conductivity, air is 10 to the -14 Siemens per meter. Only if something more conductive connects two power lines, like a bird or a hot air balloon, will there be an electrical connection between power lines.



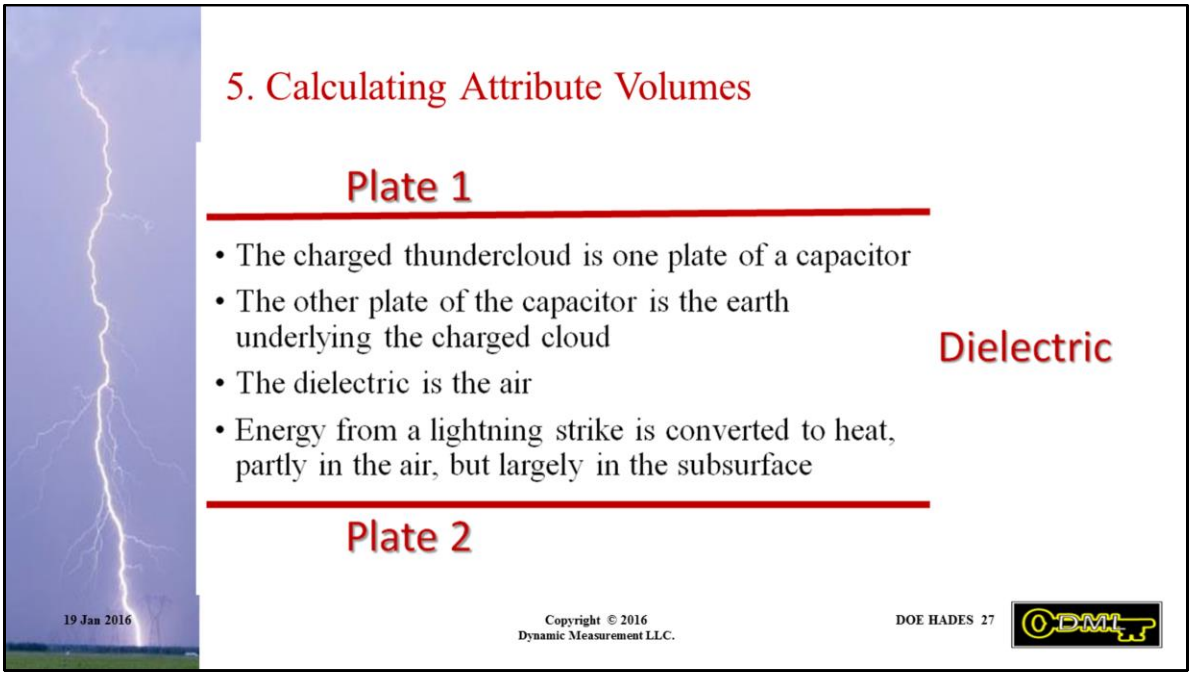
Lightning needs to build up a tremendous charge to bridge 1,000 to 15,000 feet of atmosphere. The new idea Dynamic Measurement has been pursuing is that the path of these lightning conduits through the atmosphere is guided by the combination of electrical currents around the static buildup in the clouds and interaction with electrical currents in the subsurface of the earth. Our initial assumption is that the electrical flux lines driving this connection is symmetric around the surface of the earth, as shown in the cartoon above.



An important factor is the earth is much more conductive than air. This graph shows rock conductivity for a porous rock with 100% brine saturation using Archie's equation. Note that geological conductivity is 10 to the -4 Siemens per meter, or which is about 10 to the 10^{th} times more conductive that the atmosphere. This difference makes a very good case for the impact of subsurface electrical currents on guiding lighting strike locations. We anticipate geothermal temperatures will further increase conductivity. Thus we anticipate the tools we have developed for lightning analysis will be enhanced when exploring for geothermal deposits.



From the lightning databases DML has developed ways to calculate surface resistivity and resistivity volumes. The large map above shows resistivity distributions from Sealy to the San Jacinto Monument east of I-610 in Harris County, Texas. The map to the right is resistivity over a much smaller area northwest of Houston in Milam County, Texas. The resolution on the large map would look similar to the smaller map if the map were zoomed in on. The cross-section on the bottom is a vertical cross-section from a resistivity volume calculated from the lightning database. Note this cross-section crosses the major metropolitan area of Houston, and infrastructure seems to have a minor impact on data quality and continuity. DML has a US patent for the process of using lightning databases for natural resource exploration. This patent was issued 01 January 2013.



The first volumes Les figured out how to create were resistivity volumes. The concept starts with the fact lightning strikes are an electric breakdown across a capacitor. The upper plate is the source of the lightning strike in the clouds, The base capacitor is the accumulation of telluric currents in the subsurface underneath the charged clouds. Air and geology make up the dielectric between the plates. Energy from each lightning strike is converted to heat, partly in the air and largely in the subsurface.

Lightning a Dielectric Breakdown

- Lightning occurs when the voltage across the atmospheric capacitor exceeds the dielectric strength of the air.
- Resistance in the atmosphere is very low once the path is ionized.
- Resistance in the subsurface is approximately constant over long periods of time.
- Atmospheric factors vary with each stroke.

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A lightning stroke occurs when voltage across the atmospheric capacitor exceeds the dielectric strength of the air. As a static charge builds up in the clouds, lightning leaders work their way down towards the ground until they meet upcoming leaders. Once a connection is made, the path becomes ionized and there is basically no resistance in along the ionized stroke path. Over long periods of time the resistance and electrical currents in the subsurface is approximately constant. However, the atmosphere varies with each individual lightning stroke. The fact the geology is constant is what makes it possible to stack the data, similar to how we stack seismic traces, to increase single and decrease noise.

Can we separate rock resistance?

- The physics of lightning discharge are similar to the physics of a neon-tube relaxation oscillator.
- In each case, voltage builds across a capacitor until an insulating gas ionizes and becomes a conductor

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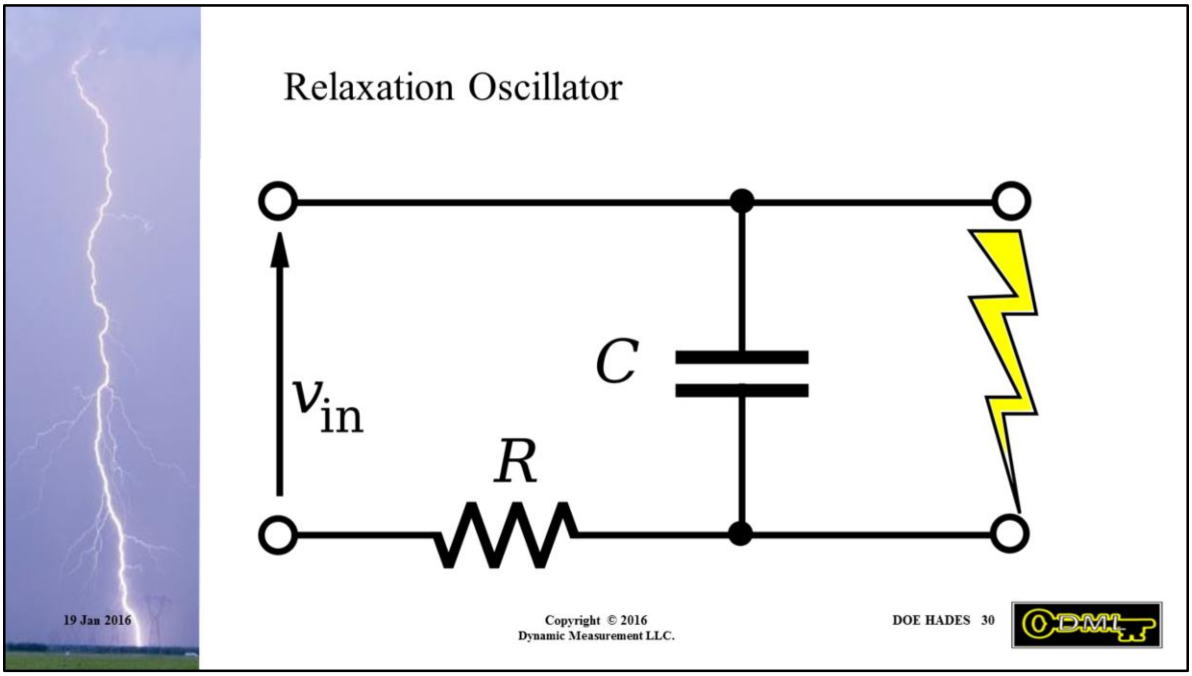
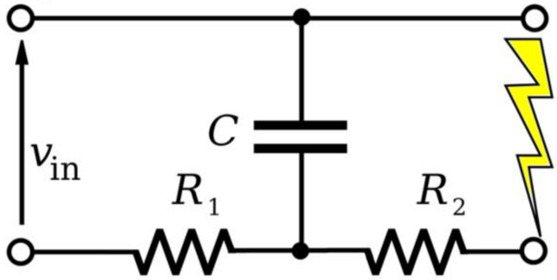
In looking for an analog to the physics of a lightning stroke, Les recognized each stroke is similar to the physics of a neon-tube relaxation oscillator. In each case, the voltage builds up across the capacitor until the insulating gas ionizes and becomes a conductor. Neon tubes have different colors because of the different inert gases which are placed in the tubes. Lightning is bright white because it includes all colors.



The image above is a circuit diagram for a relaxation oscillator. A voltage is put into the circuit, which builds up a charge across the capacitor until the spark discharges across the dielectric. When the voltage is sufficient for a continuous discharge, the sparks light up the inert gas in the neon tube.

Lightning

- The atmospheric capacitor is nearly the same
- Just an additional resistance (R_2) limiting the current
- R_2 is the resistance between the lightning strike point and the bottom plate of the capacitor



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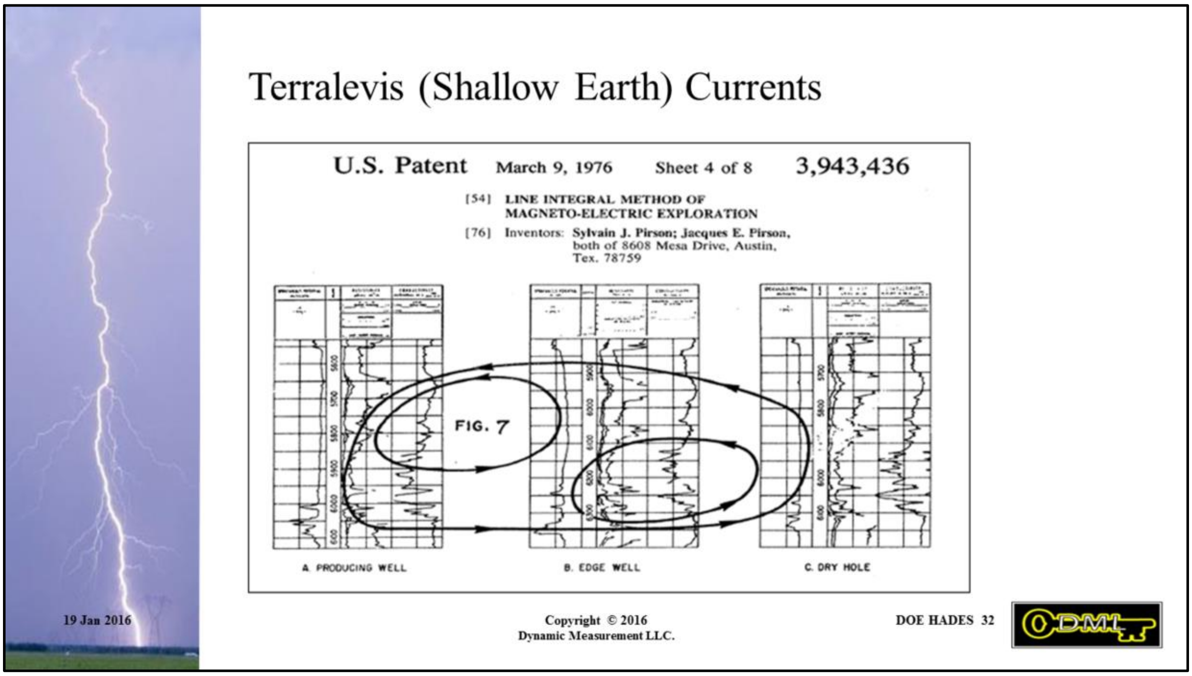
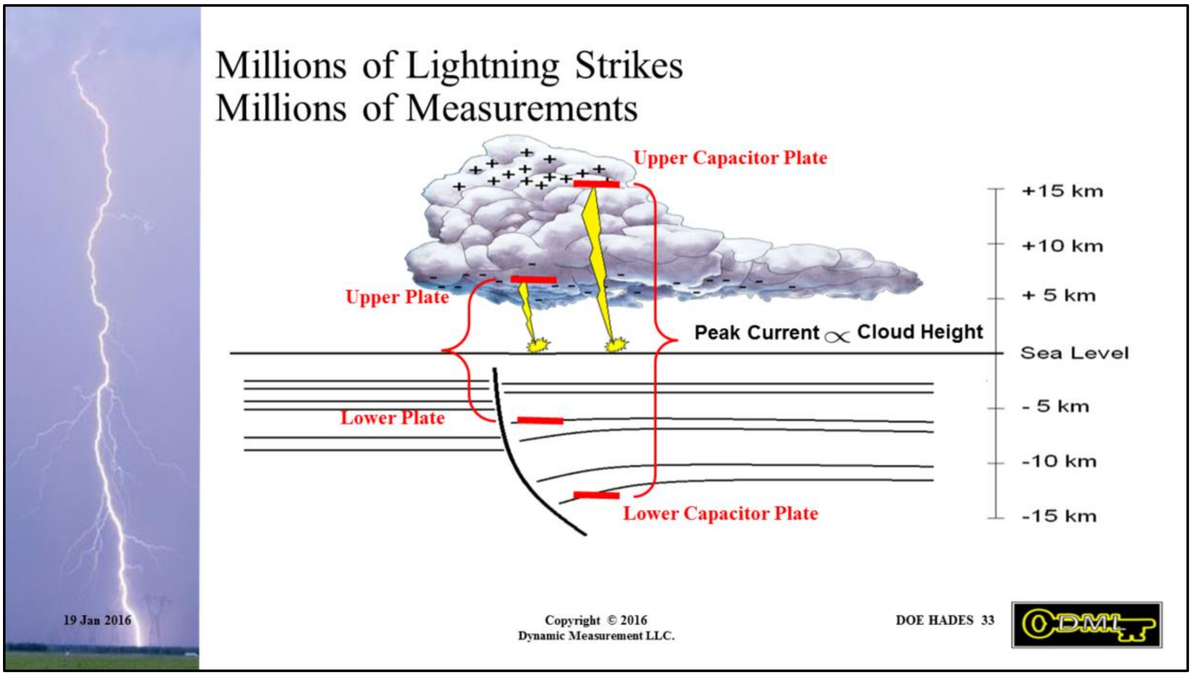
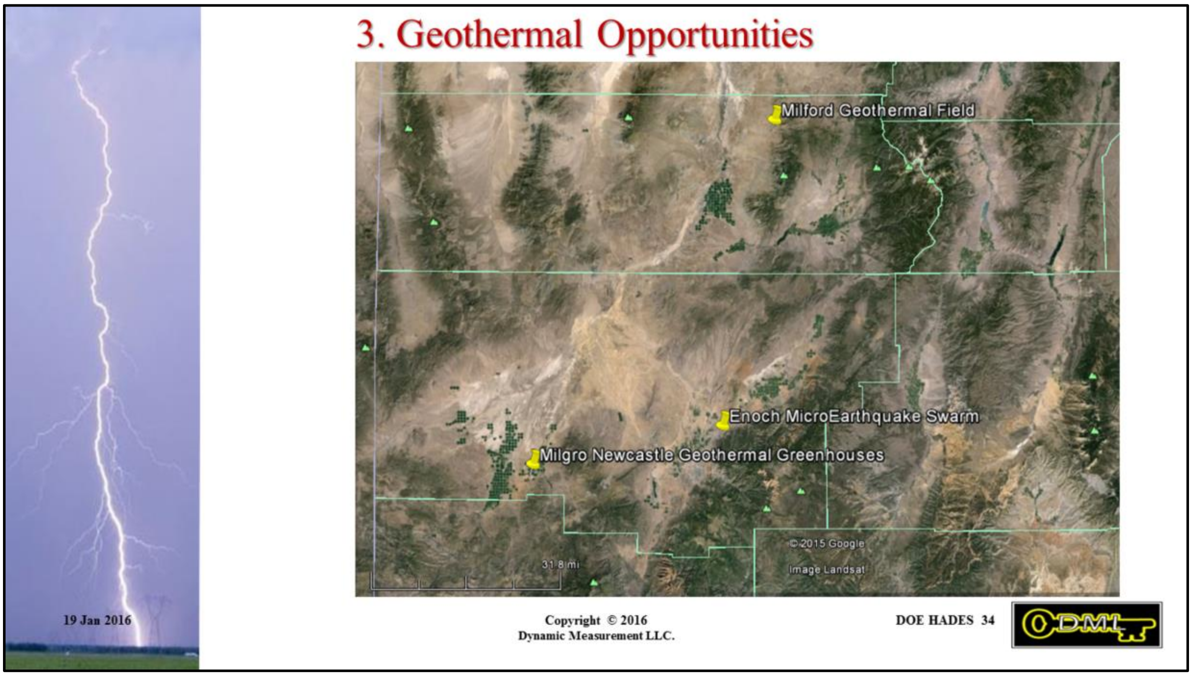
The electric circuit for lightning is similar. There is an addition resistance, the resistance of the earth between the lightning strike point and the bottom plate of the capacitor. Again, we are glad to do a webinar to go into this theory in more detail than is possible in the introductory presentation.



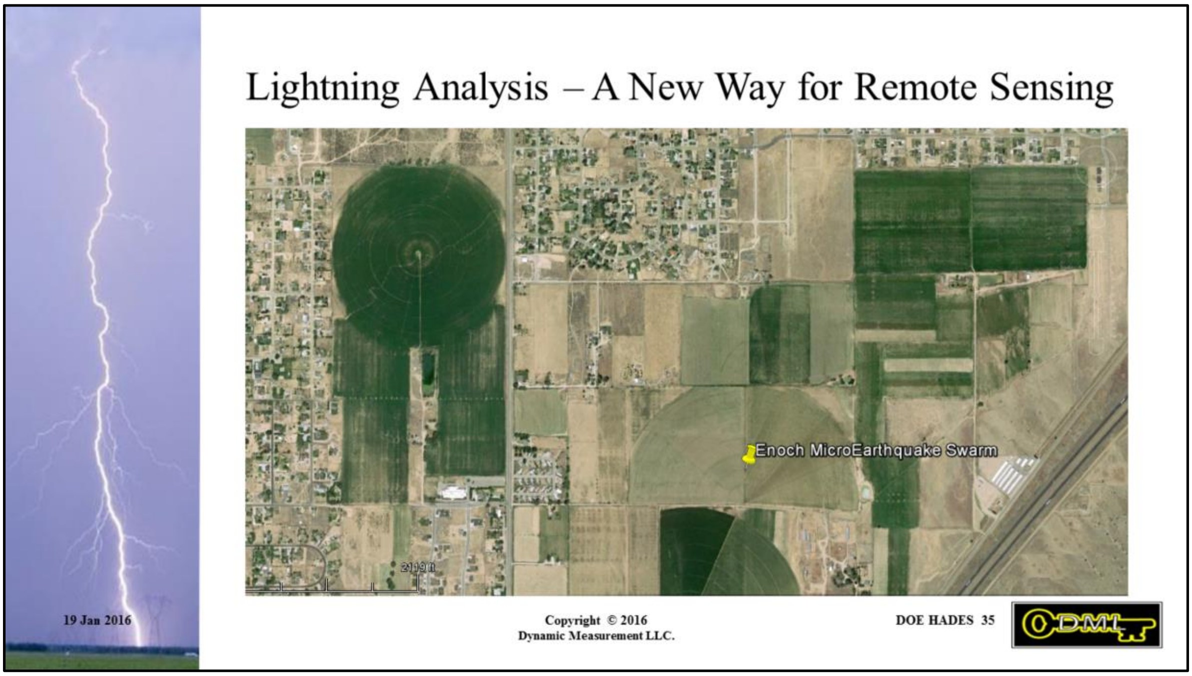
Particularly the oil and gas industry has known for decades about shallow earth currents. Terralevis is Latin for shallow earth. This example of subsurface current flow is from a patent issued in 1976 and shows shallow earth currents as defined on standard oil and gas electric logs.



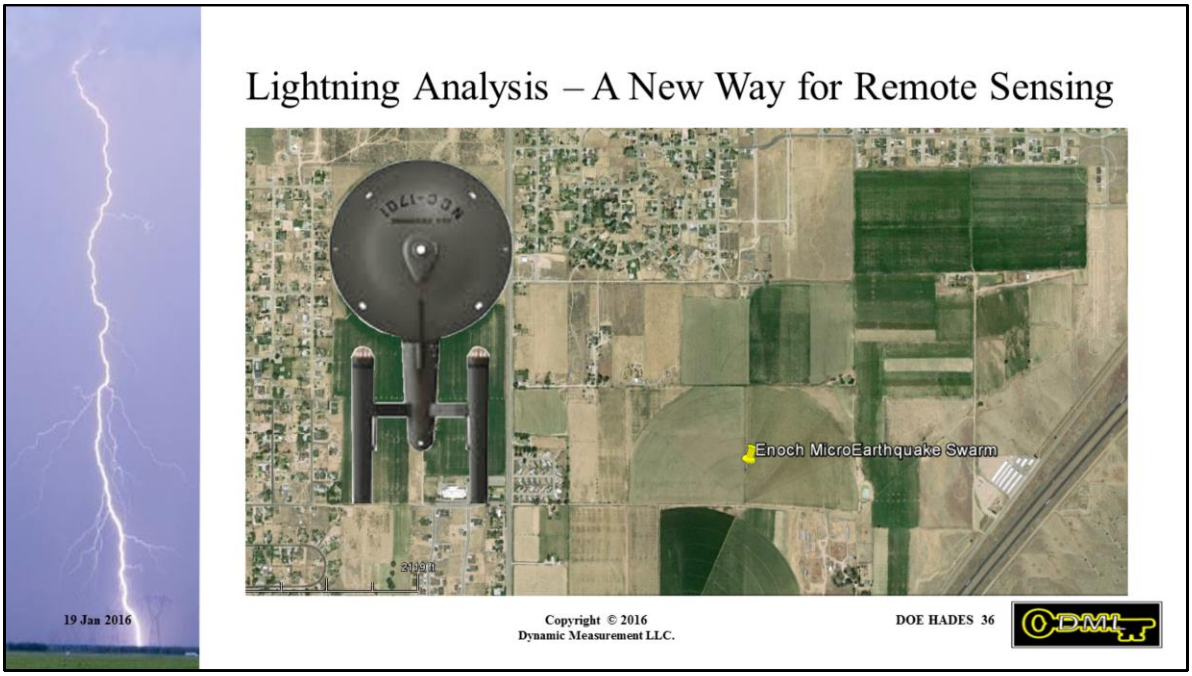
A key point to realize is that geology does not change over the time frames being discussed. Every lightning stoke in every storm is unique, like each snowflake is unique. Each stroke is part of a unique capacitor discharge. Most of the lightning strokes are negative, originating at the beginning and from the bottom of clouds. The stronger positive strikes come from the tops of the clouds at the end of the storms. These strokes are much stronger, because they have to travel so much farther through the 10 to the -14 Siemens per meter atmospheric dielectric. The Peak Current (positive or negative) is proportional to cloud height, and this is key to calculating resistivity points in the subsurface. Millions of lightning strike provide millions of subsurface resistivity and other attribute calculations. These calculated points are then interpolated to create resistivity, permittivity, rise-time, peak current, peak-to-zero, and other lightning attribute volumes.



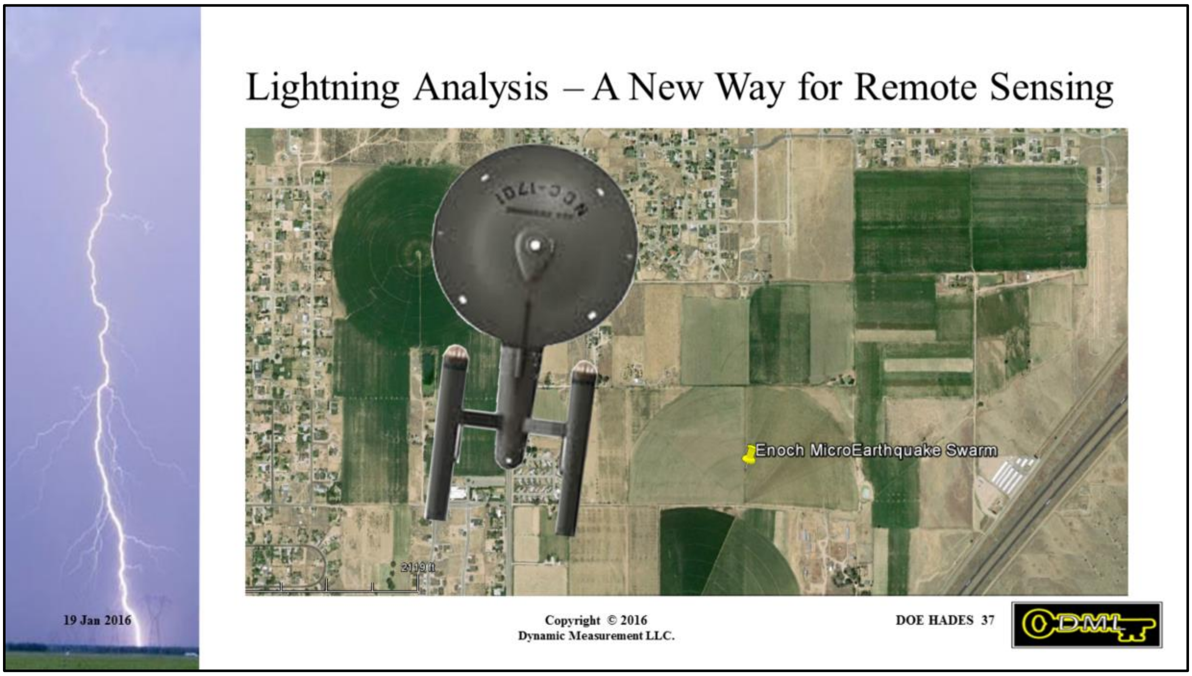
We think these lightning attribute maps and volumes have great potential in identifying, confirming, and ranking geothermal exploration opportunities. Roice Nelson lives in Cedar City, in southwestern Utah. There are two significant geothermal operations within 45 minutes of Cedar City. To the west, in Newcastle, is one of the most successful geothermal heated greenhouse operations there is. To the north is the very successful Milford geothermal power plant. Just north of Cedar City is one of the most active micro-earthquake swarms in the Rocky Mountains, which has been studied for years by University of Utah seismologists. Active micro-earthquakes often accompany geothermal opportunities, and it seems logical to merge lightning data and micro-earthquake data to see if a new and better picture of the subsurface results.



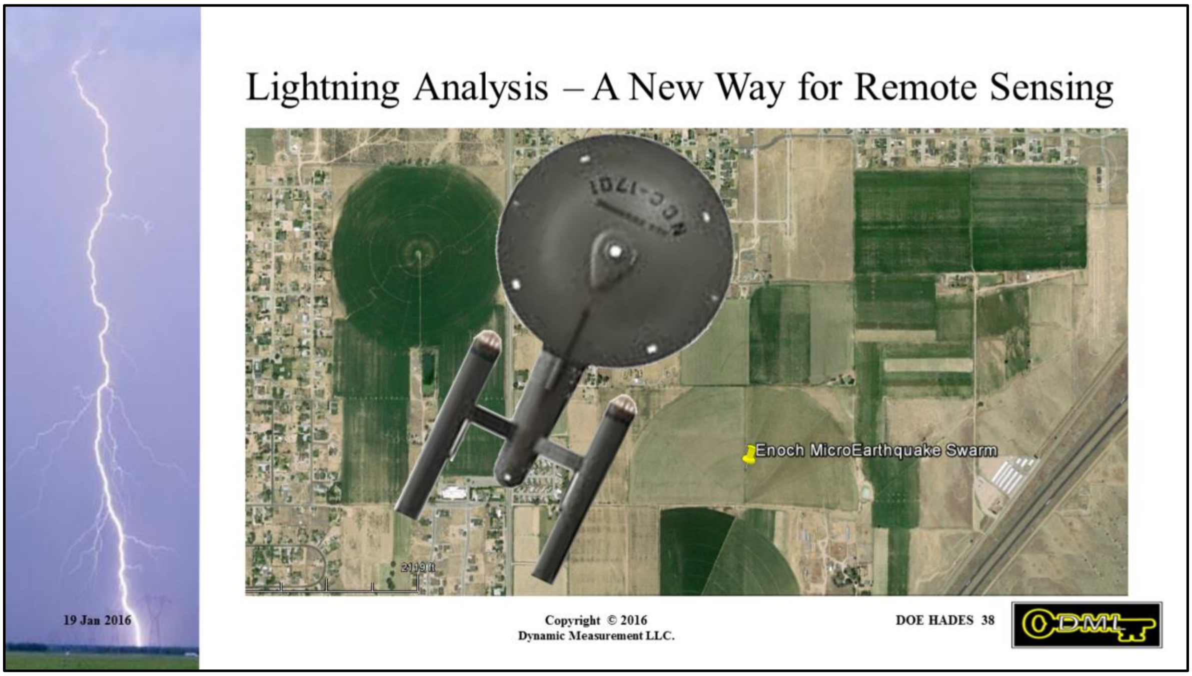
These micro-earthquakes are on Roice's Uncle Bud's and Uncle Ted's property. The farm Roice grew up on now has a crop circle and is west of the marker for the Enoch micro-earthquake swarm. As Roice explains it, he grew up on the backend of a shovel, on …



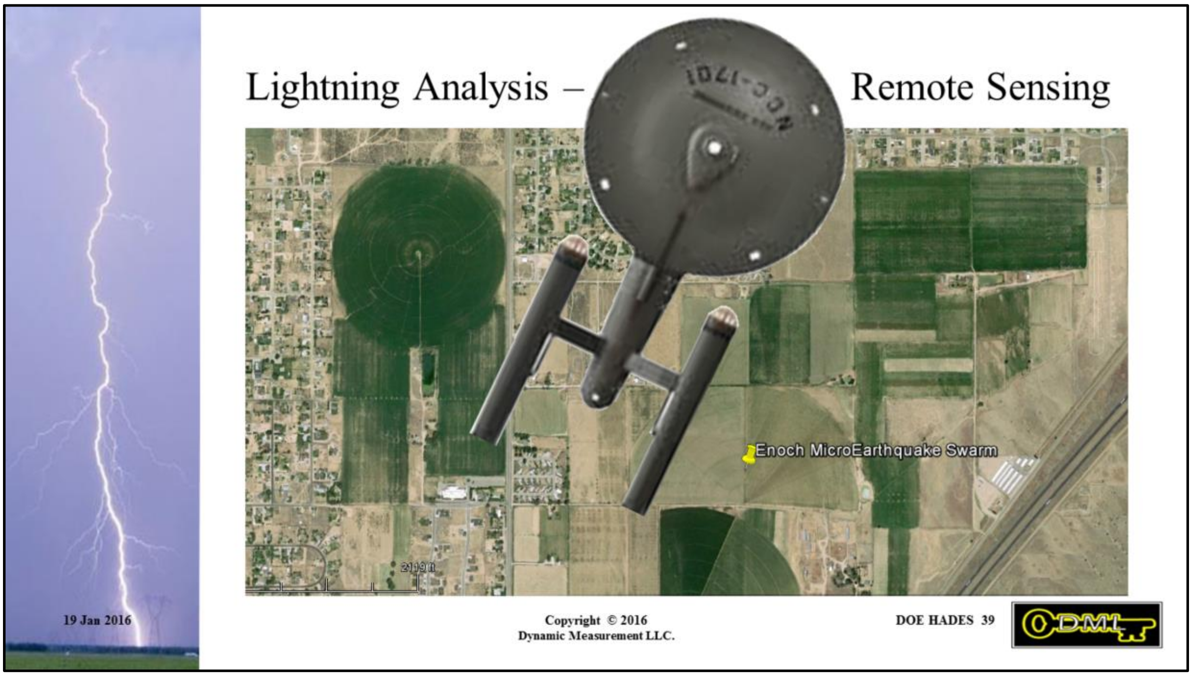
The Star Ship Enterprise, …



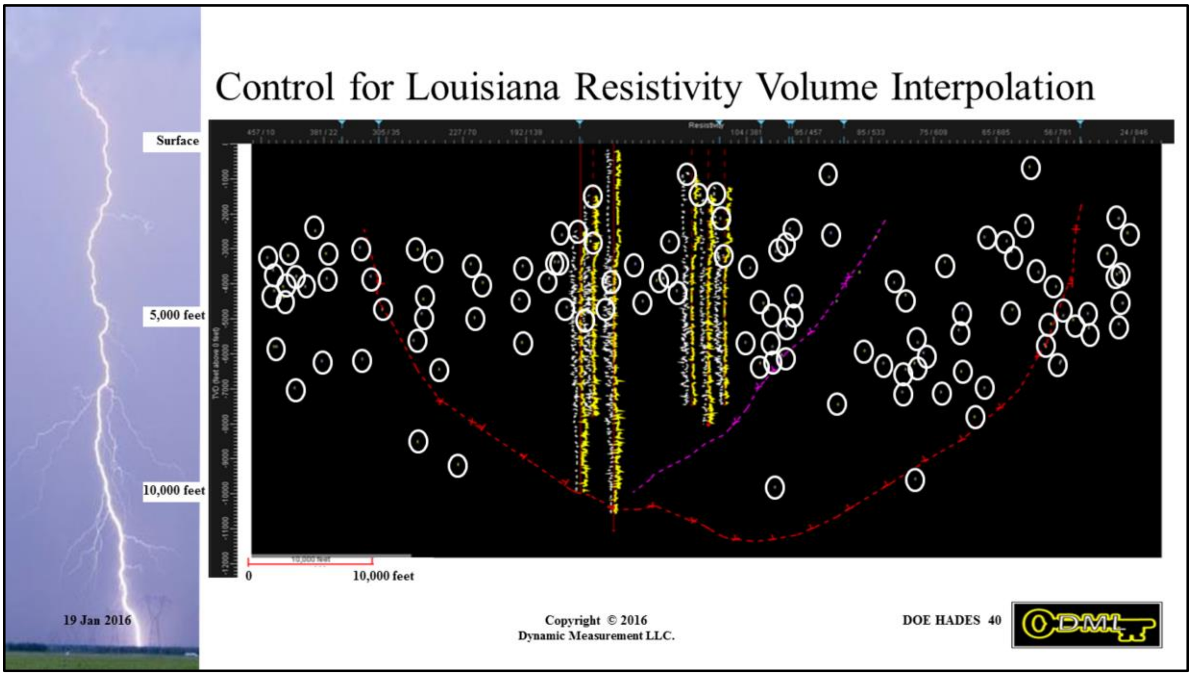
Which is appropriate for someone using lightning to map geology, because this is …



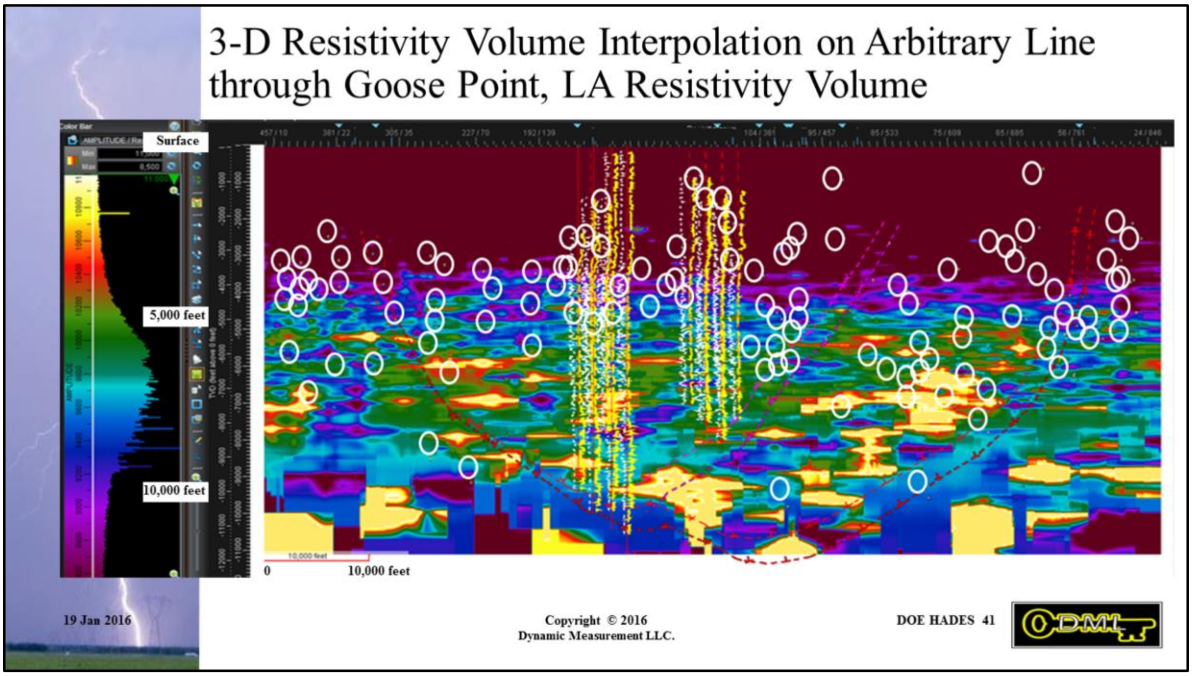
The first data type since Star Trek first proposed it used for …



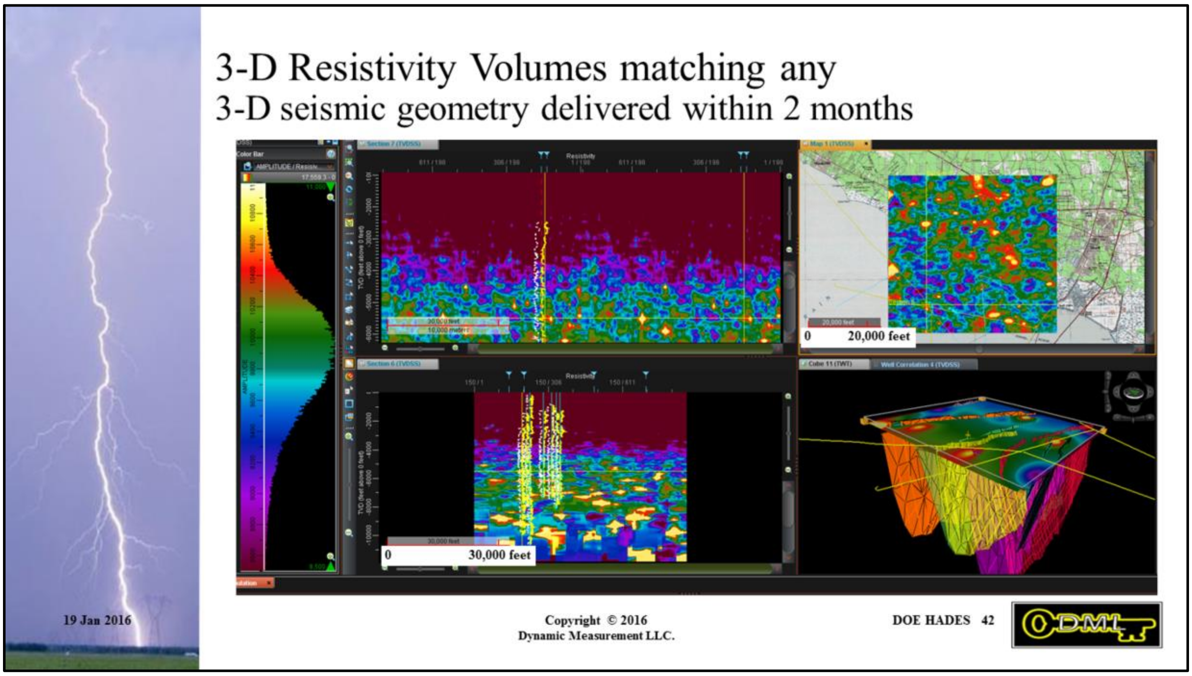
Remote mapping of geology.



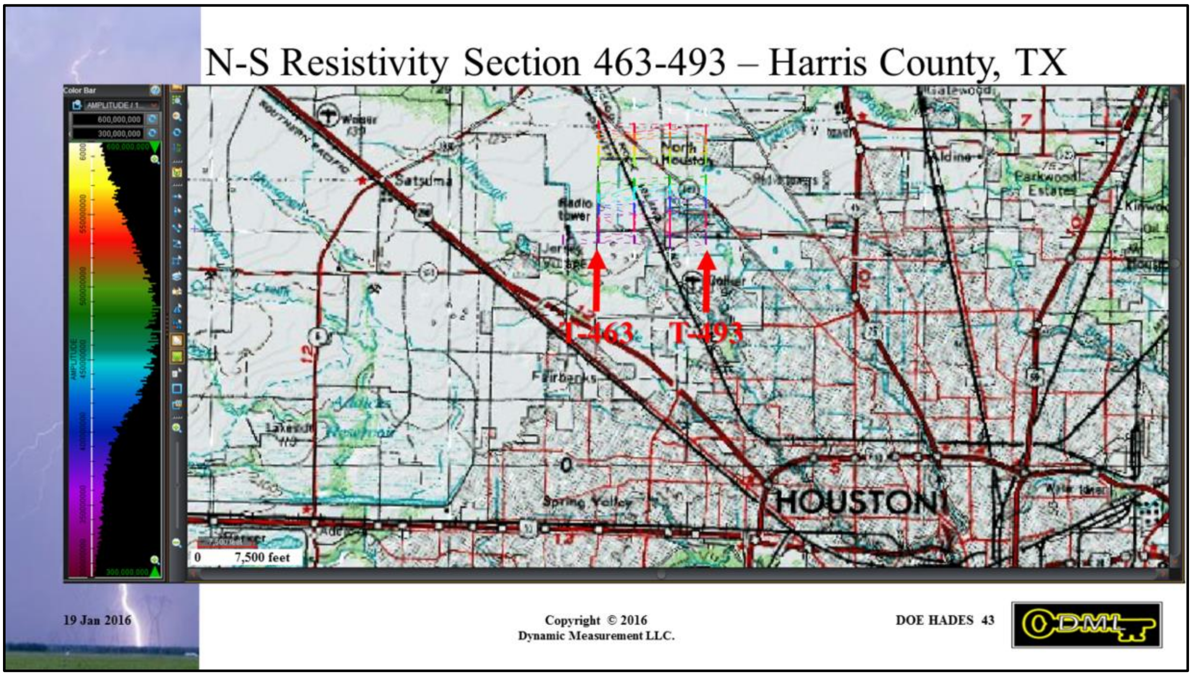
This image shows the location of calculated resistivity points for the arbitrary line through the Goose Point example shown earlier.



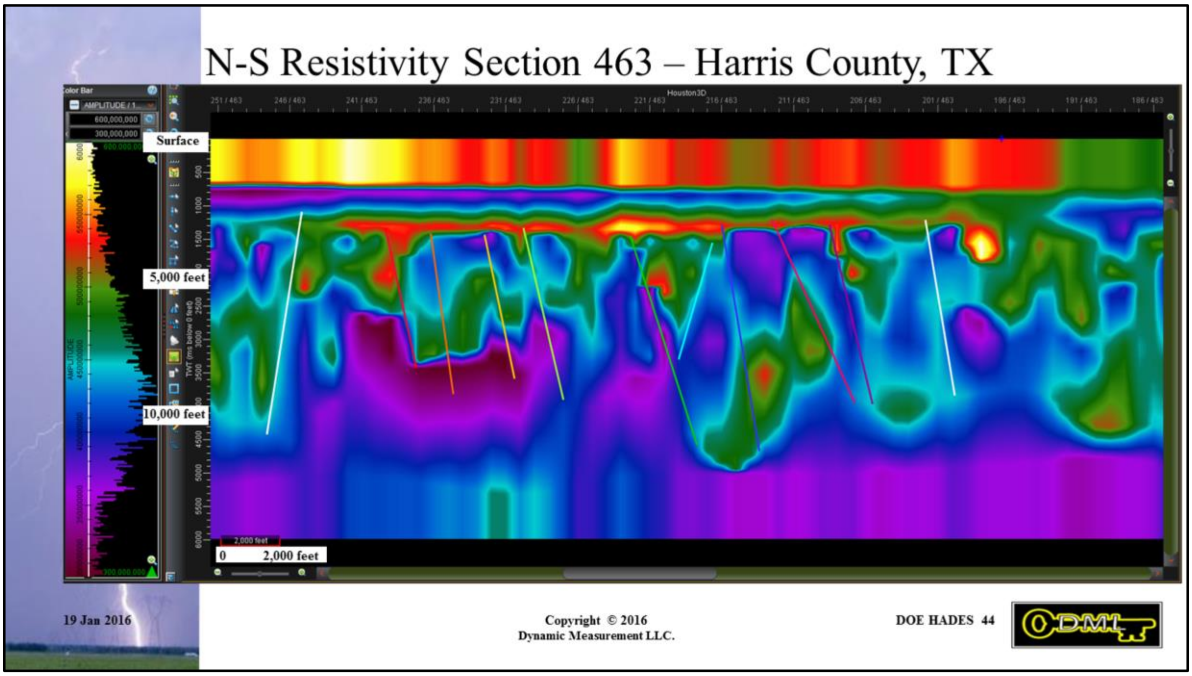
This slide shows the interpolated resistivity values calculated for this cross-section. The results improve on silo interpretations using just surface geology, or just well logs, or just sparker seismic data. The key for almost all subsurface interpretation projects is to integrate all available geological and geophysical data to come up with an optimal interpretation.



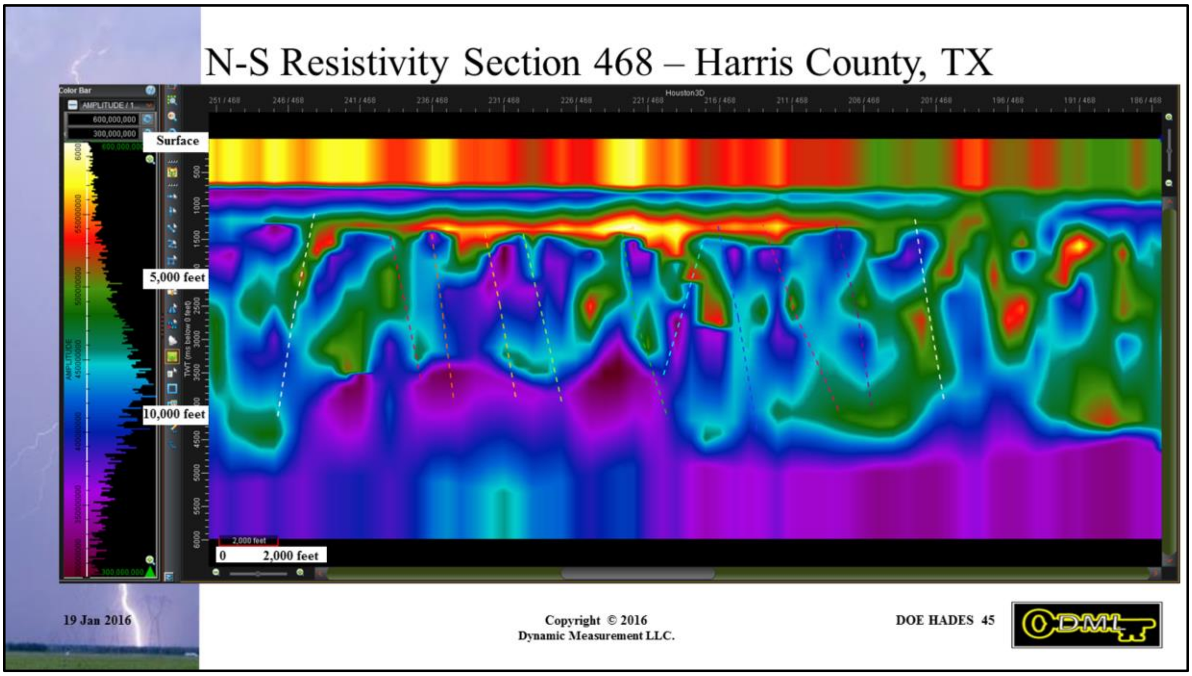
The result is a new way to look at the subsurface in cross-section (upper and lower left), map, and perspective views.



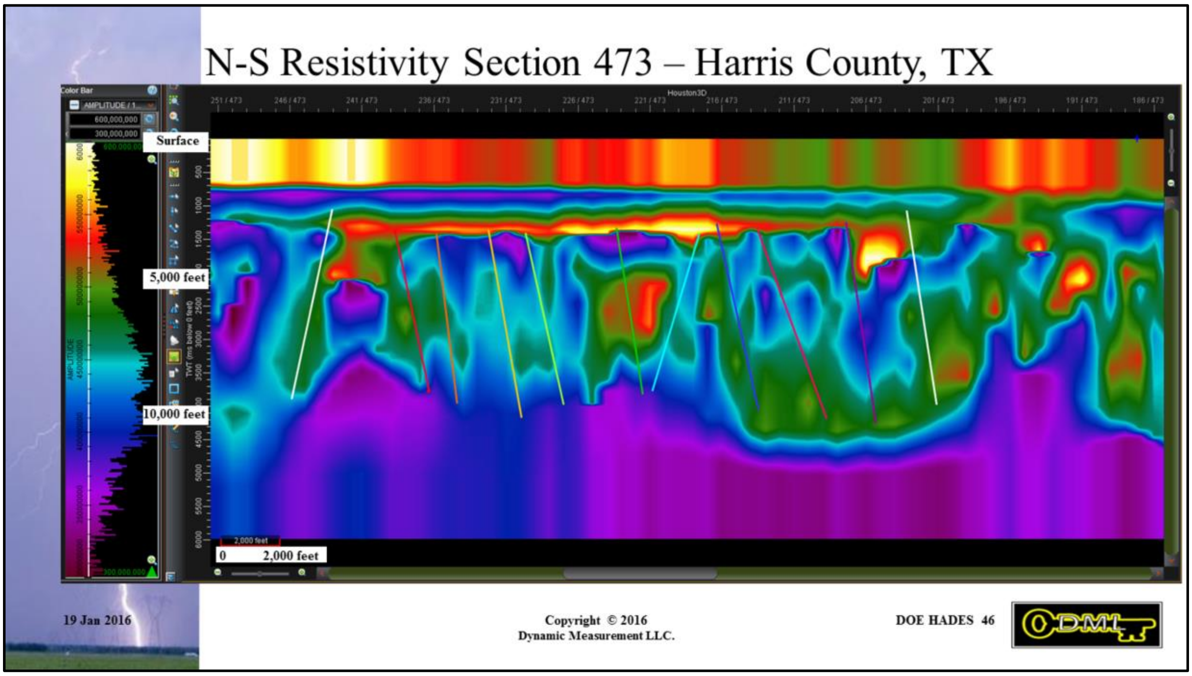
The next few slides go into a bit more detail with the resistivity volume to the northwest of downtown Houston. The following slides show every fifth cross-line from XL-463 to XL-493 across the anomaly shown in slide 14 above.



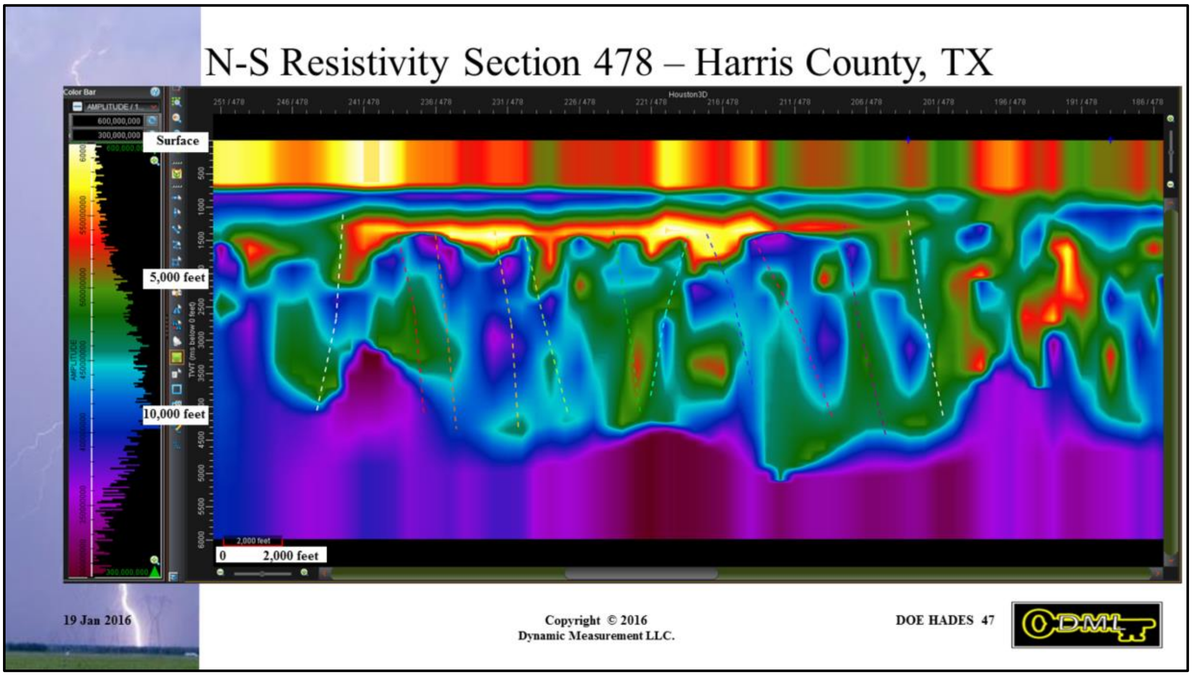
Ten faults were interpreted underneath the high resistivity (red/yellow) anomaly at 1345 ms. Note the high conductive pinchout at the top of the first good data. The first good data is tied to cloud height, and in this area the data above about 600 ms is an interpolation artifact. More recent processing algorithms includes muting this interpolated stripping out of the volume. The faults were interpreted on this section, XL-463.



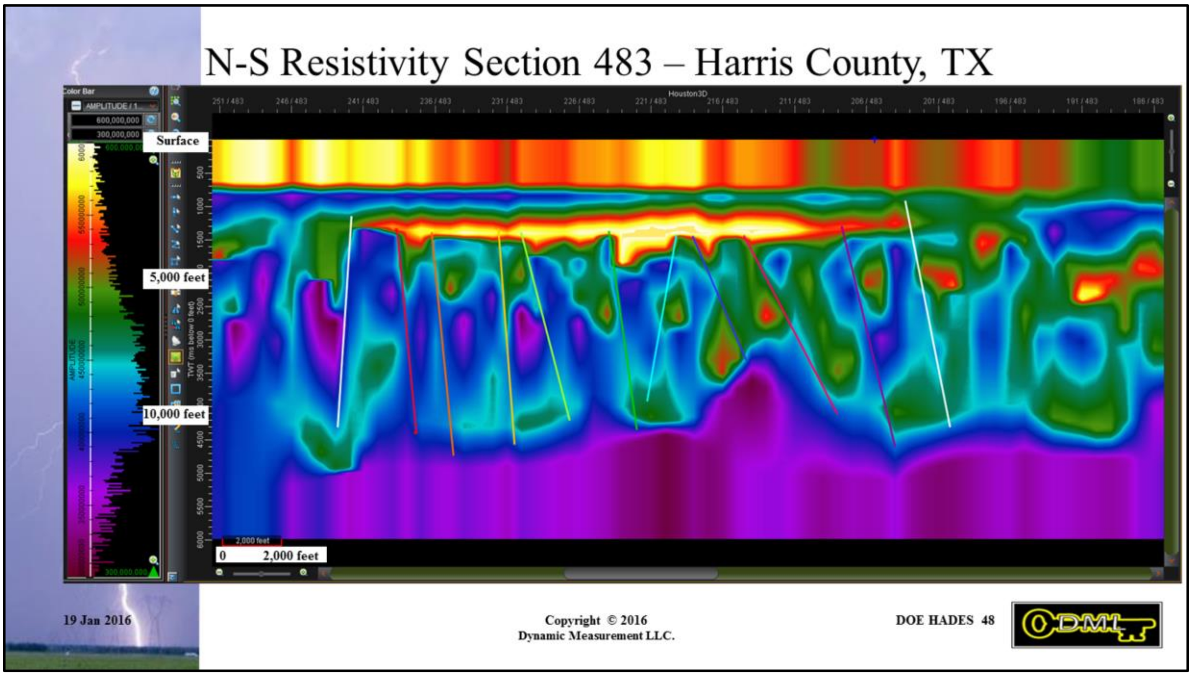
The faults were not interpolated on this section, XL-468. Note the dashed fault marks are interpolated between the section the faults were interpreted on.



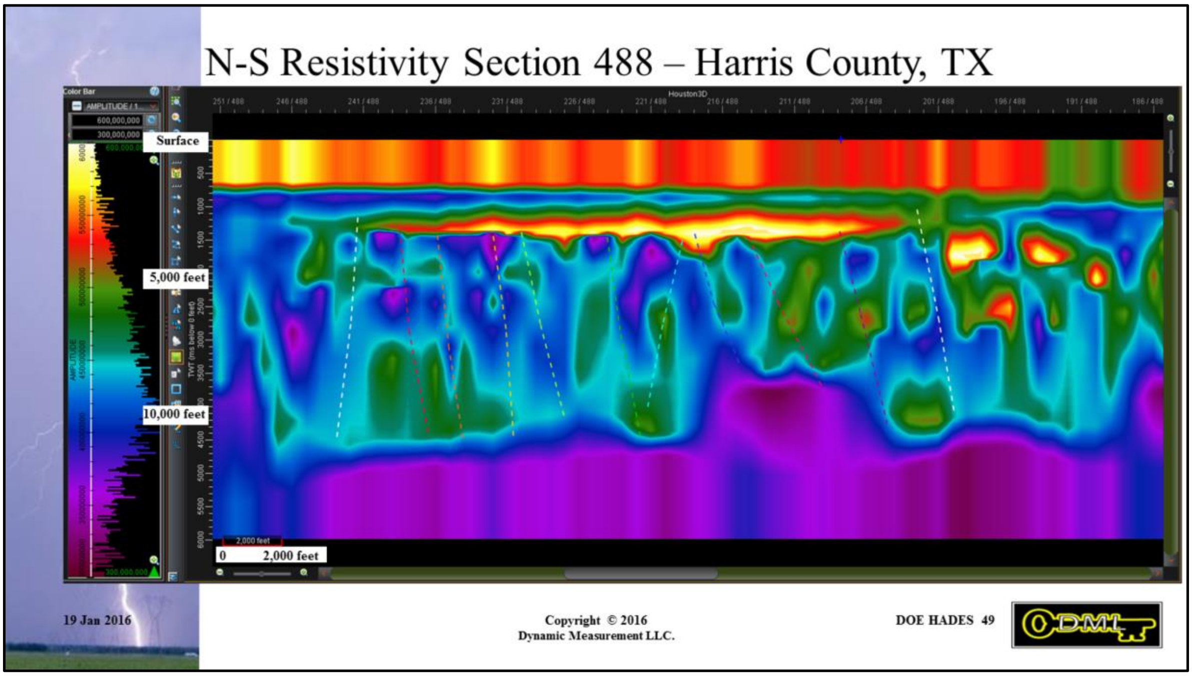
The faults were interpreted on this section, XL-473. Note how consistent the faults are line to line, as well as how consistent the high conductive pinchout and the high resistivity lens are on the three sections shown so far.



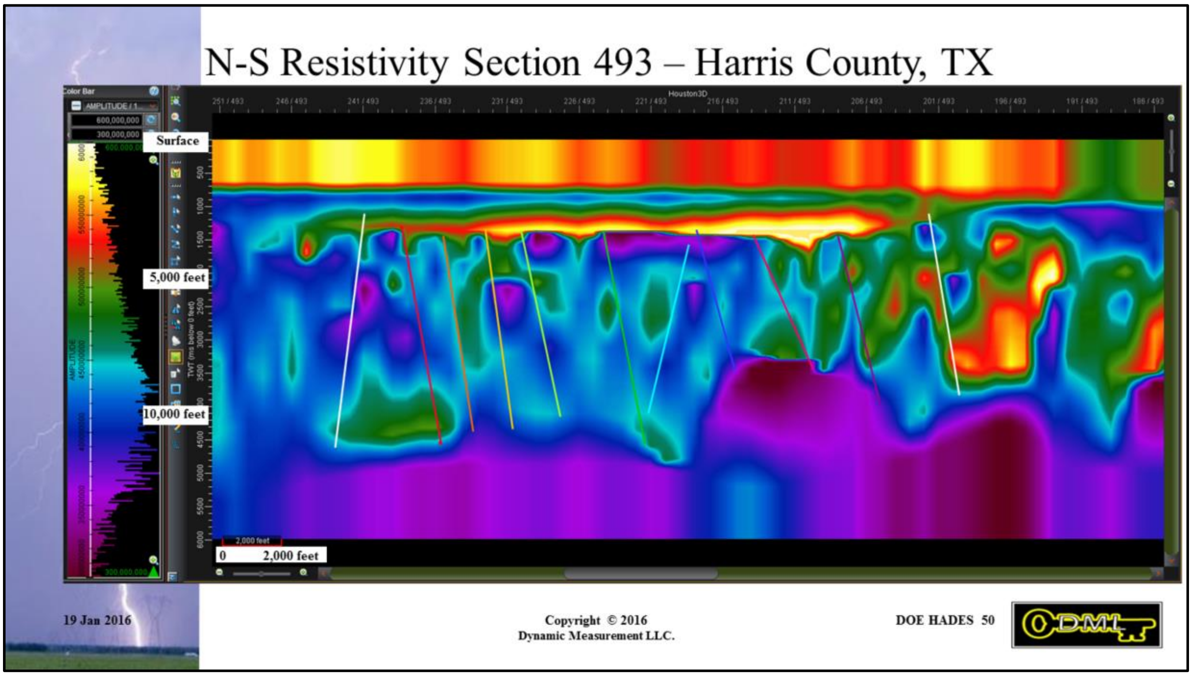
The geological consistency continues across the 7 sections shown in this example. Here, on this section XL-478, the faults are again interpolated and there are sections of the high resistivity lens which are thicker and have higher resistivity.



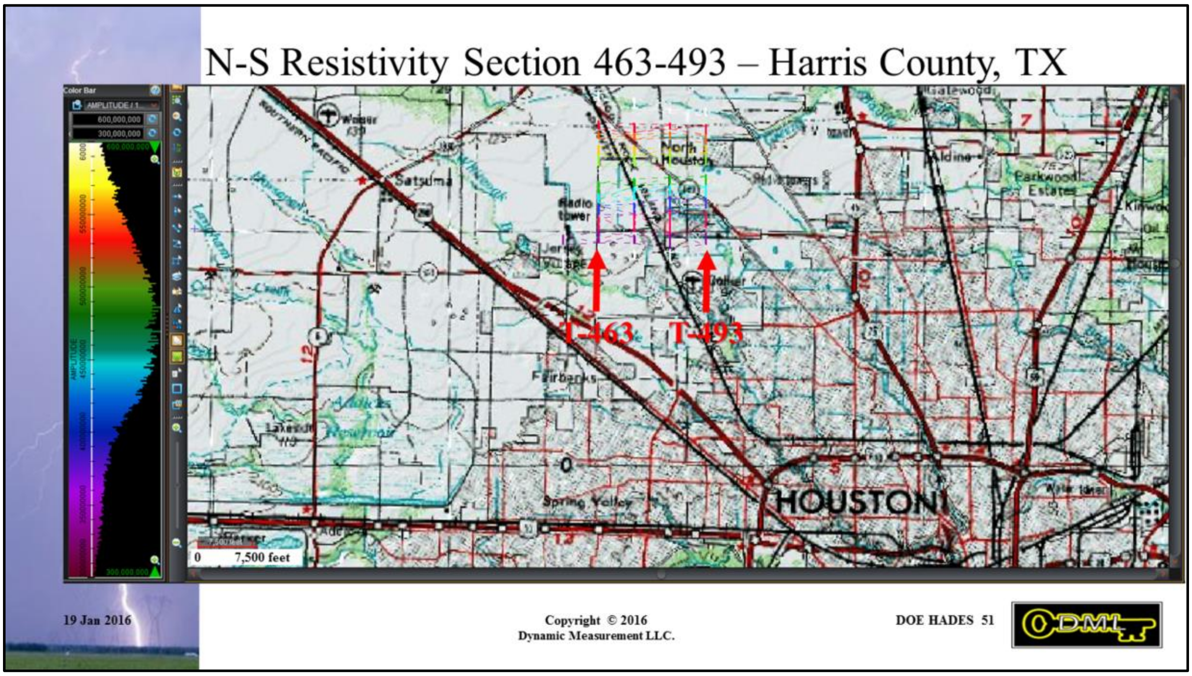
The high resistivity anomaly is at 1345 ms, which at 6,000 feet per second seismic velocities is about 4,000 feet deep. Fresh water gives high resistivity anomalies on well logs in the Gulf Coast. However, fresh water aquifers do not tend to have the lens effect seen on these seismic sections. Note how thick and how strong the resistivity lens is on this section, XL-483.



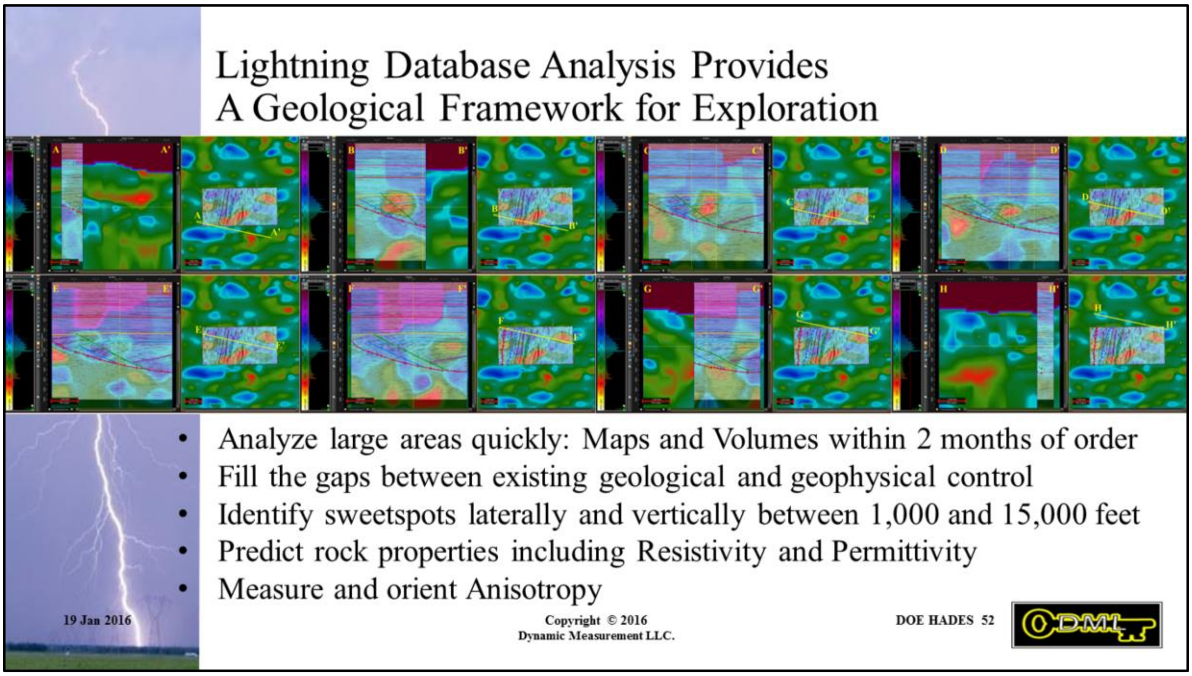
It makes sense this high resistivity lens could be a gas charged aquifer. Again, the faults are interpolated on this section, XL-488.



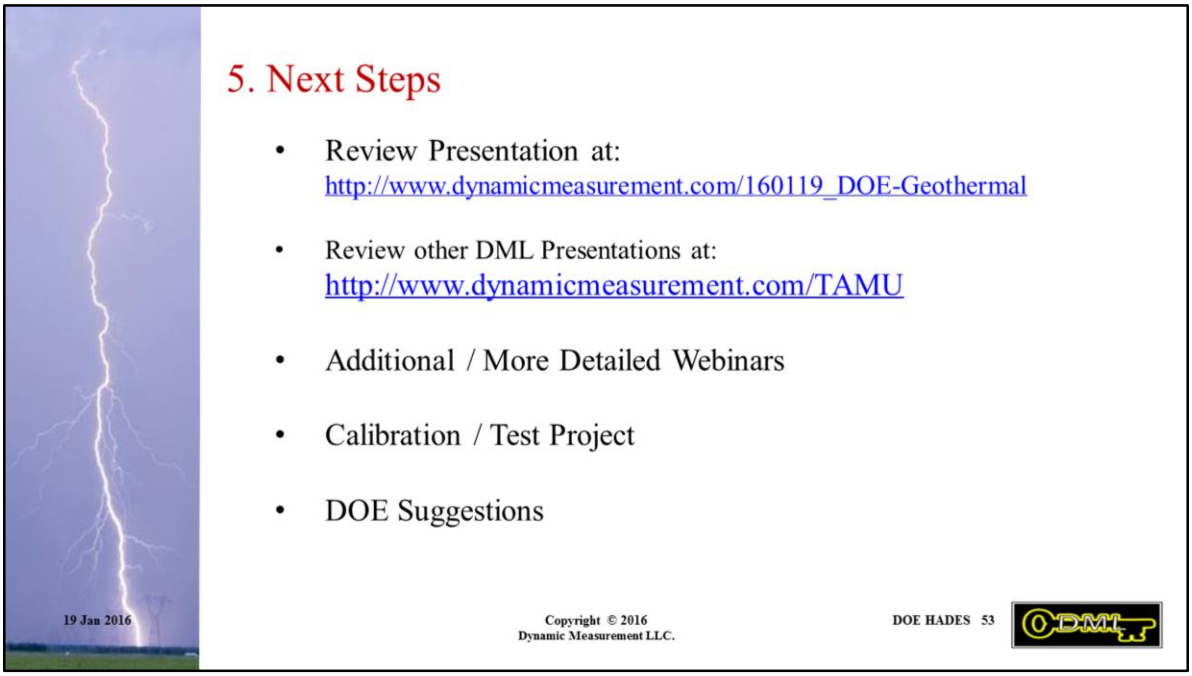
It is also possible this high resistivity anomaly has nothing to do with an aquifer, and the lightning analysis is providing a new and unique way to explore for shallow gas fields, which is what the high resistivity anomaly looks like on this section XL-493.



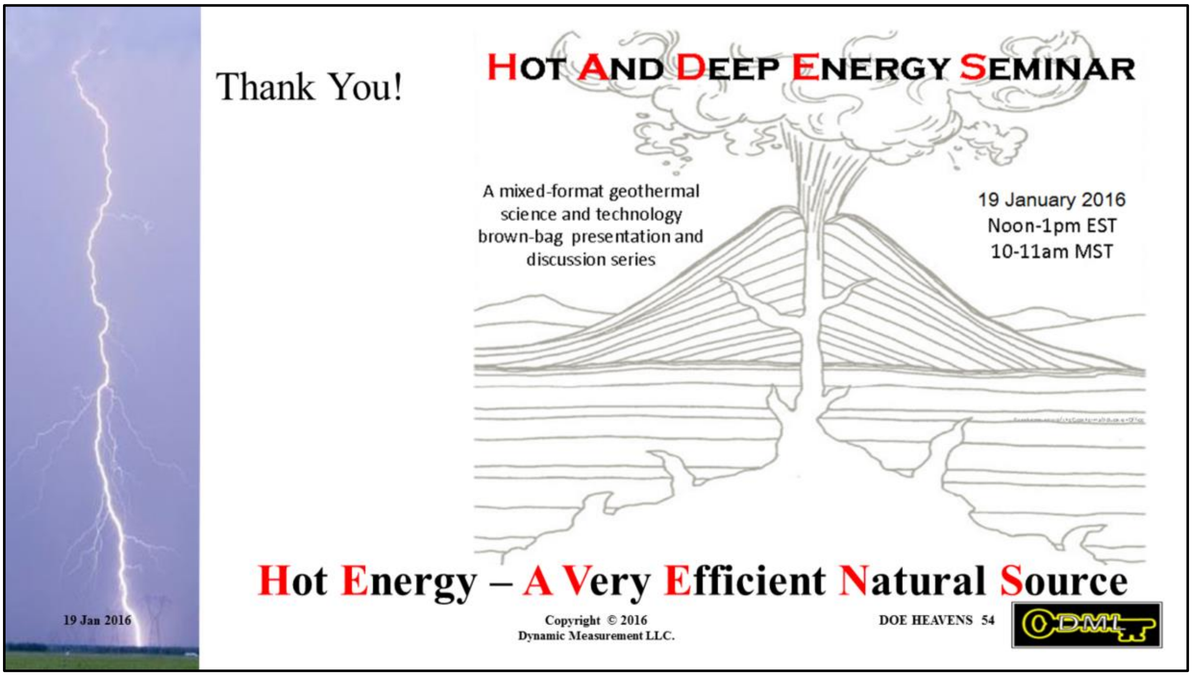
Again, the anomaly is mapped from data collected over an urban metropolis, and there is extensive infrastructure covering the area of the anomaly.



A good way to look at this new geophysical data type is that it provides a way to quickly and inexpensively build a geological framework for exploration. The images on this page show 8 dip sections through the BEG Stratton 3-D seismic survey, with lightning analysis extending beyond the seismic control. We have not done any geothermal exploration projects yet, and we are very interested in taking on and proving or disproving the value of this approach to help geothermal exploration. Lightning analysis allows evaluation of large areas quickly. DML will provide maps and volumes within 2 moths of a data order. If existing control (air mag, seismic, well, etc.) has gaps, lightning derived maps and volumes are an ideal way to fill the gaps to help build the geological framework. This becomes a very quick way to identify sweetspots laterally, and vertically between about 1,000 foot and 15,000 foot depths. The Resistivity and Permittivity volumes provide a new way to predict rock properties, and if there is good well control to calibrate and extend properties away from control. Because faulting orientation and throw can be interpreted on lightning derived volumes, this data also provides a way to measure and orient anisotropy, which seems would be critical for geothermal exploration.



This presentation is posted at [160119_DOE-Geothermal](http://www.dynamicmeasurement.com/160119_DOE-Geothermal) so you can review specific slides of interest at your leisure. Other DML public presentations can be reviewed at www.dynamicmeasurement.com/TAMU. If there are any of the areas covered in this overview any reviewing this presentation would like to go into more detail on, we would be glad to do another more detailed webinar for you. Of course we are particularly interested in doing a calibration or test project for DOE, and we are interested in your suggestions as to next steps.



Thank you, and to make a play on your HADES, we think we can give you an introductions to HEAVENS (Hot Energy A Very Efficient Natural Source).

This is key contact information: Roice Nelson is a geophysicist, Dr. Jim Siebert is a meteorologist, and Kathy Haggar is a geologist with 4 years experience at Chevron, Greenhill, and running her own environmental company for the last 11 years. Kathy is also the key contact and sales support for DOE.