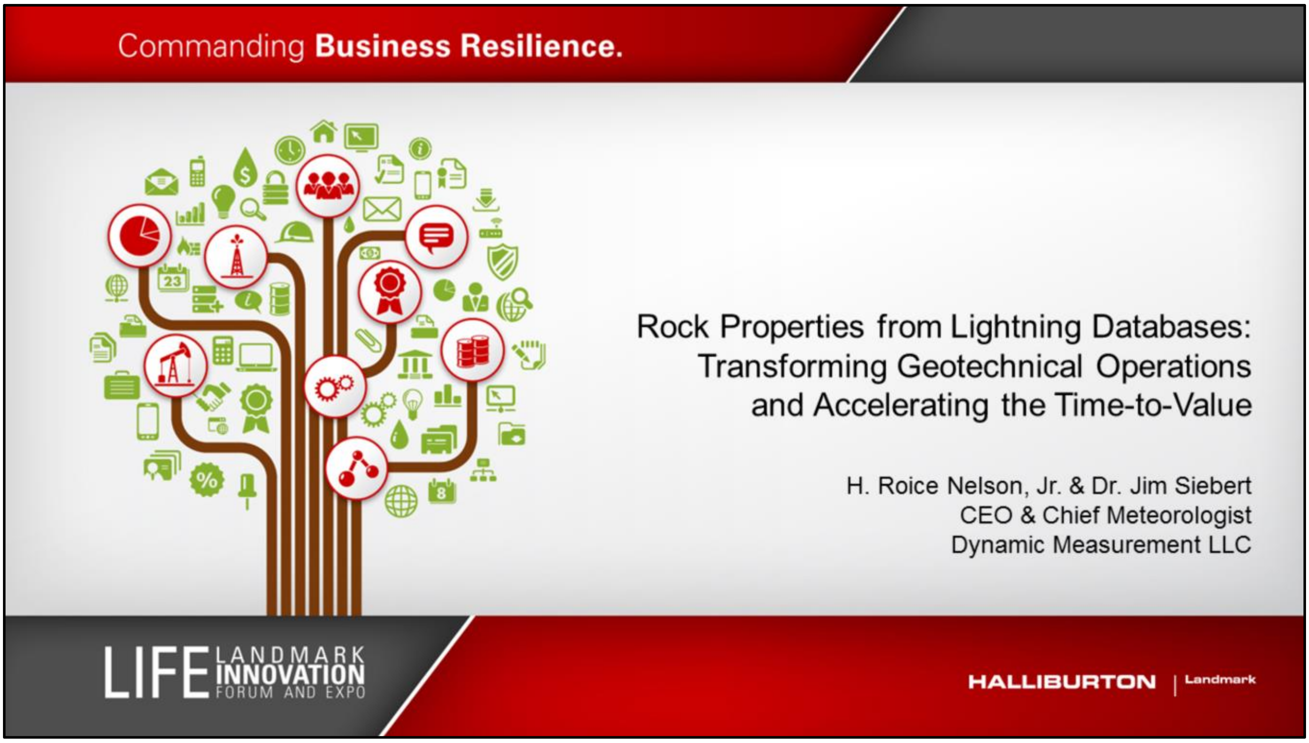
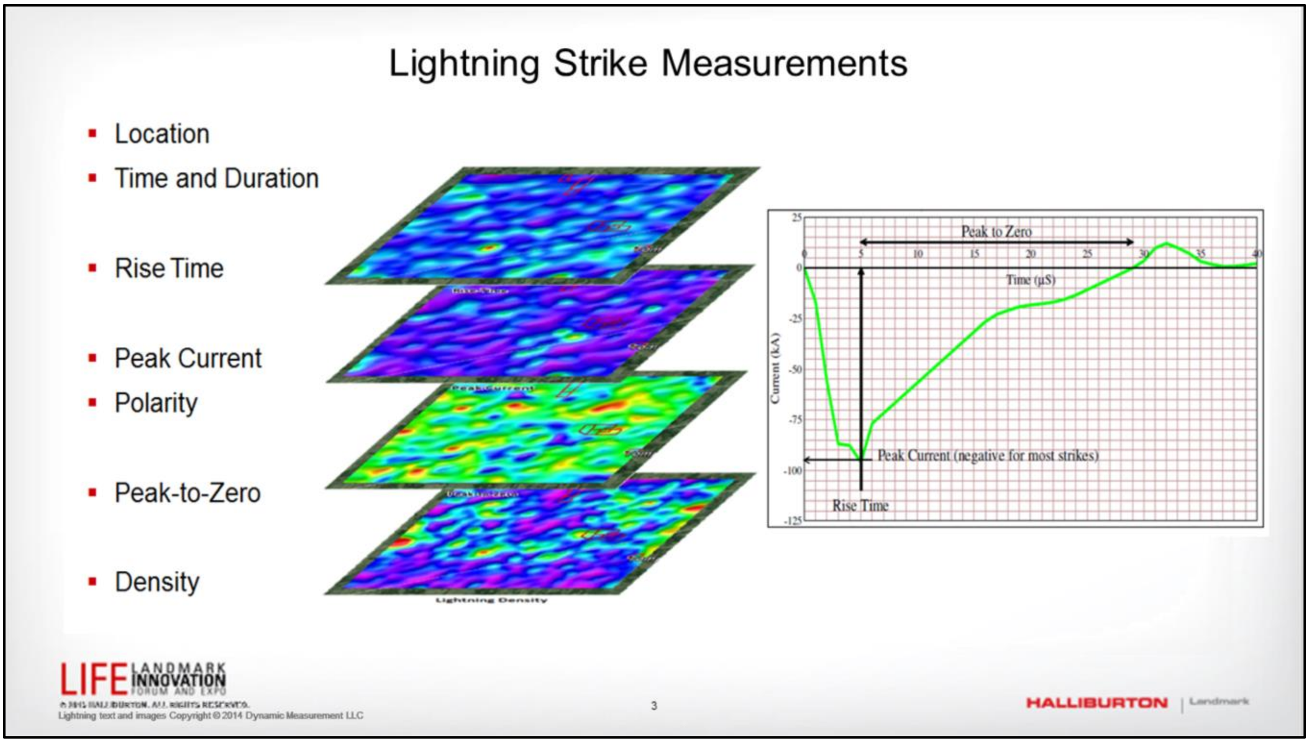
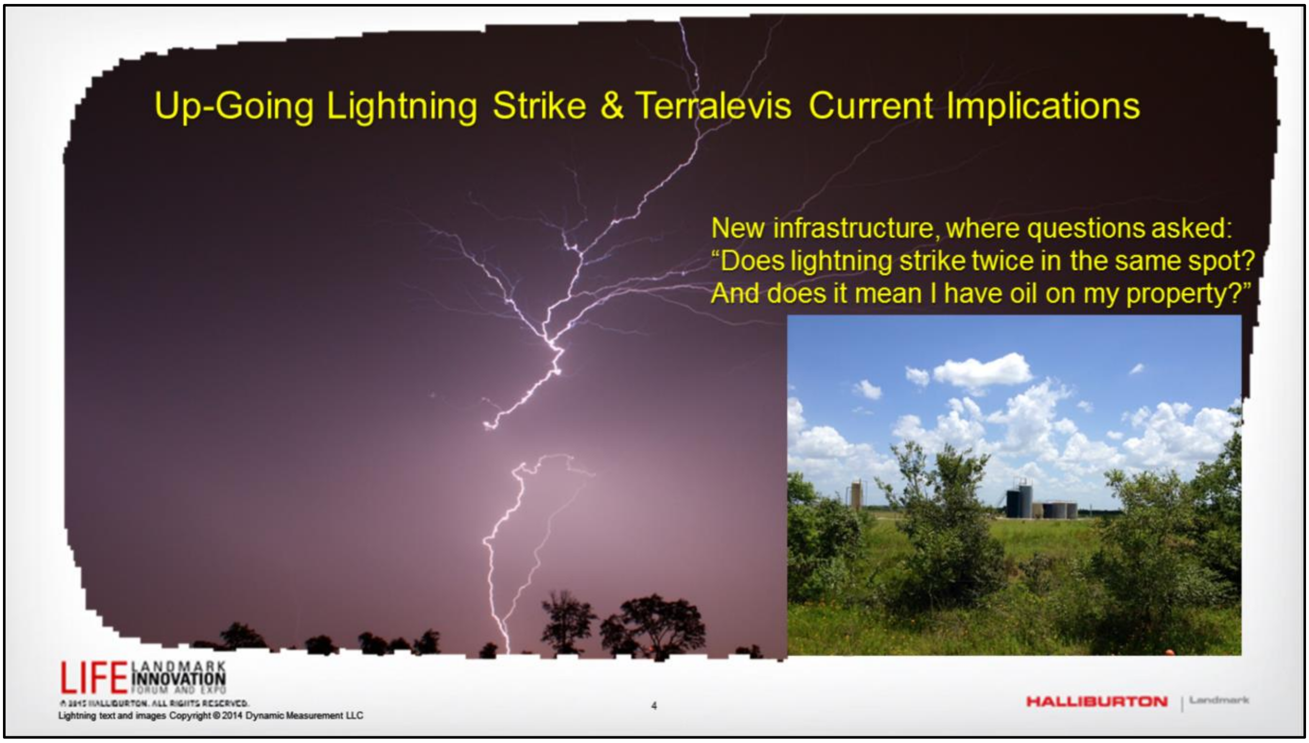


We are introducing derivation of rock properties from lightning databases, and describing how this technology will transform geotechnical operations for those who take advantage of it. This presentation is a continuation of last year's presentation, which introduced using lightning databases as a new geophysical data type to map subsurface geology and introduced the concept of using this data to enhance reservoir characterization. You can download and review last year's presentation by going to http://www.dynamicmeasurement.com/TAMU/140904_LmrkInnovationForum2014_Lightning_Strikes.pdf.

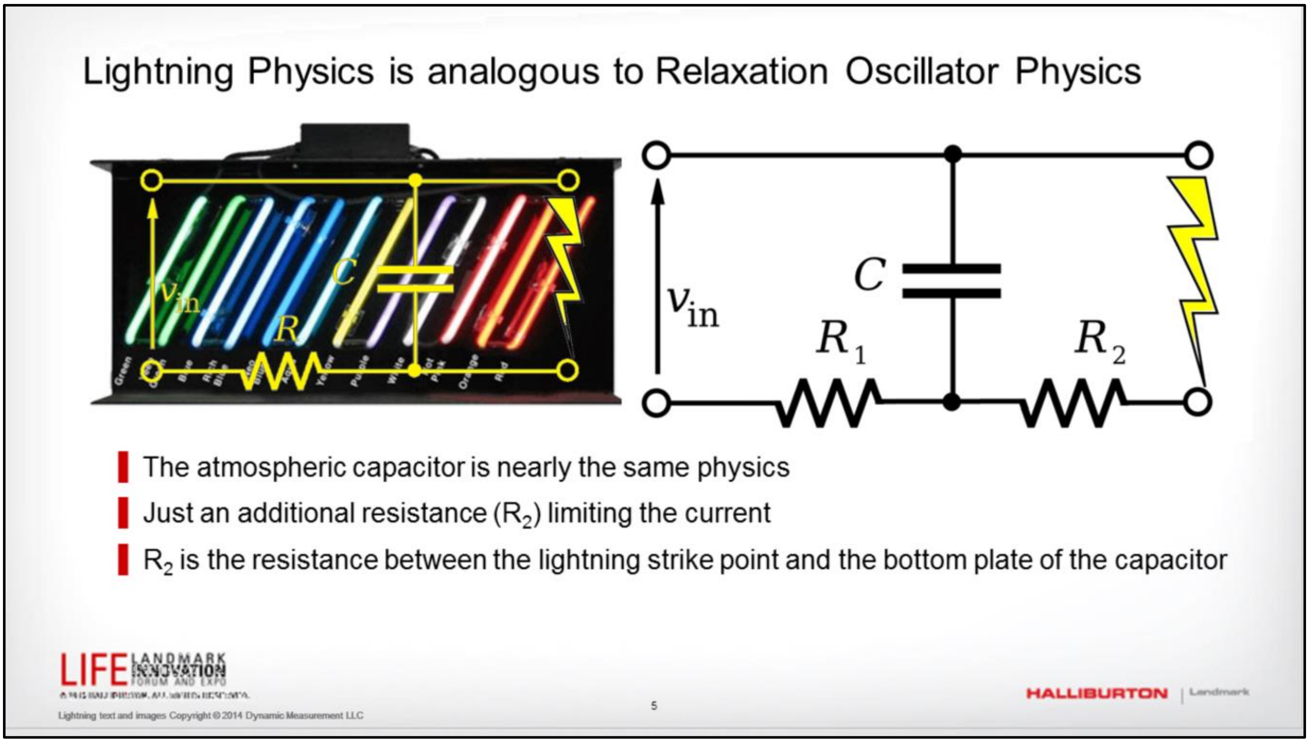
Rock property spatial distributions are key to successfully exploring for oil, gas, minerals, water, and other natural resources. Boreholes are the traditional source of rock property data. Rock property data from boreholes is, of course, limited to the location of the well pathway. Lightning derived rock properties can be collected anywhere. These rock properties can be integrated with other geophysical data, including seismic and potential field data. These rock properties fill in the gaps between existing surveys, and provide a framework for defining where other geophysical surveys need to be collected.



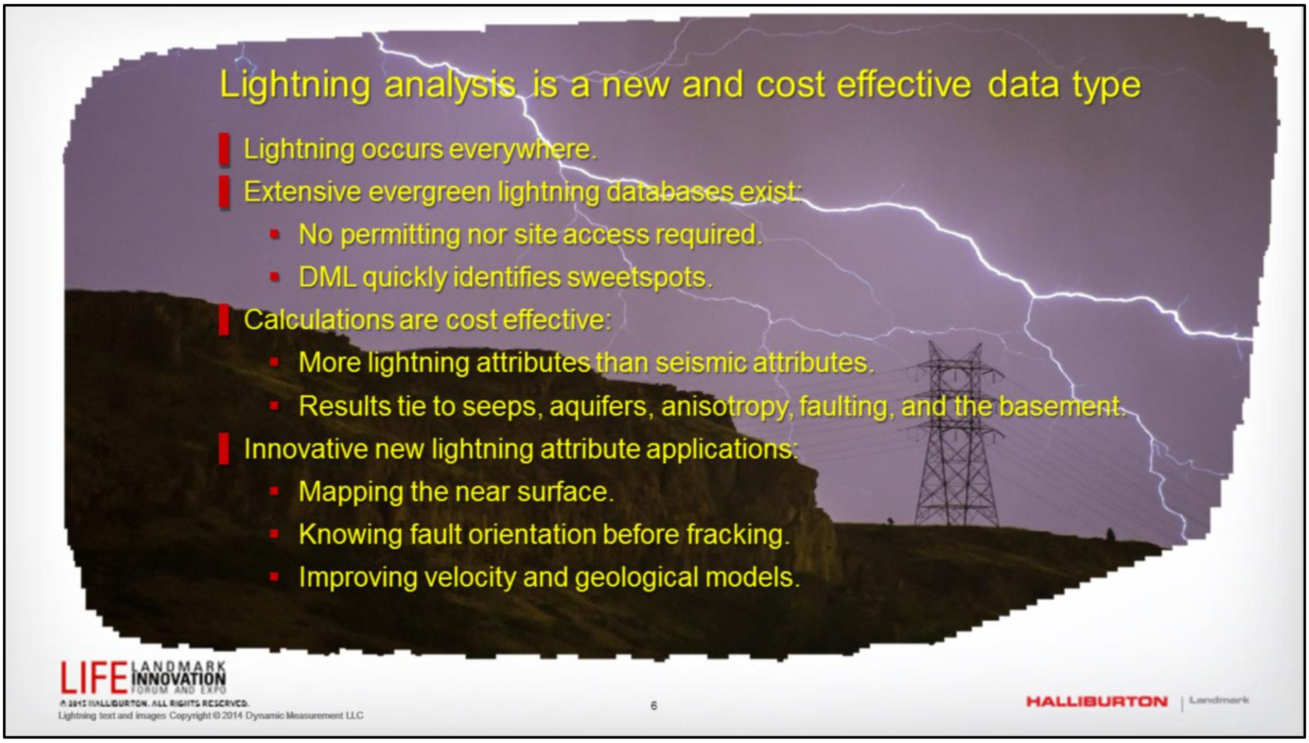
Lightning derived rock properties are calculated from the basic data in lighting databases. This data starts with the location of the strike. The accuracy of these locations is generally stated as +/- 100 meters (+/- 300 feet). However, geological lineaments (faults, terminations, etc.) have been demonstrated to have a spatial accuracy of +/- 10 meters (+/- 30 feet). The timing of lighting strikes is accurate to the microsecond across 15 years of data. Rise-Time is the time it takes to go from the electromagnetic background to Peak Current. Note Peak Current can be plus or minus. Peak-to-Zero is the time it takes to go from Peak Current back to the electromagnetic background. Lightning strikes do occur at the same place. Lightning strikes cluster, and these clusters are fairly consistent across time. This consistency is what allows DML to “stack” lightning strike measurements and to create maps related to geology and natural resources.



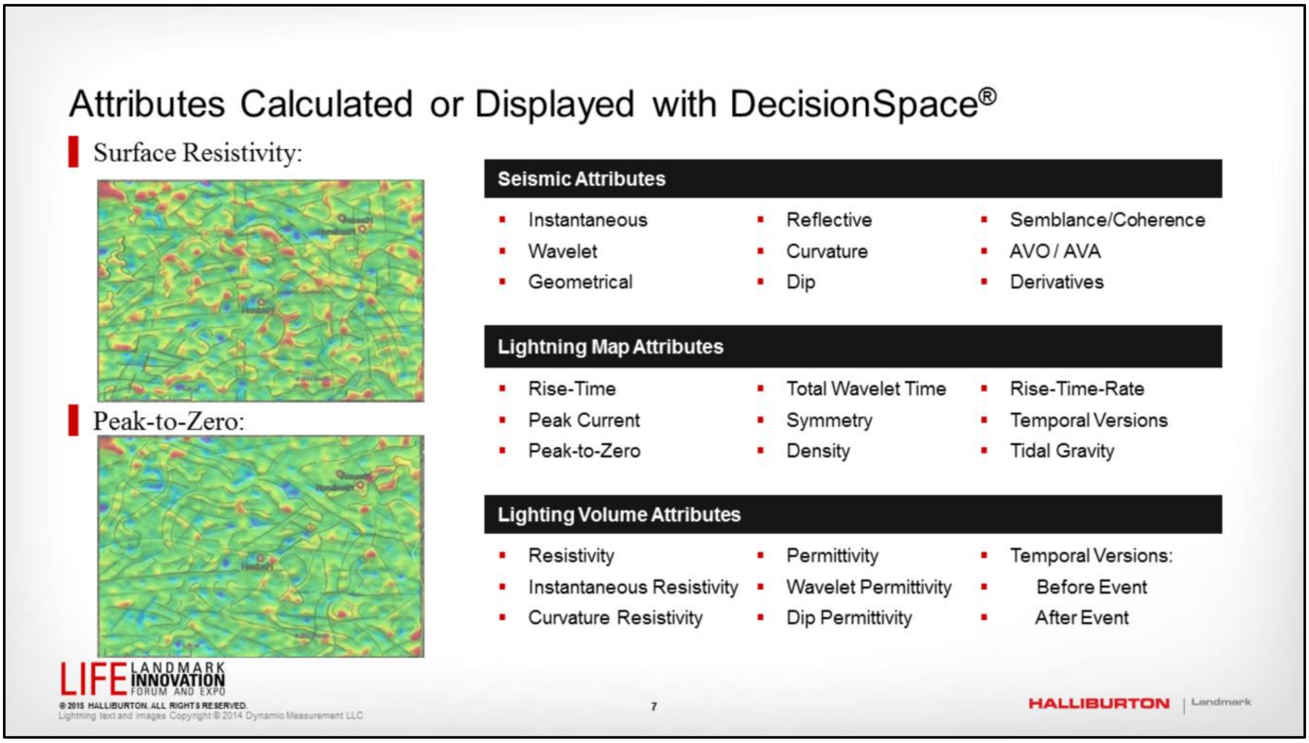
The insert shows new oil and gas tanks and infrastructure at the location where the questions which started Dynamic Measurement LLC were asked. After experiencing lightning strikes at the same location a year apart, the questions asked were: “Does lightning strike twice at the same place? Does it mean I have oil on my property?” Eight years later there is a definitive answer to both questions: “Yes!” The background image shows an up-going lightning strike. This would not be possible if there were not electrical currents in the shallow subsurface which are building up over time, just as electrical charges build up in clouds. These shallow earth currents are extensions of telluric currents, and we call them terralevis (shallow earth) currents.



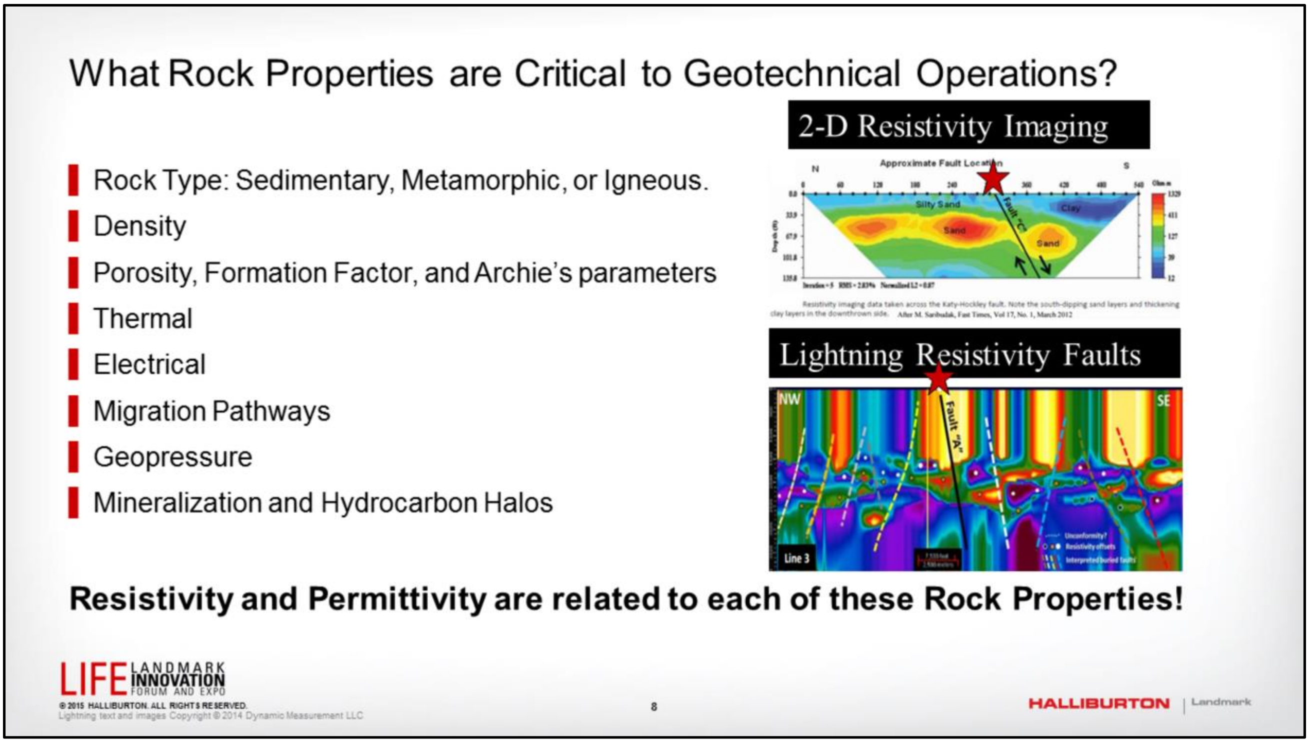
The physics behind lightning analysis is analogous to the physics of a relaxation oscillator, or a neon light tube. A charge across a capacitor is built up from an input voltage in series with a resistor until there is a spark. The spark excites noble gases in neon tubes (background image) to create a continuous glow. With lightning the top plate of the capacitor is in the clouds and the base plate is at the surface of the ground. There is an additional resistance, associated with the lithology and fluids. Based on these basic concepts, DML has been able to derive formulas for calculating the resistivity and permittivity at various depths in the subsurface. These calculated values can be interpolated to create rock property volumes. A more detailed description of the calculations was presented to the GSH Potential Fields SIG, and can be reviewed at www.dynamicmeasurement.com/TAMU/150115_GSH_Potential_Fields_SIG.pdf.



The bottom line is lightning databases provide a new cost effective data type. Lightning occurs everywhere. Databases have been built for years, and are continuing to be added to in an evergreen fashion, for insurance, meteorology, and safety purposes. No permitting is required to create lightning attribute maps or rock property volumes, and these results quickly identify sweetspots. The data retrieval and calculations are cost effective, and analysis has generated more attributes than seismic attributes. Results tie to seeps, aquifers, anisotropy, faulting, and geologic basement. This innovative new geophysical data type allows near surface mapping, an understanding of fault orientation before fracking, and a improvement of velocity, geological, and earth models.



DecisionSpace users have a plethora of valuable seismic attributes options to choose from. Because lighting analysis generates lightning attribute maps as well as rock property volumes, both map and volume attributes are available for mapping and analysis. As with seismic attributes, lighting attributes can be used to enhance geomorphology and fault trend interpretation. Shown here are two lightning attribute maps (surface resistivity and peak-to-zero) from central Texas. This interpretation work was done by Kathleen S. Haggar and can be reviewed at www.dynamicmeasurement.com/TAMU/141119_LGS-SIPES_Lafayette.pdf.



Understanding rock properties is at the root of accurate geological and geophysical interpretation. We need to know if the rocks are sedimentary, metamorphic, or igneous. We need to know the density to know lithology, porosity, and permeability. We need to know the porosity, formation factor, and Archie's parameters to know production capabilities. Thermal and electrical characteristics tell us about lithologies and fluids. Migration pathways and traps are critical for predicting hydrocarbons. Geopressure ties to hydrocarbon accumulations. Mineralization and hydrocarbon halos are under utilized. Resistivity and permittivity rock property volumes tie to each of these rock properties. The images on the right compare an EM resistivity survey fault interpretation with a fault interpretation on an equivalent cross-section from a lighting derived resistivity volume. This work was done by Louis Berent and can be reviewed at www.dynamicmeasurement.com/TAMU/150625_Hockley_Radial_Faults.pdf.

Rock Property Specifics

Method	Type of measurement	Physical property detected
Gravity	Spatial variations in the strength of the Earth's gravitational field	Density
Magnetic	Spatial variations in the strength of the Earth's magnetic field.	Magnetic susceptibility
Seismic	Travel times of seismic waves	Density and elastic moduli
Electrical Resistivity	Electrical resistance	Resistance
Electromagnetic	Response to electromagnetic radiation	Resistance and Inductance
Induced Polarization (IP)	Apparent permittivity	Capacitance
Ground Penetrating Radar (GPR)	Travel time of radar pulses	Dielectric constant
Lightning	Location, Time, Rise-Time, Peak Current, Peak-to-Zero	Resistivity and Permittivity

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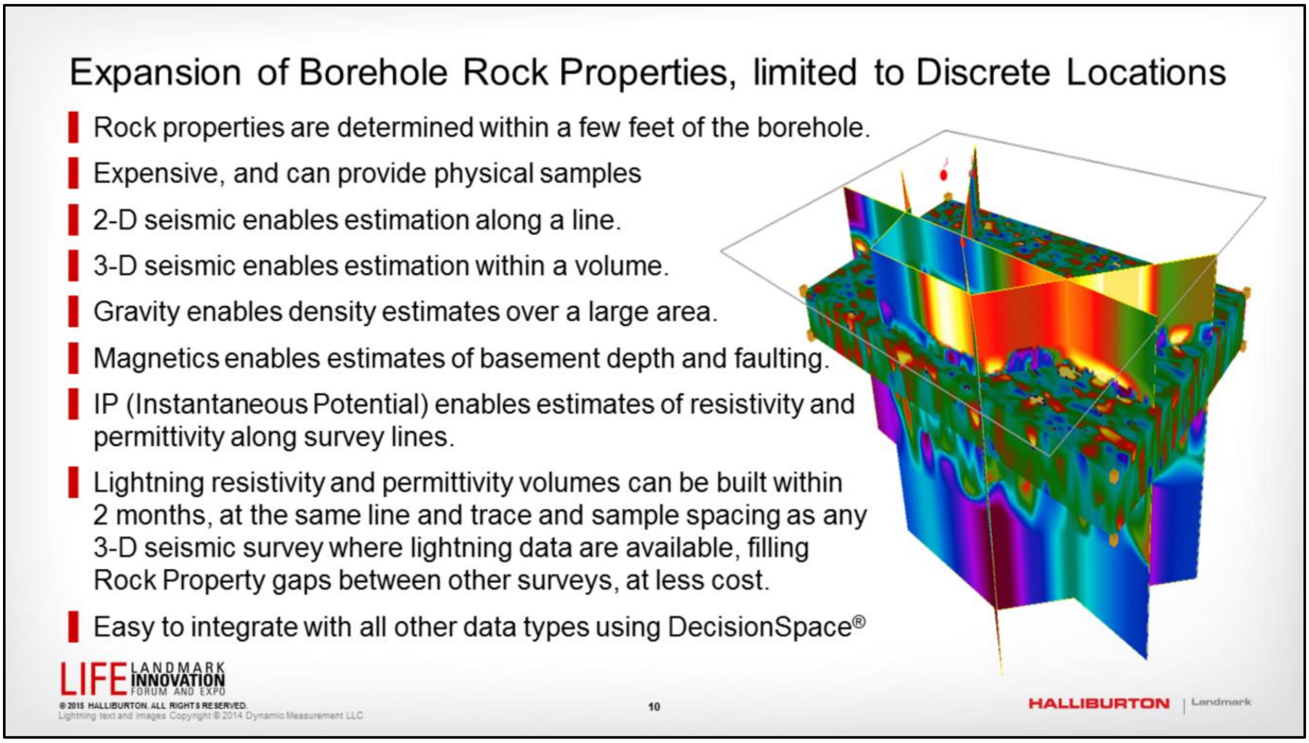
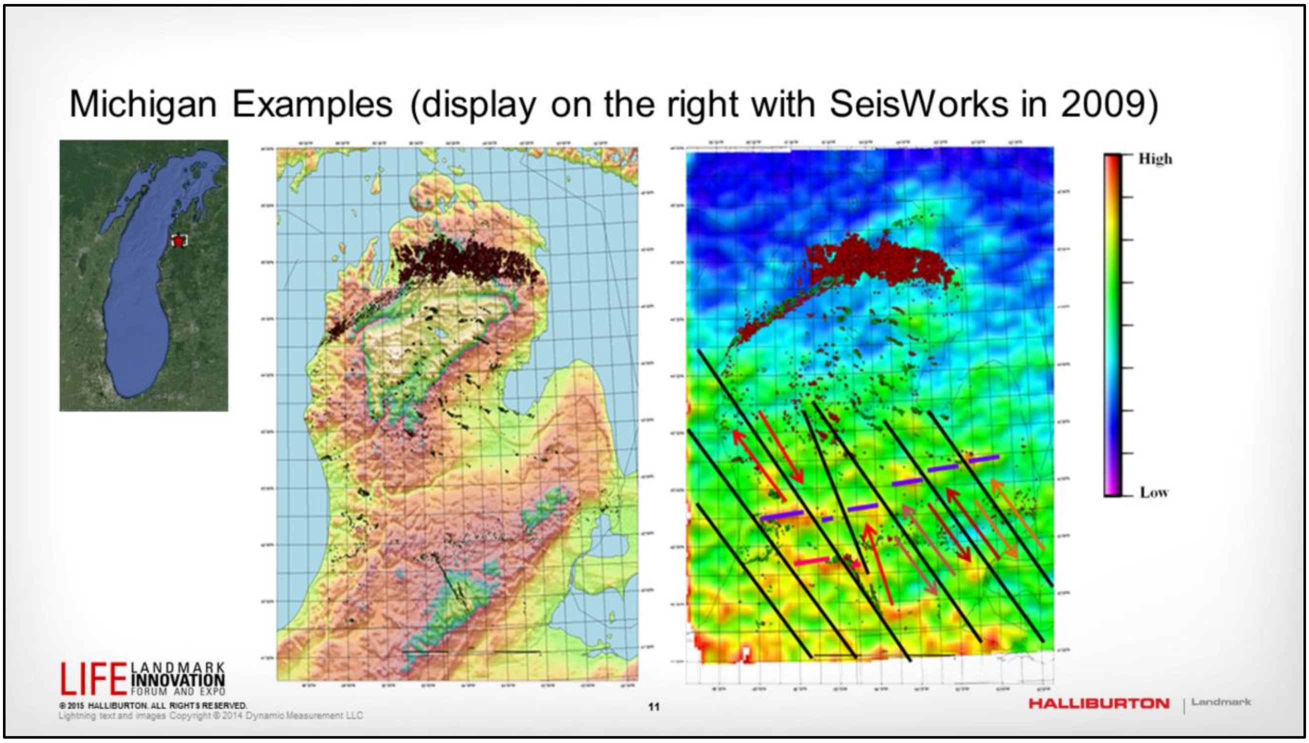
This table provides specifics on rock properties measured with different geophysical technologies. We all know integrated interpretations are better than an interpretation based on one geophysical data type. Tools like DecisionSpace make it possible to routinely include in our interpretations all of the different geophysical data types available within our project area. Dynamic Measurement LLC is working to see lighting derived rock property information become the framework for integrating and filling the gaps between other available data types and extend the geophysical rock properties from each type of measurement.



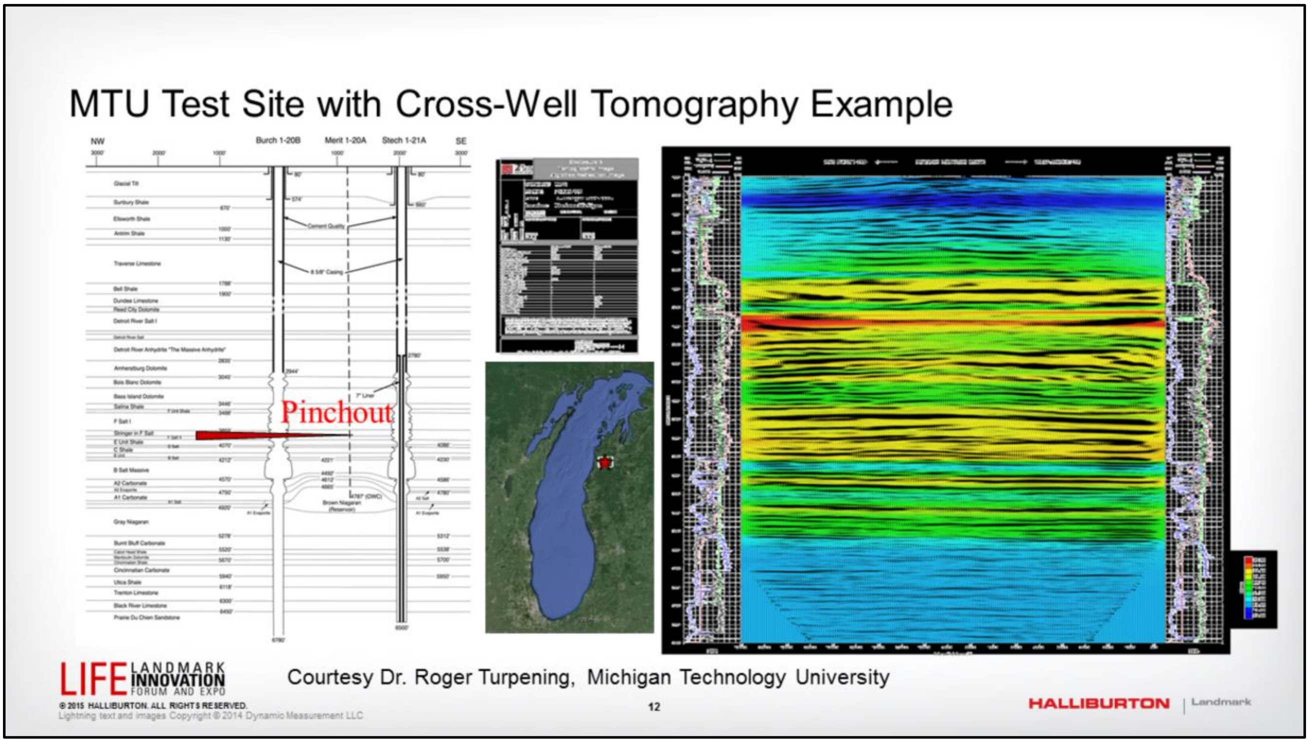
A key issue with borehole derived rock proprieties are they are limited to discrete locations within a few feet of the borehole. They are also very expensive. However, boreholes do provide us physical samples which can be measured and tested in the lab. To some degree borehole data can be expanded along a line with 2-D seismic, or across a volume with 3-D seismic. Gravity enables density estimates over a large area, and magnetics provides estimates of basement depth and faulting. Instantaneous Potential surveys provide resistivity and permittivity measurements along survey lines. Lightning rock property volumes expand on all of these, at less cost, and are easy to integrate with other geophysical data types with DecisionSpace.



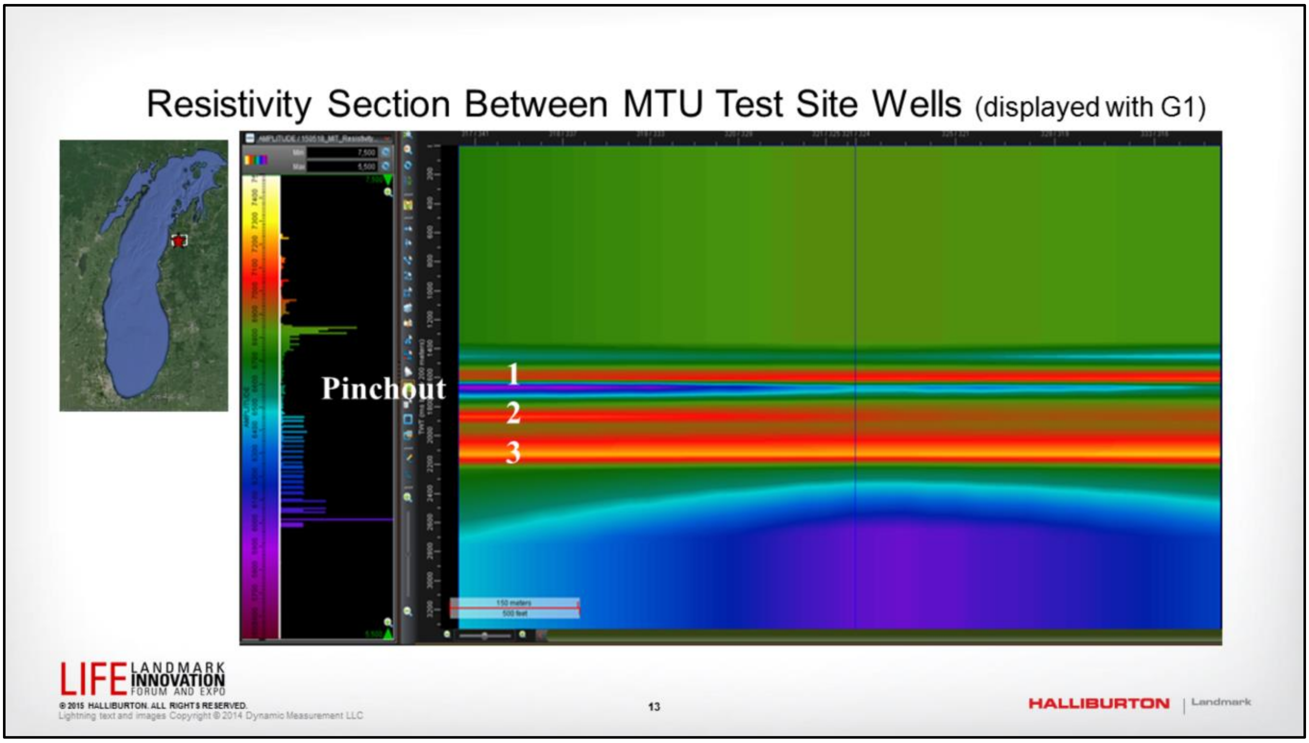
Our first examples of lightning analysis are from the Michigan peninsula. The map on the left shows the topography and surrounding Great Lakes. The red dots on both maps are gas well locations and the greed dots are oil well locations. The map on the right is lightning density with a strike-slip fault interpretation overlaid. The Albion-Scipio Field is hydrothermal alteration along a strike-slip fault, and the Stoney Point field is a splay off of this fault. The lightning density variations provided the basis for this strike-slip interpretation.

Other interesting aspects of the lightning density map:

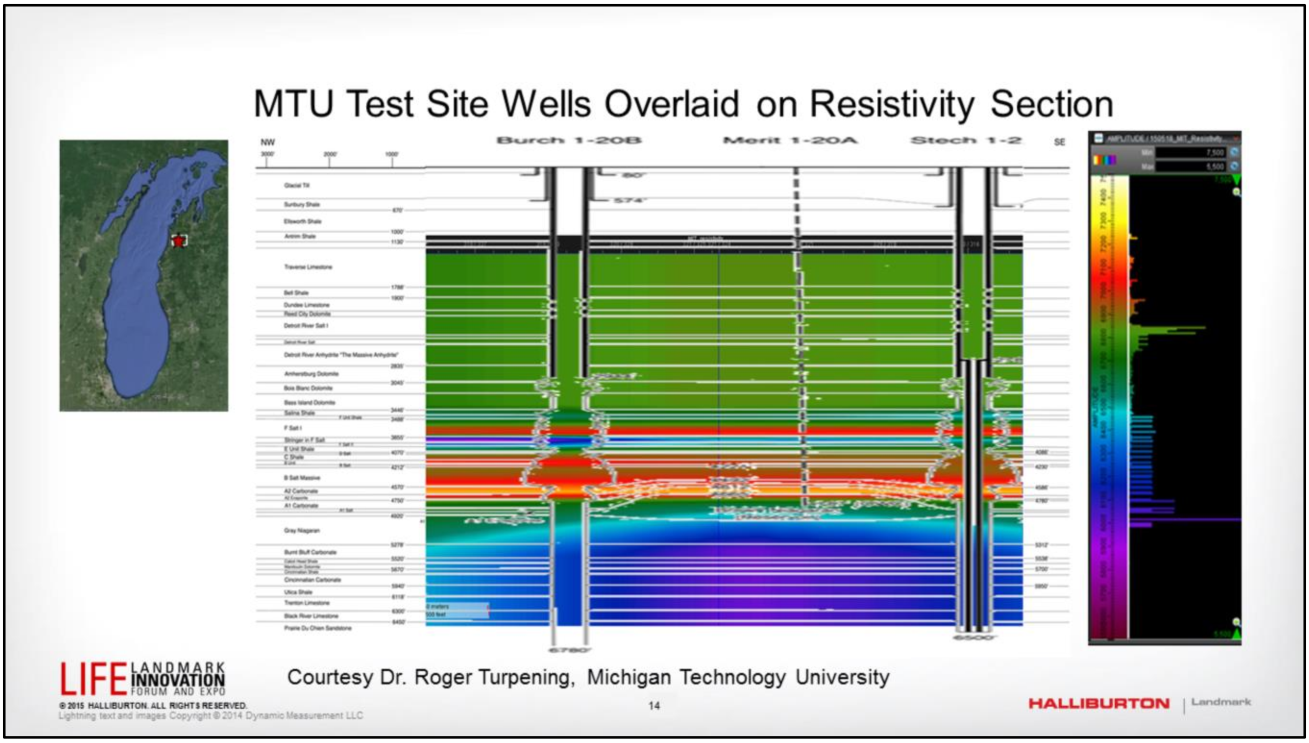
- There are fewer lightning strikes in the north. This is because there is snow on the ground more of the year, which creates an additional fresh water dielectric, and cuts down on connection with terralevis currents.
- There are no anomalous lightning densities at Detroit, where there is a lot of metal infrastructure.
- Note the patterns in the lightning density continue offshore.



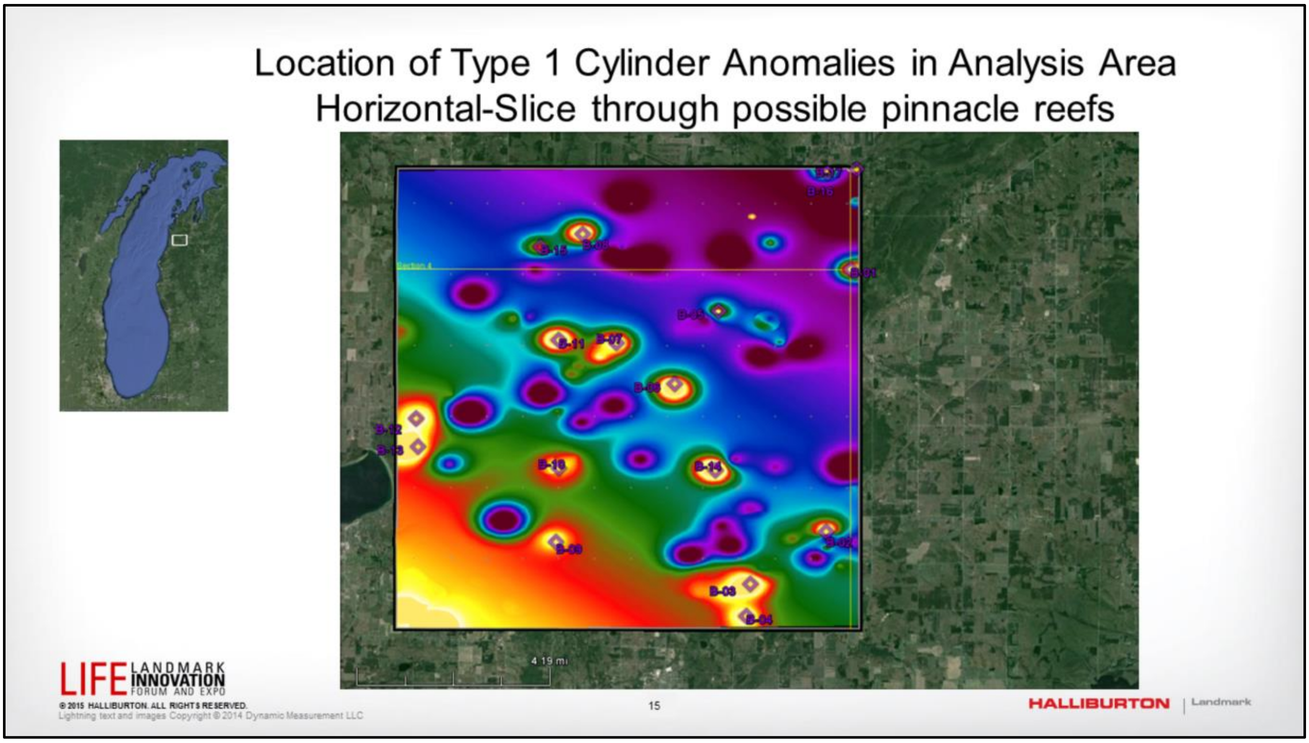
This slide shows a detailed interpretation of two wells at the Michigan Technology University Test Site. Dr. Roger Turpening and his students test different downhole tools in these wells, creating results like the cross-well tomography example shown on the right. One of the issues we face with lightning analysis and lightning rock properties is vertical and amplitude calibration of the rock property values derived from the lightning databases. The next few slides show our initial steps in accomplishing this type calibration and validation.



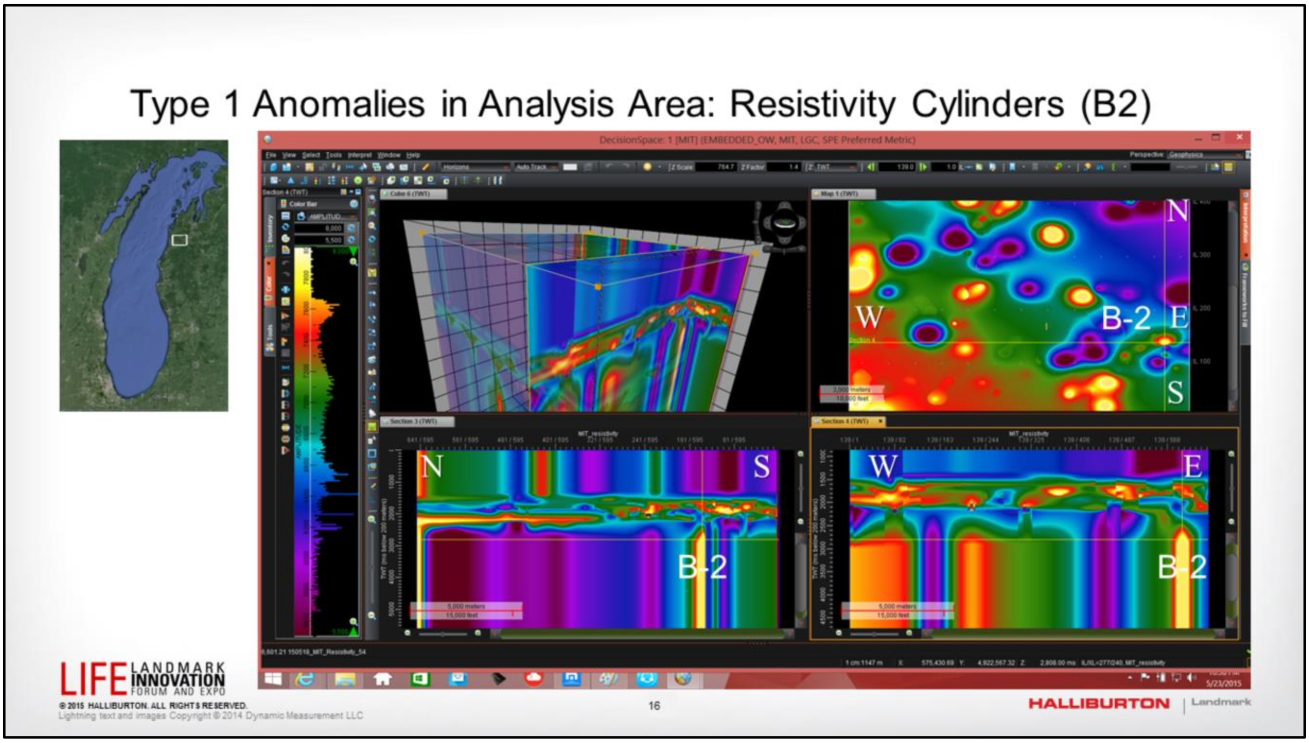
To start our calibration, DML created 100 square mile rock property volumes centered on the MTU Test Site. This 3,000 foot section is pulled from the resistivity rock property volume between the two well locations. Note the 3 resistive layers, the pinchout of a conductive layer just under the first resistive layer, and the curvature of the conductive layer underneath the bottom thicker resistivity layer. This information is derived by interpolating resistivity values calculated from the lightning database DML has an exclusive license for using for natural resource exploration. Note there is patent pending status on the process DML uses for calculation of resistivity volumes from lightning databases.



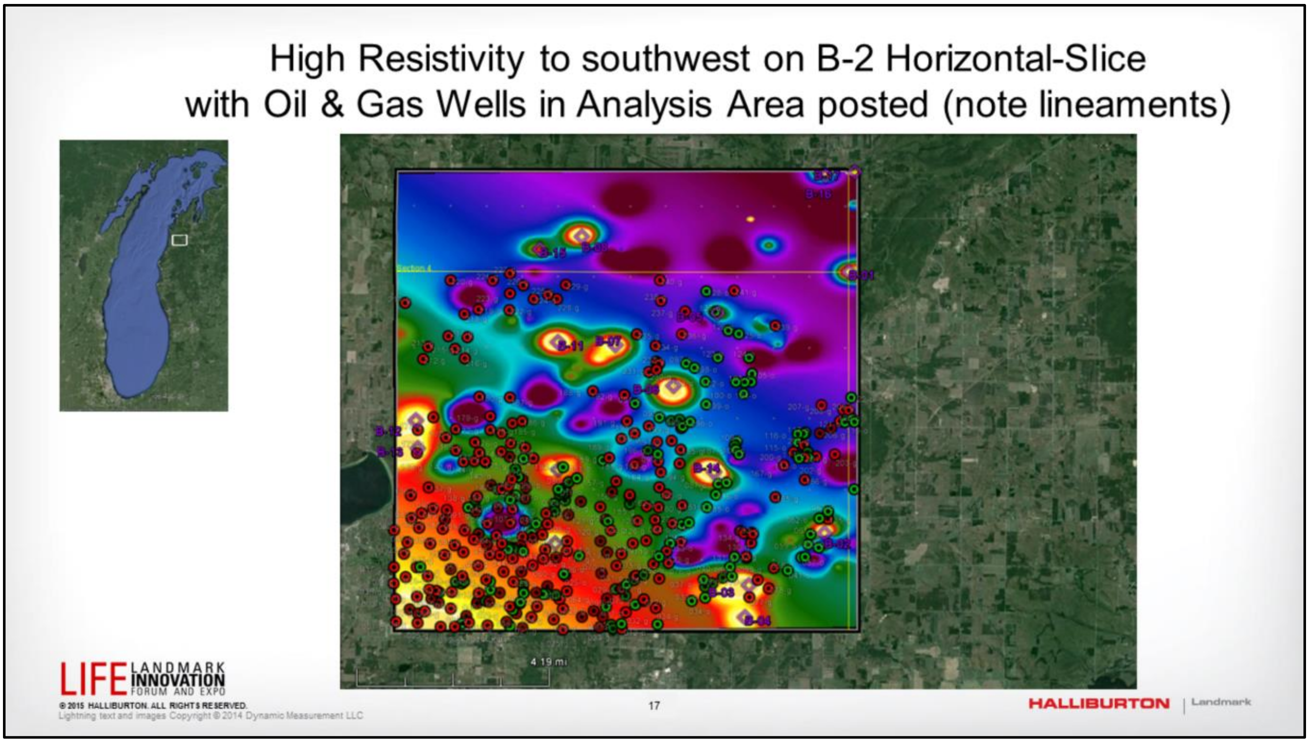
The next step in our calibration was to overlay the MTU lithology cross-section on the lightning derived resistivity cross-section. The three strongest resistivity layers correlate with salt layers in the MTU cross-section. The more conductive layer correlates with the top of the limestone reef defined on the MTU lithology cross-section. As a first pass, it appears we have good correlation between the lightning derived resistivity and the MTU lithology cross-section, including the conductive pinchout.



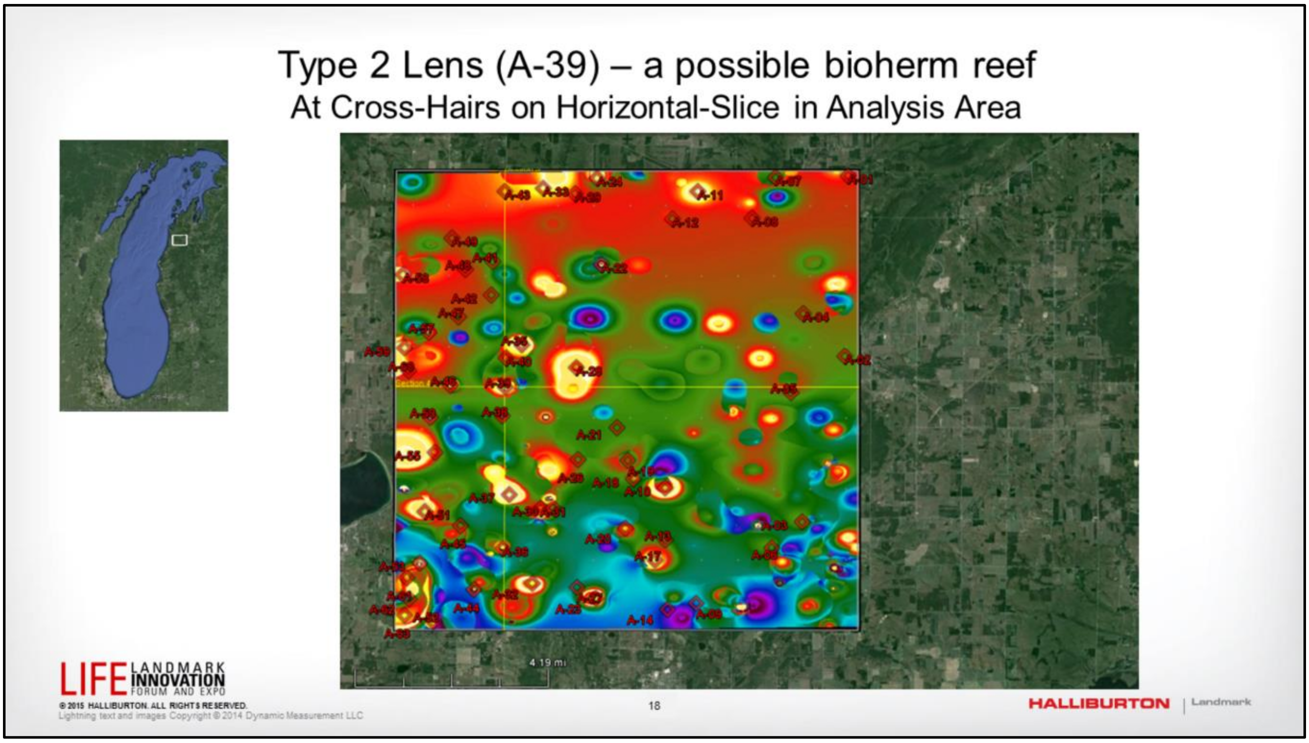
Stepping the view out and looking at a horizontal slice across the entire resistivity volume shows very interesting circular anomalies. As shown in the first slide in this section (slide 11), there are many wells in this area. This slide shows possible drilling locations for wells which would test these circular high resistivity anomalies. In cross-section these circular anomalies continue to the bottom of the calculated resistivity volume. We call these Type 1 Cylinder Anomalies, and they possibly define pinnacle reefs in this area.



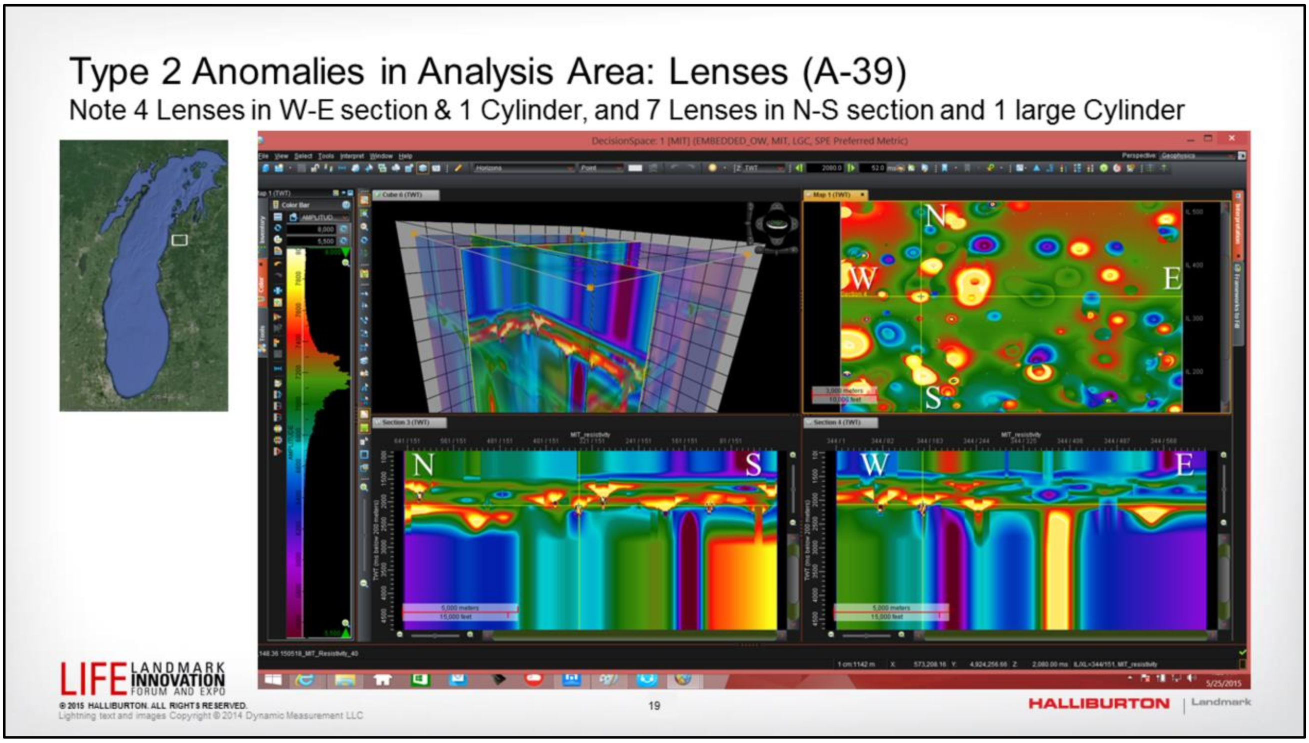
This DecisionSpace display shows north-south and west-east cross sections and slightly shallower horizontal slice through anomaly B2, showing three views of a typical Type 1 Resistivity Cylinder.



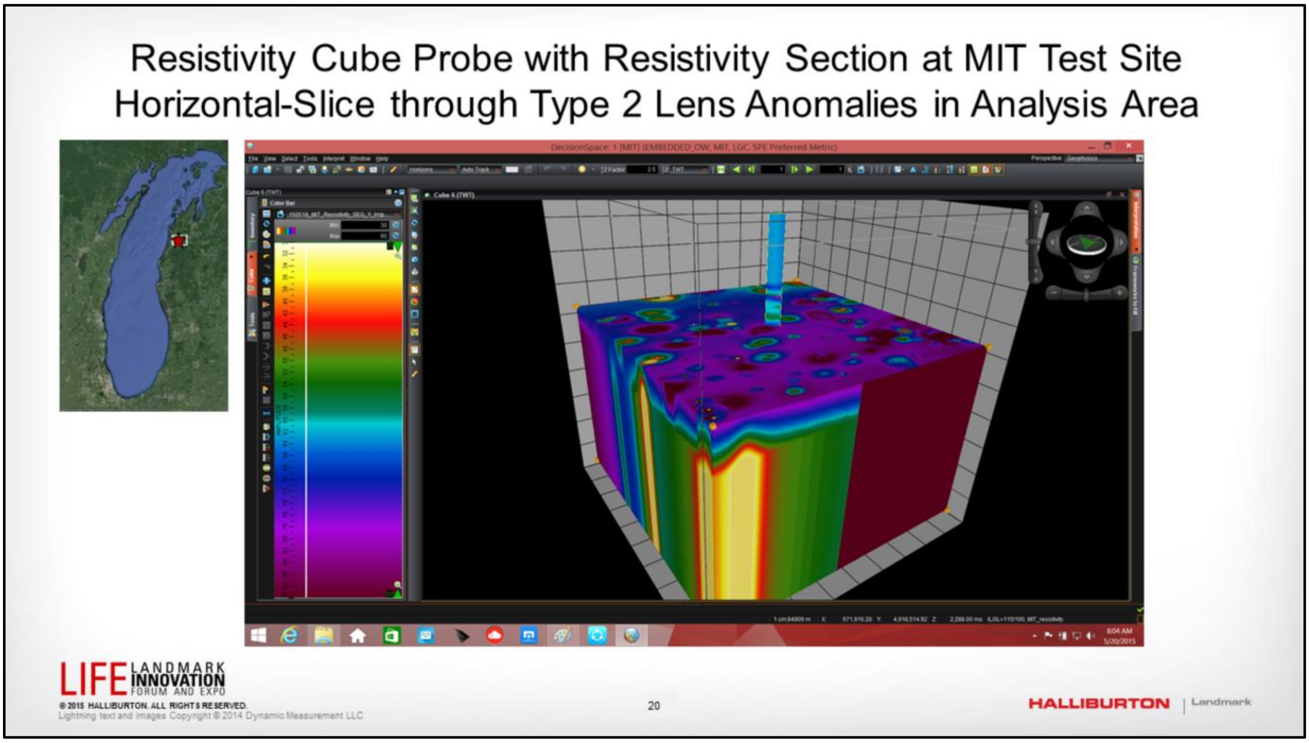
This enlargement of the 2800 ms horizontal-slice includes an overlay of oil (green) and gas (red) wells from the Michigan Geological Survey Map. Note most of the gas wells are in the southwest quadrant, which is where the highest resistivity measurements derived from the lightning database are located at this horizontal slice. Also note the linear nature of many of the oil wells, and how these lineaments line up with variations seen on the resistivity horizontal slice. Also note the halo of oil wells around the Type 1 Cylindrical Resistivity Anomaly just right of the center of the horizontal slice. These preliminary results encourage additional analysis and calibration.



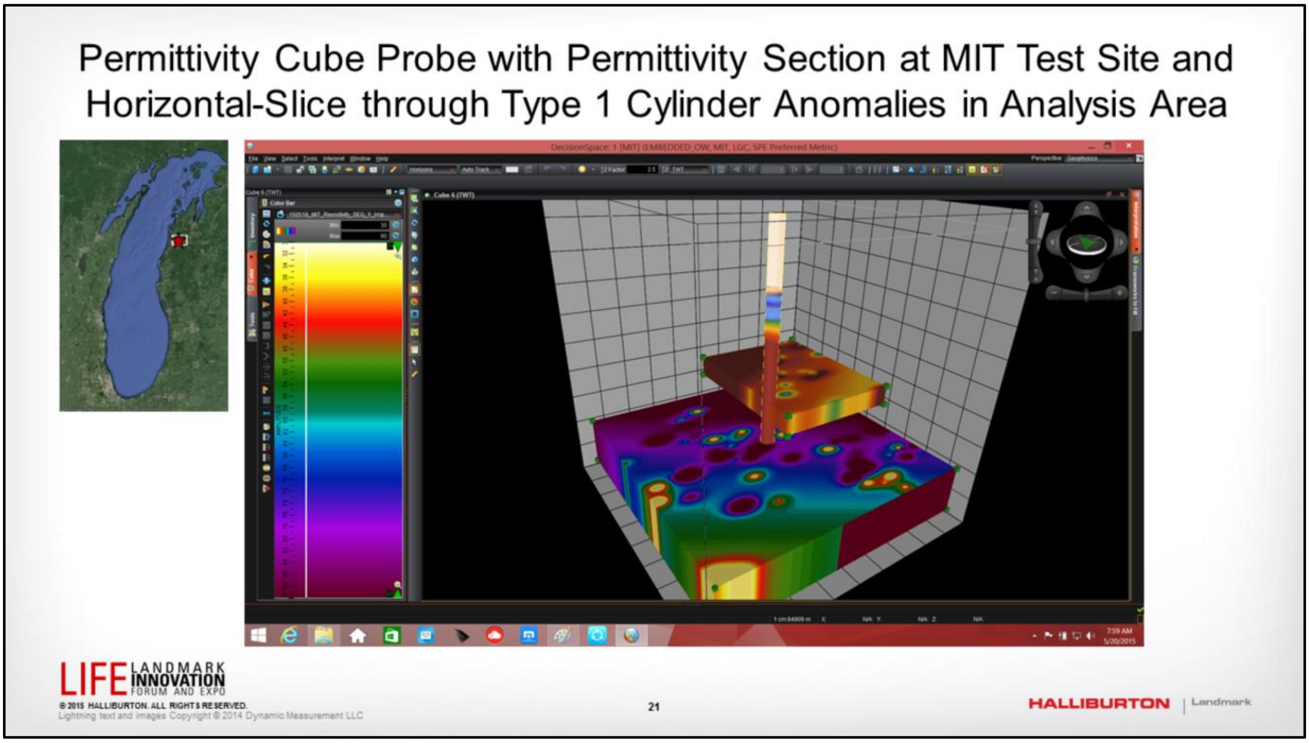
Moving the horizontal slice up to 2100 ms, there are many examples of a different type of circular anomaly. We call these Type 2 Lens Anomalies, and they possibly define bioherm reefs in the area. There are many more of the Type 2 Lens Anomalies, than there are Type 1 Cylinder Anomalies in the lightning derived resistivity volume.



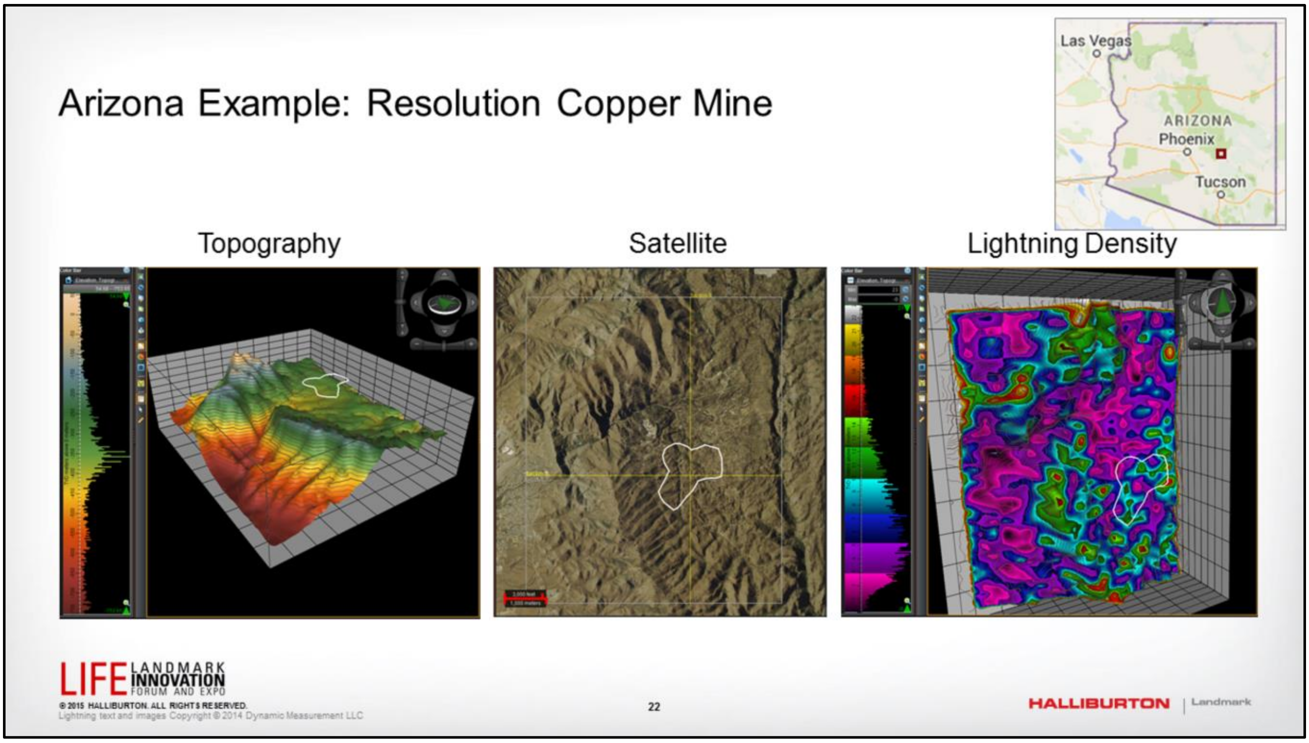
This DecisionSpace display shows north-south and west-east cross sections and the 2100 ms horizontal slice through anomaly B2 - showing three views of a typical Type 2 Resistivity Lens. In fact, there are about 17 separate lenses on the two shown vertical cross-sections. Again, these preliminary results encourage additional analysis and calibration.



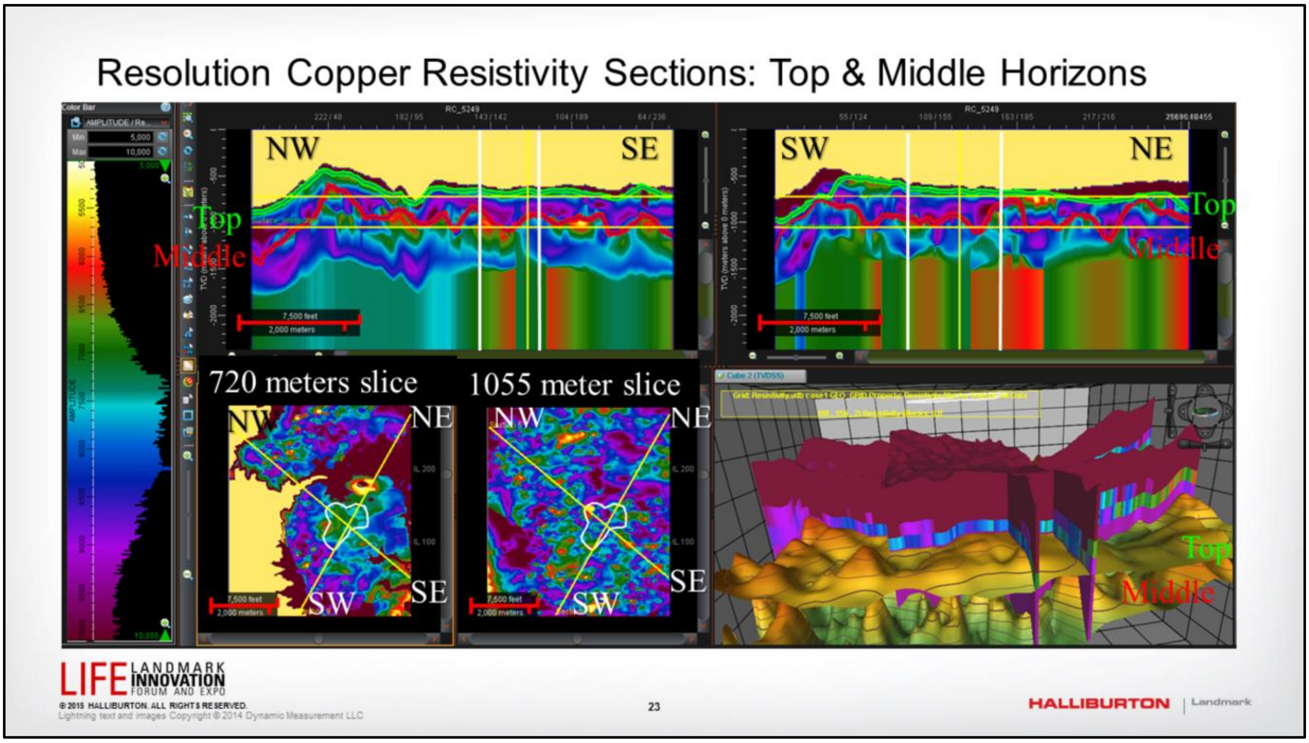
This DecisionSpace display highlights the relative scale of the 100 square mile resistivity volume and the 3,000 foot resistivity cross-section between the wells at the MTU Test Site.



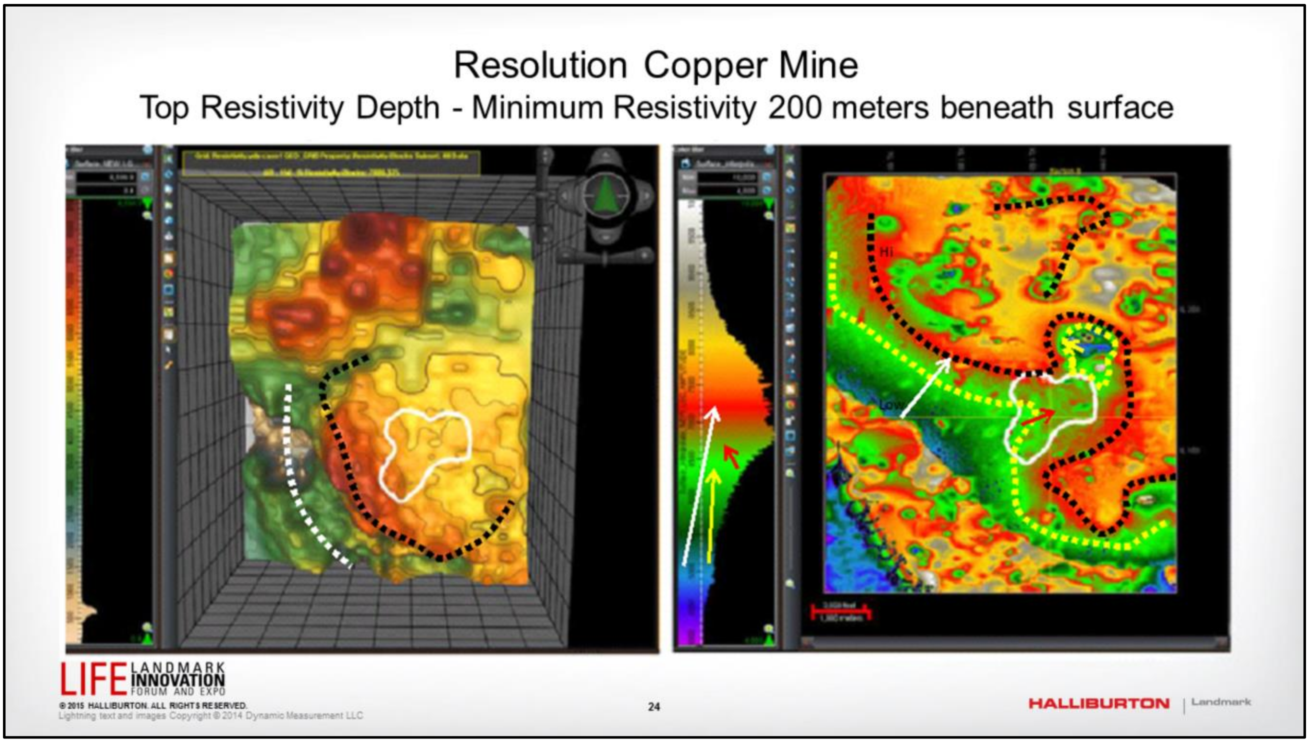
This DecisionSpace display lowers the height of the top horizontal slice on the resistivity box probe, showing a permittivity box probe, and changing the 3,000 foot cross-section to a permittivity cross-sections between the wells at the MTU Test Site. As time and funding allows, DML will obtain well logs for all of the wells in this area, load them into DecisionSpace, and use this as a next step in our calibration and validation of rock property volumes in an environment with reefs, salt, and clastic deposition where there has been extensive hydrocarbon exploration.



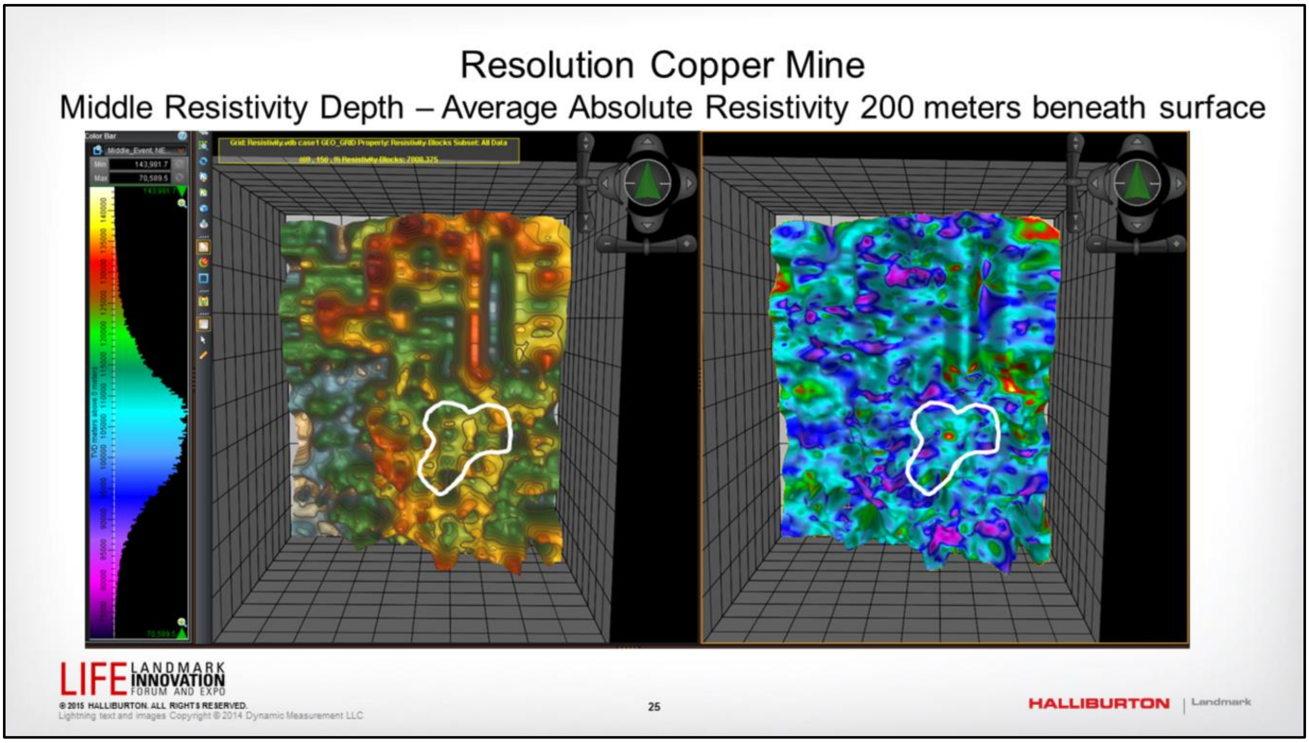
Mineral exploration requires working with a different type of geology. This example is from a project across the recently approved $6 billion Resolution Copper mine near Superior, Arizona, about 100 miles east of Phoenix. There is much more topographic variation at this site than there is in northern Michigan, as shown in the topographic map on the left. The location of a copper porphyry intrusion is outlined on each of the topography, satellite, and lightning density maps. Topography does have some impact on lighting density, in that there are up to 25 lightning strikes per interpolation cell on some of the peaks to the north, and there are 2-5 lightning strikes per interpolation cell in the valley, up the canyon, and on part of the plateau. The distribution of the lightning attributes is not impacted in the same way by the topography.



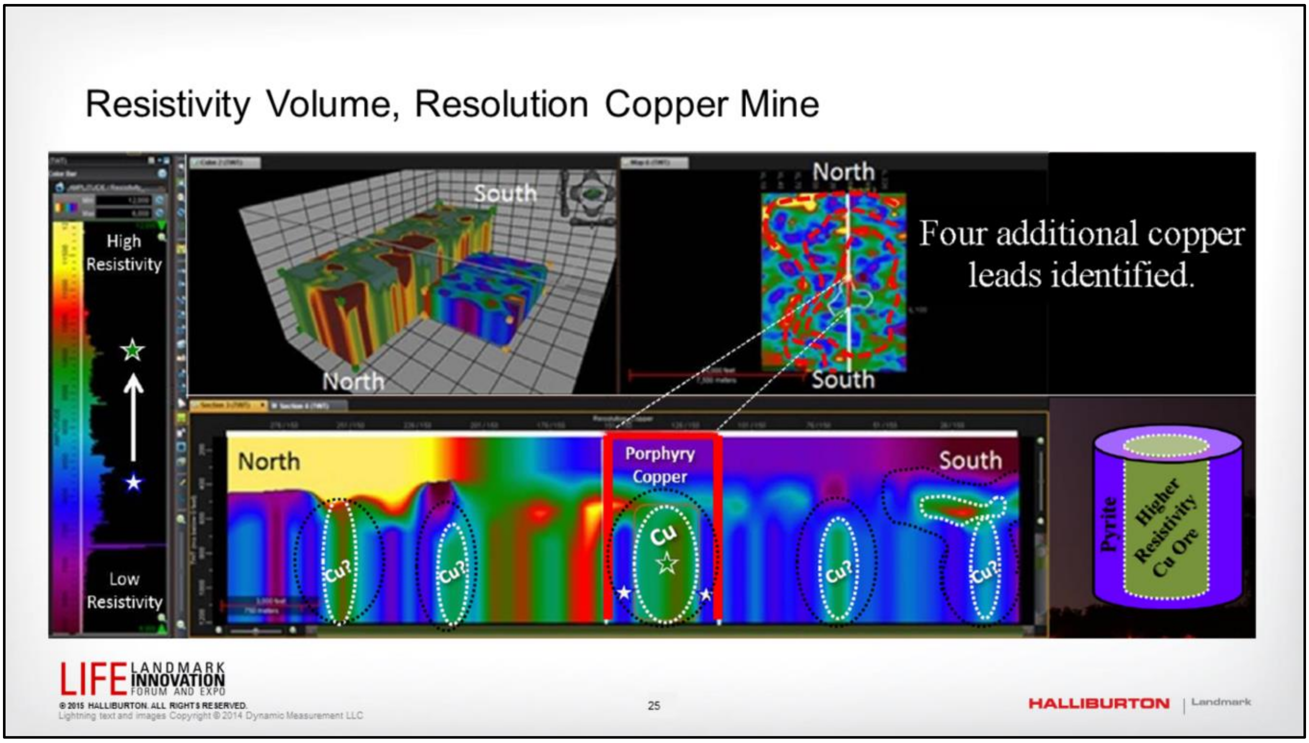
As a preview of the area, this DecisionSpace screen capture shows a NW-SE and SW-NE cross section, two horizontal slices, and highlights 2 horizons interpreted in the resistivity volume. The horizons were named Top, for Top of highest resistivity anomalies, and Middle, for Top of resistivity anomalies in the middle of the best calculated resistivity data. A 3-D celluar grid was calculated between the Topography and the Top and Middle surfaces. The Top and Middle surfaces are displayed as Frameworks with cross-section and a small box probe in the cube display at the bottom right. The rock property volumes were loaded as depth volumes in DecisionSpace.



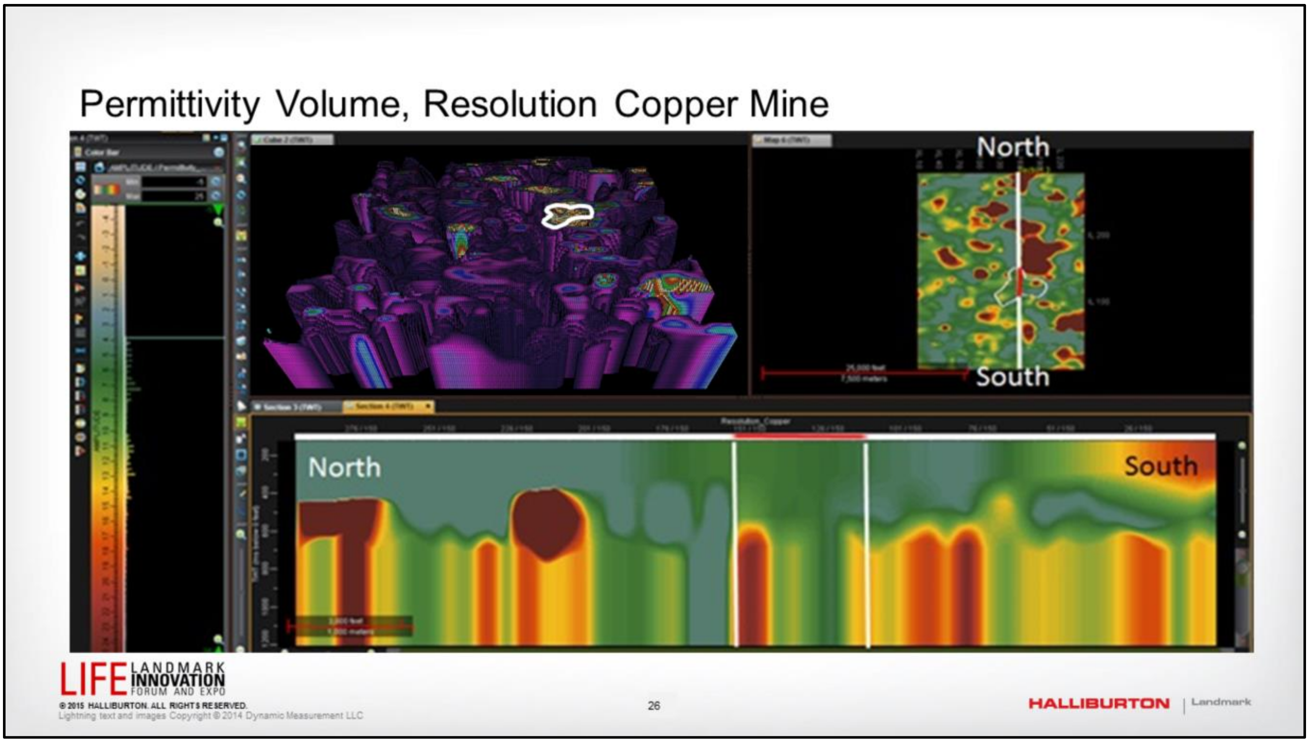
This display shows the top of the Top Surface as a DecisionSpace framework. Note the structural high "halo" around the outline of the copper porphyry. From a mineral exploration standpoint, it is important to be able to derive this type of information from a regional survey without having to obtain permits or let landowners or competition know you are doing an analysis of an area. Because the resistivity volume is loaded the same way as a seismic volume, you can do similar types of analysis as is done on seismic volumes. The map on the right is an extraction of minimum resistivity for the 200 meters. Note there is a large difference in the minimum resistivity where the copper porphyry intrusion is outlined. There is also a large anomaly just north east of the planned mine.



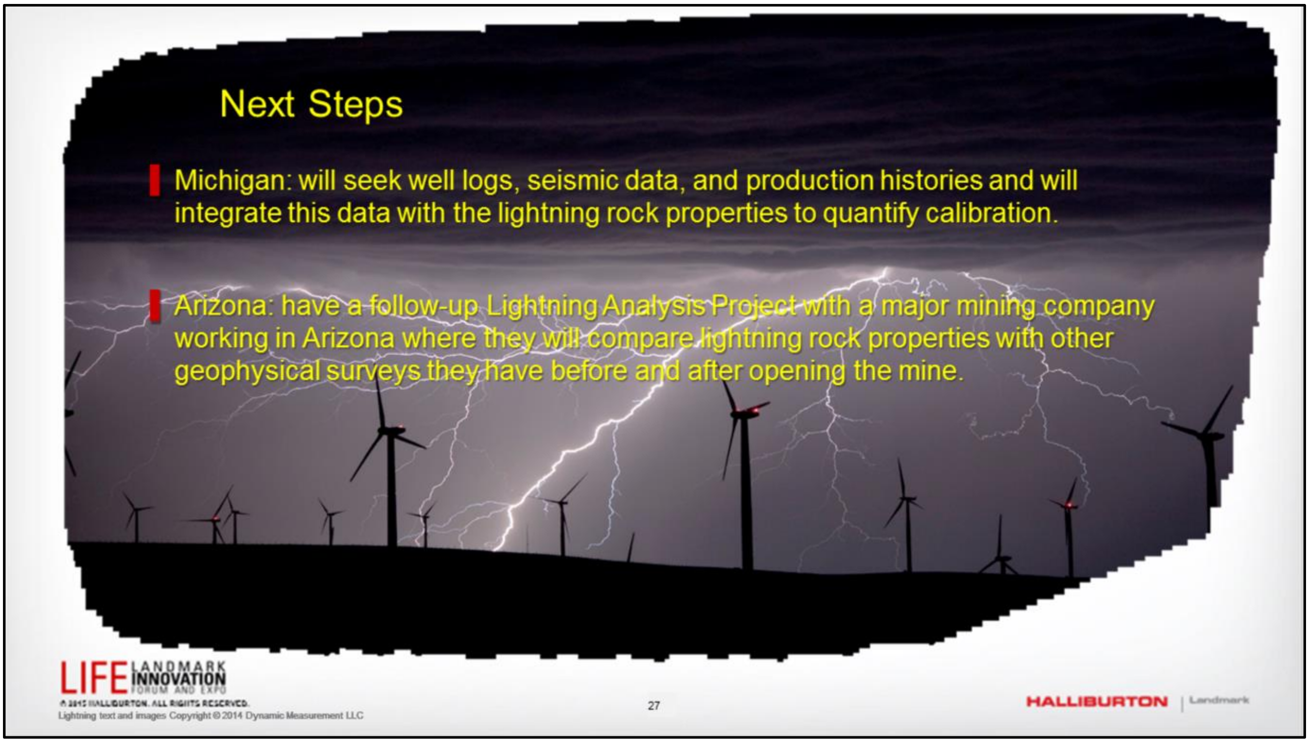
Stepping down the framework map display of the Middle horizon, there is the same type of halo around the copper porphyry outline. The display is the average absolute resistivity from 200 meters beneath the Middle horizon. There is a maximum in the center of the copper porphyry outline, with a halo of lower values surrounding the outline. We are showing these results to demonstrate how we are using DecisionSpace to better understand the rock property volumes and the results we are starting to find. We anticipate being much further along with calibration and validation next year.



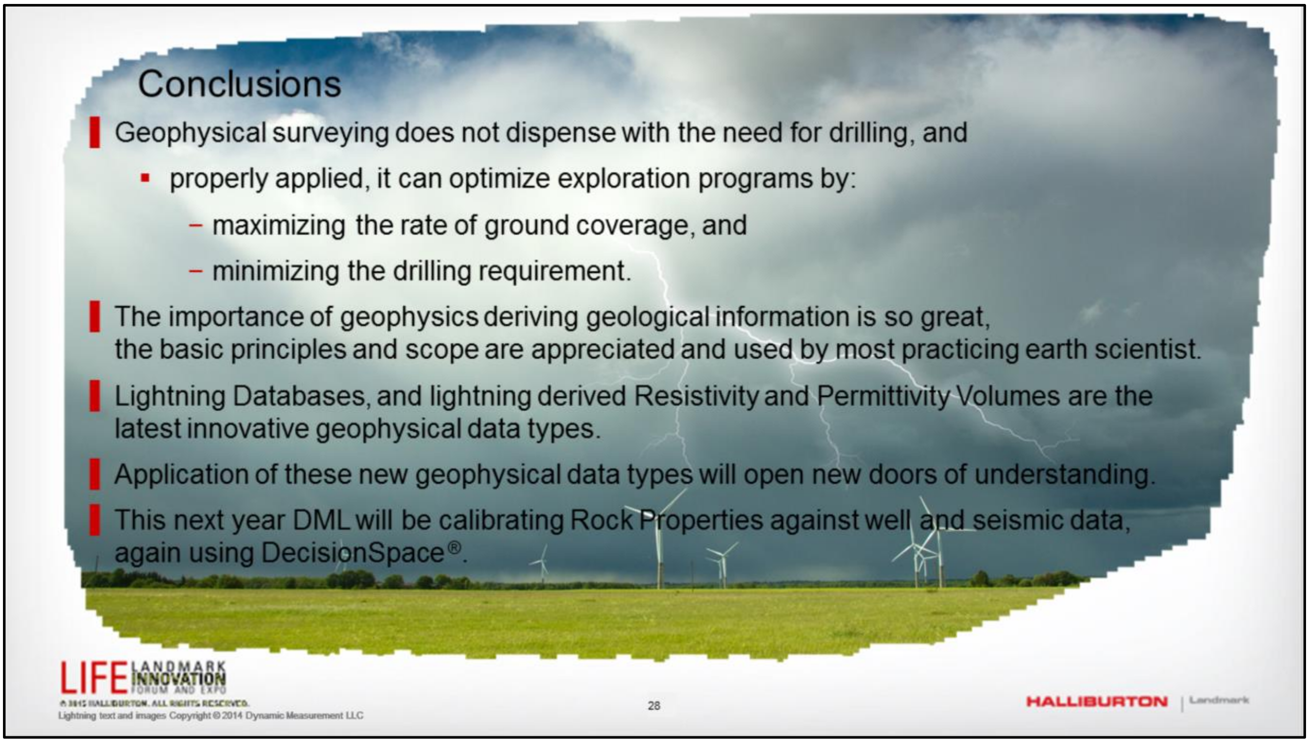
This DecisionSpace screen capture shows a permittivity box probe, and a resistivity box probe in the upper left window. The upper right window is a horizontal slice, with an interpretation of more conductive halos around the copper porphyry outline. This is the pattern which is expected for this type of a deposit. The north-south cross-section on the bottom shows the resistivity response across the porphyry deposit. Interpretation was done by Louis Berent.



This DecisionSpace screen capture shows the same horizontal slice and cross-section derived from the permittivity volume calculated over the same area. The upper right window shows a 3-D grid calculated from the rock property volumes with the approximate location of the copper porphyry outline. We are just beginning to understand the value and the limitations of the rock property volumes over this mineral deposit.



As summarized on this slide, DML will be expanding on this work over the next year, in order to be able to more completely describe correlations and non-correlations with the data and existing data in these two areas.



In conclusion, geophysical surveying does not dispense with the need for drilling. However, properly applied, geophysical surveying can optimize an exploration program by maximizing the rate of ground coverage and minimizing the drilling requirement. The value of these surveys in deriving geological information is so great, the basic principles and scope are appreciated and used by most practicing earth scientists. Lightning derived resistivity and permittivity volumes are the latest innovative geophysical data types. Application of these new geophysical data types will open new doors of understanding. We appreciate the opportunity to present our journey at LIFE and look forward to showing new developments next year.

Thank you for your interest, and we look forward to answering questions about our technology and approach.