Regional Lightning Analysis

Introducing how a new type of potential field analysis is being used for regional analysis in southern Mountrail, Ward, McHenry, and Pierce Counties in the Williston Basin, North Dakota.

Les R. Denham[a], Dr. Dan Ebrom[b], and H. Roice Nelson, Jr.[a]
[a] Dynamic Measurement LLC; [b] Geopressure Geophysical Consultant

Need

Exploration needs a geologic framework. Explorationists need new economical ways to identify and focus on sweetspots within the geologic framework of their exploration Area-Of-Interest (AOI).

Geophysical Services Meeting These Needs

Lightning analysis is based on a new geophysical data type, lightning strike databases. Map and volume results can easily be integrated with other geological and geophysical control. This provides additional and independent dimensions of control and interpretation confirmation. Lightning analysis uniquely enables economic exploration across a spectrum of exploration activities: from aquifers to minerals to critical minerals to hydrates to coal bed methane to sweetspots in shale plays to hydrocarbon migration pathways to exploration for traditional oil and gas fields, and to prediction of areas likely to have earthquakes or volcanic eruptions. This paper introduces a regional analysis of the transition out of the Bakken Shale on the eastern side of the Williston Basin in North Dakota.

Potential Field Data

Proven exploration processes include measurements of gravity, magnetic, electrical, or electromagnetic fields. These potential fields obey the Laplace equation, a differential equation describing field behavior in free space.[1] Potential field measurements are much less expensive than drilling wells to measure the subsurface, and less expensive than common geophysical exploration techniques like 2-D and 3-D reflection seismology. Results from potential field data often have less resolution than seismic, and are primarily used to provide an exploration framework.

Lightning is an electromagnetic phenomenon which has traditionally been considered random. Lightning strike data has been collected since the early 1980's.[2] Insurance companies are the main user of this data, primarily to confirm lightning occurred in the vicinity of a damage claim. Television meteorologists use this data to show storm concentrations. Airports, golf courses, and other public facilities use real-time versions of this data to enhance safety precautions. In 2008, Dynamic Measurement LLC was formed to research and commercialize geophysical exploration services based on lightning strike databases. An exclusive license to the best lightning databases available has been supplemented with 2 issued U.S. Patents, and dozens of proof-of-concept projects. Publications, including two GCAGS Best Papers,[3&4] have demonstrated the power of this new geophysical data type.[5]

The static buildup in the atmosphere forming each lightning strike is random. As electrical charges build up in the cloud, the resulting electrical field interacts with subsurface telluric (earth current) fields. Lightning Strokes last microseconds, and build up occurs over tens of milliseconds. A 24 hertz signal, with a wavelength of 42 milliseconds, can have skin depths of 375-500 miles (600-800 km). This means lightning is interacting with geology down to the Mohorovičić Discontinuity. Lightning is key to charging telluric currents used in magnetotelluric and Tipper exploration. Each lightning strike is a giant spark across a giant capacitor. This spark is guided along field lines by interaction between atmospheric and geologic electromagnetic fields.[6] Knowing this, it is possible to create maps and volumes of lightning strike attributes and two derived rock properties (apparent resistivity and apparent permittivity), which help define subsurface geology and allow interpretation and creation of geologic frameworks.

Williston Basin Project

When Dr. Dan Ebrom attended Dynamic's school: Lightning Analysis Basics, discussions turned to the Williston Basin, and an old, but new, exploration idea. As kerogens have thermally matured to become hydrocarbons in the tight Bakken Shale, geopressure has built up. Theoretically, this anomalous overpressure impacts seismic velocities, creating a velocity corona around the sweetspots.[7] This paper details the first phase of work to see if lightning analysis can help identify these sweetspot coronas.

Typical projects start with a data order over the client AOI, and paying Vaisala, Inc., Dynamic's lightning data vendor, for the lightning data. Dynamic has a regional set of test lightning data over the Williston Basin AOI, which had not been used to create volumes. This data set includes 719,988 lightning strikes from the 10 years between 28 March 1999 to 06 November 2008. Between 2 and 50 sensors recorded each lightning strike. A new data order over this same area would have about 2.2 times as many lightning strikes, or about 1.6 million strikes. This is important because the more data, the higher quality the results. The lightning analysis process is the reciprocal of 3-D seismic. With lightning you have hundreds of thousands of sources and hundreds of receivers. The processing of this lightning data can be compared to "stacking" seismic traces, where signal is enhanced and noise is cancelled as data are merged.

This Williston Basin project is based on creating 4 lightning analysis projects (see Figure 1):

1. The Red SPOT^{sm}, a 6.675 km (4.12-mile) diameter project over the Antelope Field on the Nessen Anticline, with 25-meter (82-foot) trace spacing.
2. The Blue SPOT^{sm}, an equivalent project east of the Bakken Shale in Pierce County.
3. The 224.1 km (139.25 miles) LINE^{sm} project, 3.3 km (2.05 miles) wide with 100-meter (328 foot) trace spacing, connecting the 2 SPOT^{sm} surveys.
4. A d.NSEM^{sm} project over the main part of the Nessen Anticline (85.15 km [52.91 miles] x 67.85 km [42.16 miles] with 50-meter [164-foot] trace spacing).

Lightning Processing and Initial Analysis

The first step in processing lightning data is to clean the data. The original data for each strike includes: Location; Time and Duration; Rise Time; Peak Current; Peak-to-Zero; Polarity; Chi-Squared (a quality measure); Number of Sensors recording strike; and semi-major and semi-minor axes of error ellipse. Additional public domain data is added, including: topography from the USGS; solar and lunar locations tied to earth tides and other processes which connect to the location and time of each lightning strike.

The 25 maps (ASCII, xyz, pdf, or kmz formats) and 25 volumes (ASCII Voxel or SEG-Y formats) created for each of the 4 projects described above include: Rise-Time; Peak Current (positive, negative, and absolute); Peak-to-Zero; Wavelet Symmetry; Wavelet Total Time; Apparent Permittivity; Apparent Resistivity; Elevation; Energy (positive, negative, and absolute); Stroke Energy (positive, negative, and absolute); Frequency; Chi-Square; Day-of-Year; Sun Local Longitude; Moon Local Longitude; Moon Phase; Number of Sensors; Tide; Tidal Gravity; Tide Gradient; and Spike.

Landmark Graphics' DecisionSpace^{tm} enabled creation of numerous additional map and cross-section attributes. For example, the "amplitude thickness" of the top 500 meters of each trace in the LINE^{sm} volume, is shown in the map on the top of Figure 1. These results tie surface anomalies on the shaded relief map. Phase, Frequency, Reflection Strength, Azimuth, Dip, Curvature, Relief, and numerous other trace attributes can also be calculated for each SEG-Y volume. The instantaneous phase of the apparent resistivity volume shows dips which were helpful in calibrating against Meisner's geologic cross-sections. The Meisner extent of the Bakken Shale is overlaid on the Apparent Resistivity top cross-section in Figure 2. The bottom cross-section is Apparent Permittivity. Note the strong apparent resistivity anomaly above the pinchout of the Bakken Shale in both Figure 1 and Figure 2. It is logical this anomaly is related to hydrocarbon leakage from the up-dip pinchout of the Bakken Shale, possibly defining a new play in the basin.

There were too many displays generated for inclusion in this introductory paper. However, an animated gif associated steps through examples of maps and volumes for each of the 4 projects described above.

Additional Work

Building the project data bases, as described herein, is a first phase of any interpretation project. The intention is to tie additional data (digital well logs, digital seismic sections and volumes, temperatures, pressures, production, etc.) into these projects for better calibration and better understanding of the strengths and weaknesses of lightning analysis as a geophysical framework tool. If you would like to participate in this effort, please contact Dan Ebrom dan_ebrom@yahoo.com (832) 274-8393 or Roice Nelson roice@dynamicmeasurement.com (713) 542-2207. We intend to publish the additional work.

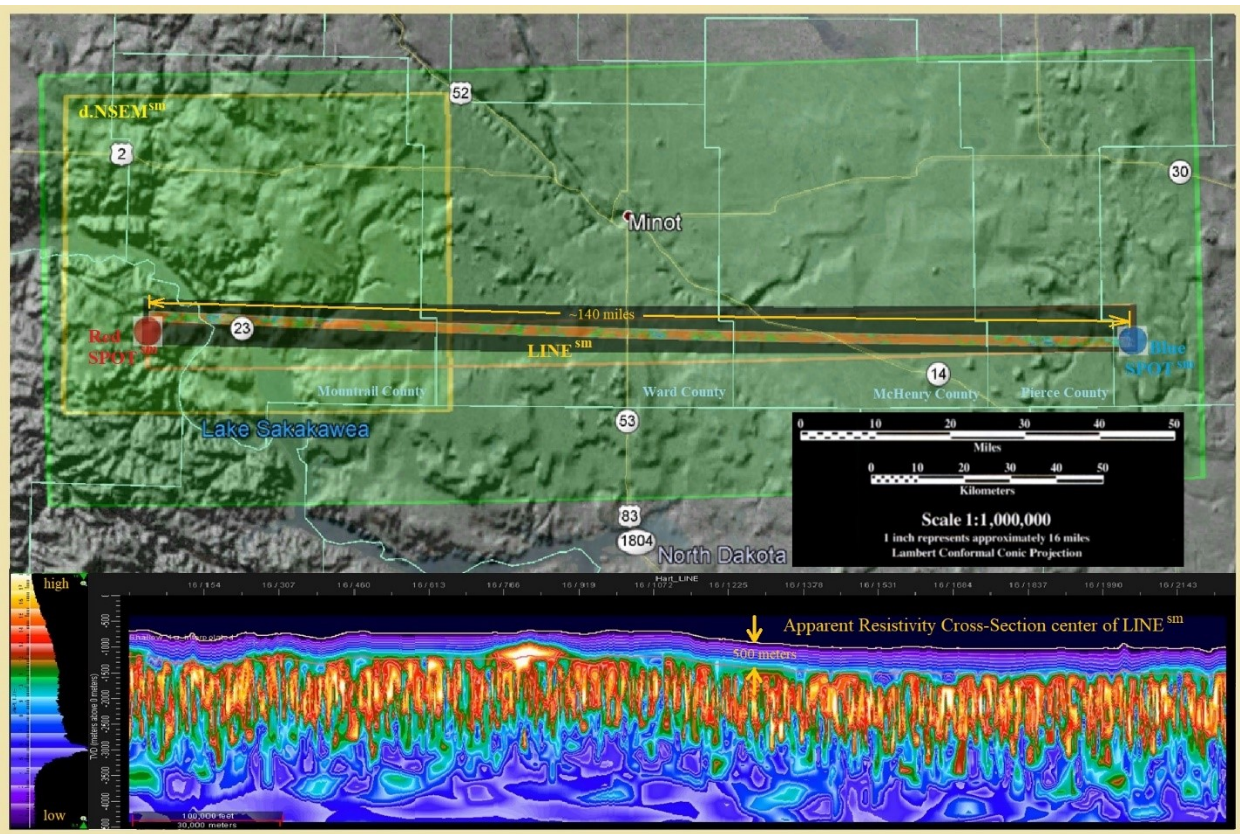

Figure 1. The Williston Basin AOI (shaded green) over Shaded Relief of North Dakota.[8] Four lightning analysis projects were created within this area: 1. Red SPOTsm; 2. Blue SPOTsm; 3. LINEsm; and 4. d.NSEMsm (Dynamic Natural Sourced Electro-Magnetics).The cross-section at the base is an 140-mile long Apparent Resistivity Cross-Section, derived from lightning databases, down the center of the LINEsm, where bright colors are higher apparent resistivities. The map is amplitude thickness from the Apparent Resistivity Volume for the first 500 meters depth (between arrows). Note this amplitude thickness map matches rivers and other anomalies on the Shaded Relief map.

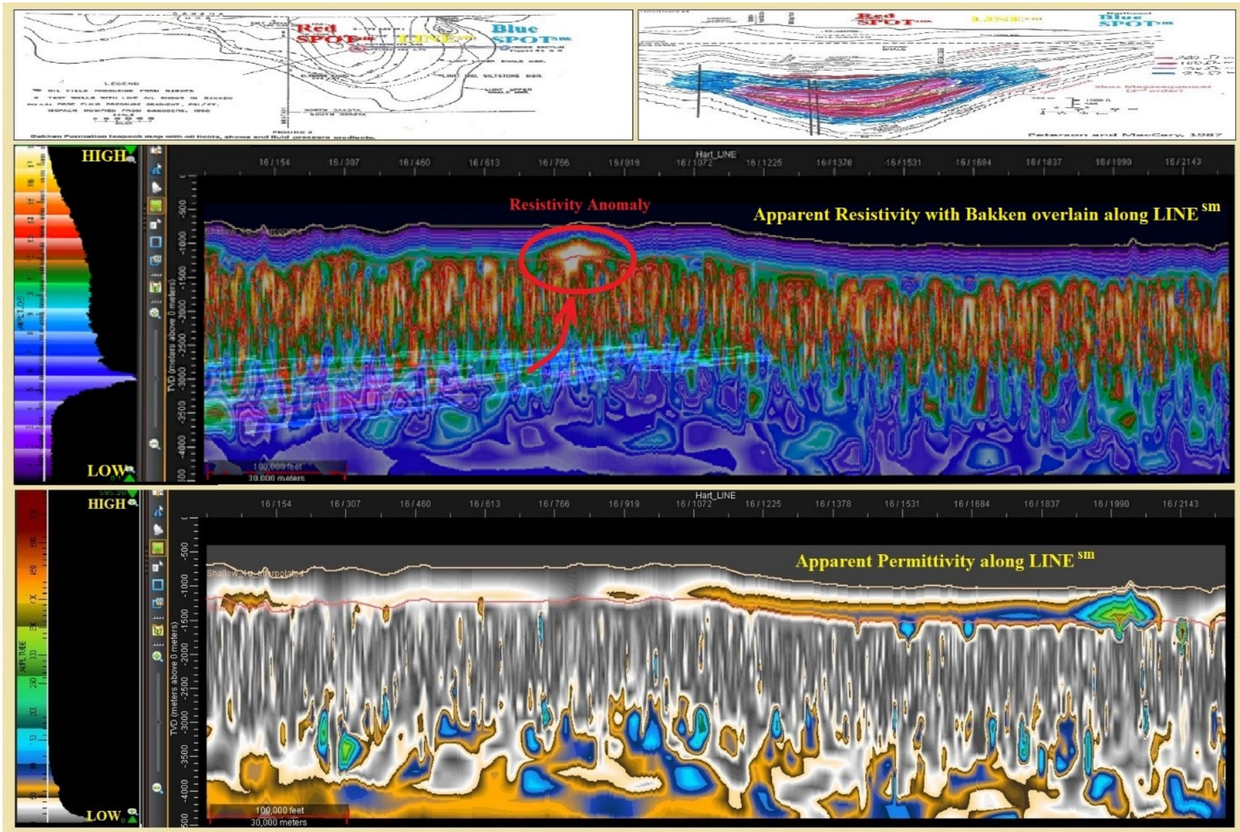

Figure 2. Two rock property cross-sections derived from Lightning Analysis. Meissner location map and cross-section shown at the top, and taken from AAPG Memoir 35. The top cross-section is Apparent Resistivity, with the appropriate portion of the Meissner cross-section overlain. Note at these scales the dips match. The apparent resistivity anomaly above the termination of the Bakken Shale, circled in red, which is likely due to hydrocarbon seeps, and could define a new exploration play. The bottom cross-section is Apparent Permittivity. The shallow high permittivity values east of the extent of the Bakken Shale appear to tie the Hell Creek Formation outcrop, which is at the global standard for understanding the Cretaceous-Paleogene (K-Pg) extinction event, with concentrations of high insulation or high permittivity iridium, tied to the impact of a massive comet or asteroid at the Chicxulub crater in the Gulf of Mexico's Yucatan Peninsula.[9]

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