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Mining and Oil & Gas Applications of Lightning Analysis

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Abstract

New geophysical data types trigger a step change in new revenues and cost avoidance for mining and for oil & gas exploration companies. The synergies developed by integration of multiple data types historically generates new opportunities and higher profits. NSEM (Natural Sourced Electromagnetic Method), integrates non-seismic geophysical techniques with seismic, well, and production data. NSEM is a passive geophysical approach, based on datamining Vaisala's lightning databases (Nelson, et al, 2013). Because lightning occurs virtually everywhere, NSEM technology can be integrated into multi-disciplinary frameworks for geophysical and geological studies in most mining and oil & gas exploration environments worldwide (Denham, et al, 2013).

Dynamic Measurement LLC. (Dynamic) is bridging the gap between meteorologists and geoscientists. Meteorologists see lightning as an atmospheric event with little interaction with geology. Fulgurites and skin depth formulas imply lightning penetrates geology at most a few hundred meters. Potential Fields Geophysicists have been studying lightning as the primary source of telluric, or earth currents, since the 1950's. These telluric currents are known to exist all the way to the Mohorovičić discontinuity, separating the mantle and the crust and up to 50 km deep. Skin Effect is the depth the current is reduced to 1/e, or about 0.37 of the surface current. Given δ is skin depth in meters, μ_r is relative magnetic permeability of the medium, ρ is the resistivity of the medium in ohm-meters, and f is the frequency of the current in kilo-hertz:

$$\delta = 503\sqrt{\frac{\rho}{\mu_r f}},$$

and at 2,000 meters current density is still about 2% of near-surface value. A 20 kA Peak Current strike effects an area of 0.01 m^2, with a current density of 2,000 kA/m^2. At 2% of the initial value, current density will still be 40,000 A/m^2. Lightning can be looked at like a current along a wire, inducing a magnetic field, which interacts with telluric currents at thousands of feet in the subsurface. These telluric currents have more impact on lightning strike locations than vegetation, infrastructure, or topography. There is extensive professional literature on magnetotellurics (Alumbaugh, et. al., 2016), ElectroSeis (Thompson, et. al., 2007), Tipper (Labson and Becker, 1987), and other geophysical exploration techniques based on passive measurements of lightning induced currents.

Dynamic has completed some 30 NSEM lightning analysis projects. All projects to date have been within the continental U.S., and all but one was based on Vaisala's NLDN (National Lightning Detection Network) lightning database. One project was run twice; first with the NLDN database, and then with Vaisala's GLD360 (Global Lightning Dataset – GLD360) lightning database. Example case histories to be shared include lightning analysis across a gold mine in California, a copper mine in Arizona, an oil and gas field in West Texas, and Gulf Coast exploration projects in Louisiana and Texas.

Lightning analysis projects start by signing a contract with the client, which insures Vaisala retains all rights to and control of their lightning data. Within the defined area, the data are ordered, followed by a cleaning process applied to exclude low quality data. After cleaning, both maps and volumes are made for up to 24 lightning attributes. Intellectual property rights for the data cleaning, processing, and interpretation are retained through trade secrets and a 2011 Patent (Nelson, et al, 2011). A recent significant development is the ability to calculate apparent resistivity and apparent

permittivity (rock properties) from the Vaisala lightning databases (Denham, et al, 2016). The case histories presented will use these lightning derived maps and volumes to illustrate building geological frameworks anywhere. For example, lightning is relatively rare within much of California. Nonetheless, there is still sufficient, since Vaisala has over 18 years of lightning strikes. “Stacking” this data provided 3-36 lightning strikes per square kilometer per year in the San Bernardino County study area. Results from this project include prediction of a new area to explore for gold.

The Arizona copper mine is in an area with significant topographic changes. The spatial resolution of raw lightning data from two separate lightning databases are quantified. A method to correct for topography is presented. As with the other projects described in this presentation, a lightning-derived geologic framework provides the basis for integrating geological data, copper mine production data, and various types of geophysical data (Berent, et al, 2017).

The West Texas oil field example shows the importance of identifying Risk Points, or the probability of additional lightning strikes hitting specific locations. This quantification of lightning strike clustering demonstrates how Risk Points locate opportunities for safety improvement. This includes where to protect pipelines from corrosion, where to protect power lines from electrical leakage, where not to place temporary crew quarters, and, from an exploration standpoint, locations of possibly missed exploration sweetspots in the existing field.

Gulf Coast exploration projects demonstrate integration of lightning-derived rock properties (apparent resistivity and apparent permittivity) maps and volumes as well as other lightning attribute maps and SEG-Y volumes with geologic maps, conventional cross-sections, seismic data, well logs, production data, surface faulting, EM surveys, and other geological and geophysical exploration and production data (Haggar, et al, 2014, 2015). From an exploration standpoint, a key use of lightning data analysis is to predict migration pathways.

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