Telluric and Earth Currents, Lightning Strike Locations, and Natural Resource Exploration*

H. R. Nelson[1], Les R. Denham[2], and D James Siebert[2]

Search and Discovery Article #41332 (2014)
Posted May 12, 2014

*Adapted from extended abstract prepared in conjunction with oral presentation at AAPG 2014 Annual Convention and Exhibition, Houston, Texas, April 6-9, 2014,

[1]Dynamic Measurement LLC (DML), Barker, TX, USA (RoiceNelson@gmail.com)
[2]Dynamic Measurement LLC (DML), Barker, TX, USA

Abstract

Telluric currents are natural electric currents flowing in the Earth's crust and mantle. The boundary between the crust and the mantle is the Mohorovičić discontinuity, which is 20 to 90 km (12.4–55.9 mi), or an average of 35 km (21.7 mi), beneath the typical continent.

Telluric currents have been used by geophysicists to map subsurface structures, such as sedimentary basins, layered rocks, and faults since the 1950's using magnetotellurics. Telluric currents balance currents in the ionosphere, a shell of electrically charged atoms and molecules surrounding the earth from a height of about 50 km (31.1 mi) to more than 1,000 km (621.4 mi).

Lightning strikes balance telluric/ionosphere capacitance by bridging the lower atmosphere dielectric with static bursts creating about 350 million annual cloud-to-ground (CG) strikes. Most lightning comes from cumulonimbus clouds which generate lightning from the base at 1-2 km (0.6-1.2 miles) above the ground to the tops, up to 15 km (9.3 mi). Upper-atmospheric lightning, known as sprites, blue jets, and ELVES range in height from 20 km (12.4 mi) to 100 km (62.1 mi).

In many natural phenomena, events at boundaries generate the most information. For CG lightning, the boundary is the strike point, and attributes of the lightning stroke contain the information. While topography, certain trees, and infrastructure have an impact on where lightning strikes, the composite conductivity or resistivity of the rock matrix and cracks in this rock matrix appear to have more influence on where CG strikes occur and on lightning attributes like rise-time, peak current, and peak-to-zero time.

The strike skin depth is negligible relative to natural resource exploration depths. However, as described above, the telluric and ionospheres' and meteorological currents setting up lightning strikes greatly exceed typical exploration depths. Based on numerous lightning data analyses, we have come to the conclusion there are earth currents, which we call terralevis (shallow earth) currents, in the depth range of natural resource exploration, and which have a controlling impact on CG lightning strike locations and attributes. We present lightning analysis examples leading to this conclusion. In some ways, this work is an extension of Nikola Tesla's experiment at his Pike's Peak laboratory in 1889 when

he confirmed the Earth itself could be used as an electrical conductor, and verified some of his suspicions regarding the conductivity of the ionosphere.

Previous Work

Geophysicists have known for decades there are electrical currents in the earth and that these electrical currents are modified by natural resources which can be resistive (fresh water aquifers, oil, gas. salt, etc.) or conductive (brines; clays; minerals like copper, iron, lead, zinc, gold, silver, and rare earths; Kimberlite Pipes; etc.). One of the earliest documents we found is a U.S. Patent applied for on 02 August 1940 by Harvey C. Hayes for doing electrical prospecting (see Figure 1), This patent sets forth a method to determine the probably boundaries of oil-bearing formations, along with their depths and inclinations. Specifically a set of five surface profile locations are shown crossing the Rodessa Fault area of Louisiana where there are oil bearing sands at depth. The five profiles show the derived potential differential profile curves, which correlate to the extent of production shown on the map. Soil analysis work of Sokolov and Mogilevskii in Russia showed halo-like concentrations of hydrocarbons at the surface outlining the limits of underlying oil bearing structures. Within the halo both methane and ethane gases are found in measurable quantities. According to the inventor it appears the lighter hydrocarbon components tend to slowly seep upward towards the surface and this may be the cause of the electormotive forces (Hayes, 1945). He also relates the magnitude to the temperature and pressure conditions within the structure.

Another document describes a method of exploring for deposits of oil, gas, geothermal energy, sulfide ore, and other minerals based on the existence of electrotelluric currents which are generated spontaneously by such deposits because of the geochemical modifications caused by their presence within the proximity of such deposits (Pirson and Pirson, 1976). The exploration method consists of measuring magnetic perturbations caused by these electrotelluric currents in the normally existing earth magnetic field. When these electrotelluric currents exist, the authors claim closed line-integrals of the earth magnetic field are a direct function of the magnitude and polarity of electrotelluric current flux densities generated by the underground mineral deposits sought. This is different that magneto-telluric measurements which make deep crustal studies of the earth to depths of 50 to 100 km for the purpose of determining rock resistivities (Cagniard, 1970). Figure 2 shows the various self-potential (SP) gradients from three wells around a small oil field discovered in the Denver-Julesburg Basin, Colorado. The 3-D drawing illustrates SP gradients associated with a hypothetical oil and gas field, along with gamma-ray intensity modifications of shaly marker beds observed above some oil and gas fields.

Lightning Topography Observations

The common perception is lightning strikes the tops of mountains, infrastructure, and certain types of trees. Our observations show these perceptions are at best not complete. For instance, we did an analysis in North Dakota, where there is little topography. Figure 3 shows there is no correlation between topography and lightning strike density. In fact, with detailed analysis we discovered in North Dakota there is a linear increase in the number of lightning strikes with changes in local relief (see Figure 4). On average, with 8 meters relief over a 2,000 meter radius, there will be 1 strike, 2 strikes with 16 meters local relief, 4 lightning strikes with 28 meters of local relief, and 8 lightning strikes with 40 meters of local relief. The location impact of these small variations in local relief on the location of lightning strikes can only be explained by the shortening of the lightning path through the atmosphere. Shorting this pathway by 8 to 40 meters out of 2,000 meter cloud height, is shortening the atmospheric lightning path by between 0.5% and 2.0%.

Obviously the atmosphere is an effective insulator. The electrical conductivity of air is 0.3-0.8 * 10^{-14} siemens per meter. The effectiveness is seen in air's common use separating high voltage transmission lines from the ground, from towers used to support the lines, and from lines carrying different voltages and different phases. The earth is much more conductivity than air. Assuming a typical sedimentary rock has 5% porosity, the electrical conductivity of this rock is 5.0 * 10^{-4} siemens per meter, or about 10^{10} times the conductivity of air. Figure 5 shows a graph of rock conductivity computed for a porous rock with 100% brine saturation using Archie's equation. Variations in porosity or fluid resistivity in the earth, with orders of magnitude more conductivity than the atmosphere must have a larger impact on lightning strike location. This reasoning helps explain why lightning will travel 250 kilometers cloud to cloud before going to ground.

Lightning Infrastructure Observations

One concern as we started data mining lightning data across existing oil and gas fields was that the lightning strike locations were being controlled by cased wells, where these conductive steel tubes act as giant lightning rods. However, the more we looked at the data, the more we realized infrastructure is not the driving force of lightning strike locations. Figure 6 shows a lightning density map overlaid on wells (black) on the Nesson Anticline in North Dakota. Note that 50 miles east and west of the Nesson Anticline the density and patterns of lightning strikes is similar. Our conclusion is electrical currents in the rock matrix have much more impact on lightning strike locations than infrastructure.

This conclusion is supported by the fact there are up to 25% more lightning strikes at high lunar tide when compared to the number of lightning strikes at low lunar tide (see Figure 7). As the moon goes around the earth, its gravity not only raises the oceans, it also raises the ground. This earth tide is much smaller than the ocean tides. However, it appears to have a significant impact on earth currents. The sun causes about a third as much of an earth tide as the moon does. So earth tides need to be calculated using both the position of the moon and of the sun.

Lightning Vegetation Observations

We do not find vegetation having an impact on lightning strike locations. The one exception was an analysis project in Colorado County, Texas where there is a band of oak trees on the west side of the county as shown in Figure 8. We did find a similar pattern on one of the 100 different maps of lightning attributes made. The density of positive lightning strikes has a similar pattern to the extent of oak trees. Note, positive lightning strikes typically occur at the end of lightning storms, and they tend to come from the tops of the clouds, which are several hundred meters higher than the base of the clouds. The 10-15 meter height of oak trees is much less than the additional travel path to the top of the storm.

Summary

Looking at the patterns from lightning analysis in the Houston urban setting, we see patterns supporting previous lightning analysis projects.

We obtained shape files from Susan Horvath of Rosetta Resources defining the location of surface faulting in the Houston area. These fault lines are overlaid on lightning strike density and negative peak current maps in Figure 9. The center panel shows the average number of lightning strikes within 50” longitude x 25” latitude cells across this area (~1,200 meters x 750 meter cells at this latitude). Roads are overlaid by posting the image in Google Earth, The densest lightning strikes are just east of downtown, which is probably related to the urban weather effects. The patterns and lineaments on this map seem to follow the fault lines more than the roads. This is even more evident in the bottom panel, which shows average negative peak current at the same cell size described above. In addition to lineaments following the fault lines, this panel shows stronger negative lightning strikes downtown, along I-59 where there are many office buildings, and in the Galleria area.

Lightning is an electrical phenomenon. Electricity travels at the speed of light in a vacuum. It travels at 95-97% of this speed in an unshielded copper conductor, and the speed of electricity in a typical coaxial cable is about 66% the speed of light. From our analysis it appears possible to relate the height of the clouds to the depth of electrical currents impacting lightning strike location. Electrical currents in the rock matrix appear to have a larger impact on the location of lightning strikes than atmospheric dielectric variations, topography, infrastructure, or vegetation, including oak and elm trees. While lightning strike skin depth is negligible relative to natural resource exploration depths, it appears reasonable the earth currents impacting lightning strike location are in the 1,000-10,000 meter depth range.

Based on numerous lightning data analyses, we have come to the conclusion there are earth currents, which we call terralevis (shallow earth) currents, in the depth range of natural resource exploration which have a controlling impact on CG lightning strike locations and attributes. We present lightning analysis examples confirming this conclusion. Data mining lightning strike databases opens a new and less expensive window into mapping faults, predicting the geotectonic framework, estimating anisotropy, looking for seeps, and enhancing exploration programs by optimizing data acquisition and directly mapping sweet spots.

In some ways, this work is an extension of Nikola Tesla’s experiment at his Pike’s Peak laboratory in 1889 when he confirmed the Earth itself could be used as an electrical conductor, and where he also verified some of his suspicions regarding the conductivity of the ionosphere.

Acknowledgements

We would like to thank Vaisala Inc. for providing the data for these studies.

References Cited

Cagniard, L.P.E., 1970, Method of submarine magnetotelluric surveying and apparatus for carrying out same: U.S. Patent, 3,514,693, Filed 14 June 1967, Serial No. 646,105.

Hayes, H.C., 1945, Electrical Prospecting: U.S. Patent 2,368,217, Application 02 August 1940, Serial No. 350,002, 10 Claims.

Pirson, S.J., and J.E. Pirson, 1976, Line Integral Method of Magneto-Electric Exploration: U.S. Patent 3942436, Application 21 January 1974, Application No. 435,120, 14 Claims.

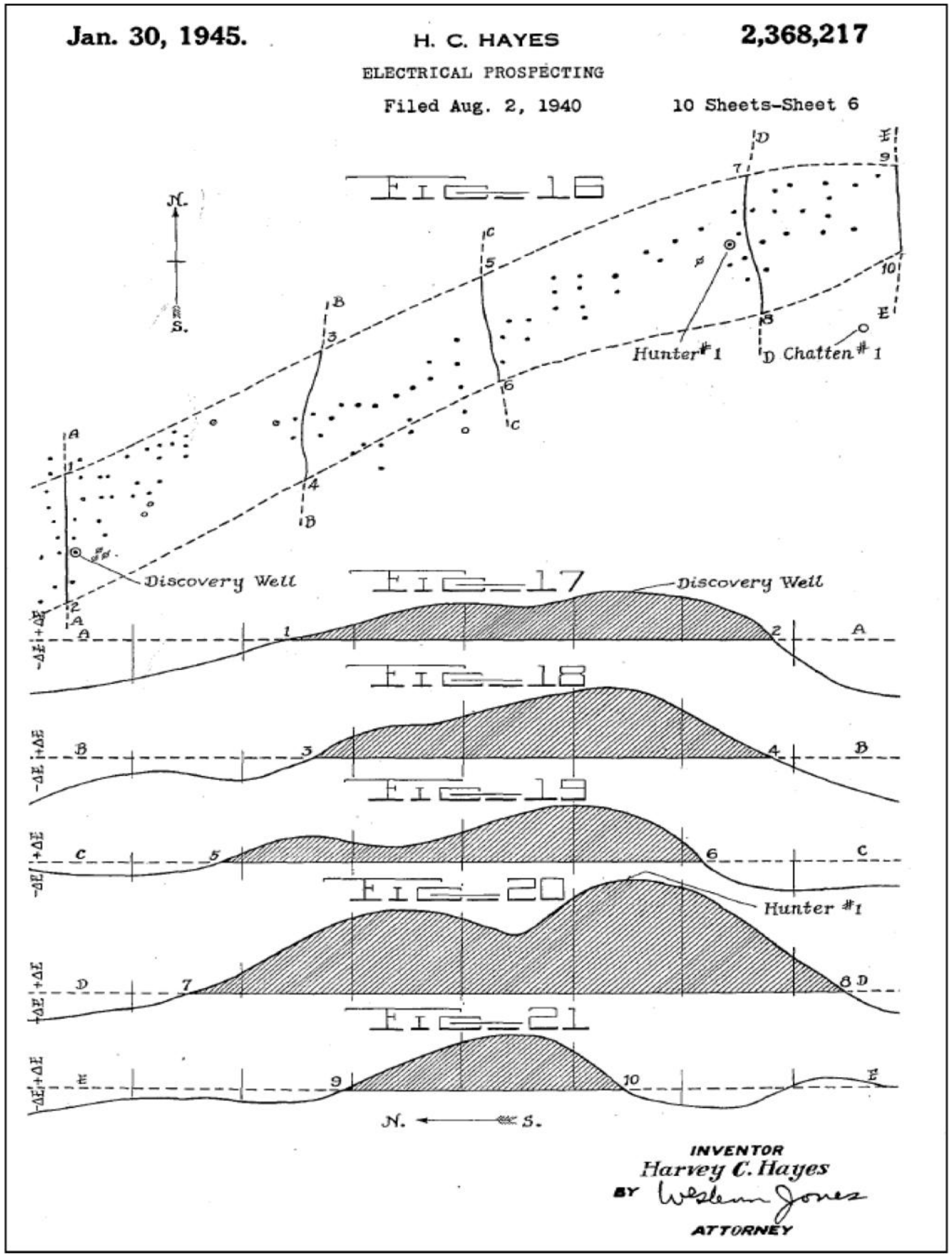


Figure 1. Earth resistivity profiles from H.C. Hayes 1945 Electrical Prospecting U.S. Patent.

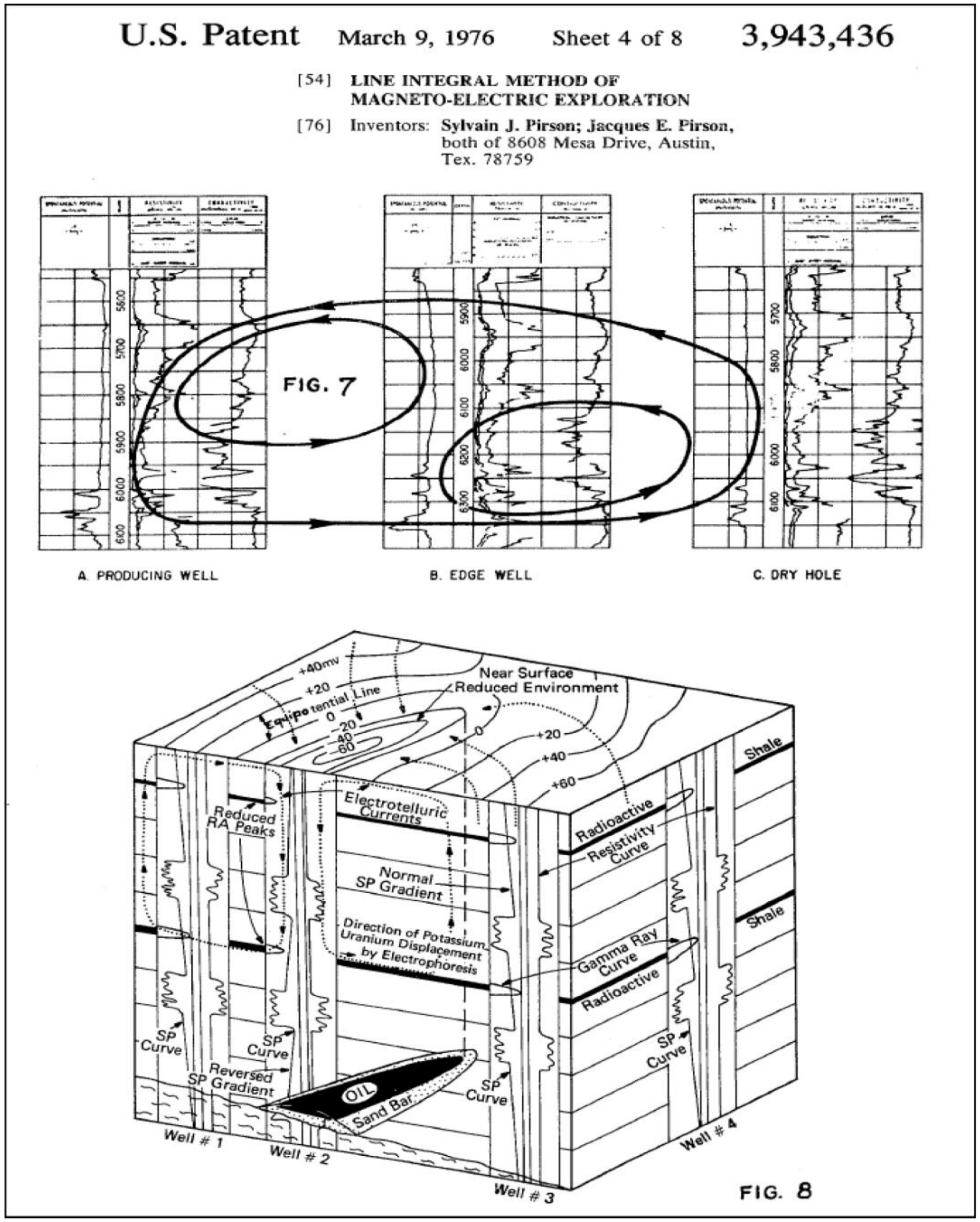
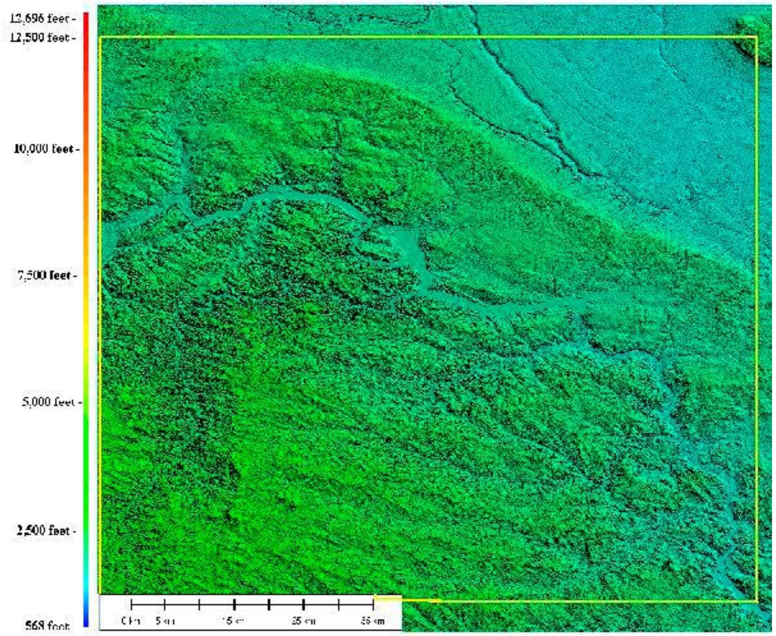
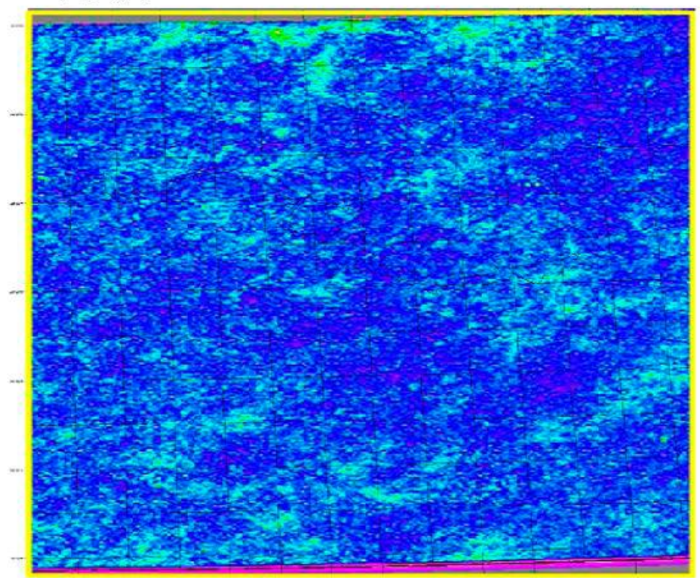


Figure 2. Electrotelluric Currents from Pirson and Pirson's 1976 magneto-electric exploration U.S. Patent.



Topography western North Dakota



Lightning Density western North Dakota

Figure 3. Top shows Topography, and bottom shows Lightning Density maps for western North Dakota.

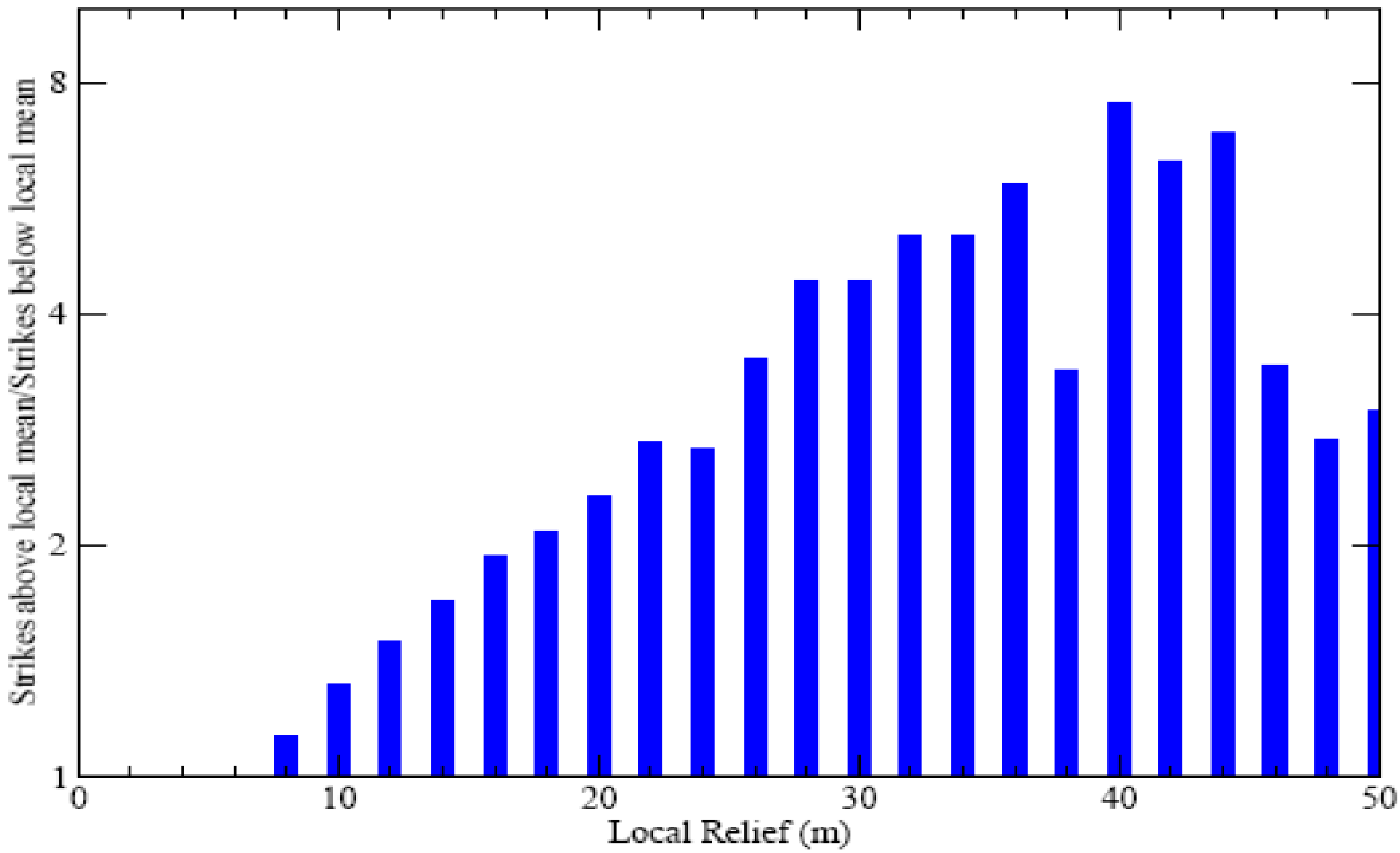


Figure 4. The linear increase in the number of lightning strikes with local relief shows the limits of the insulating ability of the atmosphere.

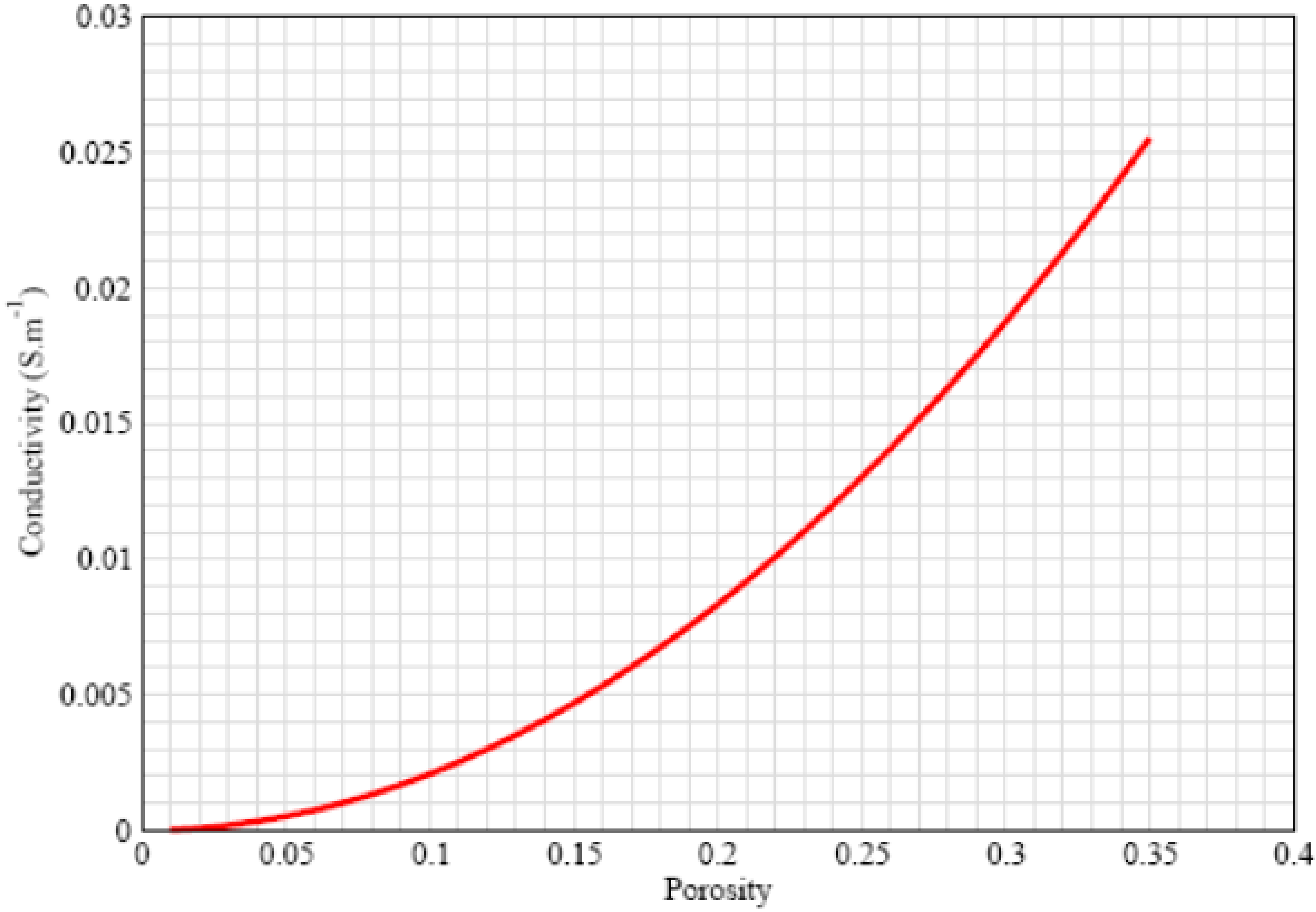


Figure 5. Rock conductivity graph computed for a porous rock with 100% brine saturation using Archie’s equation.

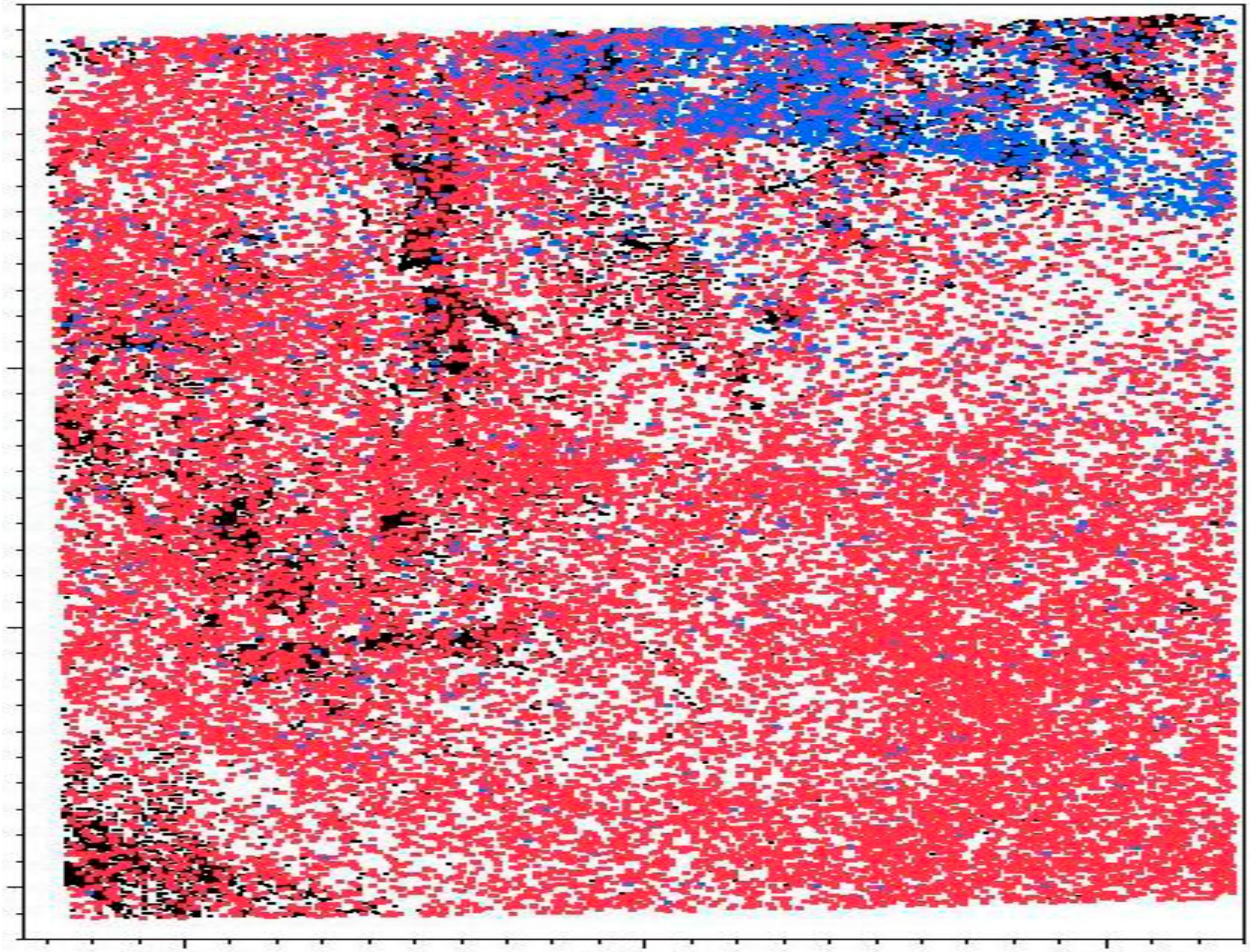


Figure 6. Lightning density overlaid on wells (black) on the Nesson Anticline, North Dakota.

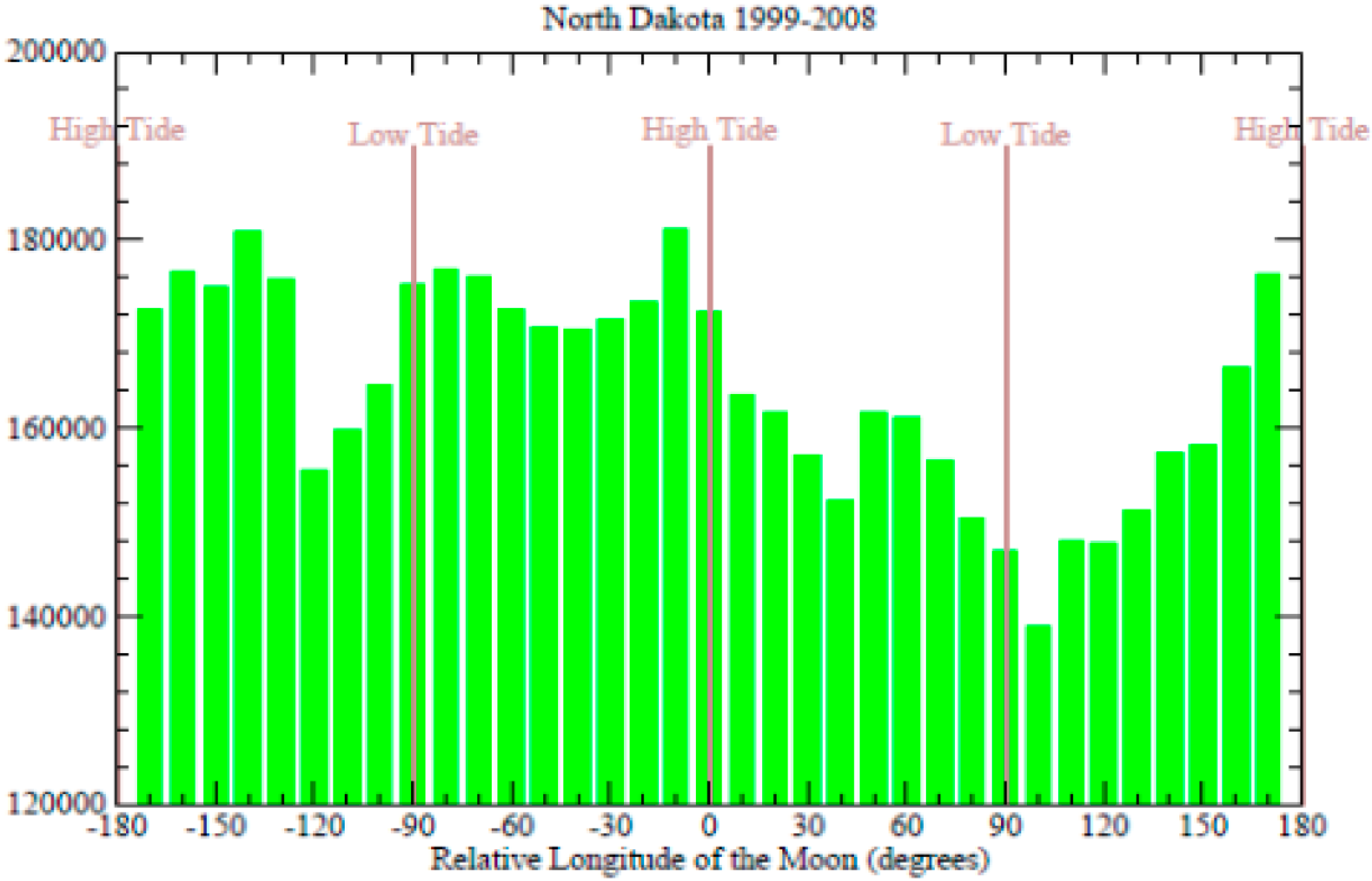
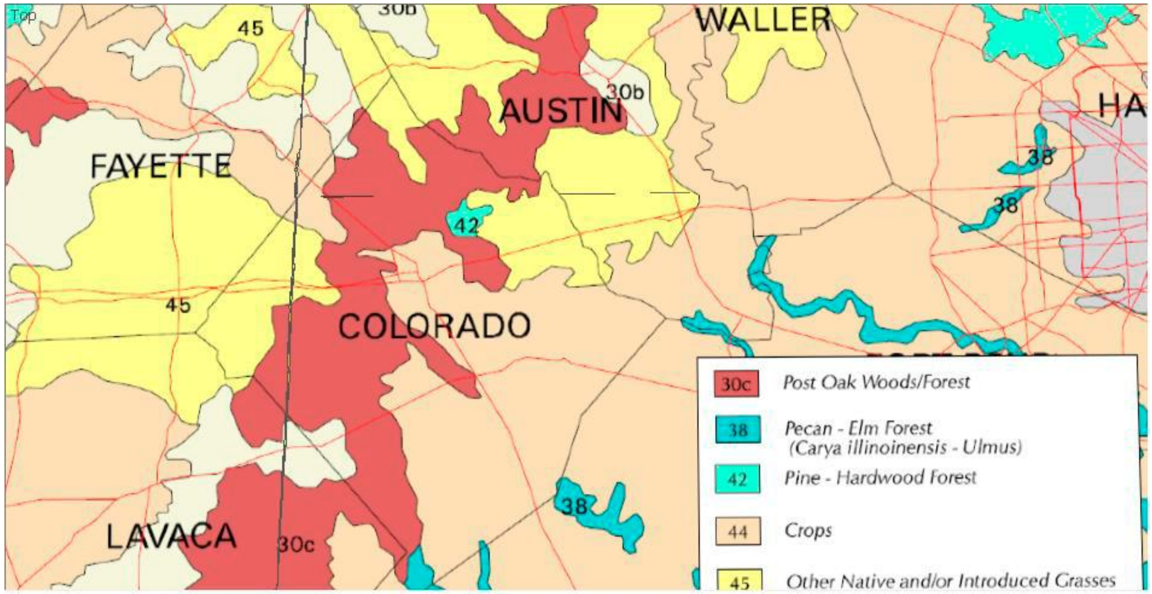
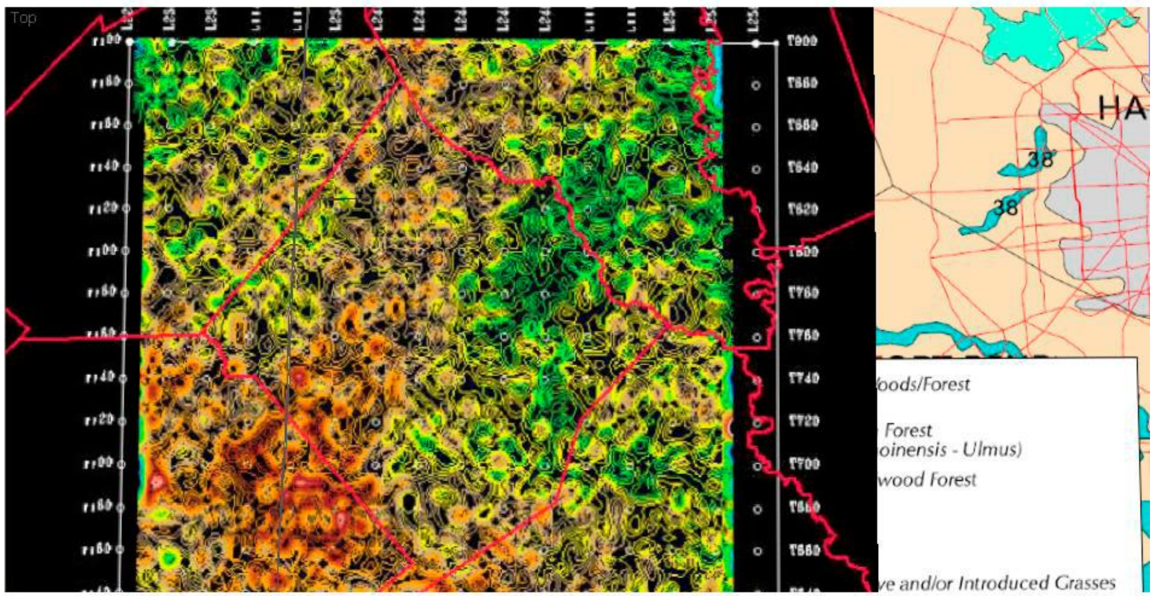


Figure 7. Strike Frequency versus Tidal Gravity.



Oak Trees in Colorado County, Texas in red.



Positive lightning strike density in Colorado County, Texas, oranges and tans higher density positive strikes.

Figure 8. The top map shows distribution of key vegetation in Colorado County, Texas. The bottom map shows the same area with positive lightning strike density.

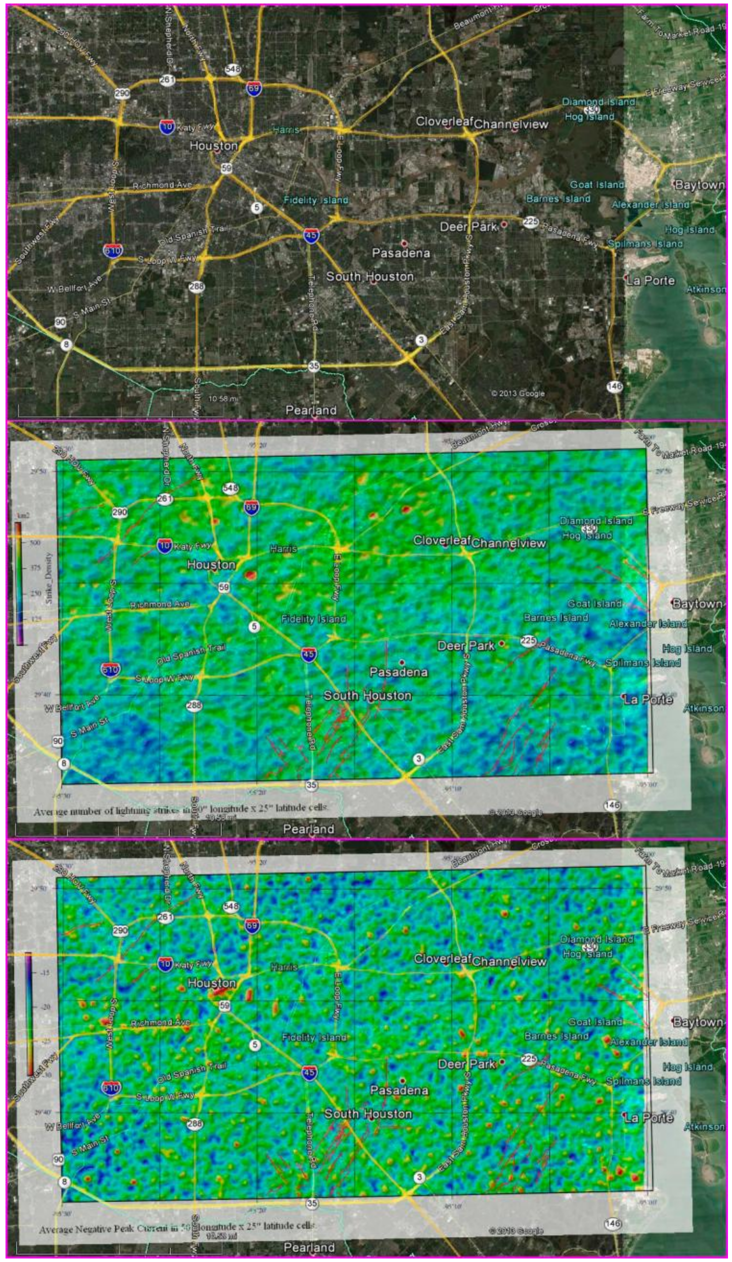


Figure 9. Roads and Google Earth map of Houston, with map of lightning strike density overlaid in the center panel and average negative peak current overlaid in the bottom panel.