Lightning Analysis: creating geo-frameworks

University of Utah
03 March 2017

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Dynamic Measurement LLC

Picking up from talk at “U” on 16 Oct 2014

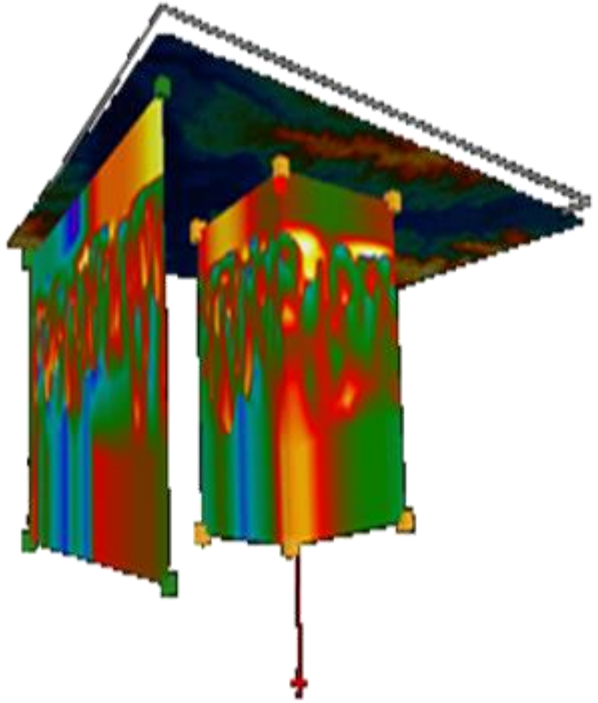
Possible Thesis/Dissertation Topics

1. Electrical characteristics of Elm and Oak trees, including root systems and preferential soil chemistries.
2. Statistical Analysis of lightning strike clusters related to topography, vegetation, infrastructure, and geology.
3. Modeling telluric currents as a means to predict lightning clusters.
4. Modeling lightning clusters as a means to predict telluric currents.
5. Relationship between lightning clusters and high altitude lightning events like blue sprites and elves.
6. Using lightning clusters as a basis for time-lapse electromagnetic measurements.
7. Lightning analysis of Iron County, UT relating strike attributes to known iron reserves and micro-earthquakes.*
8. Lightning analysis of Prince of Wales Island, Alaska to extend maps of vein-dyke rare earth deposits.*
9. Lightning analysis of Cortez Hills, NV (116^{o}-117^{o}W , 40^{o}-41^{o}N) to calibrate known gold mines and trends.*
10. Lightning analysis of San Bernardino County, CA to map the extent of the Mountain Pass Rare Earth deposit.*
11. Lightning analysis of the Mississippian Limestone hydrocarbon play in OK and KS.*
12. Quantitative correlation of South Texas lightning density with known oil and gas fields.
13. Correlation of lightning density with mapped gas hydrates offshore North Carolina.*
14. Correlation of lightning density with known oil and gas fields in Southern Louisiana.*
15. Mapping top geopressure and correlating lightning clusters with shallow depth to top geopressure in TX & LA.*
16. Correlate lightning attributes and density with gravity and magnetic and electrical and seismic data.
17. Lightning analysis Yellowstone National Park to correlate with known geothermal deposits.

*Requires licensing of lightning data.

Presentation Outline

Milam County Texas apparent-resistivity Volume



1. Lightning Occurs Everywhere
2. Lightning Database Analytics
3. Rock Property & Attribute Maps & Volumes
4. Lightning Analysis & Attributes
5. Texas, New York, Louisiana, & Arizona Examples

DML Started with 2 Questions:

1. Can lightning hit twice at the same place?

2. Does this mean there is oil on my property?

Strikes from 1 storm (colors Peak Current) 27 Sep 2011, Hockley Dome, Harris County, TX

The Answer to Both Questions is Yes!

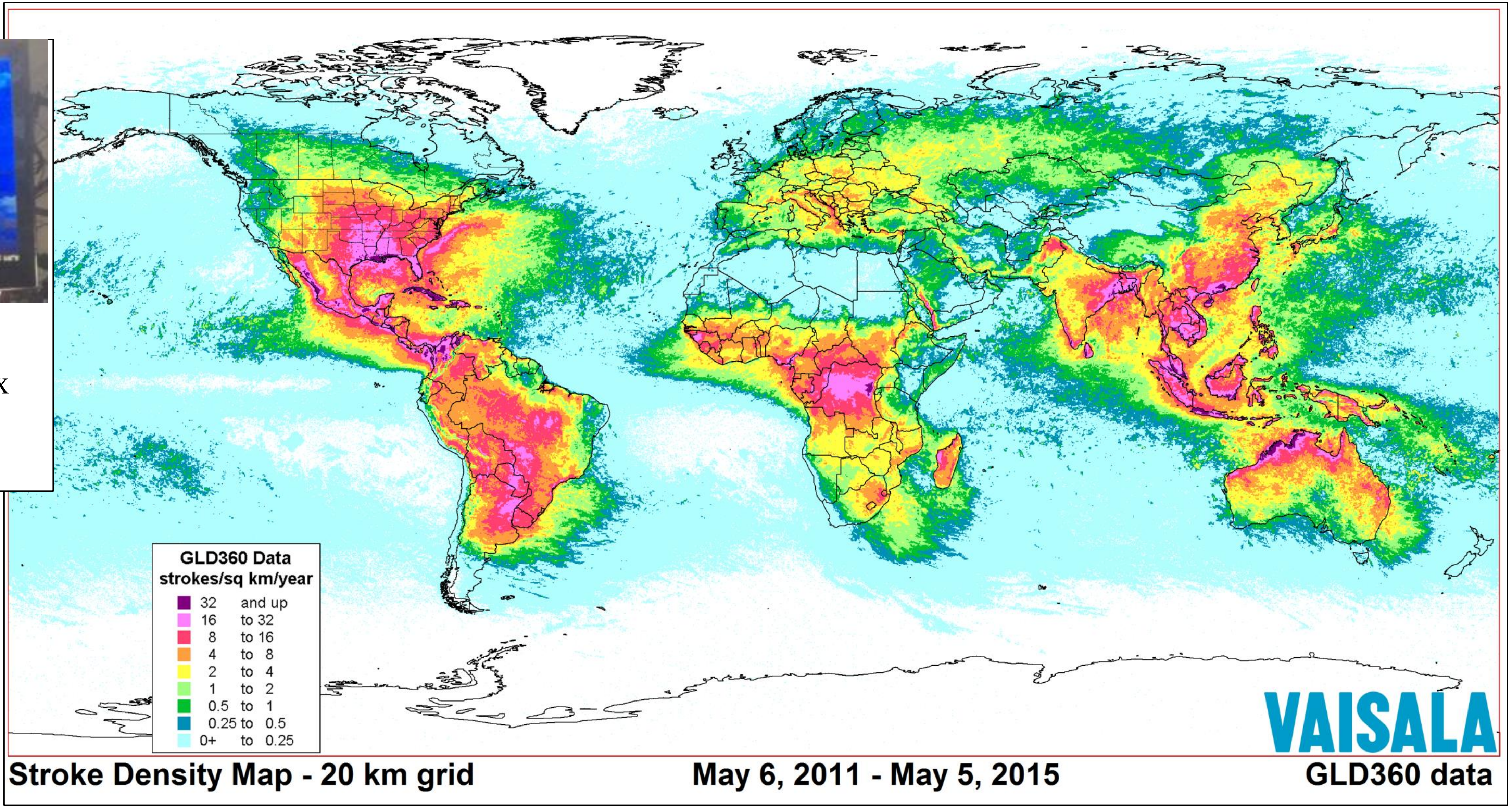
The answer to the first question is “yes,” lightning strikes cluster and the clusters are consistent over time.

The answer the second question is “there is oil here,” as shown by the tanks now at the location of the lightning strikes raising the question.

1. Lightning Occurs Everywhere

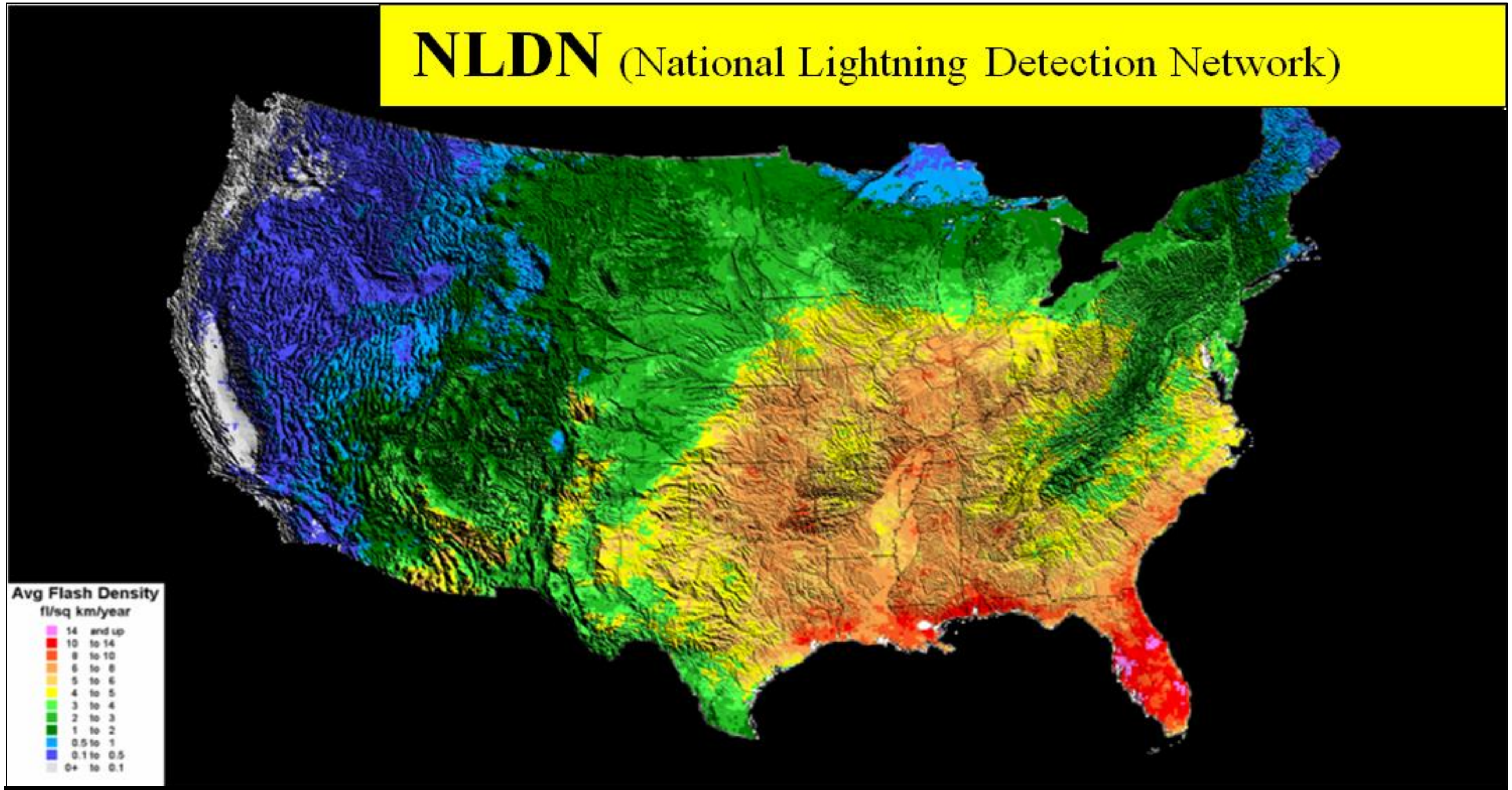
5+ years of data in GLD-360 database

Dr. Jim Siebert
Chief Meteorologist Fox News Houston and Dynamic Measurement



The U.S. & Canada have the best lightning data

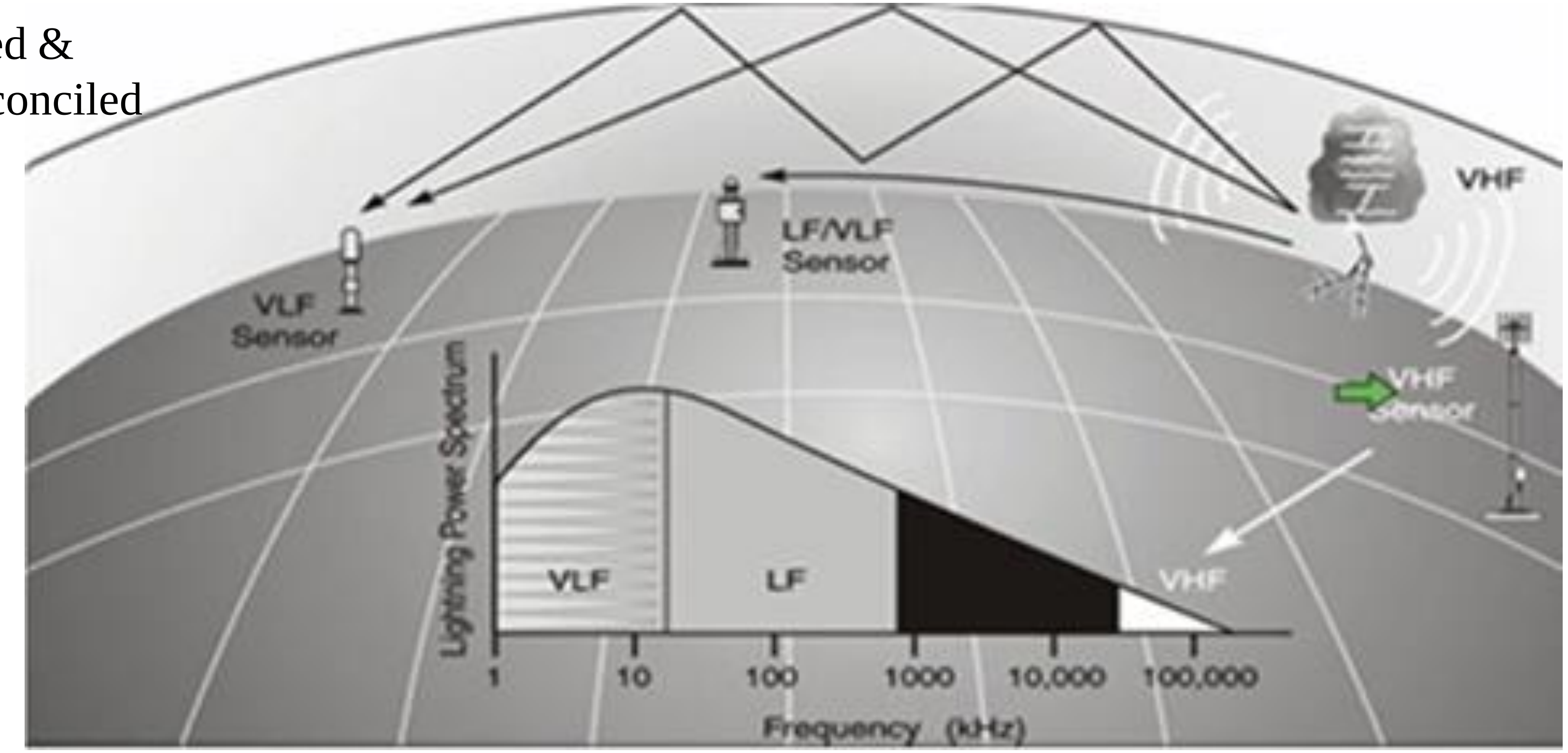
18+ Years of Data in the NLDN & CLDN Database



Originally Collected for Insurance, Meteorology, and Safety Reasons

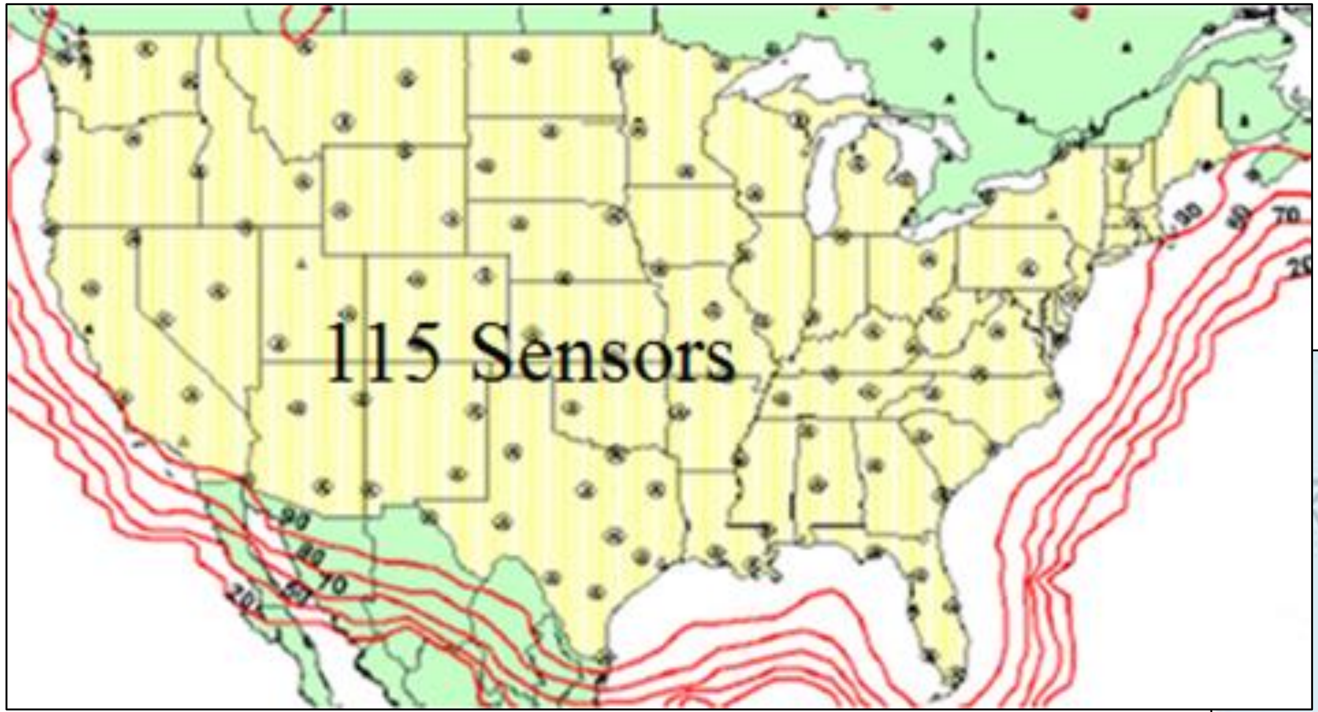
Sensors Measure Direction to Strike & Lightning Attributes

Strikes Triangulated &
Measurements Reconciled



Vaisala: Martin Murphy
2016 Webinar used with permission

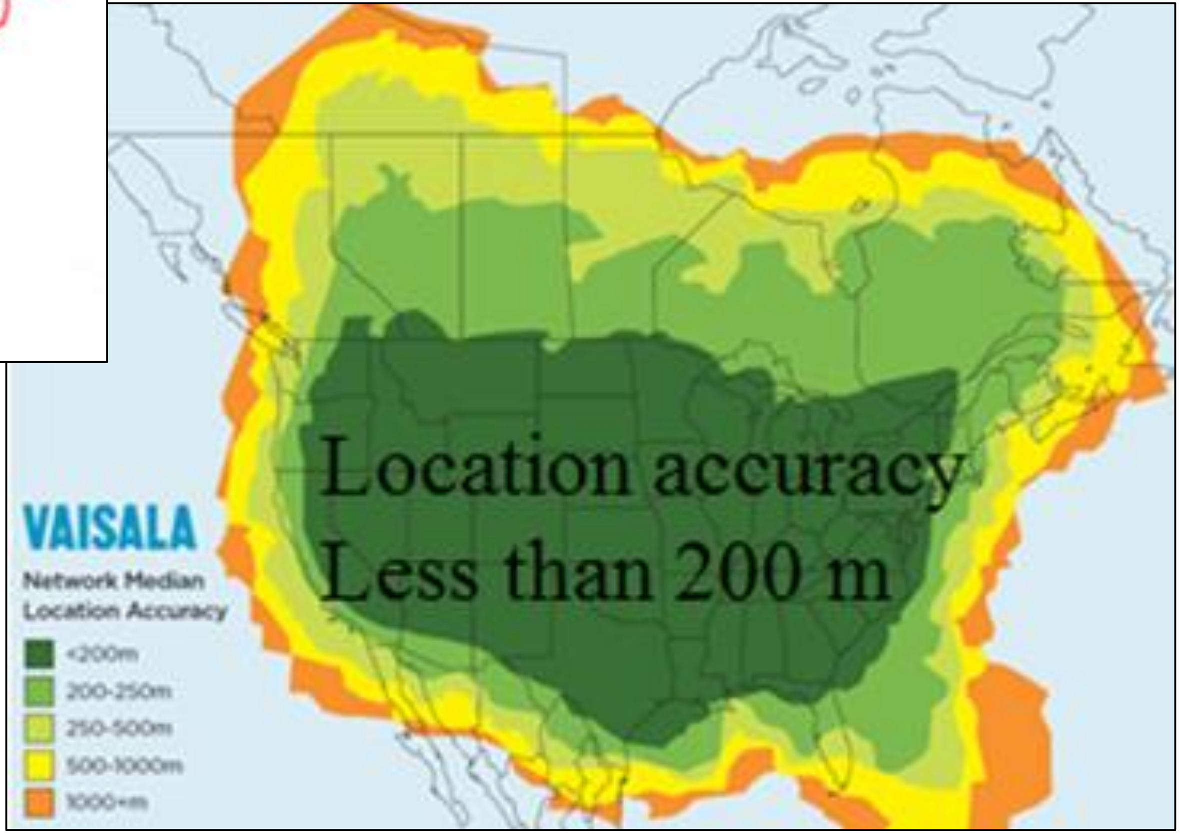
NLDN Lightning Network



In Texas 12-24 sensors record each lightning strike

Location Accuracy: 150-600 feet

Lineament Accuracy: 10-100 feet



From 2016 Vaisala Webinar: Martin Murphy
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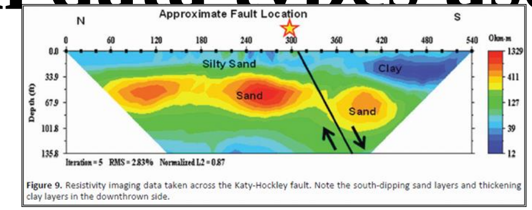
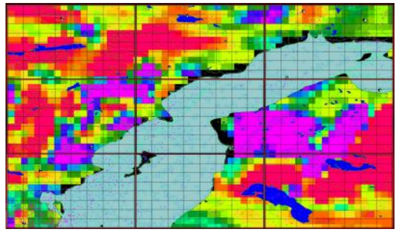
Lightning Data: A New Geophysical Data Type

Geophysical data types used for decades:

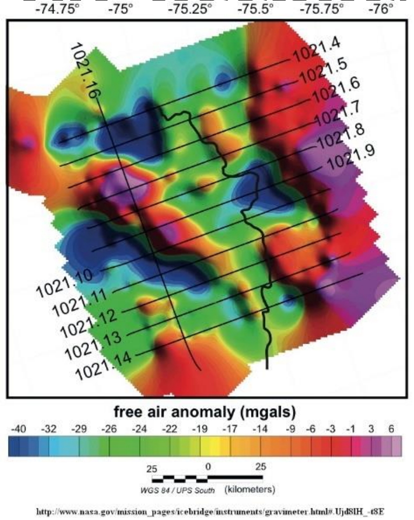
- Gravity
- Magnetics
- Magnetotellurics
- Electrical
- Seismic



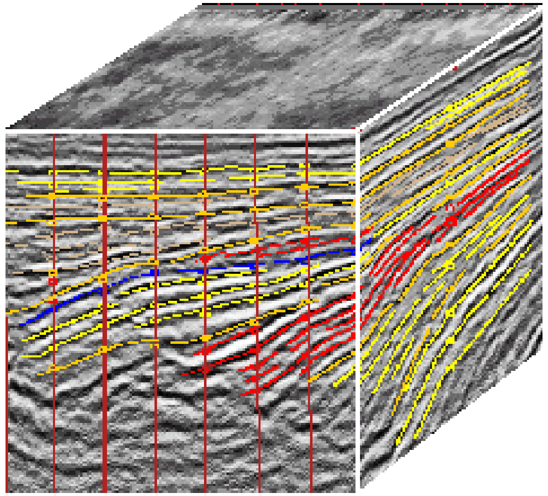
Electrical



Magnetics



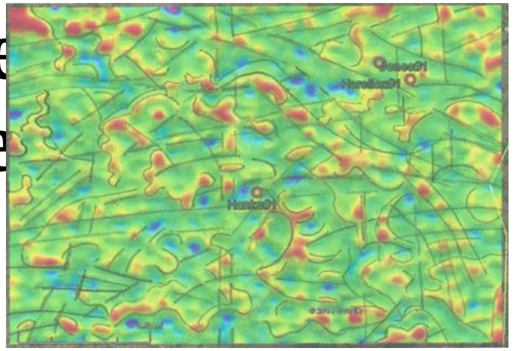
Gravity



Seismic

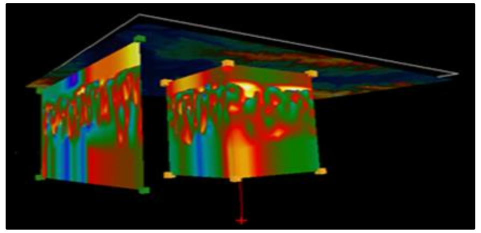
Dynamic Measurement has expanded these capabilities

- Developing and patenting ways to data mine electrical information
- Using existing lightning strike database
- Mapping faults and creating geo-frame



Surface Resistivity

Resistivity Volumes



Technical Comparison Geophysical Products

Discipline	Technique	Source	Receiver	Power
Electrical Methods	DC Resistivity	Required	Required	Low
	Electrical Resistivity Tomography (ERT)	Required	Required	Low
	Induced Polarization (IP)	Required	Required	Low
	Time-Domain IP	Required	Required	Low
	Complex Resistivity (CR)	Required	Required	Low
	Magnetotellurics (MT)	Passive	Required	Low
	Audio-Frequency MT (AMT)	Passive	Required	Low
	Controlled Source Electromagnetics (CSEM)	Required	Required	Medium
	Controlled Source Audio-Frequency MT (CSAMT)	Required	Required	Low
	Transient Electromagnetic Time-Domain EM (TEM)	Required	Required	Low
	Nano TEM Near Surface	Required	Required	Low
	Frequency-Domain EM Induction	Required	Required	Low
	AquaTrack (leak detection at dams, mines, etc.)	Required	Required	Low
	Self Potential (SP)	Passive	Required	Low
	Ground Penetrating Radar (GPR)	Required	Required	Low
	Very Low Frequency Methods (VLF)	Passive	Required	Medium
Potential Fields	Gravity	Passive	Required	High
	Magnetics	Passive	Required	High
Seismic	Earthquake Seismic	Passive	Required	High
	Refraction Seismic	Required	Required	Medium
	Reflection Seismic	Required	Required	Medium
	Micro-Seismic	Required	Required	Medium
Satellite	Spatial, Spectral, Temporal, & Geometric Resolution	Passive	Database	Low
	Radiometric Resolution: Thermal, Reflectance, Elevation	Passive	Database	Low
Lightning	National Lightning Detection Network (NLDN)	Passive	Database	High
	Global Lightning Database (GLD-360)	Passive	Database	High

Economic Comparison Geophysical Products

	Swath Size - Line Spacing	1 km	200 m	100 m	50 m
Price	Air Mag cost per 1 line km (price)	$65	$325	$650	$1,300
	Air Mag cost per 10 line km (factor 1)	$650	$3,250	$6,500	$13,000
	Magneto-Telluric cost per station	$1,000			
	EM cost per km	$10,000			
	Spec Seismic cost per sq km				$10,000
	New Seismic cost per sq km				$85,000
	Air Mag cost per 30 sq km mobilazation costs > $35,000	$36,950	$44,750	$54,500	$74,000
	MT cost per 100, 500, 1000, & 2000 stations	$100,000	$500,000	$1,000,000	$2,000,000
	EM cost per 30 sq km	$300,000	$1,500,000	$3,000,000	$6,000,000
	Spec Seismic cost per 5, 10, 15, & 30 sq km	$50,000	$100,000	$150,000	$300,000
	New Seismic cost per 5, 10, 15, & 30 sq km	$425,000	$850,000	$1,275,000	$2,550,000
	Lightning Analysis cost per 30 sq km	**$34,630**	**$34,630**	**$34,630**	**$34,630**
	Air Mag cost per 600 sq km	$390,000	$1,950,000	$3,900,000	$7,800,000
	MT cost per 2000, 10000, 20000, & 40000 stations	$2,000,000	$10,000,000	$20,000,000	$40,000,000
	EM cost per 600 sq km	$6,000,000	$30,000,000	$60,000,000	$120,000,000
	Spec Seismic cost per 600 sq km	$300,000	$1,500,000	$3,000,000	$6,000,000
	New Seismic cost per 600 sq km	$2,550,000	$12,750,000	$25,500,000	$51,000,000
	Lightning Analysis cost per 600 sq km	**$97,740**	**$97,740**	**$97,740**	**$97,740**

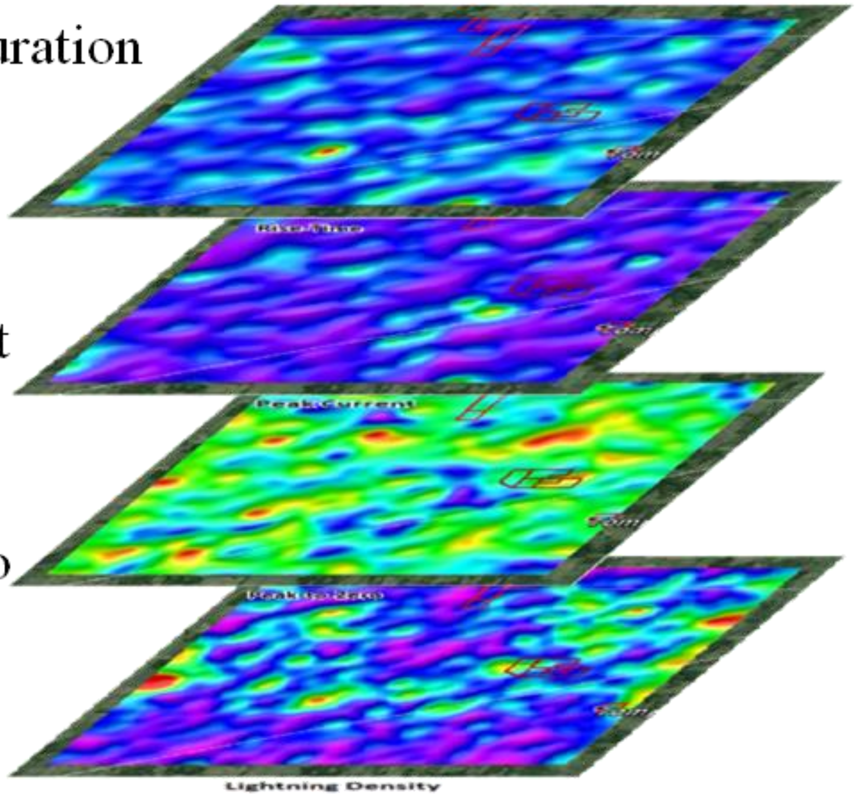
Michael Reed
COO
Dynamic Measurement

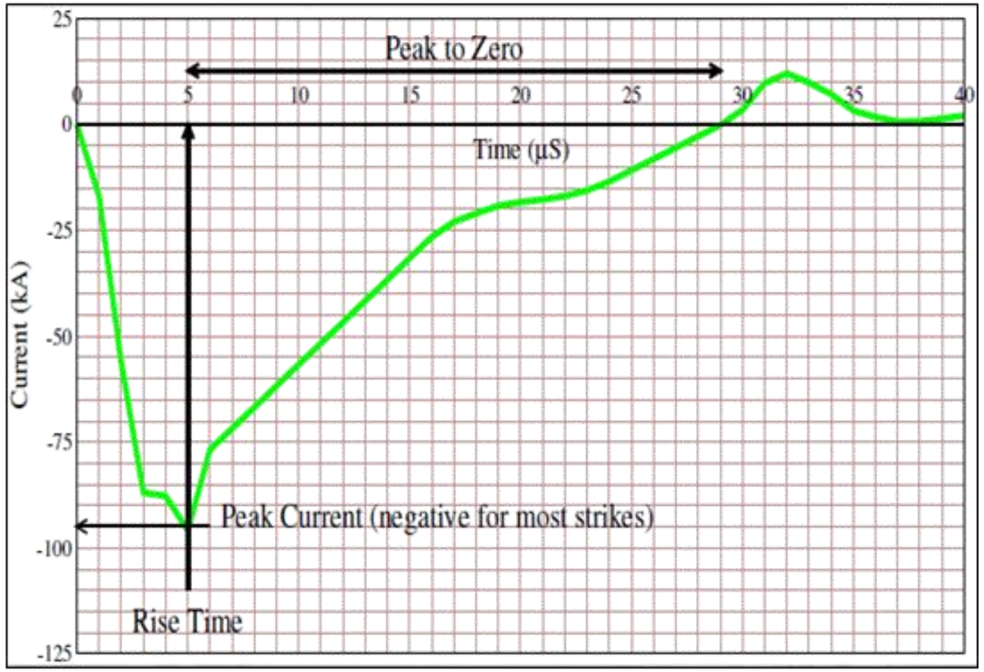
2. Lightning Database Analytics

- Typical projects have millions of lightning strikes.
- All projects to date have tied available surface and subsurface control.
- Attributes are measured or calculated for lightning strike locations, then contoured or gridded or interpolated in three-dimensions.
- Lightning strike density and electrical attribute values cluster, and these clusters are somewhat consistent over time.
- Lineaments, like fault scarps, have been mapped with 30 foot horizontal location accuracy.

Lightning Measurements

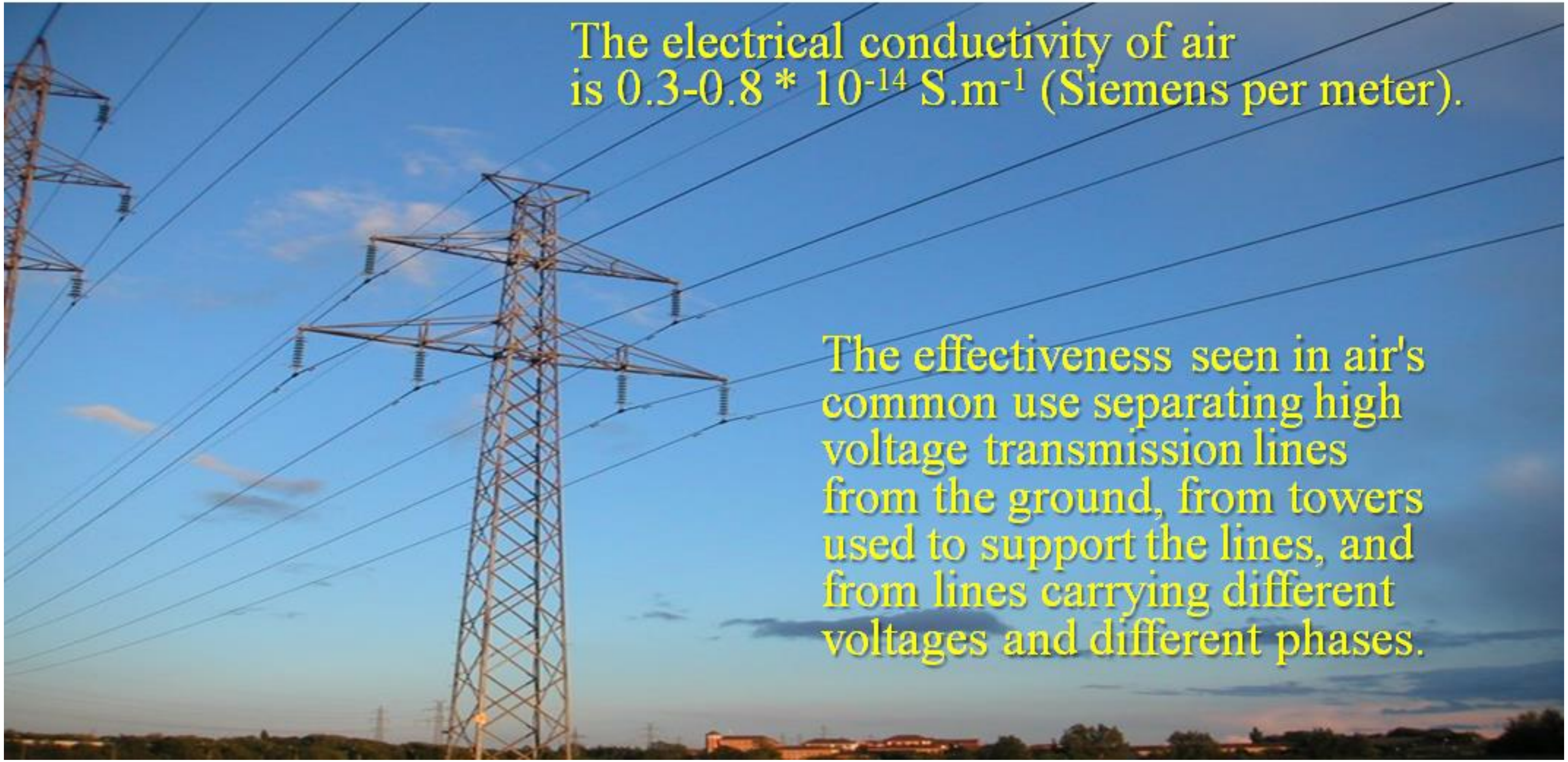
- Location
- Time and Duration
- Rise Time
- Peak Current
- Polarity
- Peak-to-Zero
- Density



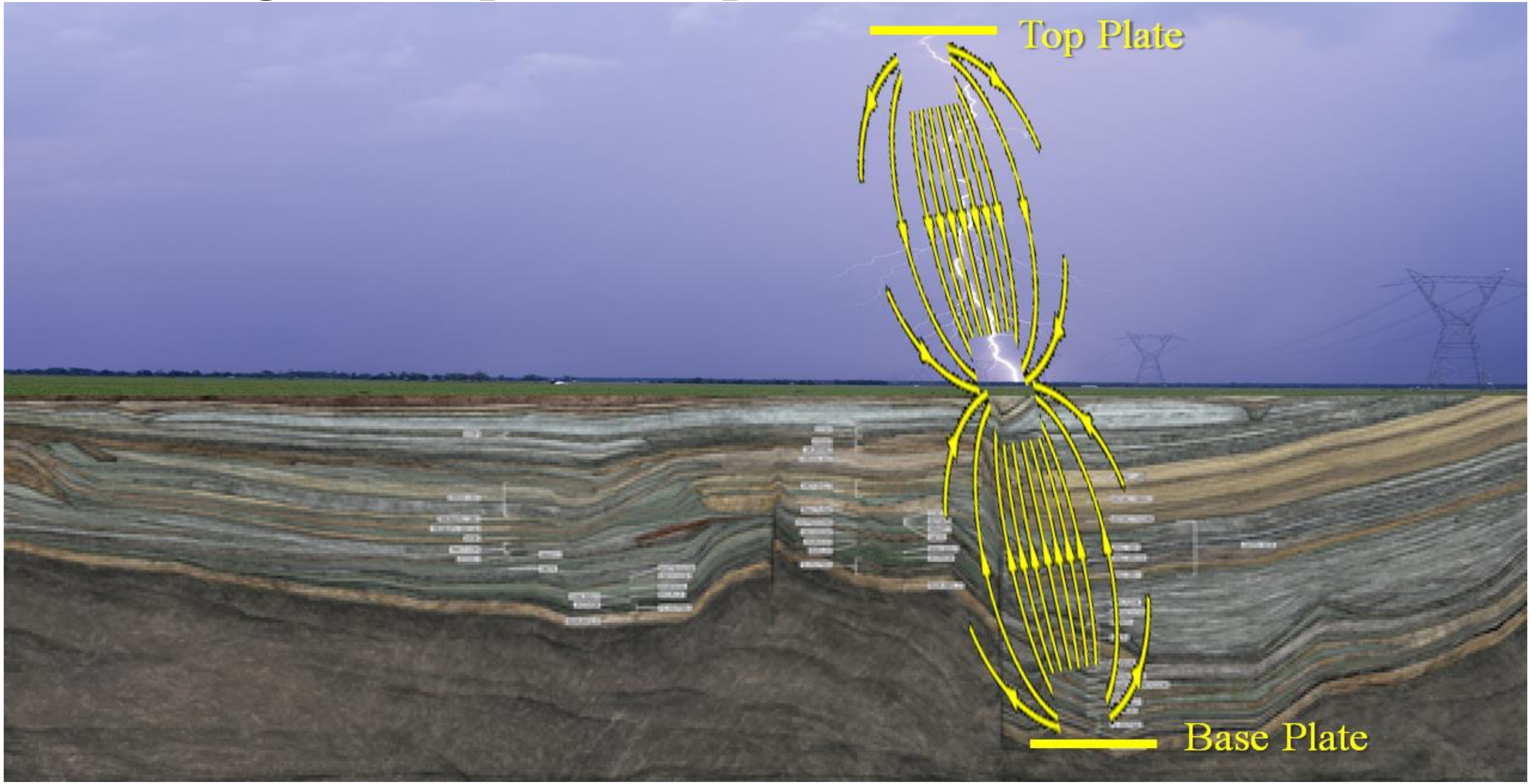


- Other attributes calculated from these measurements.
- The time of the lightning strike is correlated with solar and lunar tides.
- Measurements separated by time.

The Atmosphere is an Effective Insulator

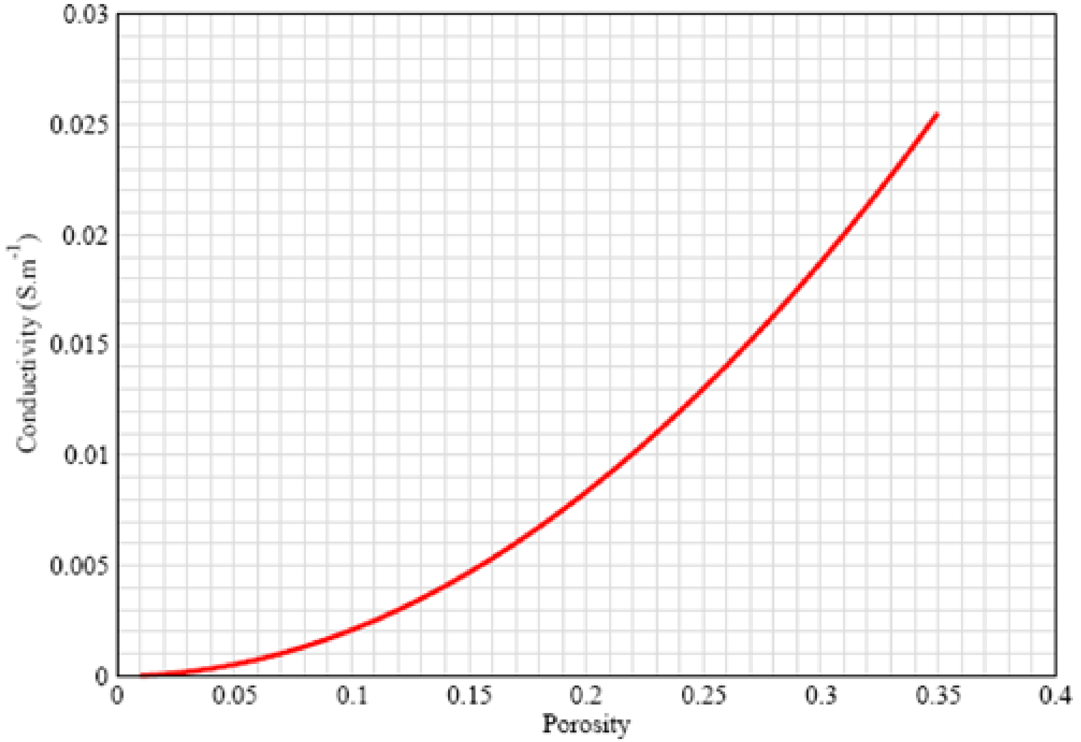


Lightning Occurs when there is Sufficient Charge to Bridge Atmospheric Capacitor



The earth is much more conductive than air

Assuming a typical sedimentary rock has 5% porosity, the electrical conductivity of rocks is $5.0 * 10^{-4}$ $S.m^{-1}$, or about 10^{10} times the conductivity of air.



Geothermal temperature increases, further increase conductivity

Rock Conductivity Graph computed for a porous rock with 100% brine saturation using Archie's equation

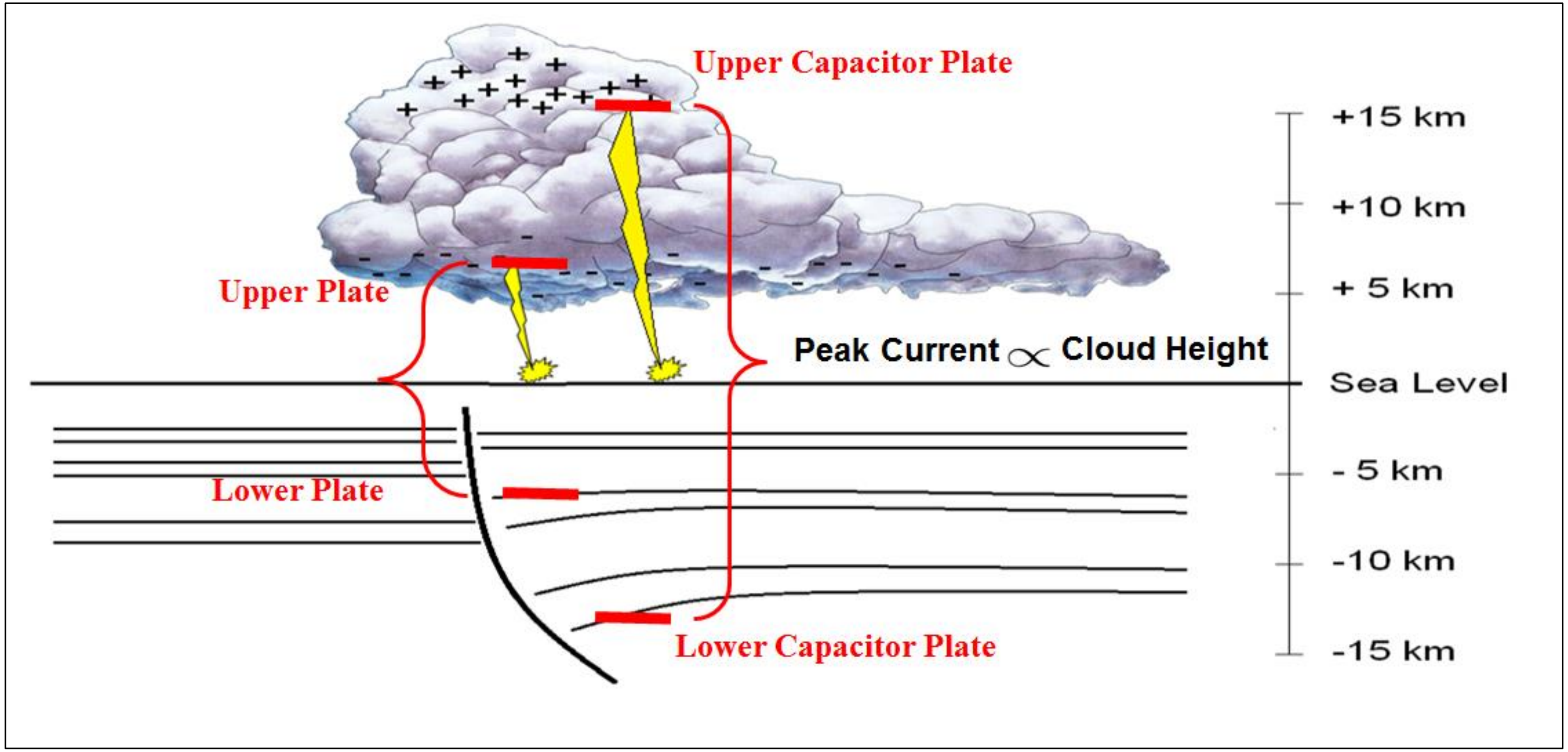
Telluric & Atmospheric Currents make up the Earth's Electrical System

2 issued patent abstracts in Appendix

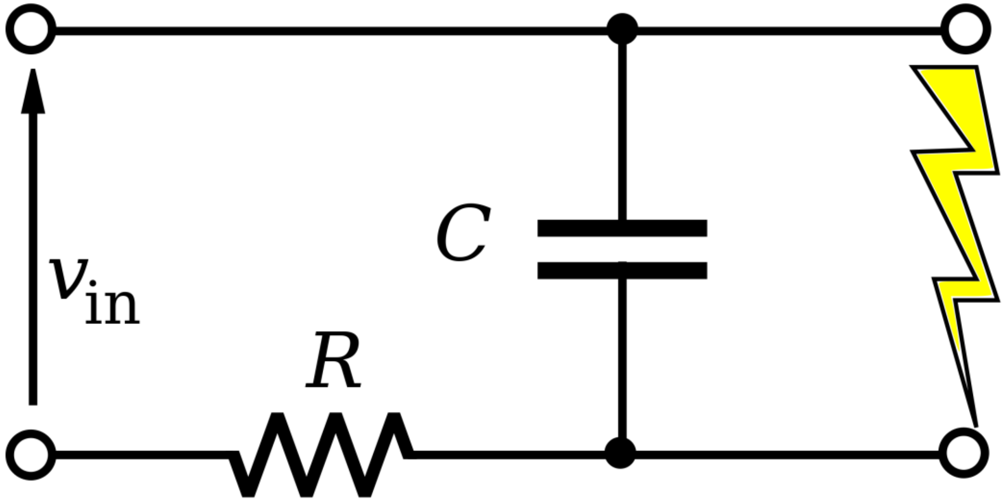
3. Rock Property & Attribute Maps & Volumes

Key Assumptions:

1. Lightning occurs when there is sufficient charge to bridge the capacitor.
2. Lightning is affected by geology to a depth proportional to cloud height, as derived from Peak Current

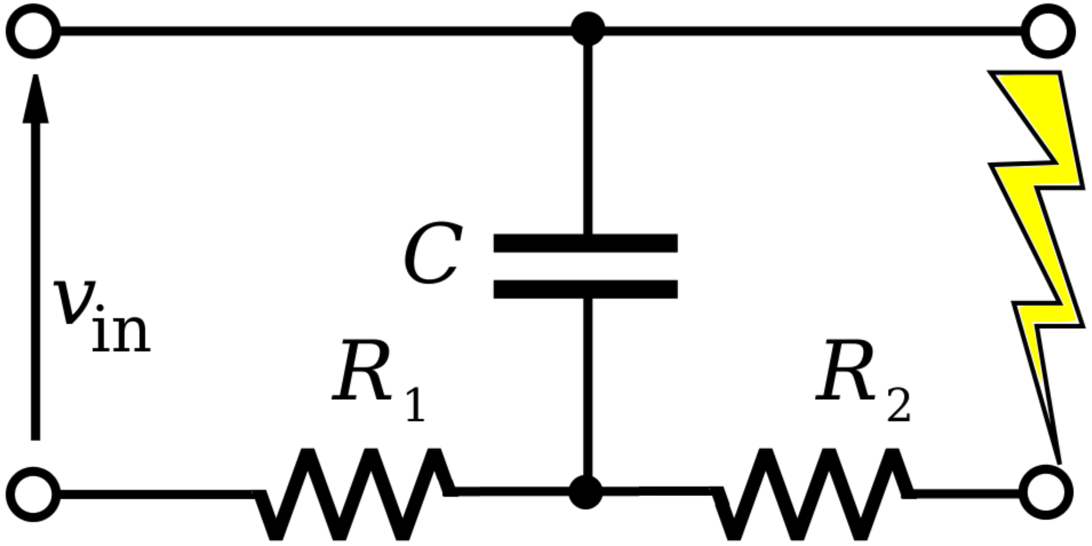


Relaxation Oscillator Physics and Lightning (a giant neon tube)

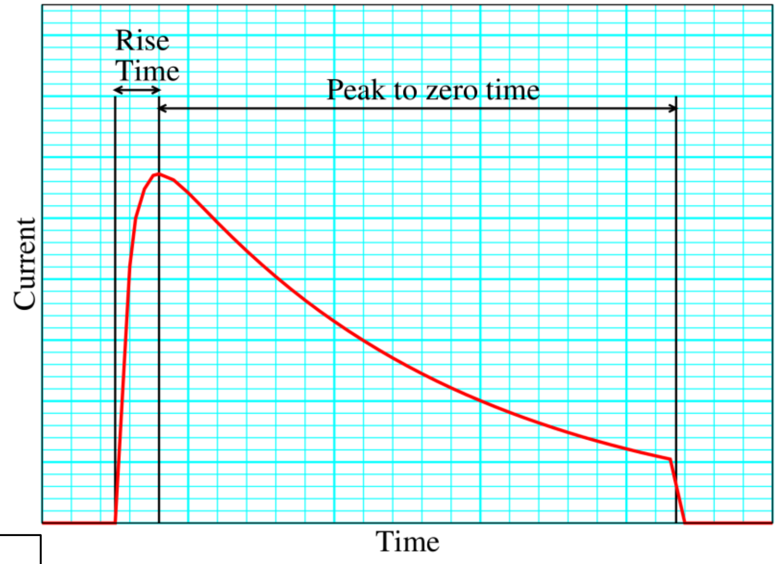


- The atmospheric capacitor is like a relaxation oscillator
- Just an additional resistance (R_2) limiting the current

- R_2 is the resistance between the lightning strike point and the bottom plate of the capacitor



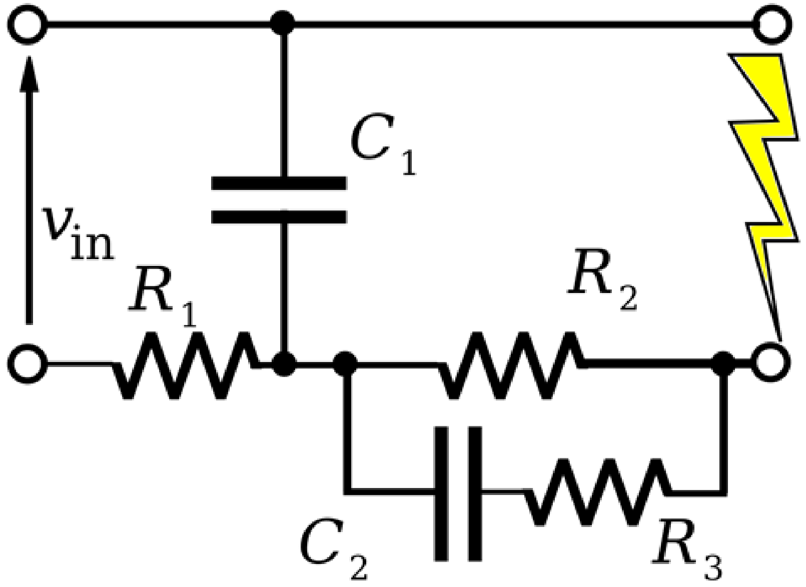
Lightning and the Induced Polarization Effect



- Lightning does not have a square waveform
- But it does have a very steep onset
- Variations in the onset as measured (rise-time) show the IP Effect

Les Denham
Chief Geophysicist
Dynamic Measurement

- By treating this steep onset as charging a capacitor (C2) through a resistor (R3), an apparent capacitance can be calculated.
- From the apparent capacitance a value for apparent permittivity can be calculated



Es Xplore Electroseismic Technology

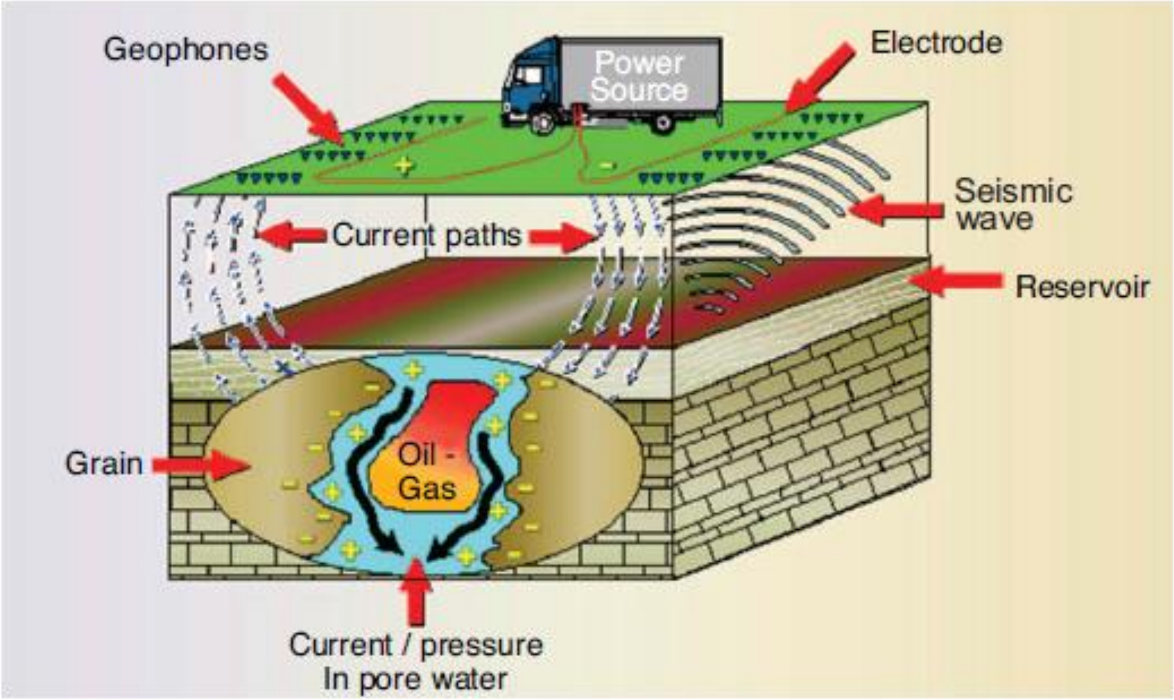


Figure 1. Description of the ES method. A current injected into the subsurface creates local field gradients at discontinuities in electrical properties. Applied fields couple to internal rock fields, including fields in the dipolar boundaries on pore surfaces. This electrokinetic coupling displaces the dipolar fluid layers causing relative movement or pressure generation in the grain space.

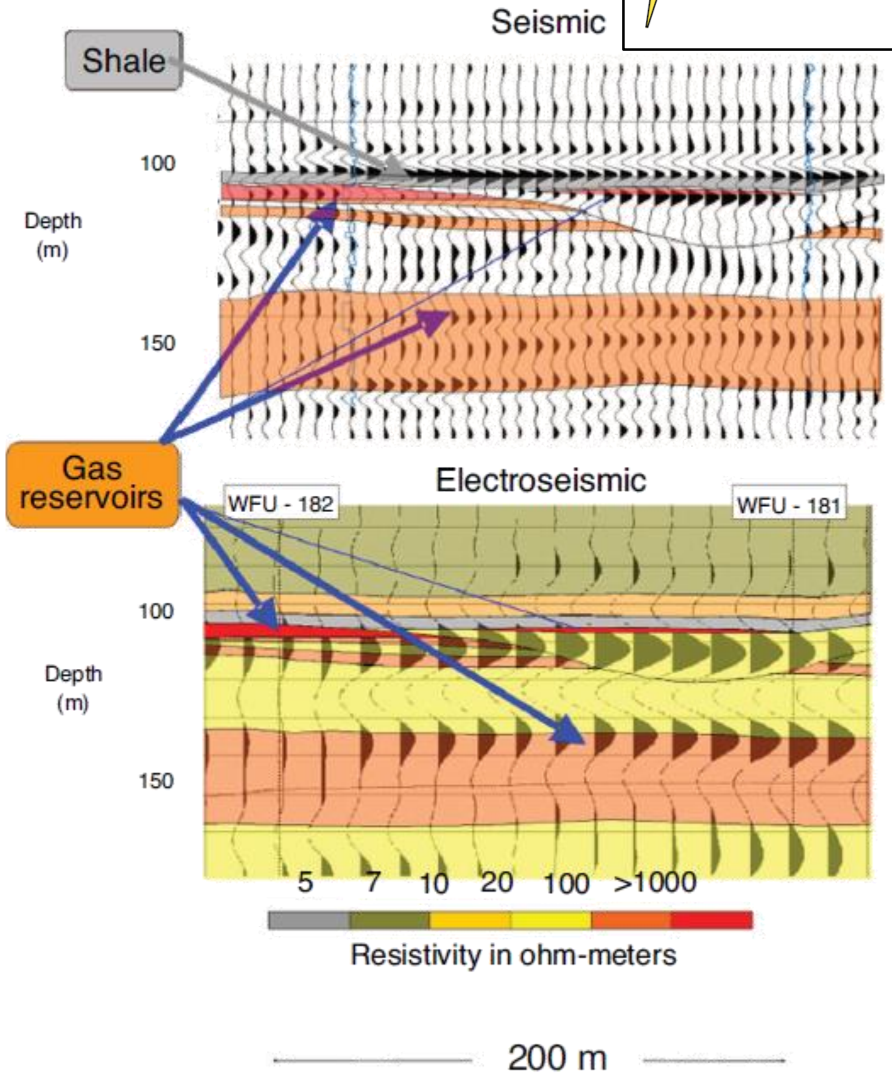


Figure 3. Webster field. Seismic, ES, and stratigraphic interpretation. The upper seismic display from the 3D seismic survey shows large amplitude response to the shale above the gas sands. The lower ES display shows large amplitude response to the gas sands.

From Field test of electorseismic hydrocarbon detection, Geophysics, Vol. 70, No. 1, Jan-Feb 2007.

Bakken example in Appendix

Stress-Induced Currents in the Laboratory

Although silicate minerals are primarily insulators, most can behave as semiconductors because they contain dormant electronic charge carriers, i.e. electricity that can be activated by stress.

When rocks are subjected to stress, first positive and then negative charge carrying currents are produced (positive or "h holes" and electrons respectively).

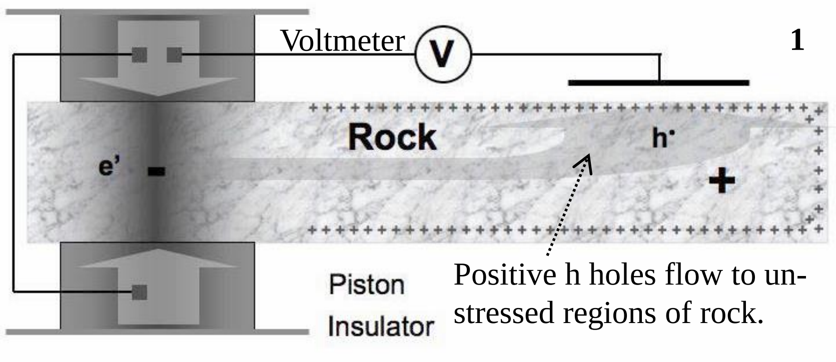
These stress-induced currents flow toward the unstressed region of rock samples and from the interior to the rock's exterior, ultimately ionizing the air.

Thus, faulted areas offer a plentiful supply of dormant charge carriers that when triggered by the attraction of overhead storm clouds, can provide the necessary current flow, in the form of "streamers," to attract opposite charged step-leaders.

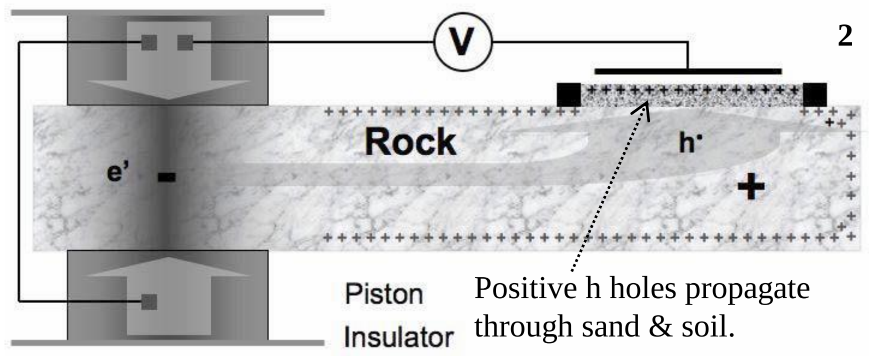
Dr. Friedemann Freund, NASA Ames Res. Ctr. , Mountain View, CA; Dept. of Physics, San Jose State Univ. San Jose, CA

Creating a Rock Battery in the Lab

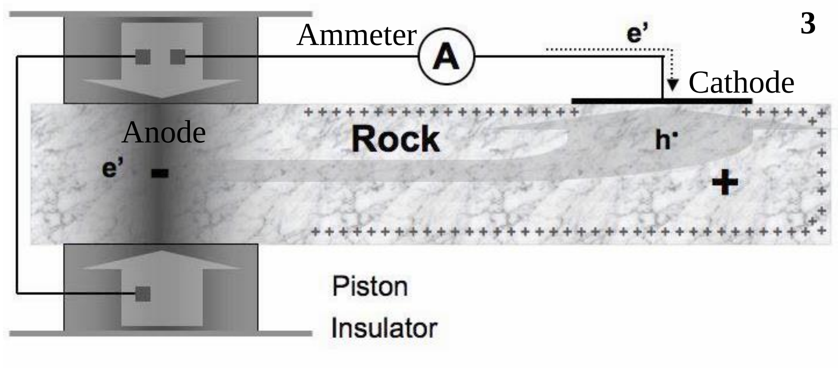
Stress-Induced Currents



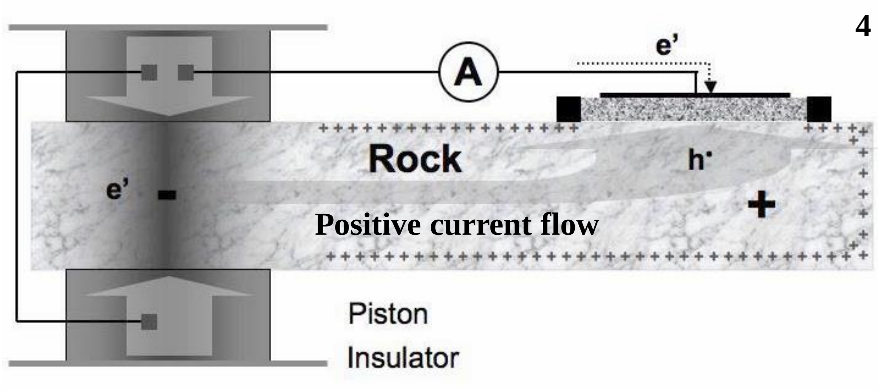
Set-up to measure the positive surface potential with a capacitive sensor.



Potential difference measured between unstressed rock & piston, indicating build-up of surface & subsurface charge.



Battery circuit completed by placing copper contact (cathode) on rock. Ammeter measures current.



Demonstrates that positive h hole current also flows through sand and soil.

"Loading simulates tectonic stresses causing existing dislocations to move & new ones to be generated in response to shear forces acting on mineral grains."

"Dislocations activate h charge carriers alongside electrons" (Freund, 2002; Freund et al., 2006)

Figures modified from Friedemann Freund, "Toward a unified solid state theory for pre-earthquake signals," Acta Geophysics 58(5):719-766 · October 2010.

Additional examples in Appendix.

Skin Depth does not Control Lightning Penetration

DYNAMIC MEASUREMENT

Charging Telluric Currents:

- Lightning strikes are passive energy pulses, and contain all frequencies.
- The skin effect of high frequency information recorded in ~50 microsecond total-wavelet time does not control the depth electrical energy interacts with telluric currents.

Interval of Interest:

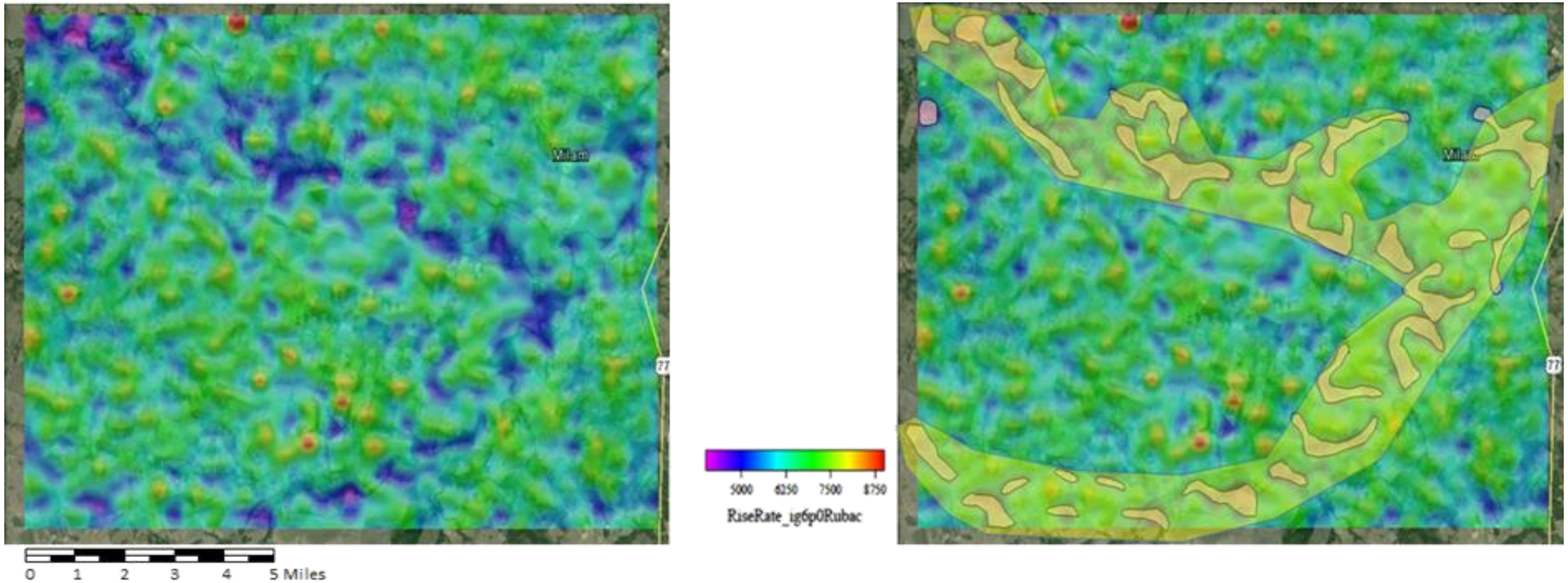
- Traditional lightning does not occur in clouds less than ~1,500 feet in height, nor for clouds higher than ~30,000 feet.
- The depth interval where lightning volumes are useful is typically from 1,500-30,000 feet.

Data Distribution:

- Maps delivered as X,Y, attribute ASCII files
- Volumes converted to SEG-Y files for workstations.
- Volumes interpolated to match aeromagnetic or 3-D seismic surveys.
- Resulting rock property or lightning attribute volumes are overlaid on the seismic or other geologic cross-sections like a velocity volume.

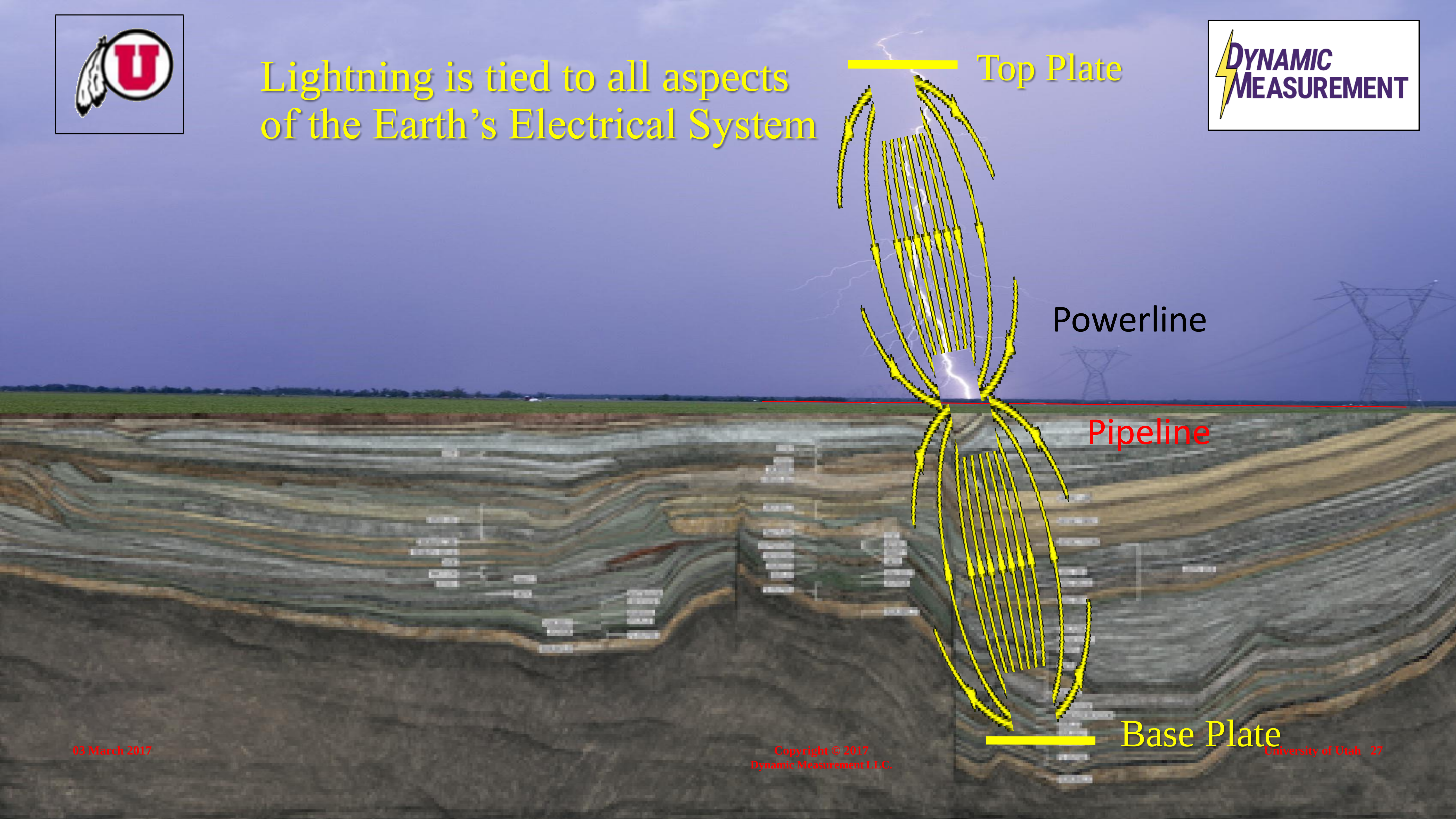
4. Lightning Analysis & Attributes

1. **Analysis area selected.**
2. **Patented and Patent-Pending Processes produce maps and volumes of derived rock properties and lightning attributes.**
3. **Existing geology and geophysics integrated with new data.**



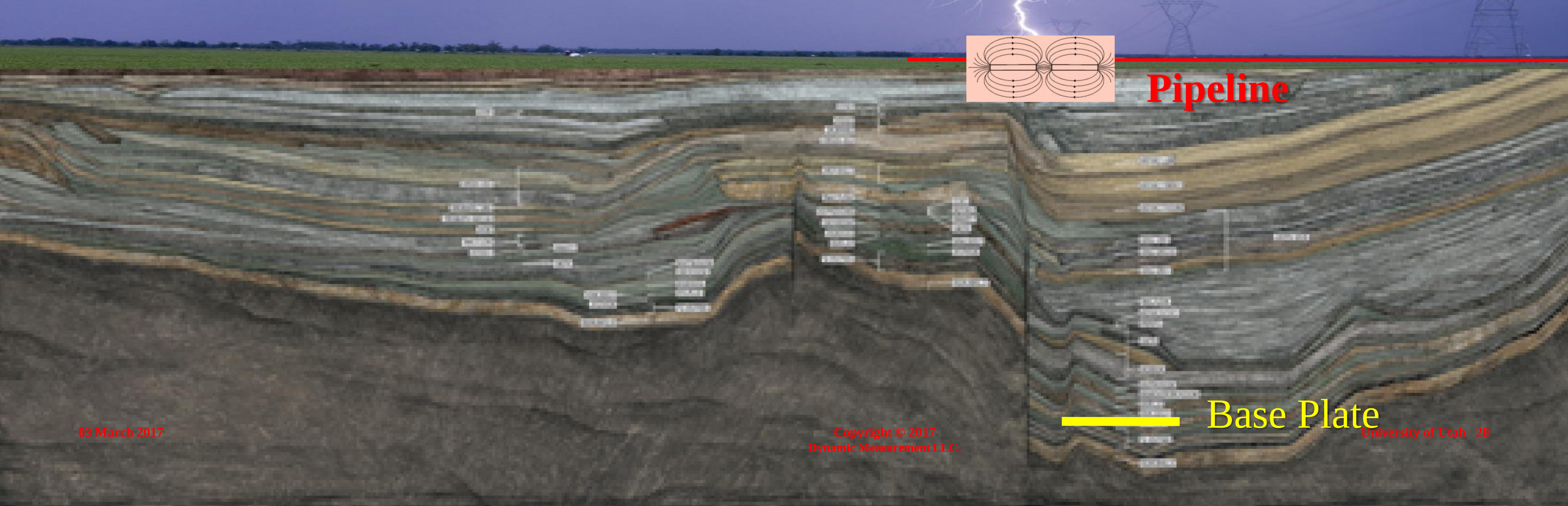
Lightning Attribute: Rate of Rise-Time – Milam County, Texas

Lightning is tied to all aspects of the Earth's Electrical System



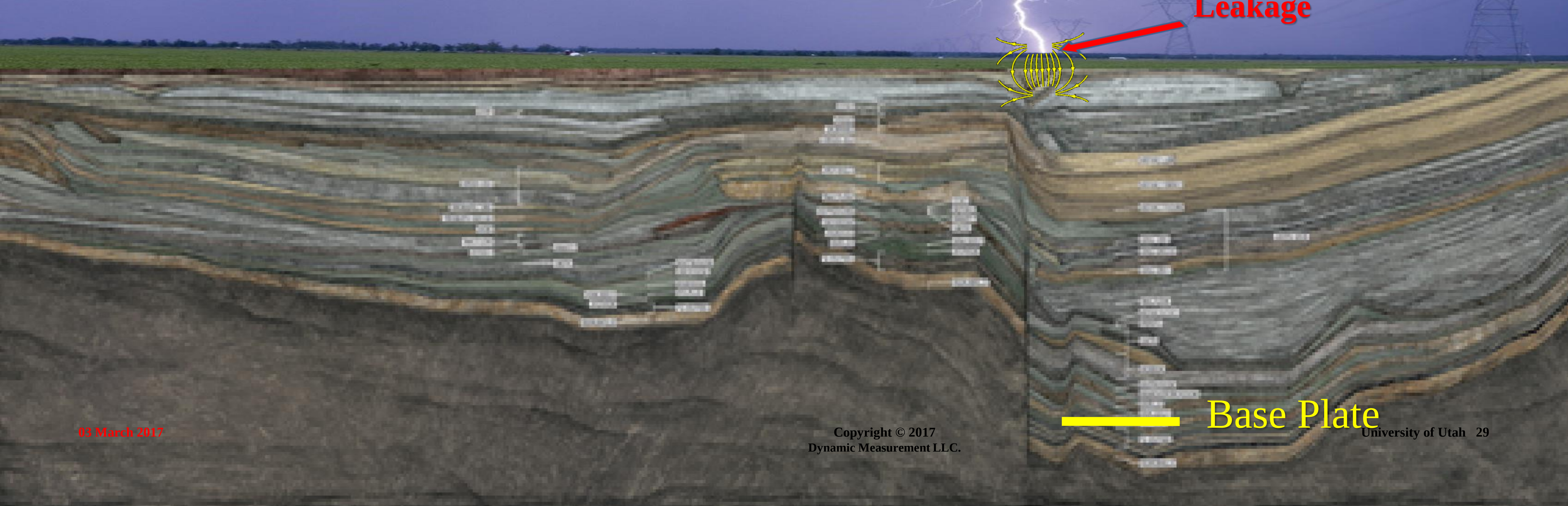
Powerline Leakage occurs at Geomagnetic Hot Zones (GHZ)

GHZs include concentrated sub-surface currents that interact with pipelines speeding up corrosion and impact integrity. Natural gas with high water content exacerbates the problem.

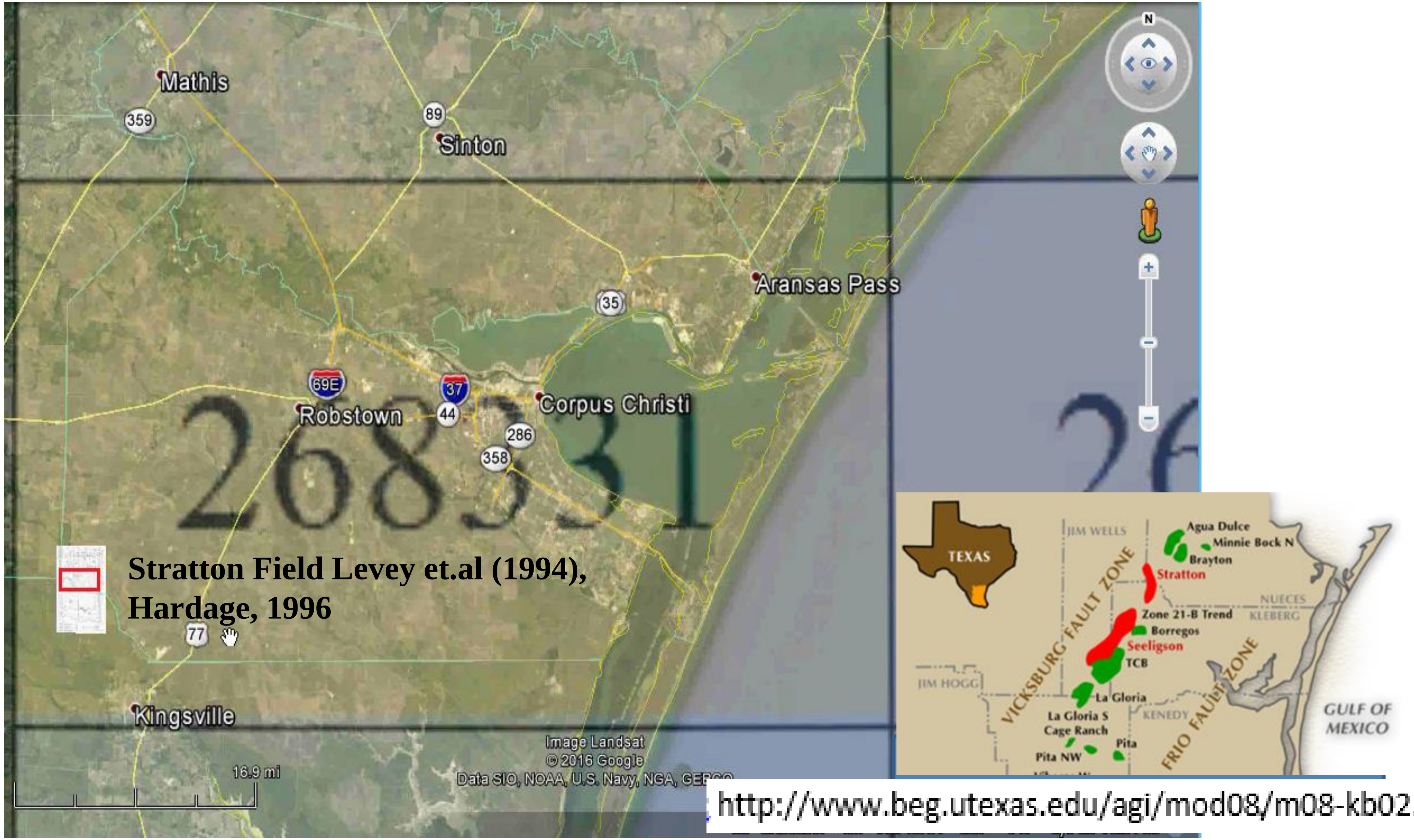


Powerline Leakage occurs at Geomagnetic Hot Zones (GHZ)

Just as GHZs attract more lightning strikes, they pull on electrical current during power transmission which leads to Leakage



5. Study Area around Corpus Christi

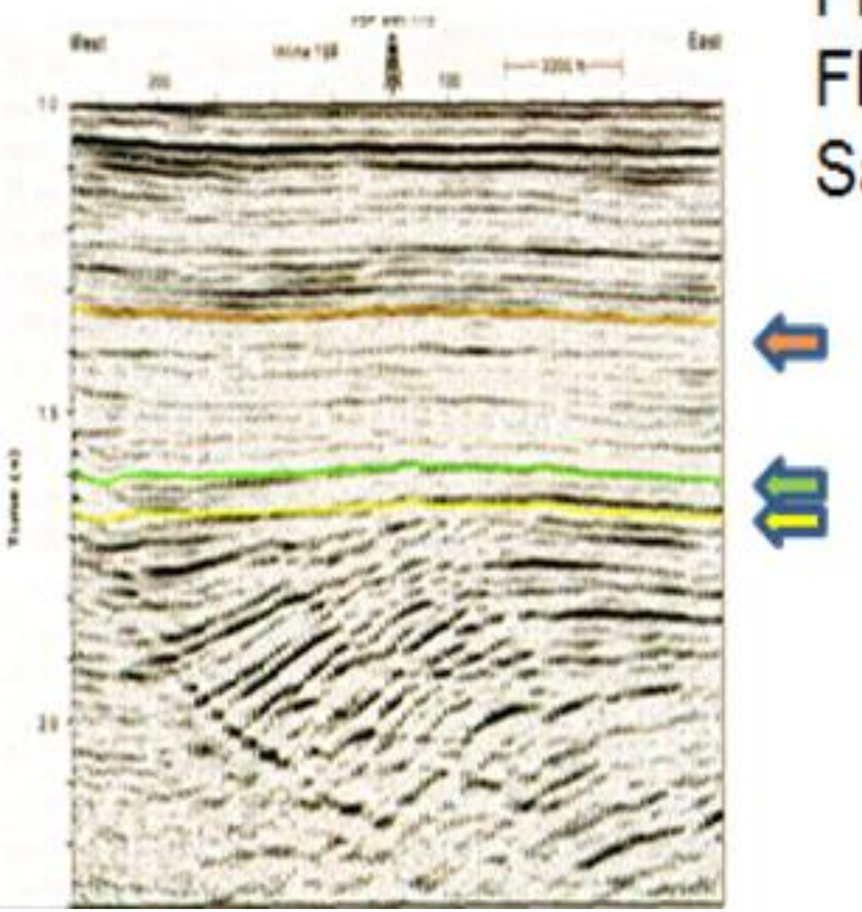


Stratton Field Levey et.al (1994), Hardage, 1996

http://www.beg.utexas.edu/agi/mod08/m08-kb02.htm

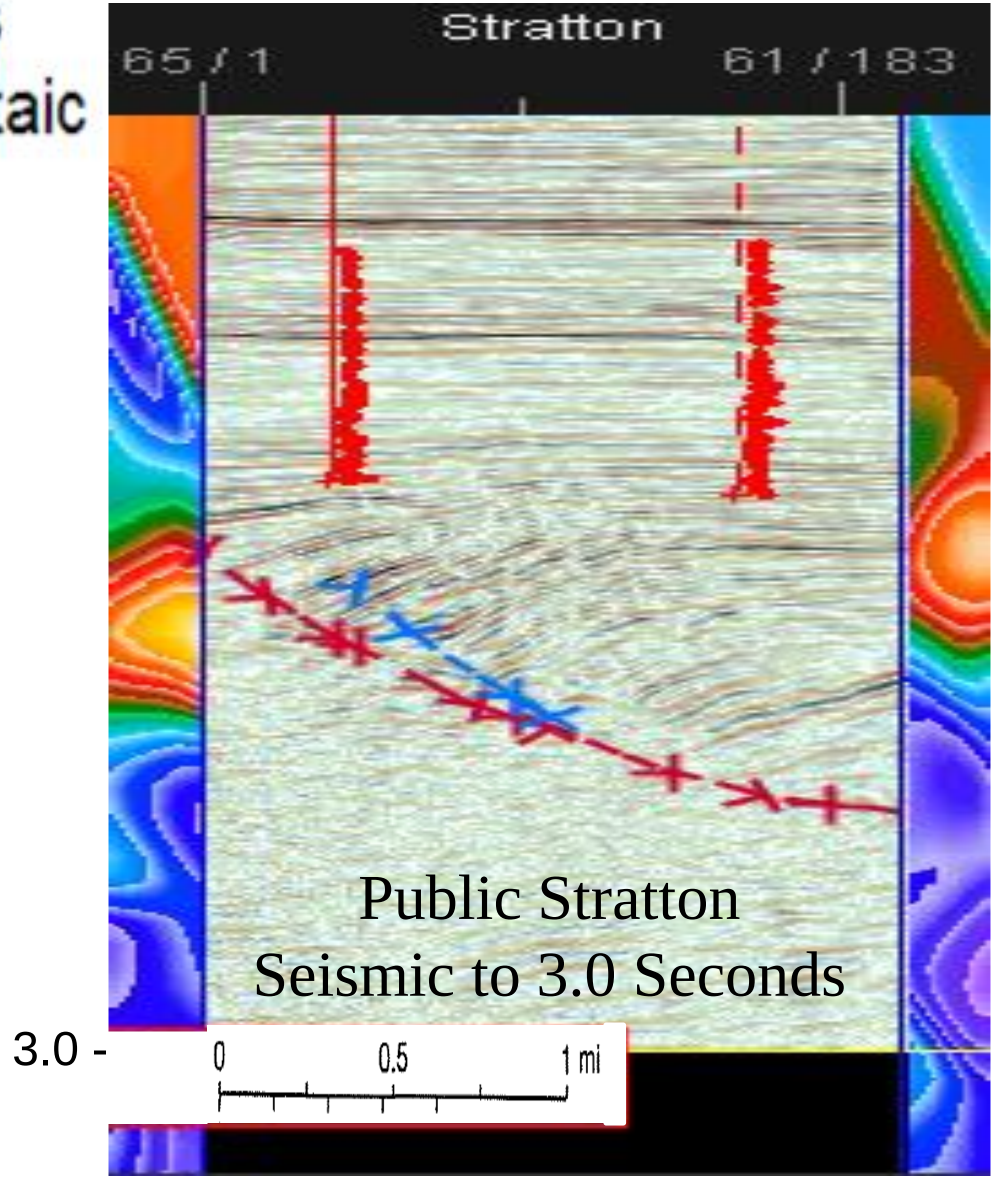
Stratton Seismic Sections, South Texas

Louie Berent,
Geophysicist
Kathy Haggar
Geologist
Dynamic Measurement



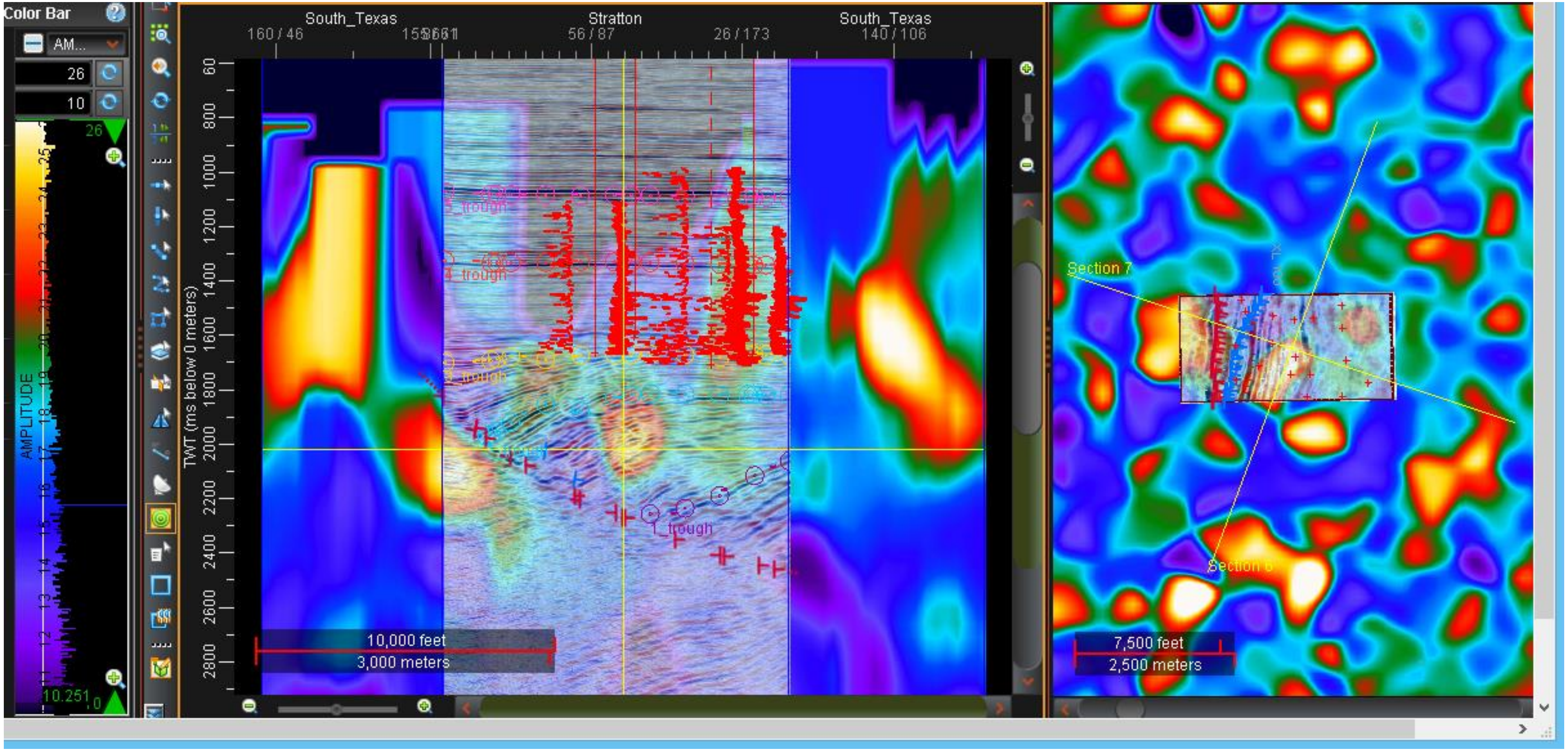
Frio Horizons
Fluvial – Deltaic
Sands

Published BEG Stratton Data to 2.3 seconds
(Hardage, 1986)



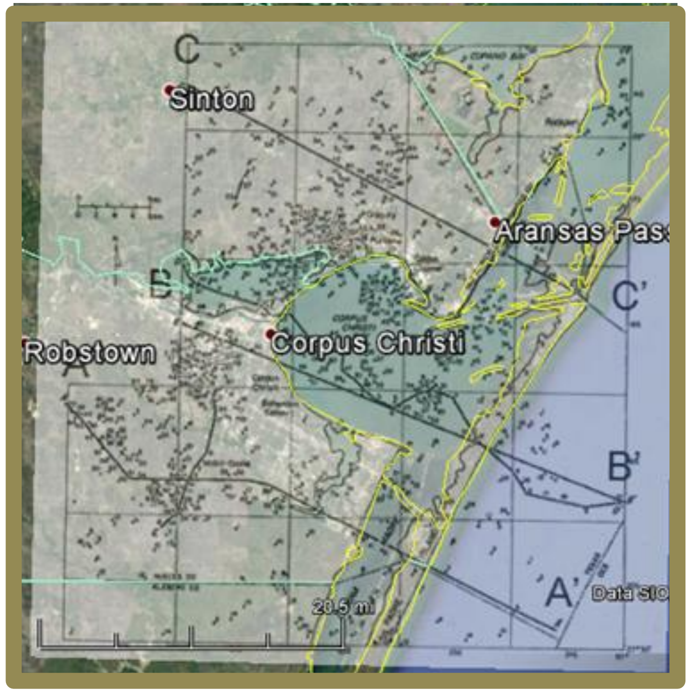
Public Stratton
Seismic to 3.0 Seconds

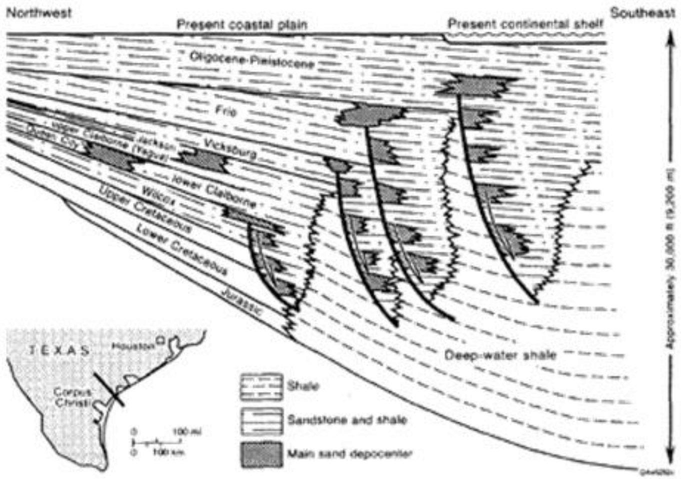
Stratton Apparent - Resistivity Sections

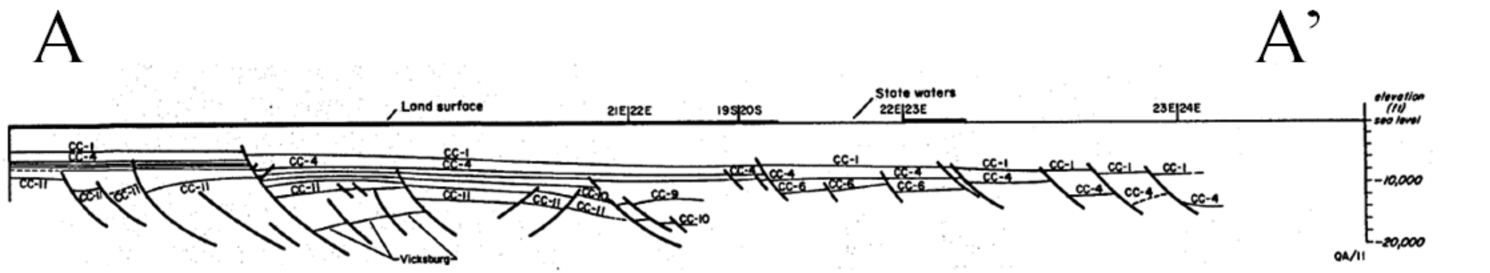


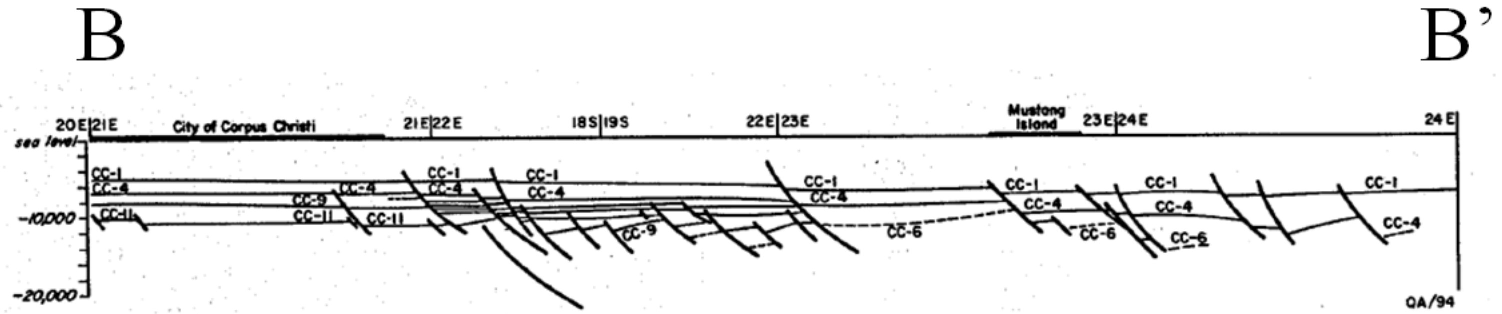
Working on calibrating depth and calculated vs. measured resistivity

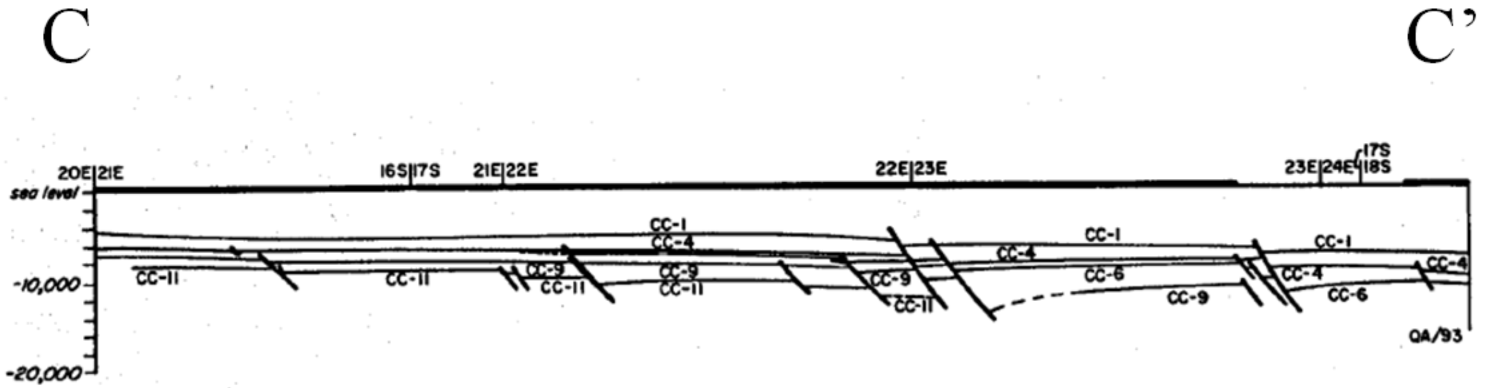
Study Area - Geology and Structure Corpus Christi from Ewing (1986)





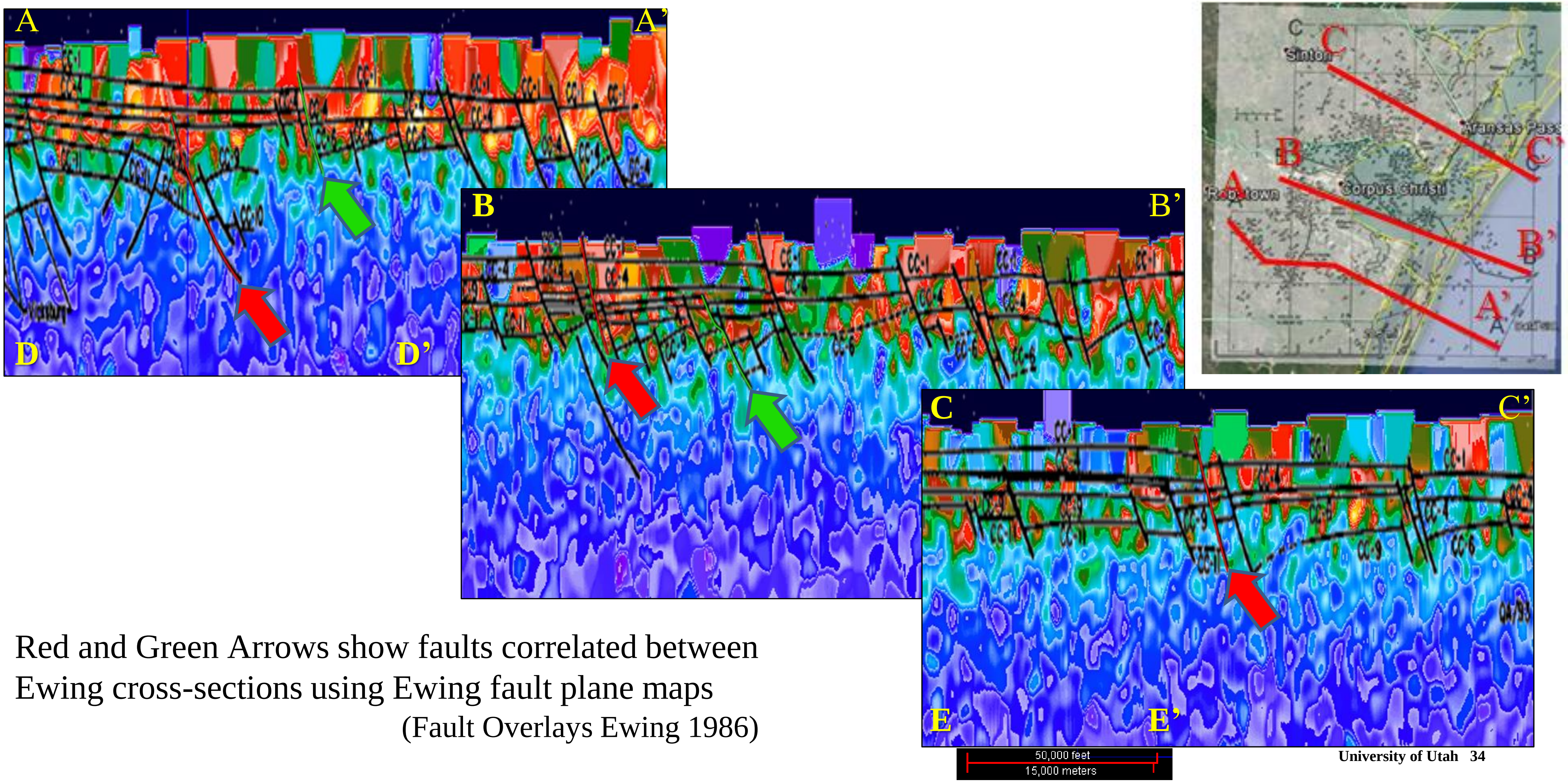






From Levey, et al,1994
Bebout and others,1982

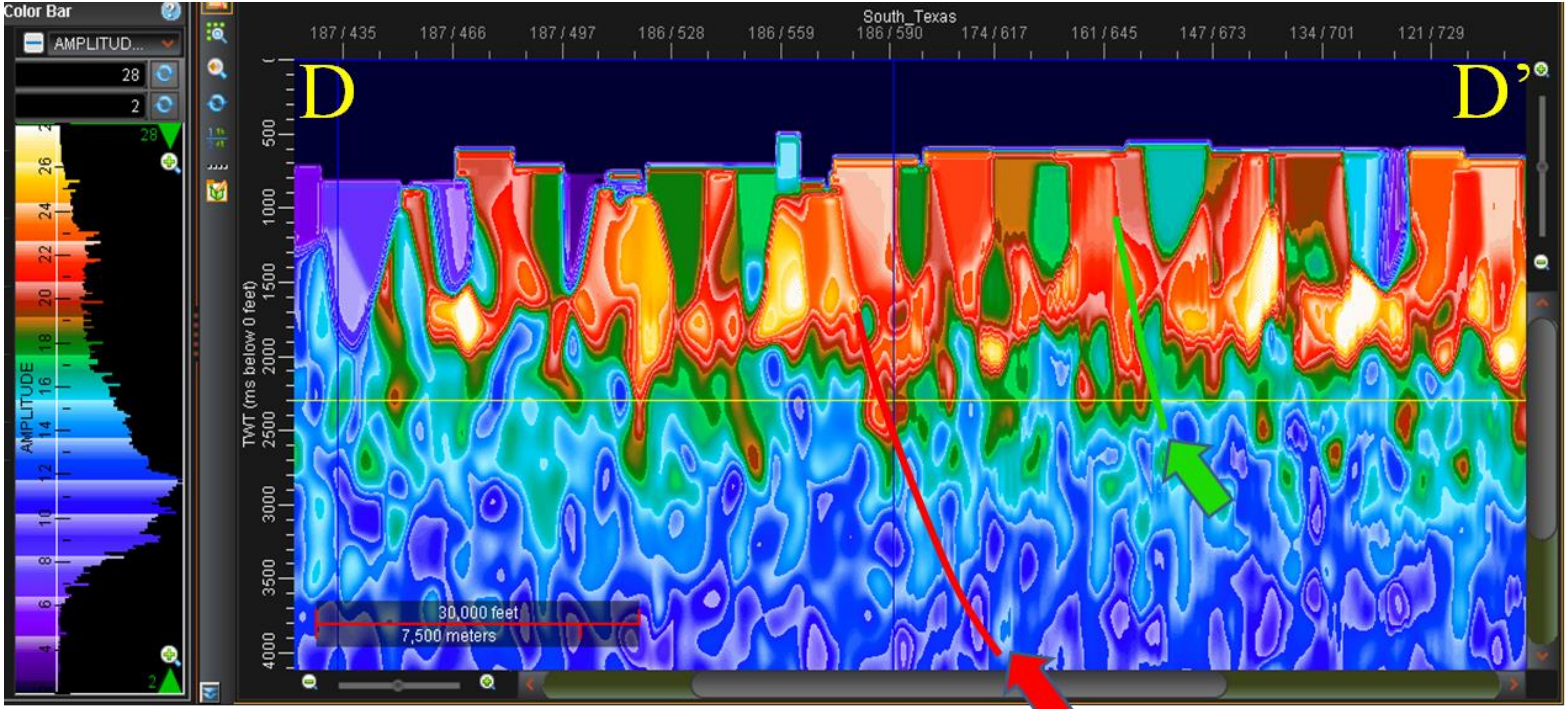
2016 Lightning-Derived Resistivity Cross-Sections Match Geology on 1986 Ewing Interpretation Overlay



Red and Green Arrows show faults correlated between Ewing cross-sections using Ewing fault plane maps

(Fault Overlays Ewing 1986)

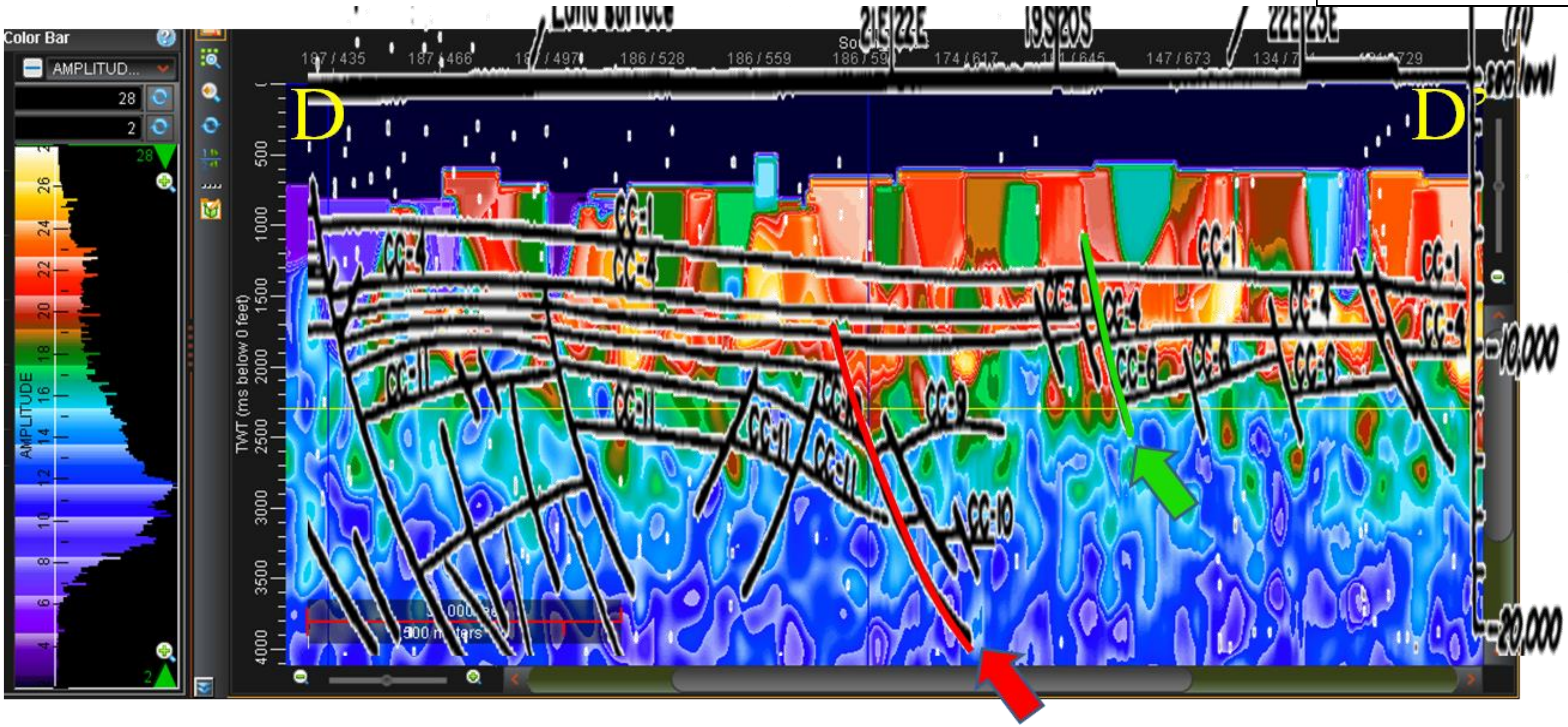
D-D’ Close-Up on Graben on A-A’ without overlay



Red and Green Faults were major faults on Ewing’s maps. Note high apparent-resistivity events (bright) appear to have plumes above these faults.

D-D’ Close-Up on west Graben

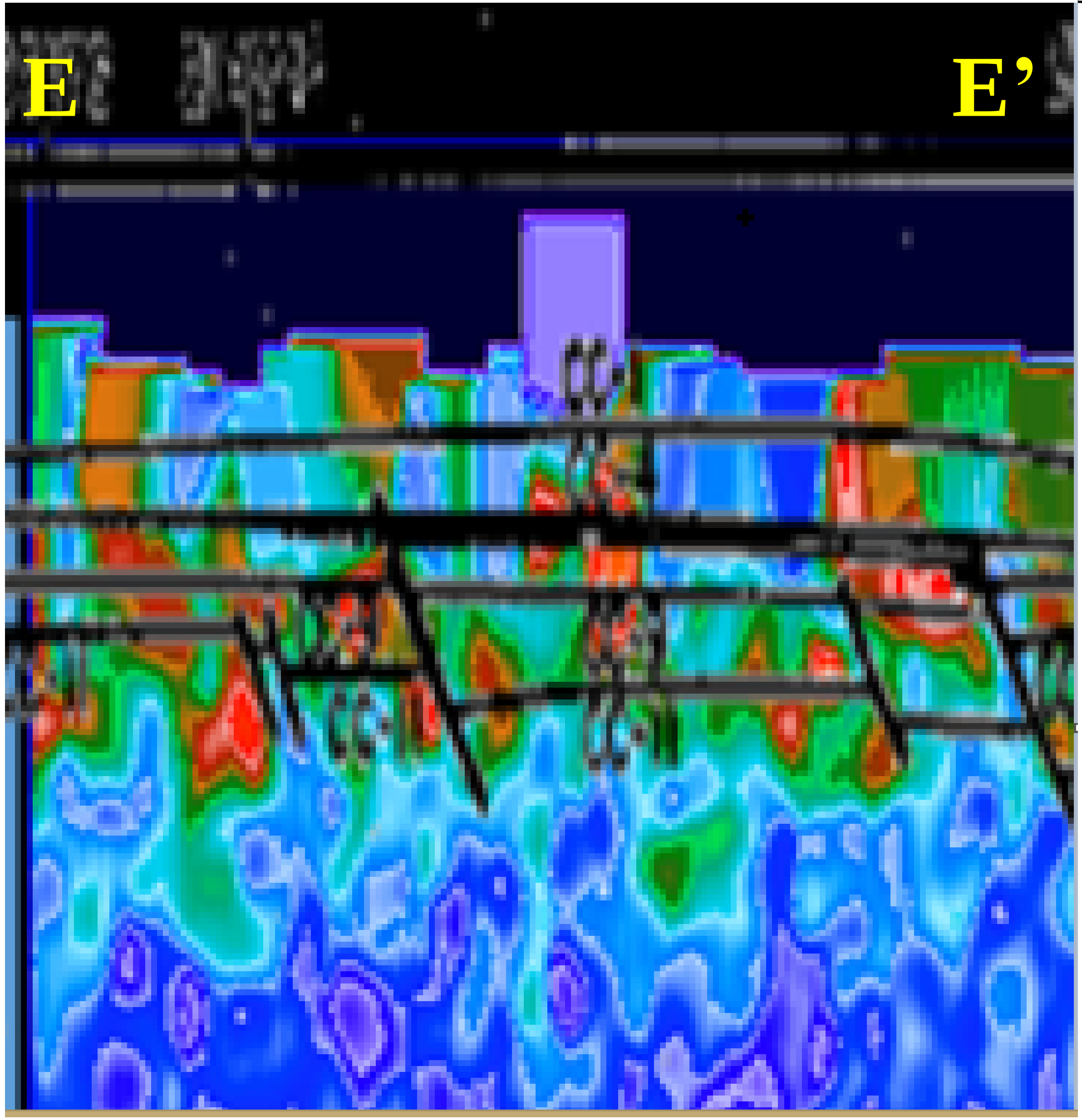
Interpretation 1986 by Tom Ewing, Apparent Resistivity 2016 from Lightning Databases



Note: interpretation by Tom Ewing in 1986. The resistivity section calculated from lightning in 2016. Co-located sections show breaks where faults were interpreted. There are resistivity plumes tied to faults.

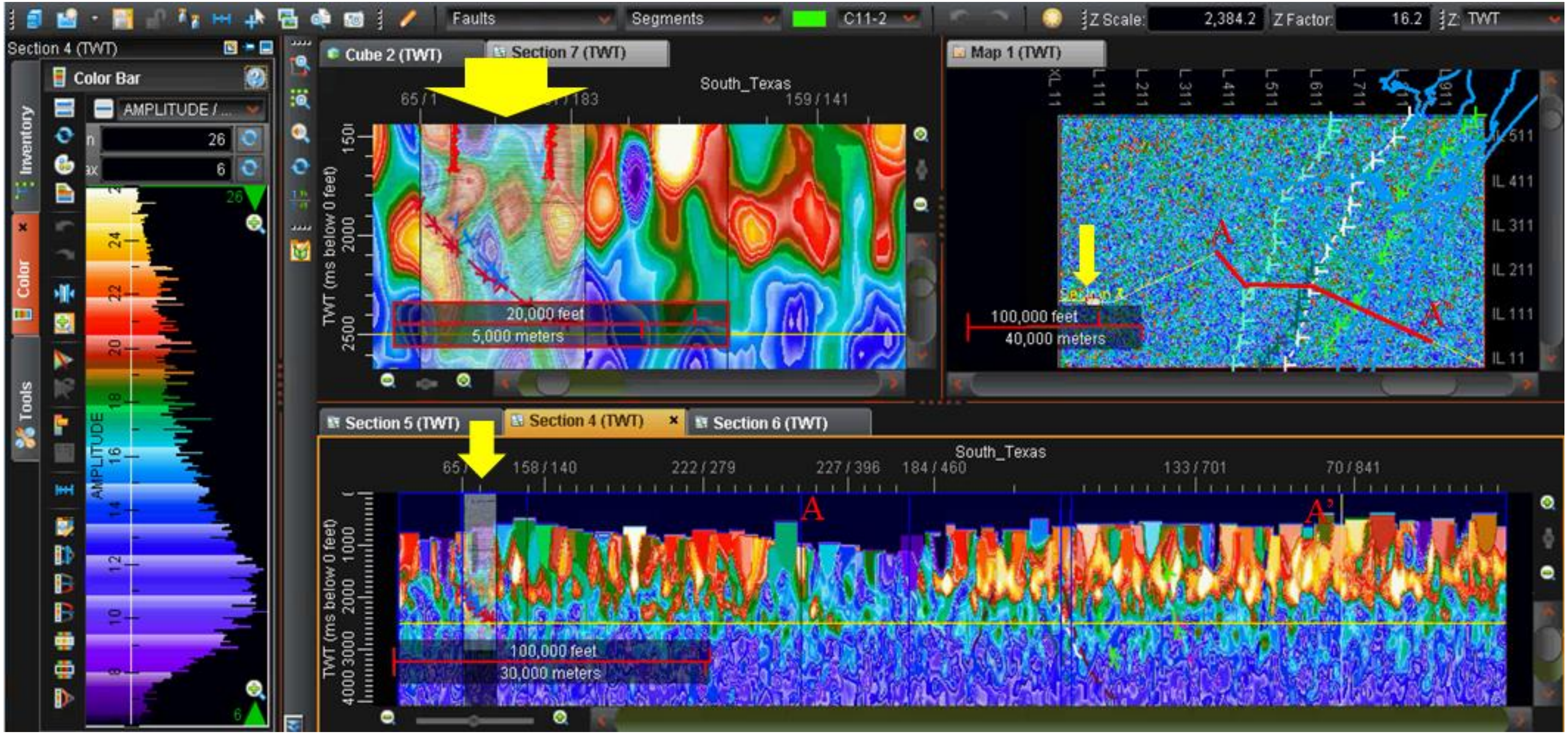
E-E' on the Northwest End of Ewing's C-C'

Note offsets in adjacent "Packages" of Higher Values of Apparent Resistivity



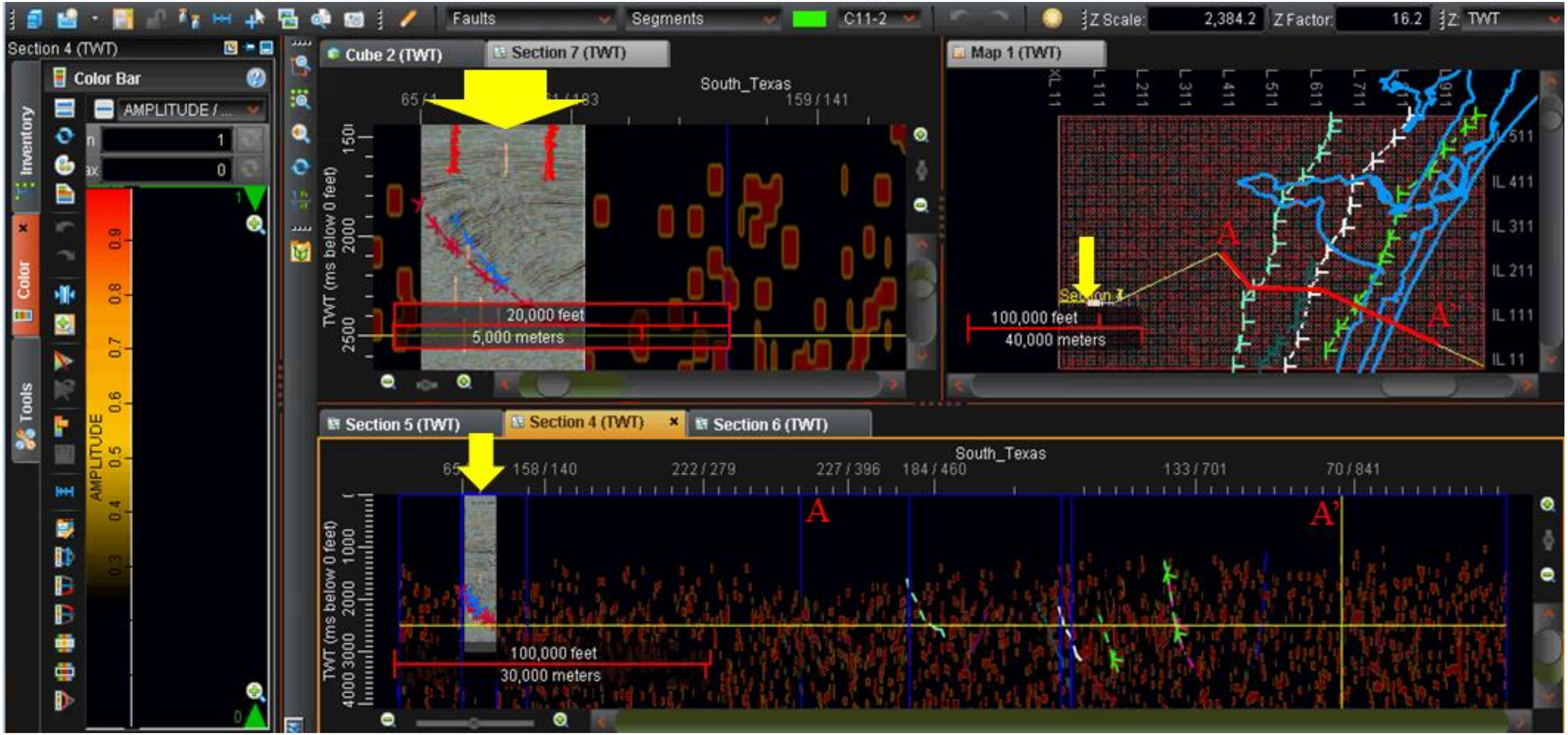
03 March 2017

Apparent-Resistivity extension of Ewing (1986) A-A' through Stratton seismic data



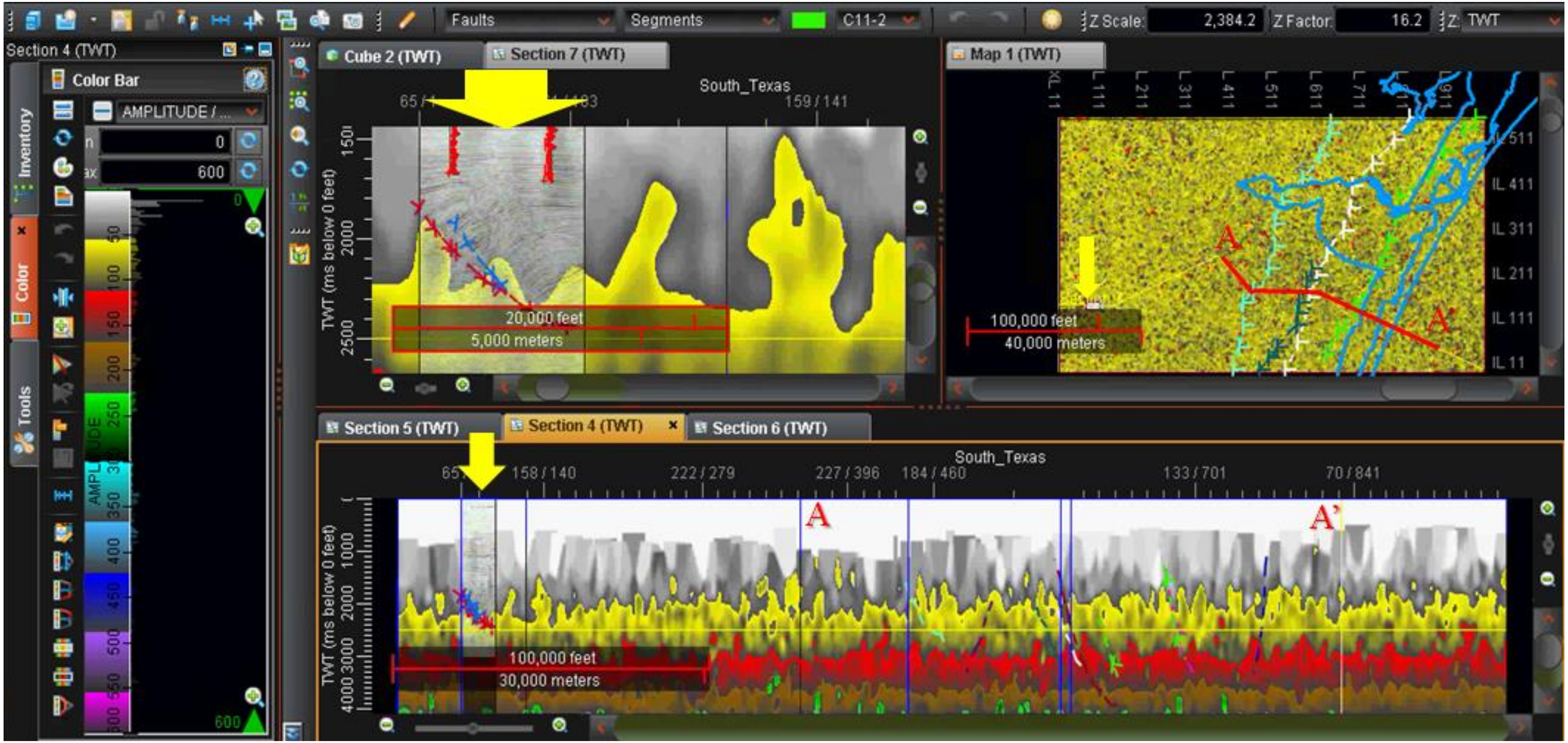
(ohm-meters)

2 of 18 Lightning Attributes - Spike



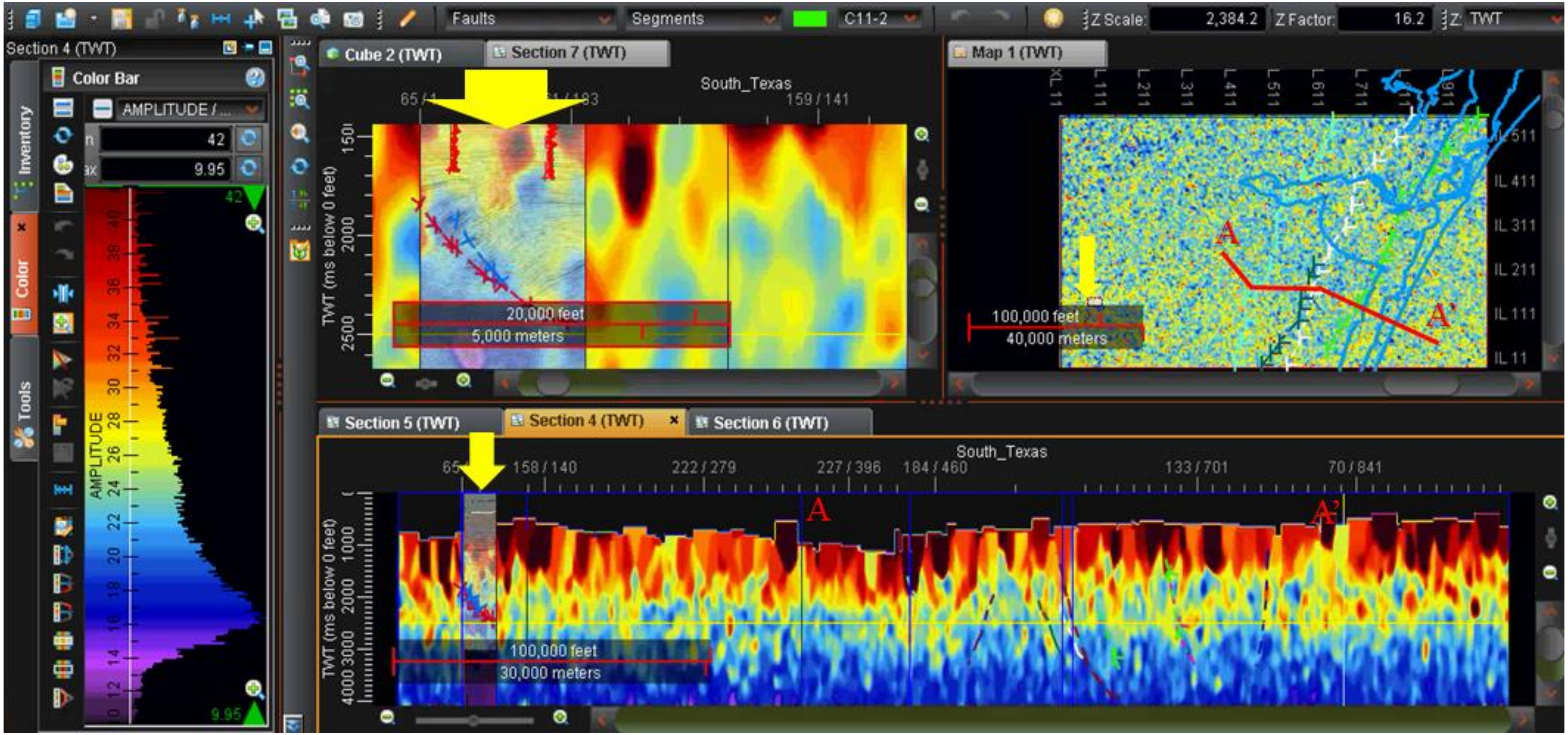
(position of strike)

3 of 18 Lightning Attributes - Energy



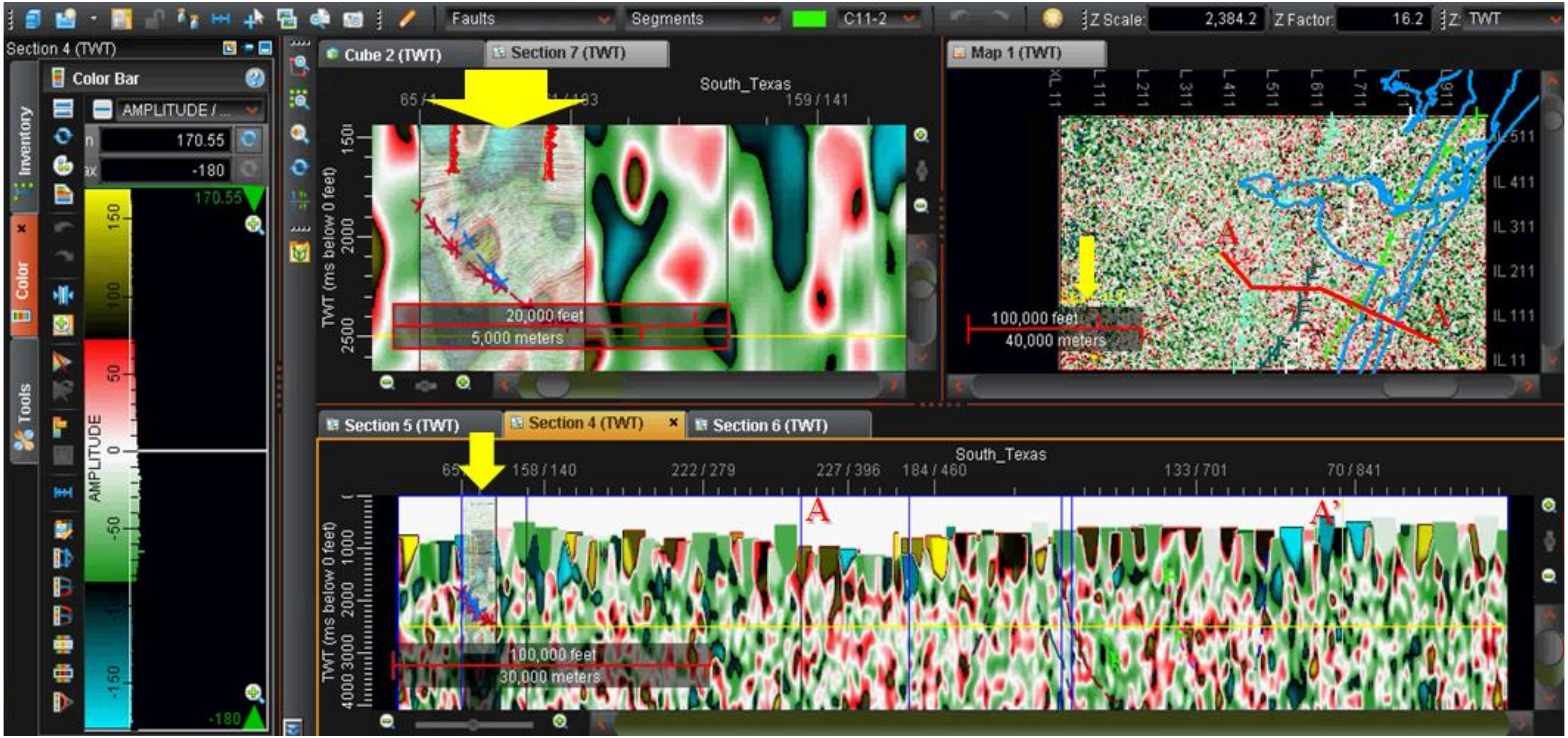
(milliampere-seconds)

4 of 18 Lightning Attributes - Frequency



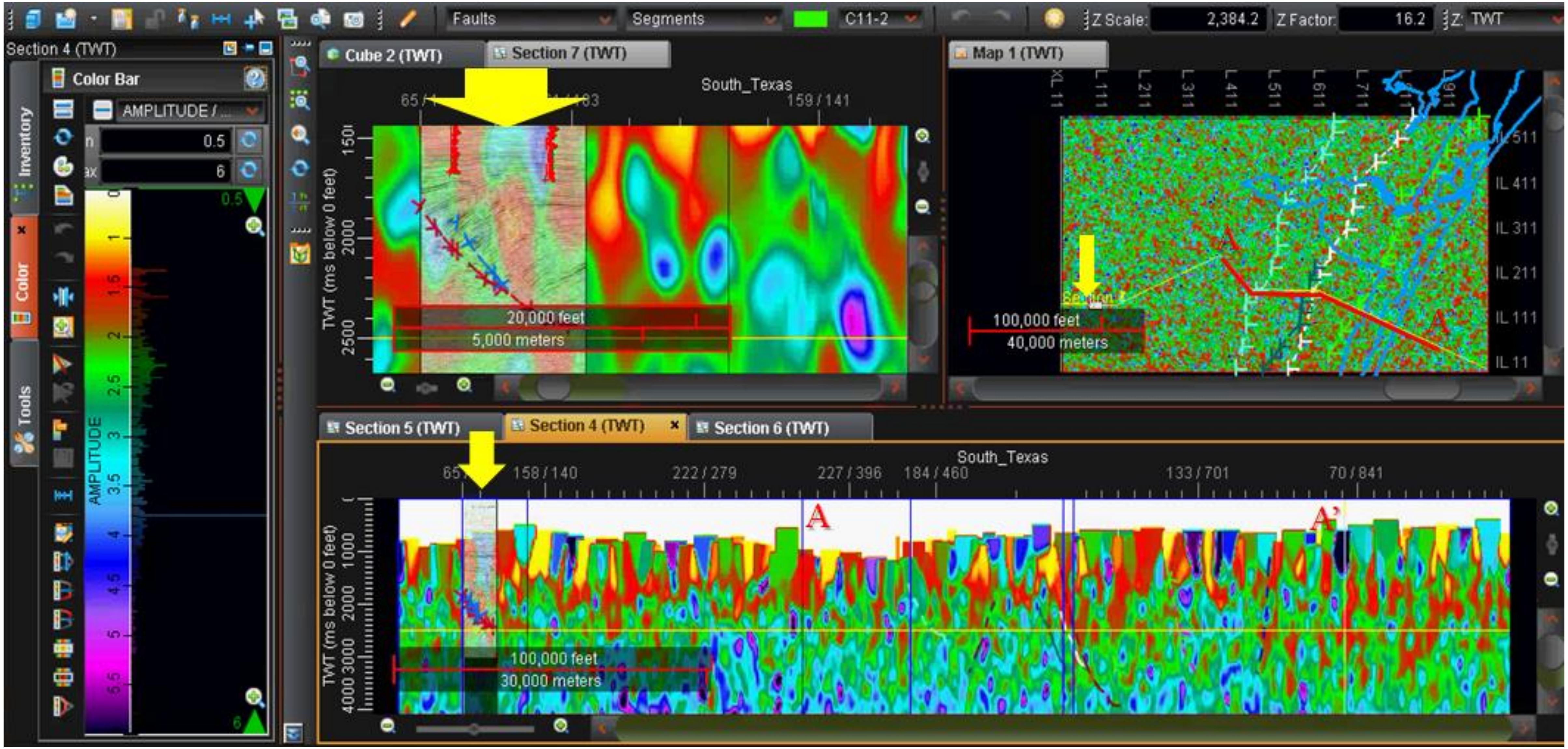
(kilohertz)

Lightning Attributes - Moon Local Longitude



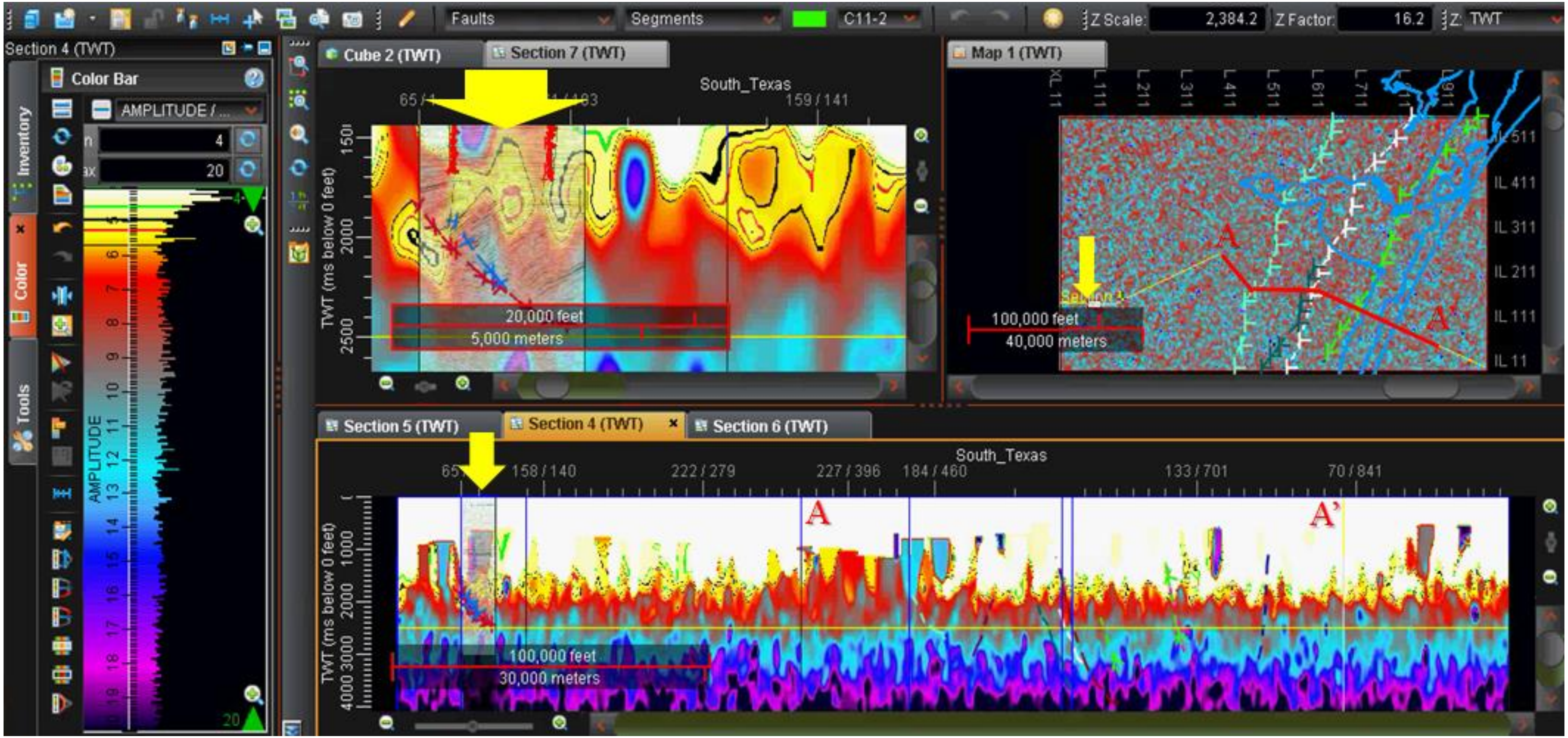
(degrees [-180 to 180]s)

6 of 18 Lightning Attributes - Rise Time



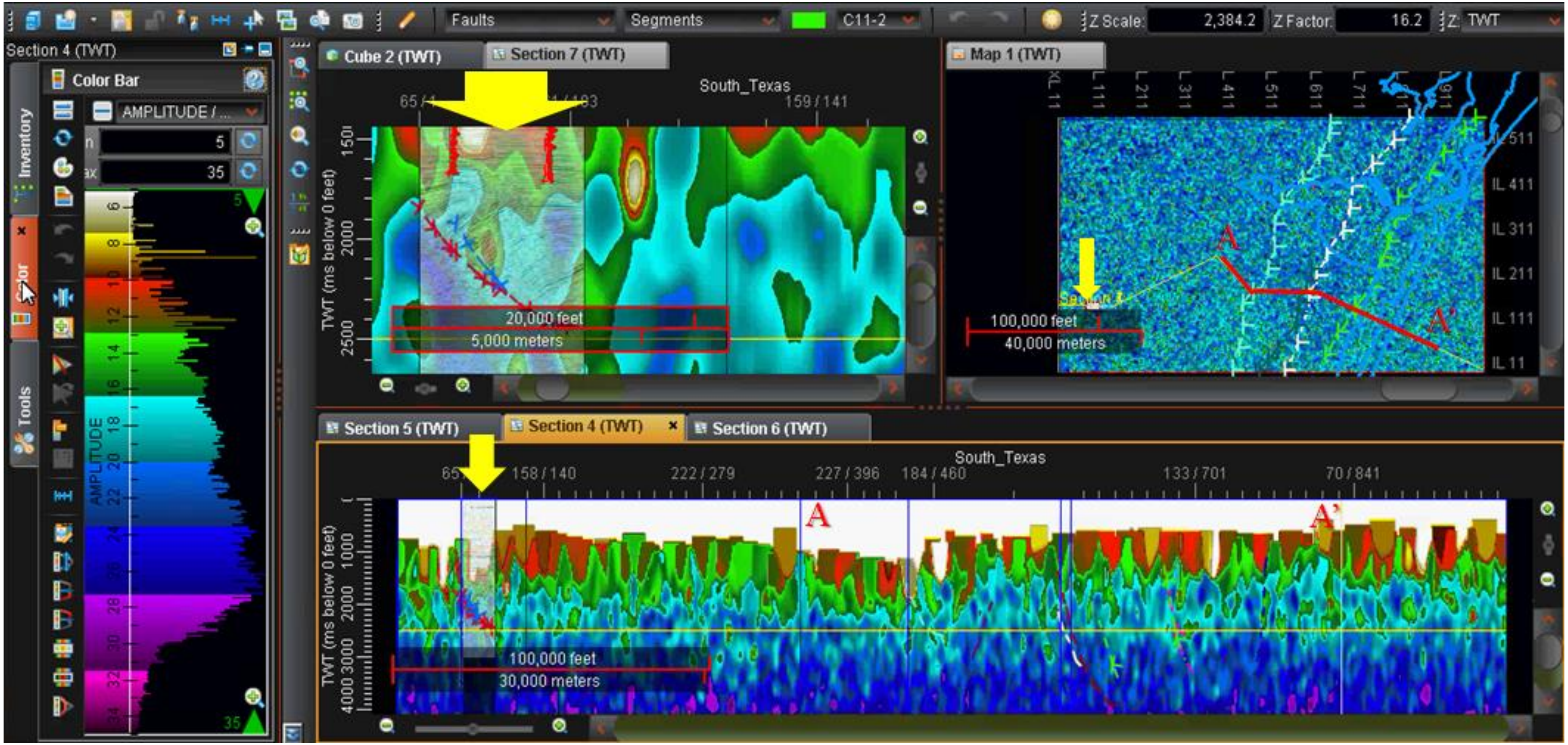
(microseconds)

7 of 18 Lightning Attributes - Peak Current



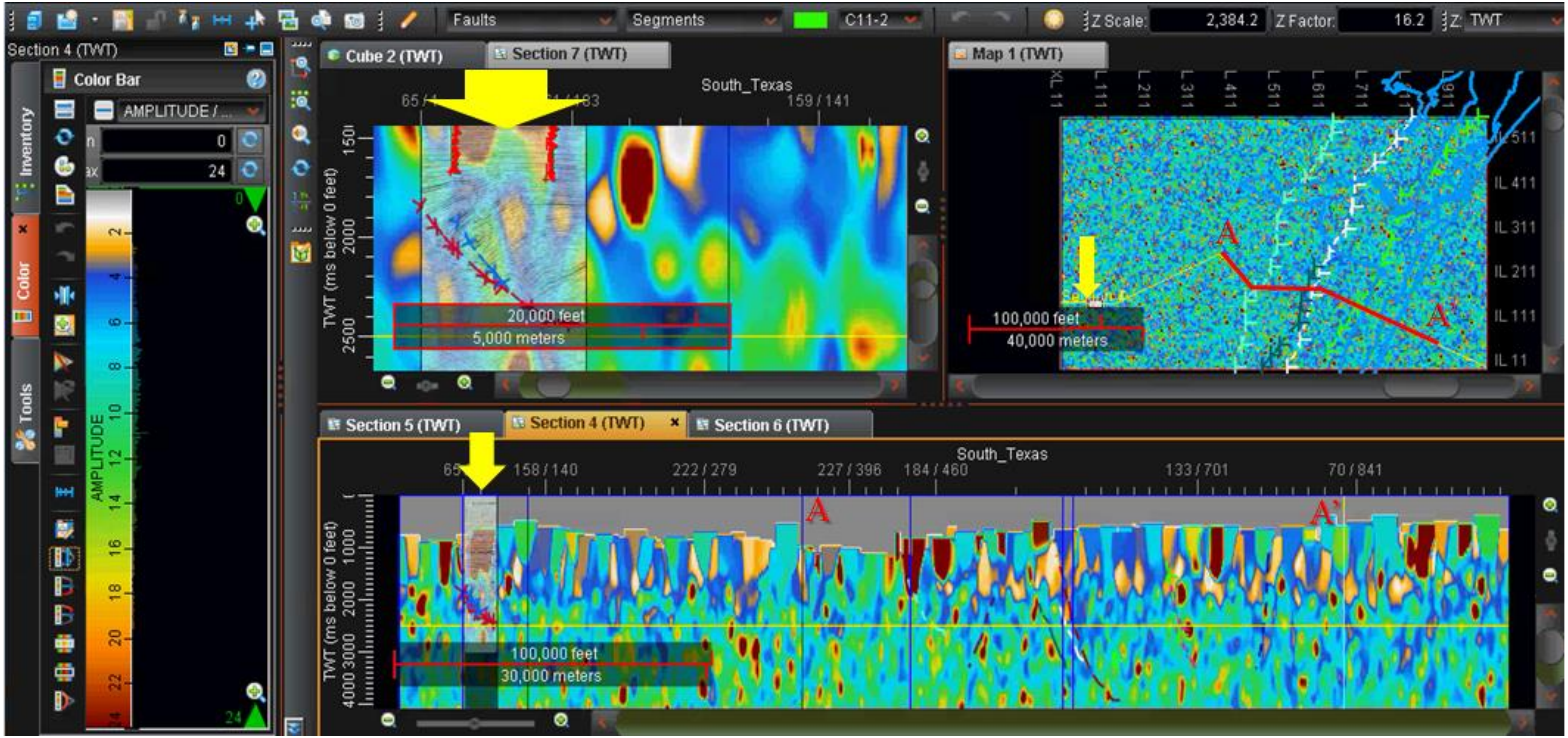
(kiloamperes)

8 of 18 Lightning Attributes - Peak to Zero



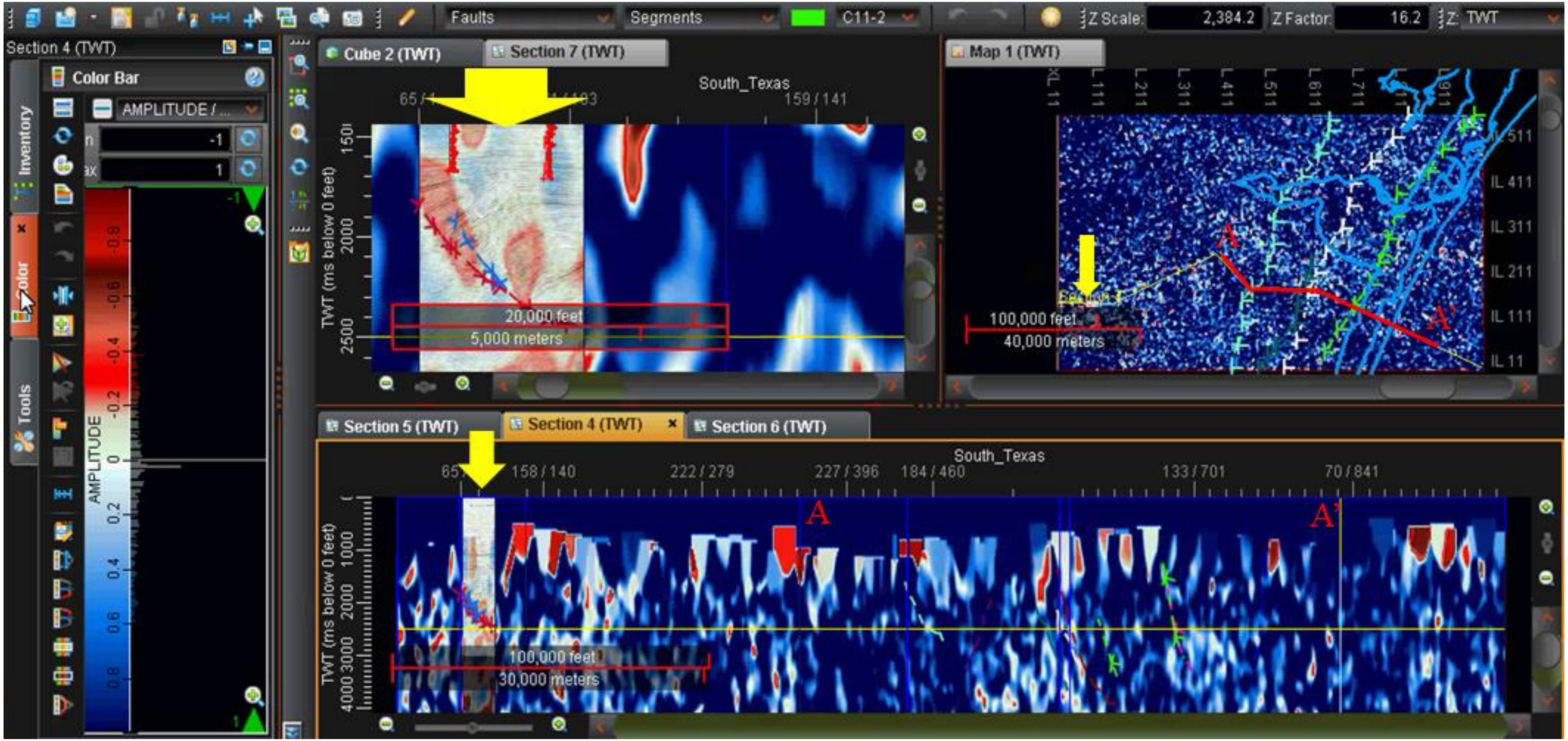
(microseconds)

9 of 18 Lightning Attributes - Apparent Permittivity



(microfarads per meter)

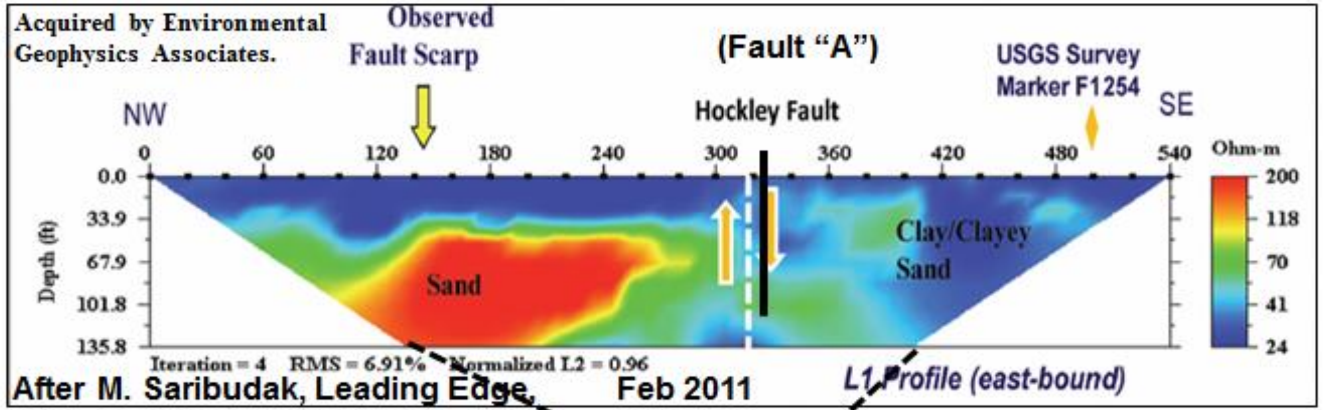
Lightning Attributes - Tide Gradient



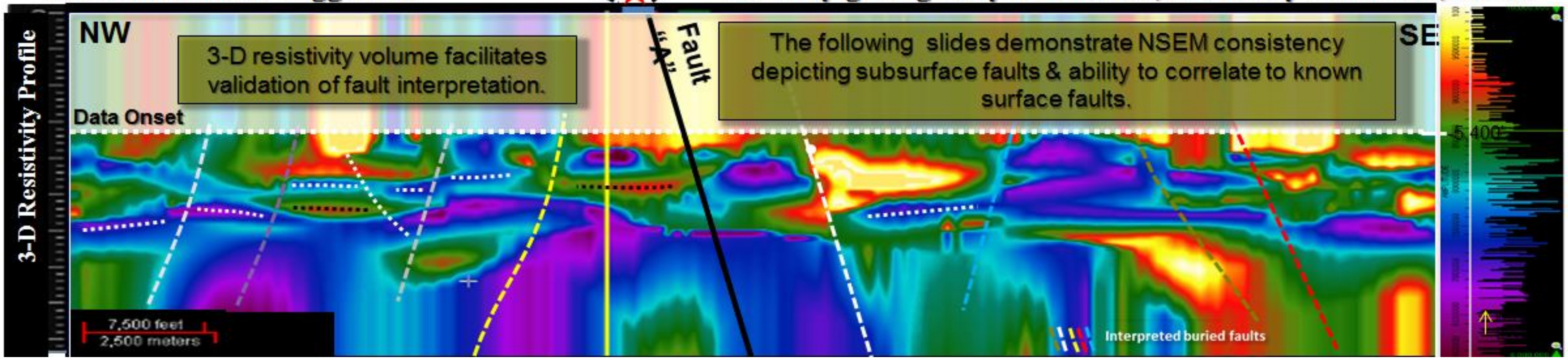
(first derivative of Tide)

Other Attributes in Appendix

5. One Last Texas Example

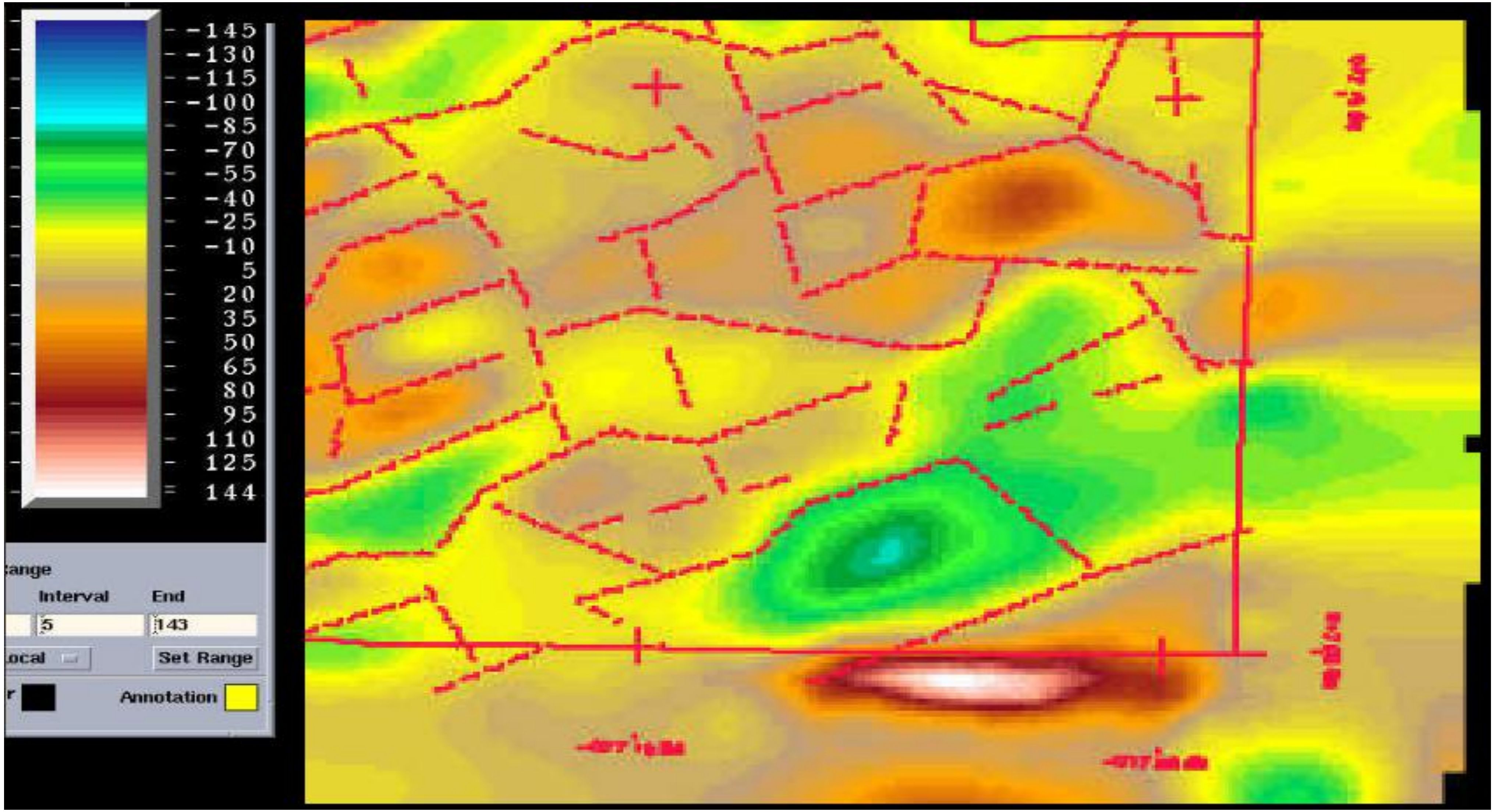


Additional faults suggested. Are they geologically reasonable, internally consistent, valid?



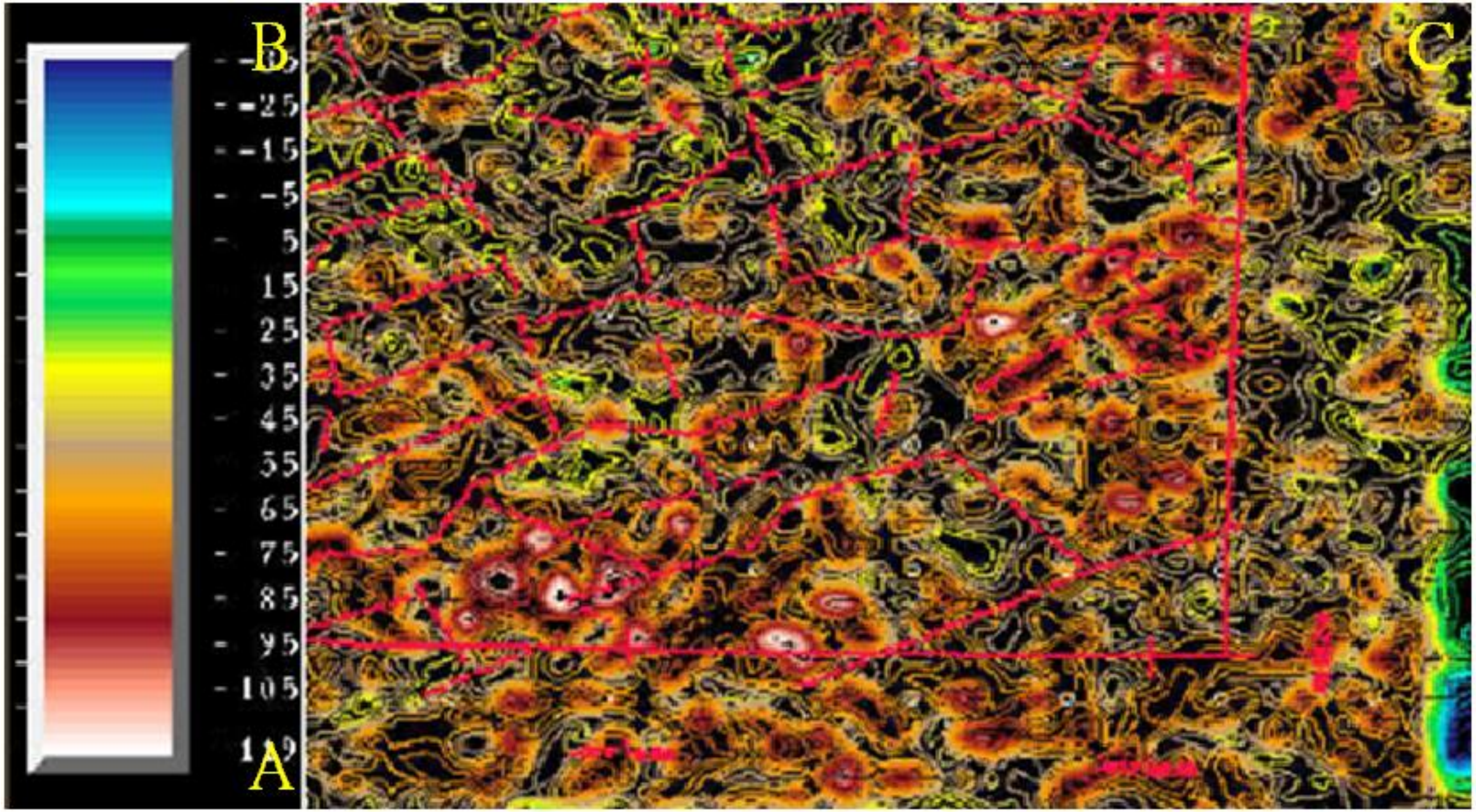
2-D Resistivity Survey ties Lightning-Derived Resistivity Cross-Section

5. Steuben County, New York Example



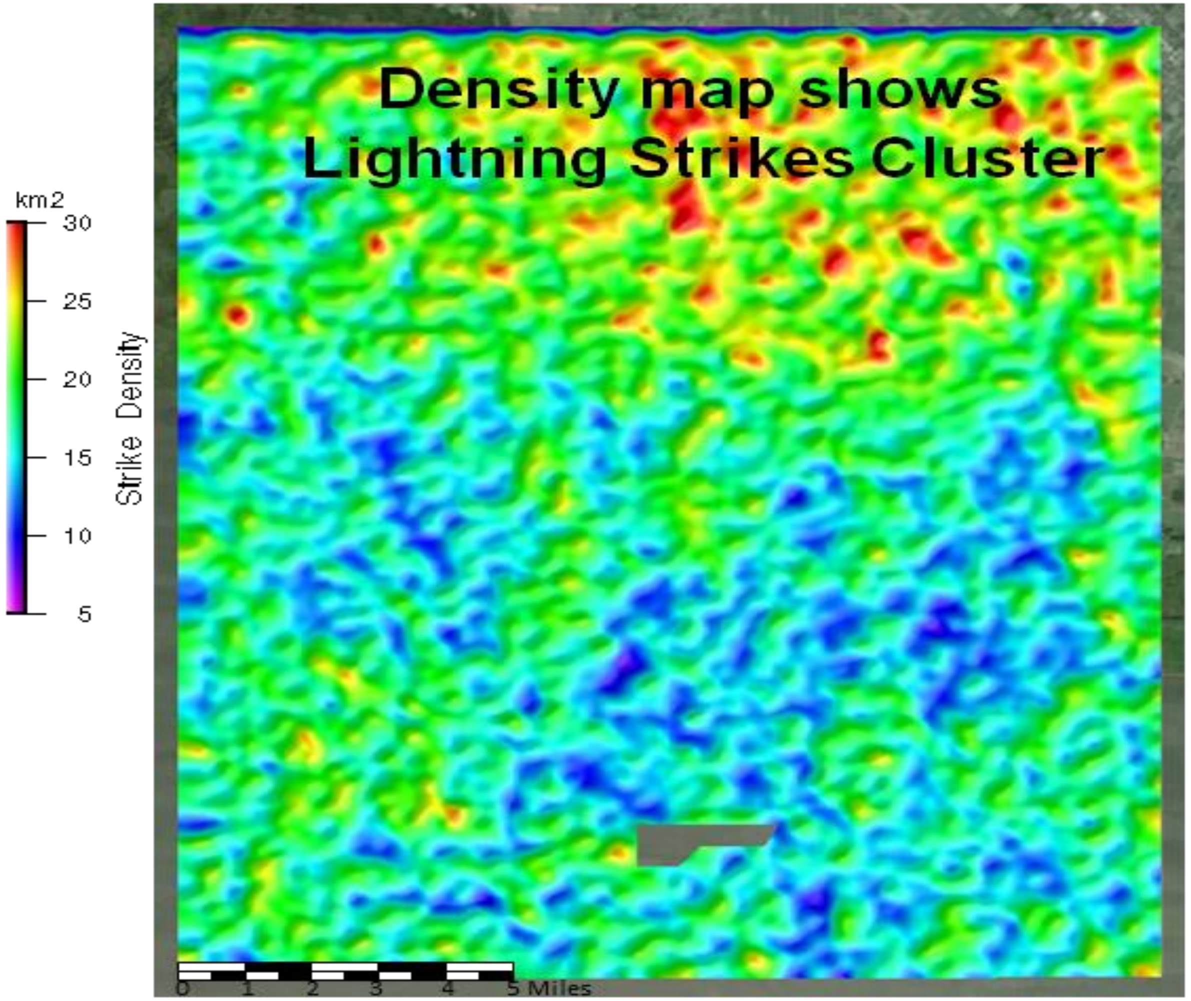
Interpolated NewMag® and Interpretation Overlay

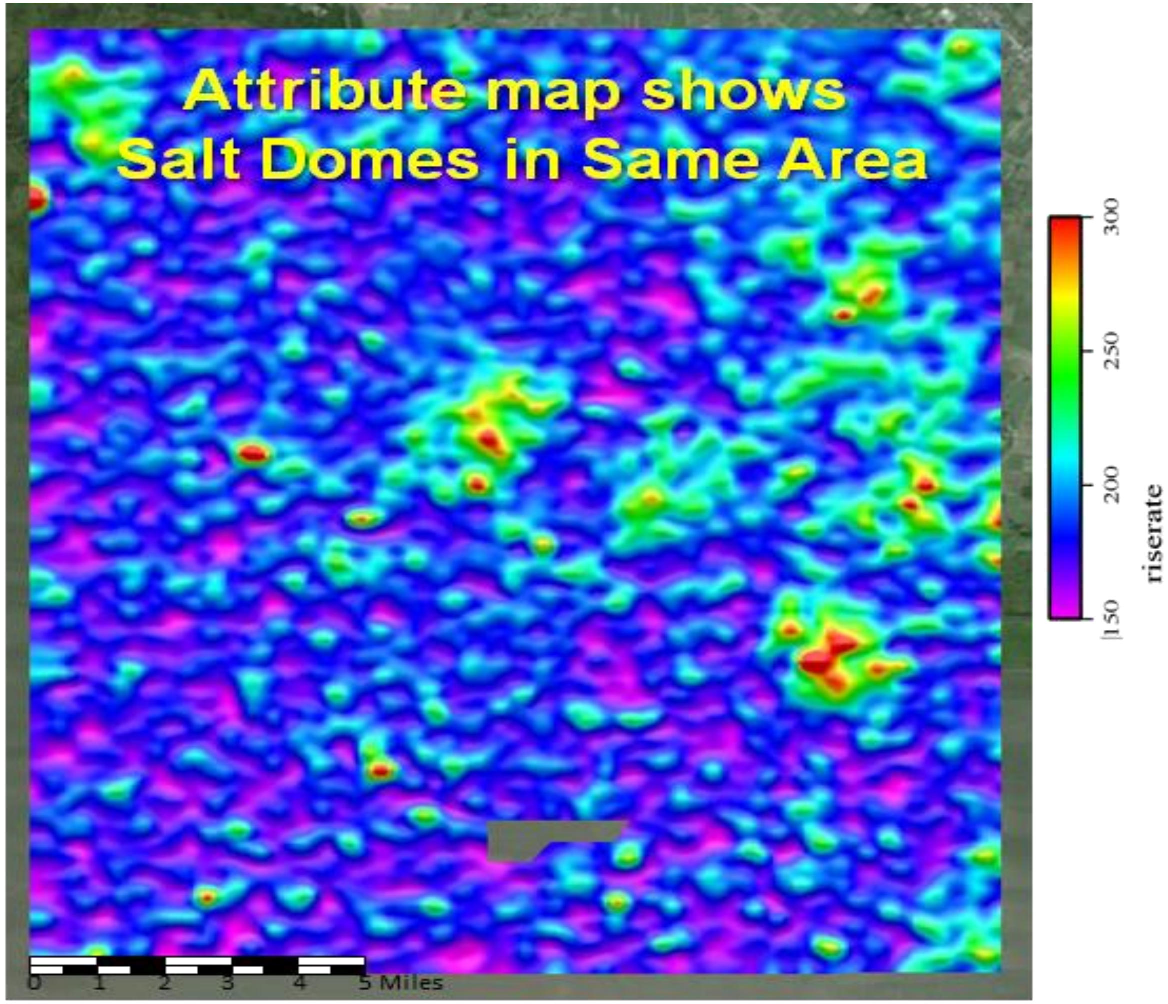
5. Steuben County, New York Example continued



Lightning Density Map and NewMag® Interpretation

5. Louisiana Example – salt domes

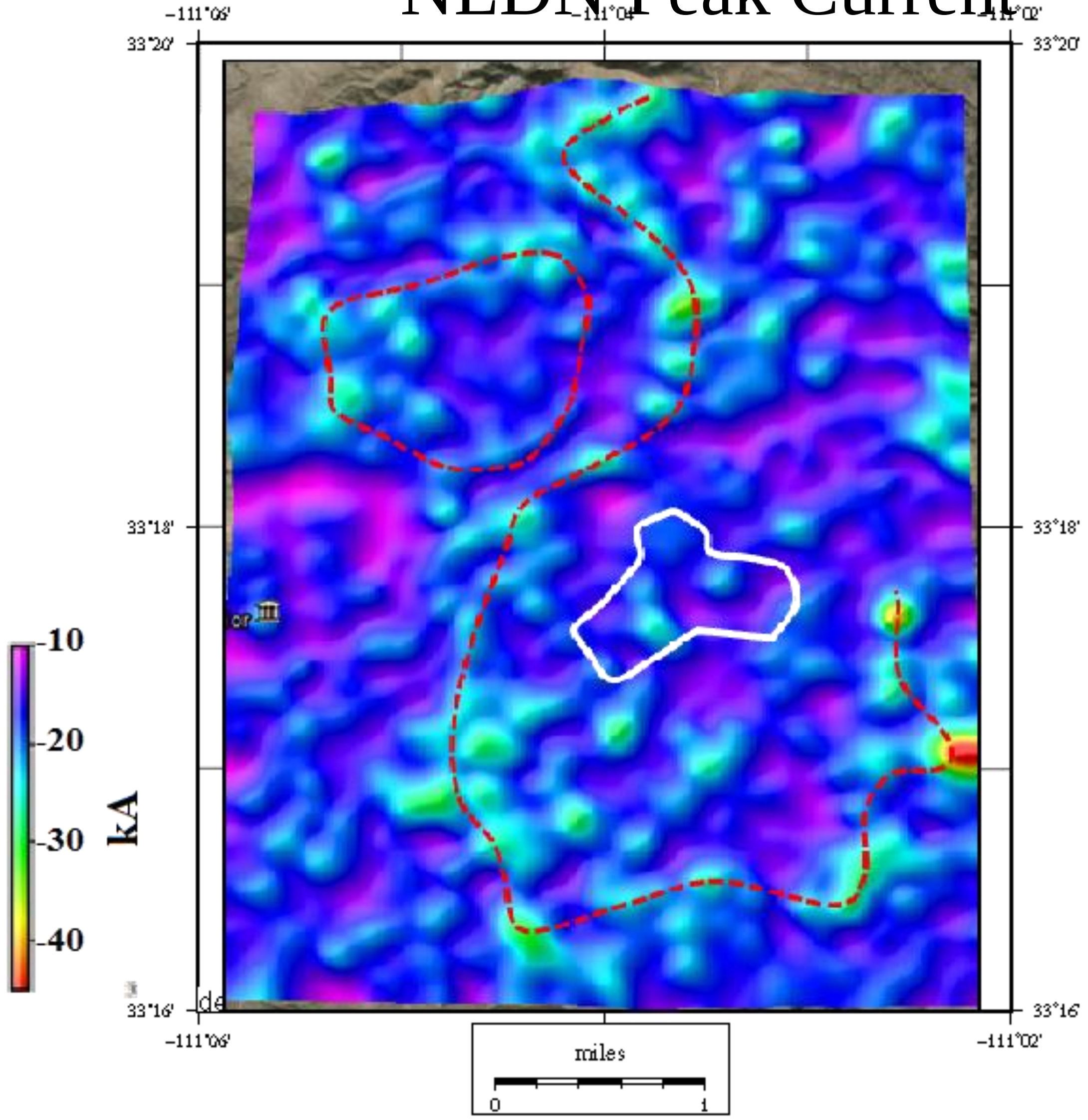


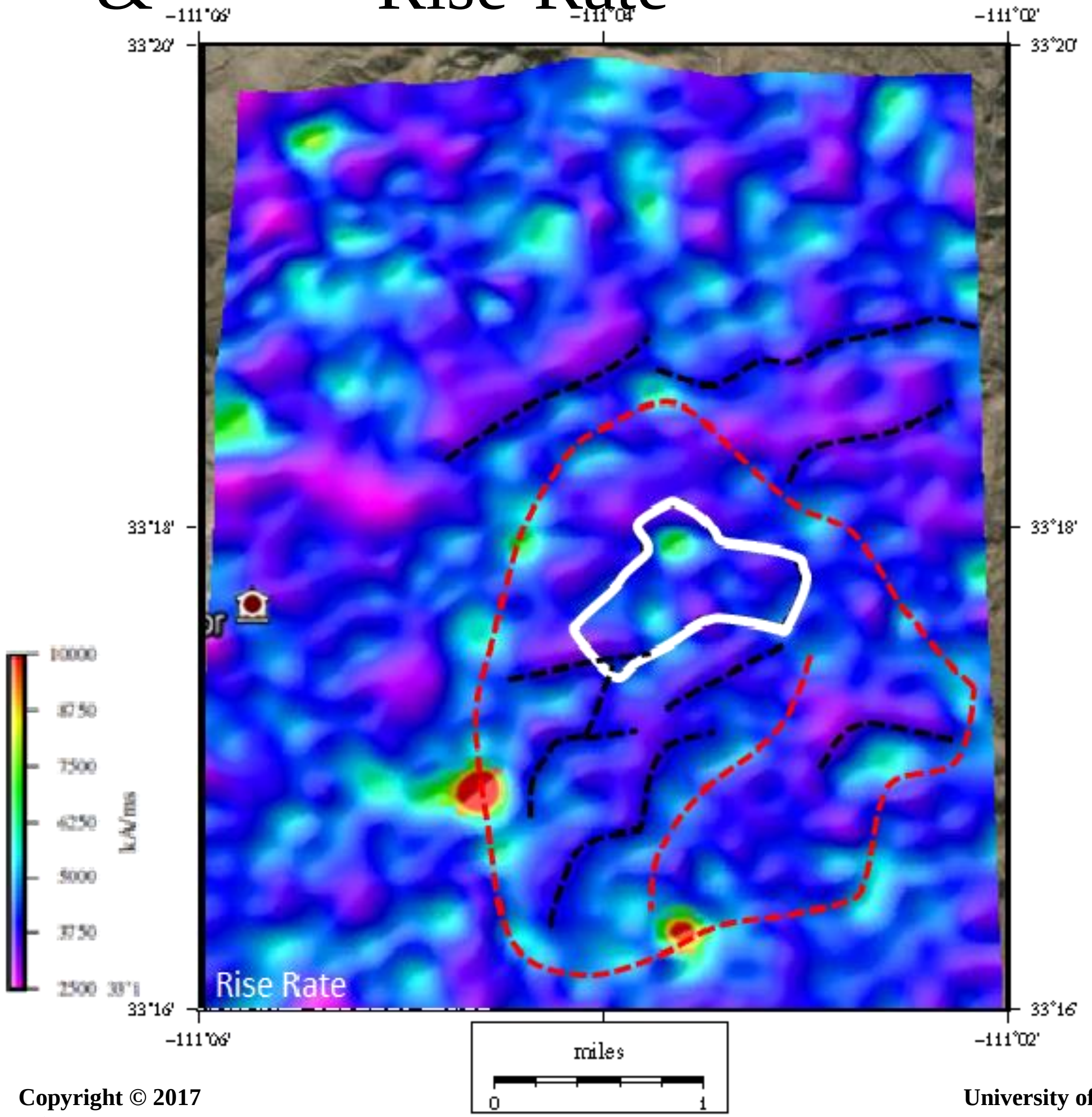


Density Map & Rate-of-Rise-Time Map

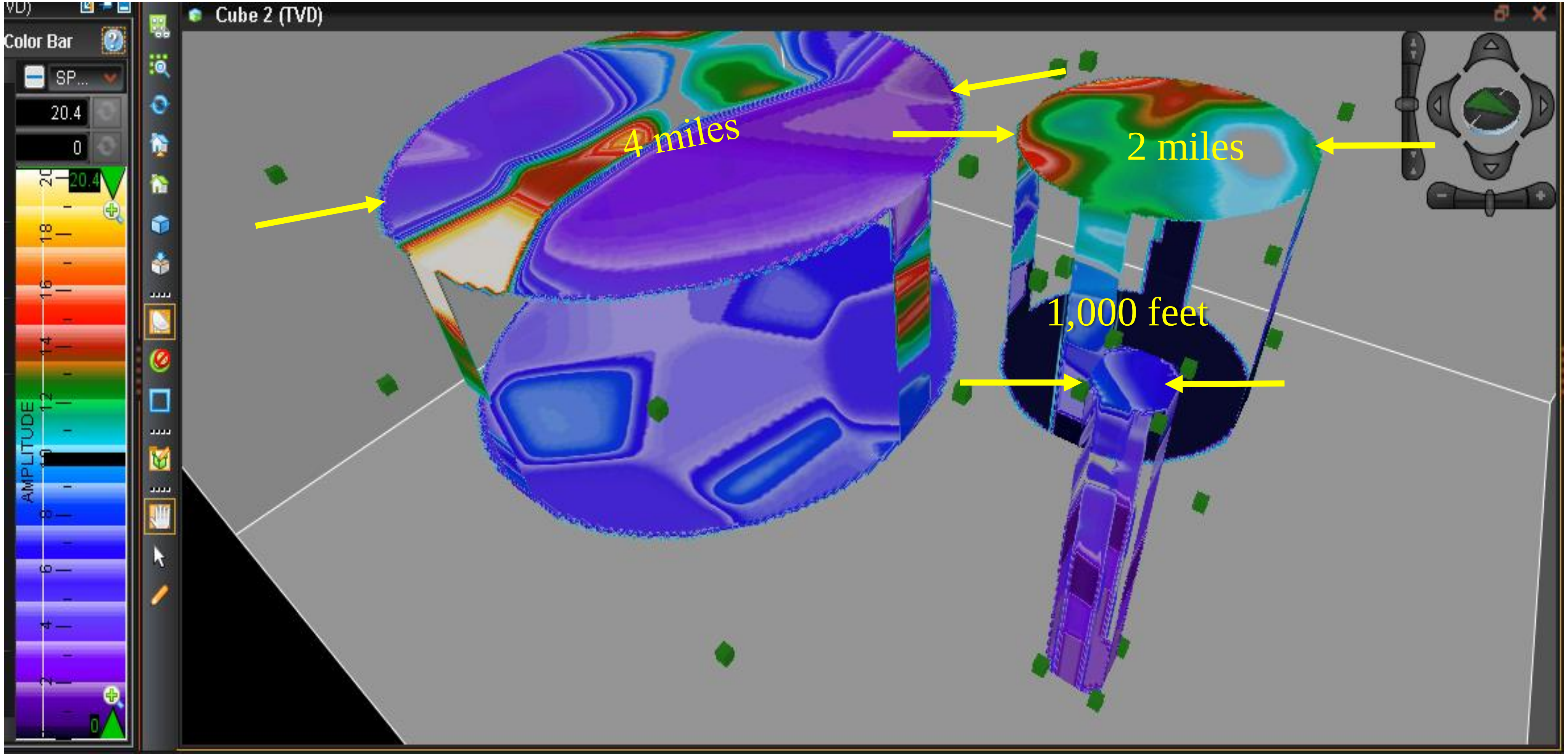
5. Arizona Example: Resolution Copper

NLDN Peak Current & Rise-Rate

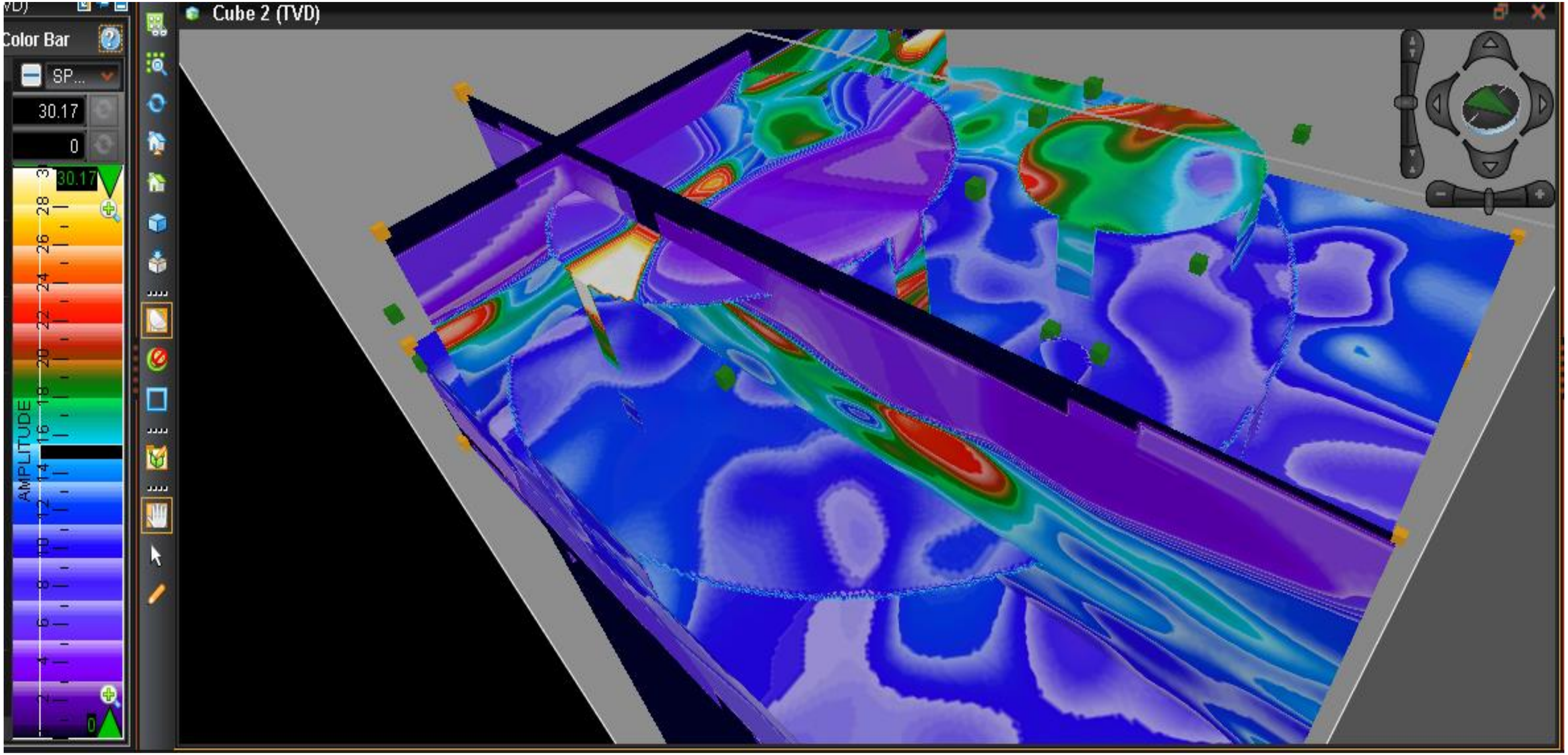




3 Example SPOT^{SM} Apparent-Resistivity Cylinders

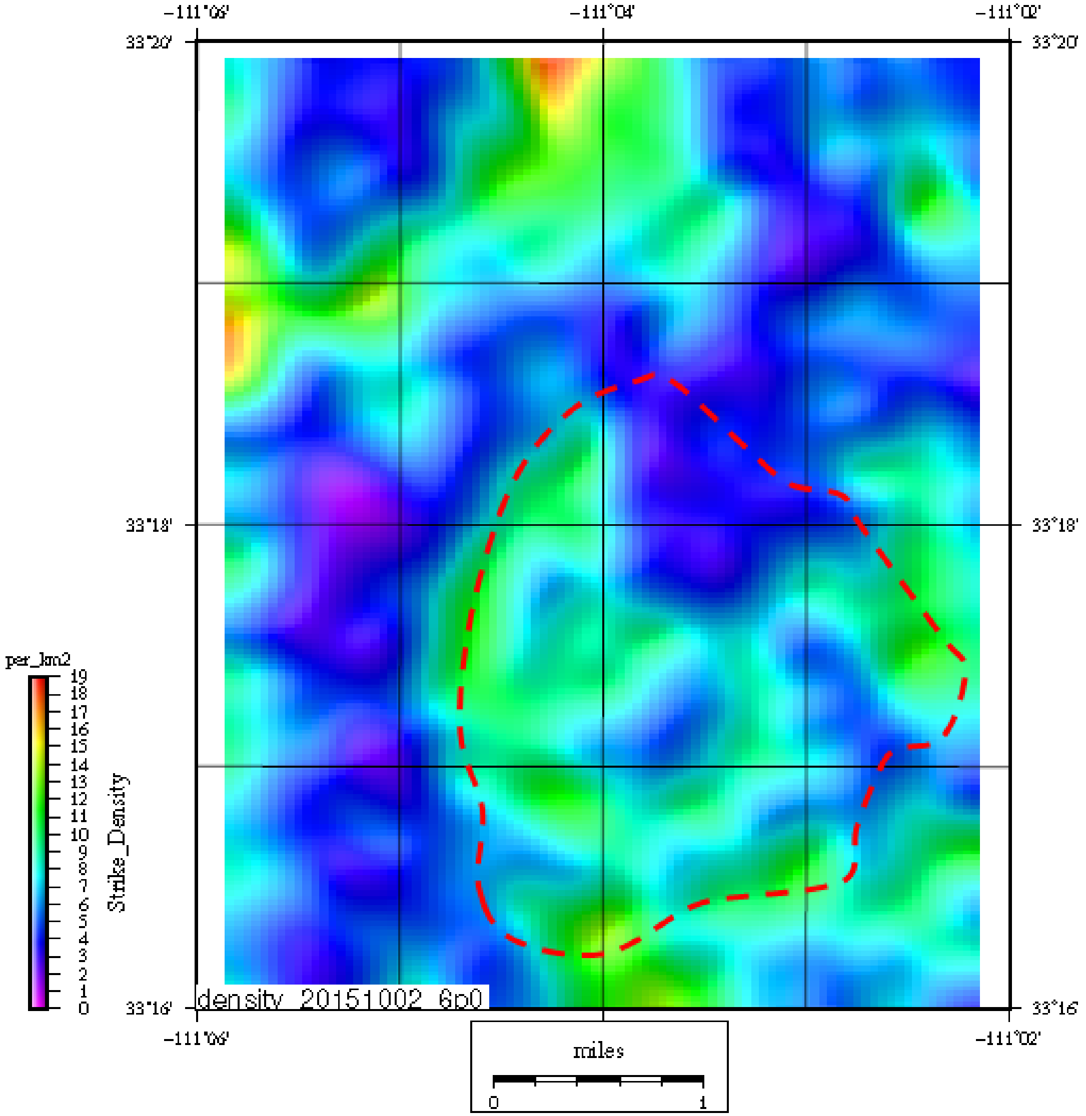


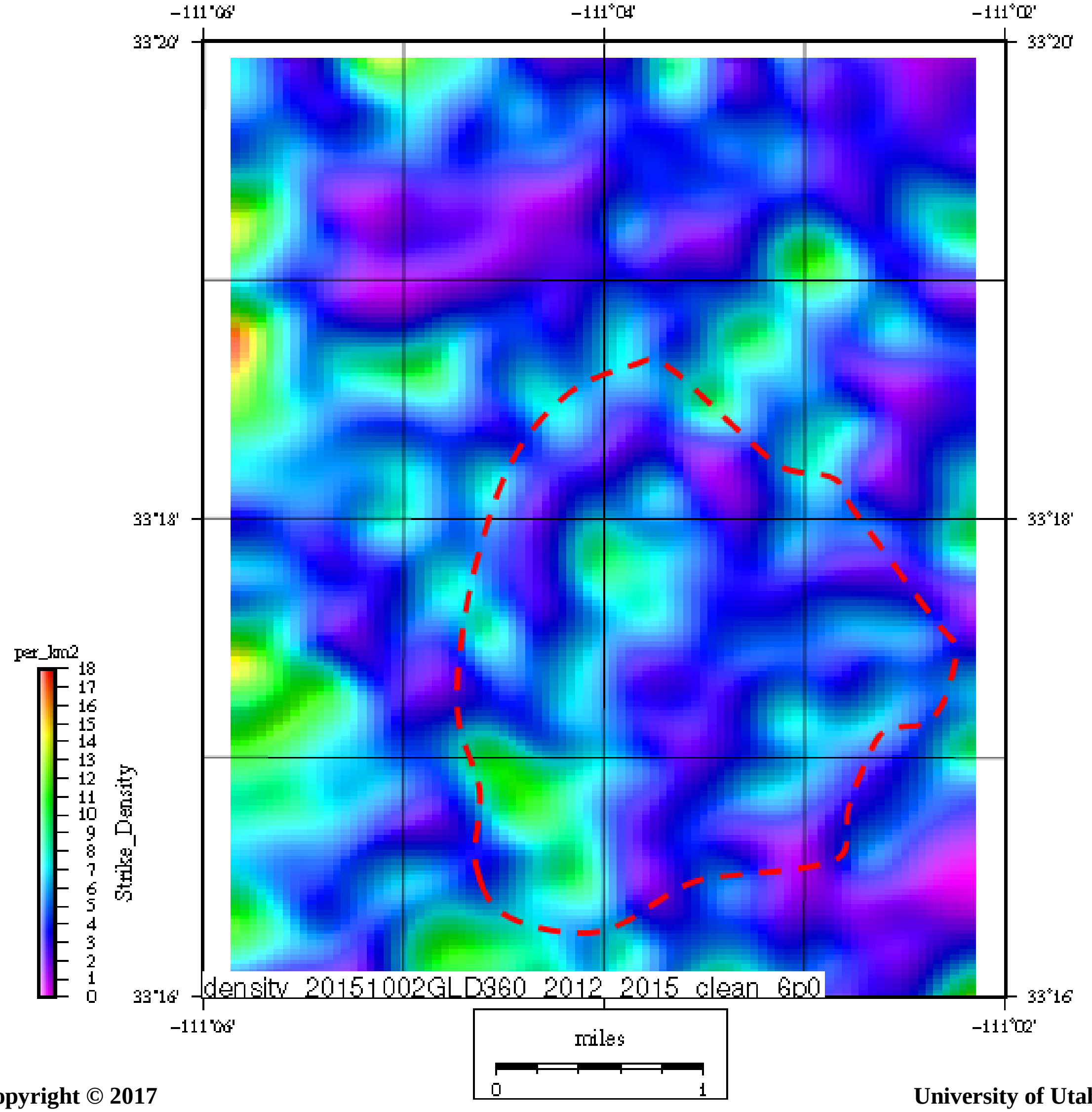
Integrating Resistivity in Three-Dimensions



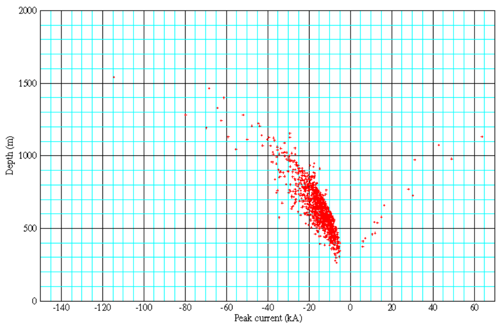
Comparing NLDN and GLD-360

NLDN Density 1998-2015 & GLD-360 Density 2012-2015





Resolution Copper Cross-Plots



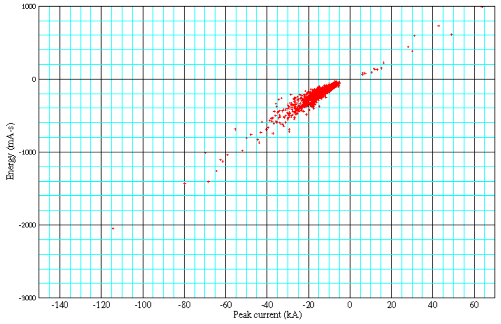
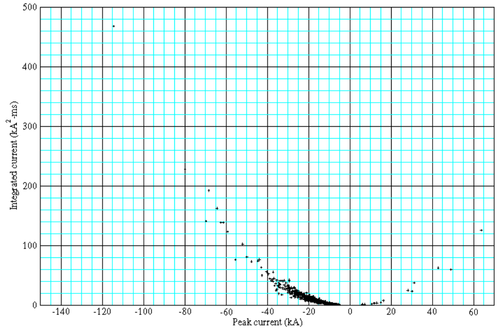


Figure 6: Peak current vs energy



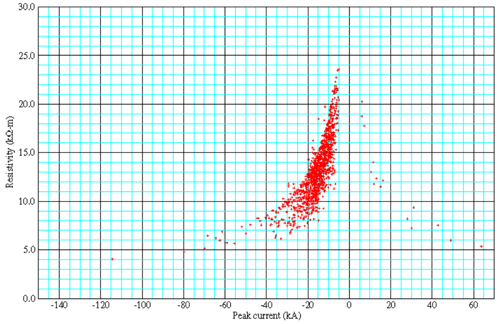


Figure 13: Peak current vs resistivity

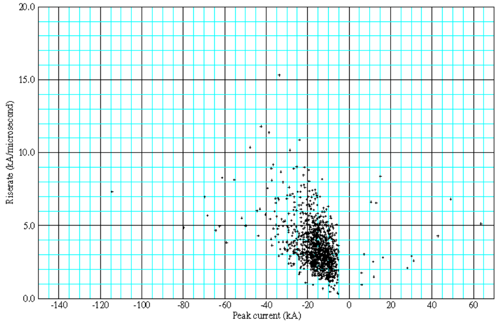


Figure 14: Peak current vs riserate

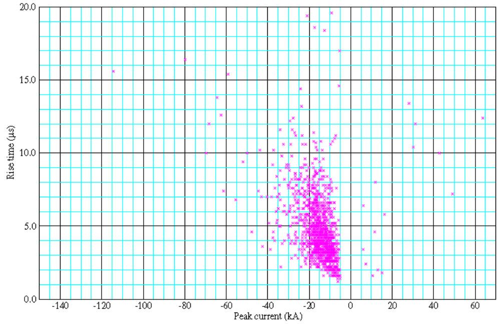


Figure 15: Peak current vs risetime

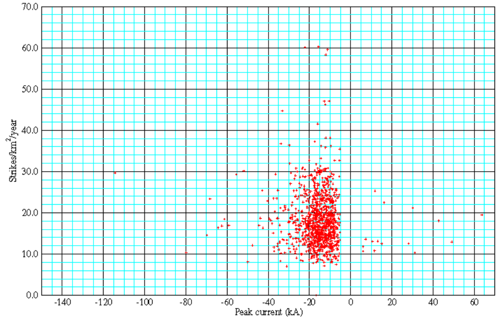


Figure 1: Peak current vs strike density

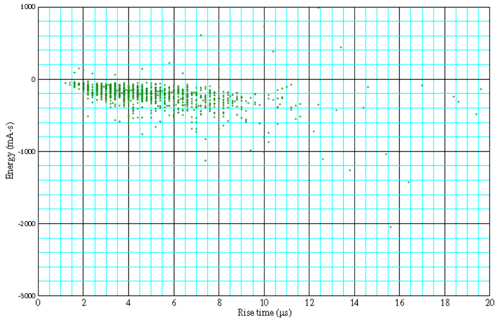


Figure 28: Rise time vs energy

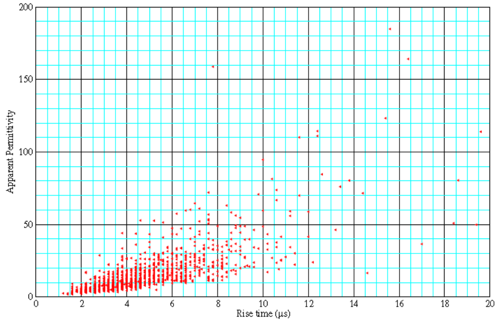


Figure 34: Rise time vs permittivity

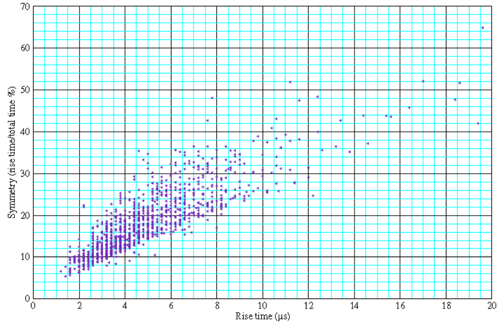


Figure 38: Rise time vs symmetry

Interns at Dynamic Measurement

Well received similar presentation at BYU & SMU
Dynamic is a start-up with only non-paid Interns

Intern Contributions:

- J. D. Shumway (BYU, graduated): liked the flexibility, represented Dynamic in our booths at 2015 AAPG in Denver, 2015 GCAGS in Houston, and fall 2016 DHI Consortium.
- Dustin Northrup (BYU): co-author on article submitted to The Leading Edge (being reworked) and paper submitted to 2017 AAPG
- Corbin Lewis (BYU): co-author on article submitted to The Leading Edge (being reworked) and paper submitted to 2017 AAPG
- Tucker Zukowski (SMU): exploring opportunities, looking at tying heat flow study to California gold exploration project

J.D., Dustin, and Corbin each have lightning analysis projects they have worked on where they used Landmark's DecisionSpace™ software to interpret lightning analysis projects

Summary

- Dynamic Measurement has made a lot of progress in understanding lightning data analysis since last presenting at the U, 2 1/3rd years ago.
- Dynamic has demonstrated the ability to map faults, and to create geo-frameworks in a variety of geological environments.
- As with the development of any new geophysical data type, there is much more to be discovered about approach strengths and weaknesses.
- There is an opportunity to develop the mathematics to (see Appendix):
  - correct for topography and remove topographic distortions;
  - define the electromagnetic fields around a lightning stroke path;
  - optimally stacking and interpolating lightning derived volumes using kriging;
  - model the telluric electrical fields controlling lightning strike locations; and
  - many other basics tied to this new geophysical data type.
- Dynamic is interested in providing interesting projects for Interns.

Acknowledgements:

- Les Denham, DML Chief Geophysicist.
- Kathy Haggar, DML Geologist.
- Louie Berent, DML Geophysicist.
- BYU Interns Dustin Northrop and R. Corbin Lewis.
- Tom Ewing (BEG) for regional South Texas geology.
- Bob Hardage & Ray Levy (BEG) for Stratton seismic survey.
- Andrea Nelson, my wife, for enduring the startup phase.

This presentation can be downloaded from:
http://www.dynamicmeasurement.com/TAMU/170303_Lightning_Analysis_geo-frameworks.pdf
Or with the appendix from:
http://www.dynamicmeasurement.com/TAMU/170303_Lightning_Analysis_geo-frameworks_for_Interns.pdf

Thank You!

- H. Roice Nelson, Jr., Geophysicist

  cell: 713.542.2207

  e-mail: roice@dynamicmeasurement.com

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  Barker, TX 77413
  - Office: 281.579.0172
- 2155 West 700 South #31
  Cedar City, UT 84720
  - Fax: 435.267.2668

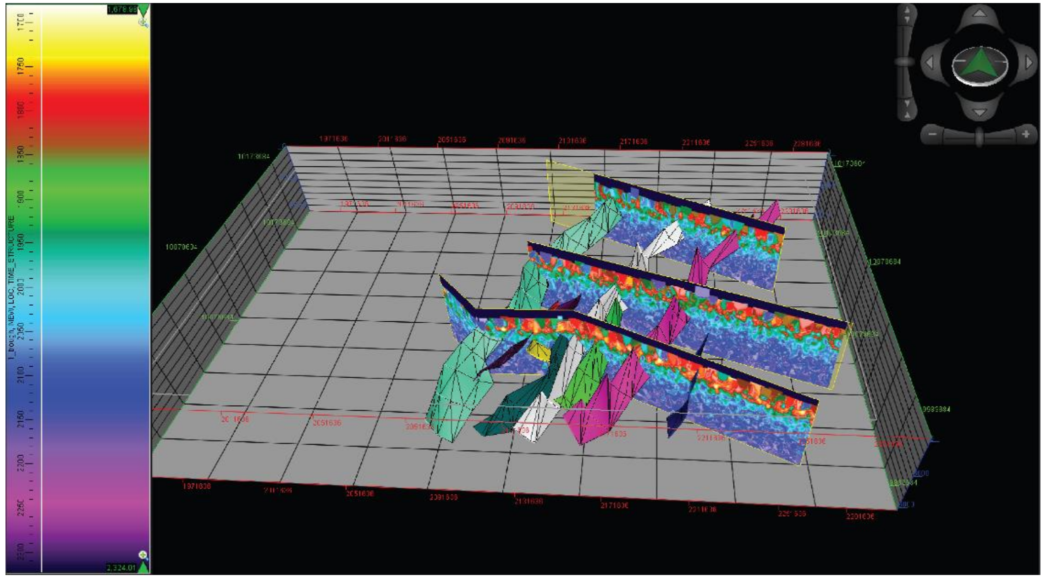
Appendix

Abstract – Lightning Analysis: creating geo-frameworks

03 March 2017, 12:00-1:00 PM in the Department of Geology and Geophysics Building, FASB 295, H. Roice Nelson, Jr., a geophysicist with a B.S. Geophysics from the University of Utah (1974), and over 45 years experience in oil, gas, and mineral exploration, will speak on work with lightning databases, demonstrating how the newly patented method for determining surface and subsurface resistivity enables the creation of geo-frameworks anyplace for a variety of exploration and infrastructure applications.

Geophysicists have used passive gravity, magnetic, and seismic measurements to understand the subsurface of the earth for decades. Dynamic Measurement has expanded these capabilities, developing and patenting ways to data mine electrical information in existing lightning strike databases to map faults, creating geo-frameworks of subsurface geology anyplace onshore and out to at least 100 meter (330 foot) water depths.

This presentation will review Dynamic's lightning technologies, and show examples from lightning analysis projects in Texas, New York, Louisiana, and Arizona. The focus will be how this new geophysical data type allows the creation of geo-frameworks, and will outline research opportunities for Interns to take advantage of as part of their earth science educational program.



Dynamic Measurement LLC Patent 1

US008344721B2

(12) **United States Patent**
Nelson, Jr. et al.

(10) **Patent No.:** **US 8,344,721 B2**
(45) **Date of Patent:** **Jan. 1, 2013**

(54) **METHOD FOR LOCATING SUB-SURFACE NATURAL RESOURCES**

(75) Inventors: **H. Roice Nelson, Jr.**, Houston, TX (US); **Joseph H. Roberts**, Houston, TX (US); **D. James Siebert**, Katy, TX (US); **Wulf F. Massell**, Conroe, TX (US); **Samuel D. LeRoy**, Houston, TX (US); **Leslie R. Denham**, Houston, TX (US); **Robert Ehrlich**, Salt Lake City, UT (US); **Richard L. Coons**, Katy, TX (US)

(73) Assignee: **Vaisala Oyj**, Helsinki (FI)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 391 days.

(21) Appl. No.: **12/655,810**

(22) Filed: **Jan. 7, 2010**

(65) **Prior Publication Data**

US 2011/0163733 A1 Jul. 7, 2011

(51) **Int. Cl.**
G01R 31/02 (2006.01)
G01N 27/00 (2006.01)
G01W 1/00 (2006.01)

(52) **U.S. Cl.** **324/72**; 324/71.1; 702/4

(58) **Field of Classification Search** 324/72, 324/71.1; 702/4

See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

5,417,282 A *	5/1995	Nix	....	166/248
2010/0023267 A1*	1/2010	Karabin et al.	....	702/4

* cited by examiner

Primary Examiner — Amy He
(74) *Attorney, Agent, or Firm* — Portland Intellectual Property, LLC

(57) **ABSTRACT**

A method for locating sub-surface natural resources. The method utilizes lightning data to discern relatively likely locations for finding the sub-surface natural resources.

16 Claims, 8 Drawing Sheets

Natural Resources defined as:

- Diamonds;
- Other Gemstones;
- Gold;
- Silver;
- Copper;
- Other Minerals;
- Geothermal Deposits;
- Oil;
- Gas;
- Water;
- Other sub-surface natural resources sharing inherent similarities.

Dynamic Measurement LLC Patent 2

US009523785B2

(12) **United States Patent**
Denham et al.

(10) **Patent No.:** **US 9,523,785 B2**
(45) **Date of Patent:** **Dec. 20, 2016**

(54) **METHOD FOR DETERMINING GEOLOGICAL SURFACE AND SUBSURFACE RESISTIVITY**

(71) Applicant: **Dynamic Measurement, LLC**, Cedar City, UT (US)

(72) Inventors: **L. R. Denham**, Houston, TX (US); **H. Roice Nelson, Jr.**, Cedar City, UT (US); **D. James Siebert**, Katy, TX (US)

(73) Assignee: **Dynamic Measurement, LLC**

(57) **ABSTRACT**

A method for determining geological subsurface resistivity. The method includes obtaining a set of lightning parameters associated with a lighting strike received by a geological volume of material, the set of lightning parameters including an indicium of the current of the lightning strike at a first initial time and an indicium of the current of the lightning strike at a first decay time subsequent to the first initial time, and inferring the resistance of the volume of geological material, at least in part, from the set of lightning parameters.

6 Claims, 2 Drawing Sheets

Es Xplore Electroseis Technology Summary

- ES Xplore awarded 11 patents on this technology.
- The earth's atmosphere is a source of EM pulses, e.g. lightning.
- Some horizontally polarized energy rotated to vertical fields as it crosses the boundary between the Earth's surface and the atmosphere.
- "Mode Rotation" is detected at the surface by an EM sensor.
- Horizontal current is attenuated by high horizontal electrical conductivity, while the vertical current passes only weakly attenuated.
- After current is redirected by many inhomogeneities, only the vertical current and the electric field remain ad depths greater than skin depth.
- Electric field rotation can be modeled using known anisotropic electrical properties of the subsurface, an inhomogeneous resistor network.
- At depth, vertical electrical fields interact with hydrocarbon reservoirs, where part its energy is converted though the electroseismic effect into a seismic wave.

Es Xplore Electroseismic Technology continued

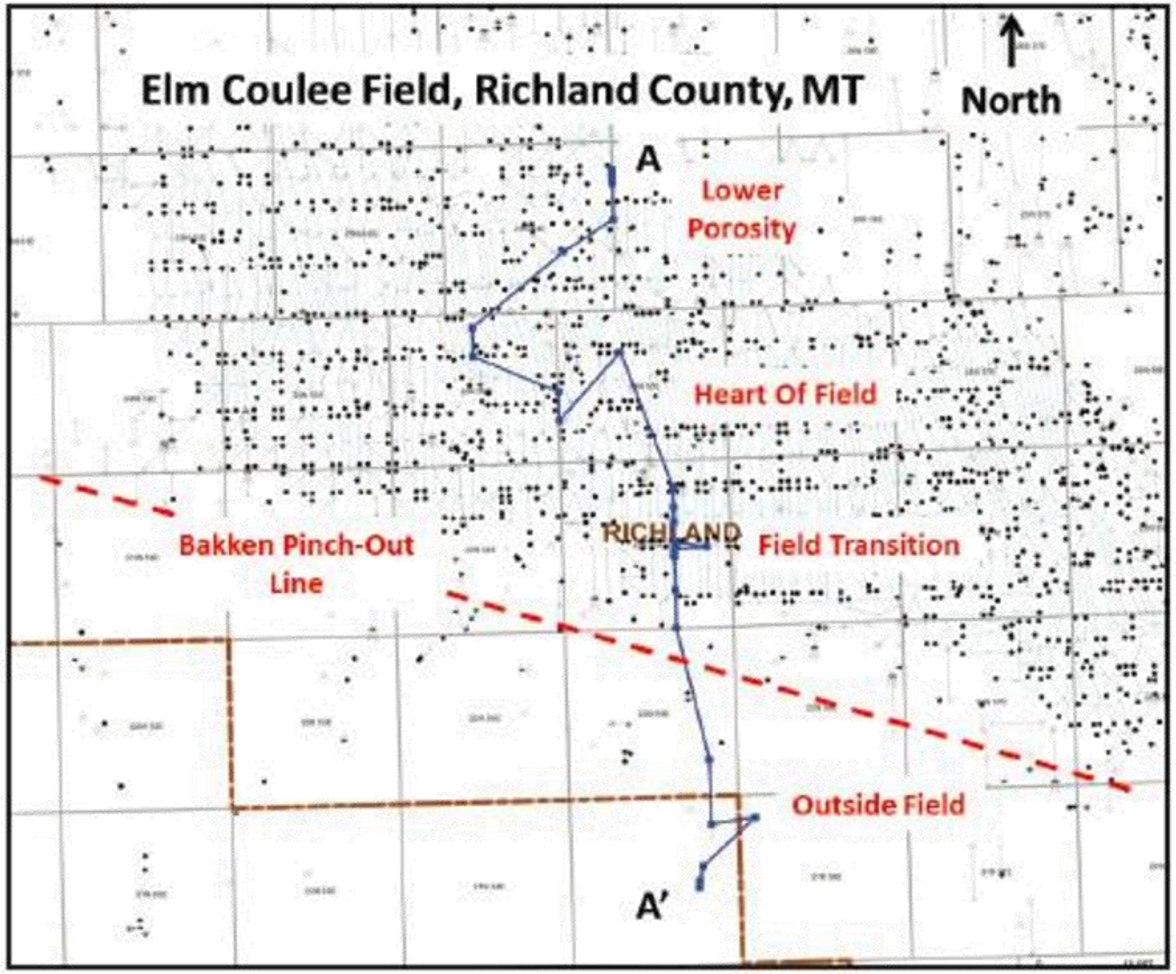


FIGURE 2a. This figure illustrates a well-defined Bakken pinchout line to the south of the field. The field's porosity decreases to the north of the field center. (Source: ES Xplore)

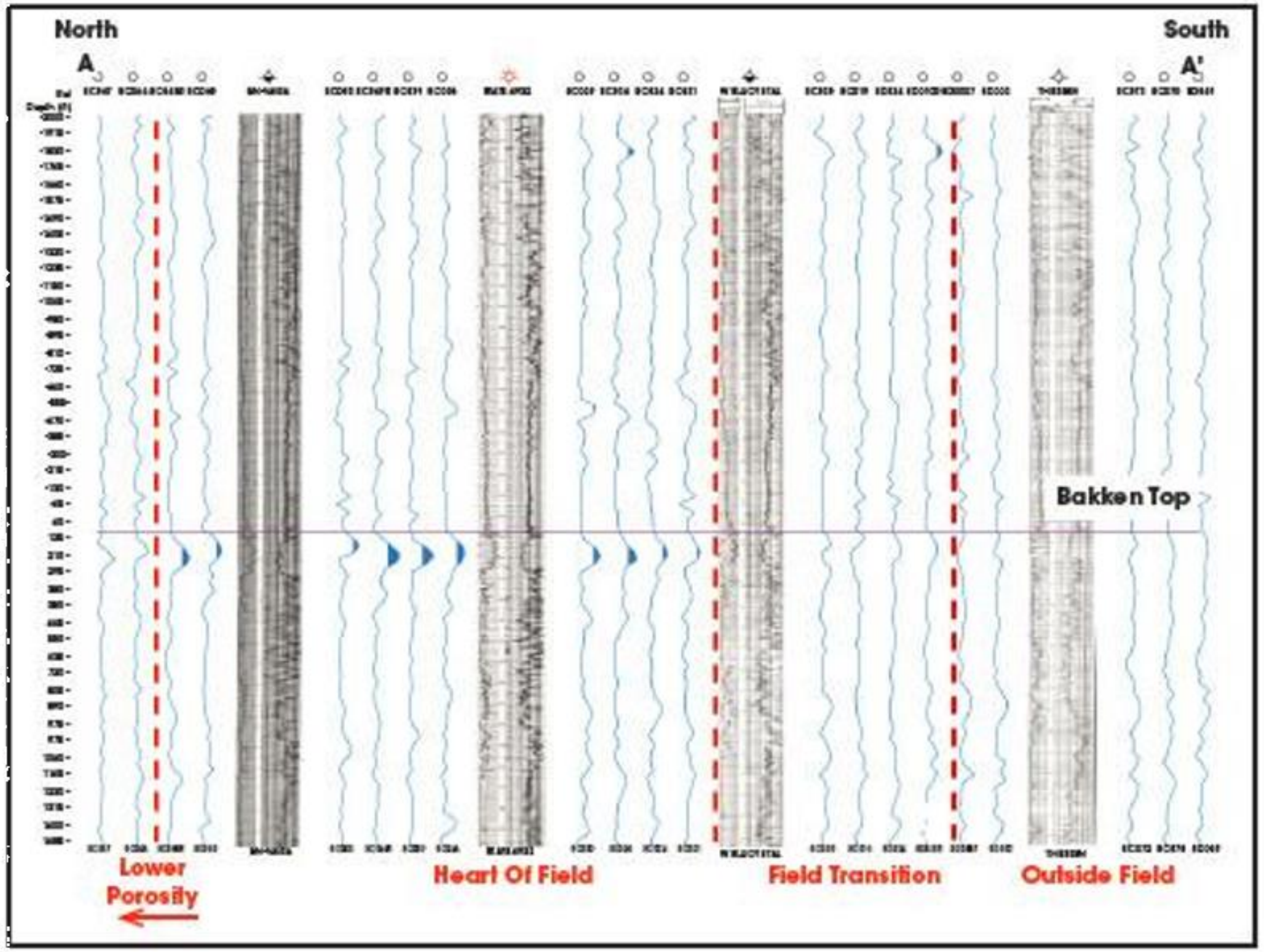


FIGURE 2b. This figure shows a cross section of results displayed in stratigraphic log form, with depth along the vertical axis. The magnitude of the log deflection is related to the amplitude of the electroseismic response at that depth. (Source: ES Xplore)

http://www.epmag.com/promise-electroseismic-technology-1461136#p=full

Stress-Induced Changes of Electrical Rock Properties

- Creation of dormant charge carriers.
- Localized electrical currents generated.
- Provides reservoir of positive & negatively charged particles.
- Streamers capable of influencing lightning.

Conductivity of dry granite increases with uniaxial stress.

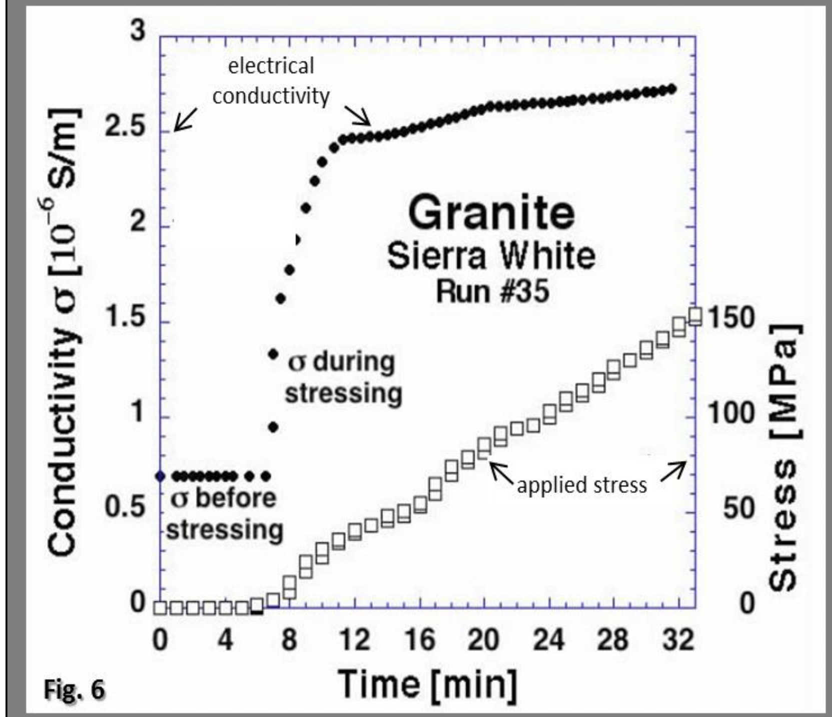


Fig. 6

Surface potential of gabbro increases with stress, initially strongly positive then weakly negative.

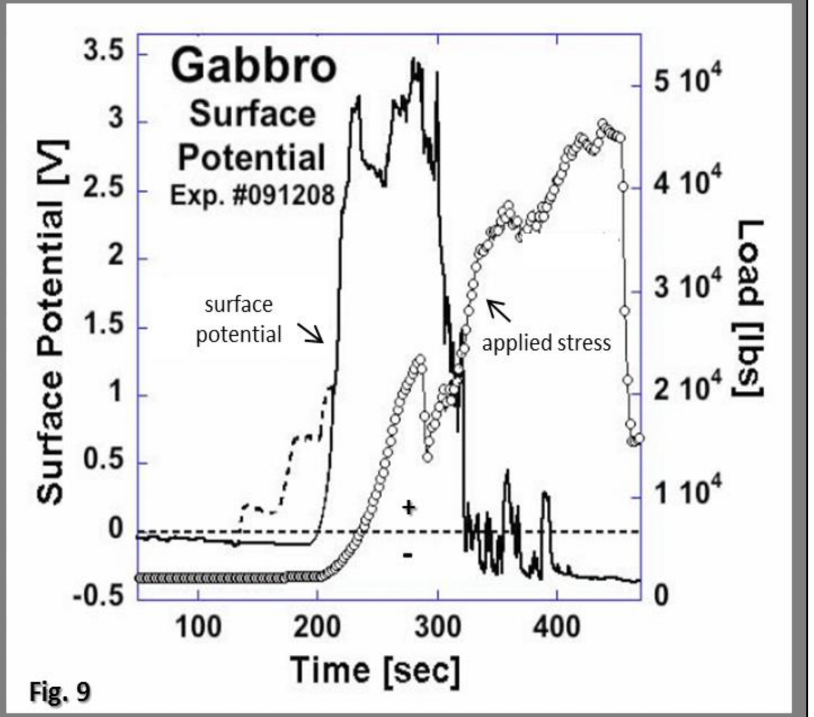


Fig. 9

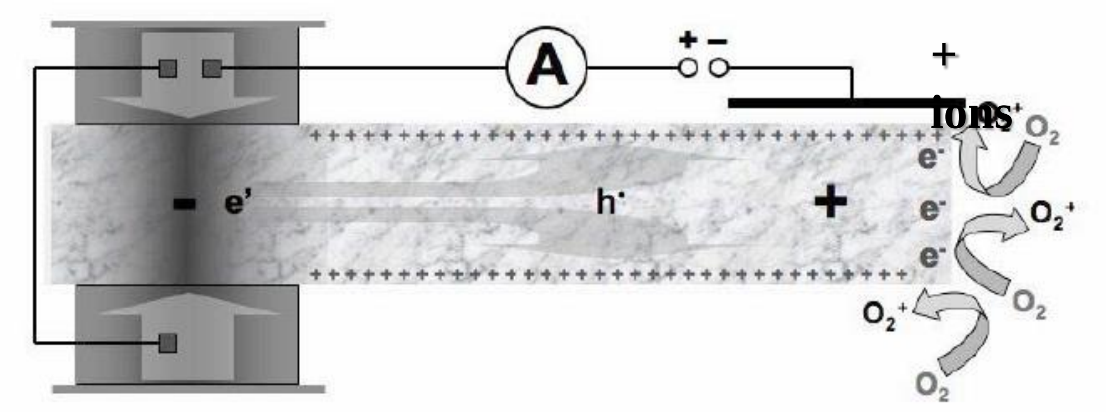
Above figures modified from F. Freund, "Toward a unified solid state theory for pre-earthquake Signals," Acta Geophysica - October 2010, DOI: 10.2478/s11600-009-0066-x . * From F. Freund's rock stress-EM signal theory.

* Recent studies by F. Freund suggest that stress-induced increases in conductivity and the generation of both positive and negative currents and surface potential, are not solely influenced by improved grain-to-grain contacts.

* It is likely that changes in electrical rock properties are caused by an increase in the number of electrons, negative ions and positive hole charge carriers produced when rock volumes are stressed.

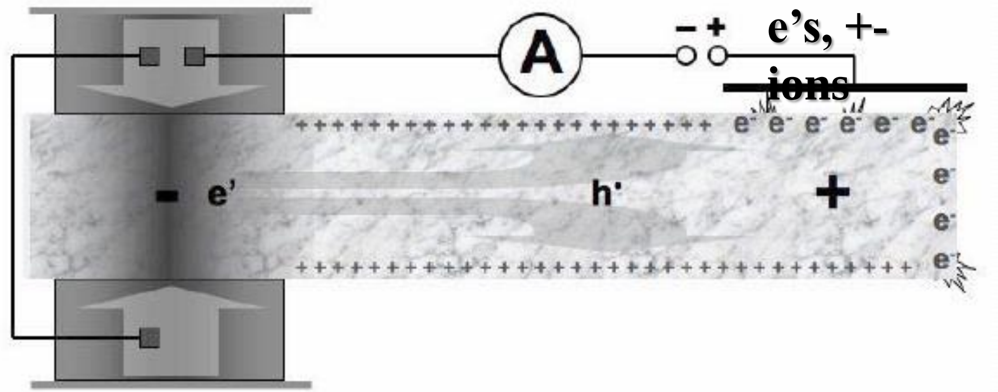
Field Ionization of Air Molecules

Faults & lateral variation in electrical rock properties due to hydrocarbons, pore fluid and salinity variations for example, can produce localized pos./neg. electric currents that can ionize air molecules and supply streamers to attract step-leaders during storms.



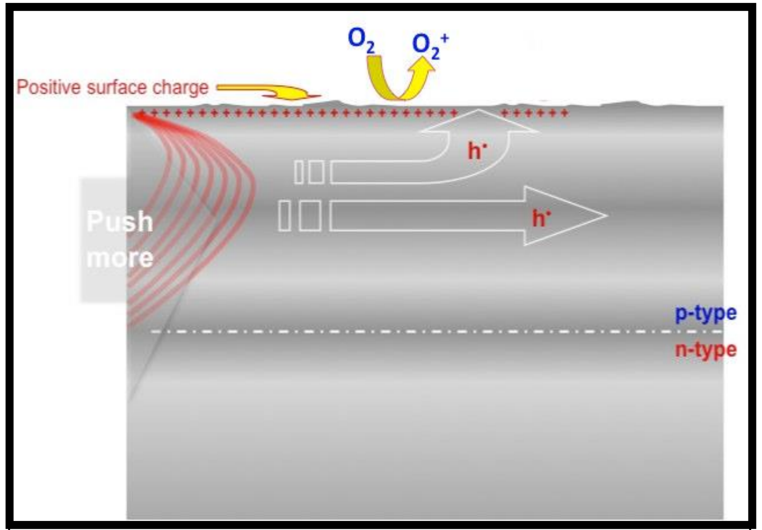
Lab set-up demonstrates how air molecules (O_{2})) , are ionized when rock samples are stressed, resulting in airborne positive ions capable of forming into streamers during thunderstorms. These supplies of positive ions would attract negative lightning strikes

Dr. Friedemann Freund, NASA Ames Res. Ctr. , Mountain View, CA; Dept. of Physics, San Jose State Univ. San Jose, CA

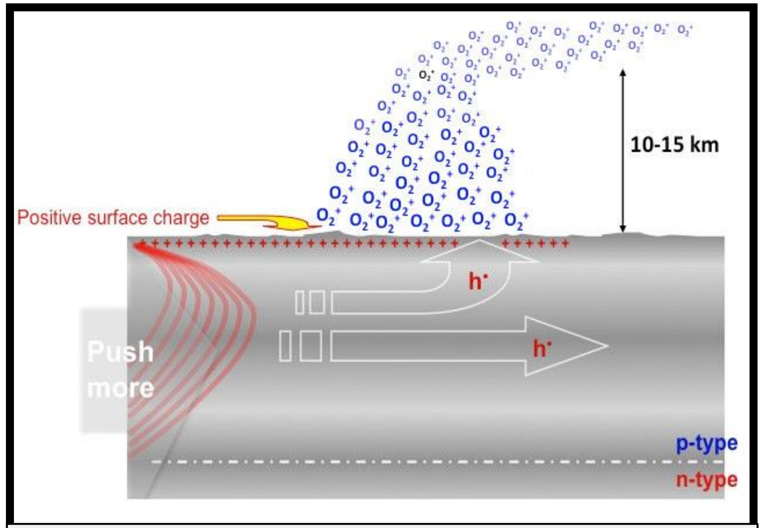


"When electric fields at the rock surface increase sufficiently, electrons can accelerate to cause impact-ionization of neutral gas molecules, triggering corona discharges (depicted as small flashes at the rock surface). This produces free electrons and negative & positive airborne ions." These currents could supply streamers for both positive and negative lightning strikes respectively.

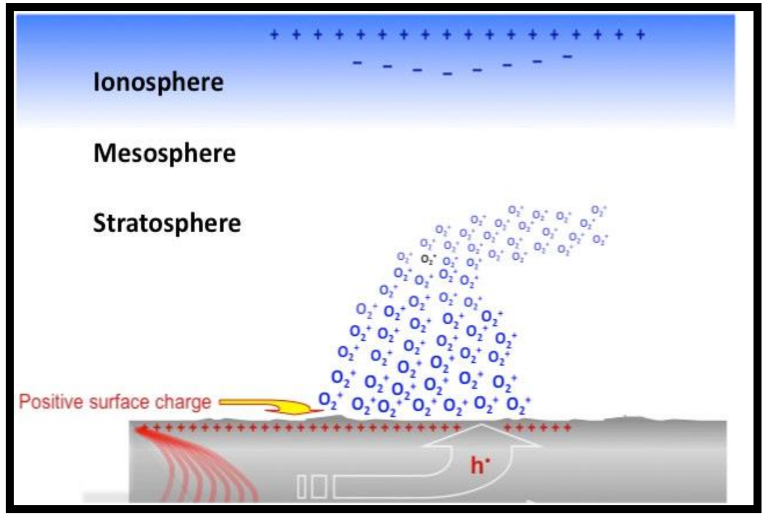
Air Ionization



Laboratory studies of air ionization at the rock-air interface & field observations of bursts of high air ion concentrations, suggest a mechanism for how bottom-up electromagnetic coupling between the Earth & the ionosphere occurs.

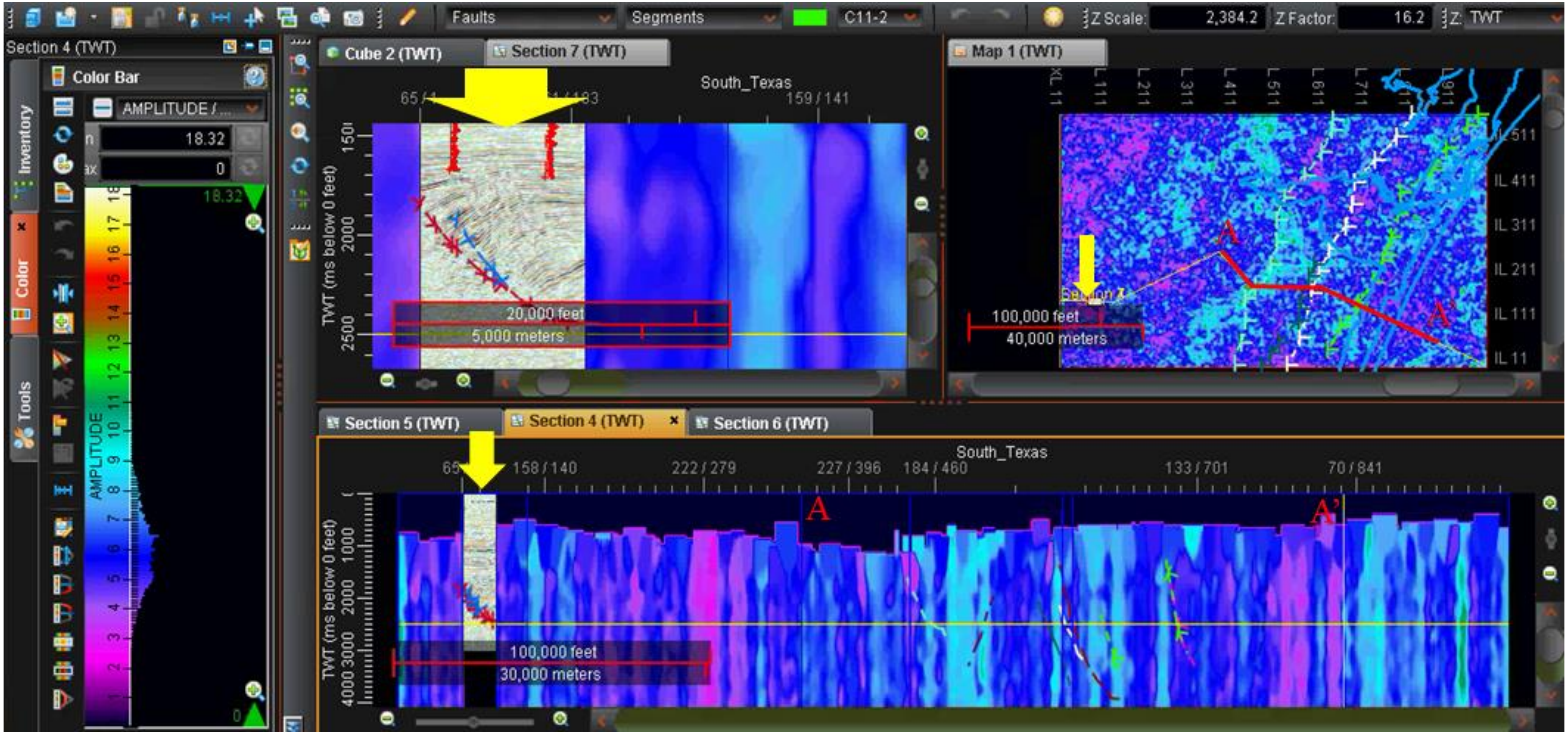


As stresses build up deep in the crust, positive hole charge carriers arrive at the Earth surface in ever larger numbers.



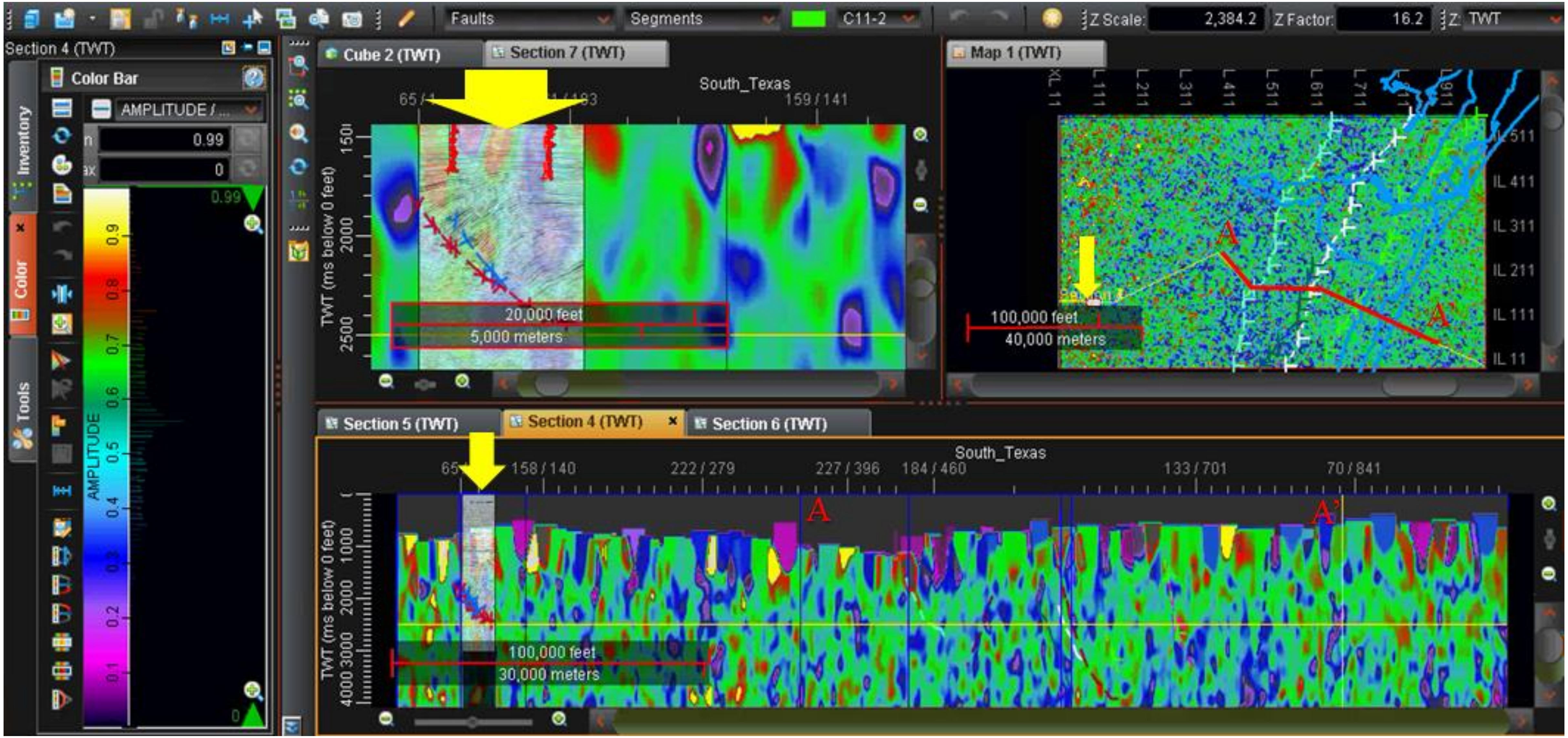
The positive holes cause the air at the ground-to-air interface to become ionized, generating positive ions. Air laden with positive ions expands upward to the stratosphere, dragging along Earth ground potential, changing the vertical electric field.

10 of 18 Lightning Attributes - Density



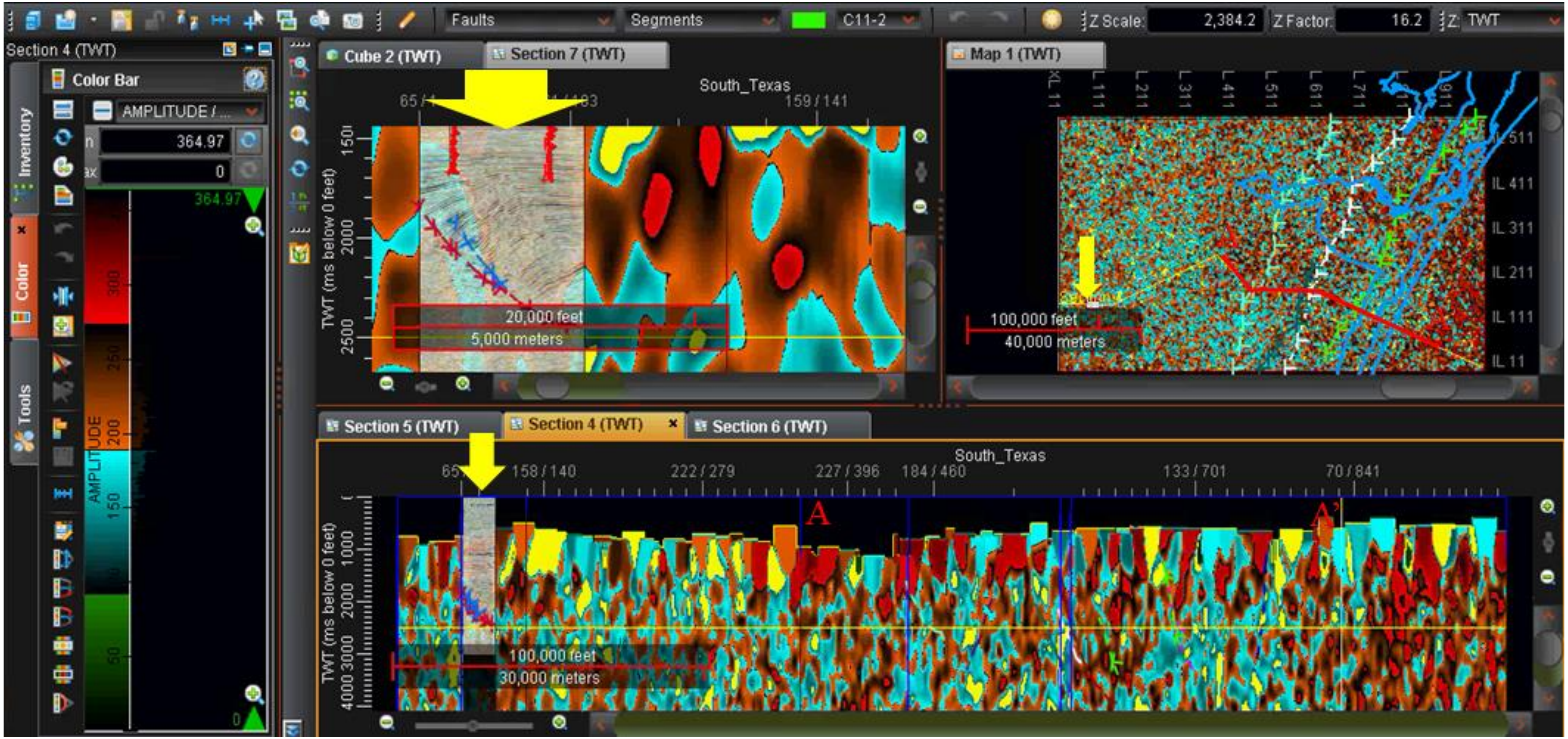
(Strikes per square kilometer)

11 of 18 Lightning Attributes - Day of Year



(Decimal fraction calendar year)

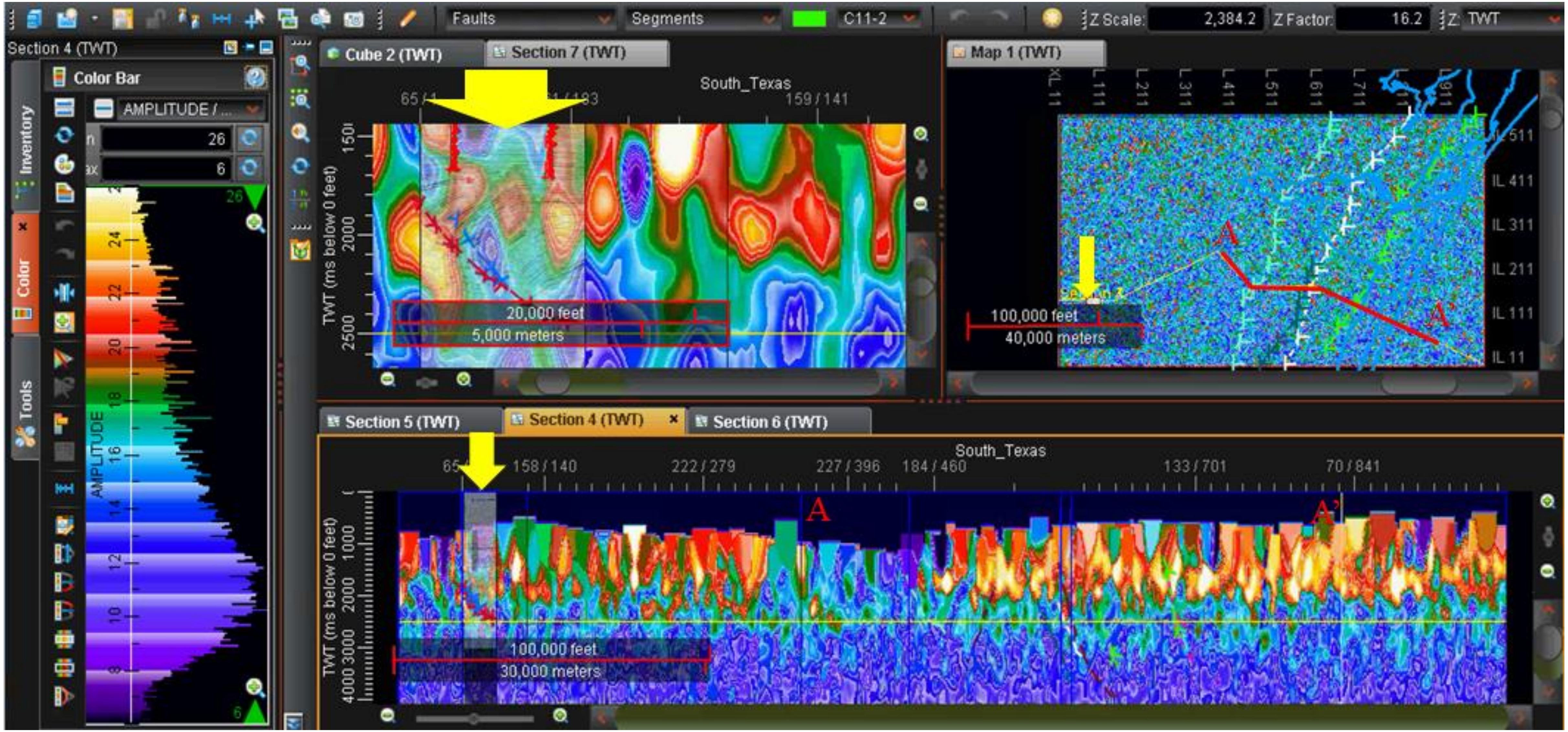
12 of 18 Lightning Attributes - Moon Phase



(degrees [0-360])

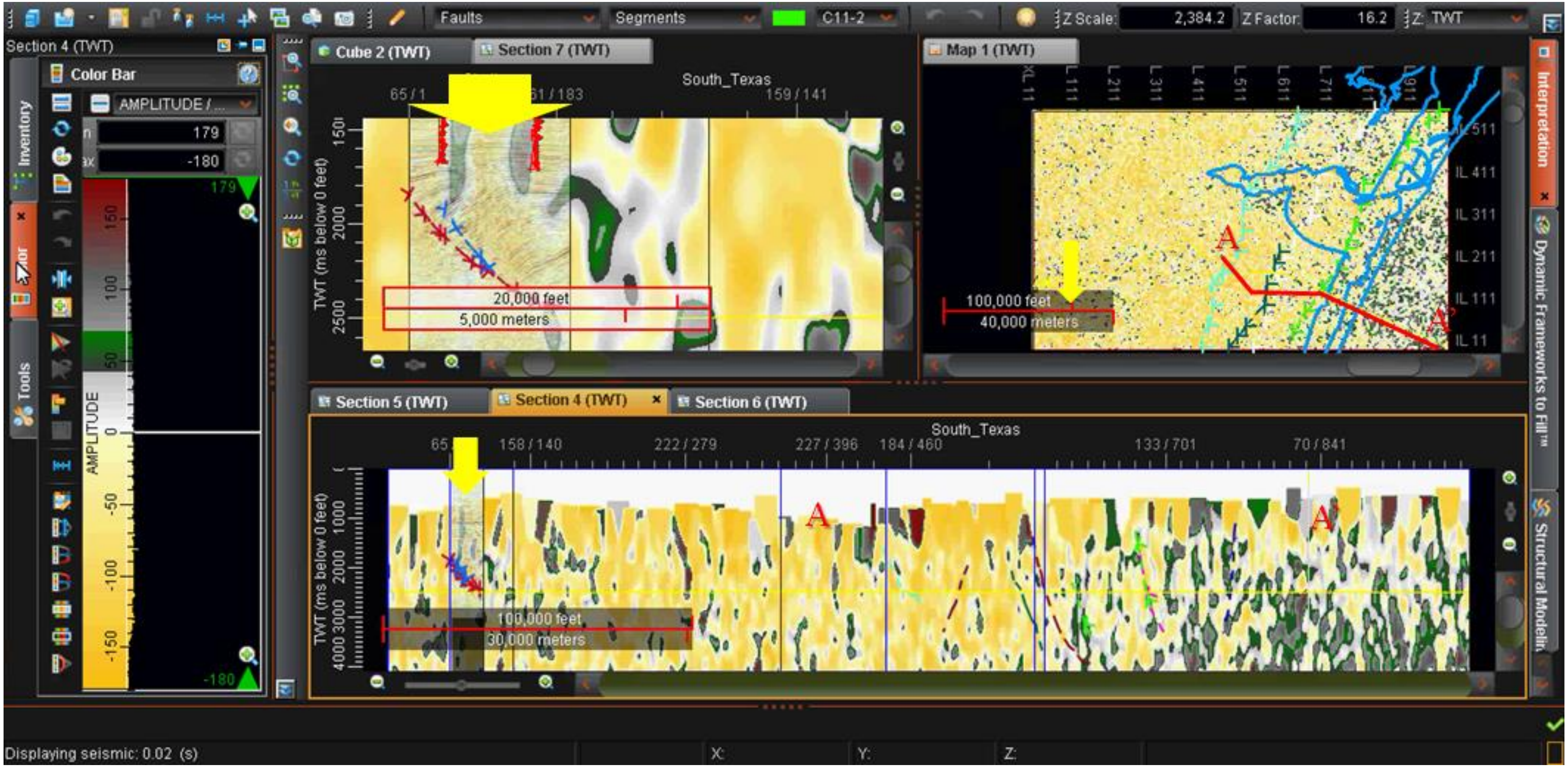
13 of 18 Lightning Attributes - Apparent Resistivity

Used to correlate Ewing's 1986 cross-sections



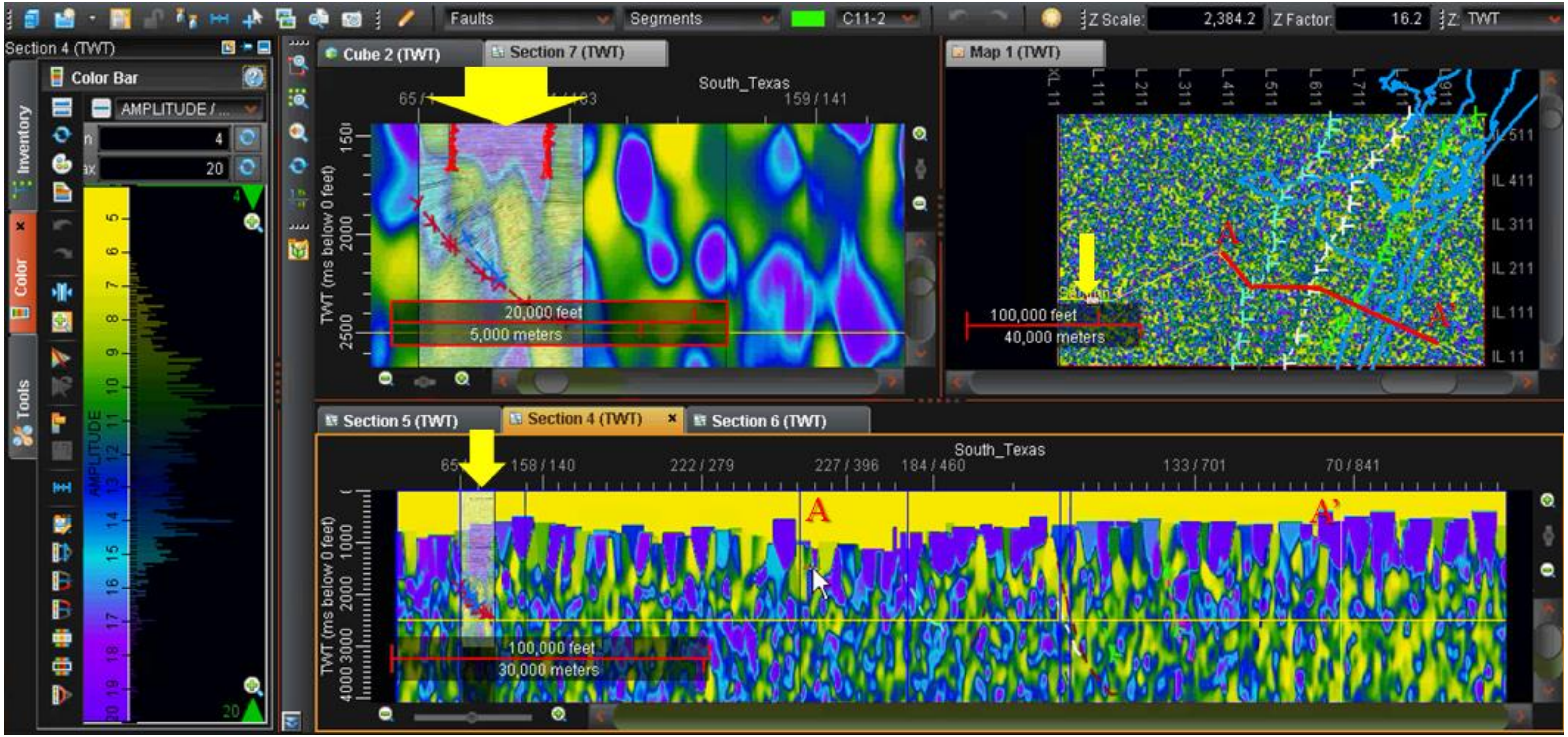
(ohm-meters)

14 of 18 Lightning Attributes - Sun Local Longitude



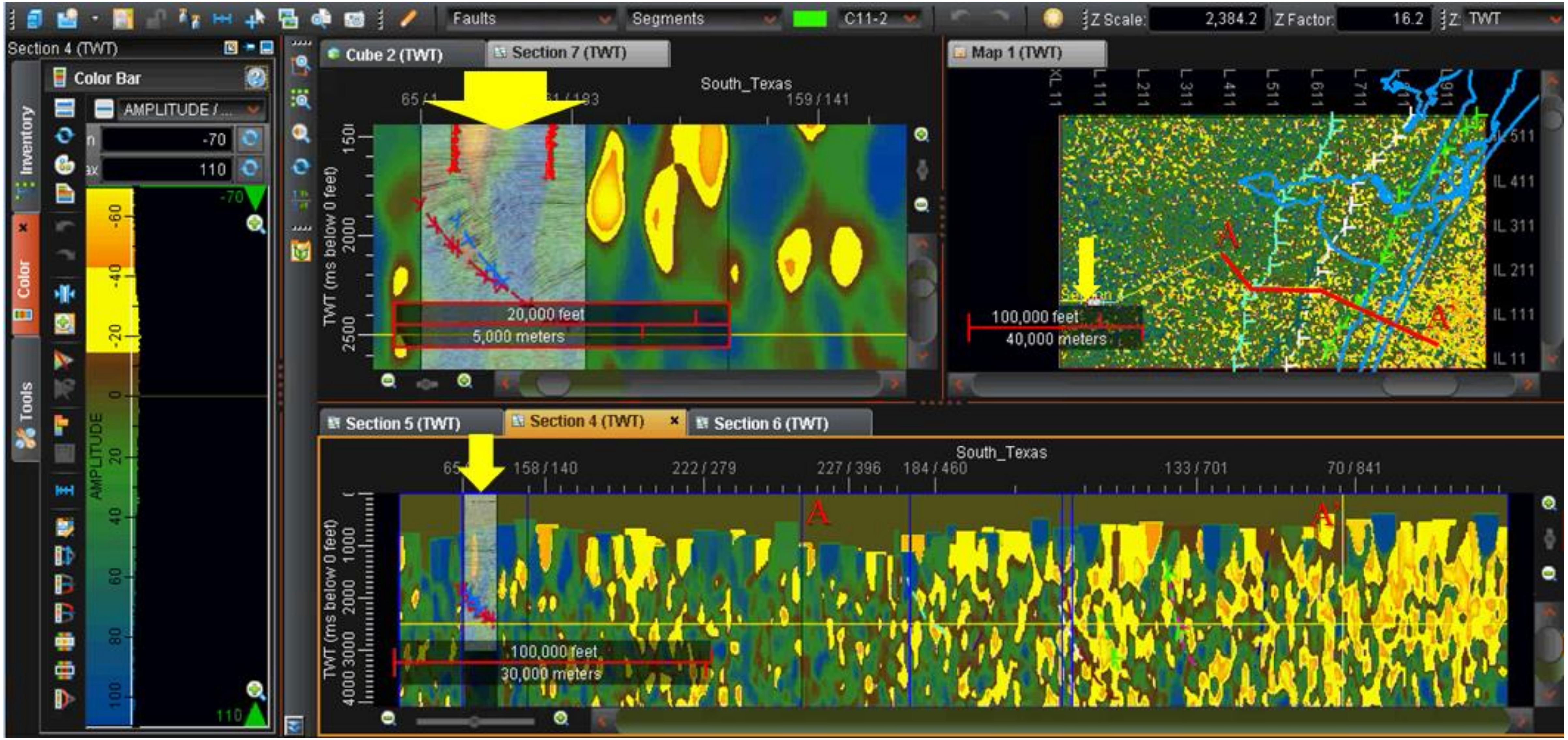
(degrees [-180 to 180])

15 of 18 Lightning Attributes - Symmetry



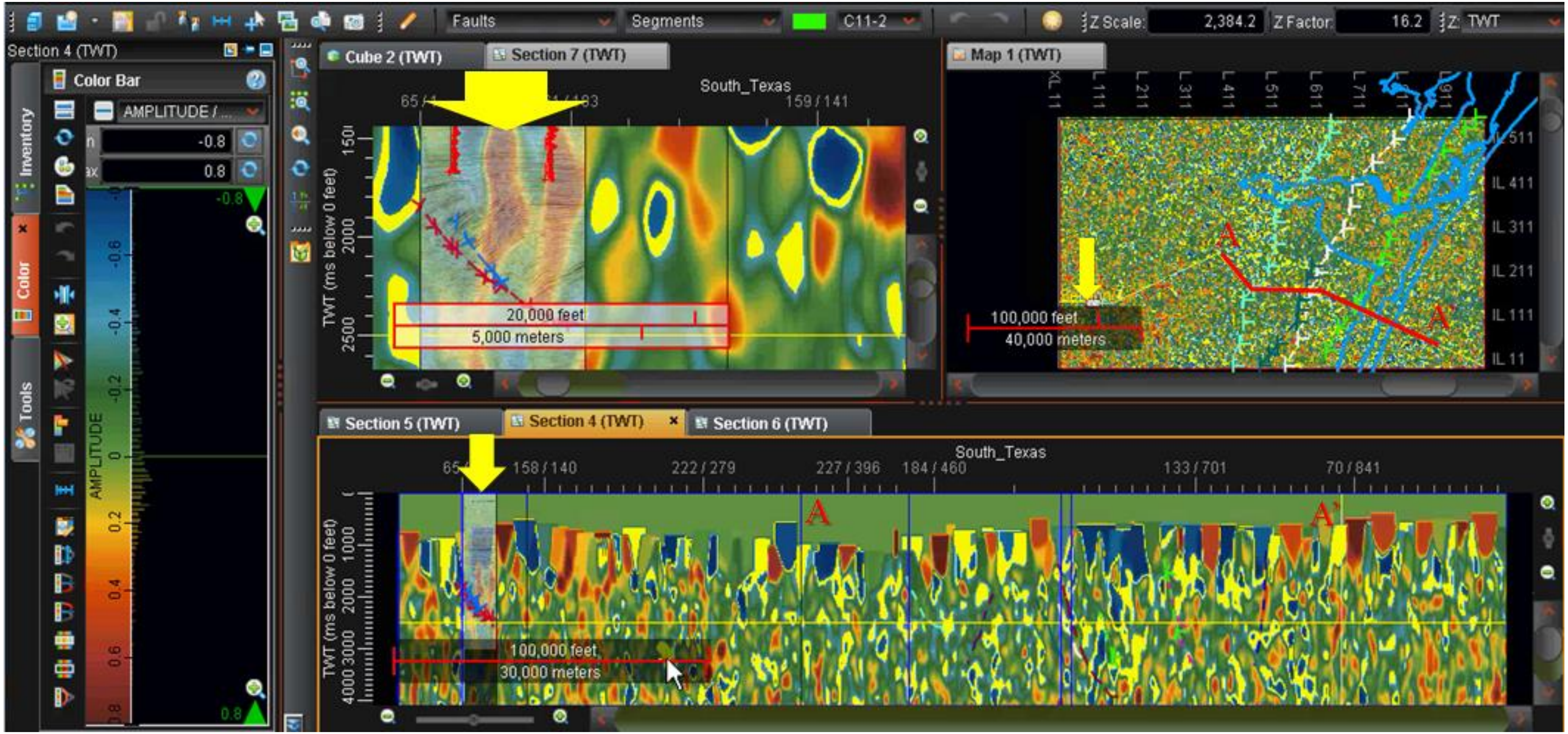
(% [<50: rt<pz; 50: rt=pz; >50: rt>pz])

16 of 18 Lightning Attributes - Tidal Gravity



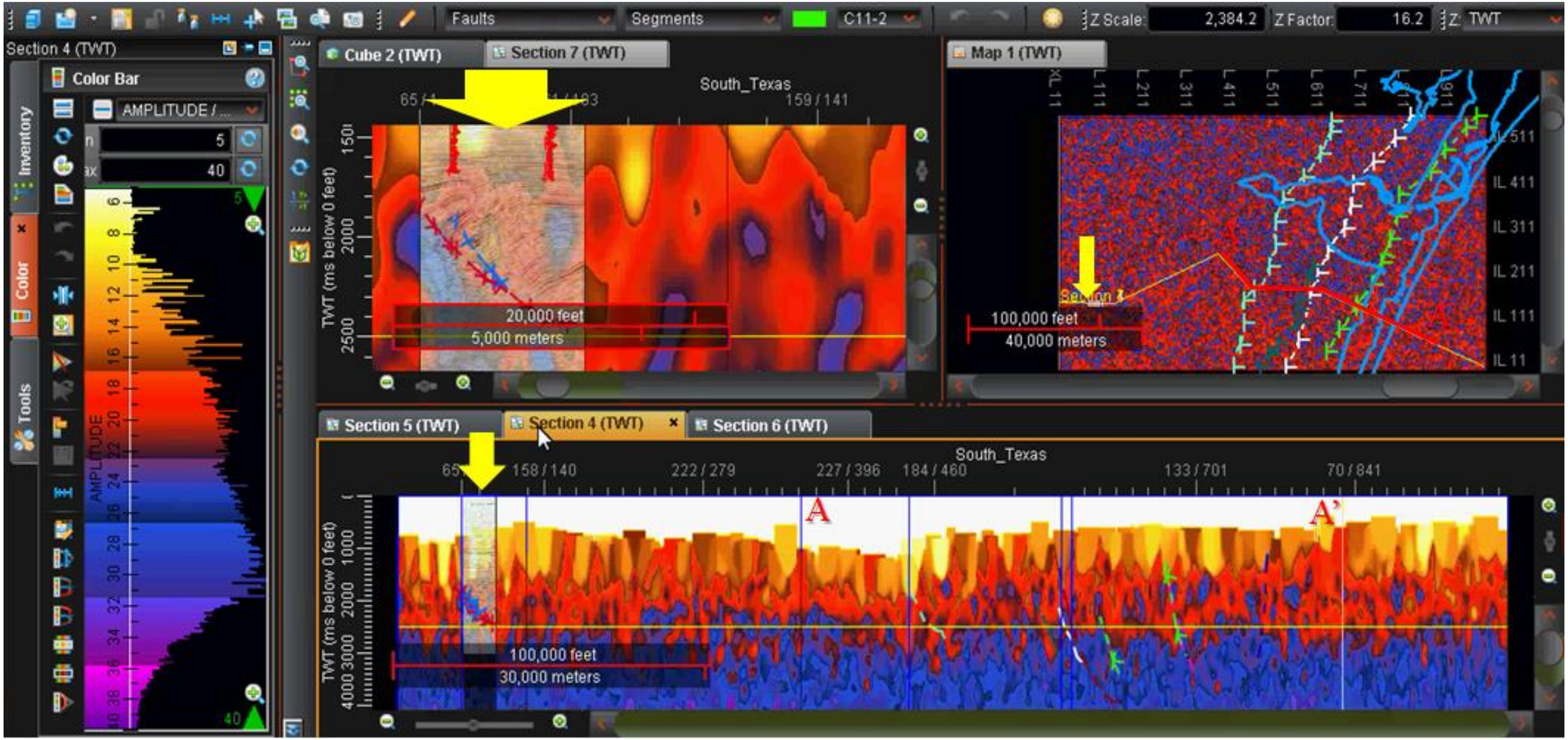
(microgals)

17 of 18 Lightning Attributes - Tide



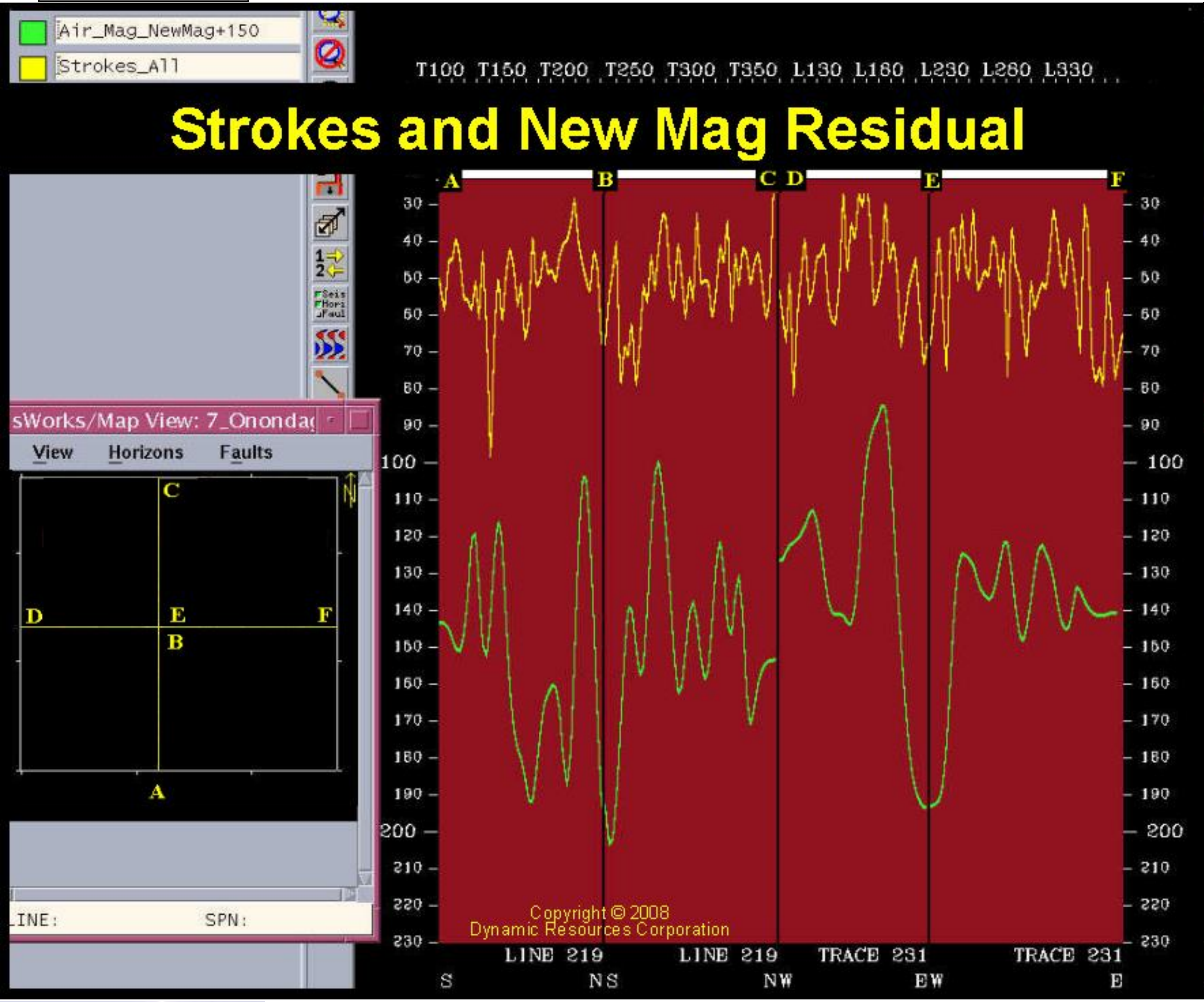
([-1.0: low spring tide; 0.0: mean tide; 1.0: high spring tide])

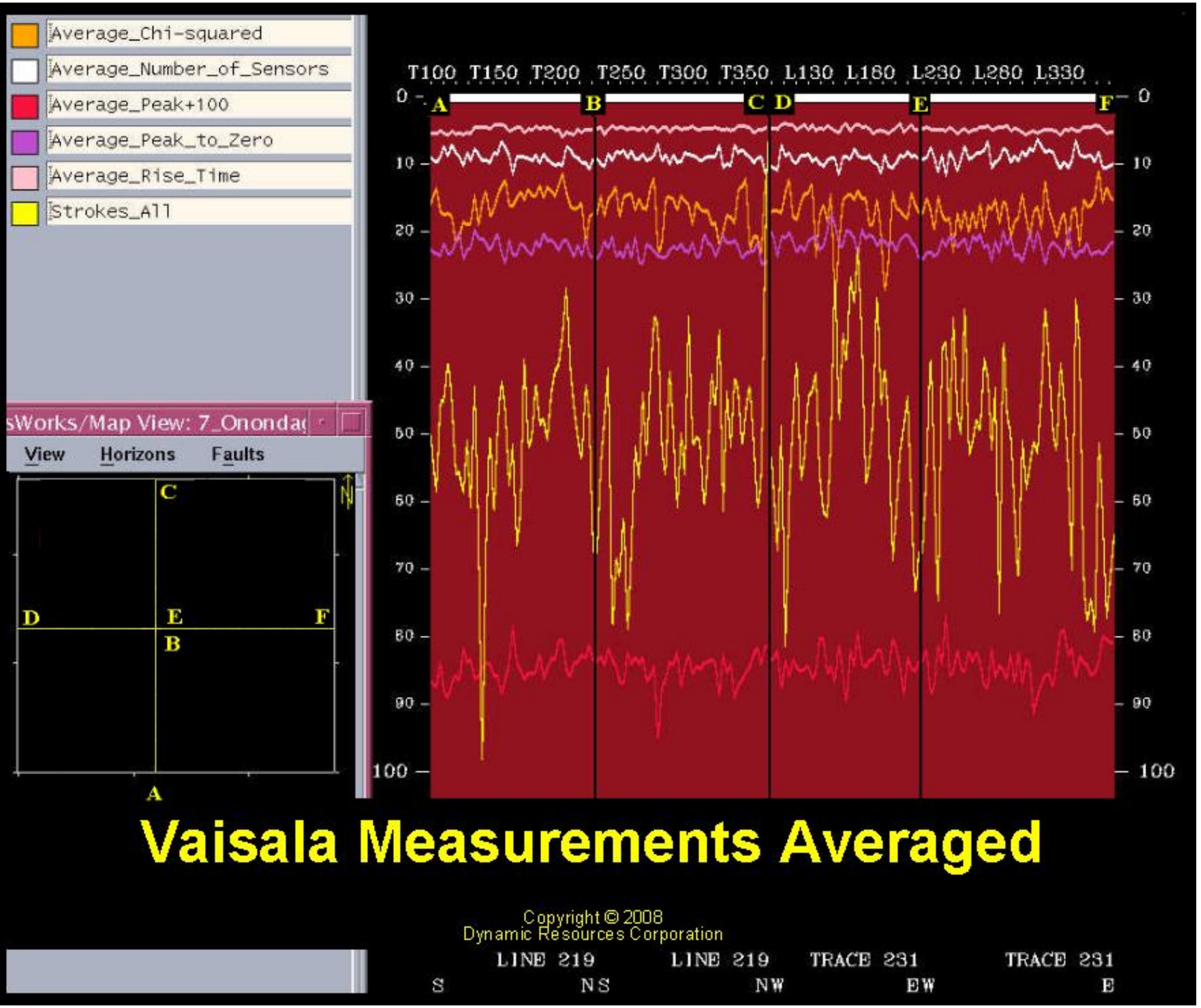
Lightning Attributes - Total-Wavelet Time



(microseconds)

5. Steuben County, New York Example continued



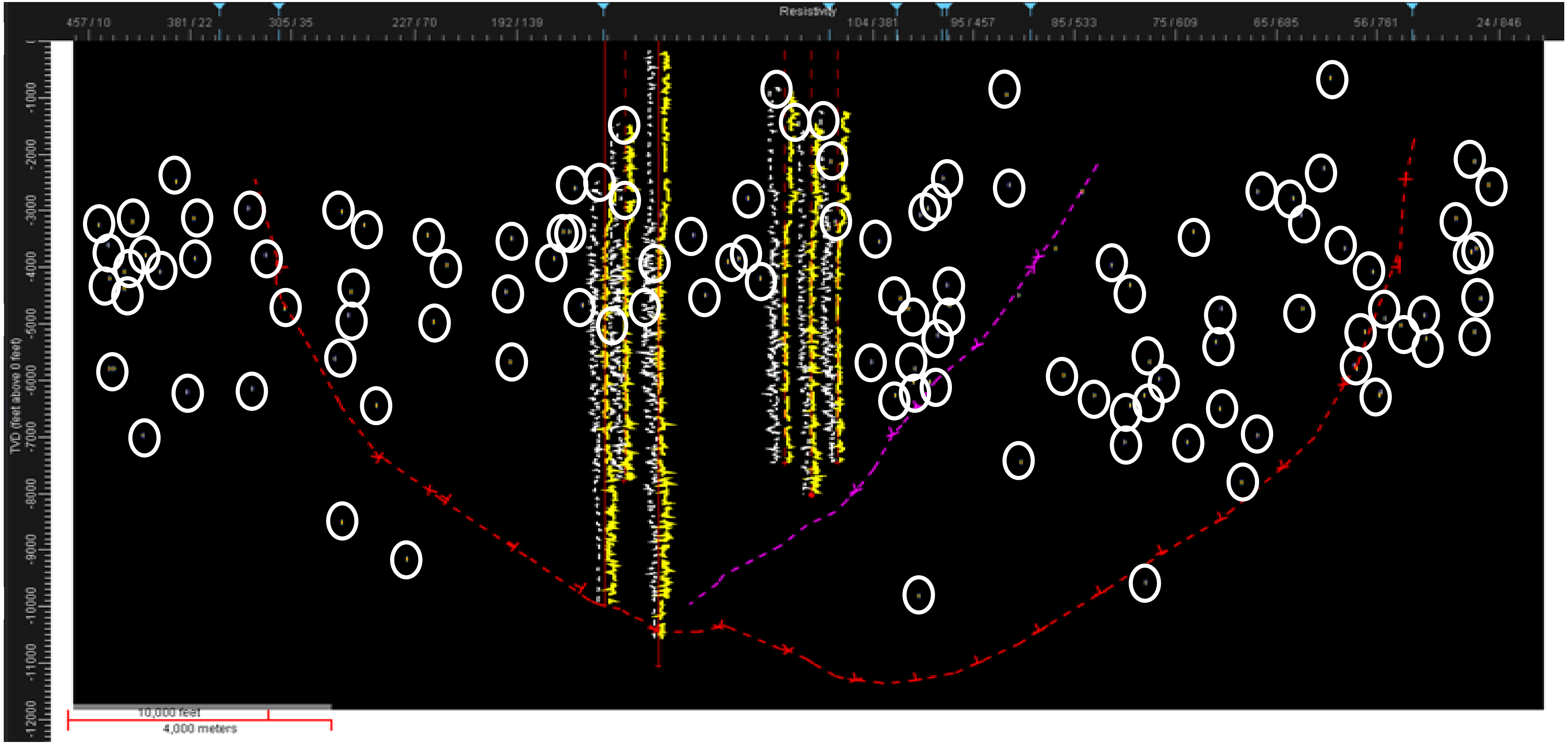


Control Louisiana Resistivity Volume Interpolation – Goose Point, LA

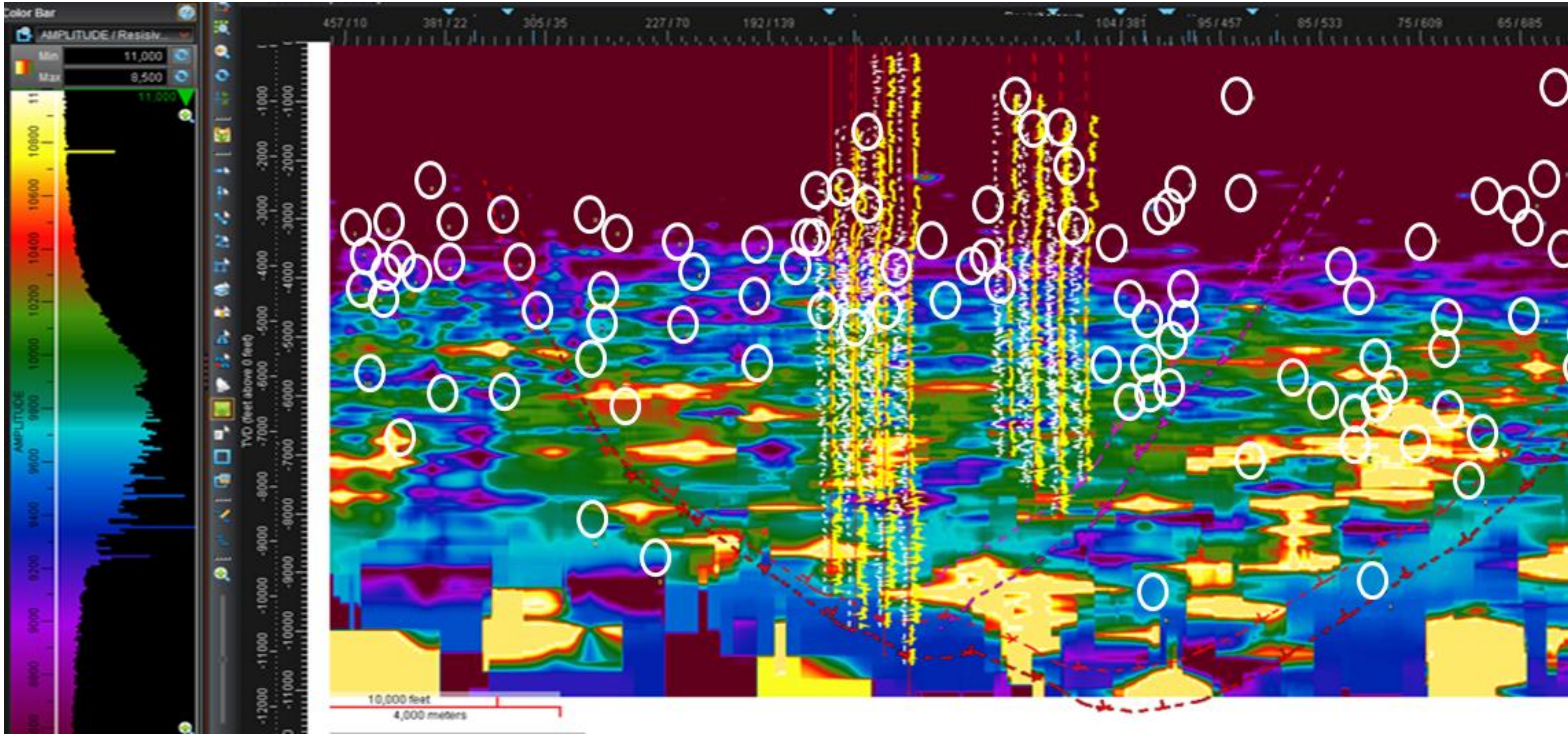
Surface

5,000 feet

10,000 feet

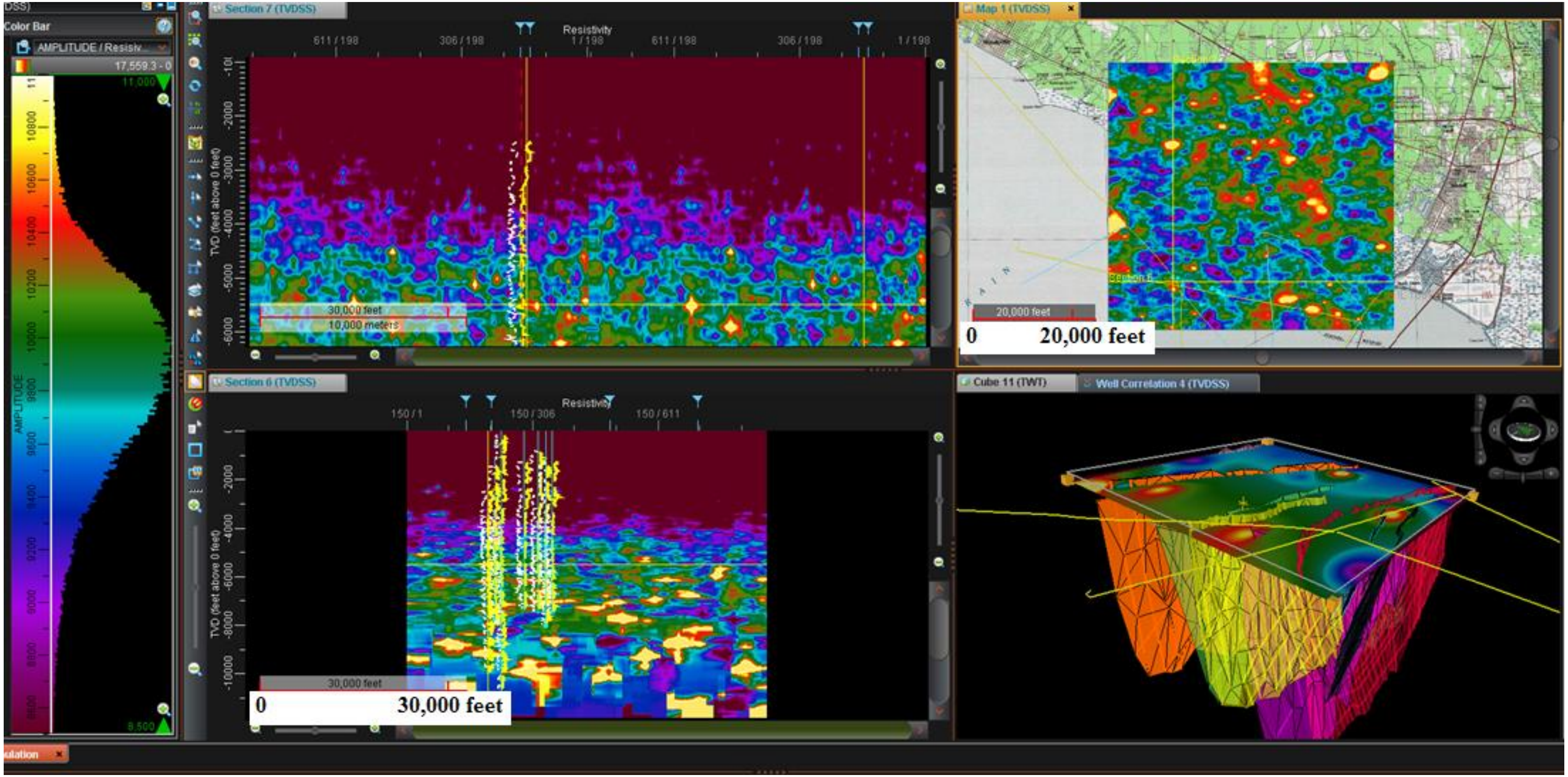


Interpolated Resistivity Volume– Goose Point, LA

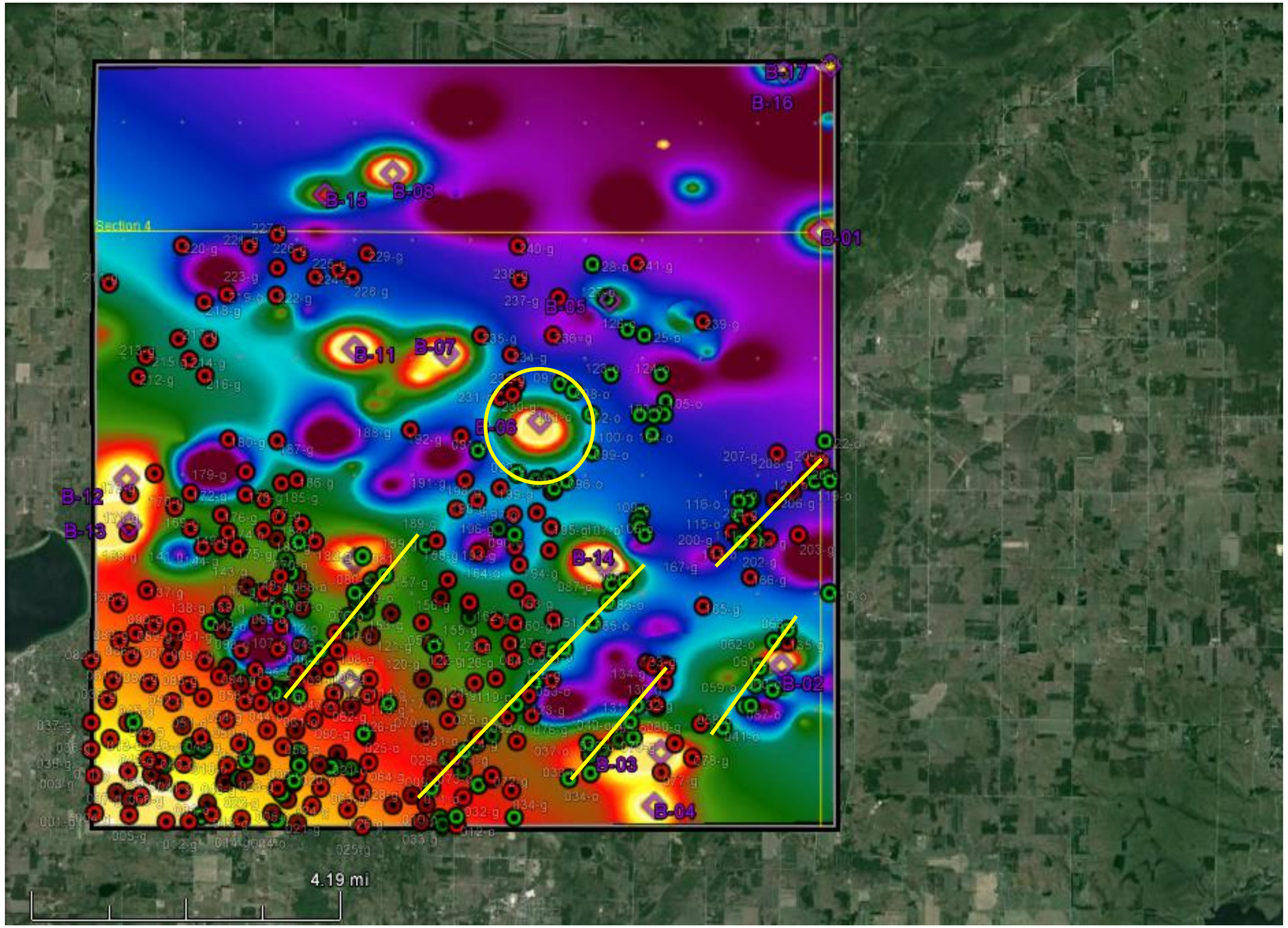


Lightning Resistivity Cross-Section Faults and Wells

In-Line, Cross-Line, Horizontal-Slice, & Fault Framework Interpretation, Goose Point, LA



5. Michigan Example



High Resistivity to SW on B-2 Horizontal-Slice with
Oil & Gas Wells in Analysis Area posted (note lineaments)

Telluric Current 1

GEOPHYSICS, VOL. 40, NO. 1 (FEBRUARY 1975), P. 91–95, 4 FIGS.

TOPOGRAPHIC DISTORTION OF TELLURIC CURRENTS: A SIMPLE CALCULATION

RICHARD E. THAYER*

An analytic solution of the electric field near a two-dimensional offset in the earth's surface is presented as a means of estimating the effects of nonplanar topography on telluric measurements. Results indicate that, for an offset height *d*, the field at the earth's surface is within ten percent of its undisturbed value for distances greater than 2.5 *d* from the offset on the lower side and for distances greater than 4 *d* on the upper side. The disturbance due to the offset extends even less far out in situations where the telluric currents are channeled close to the surface.

Topographic Corrections 2

GEOPHYSICS, VOL. 41, NO. 6 (DECEMBER 1976), P. 1346–1352, 8 FIGS., 1 TABLE

TOPOGRAHIC CORRECTIONS FOR GRADIENTS IN AIRBORNE GRAVIMETRY

SIGMUND HAMMER*

Progress in airborne gradiometer instrumentation has advanced to the point that procedures for determining corrections for the variable effects of topography merit consideration. An approximate practical method, based on real-time recording of flight elevation and variable terrain clearance as a function of position along the flight line, appears to be appropriate for the purpose. The procedure is similar to that for determing topographic corrections for airborne gravity published previously by the author in GEOPHYSICS (Hammer, 1974a).

Telluric Current Induction

GEOPHYSICS, VOL. 43, NO. 5 (AUGUST 1978); P. 1019–1022

SHORT NOTE

ELECTROMAGNETIC FIELDS ABOUT A HORIZONTAL ELECTRIC WIRE SOURCE OF ARBITRARY LENGTH

JAMES KAUAHIKAUA*

INTRODUCTION

The electromagnetic fields about an electric wire source of an arbitrary finite length are usually calculated by numerical integration of the dipole field equations along the length of the wire (Scriba, 1974; Anderson, 1974). However, many of the required integrals for the fields over a multilayered half-space can be solved analytically. The integrations may also be extended to solve for the fields about an infinitely long wire source. In so doing, it becomes clear which portions of each field component are produced by the wire and which are produced by its grounded ends. Although the horizontal electric fields of.a finite wire source have been derived previously (Sunde, 1949), the complete field equations for a finite-length wire appear here for the first time in explicit form.

Current "stacking" is related to Kriging

GEOPHYSICS, VOL. 45, NO. 6 (JUNE 1980): P. 1017–1041, 28 FIGS.

A comparison of seismic trace summing techniques

D. R. Gimlin* and J. W. Smith*

The results of an analysis and comparison of mantissa only, sign bit, true amplitude, automatic volume control, and diversity stack signal trace summations are presented. The results show that under conditions frequently encountered for low-level sources, all these summation methods preserve the fidelity of input signals to within a time variant scale factor. The value of the signal-to-noise (S/N) average power ratio of the true amplitude summer is shown to be much more sensitive to intertrace noise variance differences than the other summing techniques. Excessive signal distortion may occur for mantissa only or sign bit summers when instantaneous input signal magnitude is large in comparison with the input noise standard deviations of the summed data. There will be no significant differences in the performance of mantissa only and sign bit summers under conditions frequently encountered for low-level sources. The effects of signal summation methods are not directly dependent upon any instantaneous gain ranging characteristics of the amplifier used to create the input data.

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