Using Lightning Databases to derive
Rock Property and Lightning Attribute Maps and Volumes
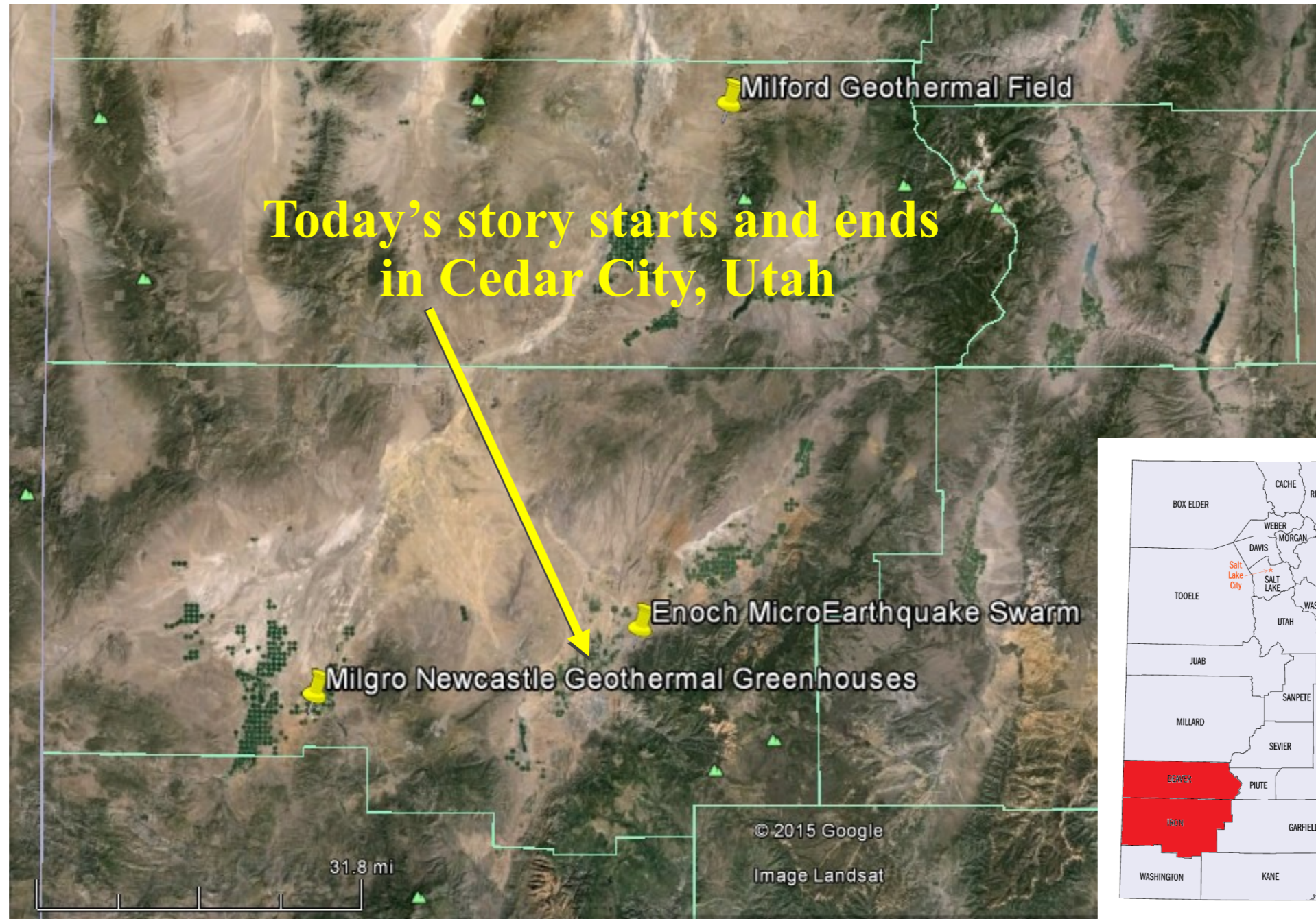
H. Roice Nelson, Jr. & Dr. Jim Siebert
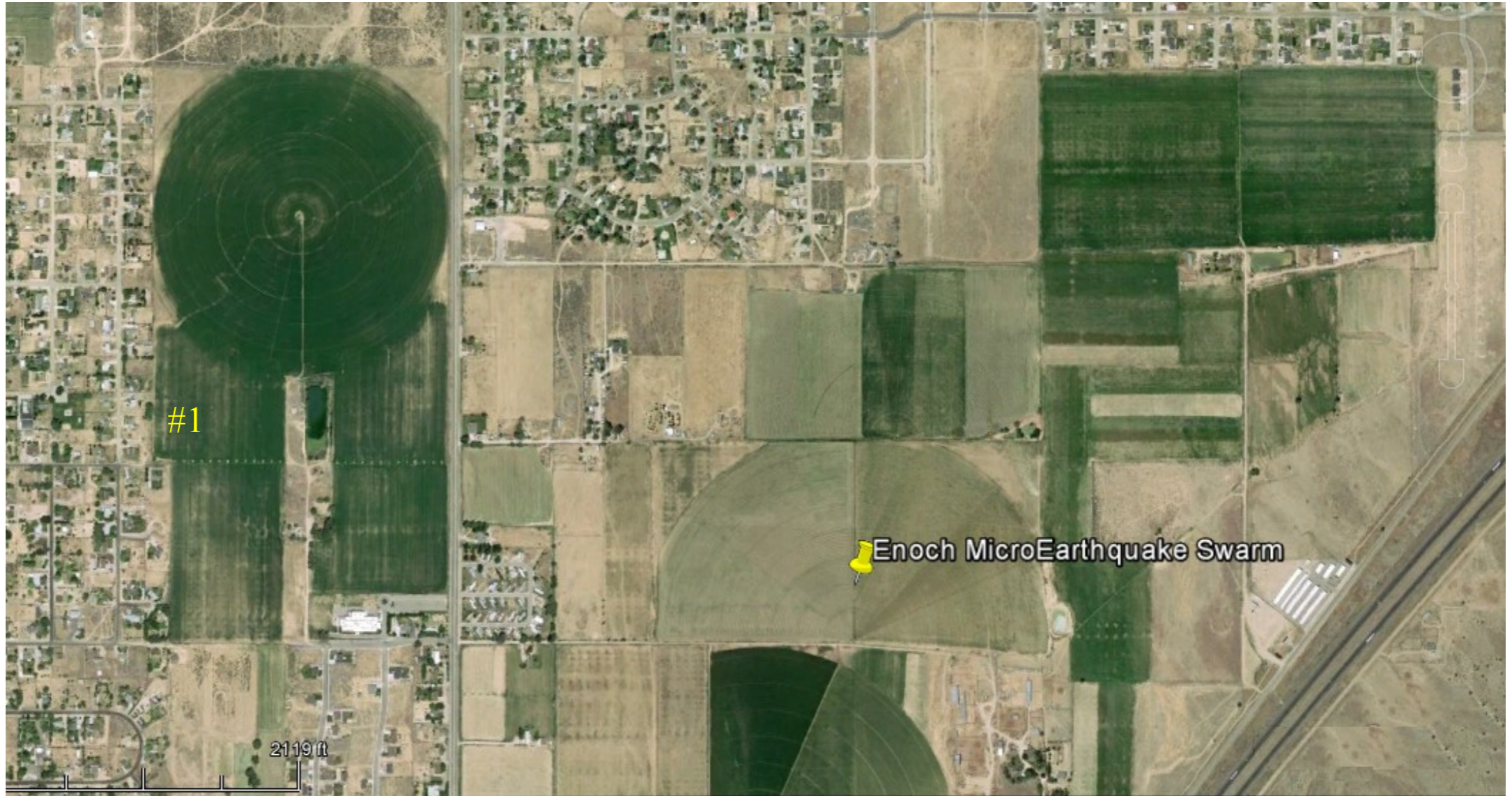
14 October 2016

Today's story starts and ends in Cedar City, Utah

Milford Geothermal Field

Enoch MicroEarthquake Swarm

Milgro Newcastle Geothermal Greenhouses

© 2015 Google
Image Landsat

31.8 mi

Roice Nelson grew up on the back end of a shovel …

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Dynamic Measurement LLC.

… on the Star Ship Enterprise
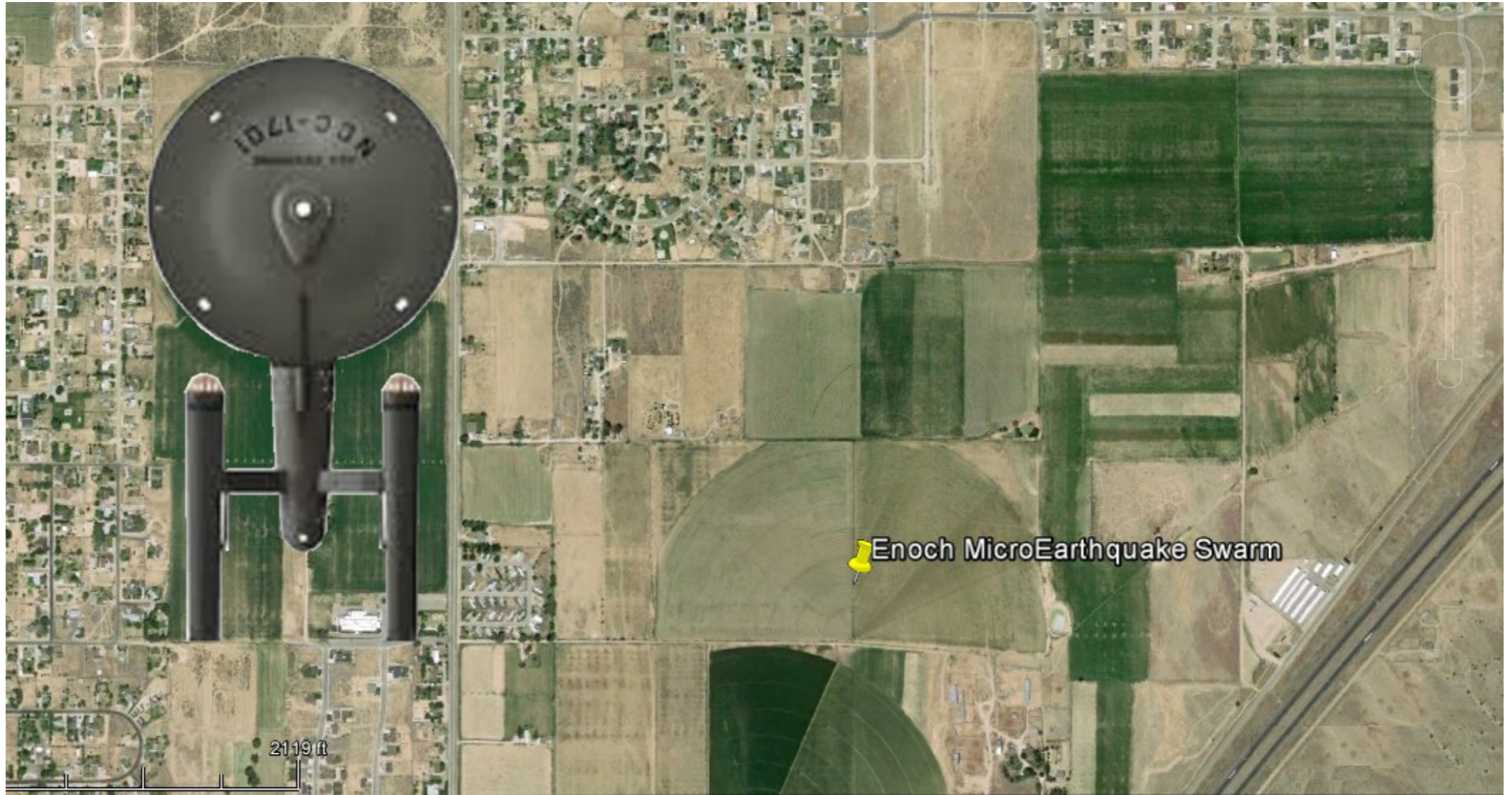
Enoch MicroEarthquake Swarm

SMU Geothermal Lab   4

Roice received an MBA from SMU in 1982 with an emphasis in Entrepreneurship 34 years ago

SMU | COX SCHOOL OF BUSINESS

HOME | PROSPECTIVE STUDENTS | EXECUTIVE EDUCATION | CURRENT STUDENTS | DEPARTMENTS | ABOUT | NEWS | CENTERS AND INSTITUTES | ALUMNI

Caruth Institute for Entrepreneurship

Cox School of Business / Centers and Institutes / Caruth Institute for Entrepreneurship

Caruth Institute for Entrepreneurship

Since its founding more than three decades ago, the Caruth Institute has continuously developed innovative courses and programs to help individuals keep pace with the dynamic, rapidly changing field of entrepreneurship. The Institute currently offers more than 18 custom-designed courses to give students the skills and knowledge necessary to launch and manage successful entrepreneurial ventures. Courses include:

Founder of Landmark Graphics as well as Dynamic Measurement

1984 World Oil Cover

1991 O&G Journal Cover
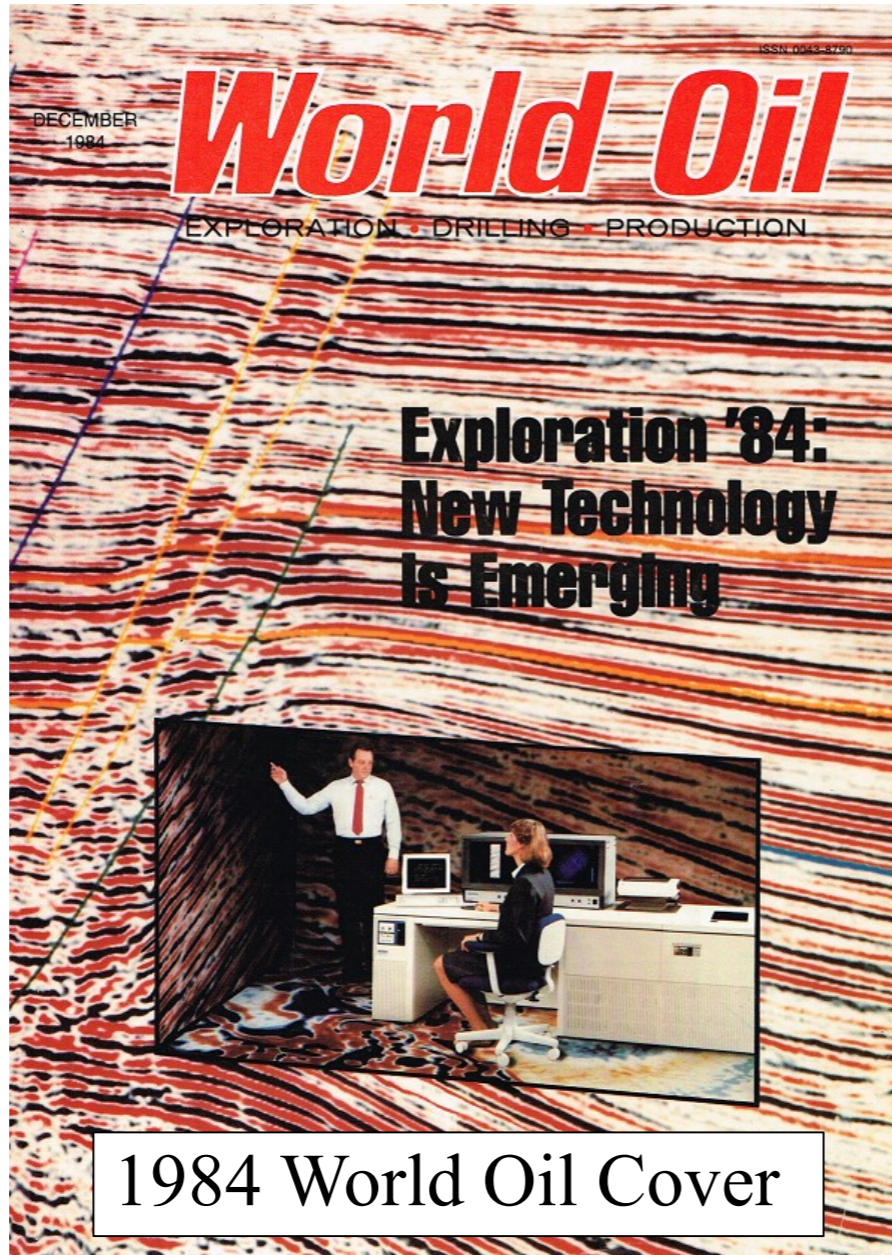
Dr. Jim Siebert in front of a green-screen at Fox News Houston

Sometimes it is a circus, and sometimes it is a game

Always Science, and Always Helping Ward of Danger

Sometimes fun, and always giving the best report possible
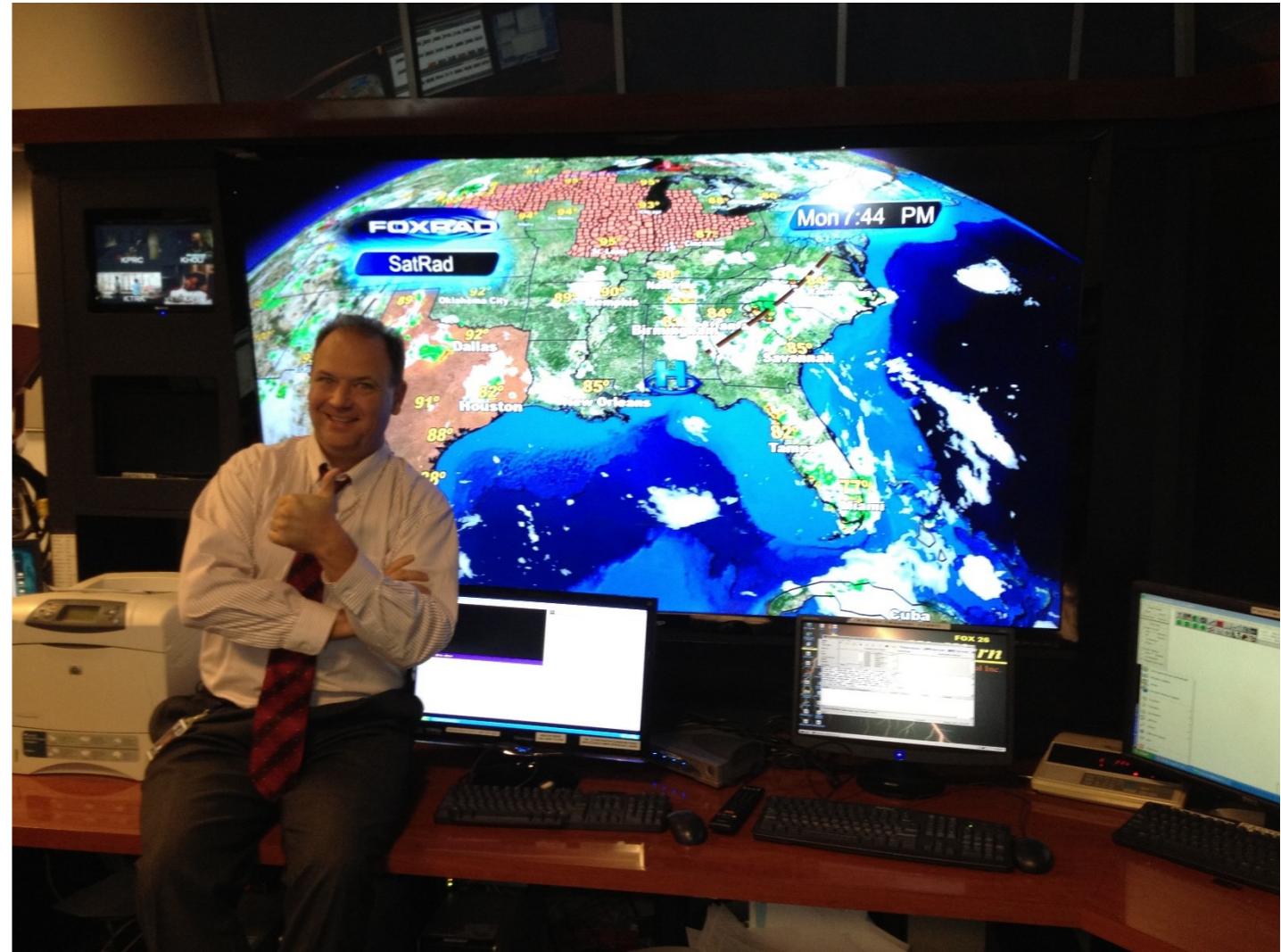
Presentation Outline

Milam County Texas Apparent Resistivity Volume

1. **Lightning Occurs Everywhere**

2. **Lightning Database Analytics**

3. **Lightning Analysis & Attributes**

4. **Rock Property & Attribute Maps & Volumes**

5. **Arizona, Louisiana, Michigan, & Texas Examples**
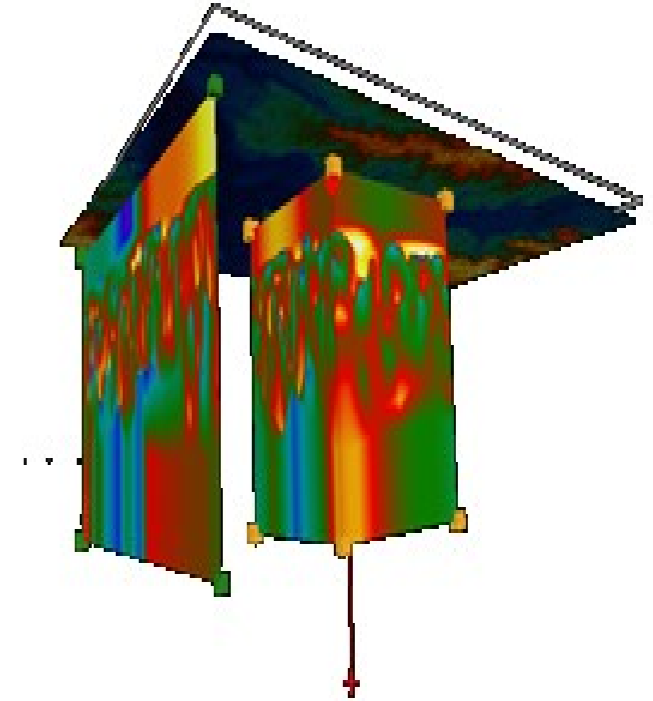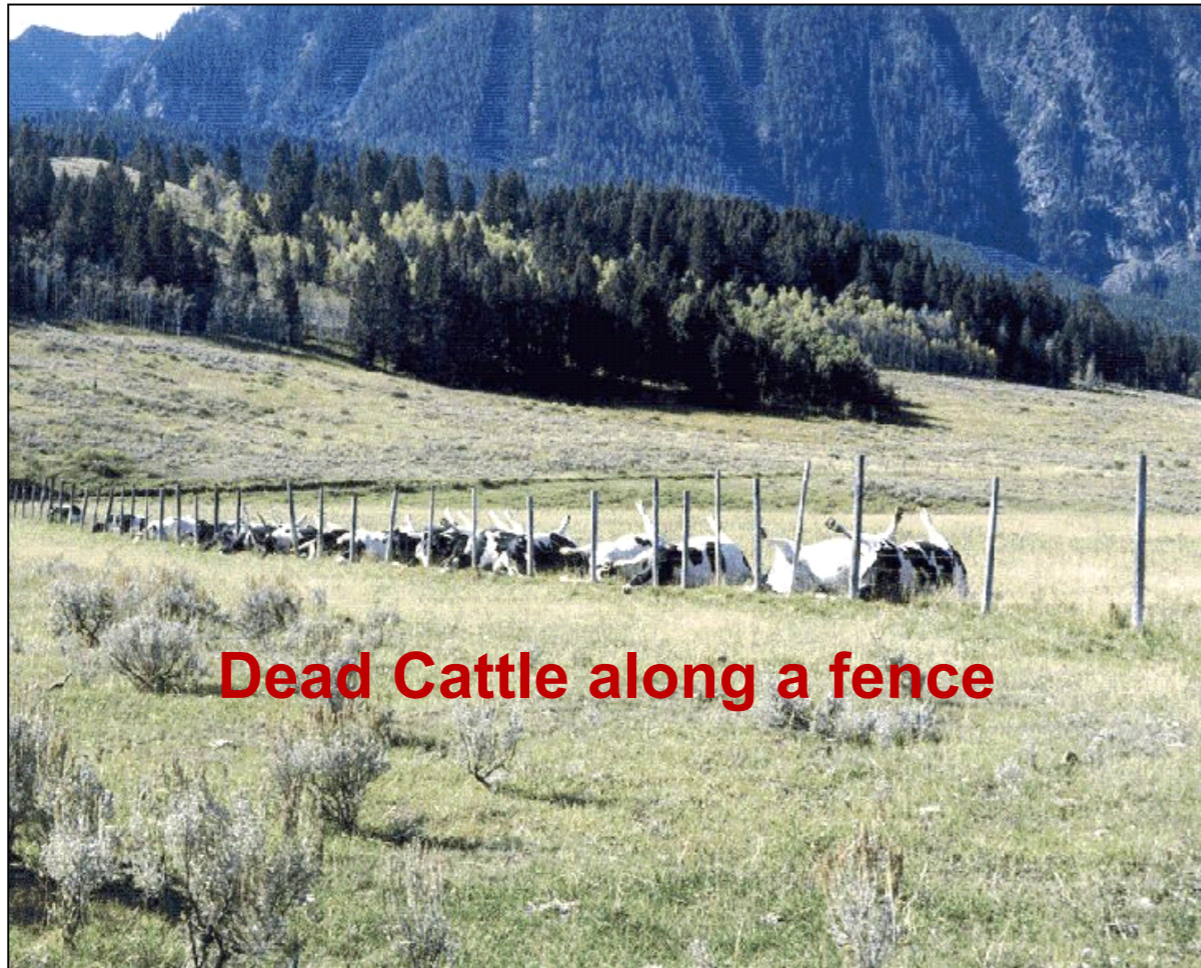
Dynamic Measurement LLC

A Texas Duck Hunting Story

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Dynamic Measurement LLC.

Lightning recorded for early storm warning, safety, insurance, and meteorological purposes

Dead Cattle along a fence
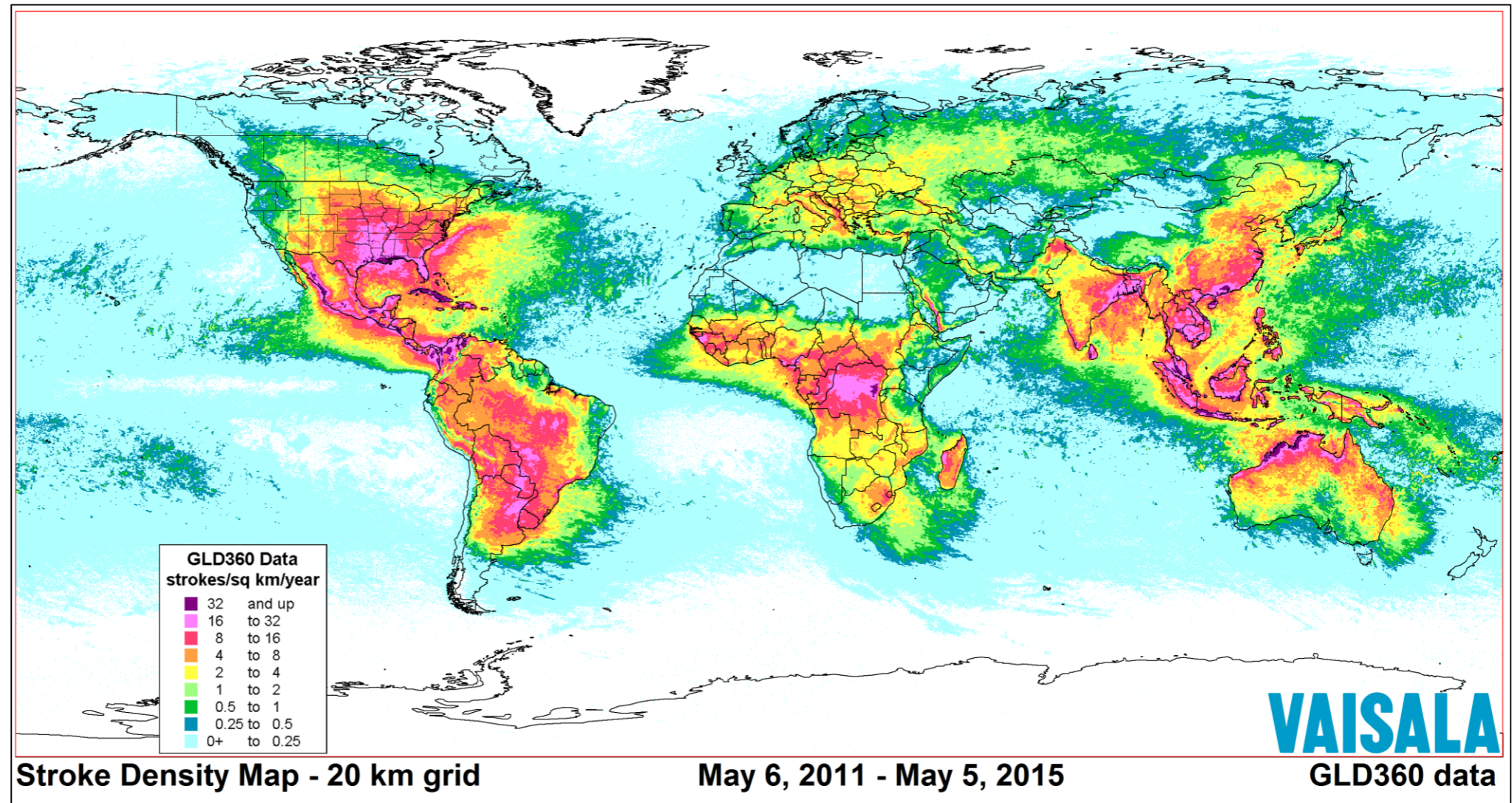
1. Lightning Occurs Everywhere
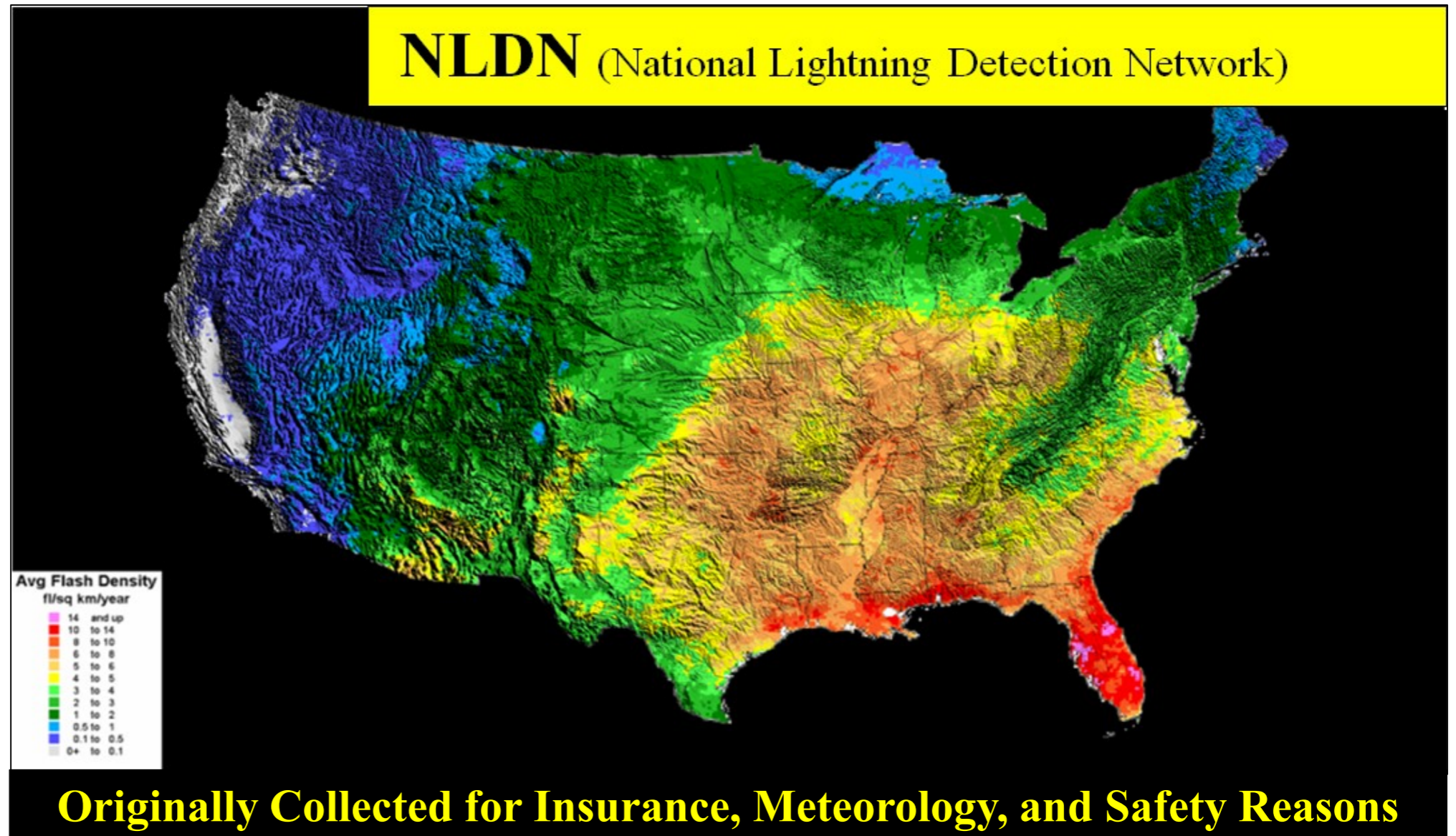## 5+ Years of Data in GLD-360 Data Base

GLD360 Data
strokes/sq km/year

32	and up
16	to 32
8	to 16
4	to 8
2	to 4
1	to 2
0.5	to 1
0.25	to 0.5
0+	to 0.25

Stroke Density Map - 20 km grid   **May 6, 2011 - May 5, 2015**   **VAISALA**   GLD360 data

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Dynamic Measurement LLC.

The U.S. has the most complete database
18+ Years of Data in the NLDN Data Base

NLDN (National Lightning Detection Network)

Avg Flash Density
fl/sq km/year

14	and up
10	to 14
8	to 10
6	to 8
5	to 6
4	to 5
3	to 4
2	to 3
1	to 2
0.5	to 1
0.1	to 0.5
0+	to 0.1

Originally Collected for Insurance, Meteorology, and Safety Reasons

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Dynamic Measurement LLC.

350 million annual Lightning Strikes - a rich database to mine
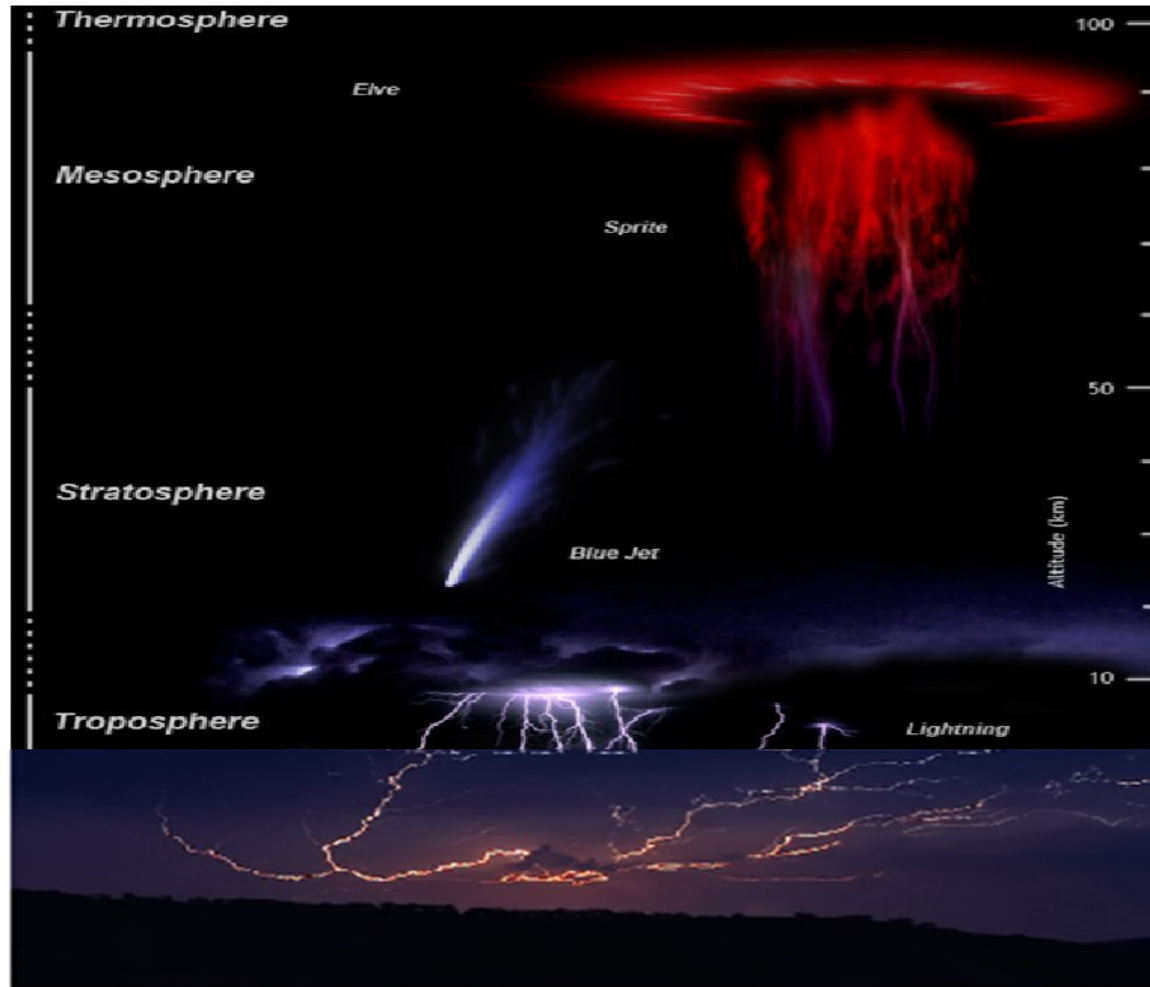
Lightning Strikes can travel 250 km (155 miles) cloud-to-cloud, or 2 ½ times the distance of Sprites or Elves.

Lightning Strike locations primarily controlled by terralevis (shallow earth) currents.

Sensors measure Direction to strike & Lightning Attributes

Strike Triangulated & Measurements Reconciled

Vaisala: Martin Murphy
2016 Webinar used with permission

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Dynamic Measurement LLC.
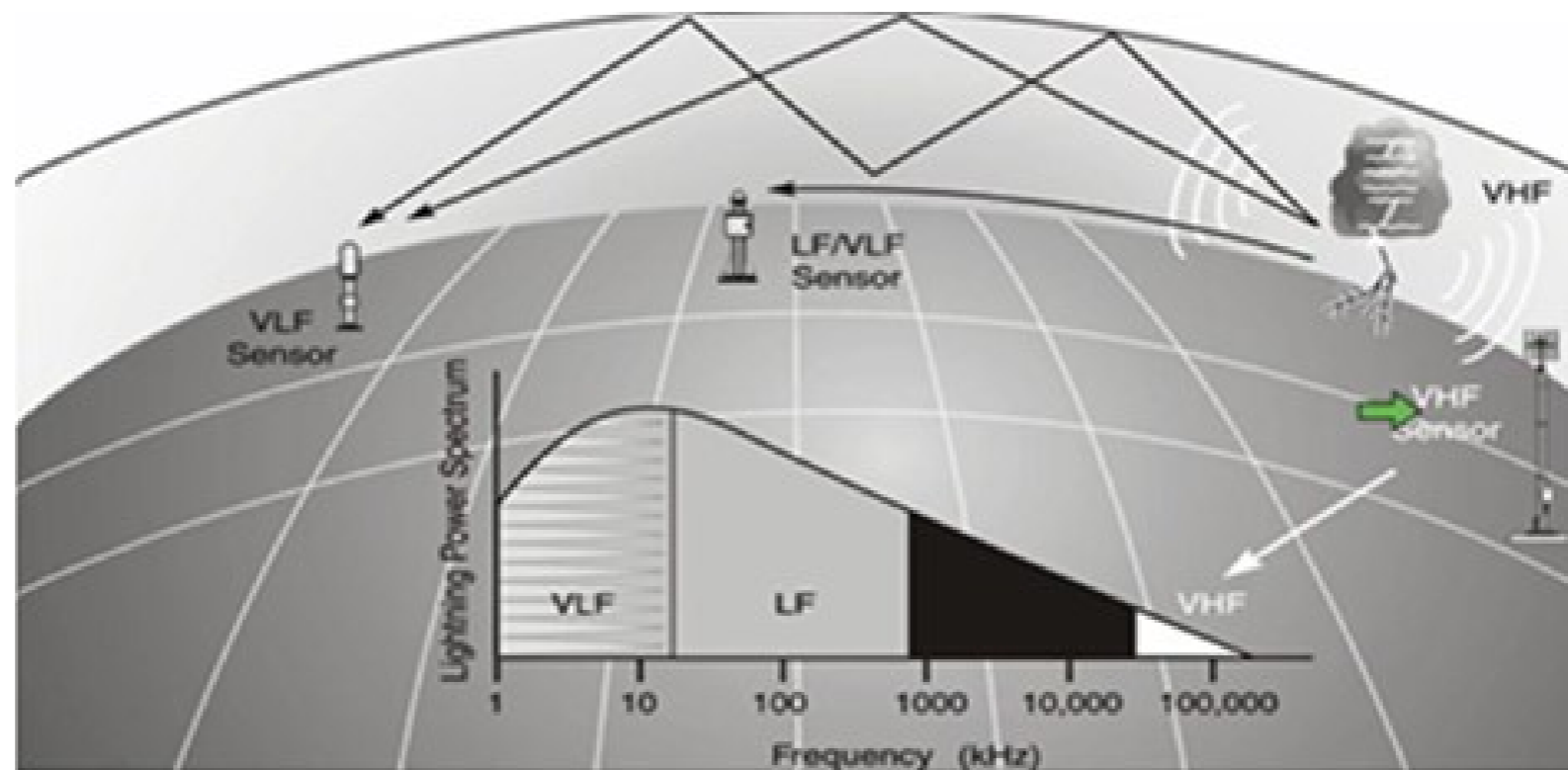
Vaisala's NLDN Lightning Detection Network

115 Sensors
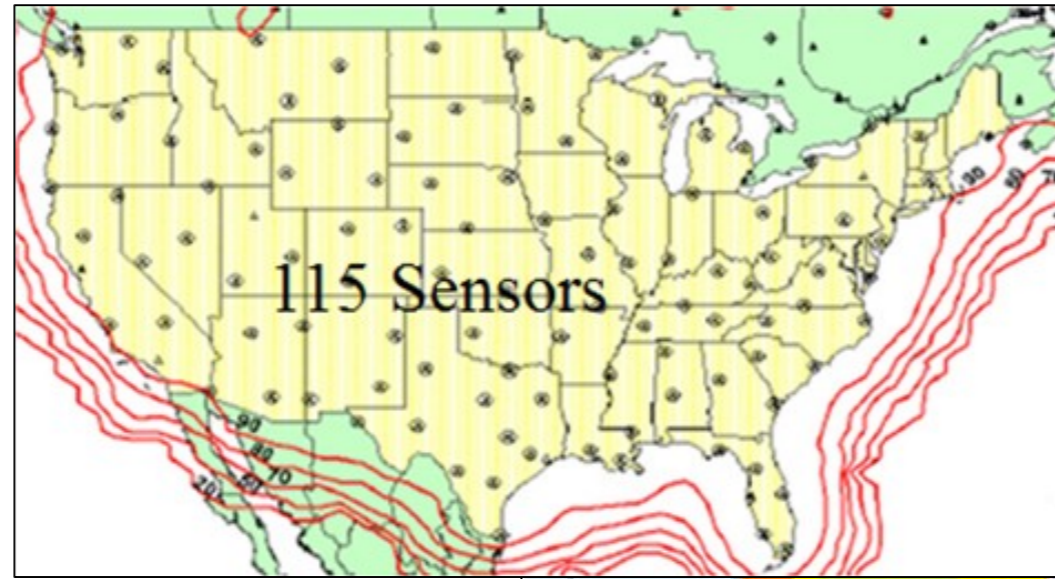
In Texas 12-24 Sensors
record each Lightning Strike

Location Accuracy:
150-600 feet

Lineament Accuracy:
10-100 feet

Location accuracy
Less than 200 m

VAISALA
Network Median
Location Accuracy

- <200m
- 200-250m
- 250-500m
- 500-1000m
- 1000+m
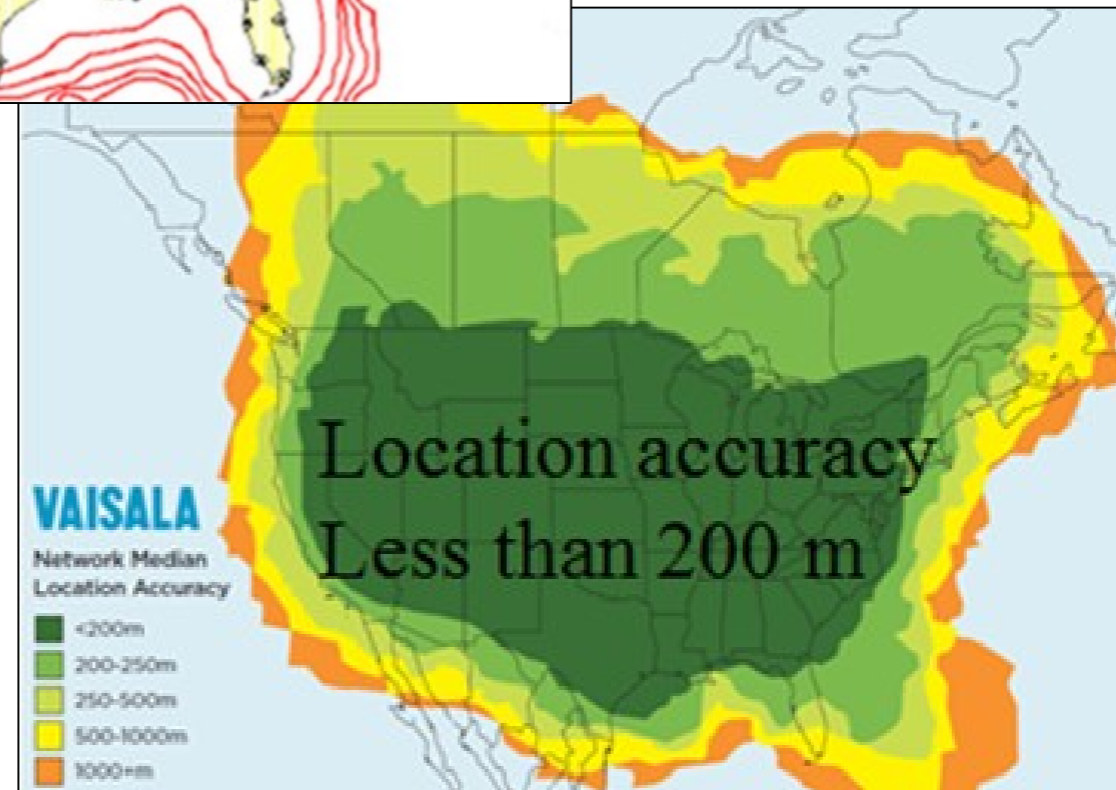
From 2016 Vaisala
Webinar: Martin Murphy,
used with permission

2. Lightning Database Analytics

- Typical projects have millions of lightning strikes.
- To date all projects have tied subsurface control.
- Attributes are measured or calculated for lightning strike locations, then contoured or gridded.
- Lightning strike density and 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
- Major/Minor Axe
- Chi-Squared

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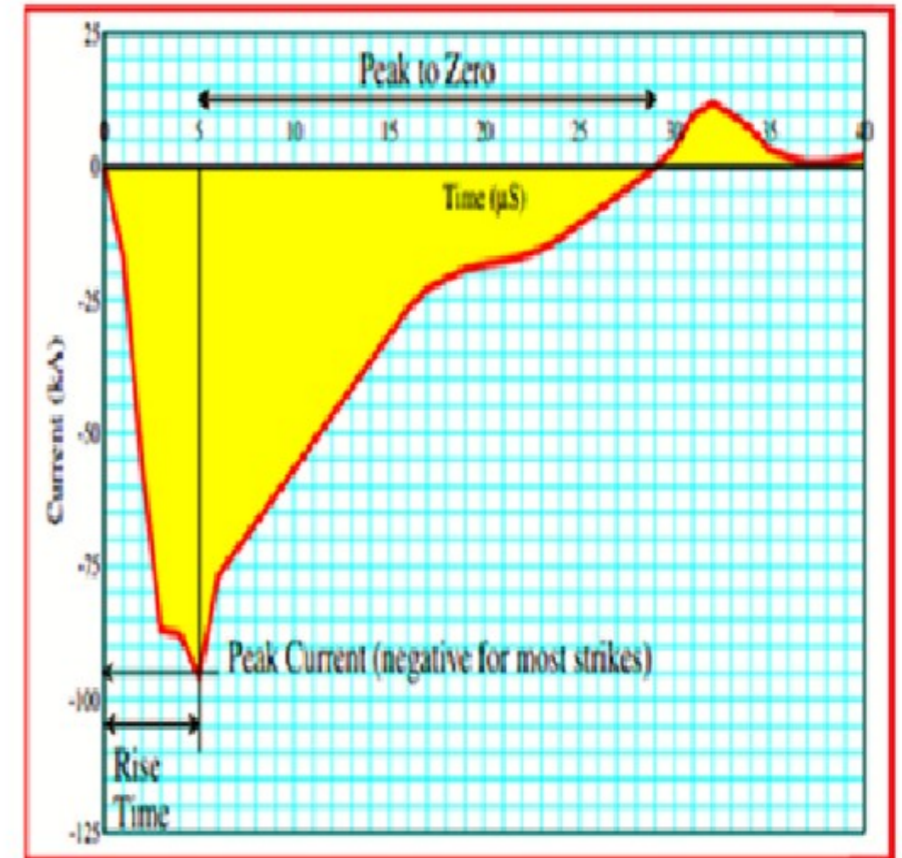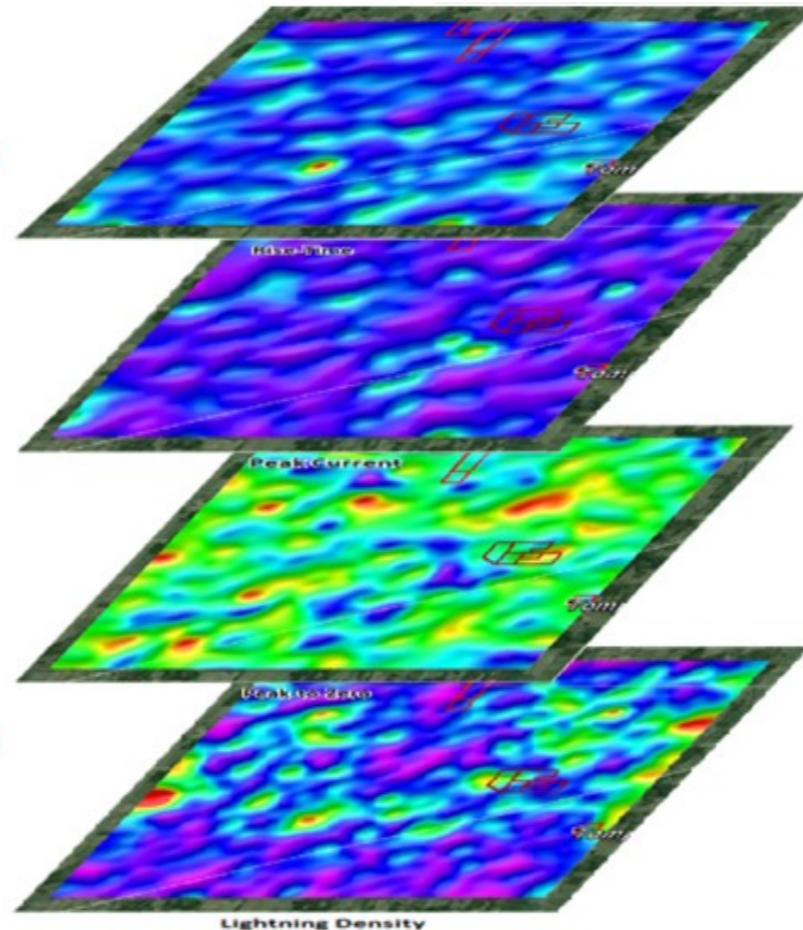
- Other attributes calculated from these measurements.
- The time of the lightning strike is correlated with solar and lunar tides.
- Measurements separated by time.

3. 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.
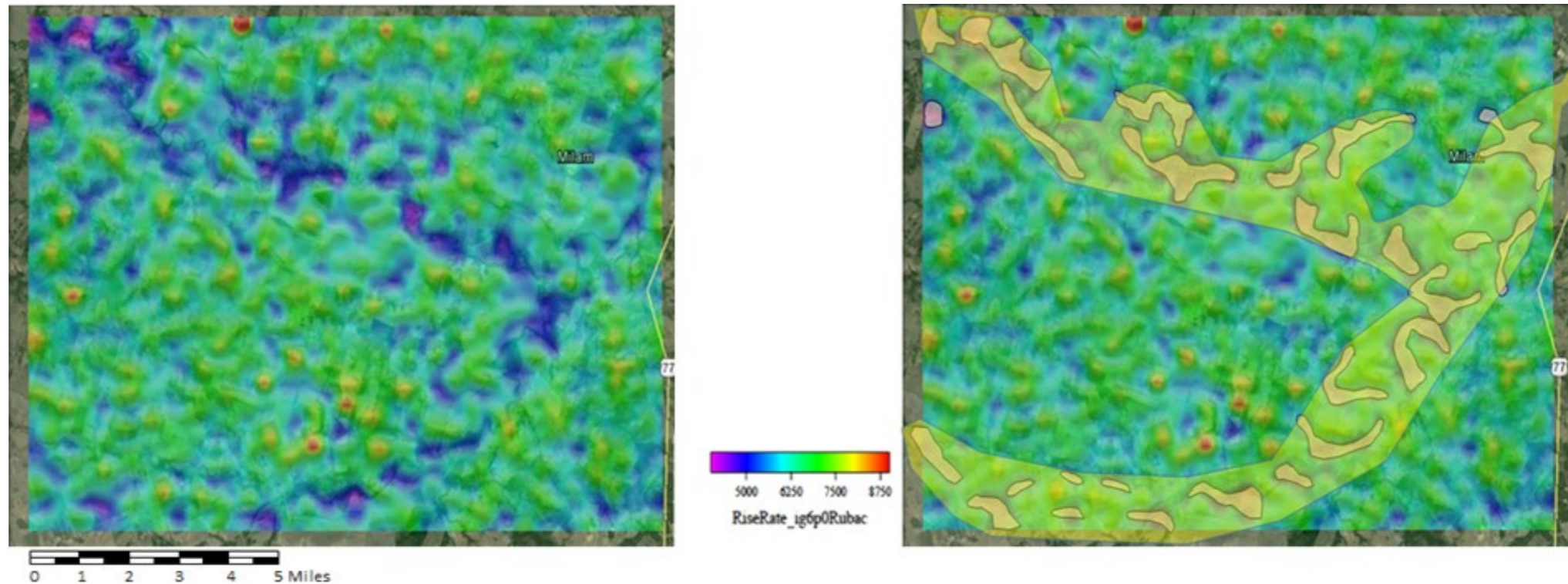
Lightning Attribute: Rate of Rise-Time – Milam County, Texas

4. 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

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Dynamic Measurement LLC.
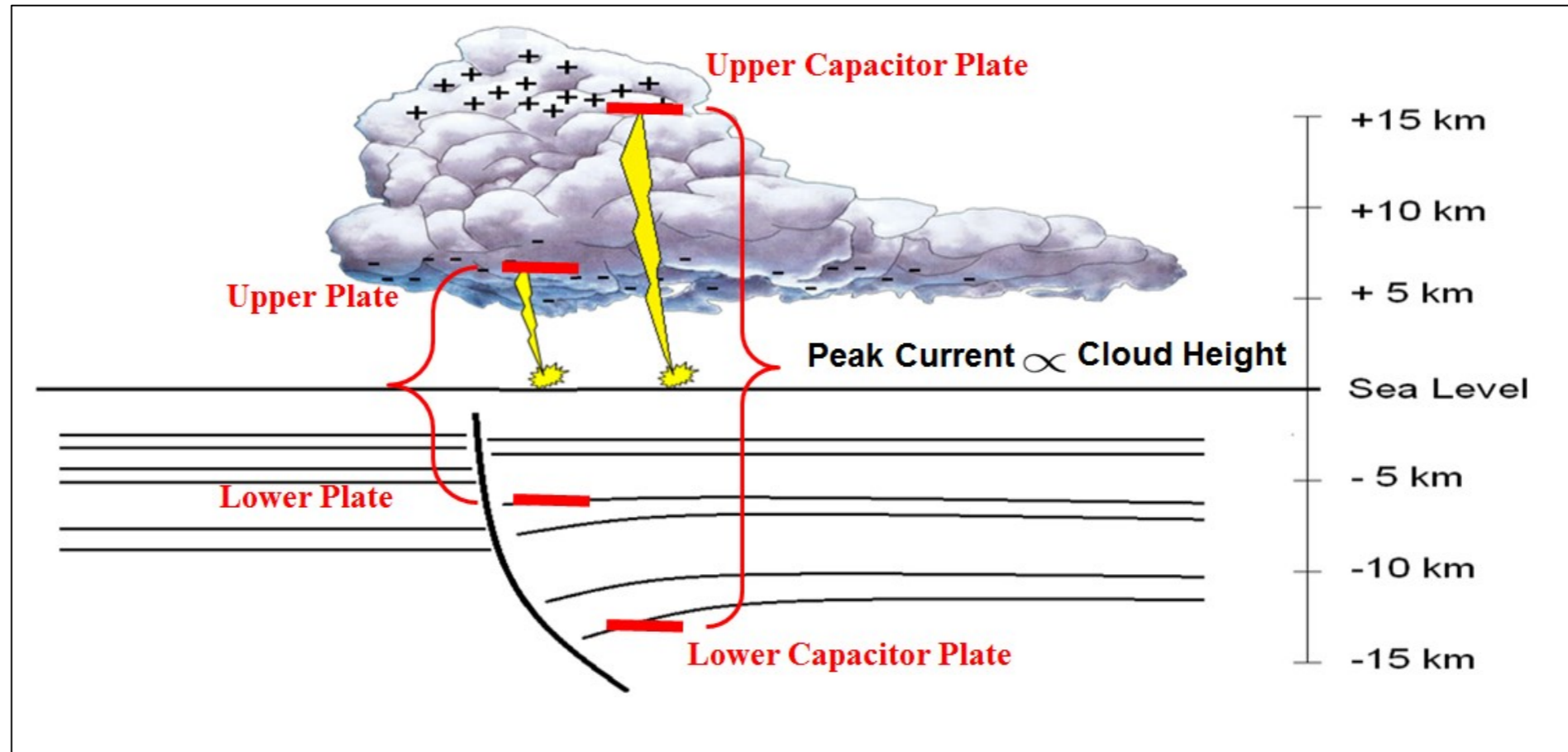
Relaxation Oscillator Physics and Lightning
(a giant neon tube)
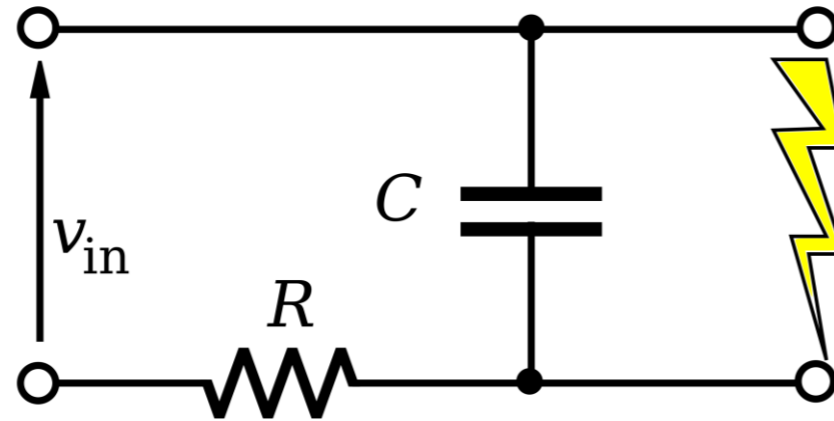
- The atmospheric capacitor is like a relaxation oscillator

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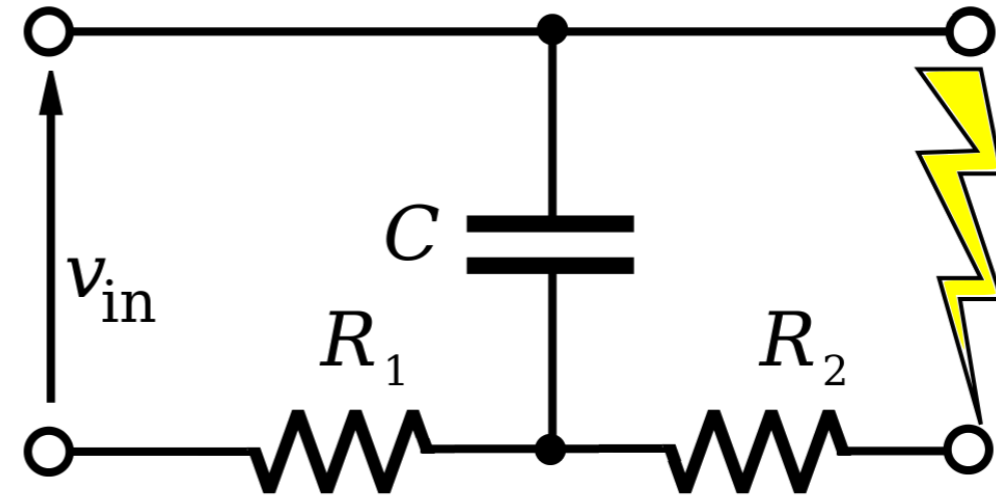
Lightning and the Induced Polarization Effect
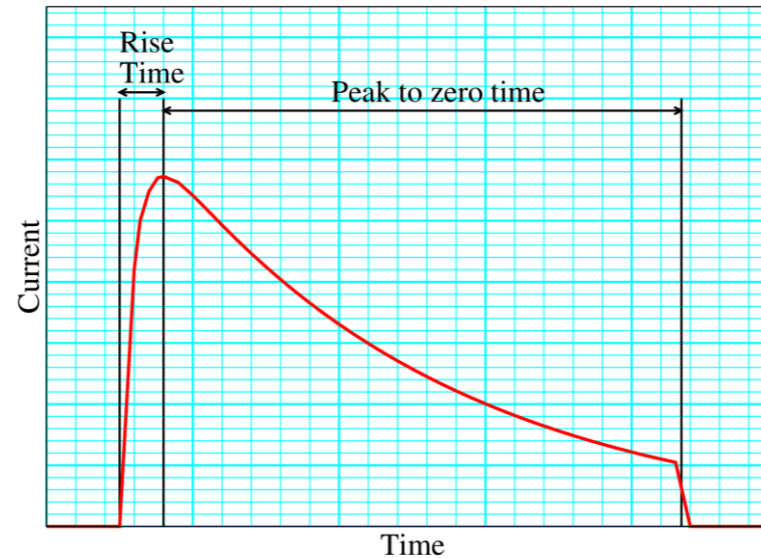
- Lightning does not have a square waveform
- But it does have a very steep onset
- Variations in the onset as measured (rise-time) show the IP Effect

- 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 average permittivity can be calculated
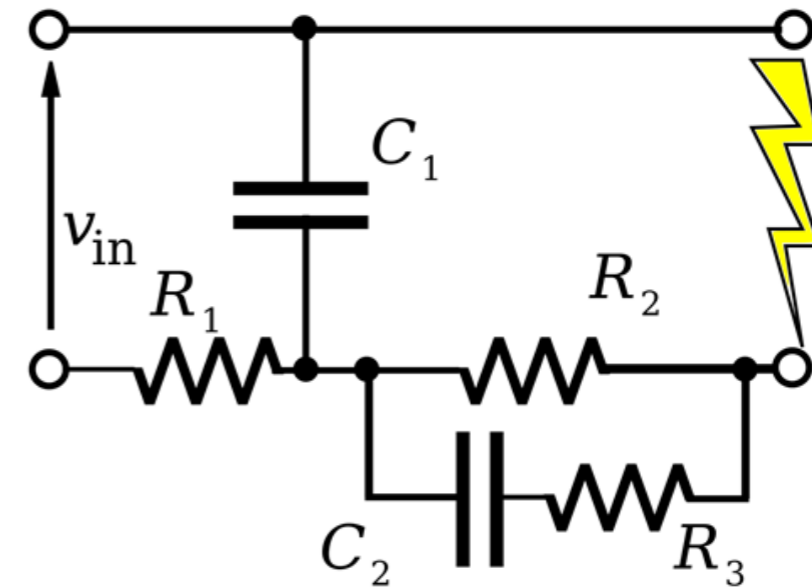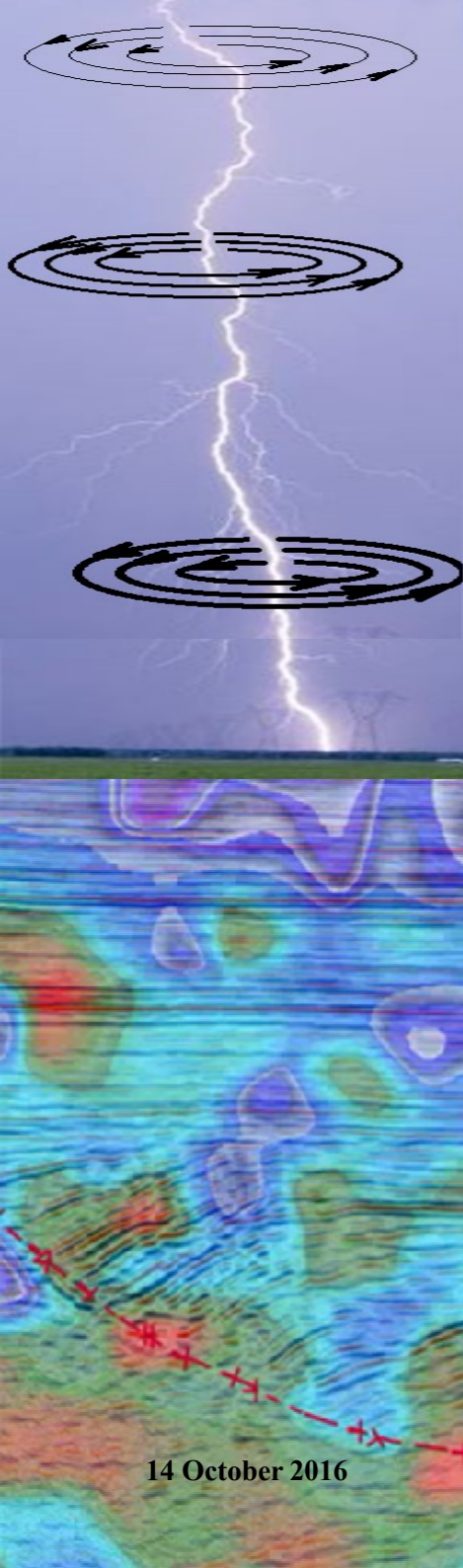
Skin Depth is NOT the Controlling Factor

Charging Telluric Currents:

Lightning strikes are passive energy pulses, and contain all frequencies.

The skin effect of the high frequency information recorded in the ~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:

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.

Stratton Seismic Sections, South Texas

Frio Horizons
Fluvial – Deltaic
Sands
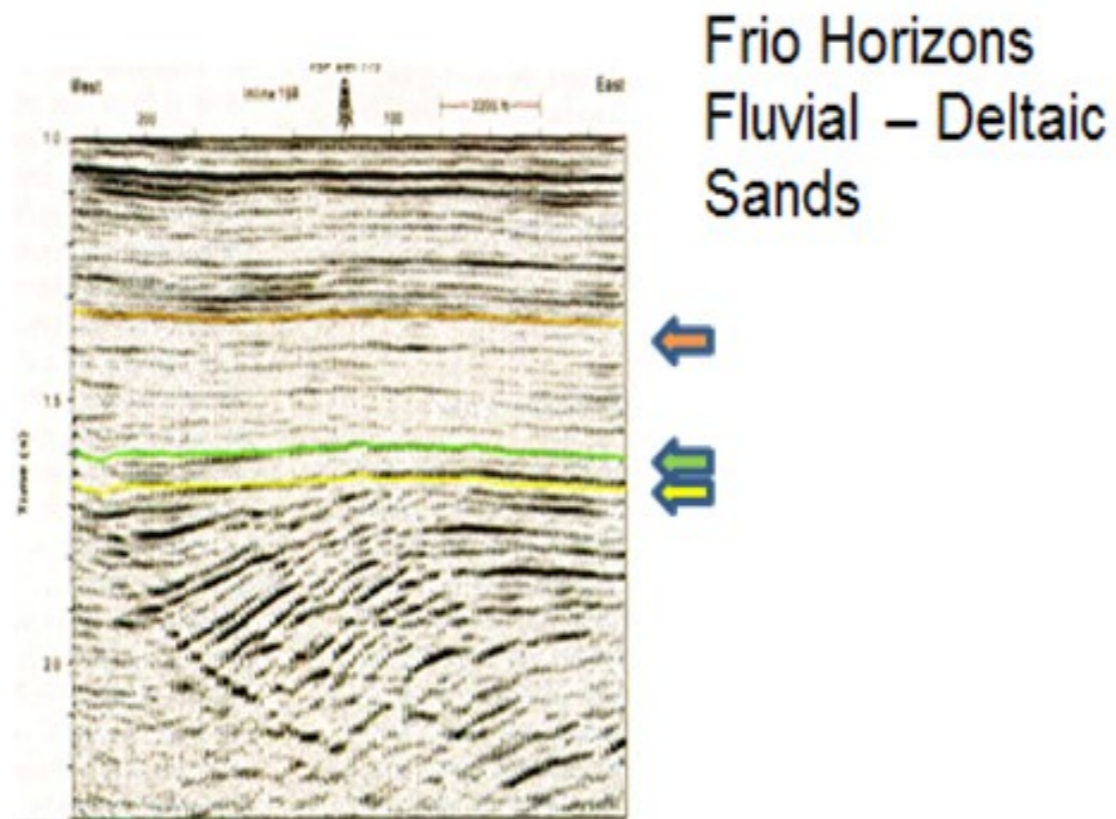
Published BEG Stratton
Data to 2.3 seconds
(Hardage, 1986)

Public Stratton
Seismic to 3.0 Seconds
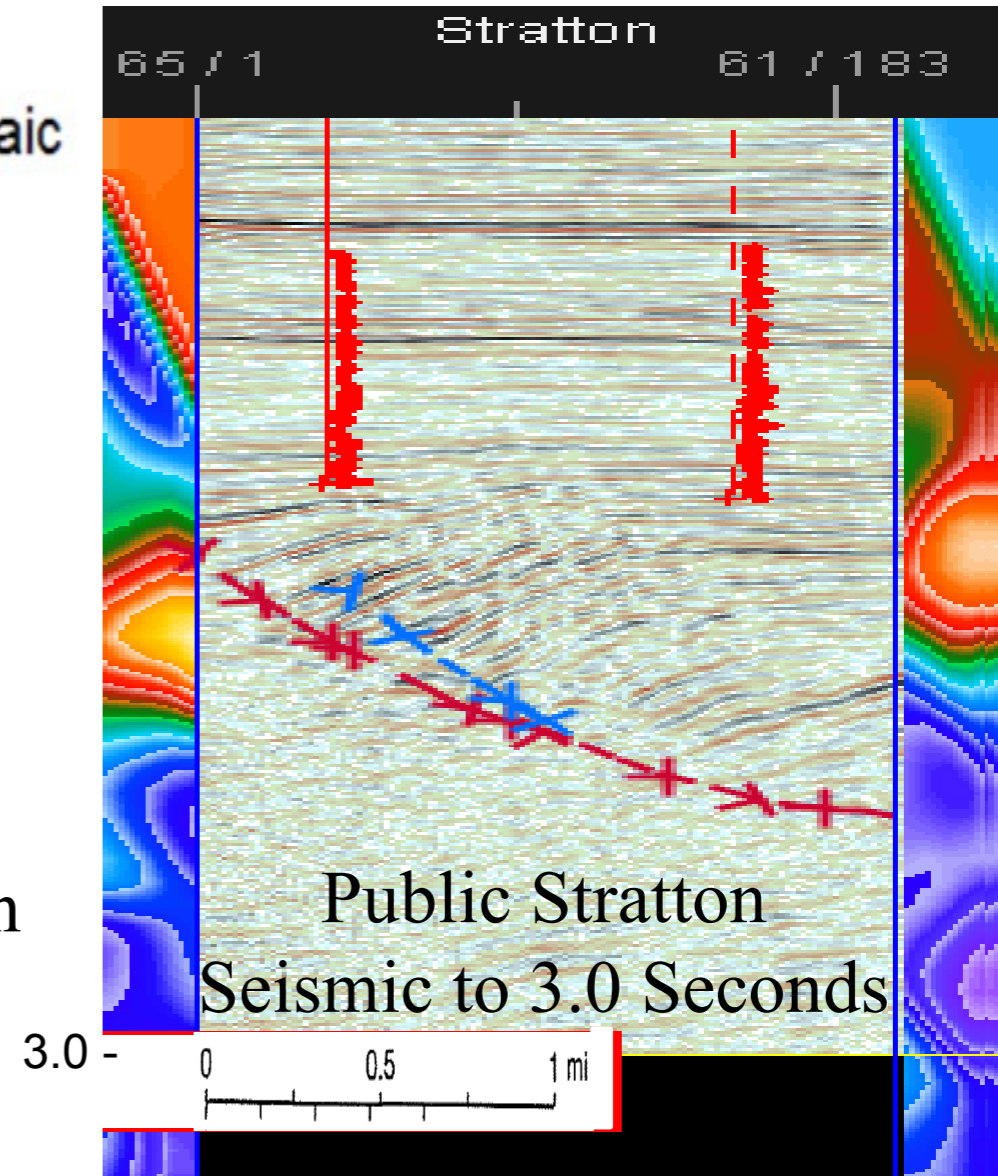
Study Area around Corpus Christi

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

http://www.beg.utexas.edu/agi/mod08/m08-kb02.htm
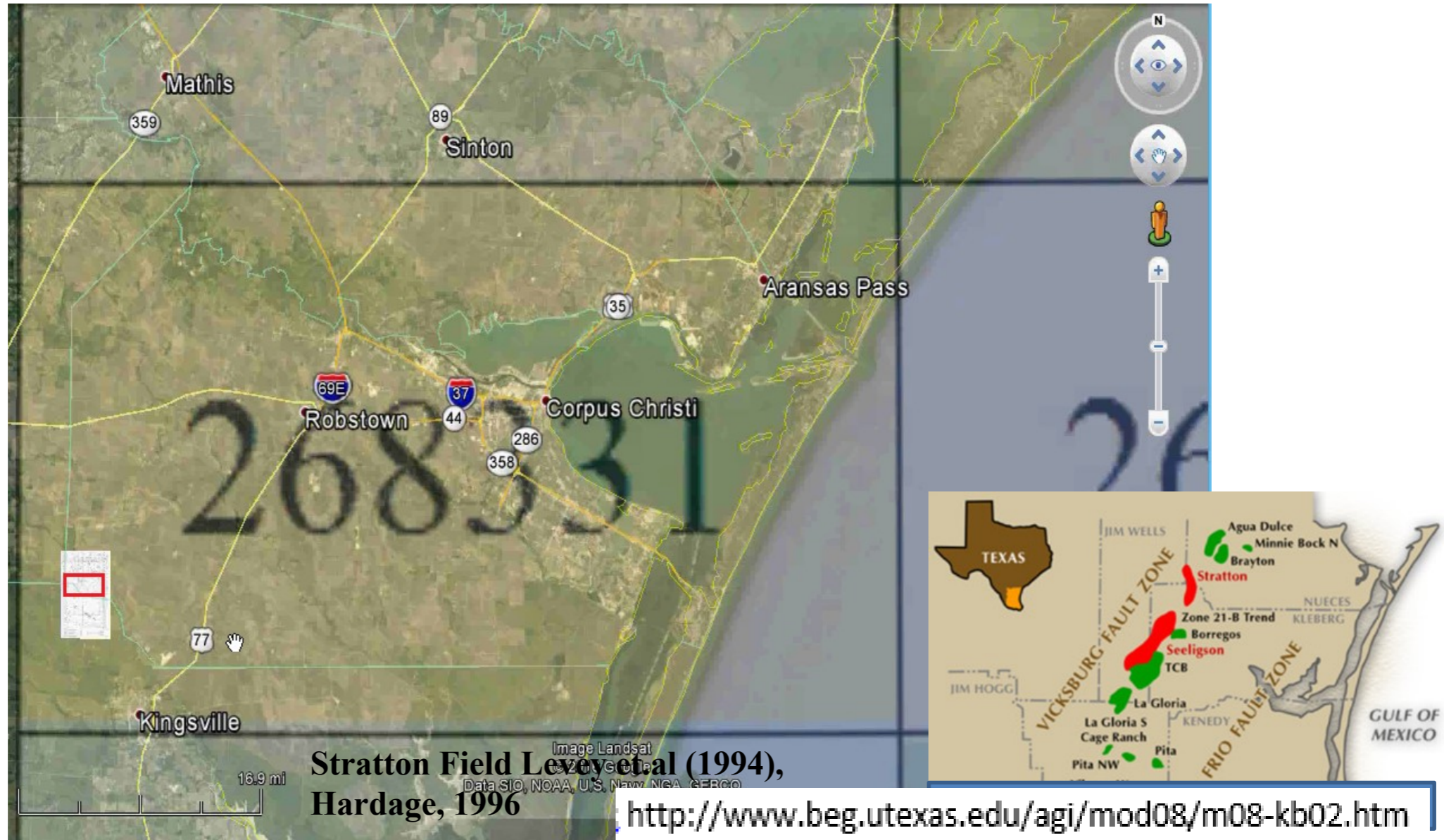
Stratton Apparent Resistivity Sections
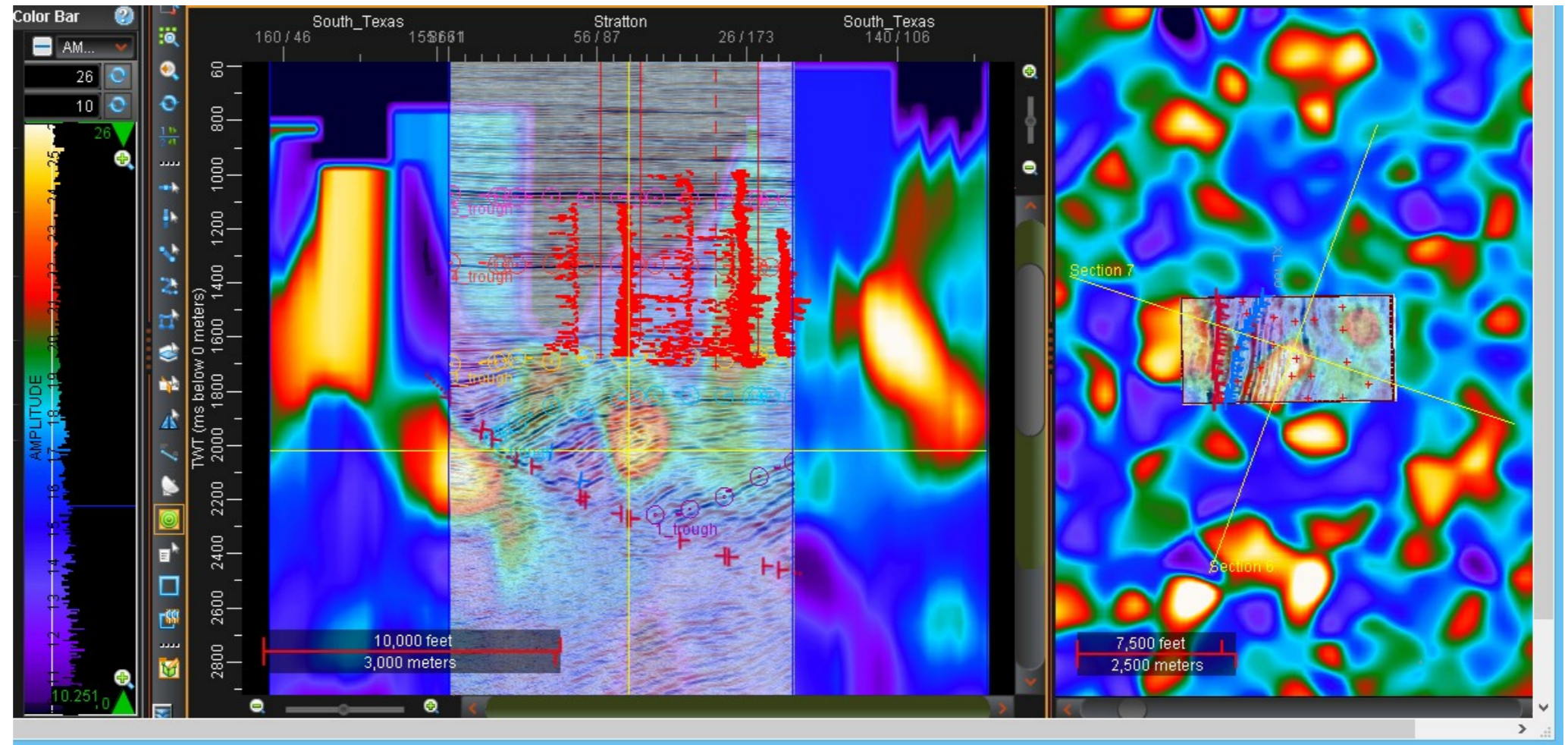
Working on calibrating depth and calculated vs. measured resistivity

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

From Levey, et al,1994
Bebout and others,1982
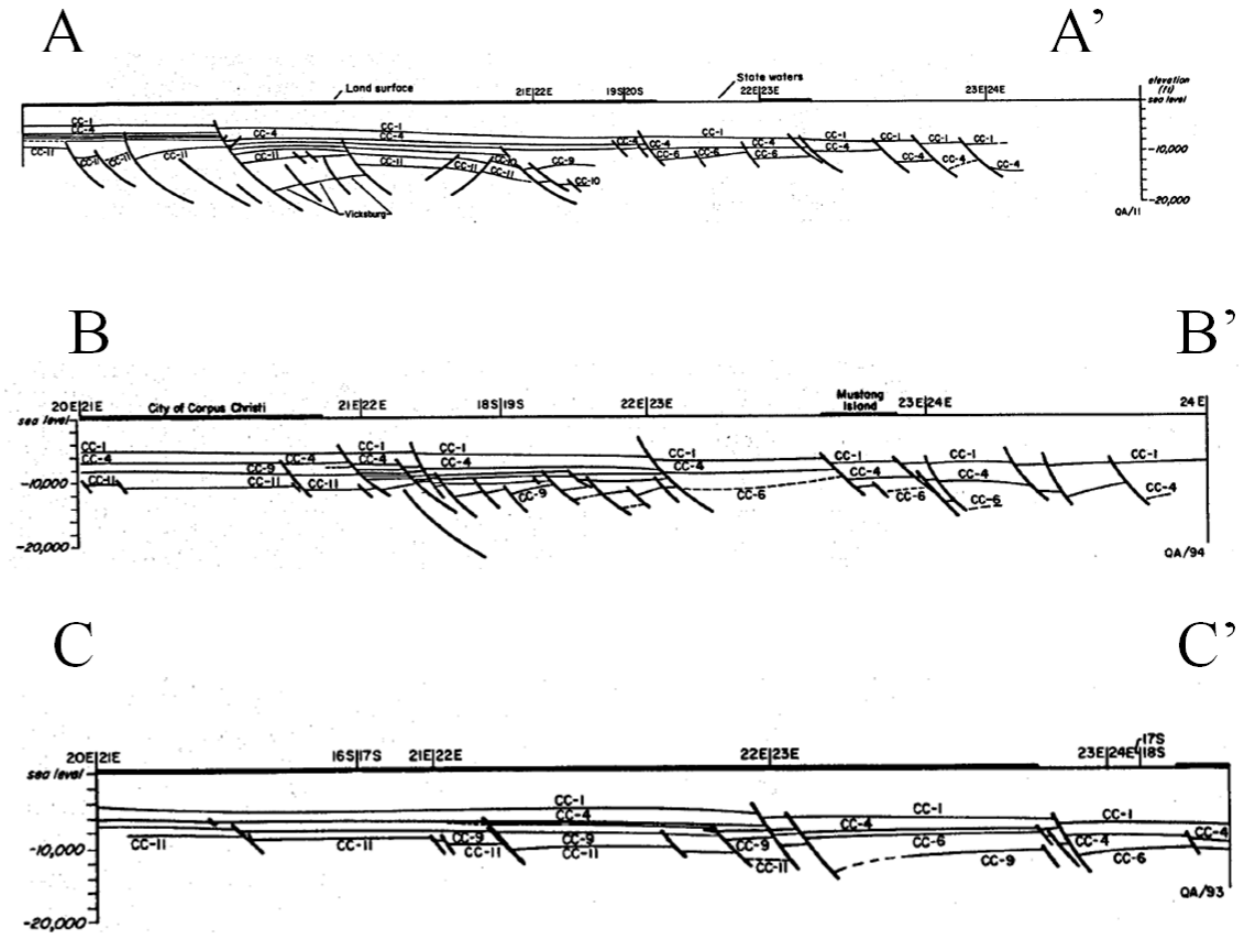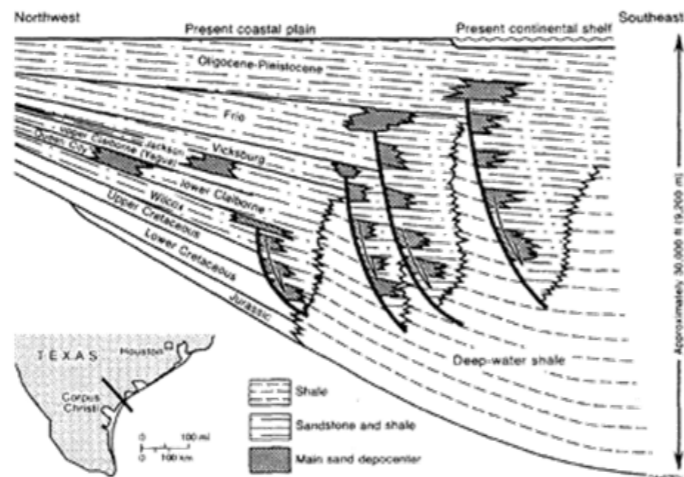
2016 Lightning Derived Resistivity Cross-Sections Match Geology on 1986 Ewing Interpretation Overlay
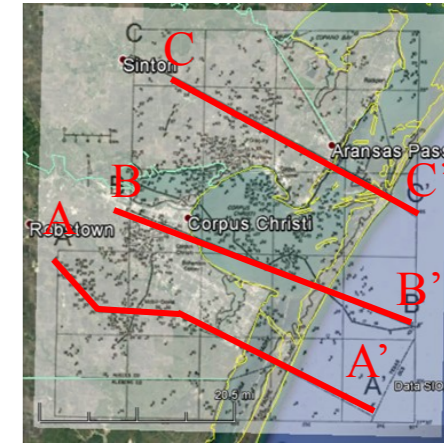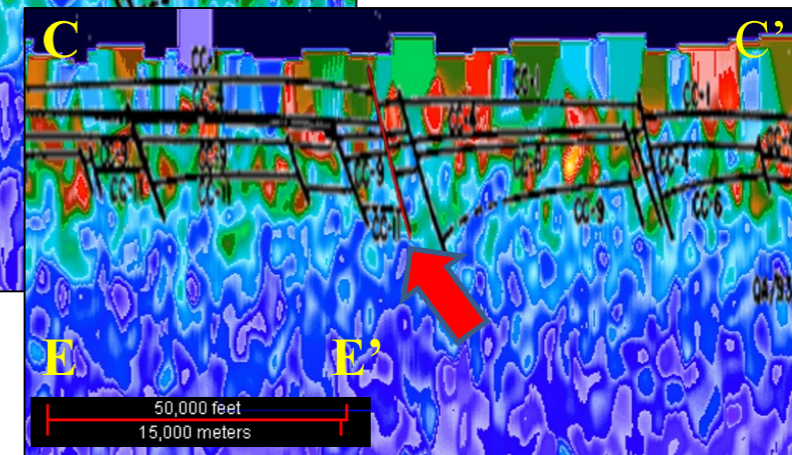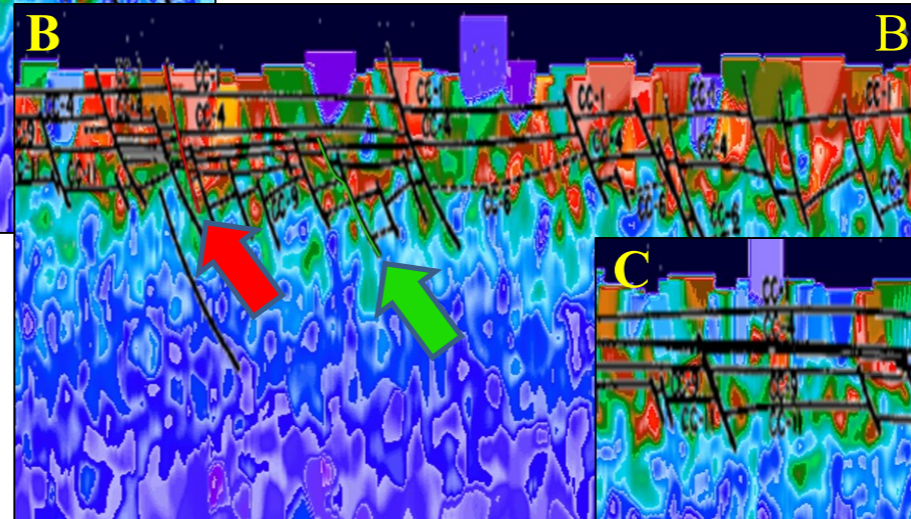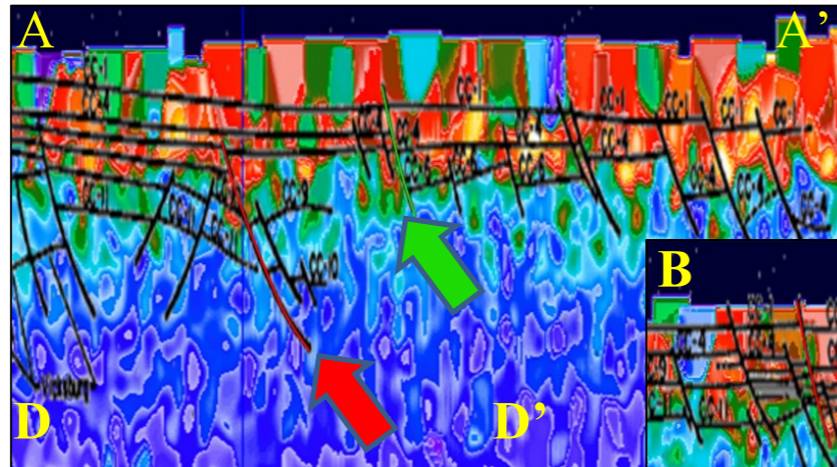
Red and Green Arrows
show faults correlated
between Ewing cross-sections
using Ewing fault plane maps

(Fault Overlays Ewing 1986)

D-D' Close-Up on Graben on A-A' without overlay
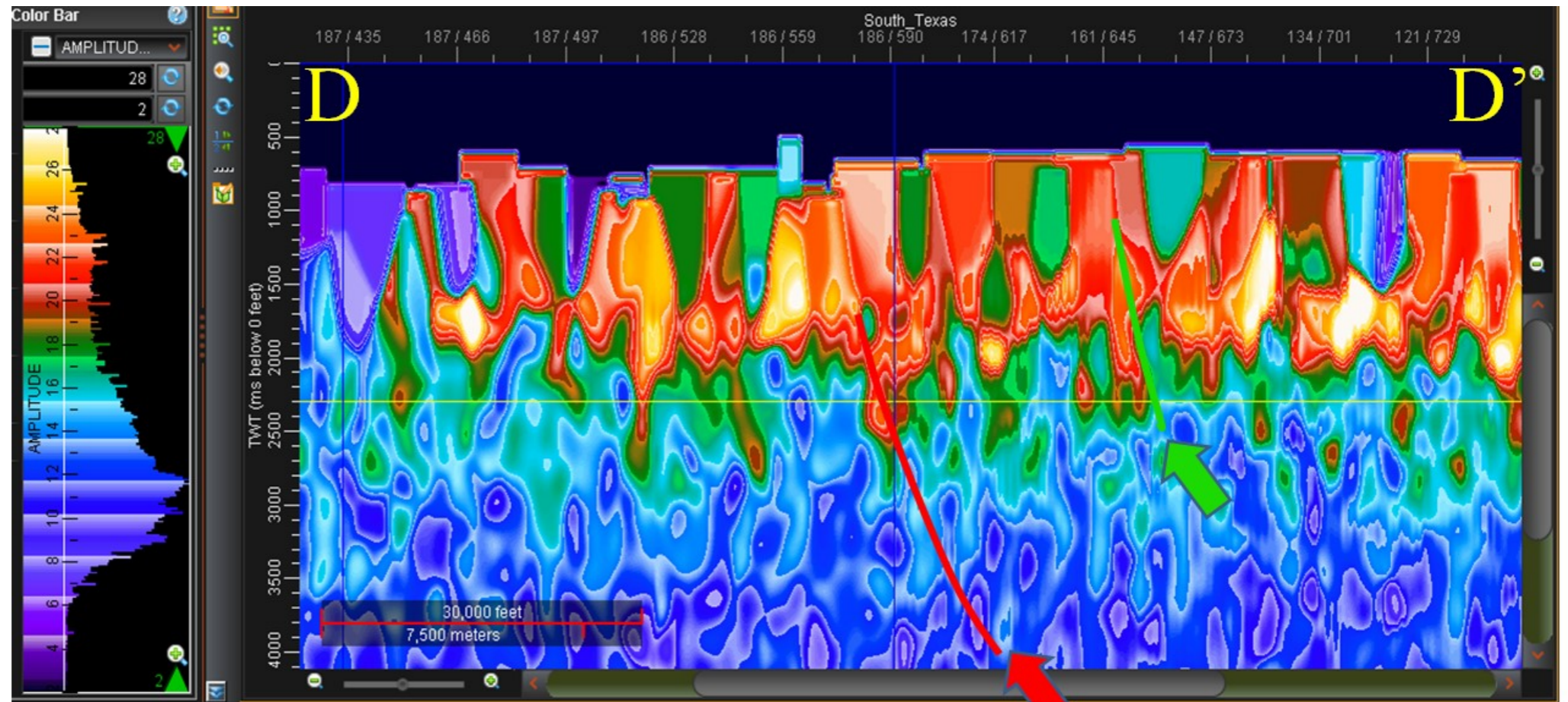
Red and Green Faults were major faults on Ewing's maps. Note high apparent resistivity (bright) appear to have plumes above these faults.

D-D' Close-Up on Graben to the west
Interpretation 1986 by Tom Ewing, Apparent Resistivity 2016 from Lightning Databases
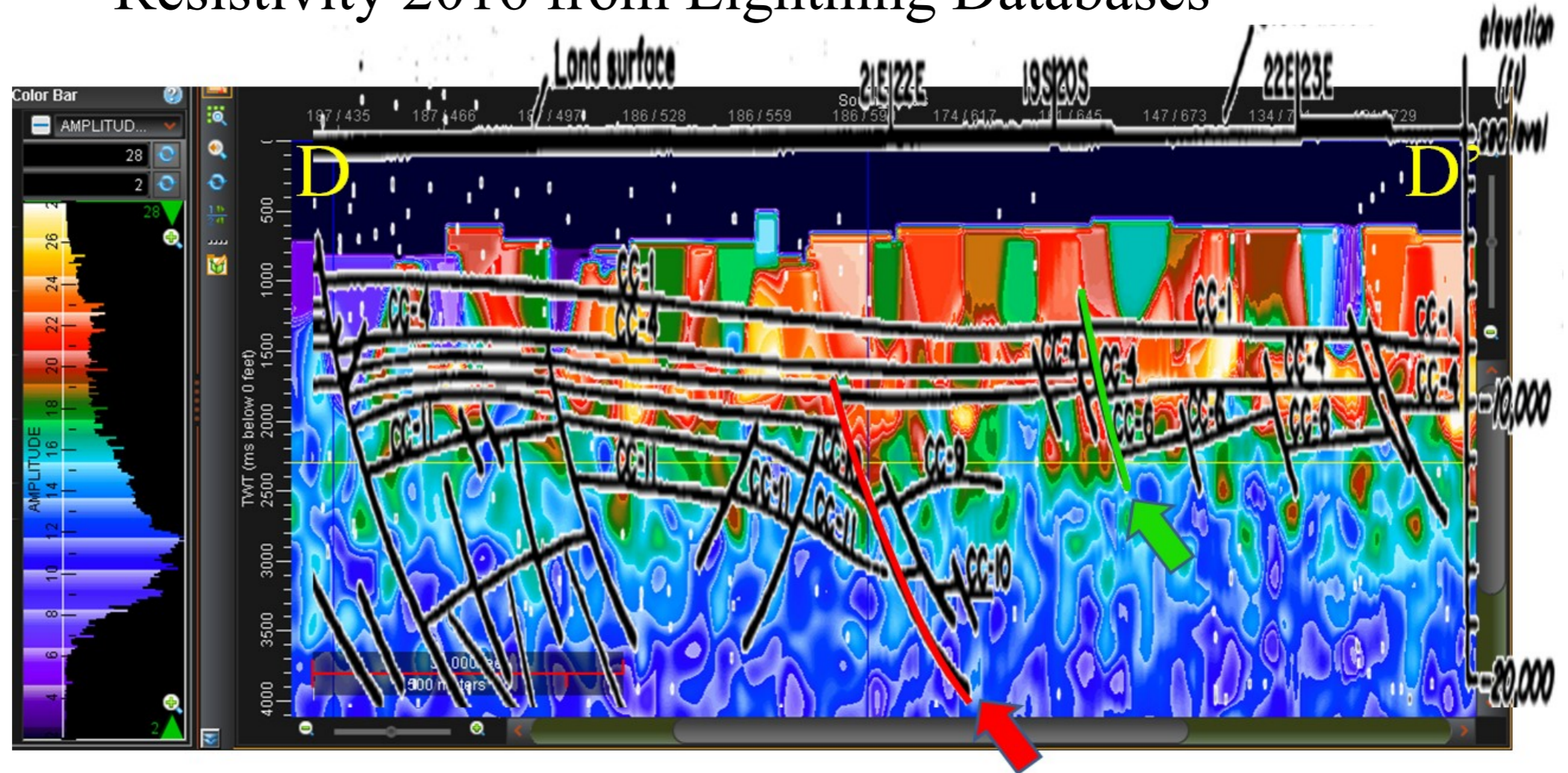
Note: interpretation by Tom Ewing in 1986. The resistivity section calculated from lightning in 2016. Co-located sections show breaks where faults were interpreted. There are resistivity plumes tied to faults.

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

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

556 / 606   530 / 661   503 / 716

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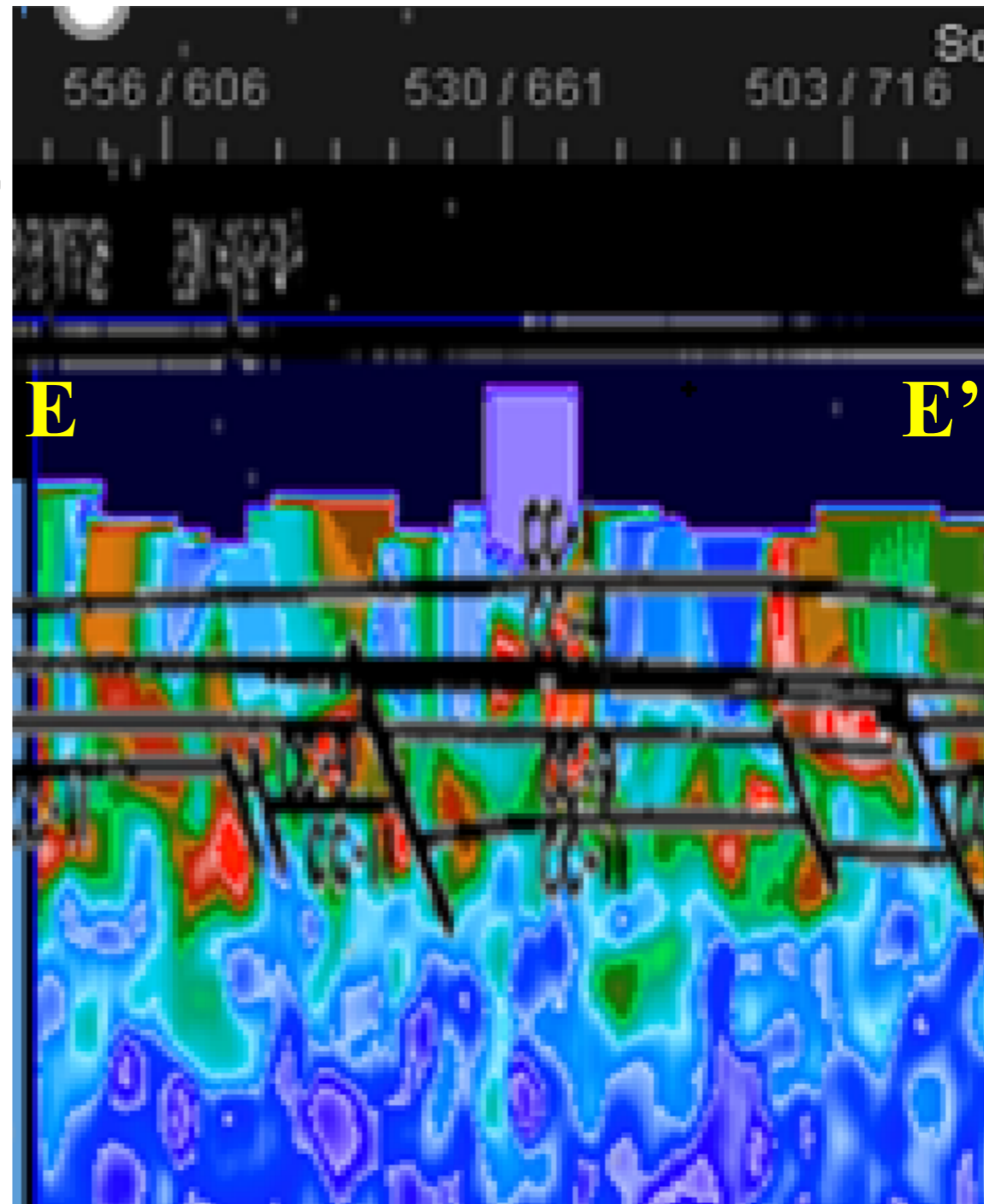
Apparent Resistivity
Extension of Ewing (1986) A-A'
through Stratton seismic data

(ohm-meters)

1 of 18 Lightning Attributes - Density

(Strikes per square kilometer)
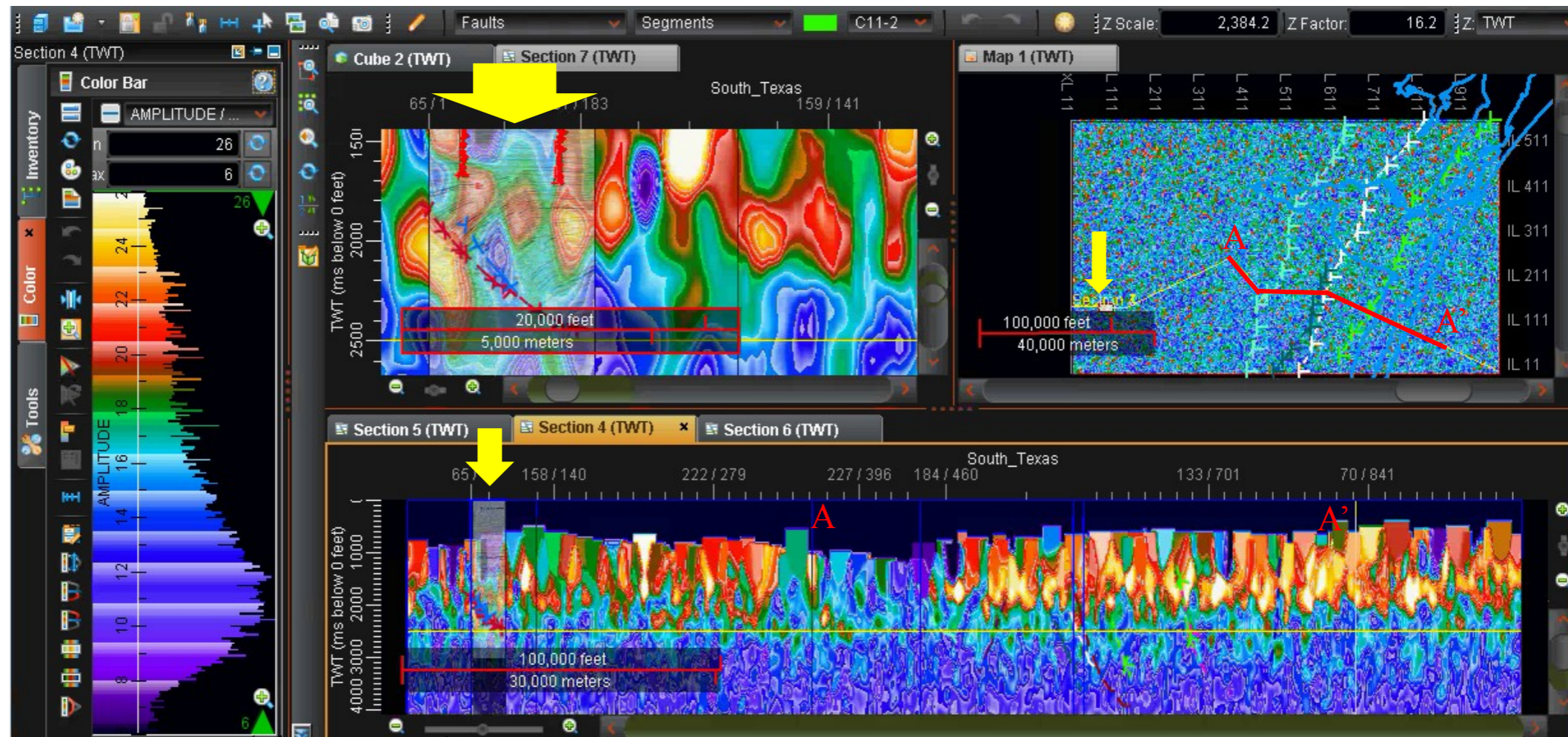
2 of 18 Lightning Attributes - Day of Year
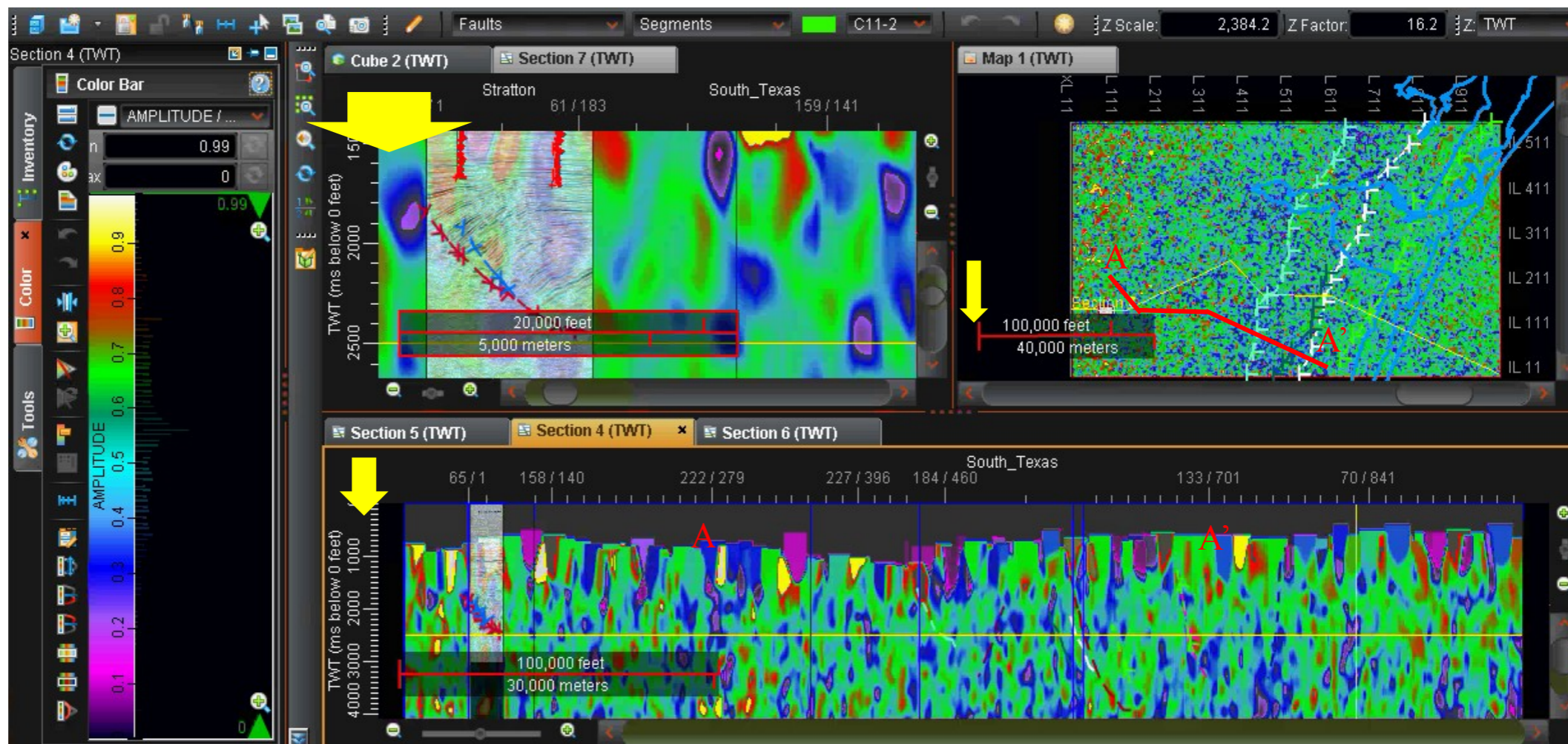
(Decimal fraction calendar year)

3 of 18 Lightning Attributes - Energy
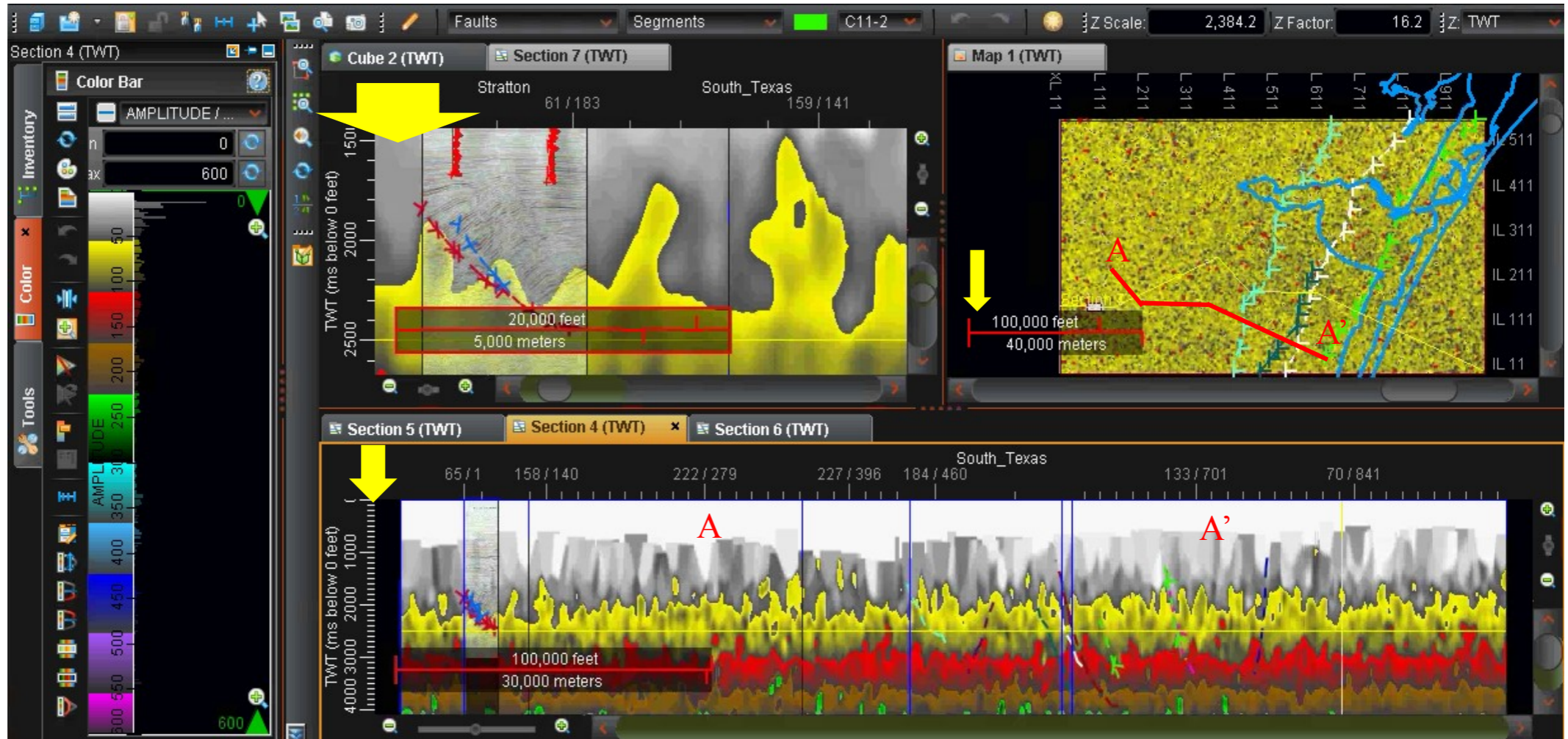
(milli-ampere-seconds)
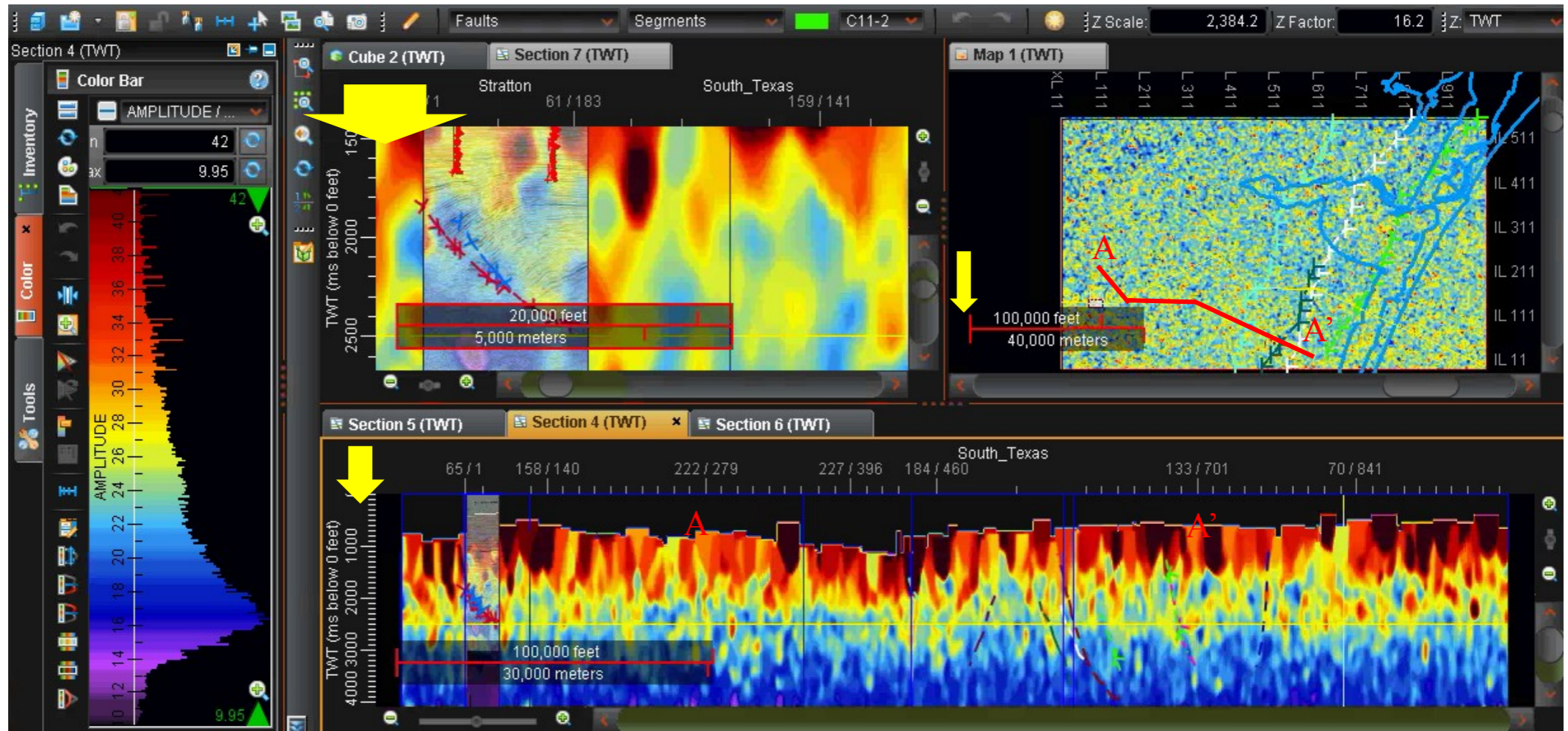
(kilohertz)

(degrees [-180 to 180]s)

6 of 18 Lightning Attributes - Moon Phase
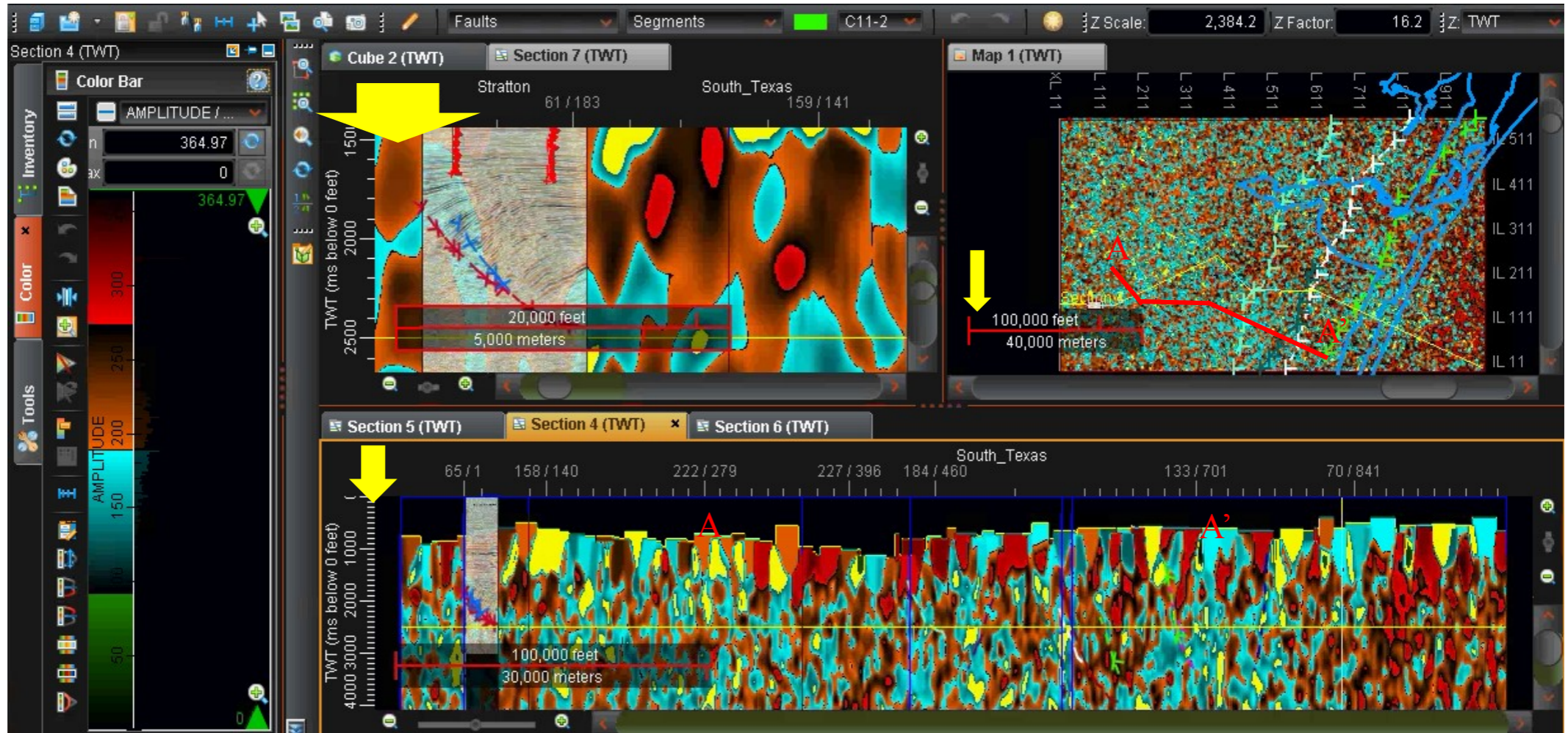
(degrees [0-360])

(microseconds)

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Dynamic Measurement LLC.

8 of 18 Lightning Attributes - Peak Current
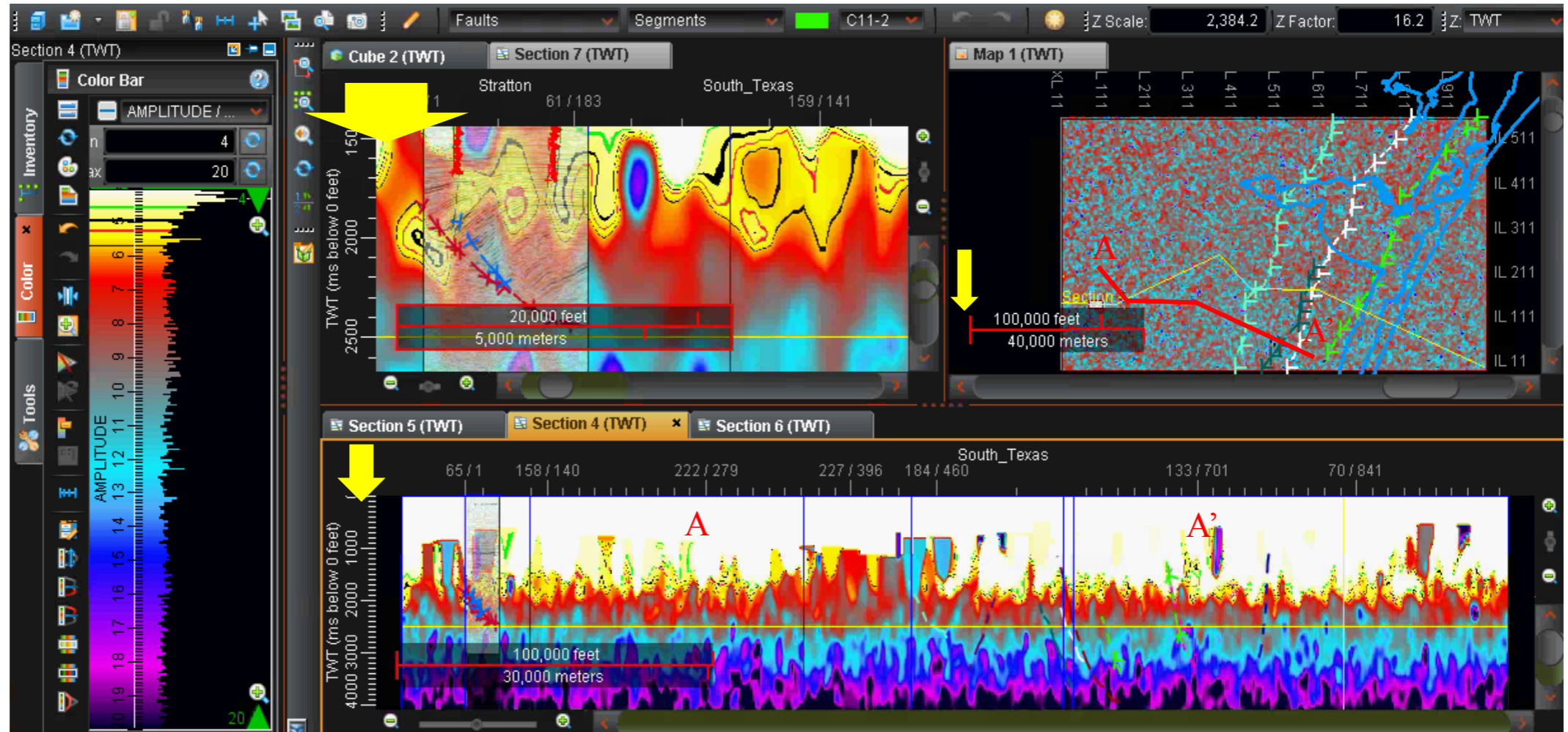
(kilo-amperes)
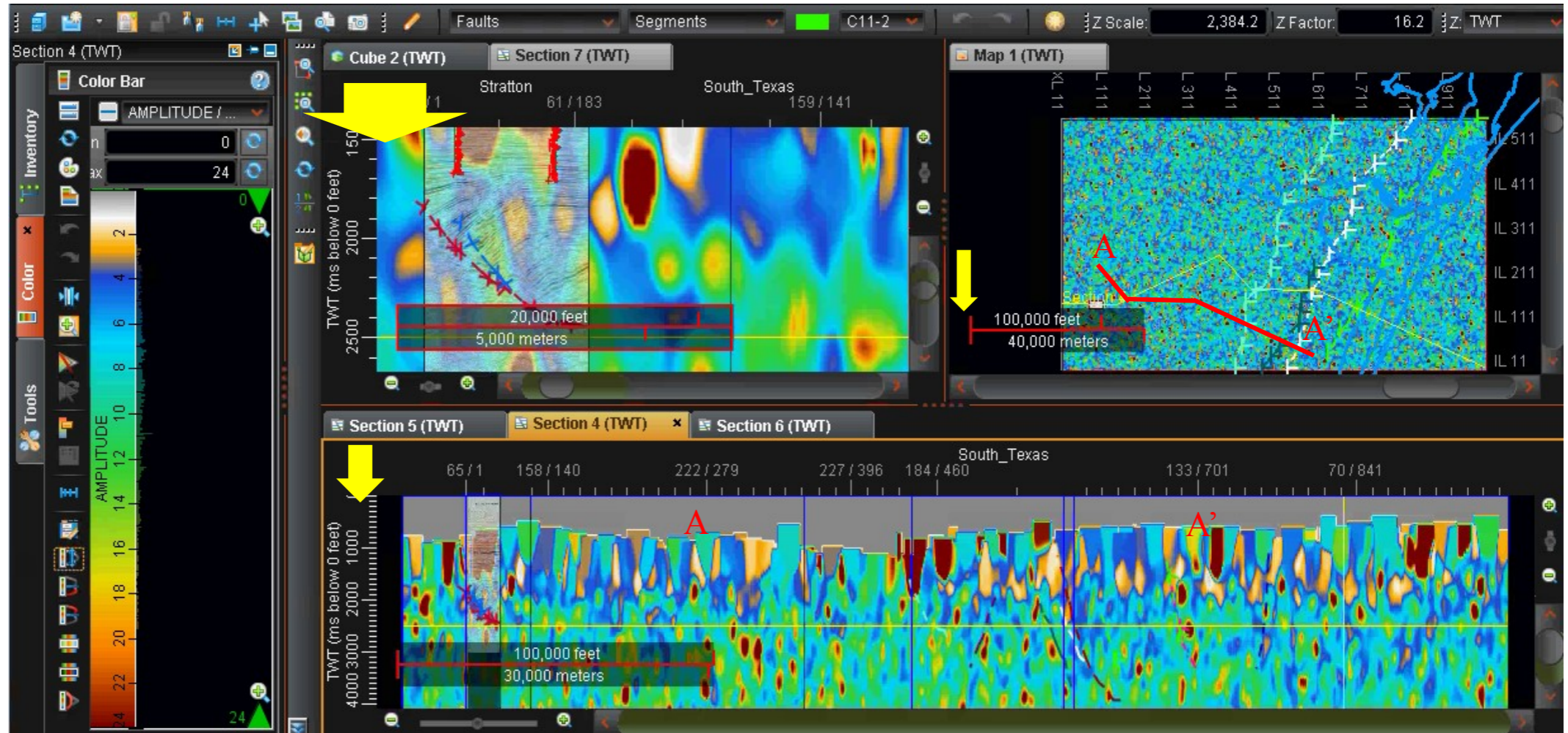
Copyright © 2016
Dynamic Measurement LLC.

(microfarads per meter)

Used to correlate Ewing's 1986 cross-sections

(ohm-meters)

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Dynamic Measurement LLC.
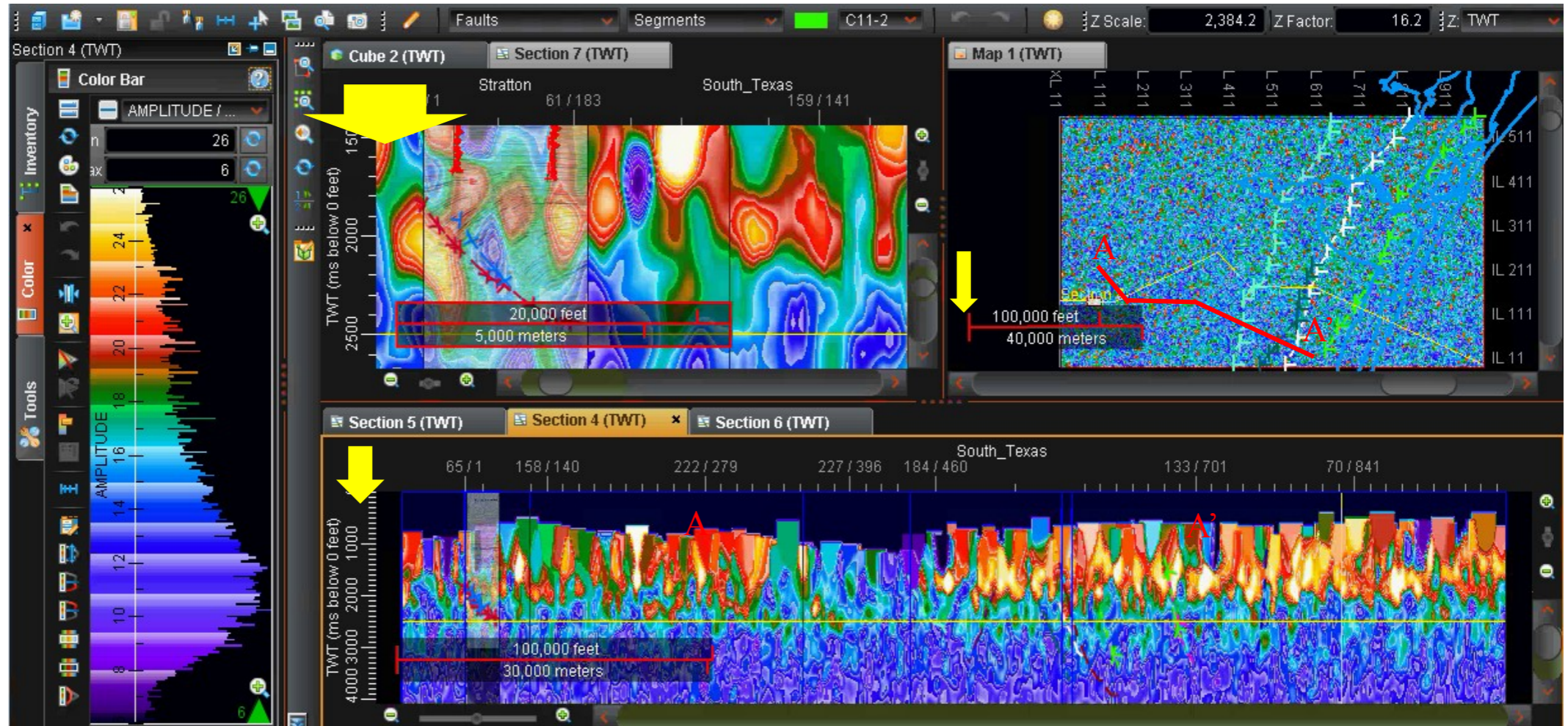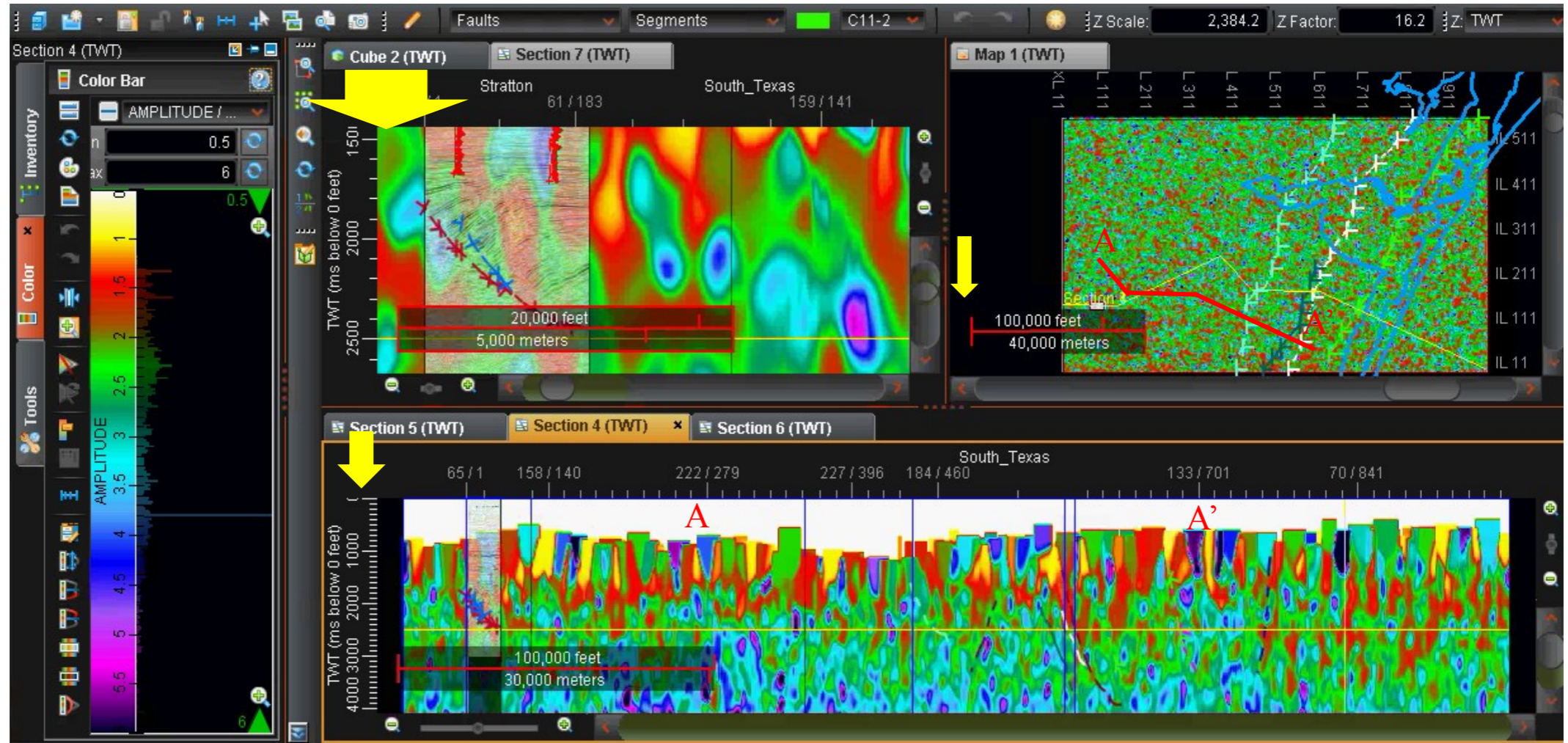
(microseconds)

12 of 18 Lightning Attributes - Spike
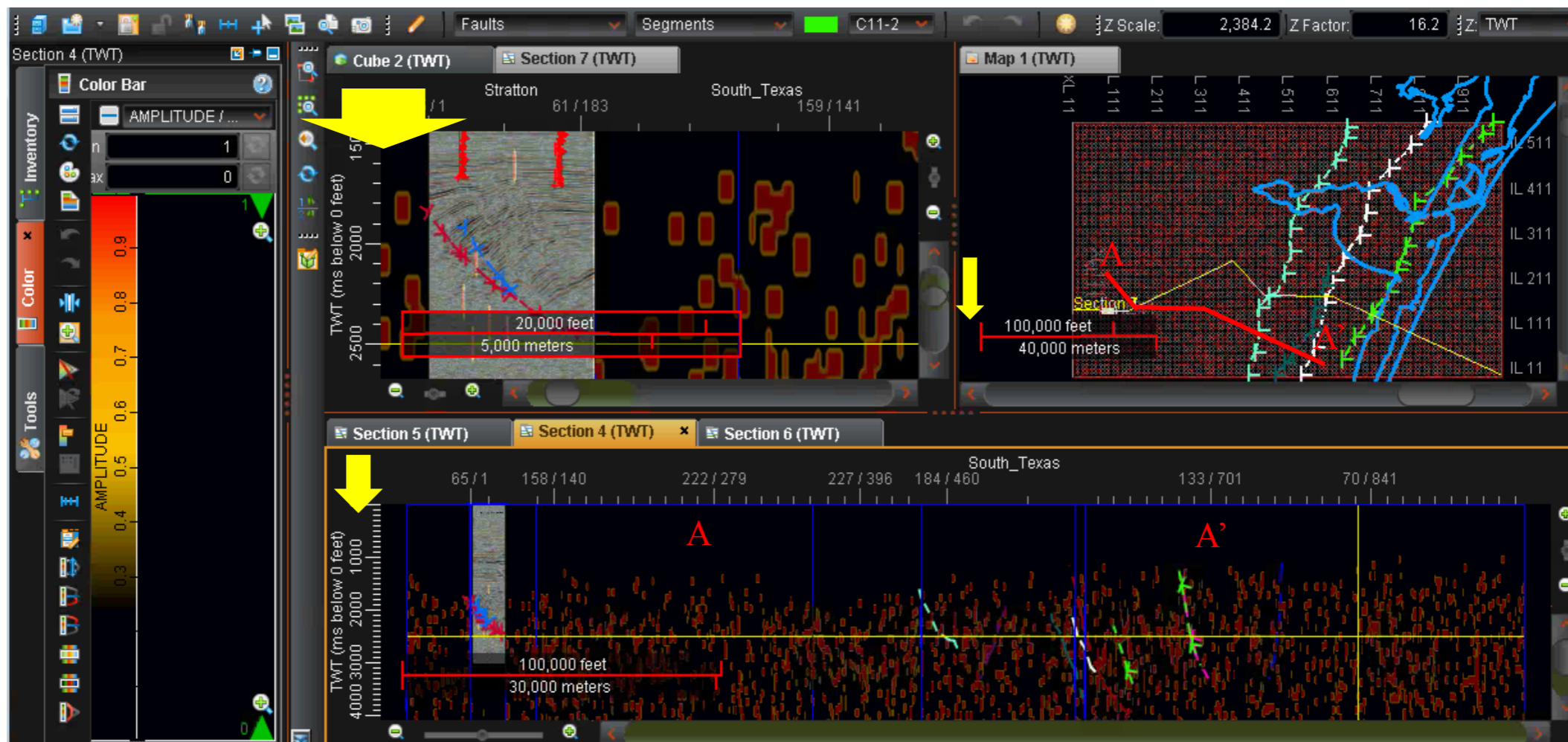
(position of strike)
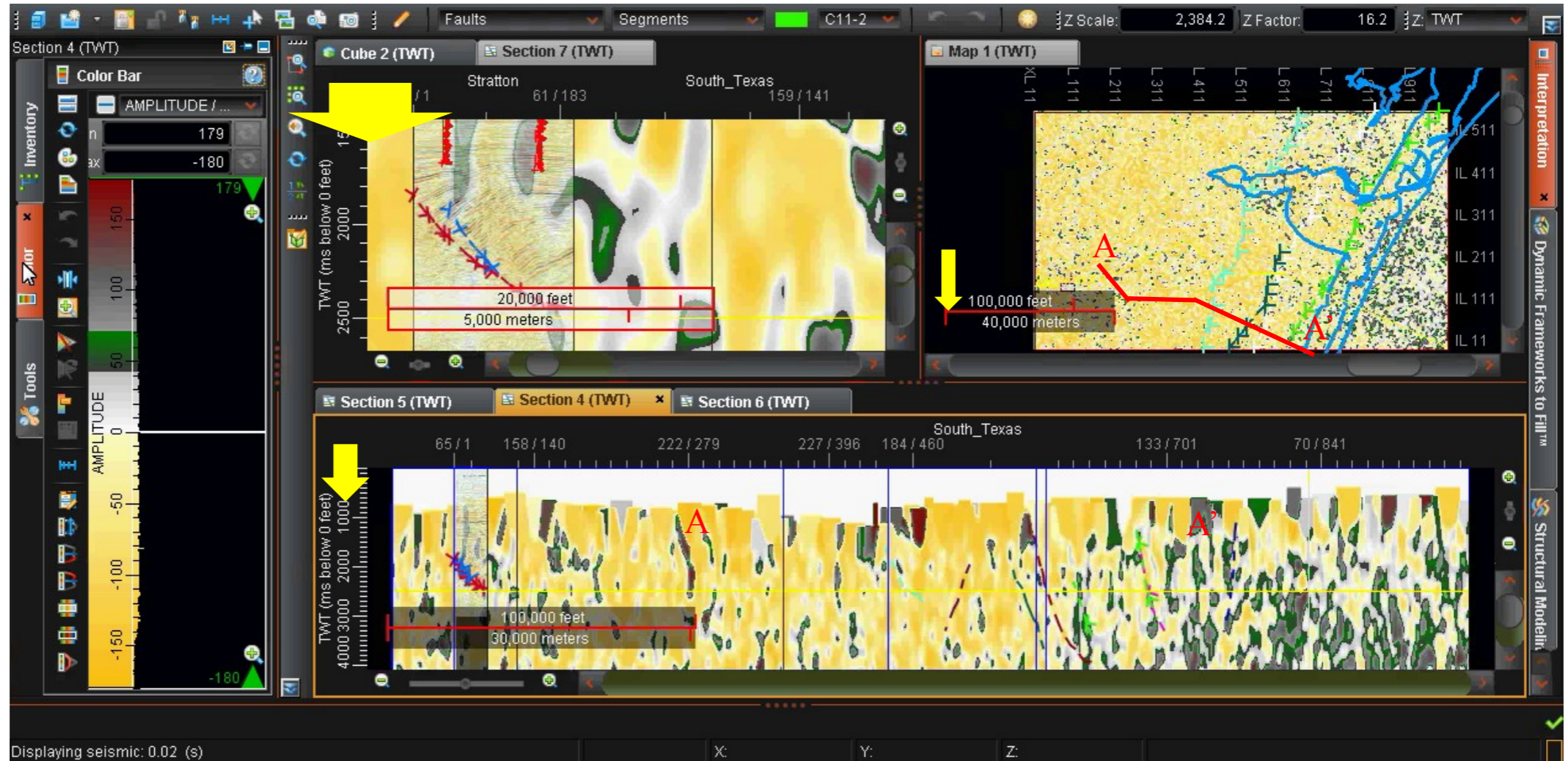
(degrees [-180 to 180])

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

Copyright © 2016
Dynamic Measurement LLC.
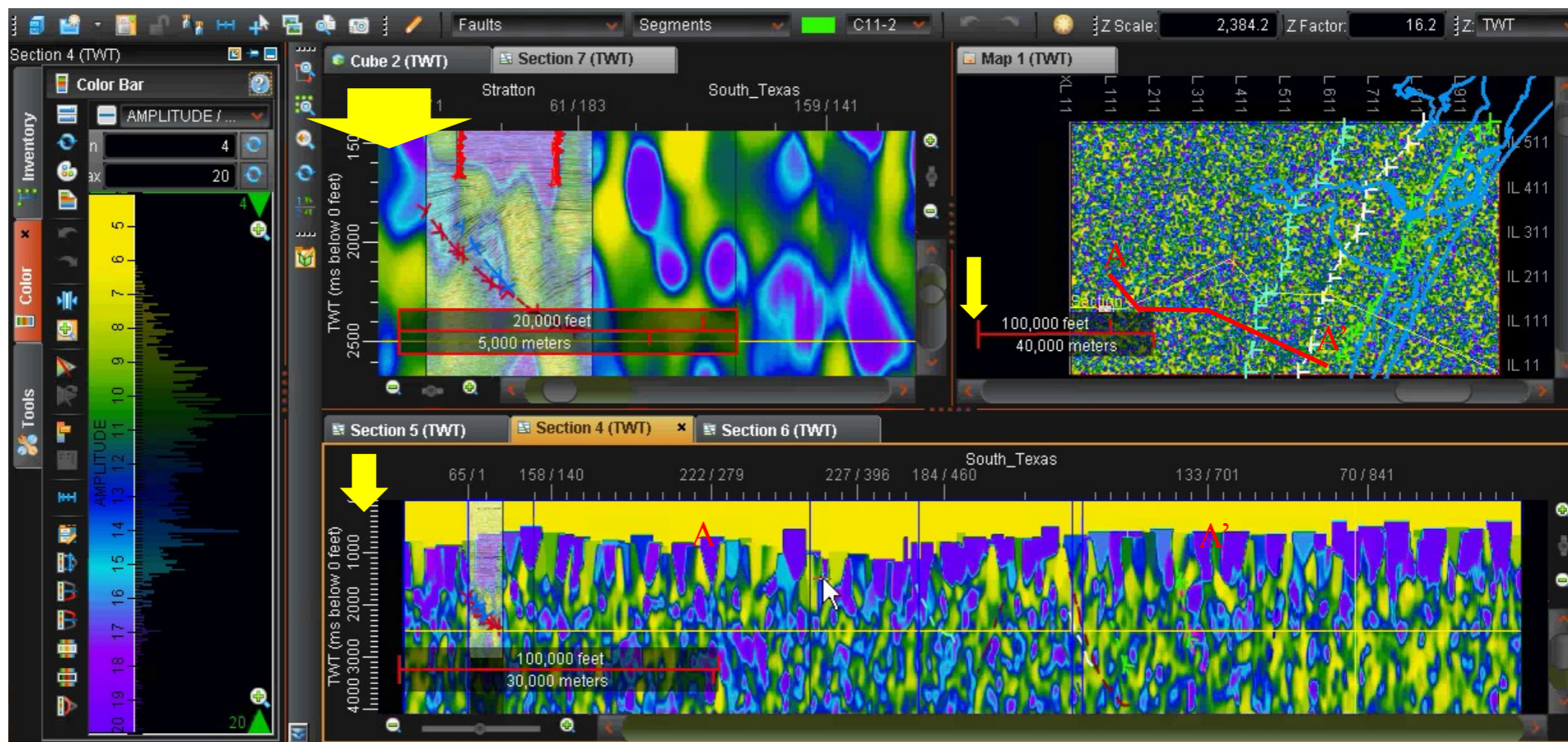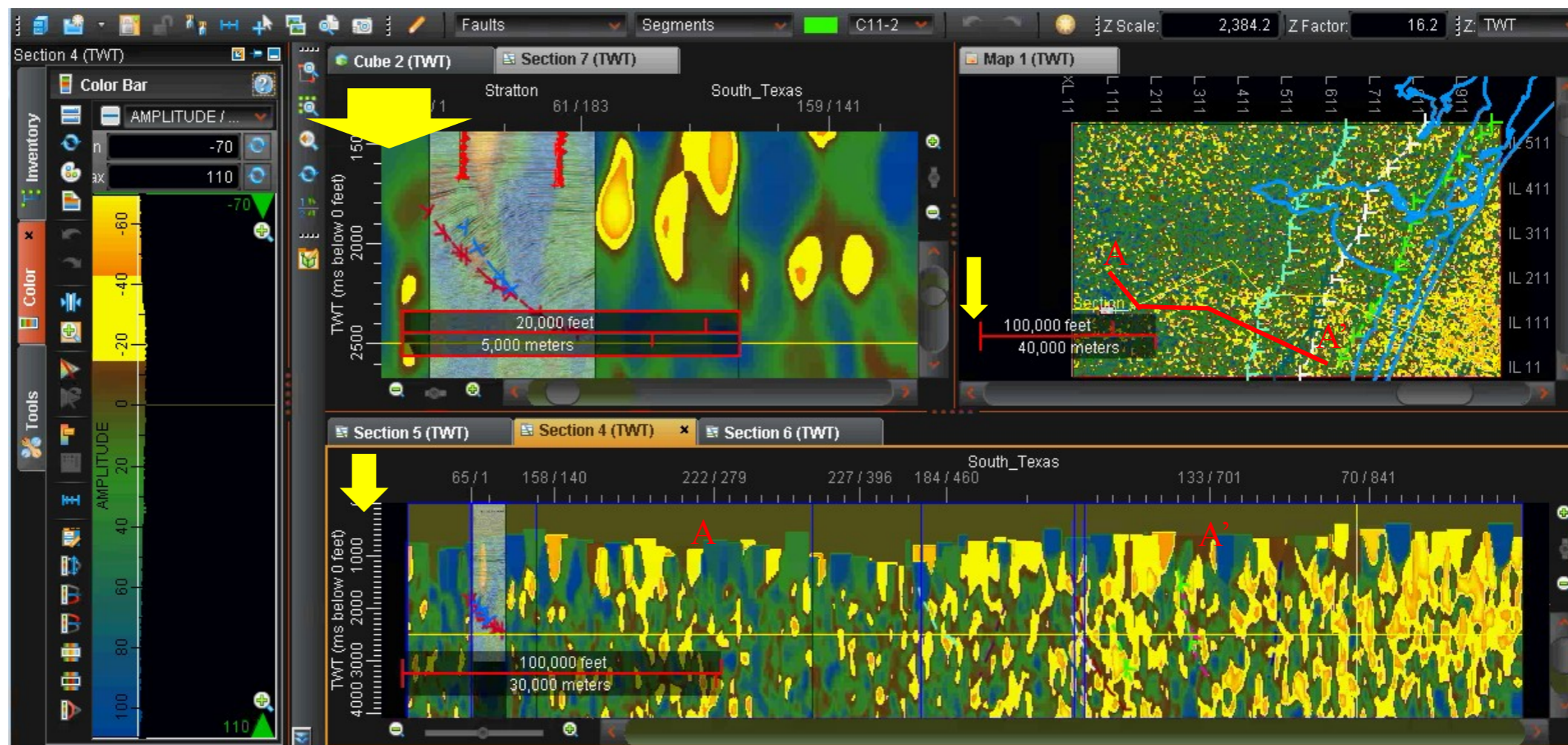
(microgals)

([-1.0: low spring tide; 0.0: mean tide; 1.0: high spring tide])
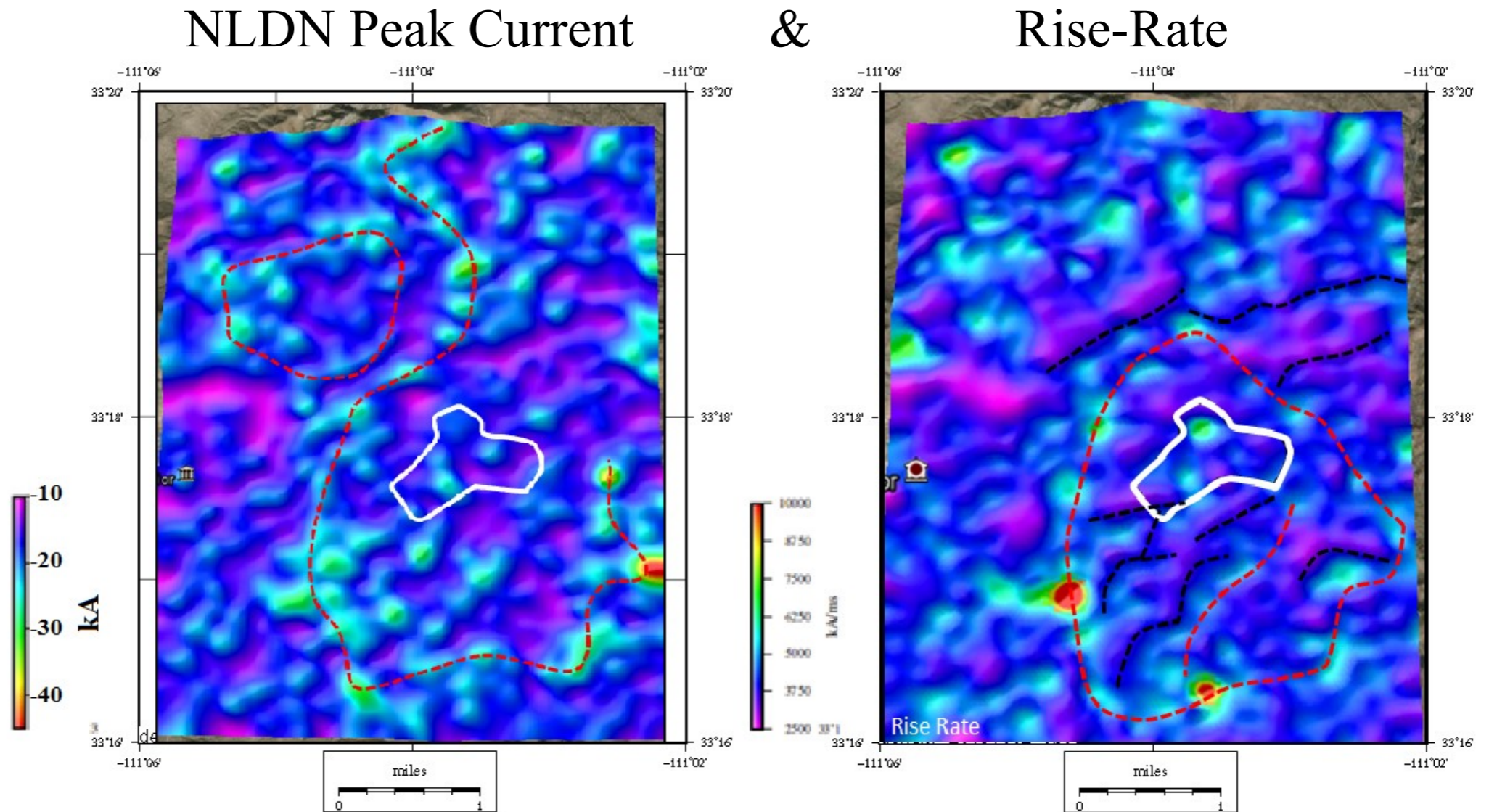
(first derivative of Tide)

18 of 18 Lightning Attributes - Total Wavelet Time
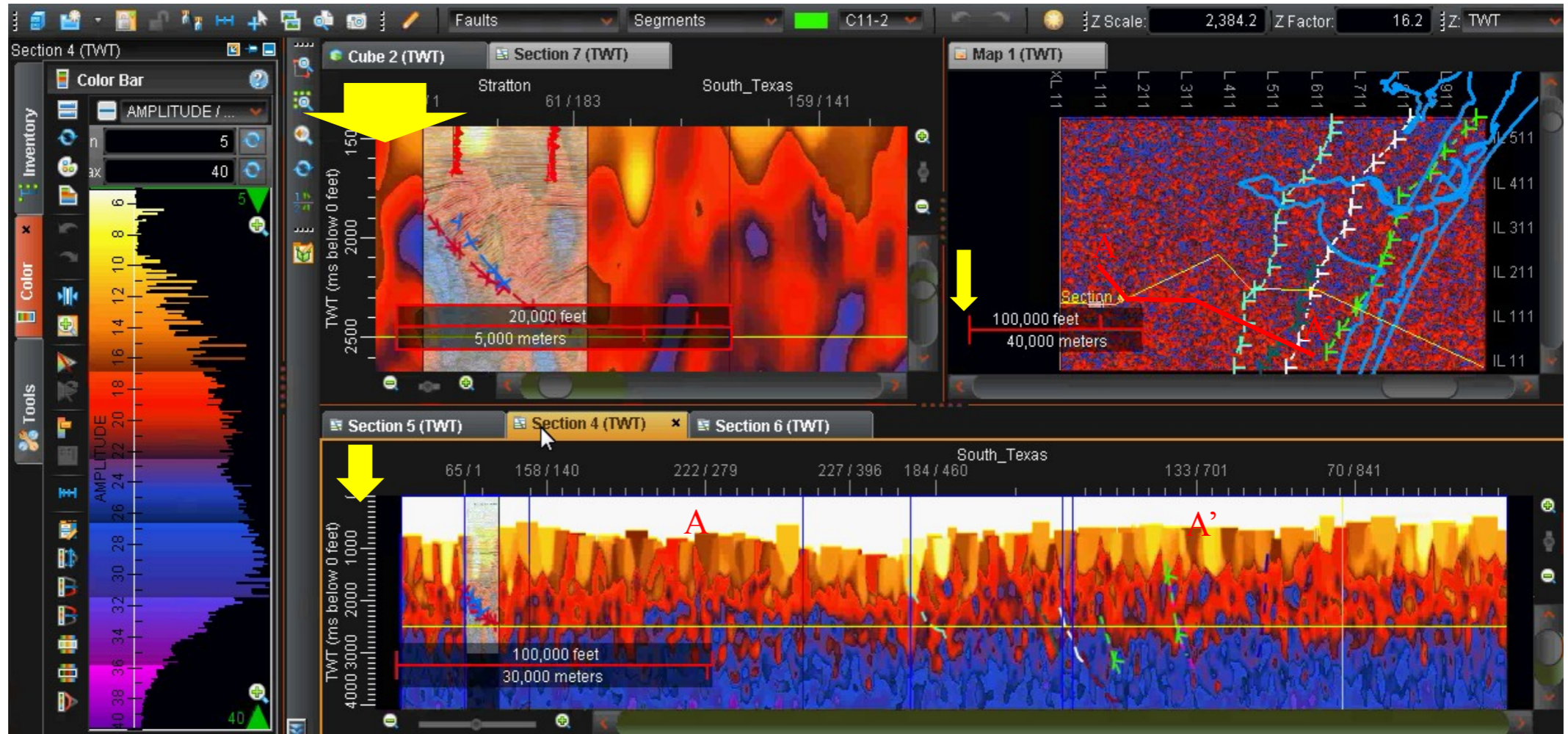
(microseconds)

5a. Arizona Examples: Resolution Copper

NLDN Peak Current   &   Rise-Rate

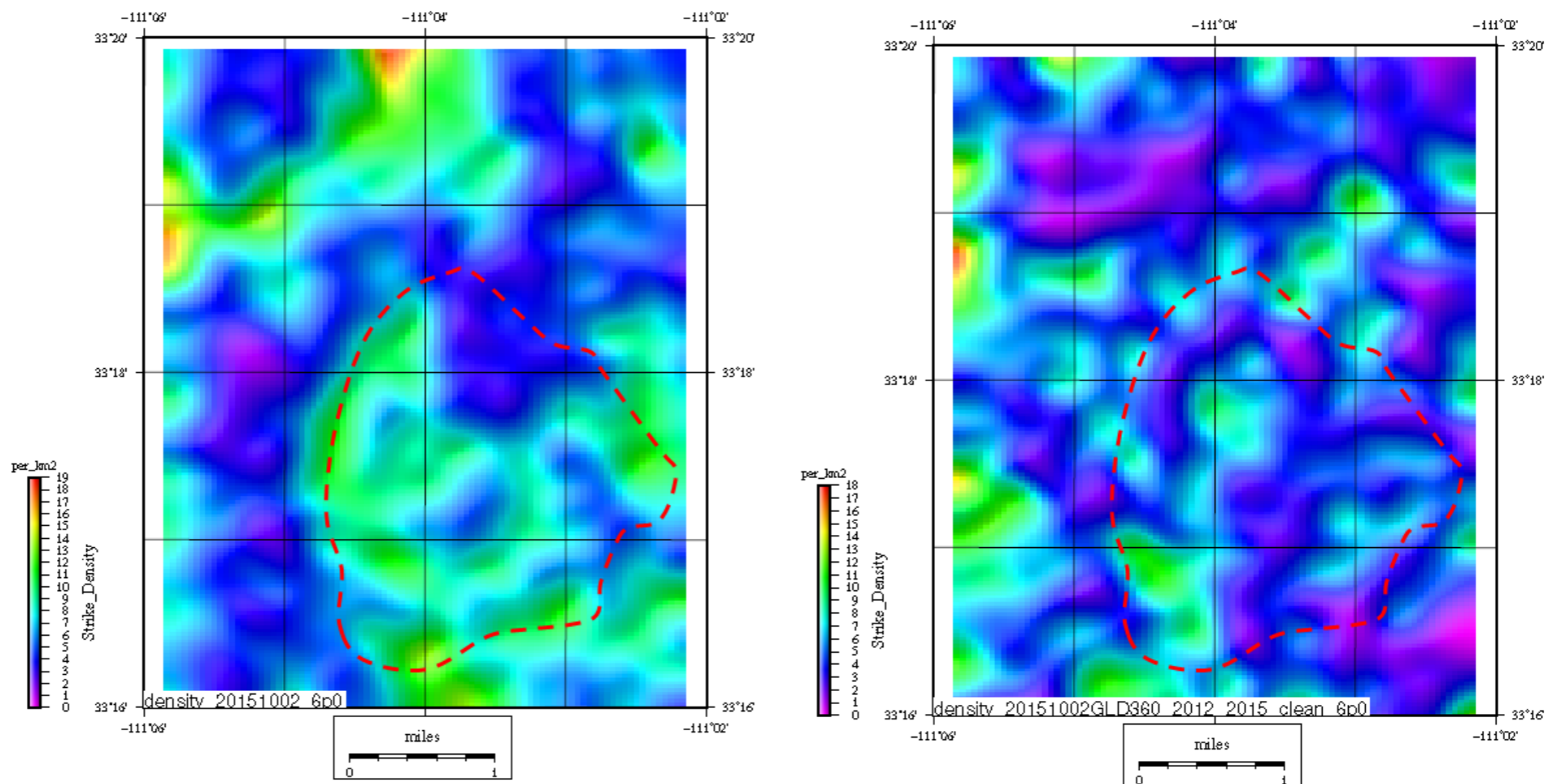# 3 Example SPOT[SM] Apparent Resistivity Cylinders
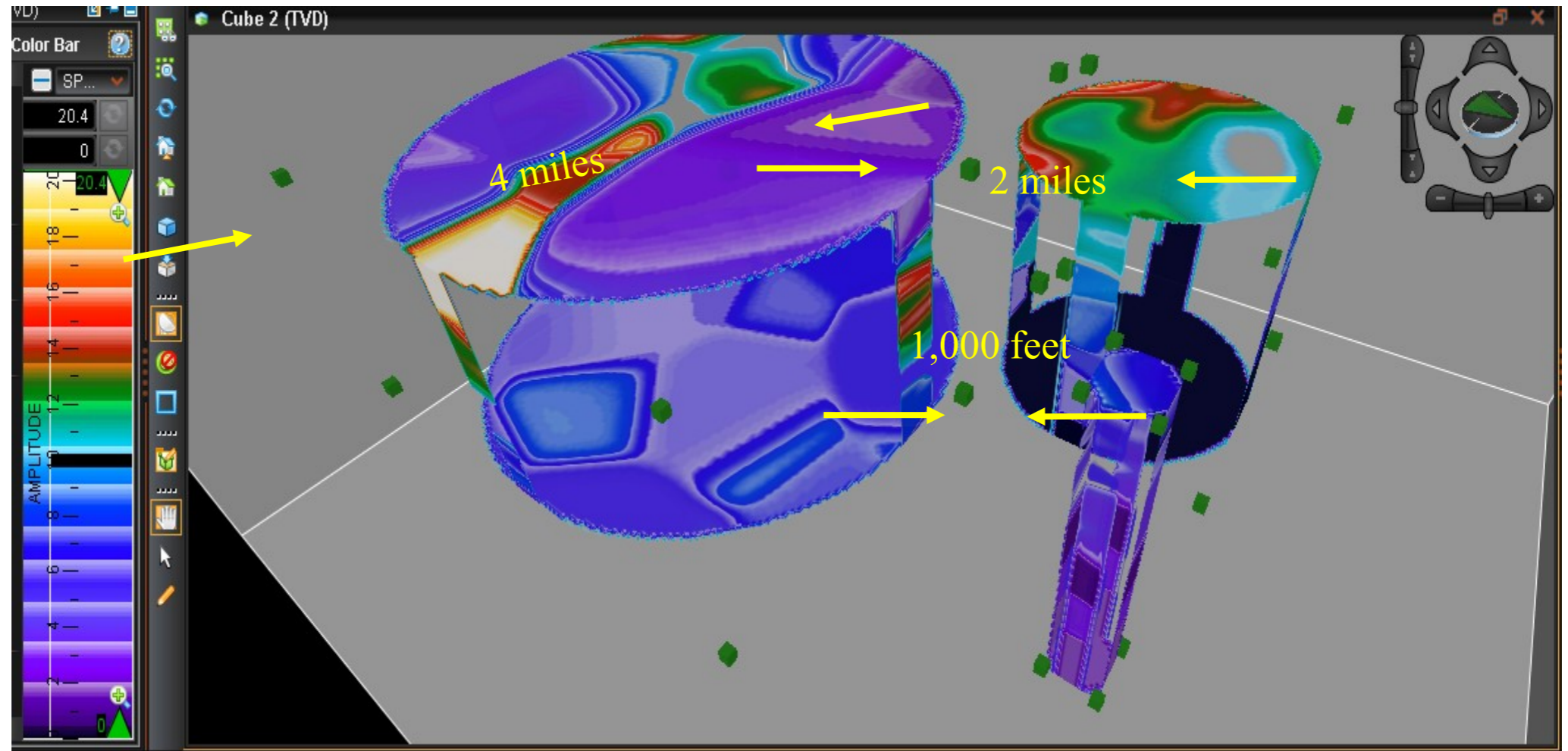
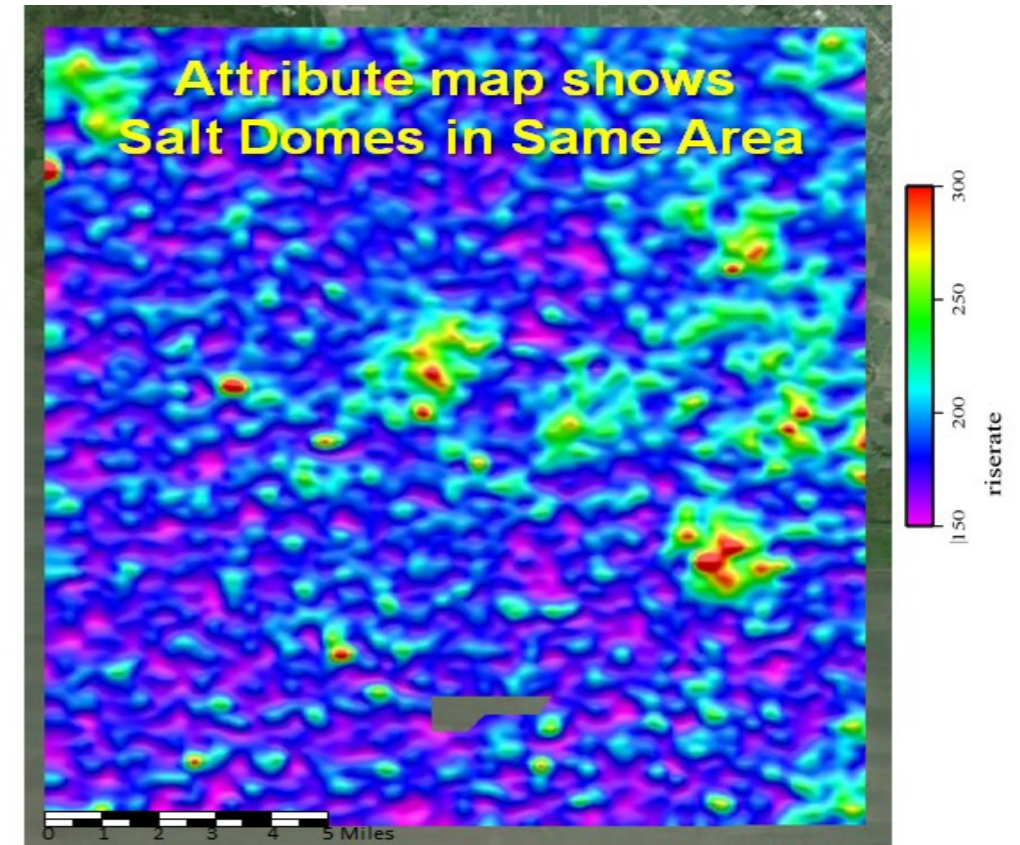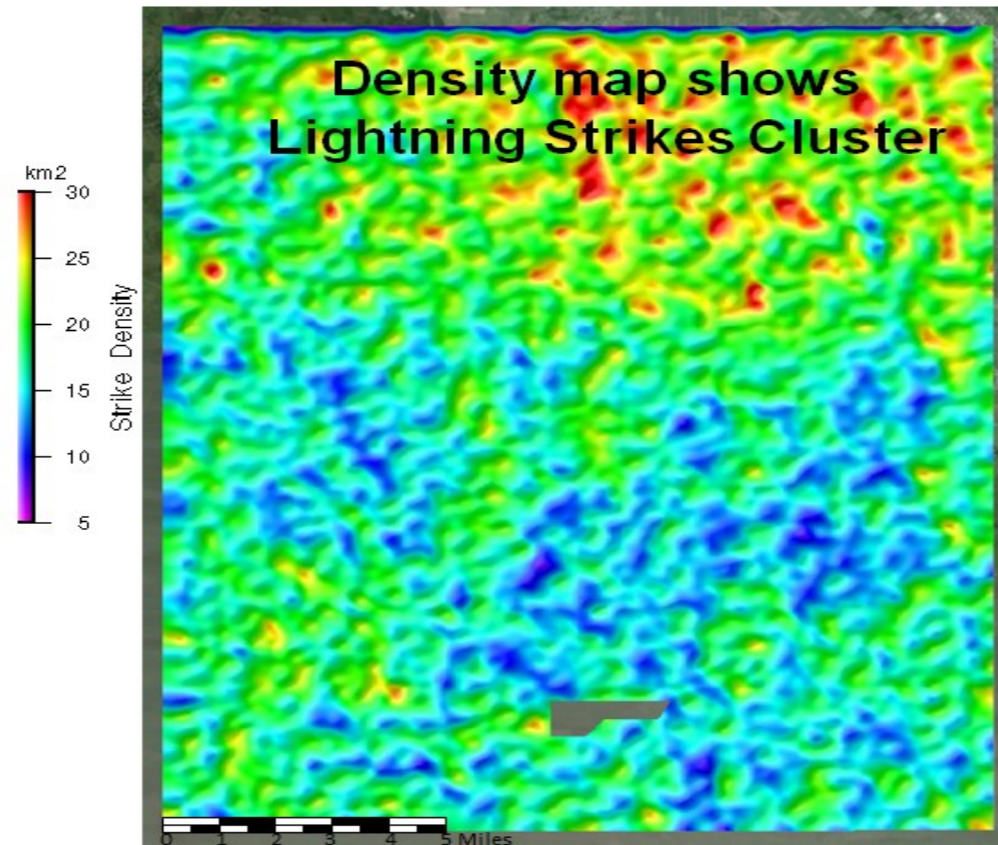# Integrating Resistivity in Three-Dimensions
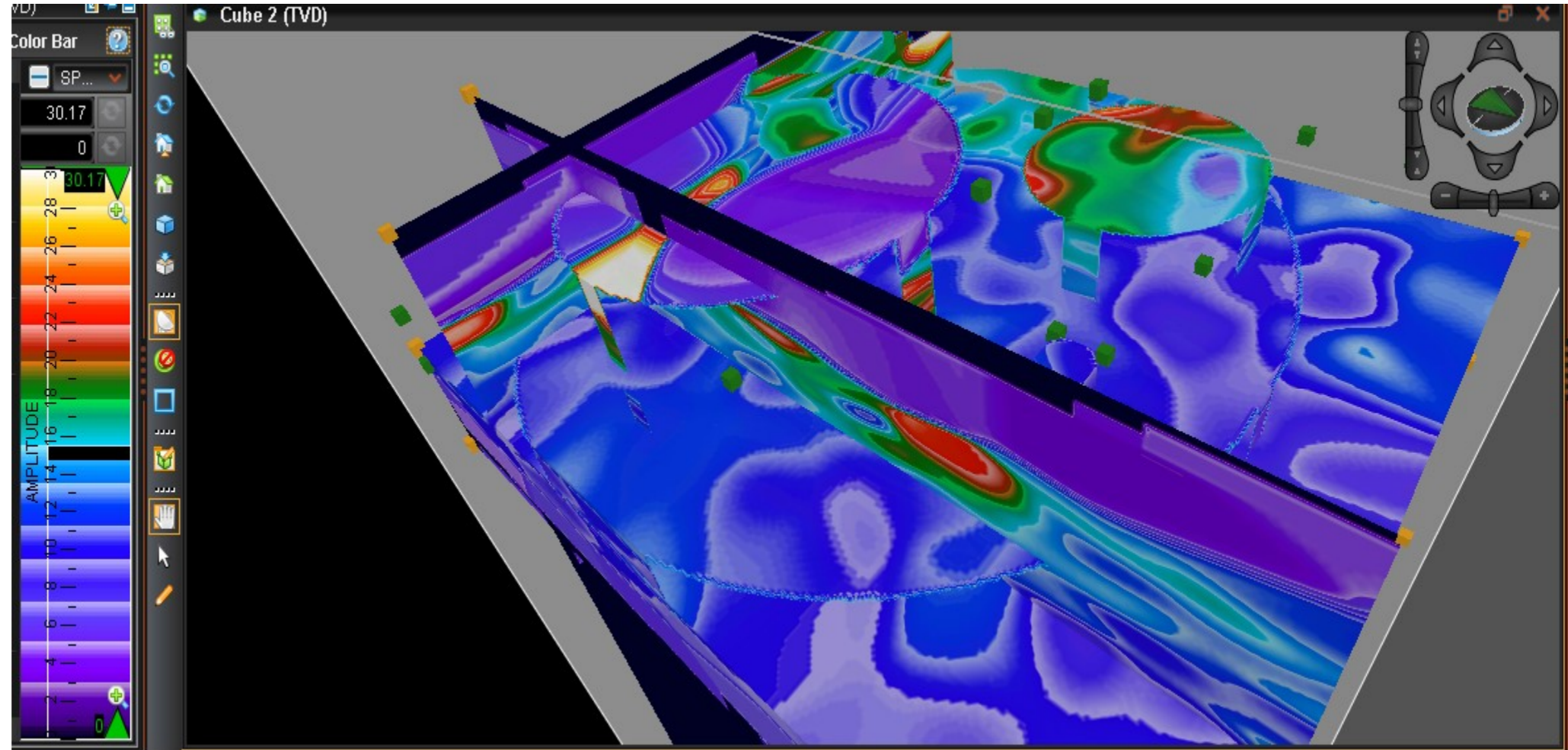
Comparing NLDN and GLD-360 data

NLDN Density 1998-2015 & GLD-360 Density 2012-2015
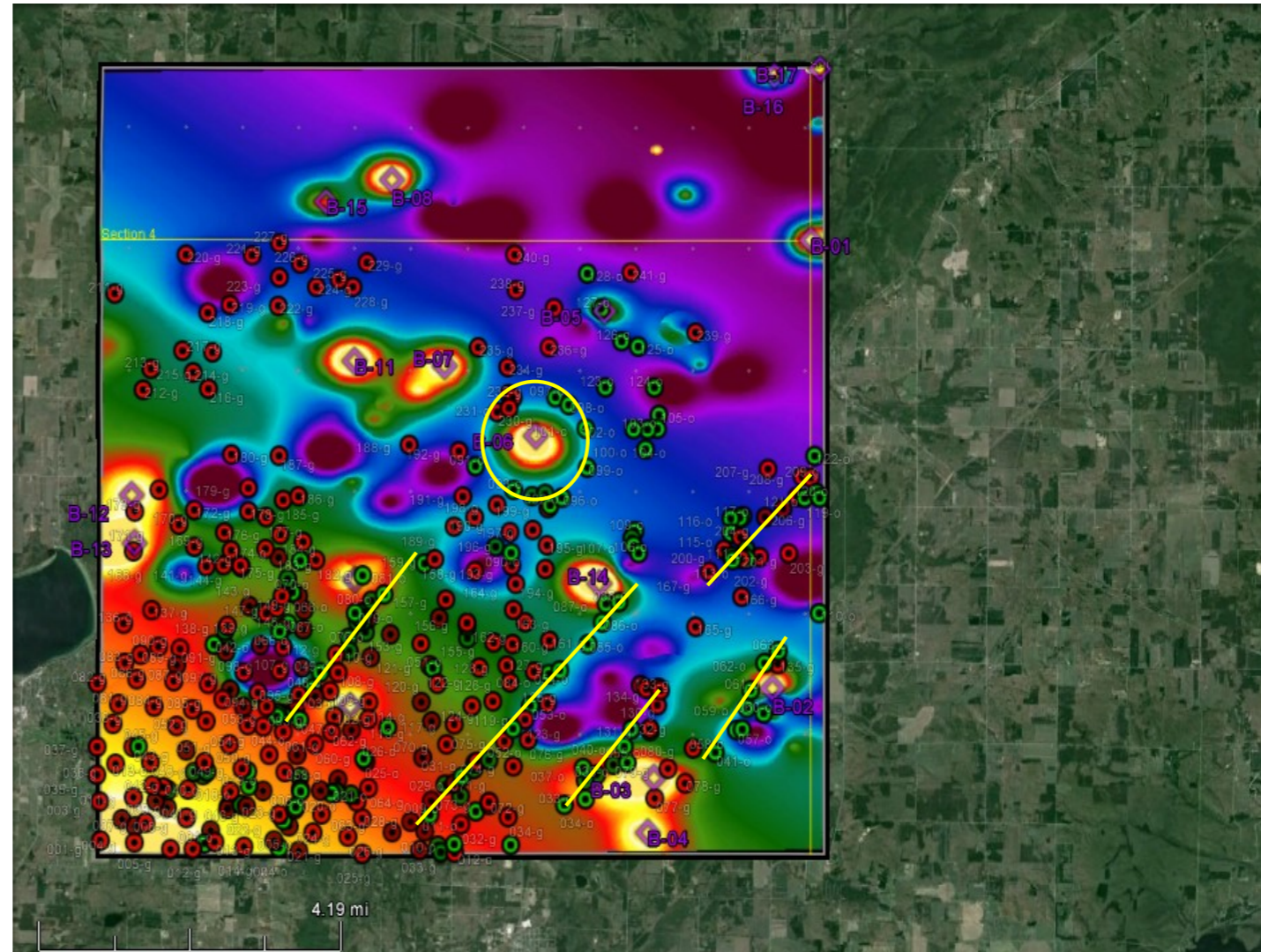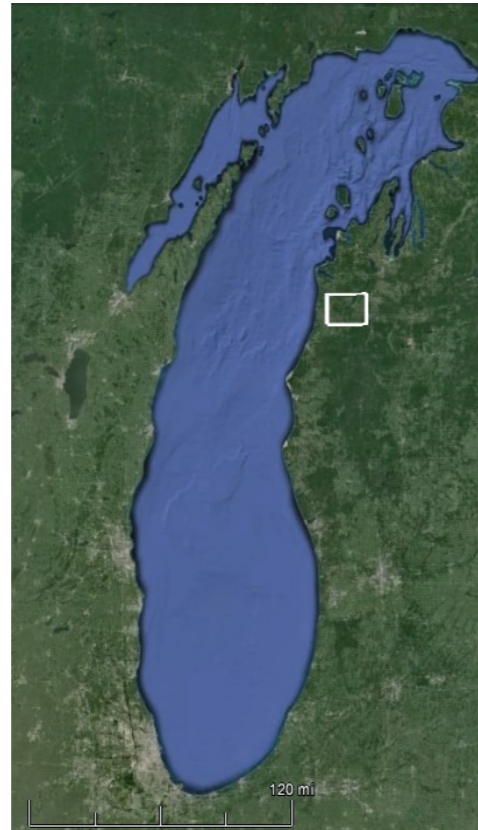
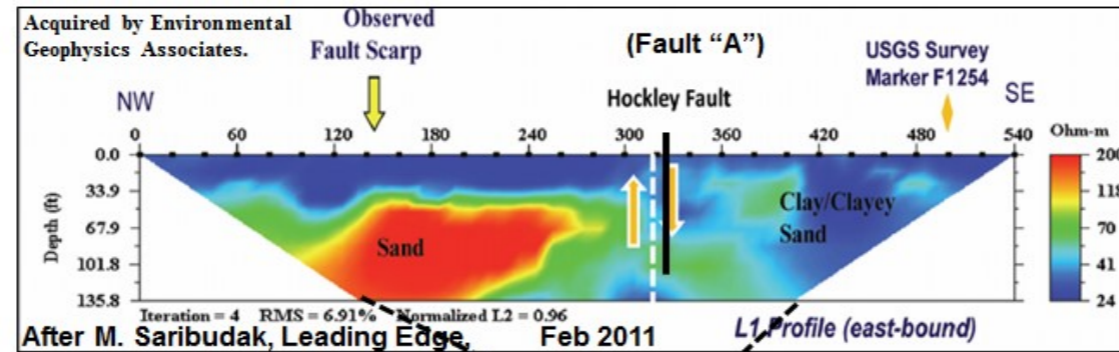# 5b. Louisiana Example

Density Map   &   Rate-of-Rise-Time Map

5c. Michigan Example
High Resistivity to SW on B-2 Horizontal-Slice
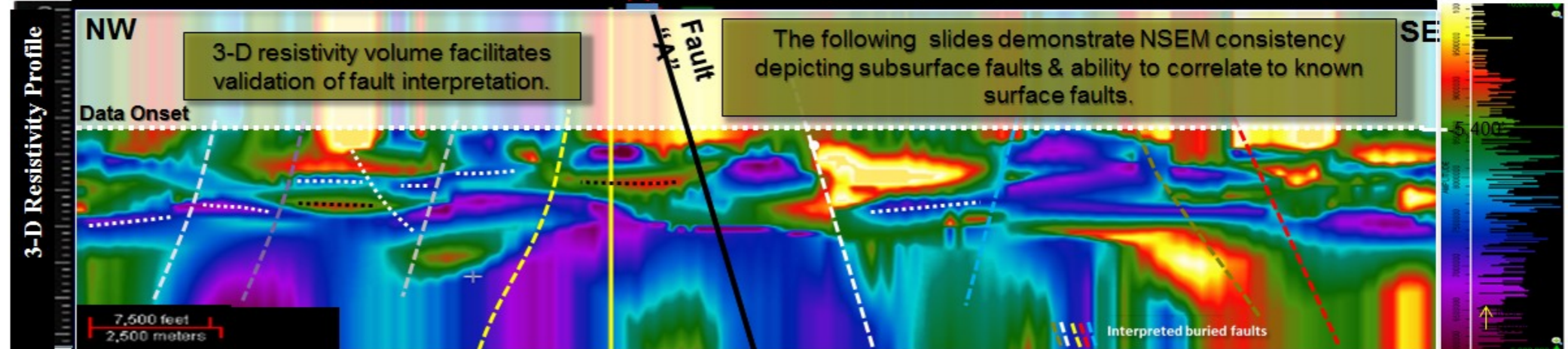with Oil & Gas Wells in Analysis Area posted (note lineaments)

5d. One Last Texas Example

After M. Saribudak, Leading Edge, Feb 2011

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

Cedar City, Utah
Near the Iron Mines & Geothermal Deposits
SMU and DML are planning to study
direct geothermal indicators

Milford Geothermal Field

Enoch MicroEarthquake Swarm

Milgro Newcastle Geothermal Greenhouses

© 2015 Google
Image Landsat
31.8 mi
5676 ft

1
2
3
4
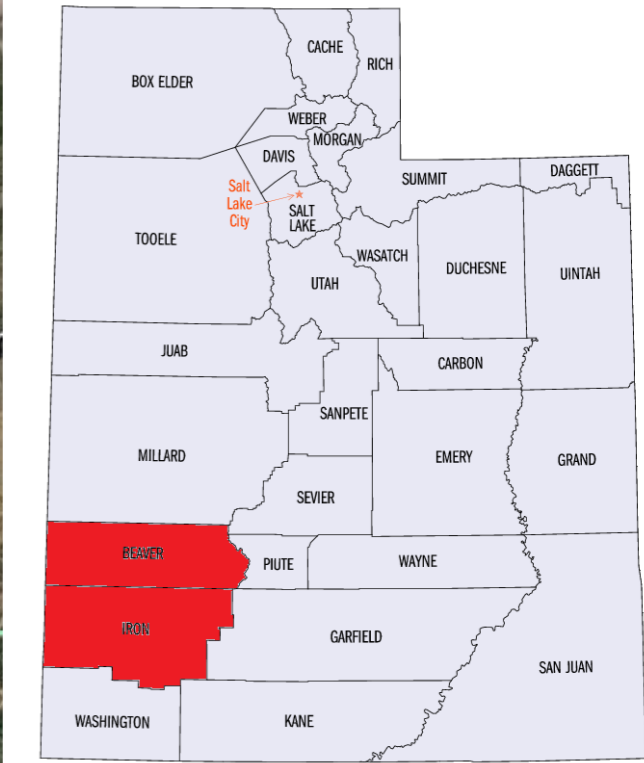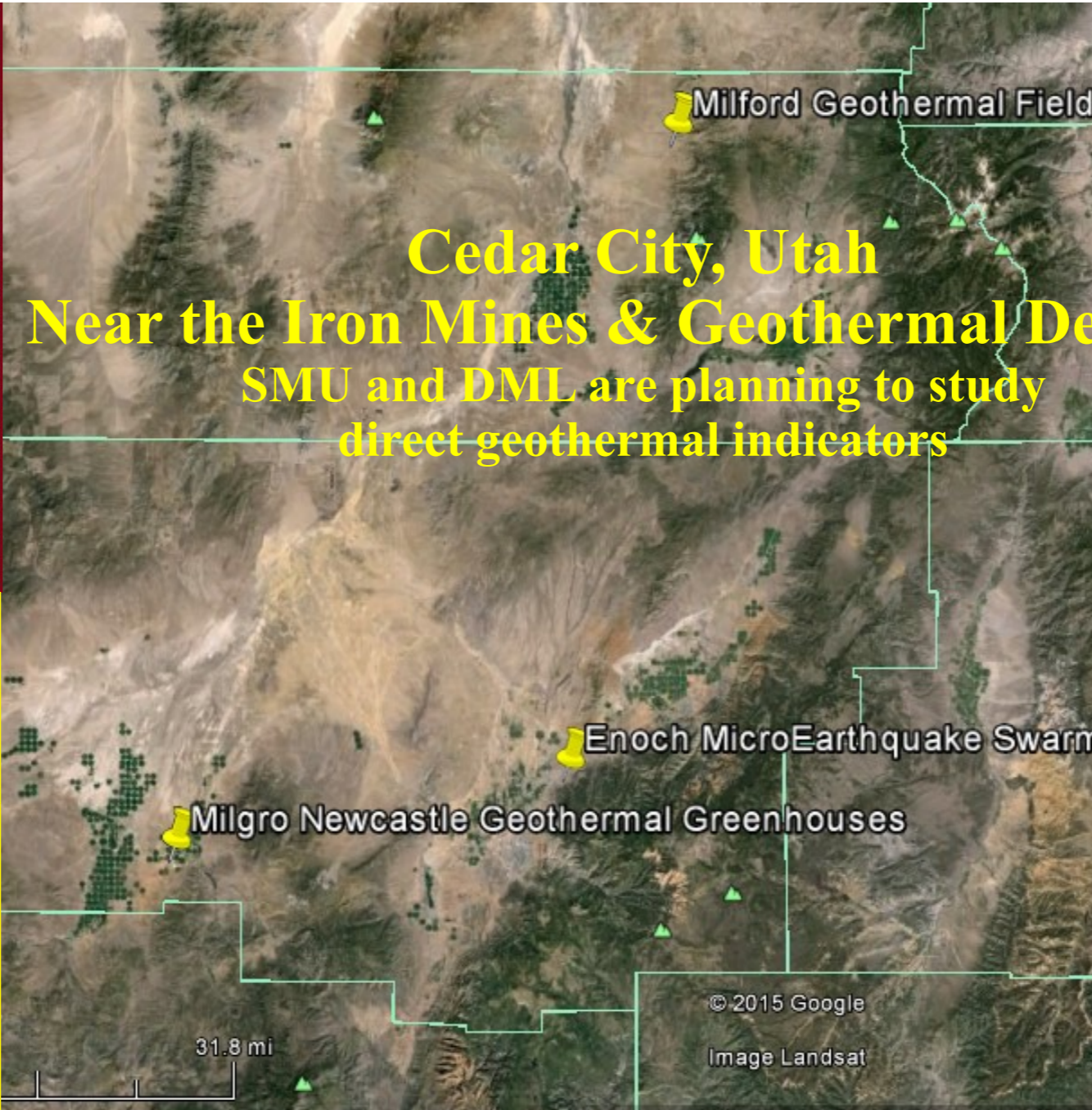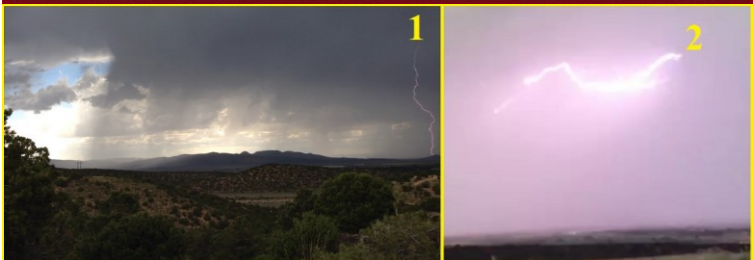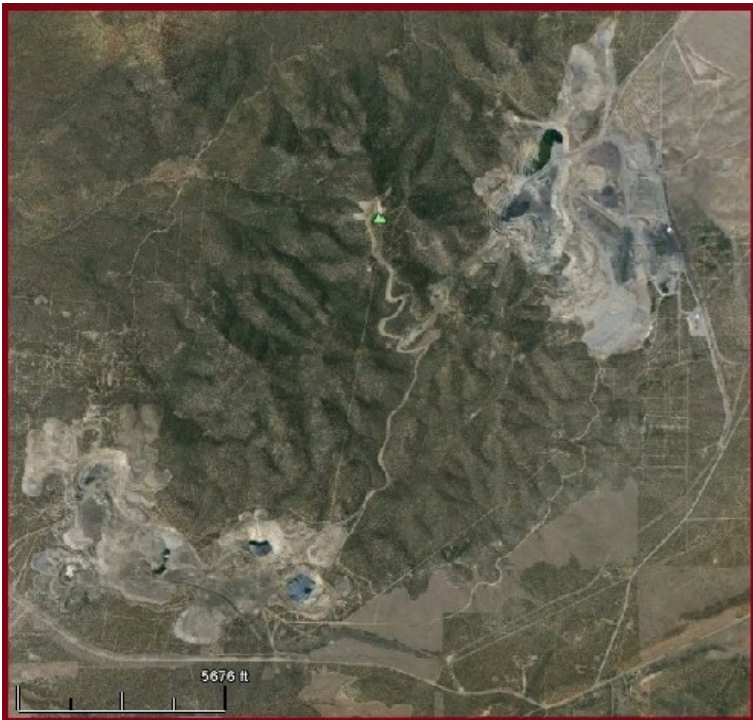
Interns at Dynamic Measurement

Mobbed when gave a similar presentation at BYU
Start-up with only non-paid Interns
Intern Contributions:

J. D. Shumway: likes the flexibility, represented Dynamic in our booths at 2015 AAPG in Denver, 2015 GCAGS in Houston, and recent DHI Consortium

Dustin Northrup: co-author on article submitted to The Leading Edge and paper submitted to 2017 AAPG

Corbin Lewis: co-author on article submitted to The Leading Edge and paper submitted to 2017 AAPG

J.D., Dustin, and Corbin each have lightning analysis projects they are working on where they are using Landmark's DecisionSpace^{TM} software to interpret lightning analysis projects

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Thank You

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These slides are posted at:
http://www.dynamicmeasurement.com/TAMU/161014_Using_Lightning_Databases_to_derived_Rock_Property_and_Lightning_Attributes.pdf