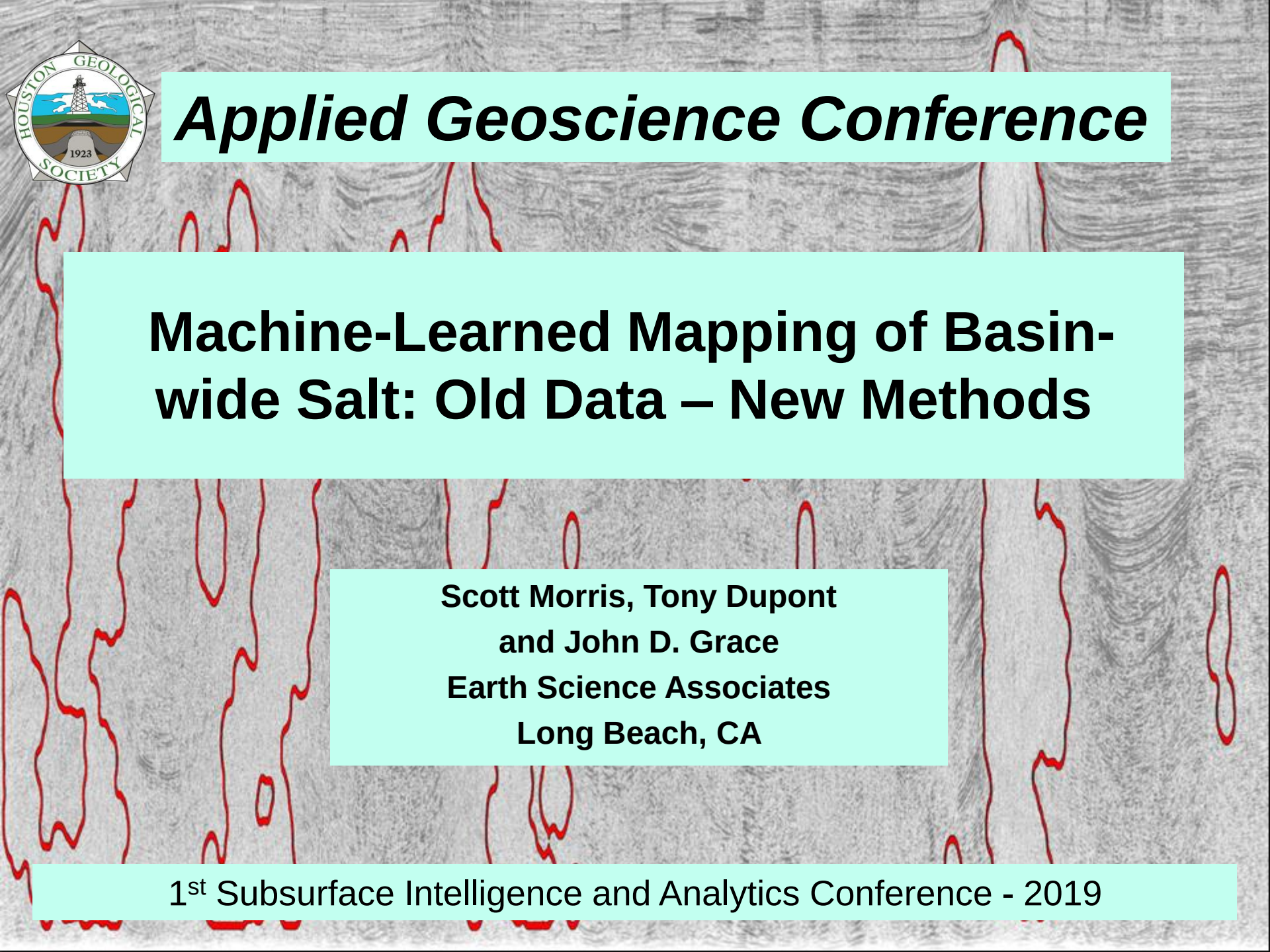
Machine-Learned Mapping of Basin-wide Salt: Old Data - New Methods

Scott Morris, Earth Science Associates

- Data Scientist, Earth Science Associates

- B.S. Statistics, University of California, Riverside
- M.S. Applied Mathematics, California State University, Fullerton.

- 6+ years at Earth Science Associate
  - Created a variety of data driven analytics tools supported by statistical models
    - Aid O&G exploration of hydrocarbons
    - Intelligence for lease activity in the Gulf of Mexico



Applied Geoscience Conference

Machine-Learned Mapping of Basin-wide Salt: Old Data – New Methods

Scott Morris, Tony Dupont
and John D. Grace
Earth Science Associates
Long Beach, CA

1st Subsurface Intelligence and Analytics Conference - 2019

Can Machines Learn at a Basin Scale?

- **20 yrs developing automated salt recognition in seismic**
  - Experiments based on a few lines from a single, modern survey
  - Usually employ “supervised” learning algorithms – high expert input
- **Big returns to machine learning come from:**
  - Application to *massive data* sets
  - Methods robust for *old, disparate, noisy data*
  - Probabilistic *evaluation of certainty of results*
- **Test by mapping basin-wide top of salt for Gulf of Mexico**
  - *8,000+ 2D SEG-Y files*: >250,000 line-miles covering ~ 100,000 mi^2
  - Old, disparate data: 82 surveys *shot from 1981 – 1992*
  - Minimize expert costs by “unsupervised” learning algorithms
- ***New value from massive legacy seismic resources***
- **Foundation for *iterative supervision* approach**

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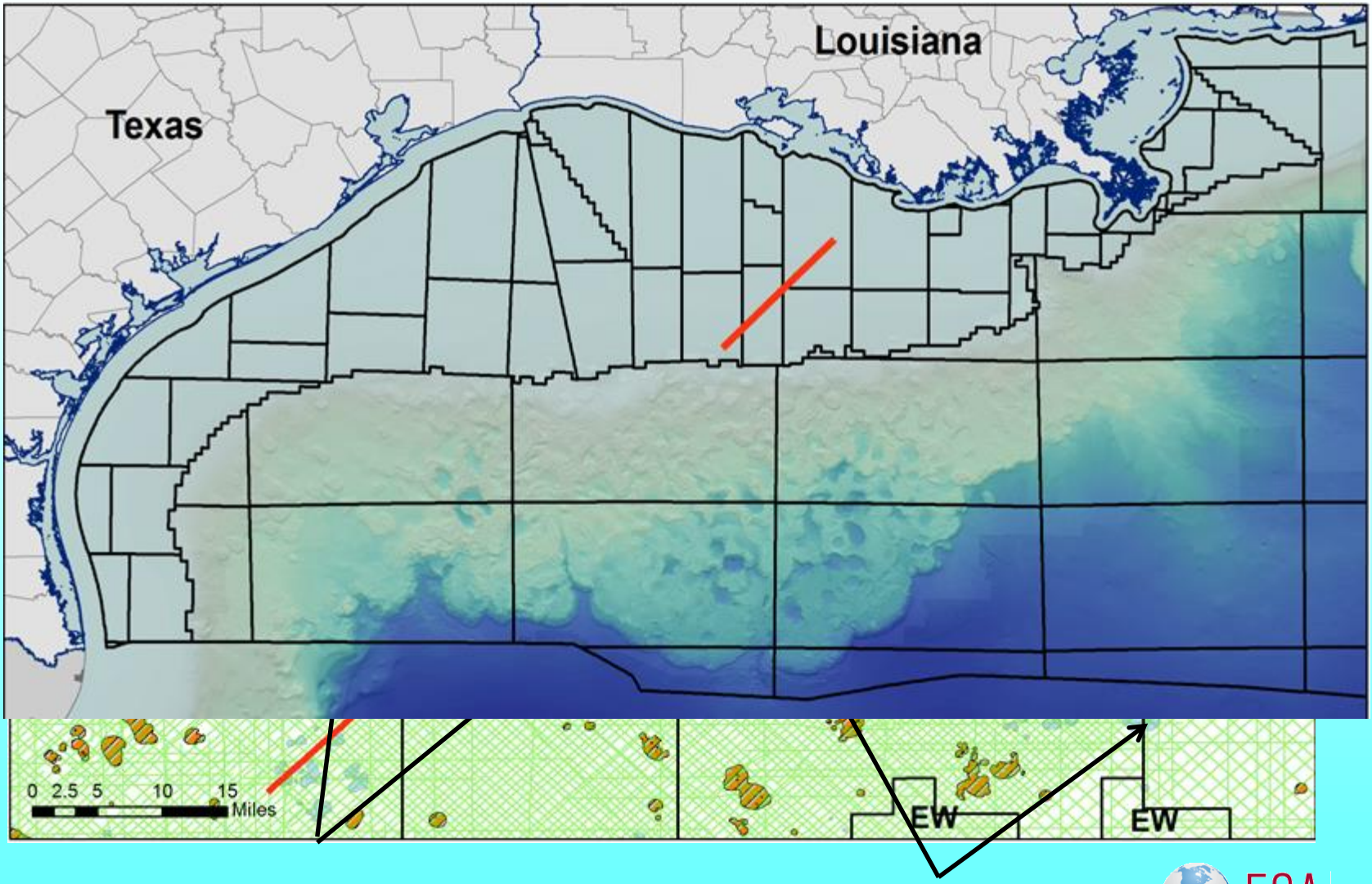
Data Coverage



Fields with Salt-Related Trapping

Fields with Other Trapping

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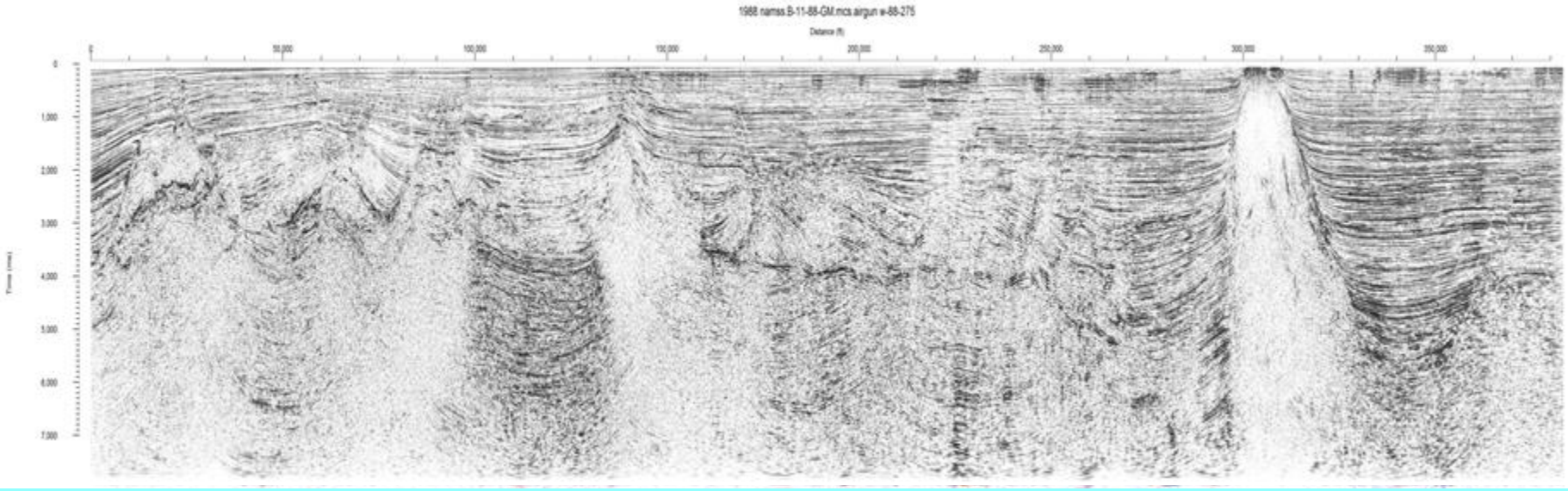
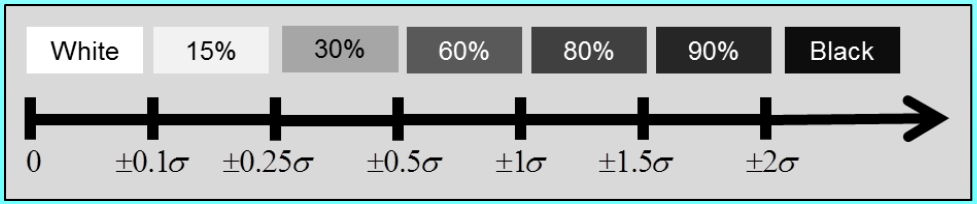
Salt's Seismic "Texture"





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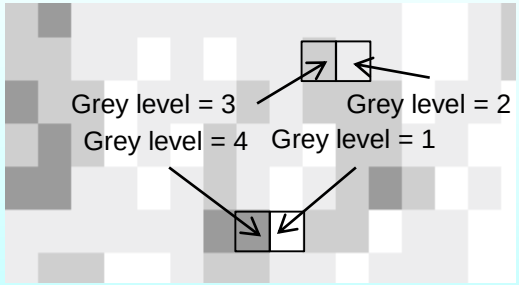
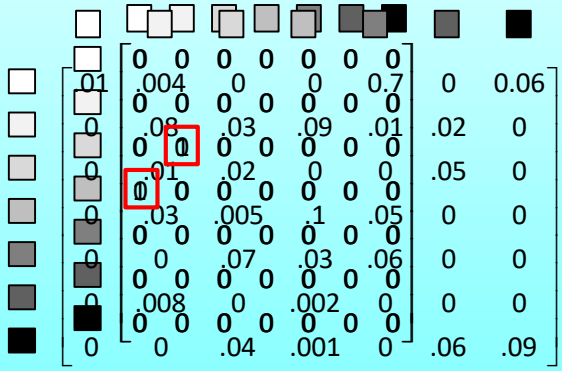
GLCM

Grey Level Co-occurrence Matrix

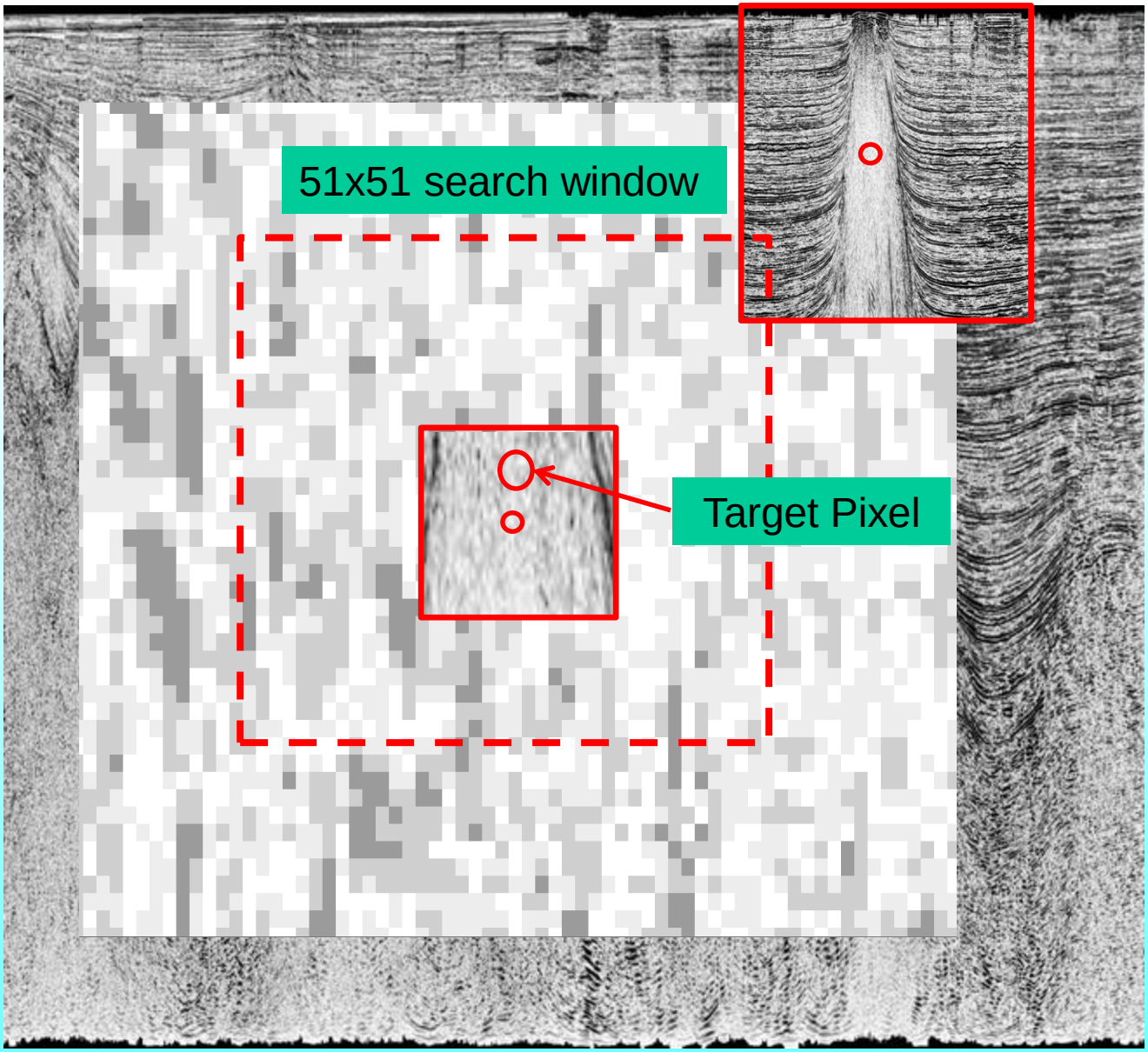




Compute probabilities for all co-occurrences = GLCM

Compute statistics for GLCM

Assign statistics to pixel as attributes



Then move to the next pixel & repeat

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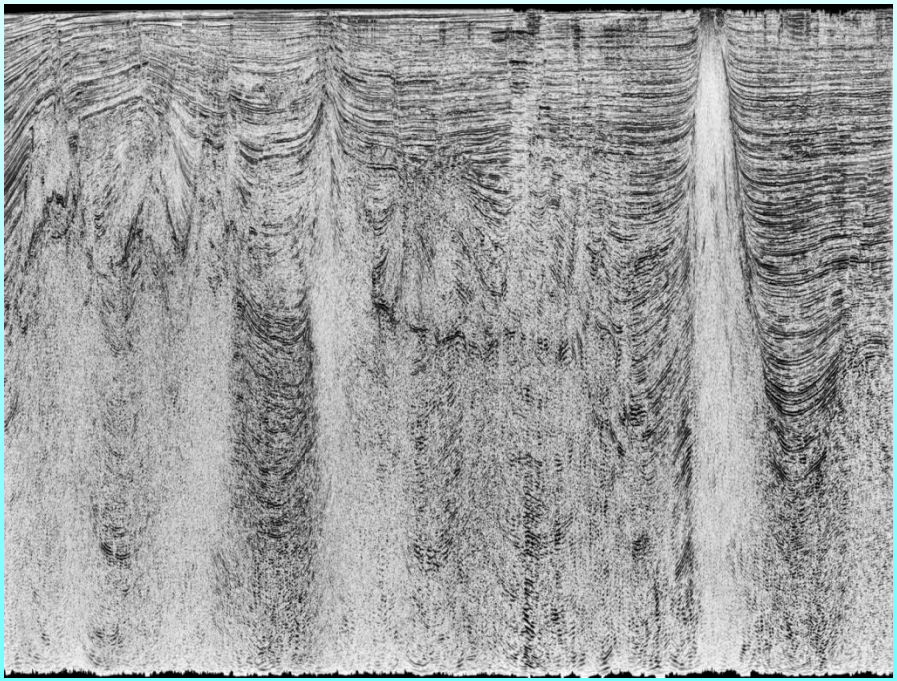
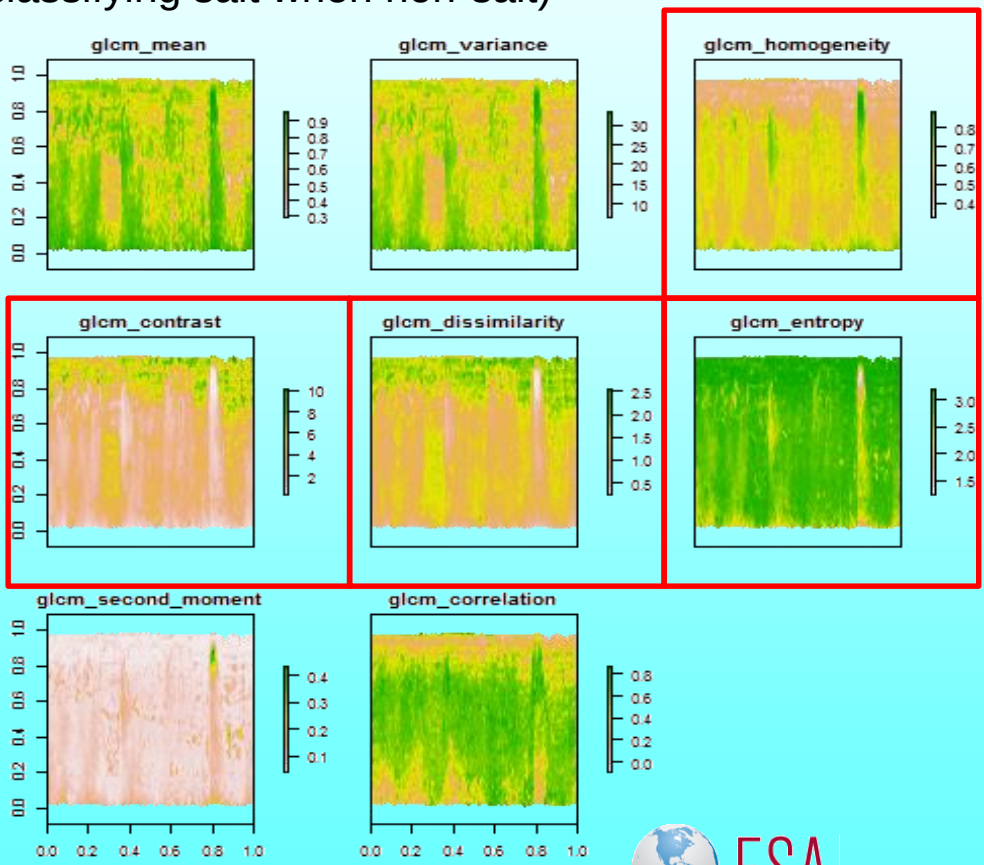
GLCM Statistics

Of suite of 8 GLCM statistics computed, choose

- Best salt/non-salt discriminators
- Minimization of false positives (classifying salt when non-salt)





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Reflector Analysis

- **Analyze whole reflectors for information on salt**

salt/non-salt

- **How are reflectors extracted?**
  - **Apply “Raster to Polygon” tool in ArcGIS to produce polygons around reflectors**
  - **Extract polygons & lines in ArcGIS**
  - **Attribute lines (reflectors) from data on enclosing polygons**

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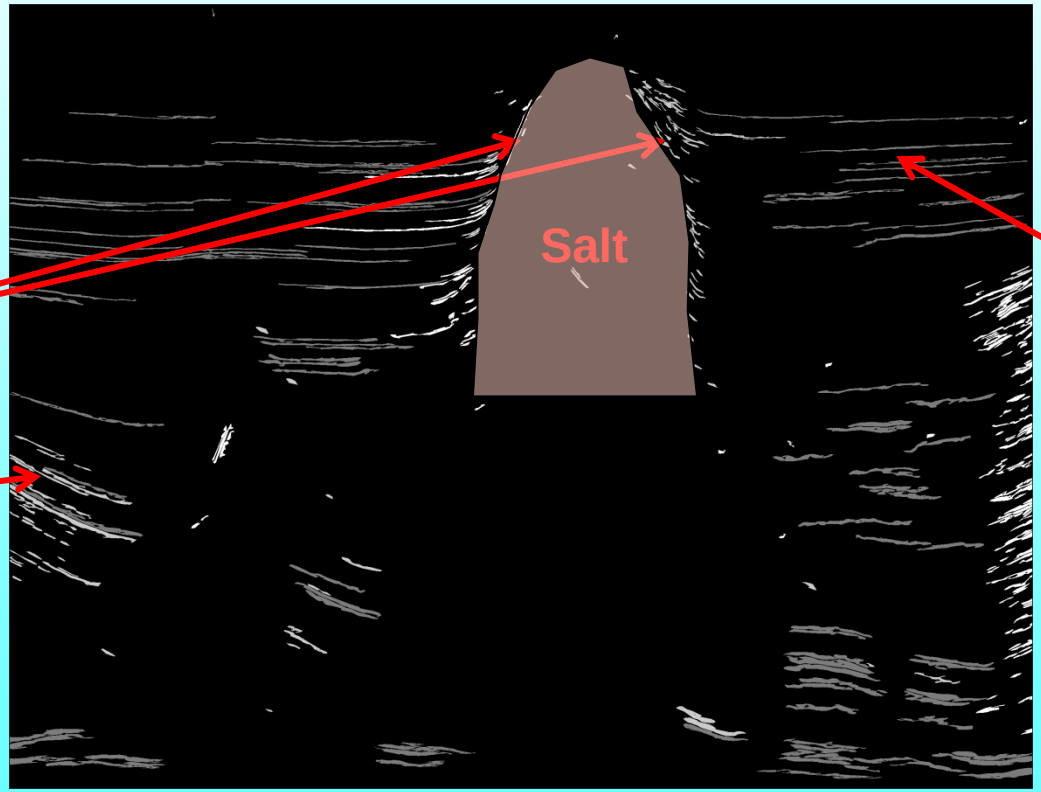
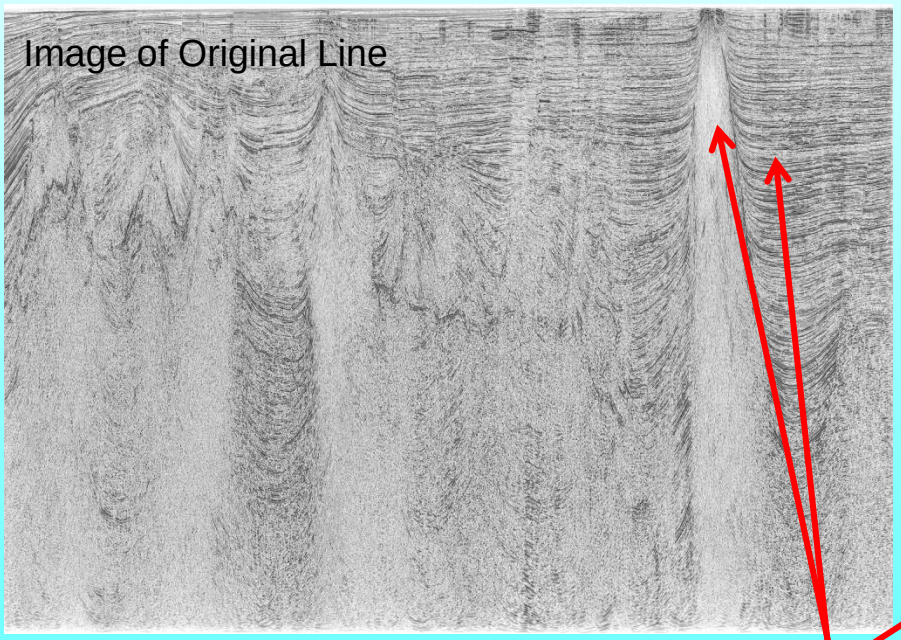
Geometry of High-Angle Reflectors

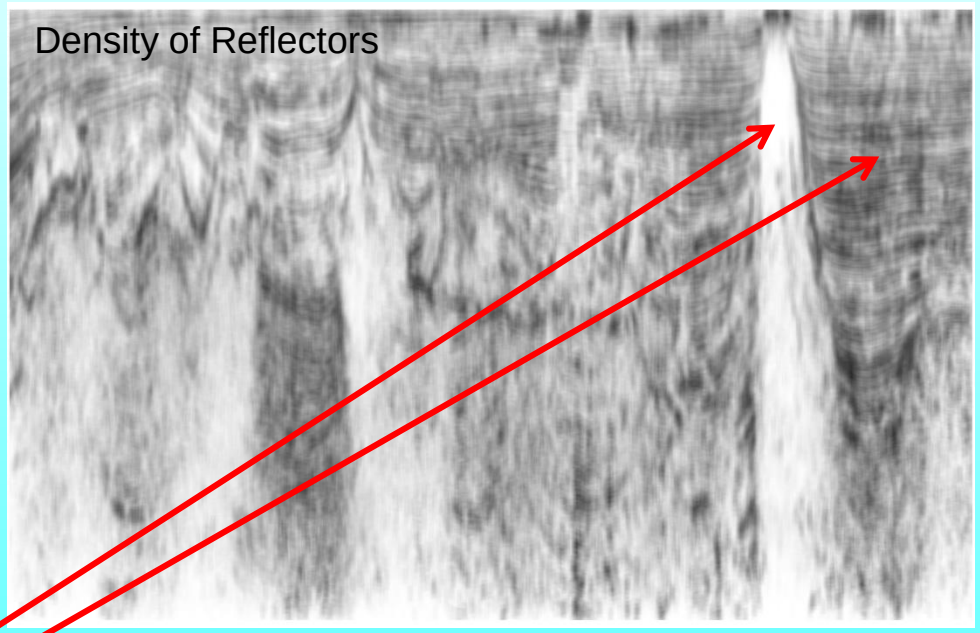
- **Paired high-angle reflectors indicate boundary of salt**
  - Look at only high dipping and strong reflectors



Reflector Density Attribute

- **Salt domes:**
  - few, short, randomly oriented reflectors → *low* densities
- **Bedded rock:**
  - many, long, oriented reflectors → *high* densities

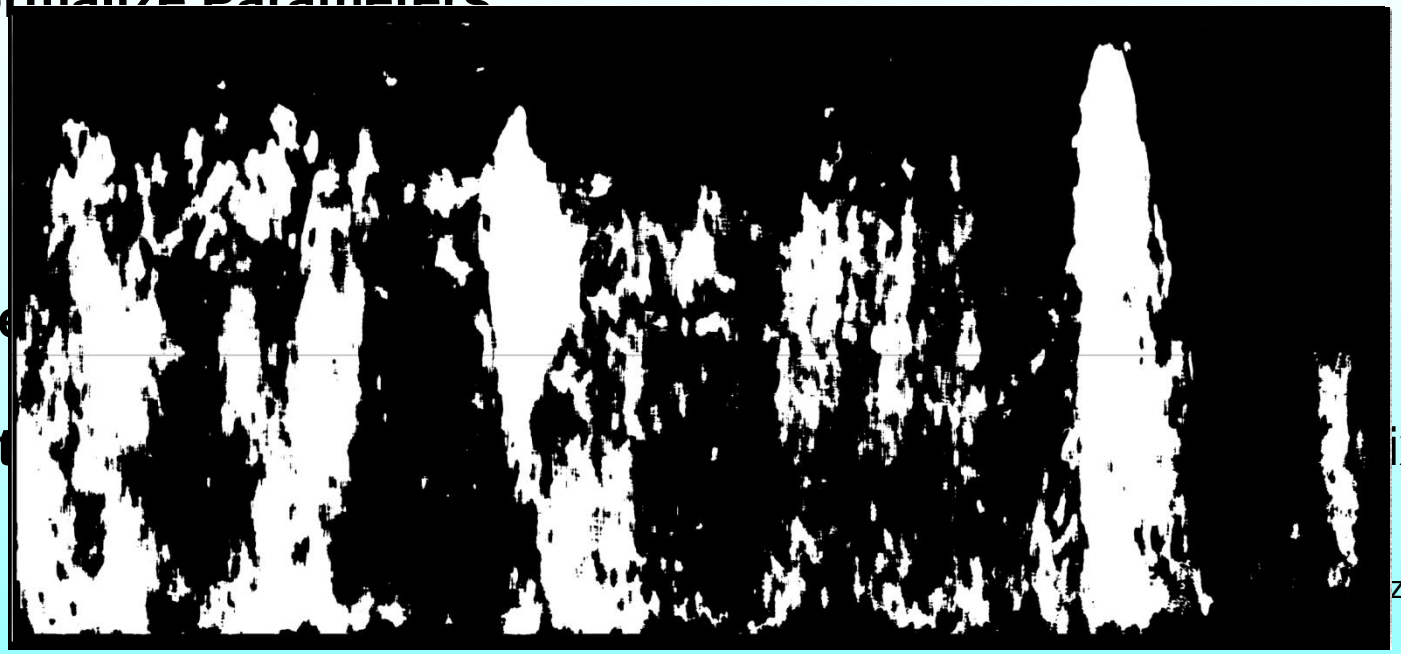




High reflector densities in salt Low reflector densities in salt outside salt

Create Salt Score & Threshold

- **Normalize Parameters:**
- **Ave**
- **Est** **ixels**

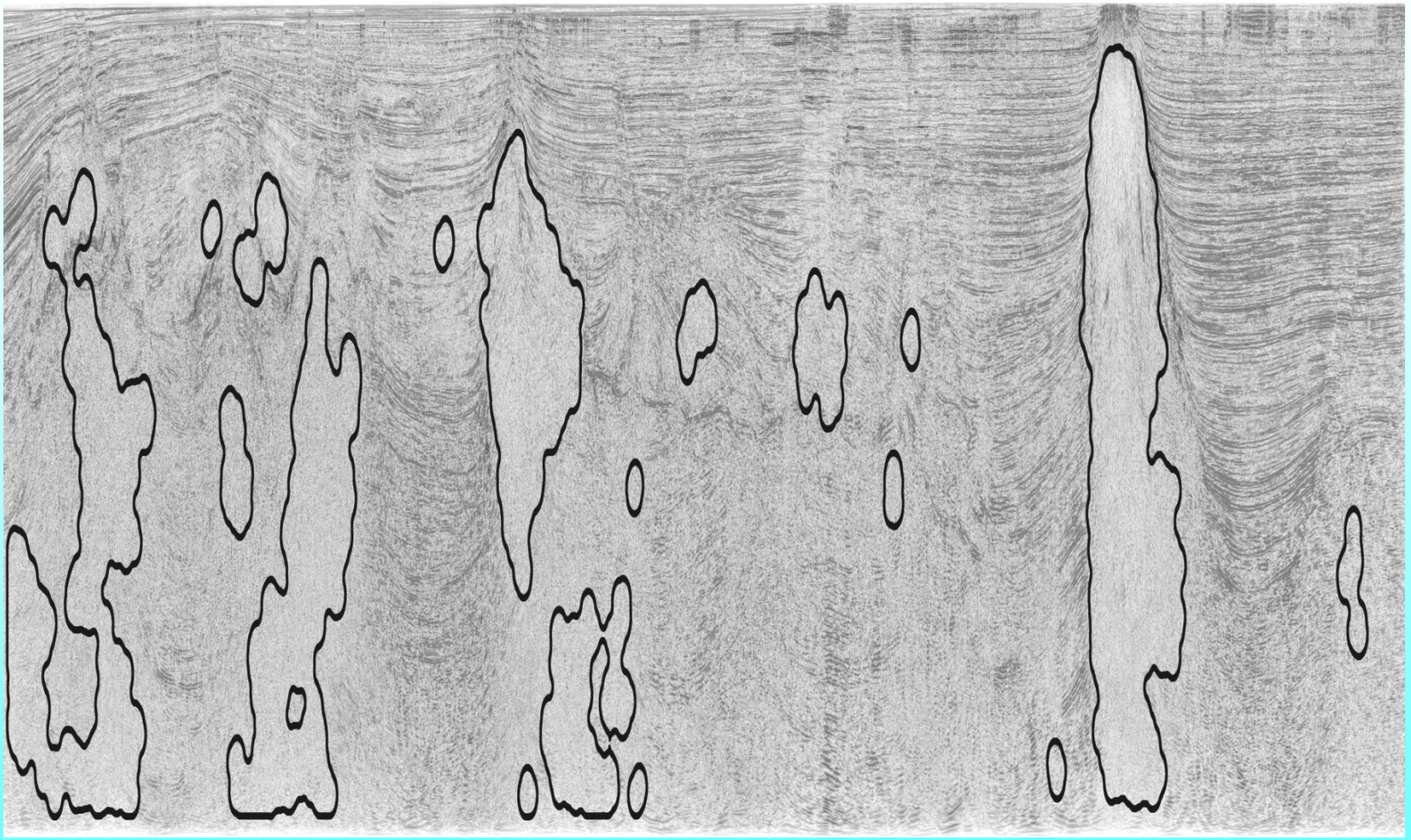


ze

  - Output = binary image (salt = white; non-salt = black)

Post-Th Salt Image

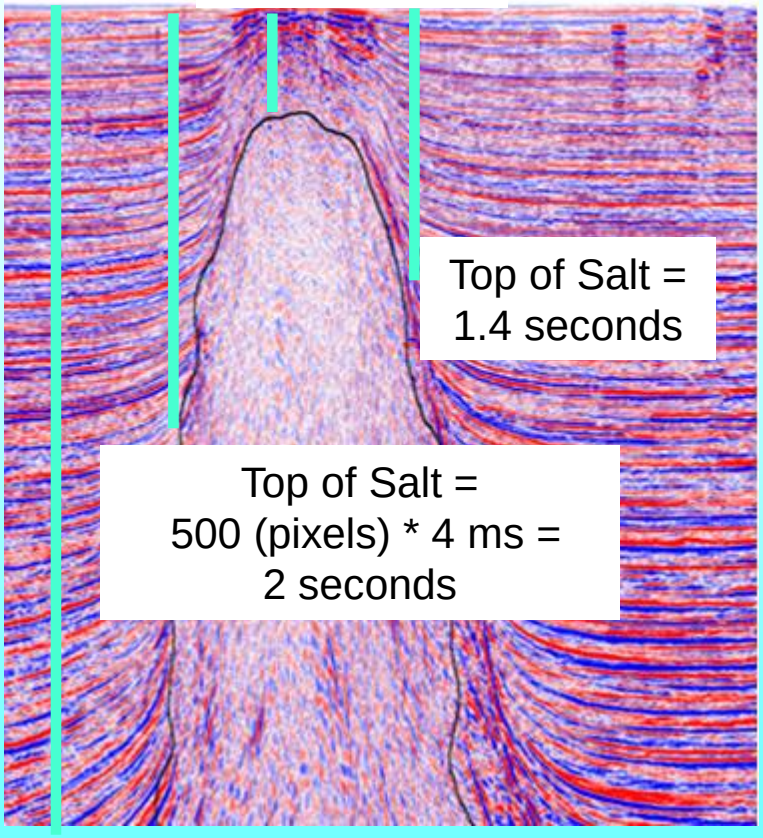
Morphological Clean-Up



Top of Salt: Time

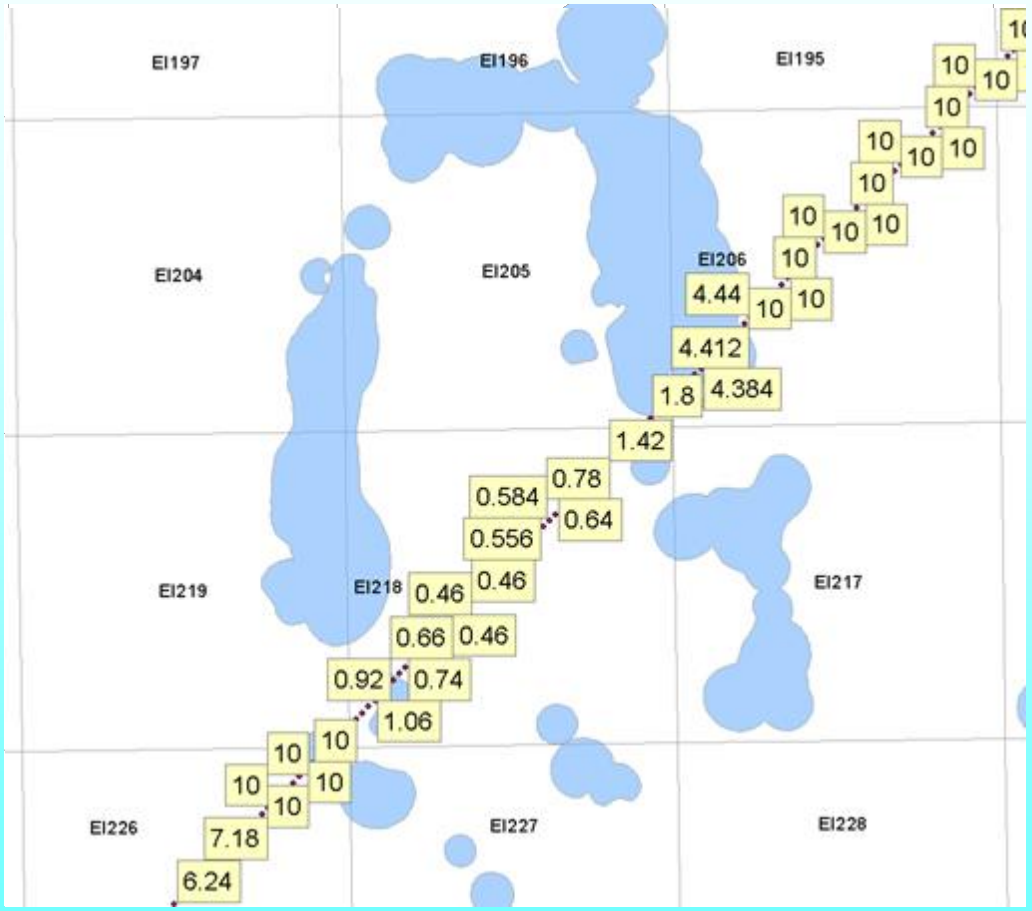
Top of Salt not found

Top of Salt = 0.57 seconds

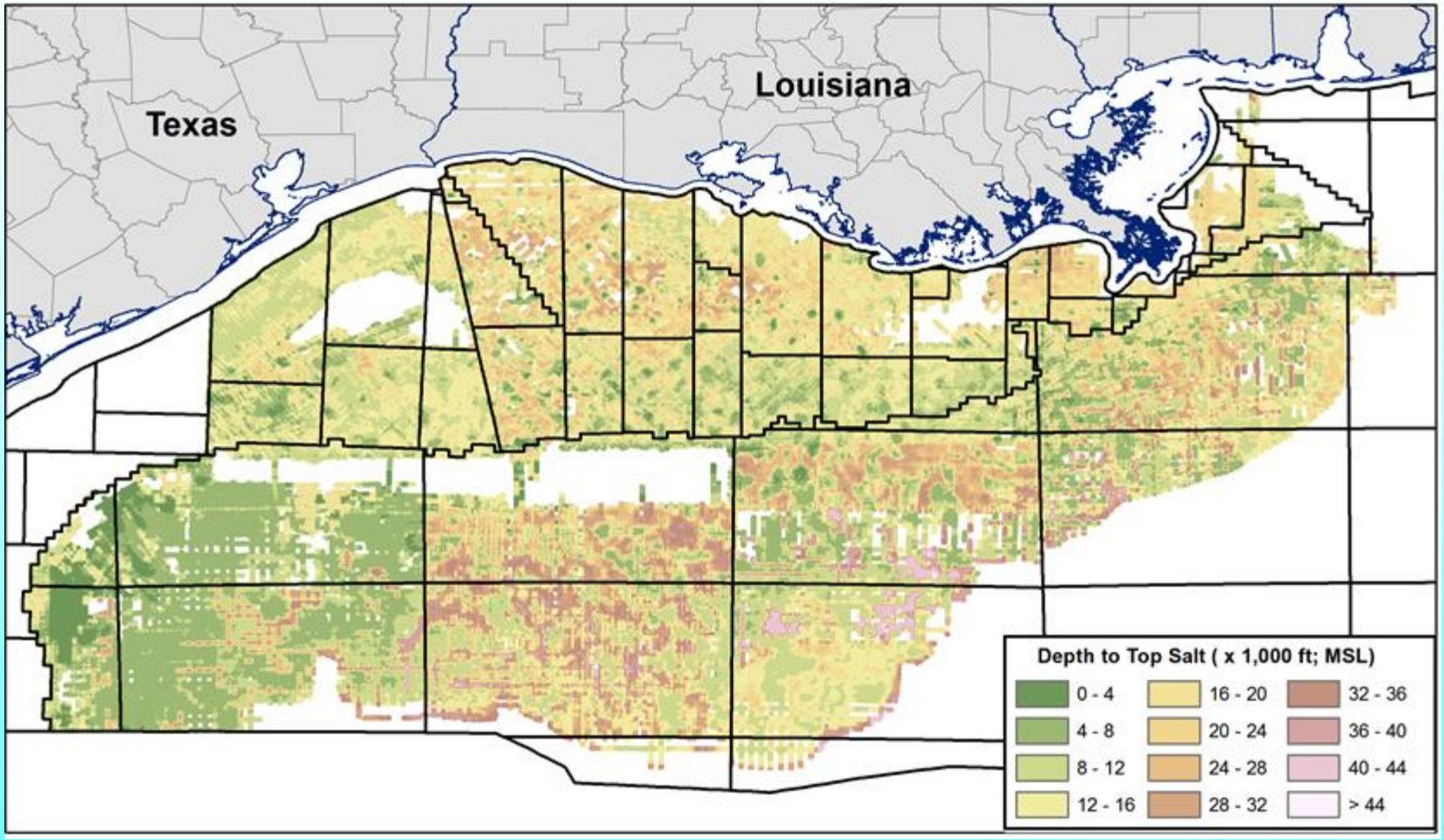


Top of Salt = 1.4 seconds

Top of Salt = 500 (pixels) * 4 ms = 2 seconds



Top of Salt: Time→ Depth

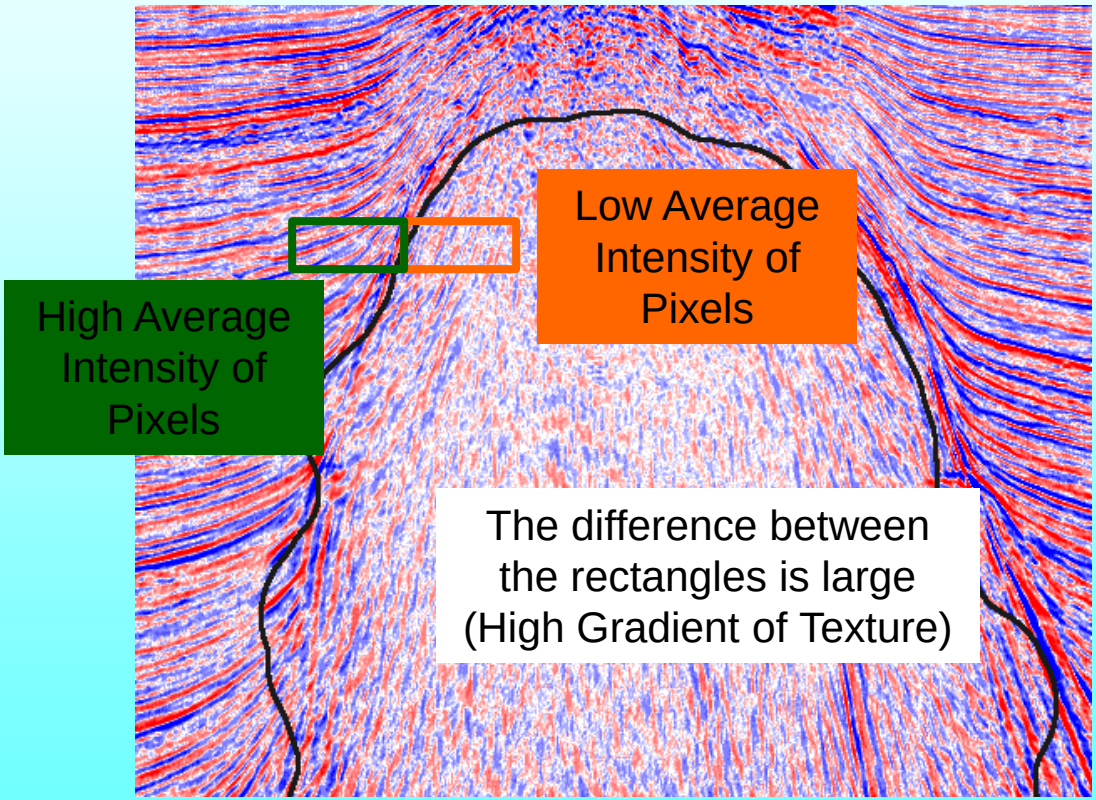


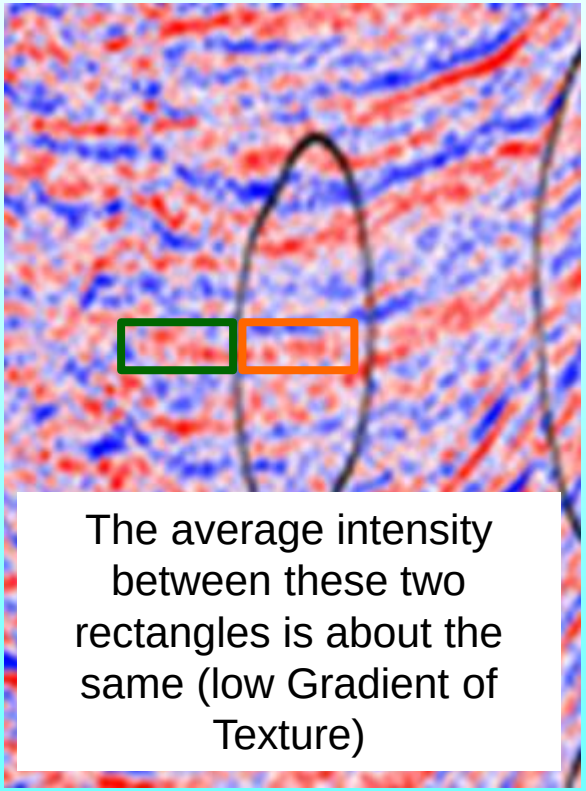
Estimated Velocity Field

Depth to Top of Salt

Boundary & Feature Evaluation

- **Evaluate boundaries by gradient of texture (GoT)**
  - Characterize pixel intensity on both sides of boundaries
  - Remove polygons with boundaries having GoT < 0.9 $(GoT)_{Biggest}$





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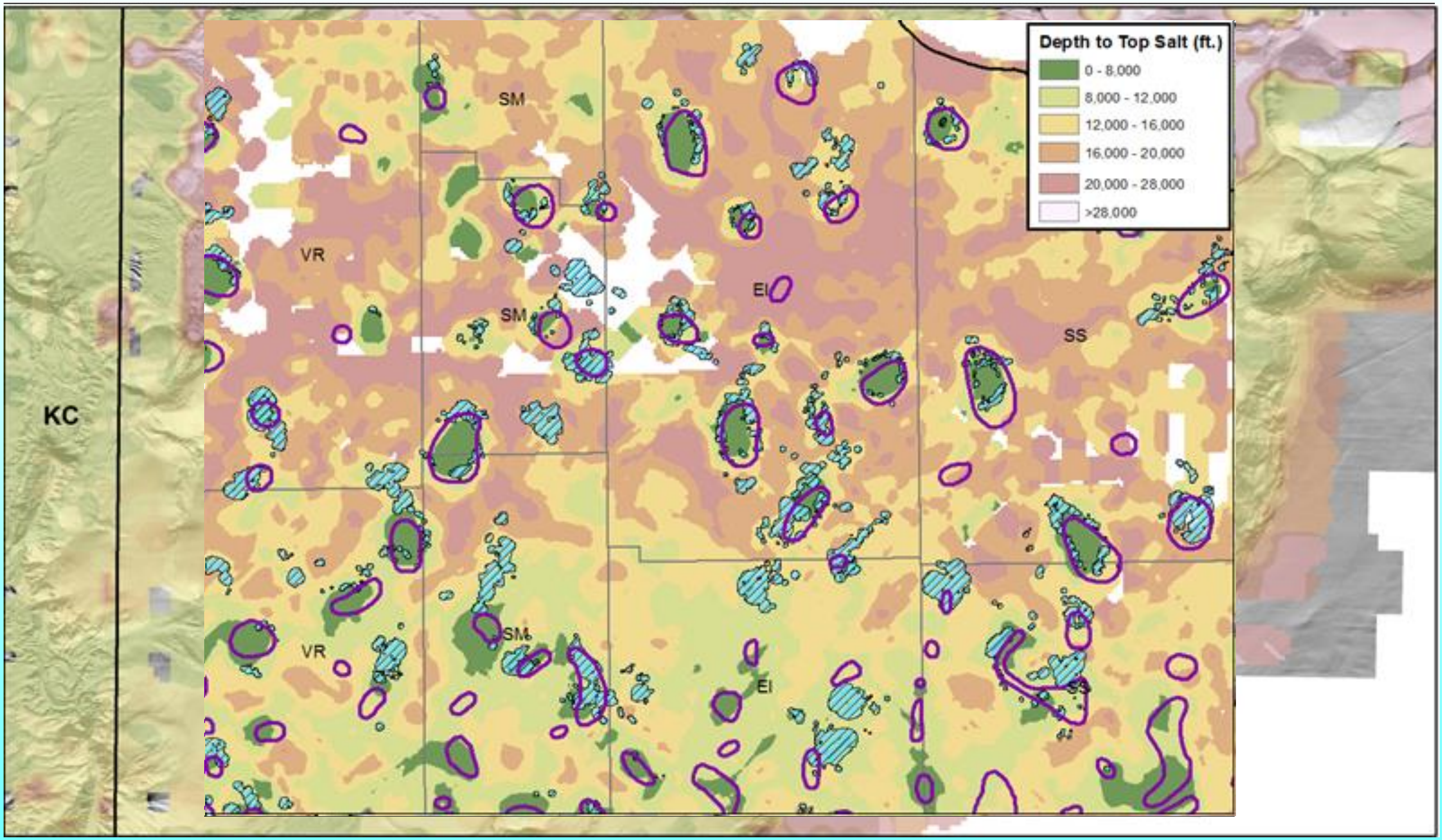
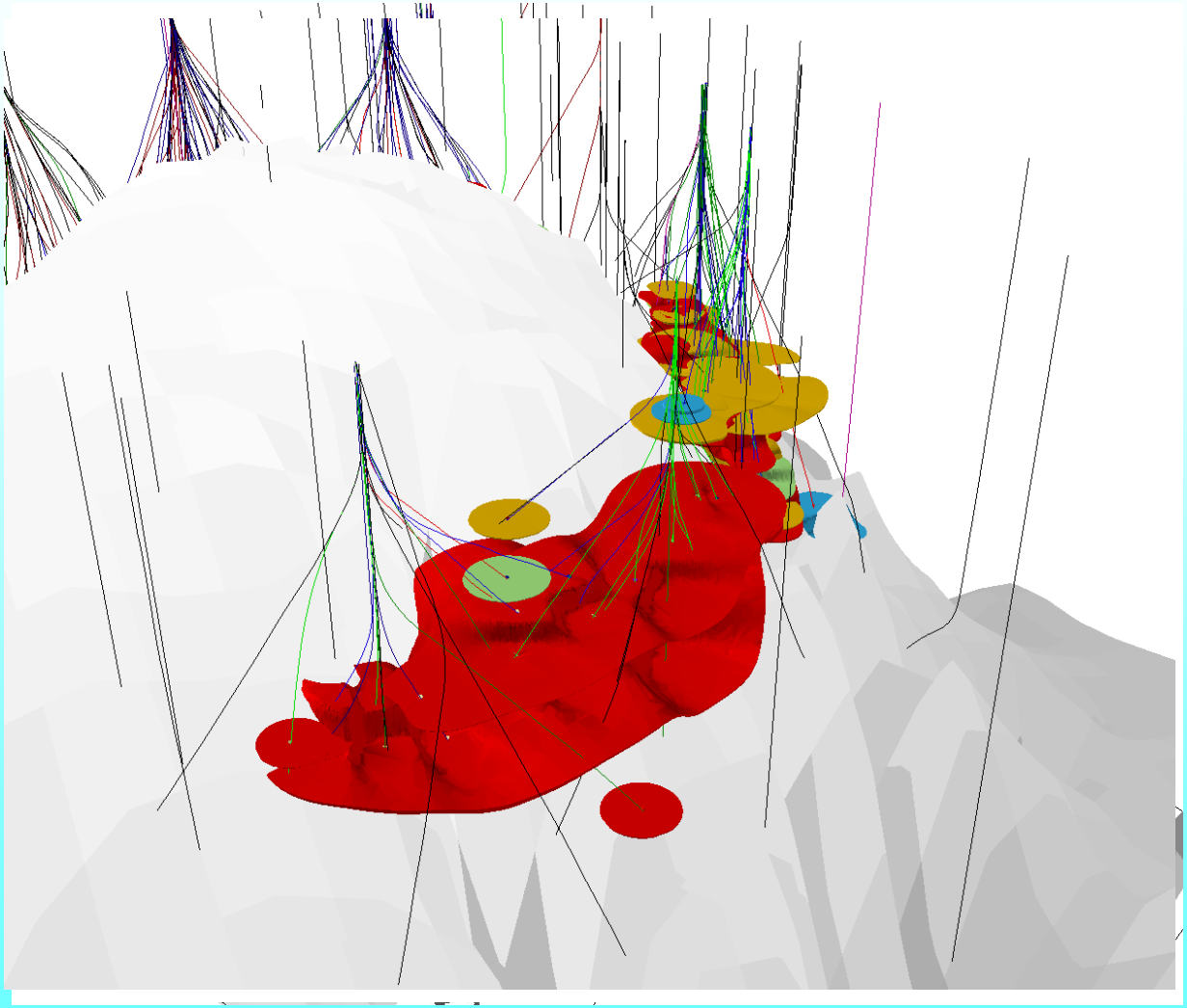
Coarse Accuracy – 2D



High-Resolution Bathymetry
Overlaid with Top of Salt
Walker Ridge

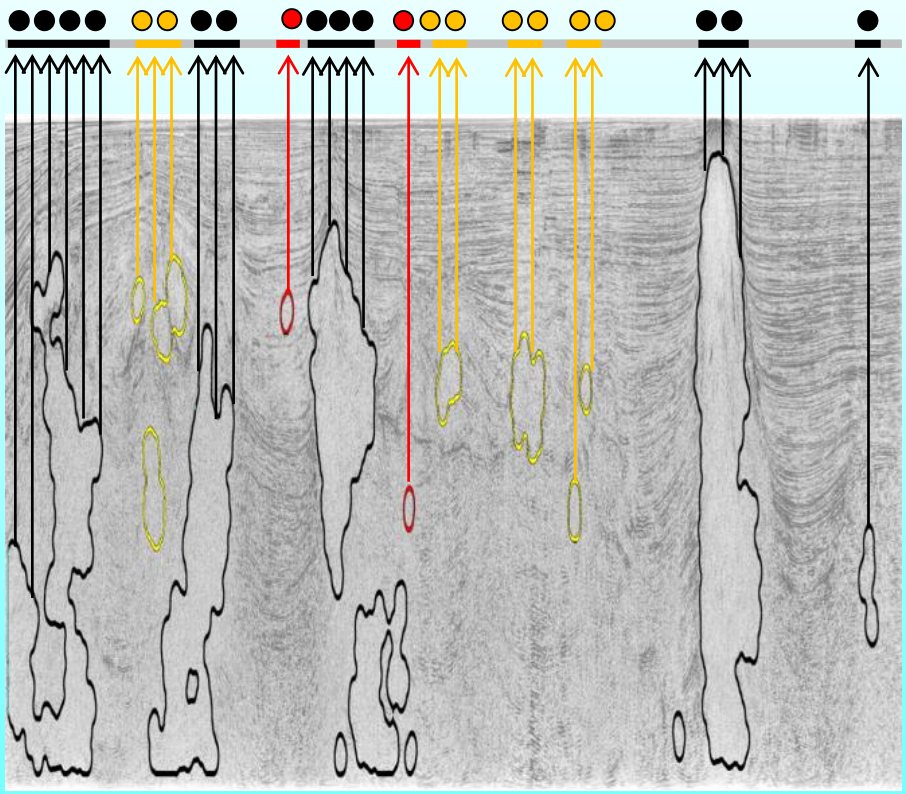
Coarse Accuracy - 3D



High-Resolution Assessment of Salt Boundary Accuracy

Grade for Line:

Color	Grade	% of Line	Wt'd Grade
Black	4	69	2.75
Yellow	3	24	0.74
Red	2	7	0.15
Total			**3.61**



Nav Line

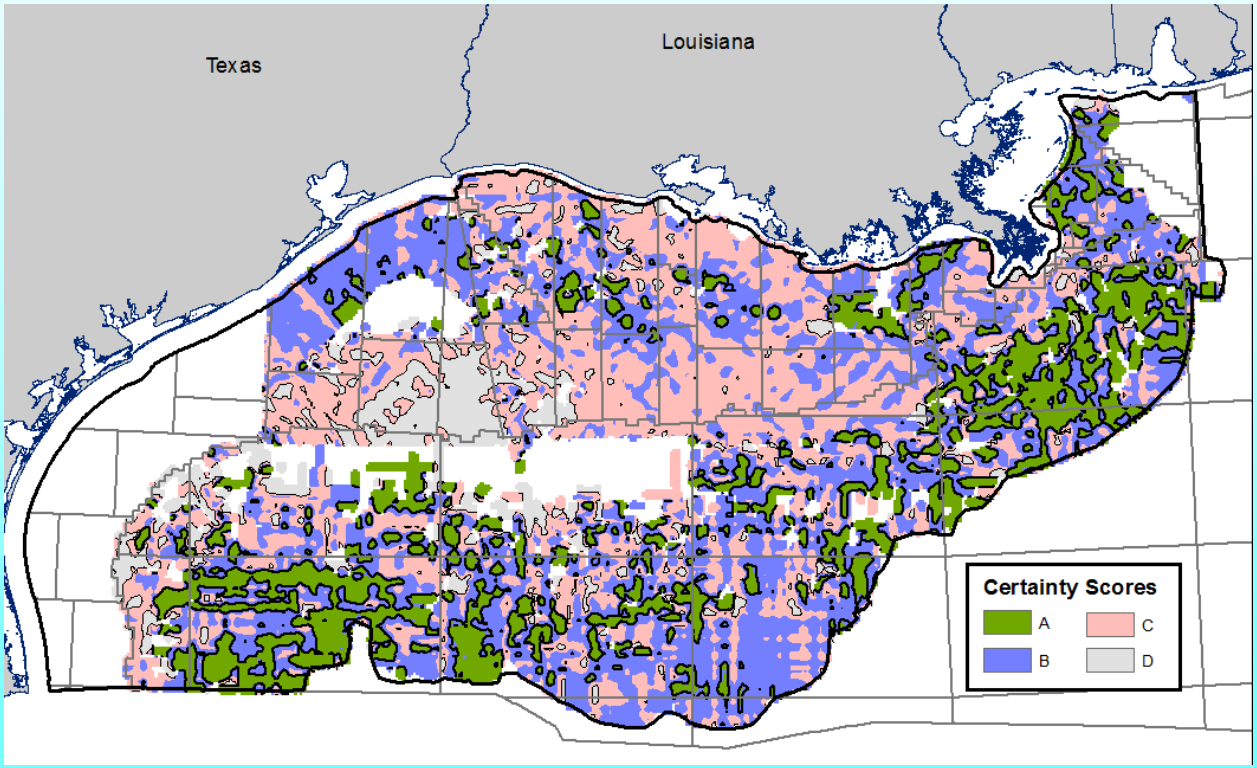
Point-Wise Grade:

- Decimate Graded Line
- Estimate Grade Surface via Kriging
- Estimate Prediction Error Surface
- Produce Regional Maps

Translation of Graded Salt Boundaries to Nav Line

Gridded Salt Boundaries

Regional Certainty Map



Results & Conclusions

- **Workflow of unsupervised learning algorithm + macro editing produced reasonable regional salt map for GOM**
  - Domes recognized with high accuracy & good spatial precision
  - Supplemental model needed for slope due to change in salt morphology
  - Survey/regional problems revealed in macro-editing: fixed or dropped
- **Very low marginal cost to exploit large legacy assets**
  - Do project starting with 8,000 SEG-Y files
    - About 2 weeks of expert time
    - About 400 hours of (desktop) computer time
  - Methods robust with variety of surveys and old data
  - Same techniques apply to modern data with much higher returns
- **Unsupervised project is foundation of iterative model**

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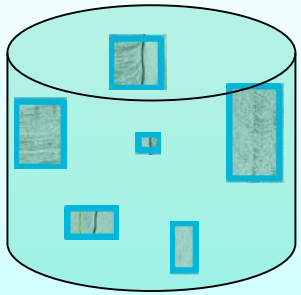
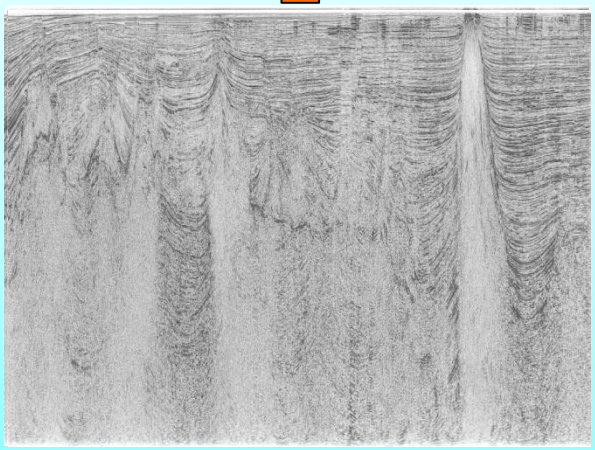
Next Step: Iterated Supervision

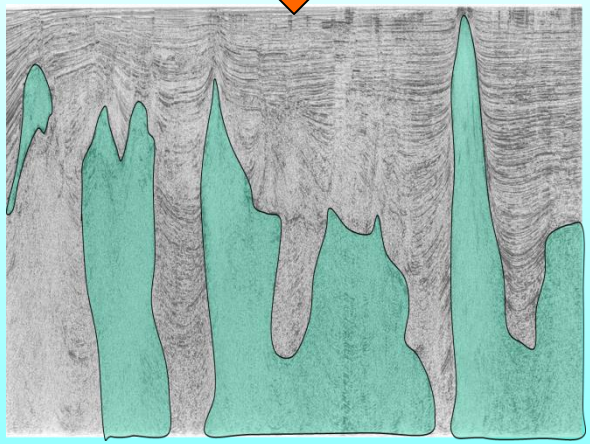


3. Intelligently sample results & *retain grading*



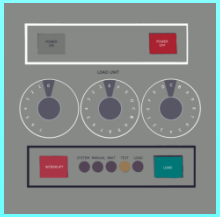
4. Build very large, labeled & graded exemplar library

5. Execute *supervised* classification



6. Extract updated parameters for new iteration of *unsupervised*

7. Adjust raster & vector parameters for new *unsupervised*ed iteration



8. Rerun *unsupervised* with new parameters

12. Get updated boundaries from supervised classification

Stopping Rule: Convergence Of Successive Iterations < α

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