

Automated Salt Recognition in 2D Seismic and Mapping Basin-Wide Salt in the Gulf of Mexico*

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Abstract

Seismic technology's advance over the last three decades, particularly the transition from 2D to 3D, has seemingly rendered enormous volumes of vintage 2D data obsolete. However, innovative methods applied to these legacy assets provide paths for extraction of valuable new insights at very low marginal costs. Here, automated pattern recognition techniques were utilized in the analysis of a set of more than 7,000 2D poststack, migrated SEG-Y lines, covering approximately 400,000 km² (154,441 mi²) across the main petroliferous area of the Gulf of Mexico, producing a basin-wide map of top of salt.

Two analytic approaches were taken to the unsupervised machine identification of salt in old (pre-1992) seismic time sections. The first, based on image texture analysis, assigned a salt-likelihood score to each pixel in a seismic section through application of a grey-level co-occurrence matrix and statistics on the resultant rasters. Several texture statistics were found efficient for differentiating salt and non-salt regions. The second, based on vector analysis of reflectors extracted from seismic images, discriminated salt/non-salt based on the densities of low-dip and high-dip reflectors.

These measures were evaluated, without interpreter intervention, and combined to estimate salt/non-salt boundaries in sections with salt and to identify sections with no salt. Levels of confidence in the boundaries were statistically estimated to convey certainty in the existence and location of the salt boundaries.

Final estimates of the top of salt were contoured in time. Based on a data set of more than 3,000 velocity surveys, the time contours were transformed to depth. A 3D surface was estimated on the depth map so the salt surface could be visualized and further studied in a basin-wide 3D geographic information system in which other geologic, geophysical, production and facility data were available.

Processing each line took several minutes of computer time. However, the analysis can be easily parallelized, reducing the computational impediment to batch machine analysis of thousands of lines.

The background of the slide is a grayscale seismic reflection image. Overlaid on this image are numerous red, irregular, closed-loop outlines that represent identified salt bodies. These outlines vary in size and shape, with some being elongated and others more circular. The text is centered over the image.

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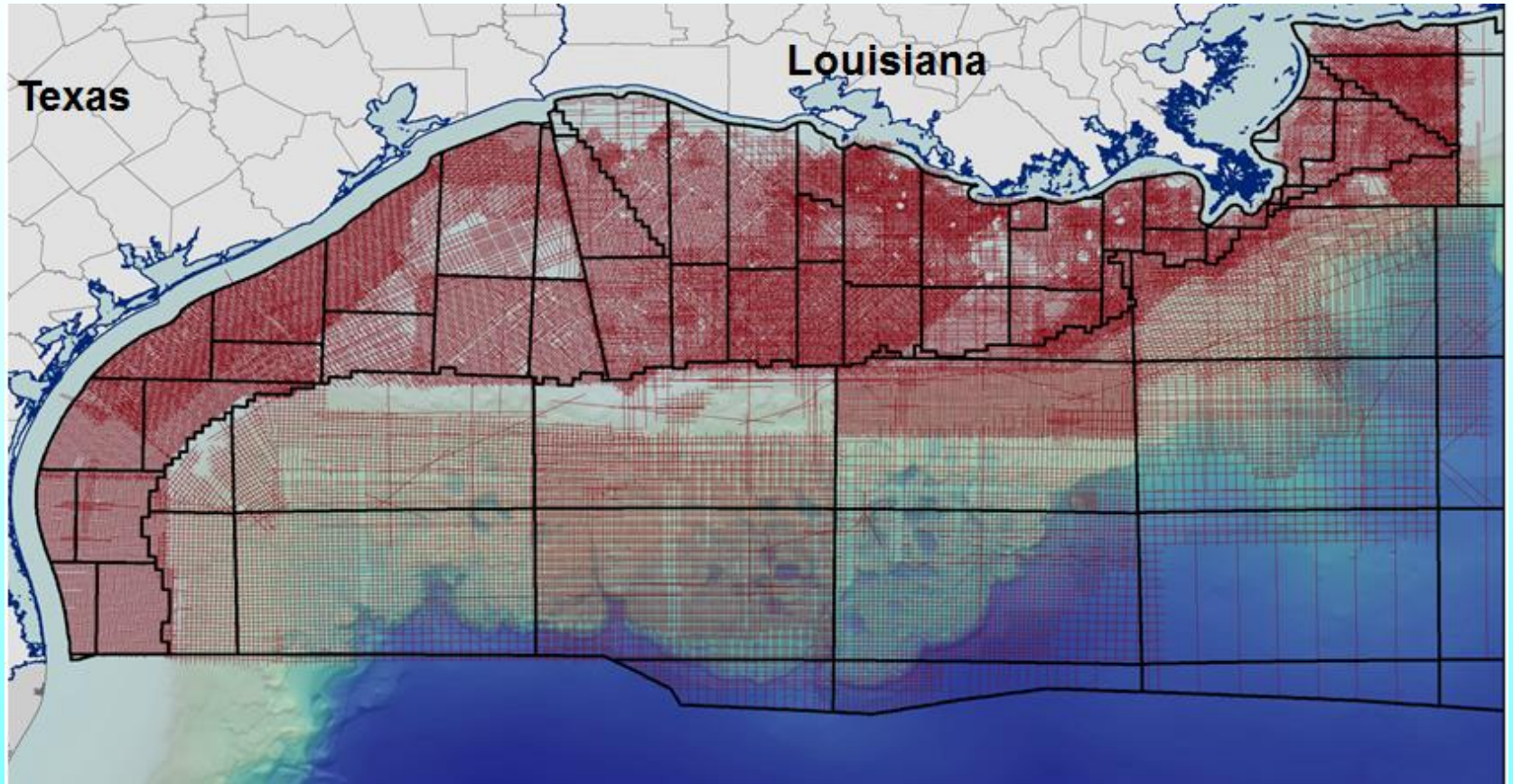
May 21, 2018

AAPG 2018 – Salt Lake City

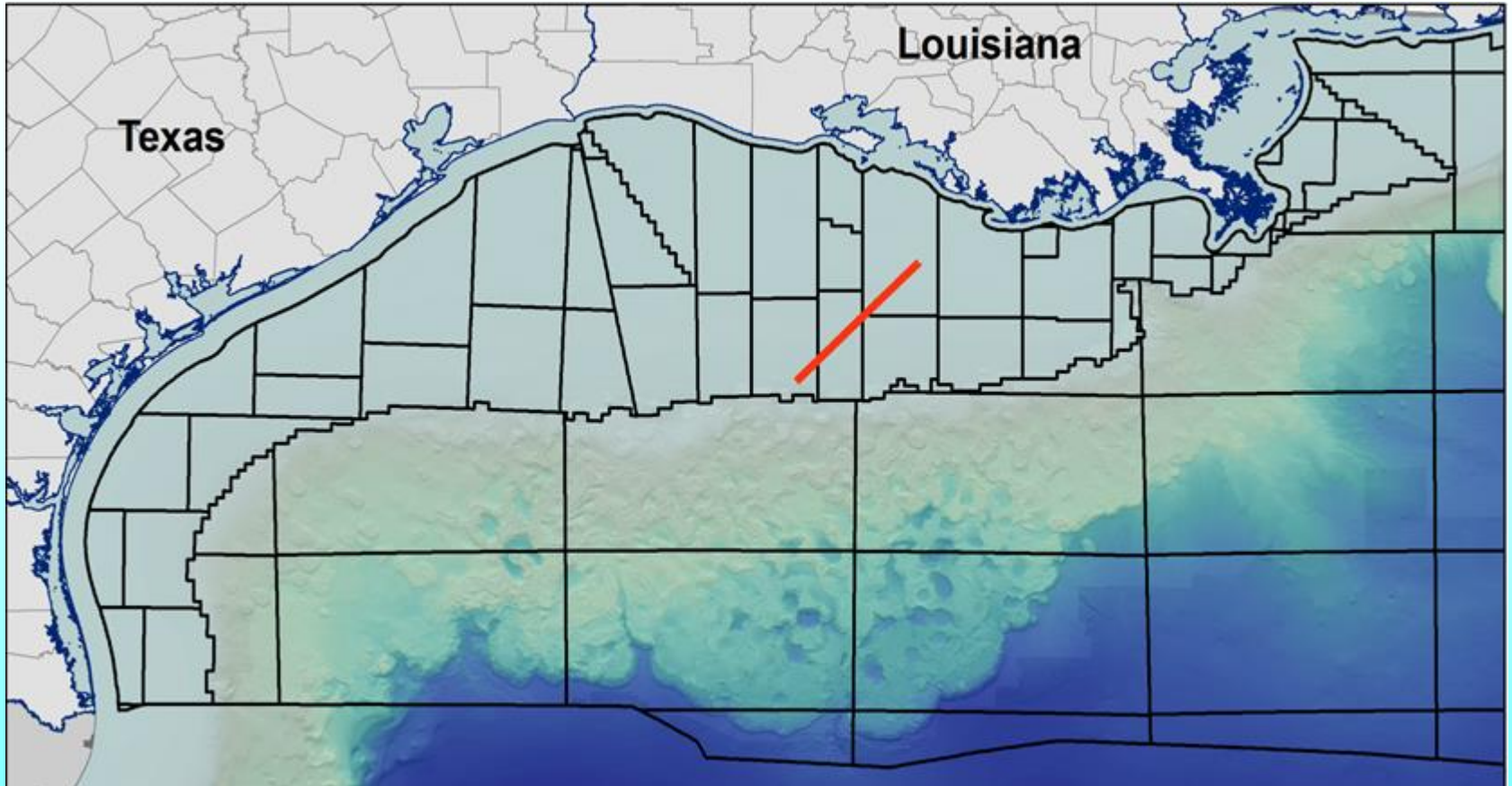
Can Machines Learn at a Basin Scale?

- **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 mi²
 - 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**

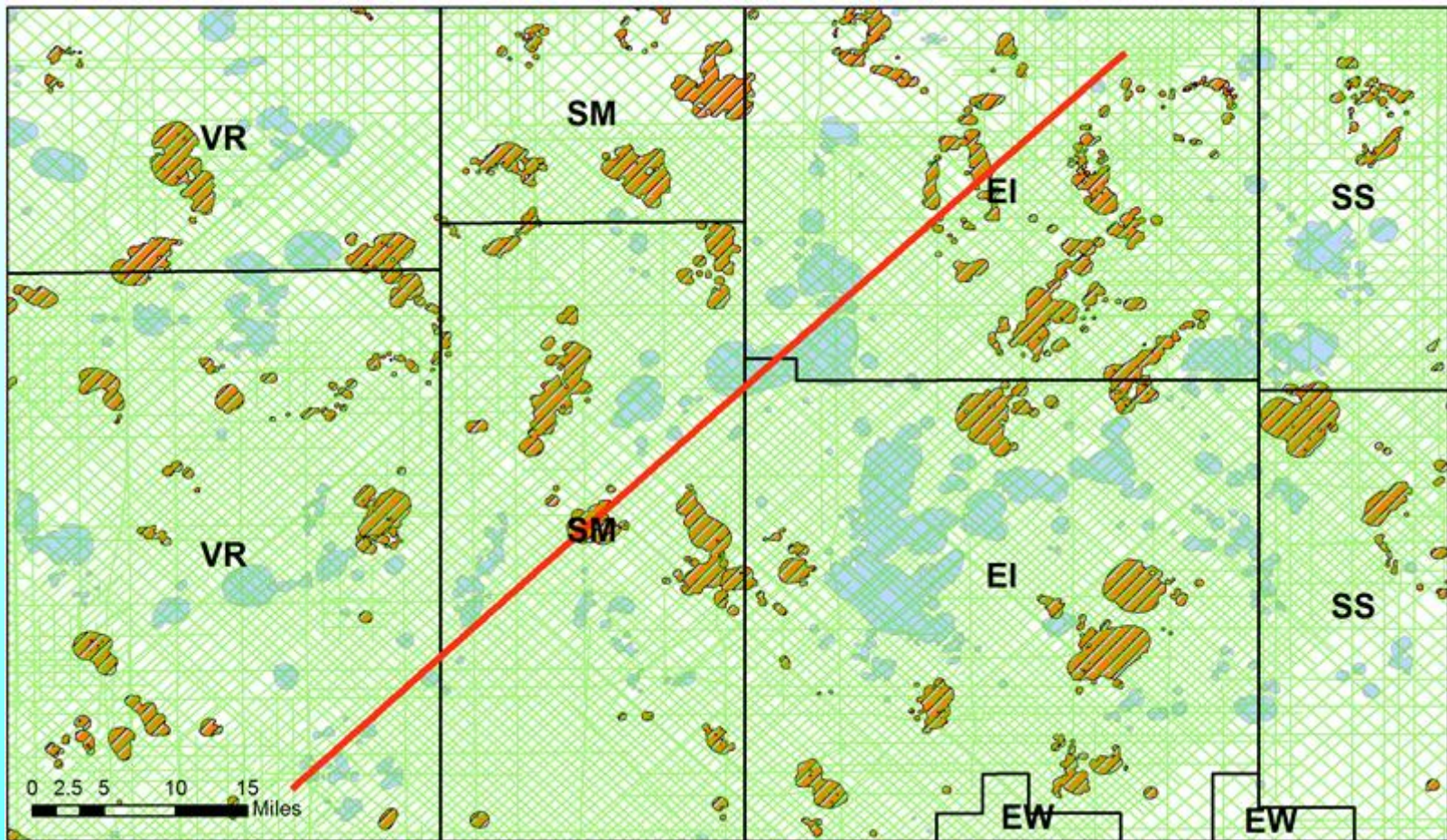
Data Coverage



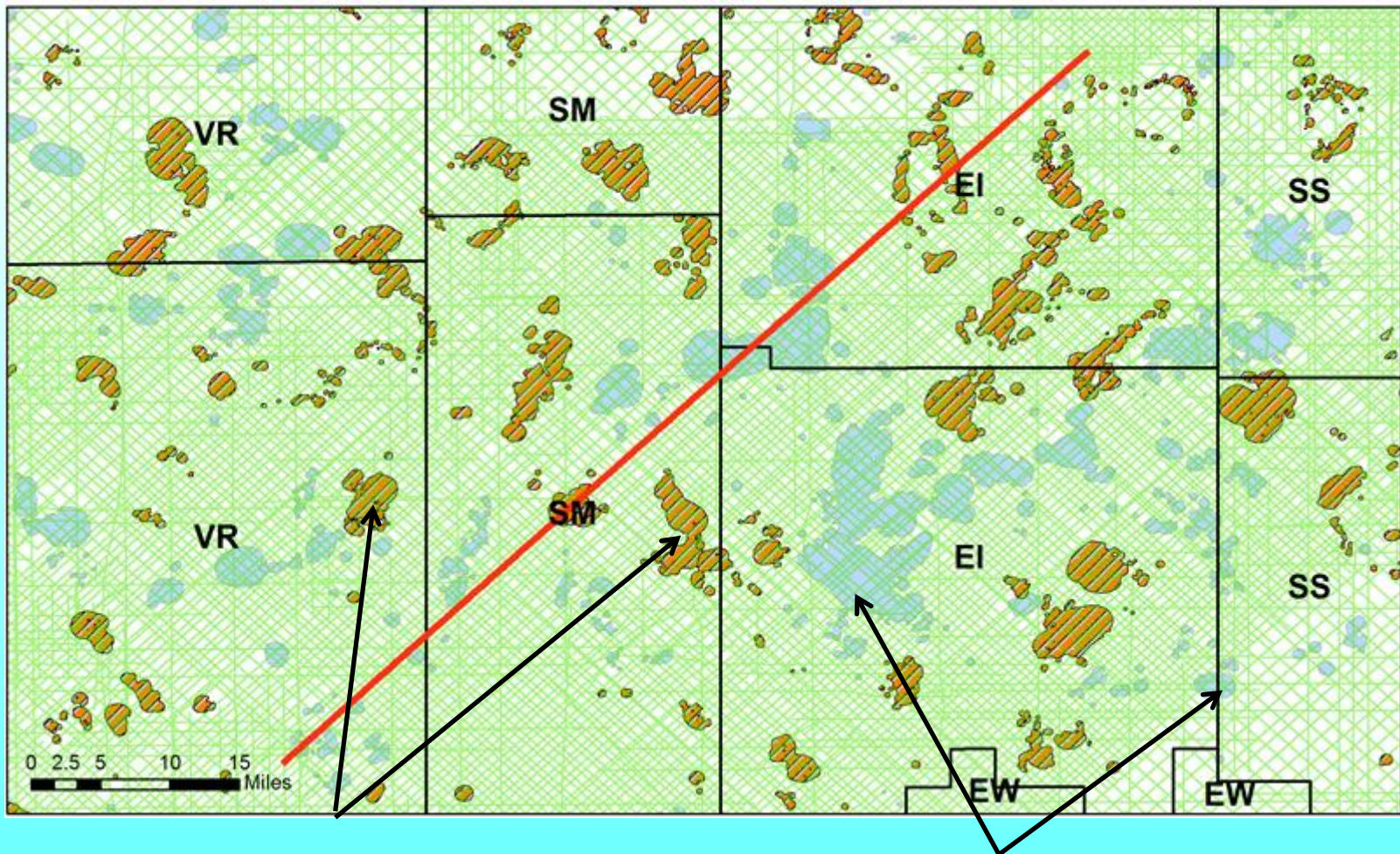
Data Coverage



Data Coverage



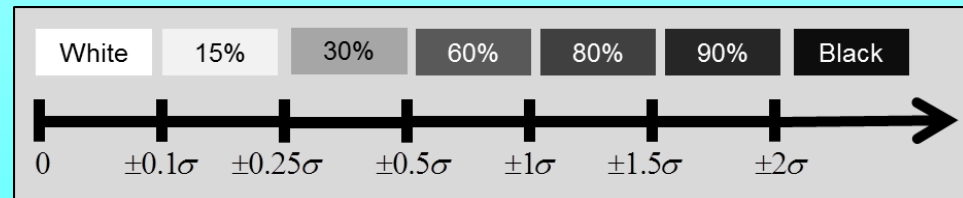
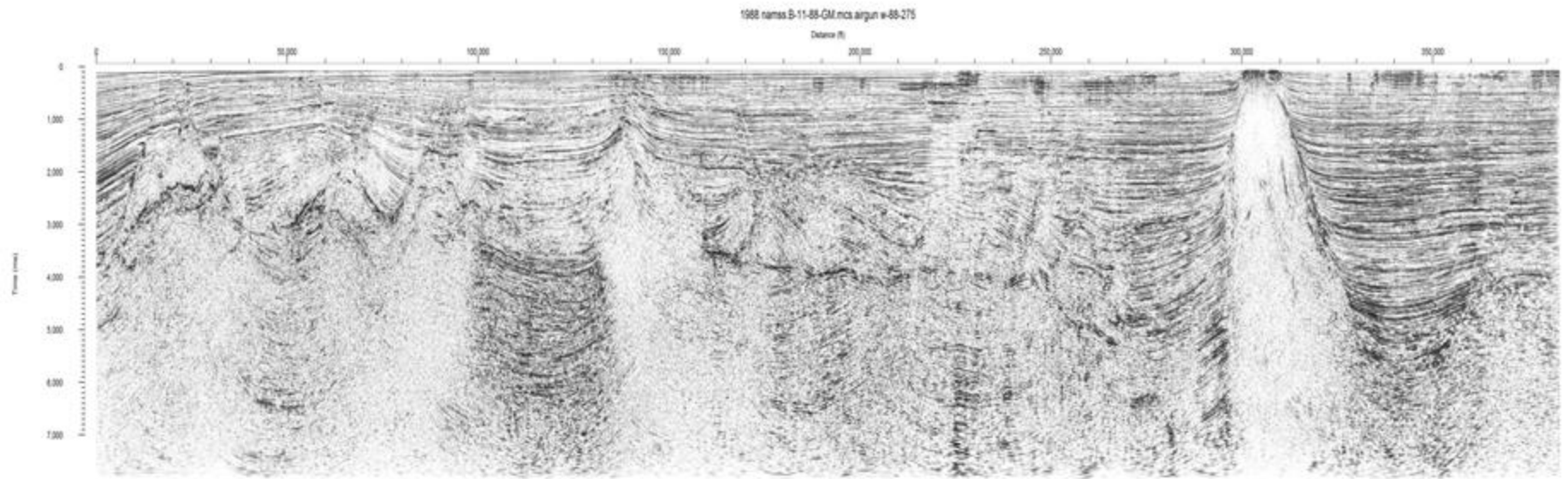
Data Coverage



Fields with Salt-Related Trapping

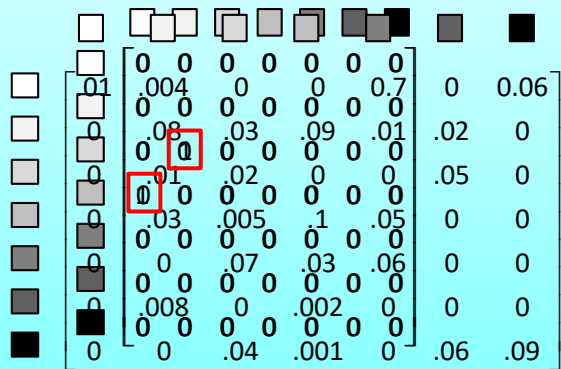
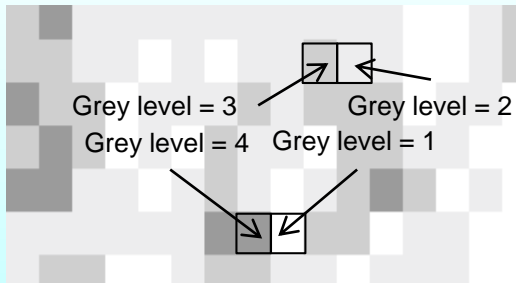
Fields with Other Trapping

Salt's Seismic “Texture”



GLCM

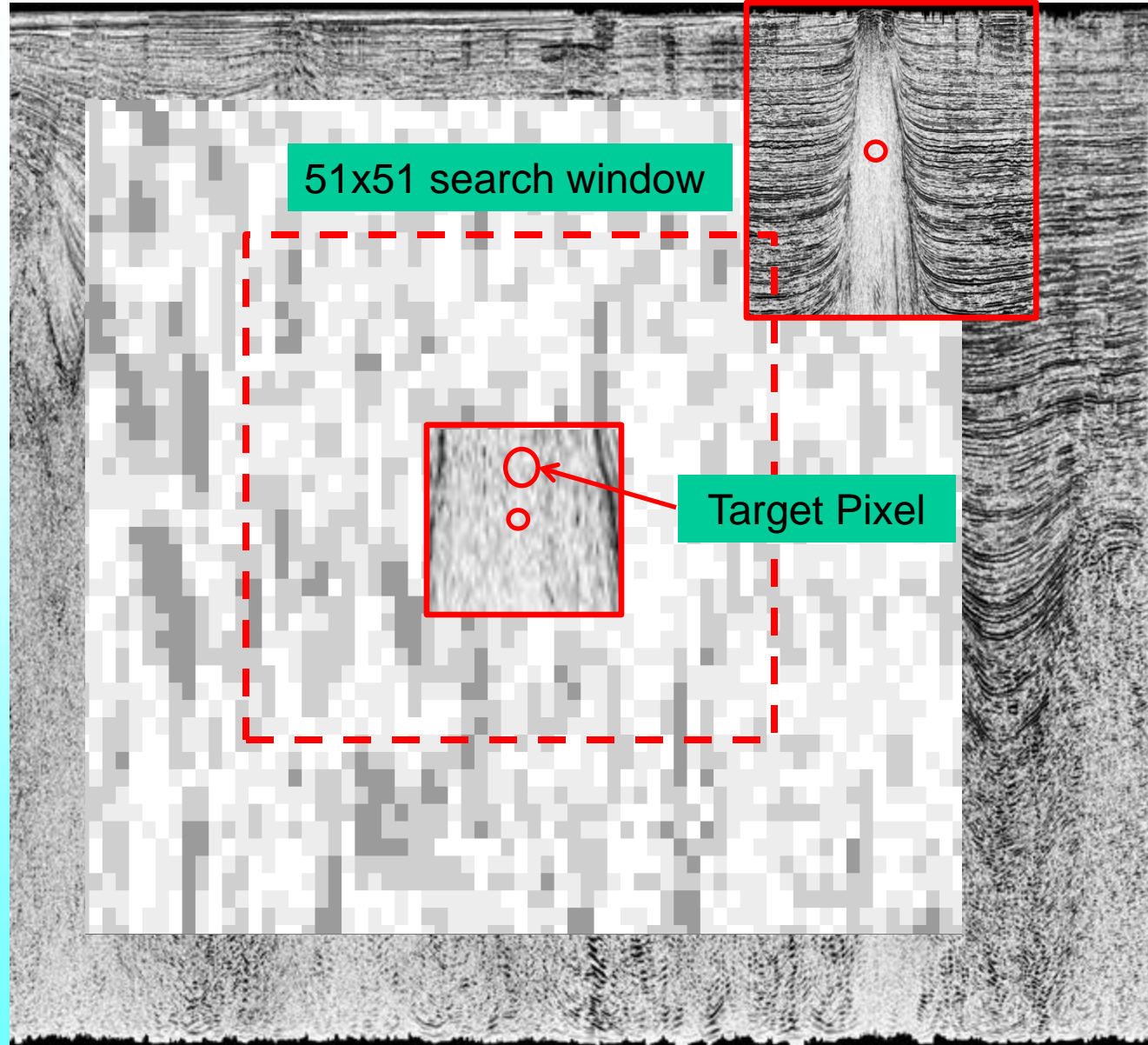
Grey Level Co-occurrence Matrix



Compute probabilities for all co-occurrences = GLCM

Compute statistics for GLCM

Assign statistics to pixel as attributes

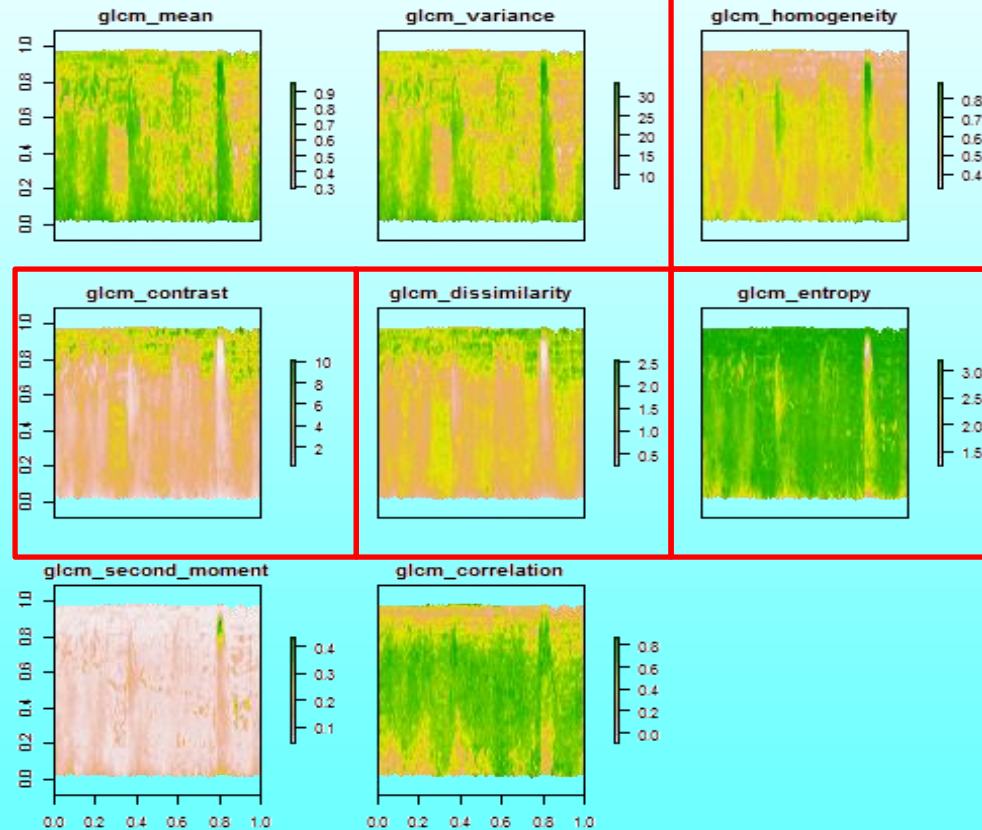
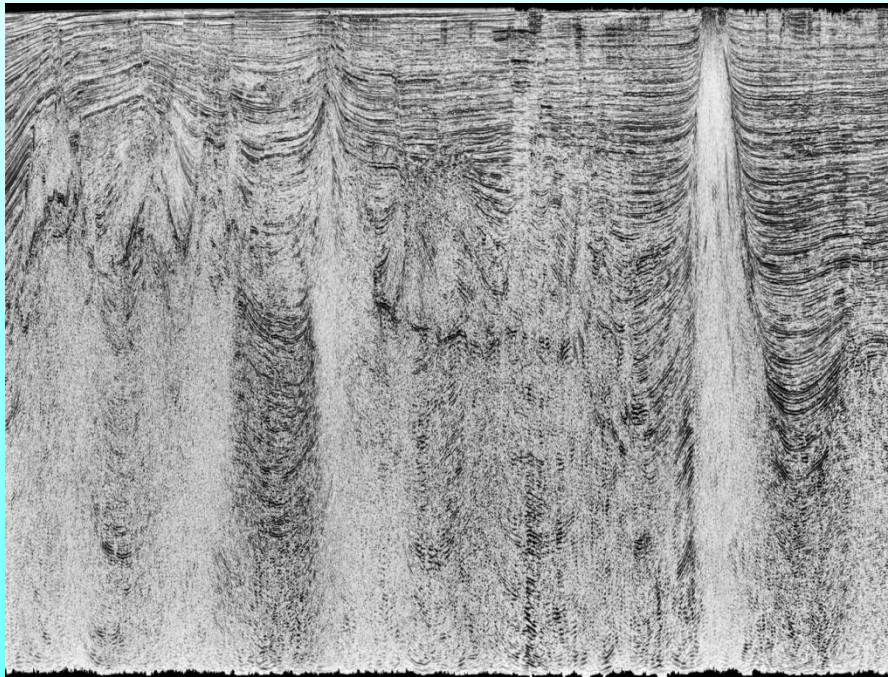


Then move to the next pixel & repeat

GLCM Statistics

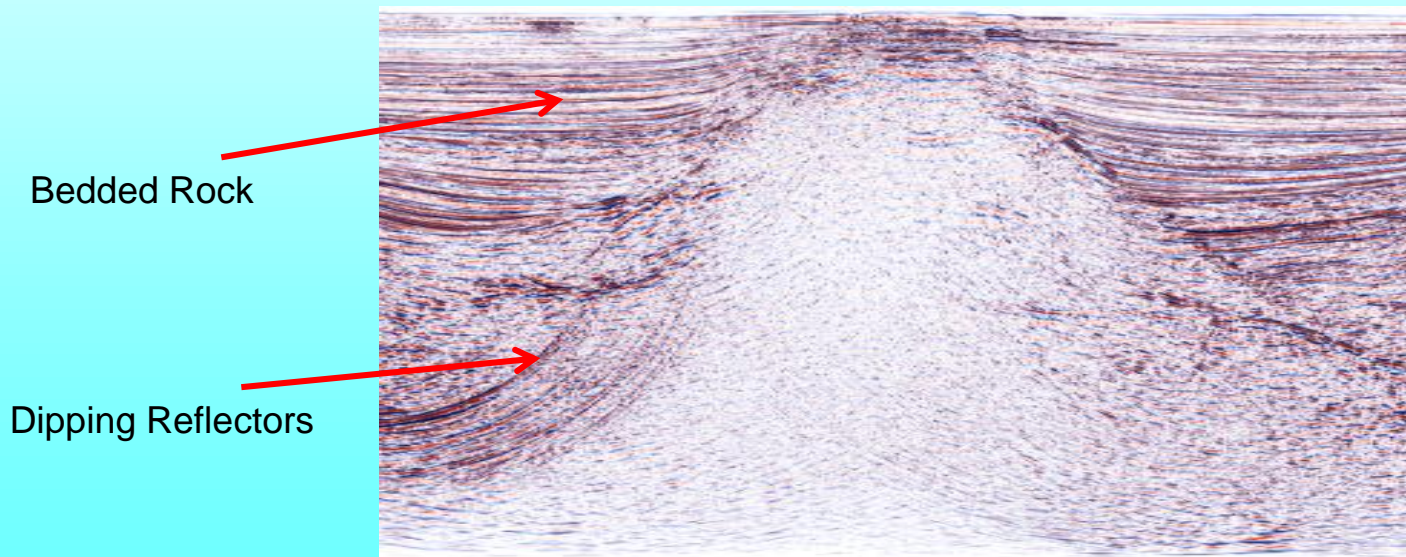
Of suite of 8 GLCM statistics computed, choose

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



Reflector Analysis

- **Analyze whole reflectors for information on salt**
 - Clear connection to geology
 - Salt is bounded by strong dipping reflectors
 - Reflectors limit the location where salt is located
 - Independent information on the location of boundaries between salt/non-salt



Reflector Analysis

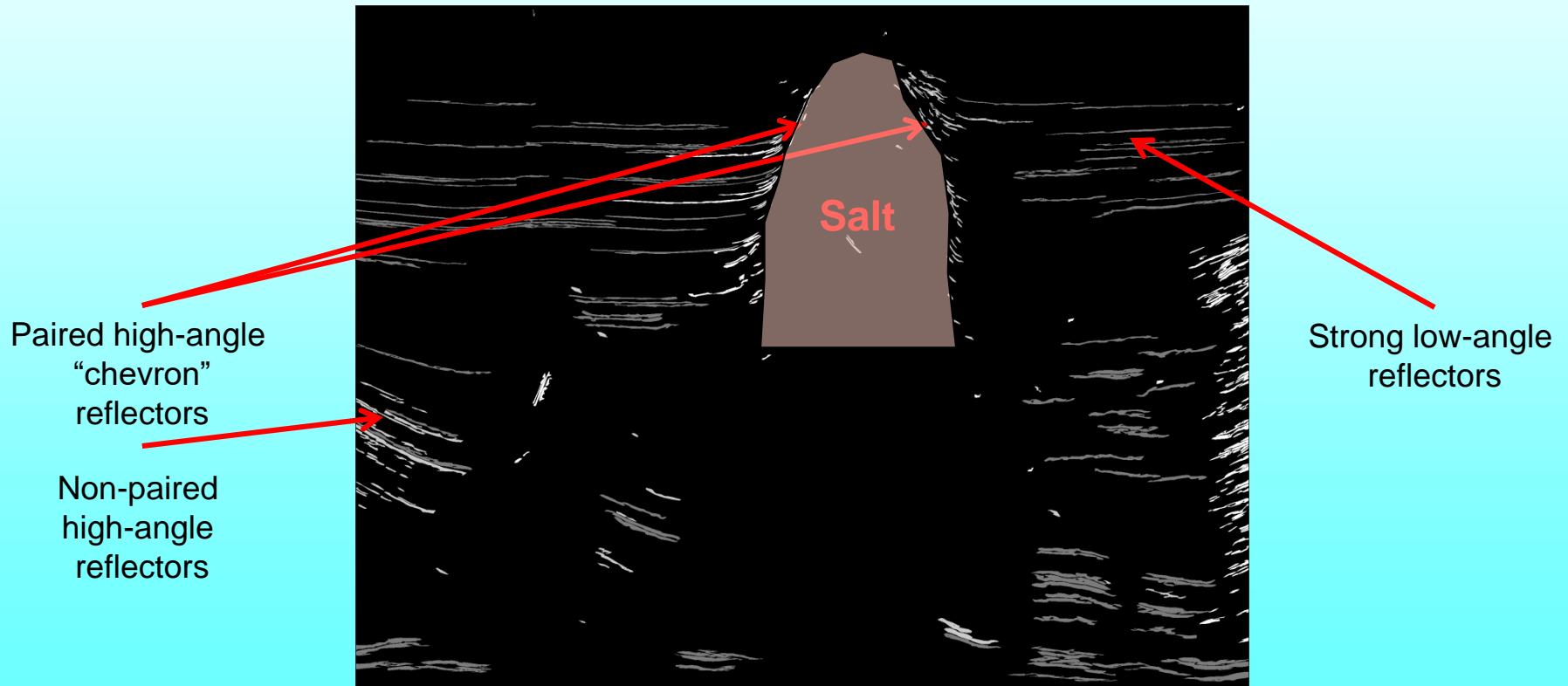
How are reflectors extracted?

- Apply “Raster to Polygon” tool in ArcInfo to produce polygons around reflectors
- Extract polygons & lines in ArcPro (GIS)
- Attribute lines (reflectors) from data on enclosing polygons



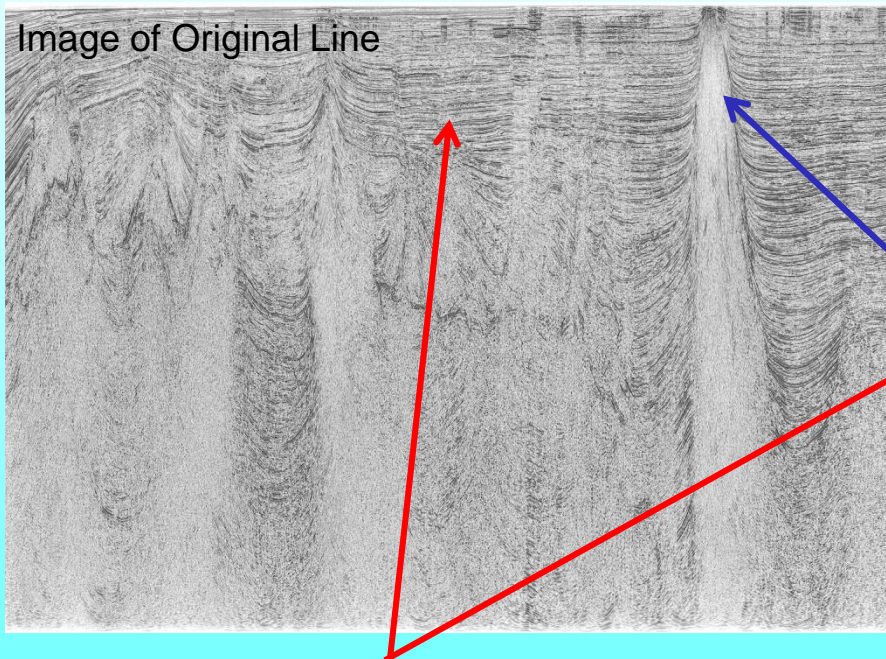
Geometry of High-Angle Reflectors

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

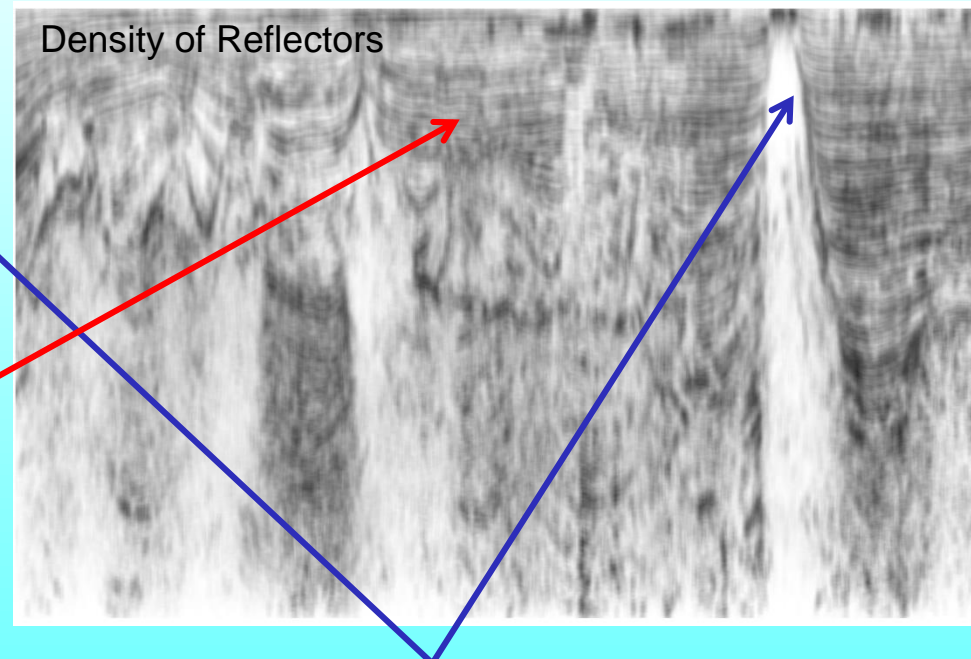


Reflector Density Attribute

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



High reflector densities bedded section outside salt

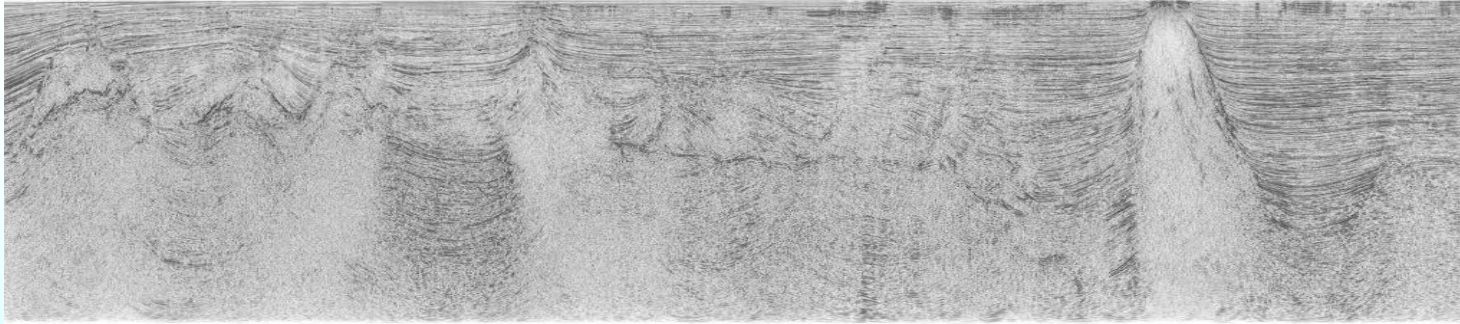


Low reflector densities in salt

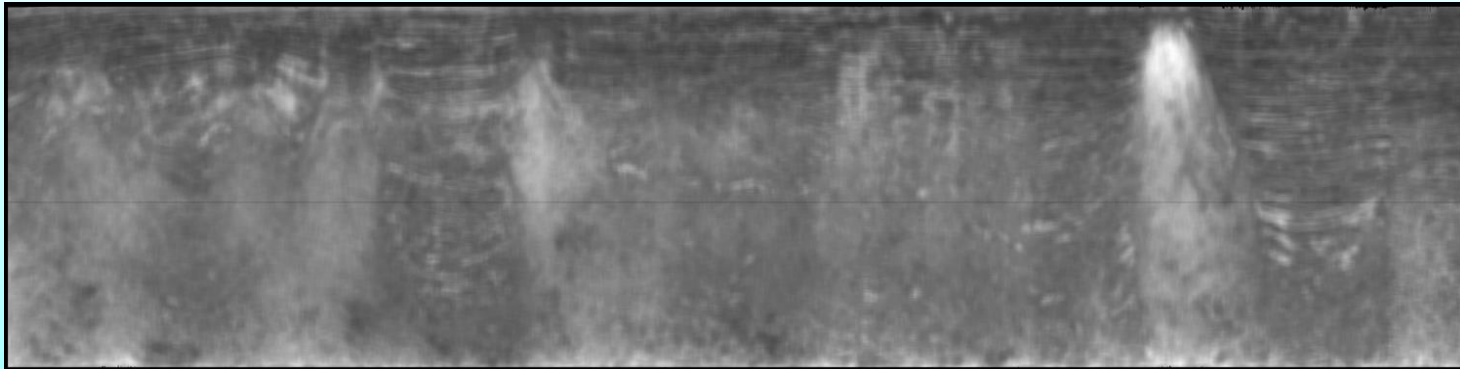
Create Salt Score & Threshold

- **Normalize Parameters:**
 - Convert to 0-1 scale:
 - Texture: GLCM entropy, homogeneity, dissimilarity & contrast
 - Reflector: density of reflectors
 - Treat as 0/1 dummy:
 - Reflector: Area between high-angle, “chevroned” reflectors
- **Average 6 normalized parameters → “Salt Score”**
- **Estimate optimal threshold to discriminate salt/non-salt pixels**
 - 2-class clustering of *Otsu (1979)*
 - Extension of Fisher’s discriminant analysis
 - Divide pixels into 2 groups to minimize within-group variance of Salt Score and maximize between-group variance of Salt Score
 - Output = binary image (salt = white; non-salt = black)

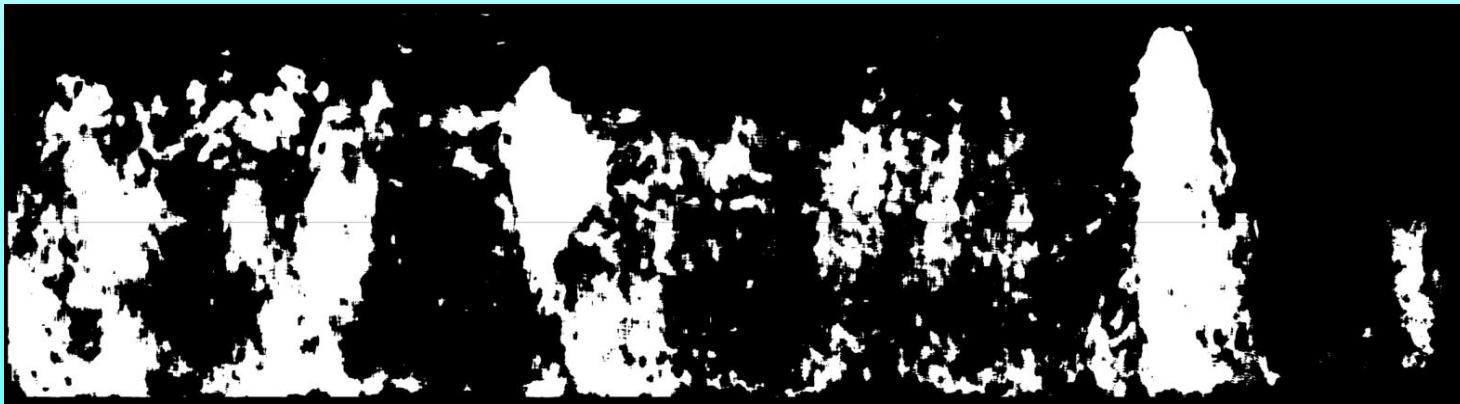
Salt Score & Threshold



Original

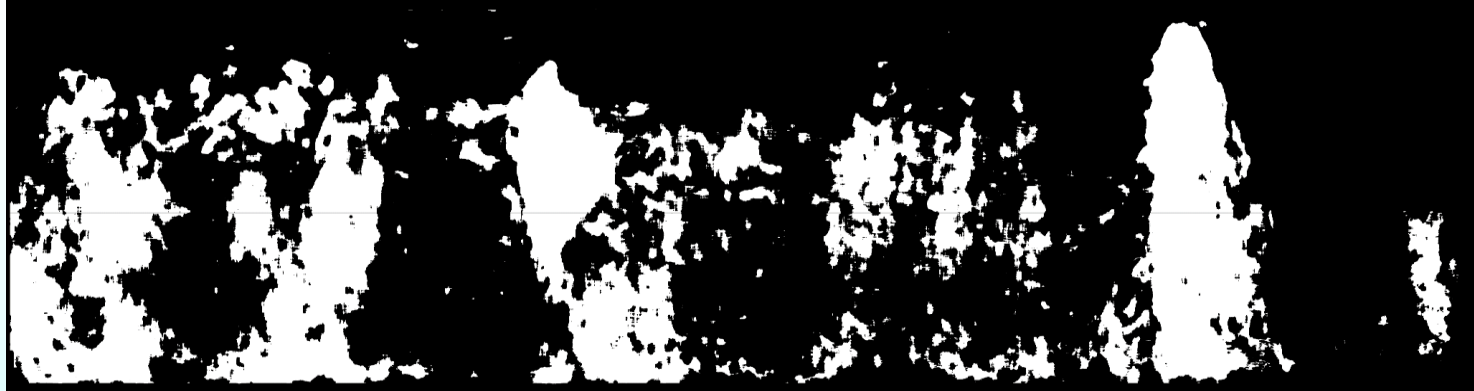


Salt Score



Threshold

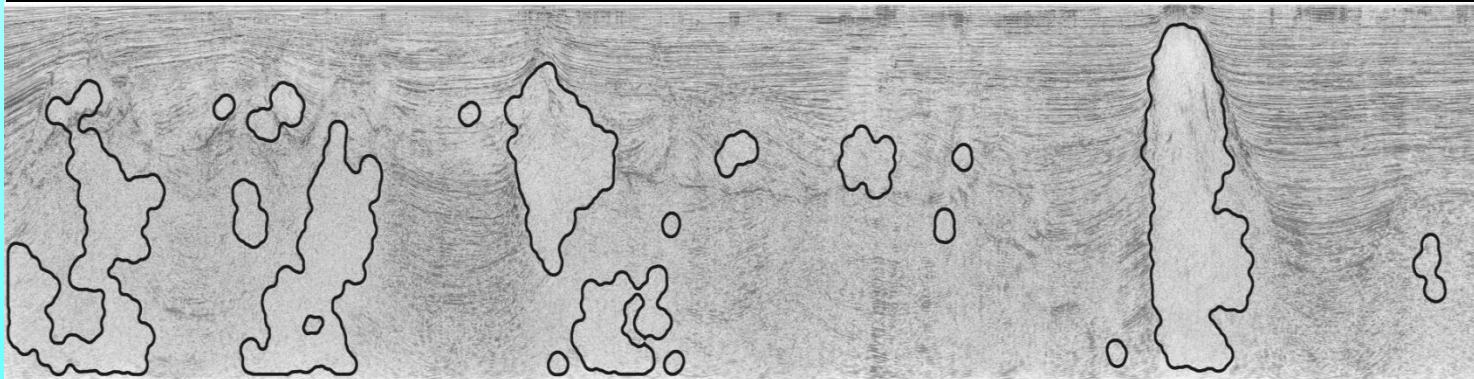
Morphological Clean-Up



After
Threshold



Morphological
Cleanup



Boundary
Extracted

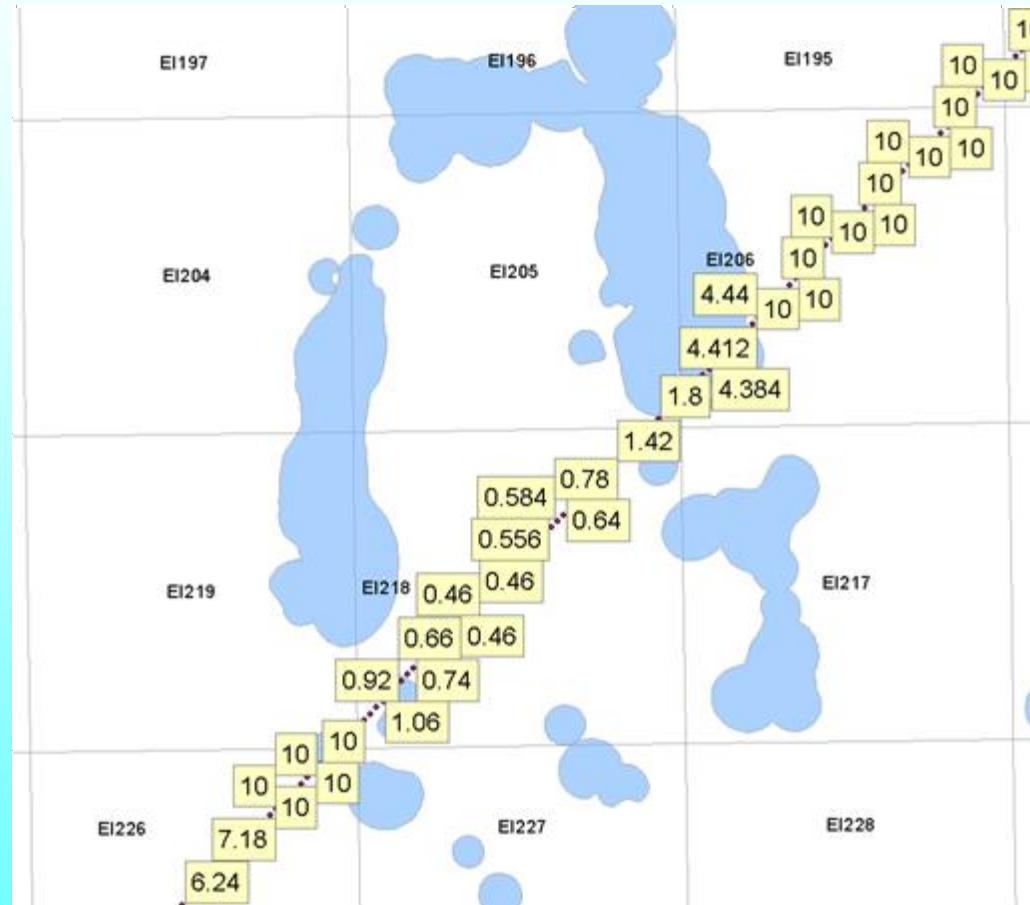
Top of Salt: Time

Top of Salt
not found

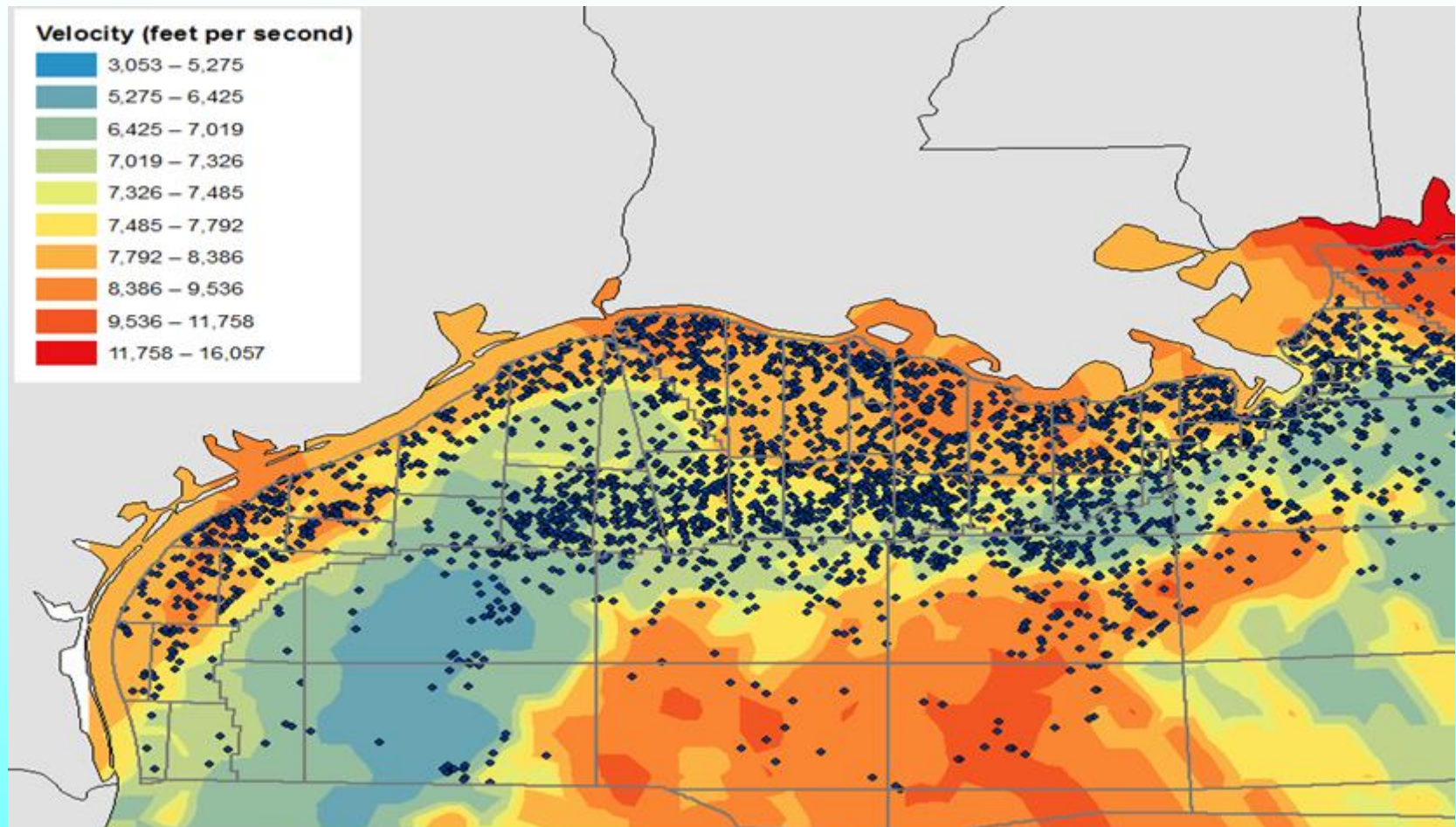
Top of Salt =
0.57 seconds

Top of Salt =
1.4 seconds

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

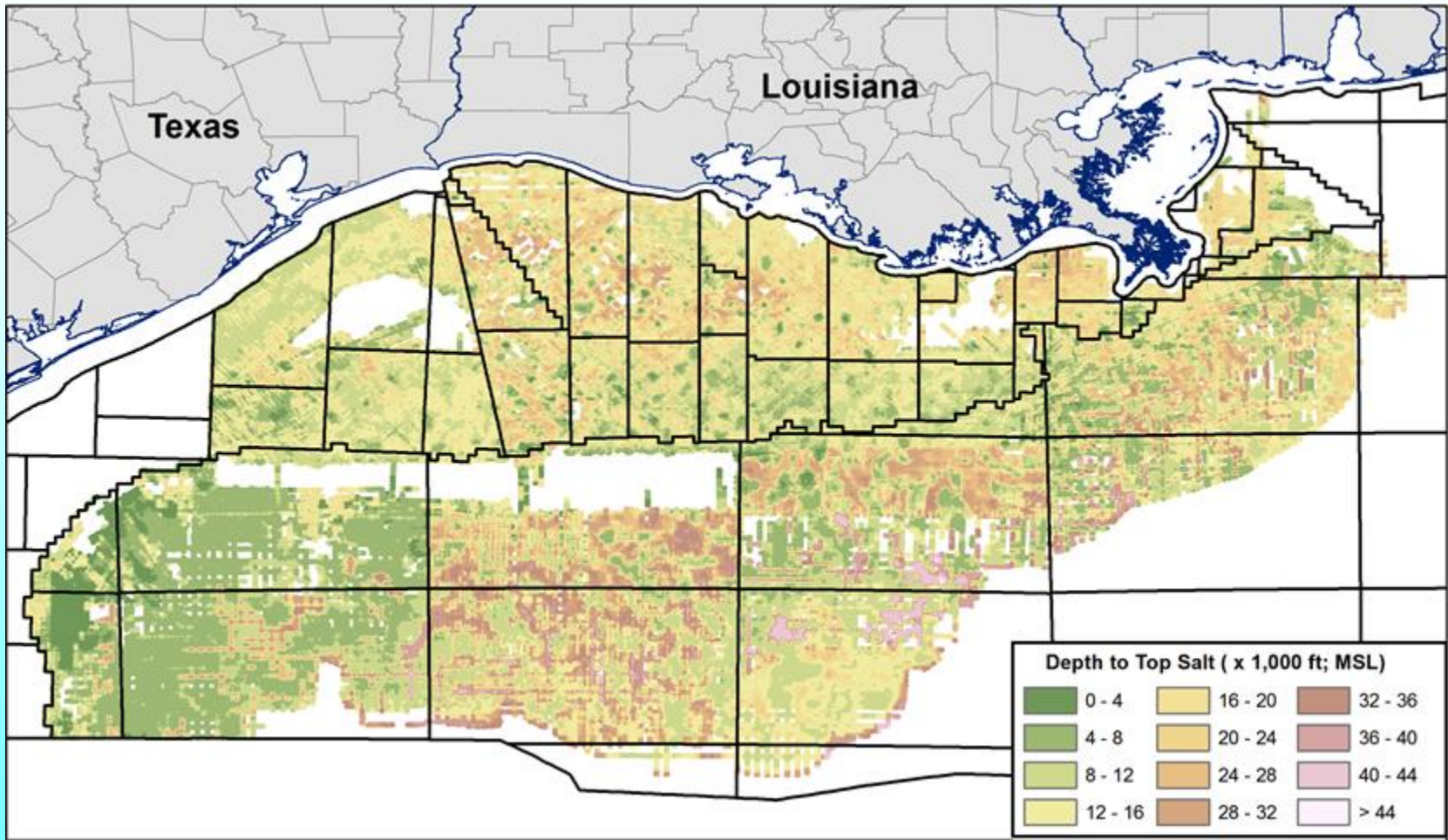


Time → Depth



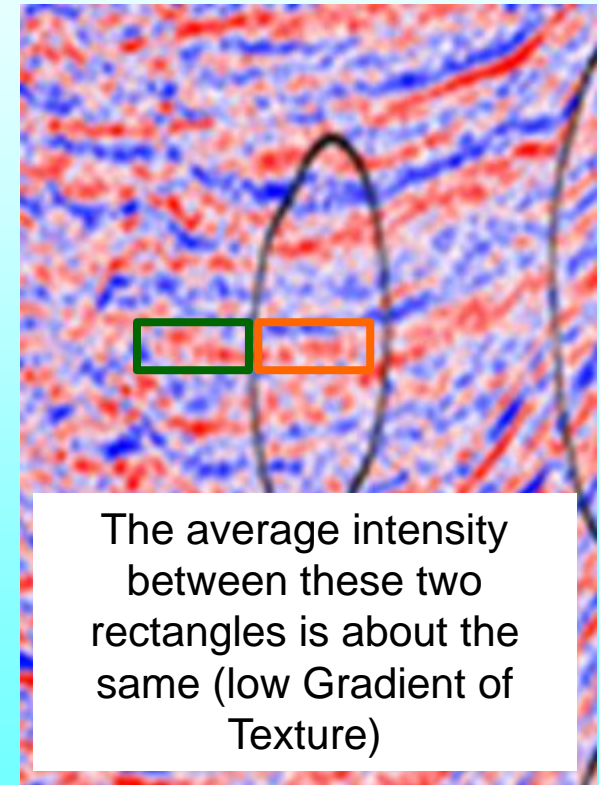
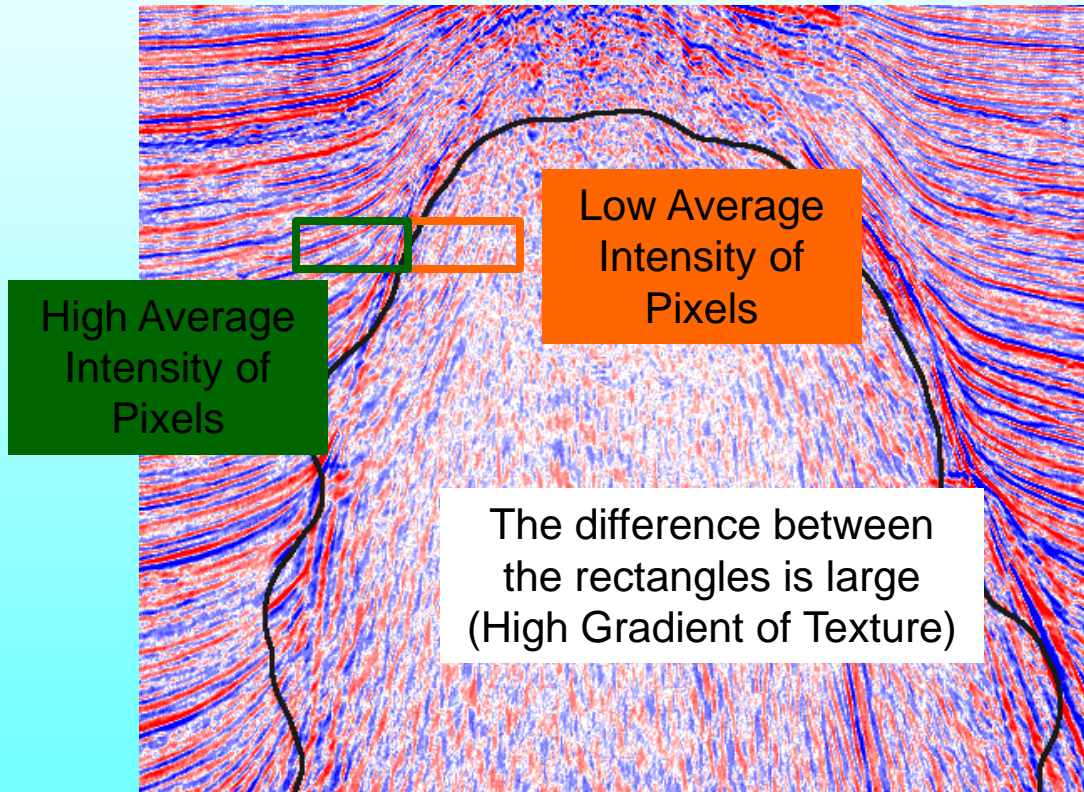
Estimated Velocity Field Using Velocity Surveys

Estimated Top of Salt

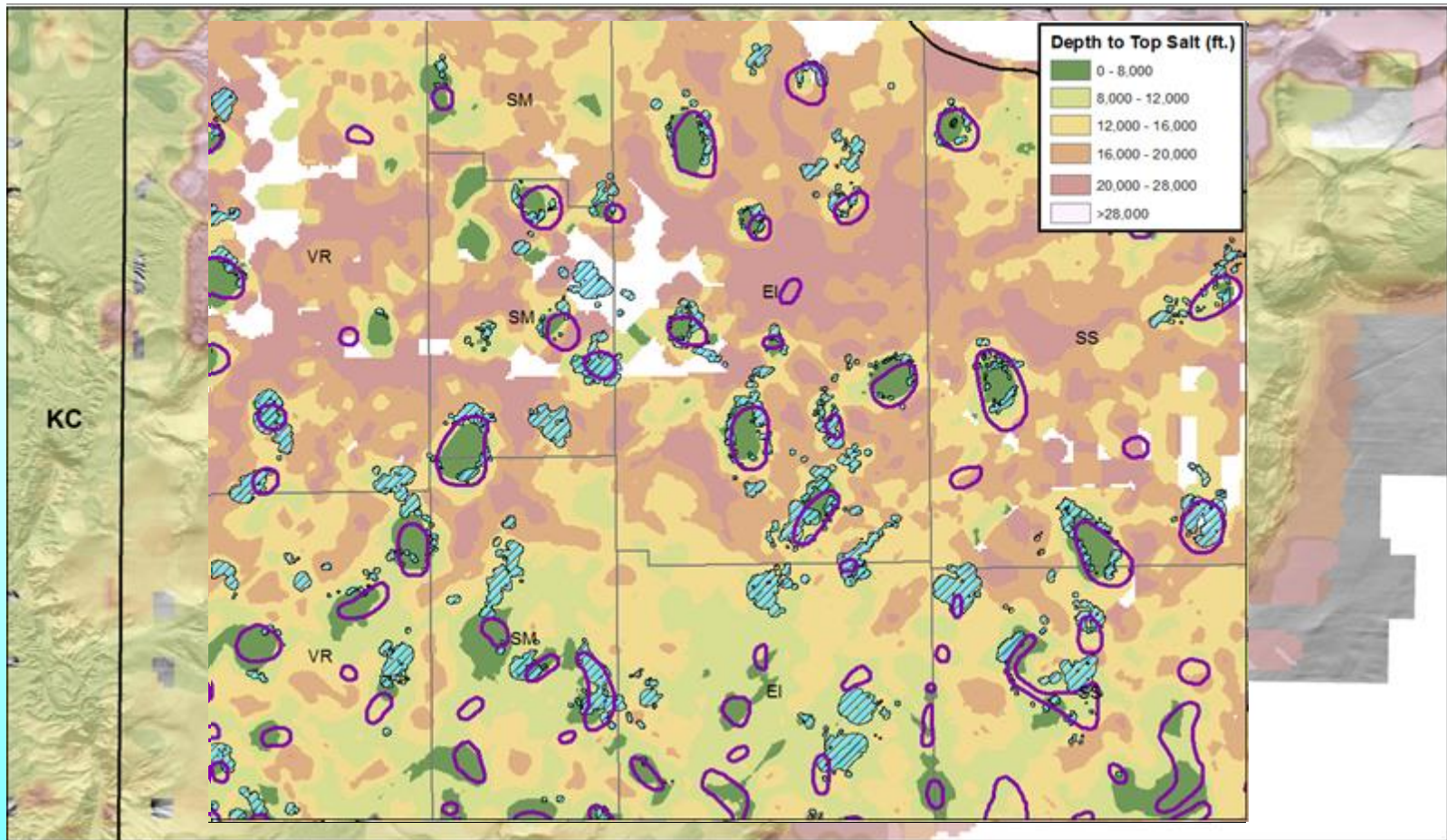


Boundary & Feature Evaluation

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



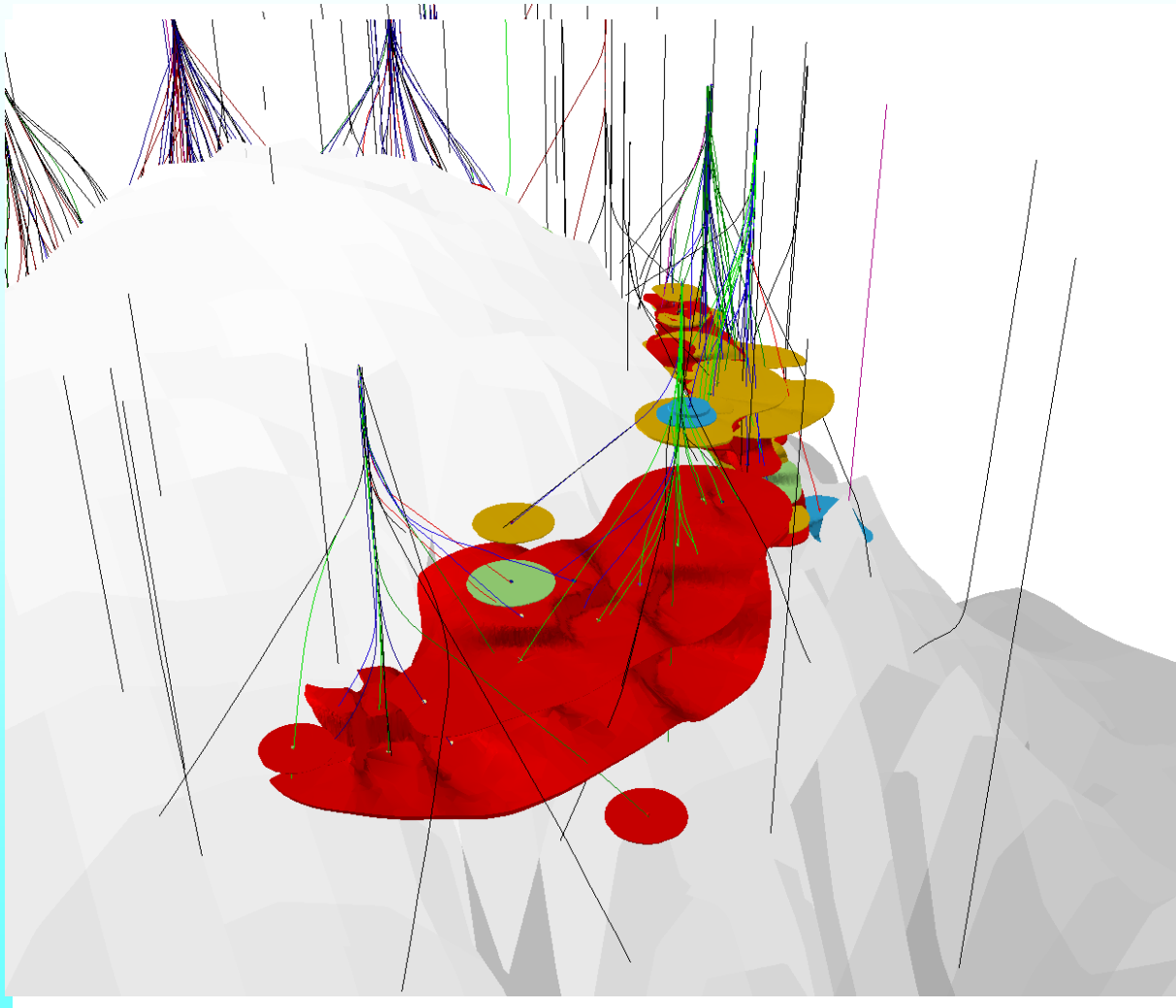
Coarse Accuracy – 2D



- Hand-Mapped Salt from 1990s (Purple Polys)
- Salt-Trapped Fields (Blue-Striped Polys)
- Bathymetry Overlaid with Top of Salt

Coarse Accuracy - 3D

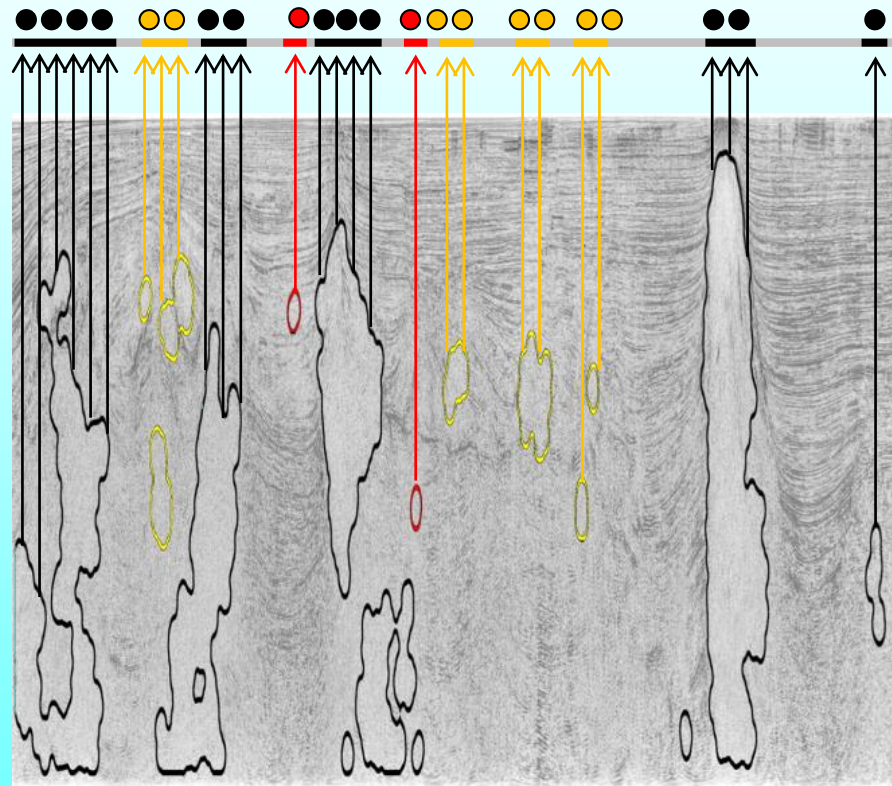
SEM003



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

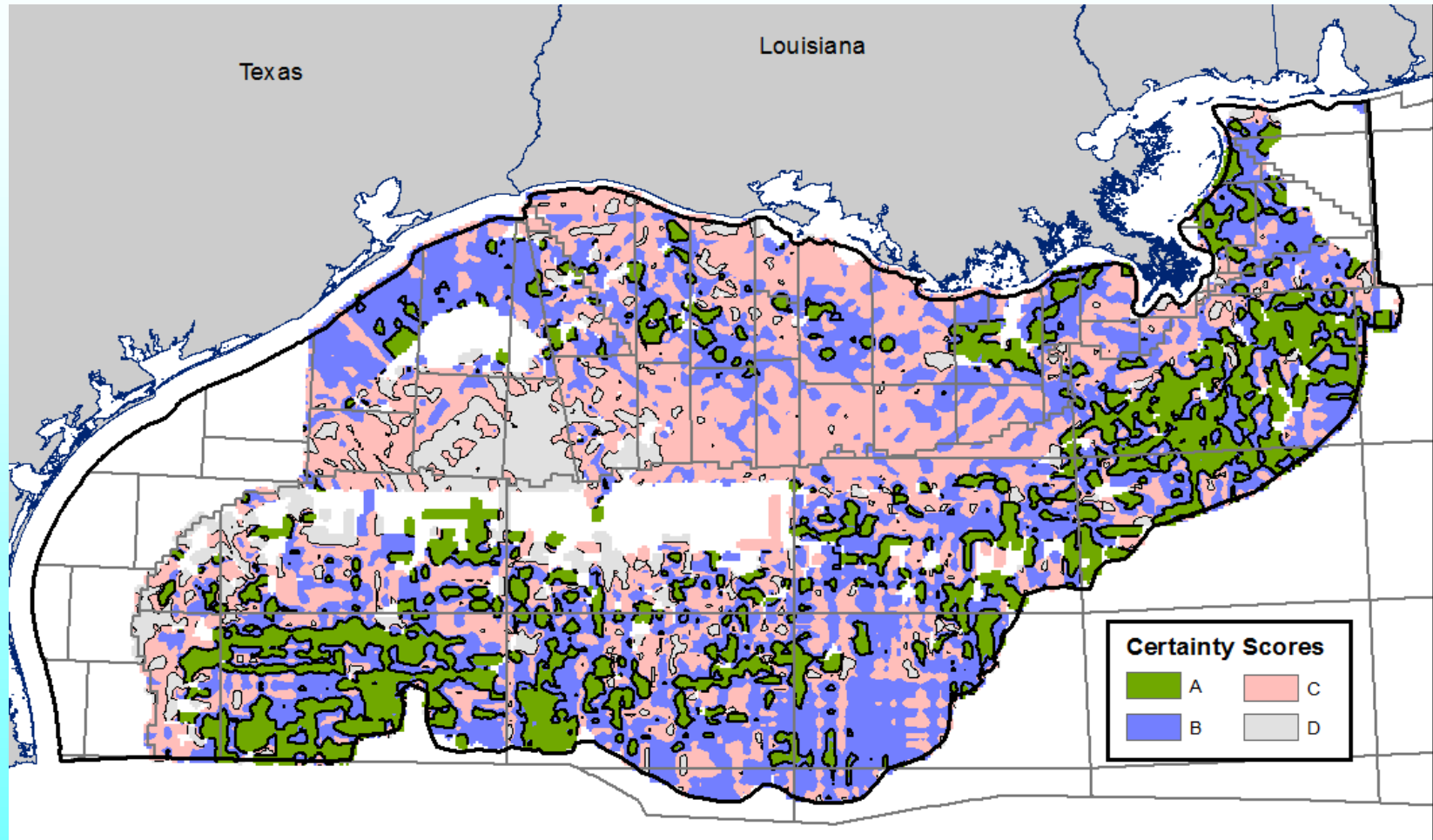


Nav Line

Point-Wise Grade:

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

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**

Next Step: Iterated Supervision

