Geostatistical Analysis of Production Trends in the Permian Basin

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Presentation Overview

- Background
- Problem and Challenges
- Goals and Objectives
- Methodology
- Results
- Summary
- Acknowledgements & References

Background: Geography

- The Permian Basin covers a huge area in western Texas and southeastern New Mexico
  - 52 counties
  - 75,000 square miles
    - (48 million acres)
  - The Permian Basin is split into 2 main sub-basins
    - Midland Basin
    - Delaware Basin

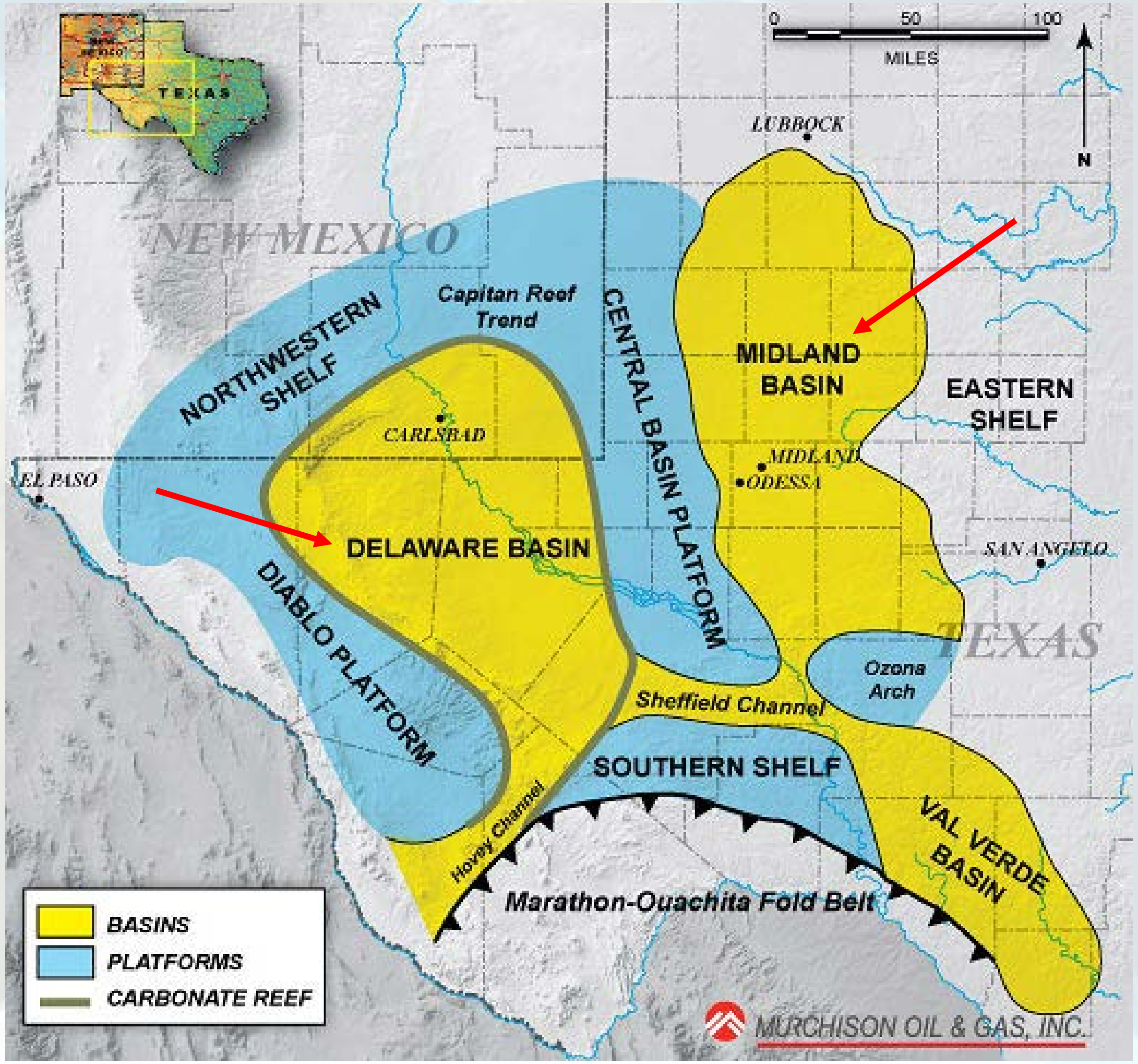


Fig. 1. Map of Permian Basin Structural Setting. *Murchison Oil and Gas*. 2010. Web. 9 Oct 2015.

Background: Oil and Gas Industry

- 23 prospective formations with up to 25,000 ft of multiple, stacked, petroleum systems
- Extensive drilling, coring and geological studies since 1920s
- >1,000 operators
- >500k wells
- Cumulative production
  - >29 BBO
  - >75 Tcf of gas

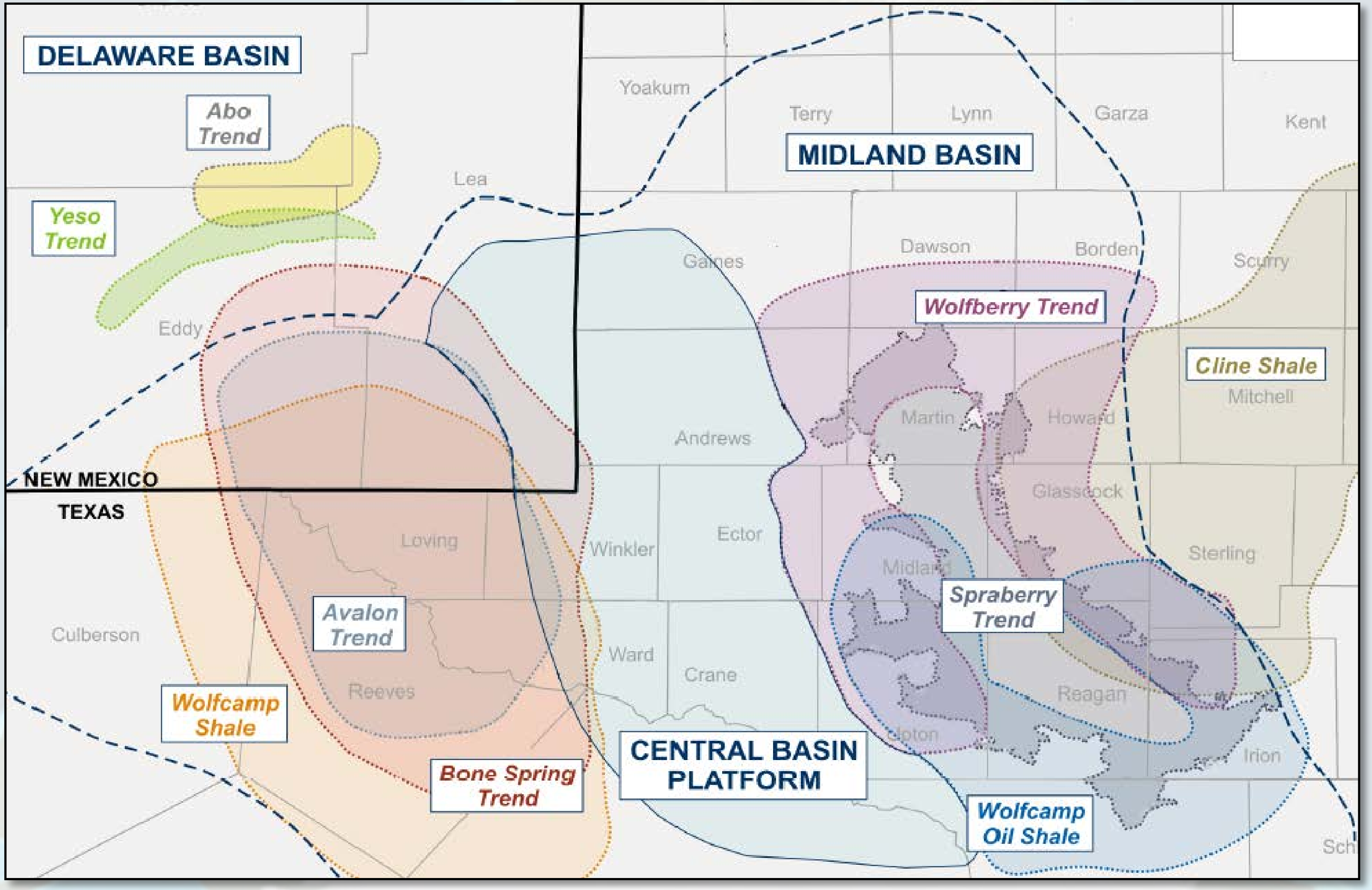


Fig. 3. Map of Sub-Basins in the Permian. *Shale Experts.* 2015.

Problem and Challenges

- Operator reported producing formation not specific enough
- Analyzing individual well log data time-intensive to capture
- Visualizing production data on 2D map does not offer perspective of stacked play
- Integrating large volumes of data

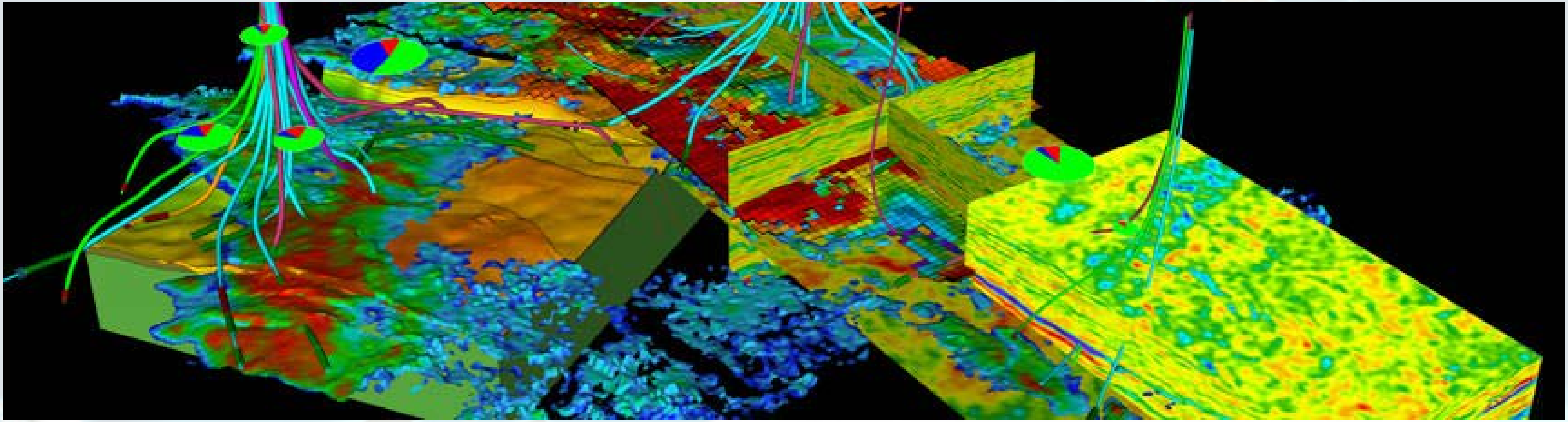


Fig. 5. Integrated 3D model displaying data from different disciplines including well deviation surveys, a seismic cross section and 3D volume, and production information displayed in the pie charts. Dynamic Graphics. 2015.

Goals and Objectives

- Develop workflow to improve efficiency of regional basin analysis
- Interpolate well log data to sub-delineate formations into contiguous producing horizons
- Specify completion and production from productive horizons
- Create surfaces for petrophysical parameters
- Interpolate well log metrics from control locations to wells that have not been interpreted

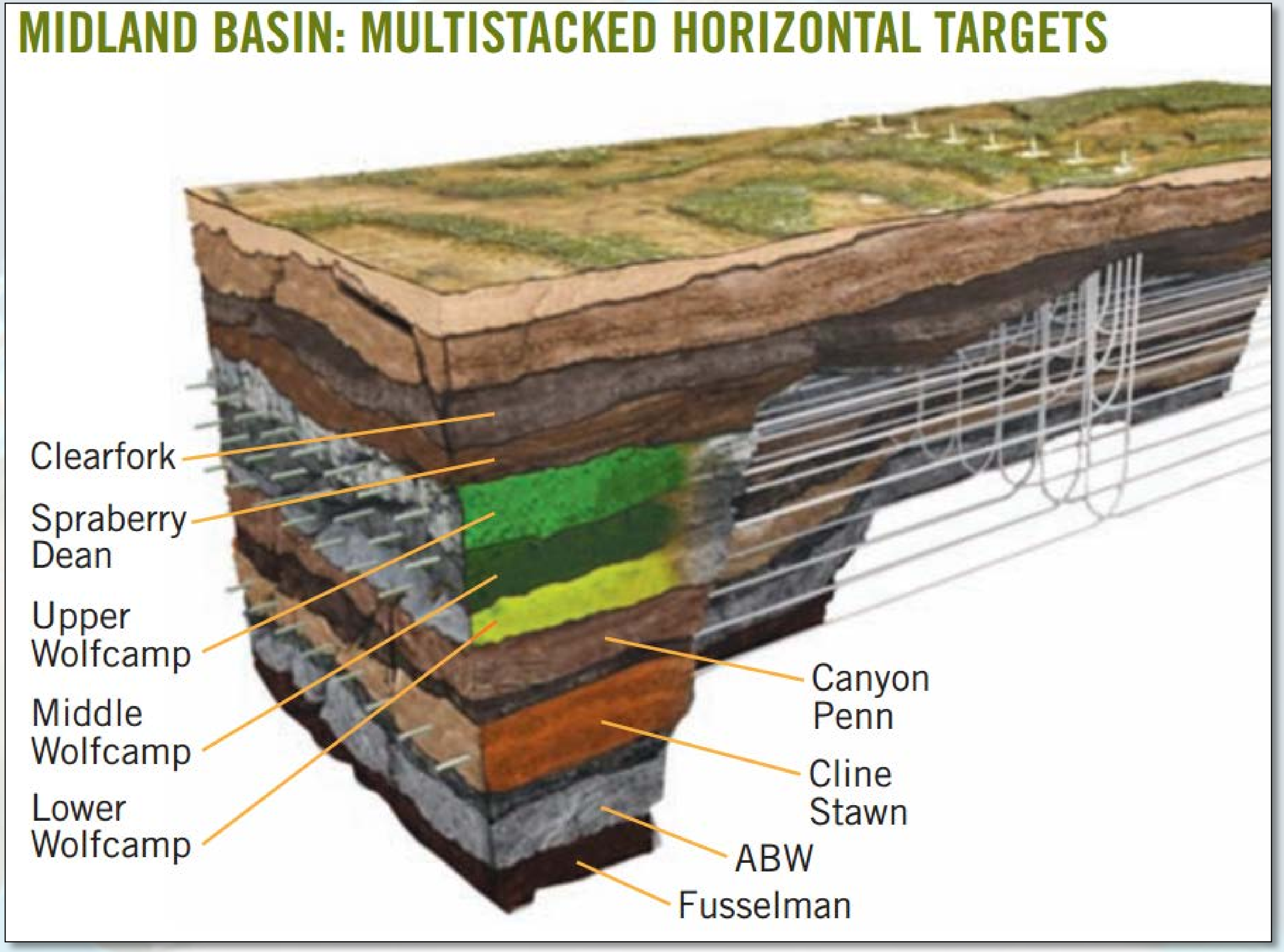


Fig. 6. Map showing stacked formations. *Midland Basin: Multi-stacked Horizontal Targets.* Oil & Gas Journal. 2015.

Methodology: Mapping Formations & Well Log Attributes

- Obtain text file of geologist's interpreted data
  - Unique identifier (API)
  - Coordinates
  - Horizon name
  - Total vertical depth subsea (TVDSS)
  - Metrics from raw well log data
    - Gamma ray (API units)
      - measures the radioactivity of rocks to determine the amount of shale in a formation
    - Resistivity (ohm•m)
      - measures electrical resistivity for formation evaluation
    - Neutron porosity (porosity units)
      - measures the hydrogen content in a formation
    - Bulk density (g/cm3)
      - used in conjunction with neutron density to determine porosity and identify hydrocarbons

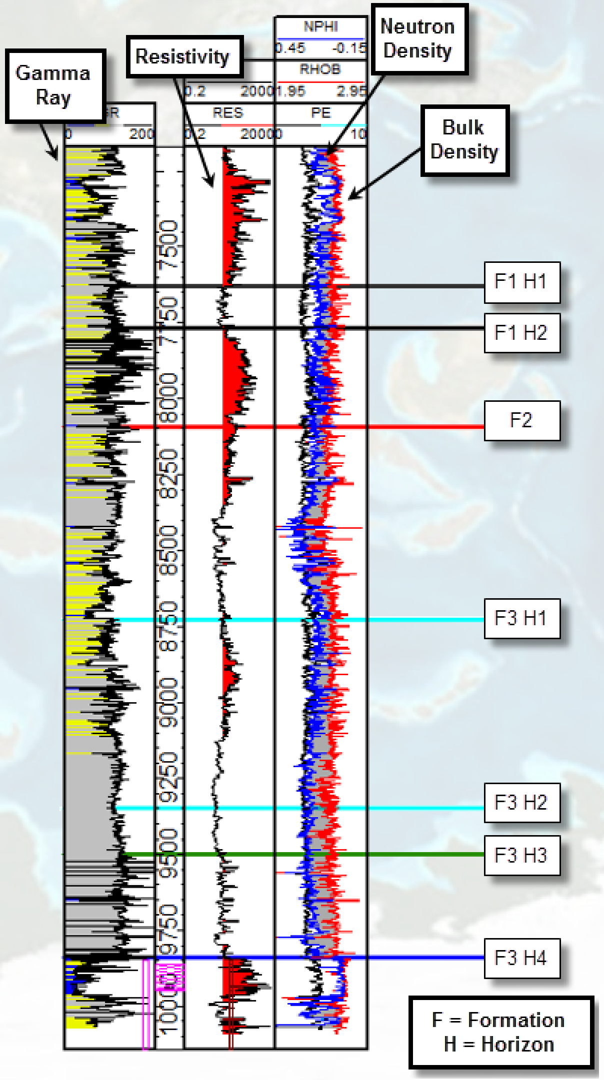
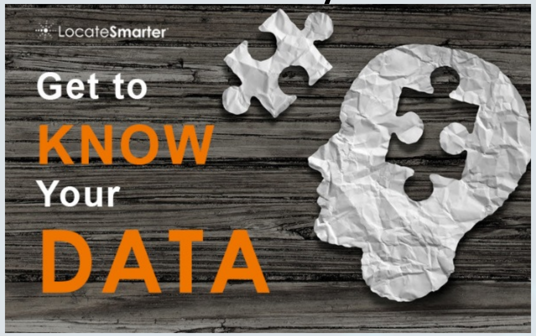
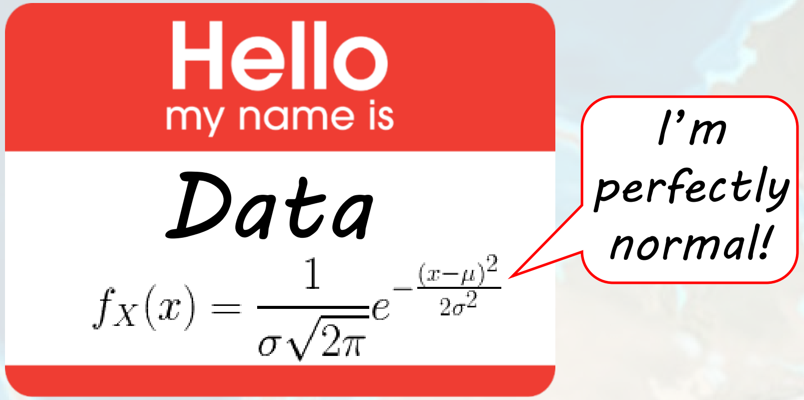


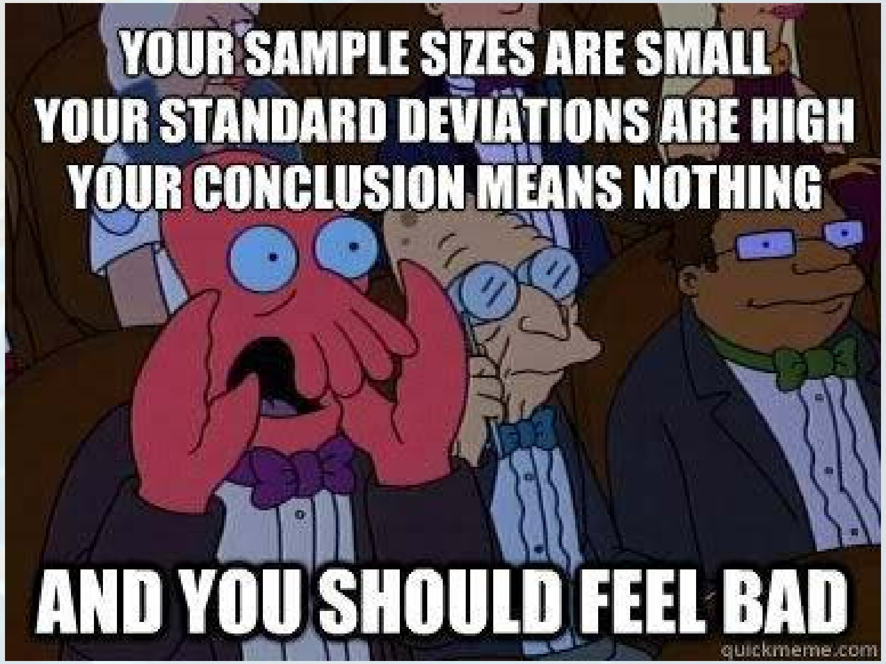
Fig. 7. Interpreted well log. *Matt Boyce, PhD*. 2013. Southwestern Energy.

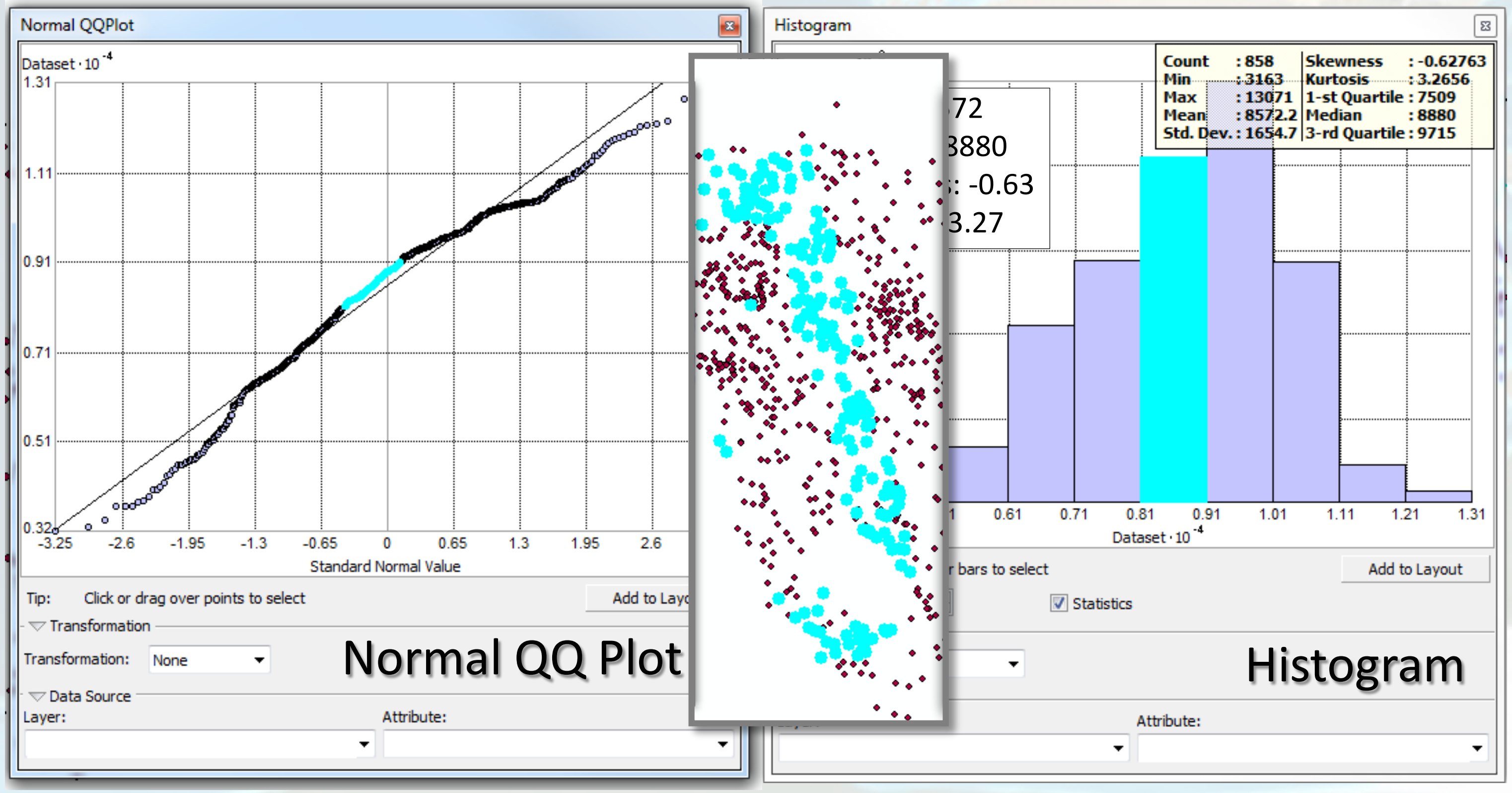
Methodology: Exploratory Spatial Data Analysis

- Get to know your data







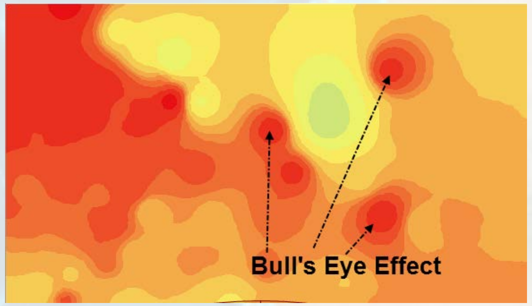


Indicators of a normal distribution

- Bell-shaped curve
- Mean & median close to the same value
- Skewness close to 0
- Kurtosis close to 3

Methodology: Interpolation Methods

- Deterministic Methods
  - Use defined algorithms that take into account the distance between a known location and a queried location
    - Natural neighbors
    - Inverse distance weighting (IDW)
    - Spline
    - Trend



Advantages	Disadvantages
Computationally fast	Does not account for spatial relationship of data
Easy to run	Produces boundary bias
Available in most software packages	Creates bull's eye effect

- Probabilistic Methods
  - Use a statistical approach to quantify the uncertainty associated with the prediction
    - Kriging
      - Simple
      - Ordinary
      - Universal
      - Empirical Bayesian kriging

Advantages	Disadvantages
Accounts for spatial relationship of data	Slower to run than deterministic methods
Produces more accurate results than deterministic methods	Parameters less intuitive than deterministic methods
Best linear unbiased prediction (BLUP)	Must investigate dataset before modelling

Methodology: Kriging – Background

Kriging

- Kriging uses a Gaussian statistical model to optimize spatial prediction
- Used in meteorology, mining, forestry, hydrology, soil sciences, geology, public health, petroleum engineering

Origins

- Danie Gerhardus Krige – South African Mining Engineer (1951)
- Georges Matheron – French mathematician and geologist, formalized Krige's work and founded mathematical morphology

Other Contributors

- Mercer and Hall (1911)
- Youden and Mehlich (1937)
- Kolmogorov (1941)
- Lev Gandin (1959)
- Matérn (1960)

Fig. 7. Danie Gerhardus Krige (1939). *Royal Society of South Africa.* 2013.

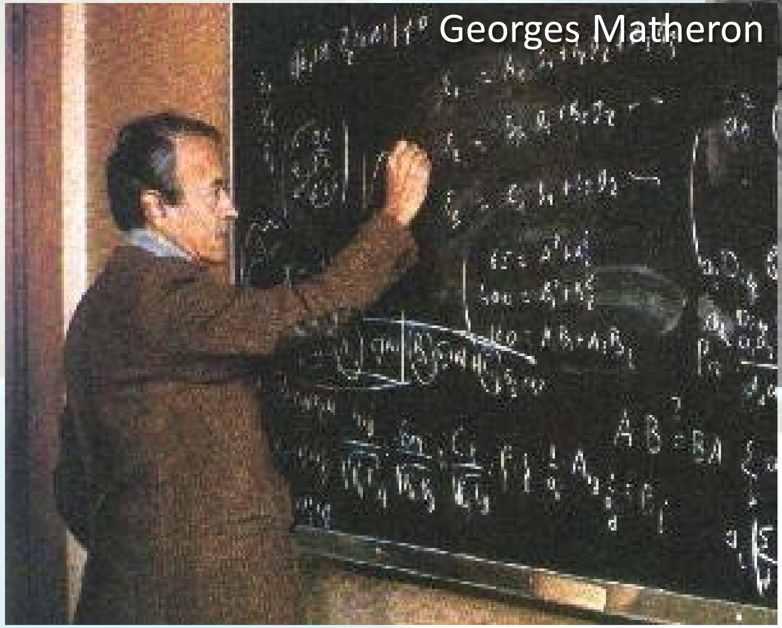


Fig. 8. Georges Matheron (1939). *MINES ParisTech - Centre de Géosciences.*

Methodology: Kriging – Benefits and Limitations

Benefits

- Accounts for distance and direction of the data
- Optimal predictor
- Best unbiased linear predictor (BLUP)
- Generally have smaller error than other interpolation models
- Ability to filter out measurement errors
- Uses a semivariogram to quantify spatial dependence in the data
- Ability to generate prediction, quantile, and standard error maps
- Includes cross-validation

Direction

Limitations

- Assumes the semivariogram is always correct when applying function to the data
- If data does not have a normal distribution the error associated with the prediction is underestimated

Methodology: Empirical Bayesian Kriging (EBK)

- Accounts for uncertainty introduced in the semivariogram
- Uses "intrinsic random functions" that inherently correct for trends in the data
- Able to remove local trend in dataset
- Can be used to interpolate non-stationary data for large areas
- Generally more accurate than other kriging for small datasets
- Many methods to model the semivariogram
    - Power, linear, exponential, thin plate spline, whittle, and K-Bessel
    - Different models impact the model's flexibility, accuracy, and calculation time

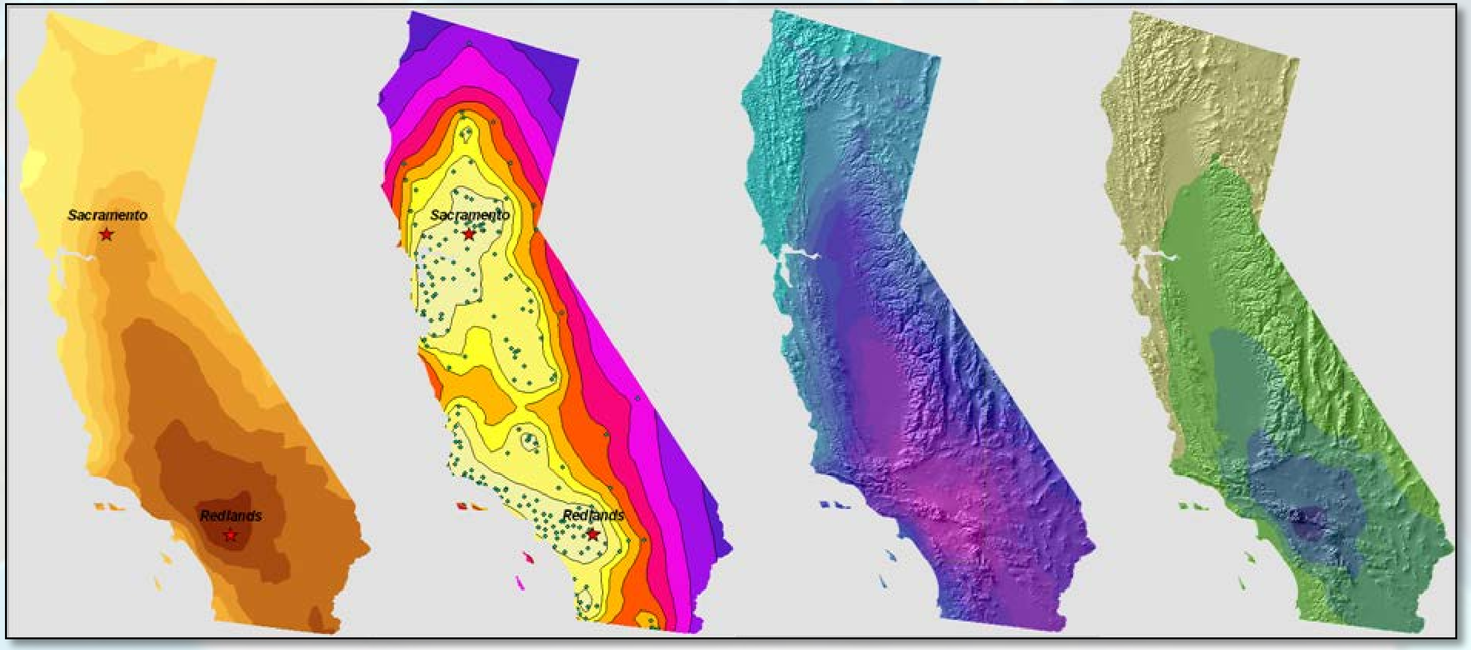
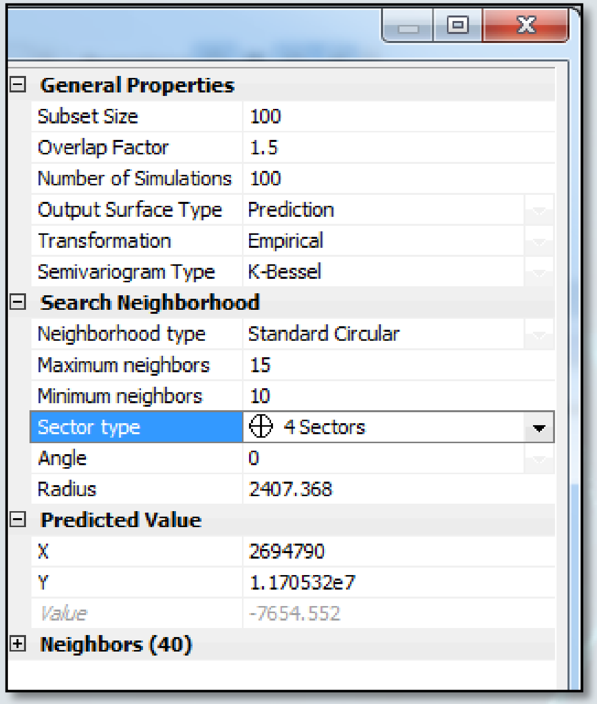
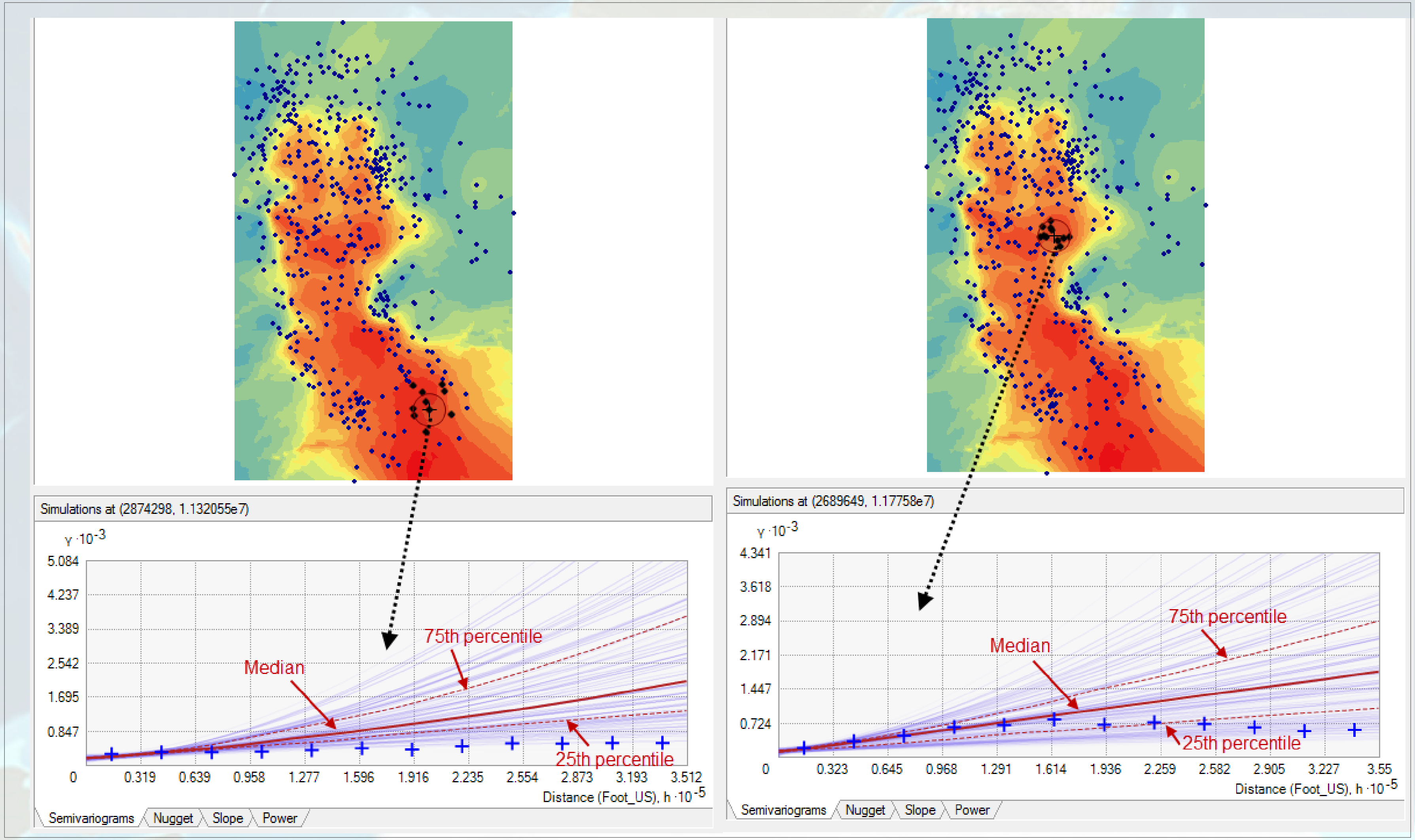


Fig. 9. Output surfaces from geostatistical analyst. Esri Japan, 2016.

Methodology: EBK – Parameters & Glorious Semivariograms



- Unique distribution of semivariograms for each point in dataset
- Median distribution indicated with dark red line
- Percentiles shown with dashed red lines

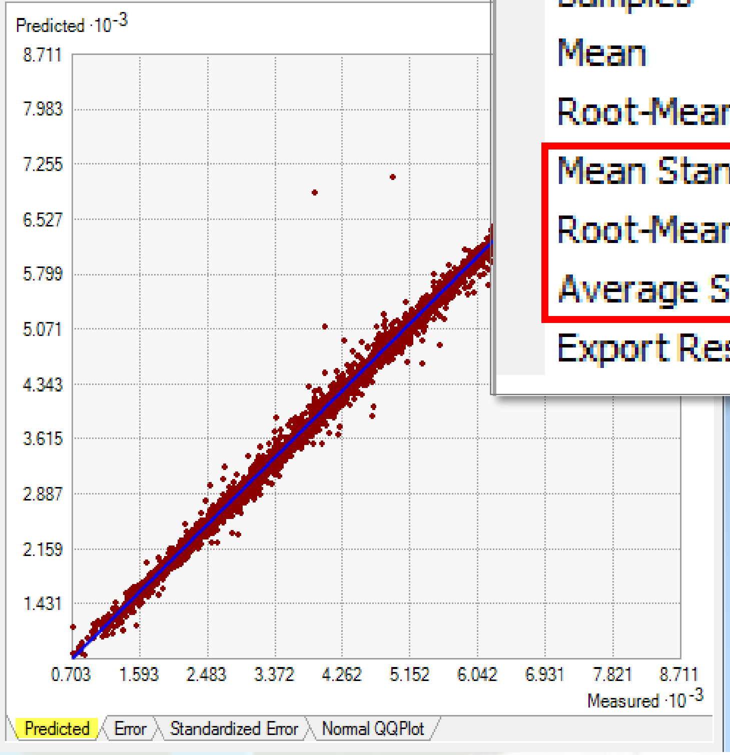


Methodology: EBK – Cross Validation

- View error associated with each predicted point
- Optimize results to obtain most precise grid
- “Cross-linking” enabled

Geostatistical wizard - Empirical Bayesian Kriging step 3 of 3 - Cross Validation

S...	Me...	Predicted	Error	Standard Error	Standardized E...
1	860	769.0835161634...	-90.916483836...	74.02006250...	-1.2282681310...
2	703	791.9917680452...	88.991768045...	171.7087143...	0.5182717044...
3	782	864.8171430427...	82.817143042...	73.83360312...	1.1216727822...
4	769	813.7611458979...	44.761145897...	78.87179805...	0.5675177567...
5	905	987.8014236762...	82.801423676...	184.0665916...	0.4498449334...
6	818	776.716960348272	-41.283039651...	84.70309451...	-0.4873852588...
7	825	906.6938990086...	81.693899008...	176.9755008...	0.4616113451...
8	1086	1016.362339752...	-69.637660247...	103.7071463...	-0.6714837180...
9	1068	1172.782436269...	104.78243626...	100.9807633...	1.0376474961...
10	1134	1107.127438127...	-26.872561872...	106.0660272...	-0.2533569188...
11	780	861.1899344444...	81.189934444...	93.22385025...	0.8709137652...
12	1214	1227.952940708...	13.952940708...	113.9273178...	0.1224723004...
13	996	1087.937560322...	91.937560322...	151.6769717...	0.6061405319...
14	825	926.5820249783...	101.58202497...	73.94043229...	1.3738359626...
15	980	997.2298640099...	17.229864009...	83.09300346...	0.2073563752...
16	970	1008.494430673...	38.494430673...	76.24228074...	0.5048961061...
17	1352	1183.295802749...	-168.70419725...	124.5227338...	-1.3548064043...
18	950	1065.198703912...	115.19870391...	111.4730777...	1.0334217577...
19	1000	1125.568795749...	125.56879574...	59.79619317...	2.0999463189...
20	1370	1087.733542740...	-282.26645725...	80.05976904...	-3.5256966215...
21	1337	1204.368104328...	-132.63189567...	104.1488474...	-1.2734840468...
22	1220	1057.084546022...	-162.91545397...	77.90264234...	-2.0912699374...
23	1170	1183.415631811...	13.415631811...	50.90952410...	0.2635190968...
24	1146	1095.280678869...	-50.719321130...	61.61121029...	-0.8232157895...
25	1200	1204.613314060...	4.6133140600...	44.92864004...	0.1026809192...
26	1290	1237.100334050...	-52.899665949...	51.19700660...	-1.0332570097...
27	1150	1208.771927538...	58.771927538...	74.53665619...	0.7884969696...



Prediction Errors for Entire Dataset

Prediction Errors	
Samples	41503 of 41503
Mean	-0.2402072
Root-Mean-Square	49.29904
Mean Standardized	-0.003736352
Root-Mean-Square Standardized	0.9802805
Average Standard Error	45.27638
Export Result Table	

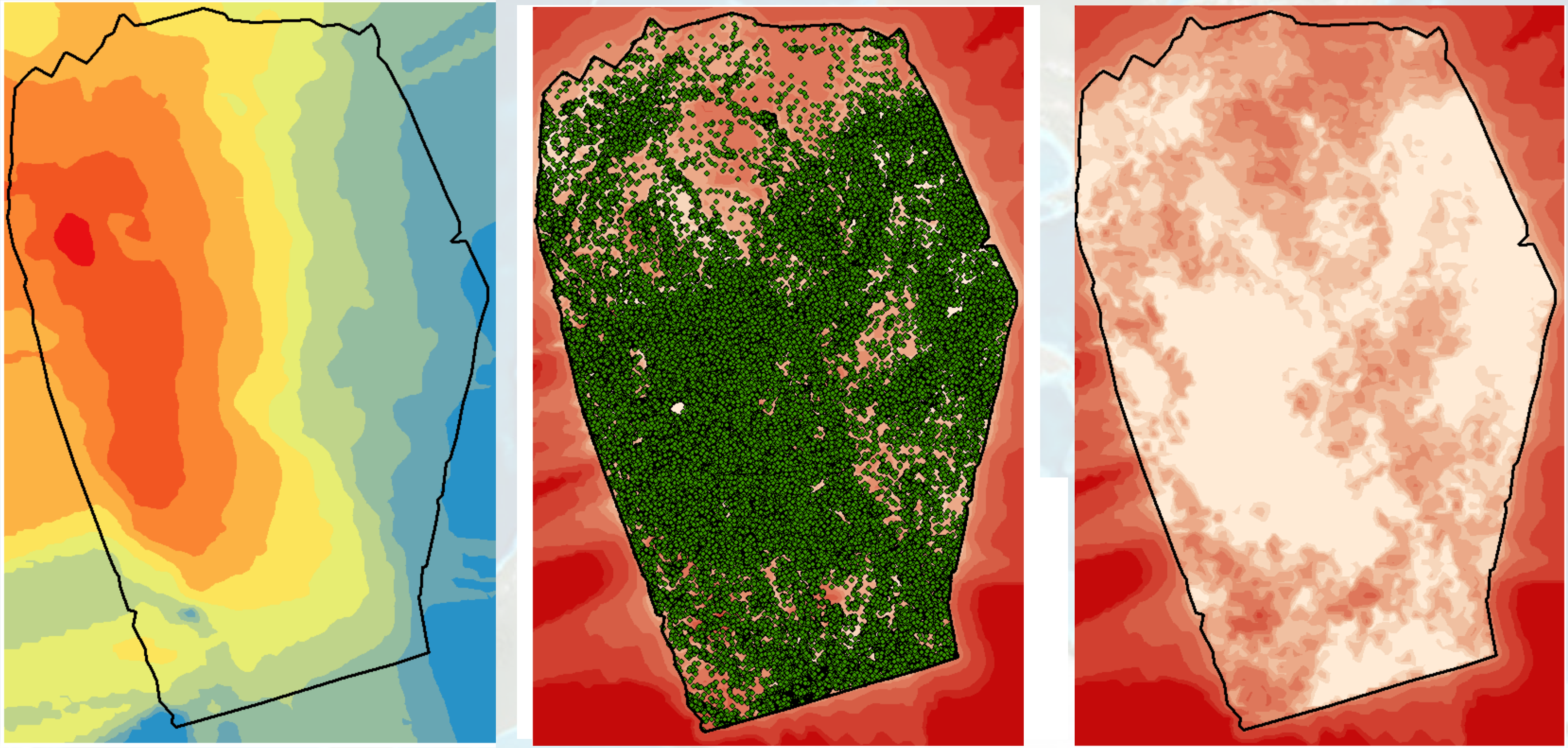
Prediction errors for dataset should have:

- Mean Standardized Error near 0
- Root-Mean-Square Stnd Error near 1
- Average Standard Error as small as possible

* *RMS near 1 is key to a stable model*

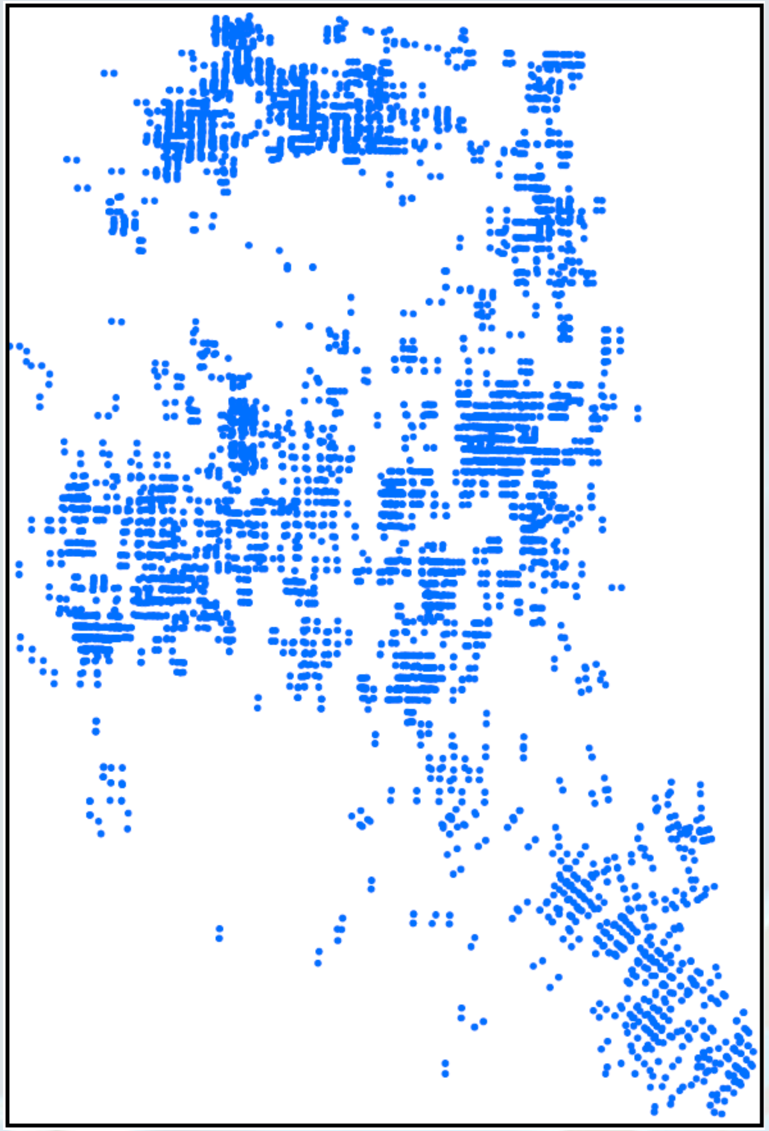
Results: EBK – Contiguous Prediction & Standard Error Maps

AOI covers 21,075,775 acres



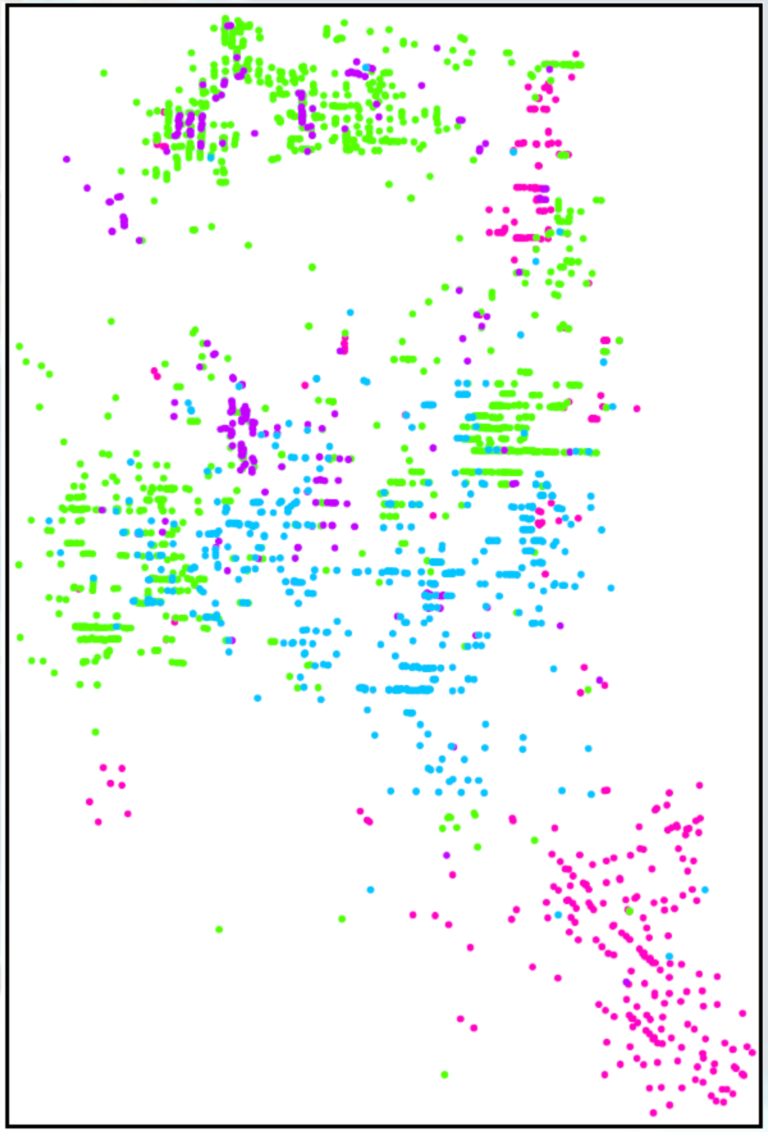
Prediction Map — Control Points — Prediction Standard Error Map

Results – Well Horizon Classification



State Data – Formation 1

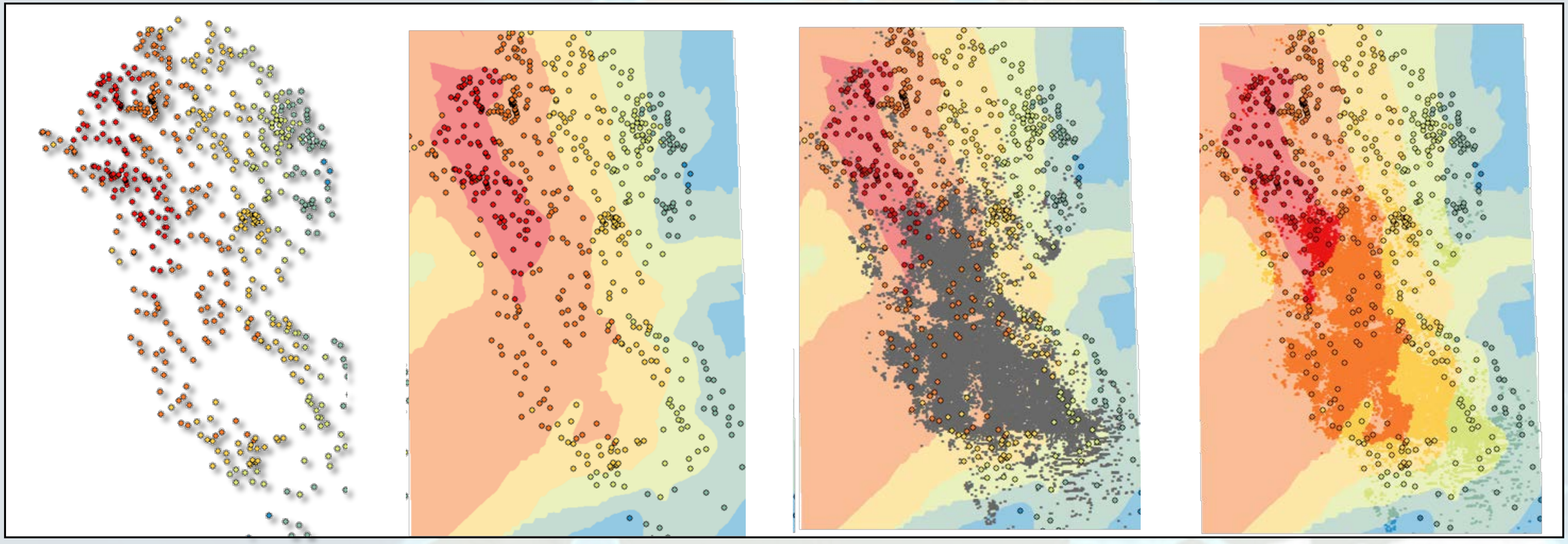
Internal Sub-delineation – Formation 1d



Internal Horizons – Formation 1a-d

Results – Well Log Attribute Classification

- Interpolated grids for well log attributes for each formation
- Extracted petrophysical well log attributes from grids and applied to all wells in the horizon

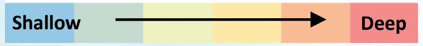


Well control points with interpreted petrophysical property are shown symbolized from a low-to-high value

Grids are created from control points for petrophysical parameter using EBK

Wells producing from the same horizon that have not been evaluated are shown in grey

Extract value from EBK grid to State's well dataset; the values for each of the petrophysical properties was extracted to the well bore



Results – 2D and 3D Grids

- EBK interpolated grids for each horizon (SSTVD)

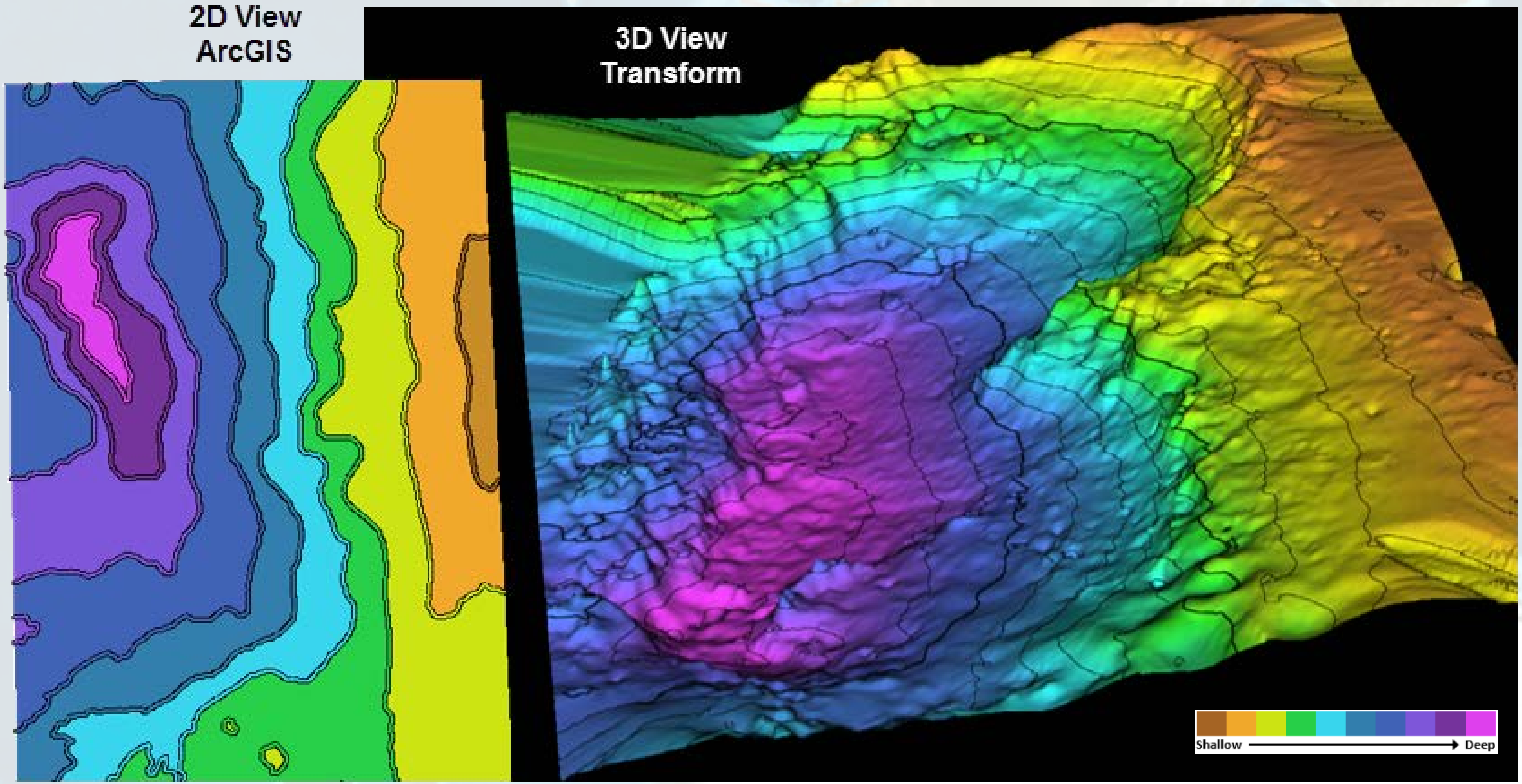


Fig. 9. Screenshot of geologic horizon shown in 2D view in ArcMap (left) and in 3D view in Transform software (right). Horizon generated using EBK process in GIS. Transform screenshot provided by Cullen Hogan, January 6, 2016.

Results – Well Landing Zone Classifications

- Convert Esri GA Layers to raster grid format for use in other software
- Provide geophysicist grids for use in 3D model
- Integrate data
- Visualize and classify producing horizons

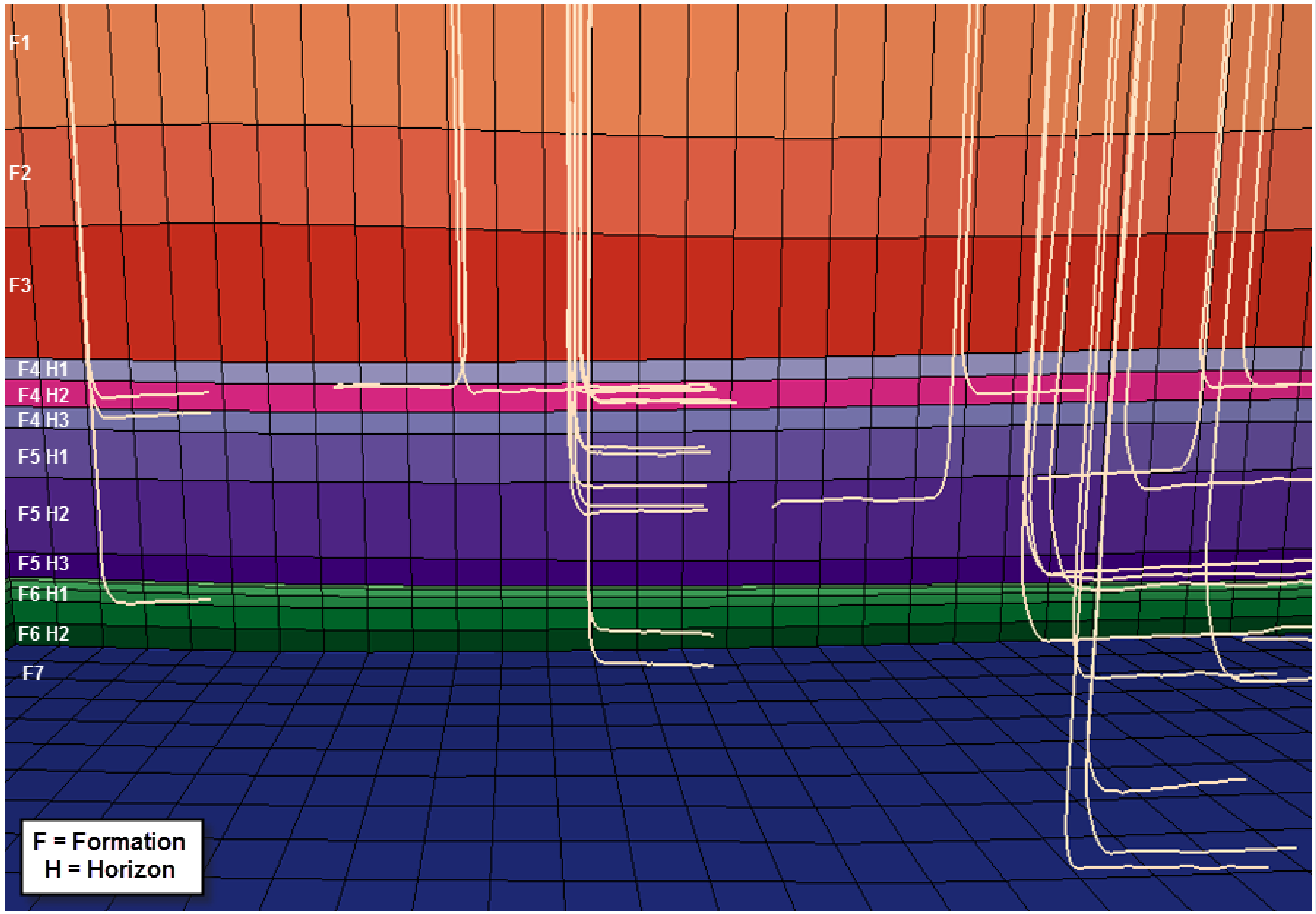
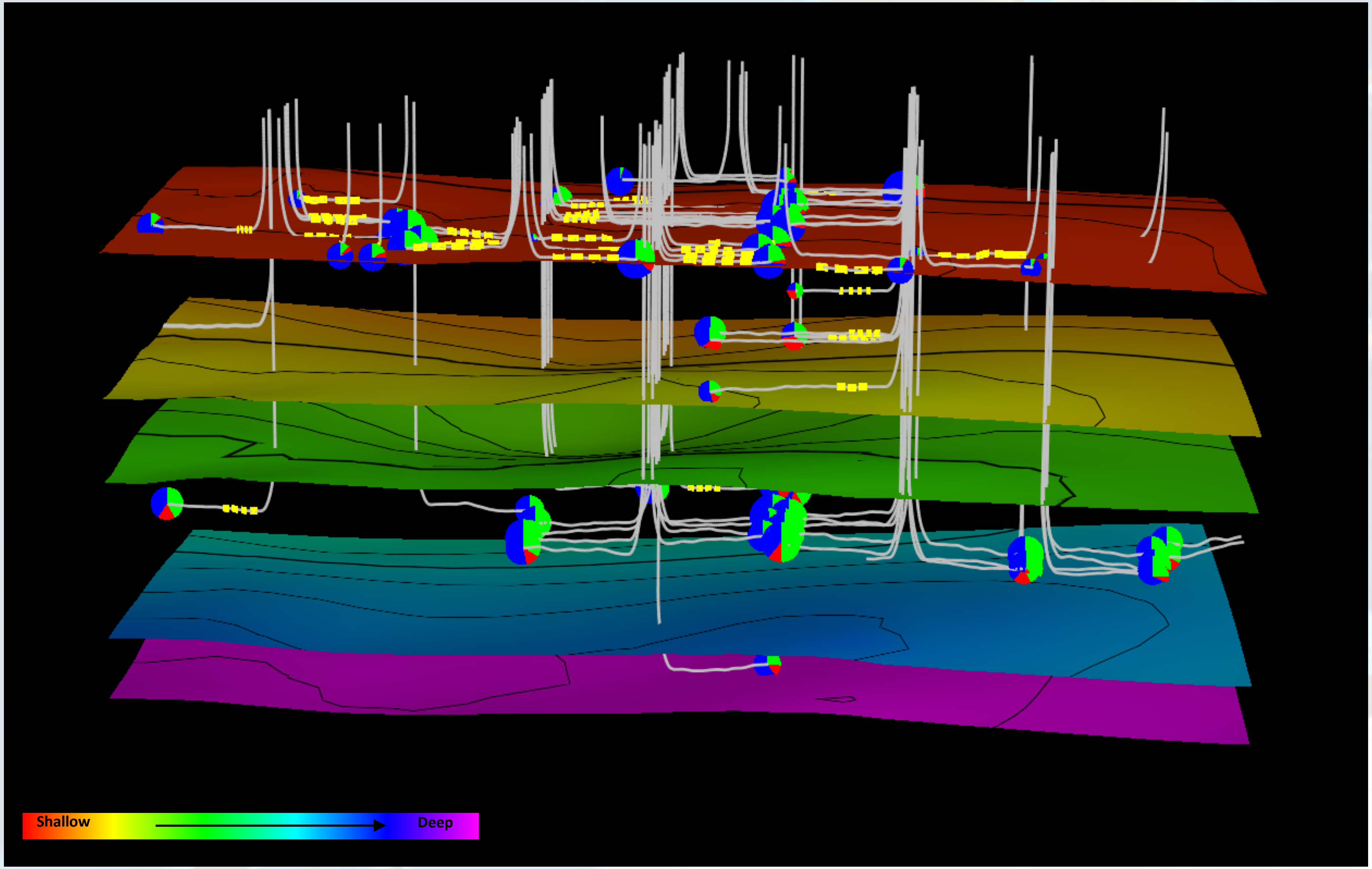


Fig. 10. Screenshot of structural model in JewelSuite software displaying wells intersecting target formations. Screenshot provided by Cullen Hogan, February 4, 2016.

Summary



Acknowledgements & Credits

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Southwestern Energy's Permian Basin Team

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Kyle Magrini – Staff Reservoir Engineer

Matt Boyce, PhD – Staff Geologist

Thank you!

Questions?