# [PS]Exploring for Tight Oil in the Pennsylvanian Cleveland Sandstone on the Nemaha Ridge Using High Resolution 3-D Seismic and Stratigraphic Analysis: A New Play in an Old Area*

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## Abstract

Although an active development target in the panhandles of Texas and Oklahoma, the Upper Pennsylvanian Cleveland Sandstone along the Nemaha Ridge of north-central Oklahoma and south-central Kansas has traditionally been viewed as a shallow (2,500'-3,000'), tight oil "teaser" or tertiary objective on the way down to other more economic objectives since the 1920's. Much of the areal extent of the Cleveland is too thin and tight to be produced economically. However, by integrating high-resolution 3D seismic and detailed sequence stratigraphic analysis, thicker, productive Cleveland reservoir fairways can be identified and drilled economically on the Nemaha Ridge.

Cleveland depositional systems in the Nemaha Ridge area include river-dominated deltas and incised valleys, each with distinctive log and seismic characteristics. Deltaic reservoir successions occur in the upper two thirds of the Cleveland interval and are usually the best reservoirs. The deltaic reservoir units are composed of very fine to fine-grained sanding upward successions exhibiting dip-elongate behavior and rapid changes along strike. Cleveland valleys in the study area are blocky to fining-upward, lower medium to very fine grained units that occur in the lower part of the Cleveland succession.

Optimal drilling locations are best identified by fine-scale correlations and seismic mapping, linked to subtle syn-sedimentary tectonics. High-resolution 3D seismic (up to 1.4 million traces per square mile) has proven a key tool in differentiating and predicting optimal reservoir trends in this new play concept on the Nemaha Ridge.

# *Exploring for Tight Oil in the Pennsylvanian Cleveland Sandstone on the Nemaha Ridge Using High Resolution 3D Seismic & Stratigraphic Analysis: A New Play in an Old Area*

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## ABSTRACT

Tight sands in the Upper Pennsylvanian Cleveland Fm. are an active development target in the panhandles of Texas and Oklahoma, however, since drilling started in the 1920's along the Nemaha Ridge of north central Oklahoma and south central Kansas the Cleveland has traditionally been viewed as a shallow (2,500'-3,000'), thin, tight-oil "teaser" or tertiary objective on the way down to other more economic objectives. By integrating high-resolution 3D seismic and detailed sequence stratigraphic analysis, thicker, productive Cleveland reservoir fairways can be identified and drilled economically on the Nemaha Ridge.

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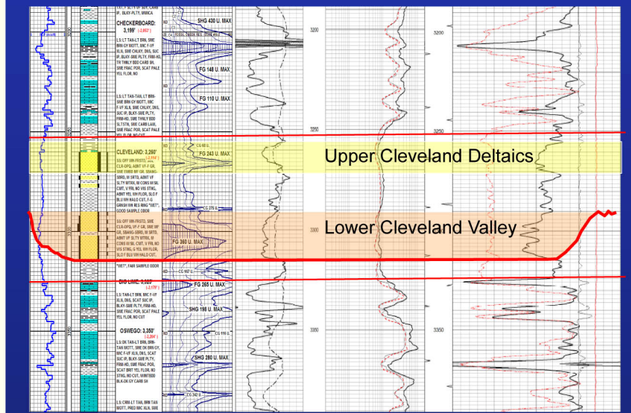
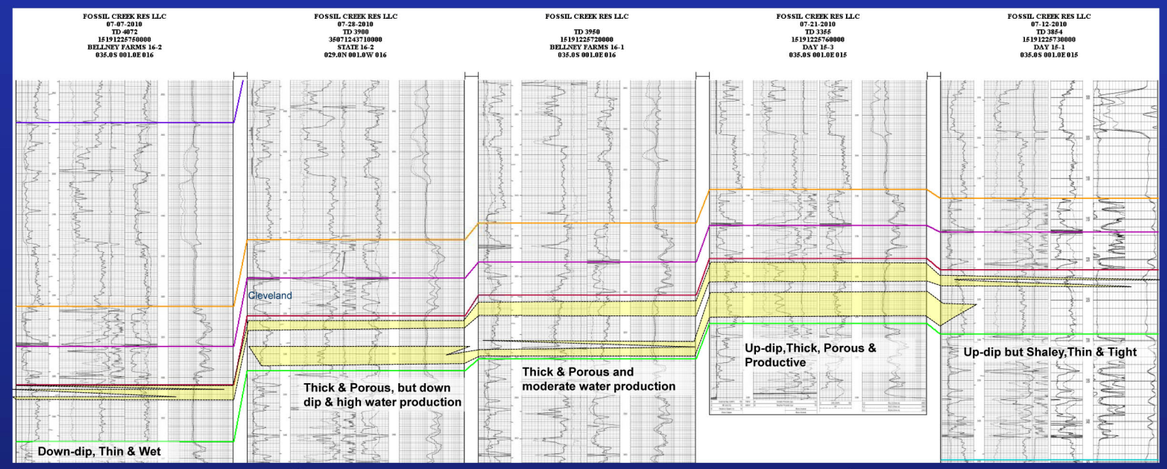
Optimal drilling locations are best identified by fine-scale correlations and seismic mapping, linked to subtle syn-sedimentary tectonics. High-resolution 3D seismic (up to 1.4 million traces per square mile) and seis-facies analysis has proven a key tool in differentiating and predicting optimal reservoir trends in this new play concept on the Nemaha Ridge and sets up and opportunity for focused horizontal exploitation. This type of analysis is broadly applicable to a number of other similar plays in old development areas.

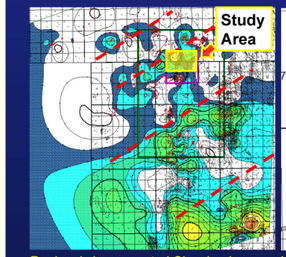

## *Geology: Laterally Discontinuous Valley Fill & River-Dominated Deltaic Sands*



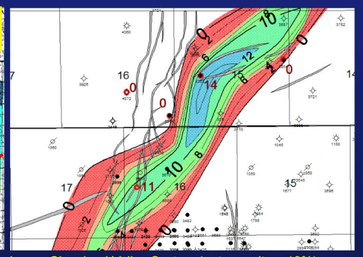

Lower & Upper Cleveland Log Character: Lower Cleveland is the fill of an incised valley and Upper Cleveland is river-dominated deltaic lobes. Both systems have good porosity and 38-42 gravity oil.



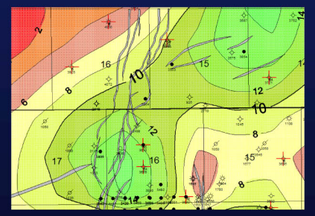

Structural Cross Section showing the draping of Cleveland stratigraphy over the North Braman structure. This section follow s the same line of section as the seismic image above.



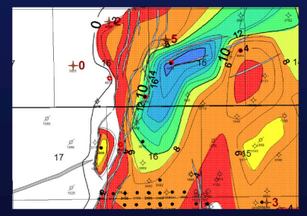

Regional shears control Cleveland deposition/preservation.



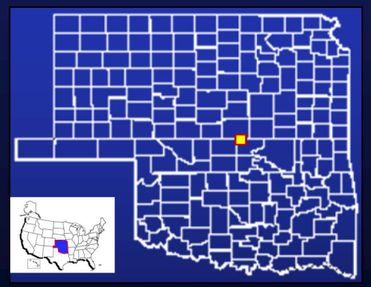
Lower Cleveland Valley System (net porosity > 10%).



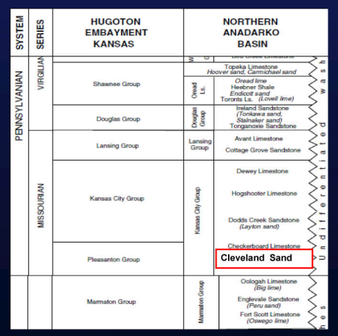
Gross Upper Cleveland deltaic sand isopach map from well control.



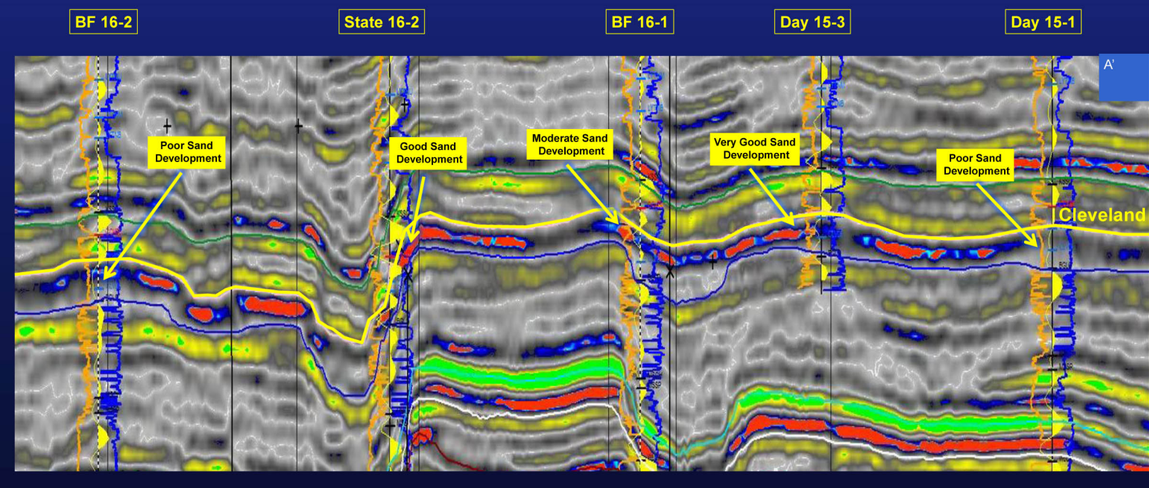
Net (>10% Porosity) Upper Cleveland deltaic sand isopach map from well control.



Index Map of Study Area in NW Kay County, OK and SE Sumner County, KS




Regional stratigraphy encompassing the Pennsylvanian Cleveland Sand succession. The Cleveland is overlain & underlain by consistent marine carbonate benches, enhancing seismic detection of slow, porous sand.

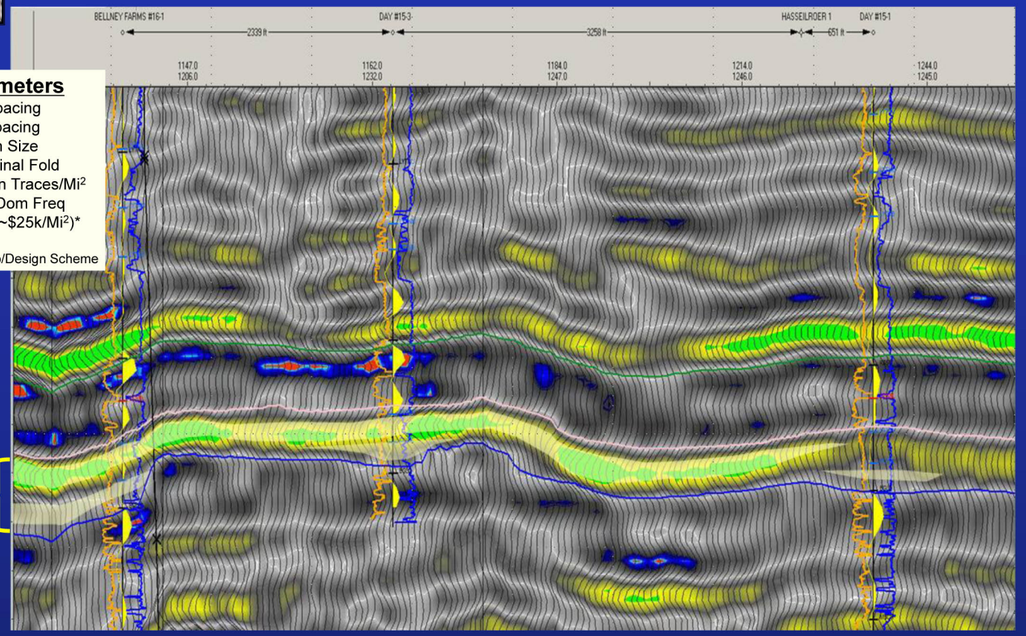



Seismic section showing the nature of the structure draped by the Lower and Upper Cleveland sands on the north plunge of the North Braman structure. This section follows the same line of section as the well-log cross section below.. Note the strong amplitude anomalies associated with thick, porous sand development and the lack of response to thin sand development.

# *Seismic Delineation of Cleveland Porosity*

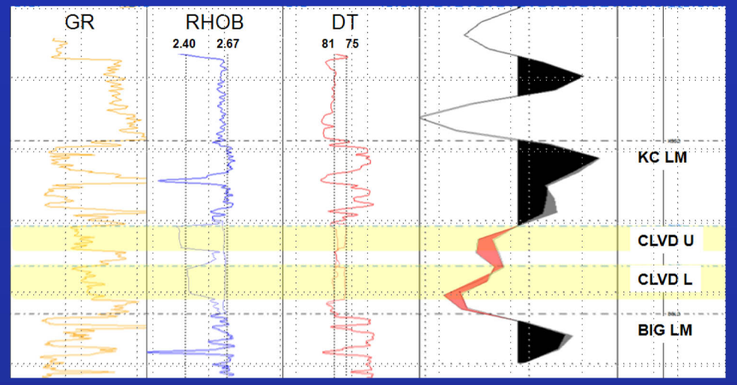
**3D Parameters**
- 330' RL Spacing
- 440' SL Spacing
- 55'x55' Bin Size
- 250+ Nominal Fold
- 1.5+ Million Traces/Mi$^2$
- 65-70 Hz Dom Freq
- Low cost (~$25k/Mi$^2$)*

* Novel Sweep/Design Scheme



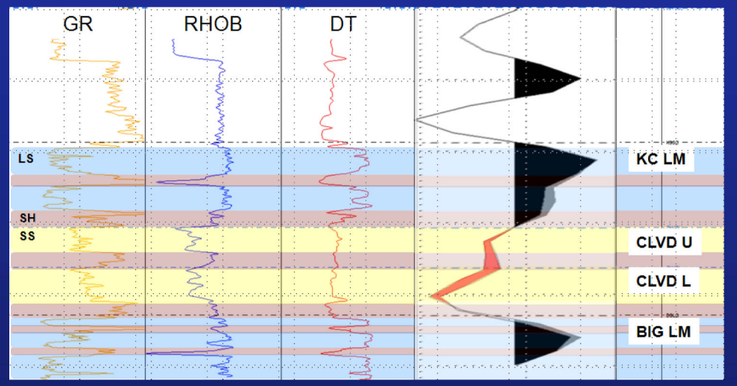

Seismic section from a running summation volume through key wells demonstrating changes in amplitude associated with thickness of net sand in the Cleveland interval.

## Sand with Shale Model Overlay




Modeled sand and shale trace overlay showing excursion of elastic well log and synthetic response.

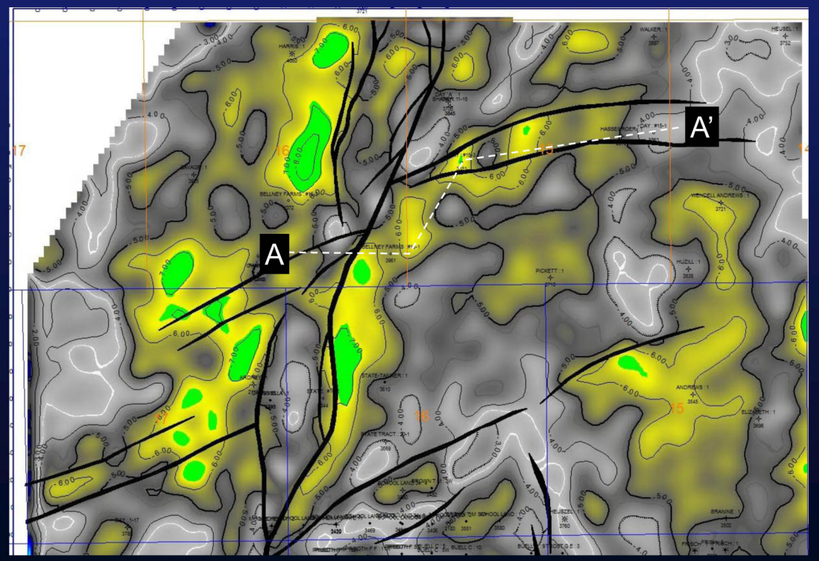
## In-Situ with Shale Model Overlay



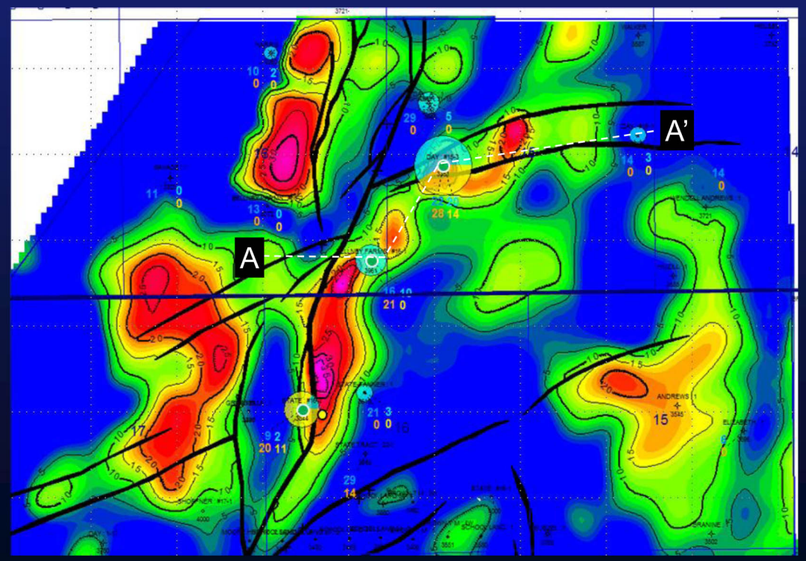

In-situ log response with modeled sand synthetic trace overlay.

## Modeling Summary

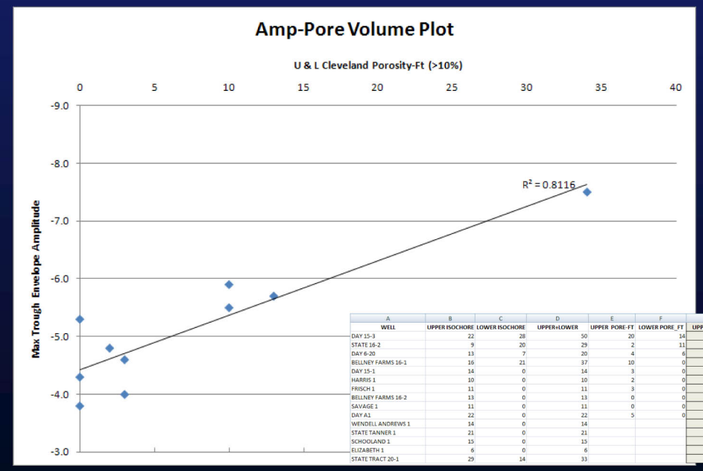
1. Troughs within Cleveland zones are increased due to lower impedance of Cleveland sands
2. The reduced impedance is driven by increased porosity, as observed in density curve
3. Both peaks associated with the overlying KC carbonate and underlying Big Lime carbonate are increased as more lower- impedance Cleveland sand is introduced
4. Instantaneous attributes (e.g. maximum trough envelope) respond well to observed modeled response




Maximum trough envelope amplitude map from the Cleveland interval illuminates areal distribution of net sand >10%.



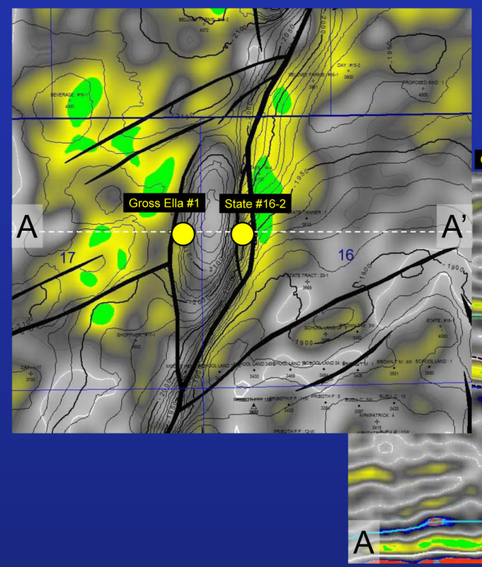

Pore-Feet map established from relationship (see cross-plot) of net sand with maximum trough envelope amplitude attribute.



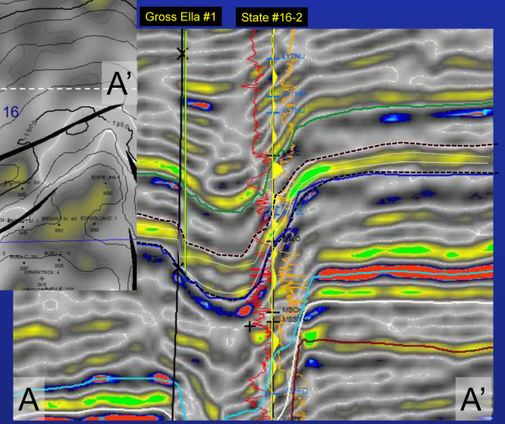

| WELL | UPPER ISOCHORE | LOWER ISOCHORE | UPPER+LOWER | UPPER PORE-FT | LOWER PORE_FT | UPPER + LOWER | AMP |
|---|---|---|---|---|---|---|---|
| DAY 15-3 | 22 | 28 | 50 | 20 | 14 | 34 | -7.2 |
| STATE 16-2 | 9 | 20 | 29 | 2 | 11 | 13 | -5.7 |
| DAY 6-20 | 13 | 7 | 20 | 4 | 6 | 10 | -5.5 |
| BELLNEY FARMS 16-1 | 16 | 21 | 37 | 10 | 0 | 10 | -5.3 |
| DAY 15-1 | 14 | 0 | 14 | 3 | 0 | 3 | -4.6 |
| HARRIS 1 | 10 | 0 | 10 | 2 | 0 | 2 | -4.6 |
| FRISCH 1 | 11 | 0 | 11 | 3 | 0 | 3 | -4.6 |
| BELLNEY FARMS 16-2 | 13 | 0 | 13 | 0 | 0 | 0 | -5.3 |
| SAVAGE 1 | 11 | 0 | 11 | 0 | 0 | 0 | -4.3 |
| DAY A1 | 22 | 0 | 22 | 5 | 0 | 0 | -3.8 |
| WENDELL ANDREWS 1 | 14 | 0 | 14 | | | | -5.8 |
| STATE TANNER 1 | 21 | 0 | 21 | | | | -4.8 |
| SCHOOLAND 1 | 15 | 0 | 15 | | | | -4.7 |
| ELIZABETH 1 | 6 | 0 | 6 | | | | -4.1 |
| STATE TRACT 20-1 | 29 | 14 | 33 | | | | -3.3 |

Cross-plot of Upper and Lower Cleveland net sand versus attribute values from key wells within the 3D survey.

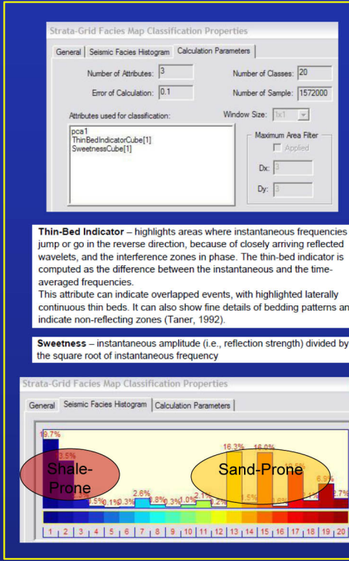
# *Ongoing Work & Conclusions*




**Gross Ella #1 Production Summary**
Drilled 1926
Re-entered: 1969
Cum Production: 89,900 Bbls
Perfs: 3371' – 3380'
Formation: Cleveland




Seismic section through known Cleveland producer offers glimpse at the potential for mapping Upper and Lower Cleveland sands separately in high resolution seismic data.

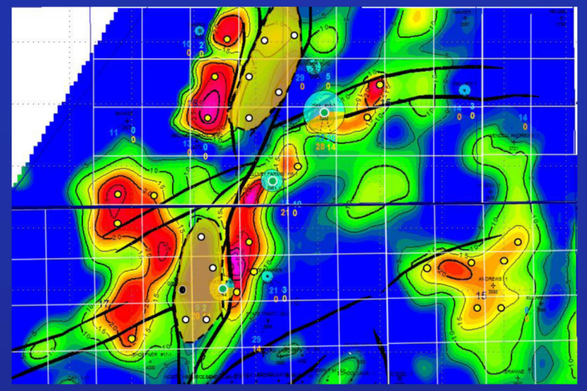



**Thin-Bed Indicator** – highlights areas where instantaneous frequencies jump or go in the reverse direction, because of closely arriving reflected wavelets, and the interference zones in phase. The thin-bed indicator is computed as the difference between the instantaneous and the time-averaged frequencies.
This attribute can indicate overlapped events, with highlighted laterally continuous thin beds. It can also show fine details of bedding patterns and indicate non-reflecting zones (Taner, 1992).

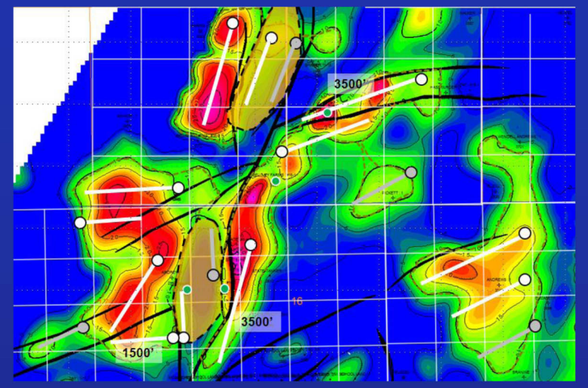
**Sweetness** – instantaneous amplitude (i.e., reflection strength) divided by the square root of instantaneous frequency



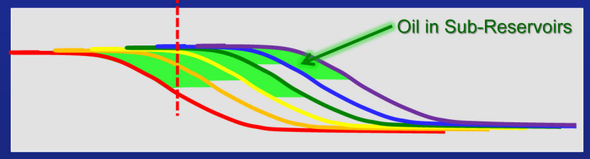

**Above:** Input volume parameters used for facies modeling.
**Below:** Facies class histogram demonstrates separation and variability of sands and shales within the ZOI.

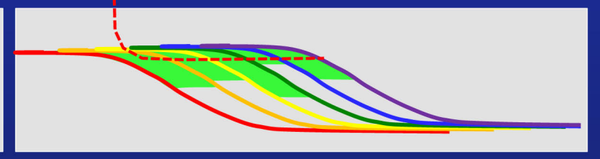


Pore-Feet map with vertical well locations based on 40 acre spacing units.

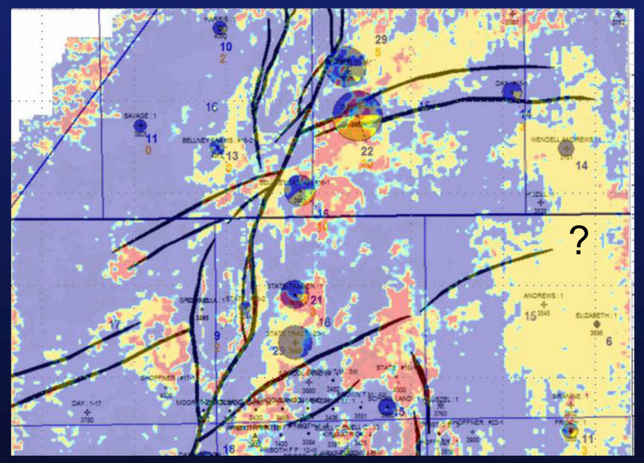



Pore-Feet map with Horizontal well locations illustrating use of various lateral lengths to more-optimally extract remaining reserves.

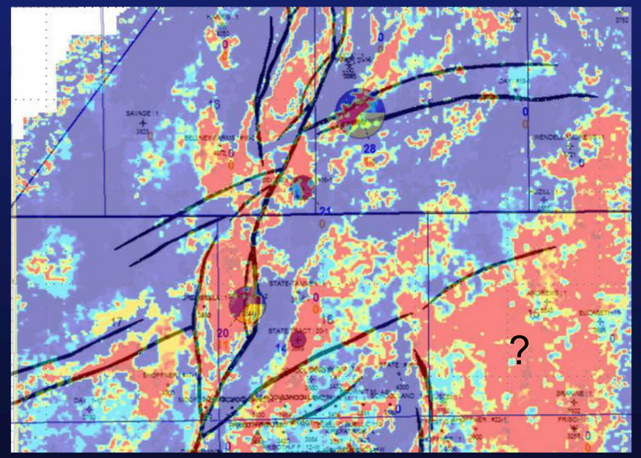



U. Cleveland River-Dominated Deltaic Sands - Heterogeneous Sub-Reservoirs: Oil saturated intervals shown as green fill. Vertical wells have inefficient recoveries vs. horizontal wells .




Facies map from stratal slice through the Upper Cleveland interval with gross/net sand bubble overlay.




Facies map from stratal slice through the Lower Cleveland interval with gross/net sand bubble overlay.

## Conclusions

- **L. Cleveland= Valley Fill Sands & U. Cleveland= River-Dominated Deltaics**
- **High-res 3D seismic delineates thick, porous Cleveland Sd.**
- **Areas of high accommodation allow seismic resolution of U & L Cleveland**
- **This work proposes numerous development & develocat wells**
- **Horizontal wells to optimize recovery in sub-reservoirs**
- **This analysis sets up a new oil play in a very old drilling province!**


## Acknowledgements

*Fossil Creek Resources, LLC*

DAWSON Dawson Geophysical Company

Geomodeling