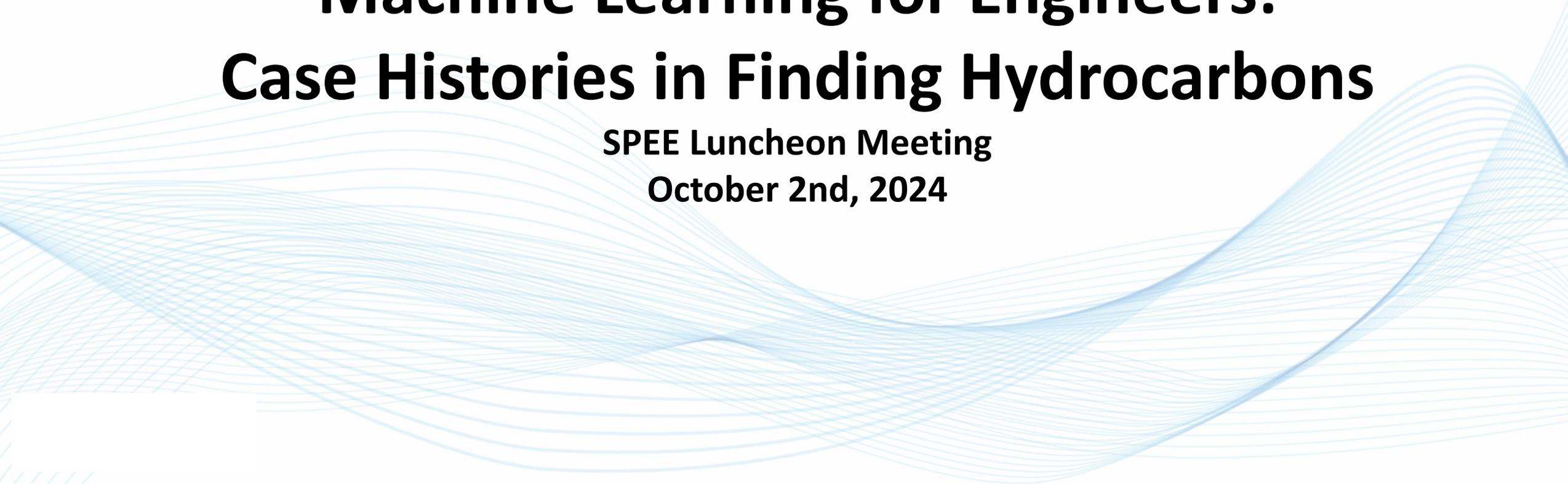# Machine Learning for Engineers:
Case Histories in Finding Hydrocarbons

SPEE Luncheon Meeting
## October 2nd, 2024

This presentation will show:

Cluster analysis using Self-organized maps can be very accurate when determining reserves when the reservoir can be identified, and

Looking for anomalous data points can be key in determining depletion providing the seismic data was acquired after most of the production had taken place and,

Using Machine learning can help give a better understanding of the subsurface when it comes to Exploration and development.

What is SOM? (Self-organized maps)
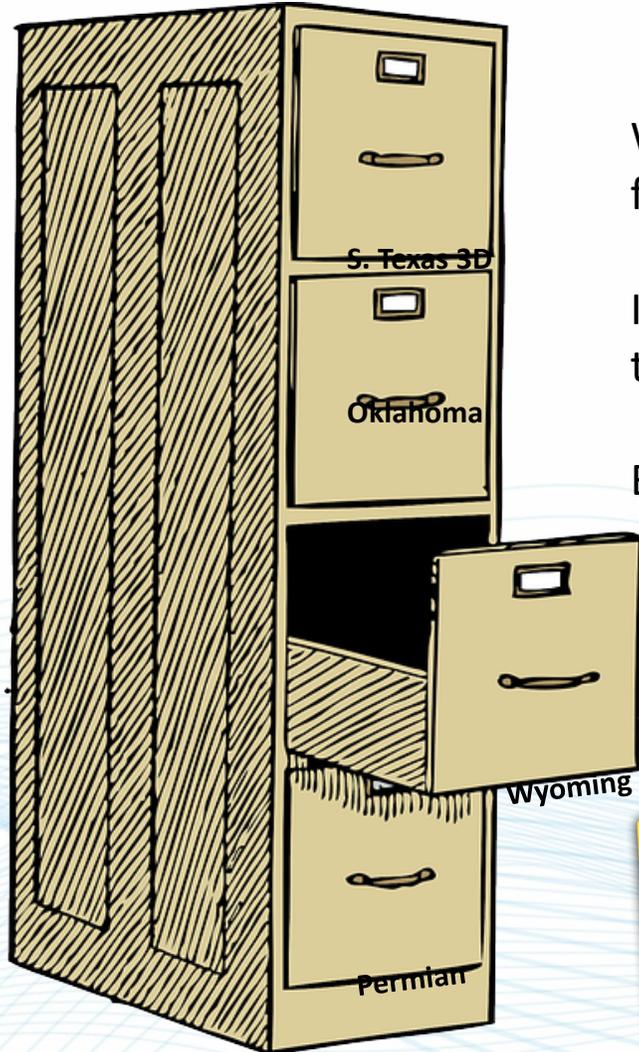
We all live in a world where data is organized – which makes it easy to "find" things for which we are looking.

In the case of seismic "organization", imagine a file drawer with different 3D's and the folders within are the seismic data files.

But we want to "organize" those attributes into something meaningful in the subsurface!

S. Texas 3D

Oklahoma

Wyoming

Permian

Phase

Amplitudes

Example of Classification of "Attributes" – T. Kohonen

This example shows how the classification process can group clusters of similar information. Using this method with seismic attributes results in a more clear view of the subsurface stratigraphy than can be done in a conventional wavelet interpretation. Using the data in SAMPLE statistics, allows fine resolution of rock properties, regardless of frequency or depth.

- Classify statistics which describe quality of life attributes such as state of health, longevity, education, income, taxation, population density, etc. (39 in total)

- Countries with similar quality of life attributes cluster together (126 countries)

- Organize data into spreadsheet

- Columns = Quality of life attributes

- Rows = Country

- 9 x 13 hexagonal neuron topology (117 neurons)

Code	Country	Code	Country	Code	Country
AFG	Afghanistan	GRC	Greece	NOR	Norway
AGO	Angola	GTM	Guatemala	NPL	Nepal
ALB	Albania	HKG	Hong Kong	NZL	New Zealand
ARE	United Arab Emirates	HND	Honduras	OAN	Taiwan, China
ARG	Argentina	HTI	Haiti	OMN	Oman
AUS	Australia	HUN	Hungary	PAK	Pakistan
AUT	Austria	HVO	Burkina Faso	PAN	Panama
BDI	Burundi	IDN	Indonesia	PER	Peru
BEL	Belgium	IND	India	PHL	Philippines
BEN	Benin	IRL	Ireland	PNG	Papua New Guinea
BGD	Bangladesh	IRN	Iran, Islamic Rep.	POL	Poland
BGR	Bulgaria	IRQ	Iraq	PRT	Portugal
BOL	Bolivia	ISR	Israel	PRY	Paraguay
BRA	Brazil	ITA	Italy	ROM	Romania
BTN	Bhutan	JAM	Jamaica	RWA	Rwanda
BUR	Myanmar	JOR	Jordan	SAU	Saudi Arabia
BWA	Botswana	JPN	Japan	SDN	Sudan
CAF	Central African Rep.	KEN	Kenya	SEN	Senegal
CAN	Canada	KHM	Cambodia	SGP	Singapore
CHE	Switzerland	KOR	Korea, Rep.	SLE	Sierra Leone
CHL	Chile	KWT	Kuwait	SLV	El Salvador
CHN	China	LAO	Lao PDR	SOM	Somalia
CIV	Cote d'Ivoire	LBN	Lebanon	SWE	Sweden
CMR	Cameroon	LBR	Liberia	SYR	Syrian Arab Rep.
COG	Congo	LBY	Libya	TCD	Chad
COL	Colombia	LKA	Sri Lanka	TGO	Togo
CRI	Costa Rica	LSO	Lesotho	THA	Thailand
CSK	Czechoslovakia	MAR	Morocco	TTO	Trinidad and Tobago
DEU	Germany	MDG	Madagascar	TUN	Tunisia
DNK	Denmark	MEX	Mexico	TUR	Turkey
DOM	Dominican Rep.	MLI	Mali	TZA	Tanzania
DZA	Algeria	MNG	Mongolia	UGA	Uganda
ECU	Ecuador	MOZ	Mozambique	URY	Uruguay
EGY	Egypt, Arab Rep.	MRT	Mauritania	USA	United States
ESP	Spain	MUS	Mauritius	VEN	Venezuela
ETH	Ethiopia	MWI	Malawi	VNM	Viet Nam
FIN	Finland	MYS	Malaysia	YEM	Yemen, Rep.
FRA	France	NAM	Namibia	YUG	Yugoslavia
GAB	Gabon	NER	Niger	ZAF	South Africa
GBR	United Kingdom	NGA	Nigeria	ZAR	Zaire
GHA	Ghana	NIC	Nicaragua	ZMB	Zambia
GIN	Guinea	NLD	Netherlands	ZWE	Zimbabwe
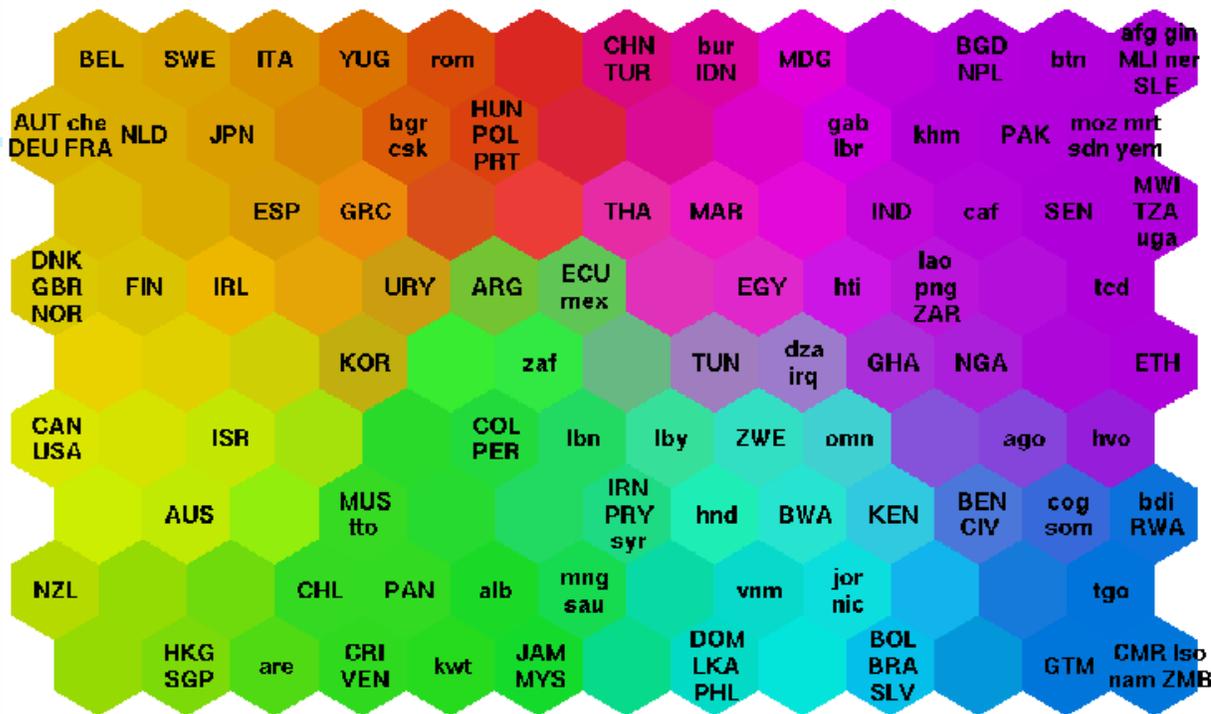
Slide courtesy of Dr. Tom Smith

**Self-Organizing Maps
(unsupervised classification
of data)**
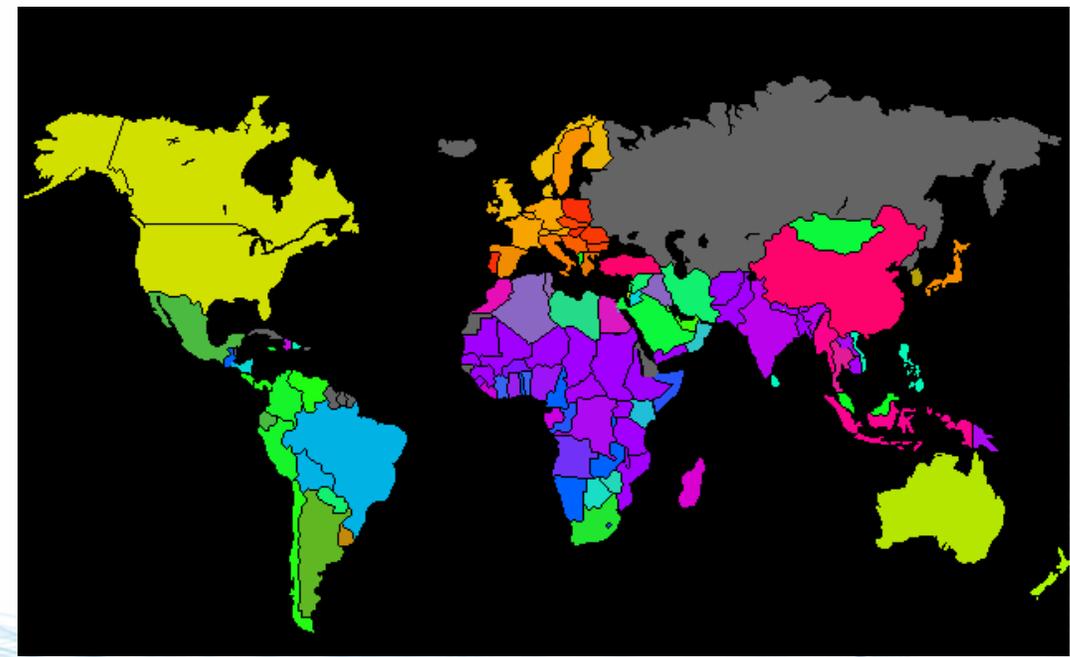
39 quality of life statistics (UN)

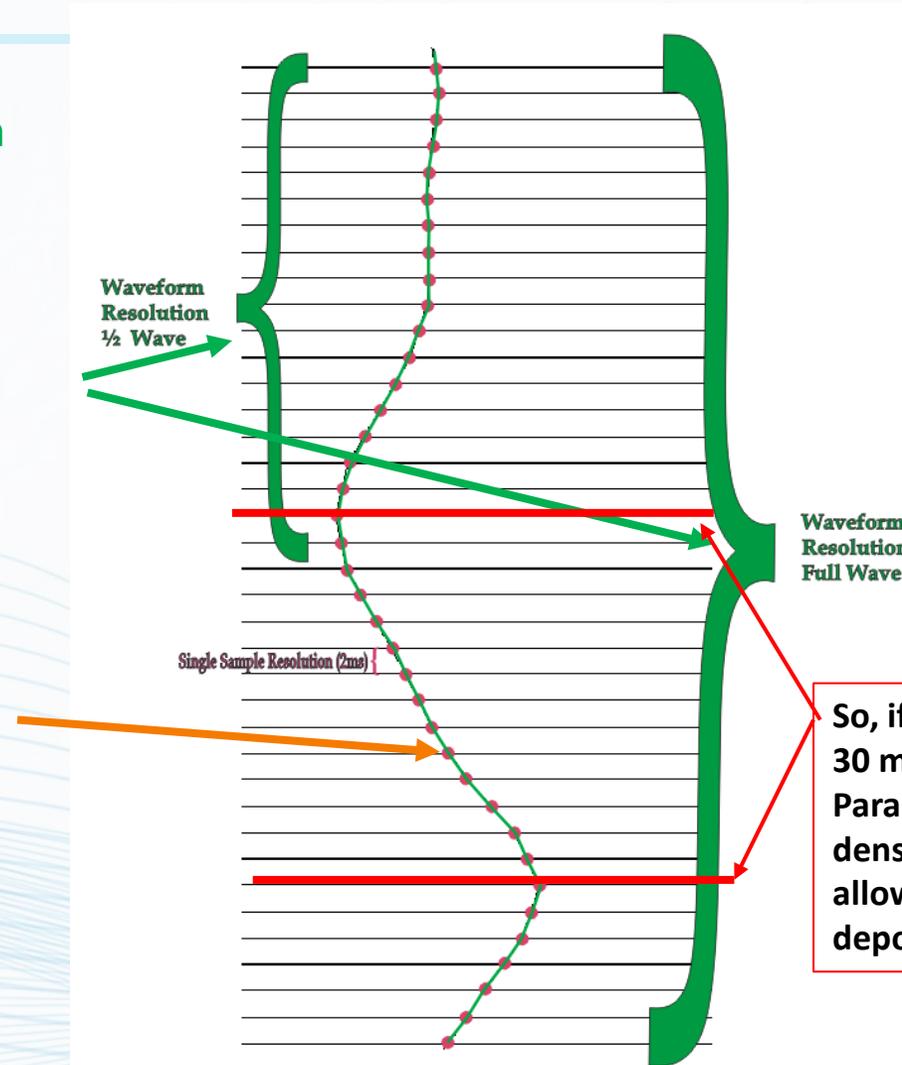*126 countries*

9X13 hexagonal neuron topology (117 neurons)

T. Kohonen, 2001

Slide courtesy of Dr. Tom Smith

4

"Single Sample Resolution" – number crunching!

All other ML software use Waveform Resolution of either ½ or Full Wave Resolution to minimize Data Processing requirements
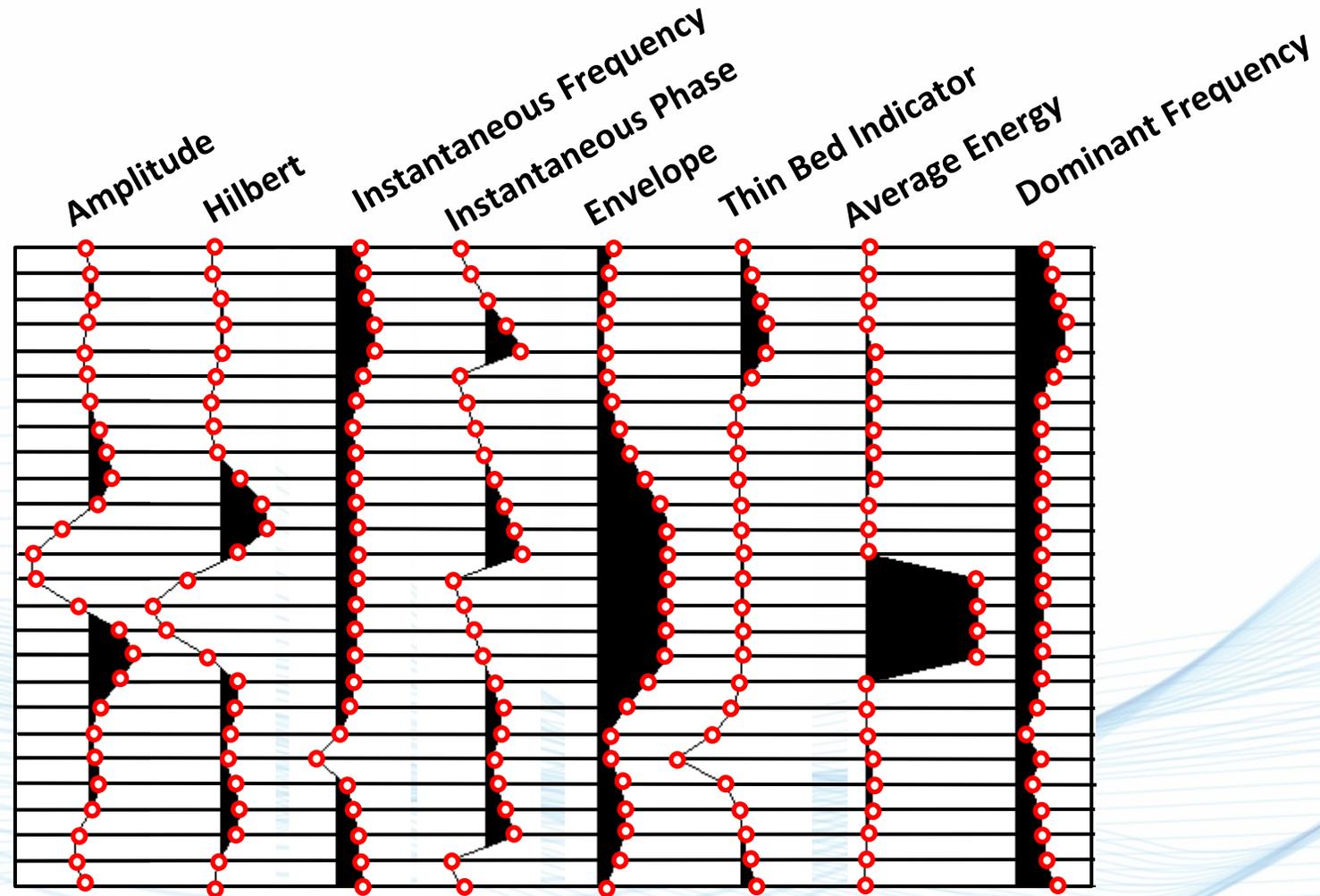
Waveform Resolution ½ Wave

Waveform Resolution Full Wave

Single Sample Resolution (2ms)

This Drawing is actual Seismic Amplitude data in 2ms sample rate

This Software uses Single Sample Resolution In order to enhance the Neural Cluster Process

So, if the Envelope (trough to peak interval) is 30 ms and you are working with 2ms sample rate, Paradise is statistically analyzing the data 15 times as densely as a mapped wavelet of peak or trough, which allows for much finer resolution in the earth of depositional features!
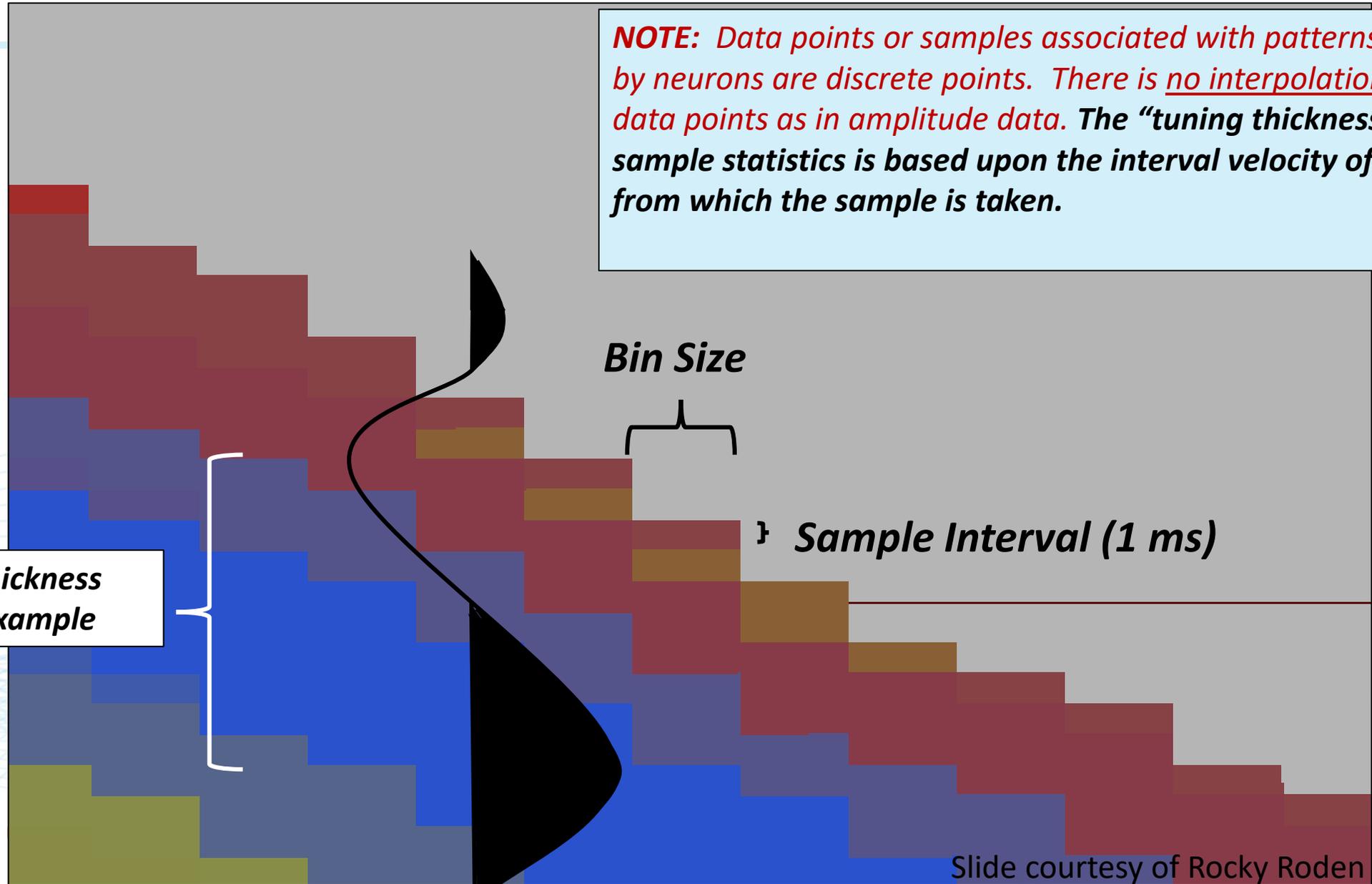
Slide courtesy of Blaine Taylor

Every Sample from each Attribute is Input into a PCA or SOM Analysis

6

Scale of SOM Results

NOTE: Data points or samples associated with patterns identified by neurons are discrete points. There is no interpolation between data points as in amplitude data. The "tuning thickness" in sample statistics is based upon the interval velocity of the rock from which the sample is taken.

Bin Size

Sample Interval (1 ms)

Tuning Thickness for this example

Slide courtesy of Rocky Roden

7

Project Objectives:

1) Discriminate production in the Meramec Formation
2) Understand the "accuracy" in the machine learning classification results

Assumptions and Challenges:

1) Production is not necessarily related to only geological changes (reason for only using straight holes for challenge)
1) Permeability could not be calculated from the log curves provided in order to calibrate well production
3) Difficulty in isolating specific production in all the wells through multiple zone perforations

Culture overlay showing production next to each well.

Square boxes represent those wells in which synthetic seismograms were created to tie the data. In all, 10 synthetic ties were created.
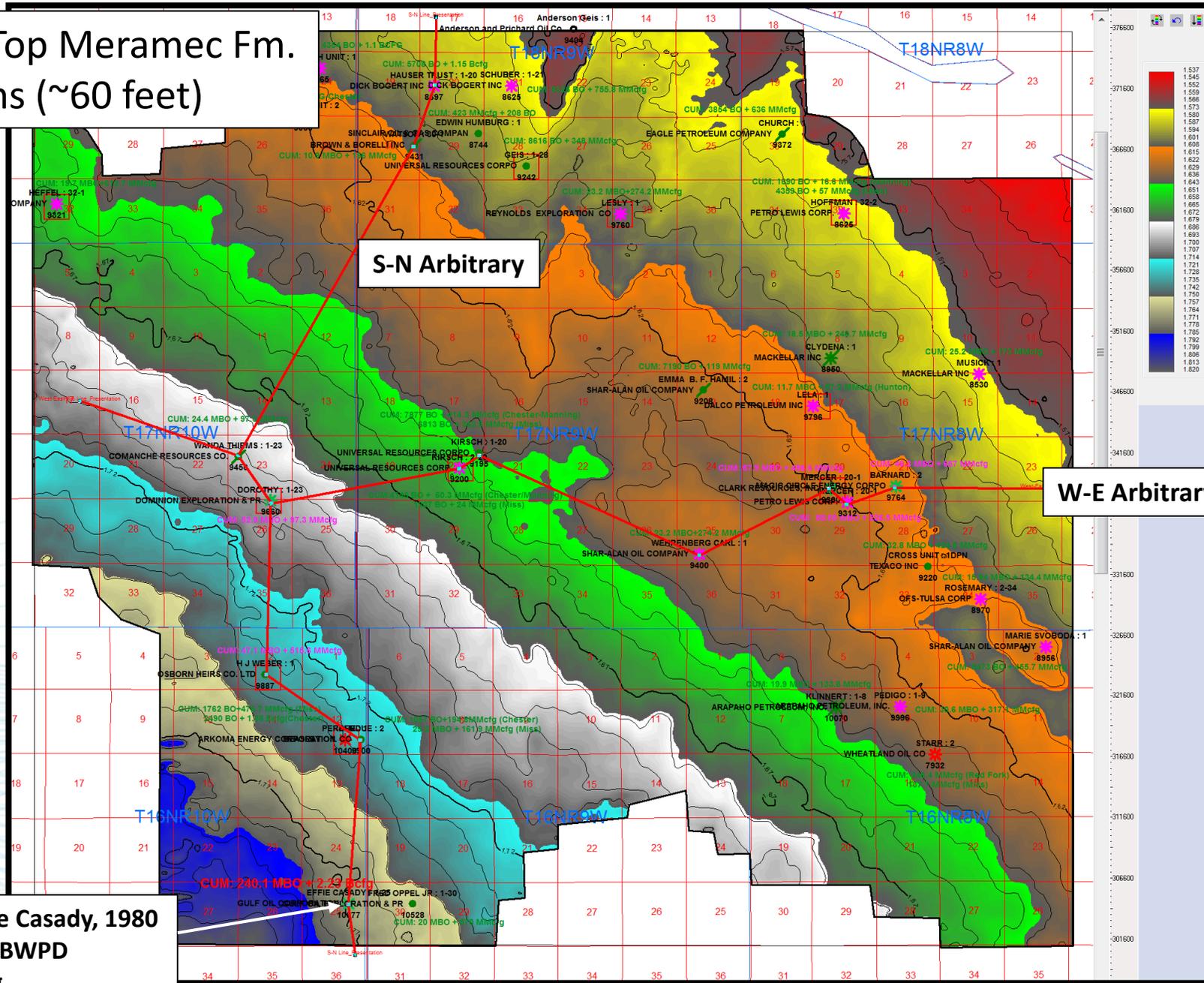
Best Well – Gulf Oil #1-25 Effie Casady, 1980
IPF: 890 BO + 1979 Mcfg + 73 BWPD
Cum: 240.1 MMBO+ 2.23 Bcfg
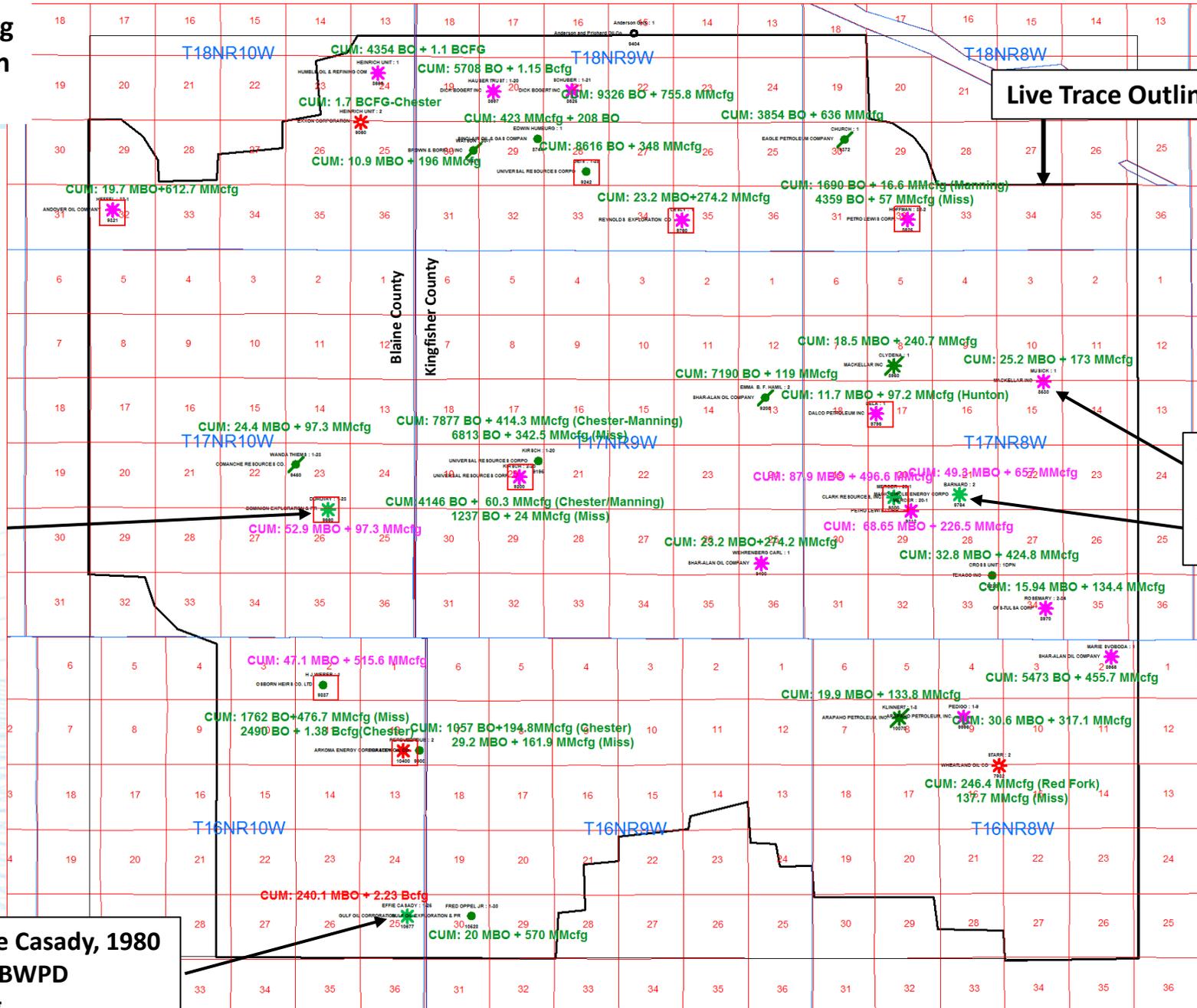
Live Trace Outline ~ 196 sq mi

Wells with production numbers in pink have produced near or over 50 MBO. Those in green have produced 35 MBO or less.

10

Time Map on Top Meramec Fm.
CI = 10 ms (~60 feet)

S-N Arbitrary

W-E Arbitrary

Best Well – Gulf Oil #1-25 Effie Casady, 1980
IPF: 890 BO + 1979 Mcfg + 73 BWPD
Cum: 240.1 MMBO+ 2.23 Bcfg

Big Lime (red)

Top Meramec (hot pink)

Perforations predominately in whole of Meramec section

Base Woodford (yellow)
Source rock for production

Top Arbuckle (blue)

Section thins considerably from south to north – important because source rock is thinning as well

How PCA relates to finding the most significant seismic attributes
(12 seismic attributes were employed)

Highest Eigenvalues on each inline

Highest Eigenvalue

Second Highest Eigenvalue
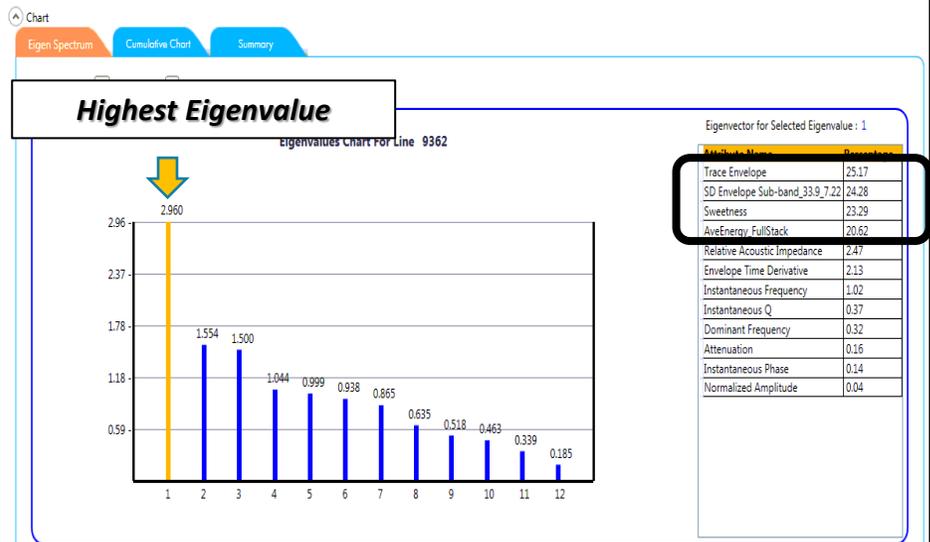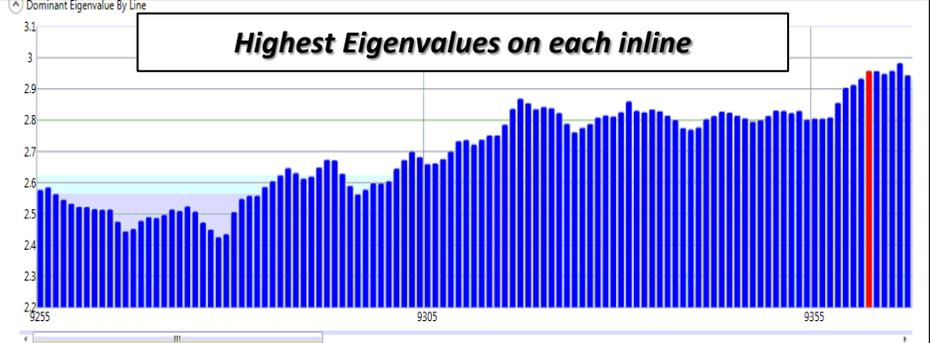
FIRST PRINCIPAL COMPONENT
Trace Envelope   25.17%
SD Envelope 33.9 Hz   24.28%
Sweetness   23.29%
Average Energy   20.62%
These 4 attributes account for more than 93% of the data found in all 12 attributes used in the analysis

The first principal component accounts for as much of the variability in the data as possible, and each succeeding component (orthogonal to previous) accounts for as much of the remaining variability as possible.
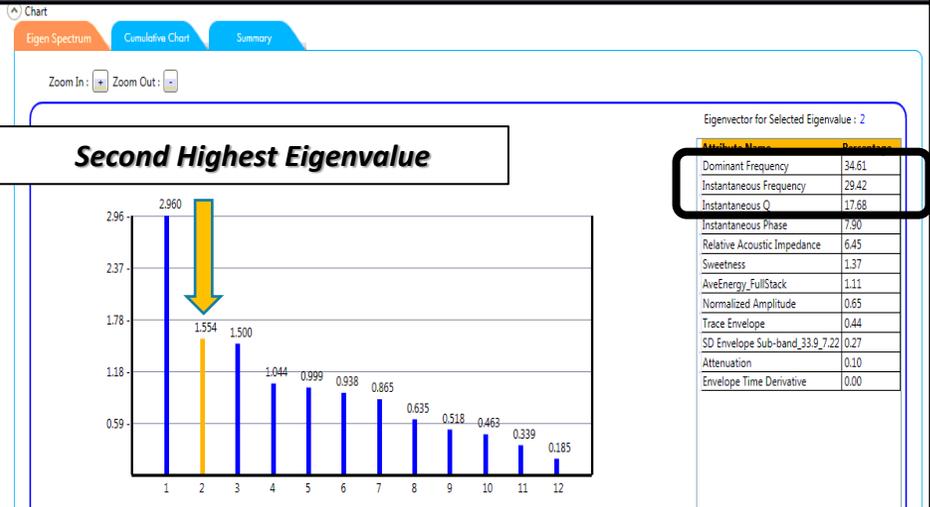
SECOND PRINCIPAL COMPONENT
Dominant Freq   34.61%
Instantaneous Freq   29.42%
Instantaneous Q   17.68%
These 3 attributes account for more than 81% of the remaining information.

13

Arbitrary Line taken from SOM in 3D Survey

Top4PCA-Inst__10x10_-10 to 0 Mer-Wood
(used top instantaneous attributes from first four Eigen Vectors in a 10x10 topology. Window of analysis is 10 ms above Meramec to Base Woodford)
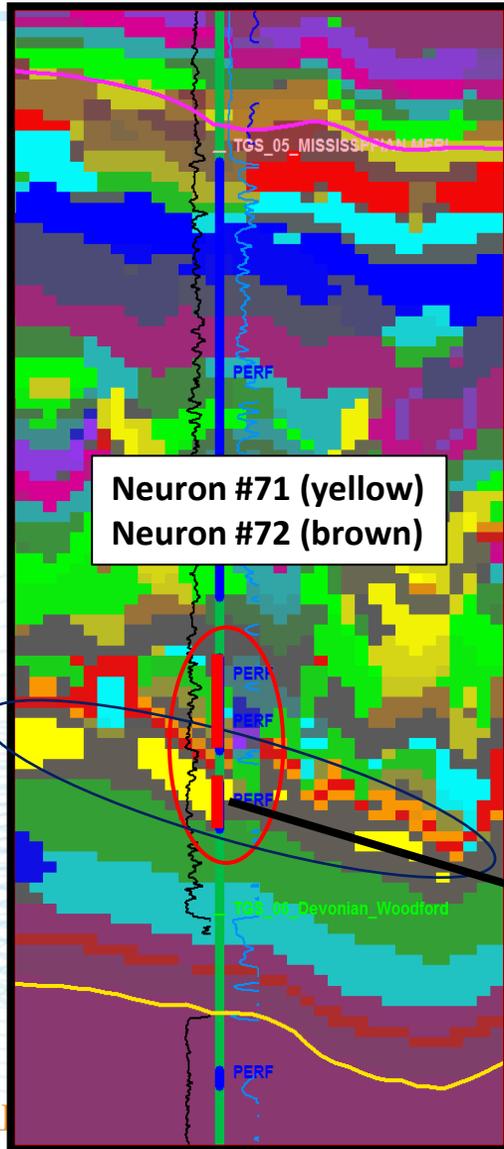
Effie Casady

S

N

Top Meramec

Effie Casady
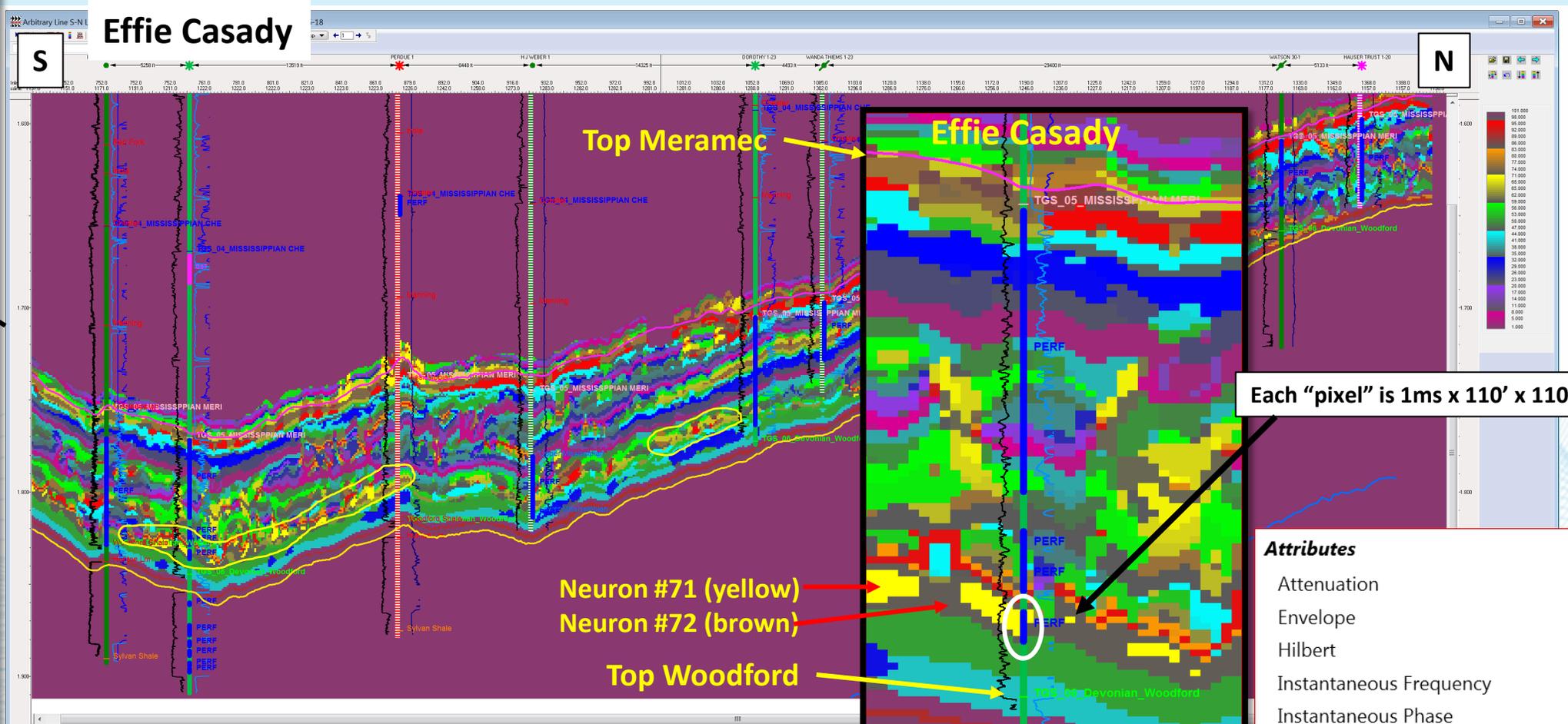
Each "pixel" is 1ms x 110' x 110'

Neuron #71 (yellow)
Neuron #72 (brown)

Top Woodford

Attributes
- Attenuation
- Envelope
- Hilbert
- Instantaneous Frequency
- Instantaneous Phase
- Normalized Amplitude
- Relative Acoustic Impedance
- Sweetness
- Thin Bed

14

Although porosity is low, there is a distinct neural pattern associated with the higher resistivity section in the log – especially at the lower perforated section of the well.

Effie Casady

Effie Casady logs

Neuron #71 (yellow)
Neuron #72 (brown)

DPHI | ILD | RHOB | Borehole

Higher Resistivity
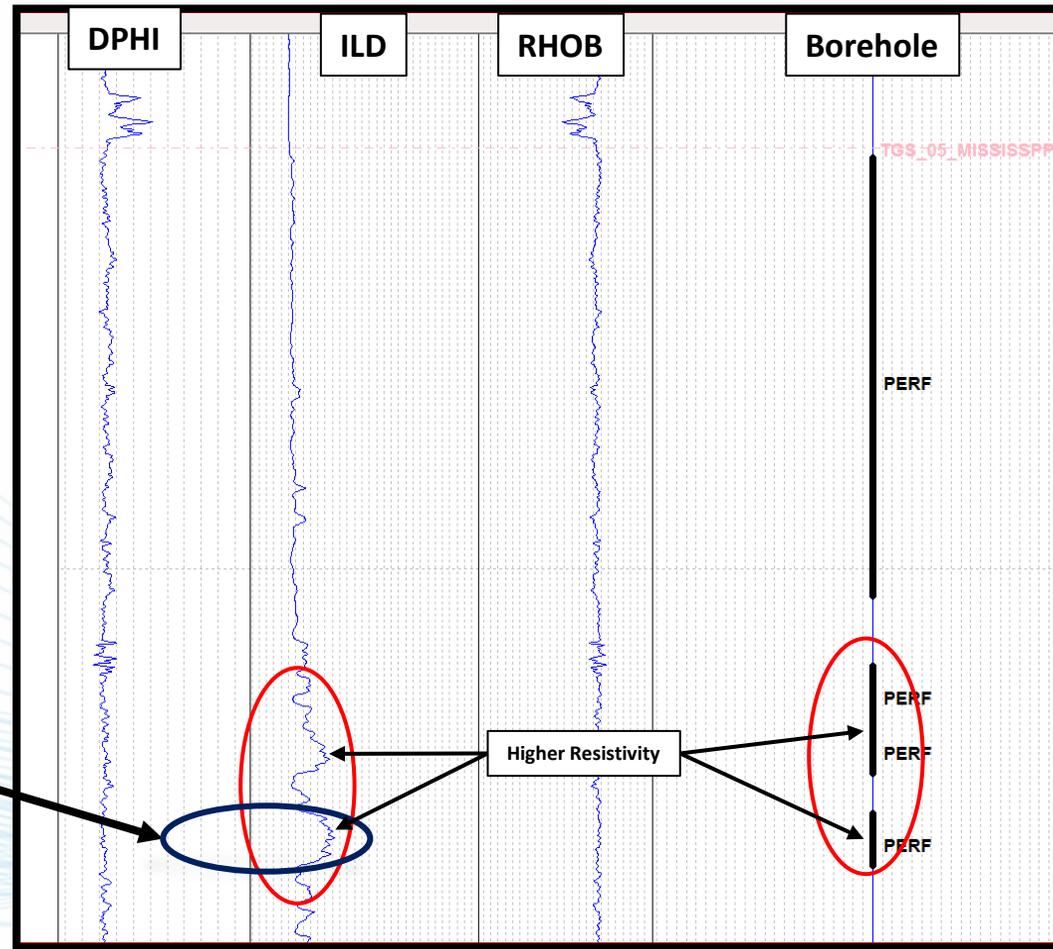
Higher resistivity was targeted in the perforations

Here are both neurons, colored in approximately the same color configuration as in the Kingdom display.
This is also a sculpted interval

These three wells had a combined total of 205.8 MBO + 1.38 BCFG

Effie Cassady
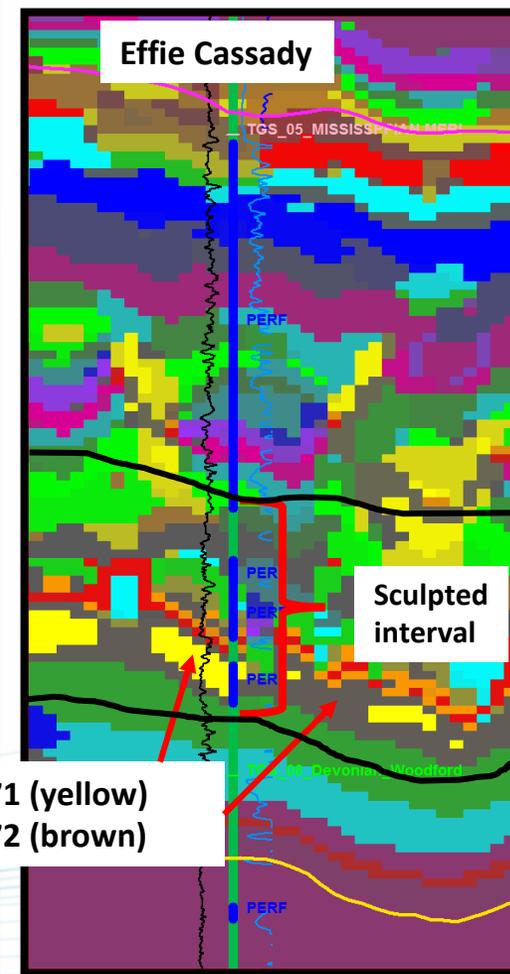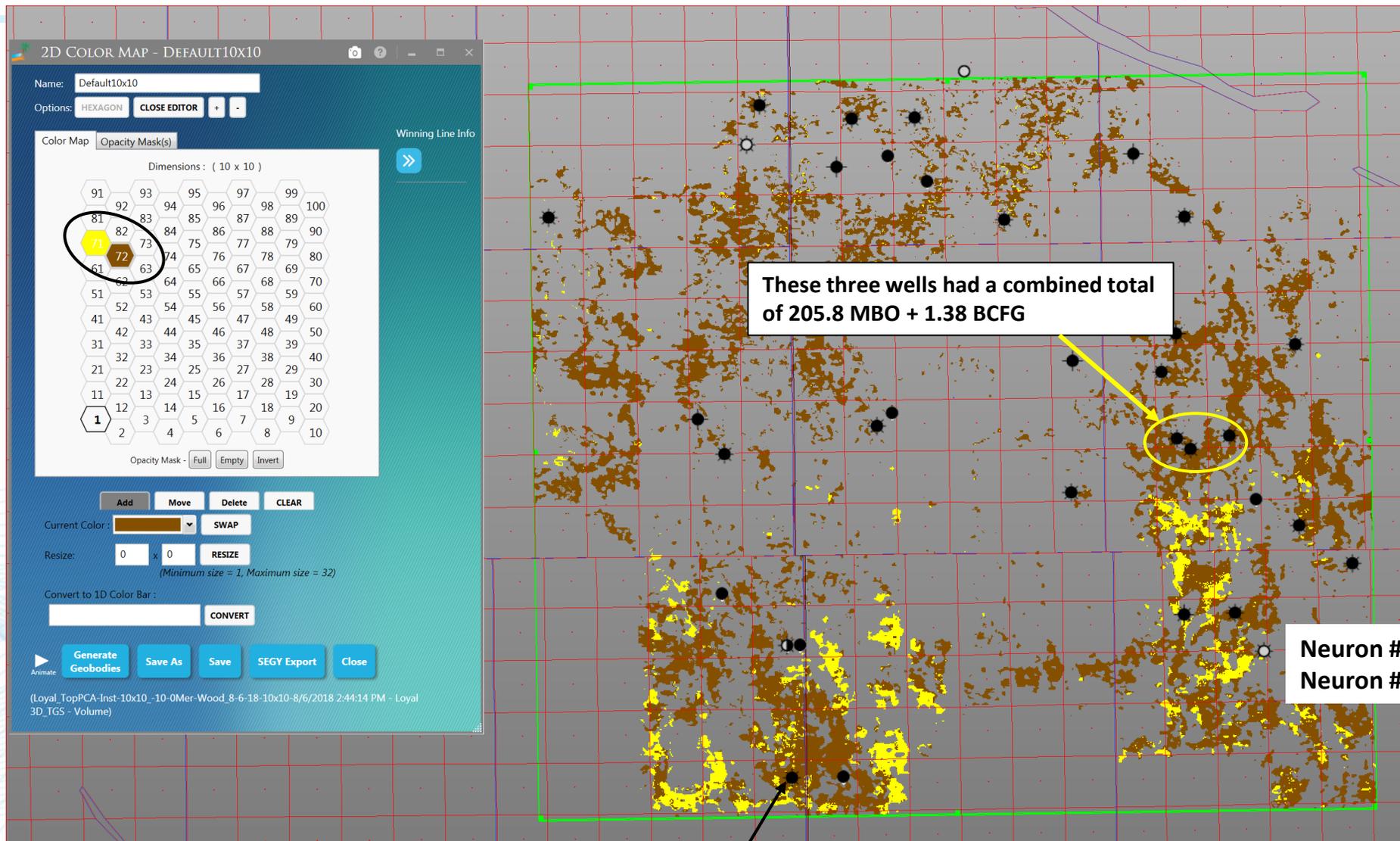
Sculpted interval

Neuron #71 (yellow)
Neuron #72 (brown)

Casady Well

16

Geobodies are on a <u>scale of bin X sample increment</u>, therefore, geobodies can be quantified.

Each <u>bin X sample increment</u> can be quantified to compute Gross Rock Volume, Hydrocarbon Pore Volume, etc.
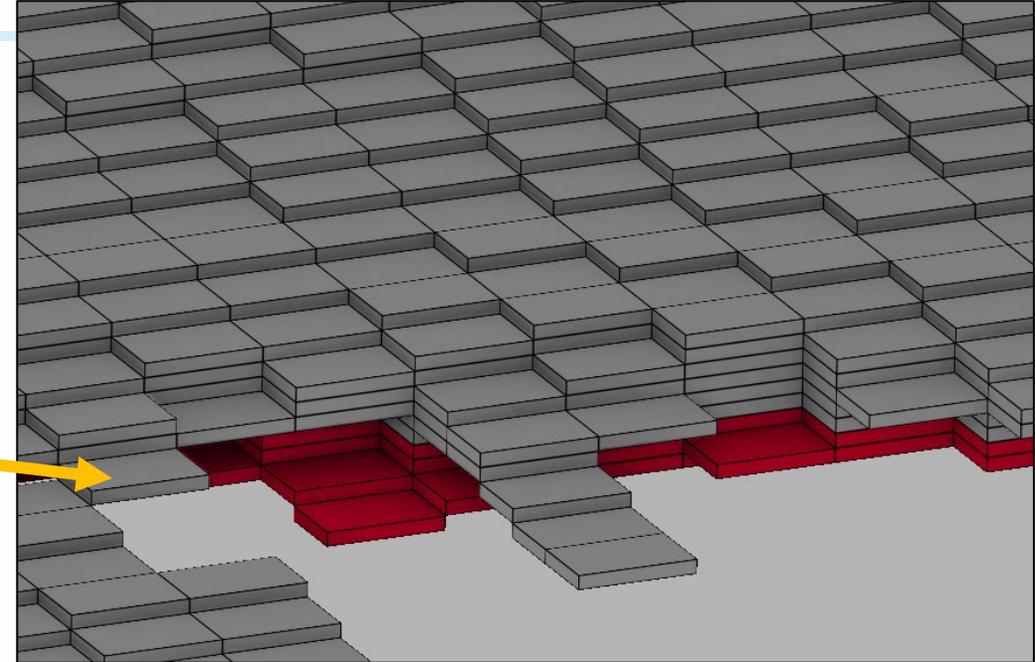
|	
Sample Volume (Time)	Calculated (Bin X * Bin Y * Bin Z(Sample in time/msec. * velocity))
Depth Conversion Velocity	5 Digit Value from User: 12000 Feet/sec (survey units)
Gross Rock Volume	GRV = Sample Volume * Sample Count
Net Rock Volume	NRV = GRV * Net Rock Factor (0-1)
Pore Volume	PV = NRV * Porosity
Hydrocarbon Pore Volume (HPV)	HPV = PV * (1-Sw)
Porosity	0-1 (from user)
Water Saturation	Percentage (by user from log data)

The two key neurons in previous slides have been scanned for Geobodies. The Geobody which may be contributing to the production in the Effie Casady well has been highlighted in green. Highlighting that geobody allows one to know the sample count it contains – which in this case is 32,439 samples (1ms x 110'x110')

Hydrocarbon Pore Volume, if all values are known, could be calculated to show possible reserve amounts (with recovery factor) and calibrated to known production for reservoir extents. Values used are "estimates" for the Meramec in this area

Effie Casady
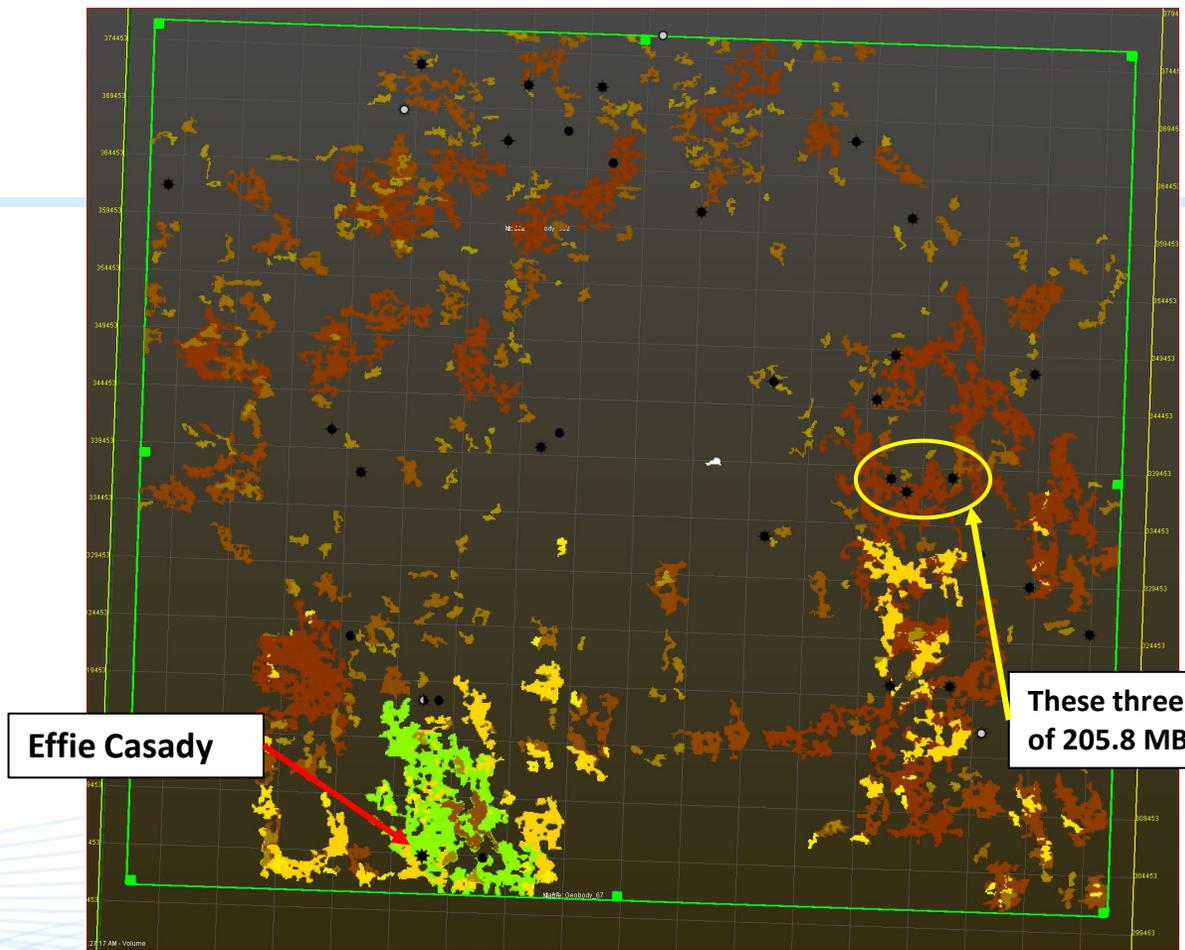
These three wells had a combined total of 205.8 MBO + 1.38 BCFG

|	
Velocity (ft/s) :	**14000 ft/sec**
Net/Gross (0-1) :	**0.6**
Porosity (0-1) :	**0.06**
Water Saturation (0-1) :	**0.4**

Geobody Details

Id: 67   Name:

ID	NAME	NEURON	SAMPLE COUNT	EXTERIOR SAMPLE COU	INTERIOR SAMPLE COU	VELOCITY (FT/S) (>=	NET/GROSS (0-	POROSITY (0-1	WATERSATURATION (0	SAMPLE VOLUME (CUBIC FEE	GROSS ROCK VOLUME (CUBIC FE	NET ROCK VOLUME (CUBIC F	PORE VOLUME (CUBIC FEE	HYDROCARBON PORE VOLUME (CUBIC FEET)
67	Geobody_67	72	32,439	24,925	7,514	14000.00	0.60	0.06	0.40	169400.10	5495169000.00	3297102000.00	197826100.00	118695700.00

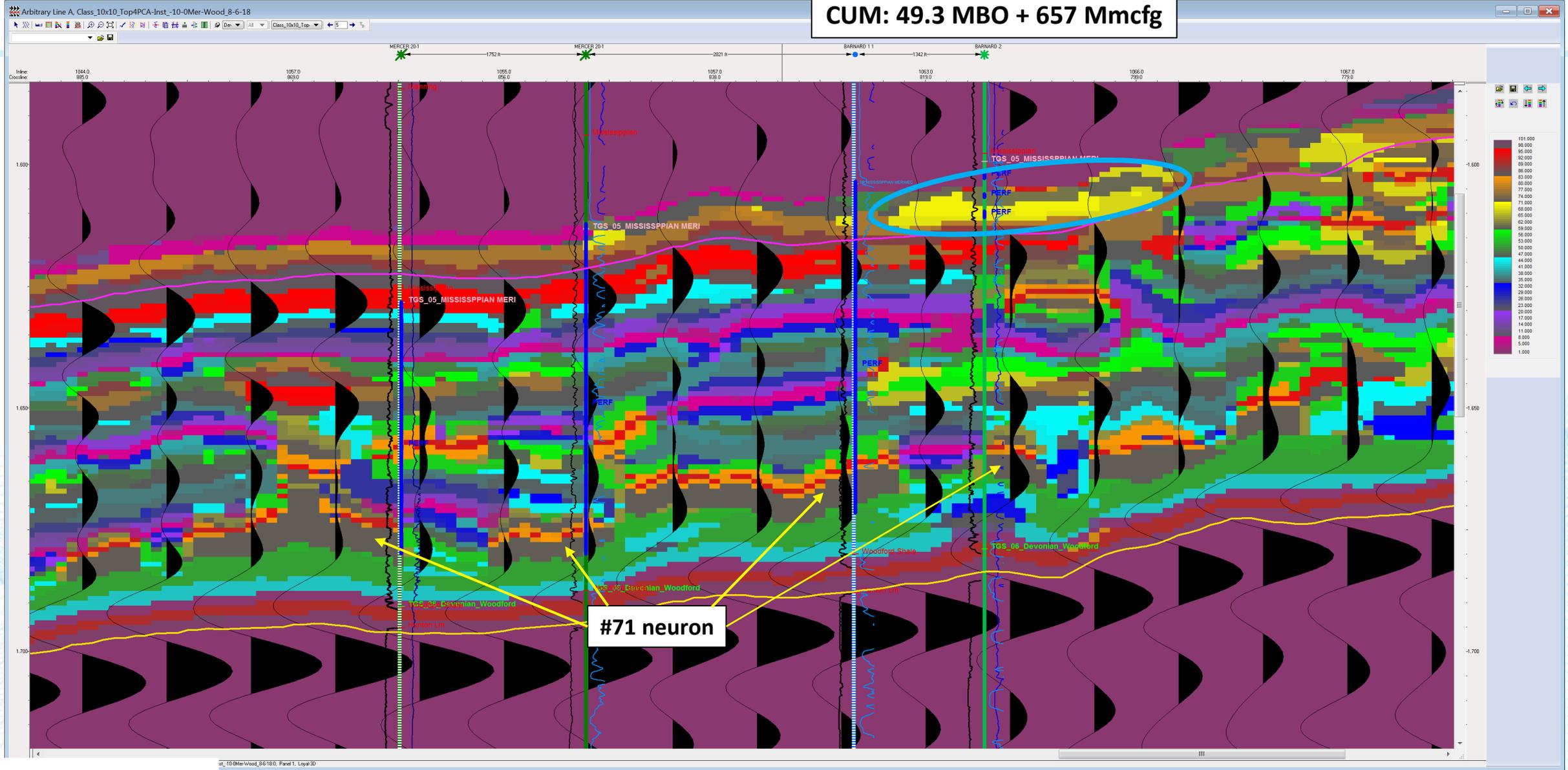**32,439 samples**

HPV = 118,695,700 cubic feet

118,695,700 CuFt/43,560 = 2725 ac-ft x 225 BOE/ac-ft = 613,125 BOE   Actual is: 611,685 BOE for the well
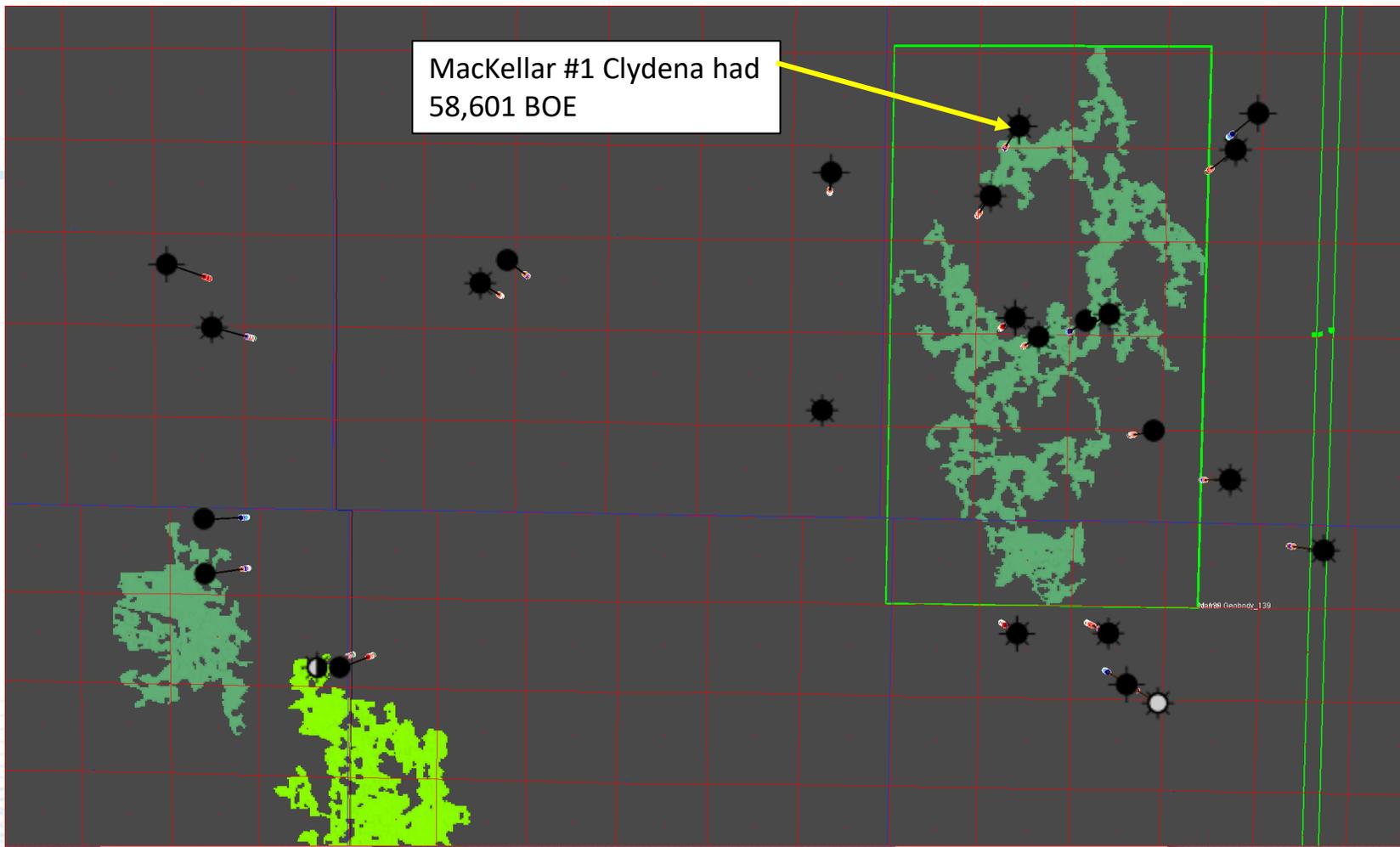
Arbitrary Line in PP5D-PRCMIG from Cassady well to other wells with key neurons
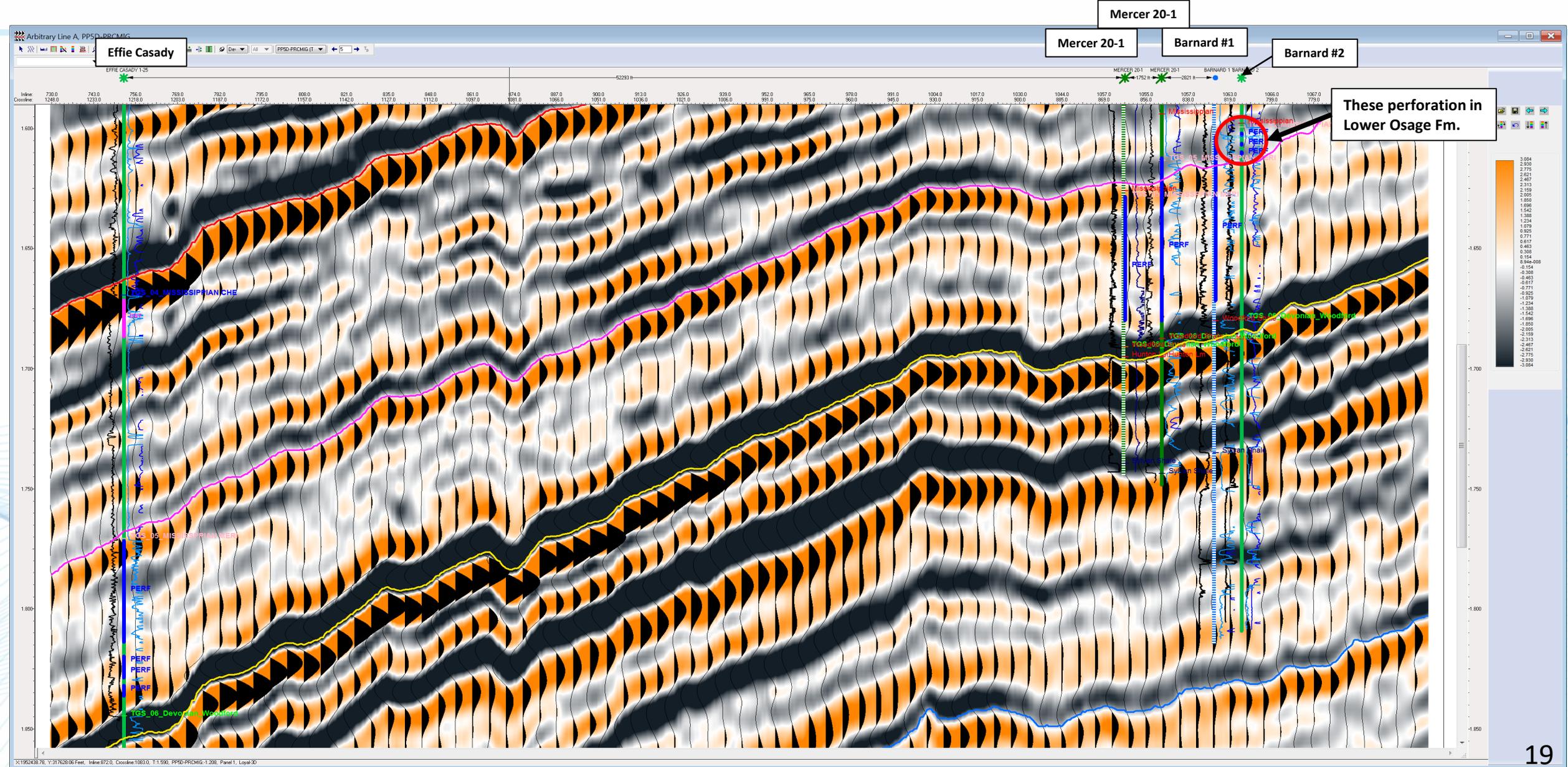
Enlarged section from previous line in Paradise SOM

Barnard
CUM: 49.3 MBO + 657 Mmcfg

#71 neuron

MacKellar #1 Clydena had 58,601 BOE

I took the total cubic feet of hydrocarbon pore volume and divided by 43,560 (# of square feet in an acre) to get Ac-Ft. Then I multiplied the number of Ac-Ft (2114.4) by the recovery factor given to me by my friend at the large independent to end up with 475,751 BOE. There were only three of the four wells which perforated the key neuron, and the total BOE of those three wells was 423,080.

However, the MacKellar #1 Clydena perforated a small interval of the key neuron, so I added the BOE production from that well to get to 481,681 BOE, which is within **2% error** from the calculated amount

SAMPLE COUNT FILTER

| Id: | 139 | | | | | | | | | | Name: | | |

RESET

GEOBODY EDITING CONTROLS

Editor Visibility

Id	Name	Neuron	Sample Count	Exterior Sample Count	Interior Sample Count	Velocity (Feet/sec) (>=0)	Net/Gross (0-1)	Porosity (0-1)	WaterSaturation (0-1)	Sample Volume (Cubic Feet)	Gross Rock Volume (Cubic Feet)	Net Rock Volume (Cubic Feet)	Pore Volume (Cubic Feet)	Hydrocarbon Pore Volume (Cubic Feet)
139	Geobody_139	72	37,758	27,786	9,972	14000.00	0.60	0.04	0.40	169400.10	6396208000.00	3837725000.00	153509000.00	92105400.00

37,758 Samples

HPV = 92,105,400 cu ft

92,105,400/43,560 = 2114.4 Ac-Ft x 225 BOE/Ac-Ft = 475,751 BOE

Actual from the three wells perforated in the neuron is 423,080 BOE + 58,601 = 481,681BOE from Neuron #72

GERONIMO PROSPECT
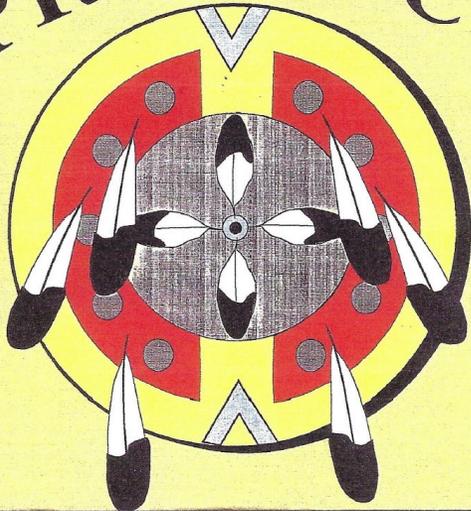
PALADIN PETROLEUM III, LLC

An "M.L. Driven" Prospect

Upper Wilcox & Queen City Targets

Duval County , TX

ORR ENERGY GROUP

22

MAJOR FIELDS IN THE UPPER WILCOX GAS TREND

The **Geronimo Prospect** is on stratigraphic trend with N.E. Thompsonville, Fandango and N.W. Rosita Fields

It has the potential of 300+ BCFGE. The structure is approximately six miles long and two miles wide. Targets are the Upper Wilcox Hinnant Sands from the UW-1 to the UW-17.

The initial test well is designed to test a large faulted, four-way closure with vertical relief in excess of 1000 feet. The prospect exhibits multiple stacked sands with thicknesses ranging from 40 to 100 feet.

Additional potential can be seen in the Queen City Fm., which would be a non-pipe test at about 9000 feet.

A 27-square mile 3D, acquired in 1998 and reprocessed by Tricon Geophysical recently is the basis for this prospect. All attributes were created using the Far Angle Stack to better support any AVO gas effect in the data.
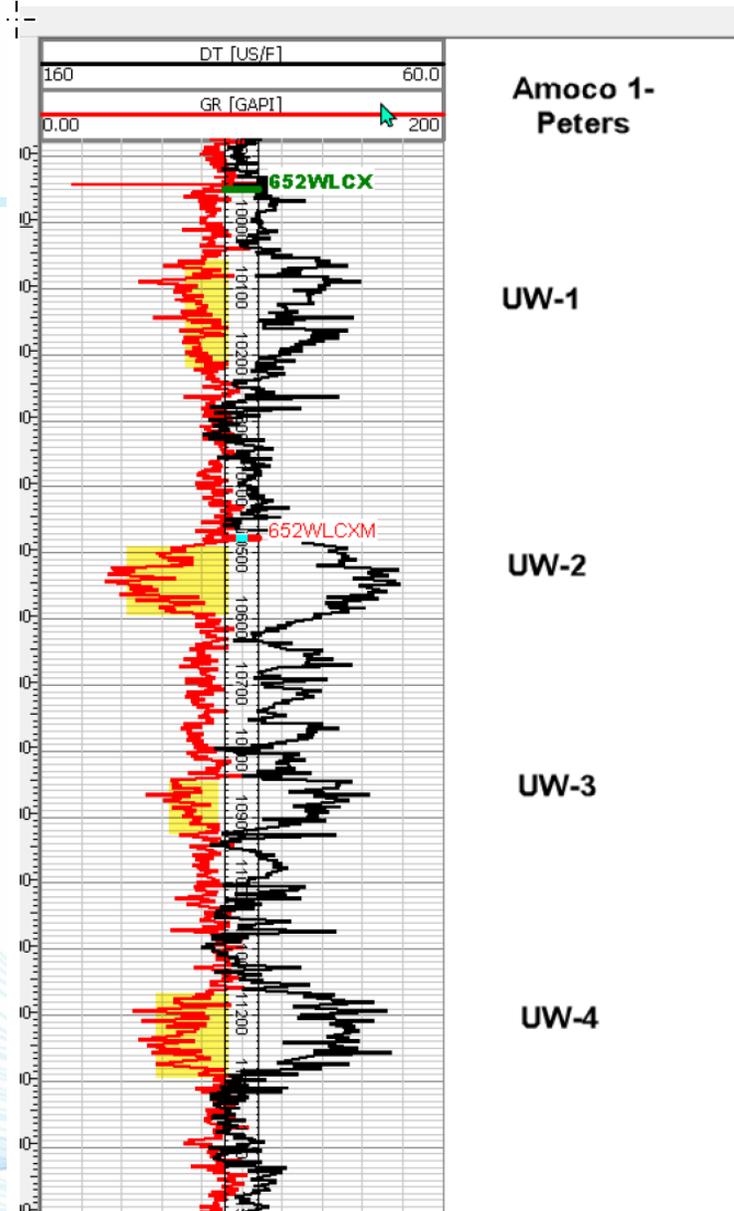
Gathers at key sands show Type 2P and Type 3 AVO characteristics.

**UPPER WILCOX HINNANT SANDS :
MUY GRANDE FIELD :
10 miles west**

260 FT TOTAL SAND

HINNANT SAND SERIES

Sonic Porosities : 22-28%
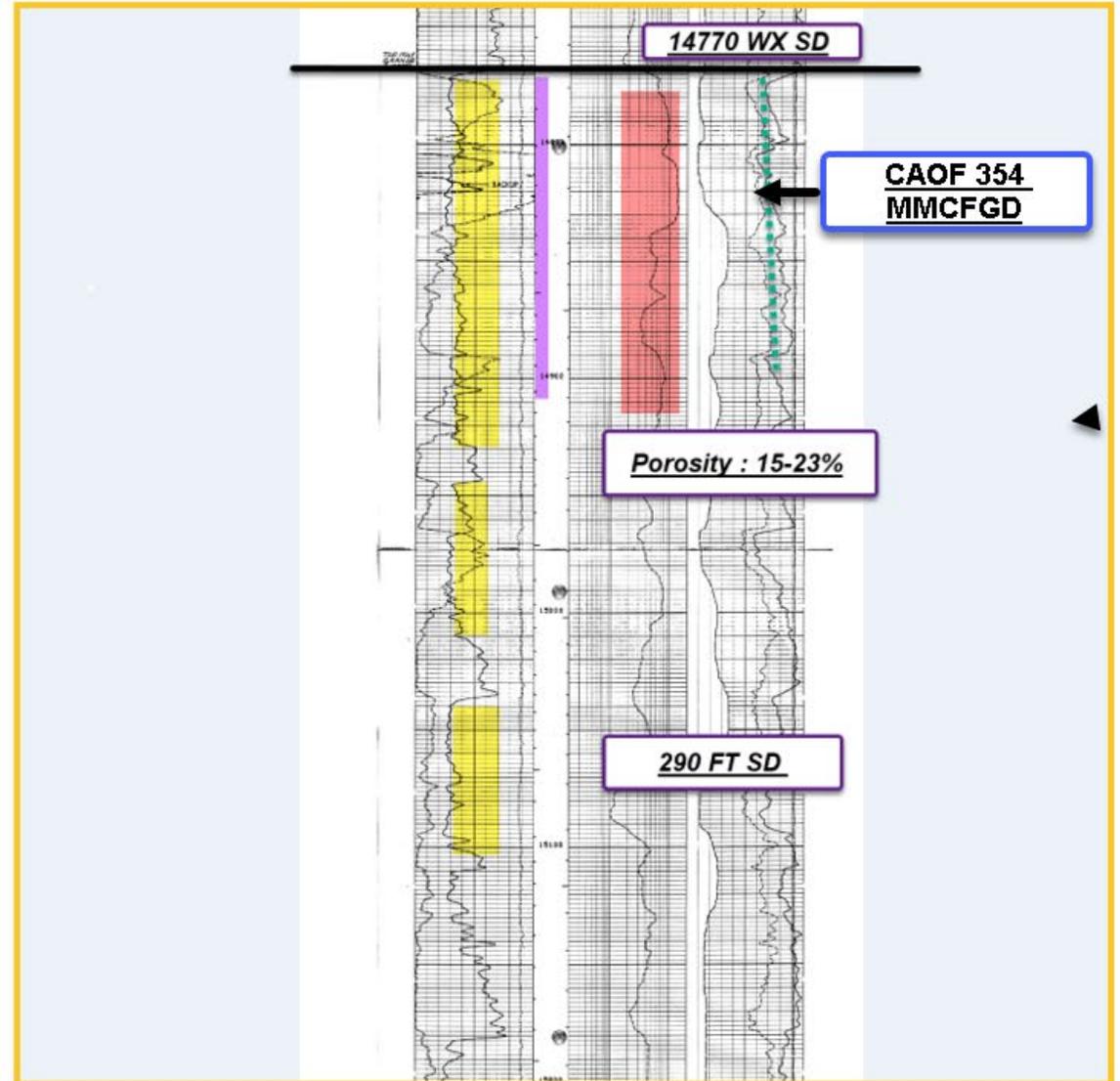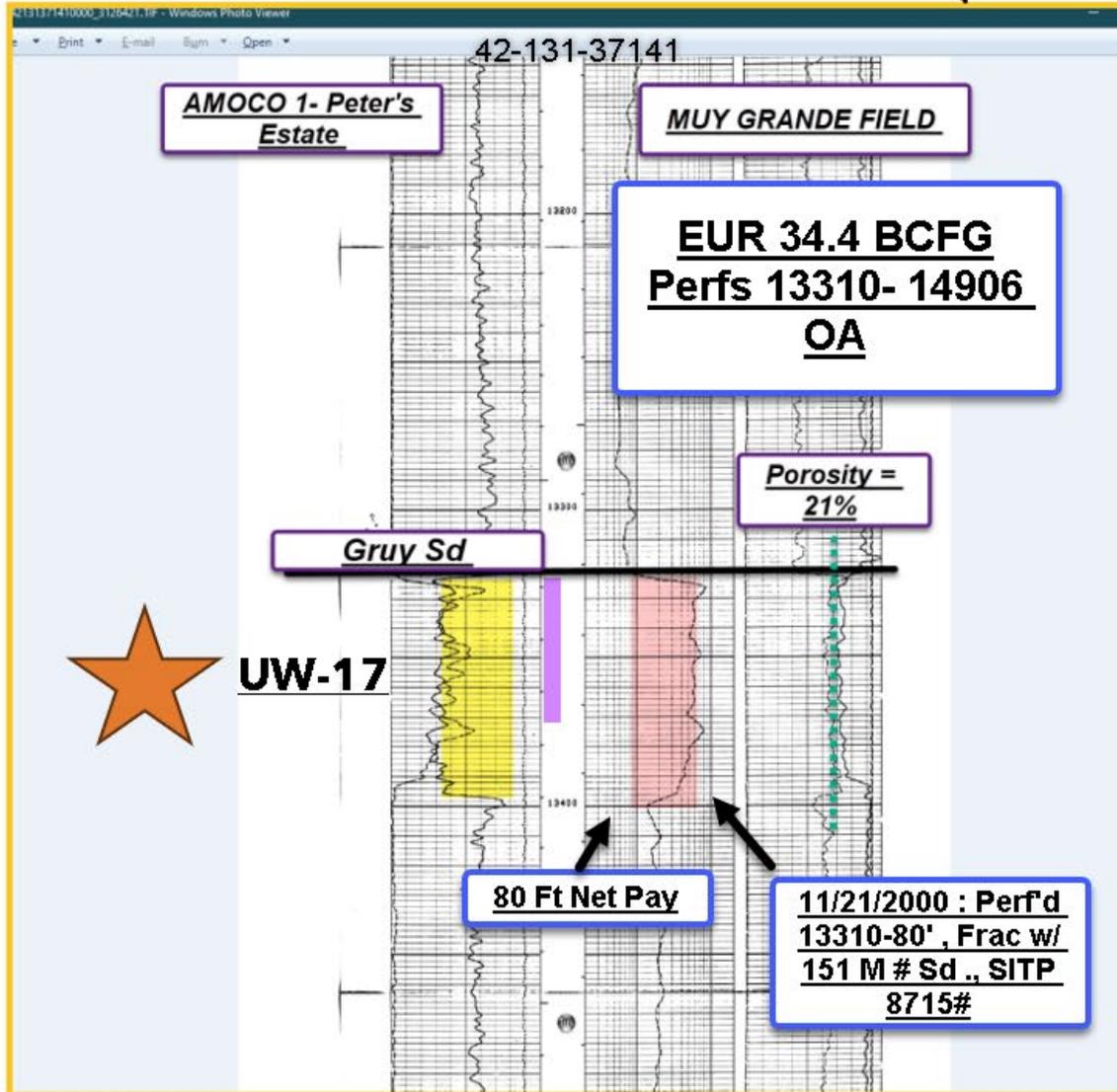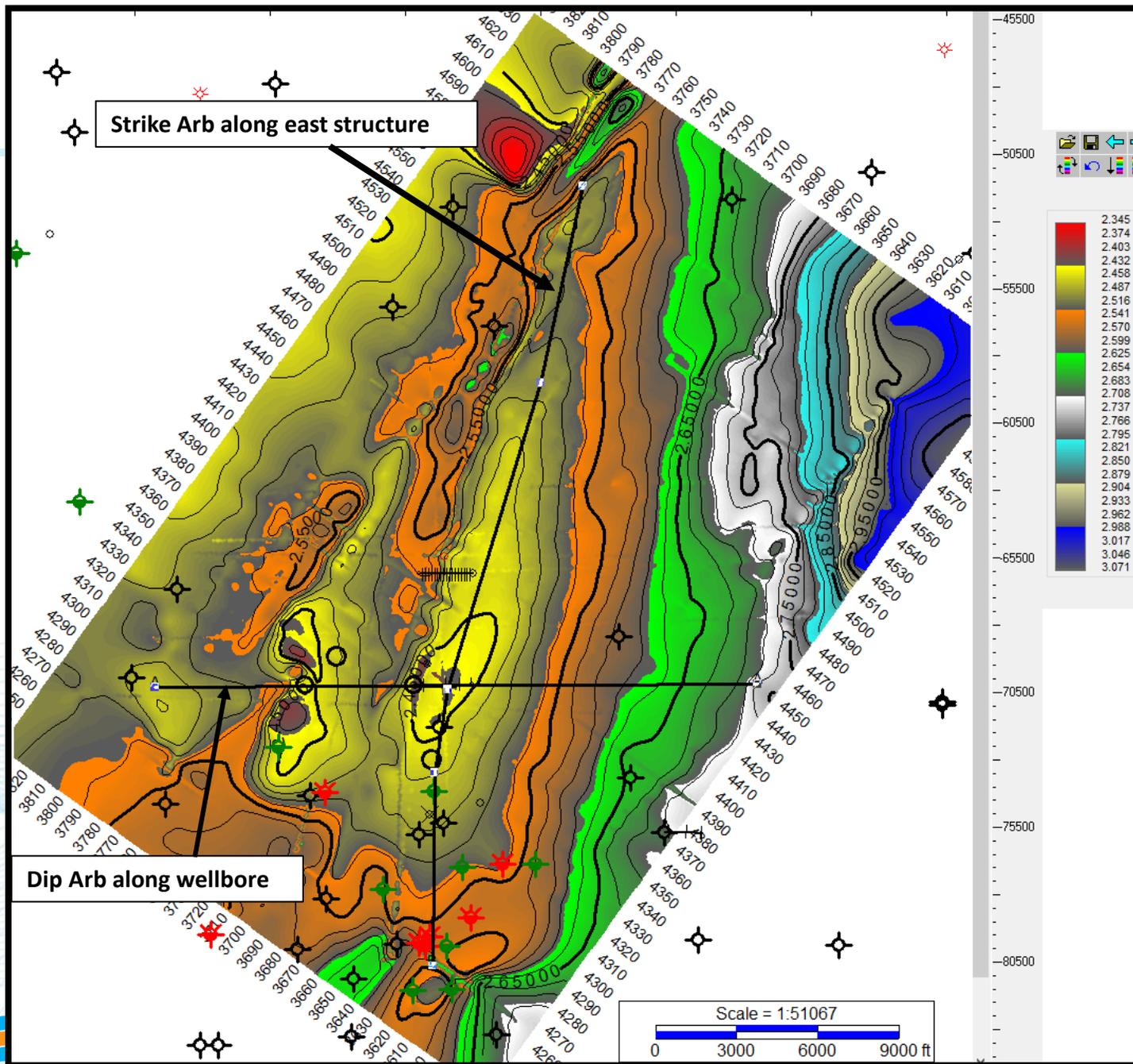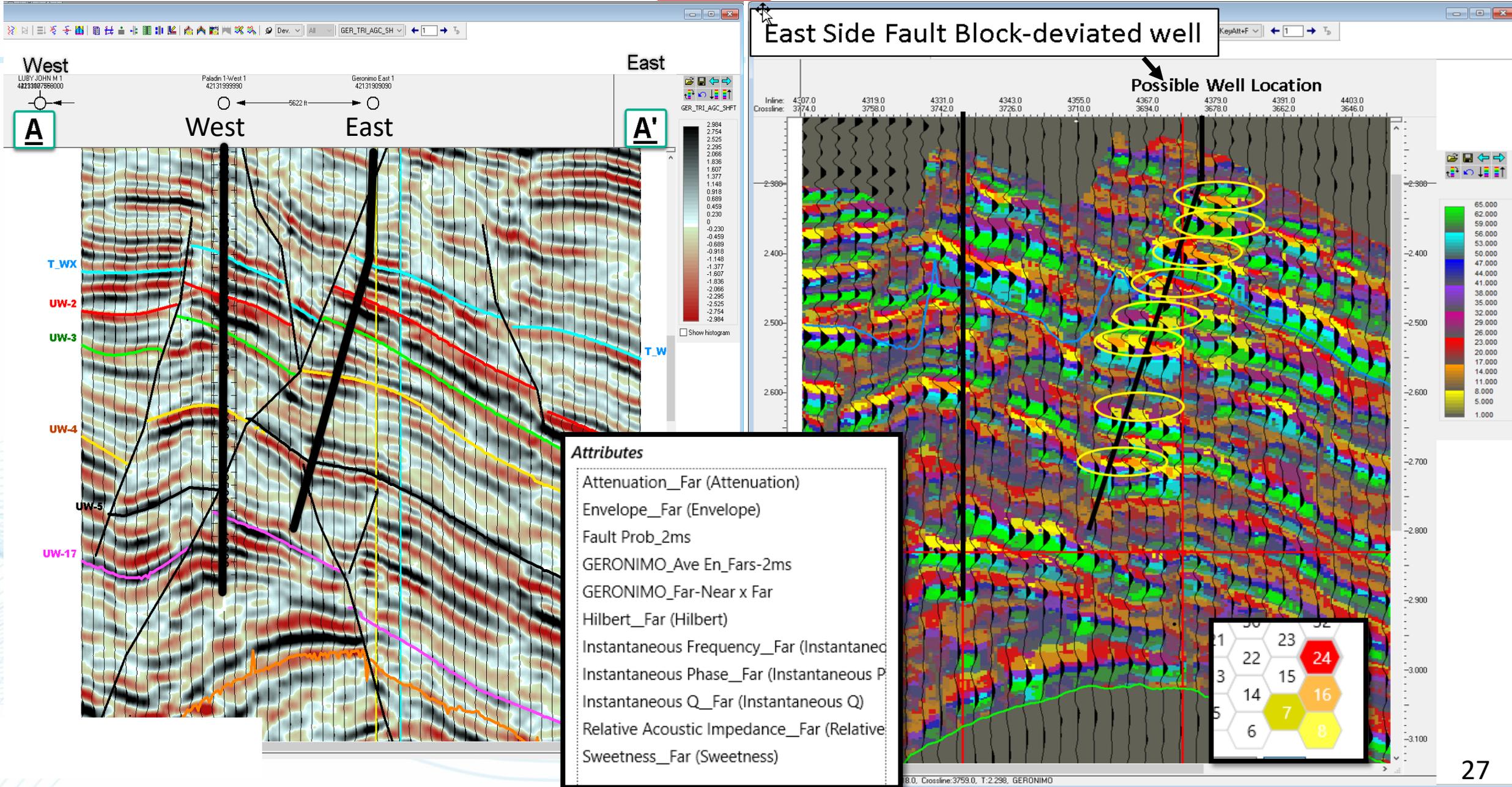
Time Structure Grid of Near Top Wilcox
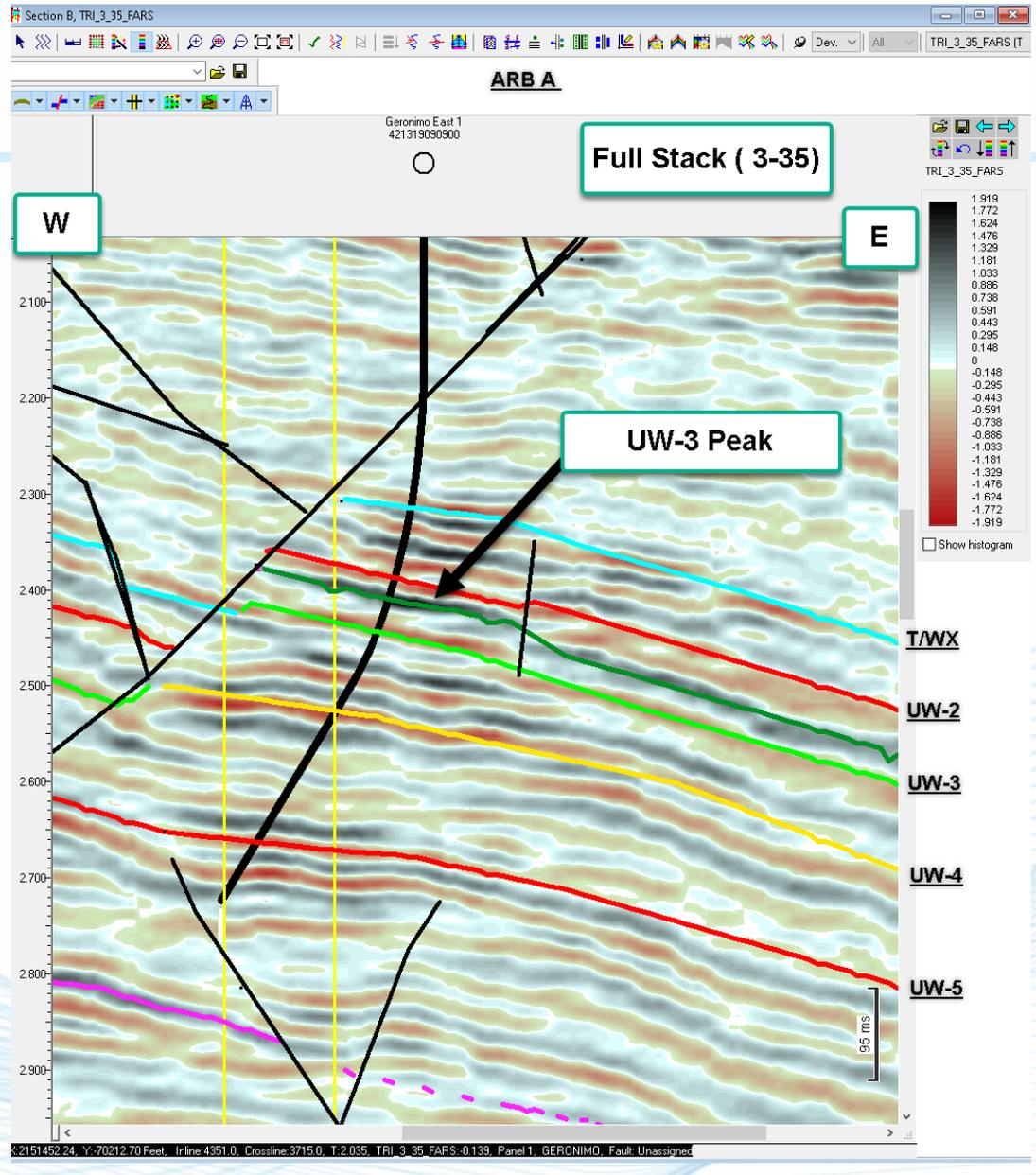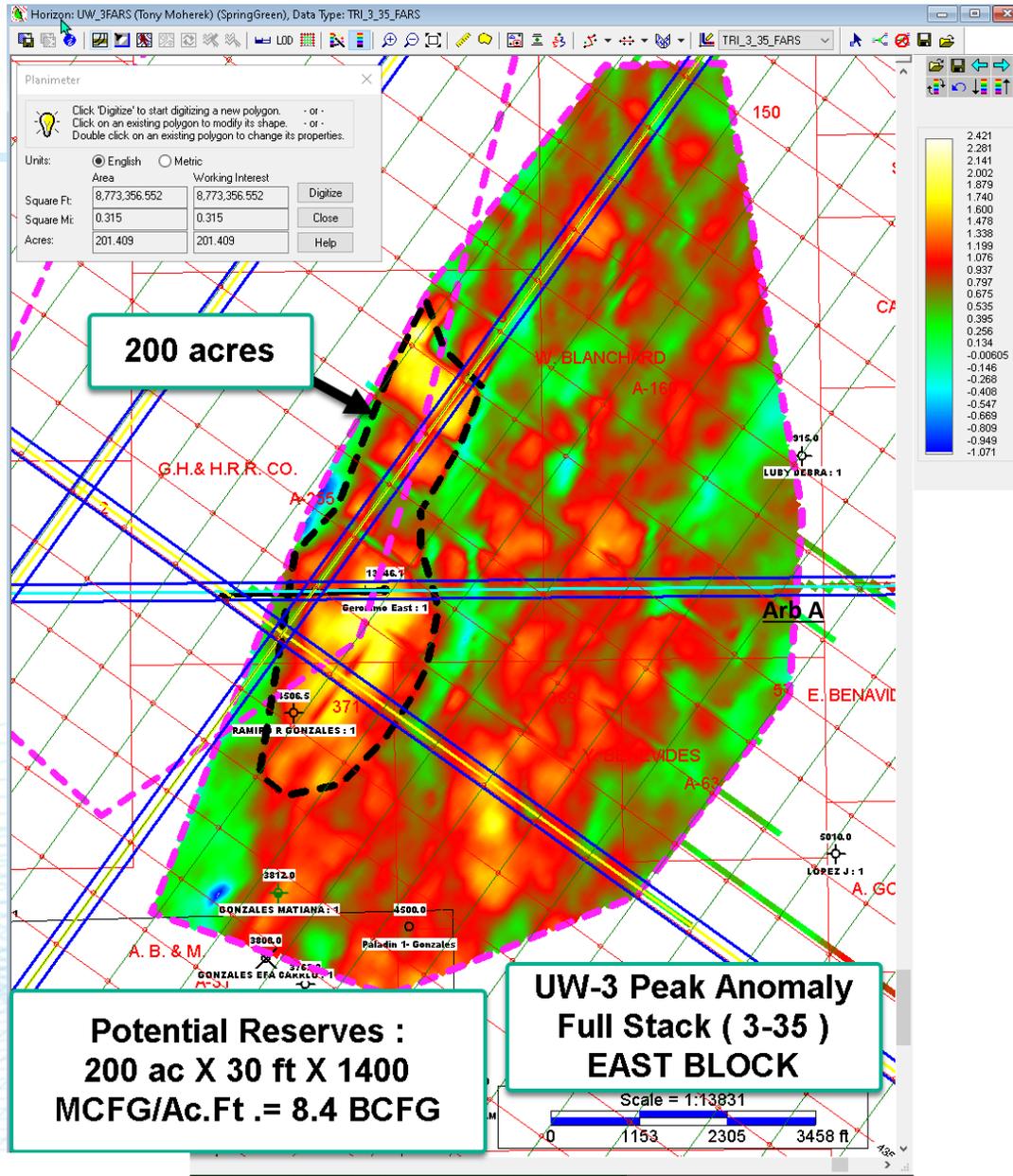CI = 20 ms (~100')

At the Top Wilcox (UW-1) the Geronimo Structure maps out as an elongate faulted anticlinal structure 6 miles in length and 2 miles in width' very similar to the N.E. Thompsonville structure.
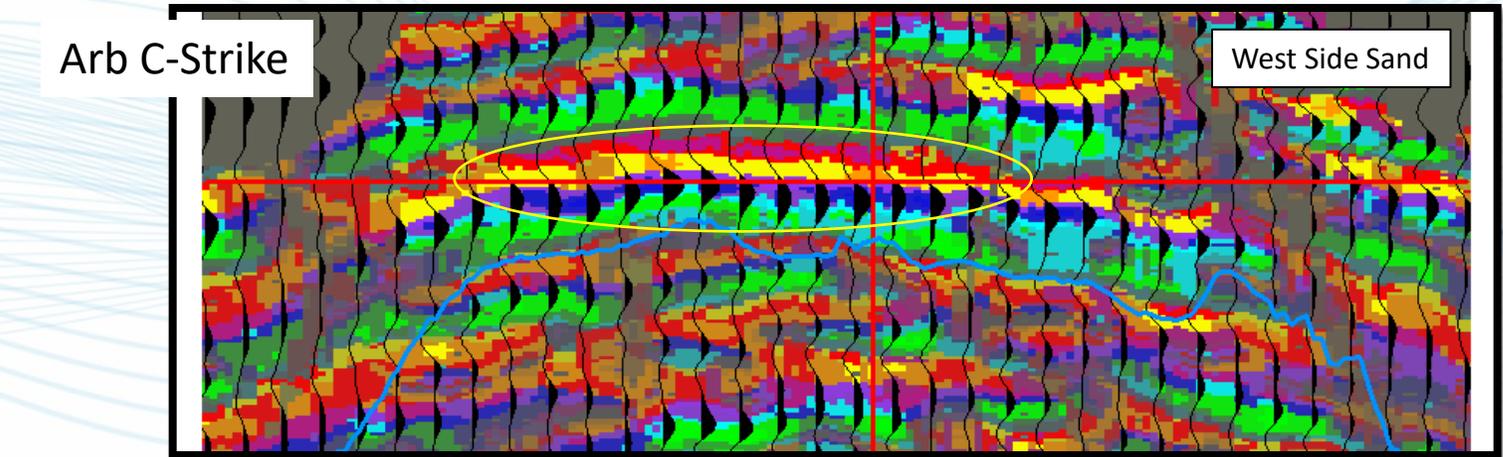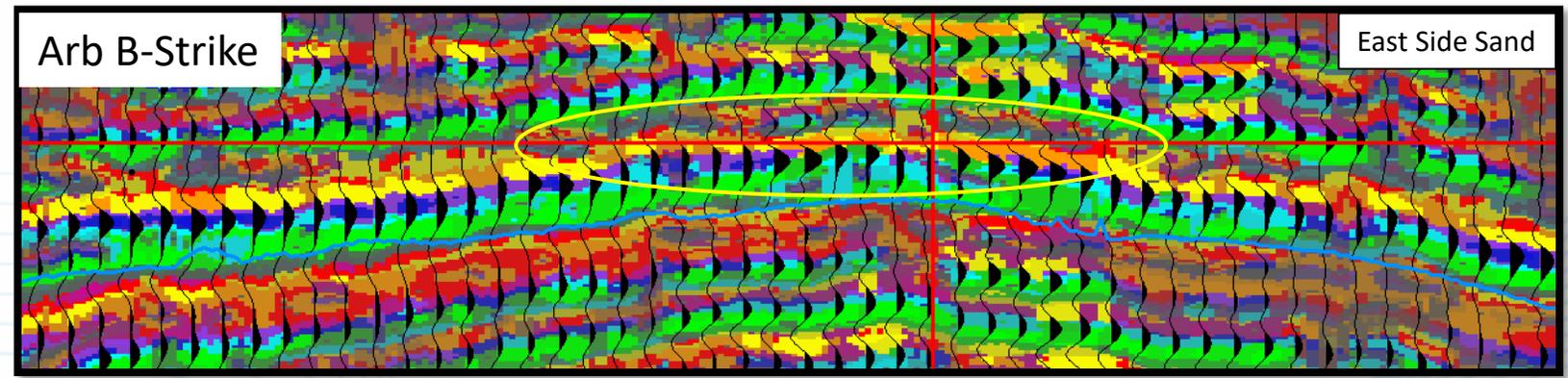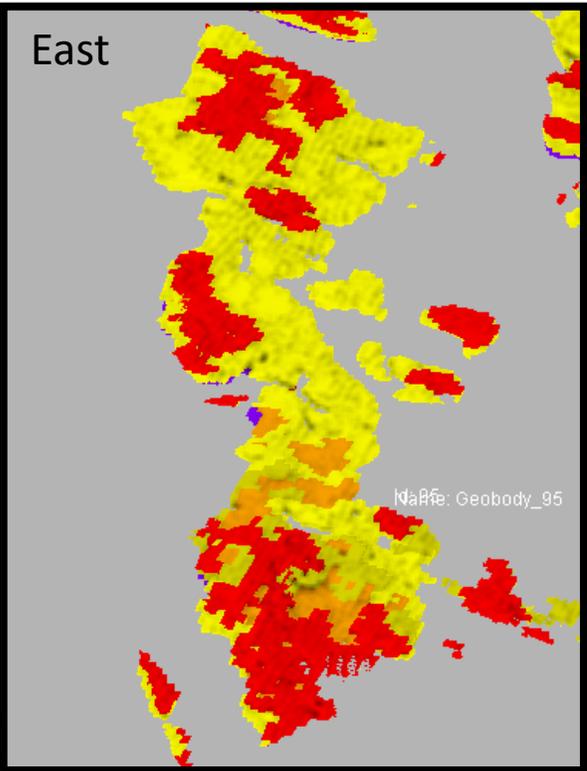
Strike Arb along east structure

Dip Arb along wellbore

Scale = 1:51067

Dip Line along proposed well bore

Tricon PSTM

ML Software

East Side Fault Block-deviated well

Possible Well Location

West

East

A

A'

West

East

T_WX
UW-2
UW-3
UW-4
UW-5
UW-17

T_W

Attributes

Attenuation__Far (Attenuation)

Envelope__Far (Envelope)

Fault Prob_2ms

GERONIMO_Ave En_Fars-2ms

GERONIMO_Far-Near x Far

Hilbert__Far (Hilbert)

Instantaneous Frequency__Far (Instantaneo

Instantaneous Phase__Far (Instantaneous P

Instantaneous Q__Far (Instantaneous Q)

Relative Acoustic Impedance__Far (Relative

Sweetness__Far (Sweetness)

27

200 acres

Potential Reserves :
200 ac X 30 ft X 1400
MCFG/Ac.Ft .= 8.4 BCFG

UW-3 Peak Anomaly
Full Stack (3-35)
EAST BLOCK

ARB A

Full Stack (3-35)

W

E

UW-3 Peak

T/WX

UW-2

UW-3

UW-4

UW-5

West

East

Name: Geobody_95

Arb A-Dip

West Side Sand

East Side Sand

2.392

Possibly wet

2.400

Arb B-Strike

East Side Sand

Arb C-Strike

West Side Sand

FROM INSIGHT TO FORESIGHT

29

Geobody Details

Velocity Units: Feet/sec Volume Units: Acre-Feet

Id: 68,104,710,746,762,2659,317,34,3050 Name:
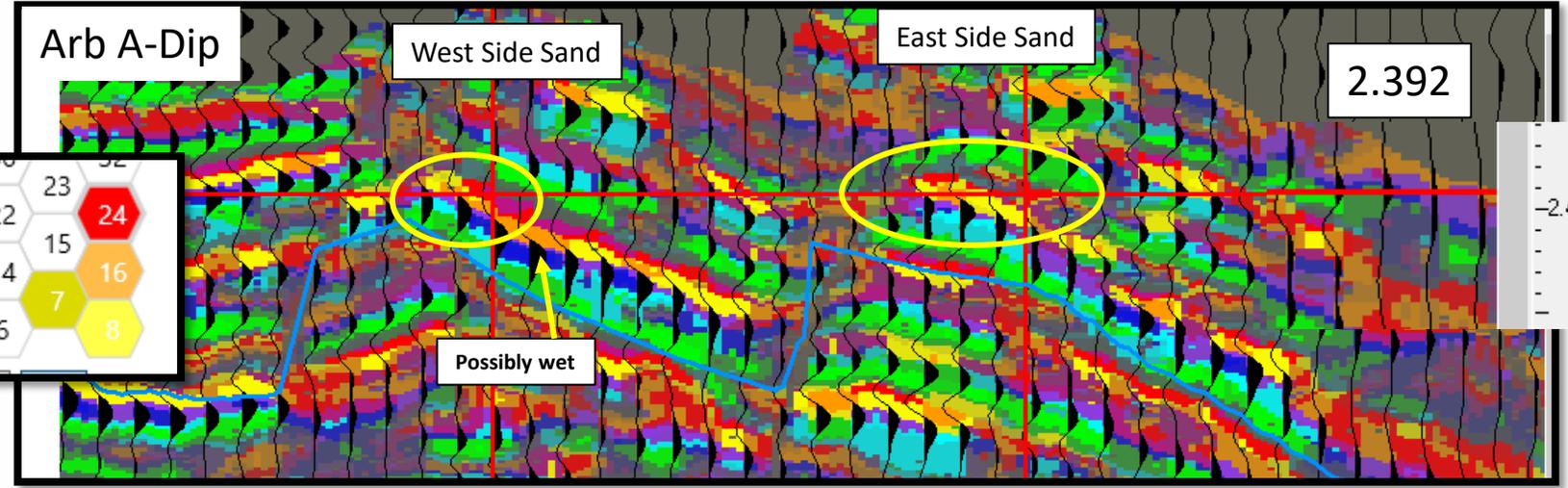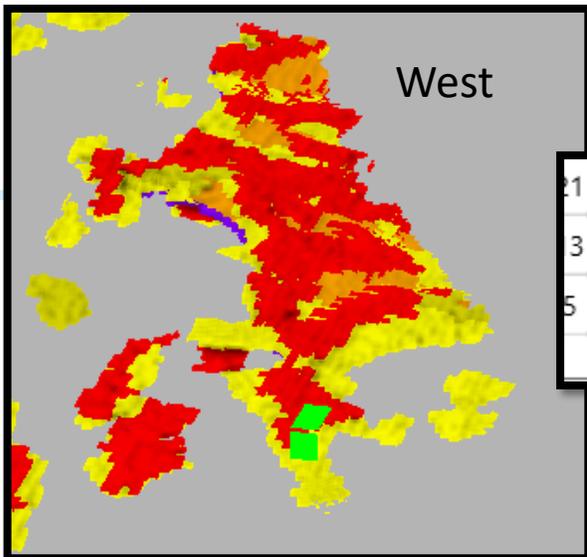
Id	Name	Neuron	Sample Count	Exterior Sample Count	Interior Sample Count	Interval Velocity (Feet/sec) (>=0)	Net/Gross (0-1)	Porosity (0-1)	WaterSaturation (0-1)	Sample Volume (Acre-Feet)	Net Rock Volume (Acre-Feet)	Hydrocarbon Pore Volume (Acre-Feet)
28	Geobody_28	16	2,113	1,327	786	11000.00	0.85	0.23	0.35	1.72	3088.92	461.79
34	Geobody_34	16	262	197	65	11000.00	0.85	0.23	0.35	1.72	383.01	57.26
68	Geobody_68	16	1,388	785	603	11000.00	0.85	0.23	0.35	1.72	2029.07	303.35
104	Geobody_104	16	500	301	199	11000.00	0.85	0.23	0.35	1.72	730.93	109.27
300	Geobody_300	24	140	139	1	11000.00	0.85	0.23	0.35	1.72	204.66	30.60
317	Geobody_317	24	165	165	0	11000.00	0.85	0.23	0.35	1.72	241.21	36.06
318	Geobody_318	24	211	210	1	11000.00	0.85	0.23	0.35	1.72	308.45	46.11
346	Geobody_346	24	3,578	3,285	293	11000.00	0.85	0.23	0.35	1.72	5230.55	781.97
353	Geobody_353	24	76	74	2	11000.00	0.85	0.23	0.35	1.72	111.10	16.61
710	Geobody_710	40	1,680	1,573	107	11000.00	0.85	0.23	0.35	1.72	2455.93	367.16
746	Geobody_746	40	168	168	0	11000.00	0.85	0.23	0.35	1.72	245.59	36.72
762	Geobody_762	40	149	147	2	11000.00	0.85	0.23	0.35	1.72	217.82	32.56
2659	Geobody_2659	7	56	56	0	11000.00	0.85	0.23	0.35	1.72	81.86	12.24
3020	Geobody_3020	8	9,166	6,307	2,859	11000.00	0.85	0.23	0.35	1.72	13399.46	2003.22
3050	Geobody_3050	8	656	532	124	11000.00	0.85	0.23	0.35	1.72	958.98	143.37

Total Acre*Feet = 4369.67 x 2000Mcfg/Ac*Ft = ~8.74 Bcfg + Liquids

Geobody Details

Velocity Units: Feet/sec Volume Units: Acre-Feet

Id: 95,141,2833,787,786,714,723,808,802 Name:

Id	Name	Neuron	Sample Count	Exterior Sample Count	Interior Sample Count	Interval Velocity (Feet/sec) (>=0)	Net/Gross (0-1)	Porosity (0-1)	WaterSaturation (0-1)	Sample Volume (Acre-Feet)	Net Rock Volume (Acre-Feet)	Hydrocarbon Pore Volume (Acre-Feet)
53	Geobody_53	16	3,608	2,150	1,458	11000.00	0.85	0.23	0.35	1.72	5274.41	788.52
141	Geobody_141	16	548	383	165	11000.00	0.85	0.23	0.35	1.72	801.10	119.76
321	Geobody_321	24	165	162	3	11000.00	0.85	0.23	0.35	1.72	241.21	36.06
326	Geobody_326	24	173	167	6	11000.00	0.85	0.23	0.35	1.72	252.90	37.81
340	Geobody_340	24	161	160	1	11000.00	0.85	0.23	0.35	1.72	235.36	35.19
344	Geobody_344	24	2,092	1,931	161	11000.00	0.85	0.23	0.35	1.72	3058.22	457.20
350	Geobody_350	24	507	461	46	11000.00	0.85	0.23	0.35	1.72	741.17	110.80
395	Geobody_395	24	2,529	2,214	315	11000.00	0.85	0.23	0.35	1.72	3697.06	552.71
495	Geobody_495	24	224	223	1	11000.00	0.85	0.23	0.35	1.72	327.46	48.95
714	Geobody_714	40	1,169	1,153	16	11000.00	0.85	0.23	0.35	1.72	1708.92	255.48
723	Geobody_723	40	2,020	1,940	80	11000.00	0.85	0.23	0.35	1.72	2952.97	441.47
786	Geobody_786	40	155	145	10	11000.00	0.85	0.23	0.35	1.72	226.59	33.88
787	Geobody_787	40	57	57	0	11000.00	0.85	0.23	0.35	1.72	83.33	12.46
802	Geobody_802	40	413	408	5	11000.00	0.85	0.23	0.35	1.72	603.75	90.26
808	Geobody_808	40	199	194	5	11000.00	0.85	0.23	0.35	1.72	290.91	43.49
2753	Geobody_2753	7	117	115	2	11000.00	0.85	0.23	0.35	1.72	171.04	25.57
2765	Geobody_2765	7	95	92	3	11000.00	0.85	0.23	0.35	1.72	138.88	20.76
2833	Geobody_2833	7	230	217	13	11000.00	0.85	0.23	0.35	1.72	336.23	50.27
2839	Geobody_2839	7	383	345	38	11000.00	0.85	0.23	0.35	1.72	559.89	83.70
3028	Geobody_3028	8	17,320	11,163	6,157	11000.00	0.85	0.23	0.35	1.72	25319.50	3785.27
3176	Geobody_3176	8	863	728	135	11000.00	0.85	0.23	0.35	1.72	1261.59	188.61

Total Acre*Feet = 7198.22 x 2000Mcfg/Ac*Ft = ~14.4 Bcfg + Liquids

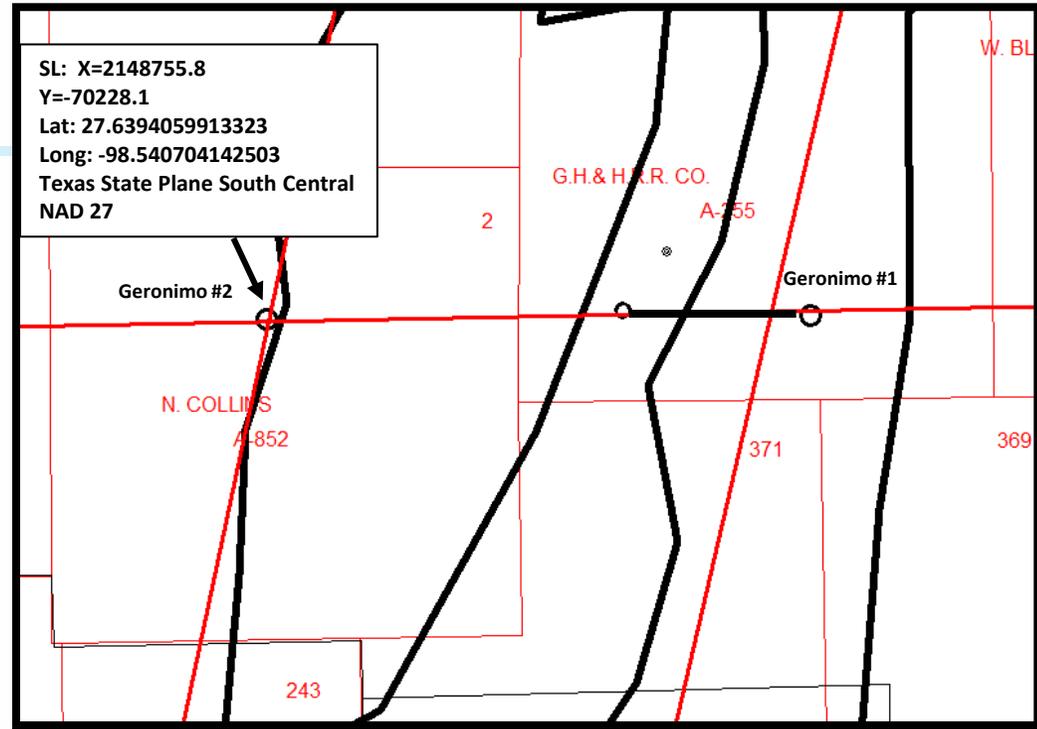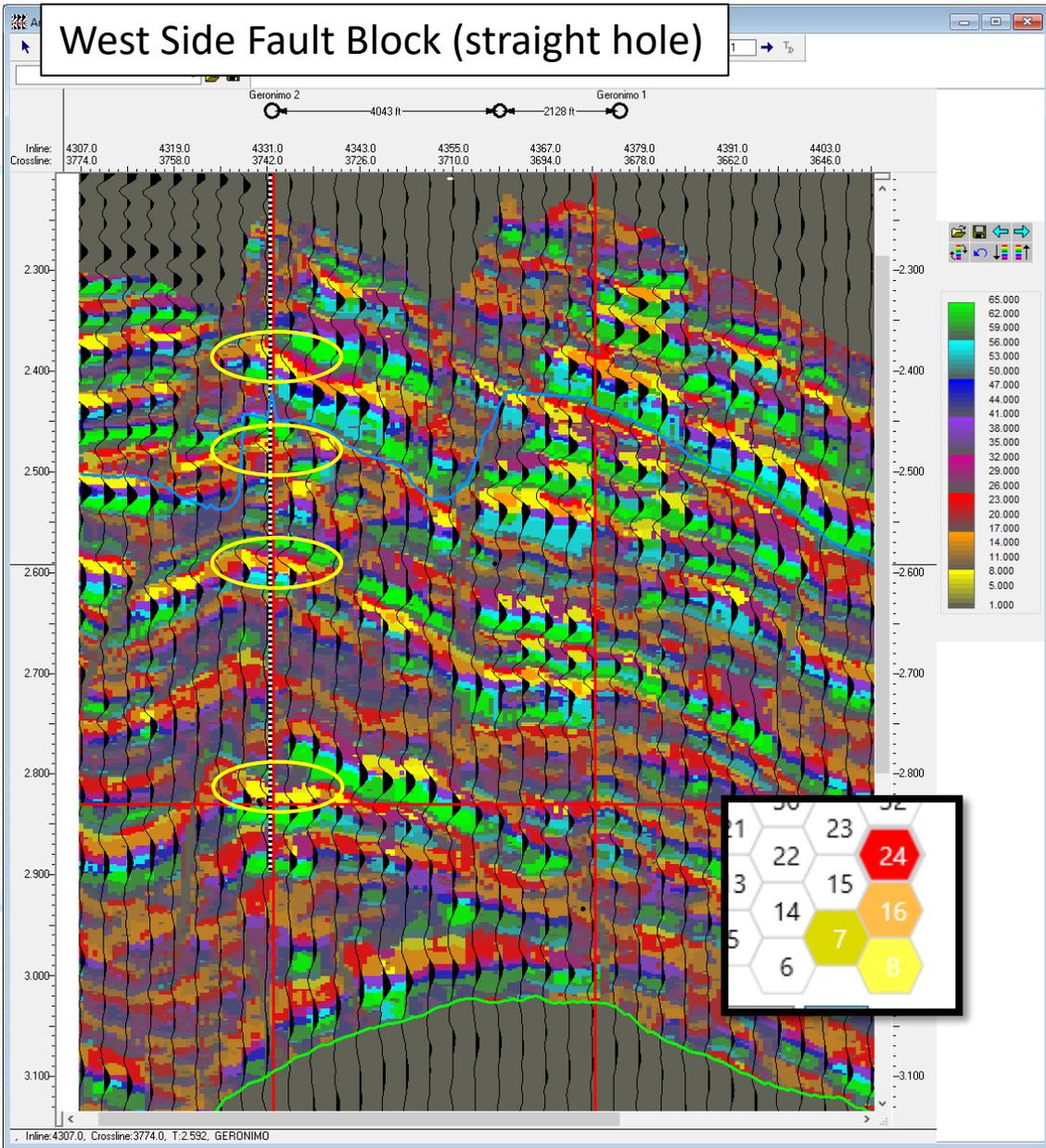East Side Fault Block-deviated well

Possible Well Location
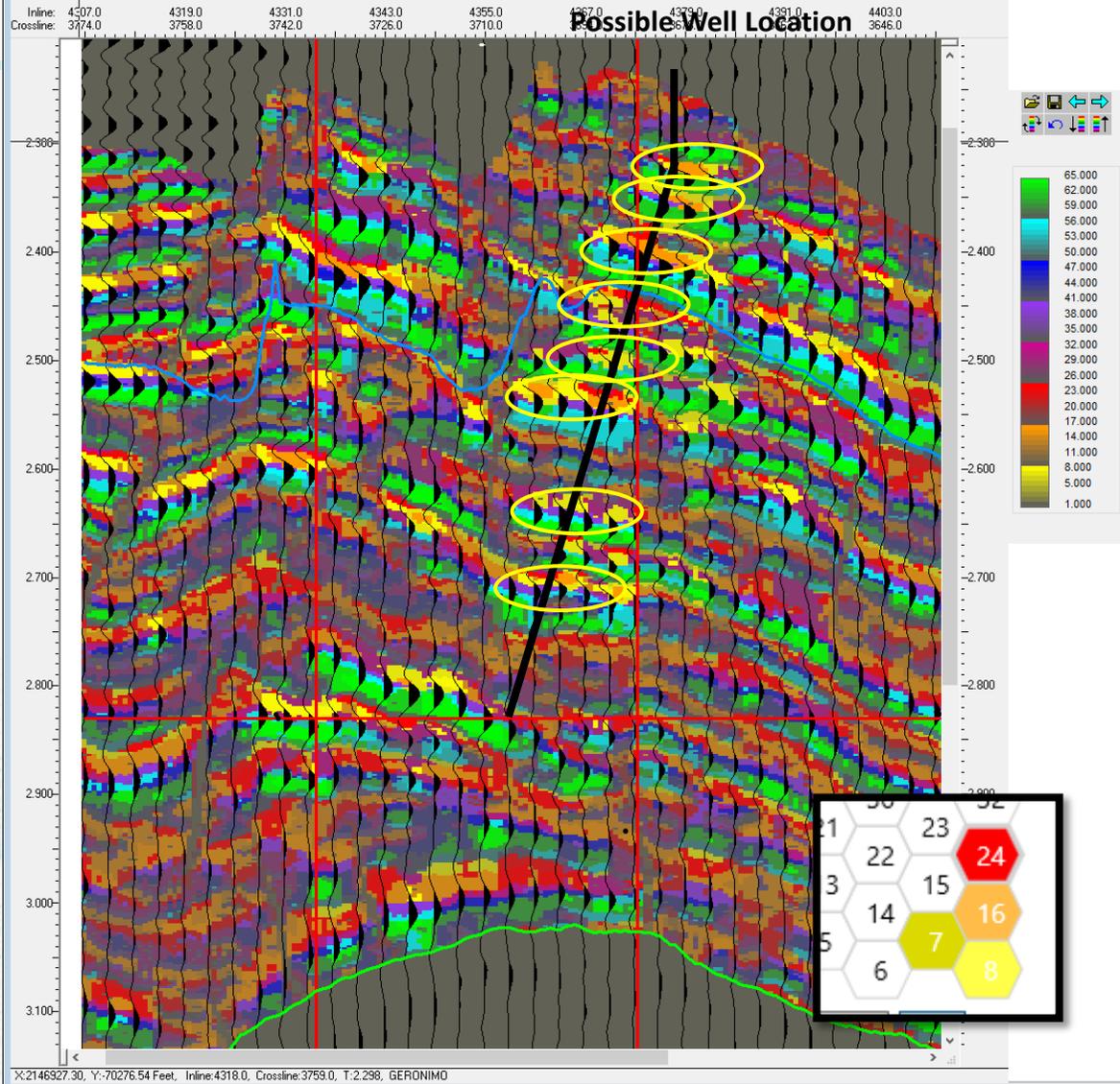
BHL (at last sand): X=2152797.9
Y=-70129.6
Lat: 27.6396326300766
Long: -98.5282229386991
Texas State Plane South Central
NAD 27

SHL: X=2154915.3
Y=-70182.6
Lat: 27.6394603172706
Long: -98.521654941071
Texas State Plane South Central
NAD 27

Approx 2100' deviation
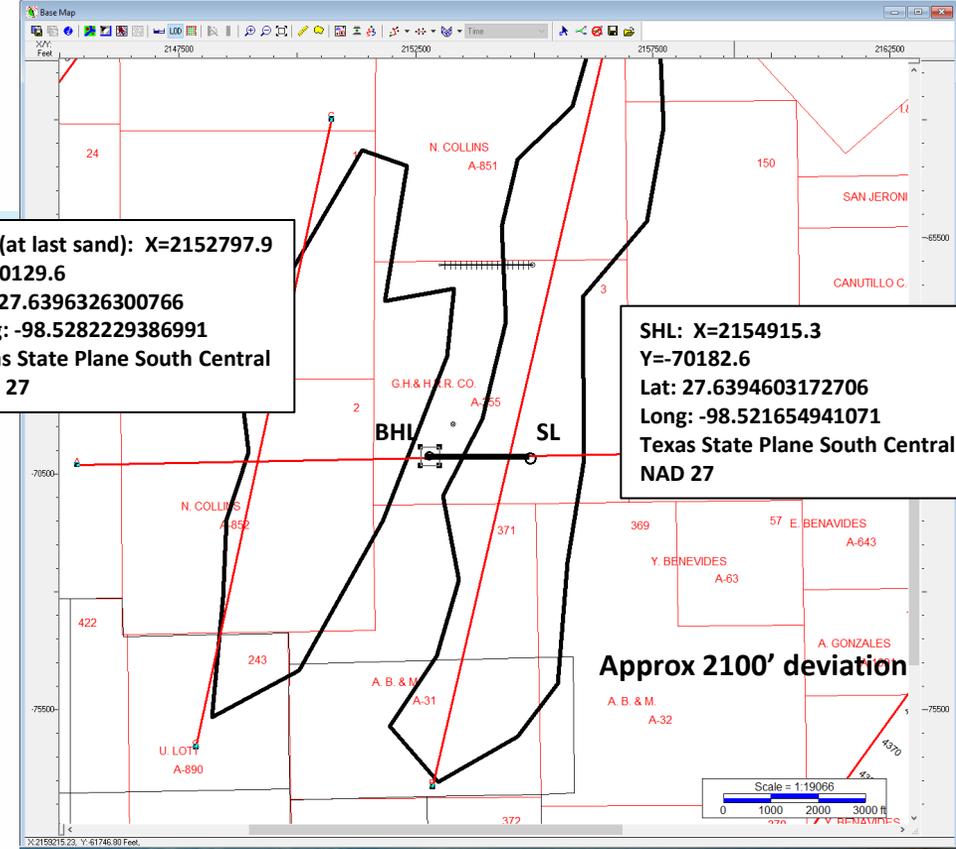
Upside potential for well for all sands intercepted could be as much as **39.66 Bcfg + Liquids**

West Side Fault Block (straight hole)

SL: X=2148755.8
Y=-70228.1
Lat: 27.6394059913323
Long: -98.540704142503
Texas State Plane South Central
NAD 27

Upside potential for well for all sands intercepted could be as much as **19.87Bcfg + Liquids**

View looking north in 3D viewer – penetration of key geobodies with first two wells.

N
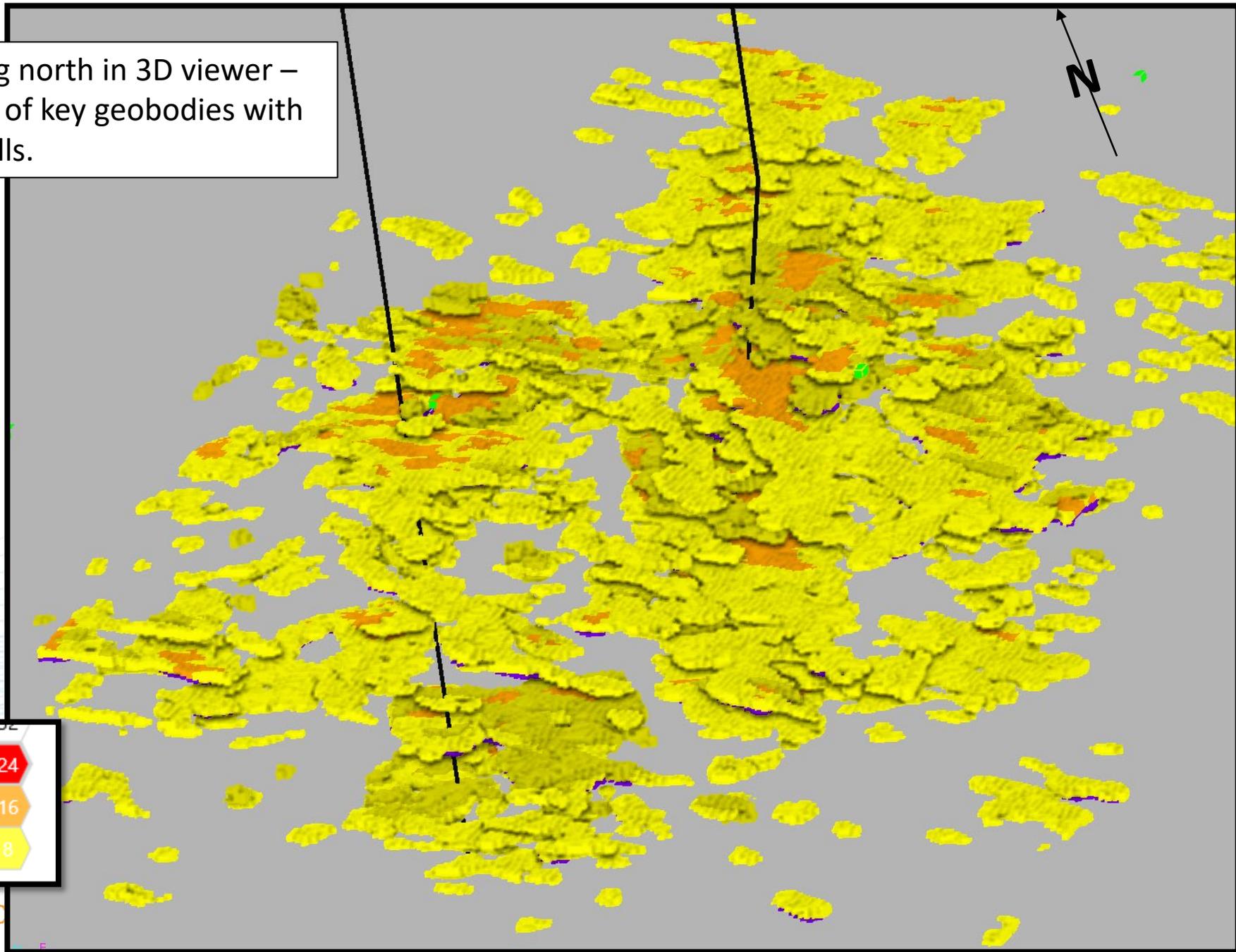
Visualizing Depletion using Low Probability Volumes

The importance of understanding "Stack" and "Halo Neurons" in ANY reservoir – but especially in Carbonates. Also – a good example of how "pre-conceived" ideas about the reservoir are not always correct! And – throw in the importance of the "Low Probability" volume assessment too!

Case History – Austin Chalk - Texas

Time Structure Map – Top Austin Chalk
CI = 10 ms (~50')
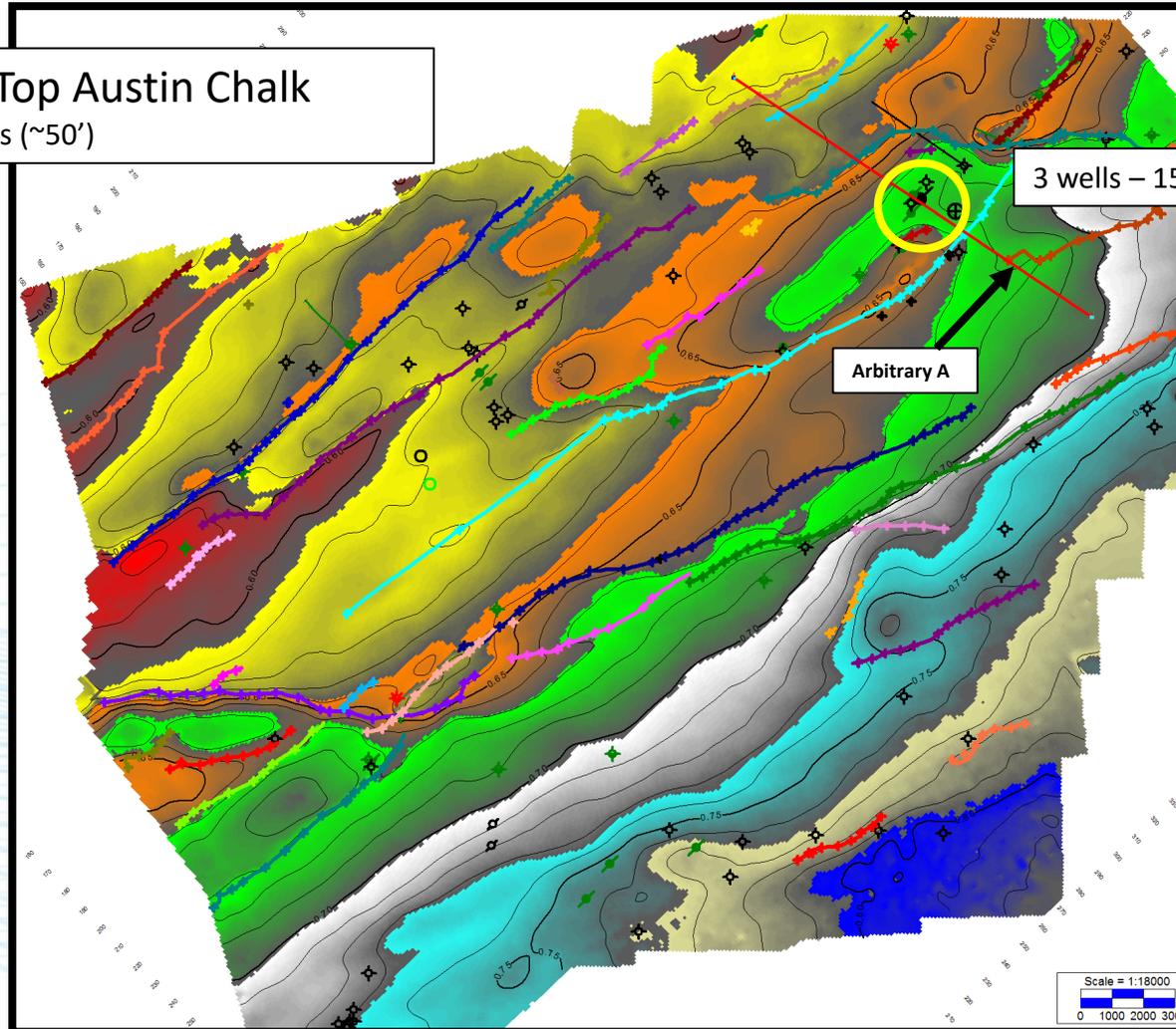
3 wells – 158 MBO at 2100 feet!

Arbitrary A

Scale = 1:18000
0   1000 2000 3000

Gather at Key well

Positive increase in angle/offset on peak event shows slight AVO effect

Top Austin Chalk
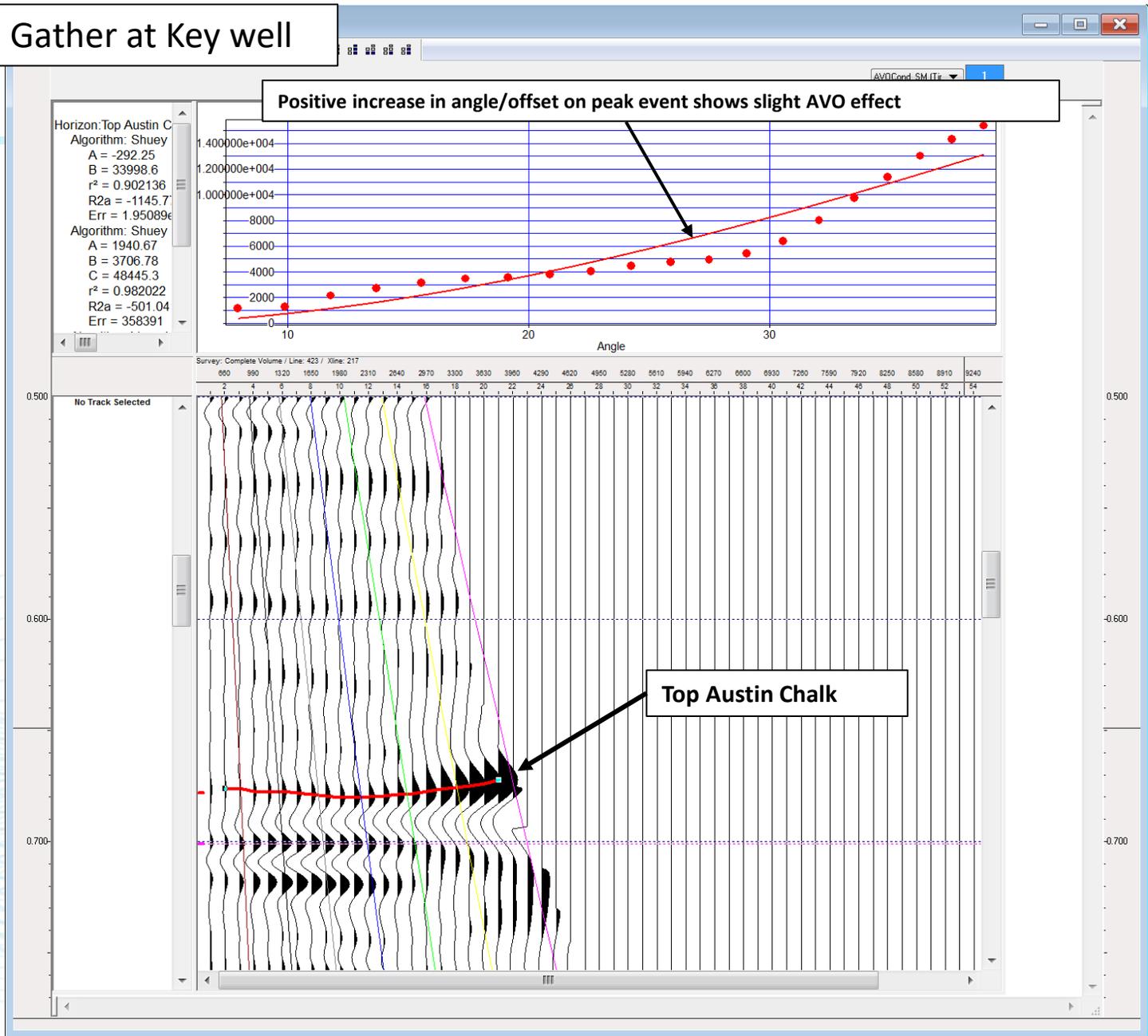
Neurons 71 (main), 53, 62, 72, and 82 (supporting) better define porosity
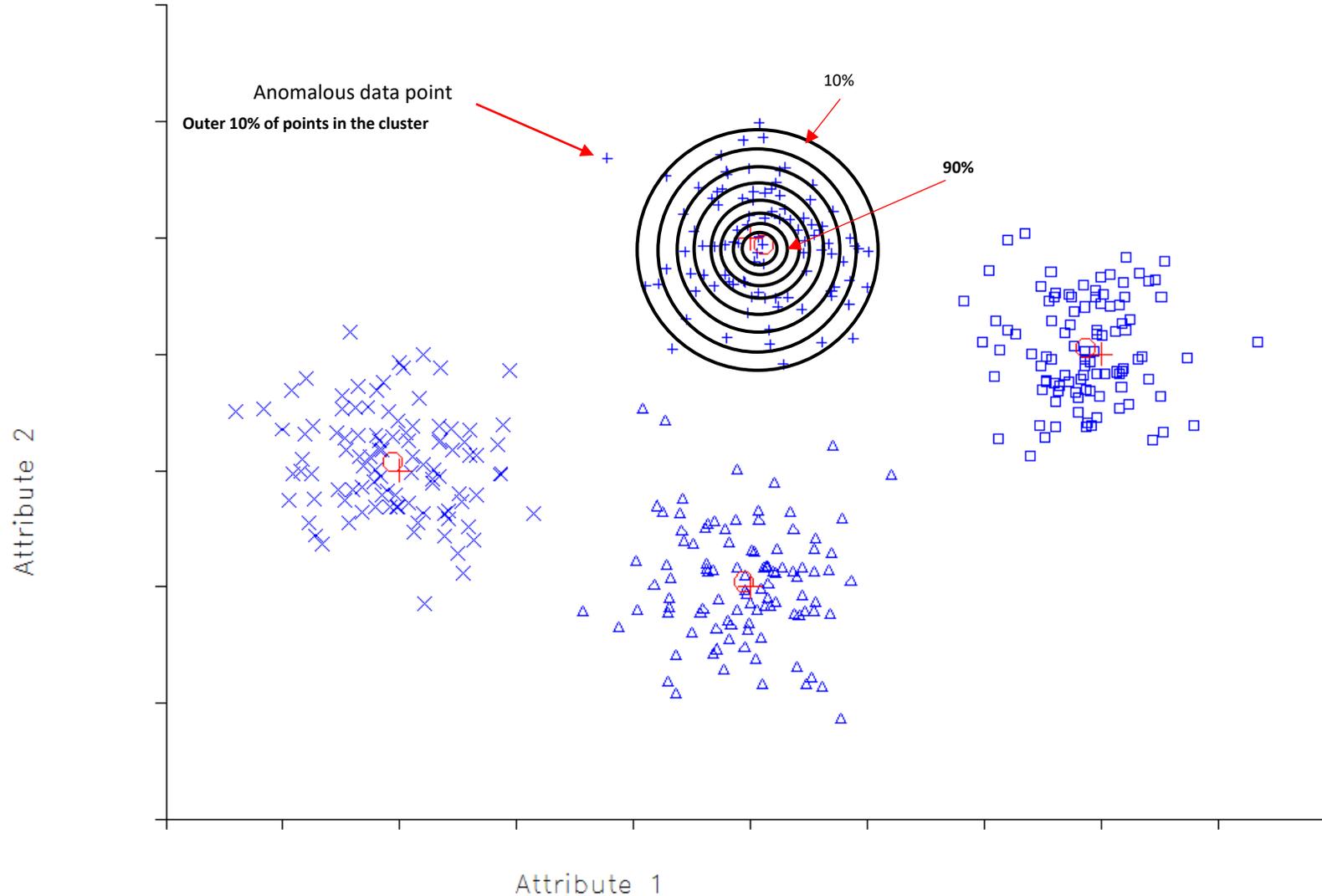

Attributes

Complete Volume_AVOStk_30-38_0005(2)
Complete Volume_Relative Acoustic Imped
Envelope-Bands-on-Envelope-Breaks
Envelope-Bands-on-Phase-Breaks
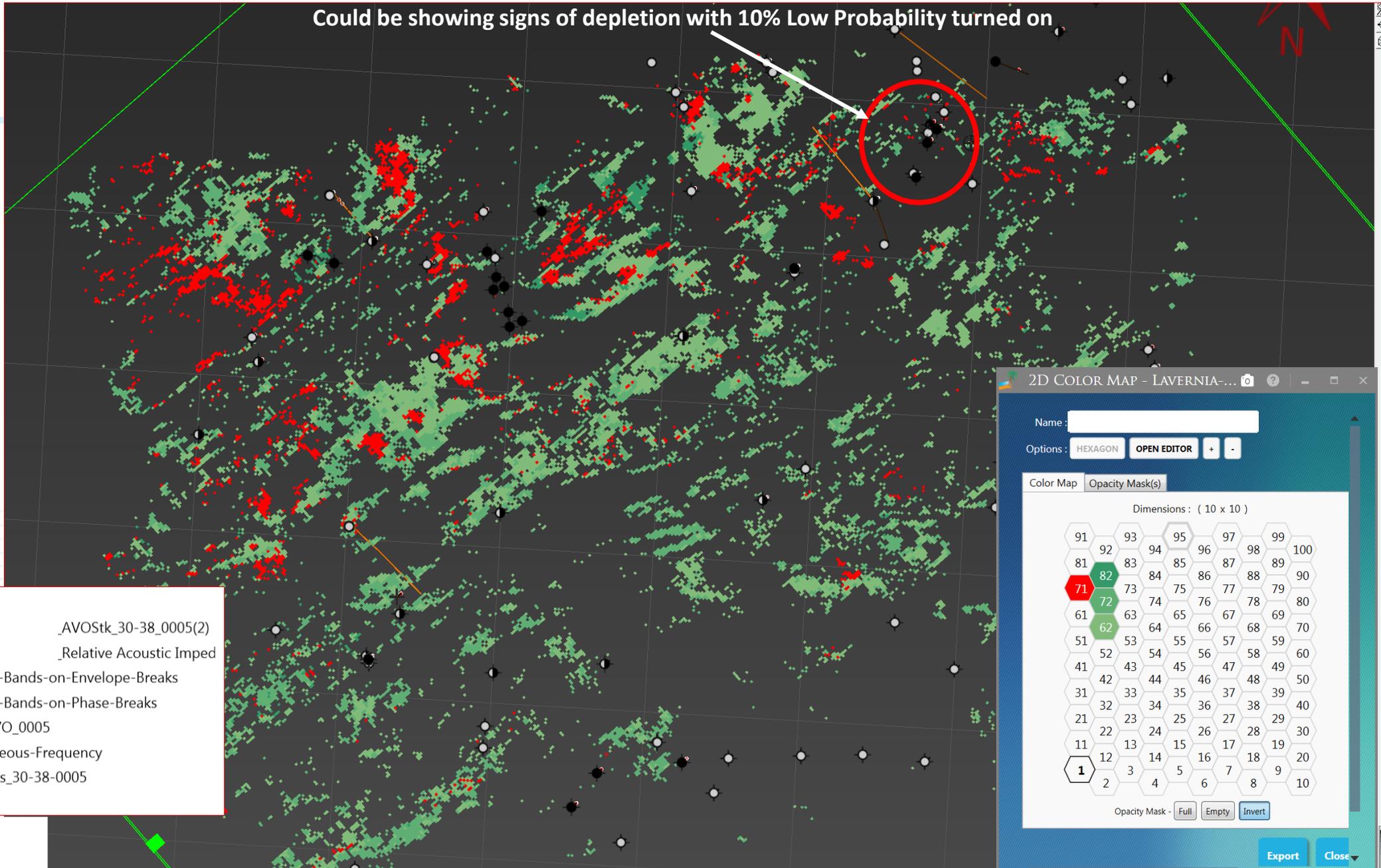F-NxF_AVO_0005
Instantaneous-Frequency
Sweetness_30-38-0005
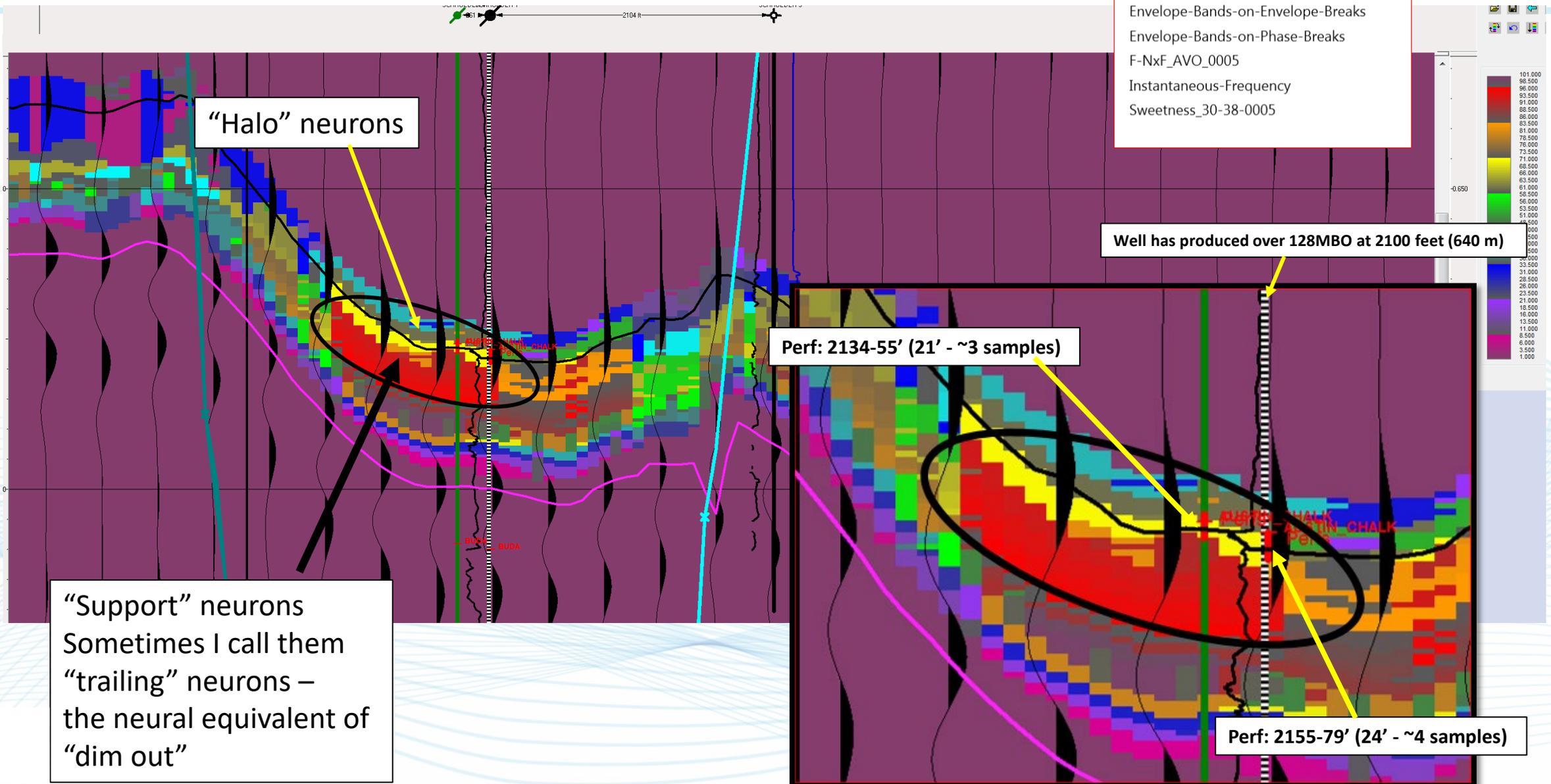
"Halo" neurons

Well has produced over 128MBO at 2100 feet (640 m)

Perf: 2134-55' (21' - ~3 samples)

"Support" neurons
Sometimes I call them
"trailing" neurons –
the neural equivalent of
"dim out"

Perf: 2155-79' (24' - ~4 samples)

37

Low Probability turned off

Dry holes drilled
Many years after depletion

Low Probability Volume – outside "edge" of data points are furthest away from
center of cluster – and are considered "most anomalous". So, if attributes are used which are "hydrocarbon indicators"
then the "low probability" anomalies could possibly be hydrocarbon indicators. At the very least, they would tend to
show the best of the properties of the attributes used in the analysis

Classified Multi-Attribute Samples

Could be showing signs of depletion with 10% Low Probability turned on

Attributes

_AVOStk_30-38_0005(2)
_Relative Acoustic Imped
Envelope-Bands-on-Envelope-Breaks
Envelope-Bands-on-Phase-Breaks
F-NxF_AVO_0005
Instantaneous-Frequency
Sweetness_30-38-0005

2D Color Map - Lavernia-...

Name :

Options : HEXAGON OPEN EDITOR + -

Color Map Opacity Mask(s)

Dimensions : (10 x 10)

Opacity Mask - Full Empty Invert

Export Close

40

Low Probability turned off

Dry holes drilled
Many years after depletion

COLOR MAP – DEFAULT10x10

Name : Default10x10

Options : HEXAGON | CLOSE EDITOR | + | -

Color Map | Opacity Mask(s)

Dimensions : (10 x 10)

91
        93   95   97   99
    92   94   96   98   100
81   83   85   87   89
    82   84   86   88   90
71   73   75   77   79
    72   74   76   78   80
61   63   65   67   69
    62   64   66   68   70
51   53   55   57   59
    52   54   56   58   60
41   43   45   47   49
    42   44   46   48   50
31   33   35   37   39
    32   34   36   38   40
21   23   25   27   29
    22   24   26   28   30
11   13   15   17   19
    12   14   16   18   20
1   3   5   7   9
    2   4   6   8   10

Opacity Mask - Full | Empty | Invert

Add | Move | Delete | CLEAR

Current Color : [red] ▾ | SWAP

Resize : 0 x 0 | RESIZE

(Minimum size = 1, Maximum size = 32)

Attributes

AVOStk_30-38_0005(2)
Relative Acoustic Imped
Envelope-Bands-on-Envelope-Breaks
Envelope-Bands-on-Phase-Breaks
F-NxF_AVO_0005
Instantaneous-Frequency
Sweetness_30-38-0005

Export | Close

22-17-10x10_Hex-9/22/2017 1:00:2(

41

Similarity_Sobel Filter on flattened time slice at Top of Austin Chalk
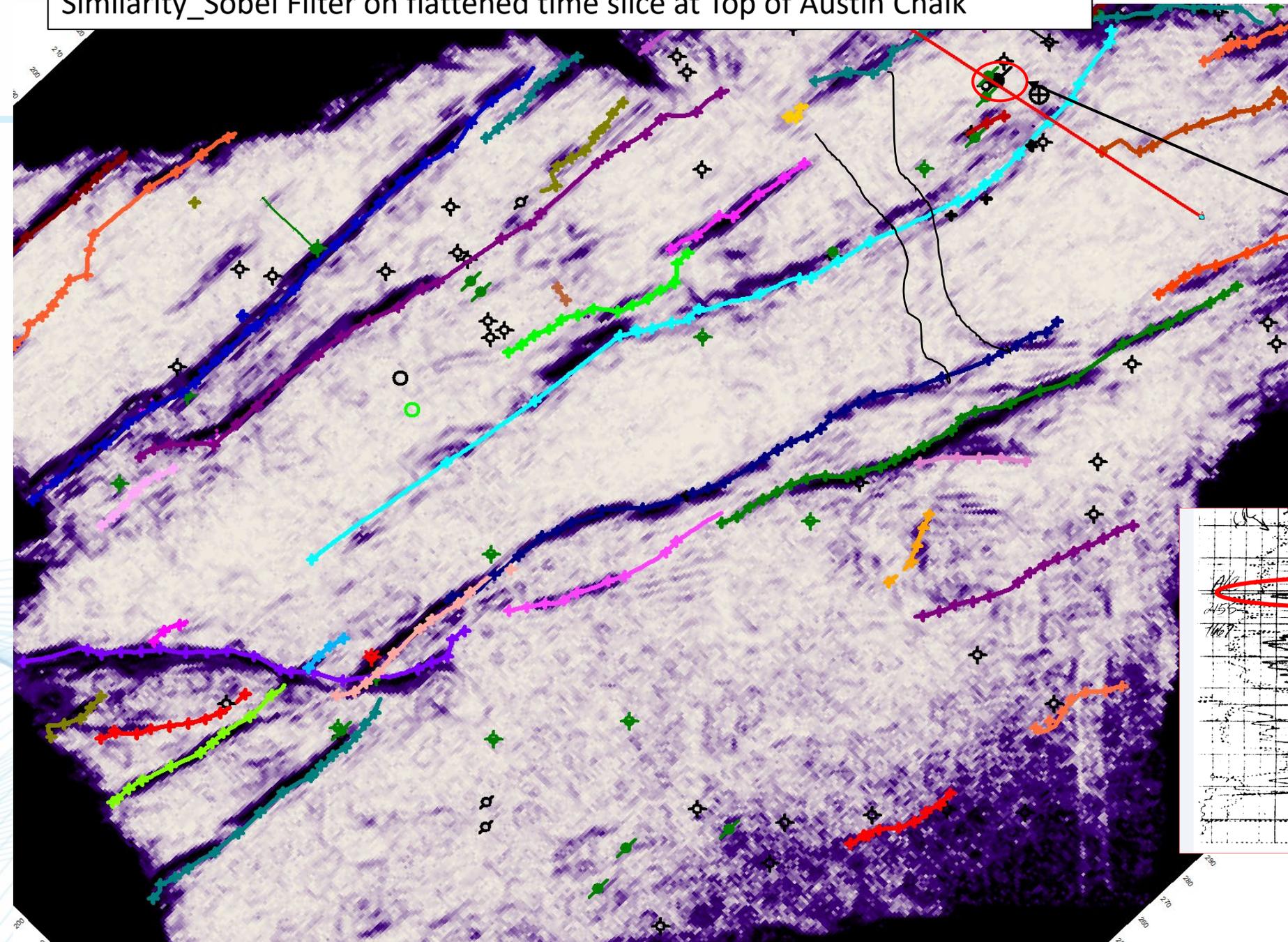
Key thin, calcareously cemented sand which was productive at the top of The Chalk

42
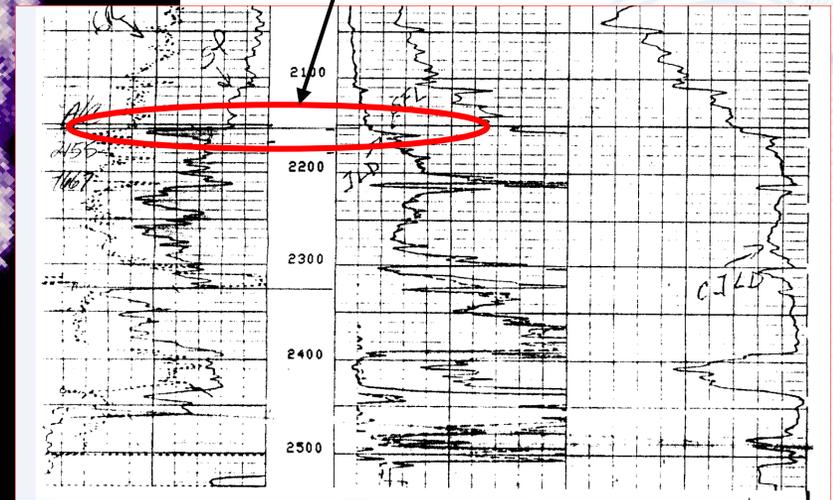
Additional Case Histories on using Machine Learning to find Hydrocarbons

Carbonates have contributed close to 70% of the world's production, yet in the Gulf Coast and other places in the US – they are often overlooked or mis-interpreted.

The key to ANY interpretation of the sub-surface with Paradise is to start out with good synthetics – because you can be "sloppy" in the wavelet world with your ties – but you can't when it comes to sample statistics!

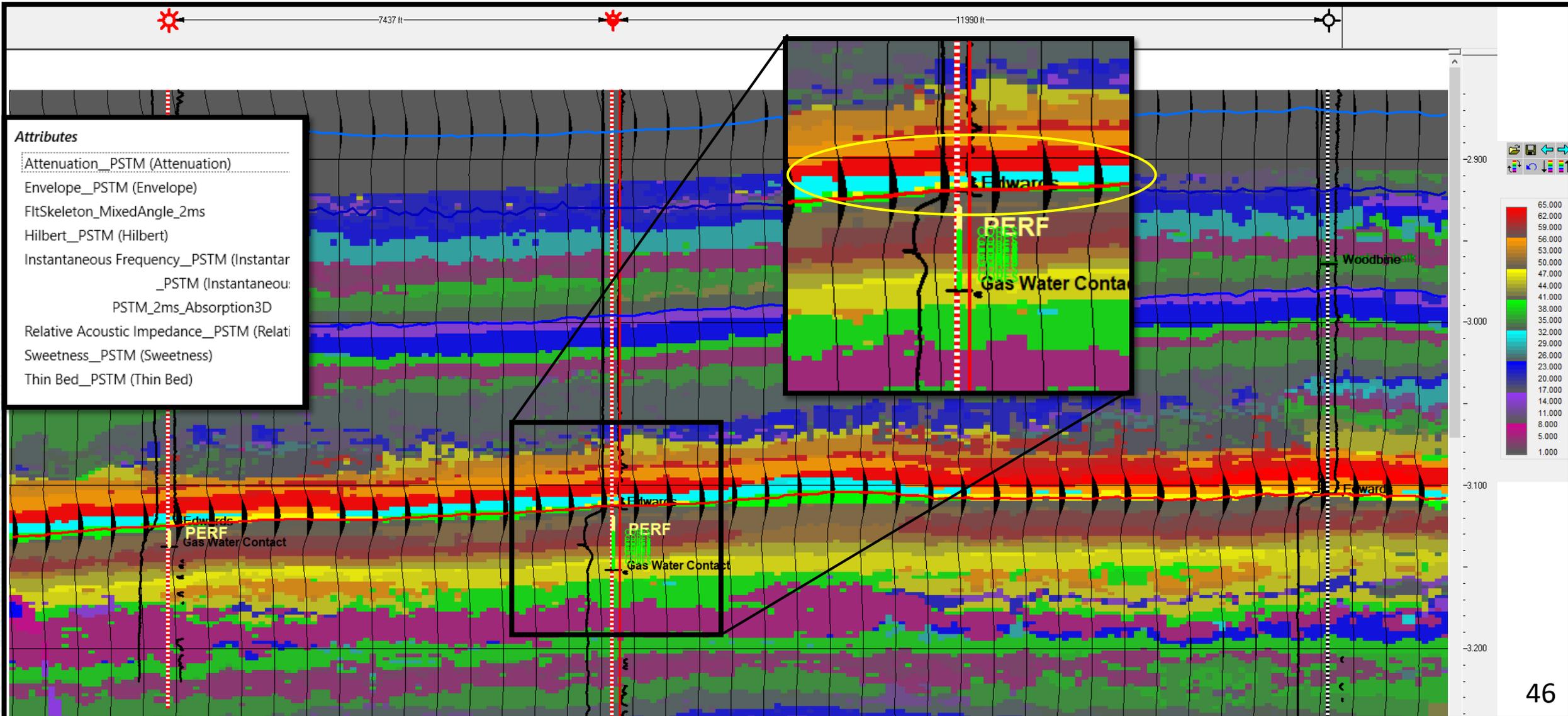Synthetic tie with a 50.6% correlation coefficient
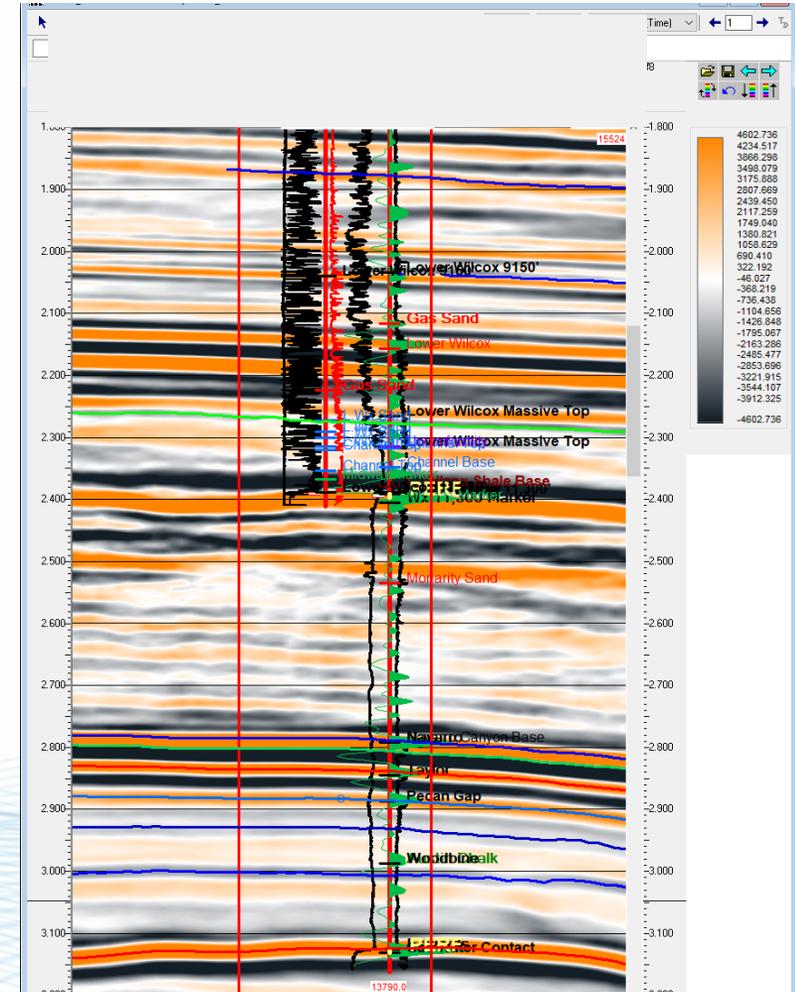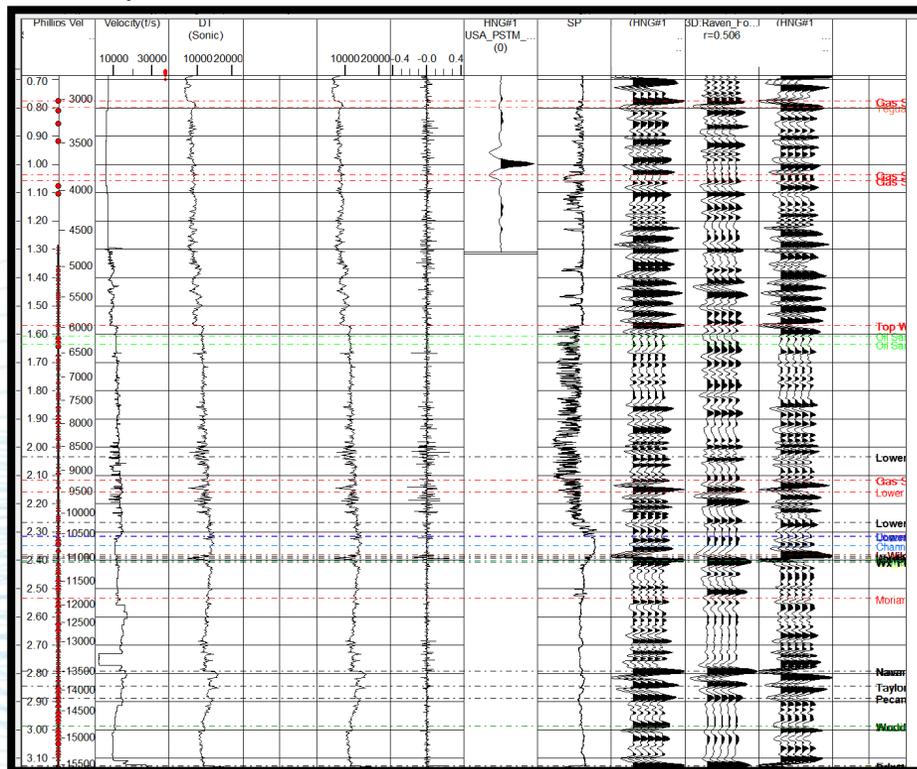
The importance of understanding "Stack" and "Halo Neurons" in ANY reservoir – but especially inCarbonates.

Case History – Edwards Reef - Texas
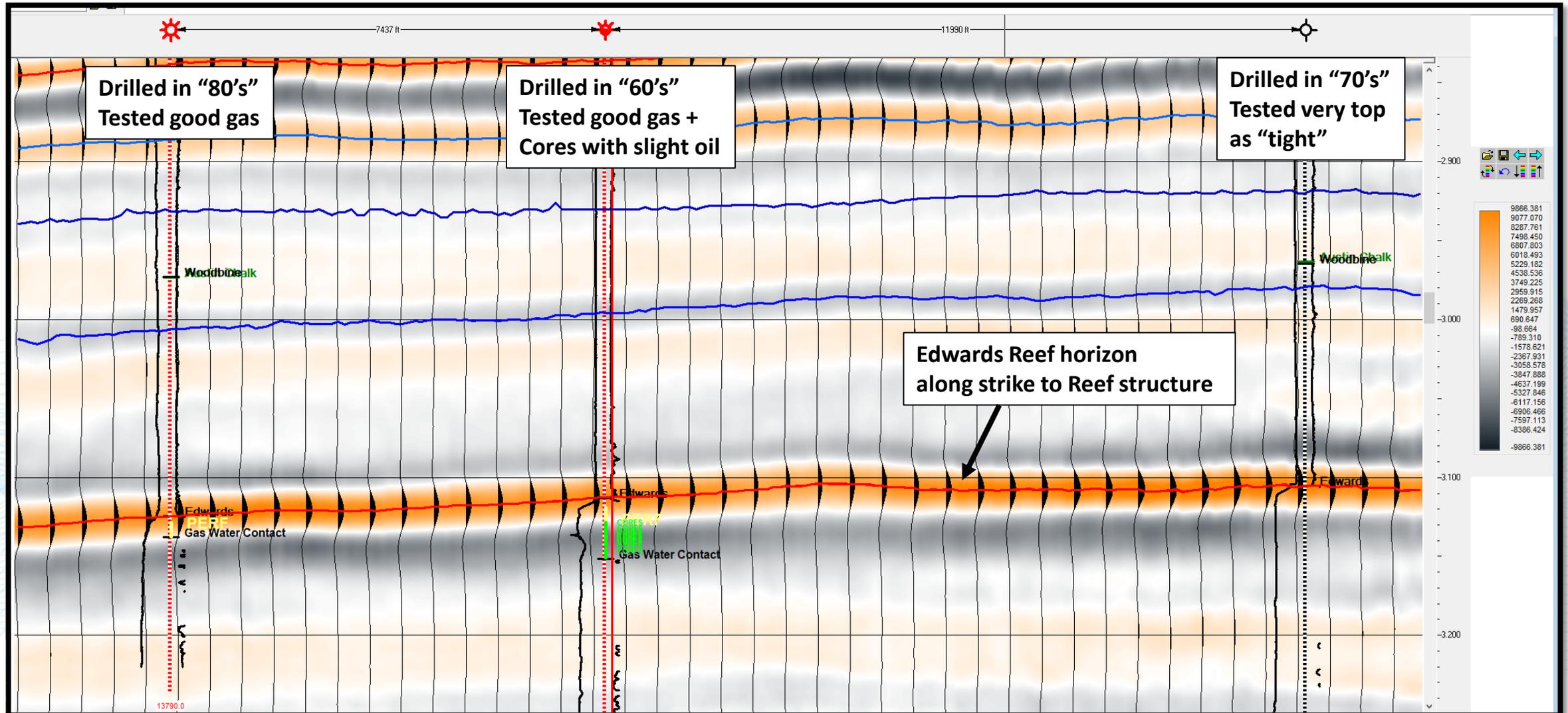
Now, after SOM has been run using the attribute list below, which consisted of the top attributes from the first three Eigen Vectors PLUS, the Fault Skeletonization from CNN – the result is obvious! There is a "halo" neuron (light blue) above the reservoir where there has been vertical percolation of hydrocarbons leaking from a highly-pressured fractured carbonate reservoir into the sealing shales above showing exactly where the reservoir is located. Both the wells with good gas shows have this "halo" neuron above them, while the dry hole does not!

Attributes

Attenuation__PSTM (Attenuation)

Envelope__PSTM (Envelope)

FltSkeleton_MixedAngle_2ms

Hilbert__PSTM (Hilbert)

Instantaneous Frequency__PSTM (Instantar

_PSTM (Instantaneou:

PSTM_2ms_Absorption3D

Relative Acoustic Impedance__PSTM (Relati

Sweetness__PSTM (Sweetness)

Thin Bed__PSTM (Thin Bed)

Areal extent of "Halo" neuron showing well placement of the three wells in the arbitrary line. Key attributes contributing to this neuron are Energy Absorption, Attenuation and Hilbert – which are good Direct Hydrocarbon Indicating attributes.

Dry hole drilled in gap between fore reef porosity and back reef porosity!
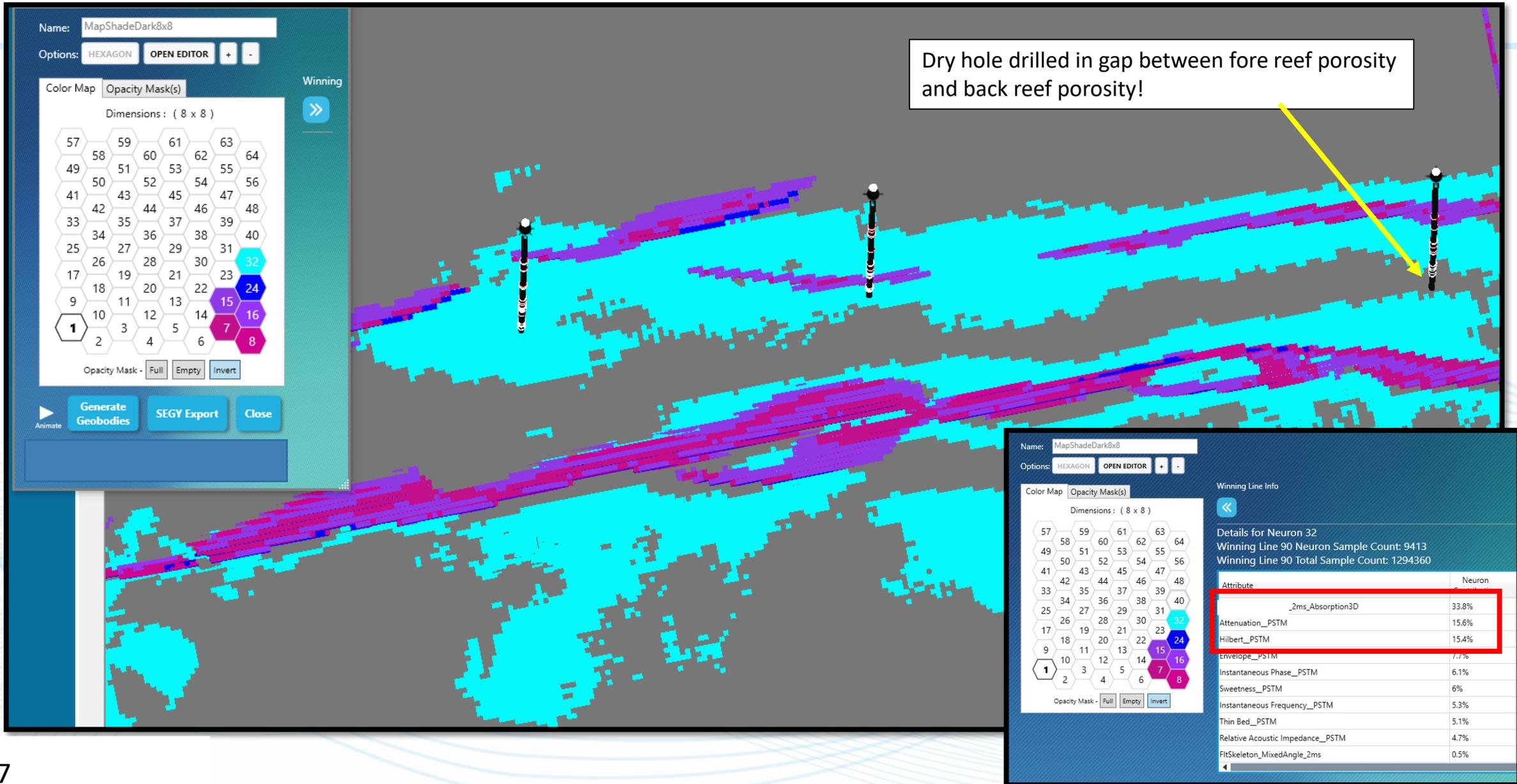
Here is a dip line through the dry hole, showing not only the structure of the Reef, but how close they came to making a significant discovery! If they had drilled 600 feet to the north – in the porosity developed on the "back reef" – they would not have had a dry hole!
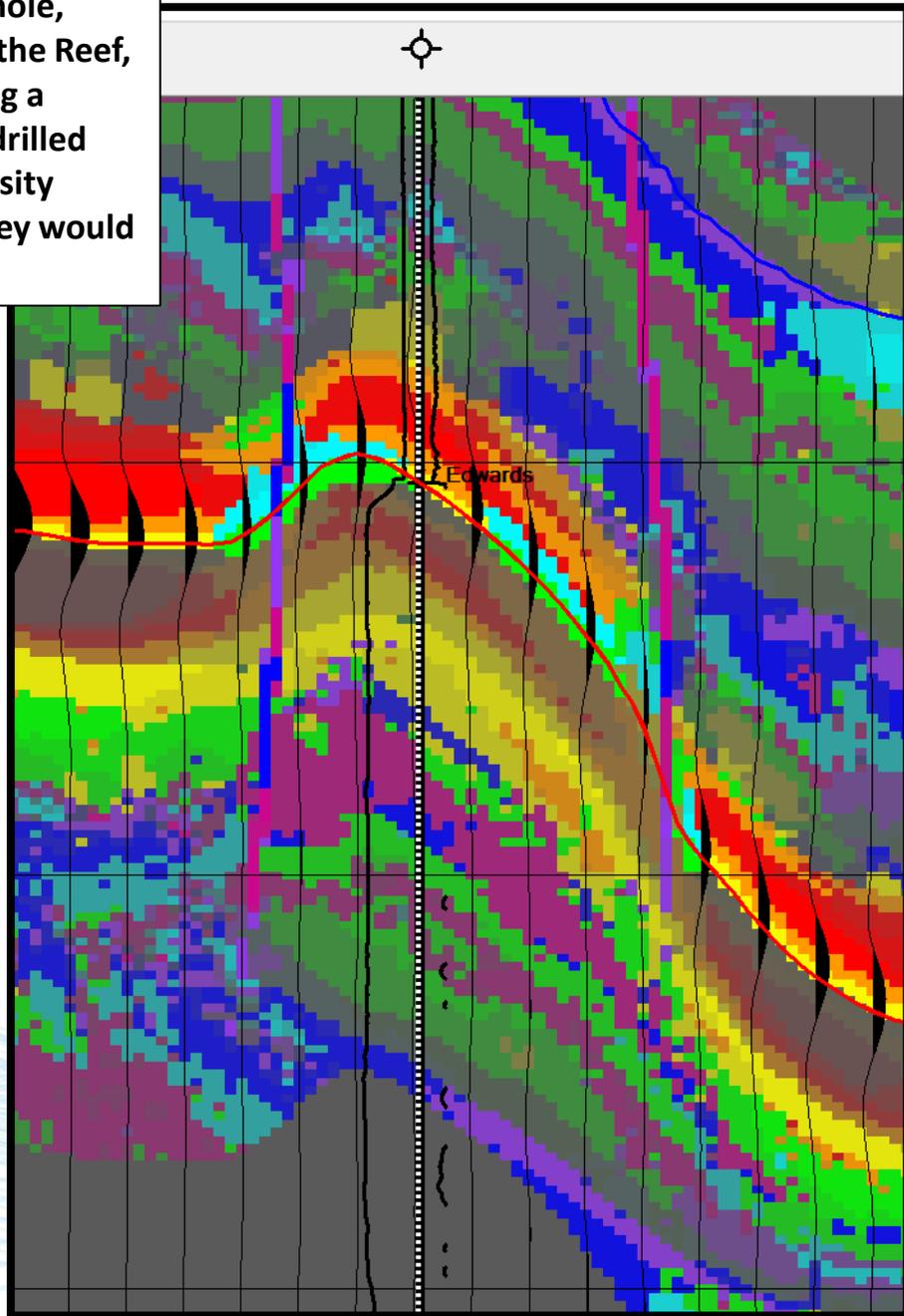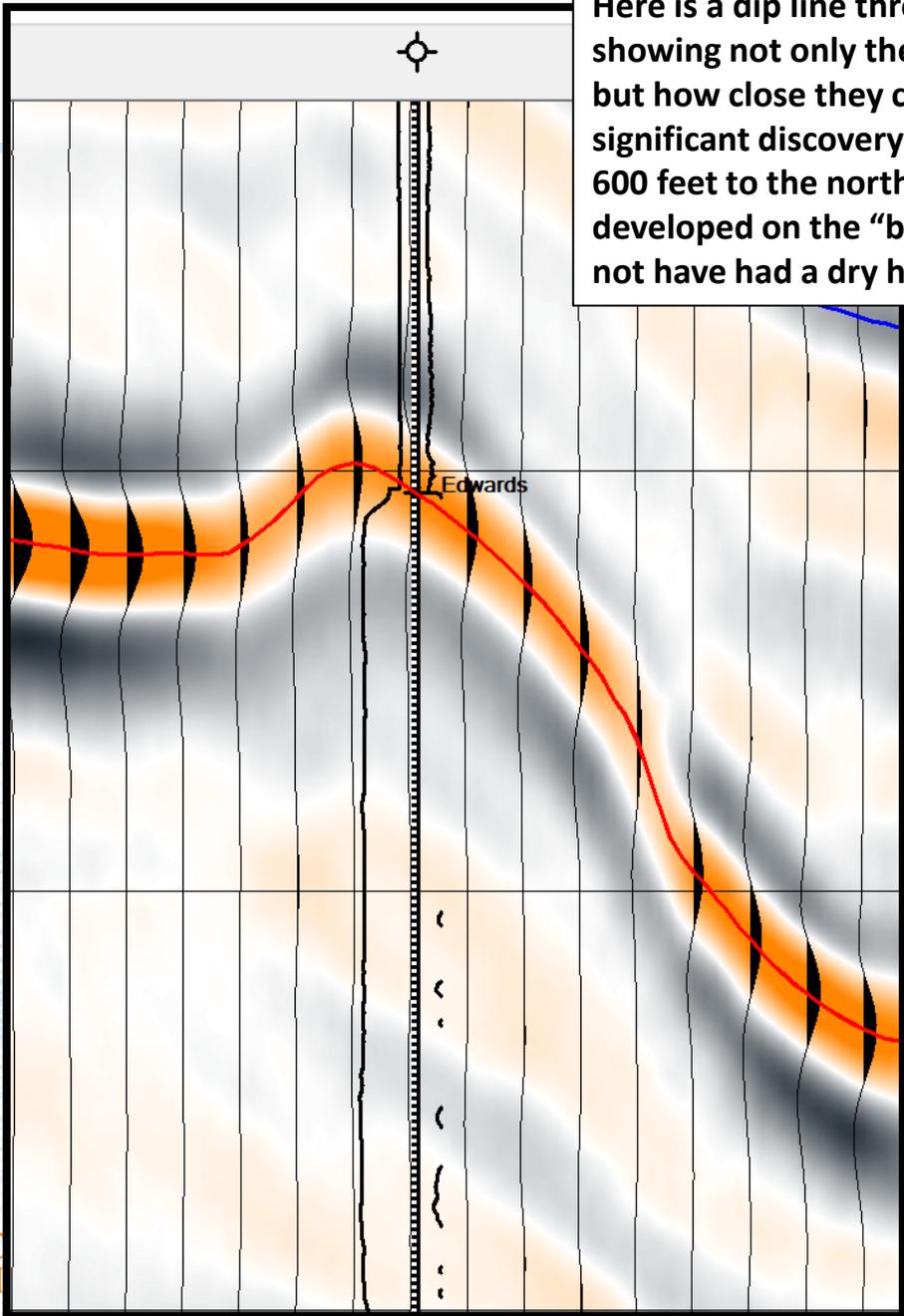
Likewise – here is a dip line through the good show well, which barely clipped the reservoir found in the back reef. If THEY had drilled a few hundred feet to the south, they would have had a "tight" dry hole with no shows!
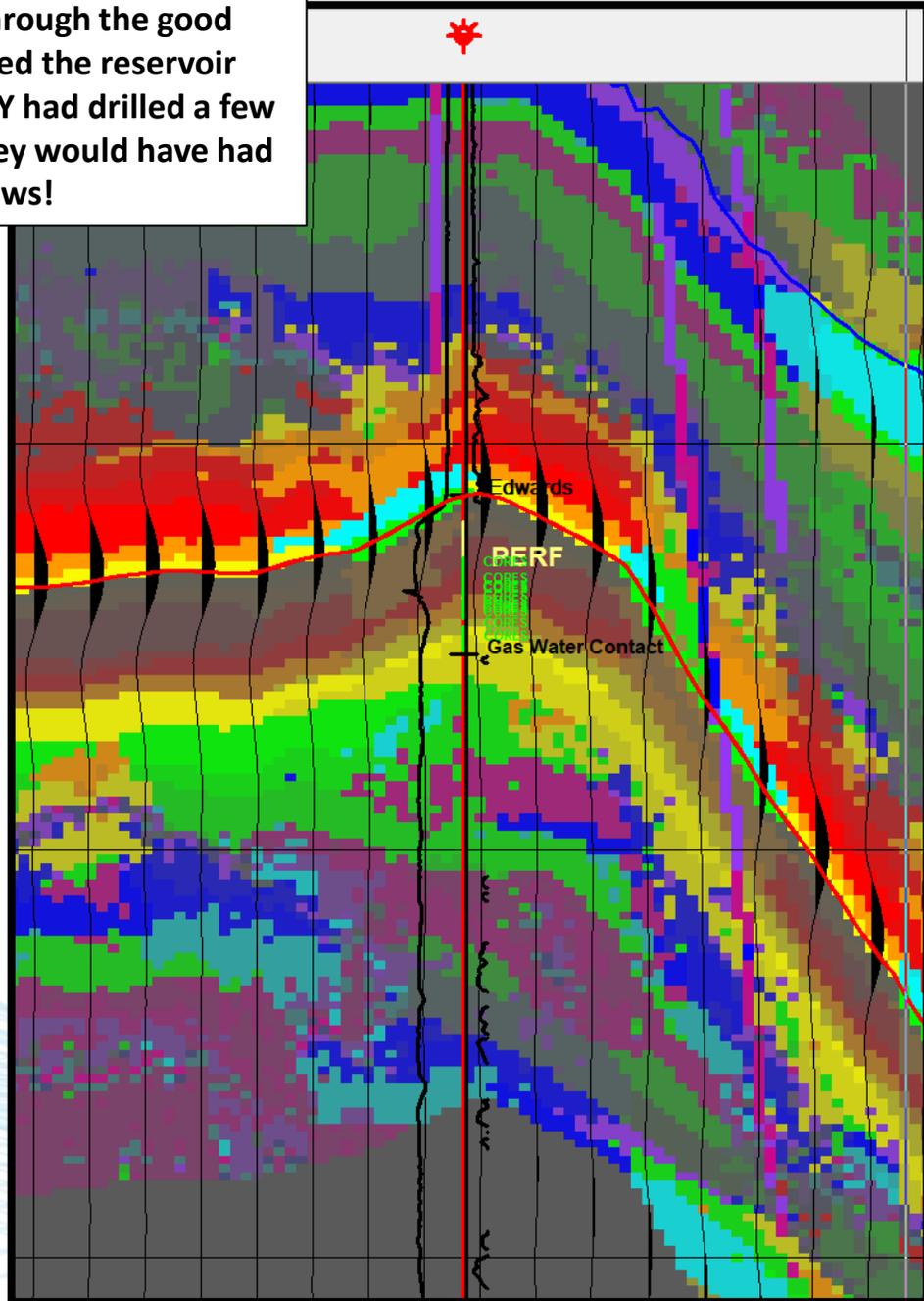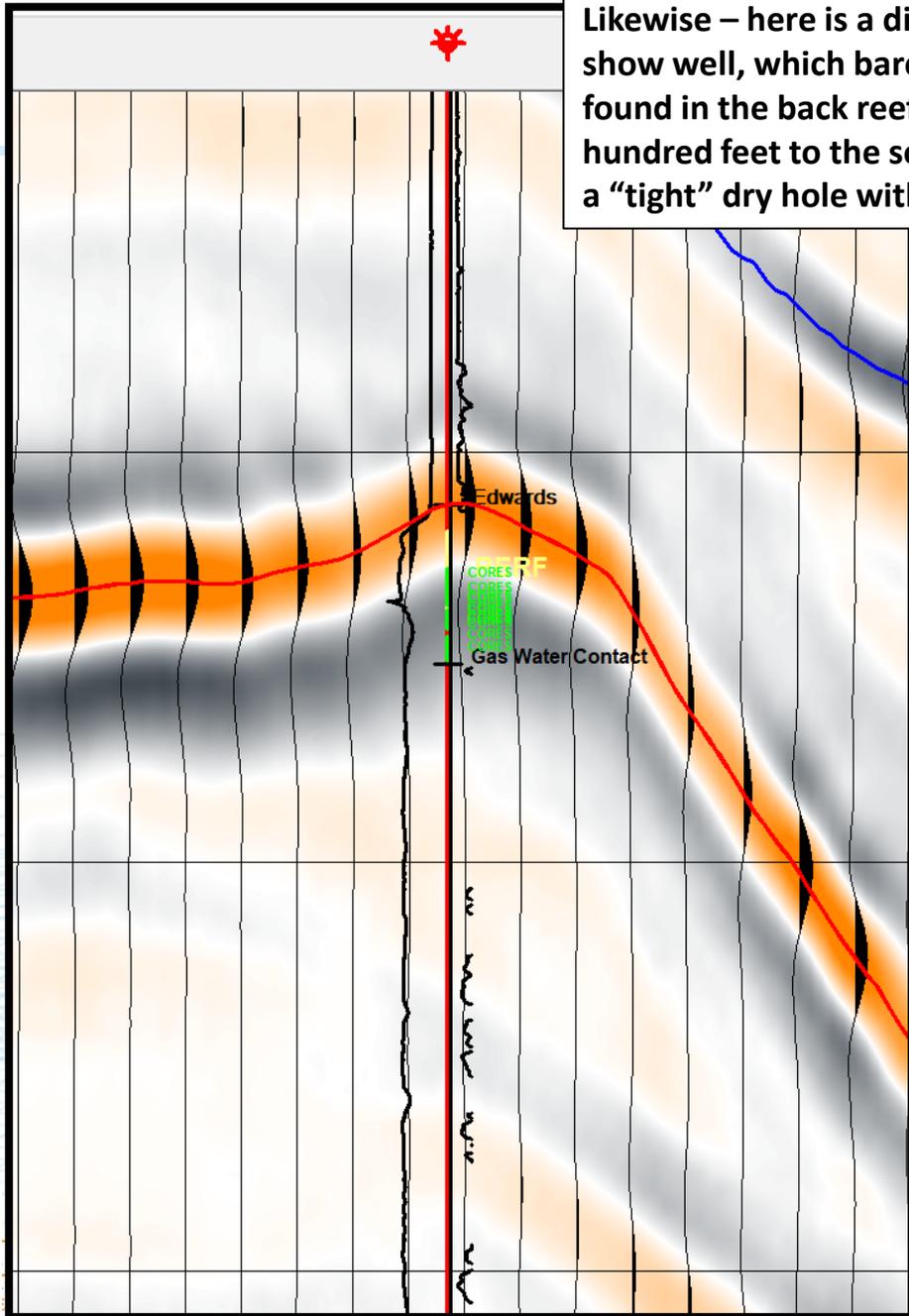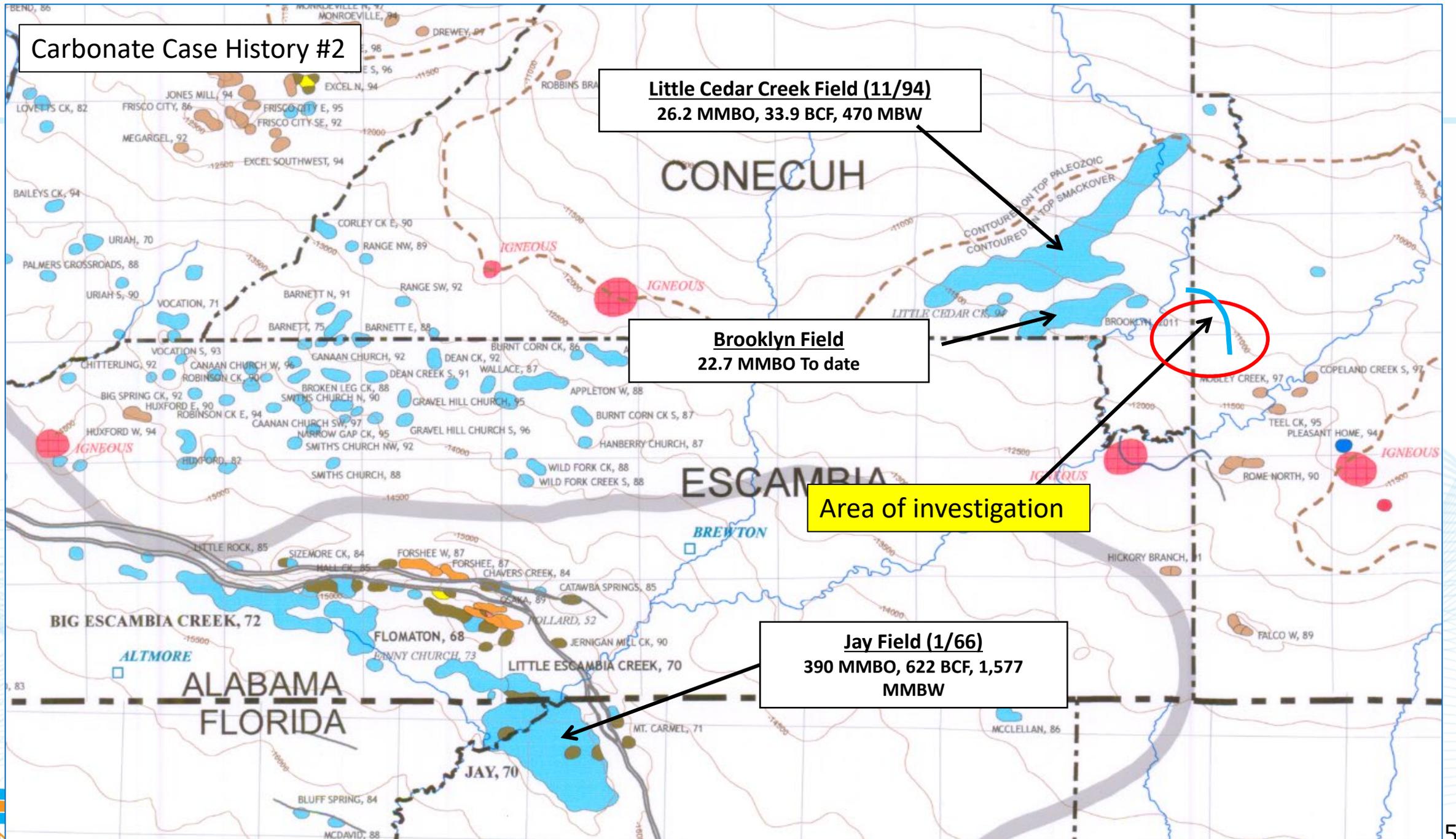
Carbonate Case History #2

Little Cedar Creek Field (11/94)
26.2 MMBO, 33.9 BCF, 470 MBW
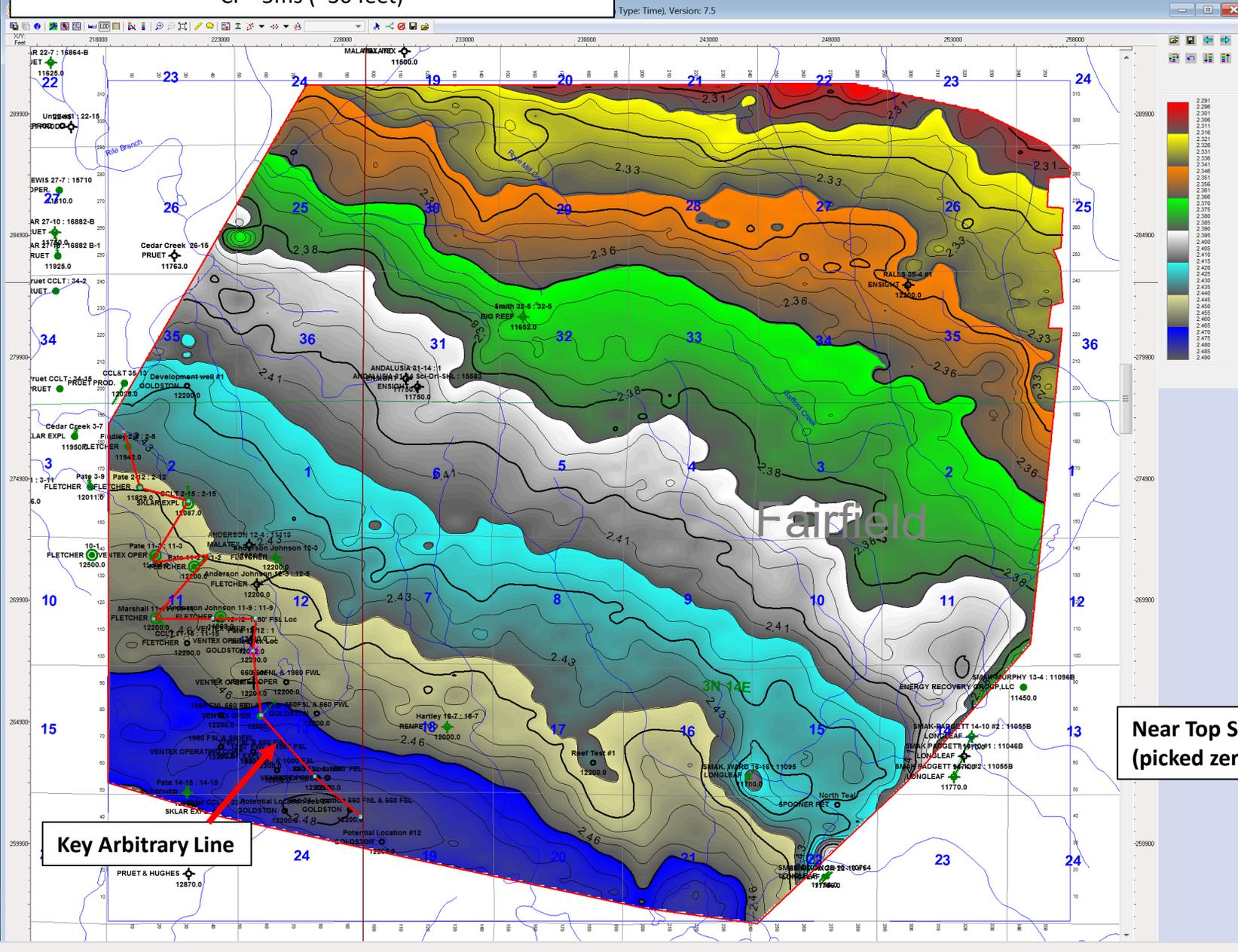
Brooklyn Field
22.7 MMBO To date

Area of investigation

Jay Field (1/66)
390 MMBO, 622 BCF, 1,577 MMBW
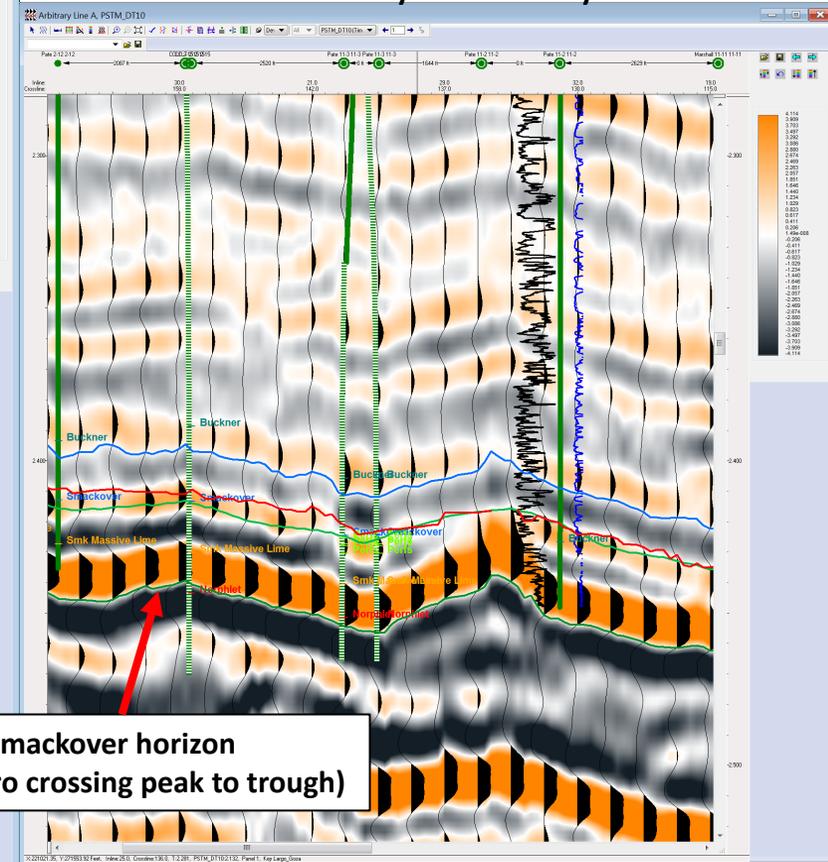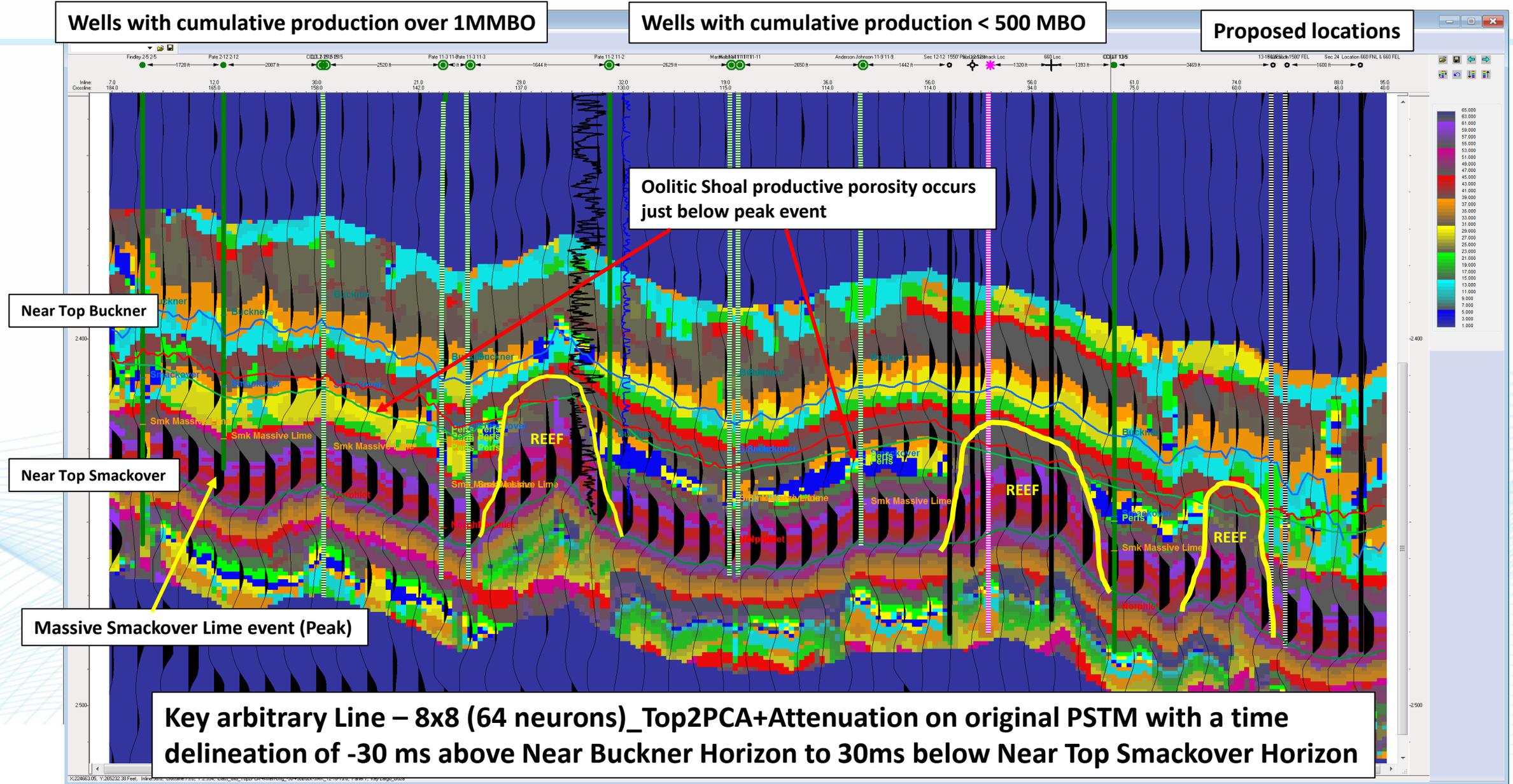
50

Time Structure on Near Top Smackover
CI = 5ms (~30 feet)

**Smackover Oolitic Shoal in East Alabama**

Portion of Key Arbitrary Line

Near Top Smackover horizon (picked zero crossing peak to trough)

Key Arbitrary Line

51

Arbitrary Line in Amplitude data – There were no Angle/offset stacks available.

52

After working through the project and creating synthetics on key wells, it is shown that the key productive unit is JUST BELOW the peak over the Massive Smackover Lime event. The better porosity and productive wells tie to Neurons #5, 28, 29, 31 and 38. Poorer wells seem to have a predominant amount of #5, and #38 in them – probably indicating tighter rock.
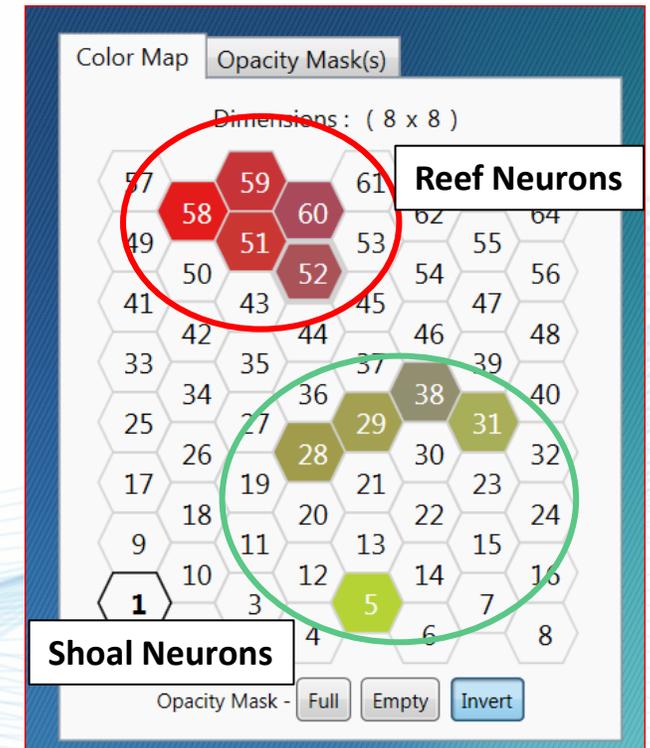

Wells with cumulative production over 1MMBO

Wells with cumulative production < 500 MBO

Proposed locations

Oolitic Shoal productive porosity occurs just below peak event

Near Top Buckner

Near Top Smackover

Massive Smackover Lime event (Peak)

REEF

Key arbitrary Line – 8x8 (64 neurons)_Top2PCA+Attenuation on original PSTM with a time delineation of -30 ms above Near Buckner Horizon to 30ms below Near Top Smackover Horizon

53

This is an enlargement of the first half of the Key Arbitrary Line showing the "patterns" of the neurons mentioned in the previous slide. The patterns tying to better porosity and production abruptly stop at the reef edge. The "Recipe" of attributes used in this analysis is shown below. These attributes were picked because they help find porosity, stratigraphic importance and are also hydrocarbon indicators.
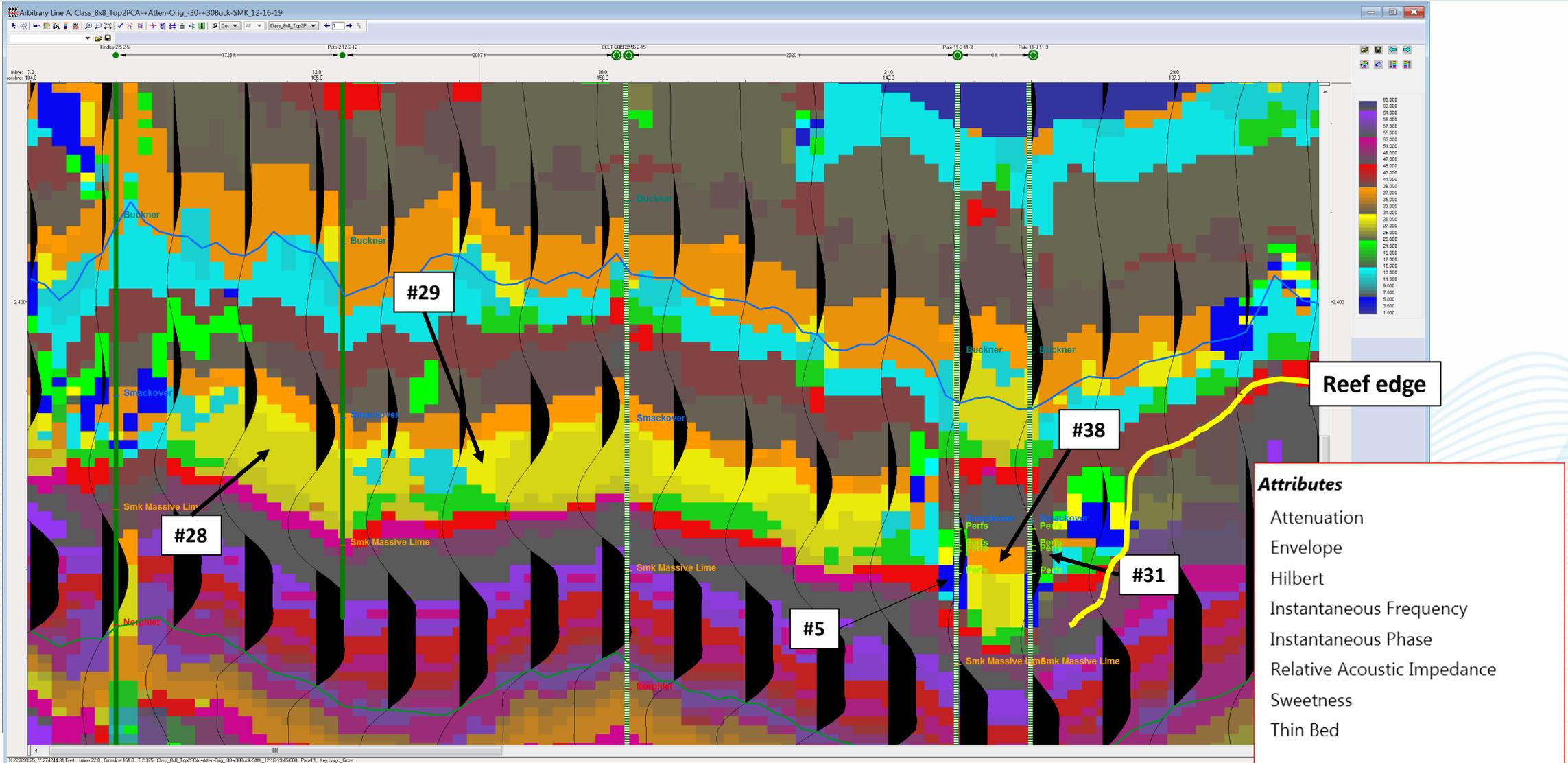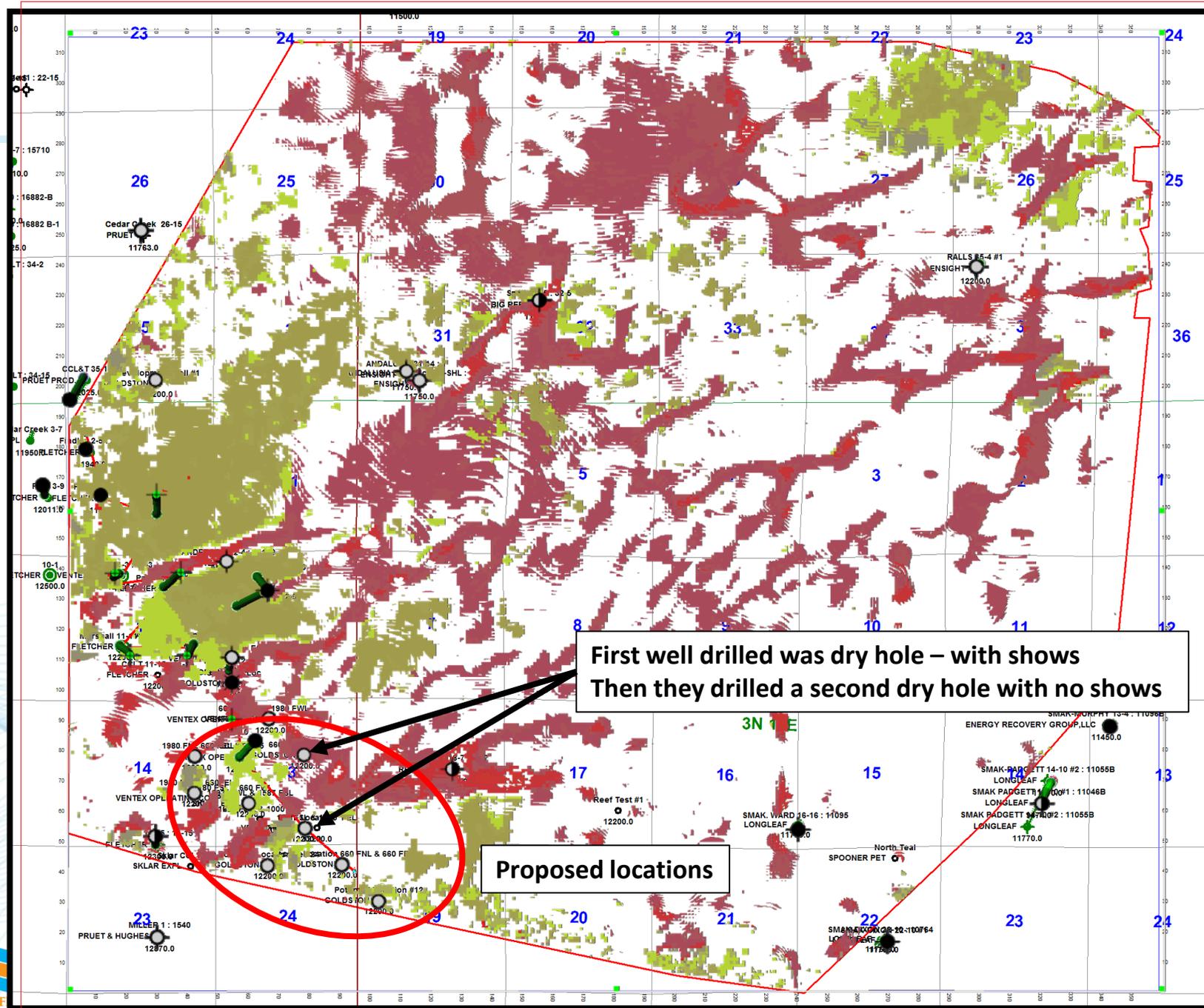
Knowing where the shoal deposition is relative to the reef material is also important.

Here, the key neurons for the Oolitic shoal deposits are shown with the reef key neurons of #51, 52, 58, 59 and 60. Understanding this relationship will also help in seeing why some wells produced more than others in the area.
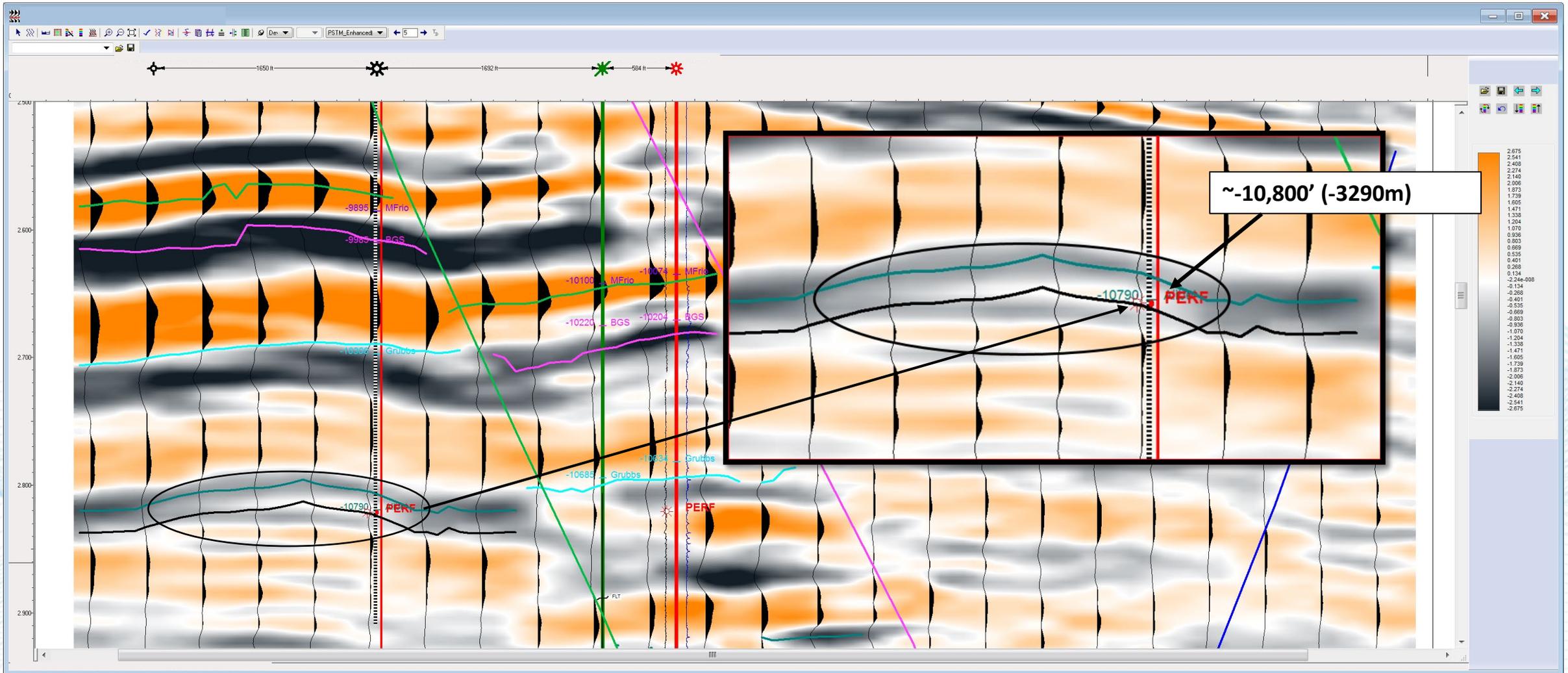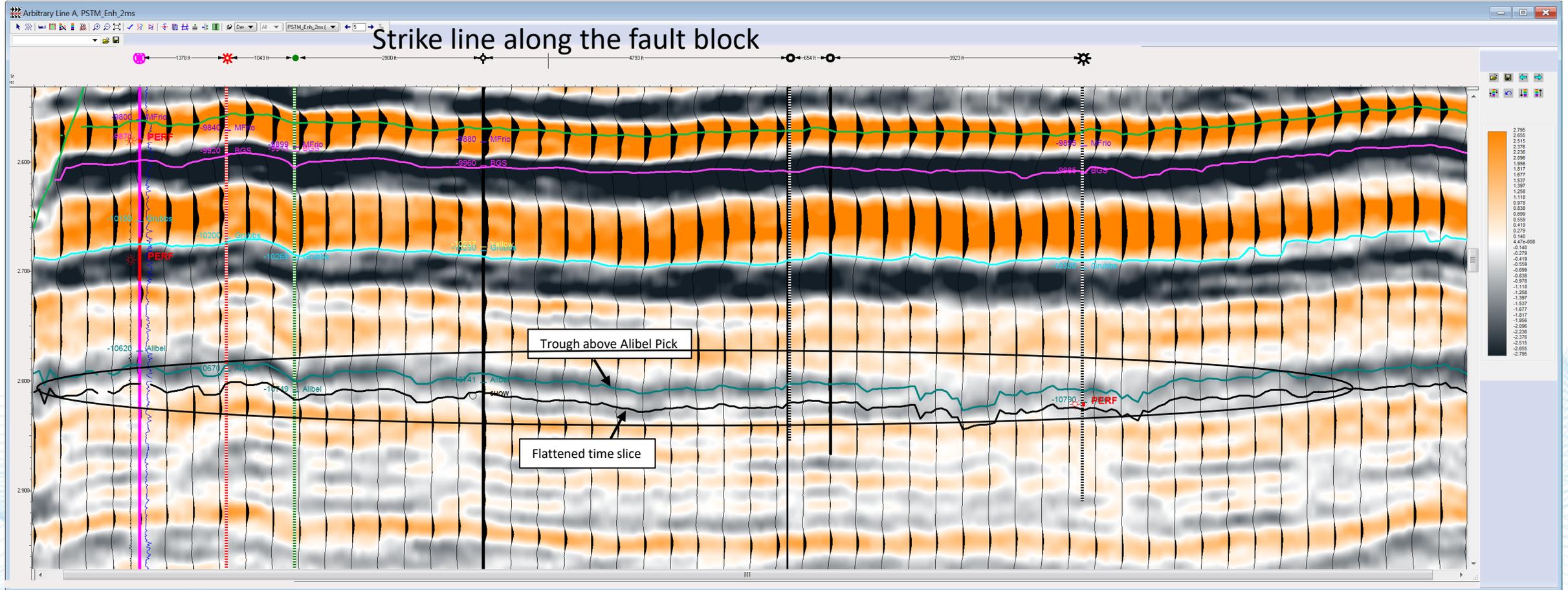
First well drilled was dry hole – with shows
Then they drilled a second dry hole with no shows

Proposed locations

Reef Neurons

Shoal Neurons

Mapping and delineation of thin-bed reservoirs (below seismic tuning)
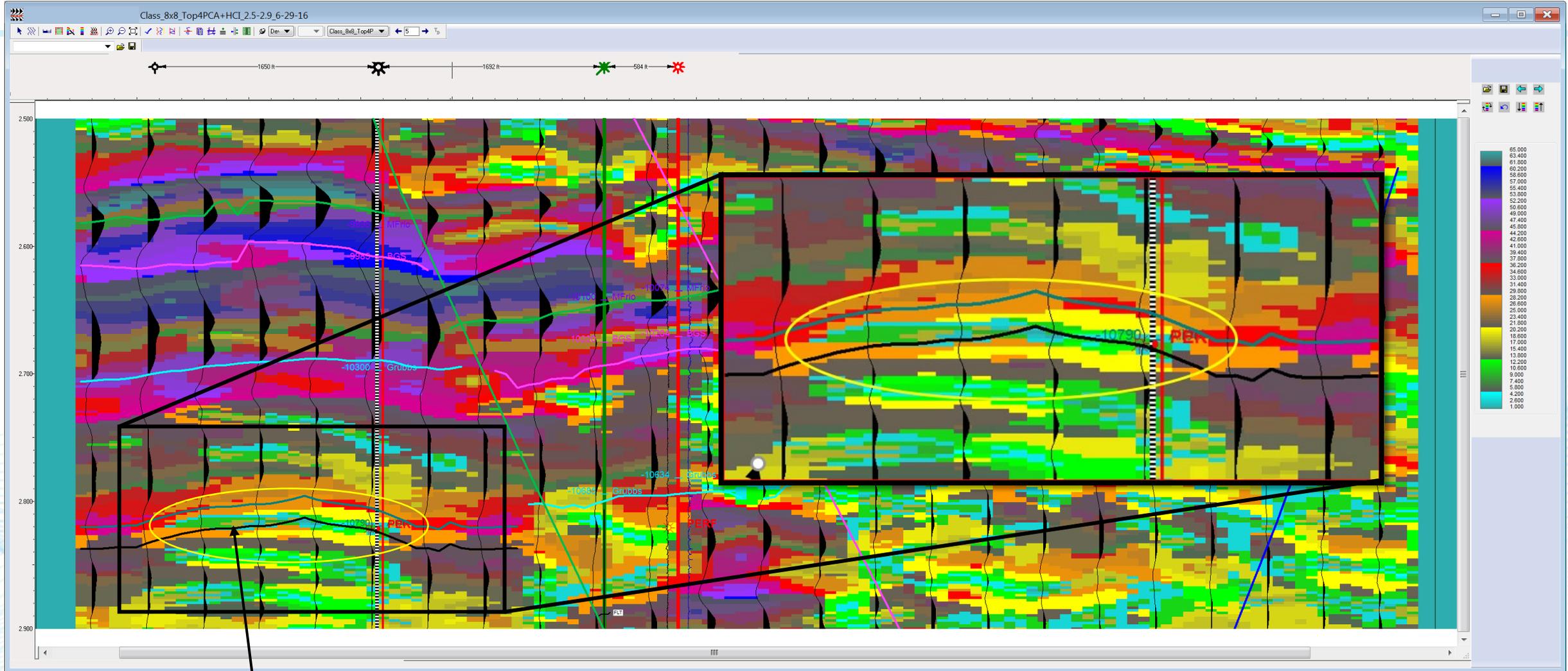
Brazoria County Middle Frio Test at 10,800 feet.

Depth Map on Top Alibel Sd.

CI = 50'

Inline

Arbitrary-Strike Line
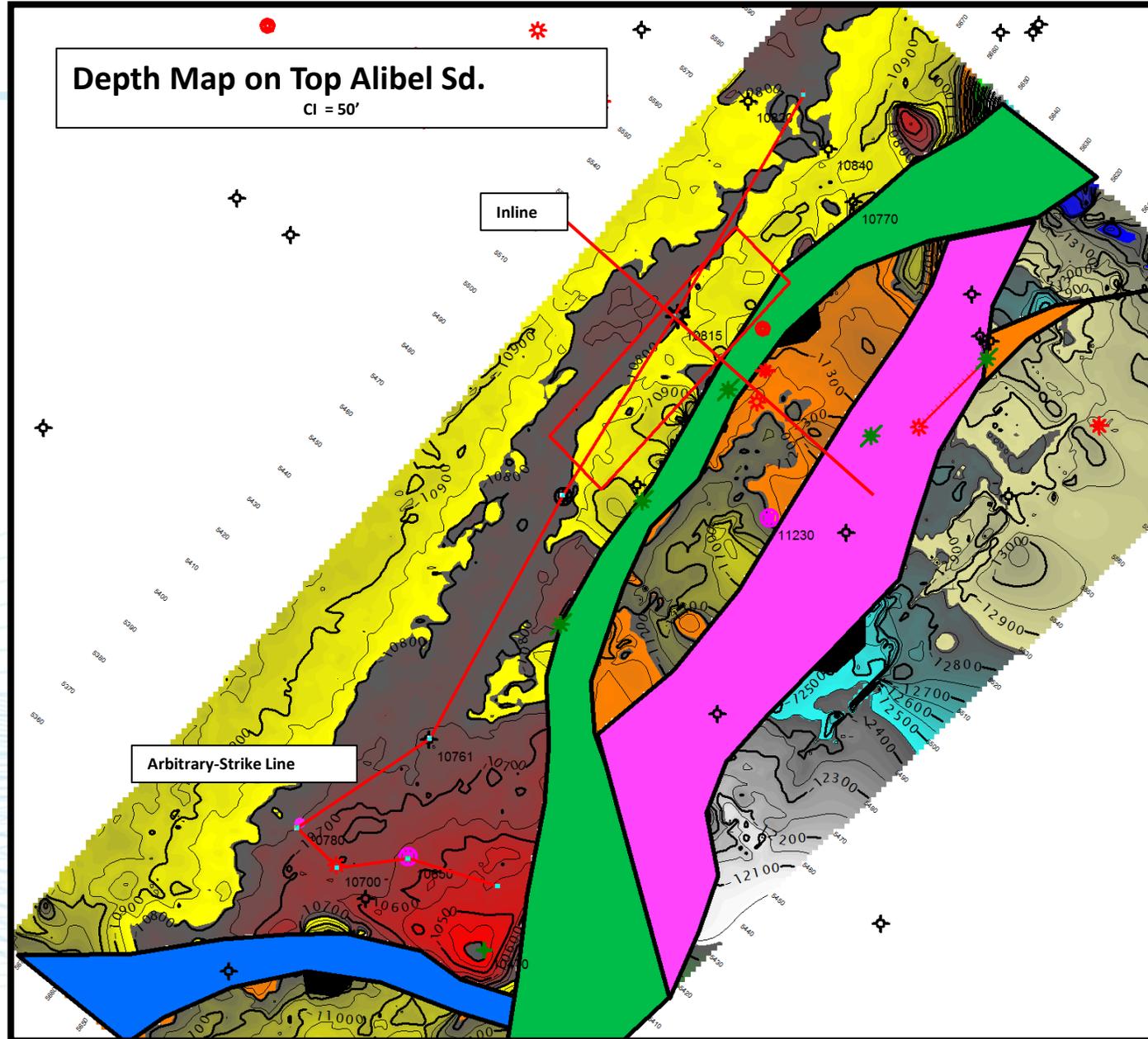
Inline showing key well which had produced over 450 MBO at the time of the analysis (PSTM Enh wiggle overlay)

~-10,800' (-3290m)

Arbitrary Line – PSTM Enhanced

Strike line along the fault block

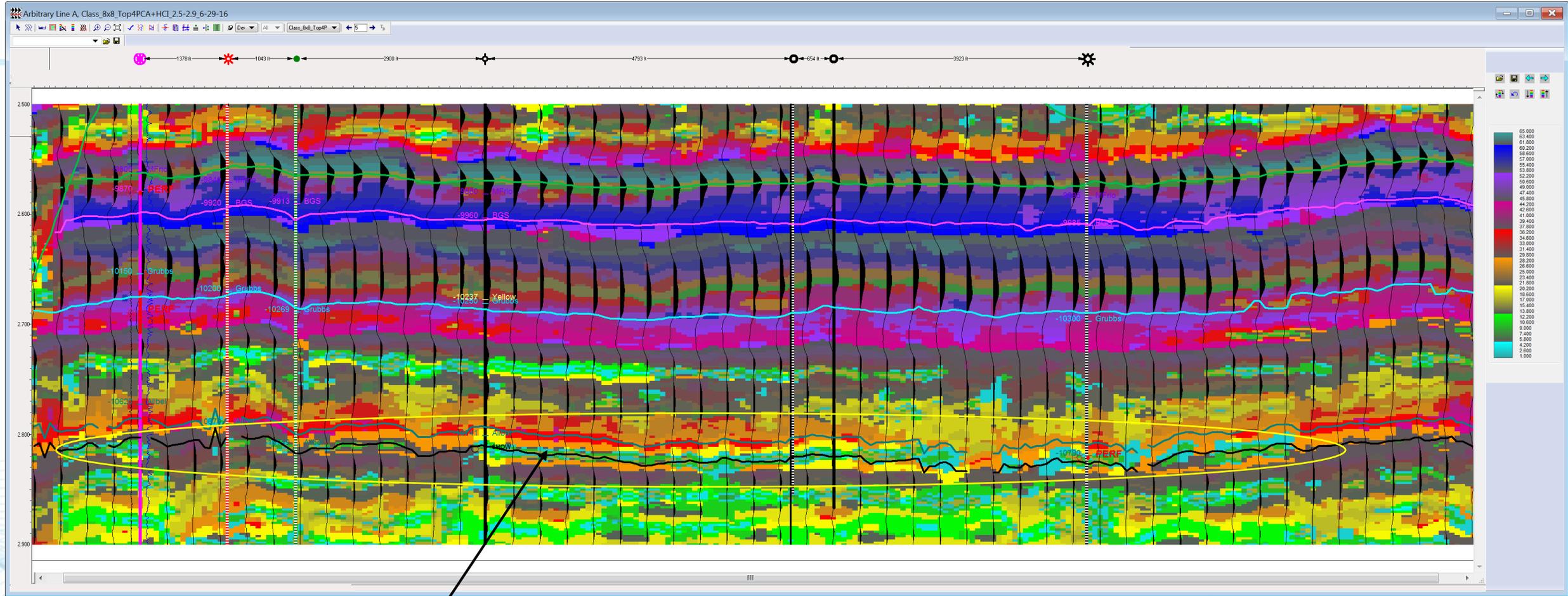Trough above Alibel Pick

Flattened time slice

Inline through Key well (PSTM Enh wiggle overlay) – Paradise display
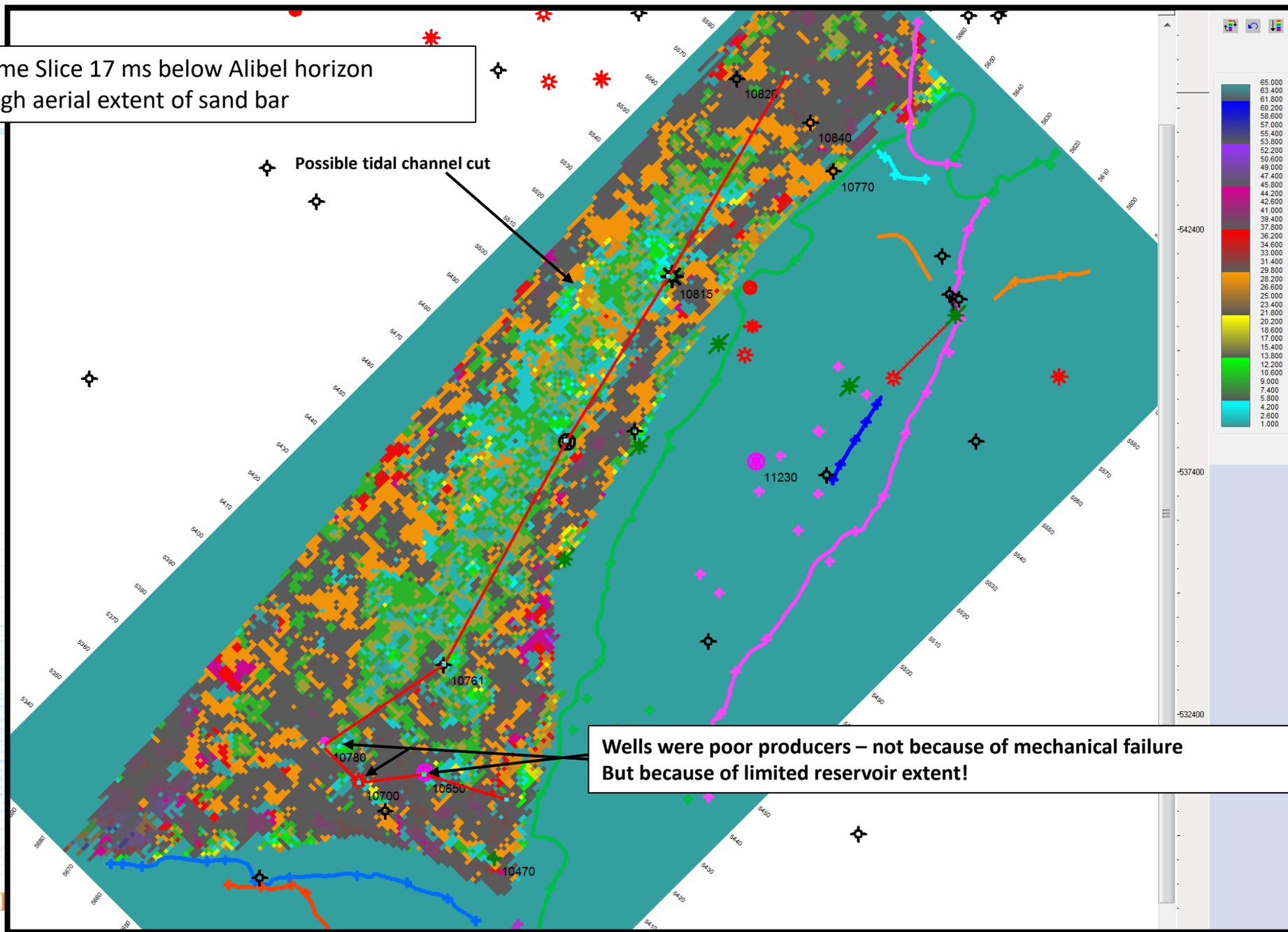

Pattern representing "bar" development in Alibel – black line is flattened time slice 17 ms below mapped Alibel surface
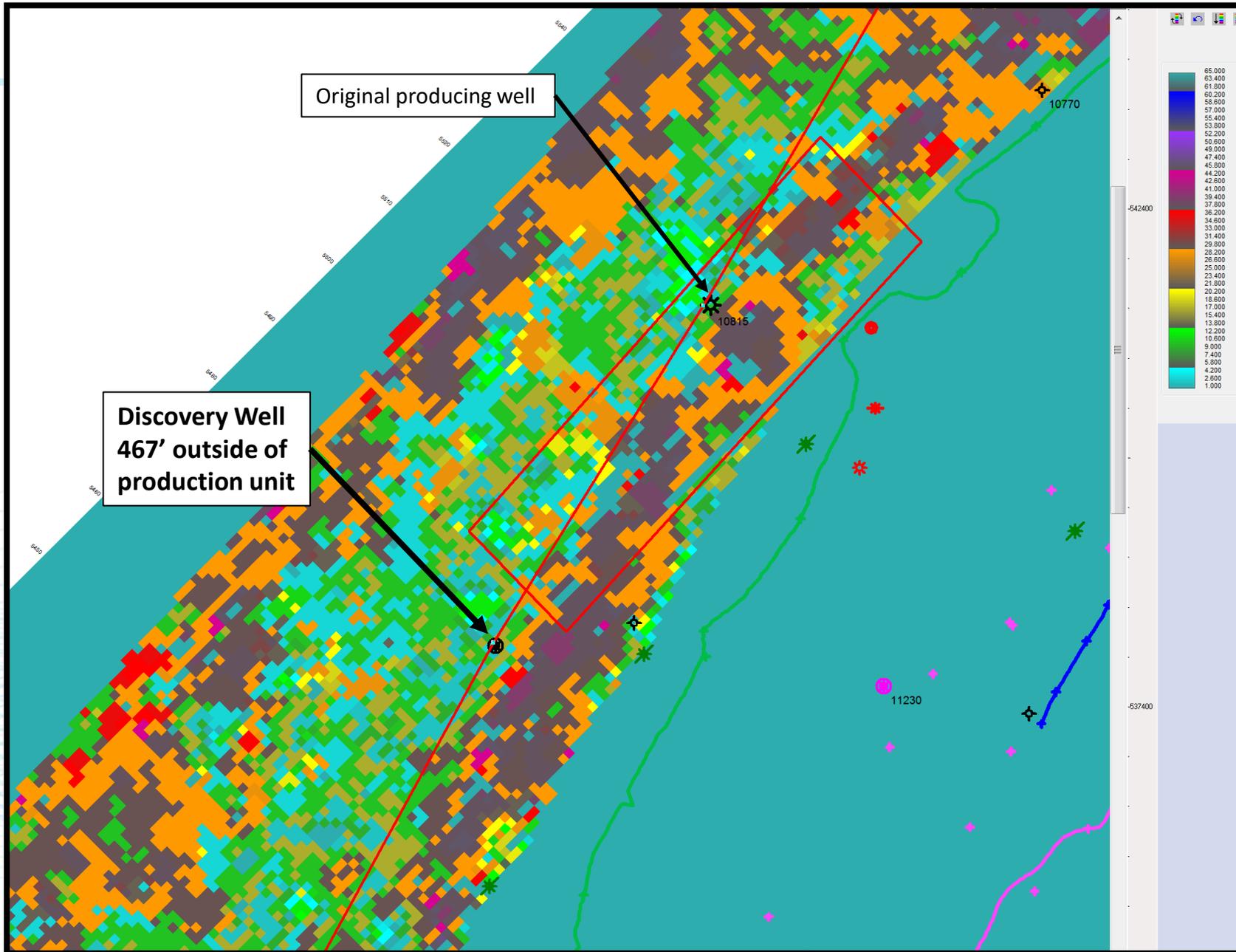
Arbitrary Line using Paradise software – attributes used were designed to find sands with porosity

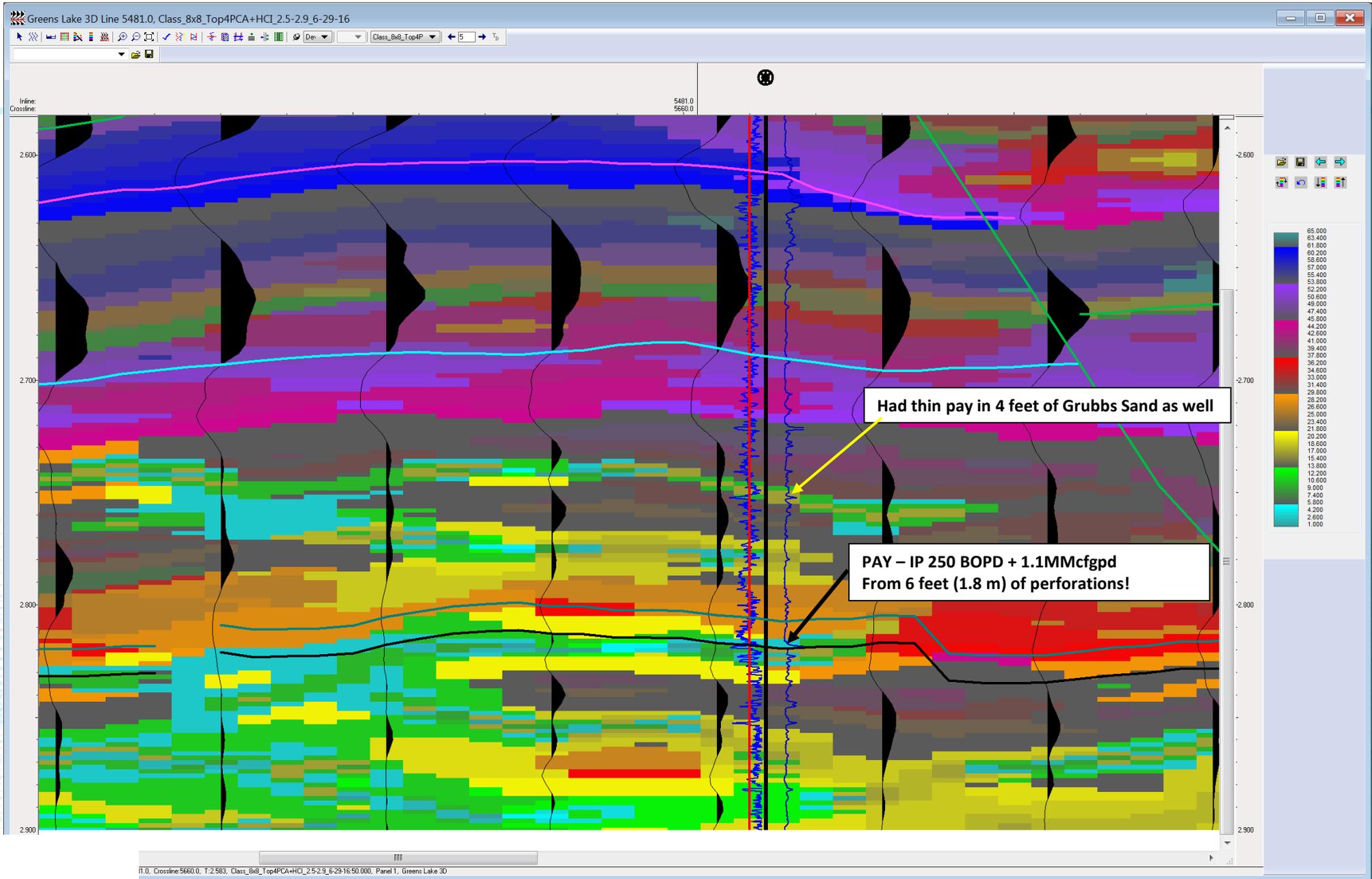Pattern representing "bar" development in Alibel – black line is flattened time slice 17 ms below mapped Alibel surface

Flattened Time Slice 17 ms below Alibel horizon showing rough aerial extent of sand bar

Possible tidal channel cut

Wells were poor producers – not because of mechanical failure
But because of limited reservoir extent!

Original producing well

Discovery Well 467' outside of production unit

63

Had thin pay in 4 feet of Grubbs Sand as well

PAY – IP 250 BOPD + 1.1MMcfgpd
From 6 feet (1.8 m) of perforations!

Total Production to date: 1210.5 MBO + 10.1 BCFG (as of 2019)

Cum: 7.4 Bcfg + 946.8MBO

New well – Original Operator (2017)
Cum: 615MMcfg + 56.2 MBO

Cum: 1.5 Bcfg + 154MBO

New well – Client (2017)
Cum: 588.4MMcfg + 53.5 MBO

Wells were poor producers – not because of mechanical failure
But because of limited reservoir extent!
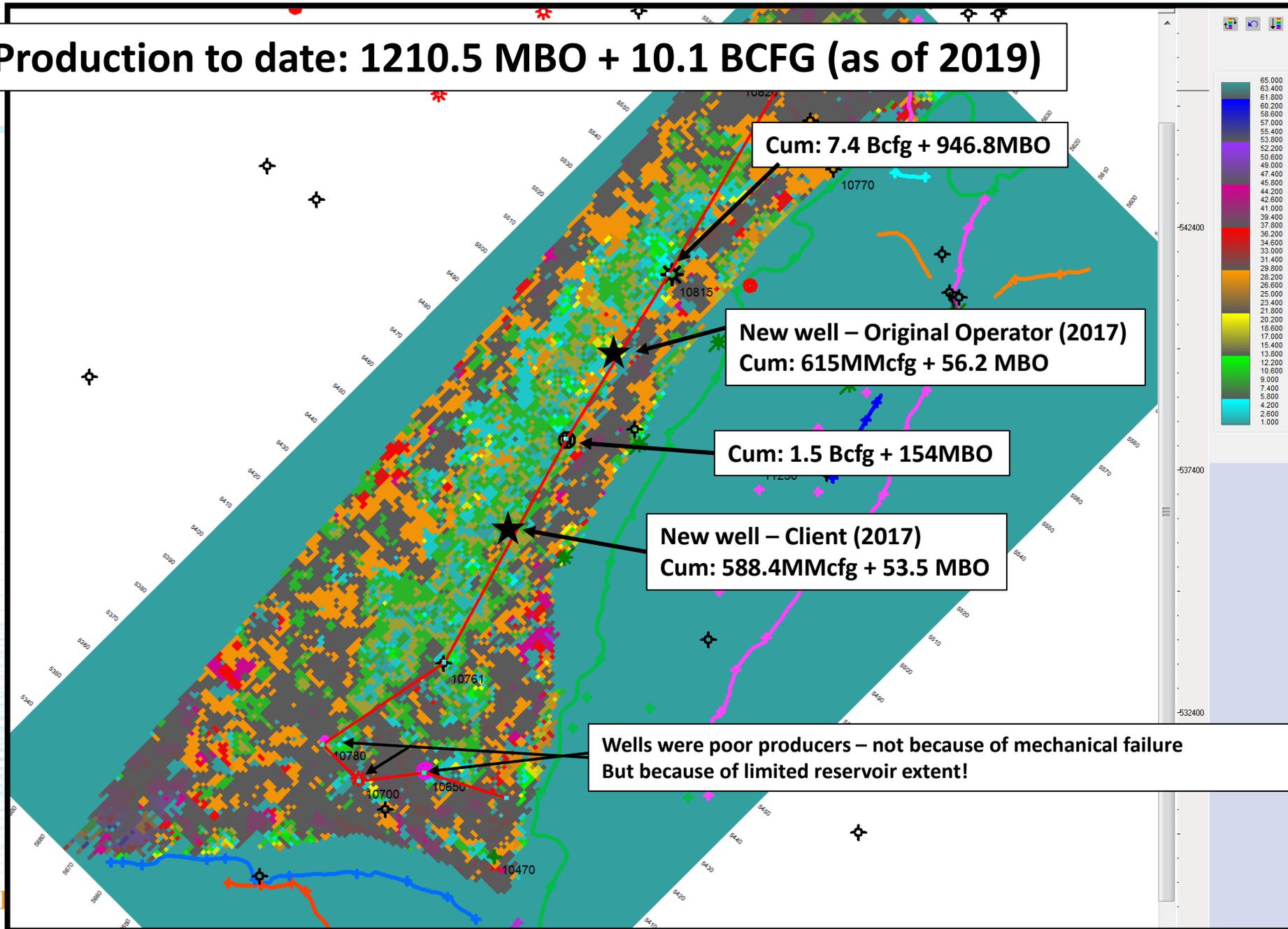
Conclusions:

It is possible to be very accurate in estimating/predicting potential reserves using geobodies derived from Self-organized Maps.

It is possible to use Low Probability volume calculated during SOM process to see depletion- if seismic data was shot AFTER most of the production had occurred, thus being able to look at possible stranded reserves.

SOM Classification using multiple attributes and working on sample statistics can work in any depositional environment. It is not "one and done", but an iterative process to calibrate to well data and learn to interpret what the patterns mean in terms of lithology and stratigraphy. A good understanding of depositional "forms" is necessary to clearly see the information the patterns are disclosing!