Integrating Seismic, Microseismic and Engineering Data to Optimize Lateral Placement and Completion Design in the Eagle Ford*

Ross Peebles[1]

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*Adapted from oral presentation at Geosciences Technology Workshop, Hydraulic Fracturing, Golden, Colorado, August 13-16, 2012, and Geoscience Technology Workshop, Shale Plays: An Integrated Approach for Enhanced Exploration Development and Valuation, Houston, Texas, November 12-14, 2012 (the latter entitled ñIntegrating Seismic Attributes, Completion Parameters, Microseismic and Production Data to Define Well Prospectivity and Productivity: Examples from the Eagle Fordò).

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Abstract

Regional and local analysis of the Eagle Ford using production data, well logs and Global Geophysical's vast multi-client seismic data library indicates substantial lateral and vertical heterogeneity throughout this play. This observation suggests the following questions:

- Can geoscience and engineering attributes be identified that are indicators of well performance?
- Can these be used to create a predictive model for well prospectivity and productivity?
- Can these models be used to "localize" individual well plans and completion designs?

The workflow demonstrated here is a multi-disciplinary integration of the geophysical, geological, petrophysical and engineering data that analyzes and combines numerous datasets, identifies the specific data types that are most related to hydrocarbon production, and produces a model that not only identifies the most prospective areas for drilling, but also provides quantitative estimates of productivity at a resolution useful for well planning and completion design.

The integration of seismic attributes and petrophysical analyses in a 3D geological model allows for the description of rock quality, stress conditions and fluid distribution in both lateral and vertical dimensions. Furthermore, the integration of seismic and microseismic analyses provides insight into the dynamic response of the resource to stimulation and production. Properly applied, this workflow can significantly reduce drilling risk and aid in the optimization of a drilling and completion program. The work presented here also demonstrates the value that seismic and microseismic data can bring to resource characterization and development planning of unconventional resources when integrated and related to well productivity.

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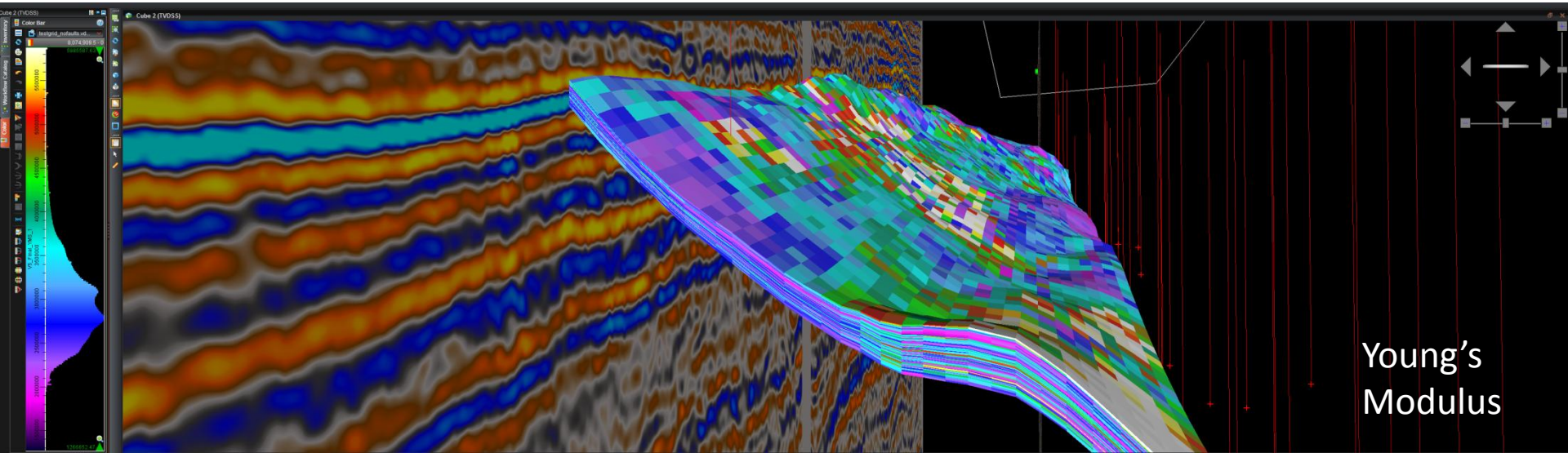
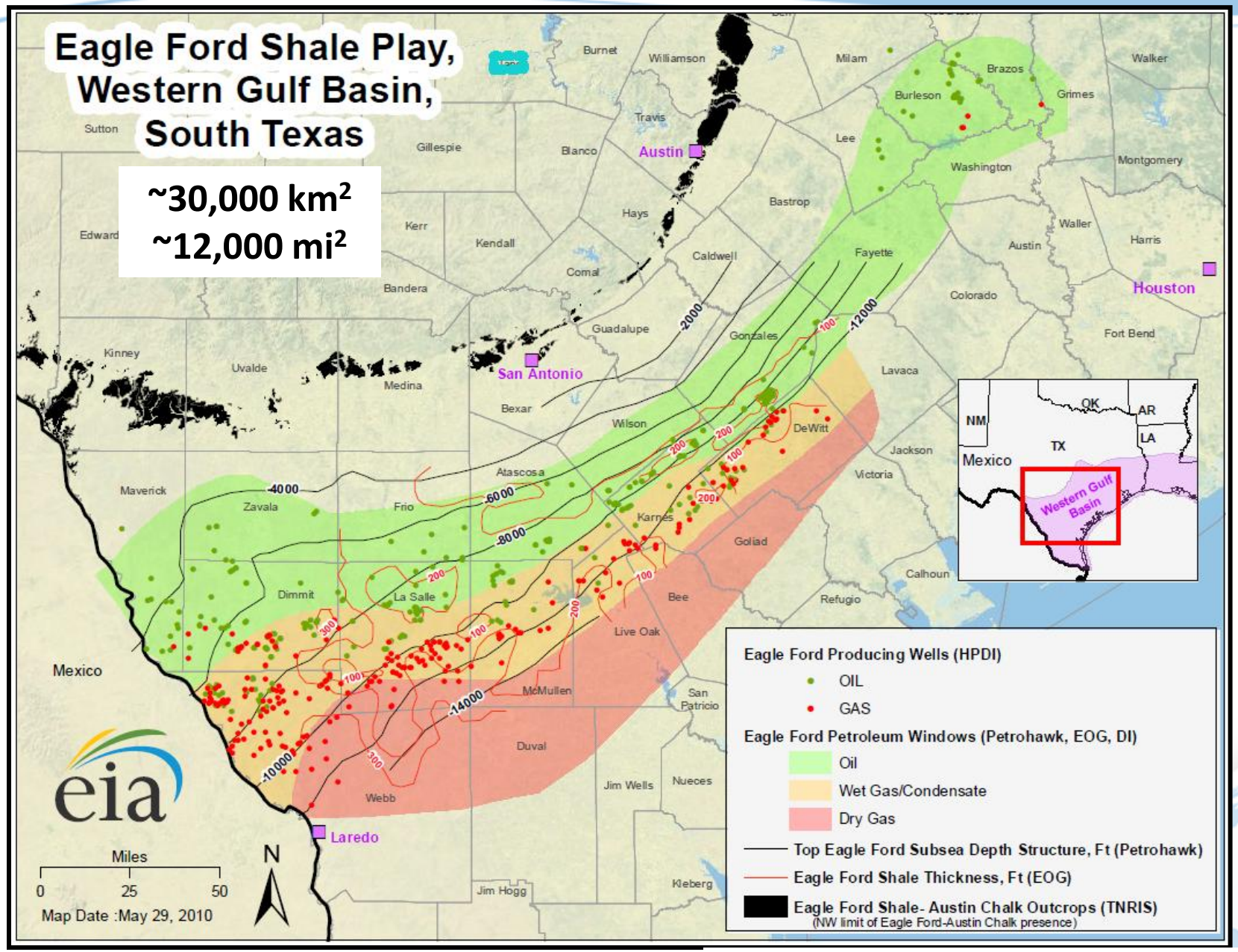
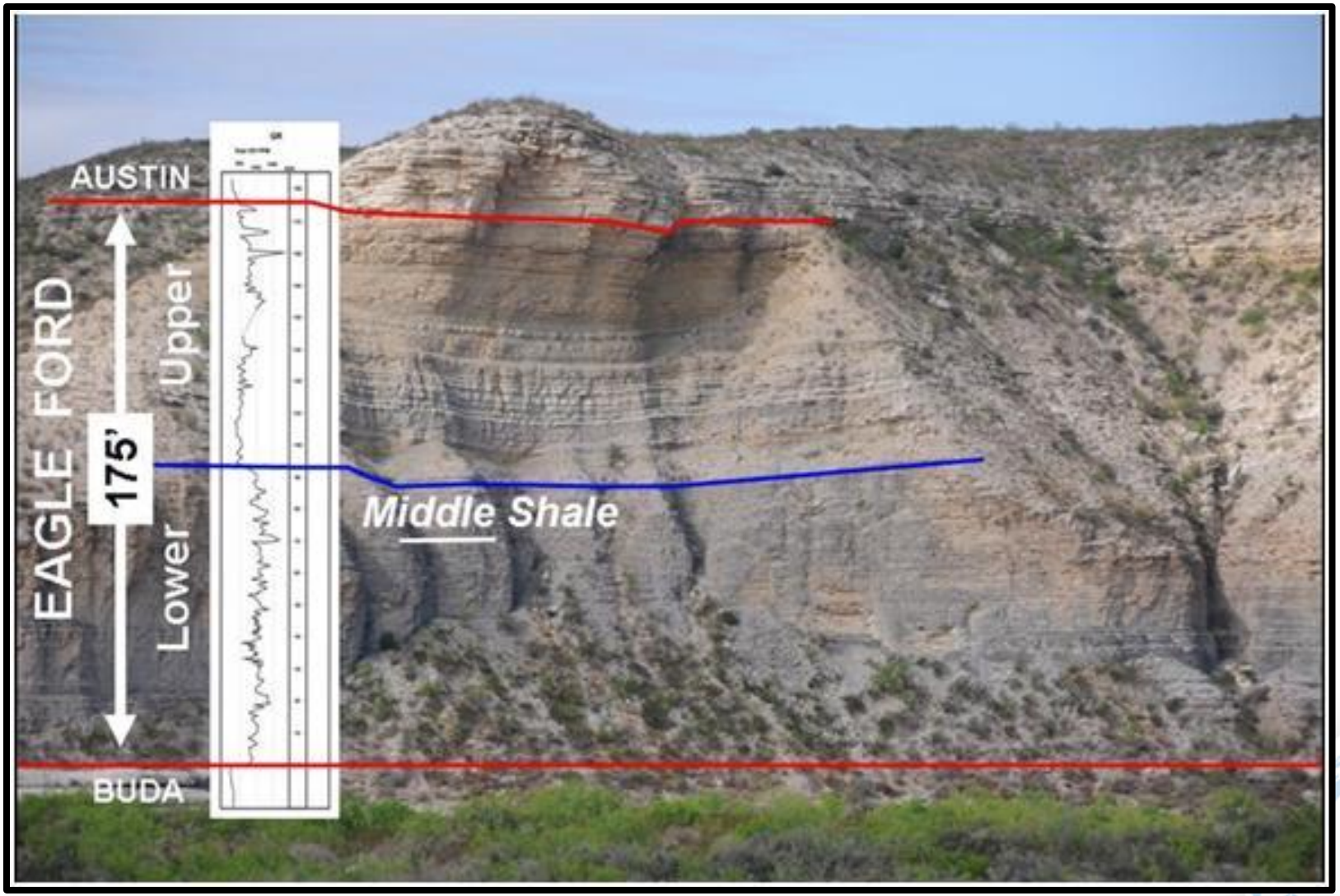
Ross Peebles
Global Geophysical

AAPG-GTW Hydraulic Fracturing
13-15 August 2012

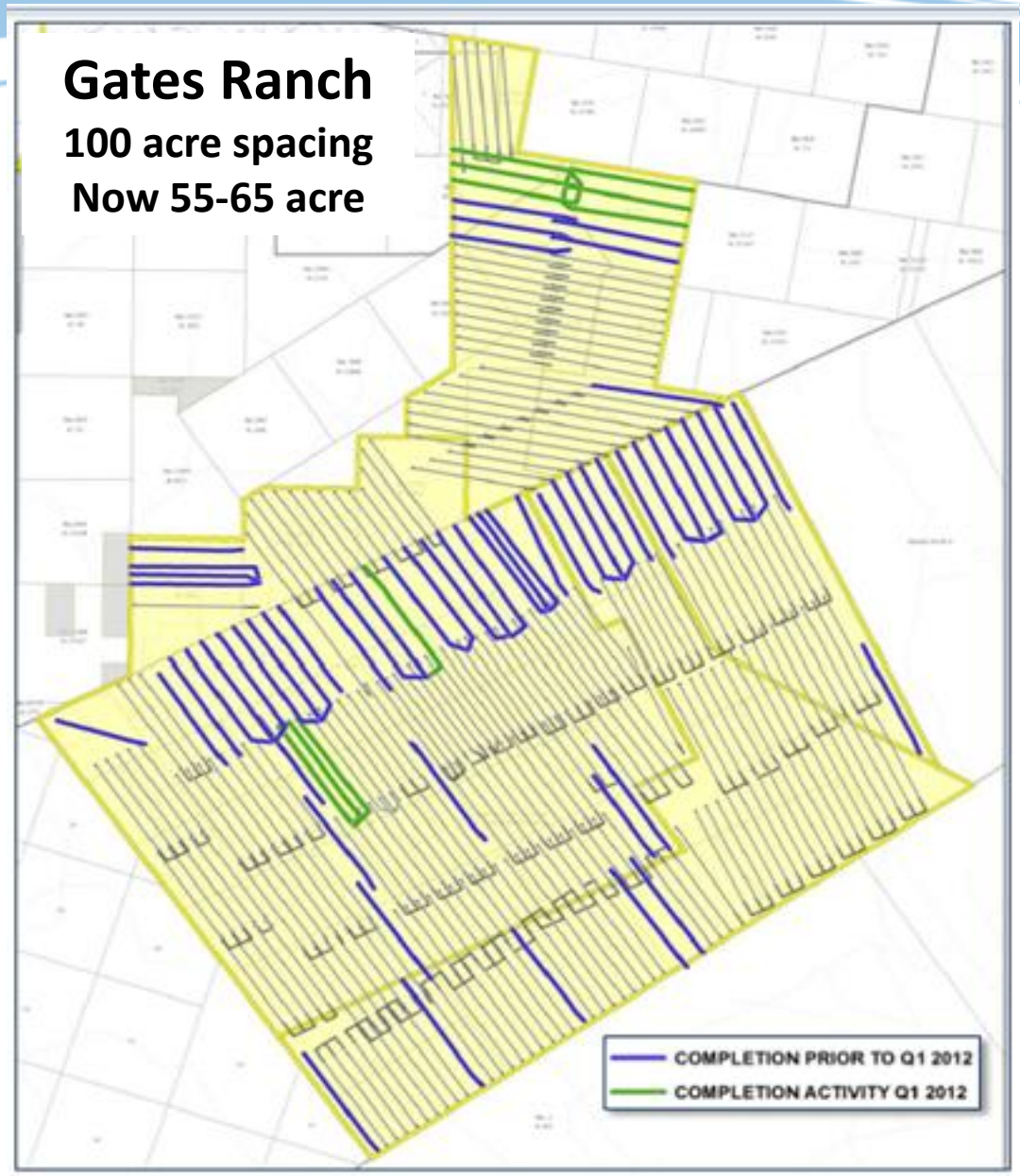


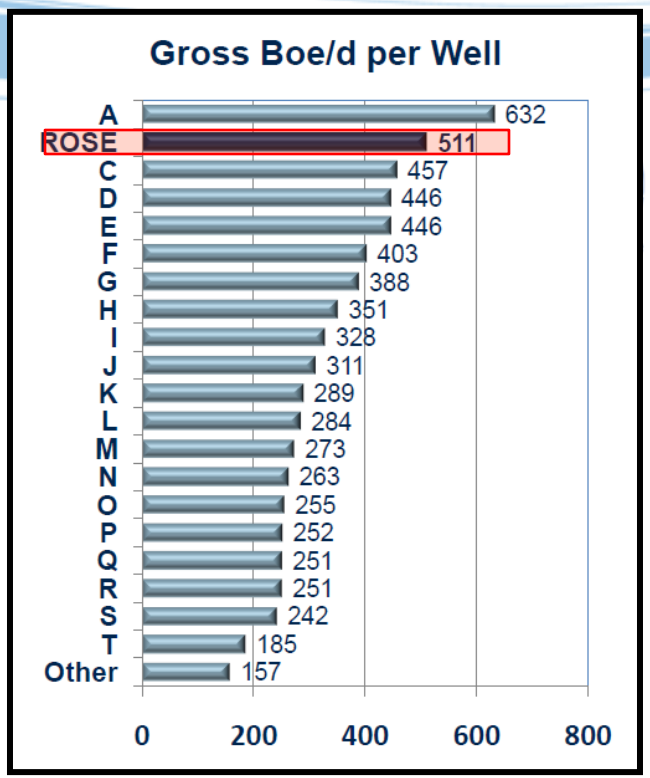

Eagle Ford Shale Play,
Western Gulf Basin,
South Texas
~30,000 km²
~12,000 mi²
Austin
San Antonio
Houston
Laredo
Mexico
Burnet
Williamson
Milam
Brazos
Walker
Burleson
Grimes
Travis
Lee
Sutton
Gillespie
Blanco
Washington
Montgomery
Bastrop
Hays
Waller
Harris
Edwards
Kerr
Kendall
Caldwell
Fayette
Austin
Comal
Colorado
Bandera
Guadalupe
Gonzales
Fort Bend
Kinney
Uvalde
Medina
Lavaca
Bexar
Wilson
DeWitt
Jackson
Atascosa
Victoria
Maverick
Zavala
Frio
Karnes
Goliad
Dimmit
La Salle
Calhoun
Bee
Refugio
Live Oak
McMullen
San Patricio
Duval
Jim Wells
Nueces
Webb
Jim Hogg
Kleberg
-2000
-4000
-6000
-8000
-10000
-12000
-14000
100
200
300
NM
OK
AR
LA
TX
Mexico
Western Gulf Basin
Eagle Ford Producing Wells (HPDI)
OIL
GAS
Eagle Ford Petroleum Windows (Petrohawk, EOG, DI)
Oil
Wet Gas/Condensate
Dry Gas
Top Eagle Ford Subsea Depth Structure, Ft (Petrohawk)
Eagle Ford Shale Thickness, Ft (EOG)
Eagle Ford Shale- Austin Chalk Outcrops (TNRIS)
(NW limit of Eagle Ford-Austin Chalk presence)
eia
Miles
0
25
50
N
Map Date :May 29, 2010

Eagle Ford - Outcrop - Lozier Canyon, South Texas



Source: Donovan, 2011



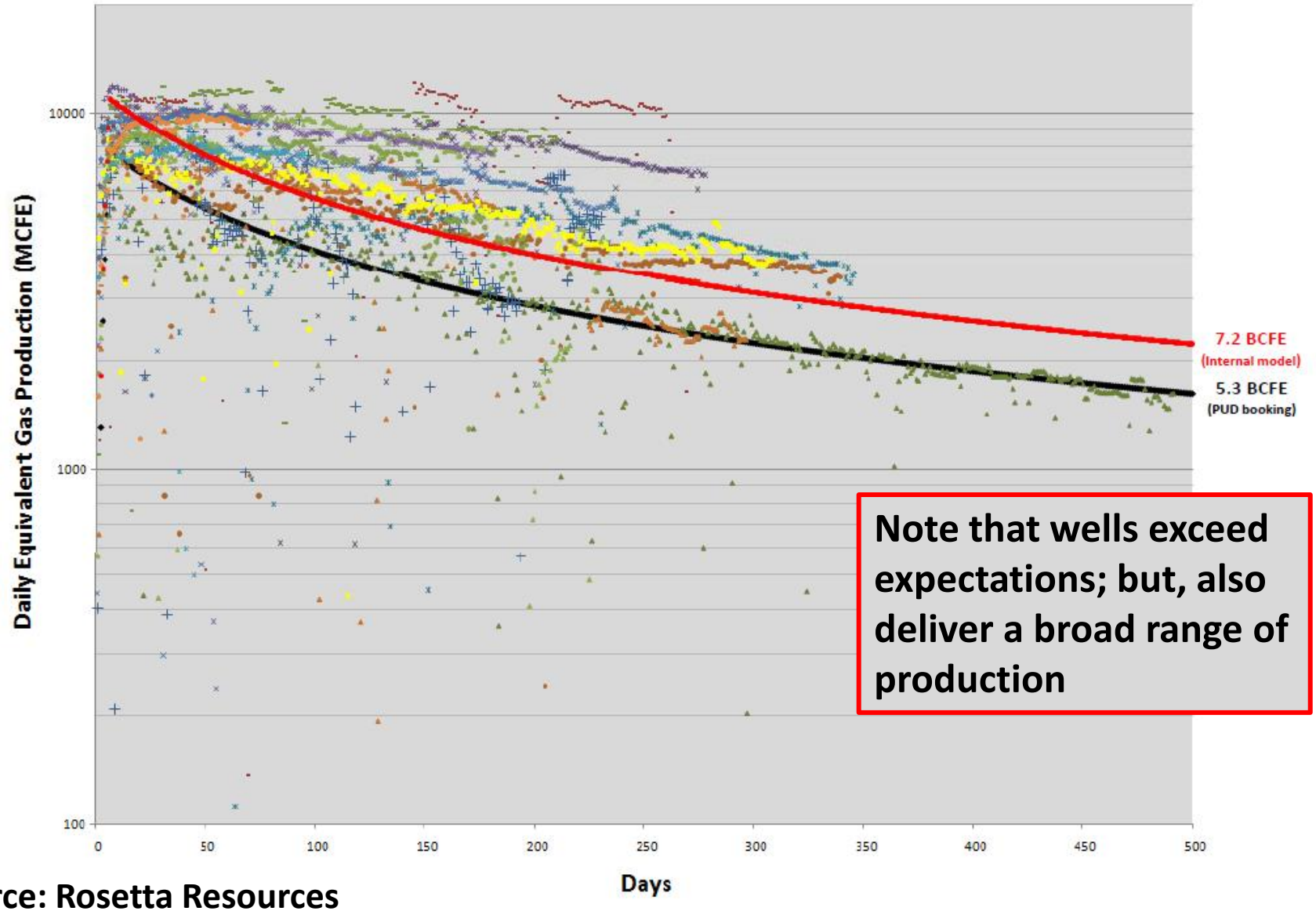


Note that development plan is based on geometric spacing to maximize acreage coverage – well azimuth is perpendicular to regional stress direction

Source: Rosetta Resources Investor Presentation, June 2012

Gates Ranch Proper – Individual Well Performance

Normalized actual results versus internal 7.2 Bcfe P50 curve and P90 PUD booking curve



Note that wells exceed expectations; but, also deliver a broad range of production

Source: Rosetta Resources

IPAA OGIS Conference, 11 April 2011

Eagle Ford Central Type Wells & Potential

DEPTH	7,000'–10,000'
CAPITAL COST	$7.0 MM–$9.0 MM
LATERAL LENGTH	4,500'–5,500'
IP 24-HOUR (6:1)	600–1,100 BOED
EUR (6:1)	400–900 MBOE
IRR	25%–>50%
F&D (6:1)	$12–$20 ($/BOE)
WELL SPACING	120 acres
INVENTORY	>200 MMBOE, ~570 locations

Note the ~100% uncertainty in expected performance of the Type Well (IP, EUR, IRR)

Reducing spacing to 80 acres adds ~100 MMBOE & 280 locations

Economics assume $4.00/MMBtu Gas, $56/Bbl NGL and $80/Bbl Oil
Note: Capital, Production and EUR are gross numbers and do not account for royalties

114

ep

Source: El Paso, 24 May 2011

RG3D™ versus Standard 3D

Full azimuth, long offset data is the key

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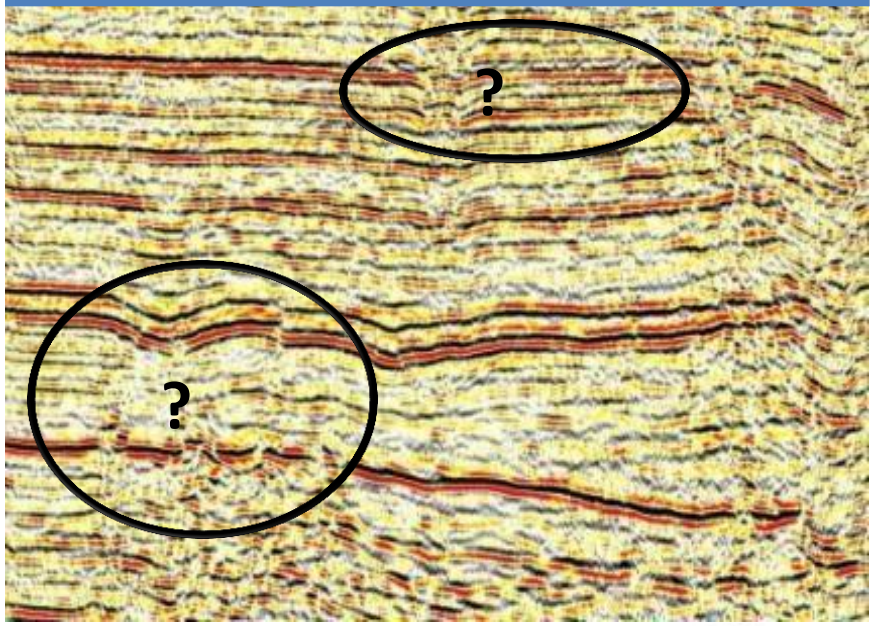
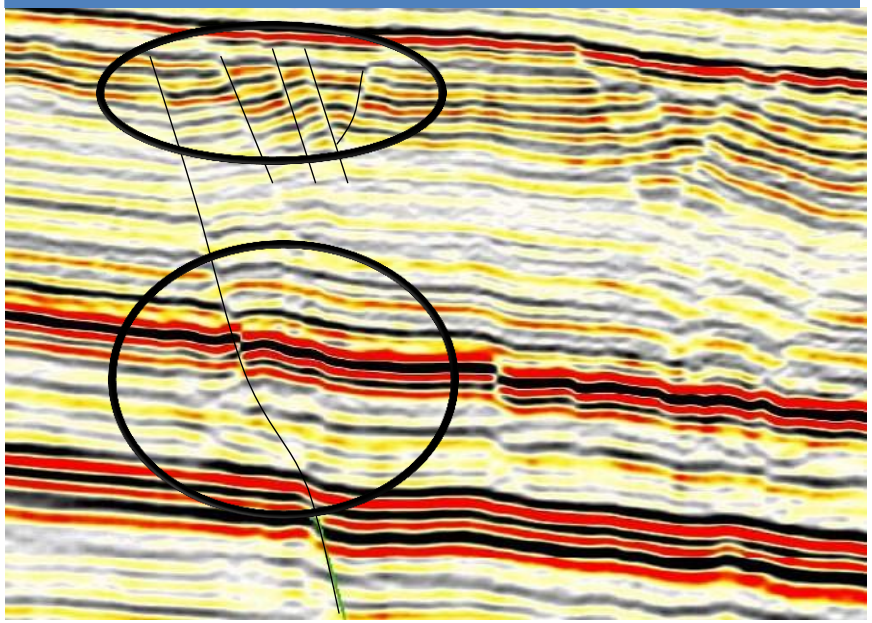
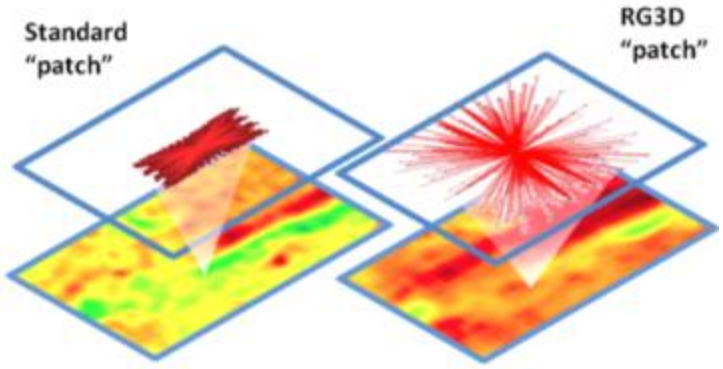
Conventional 3D seismic



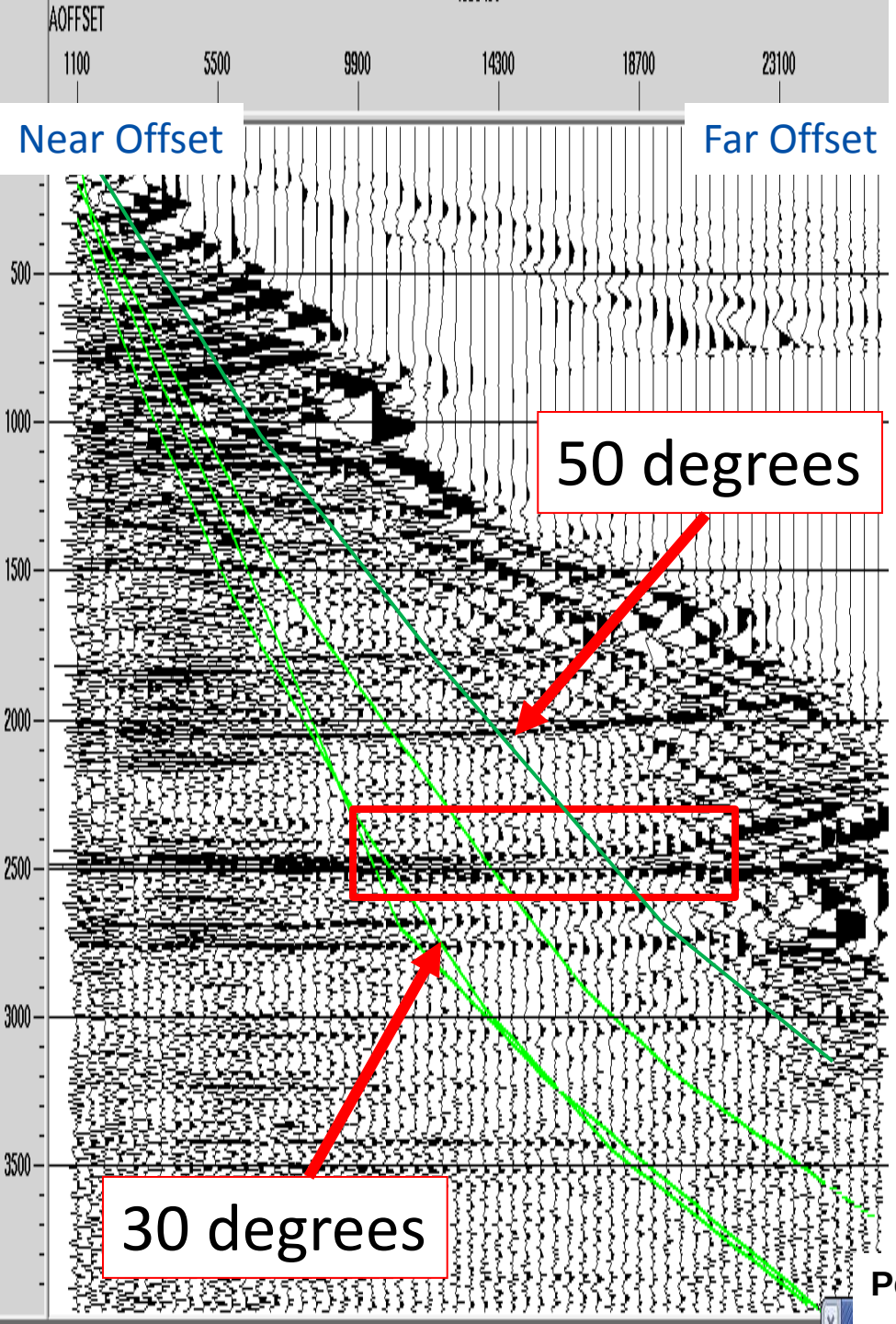
High resolution RG3D seismic





- ✓ High Channel Count
- ✓ Survey Design IP
- ✓ DP Solutions
- ✓ Experience

Seismic Characteristics for the Eagle Ford



- TOC
- Porosity
- Brittle/Ductile Quality (LMR–MuR)
- Young's Modulus
- Bulk Modulus
- Poisson's Ratio
- Differential Stress
- Stress Field Orientation
- Azimuthal Anisotropy
- Pore Pressure
- Facies (rock type, clay content)

Looking for Proxies for Producibility

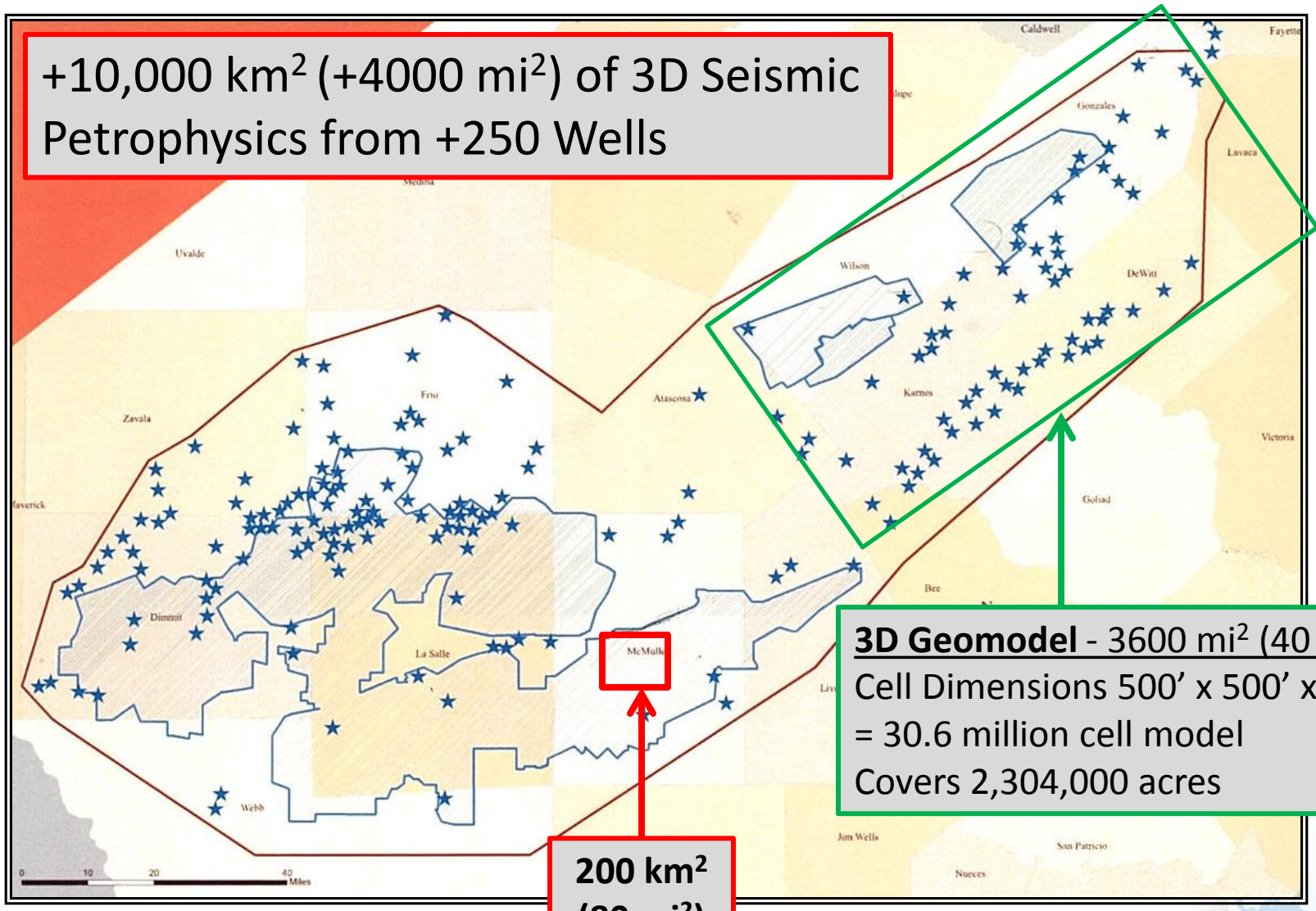
Eagle Ford Data Set

Petrophysics	Seismic	GeoModel
Conventional Logs	PSTM (isotropic)	Structural Framework
Porosity	Velocity Model	- faults
Permeability	Depth Converted Volume	- surfaces
Lithology	Azimuthal Anisotropy	Reservoir Zonation
Bulk Volume	Acoustic Impedence	Mechanical Zonation
Shale Volume	Brittle / Ductile	Property Models
Clay Volume	Lambda Rho, Mu Rho	- Porosity
Pore Size Distribution	Poisson's Ratio	- Permeability
Irreducible Water	Young's Modulus	- TOC
TOC	TOC	- Facies
Poisson's Ratio	Seismic Facies	- Oil Saturation
Bulk Modulus	Coherency	- Water Saturation
Pay Flags	Curvature	- Young's Modulus
	Spec Decomp	- Poisson's Ratio

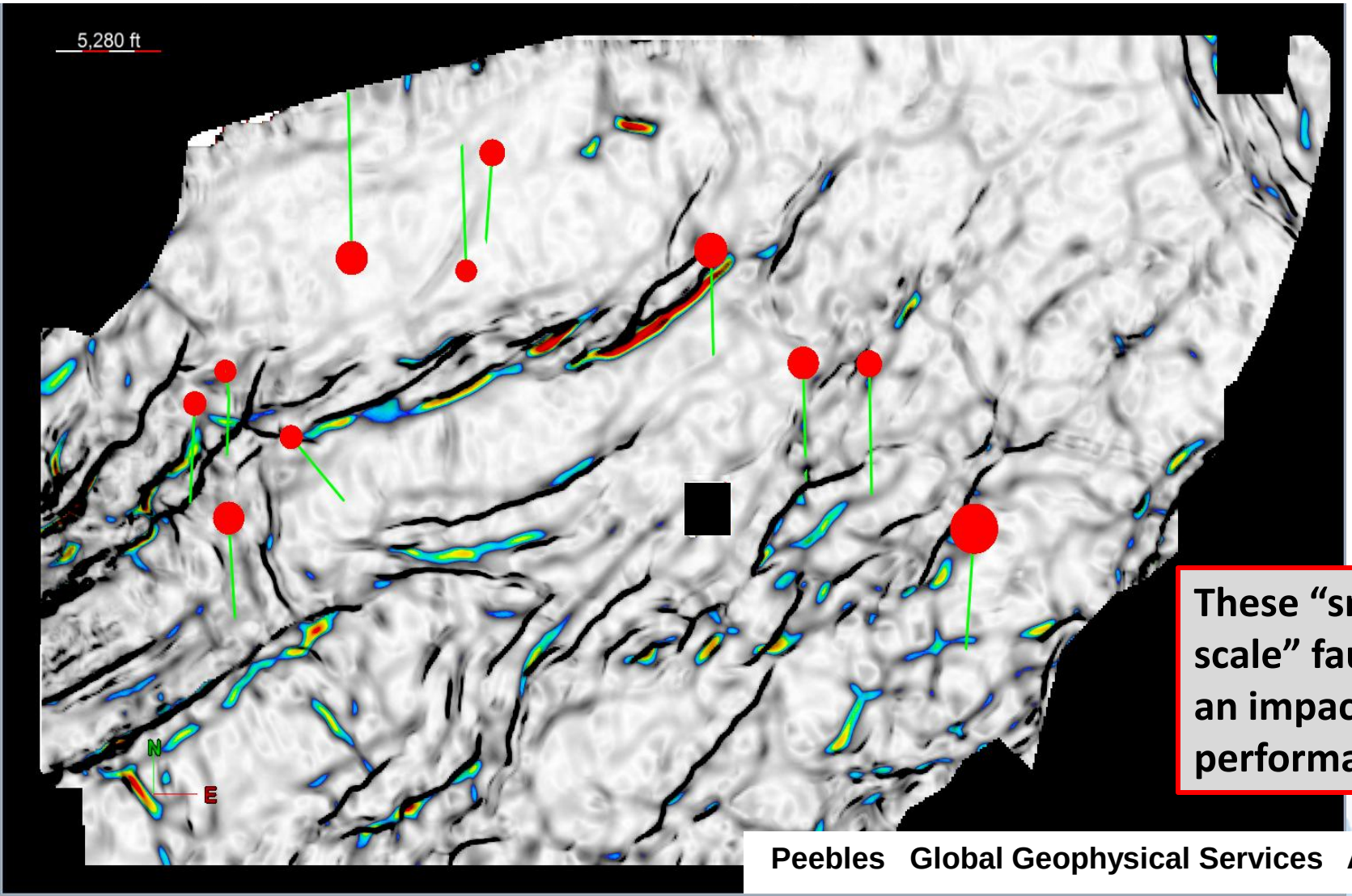
Integrated Production Analysis - Well Prospectivity & Productivity Analysis

Portfolio of Performance Indicators; Predictive Production Model

Eagle Ford Data Set



Incoherence & Max Curvature with Max Monthly Gas Production



These “small-scale” faults have an impact on well performance

Linear Correlation – Initial Assessment

Performance Metric ->

Well Attribute	CC
Well - Cum Gas - Max Monthly	1.0
Horizontal Section - Amplitude - Amp_RMS	0.517
Horizontal Section - <True Vertical Depth>	0.672
Horizontal Section - Wellbore Azimuth - Azimuth	0.296
Horizontal Section - Amplitude - ClrInv_RMS	-0.082
Horizontal Section - Azimuth - Curv_azimuth	0.044
Horizontal Section - Time Dip - Curv_dip	-0.134
Horizontal Section - Dimensionless - Curv_linearity	-0.135
Horizontal Section - Dimensionless - Curv_planarity	0.171
Horizontal Section - Amplitude - Envelope	0.577
Horizontal Section - Amplitude - FracFactor	0.649
Horizontal Section - Wellbore Horizontal Length - Horizontal Length	0.37
Horizontal Section - Amplitude - Incoherence_Max	-0.297
Horizontal Section - Amplitude - InstFrq	-0.206
Horizontal Section - Amplitude - InstPhs	0.363
Horizontal Section - Depth - Isochore	-0.191
Horizontal Section - Time-domain Curvature Squared - Kgauss_MAX	0.139
Horizontal Section - Azimuth - Kmax_azimuth	0.148
Horizontal Section - Time-domain Curvature - Kmax_MAX	0.238
Horizontal Section - Azimuth - Kmin_azimuth	-0.304
Horizontal Section - Time-domain Curvature - Kmin_MAX	0.308
Horizontal Section - Time-domain Curvature - Kminmax_MAX	0.262
Horizontal Section - Time-domain Curvature - Kneg_MAX	0.265
Horizontal Section - Time-domain Curvature - Kpos_MAX	0.238
Horizontal Section - Amplitude - PeakSpecF	-0.021
Horizontal Section - Amplitude - SpecD_10Hz	0.614
Horizontal Section - Amplitude - SpecD_12Hz	0.529
Horizontal Section - Amplitude - SpecD_14Hz	0.463
Horizontal Section - Amplitude - SpecD_16Hz	0.435
Horizontal Section - Amplitude - SpecD_20Hz	0.461
Horizontal Section - Amplitude - SpecD_24Hz	0.532
Horizontal Section - Amplitude - SpecD_28Hz	0.607
Horizontal Section - Amplitude - SpecD_32Hz	0.598
Horizontal Section - Amplitude - SpecD_36Hz	0.331
Horizontal Section - Amplitude - SpecD_40Hz	0.088
Horizontal Section - Amplitude - SpecD_50Hz	-0.15
Horizontal Section - Amplitude - SpecD_60Hz	-0.248
Horizontal Section - Amplitude - Sweetness	0.575
Horizontal Section - Velocity Anisotropy - Velocity Anisotropy	0.698
Horizontal Section - Azimuth - Vfast Azimuth	0.295

Engineering Data

Seismic Attributes

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Performance Metric = Max Monthly Gas Production

Potential Indicators:
36 Seismic Attributes
3 Engineering Attributes

No CC greater than 0.70
11 greater than 0.50

It is important to include engineering and geological "attributes" as well as seismic attributes in this initial assessment of potential performance indicators

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Engineering Attributes & Production Metrics

Completion Variables

(1) Time On Stream (months)
(2) Completion length (ft)
(3) Avg. Stage length (ft)
(4) Number of stages
(5) Average Fracture gradient (psi/ft)
(6) Breakdown Pressure (psi)
(7) ISIP (psi)
(8) Slurry volume pumped (bbl/stage)
(9) Clean Fluid pumped (bbl/stage)
(10) Acid pumped (gals/stage)
(11) Total Proppant pumped (lb/stage)
(12) Avg. Injection Rate (bbl/min)
(13) Clean Fluid rate (bpm/stage)
(14) Gas rate (bpm/stage)

Production Metrics

(1) Min Daily Avg. (MCF)
(2) Mean Daily Avg. (MCF)
(3) Max Daily Avg (MCF)
(4) Max 30 Day (MCF)
(5) 6-month Cum Production (MCF)
(6) EUR (MCF)
(7) Scaled Max 30 Day (MCF/ft)
- Scaled by completion length

(8) Scaled Max Daily Average (MCF/ft)
- Scaled by completion length

(9) Cum/time (MCF/month)

Linear Correlation - Max. Monthly Production

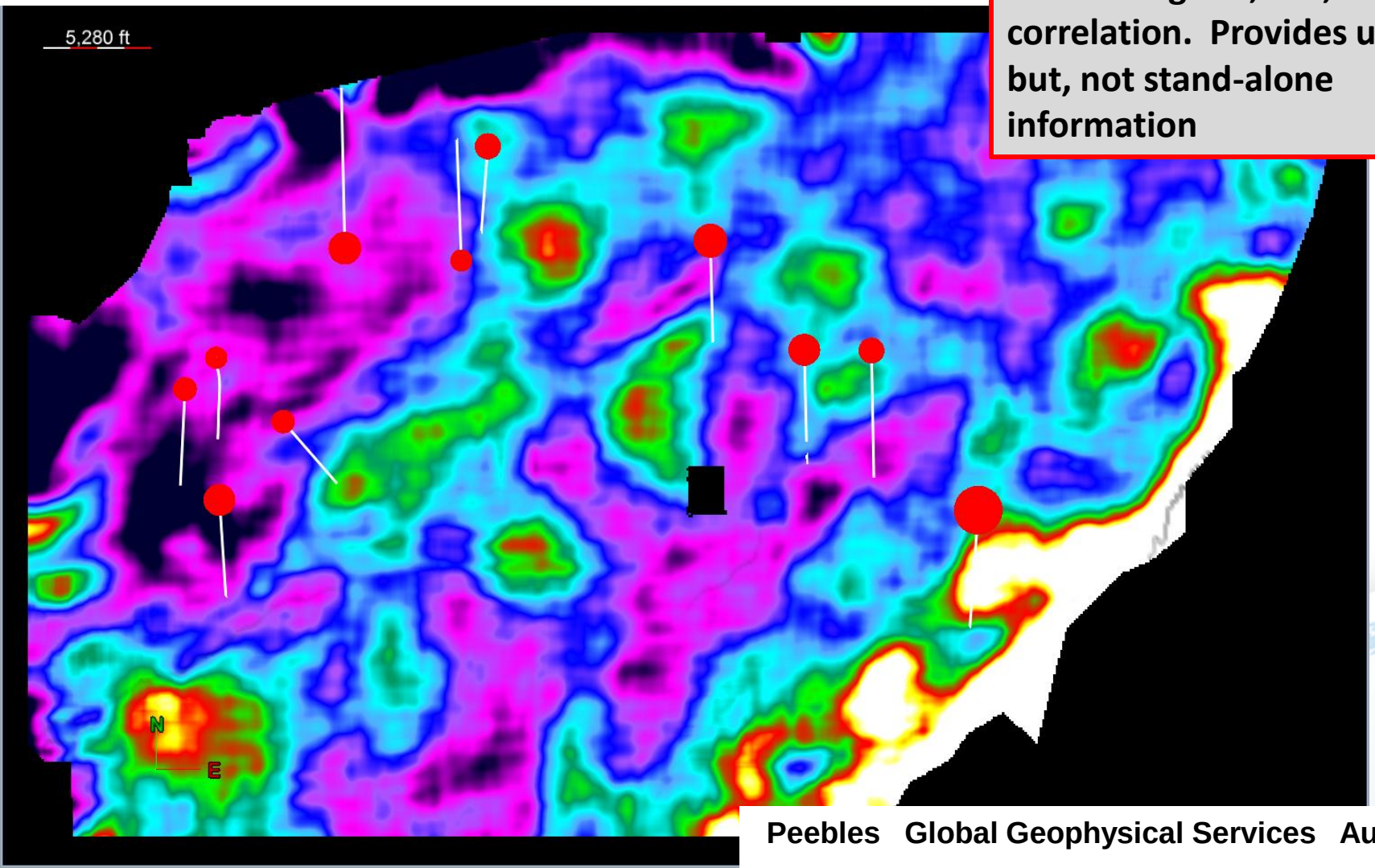
	Max Monthly Gas	FracFactor	Wellbore Length	SpecD 10Hz	SpecD 32Hz	Velocity Anisotropy
Well - Cum Gas - Max Monthly	1.0	0.649	0.37	0.614	0.598	0.698
Horizontal Section - Amplitude - FracFactor	0.649	1.0	0.103	0.698	0.745	0.578
Horizontal Section - Wellbore Horizontal Length	0.37	0.103	1.0	0.041	0.089	0.076
Horizontal Section - Amplitude - SpecD_10Hz	0.614	0.698	0.041	1.0	0.787	0.699
Horizontal Section - Amplitude - SpecD_32Hz	0.598	0.745	0.089	0.787	1.0	0.619
Horizontal Section - Velocity Anisotropy	0.698	0.578	0.076	0.699	0.619	1.0

5 Primary Performance Indicators selected:

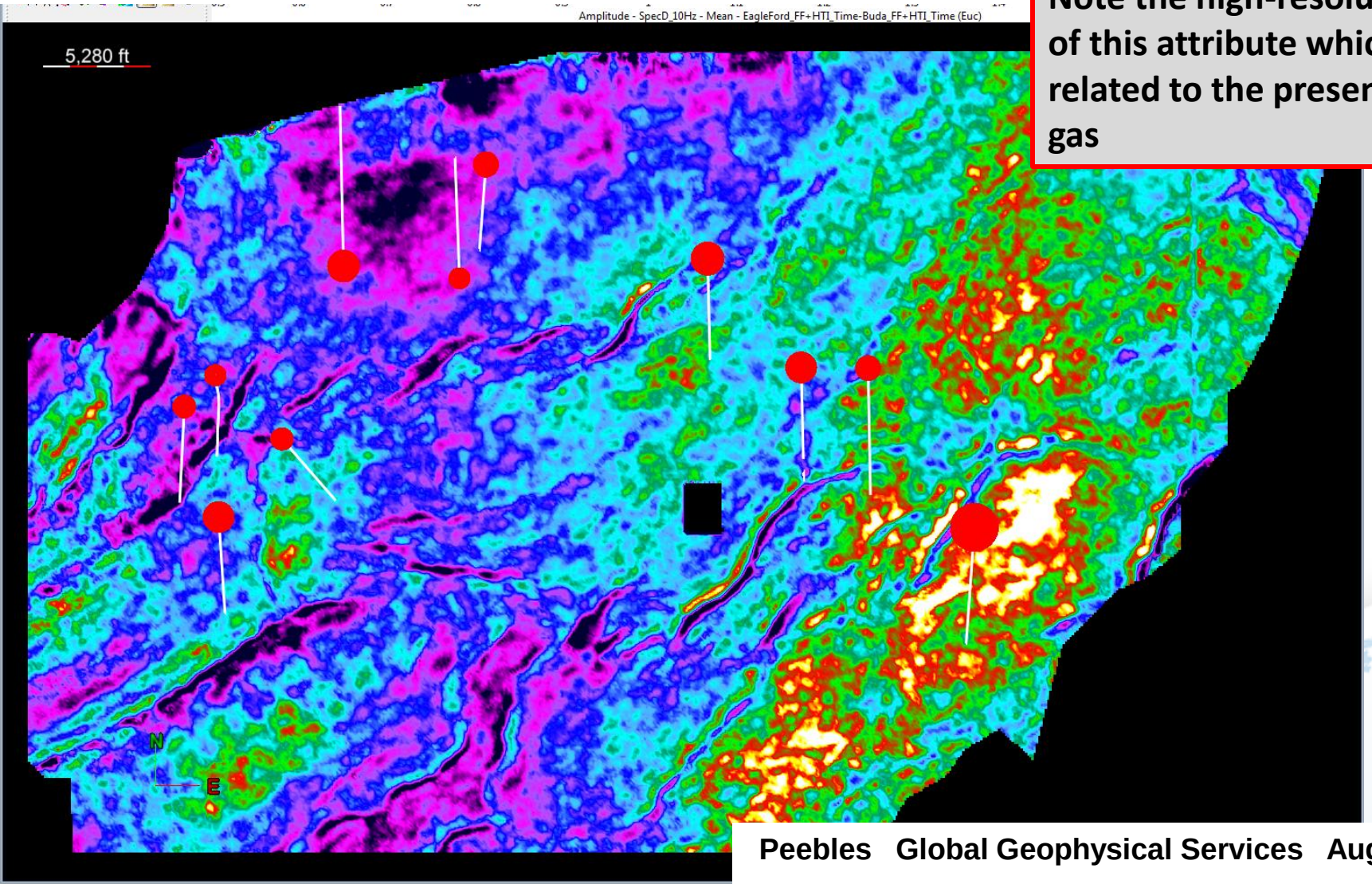
- **Lateral Length** – intersect more productive rock
- **Brittle/Ductile Elastic Inversion** - “fracability”
- **10 Hz Spectral Decomposition** – presence of gas
- **32 Hz Spectral Decomposition** – Eagle Ford thickness
- **Azimuthal Seismic Anisotropy** – differential stress

Brittle/Ductile Inversion with Max Month Gas Production

There is a good; but, not great correlation. Provides useful; but, not stand-alone information

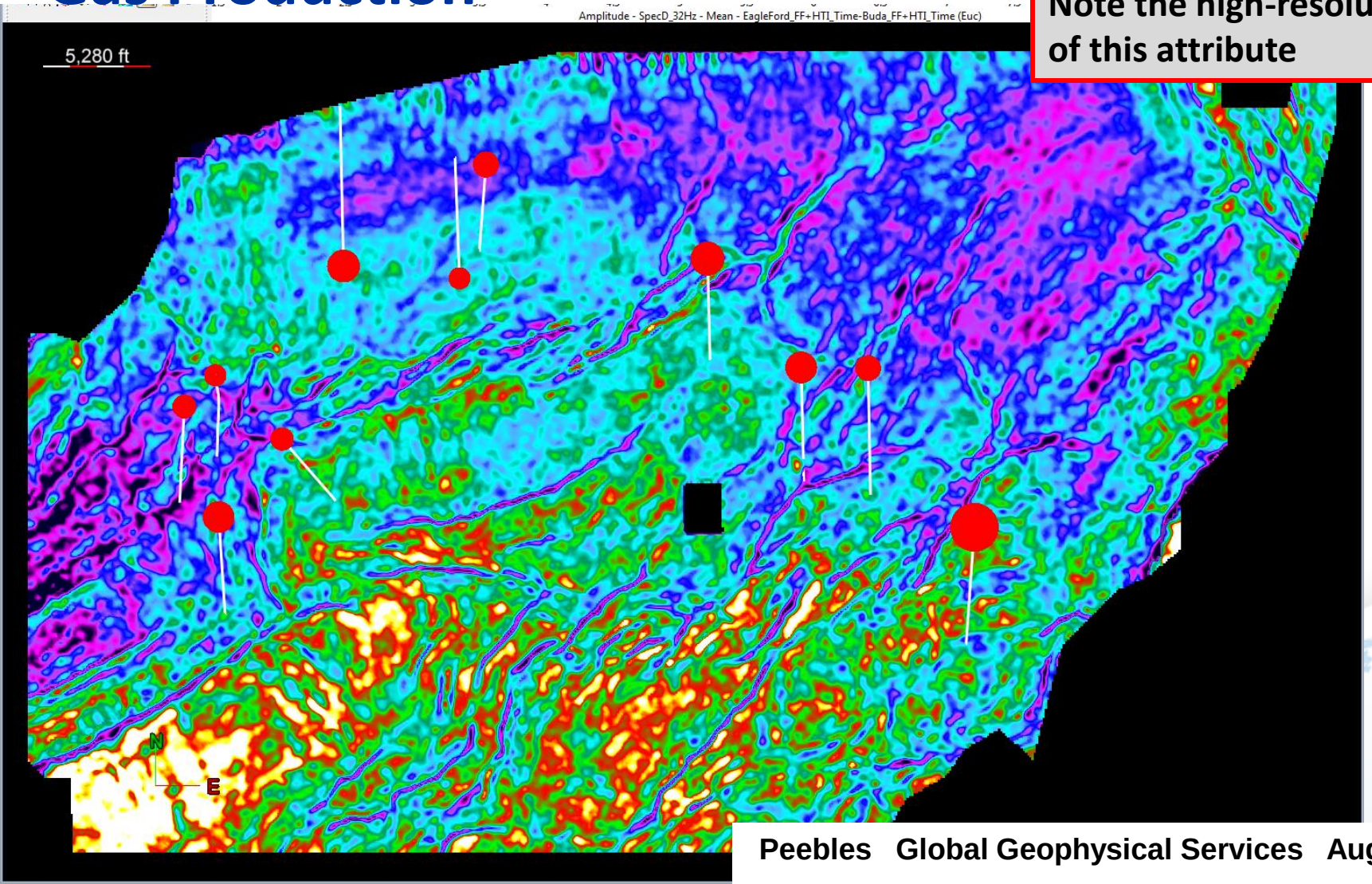


10Hz Spec Decomp with Max Month Gas Production



Note the high-resolution of this attribute which is related to the presence of gas

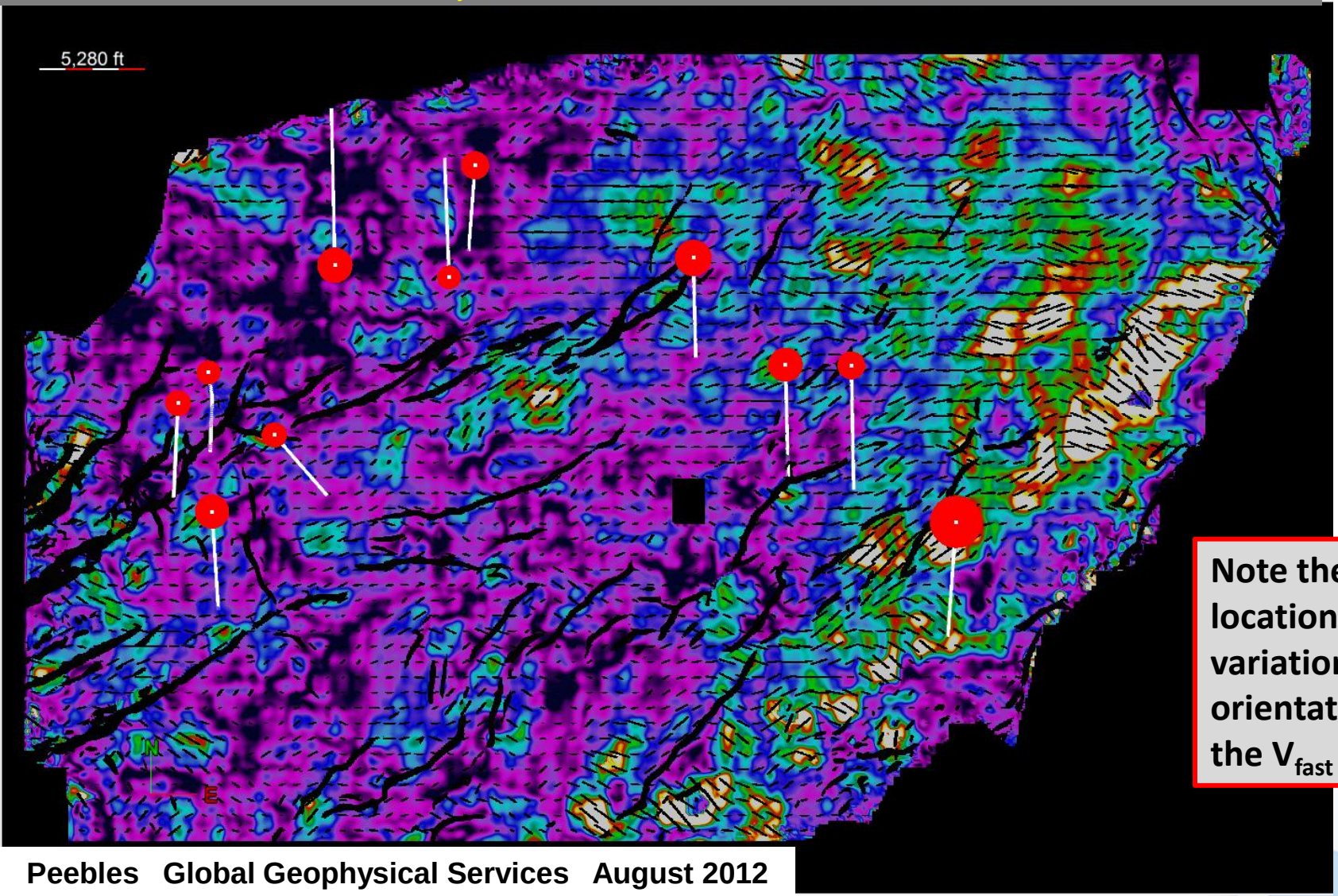
32Hz Spec Decomp with Max Month Gas Production



Note the high-resolution of this attribute

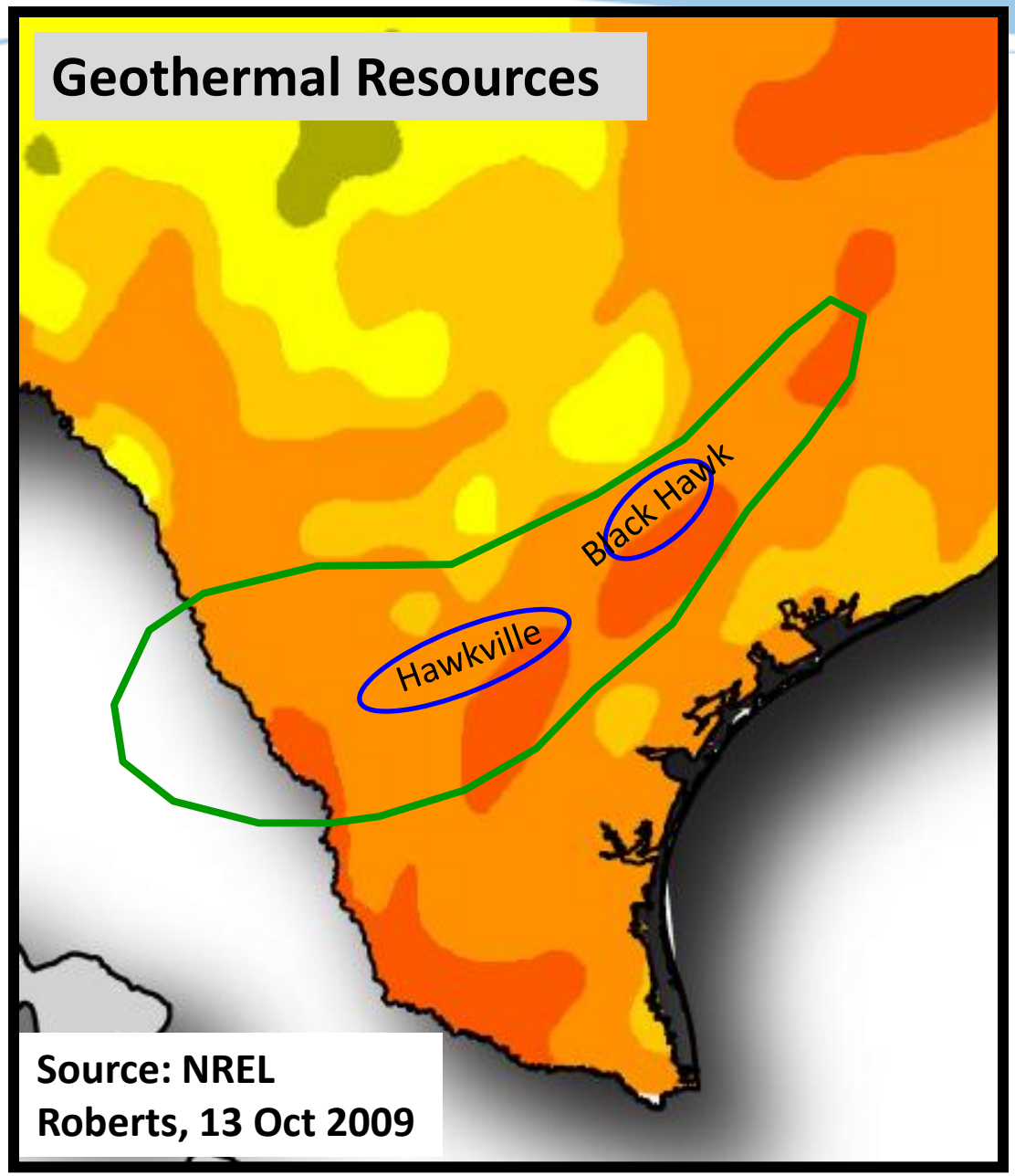
Azimuthal Anisotropy with Max Gas Production

Vectors are in the direction of V_{fast} azimuth and are scaled by the amount of anisotropy



Note the location variations in orientation of the V_{fast} azimuth

Geothermal Resources

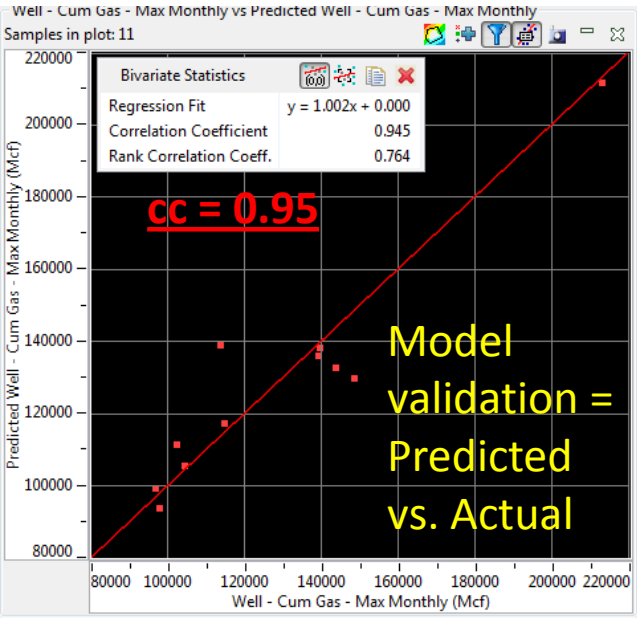


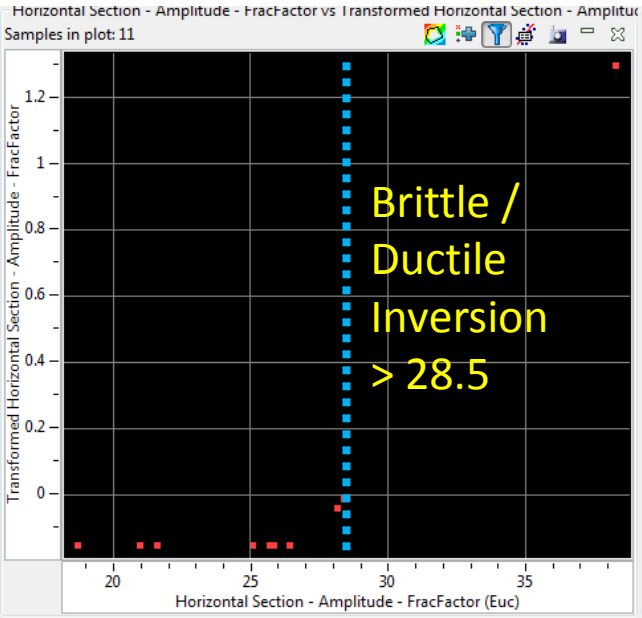
Note high heat flow downdip of major development areas.

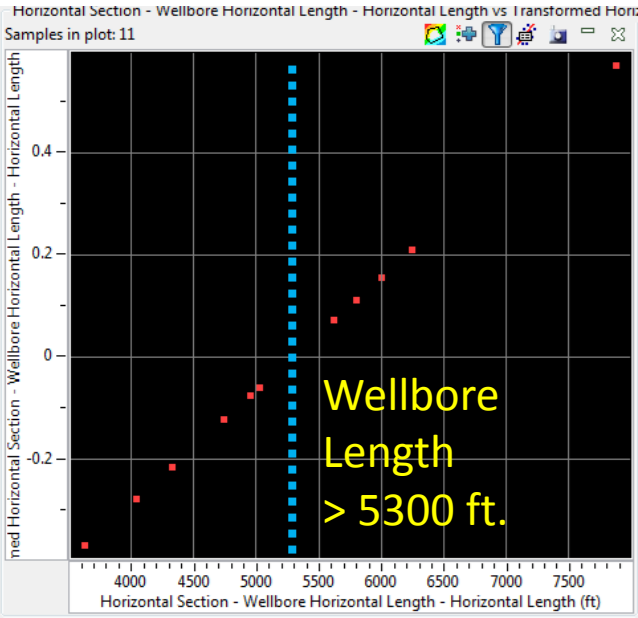
High Heat Flow Promotes:

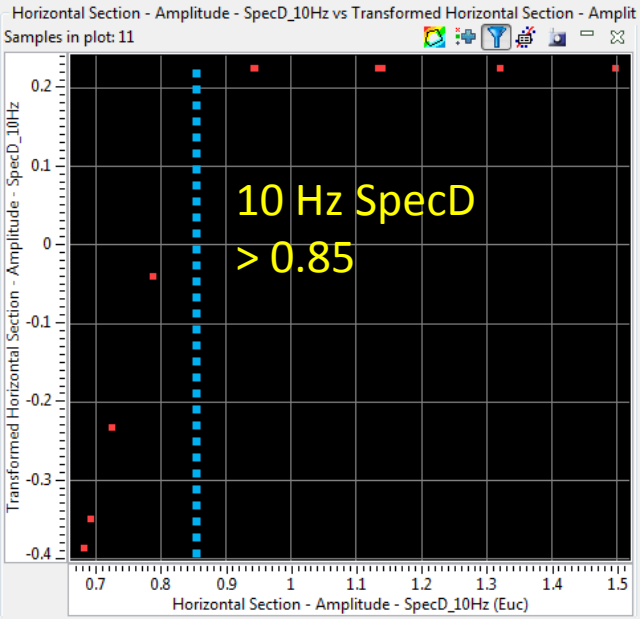
- Accelerated hydrocarbon generation
- Differential Stress
- Overpressure
- Microfracturing

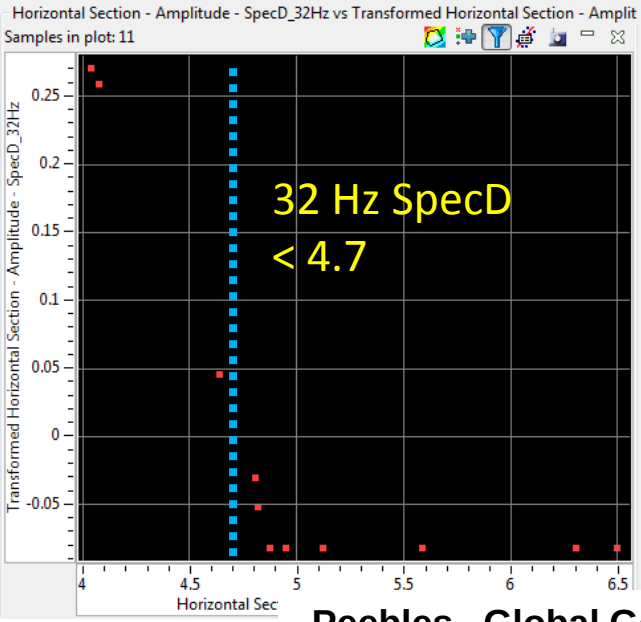
Non-linear Transformation of Portfolio of Indicators

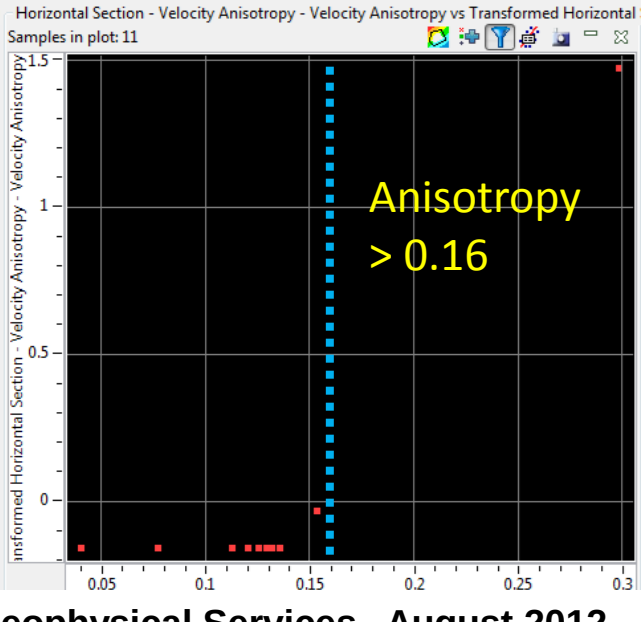




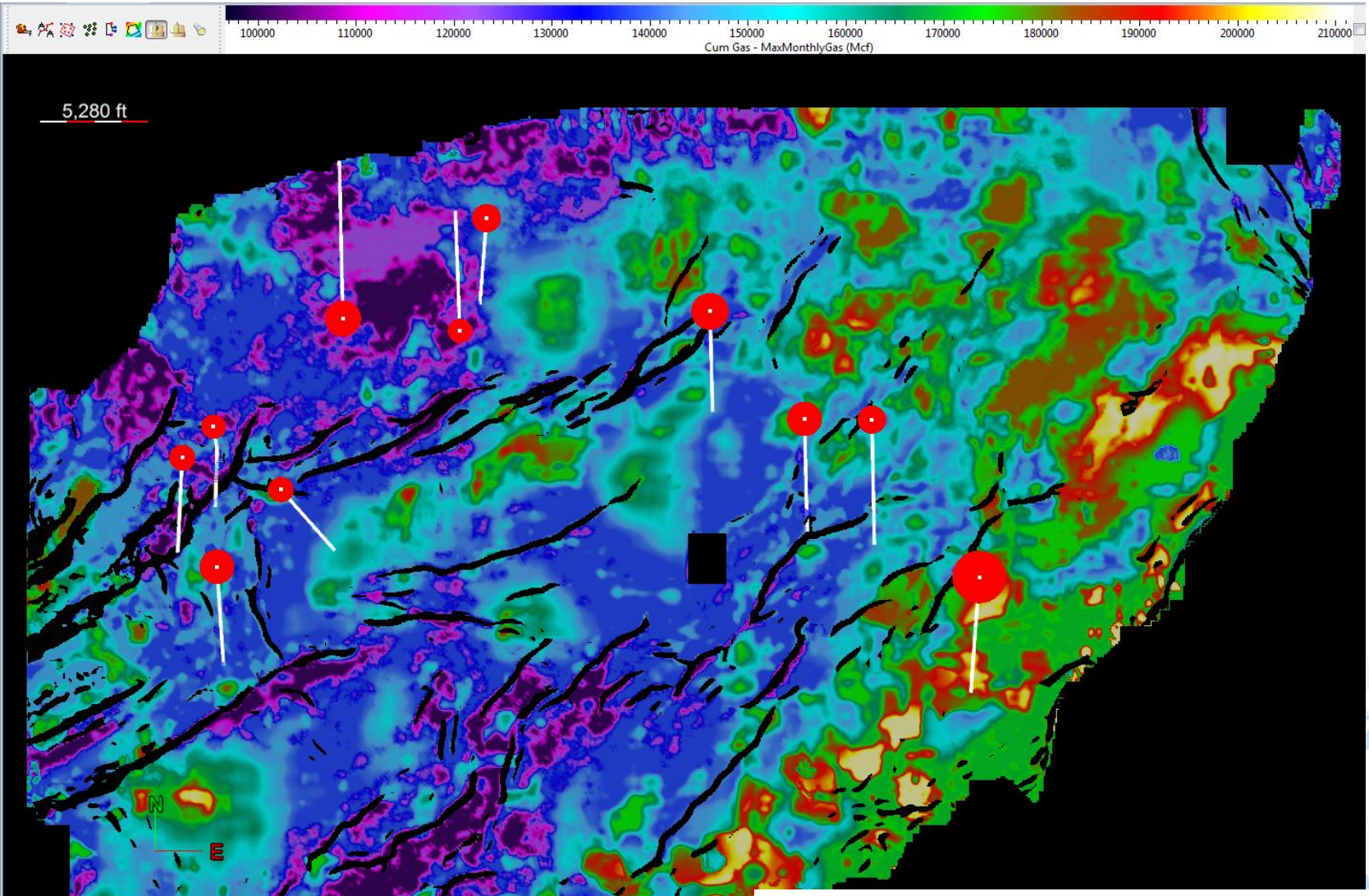




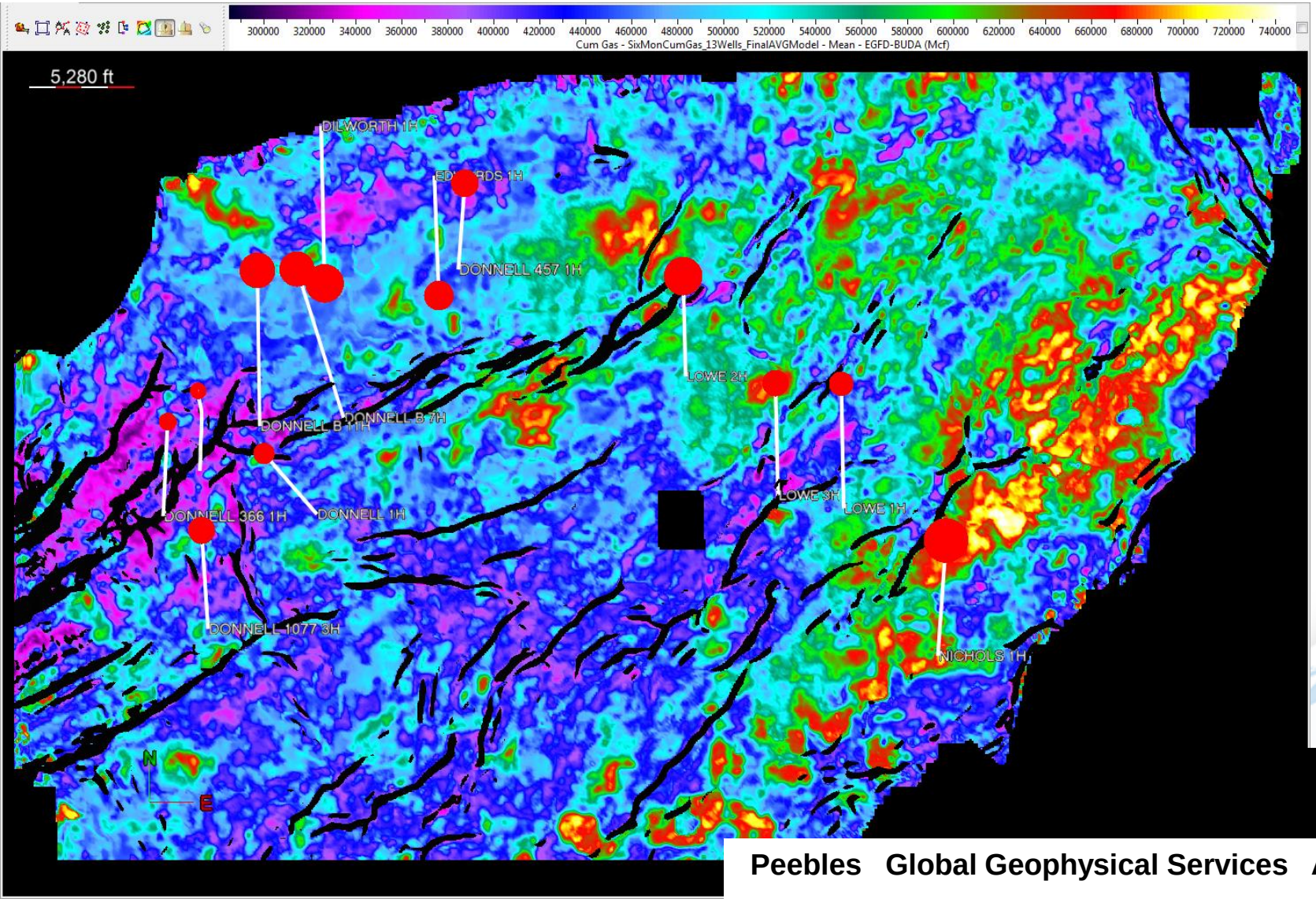




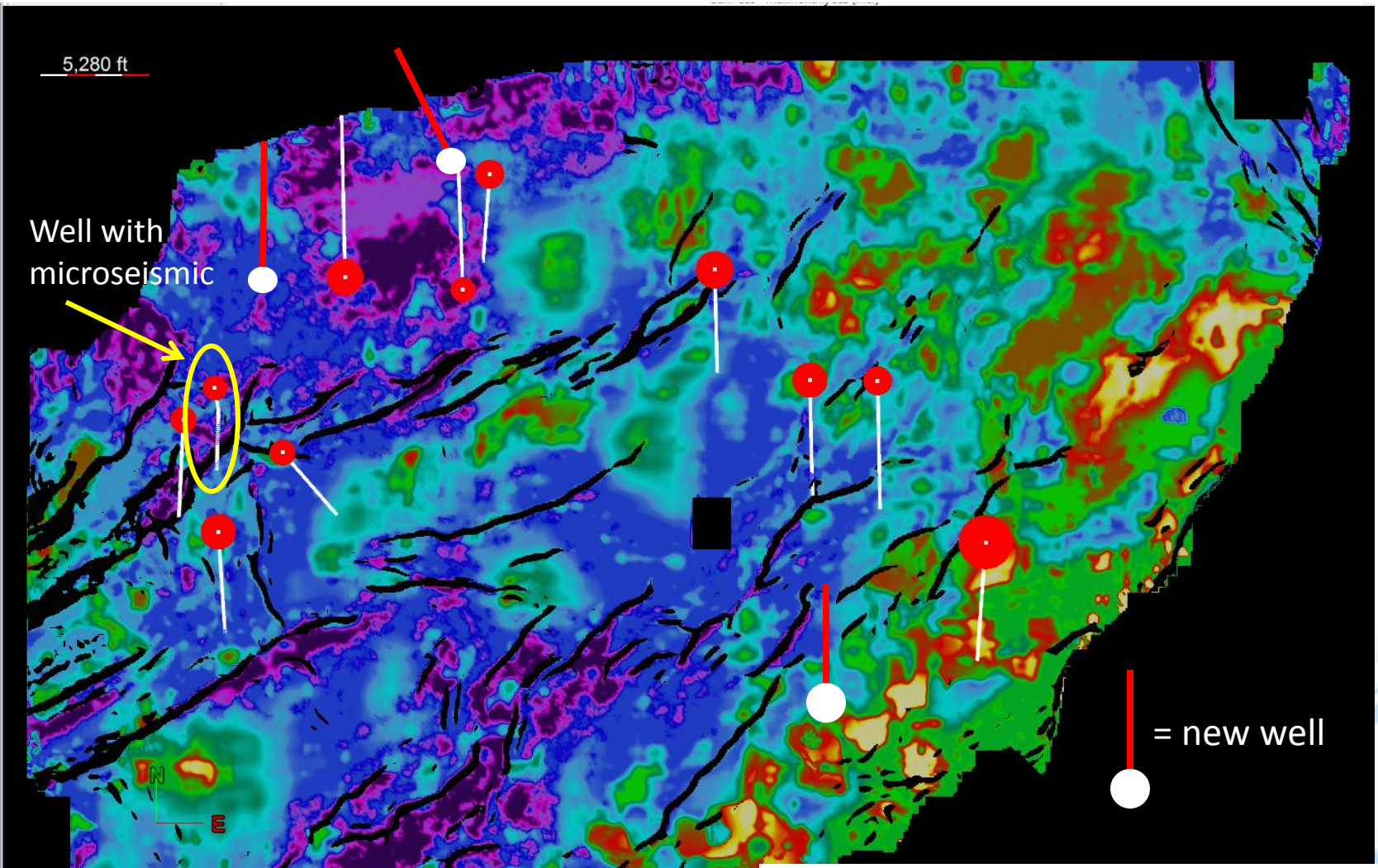
Predictive Max Monthly Gas Production
(using 11 wells)



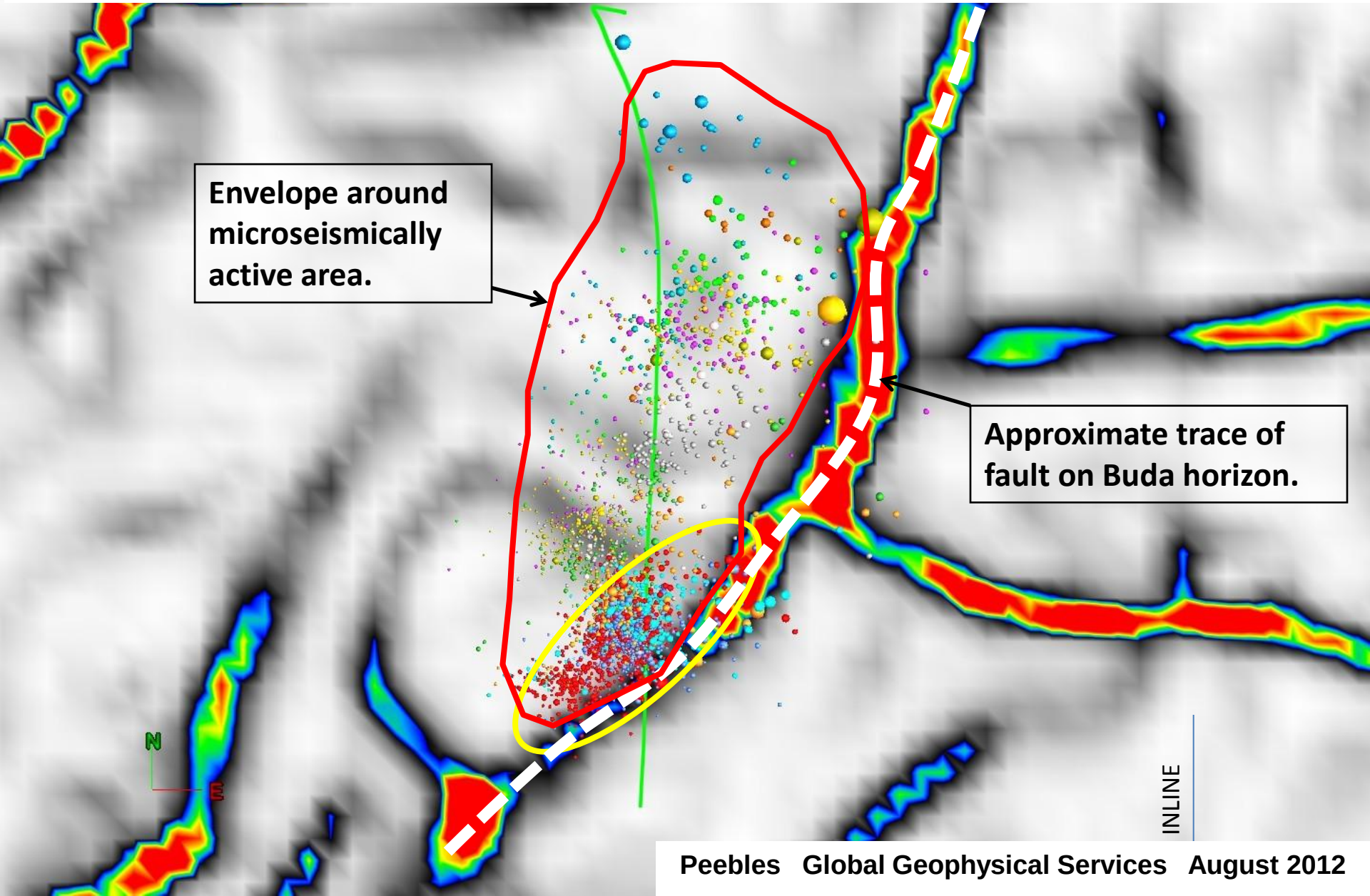
Predictive 6-month Cum Gas Production
(using 13 wells)



Predictive Max Monthly Gas Production & 3 News Wells



Analysis of a Poor-Performing Well
Microseismically Active Volume ≠ Stimulated Rock Volume



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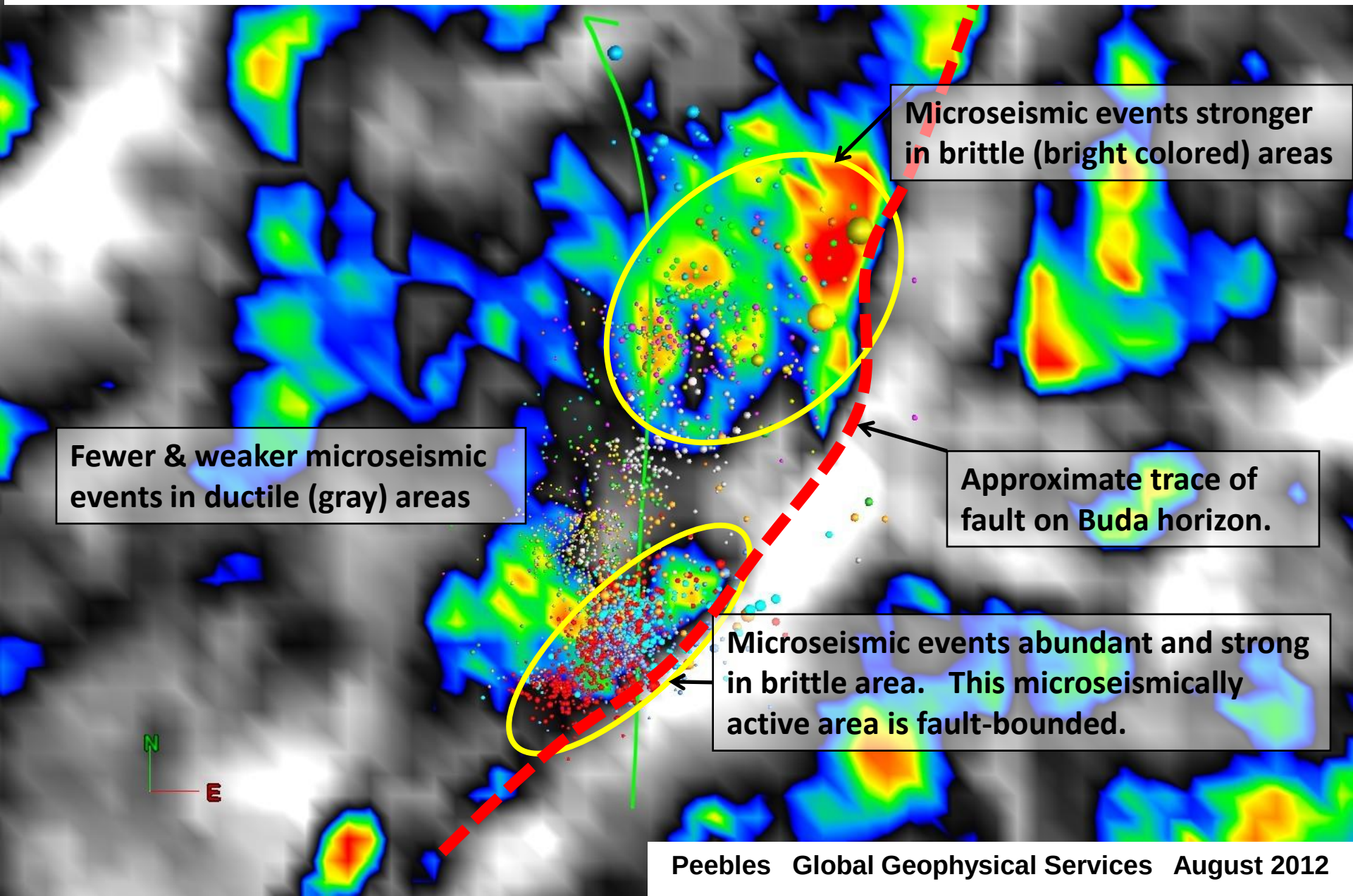
Analysis of a Poor-Performing Well
Brittle/Ductile Inversion Correlates with Event Density and Magnitude



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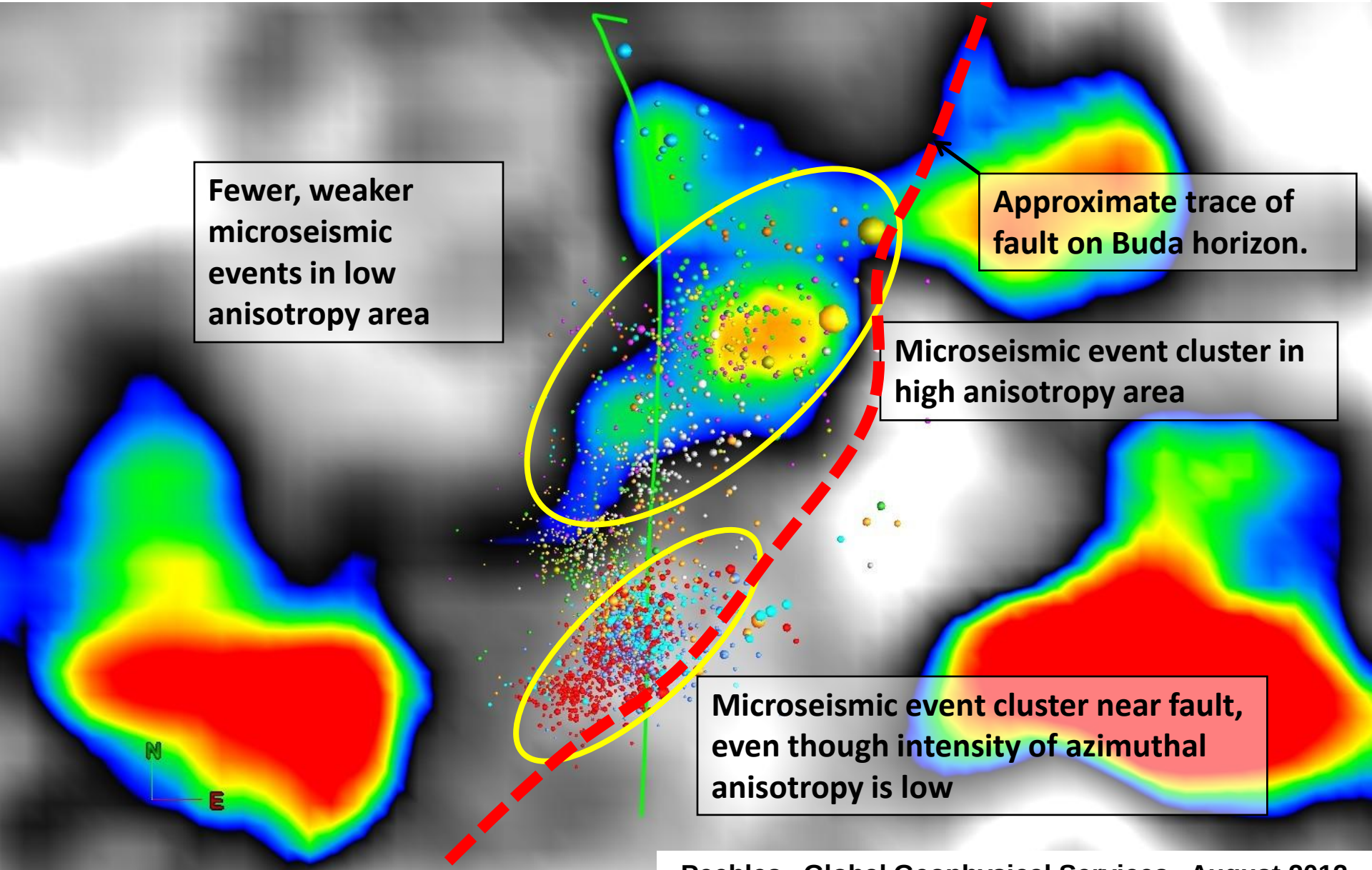
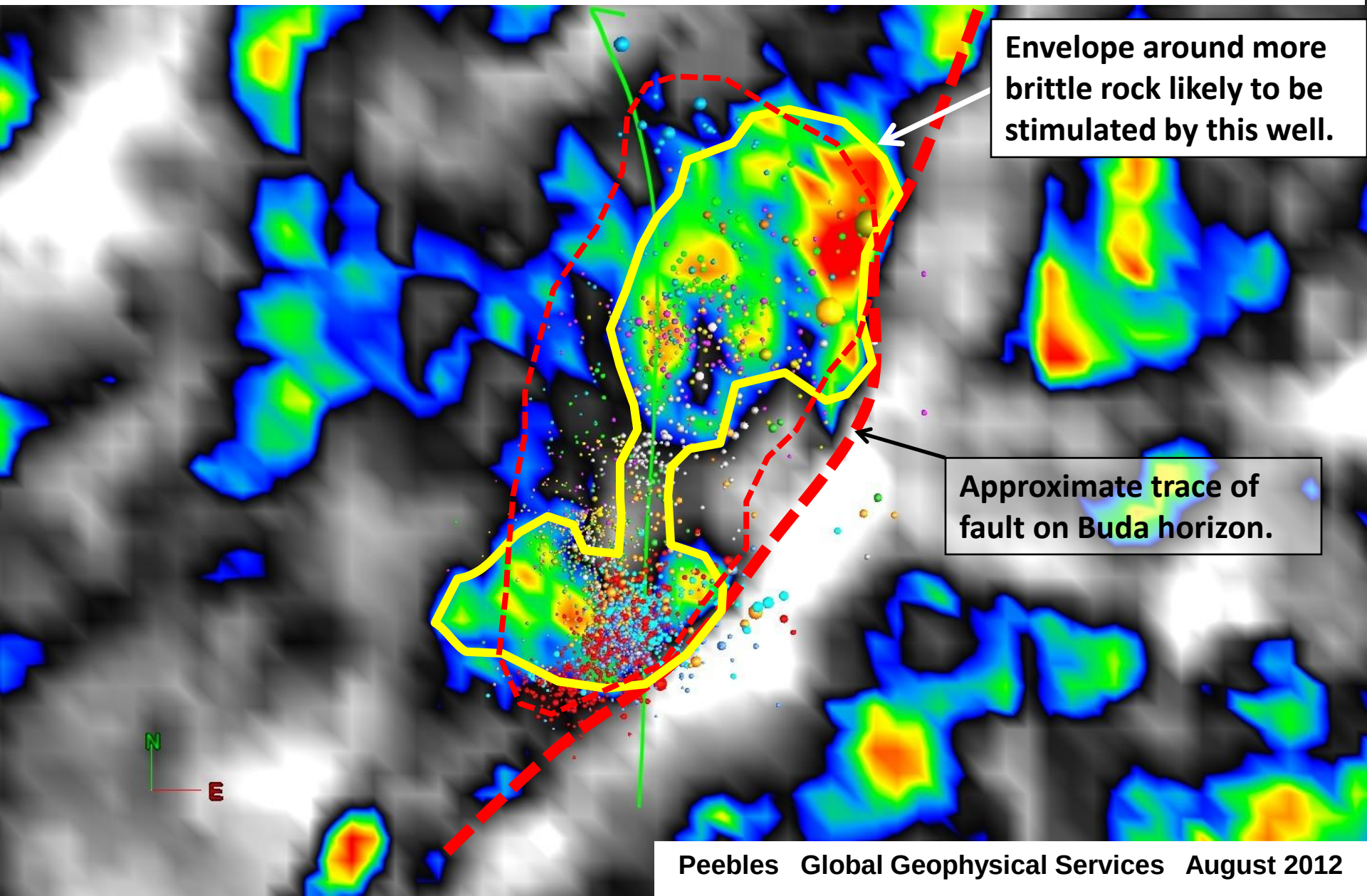
Analysis of a Poor-Performing Well
Correlation of Events with Seismic Azimuthal Anisotropy (magnitude)



Analysis of a Poor-Performing Well
"Potential " Stimulated Rock Volume based on Brittle/Ductile



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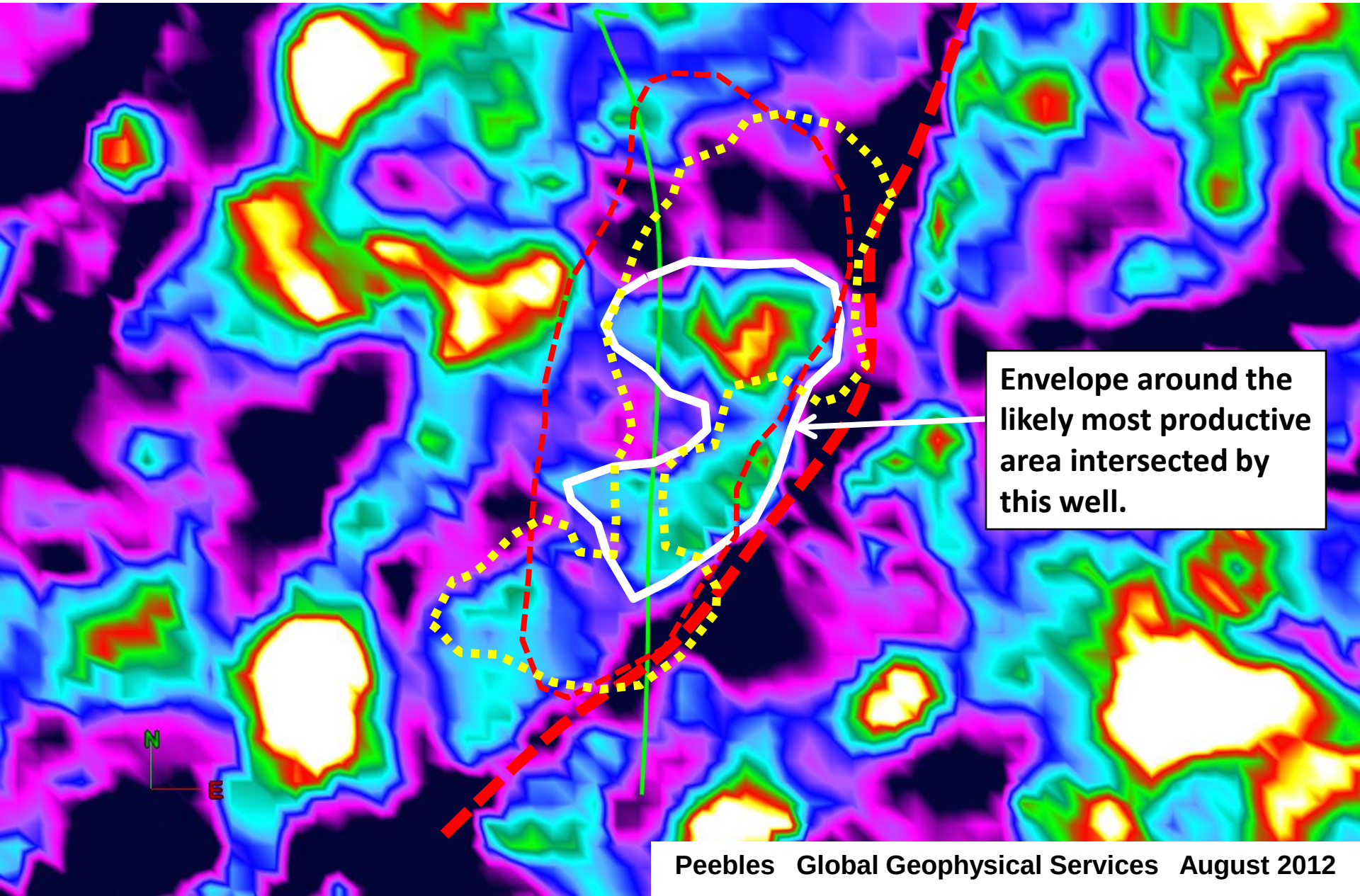
Analysis of a Poor-Performing Well

“Potential “ Most Productive Rock Volume based on Prod Prediction



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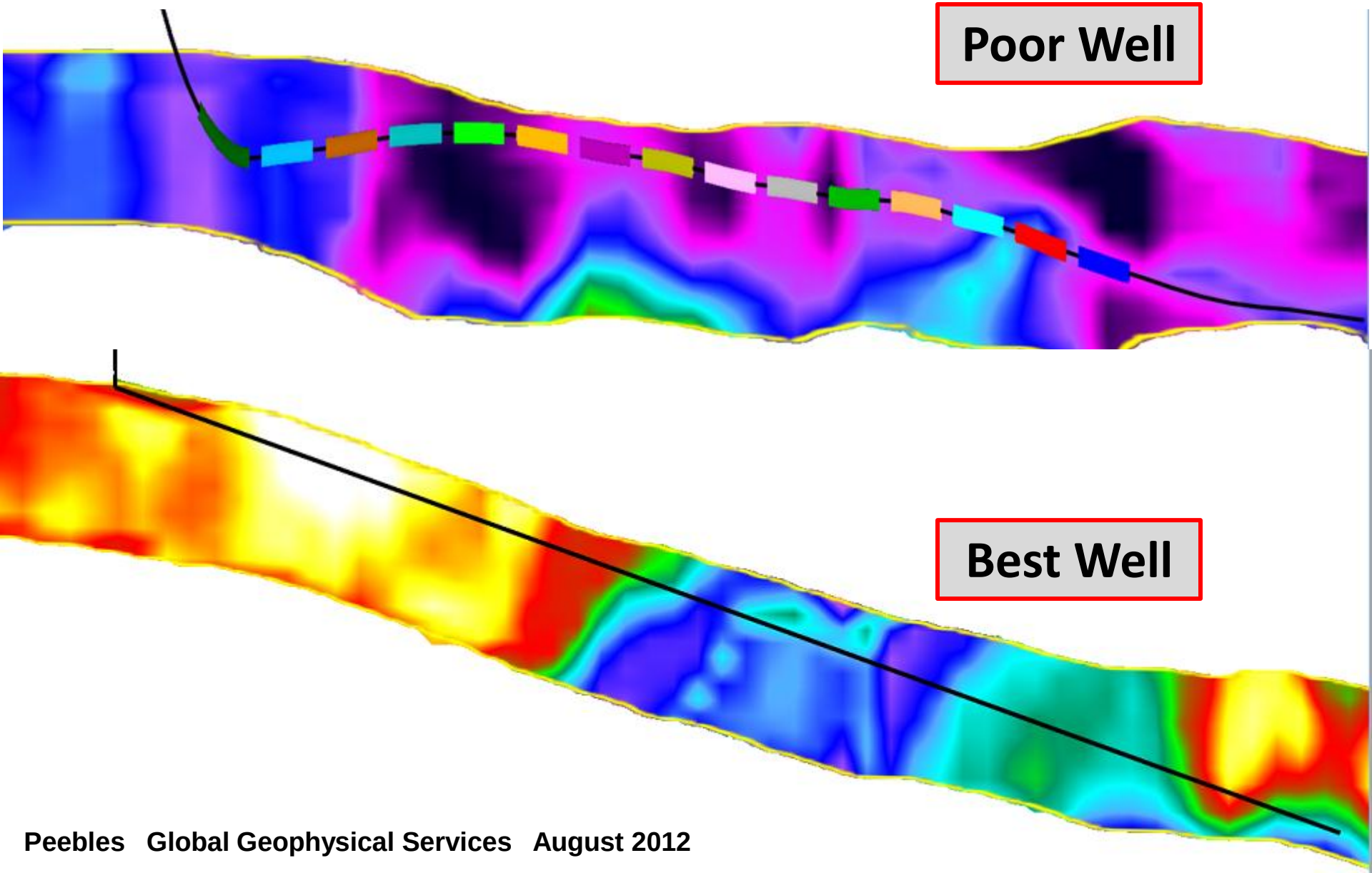
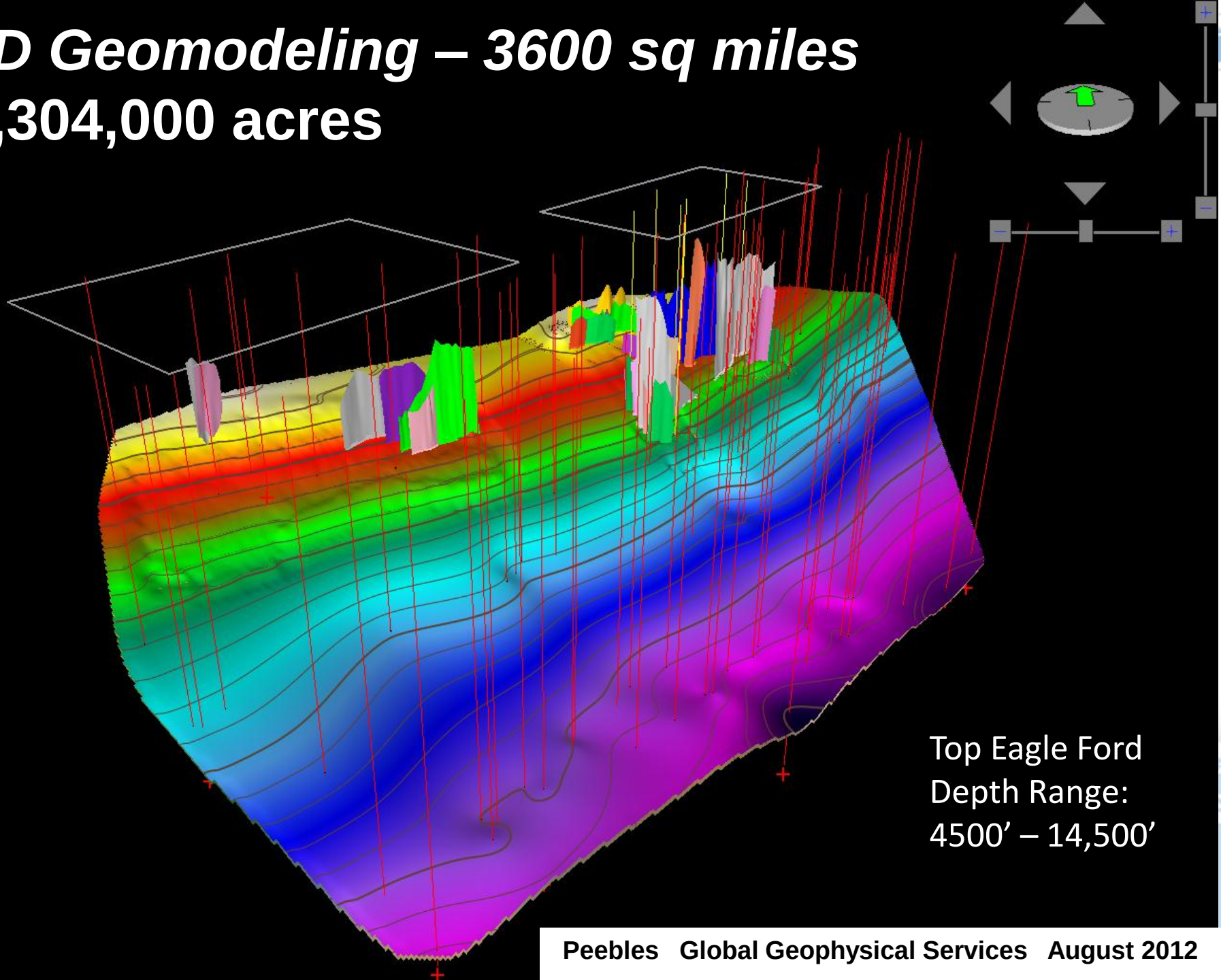
Cross-section view of Poor and Great Wells with Production Prediction Model



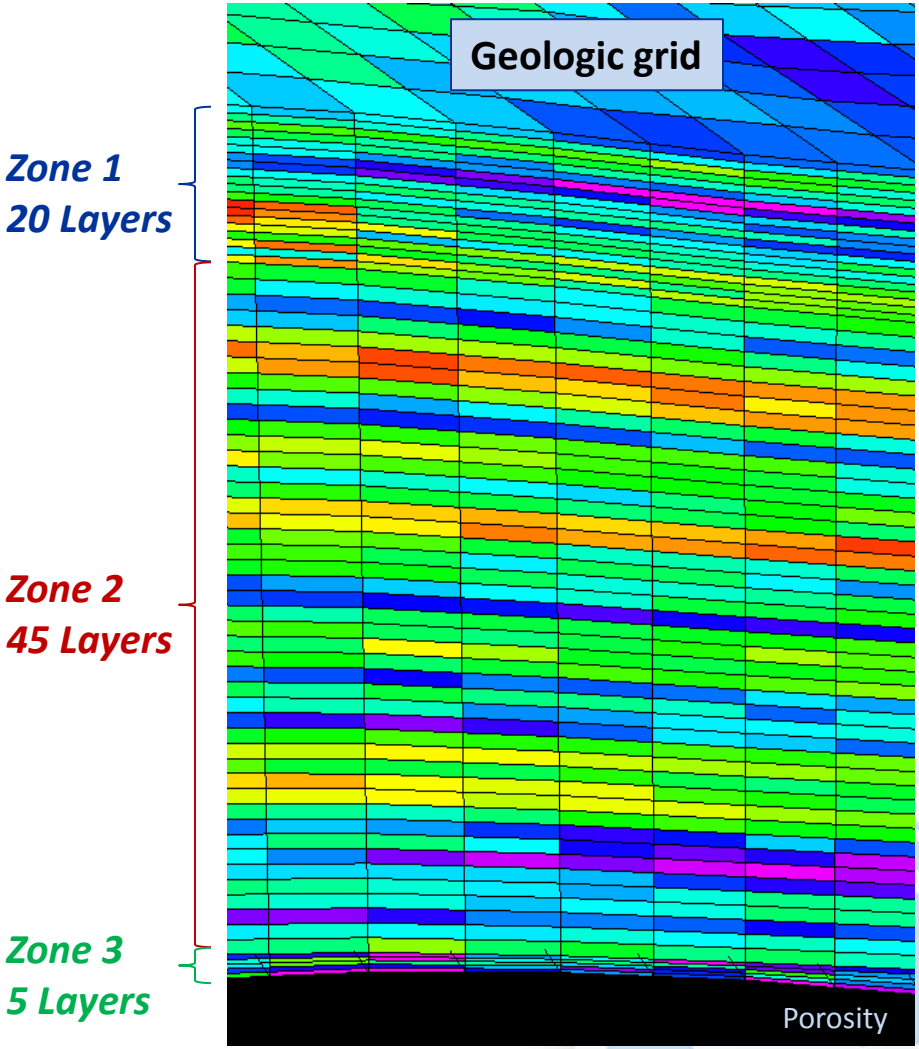
3D Geomodeling – 3600 sq miles
2,304,000 acres



Eagle Ford - North – 3D GeoModel

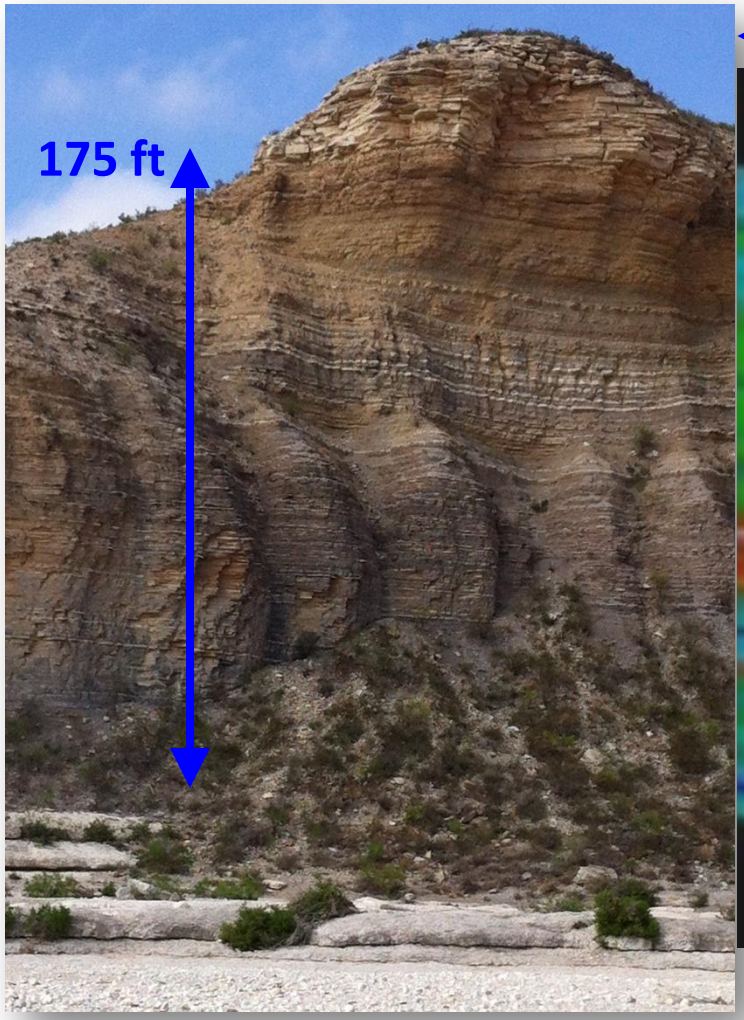
The property models include:

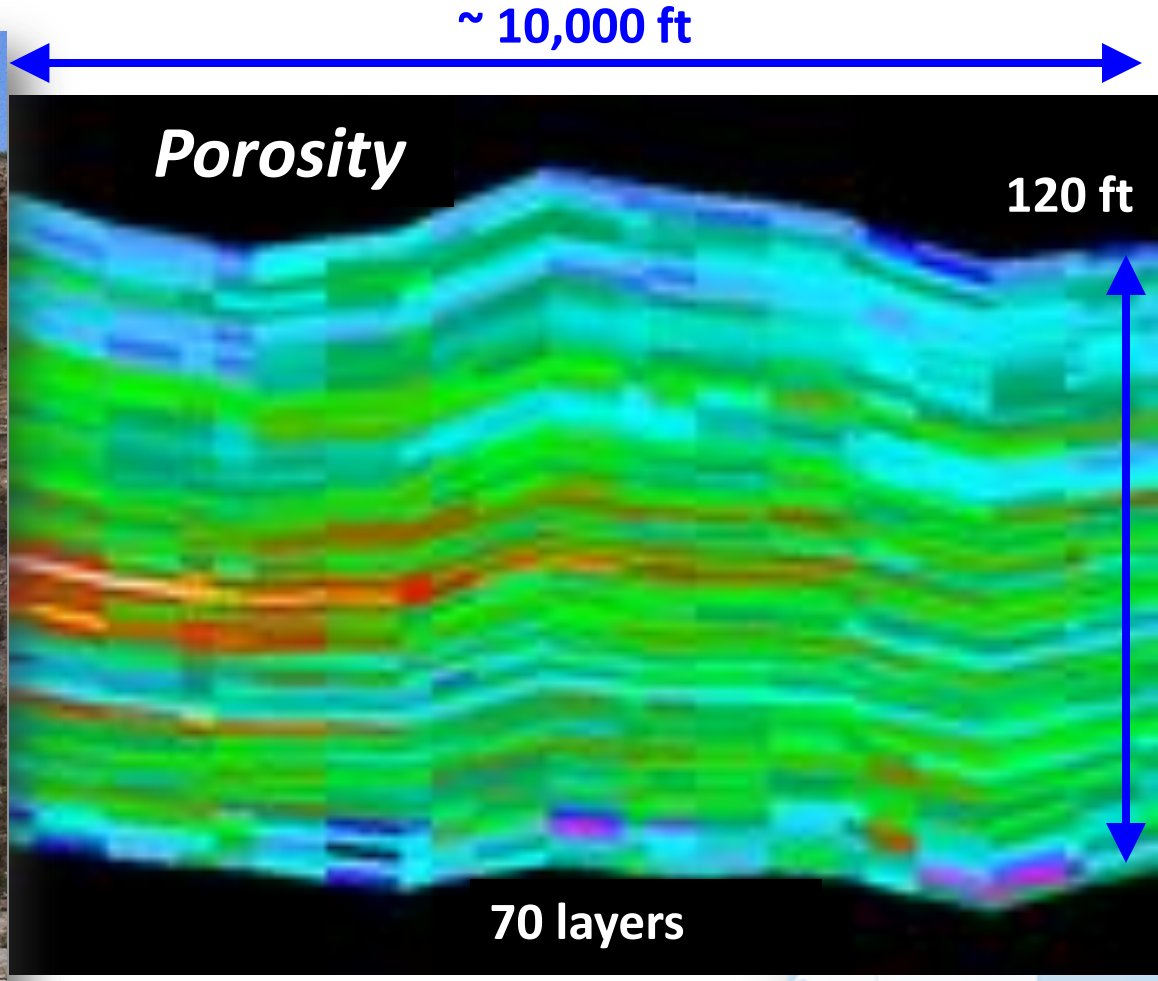
- TOC (Total Organic Carbon)
- Sw (Water Saturation)
- Young's Modulus
- Poisson's Ratio
- So (Oil Saturation)
- Sg (Gas Saturation)
- Permeability
- PHIE (Porosity)
- Adsorbed Gas
- Facies
- Brittleness
- Closure Stress



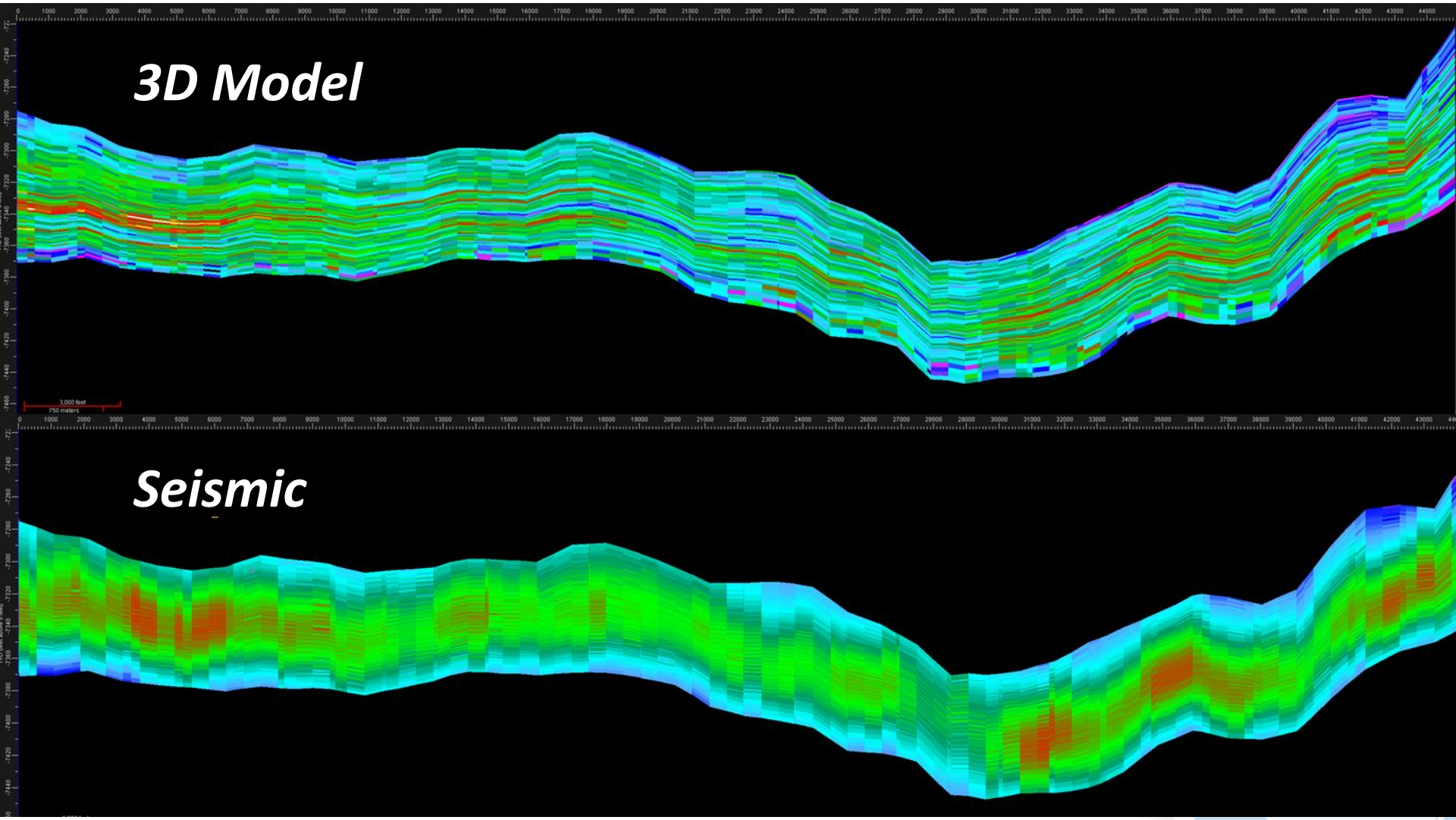
3D Geomodel – 3600 mi² - 2,304,000 acres

Eagle Ford - Lozier Canyon

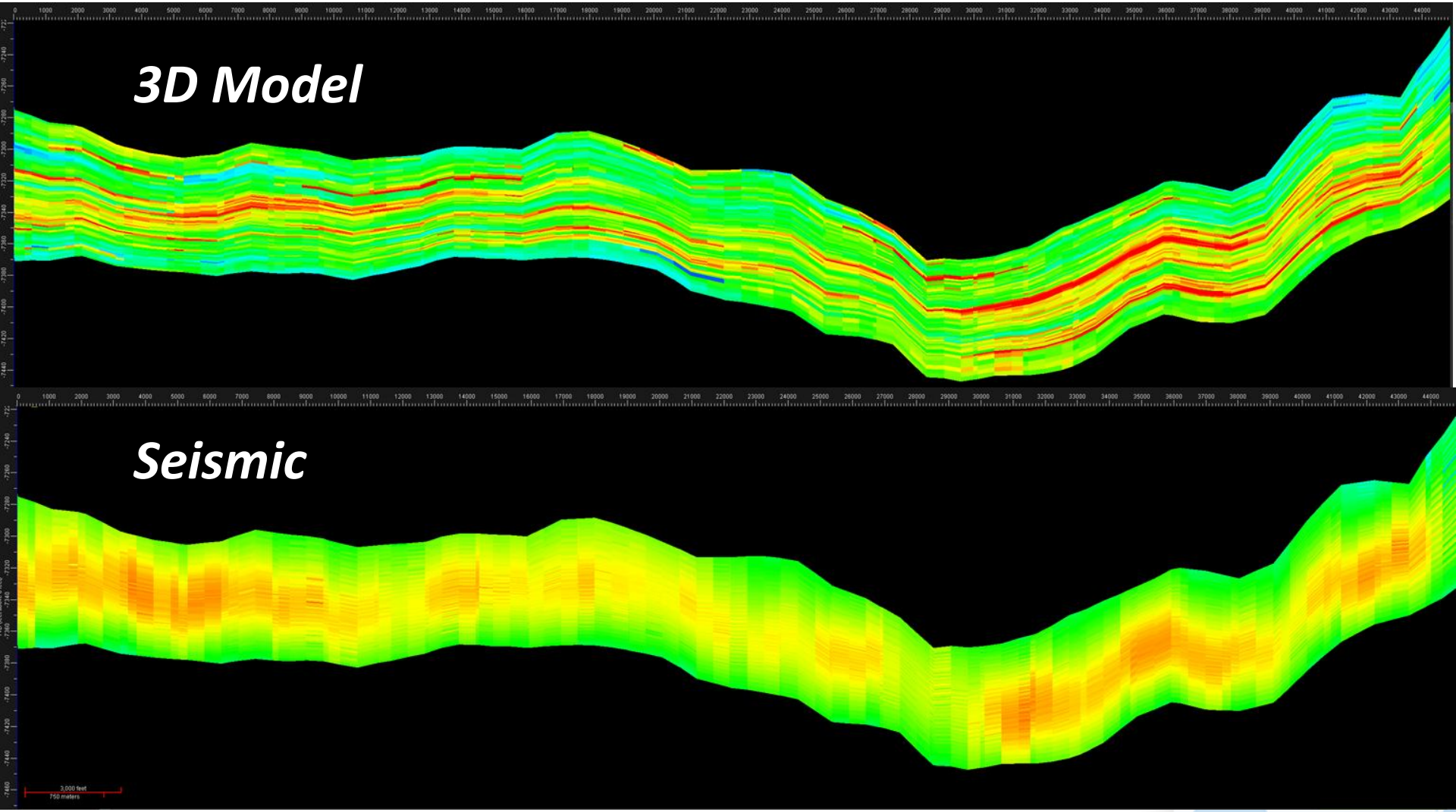


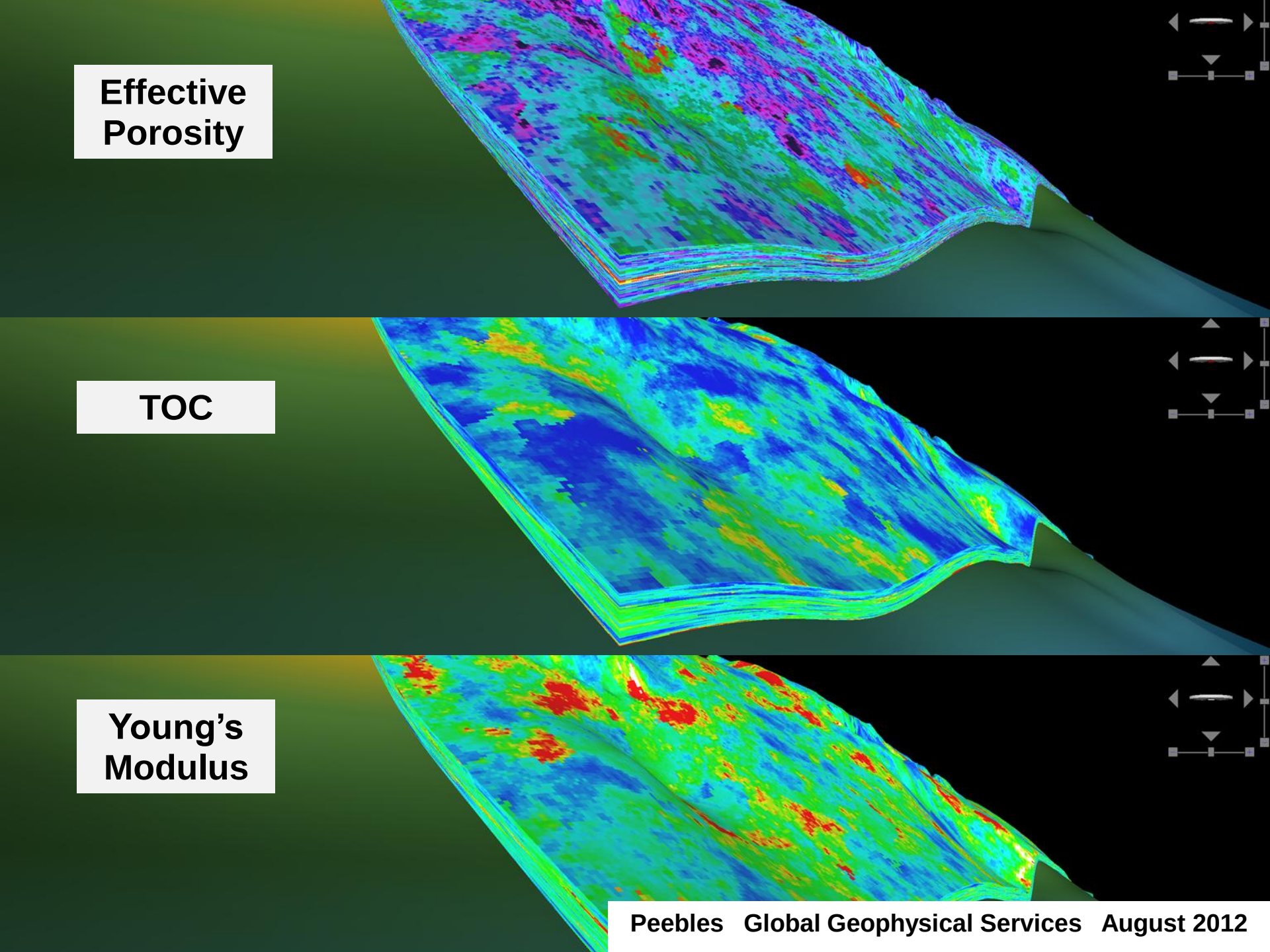


Effective Porosity – Eagle Ford



TOC – Eagle Ford





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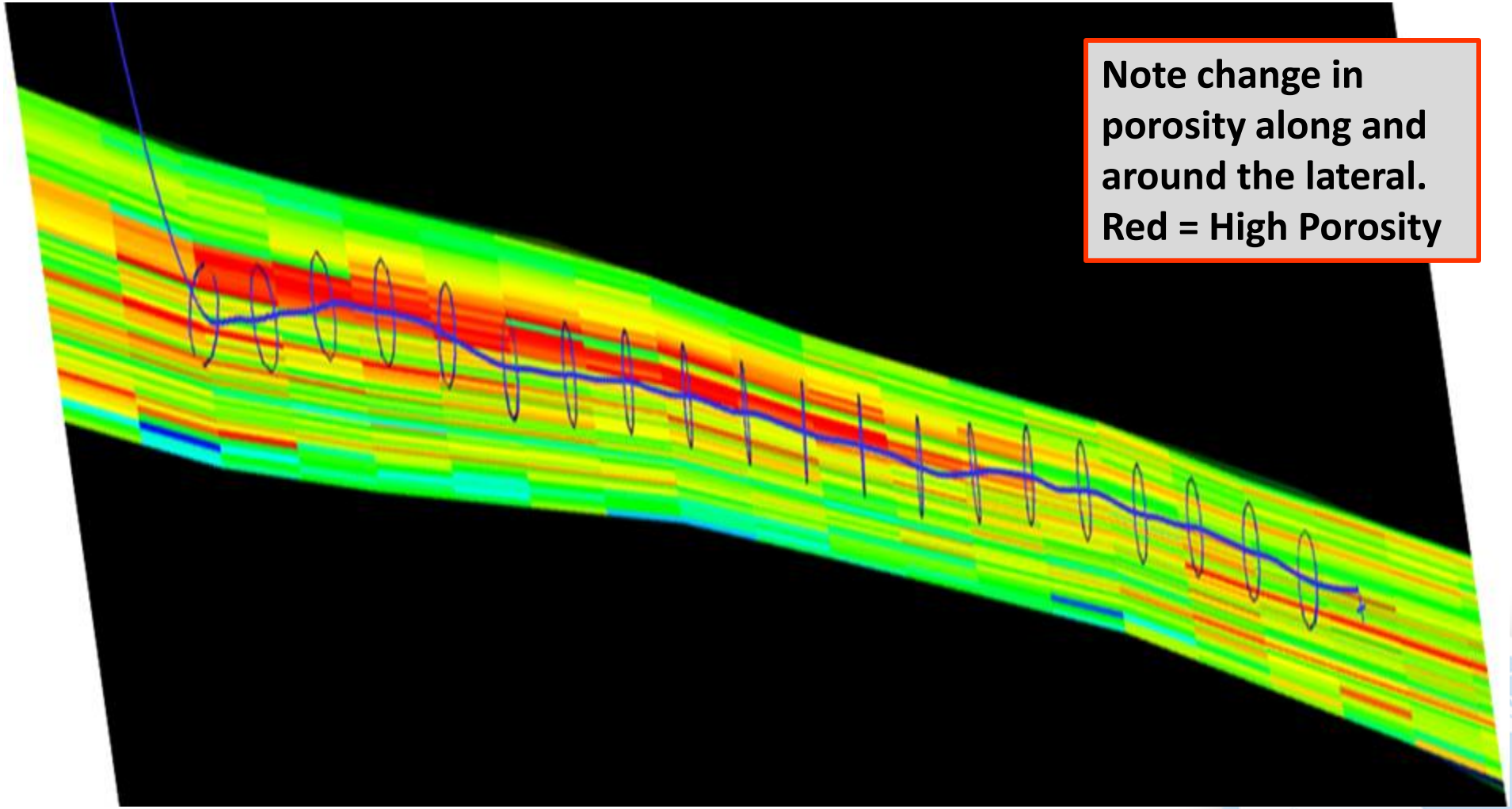
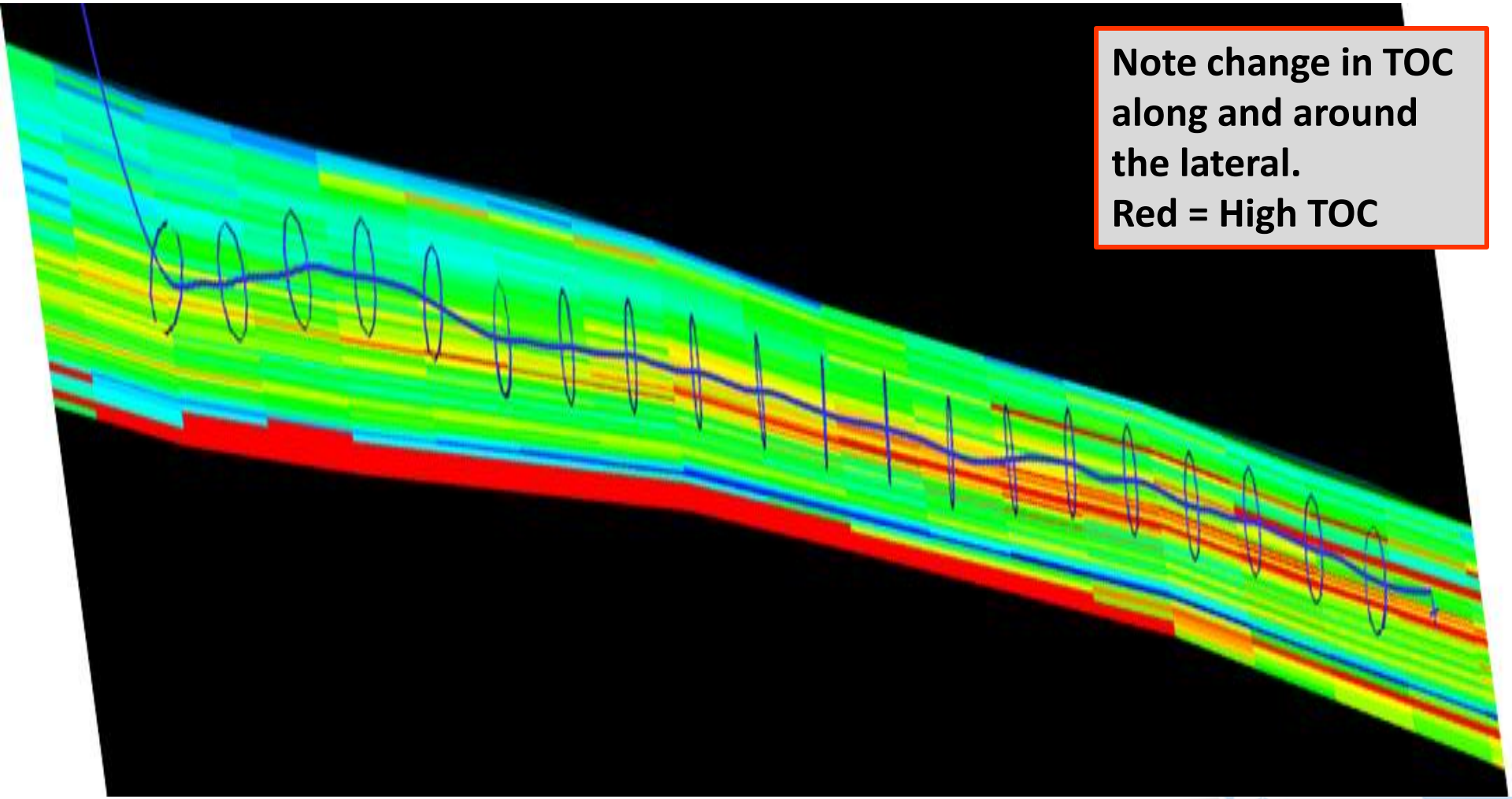
Average Producer in 3D Model - Porosity

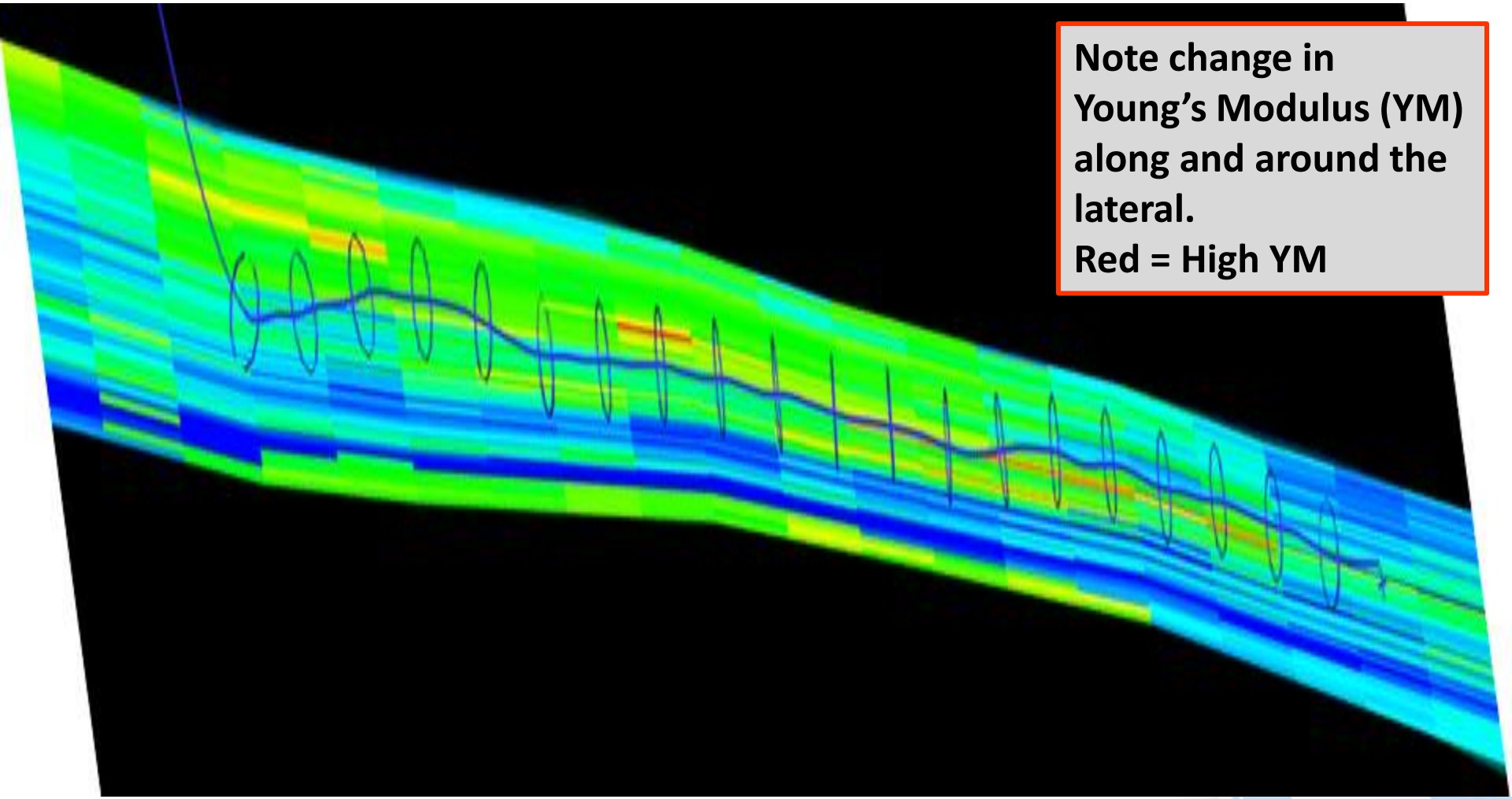


Average Producer in 3D Model - TOC



Note change in TOC along and around the lateral.
Red = High TOC

Average Producer in 3D Model - Young's Modulus



Note change in Young's Modulus (YM) along and around the lateral.
Red = High YM

Summary

- 3D Seismic attributes for geomechnical rock quality and stress = ***Potential Stimulated Rock Volume***
- Microseismic as rock's "dynamic" response to pressure; ***Microseismically Active Volume ≠ Stimulated Rock Volume***
- Portfolio of seismic & engineering attributes to predict production = ***Potential Most Productive Rock Volume***
- Use these to ***localize*** or ***individualize*** well and completion design
- 3D Geomodeling to capture vertical and lateral resolution for ***lateral placement***

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Thank you

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