AVGranite Wash Play Overview, Anadarko Basin: Stratigraphic Framework and Controls on Pennsylvanian Granite Wash Production, Anadarko Basin, Texas and Oaklahoma*

Ed LoCricchio[1]

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Introduction and Play Highlights

- Granite Wash play extends over 130 miles across 7 counties in the Anadarko Basin covering 2.5 million acres.
- Multi-stacked resource play concentrates value with potential of 40 Hz wells/section in Granite Wash.
- There are almost no federal leases.
- Established infrastructure is present.
- Landowners and state governments are industry-friendly.
- Range of cost of completed wells is $6-9MM..
- IP Range 50-3,500 BO and 3,000-30,000 MCFGPD.
- EUR Range 3-17 BCFE.
- Total Recoverable resources potential of 500 TCFE, (114 BBOE including NGL's).

Conclusion

- Desmoinesian Granite Wash Play in the Anadarko Basin is one of the most active plays in the Continental United States.
- Clastics shed from the Wichita Mountain-Amarillo Uplift were deposited in the Anadarko Basin by sediment gravity flows, creating a massive submarine sand complex.
- Anomalously pressured hydrocarbon system, both under- and overpressured.
- Produces both oil and gas, ratios vary laterally and vertically.
- Minimum of fifteen separate reservoirs.
- Advent of horizontal drilling technology and isolated multi-stage fracture stimulation has revolutionized play.

- New technology has enabled development of a giant field within a mature basin.
- As mapped today this field will take decades to develop, with new isolated reservoirs still being discovered.

References

Lyday, J.R., 1985, Atokan (Pennsylvanian) Berlin Field: Genesis of Recycled Detrital Dolomite Reservoir, Deep Anadarko Basin, Oklahoma: AAPG Bulletin, v. 69/11, p. 1931-1949.

Reading, H.G., 1986, Sedimentary environments and facie, 2nd Edition: Oxford: Blackwell Scientific, 615 p.

Granite Wash Play Overview, Anadarko Basin

Stratigraphic Framework and Controls on Pennsylvanian Granite Wash Production, Anadarko Basin, Texas and Oklahoma

Ed LoCricchio

Cordillera Energy Partners, LLC

AAPG 2012 Annual Convention

Long Beach, California

April 23, 2012 Discovery Thinking Forum

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Celebrating Ten Years

Acknowledgements

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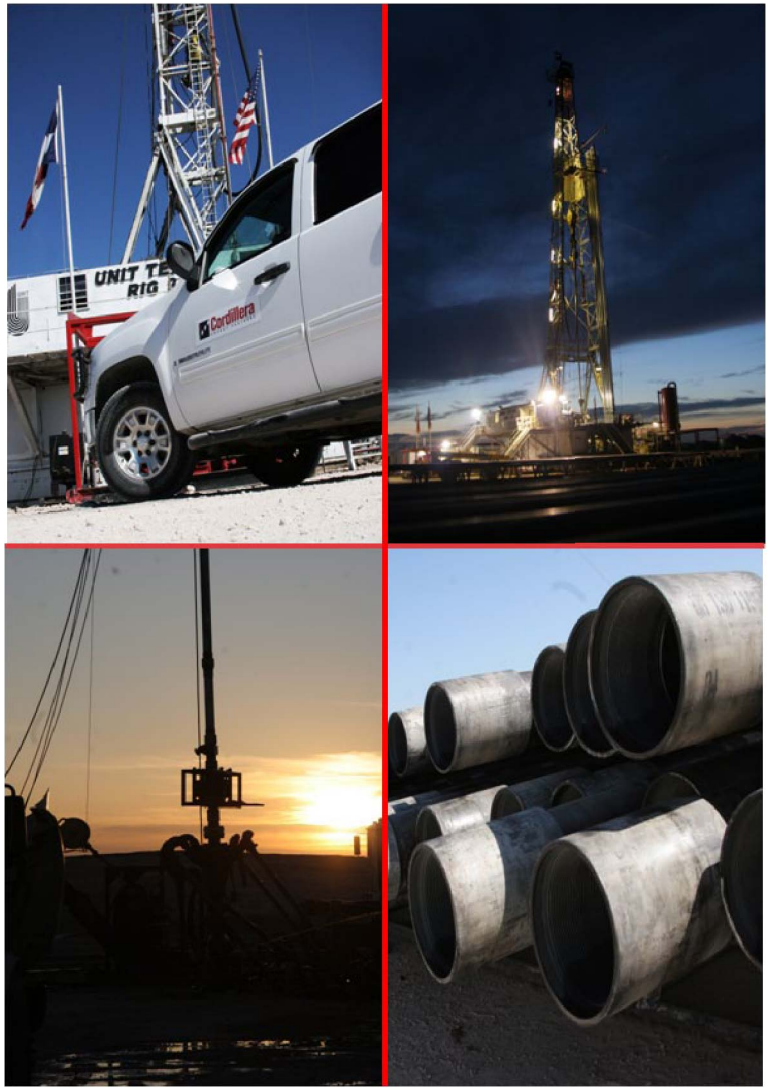
  - Barry C. McBride
  - Thom Page
  - Andrew Heger
- Core Labs
- Grace Ford, Steve Cumella, Ed Dolly, Mike Gardner and the DBLS, Colorado School of Mines



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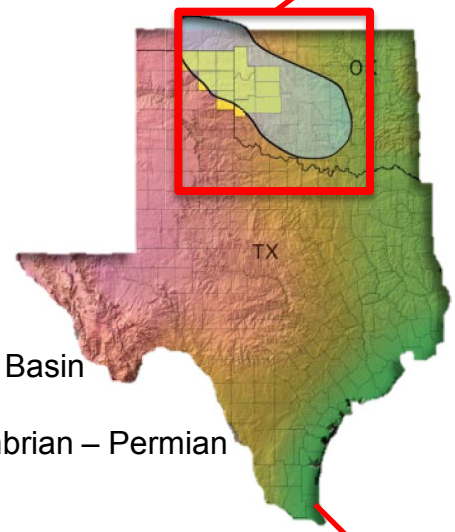
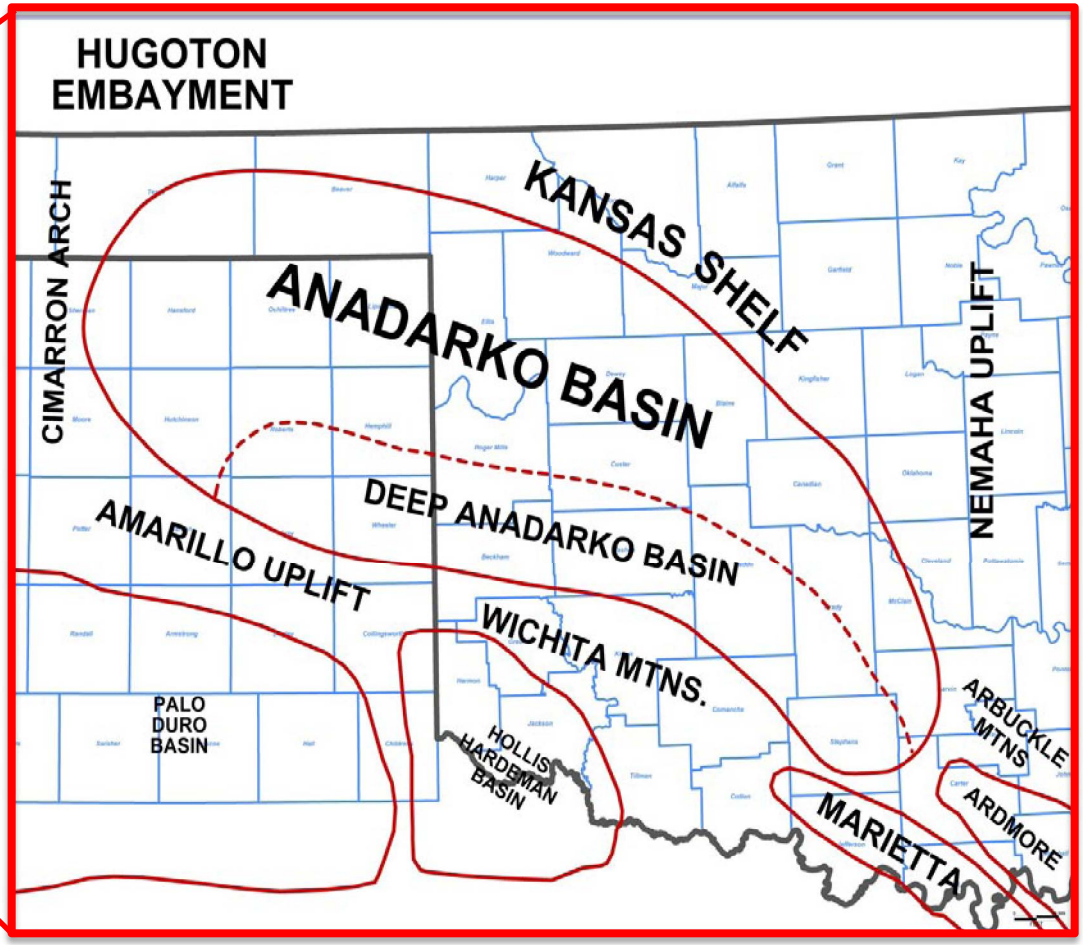
Discussion Outline

- Location Map and Stratigraphic Column
- Play extents and expansion through time
- Depositional model and hydrocarbon system
- Challenges and hurdles to Granite Wash study
- Nomenclature issues and type log
- Regional cross-sections
- Net sand isopachs
- Conclusion

Anadarko Basin





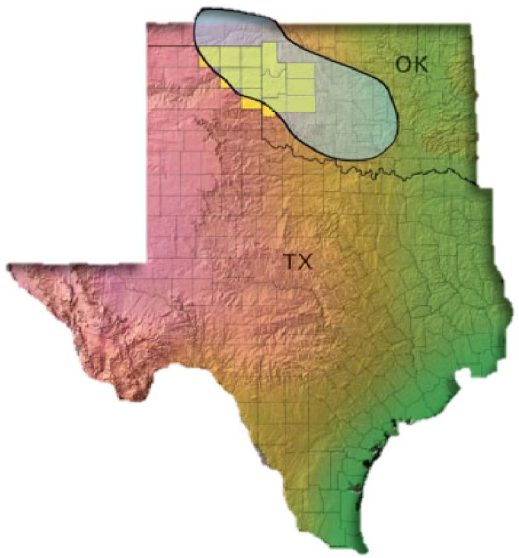
- Asymmetrical Basin
- >35,000' Cambrian – Permian Sediments
- Burial history suggests greatest subsidence in Early Pennsylvanian
- Thermal history indicates pre-GRWS source rocks entered oil generation window in Early Pennsylvanian, dry gas phase by Early Permian

Stratigraphic Column

Key Points

- The Granite Wash and associated plays are among the most attractive domestic opportunities due to liquids-rich production, stacked pay zones and high rates of return
- Horizontal drilling technology, combined with advancements in multi-stage fracture stimulation, has caused a massive expansion of the resource potential with numerous attractive stacked development opportunities

Map of Western Anadarko Basin



Focus Area

Stacked Pay Zones

Anadarko Basin			
System	**Series / Epoch**	**Generalized Stratigraphic Column**	
Lower Permian	Wolfcampian	Hugoton / Pontotoc (Brown Dolomite)	
		Chase / Council Grove	Granite Wash
		Admire	
Pennsylvanian	Virgilian	Wabaunsee	
		Shawnee	
		Douglas Tonkawa	
	Missourian	Cottage Grove	
		Hoxbar / Hogshooter	
		Checkerboard	
		Cleveland	
	Desmoinesian	Marmaton Group (Glover / Big Lime / Oswego)	
		Cherokee (Skinner / Pink Lime / Red Fork)	
	Atokan	Atoka Lime	
		13 Finger Lime	
	Morrowan	Morrow Shale / Dornick Hills Shale	
Mississippian	Chesterian - Meramecian - Osagean - Kinderhookian	Springer	
		Meramec Lime / St. Louis	
		Osage Lime / Osage Chert	
		Kinderhook / Sycamore Lime	
Devonian	Upper Devonian	Woodford	
		Hunton	

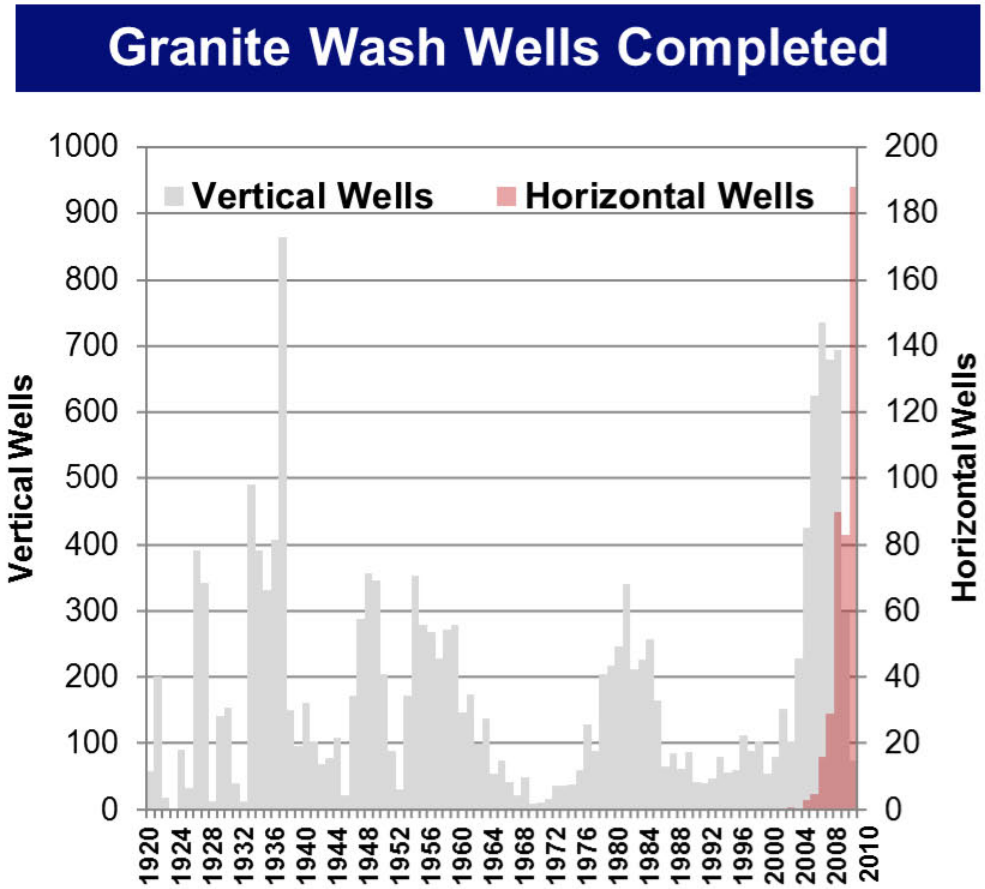
Note: Granite Wash spans from the Early Permian to the Pennsylvanian in age. Areas marked with an oil, gas or liquids symbol represent zones present in the Western Anadarko Basin.

Oil
Gas
Liquids

Anadarko Basin Goes Horizontal

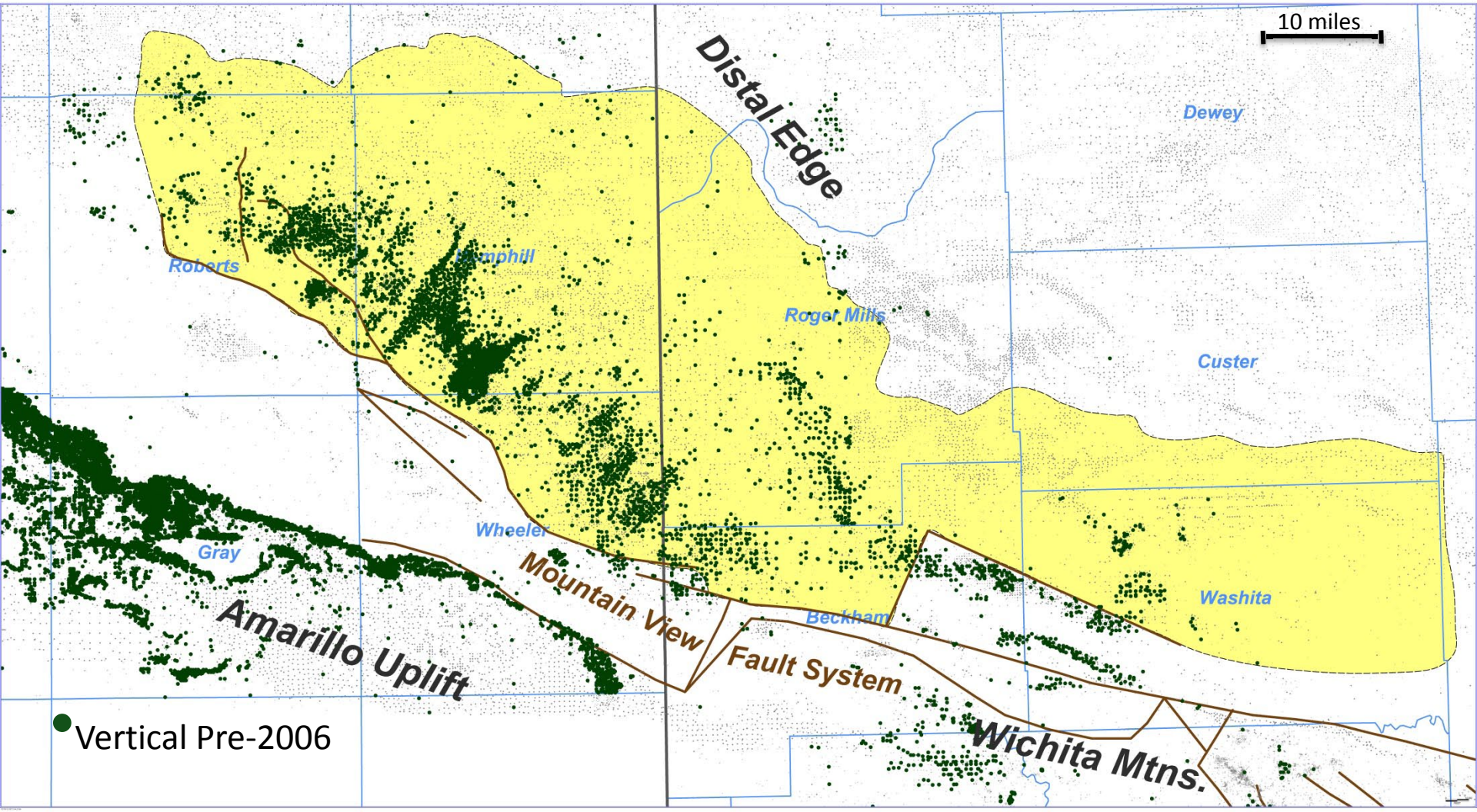
	Cleveland	Granite Wash
First Well	1951	1920
# Verticals	2,660	16,307
First Horizontal	2002	2002
# of Horiz Completions	880	415
# of Horiz Rigs	22	60
# of Horiz Permits	153	165

HZ Development Explodes in 2008

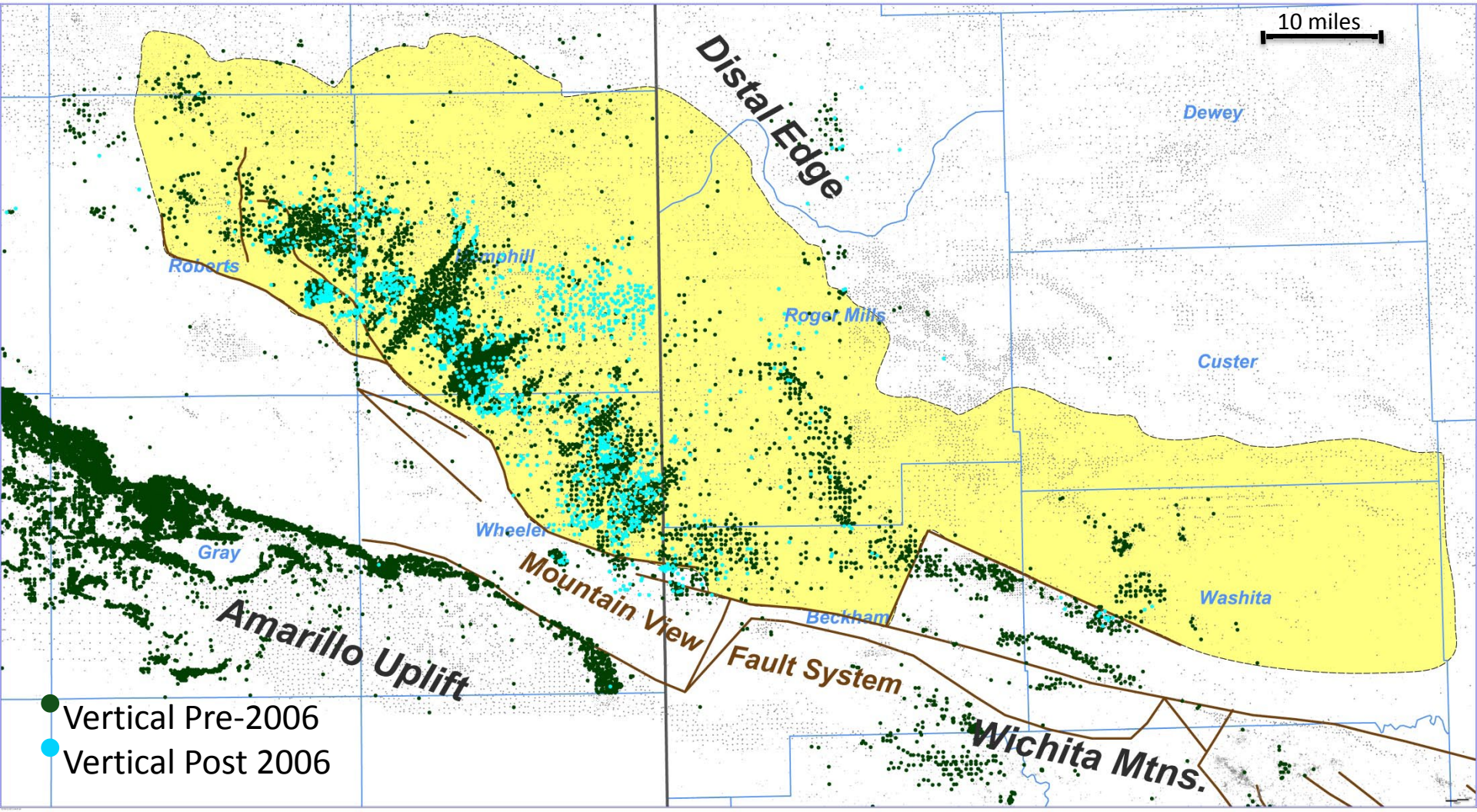


Source: IHS, Inc. – reflects YE 2010 data

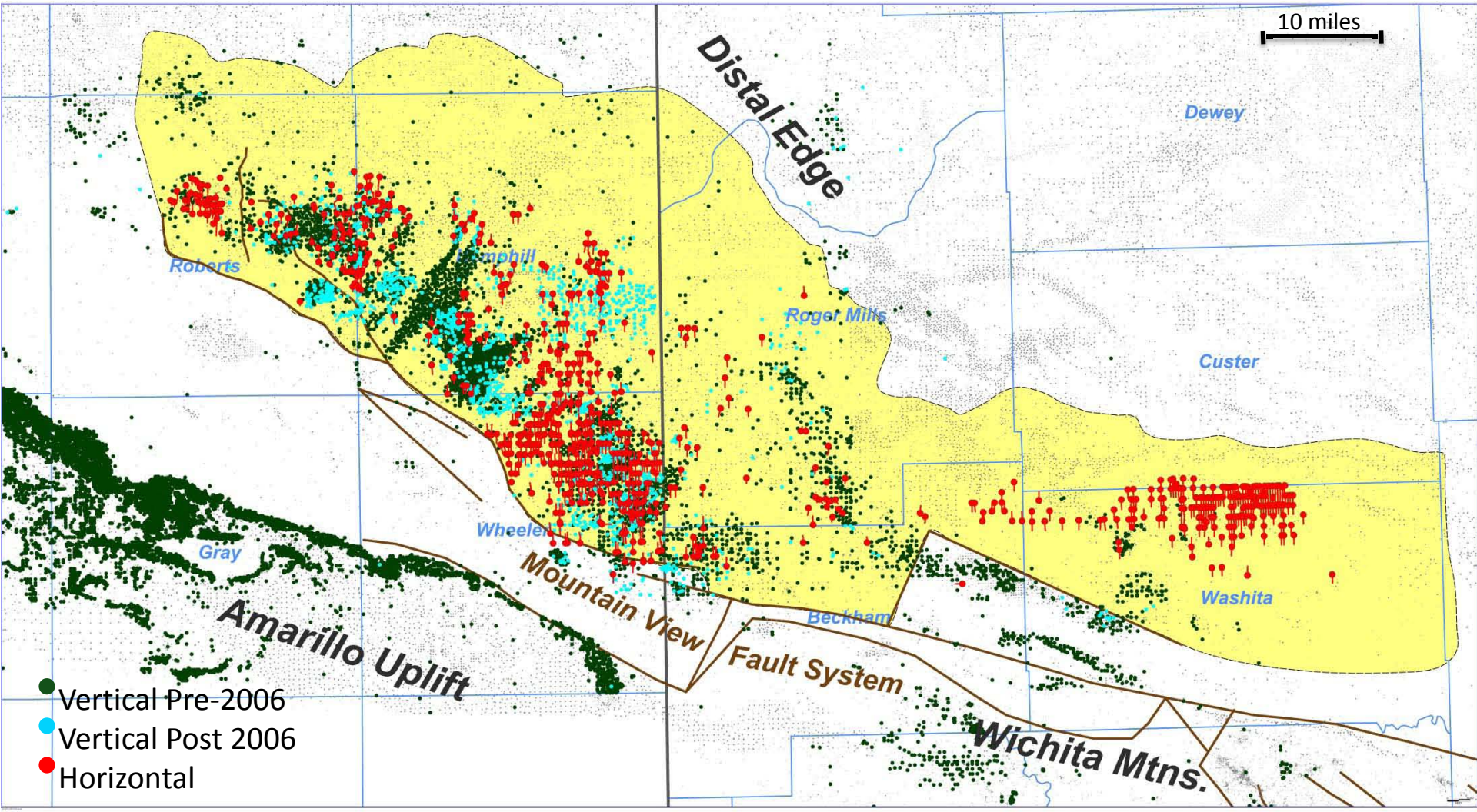
Granite Wash Vertical Completions – Pre 1/1/2006



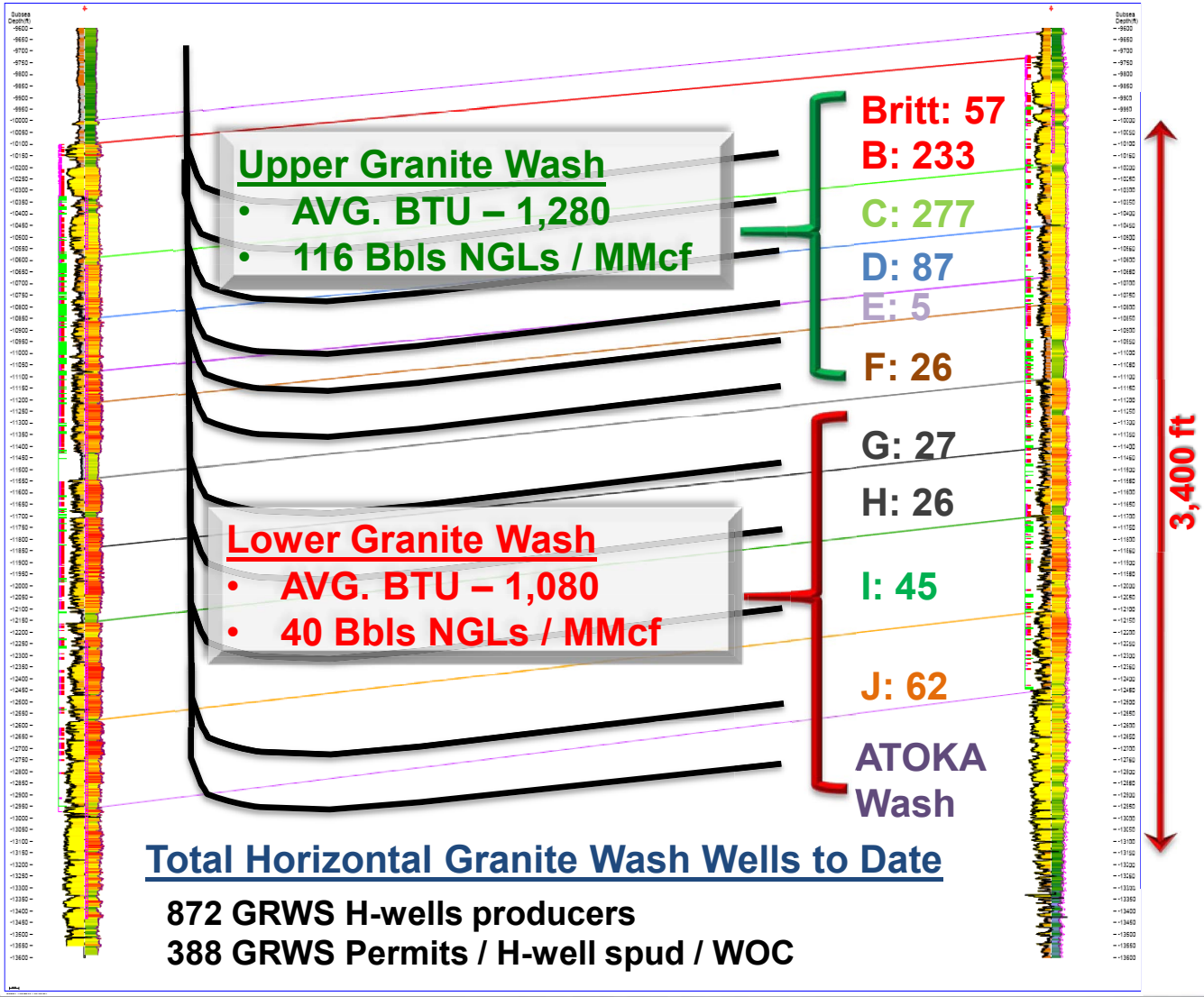
Granite Wash Vertical Completions – Post 1/1/2006



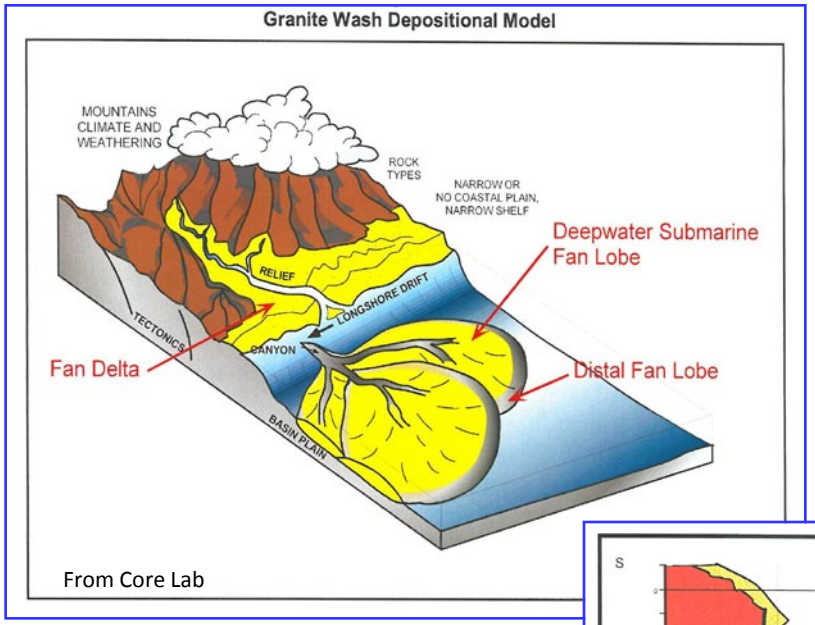
Granite Wash Vertical & Horizontal Completions



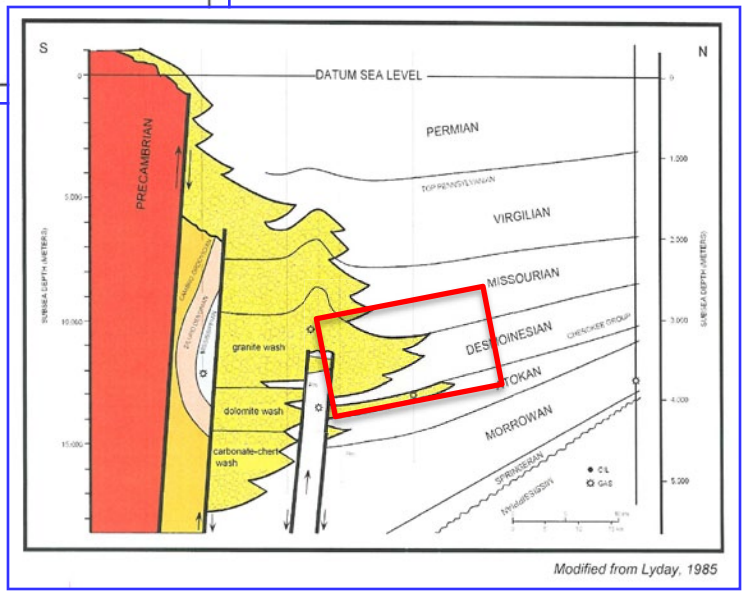
Eleven Stacked Horizons



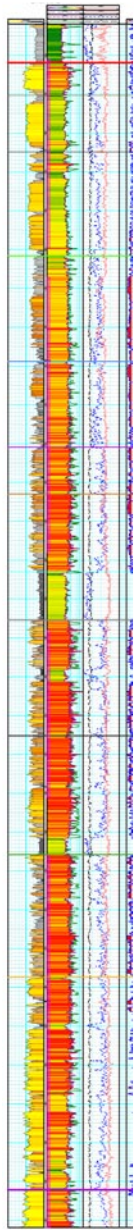
Granite Wash Depositional Model



- Massive sand deposits shed off the Amarillo uplift and Wichita Mtn. to SW, >15,000 ft of GRWS deposits preserved in the rock record
- Sediments spread laterally and stacked vertically to create a submarine sand complex
- GRWS records cyclic sandstone and siltstone deposition that corresponds to submarine fan growth and abandonment
- Focus on DSMS GRWS



- Active petroleum systems charged by multiple source rocks
- Basin-centered gas system combined with regional stratigraphic pinch-out
- Gross DSMS thickness as much as 3,400 ft
- Subdivided DSMS GRWS into 11 productive benches separated by regionally correlative shales



16,000 ft

Granite Wash
Britt
GWB
GWC
GWD
GWE
GWF
GWG
GWH
GWI
GWJ
Atoka Wash

Upper GW
Lower GW

2,900 ft

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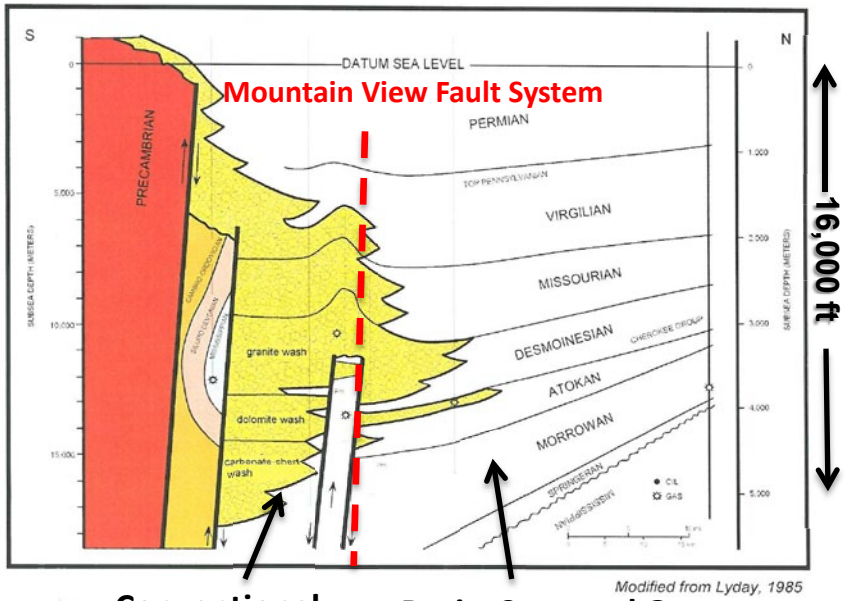
Two Plays: Conventional and Unconventional



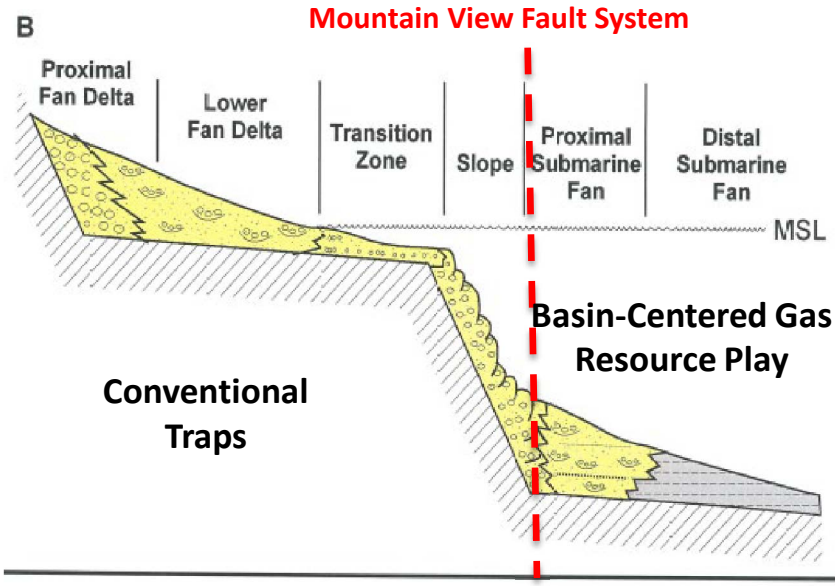


Diagram (Reading,1986) features a depositional facies models for a fan delta with a narrow shelf.

- South of Mountain View Fault System: Conventional Traps
- North of Mountain View Fault System: Basin-Centered Gas Resource Play

Challenges

- **Perception that the Granite Wash is only one or two reservoirs**
  - When it is at least fifteen reservoirs
  - At least eleven Desmoinesian-age reservoirs
- **Limited published studies**
- **Subsurface study only, no outcrops**
  - Over 30,000 wells to correlate; blessing and a curse.
  - Five years ago when we started this work there were few digital logs available
- **Petrophysical challenges**
  - Radioactive minerals
  - Variable clay content
  - Low porosity and permeability
  - Overbalanced drilling masked Granite Wash pay
- **No established stratigraphic framework**
- **Nomenclature issues are a major hurdle to overcome**

What's in a name?

Numerous different styles for naming individual Granite Wash zones

Lithology
Granite Wash
Conglomerate
Carbonate Wash
Dolomite Wash

Age Connotation
Permian Wash
Pennsylvanian Wash
Missourian Wash
Desmoinesian Wash
Atokan Wash
Morrowan Wash

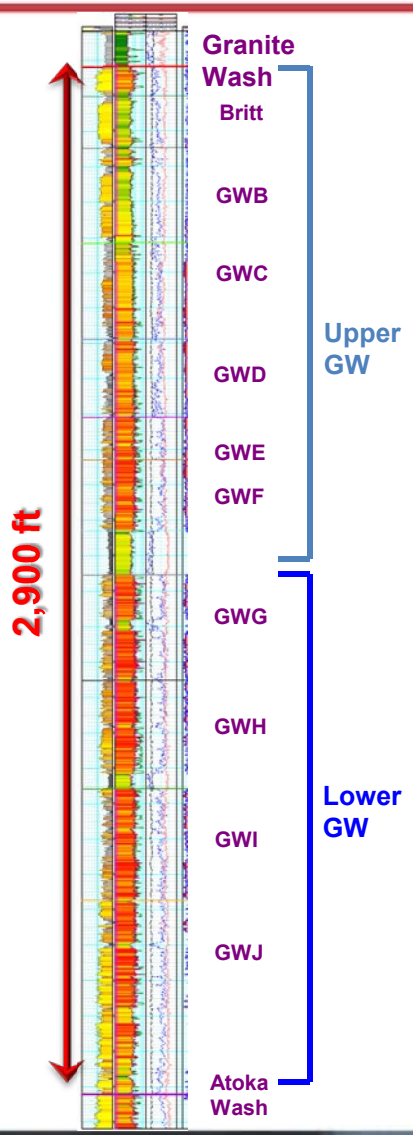
Kansas Shelf Nomenclature
Cottage Grove Wash
Hogshooter Wash
Cleveland Wash
Marmaton Wash
Cherokee Wash
Skinner Wash
Red Fork Wash
Atoka Wash
Morrow Wash

Other
Colors
Alpha-Numeric
Inverse Alphabetic

Our Nomenclature

- **Divided the Desmoinesian age Granite Wash into eleven zones**
  - Separated by regionally correlative flooding surfaces
  - Frac barriers
  - At least eleven Desmoinesian-age reservoirs

- **System is a hybrid of Core Lab study members**



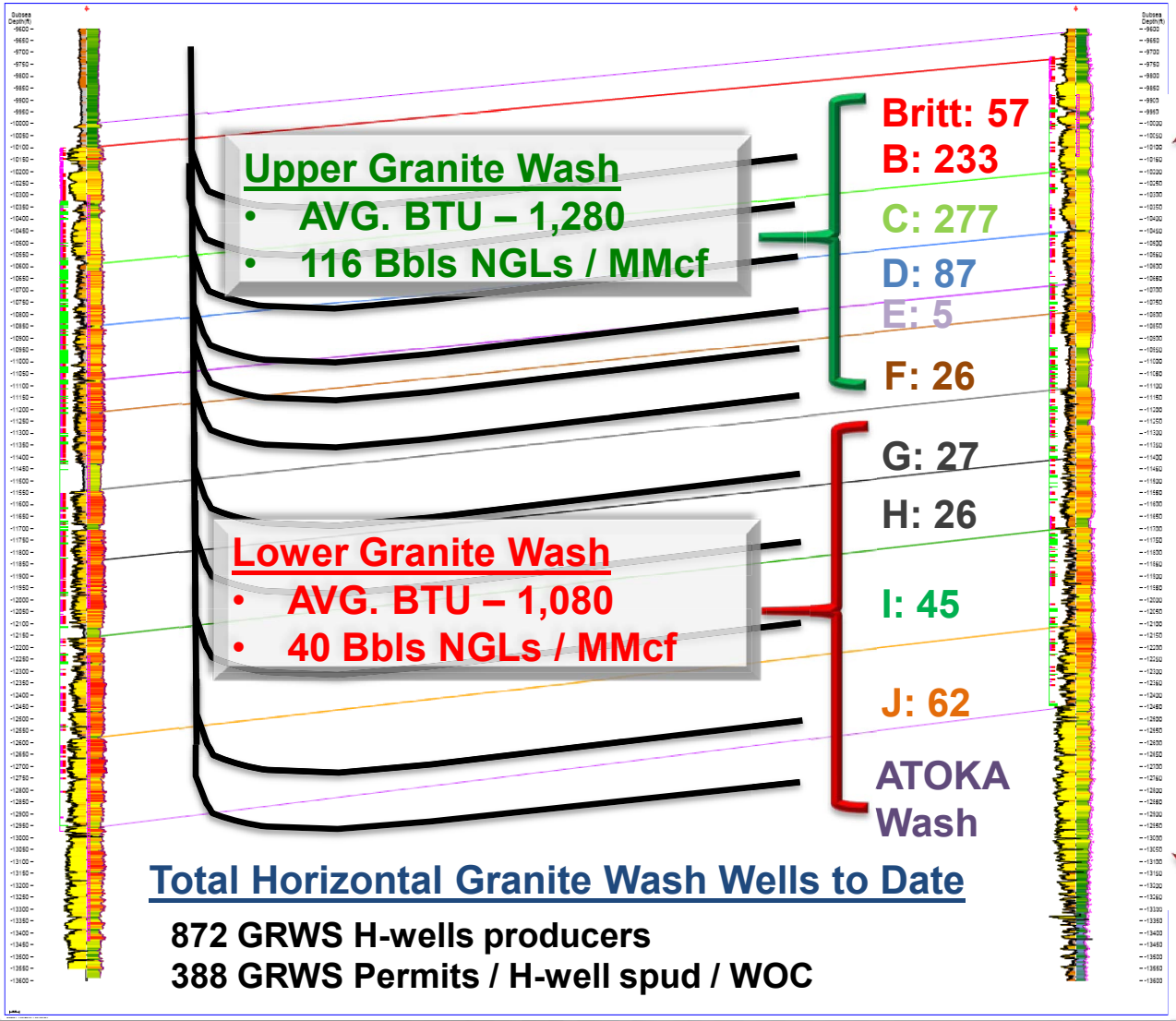
Mapping Strategy

- **Granite Wash divided into 11 zones (does not include Atoka Wash)**
  - Strategy was to correlate significant flooding surfaces across area of interest
  - Create structure maps for each surface and project those surfaces into all wells
  - Define zones based on projected surfaces to eliminate nomenclature issues and to be able to extract meaningful test, perf, and production data

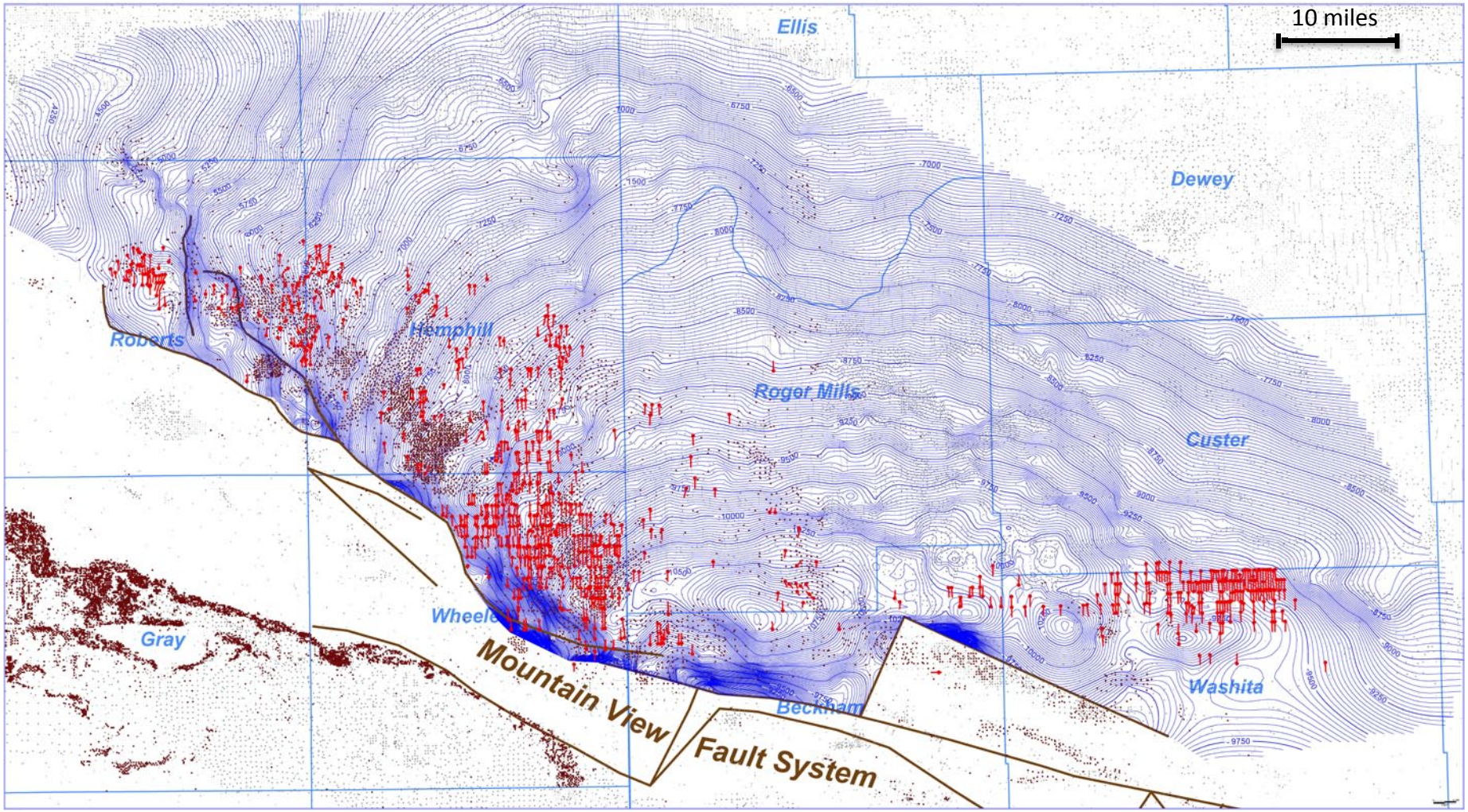
- **Net sand maps for each individual zone**
  - Only wells penetrating that zone
  - Highlight wells with perfs in that zone
  - Highlight HZ wells in zone

Eleven Stacked Horizons

- All GRWS zones proven productive by 100's to 1000's of vertical wells, and over 800 Hz wells
- Most Hz wells target the upper zones
  - Shallower drilling
  - More liquid-rich in central portion of the play



Granite Wash Structure



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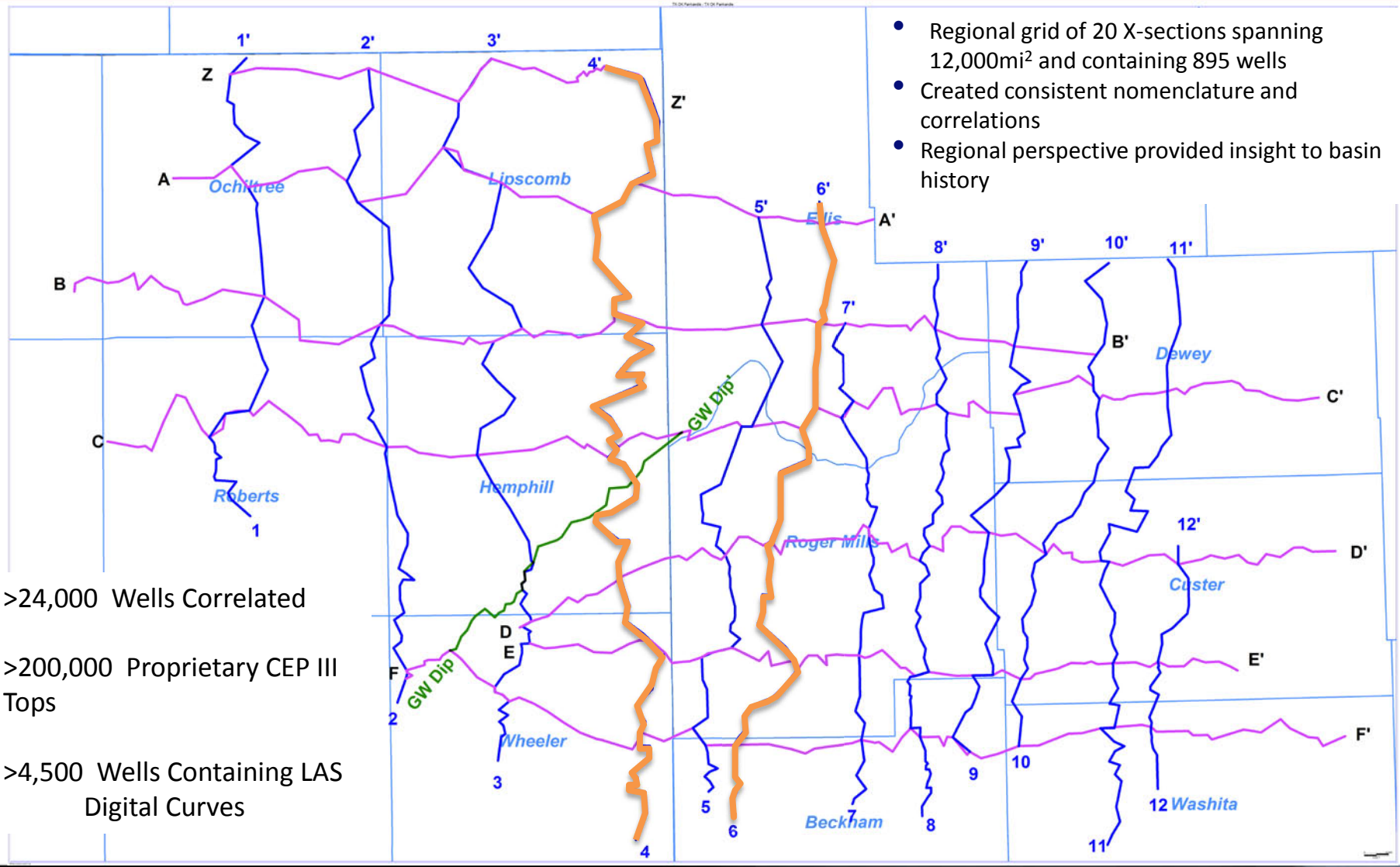
Regional Cross-Section Index Map



- Regional grid of 20 X-sections spanning 12,000mi^2 and containing 895 wells
- Created consistent nomenclature and correlations
- Regional perspective provided insight to basin history

>24,000 Wells Correlated

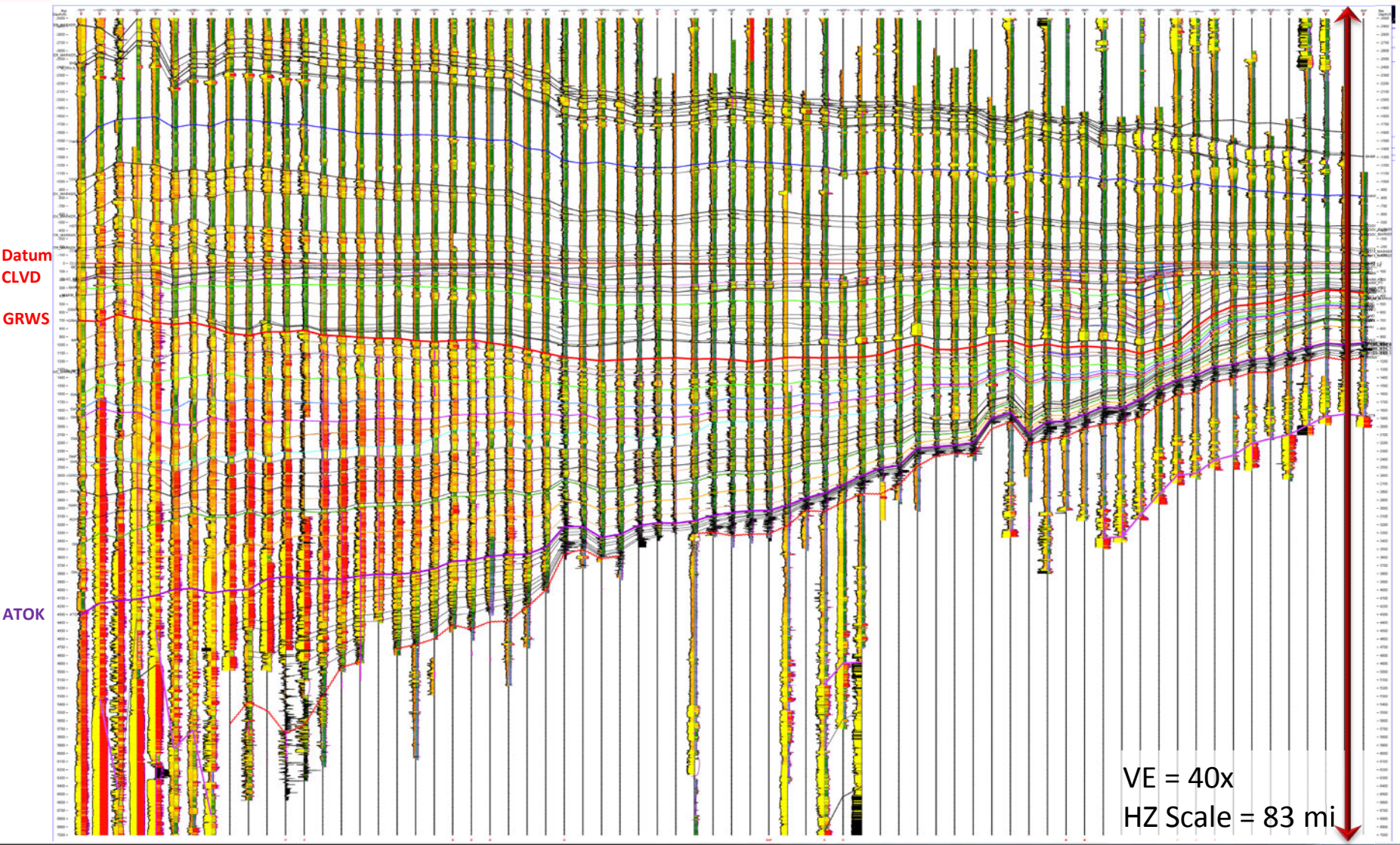
>200,000 Proprietary CEP III Tops

>4,500 Wells Containing LAS Digital Curves

Section 4

South

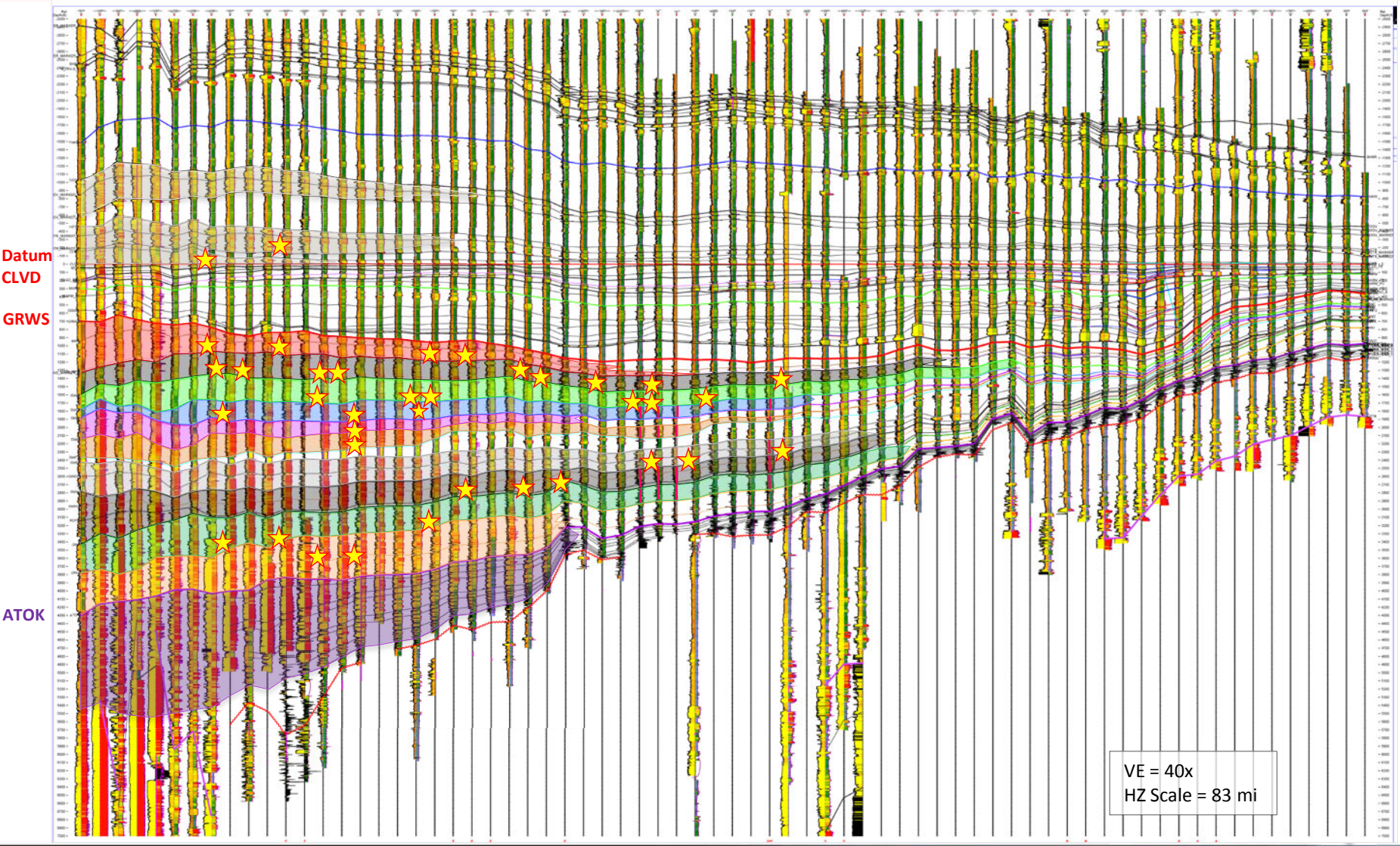
North



Section 4

South

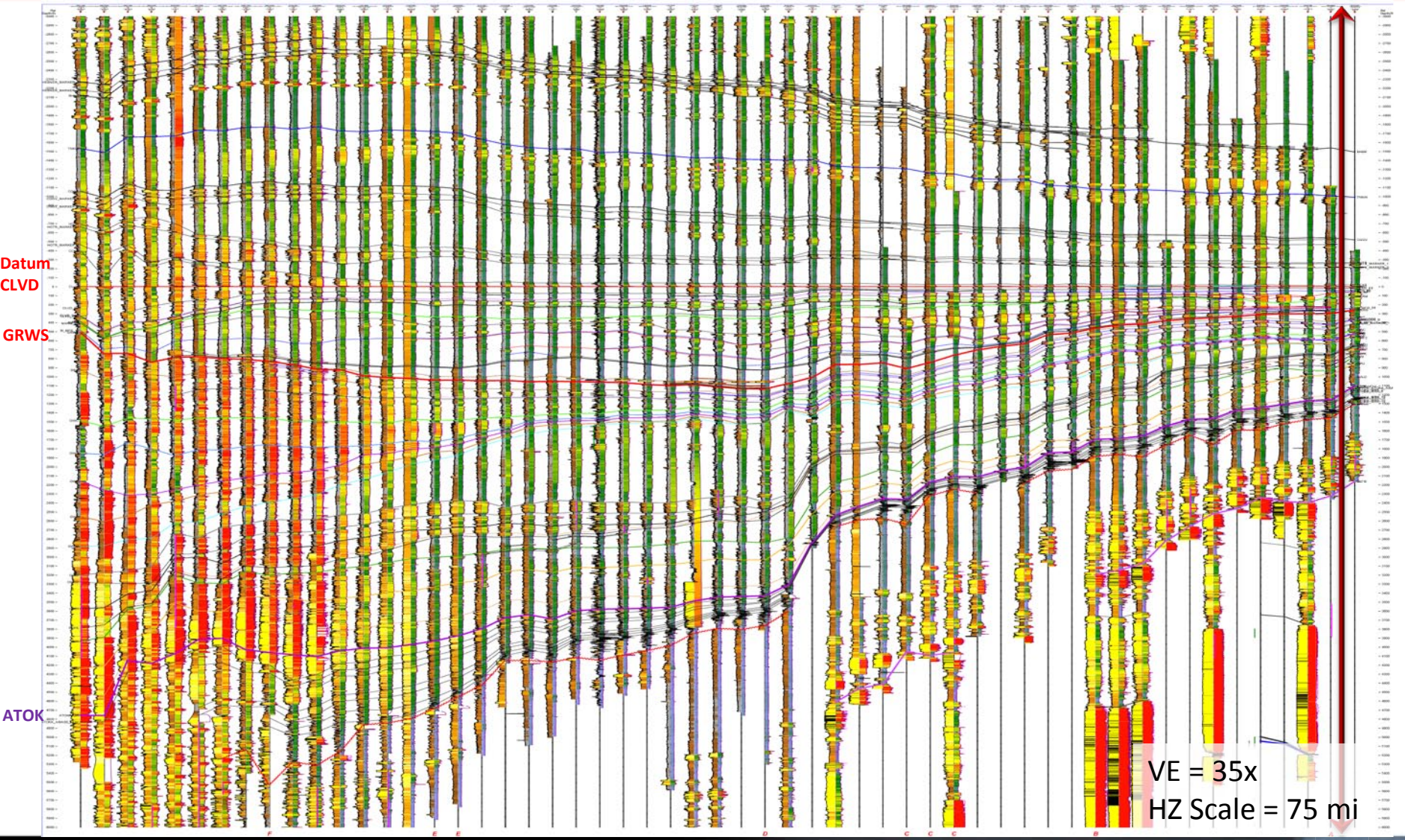
North



Section 6

South

North



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South

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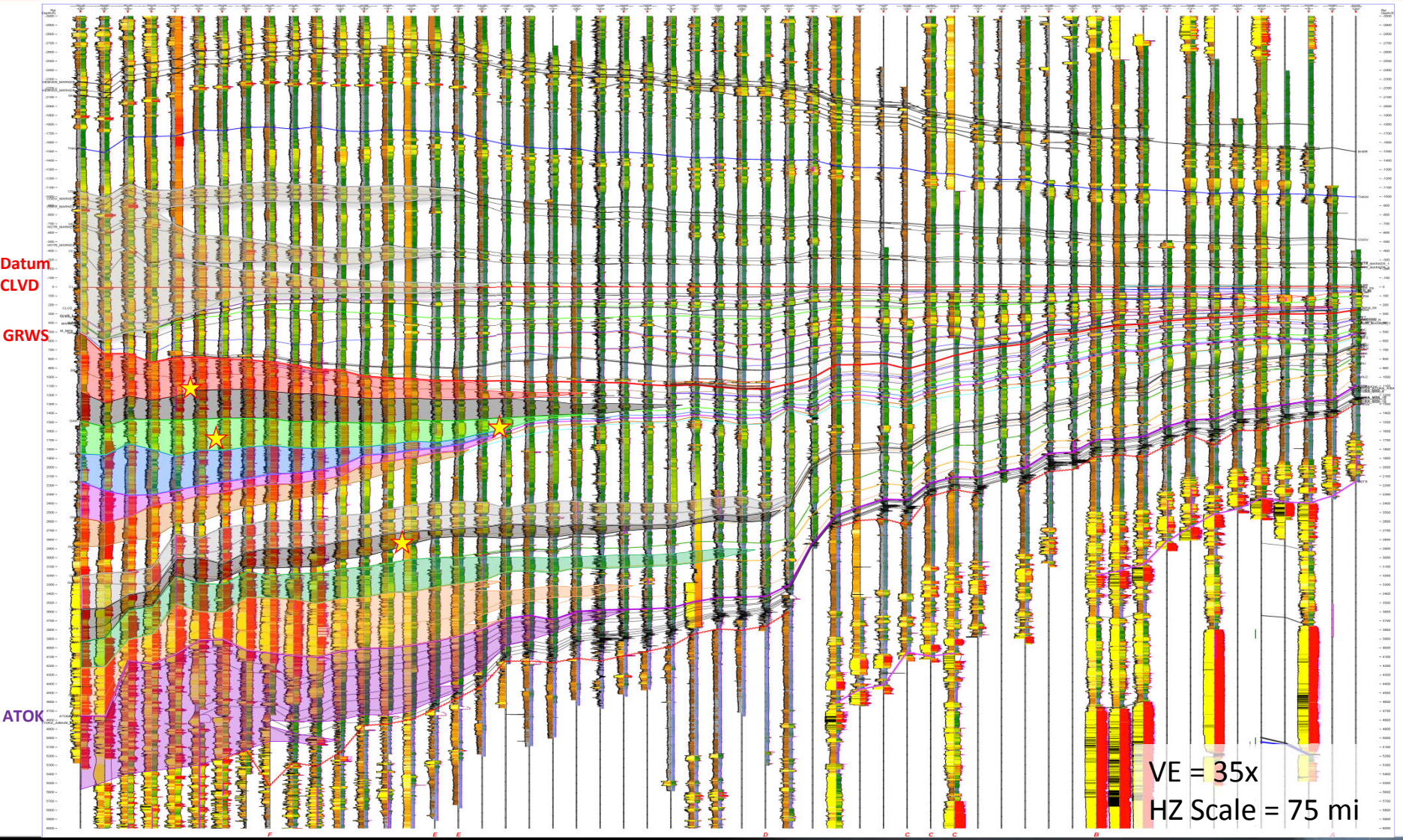
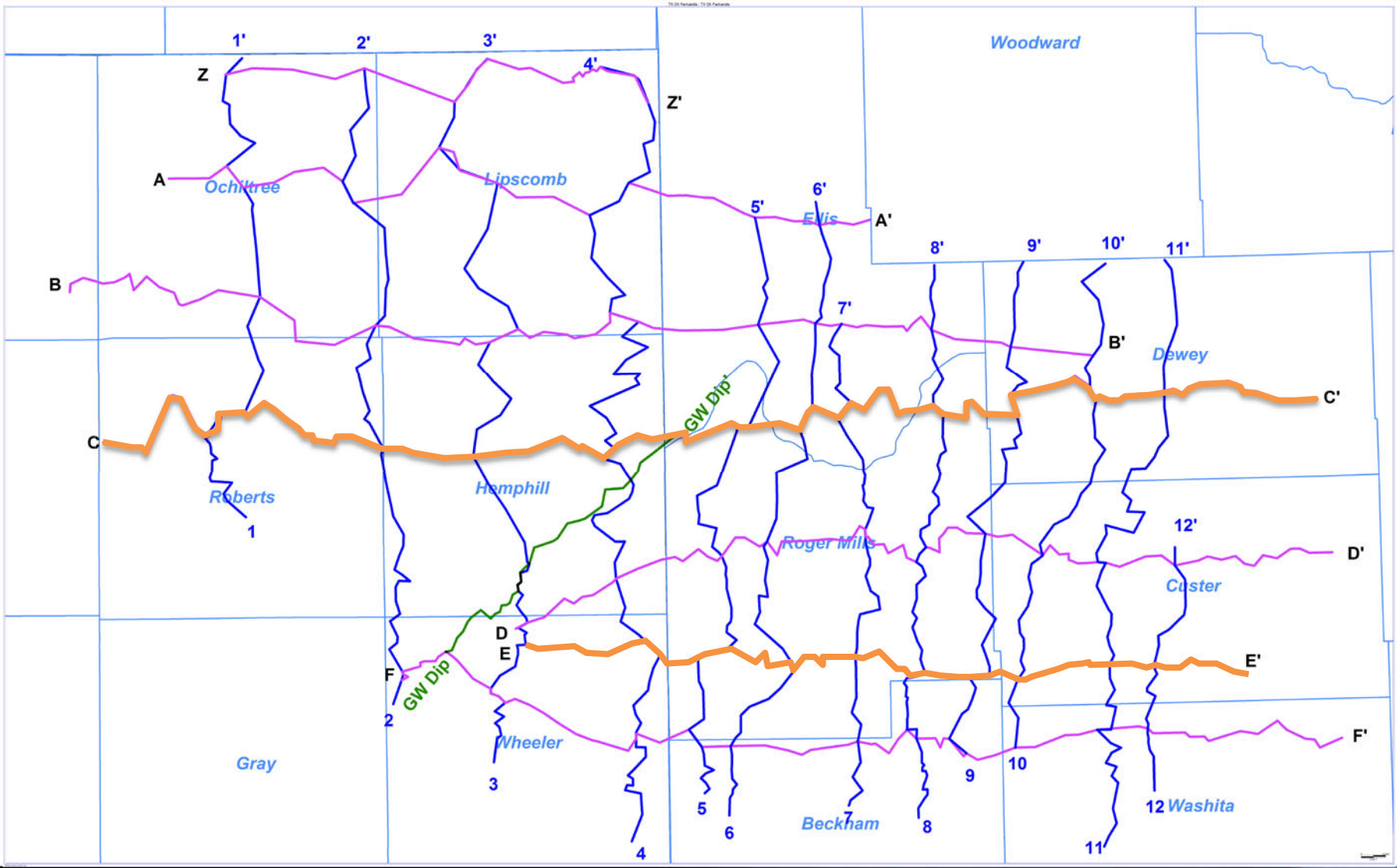


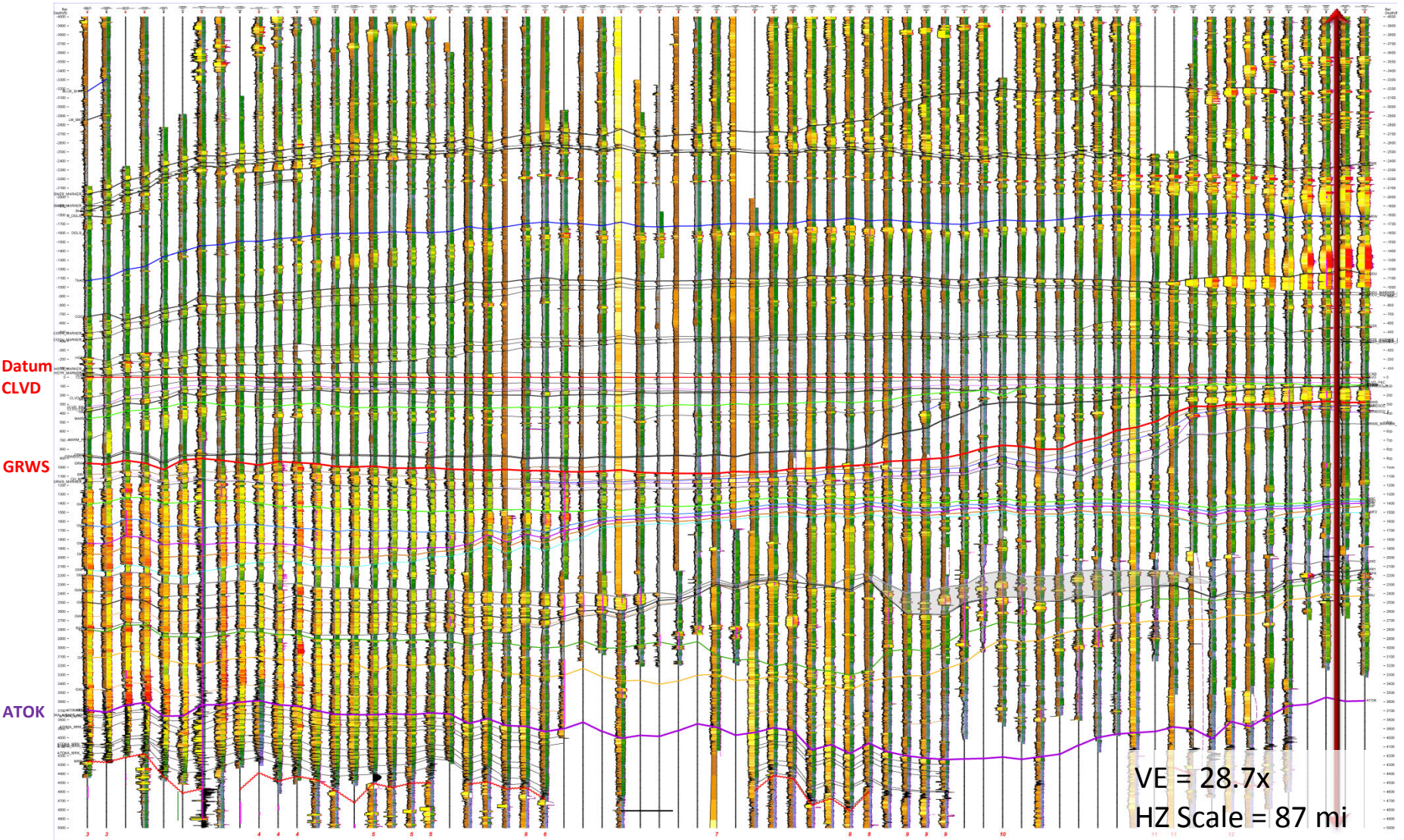
Regional Cross-Section Index Map



Section E

West

East



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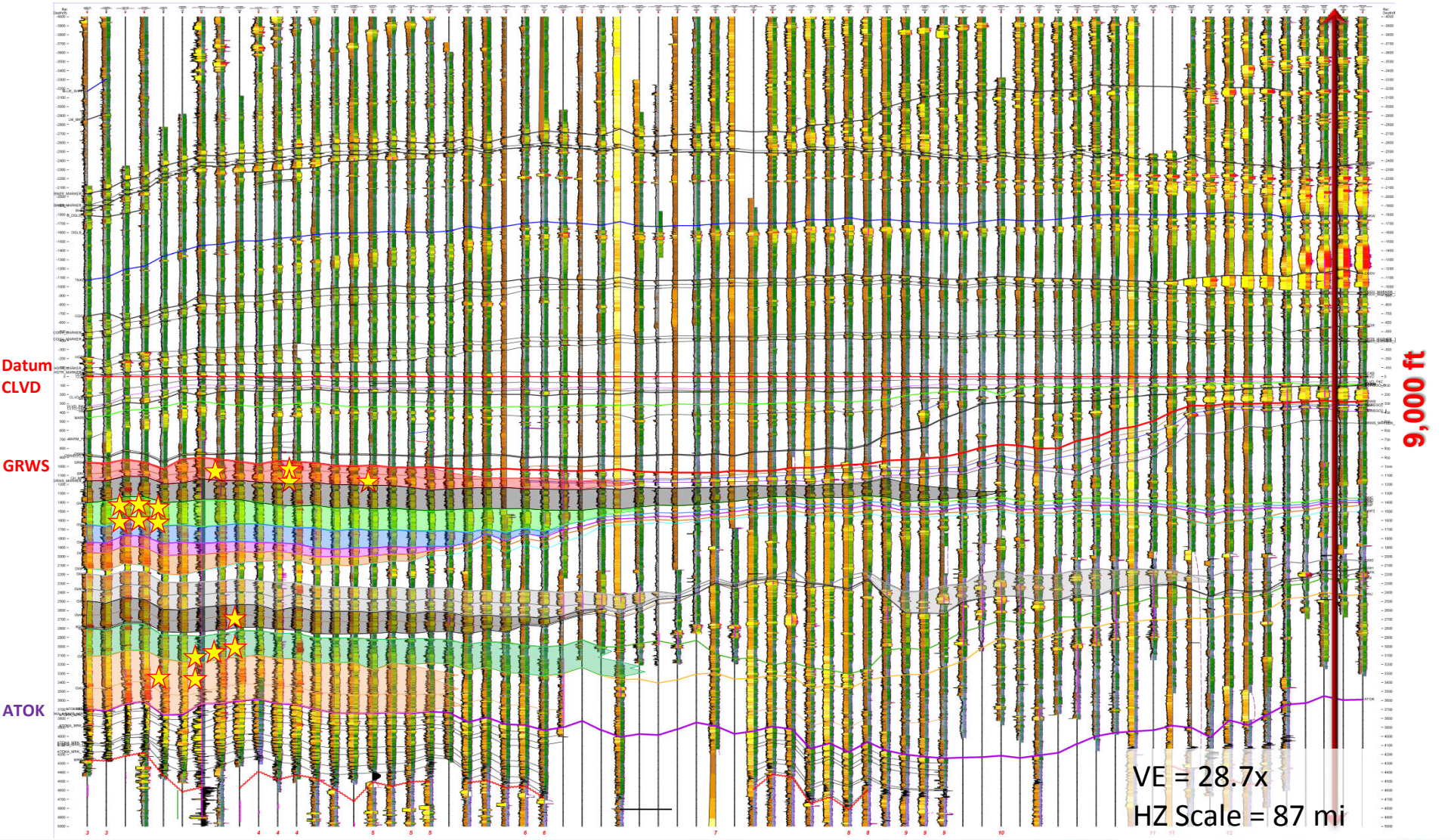

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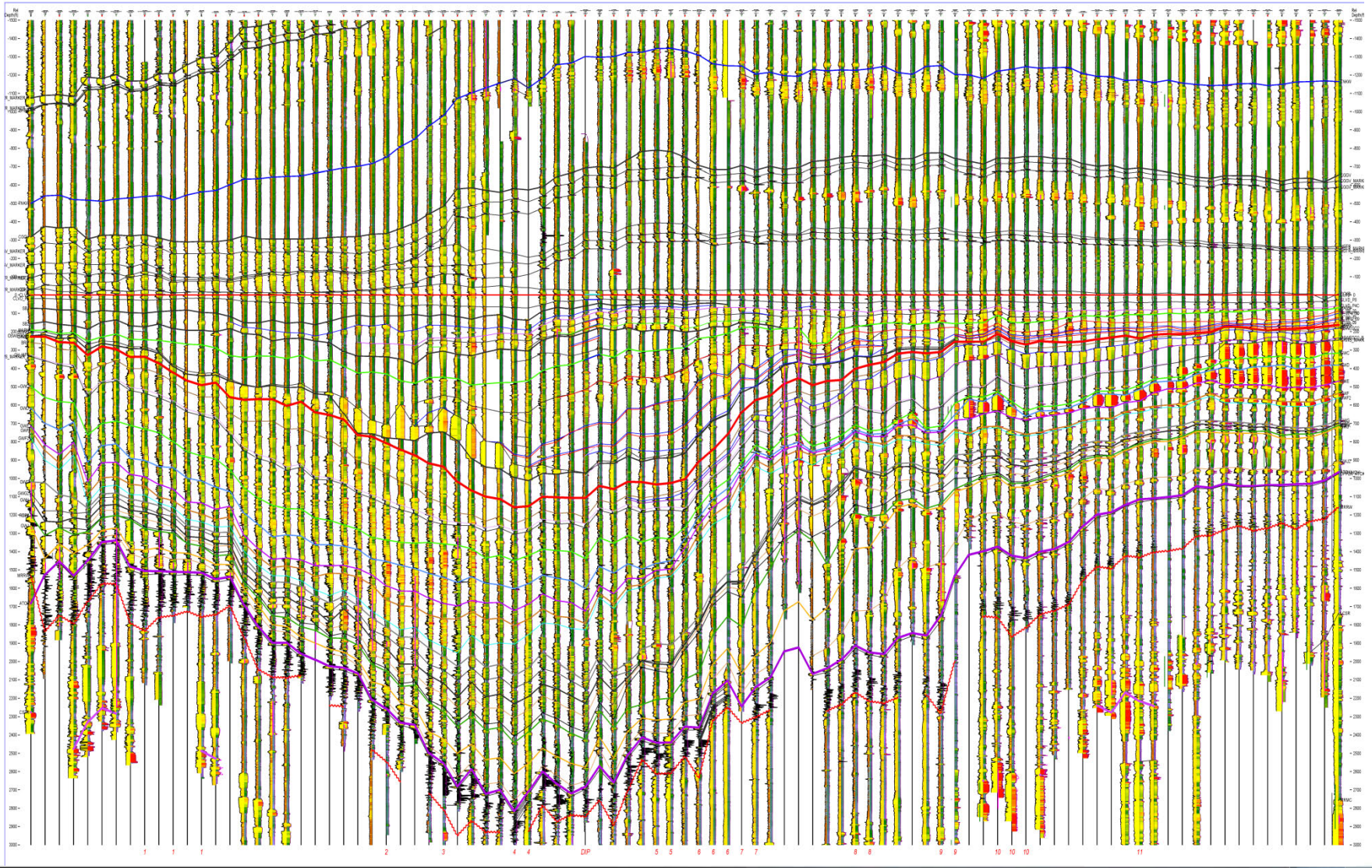
East



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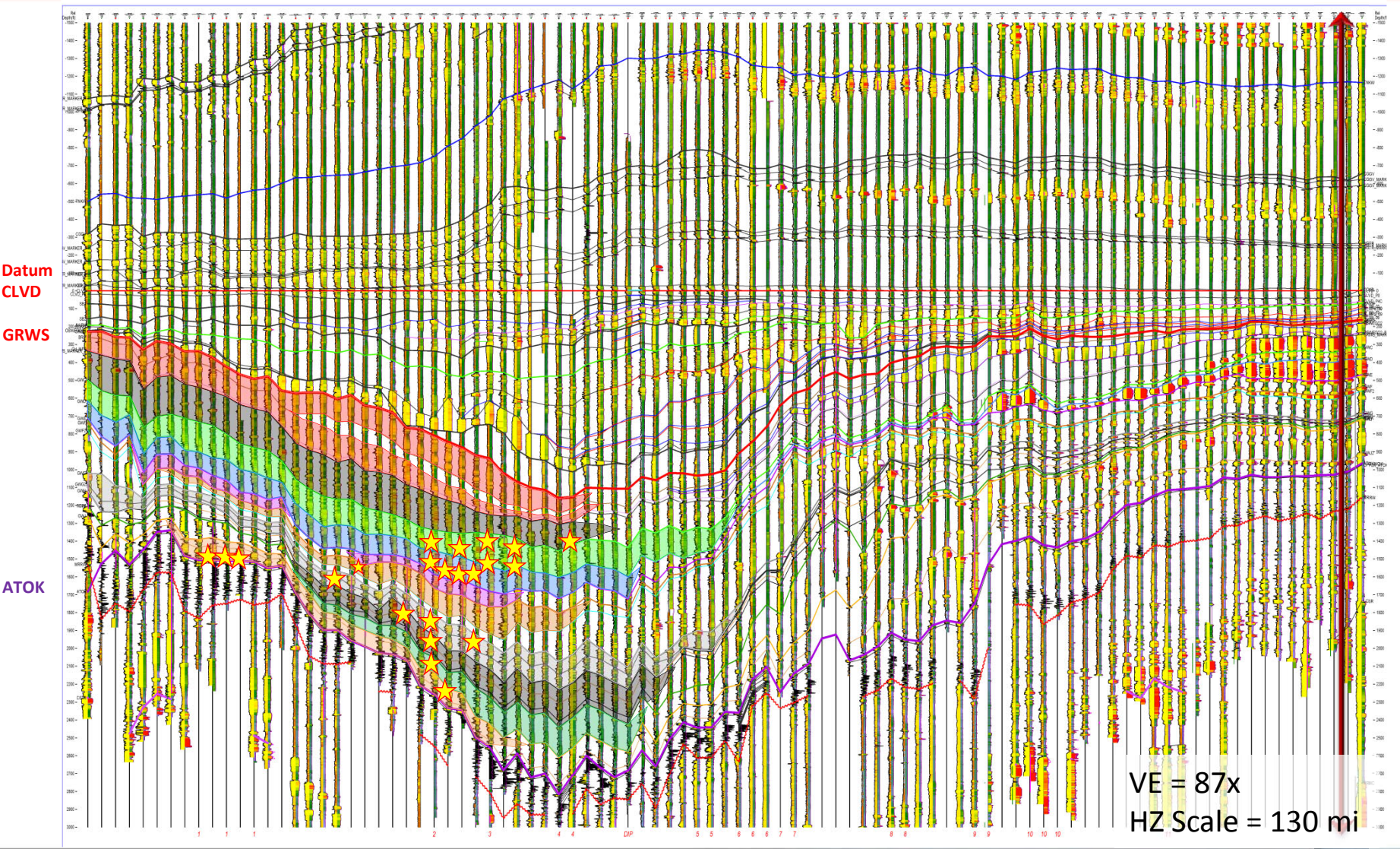

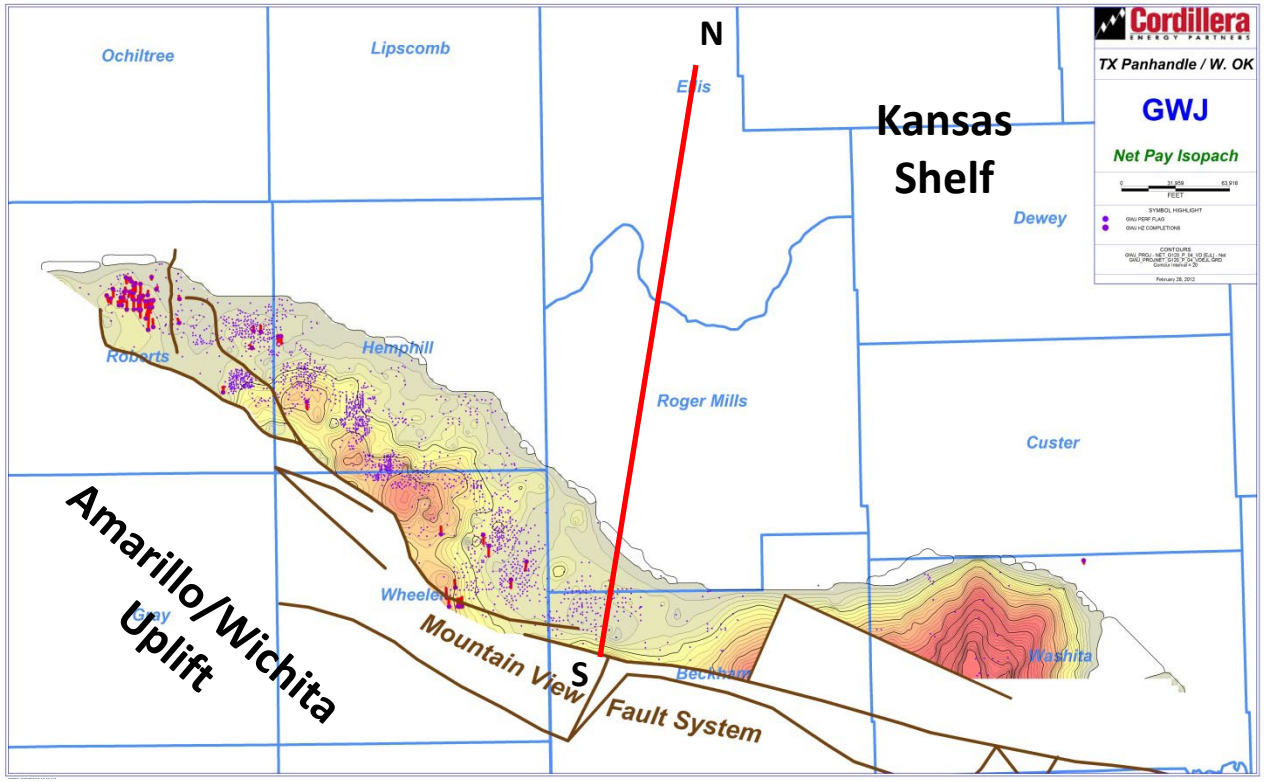
Ochiltree
Lipscomb
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Custer
Amarillo/Wichita Uplift
Wheeler
Gray
Mountain View
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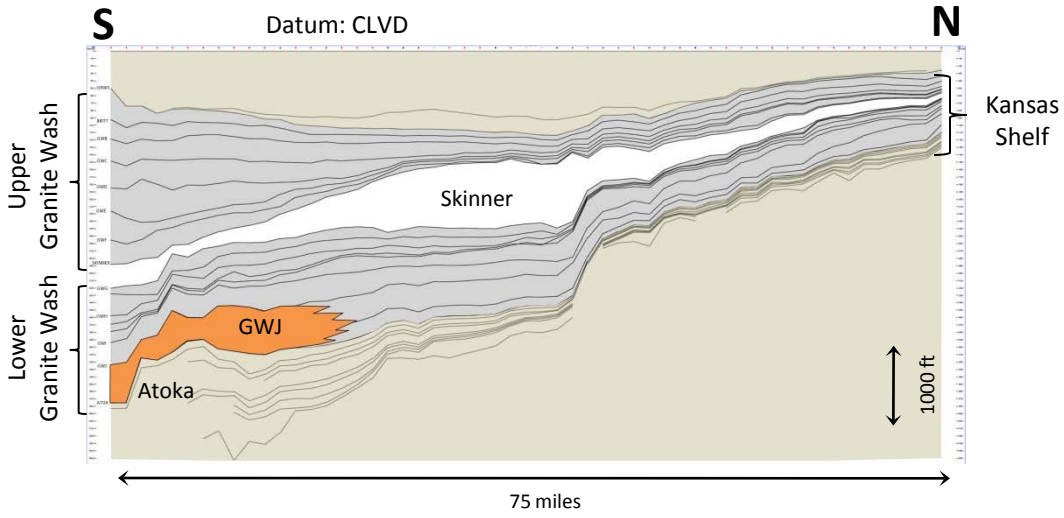
Beckham
Washita
Cordillera
TX Panhandle / W. OK
GWJ
Net Pay Isopach

C.I= 20’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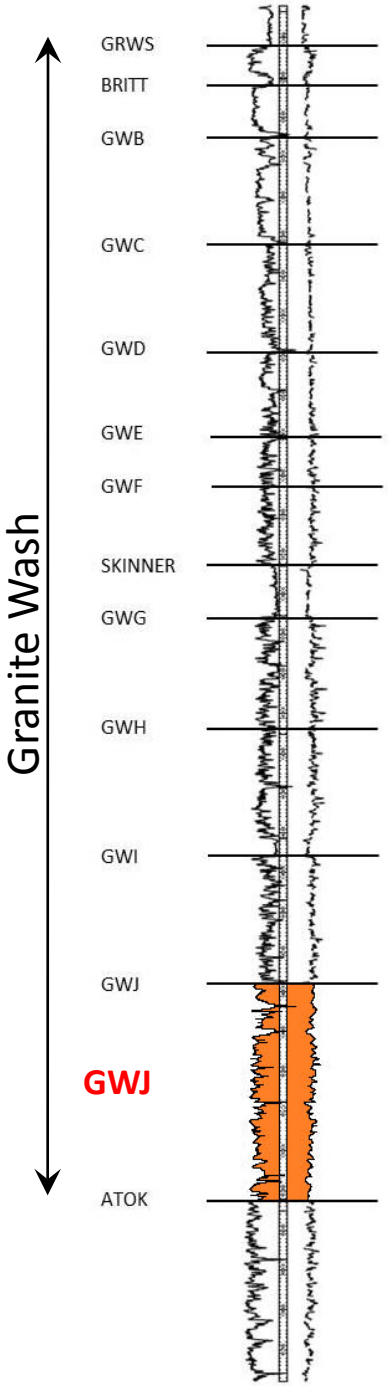
Upper Granite Wash
Lower Granite Wash
Skinner
GWJ
Atoka
Kansas Shelf
1000 ft
75 miles


Granite Wash
GRWS
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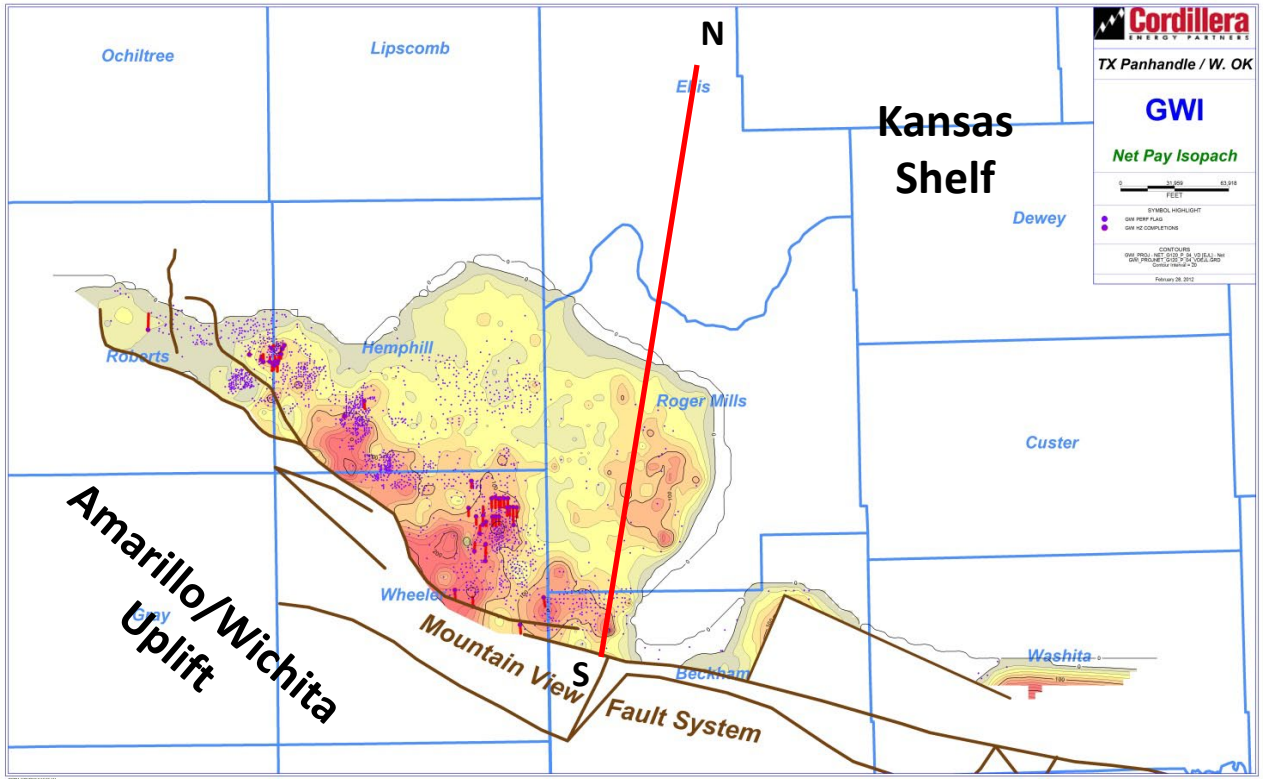
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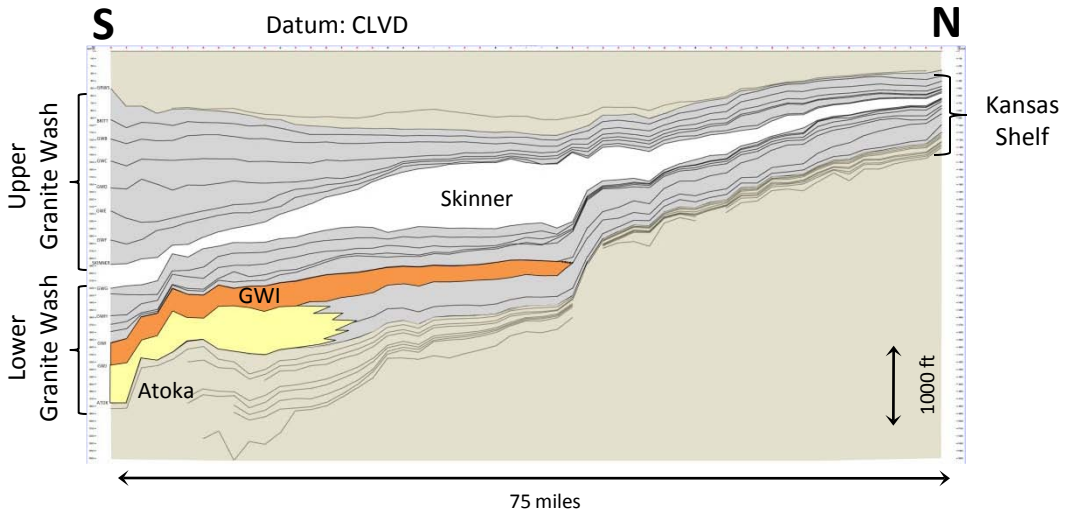
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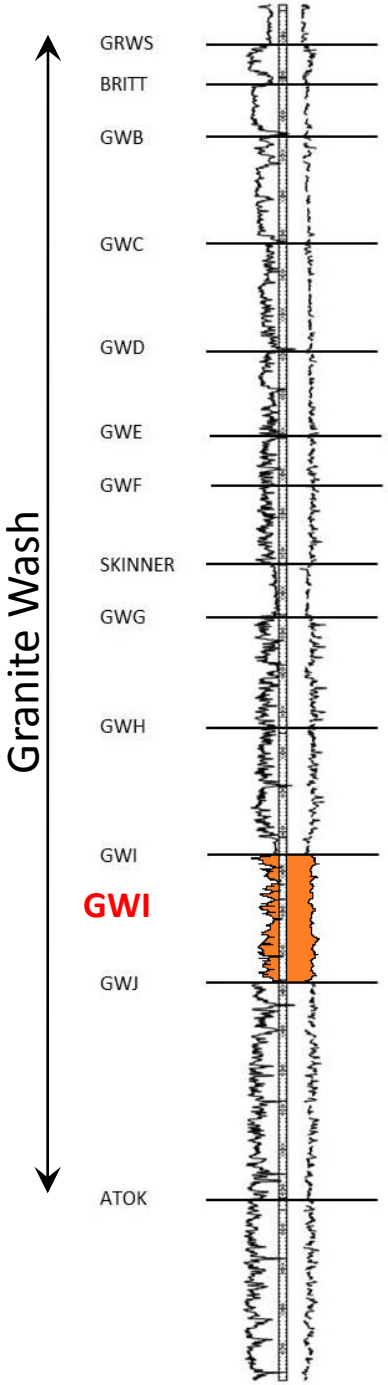
Kansas Shelf
1000 ft
75 miles


Granite Wash
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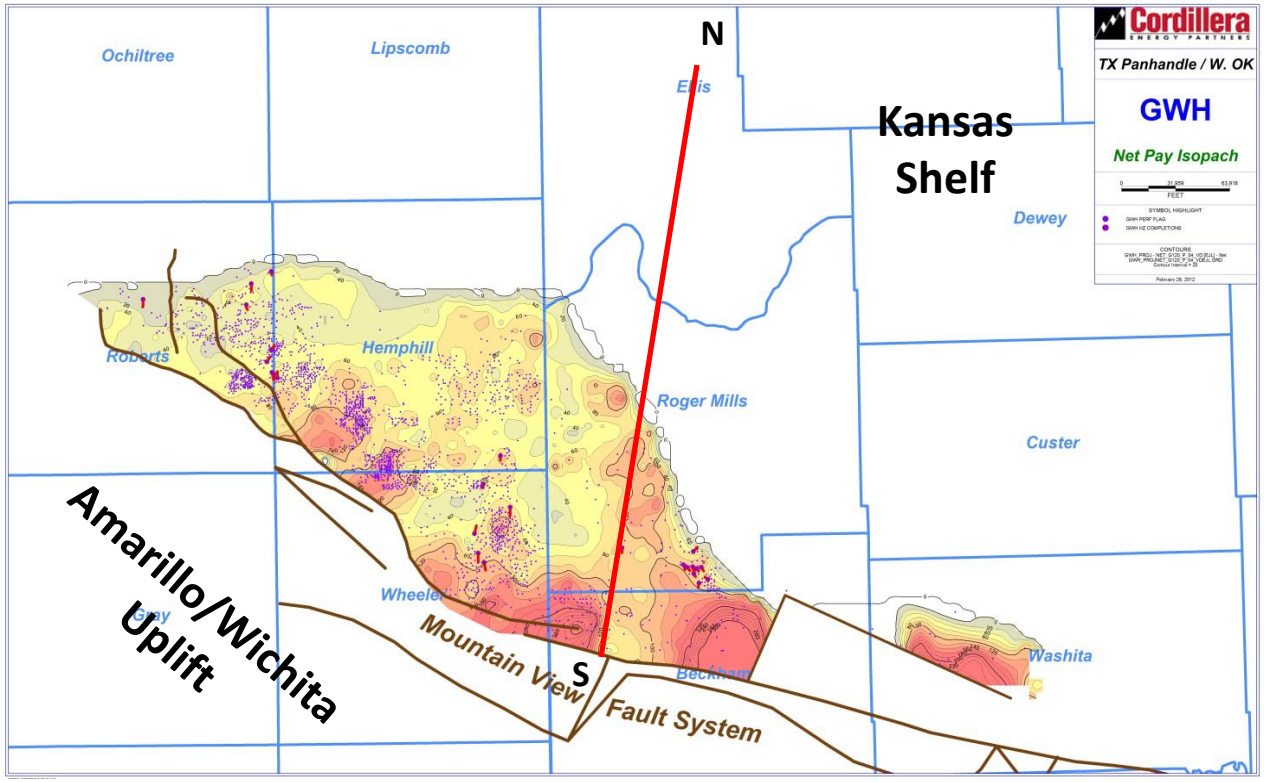
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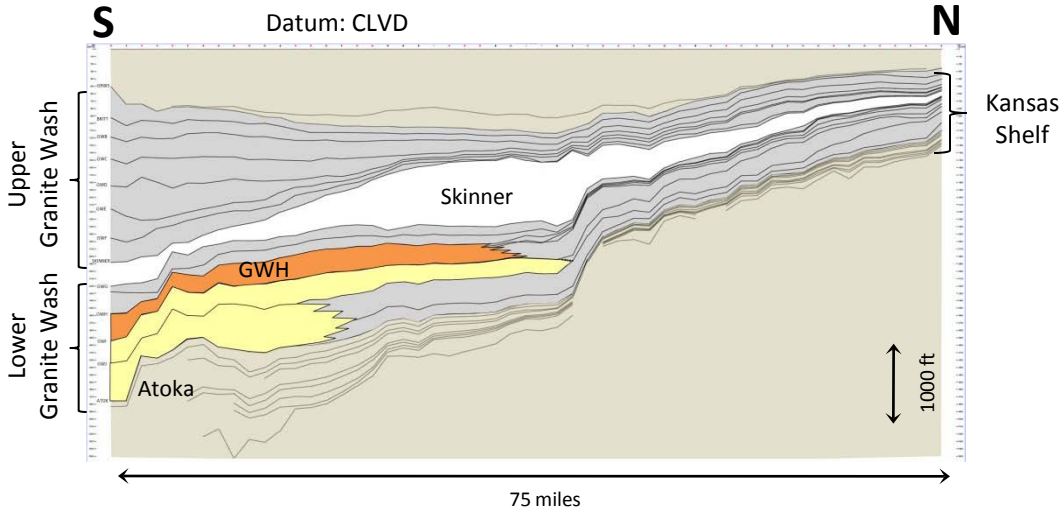
C.I= 20’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Datum: CLVD
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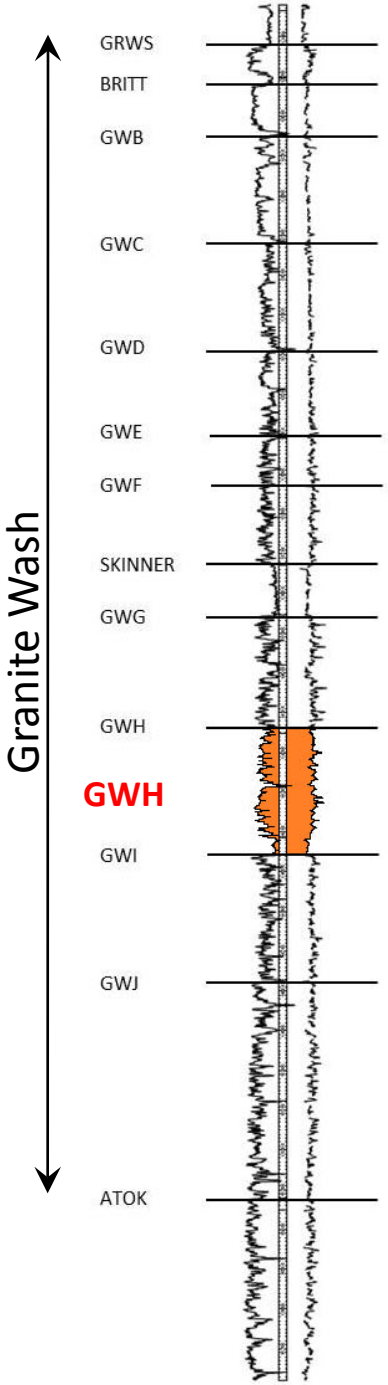
Lower Granite Wash
Skinner
GWH
Atoka
Kansas Shelf
1000 ft
75 miles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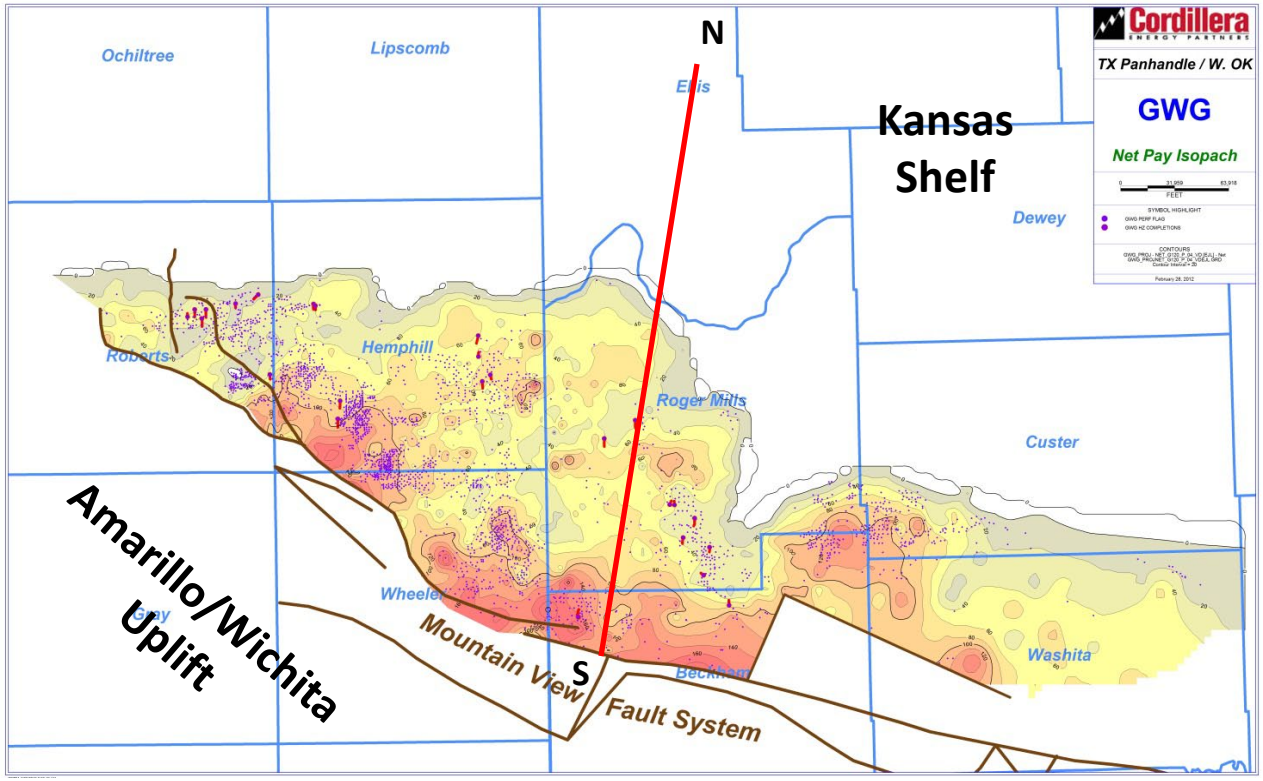
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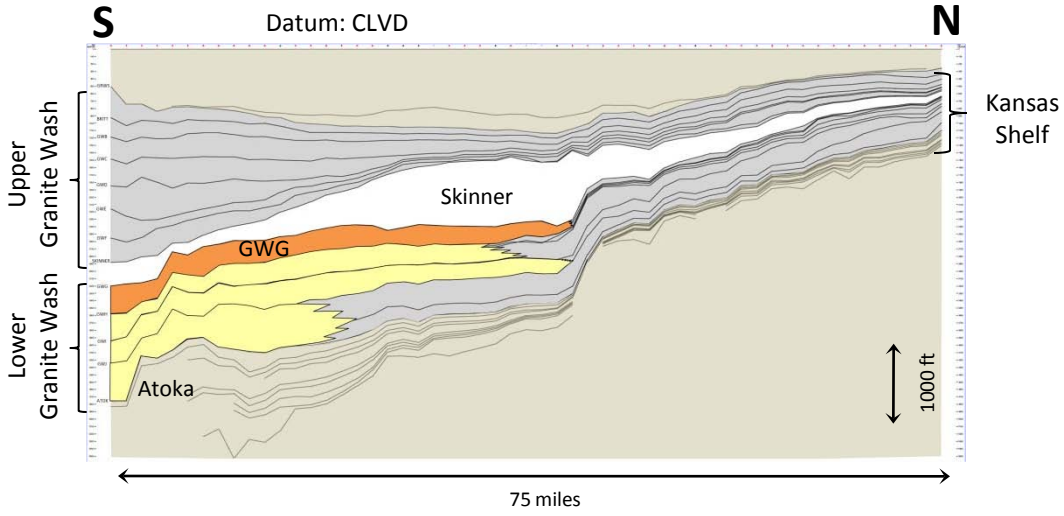
Kansas Shelf
Dewey
Cordillera
TX Panhandle / W. OK
GWG
Net Pay Isopach
Hemphill
Roberts
Roger Mills
Custer
Amarillo/Wichita Uplift
Wheeler
Gray
Mountain View
S
Fault System
Beckham
Washita

C.I= 20’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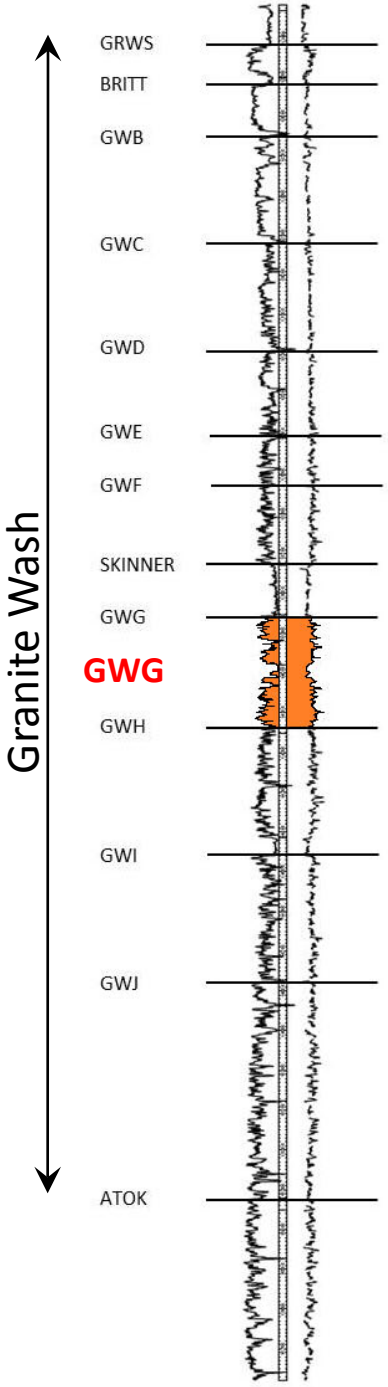
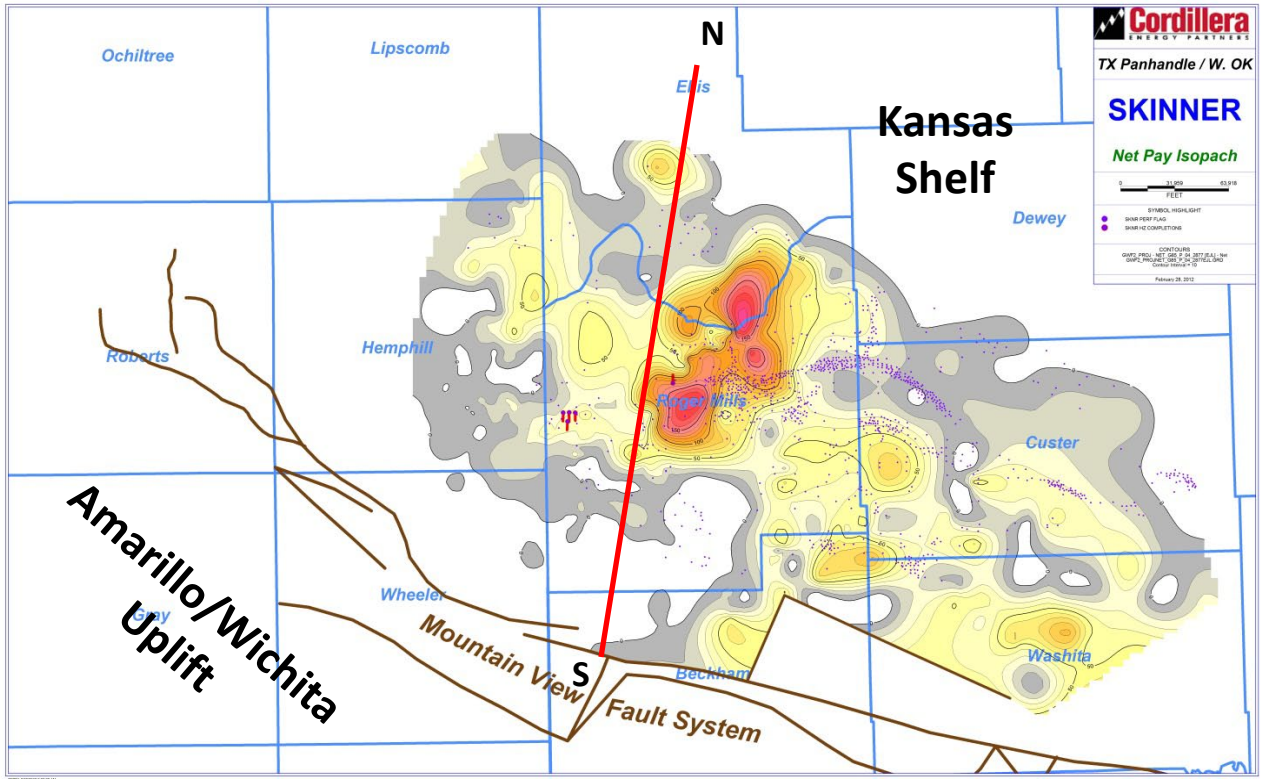
Datum: CLVD
N
Upper Granite Wash
Lower Granite Wash
Kansas Shelf
Skinner
GWG
Atoka
1000 ft
75 miles


Granite Wash
GRWS
BRITT
GWB
GWC
GWD
GWE
GWF
SKINNER
GWG
GWG
GWH
GWI
GWJ
ATOK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Lipscomb
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Ellis
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SKINNER
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Roberts
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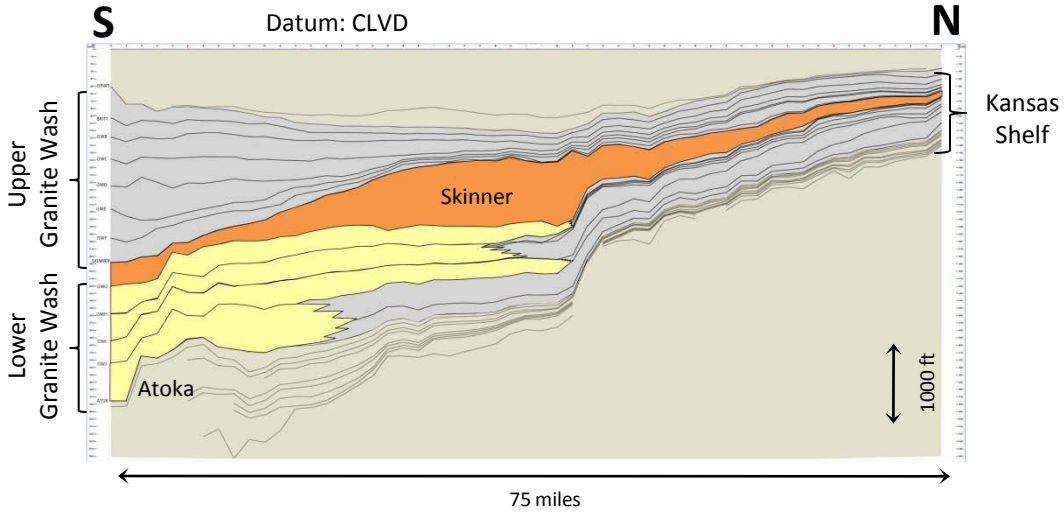
Wheeler
Gray
Mountain View
S
Fault System
Beckham
Washita

C.I= 10’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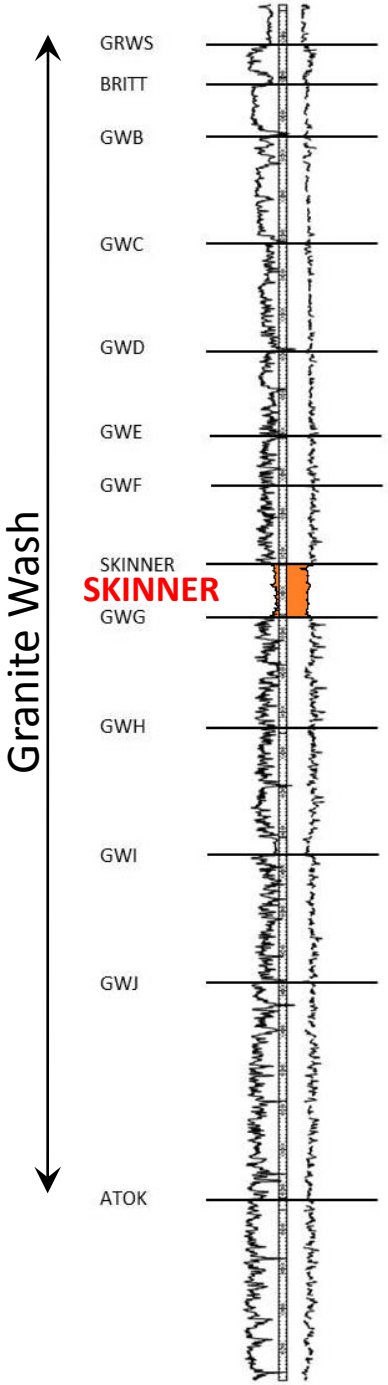
Lower Granite Wash
Skinner
Atoka
Kansas Shelf
1000 ft
75 miles


Granite Wash
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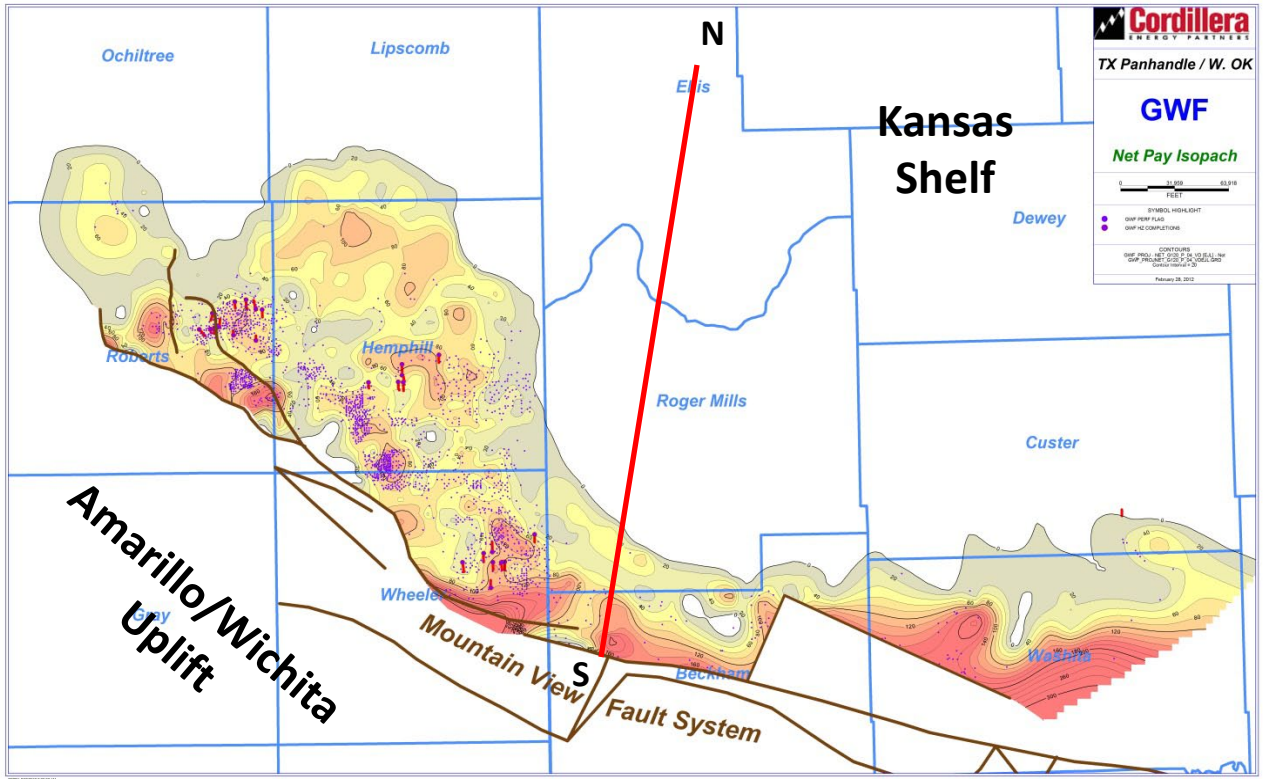
GWB
GWC
GWD
GWE
GWF
SKINNER
SKINNER
GWG
GWH
GWI
GWJ
ATOK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Cordillera
ENERGY PARTNERS
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GWF
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Hemphill
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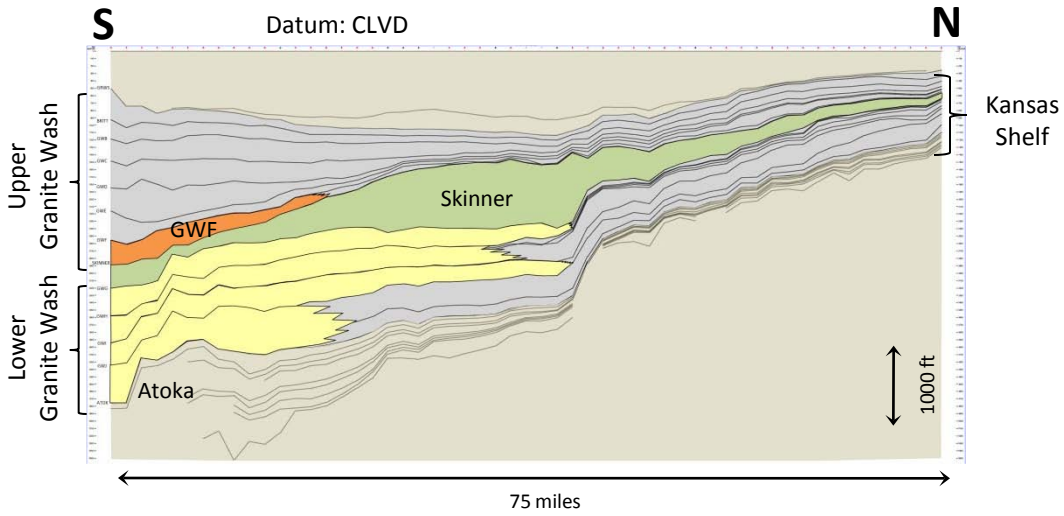
Custer
Amarillo/Wichita Uplift
Wheeler
Gray
Mountain View
S
Fault System
Beckham
Washita

C.I= 20’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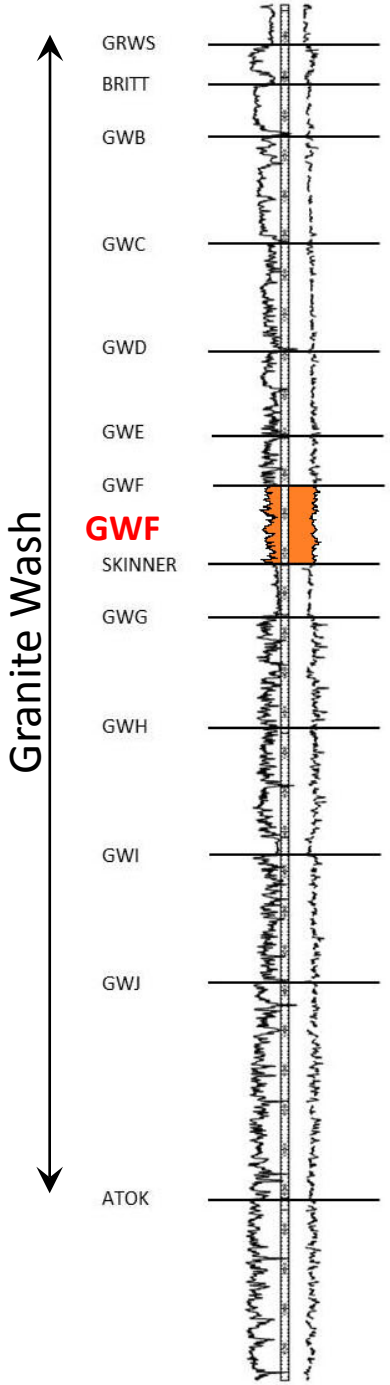
Lower Granite Wash
GWF
Skinner
Atoka
Kansas Shelf
1000 ft
75 miles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GWB
GWC
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SKINNER
GWG
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GWI
GWJ
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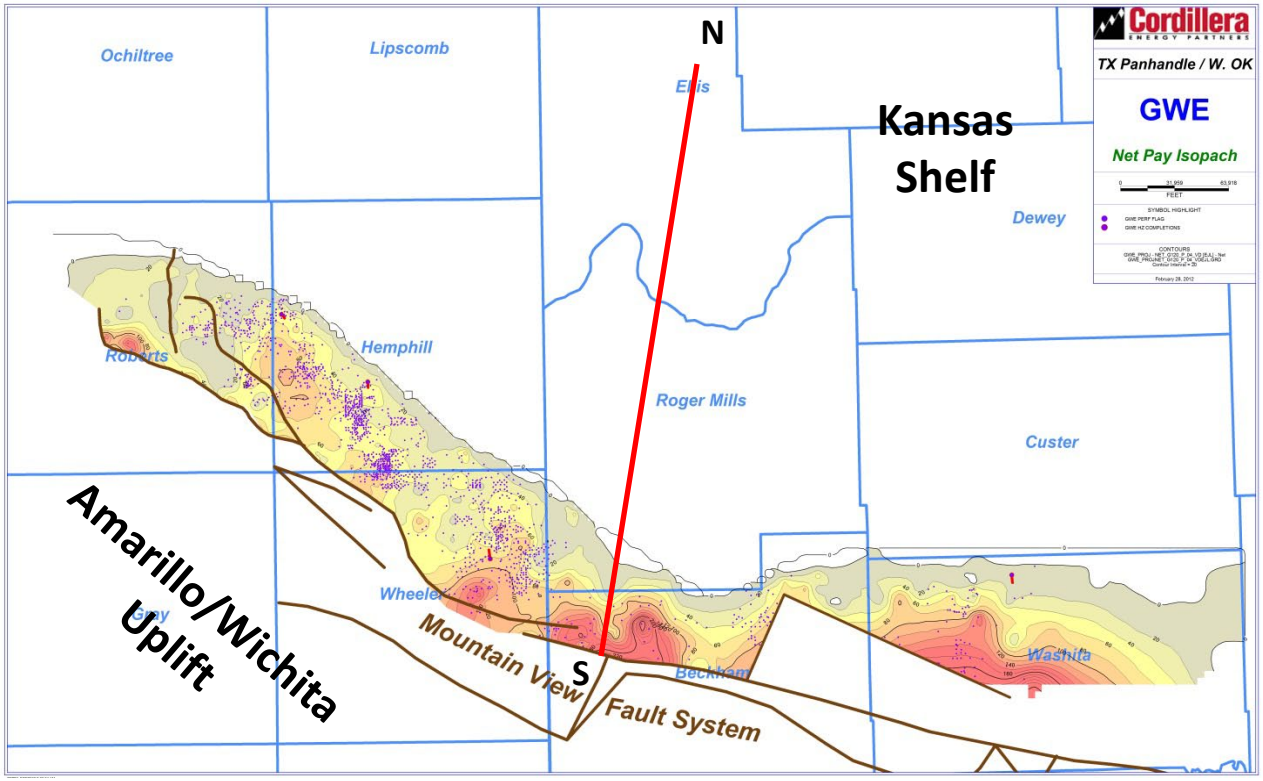
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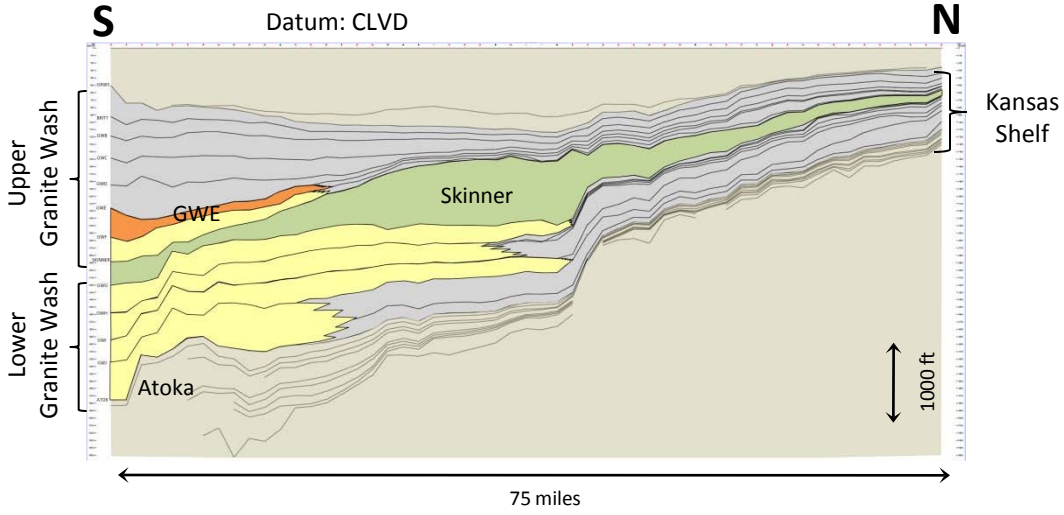
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Lower Granite Wash
GWE
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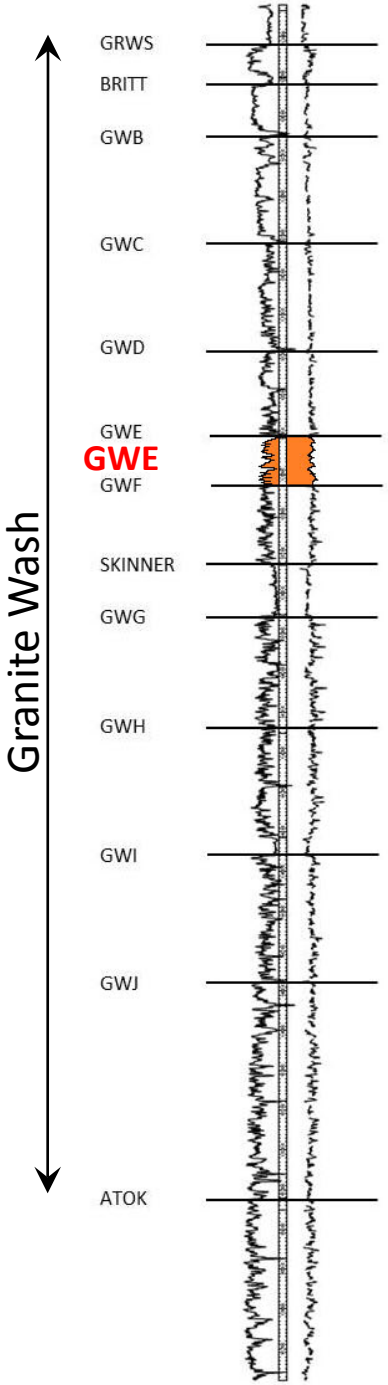
1000 ft
75 miles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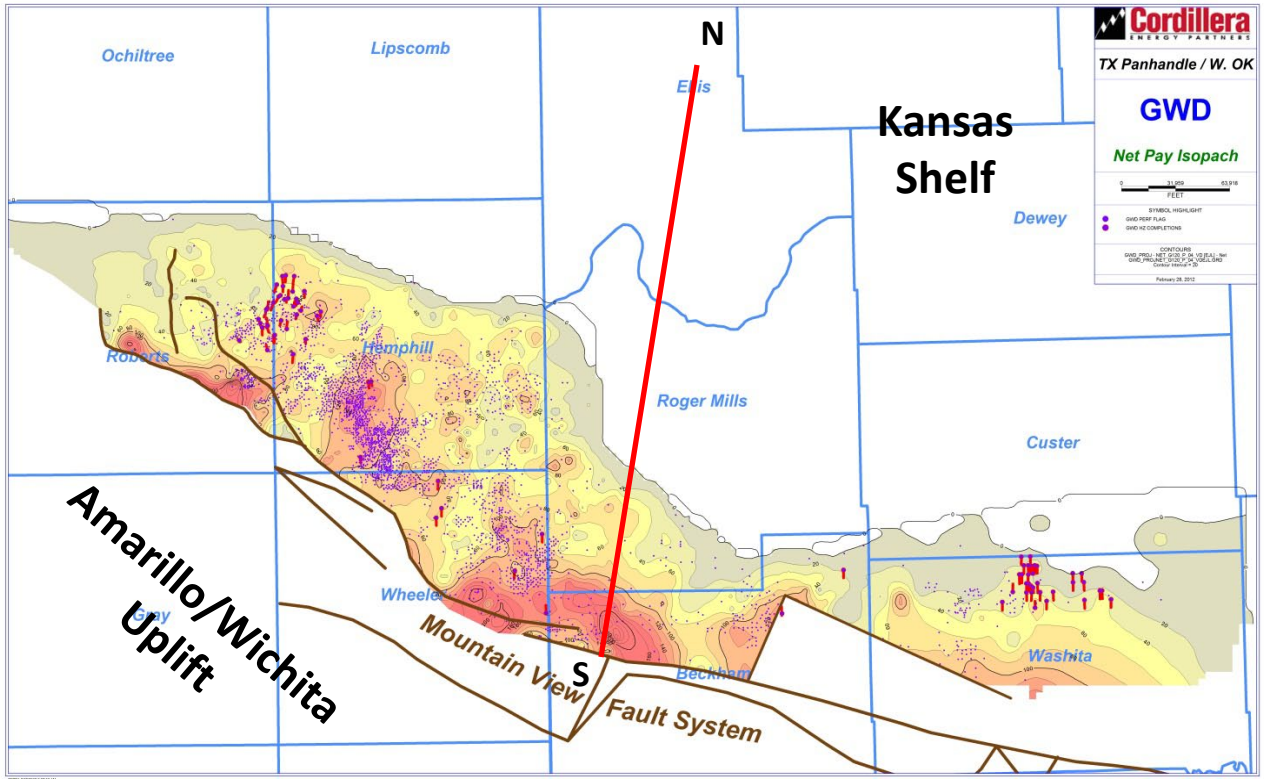
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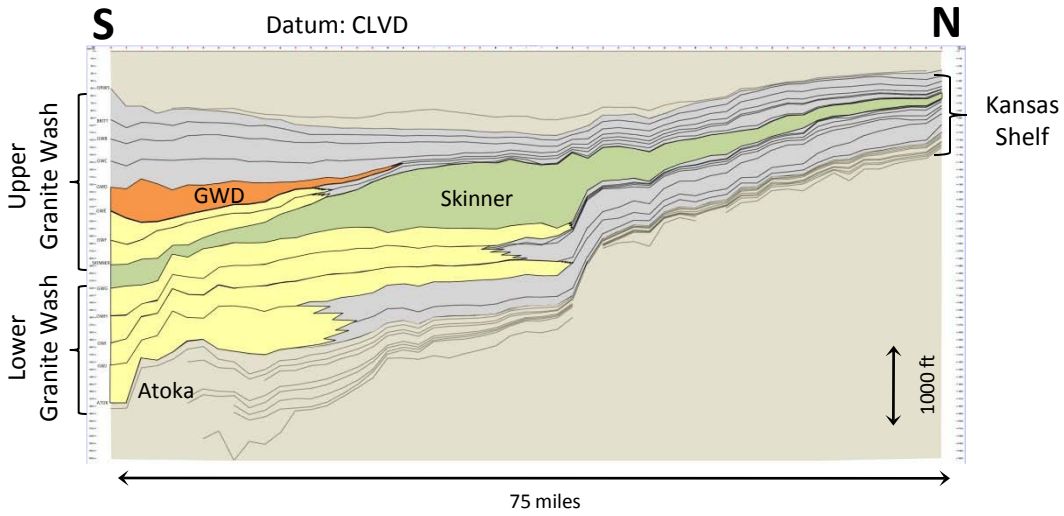
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Datum: CLVD
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Upper Granite Wash
Lower Granite Wash
GWD
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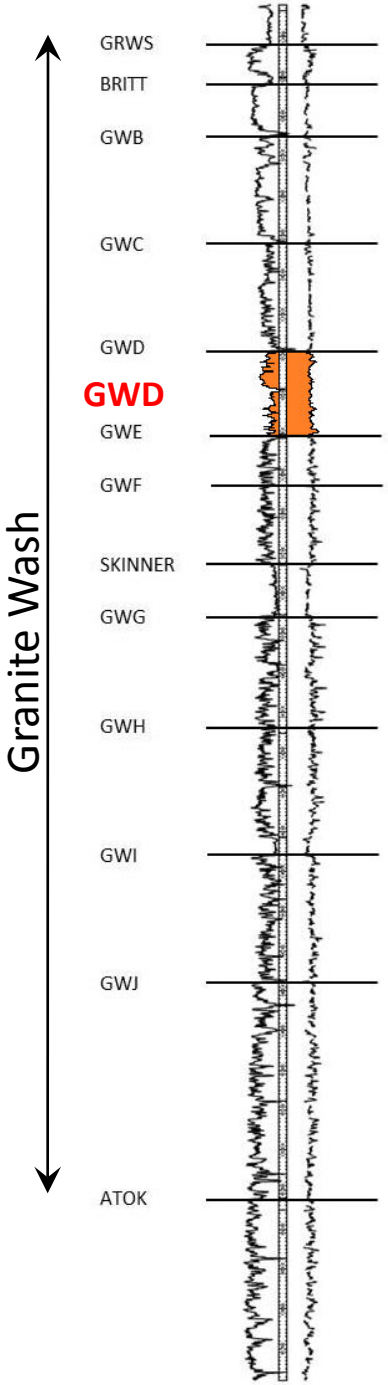
Kansas Shelf
1000 ft
75 miles


Granite Wash
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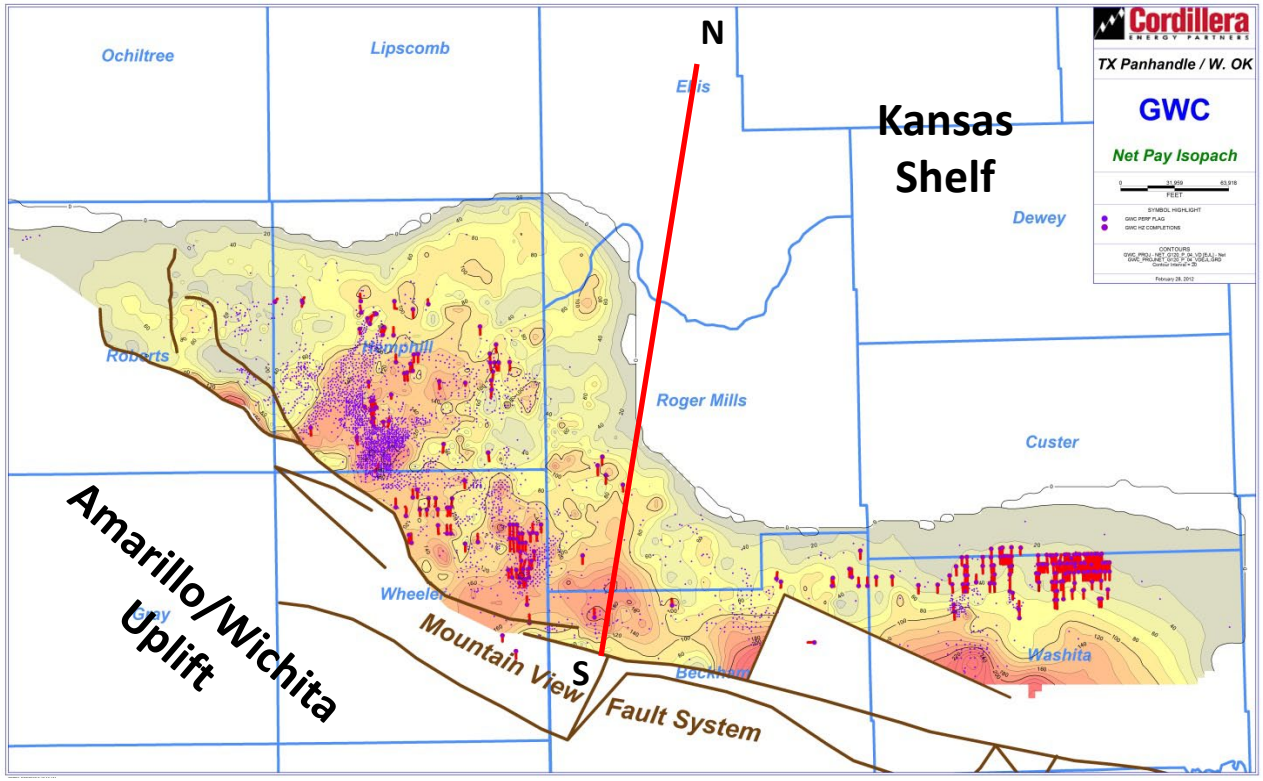
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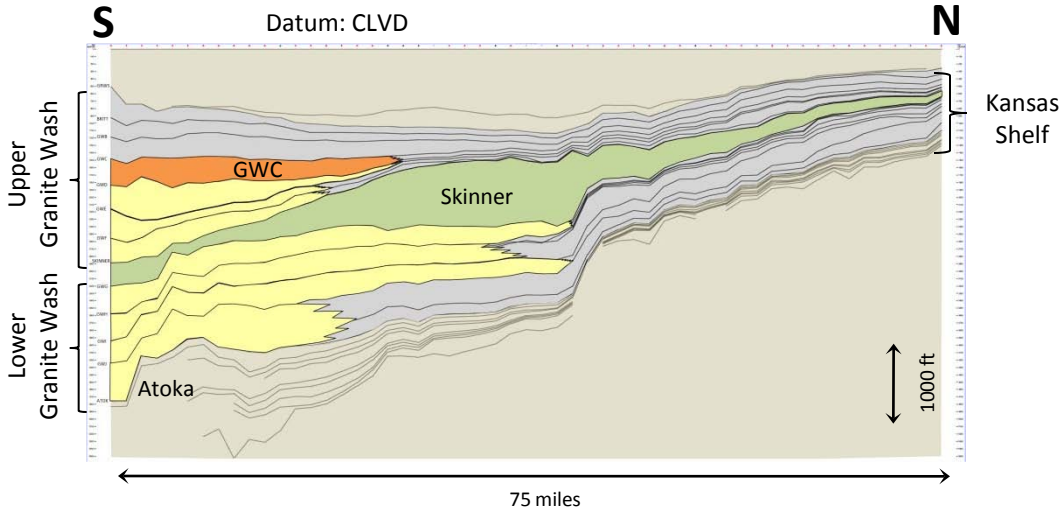
S
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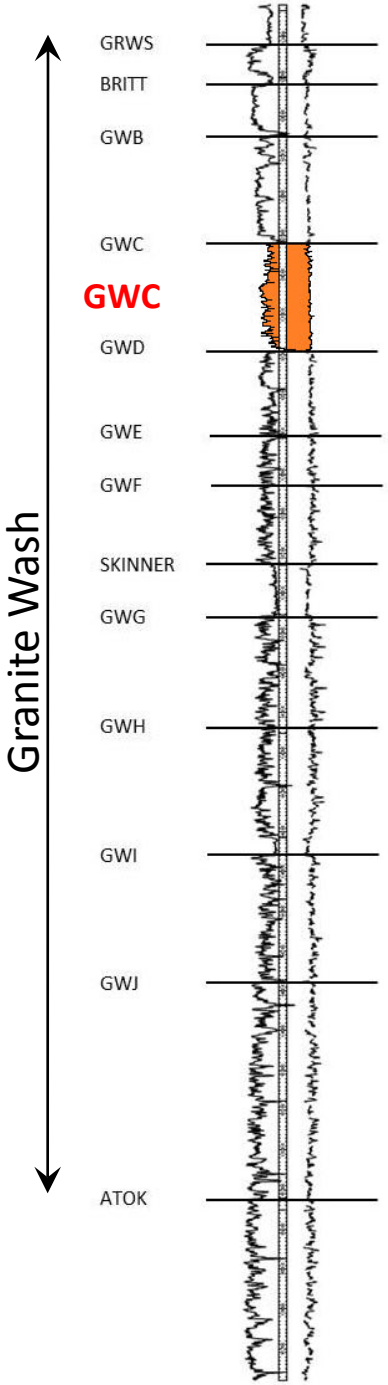
Kansas Shelf
Upper Granite Wash
Lower Granite Wash
GWC
Skinner
Atoka
1000 ft
75 miles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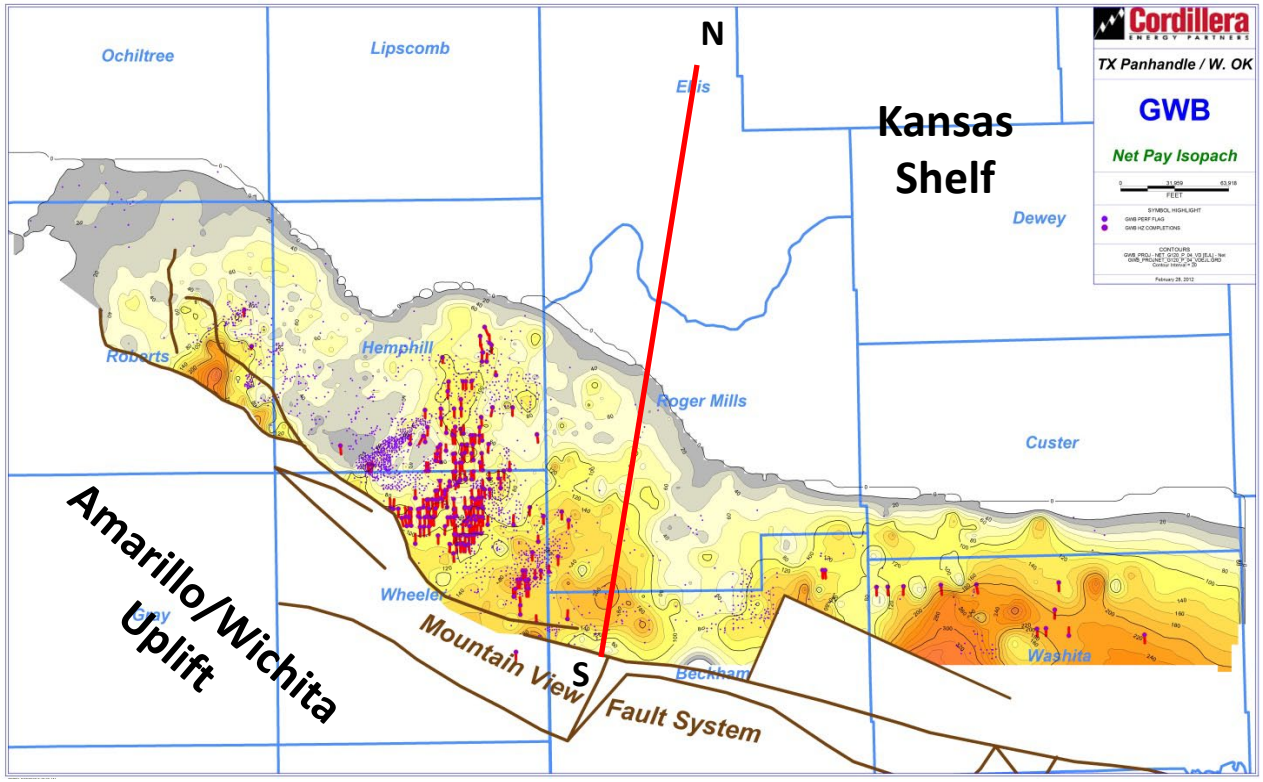
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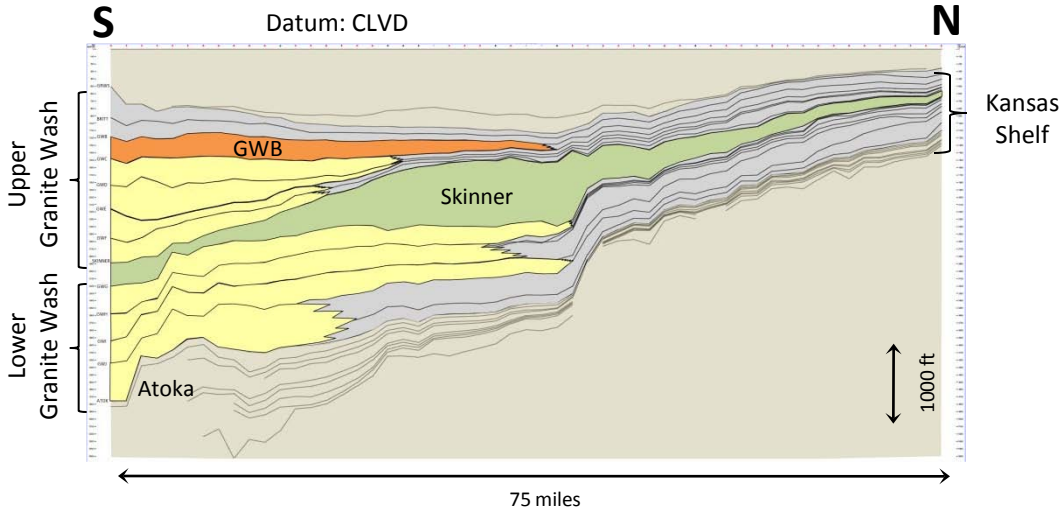
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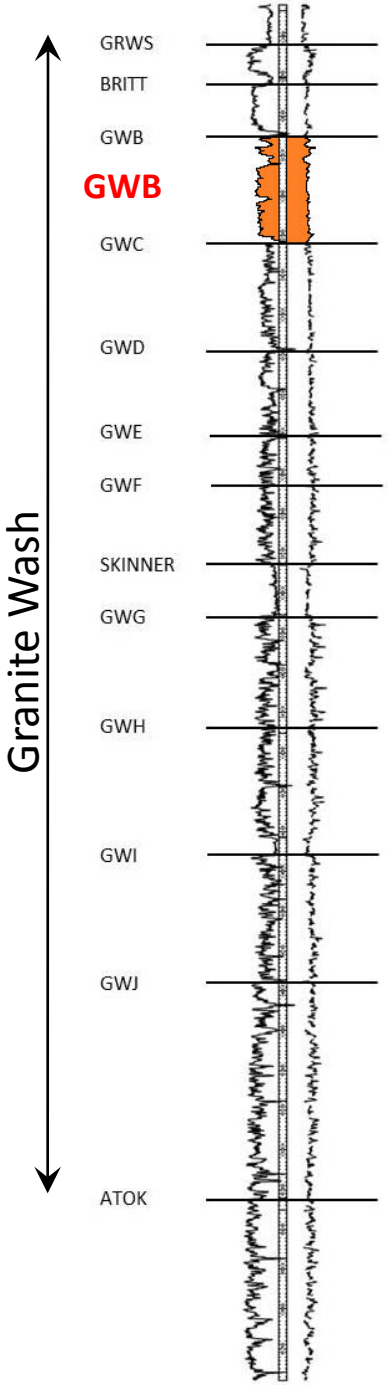
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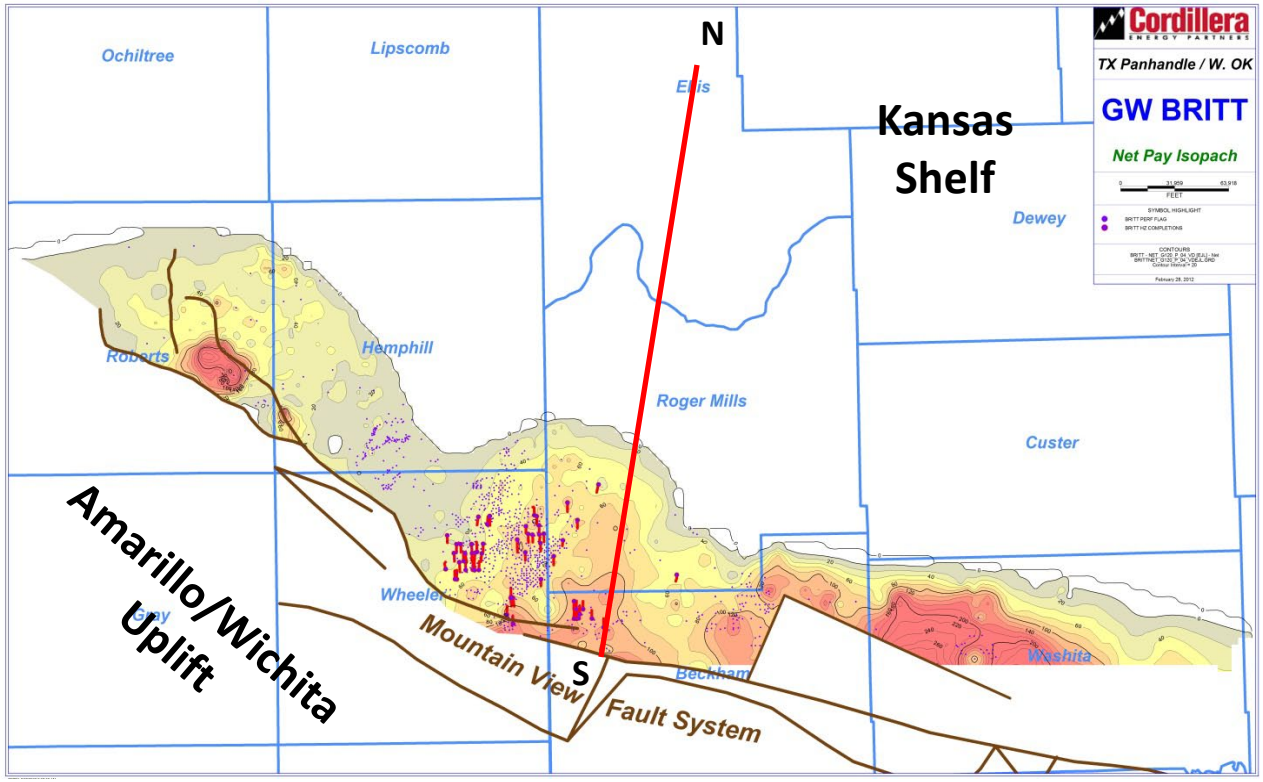
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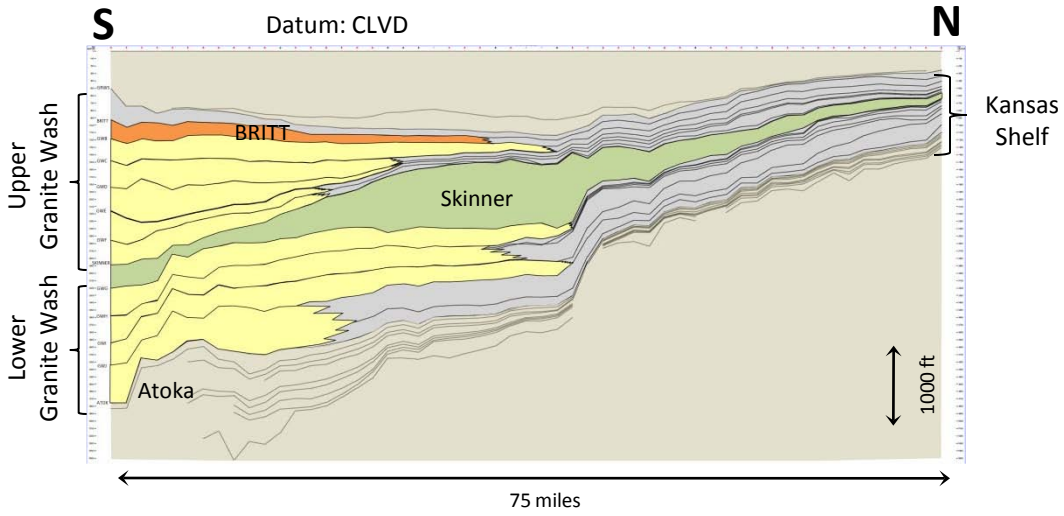
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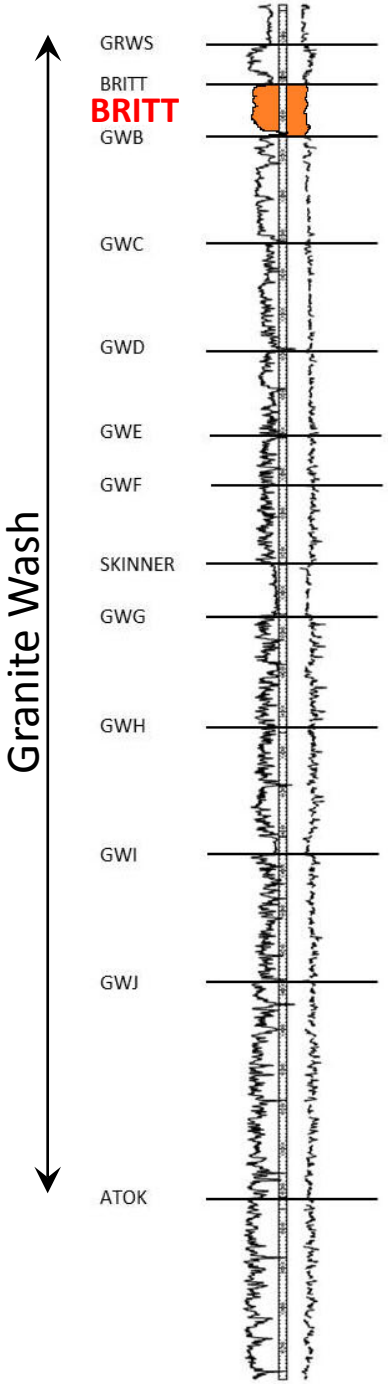
75 miles


Granite Wash
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BRITT
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SKINNER
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GWH
GWI
GWJ
ATOK

Conclusion

- Desmoinesian Granite Wash Play in the Anadarko Basin is one of the most active plays in the Continental United States.
- Clastics shed from the Wichita Mountain-Amarillo Uplift were deposited in the Anadarko Basin by sediment gravity flows creating a massive submarine sand complex.
- Anomalously pressured hydrocarbon system, both under- and overpressured.
- Produces both oil and gas; ratios vary laterally and vertically.
- Minimum of fifteen separate reservoirs.
- Advent of horizontal drilling technology and isolated multi-stage fracture stimulation has revolutionized play.
- New technology has enabled development of a giant field within a mature basin.
- As mapped today this field will take decades to develop, with new isolated reservoirs still being discovered.