Influence of Second-Order Faults on Low-Permeability Oil Reservoir (Turner Sandstone), Powder River Basin, Wyoming, USA*

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Abstract

The Upper Cretaceous-aged Turner Sandstone is a low-permeability oil reservoir that has produced 32 million BO from about 1,000 vertical wells in multiple fields in the southern Powder River Basin of NE Wyoming, USA. Economics for vertical wells have been marginal, but recently Abraxas Petroleum Corporation and other operators have attempted to exploit the known Turner oil accumulations utilizing horizontal wells and 3D seismic data.

Using outcrop, cores and logs, the Turner reservoir may be characterized as about 120 ft of interbedded very fine-grained sandstone and shale with fine- to medium-grained basal sandstone. Most of the interval is bioturbated, and the biologic mixing of sand and shale beds greatly diminishes permeability and prevents oil saturation. However, where bioturbation is absent, the sandstone beds are oil saturated. The basal sandstone provides the best reservoir quality, but its thickness varies from 0 to 20 ft. In an attempt to improve individual well performance, Abraxas drilled and completed six horizontal wells in the Turner and acquired a 26 sq mi 3D seismic data set.

Structural interpretation of 3D seismic data indicates two, prominent right-lateral strike-slip faults through the study area. The data set also contains numerous small faults that intercept the Turner reservoir. The small faults are: short (1500-4000 ft), curved, variable azimuth, both normal and reverse movement and limited in vertical extent. These faults are likely second-order deformation related to the larger strike-slip faults.

Abraxas drilled five horizontal Turner wells before acquiring the 3D seismic data. The best well serendipitously crossed one of the small faults. Recently another horizontal well was located to cross another small fault. As planned, the small fault caused fracturing and apparent enhancement of the Turner reservoir in the horizontal wellbore. The latest well is now the best well in the field.

Interpretation of small, second-order faults from 3D seismic data allows operators to locate areas of natural fracture enhancement. Natural

fractures greatly enhance the economics of an oil saturated low-permeability reservoir like the Turner.

References

Christie-Blick, N., and K.T. Biddle, 1985, Deformation and basin development along strike-slip faults, *in* K.T. Biddle, and N. Christie-Blick, (eds.) Strike-Slip Deformation, Basin Formation, and Sedimentation: Society of Economic Paleontologists and Mineralogists, Special Publications, v. 37, p. 1-34.

Du Rouchet, J., 1981, Stress fields, a key to oil migration: AAPG Bulletin, v. 65/1, p. 74-85.

Harding, A.E., 1991, Evidence of the Kane Springs Wash Caldera in the Meadow Valley Mountains, southeastern Nevada: M.S. Thesis, University of Colorado, 121 p.

Sonnenberg, S.A., and R.J. Weimer, 1993, Oil production from Niobrara Formation, Silo field, Wyoming – Fracturing associated with a possible wrench fault system(?): The Mountain Geologist, v. 30/2, p. 39-54.

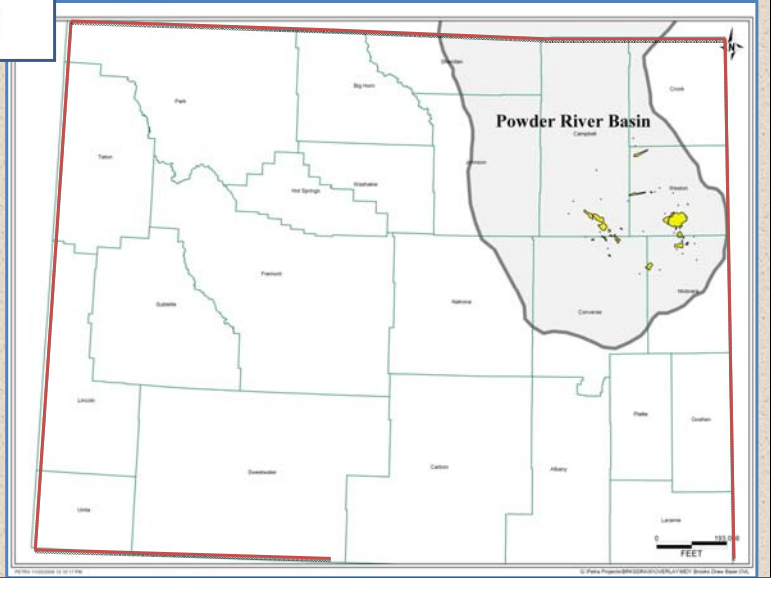
Influence of Natural Fractures from Second-Order Faults on Low-Permeability Oil Reservoir (Turner Sandstone), Powder River Basin, Wyoming, USA

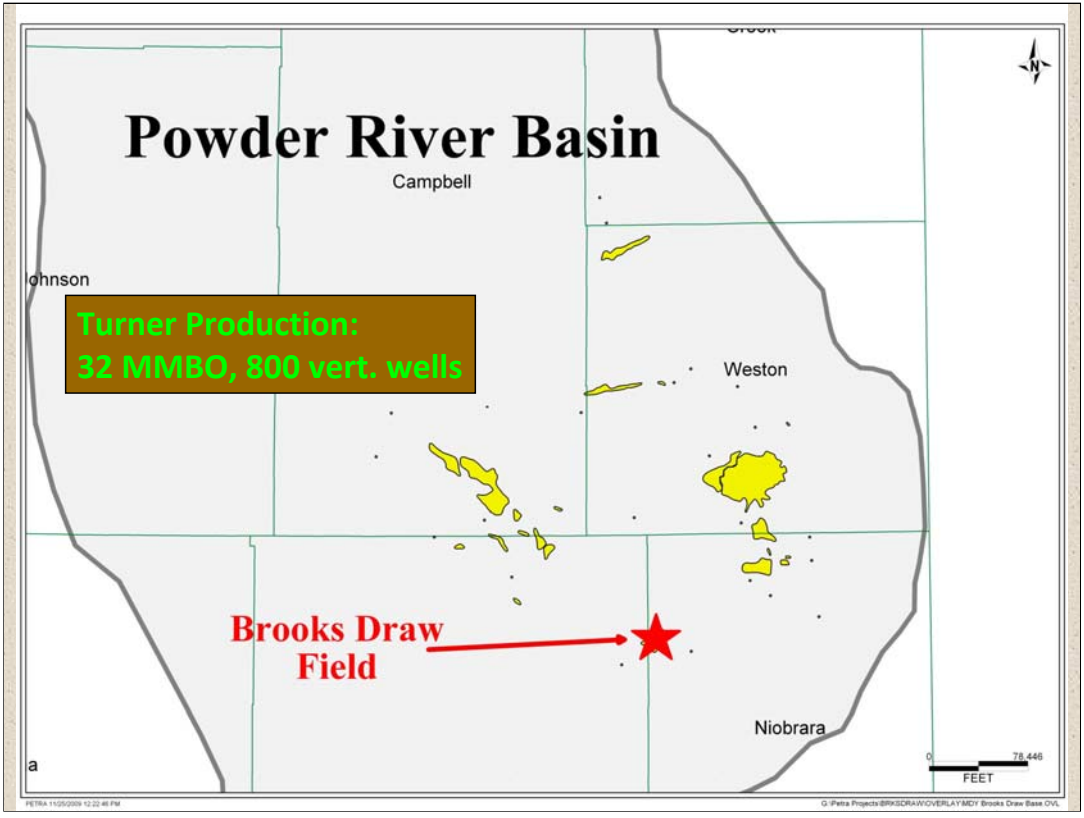
Dr. Lee T. Billingsley

ABRAXAS Petroleum Corporation

Thanks for permission

Powder River Basin, Wyoming





Presenter's notes: Yellow outlines are fields producing from Turner.

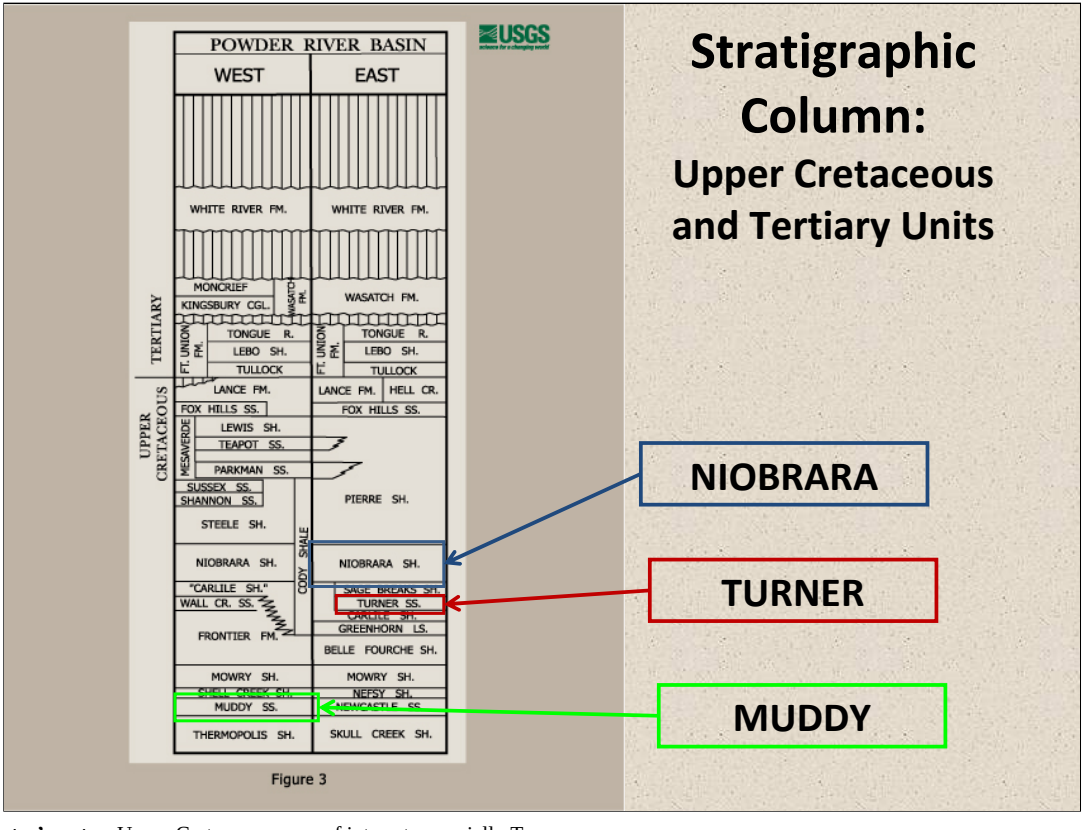
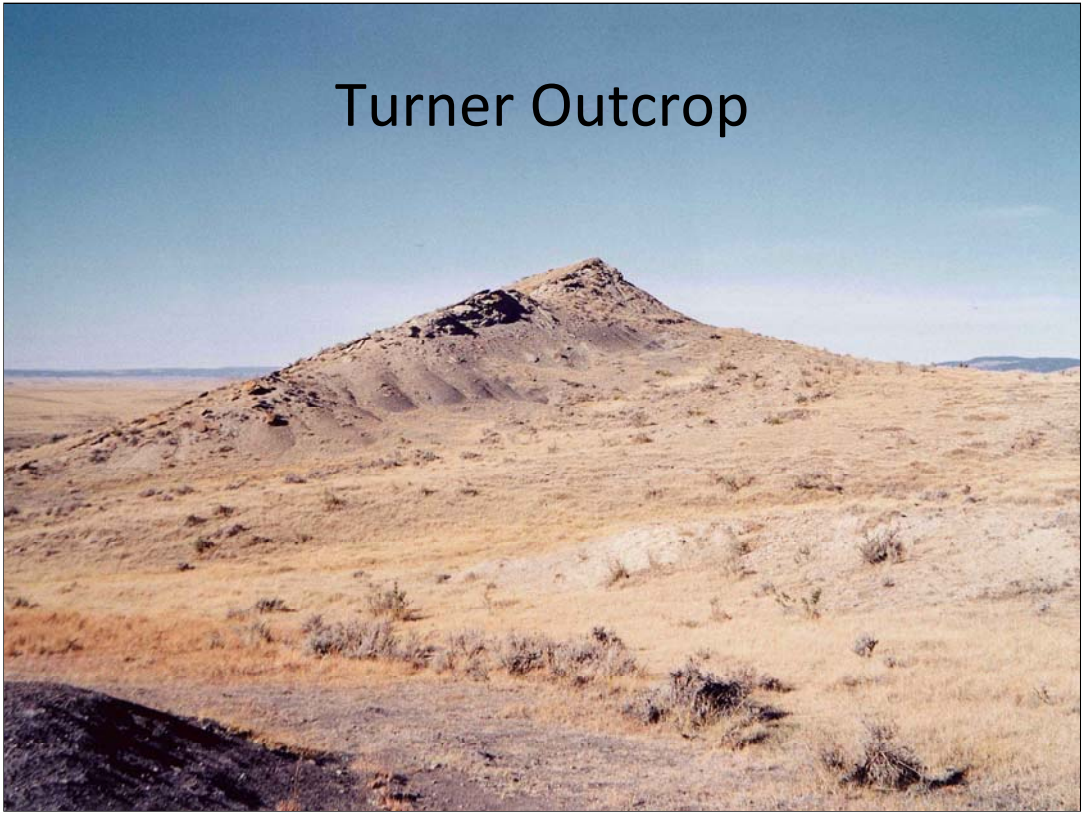
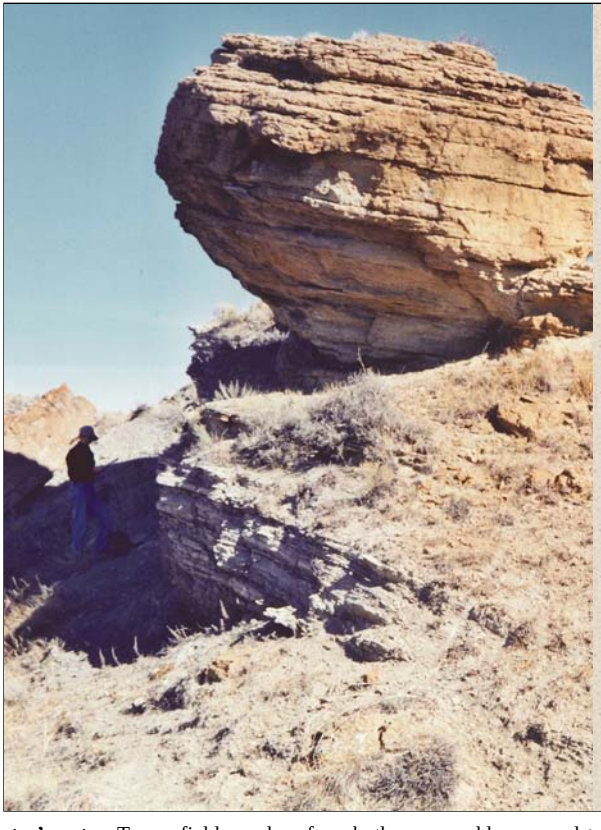


Figure 3

Presenter's notes: Upper Cretaceouszones of interest, especially Turner.

Turner Outcrop

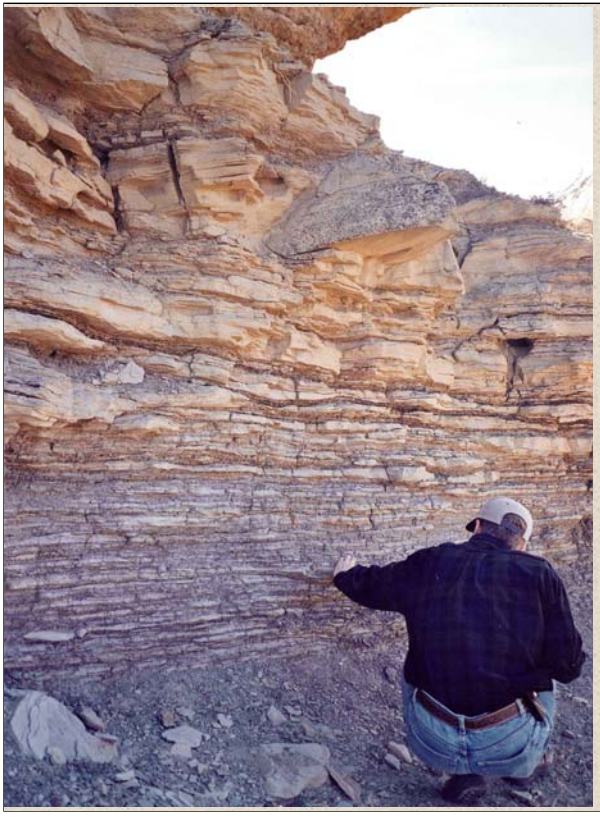




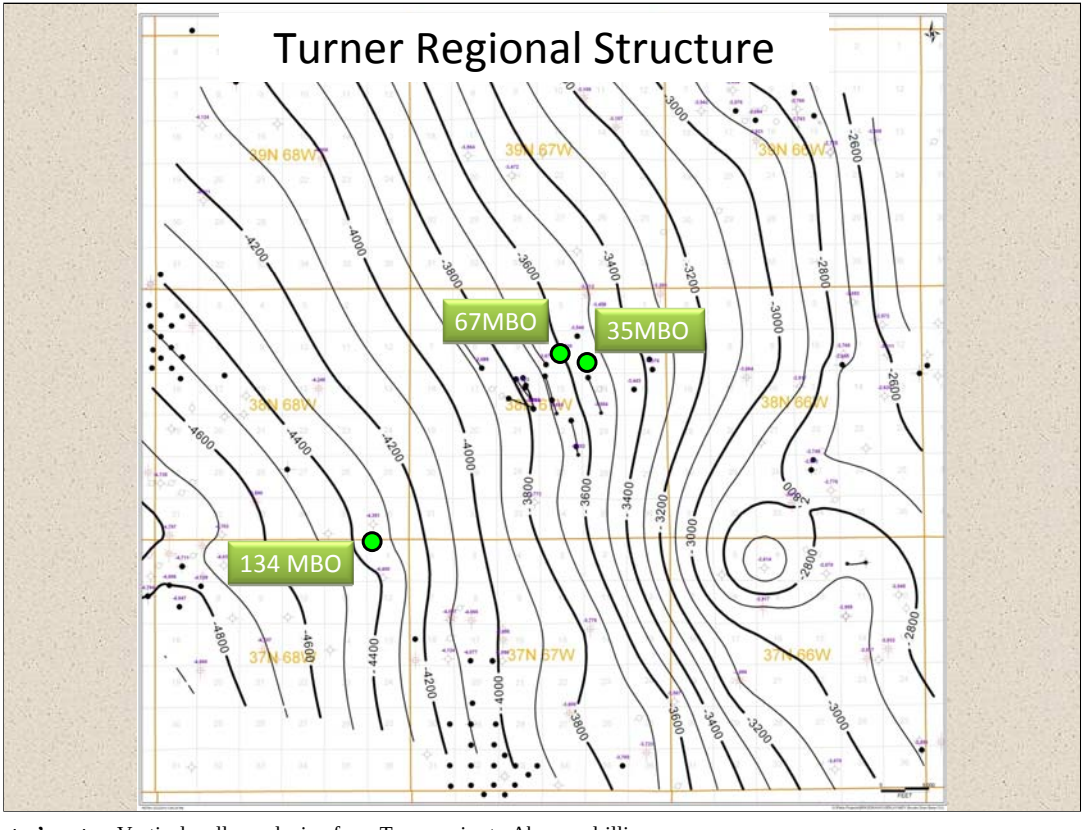
Upper Turner Sandstone

Middle Turner
Siltstone & Shale

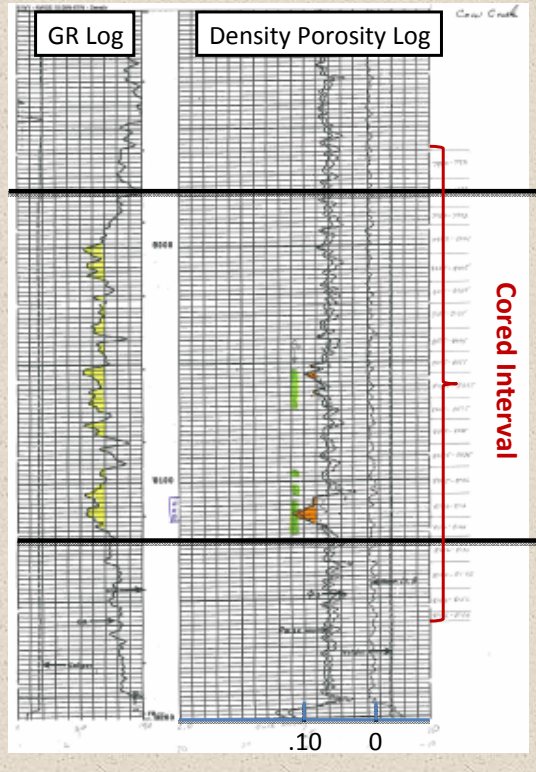
Presenter's notes: Turner fields produce from both upper and lower sandstones.



Middle Turner
Sandstone & Shale

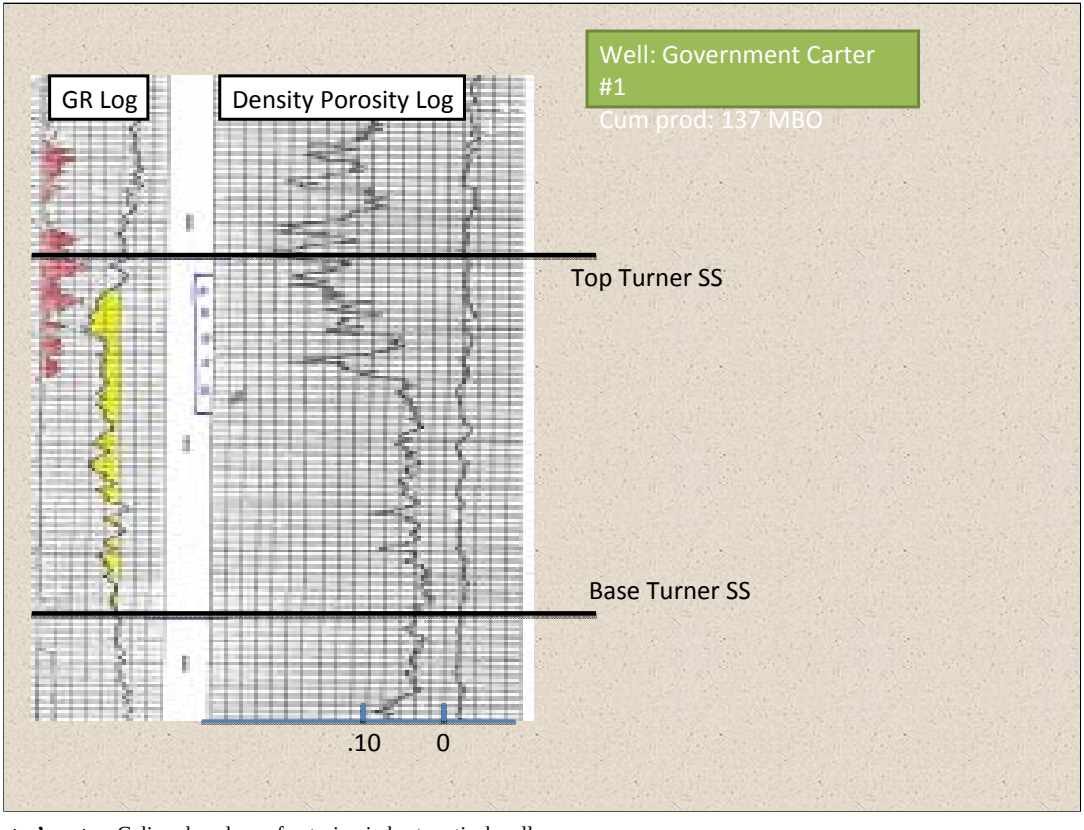


Presenter's notes: Vertical wells producing from Turner prior to Abraxas drilling.

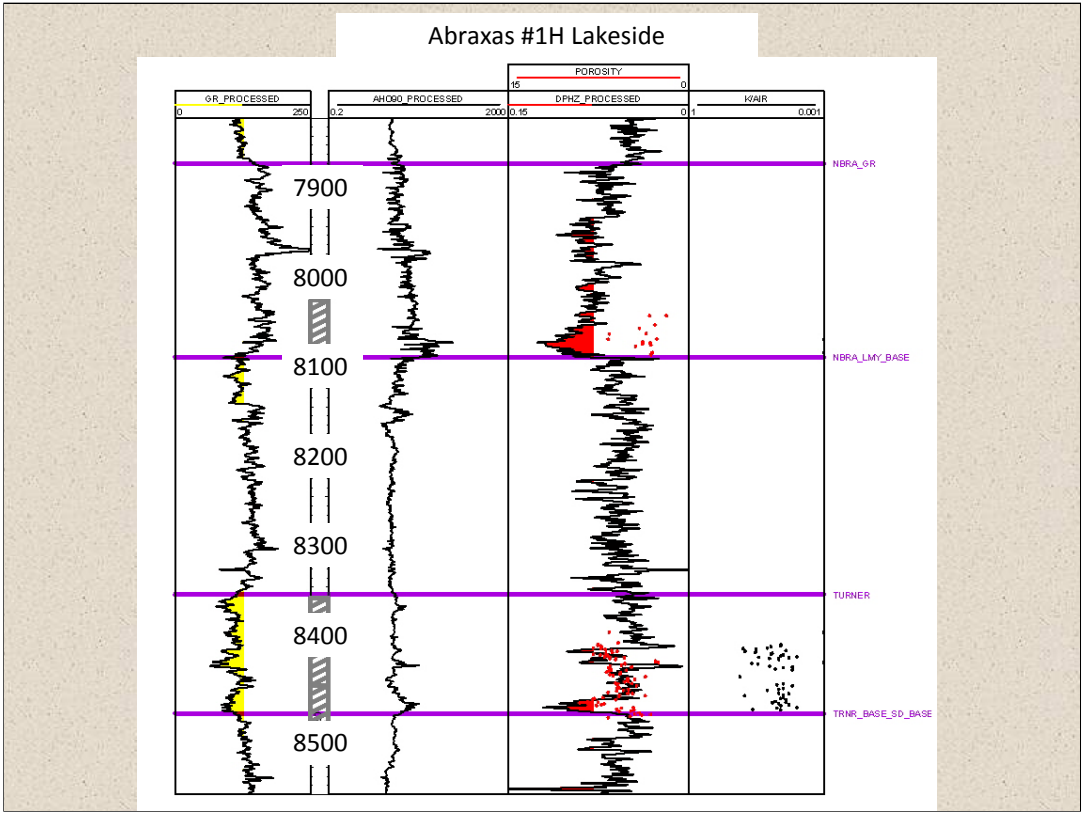


Well: Cow Creek Federal
Cum prod: 35 MBO

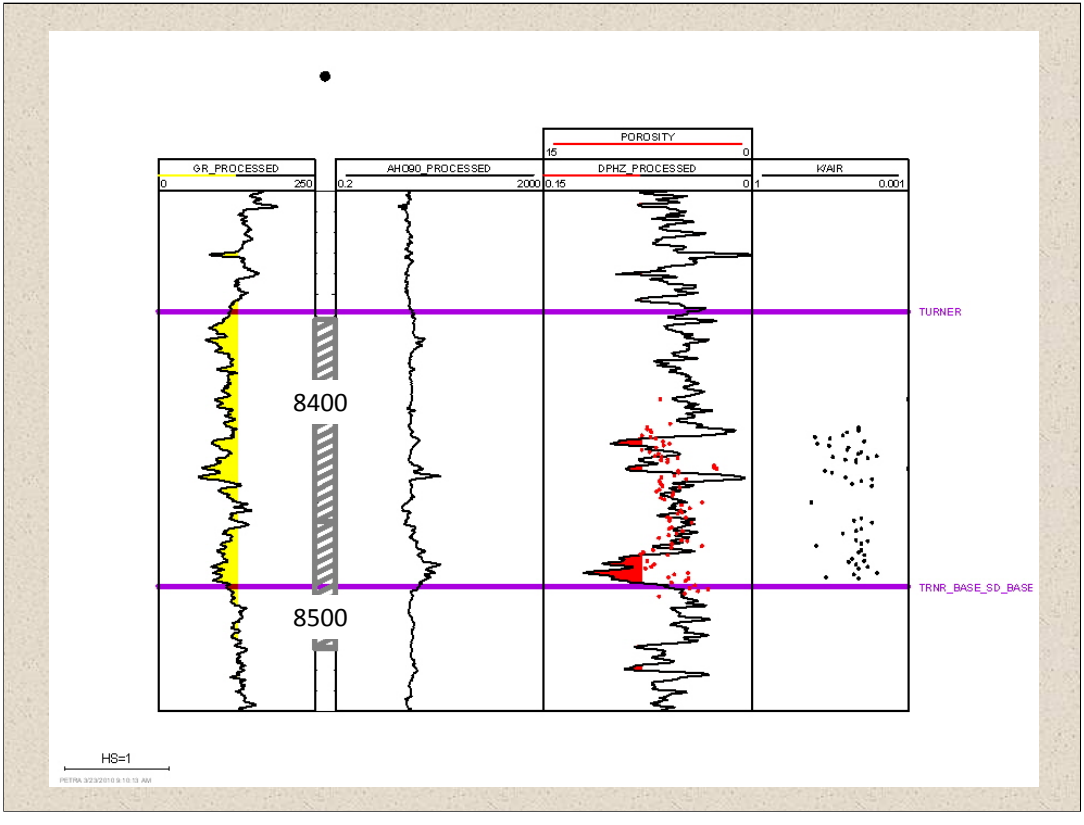
Presenter's notes: Porosity > .08 is shaded.



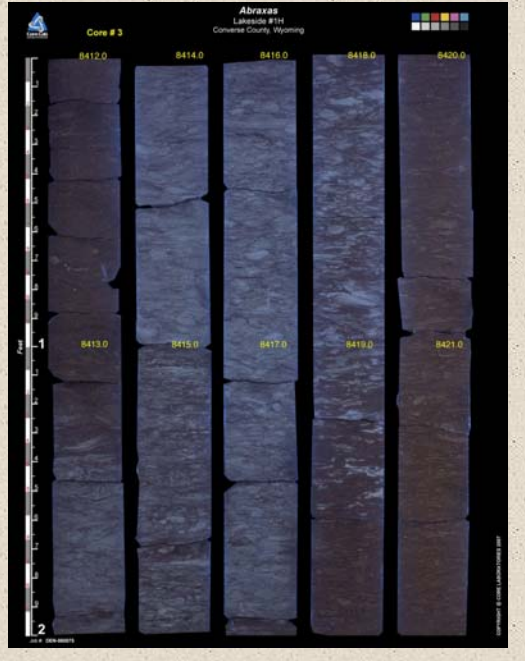
Presenter's notes: Caliper log shows fracturing in best vertical well.



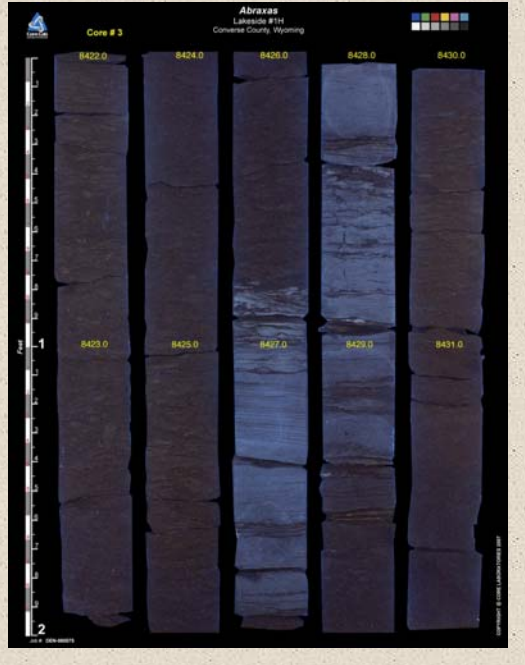
Presenter's notes: Abraxas well with full-diameter cores; k is .01-.1 md.

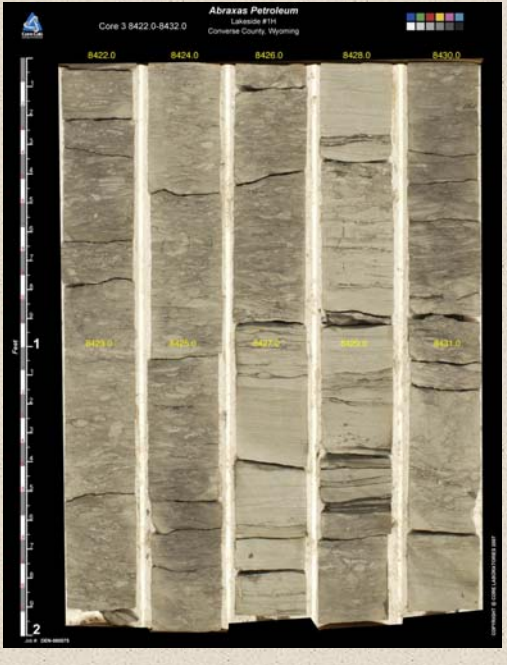


Presenter's notes: Some thin pay in mid-Turner, 10 ft basal ss.

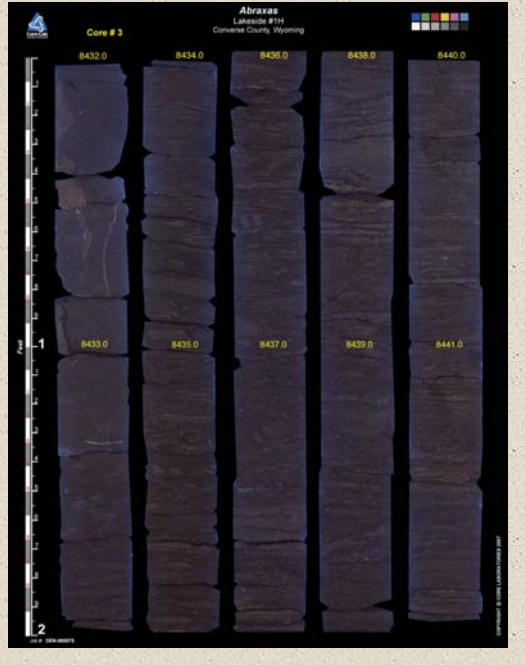


Presenter's notes: Ultra-violet on left, highly burrowed, formerly interbedded ss and shale.

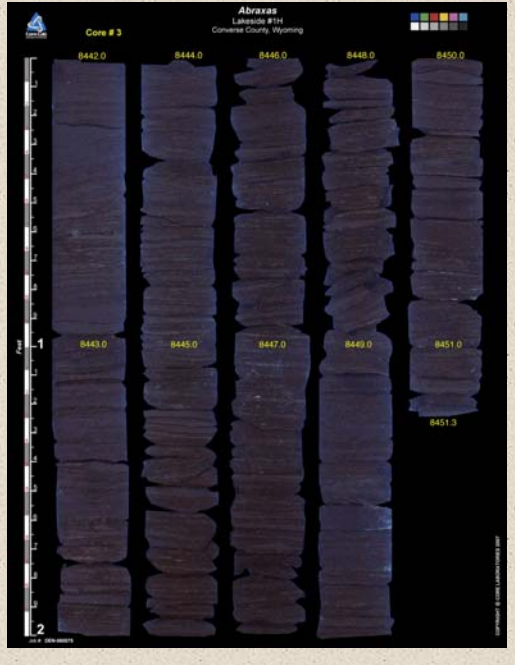


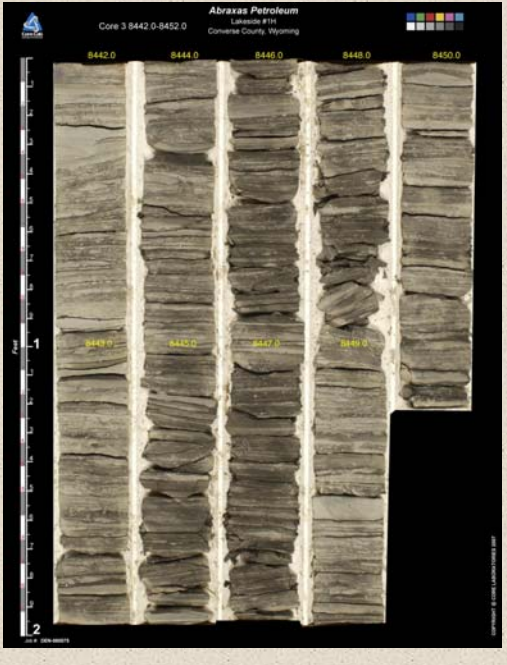


Presenter's notes: 2-ft middle Turner with non-burrowed ss.



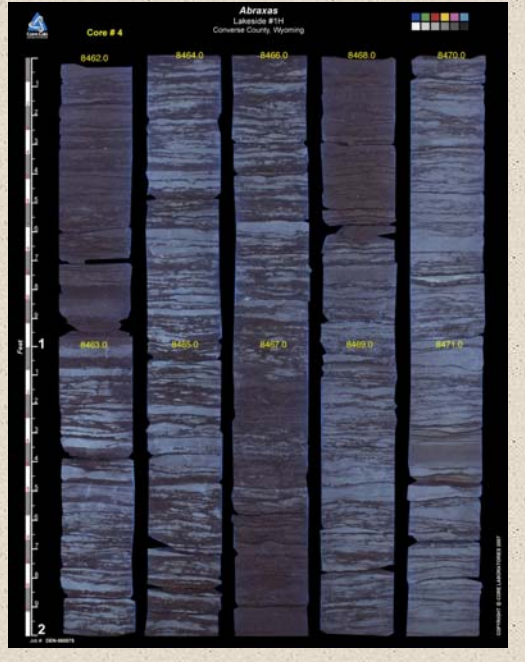
Presenter's notes: Low fluorescence.

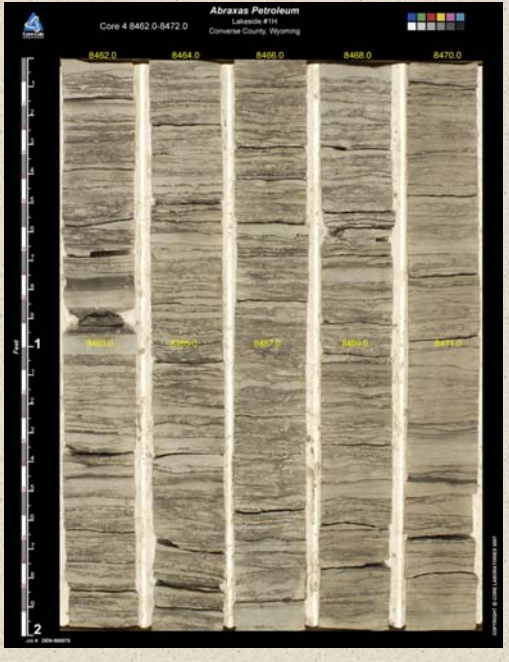

Abraxas
Lakeside #1H
Converse County, Wyoming
Core # 3
8442.0
8444.0
8446.0
8448.0
8450.0
8443.0
8445.0
8447.0
8449.0
8451.0
8451.3
Feet
1
2


Abraxas Petroleum
Lakeside #1H
Converse County, Wyoming
Core 3 8442.0-8452.0
8442.0
8444.0
8446.0
8448.0
8450.0
8443.0
8445.0
8447.0
8449.0
Feet
1
2

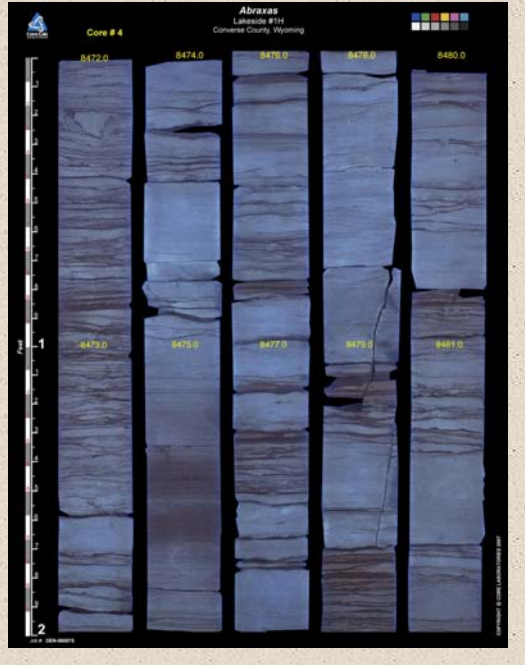

Abraxas
Lakeside #1H
Converse County, Wyoming
Core # 3 & 4
8452.3
8454.0
8456.0
8458.0
8460.0
8453.0
8455.0
8457.0
8459.0
8461.0
Feet
1
2

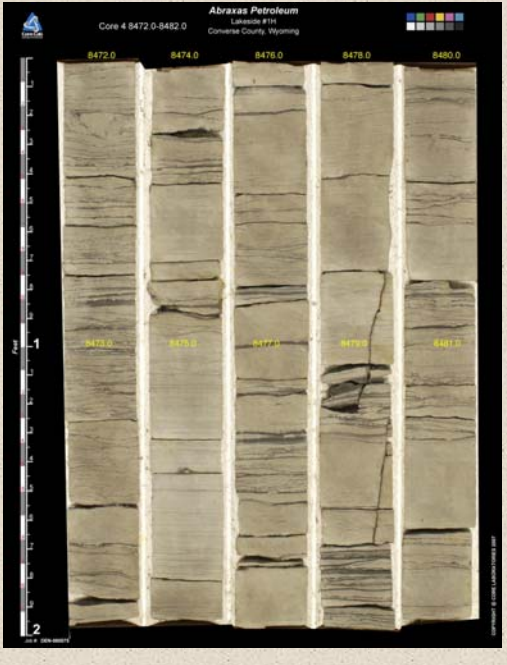

Abraxas Petroleum
Lakeside #1H
Converse County, Wyoming
Core 3 8452.0-8462.0
8452.0
8454.0
8456.0
8458.0
8460.0
8453.0
8455.0
8457.0
8459.0
8461.0
Feet
1
2



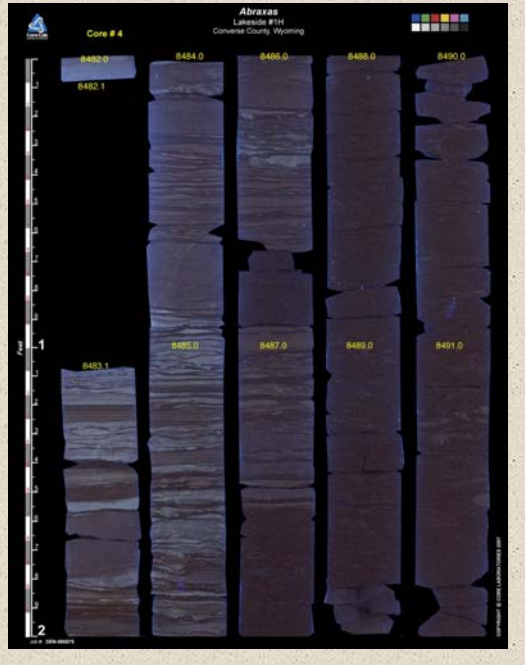


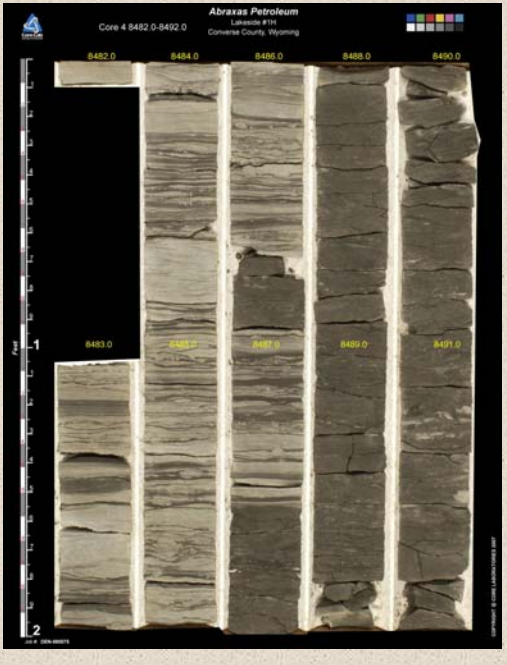
Presenter's notes: Discrete ss beds with fluorescence.





Presenter's notes: About 8 ft of net ss in 10-ft interval; good fluorescence.


Abraxas
Lakeside #1H
Converse County, Wyoming
Core # 4
8482.0
8482.1
8483.1
8484.0
8485.0
8486.0
8487.0
8488.0
8489.0
8490.0
8491.0
Feet
1
2


Abraxas Petroleum
Lakeside #1H
Converse County, Wyoming
Core 4 8482.0-8492.0
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8483.0
8484.0
8485.0
8486.0
8487.0
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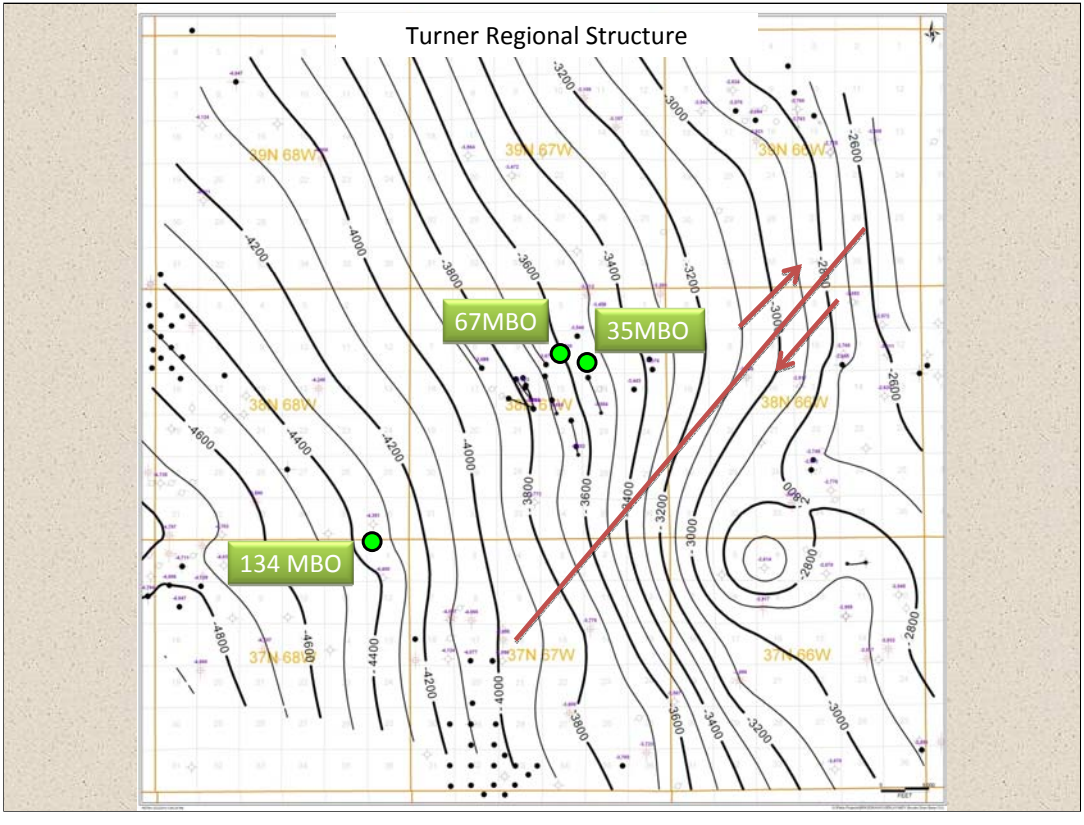
8489.0
8490.0
8491.0
Feet
1
2



Presenter's notes: Interpreted strike-slip fault from regional structure**.**

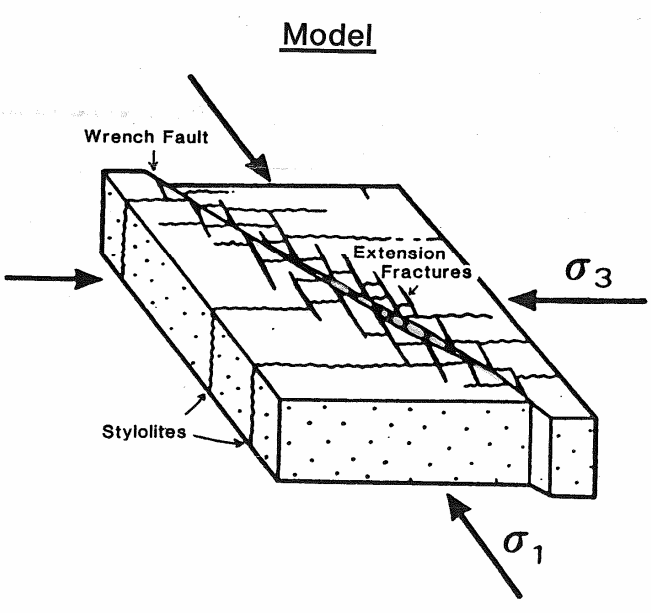
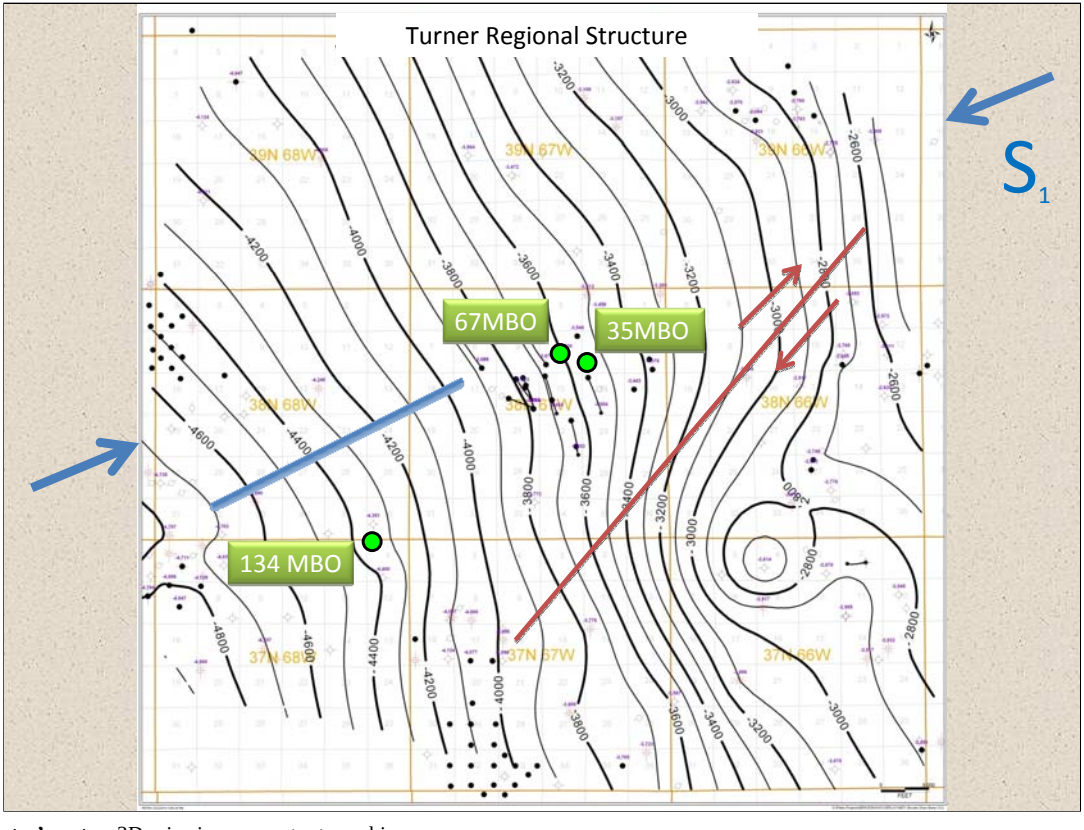


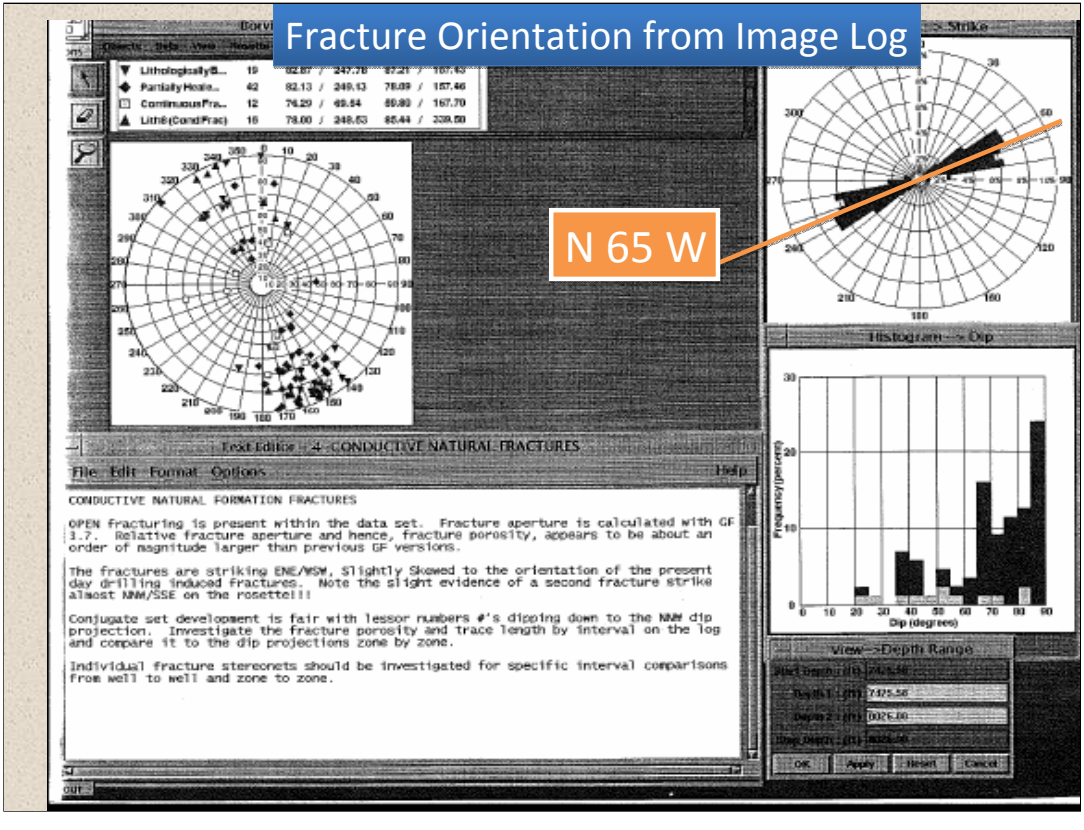
Figure 17. *Development of vertical stylolites, extensional fractures and wrench fault in overall compressive setting (from du Rouchet, 1981).*

Sonnenberg and Weimer, 1993

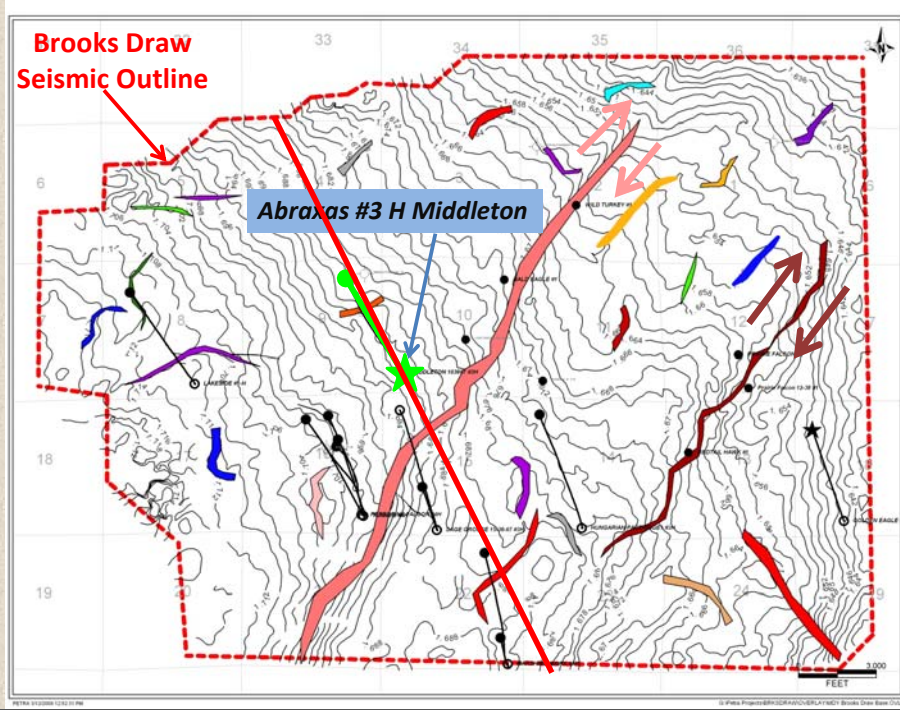


Presenter's notes: 3D seismic over center township.

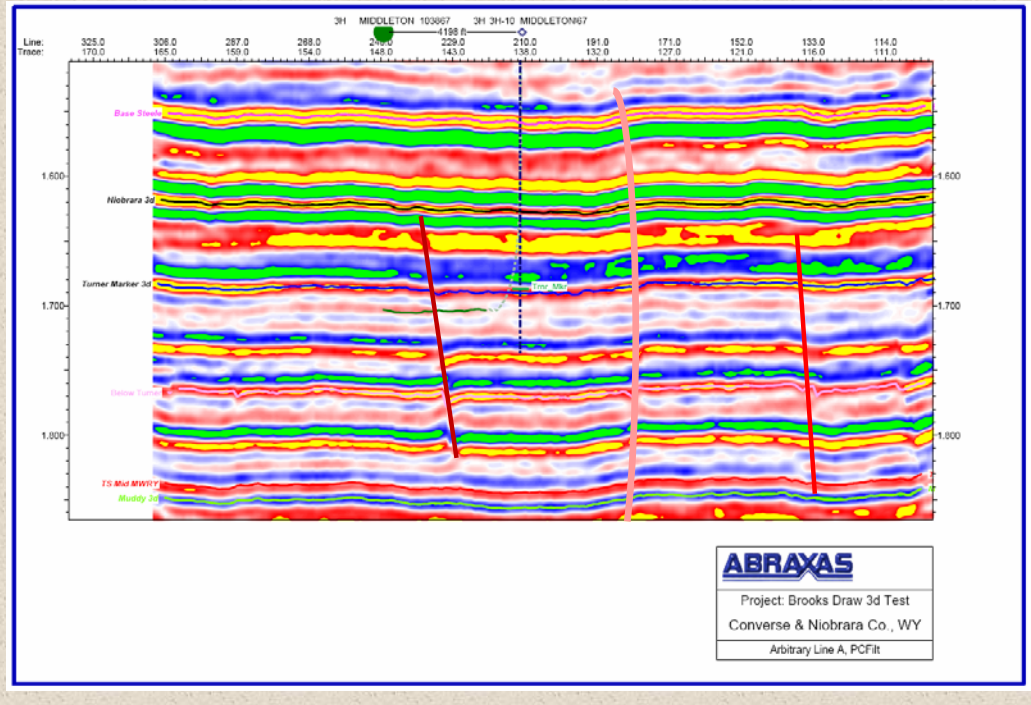
Fracture Orientation from Image Log



Turner Time Map

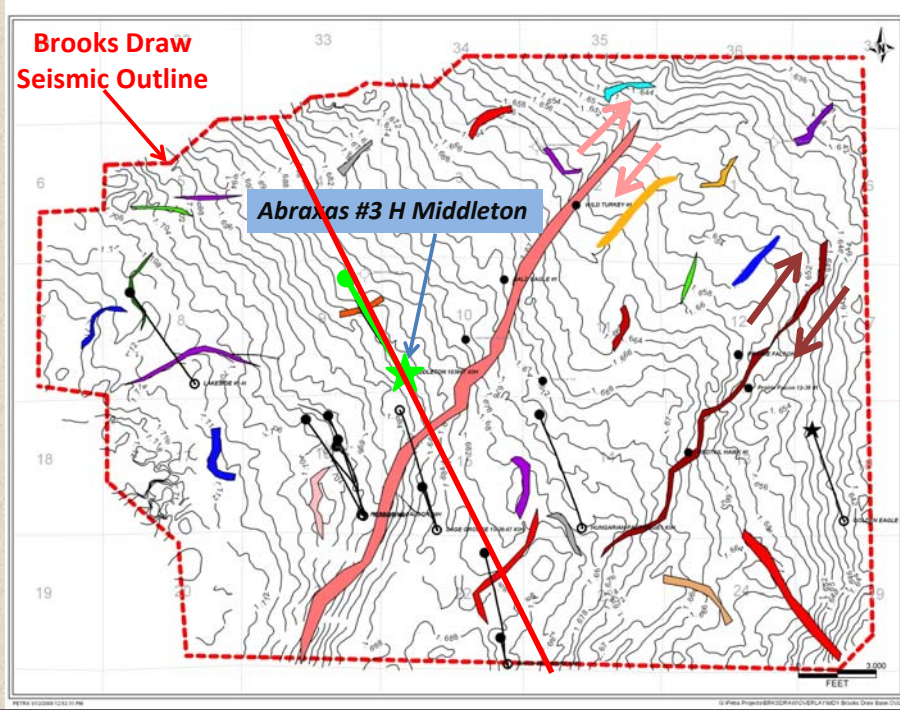


Presenter's notes: Time structure, from 3D seismic interpreted on Turner.



Middleton Arb line

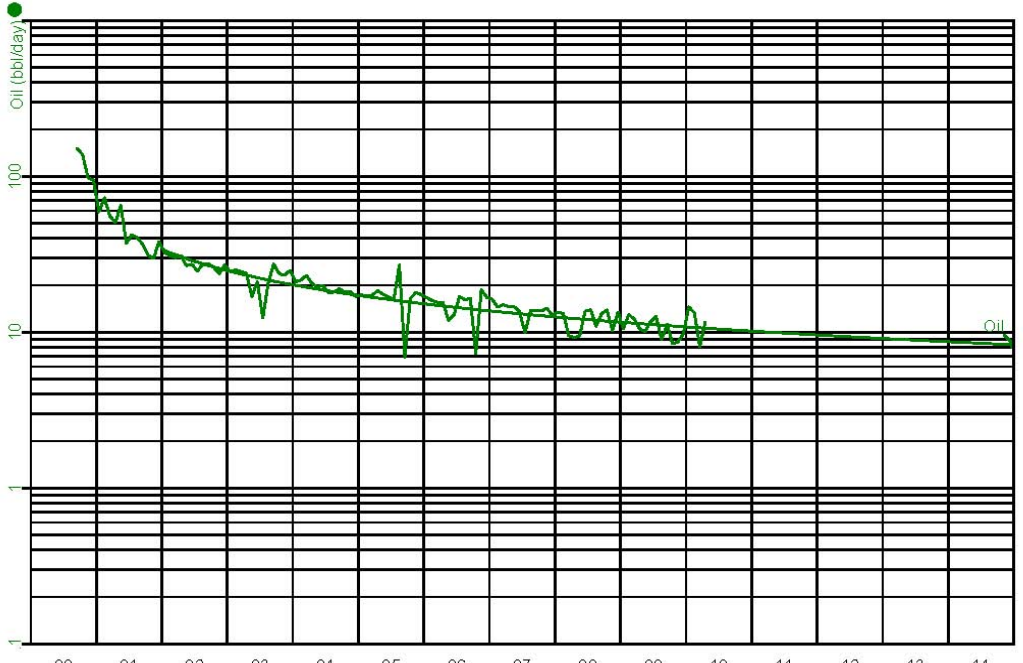
Turner Time Map



MIDDLETON 3H-10-38-67
NIOBRARA,WY
Proved Producing

Middleton 3H
EUR 159 MBO

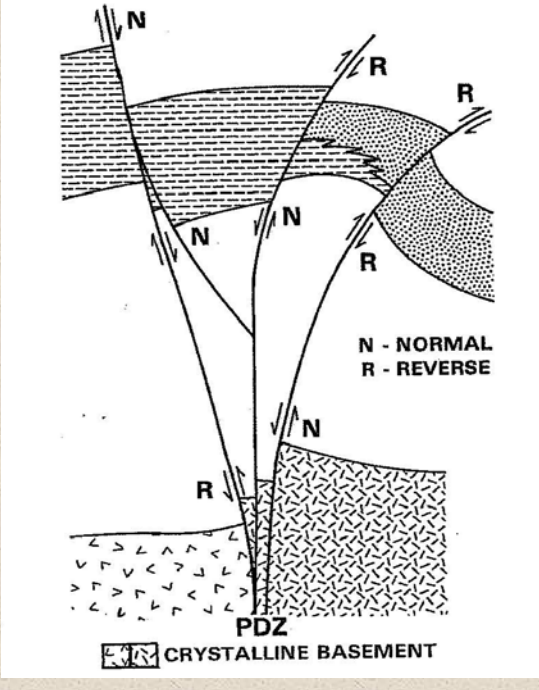
OP
ROCKIES
OP-ROCKIES/WY



Hist Oil Cum: 82.03 Mbbl
Oil Rem: 76.76 Mbbl
Oil EUR: 158.79 Mbbl

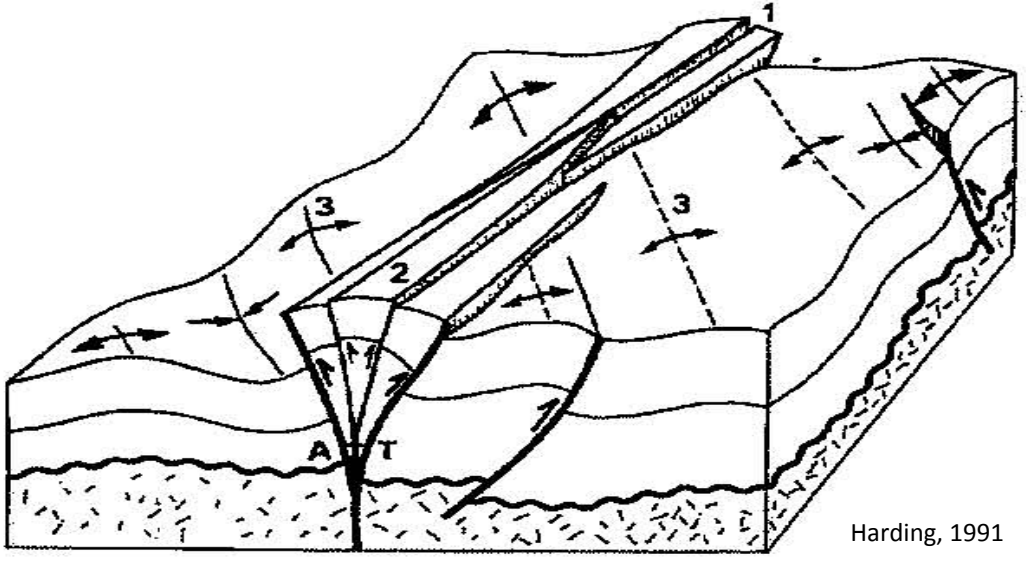
Hist Gas Cum: 70.59 MMcf
Gas Rem: 91.31 MMcf
Gas EUR: 161.90 MMcf

Cross-Section of Strike-Slip Fault



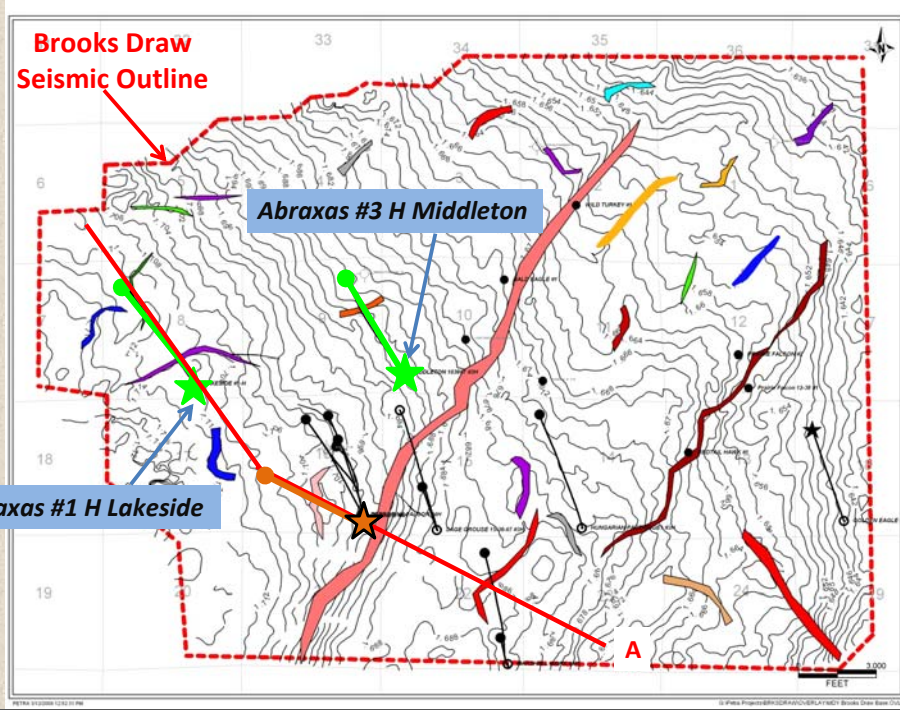
Christie-Blick and Biddle, 1985

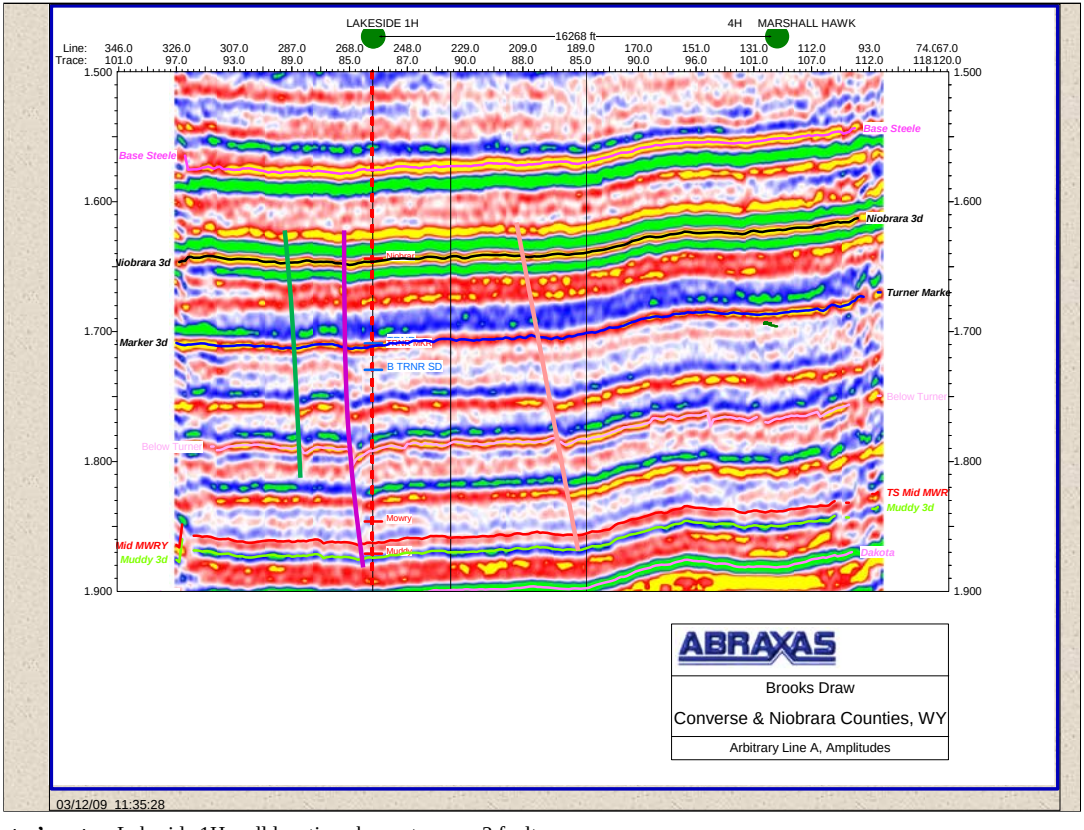
Diagram of Strike-Slip Faulting



Harding, 1991

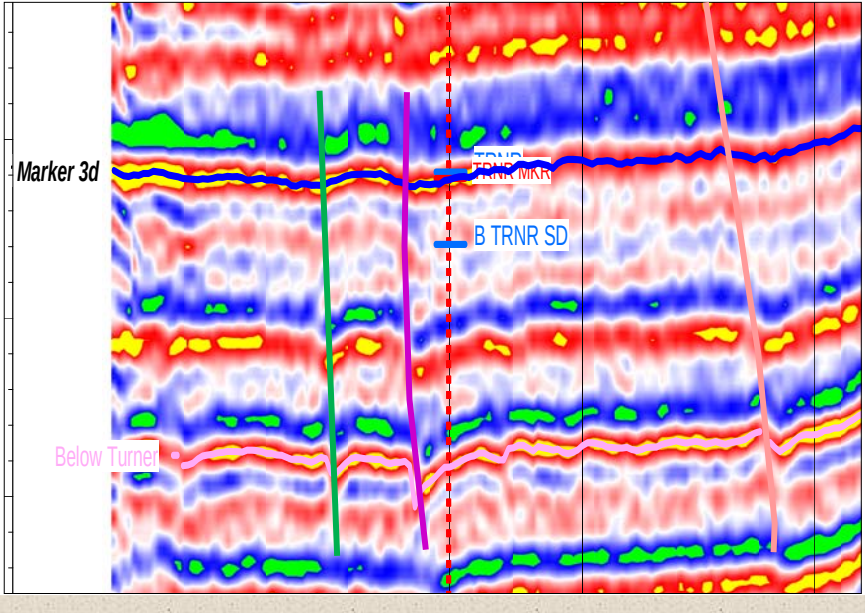
Turner Time Map



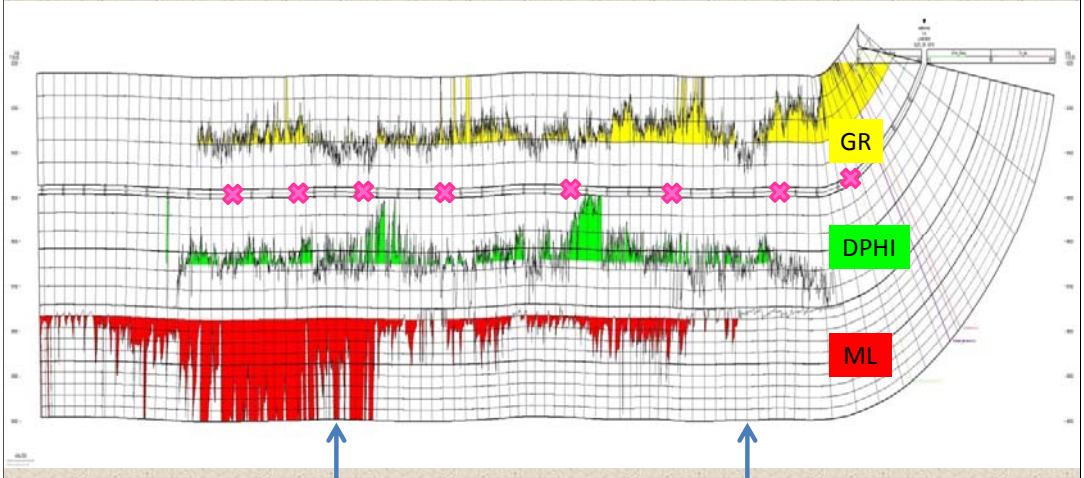


Presenter's notes: Lakeside 1H well location chosen to cross 2 faults.

Lakeside 1H and Section 16 Faults



Abraxas #1H Lakeside

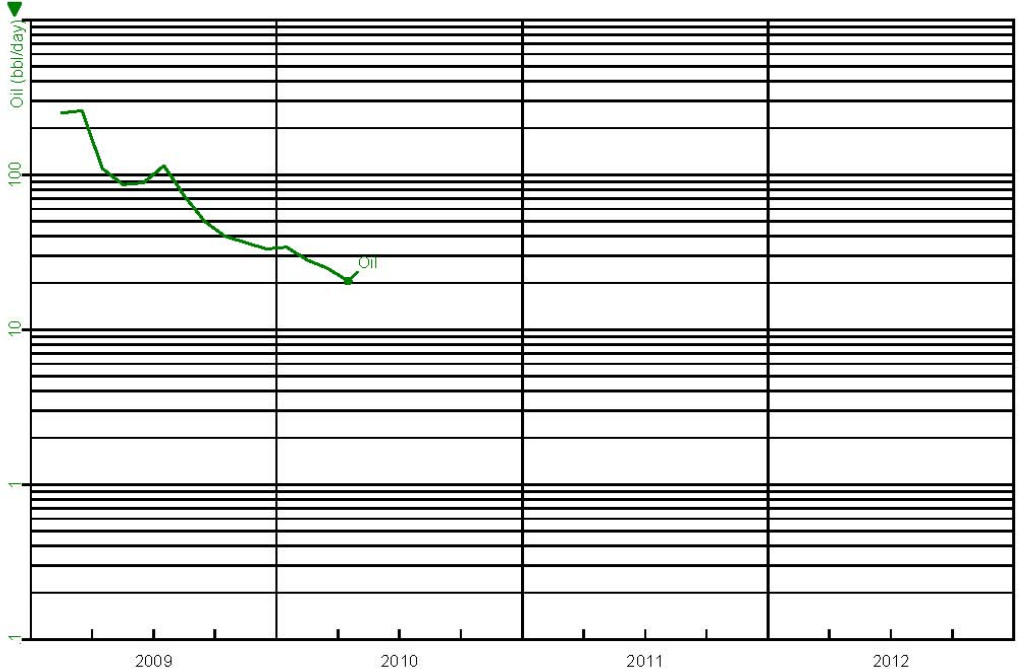


Presenter's notes: Evidence of fracturing associated with faults seen on horizontal log.

** LAKESIDE 1H
NIOBRARA,WY
Proved Producing

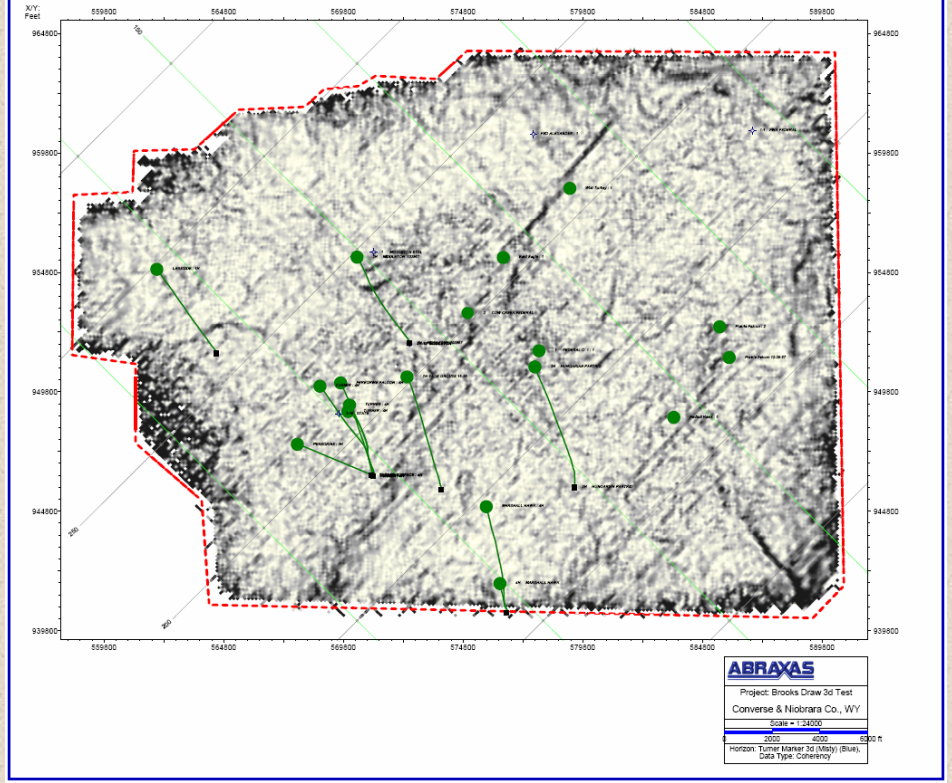
Lakeside 1H

OP
ROCKIES
OP-ROCKIES/WY



Hist Oil Cum: 23.98 Mbbl
Oil Rem: 0.00 Mbbl
Oil EUR: 23.98 Mbbl

Hist Gas Cum: 41.78 MMcf
Gas Rem: 0.00 MMcf
Gas EUR: 41.78 MMcf


X/Y:
Feet
559800
564800
569800
574800
579800
584800
589800
964800
959800
954800
949800
944800
939800
100
250
300
ABRAXAS
Project: Brooks Draw 3d Test
Converse & Niobrara Co., WY
Scale = 1:24000
0
2000
4000
6000 ft
Horizon: Turner Marker 3d (Misty) (Blue),
Data Type: Coherency

Reservoir Engineering

$$OOIP = \frac{7758\ (BO/Ac\text{-}Ft) * Porosity * Thickness * Oil\ Saturation * Area}{Formation\ Volume\ Factor}$$

$$OOIP = \frac{7758 * .08 * 10\ ft * .65 * Area\ (Ac)}{1.5\ STB/RB}$$

OOIP = 2700 BO/Ac

Recovery Factor (RF): Est .10 - .20

Reservoir Engineering

Cow Creek Federal well prod. 35 MBO from 10 ft net pay
If RF = .10, Area = 130 ac
If RF = .15, Area = 86 ac
If RF = .20, Area = 65 ac

Choose 86 ac, then drainage radius = 1100 ft
If horizontal well with 4000 ft lateral, drainage = 288 ac

Potential Recovery/10 ft =
2700 BO/Ac * .15 * 288 Ac = **117 MBO**

Presenter's notes: Natural fractures improve these results.

CONCLUSIONS

1. Turner Ss is oil-saturated reservoir in parts of PRB.
2. Upper and Lower Turner ss may offer horizontal drilling target (increase drainage area).
3. Right lateral strike-slip faults and associated 2nd order faults, interpreted from 3D seismic.
4. Open fractures associated with faults.
5. Horizontal exploitation of Turner needs 3D seismic to aid geo-steering and well placement.
6. Fault interpretation should also help Niobrara development.