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


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ABRAXAS Petroleum Corporation

Thanks for permission
Turner Production: 32 MMBO, 800 vert. wells

Brooks Draw Field

Presenter’s notes: Yellow outlines are fields producing from Turner.
Stratigraphic Column: Upper Cretaceous and Tertiary Units

Presenter’s notes: Upper Cretaceous zones of interest, especially Turner.
Turner Outcrop
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.
Presenter's notes: Discrete ss beds with fluorescence.
Presenter’s notes: About 8 ft of net ss in 10-ft interval; good fluorescence.
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

N 65 W
Presenter's notes: Time structure, from 3D seismic interpreted on Turner.
Turner Time Map

Brooks Draw Seismic Outline

Abraxas #3 H Middleton
Middleton 3H
EUR 159 MBO

Start OilCum: 52.03 Mbbi
Oil Raw: 74.76 Mbbi
Oil Exp: 159.79 Mbbi

Start GasCum: 70.59 MMcf
Gas Raw: 91.25 MMcf
Gas Exp: 161.20 MMcf
Cross-Section of Strike-Slip Fault

Christie-Blick and Biddle, 1985
Diagram of Strike-Slip Faulting

Harding, 1991
Presenter's notes: Lakeside 1H well location chosen to cross 2 faults.
Lakeside 1H and Section 16 Faults
Fault on seismic
Lost returns

Presenter’s notes: Evidence of fracturing associated with faults seen on horizontal log.
Reservoir Engineering

\[
\text{OOIP} = 7758 \ (\text{BO/Ac-Ft}) \times \text{Porosity} \times \text{Thickness} \times \text{Oil Saturation} \times \text{Area} \\
\text{Formation Volume Factor}
\]

\[
\text{OOIP} = 7758 \times 0.08 \times 10 \text{ ft} \times 0.65 \times \text{Area (Ac)} \\
1.5 \text{ STB/RB}
\]

\[
\text{OOIP} = 2700 \ \text{BO/Ac}
\]

Recovery Factor (RF): Est. 0.10 - 0.20
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.