Silo Field Niobrara Reservoir Modeling

Brian F. Towler
Tony (Panqing) Gao
Silo Field (10 miles northeast of Cheyenne)

Discovered in 1983

Hydrocarbon self sourcing

Mostly oil in SE Wyoming, mostly natural gas near Denver

Similar characteristics to other successful shale plays in the US
DJ Basin Horizontal Niobrara Play

Horizontal Technology

Niobrara

Multistage Fracs

7,000'
A cyclist cruises past a Niobrara outcrop along Colorado Highway 7, north of Boulder.

Taken by Lowell Georgia, 2010
DJ Basin Horizontal Niobrara

Average well days:
- Drilling – 20-25 days spud to rig release
- Completion – 25-30 days, not continuous operation

Average drill & complete costs:
- Exploration & Delineation – $4-5.5MM
Coexist with agricultural operations
<table>
<thead>
<tr>
<th>OPERATOR</th>
<th>WELLS</th>
<th>OPERATOR</th>
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## DEVELOPMENT OPERATORS IN SILO (1994-1995)

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<td>18/85</td>
<td>14/85</td>
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</table>
Log Interpretation

Shale volume

\[ I_{GR} = \frac{GR - GR_{\text{min}}}{GR_{\text{max}} - GR_{\text{min}}} \]

- \( I_{GR} \) = gamma ray index
- \( GR \) = gamma ray reading of formation
- \( GR_{\text{min}} \) = minimum gamma ray (clean sand or carbonate)
- \( GR_{\text{max}} \) = maximum gamma ray (shale)

Larionov - Tertiary rocks:

\[ V_{sh} = 0.083(23.7I_{GR} - 1) \]

Porosity

Light hydrocarbon

\[ \Phi = \sqrt{\Phi D^2 + \Phi N^2} \]

\[ \Phi_D = \frac{D_{ma} - DEN}{D_{ma} - D_f} - V_{sh} \cdot \frac{D_{ma} - D_{sh}}{D_{ma} - D_f} \]
Log Interpretation

Water Saturation

**Archie**

\[ S_w = \left( \frac{a \cdot R_w}{R_t \cdot \Phi^m} \right)^{1/n} \]

where:
- \( S_w \) = water saturation of the uninvaded zone
- \( R_w \) = resistivity of formation water at formation temperature
- \( R_t \) = true formation resistivity (i.e., deep induction or deep laterolog corrected for invasion)
- \( \Phi \) = porosity
- \( a \) = tortuosity factor
- \( m \) = cementation exponent
- \( n \) = saturation exponent

**Simandoux**

\[
\frac{1}{R_t} = \frac{V_{cl}}{R_{cl}} \cdot S_w^{\frac{n}{2}} + \frac{\phi_e^m S_w^n}{aR_w(1-V_{cl}^d)}
\]

Generally, \( m = n = 2 \), \( d = 1 \sim 2 \)

\[
S_w = \sqrt{\frac{aR_w}{\phi_e^m R_t R_{sh}} + \left( \frac{aR_w}{2\phi_e^m} + \frac{V_{sh}}{R_{sh}} \right)^2 - \frac{aR_w}{2\phi_e^m} \cdot \frac{V_{cl}}{R_{cl}}}
\]

If \( a = 0.8 \), \( m = 2 \), So

\[
S_w = \frac{0.4R_w}{\phi_e^2} \left[ \sqrt{\frac{5\phi_e^2}{R_t R_w} + \left( \frac{V_{sh}}{R_{sh}} \right)^2 - \frac{V_{sh}}{R_{sh}}} \right]
\]
Permeability

Timur

\[ K = \frac{0.136 \times \phi^{4.4}}{S_{wirr}^2} \]

Wyllie and Rose

\[ K = \left( \frac{250 \times \phi^3}{S_{wirr}} \right)^2 \]

K=permeability in millidarcys
Φ=porosity
\( S_{wirr} \)=water saturation (\( S_w \)) of a zone at irreducible water saturation
Vertically amplified 3D, 10 times

Model Dimension

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GAUSSIAN RANDOM FUNCTION SIMULATION

Nia-A

POROSITY

GAUSSIAN RANDOM FUNCTION SIMULATION

SEQUENTIAL GAUSSIAN SIMULATION
GAUSSIAN RANDOM FUNCTION SIMULATION

POROSITY

Nia-B1

SEQUENTIAL GAUSSIAN SIMULATION
Nia-B2
POROSITY

GAUSSIAN RANDOM FUNCTION SIMULATION

SEQUENTIAL GAUSSIAN SIMULATION
POROSITY

GAUSSIAN RANDOM FUNCTION SIMULATION

Nia-B2

Below

SEQUENTIAL GAUSSIAN SIMULATION
FT Hayes Top

GAUSSIAN RANDOM FUNCTION SIMULATION

FT Hayes

SEQUENTIAL GAUSSIAN SIMULATION

POROSITY
Poro-Gaussian Random
GAUSSIAN RANDOM FUNCTION SIMULATION

Nia-A

WATER SAT
(ARCHIE MODEL)

SEQUENTIAL GAUSSIAN SIMULATION
Nia-B1 WATER SAT (ARCHIE MODEL)

SEQUENTIAL GAUSSIAN SIMULATION

GAUSSIAN RANDOM FUNCTION SIMULATION
GAUSSIAN RANDOM FUNCTION SIMULATION

Nia-B2

WATER SAT
(ARCHIE MODEL)

SEQUENTIAL GAUSSIAN SIMULATION
GAUSSIAN RANDOM FUNCTION SIMULATION

SEQUENTIAL GAUSSIAN SIMULATION

WATER SAT (ARCHIE MODEL)

Nia-B2
Below

GAUSSIAN RANDOM FUNCTION SIMULATION
WATER SAT (ARCHIE MODEL)

SEQUENTIAL GAUSSIAN SIMULATION

FT Hayes

GAUSSIAN RANDOM FUNCTION SIMULATION
Nia-A

PERMEABILITY

(Wyllie and Rose)

SEQUENTIAL GAUSSIAN SIMULATION

GAUSSIAN RANDOM FUNCTION SIMULATION
GAUSSIAN RANDOM FUNCTION SIMULATION

Nia-B1
PERMEABILITY
(Wyllie and Rose)

SEQUENTIAL GAUSSIAN SIMULATION
Nia-B2 PERMEABILITY
(Wyllie and Rose)

SEQUENTIAL GAUSSIAN SIMULATION

GAUSSIAN RANDOM FUNCTION SIMULATION
PERMEABILITY
(Wyllie and Rose)

SEQUENTIAL GAUSSIAN SIMULATION

Nia-B2
Below

GAUSSIAN RANDOM FUNCTION SIMULATION
PERMEABILITY
(Wyllie and Rose)

SEQUENTIAL GAUSSIAN SIMULATION

FT Hayes

GAUSSIAN RANDOM FUNCTION SIMULATION
Data Still Needed

STATIC MODELING:
MORE LOGS, particularly porosity logs
DEVIATION DATA (HORIZONTAL WELLS)

PVT DATA:
RS, VISCOSITY, FVF, AND GRAVITY FOR OIL, GAS, WATER

SCAL DATA:
RELATIVE PERMEABILITY CURVES, CAP PRESSURES

INITIAL DATA
NO PRESSURE DATA AVAILABLE YET