Classification and Characterization of Barrier-Intercalations in Sandy Braided River Reservoirs of HE Oilfield, Sudan*

Guoliang Zhao¹, Longxin Mun¹, and Tianjian Sun¹

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¹African E&P, Research Institute of Petroleum Exploration and Development, CNPC, Beijing, China (zhguli@petrochina.com.cn)

Abstract

The HE oilfield is located in the Muglad Basin of Sudan. The main oil bearing zones are composed of Cretaceous massive braided reservoirs dominated by medium-coarse sand which are buried at depth of 1,600 to 1,900 m. The HE oilfield has been developed with commingled production by natural drive since 1996. After nearly 20 years of development, the recovery factor has reached 34%, while the water cut is 95%. It is predicted that 6-9% of OOIP can be further produced by horizontal wells and new production techniques. Barrier-intercalations in sandy braided river reservoirs are diverse in types, different in shape and scale, and complex in spatial distribution. Quantitative characterization of barrier-intercalations is crucially important for the further understanding of reservoir architecture and remaining oil distribution.

Based on comprehensive analysis of core data, well logs and outcrops, three hierarchies of the barrier-intercalations are developed in the sandy braided reservoirs in the study area, including barriers between the two single layers, intercalations between the two single sandbodies, and intercalations within channel bar which, accordingly, are composed of flood shale, abandoned channel shale, and shale between accretionary bodies. The barriers are delineated by well correlation referring to the abandoned channel location which are 700-1,500 m wide and 1,000-2,000 m long. Based on empirical formulae by Kelly (2006) and the measurement of 15 modern braided rivers shown on Google Earth, the relations of channel width vs. channel bar width, and the length vs. width of channel bar are created to estimate abandoned channel shale which are 170-350 m wide.
Intercalations within channel bar with the width range of 100-400 m and a length of 300-800 m are determined according to the scale of accretionary bodies which are defined by an empirical equation by Kelly (2006) and well correlation. Based on the understanding of barrier-intercalation, the geological model which accurately delineates different types of barrier-intercalations is built by facies control and stochastic modeling methods. The results provided a reliable geological base for horizontal well deployment and water shut-off operations.

References Cited


Classification and Characterization of Barrier-Intercalation in Sandy Braided River Reservoirs of HE Oilfield, Sudan

By Zhao Guoliang, Mu Longxin, Sun Tianjian

Presented by Mr. Li Zhi

Research Institute of Petroleum Exploration and Development, CNPC

September, 15, 2014
Introduction

Characteristics of barrier-intercalations

Geological model based on barrier-intercalation understandings

Summary
Background information of the oil field

- **Location**: HE ridge in Muglad Basin, Sudan
- **Well number**: 48 producers including 35 vertical wells and 13 horizon wells
- **Well spacing**: 170-500m
- **Core well**: 3 wells with total length of 59.09m
- **Target Formation**: Ben Sands in upper cretaceous
- **Sedimentary facies**: braided river
- **Porosity**: 20-30%, **Permeability**: 1000-3000md
- **OOIP**: 978 MMBBL, recoverable reserve: 265 MMBBL, remaining recoverable oil: 74 MMBBL
- **Water-cut**: 95%
Characterization of Barrier-Intercalation, Why?

◆ HE oilfield has been developed with commingle production by natural drive since 1996. After nearly 20 years of development, the recovery factor reached 34%, while the water cut reached 95%. It is predicted that 6-9% of OOIP can be more produced by horizontal wells and adaptable workover activities.

◆ For braided river reservoir, the barrier-intercalation controls the distribution of the remaining oil.

◆ Horizontal well design and workover proposals will be based on the study of barrier-intercalation distribution.
Outline

◆ Introduction

◆ **Characteristics of barrier-intercalations**

◆ Geological model based on barrier-intercalation understandings

◆ Summary
Characteristics of barrier-intercalations

- **Types:** flood mudstone barrier, (residual) abandoned channel intercalation, silting intercalation in channel bar, chute intercalation
- **Shape:** banded or local continuous in plane, stratified or lenticular in profile, controlled by channel, channel bar and chute

(a) Flood mudstone barrier

(b) Abandoned channel intercalation and chute mudstone intercalation

(c) Residual abandoned channel intercalation

(d) Silting intercalation in a channel bar
> **Chute mudstone**: gray silty mudstone or mudstone, deposited in chute on the top of channel bar during flooding

> **Silting mudstone**: gray silty mudstone, intercalations between aggradation bodies in the channel bar

> **Mud-pebble**: gray mud-pebble, diameter 1-2cm, thickness 5-10cm, scoured by channel sandy deposit and transported for a certain distance

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**Characteristics of barrier-intercalations**

<table>
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<th>Layer</th>
<th>GR/API</th>
<th>Vertical</th>
<th>Barrier-intercalation</th>
<th>R/(Ω·m)</th>
<th>pG/cm³</th>
<th>Arc(μs/m⁻¹)</th>
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**Legend**

- **Chute mudstone**: gray silty mudstone or mudstone, deposited in chute on the top of channel bar during flooding
- **Silting mudstone**: gray silty mudstone, intercalations between aggradation bodies in the channel bar
- **Mud-pebble**: gray mud-pebble, diameter 1-2cm, thickness 5-10cm, scoured by channel sandy deposit and transported for a certain distance
Calcareous intercalation: gray white calcareous siltstone or silty mudstone

Flood mudstone: gray silty mudstone or mudstone, deposited in the flood plain and on the top of channel, abandoned channel, channel bar

Abandoned channel: gray silty mudstone or mudstone
Characteristics of barrier-intercalations

Hierarchy division: 3 hierarchies of the barrier-intercalations
- Barriers between the two single layer: flooding mudstone
- Intercalation between single sand bodies: abandoned channel, residual abandoned channel
- Intercalation within channel bar: silting mudstone between aggradation bodies, chute mudstone

Presenter’s notes: Based on comprehensive analysis of core data, well logs and outcrops, three hierarchies of the barrier-intercalations are developed in the sandy braided reservoirs in the study area, including barriers between the two single layers, intercalations between the two single sandbodies, and intercalations within channel bar which, accordingly, are composed of flood shale, abandoned channel shale, and shale between accretion bodies.
Identification of barrier-intercalations in wells

To identify the barrier-intercalation on wells based on the rock evaluation index calculated by grey theory integrating with the genetic analysis of barrier-intercalation. Well logs used are GR, RLLD and Density.

Association coefficient: 
\[ L_i(i, 0) = \frac{\Delta_{\text{min}} + \rho \Delta_{\text{max}}}{\Delta_i(i, 0) + \rho \Delta_{\text{max}}} \]

Degree of association: 
\[ r_{i, 0} = \frac{1}{n} \sum_{i} L_i(i, 0) \]

Weight coefficient: 
\[ a_i = \frac{r_i}{\sum_{i} r_i} \]

Evaluation index: 
\[ REI = \sum_{i=1}^{n} a_i X_i \]

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Determination of scale of barrier-intercalations

1. Barrier between single layers—mainly flooding mudstone

- Continuous and stable, distribution area is larger.
- To determine the barrier extension by well correlation and flatting the key markers.
Determination of scale of barrier-intercalations

- Locally continuous distribution, the distribution area of B1A, B1B and B1D is larger than others
- 500-2000m in width, 1000-4000m in length
Determination of scale of barrier-intercalations

2. Intercalation between single sand bodies--mainly abandoned channel

➢ To create the relationships about the lengths and widths of channel, channel bar and chute base on statistics of more than 15 modern braided rivers.
To estimate the extension of the abandoned channel and chute mudstone based on above mentioned relationships and well correlation.

(a) Channel width vs. channel bar width

\[ w_c = 0.299 \times 4w_b^{1.0125} \]
\[ R^2 = 0.9142 \]

(b) Chute width vs. channel bar width

\[ w_d = 0.314 \times 8w_b^{0.831} \]
\[ R^2 = 0.8955 \]

(c) Chute length vs. channel bar length

\[ l_d = 0.649l_b^{0.9781} \]
\[ R^2 = 0.9591 \]

(d) Channel bar length vs. channel bar width

\[ l_b = 4.951 \times 7w_b^{0.9676} \]
\[ R^2 = 0.9596 \]

\[ l_b = 4.148 \times 8w_b^{0.9574} \]
\[ R^2 = 0.9400 \]
Determination of scale of barrier-intercalations

- Banded or local continuous, controlled by channel and chute
- Abandoned channel: 50-300m in width, 800-3000m in length
- Chute mudstone: 30-100m in width, 300-2500m in length
3. Intercalation within channel bar—mainly shale between aggradation bodies

- To calculate the angle of the shale bodies between aggradation bodies by flattening the bottom marker and well correlation, the dip angle is about 1.1° in major axis and 2-4° in minor axis.

Dip angle calculation of major-axis of channel bar

Characteristics of intercalation of channel bar in minor-axis

Characteristics of intercalation of channel bar in major-axis
The extension of the shale between aggradation bodies can be estimated by the relations of width and thickness of aggradation bodies and well correlation results.

- 100-400m in width, 300-800m in length.

Distribution characterization of intercalation in channel bar in 3D view.
Introduction

Characteristics of barrier-intercalations

**Geological model based on barrier-intercalation understandings**

Summary
Based on the understandings of barrier-intercalation, the geological model which accurately delineates different types of barrier-intercalations is built by facies-control and stochastic modeling method.

To build channel and channel bar model according to depositional facies analysis.

To take the model only including channel and channel bar as background, flood shale, abandoned channel, chute and shale between aggradation bodies are simulated by object-based method.

Porosity and permeability model are built using SGS constrained by facies model.
Based on barrier-intercalation prediction and reservoir simulation, 9 horizontal wells, 2 sidetrack, 8 recompletion wells and 7 liquid increment wells are proposed.

Compared to do nothing case, 8.9 million barrels of oil were increased by the year of 2023 according to the simulation.
Summary

◆ Barrier-Intercalation control the remaining oil distribution of reservoir deposited in the braided river with bottom water.
◆ Six types of barrier-intercalations were identified based on comprehensive analysis of core data, well logs and outcrops.
◆ Three hierarchies of the barrier-intercalations are classified in the sandy braided reservoirs in the study area, including barriers between the two single layers, intercalations between the two single sand bodies and intercalations within channel bar.
◆ Different methods were used to determination the scales of above-mentioned three hierarchies of the barrier-intercalations.
◆ Based on the understandings of barrier-intercalation, the geological model with different types of barrier-intercalations is built by facies-control and stochastic modeling method.
◆ Oil field development can be improved by horizontal wells and adaptable workovers according to the barrier-intercalation distribution based on the simulation results.
Thanks

About the Corresponding author

Mr. Zhao Guoliang
Tel: +86-01-83595197
Email: zhguli@petrochina.com.cn
Add.: African E&P Dept., RIPED, PetroChina
No. 20, Xueyuan Road, Haidian District, Beijing