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

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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 commingle 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

Kelly, S., 2006, Scaling and hierarchy in braded rivers and their deposits: examples and implications for reservoir modeling, *in* G.H. Sambrook-Smith, J.L. Best, C.S. Bristow, et al., eds., Braded Rivers: Process, deposits, ecology and management: Blackwell Publishing, Oxford, U.K., p. 75-106.

Smith, G.H., Sambrook, J.L. Best, C.S. Bristow, and G.E. Petts, eds., 2006, Braided Rivers: Process, deposits, ecology and management: International Association of Sedimentologists, Special Publication 36, 390 p.

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

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Presented by Mr. Li Zhi

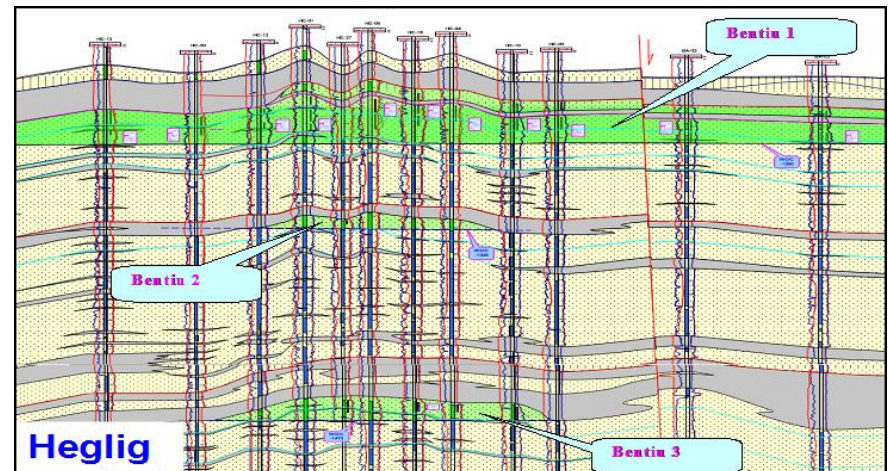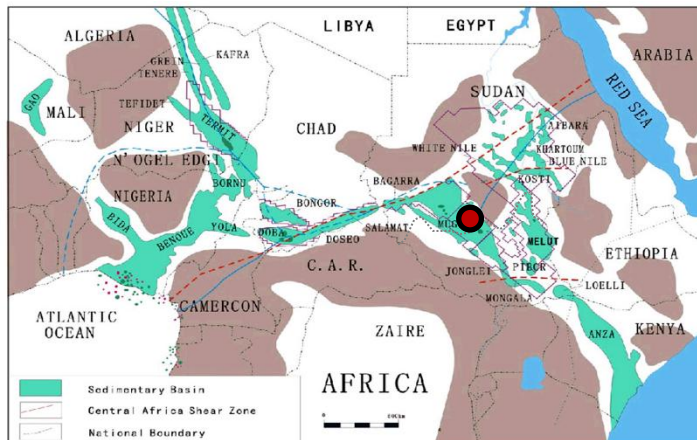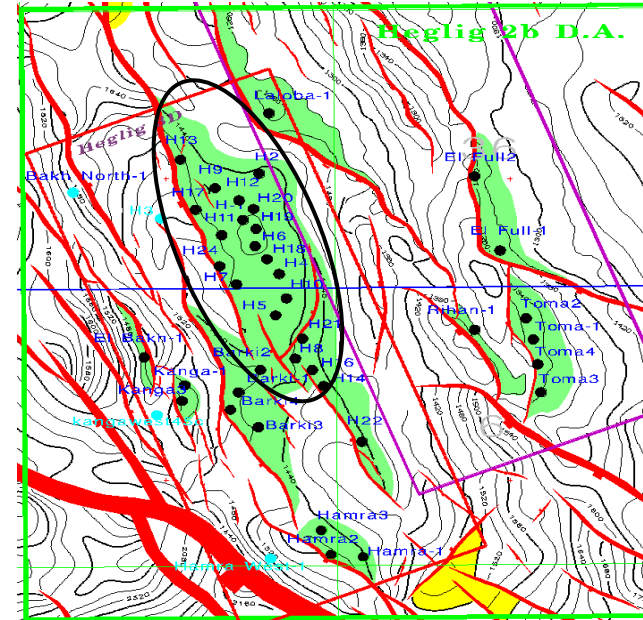Research Institute of Petroleum Exploration and Development, CNPC
September, 15, 2014

Outline

◆ **Introduction**

◆ **Characteristics of barrier-intercalations**

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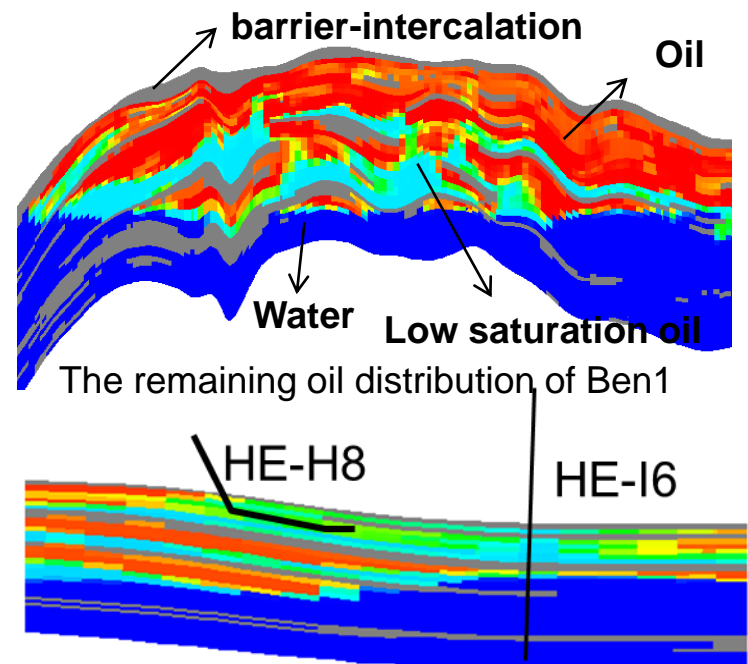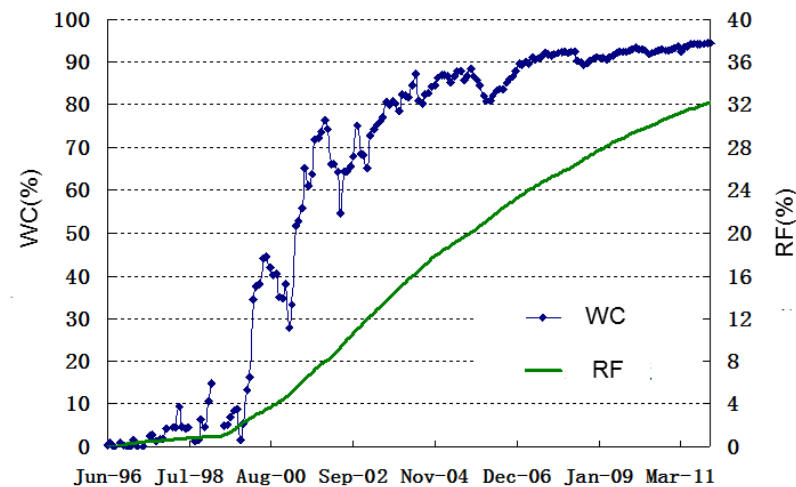
◆ **Summary**

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 MMBB, remaining recoverable oil: 74 MMBBL

- ◆ **Water-cut:** 95%

Location of HE Oilfield

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.**

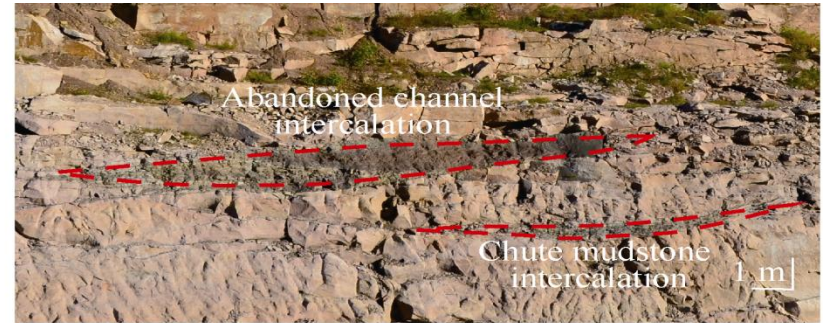The remaining oil distribution of Ben1

Outline

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

Flood mudstone barrier
Abandoned channel
Chute
Silting mudstone

(a) Flood mudstone barrier

Abandoned channel intercalation
Chute mudstone intercalation
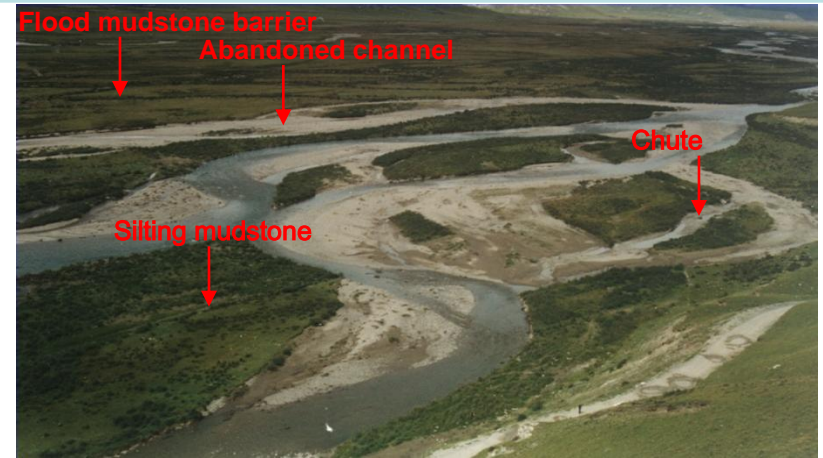
(b) Abandoned channel intercalation and chute mudstone intercalation

(c) Residual abandoned channel intercalation

(d) Silting intercalation in a channel bar

Characteristics of barrier-intercalations

➤ **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
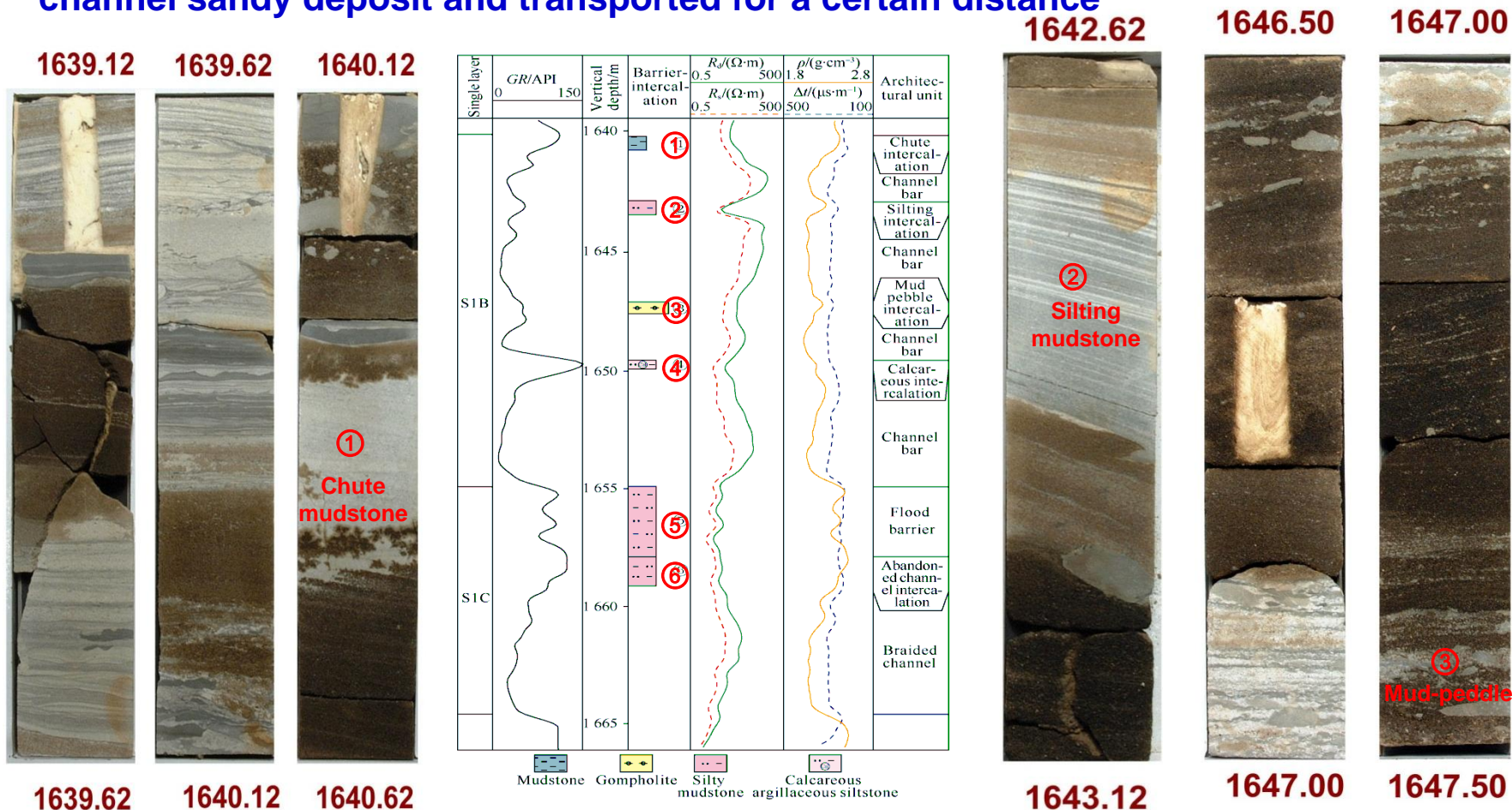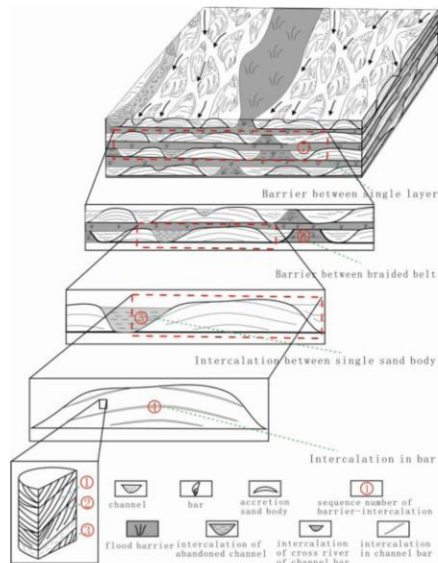
Characteristics of barrier-intercalations

➤ **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

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.

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.
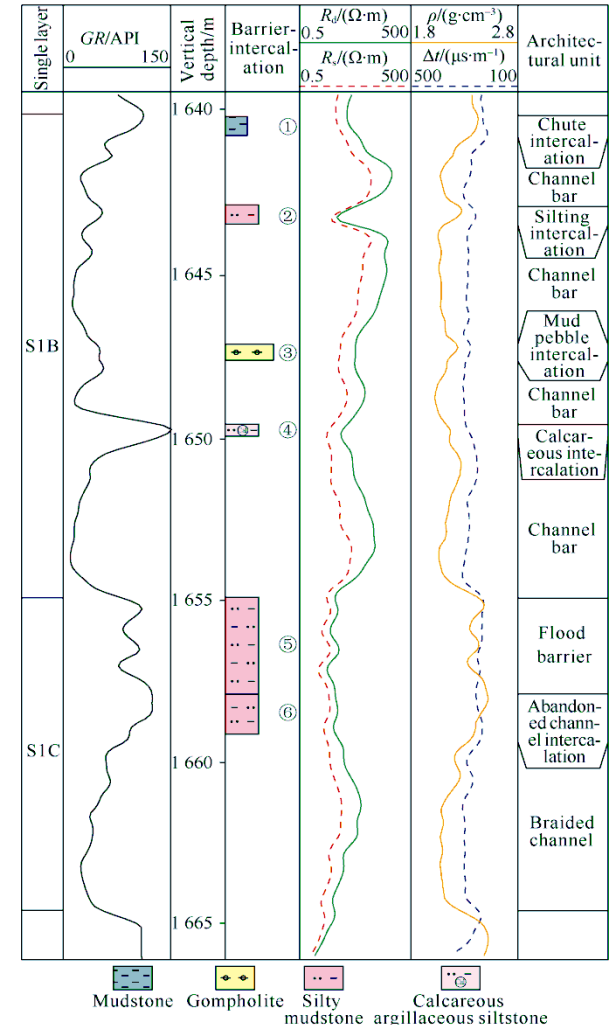
Association coefficient: $L_t(i,0) = \dfrac{\Delta_{min} + \rho\Delta_{max}}{\Delta_t(i,0) + \rho\Delta_{max}}$

Degree of association: $r_{t,0} = \dfrac{1}{n}\sum_{n}^{l} L_t(i,0)$

Weight coefficient : $a_t = \dfrac{r_t}{\sum_{t=1}^{n} r_t}$

Evaluation index: $REI = \sum_{t=1}^{n} a_t X_t$

| type	parameters and weight coefficient						identify index
calcium							0—15
argillaceous barrier-intercalation	GR	0.65	RLLD	0.20	Density	0.15	15—40
pebble intercalation							40—60
silty intercalation							60—70
sand							70—100

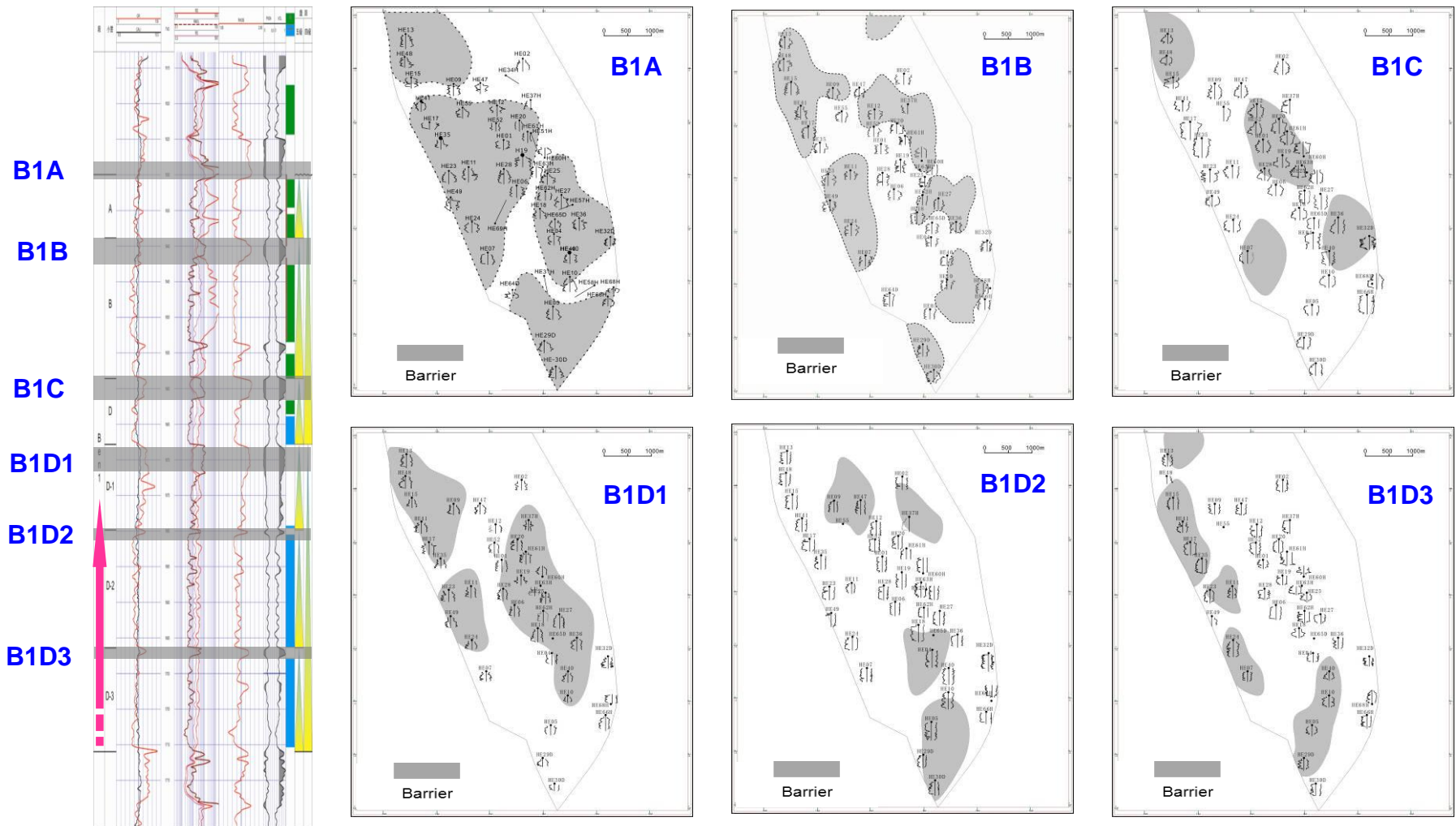# Determination of scale of barrier-intercalations

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.
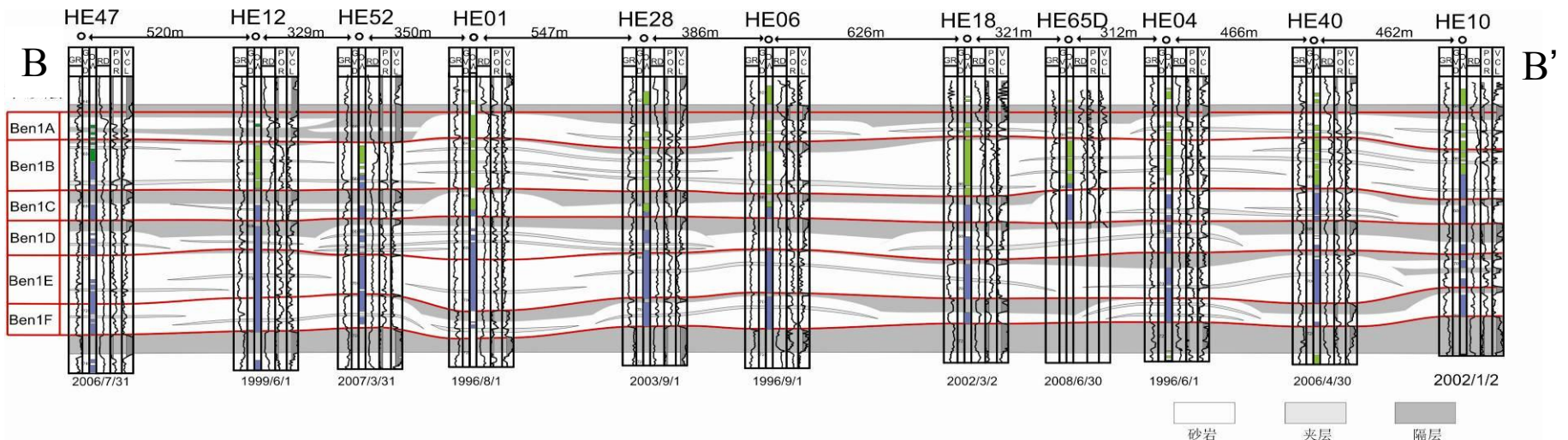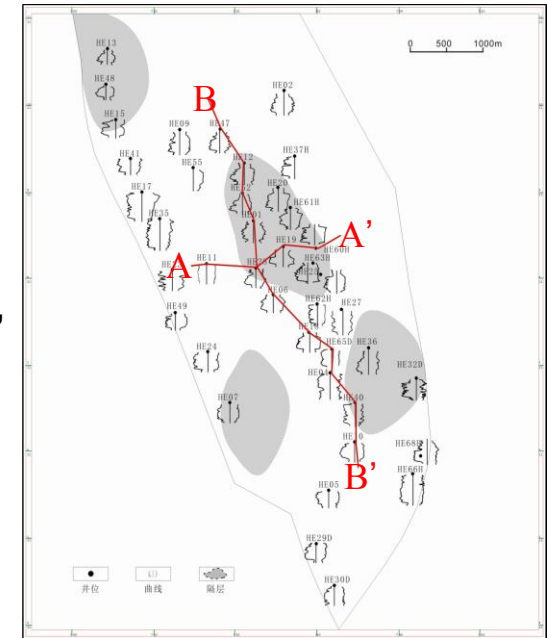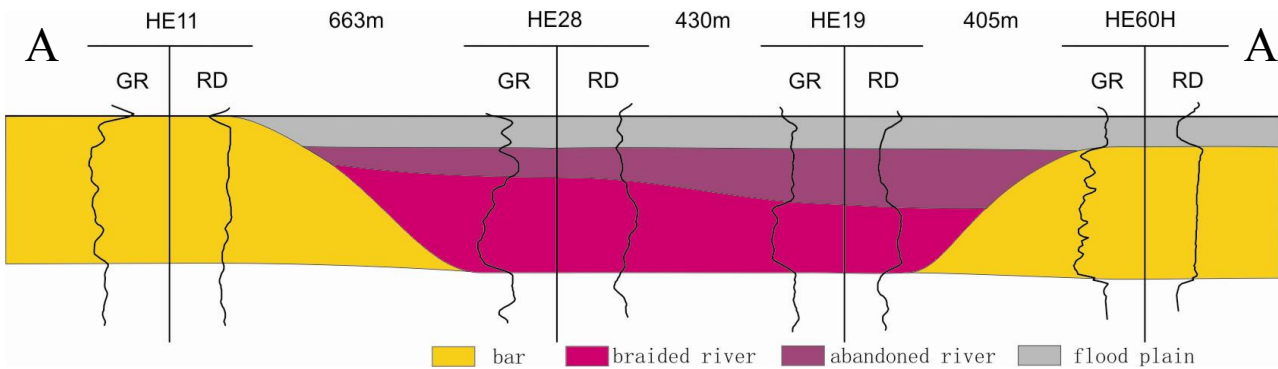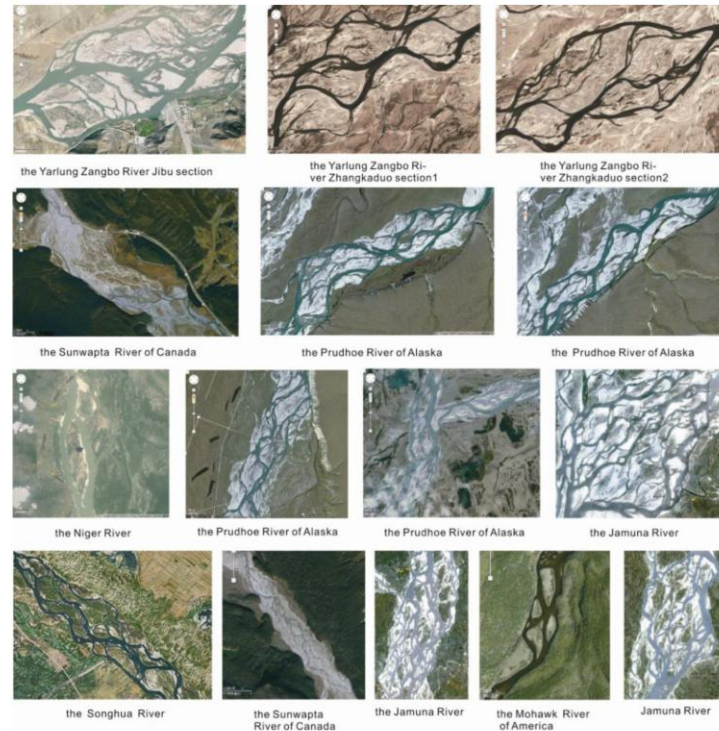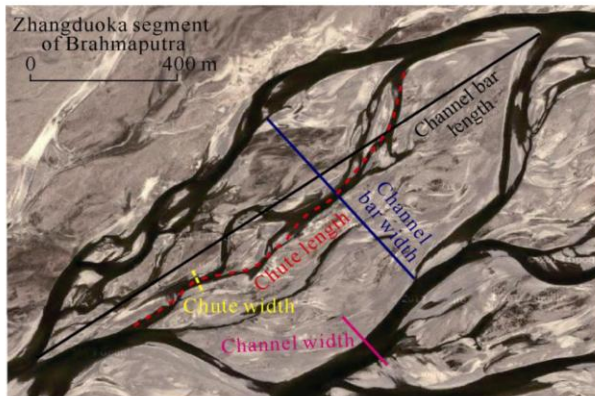
Determination of scale of barrier-intercalations

➢ **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.
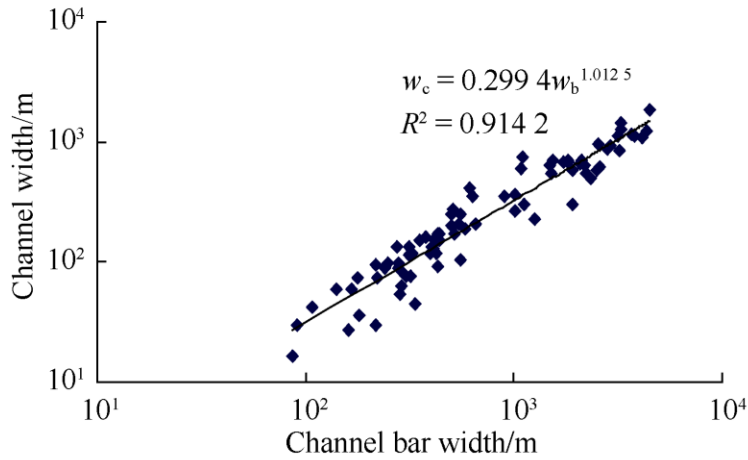

Presenter's notes: Scaling and hierarchy in braided rivers and their deposits: Examples and implications for reservoir modeling (Smith et al., 2006).
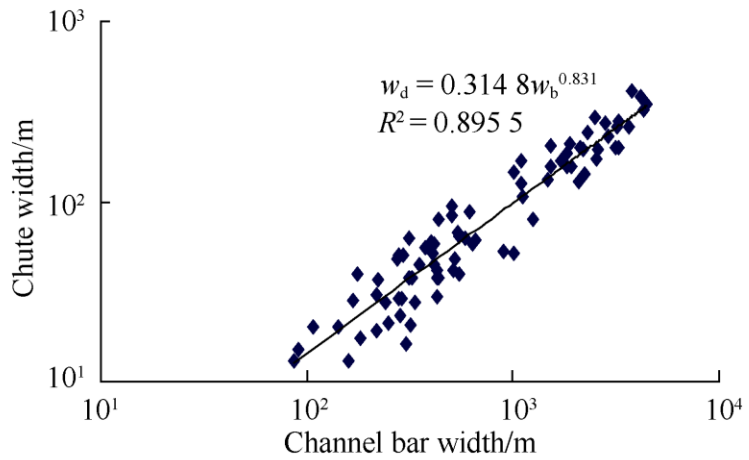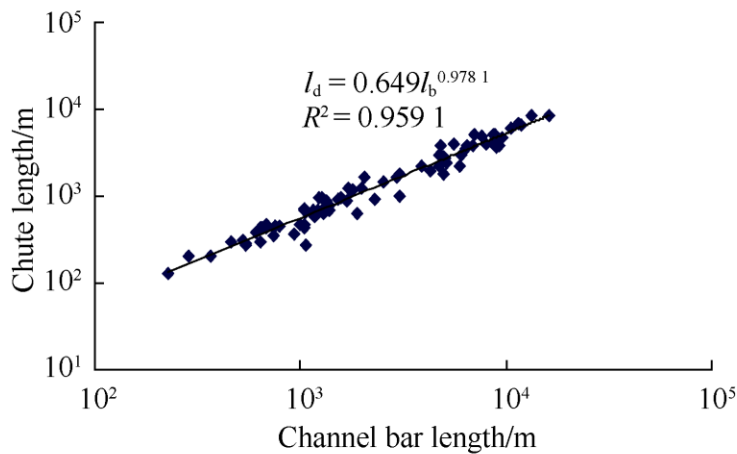
Determination of scale of barrier-intercalations

➤ **To estimate the extension of the abandoned channel and chute mudstone based on above mentioned relationships and well correlation.**
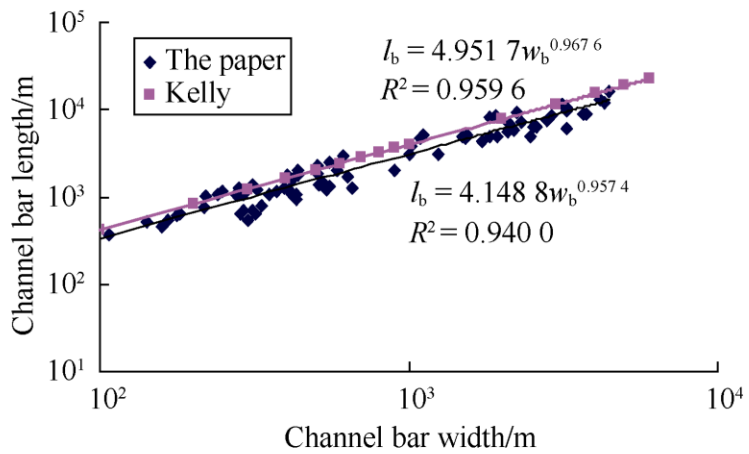

(a) Channel width vs. channel bar width

(b) Chute width vs. channel bar width
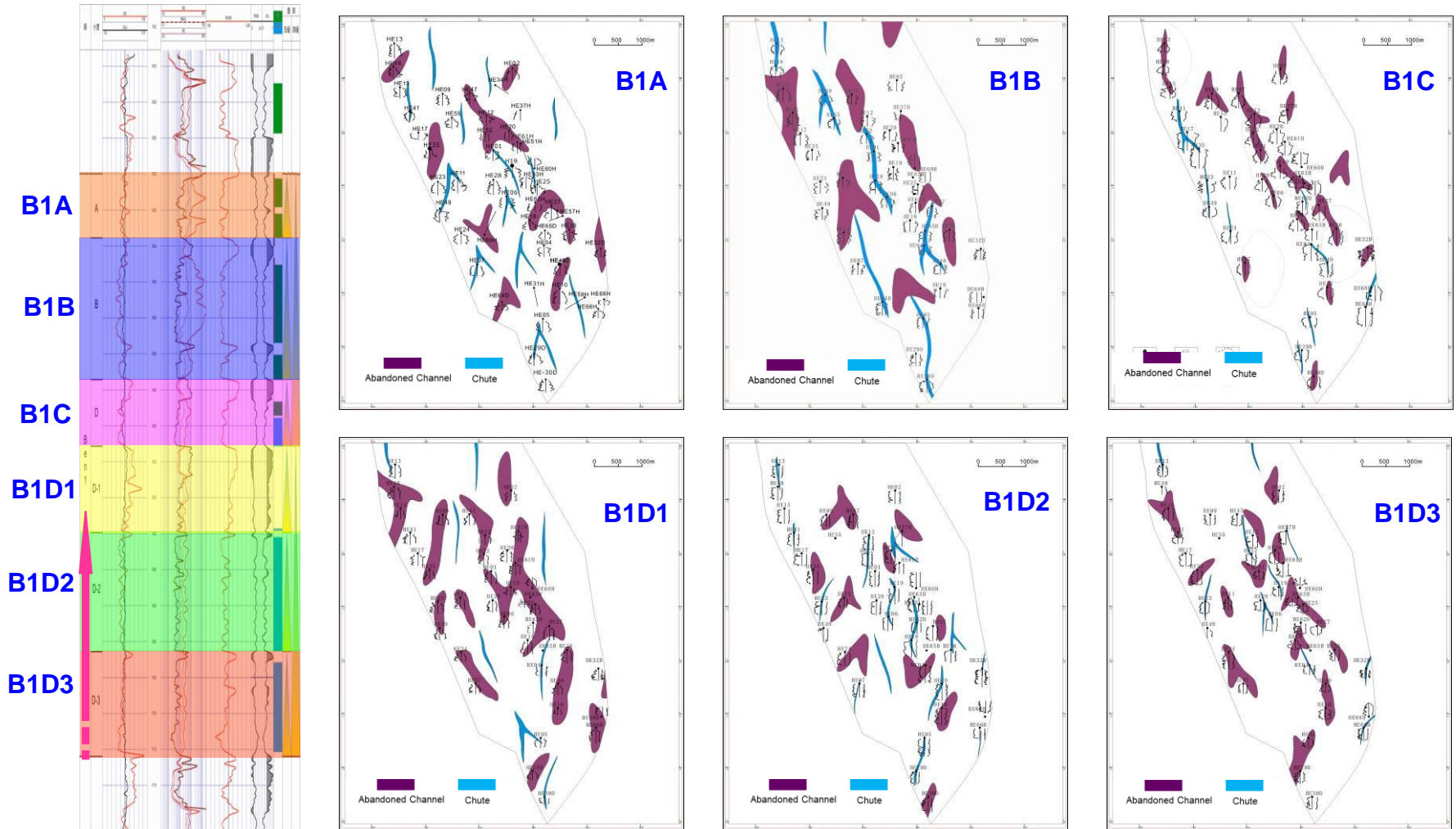
(c) Chute length vs. channel bar length

(d) Channel bar length vs. channel bar width

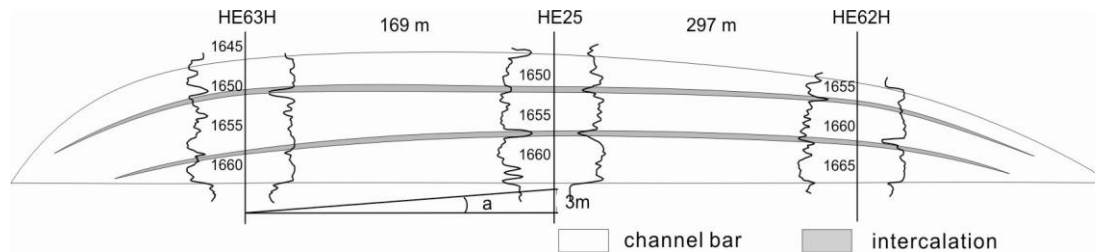# Determination of scale of barrier-intercalations

➢**Banded or local continuous, controlled by channel and chute**
➢**Abandoned channel: 50-300m in width, 800-3000m in length**
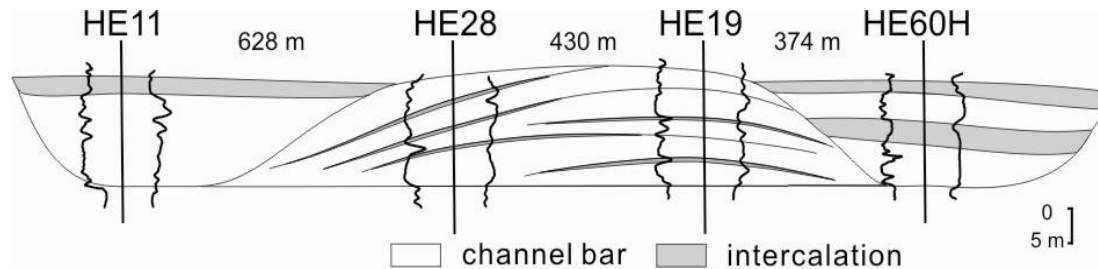➢**Chute mudstone: 30-100m in width, 300-2500m in length**

Determination of scale of barrier-intercalations

3. Intercalation within channel bar—mainly shale between aggradation bodies

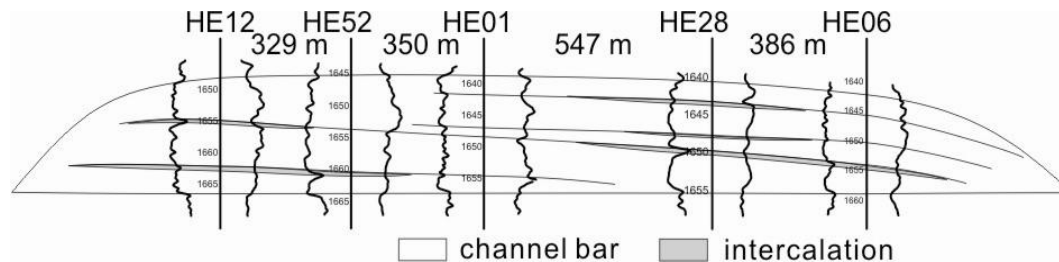➢ **To calculate the angle of the shale bodies between aggradation bodies by flatting the bottom marker and well correlation, the dip angle is about 1.1°in major axis and 2-4°in minor axis.**

Dip angle calculation of major-axis of channel bar
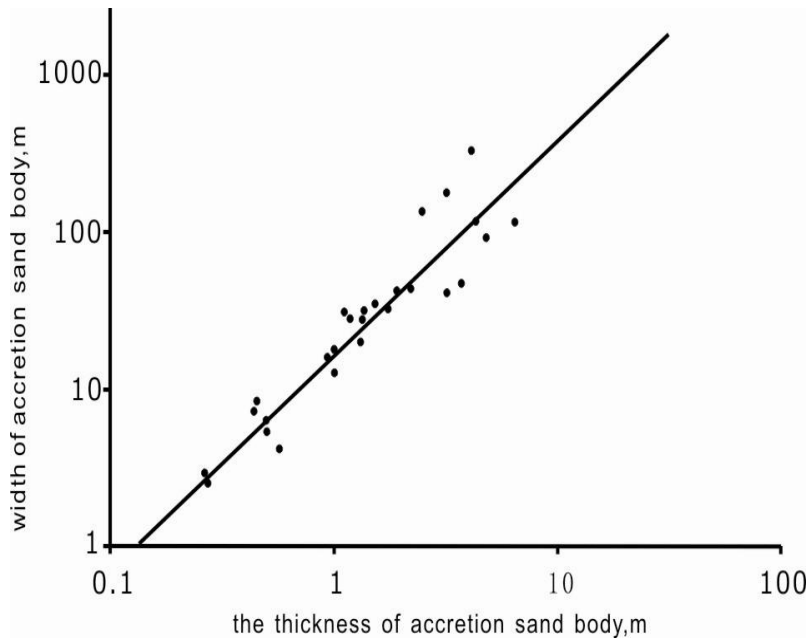
Characteristic of intercalation of channel bar in minor-axis

Characteristic of intercalation of channel bar in major-axis

Determination of scale of barrier-intercalations

➢ **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.**

Width and thickness of lateral sand body
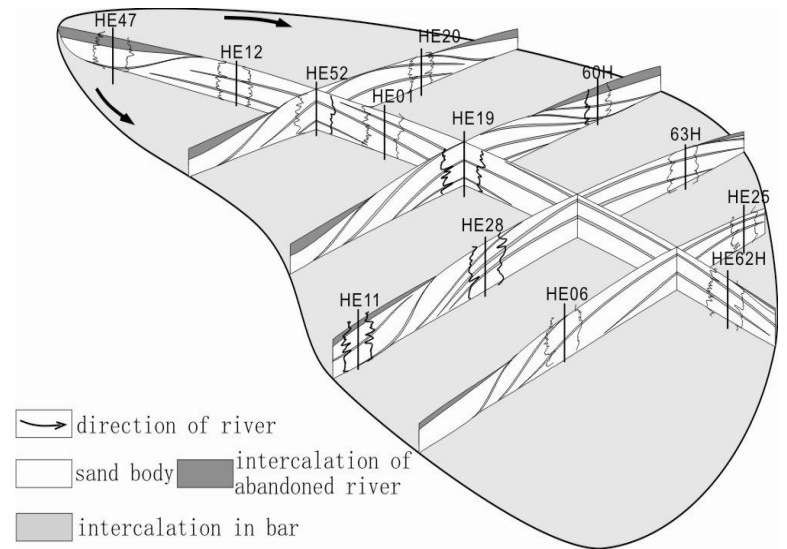
Distribution characterization of intercalation in channel bar in 3D view
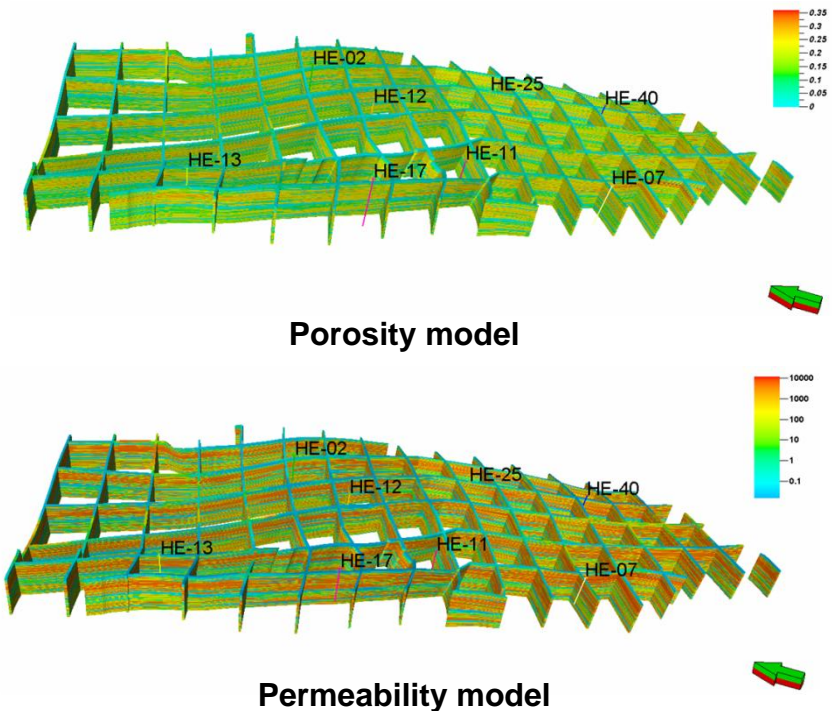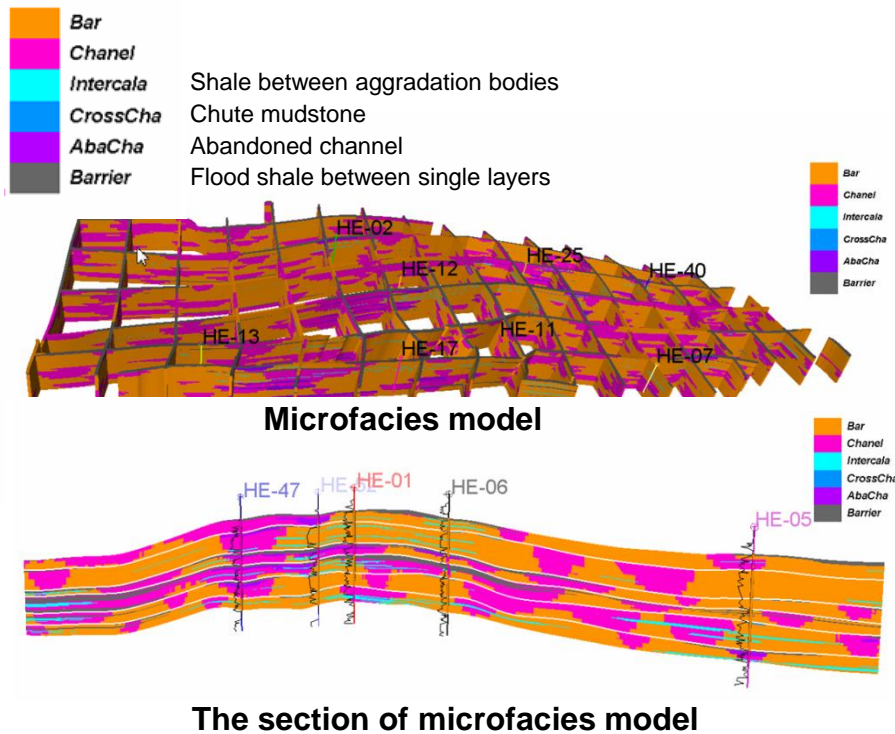
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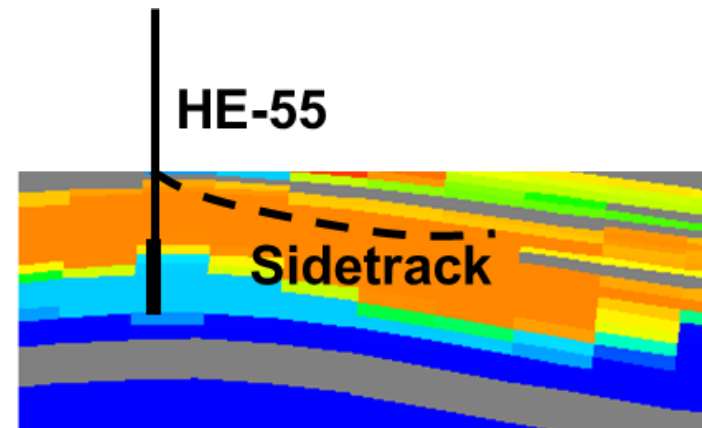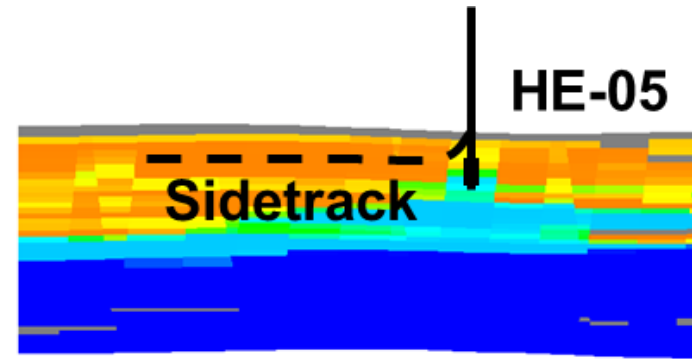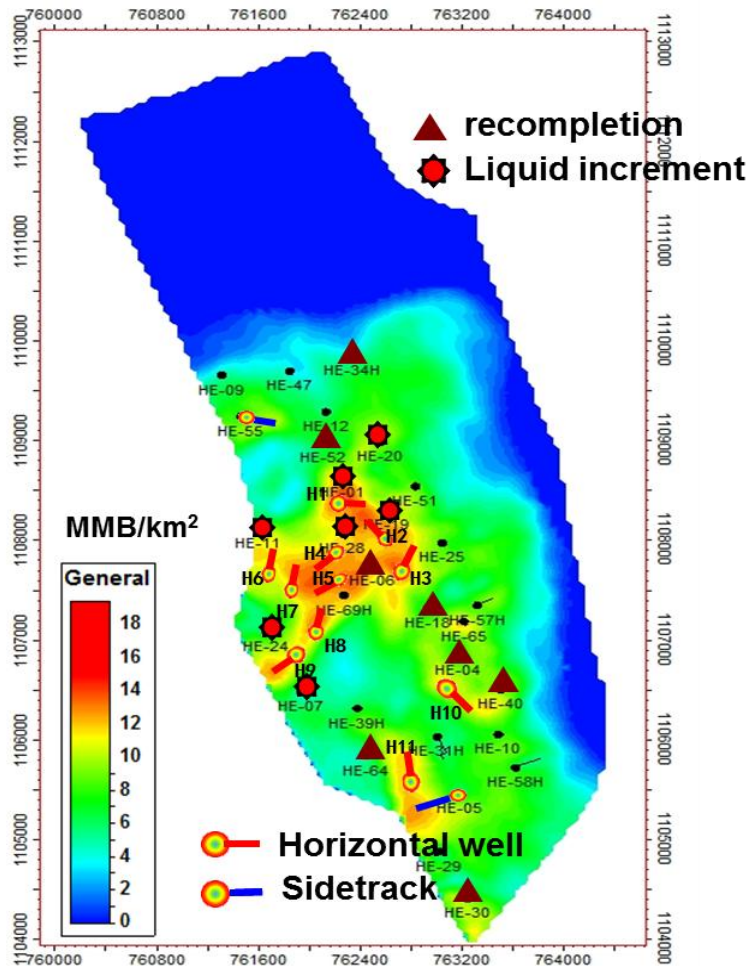
◆ **Summary**

Geological model based on barrier-intercalation understandings

- **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 aggregation bodies are simulated by object-based method.**

- **Porosity and permeability model are built using SGS constrained by facies model.**

Bar
Chanel
Intercala   Shale between aggradation bodies
CrossCha   Chute mudstone
AbaCha   Abandoned channel
Barrier   Flood shale between single layers

Microfacies model

The section of microfacies model

Porosity model

Permeability model

Geological model based on barrier-intercalation understanding

➤ **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

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