PS 3-D Geological Modeling for Tight Sand Gas Reservoir in Braided River Facies*

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Search and Discovery Article #42116 (2017)**
Posted July 31, 2017

*Adapted from poster presentation given at 2017 AAPG Annual Convention & Exhibition, Houston, Texas, April 2-5, 2017

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Abstract

The Sulige Gas Field is a typical tight sandstone field in China and is characterized by poor reservoir properties, drastic sedimentary faices changs, small scale of effective sand bodies and strong reservoir heterogeneity. Considering the poor applicability of conventional geological modeling, a new modeling method is put forward as “multi-stage constraints, hierarchical facies and multi-step models” to represent the dual reservoir structure of “effective sand bodies in normal sand bodies”. Based on prior geological knowledge, GR field was inverted by seismic and logging data through neural network recognition technology. Taking rock facies data at well points as hard data and sandstone probability volume derived from GR inversion in inter-well zones as soft data, several training images are obtained according to the reservoir differences of various developing layers, then rock facies model was established by multipoint geo-statistics method. In view that the braided-river sedimentary system has strong influences on development types, frequency and scale of sedimentary microfacies, a sedimentary microfacies model was built controlled both by rock facies and the braided-river system.

Eventually, effective sand body model was built with both of the discrete and continuous modeling methods by integrating sedimentary microfacies, effective sand body scale, and reservoir properties distribution. In this research, a series of models were set up like GR field inversions, rock facies, sedimentary microfacies, reservoir parameters and effective sands. GR field inversion ensures the quality and multiple sources of the analysis data, breaks traditional seismic resolution limits and clarifies geological meaning of predicted sands. The rock facies model is faithful to hard data at the well points and shows fluvial channel morphology well in inter-well zones. The effective sand bodies model has great consistence with statistical properties and geological knowledge. The modeling method discussed, using geological constraints as far as possible, reduces data interpretation uncertainty and improves the model's reliability. In 1200 m × 1800 m well pattern, model accuracy is up to 73% from 46% of the traditional methods, increased by 27%. It is concluded that the new modeling method can provide a more reliable geological basis for gas reservoir development.

INTRODUCTION

The Sulige gasfield in Ordos Basin (Fig. 1), is typical of tight gas in China.

- Braided river sedimentary facies with dramatic lateral change;
- Pay zone, mainly Shihezi 8 and Shanxi 1 units in Lower Permian, buried deep (3200~3500m) with low porosity (5~12%) and permeability (0.1~10md) (Fig. 2);

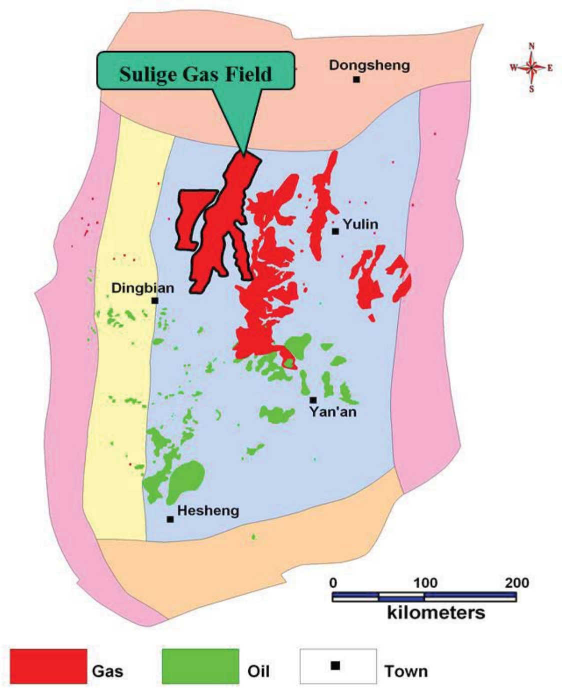

Figure 1. The Sulige gasfield location map

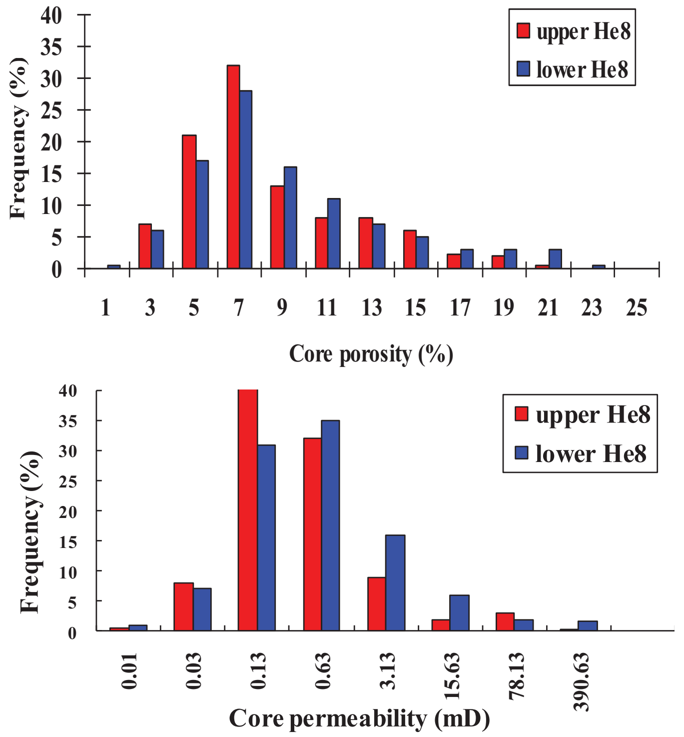

Figure 2. Core analysis of porosity and permeability

- Strong heterogeneity, normal sandbodies and effective sandbodies form a dual structure of "net pays encased in tight sands"(Fig. 3);
- Net pays, coarse-grained sandstones with relatively high permeability, small scale and poor stability, mainly located in channel bars microfacies.

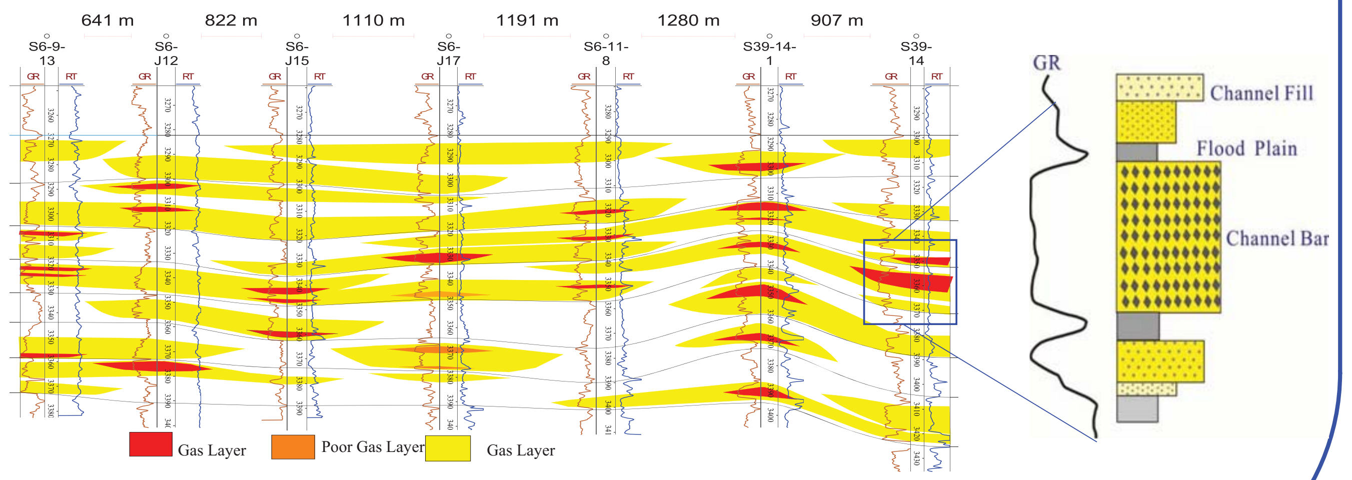

Figure 3. Cross-section of the Sulige Gas Field from well Su6-9-13 to Su 39-14

STUDY STRATEGY

The complicated geological conditions make conventional modeling method not applicable:

- The combining effect of well logging and seismic data is not ideal;
- Sedimentary bodies are simulated according to fixed proportion and nearly the same scale;
- Geological constraints are not enough to identify and predict inter-well effective sands.

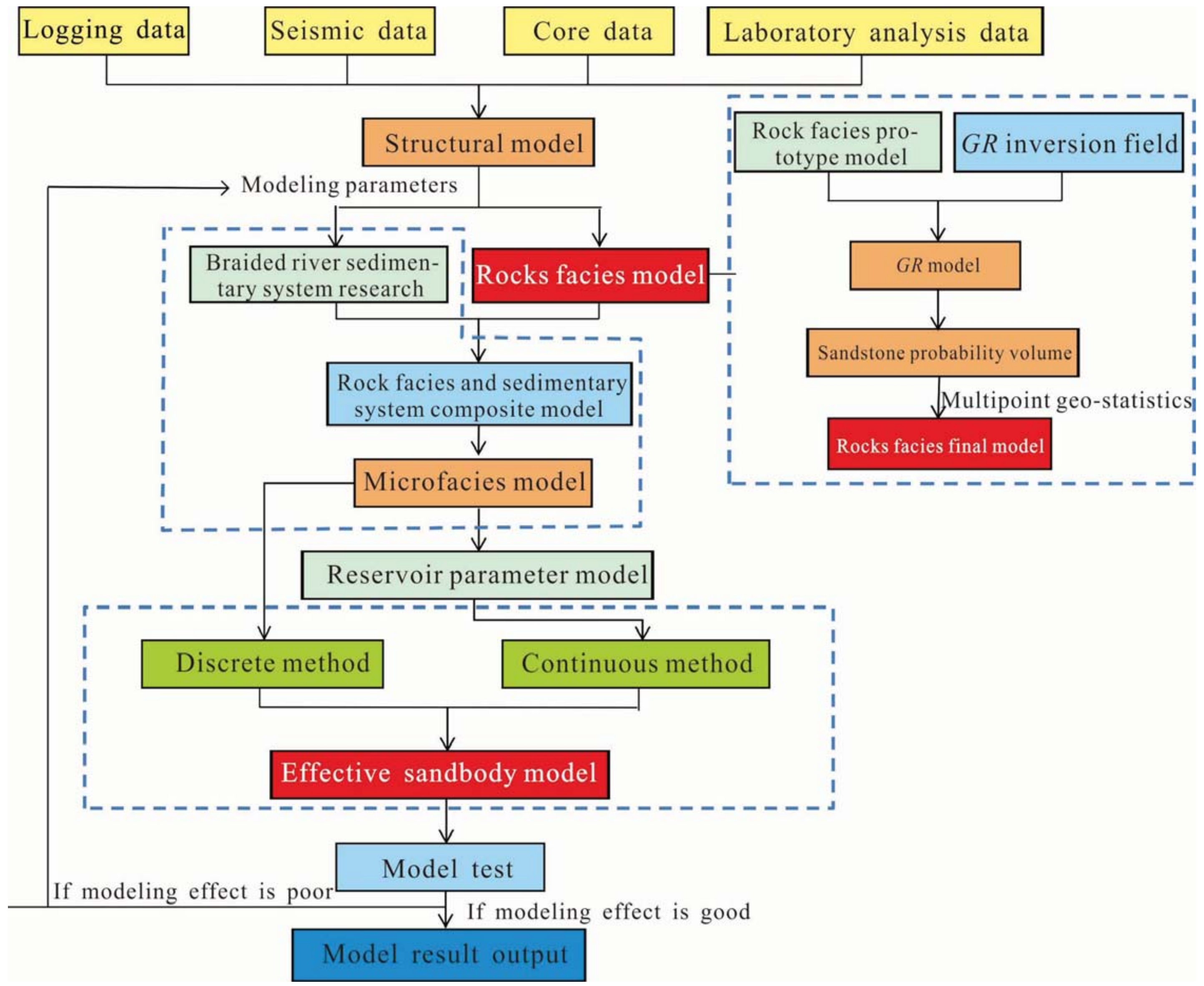

Figure 4. Geological modeling process

Considering the limits of the existent methods and the geological features of Sulige gasfield, a new modeling method is put forward to represent the dual reservoir structure (Fig.4).

- **Multi-stage constraints**: adding lots of geological constraints to reduce data ambiguity;
- **Hierarchical facies**: facies restricted by rock facies and braided-river sedimentary system;
- **Multi-step modeling**: rock facies, sedimentary facies, reservoir property and effective sandbody modelings. Each step is controlled by the previous steps.

RESERVOIR FINE DESCRIPTION

Reservoir fine description research provides accurate parameters for modeling.

- 4 types distribution pattern of effective sandbodies, >70% are isolated thin layers(Fig.5);
- Single effective sand body thickness 1 ~ 5 m, width 100 ~ 500 m, length 200 ~ 600 m (Fig. 6);
- 1 ~ 2 effective sand bodies are developed in single layer, and 20 ~ 30 are developed per km^2.

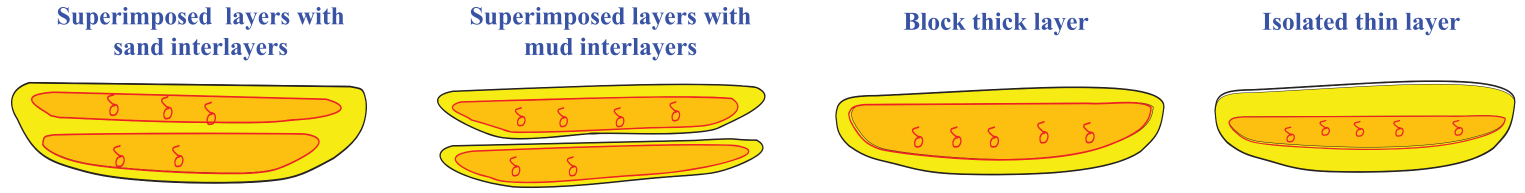

Figure 5. Effective sandbodies spatial distribution pattern

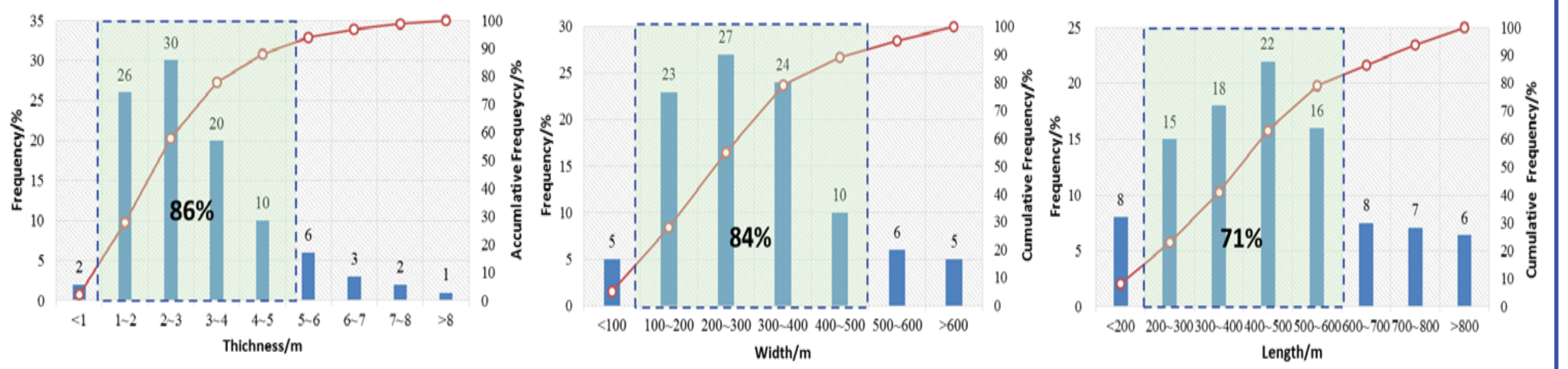

Figure 6. Distribution frequency histogram of effective sand bodies scale

ROCK FACIES MODEL

Using neural network recognition technology, the GR field was inverted with seismic data by constraint of GR logging curve (Fig. 7), the most sensitive to lithological change.

GR field inversion ensures the quality and multiple sources of the analysis data, breaks the traditional seismic resolution limits, and can obtain the same resolution as the logging data.

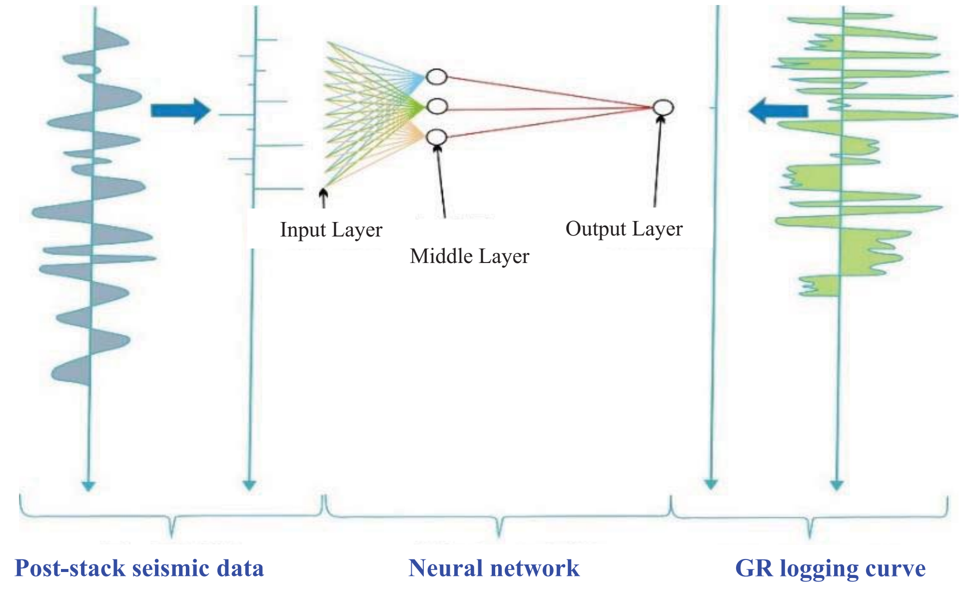

Figure 7. Schematic diagram of neural network pattern recognition

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The wave impedance is not suitable to identify sand from mud because the values of sand and mud are both in range (10.0 ~ 12.8) ×10⁶ kg/ (m²•s) (Fig. 8a), While inverted GR field can distinguish sand with good effect (Fig. 8b).

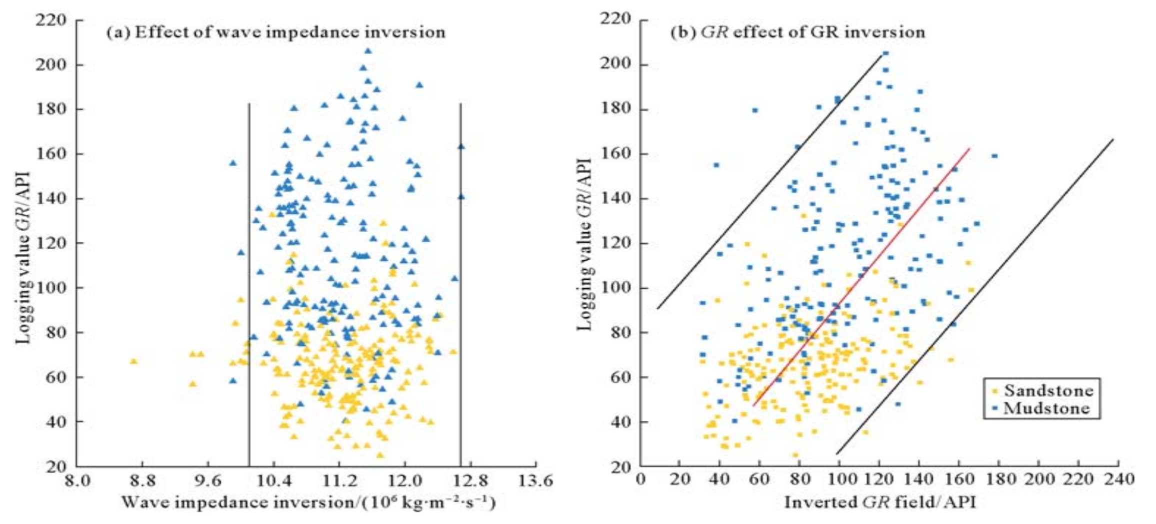

Figure 8. Comparison of wave impedance inversion and GR inversion

Building GR model with GR values at well points, inverted GR field at interwell zones and geological constraints such as source direction, major, minor and vertical variation range of sand body(Fig. 9).

Based on the statistics between GR values and sandstone probability, transforming GR model is into sandstone probability volume (Fig. 10). It can provide multiple choices for rock facies model and avoid the rock facies identification mistake resulted by only one GR threshold.

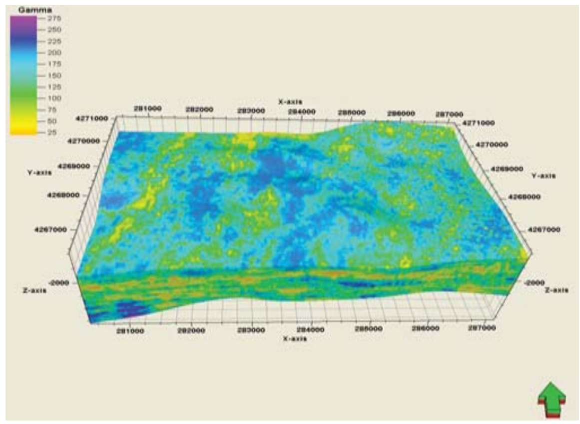

Figure 9. GR model

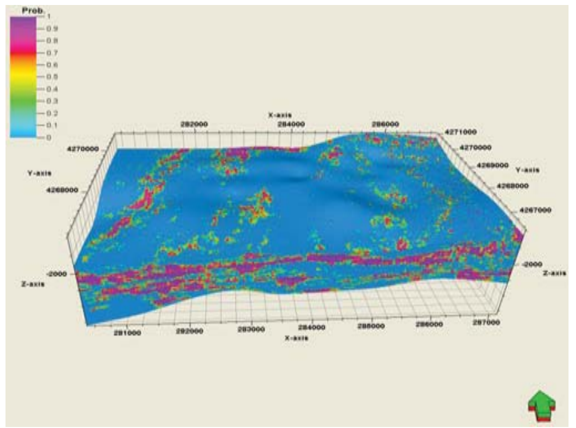

Figure 10. Sandstone probability volume model

Multipoint geo-statistics(Fig. 11a), with training image as the key basis, can both reveal the geological variables' spatial structure and is loyal to hard data, is the most advanced facies model method currently in the world,.

Considering the difference between each develop layer, 3-D training images of 7 development layers are set up respectively(Fig. 11b&c).

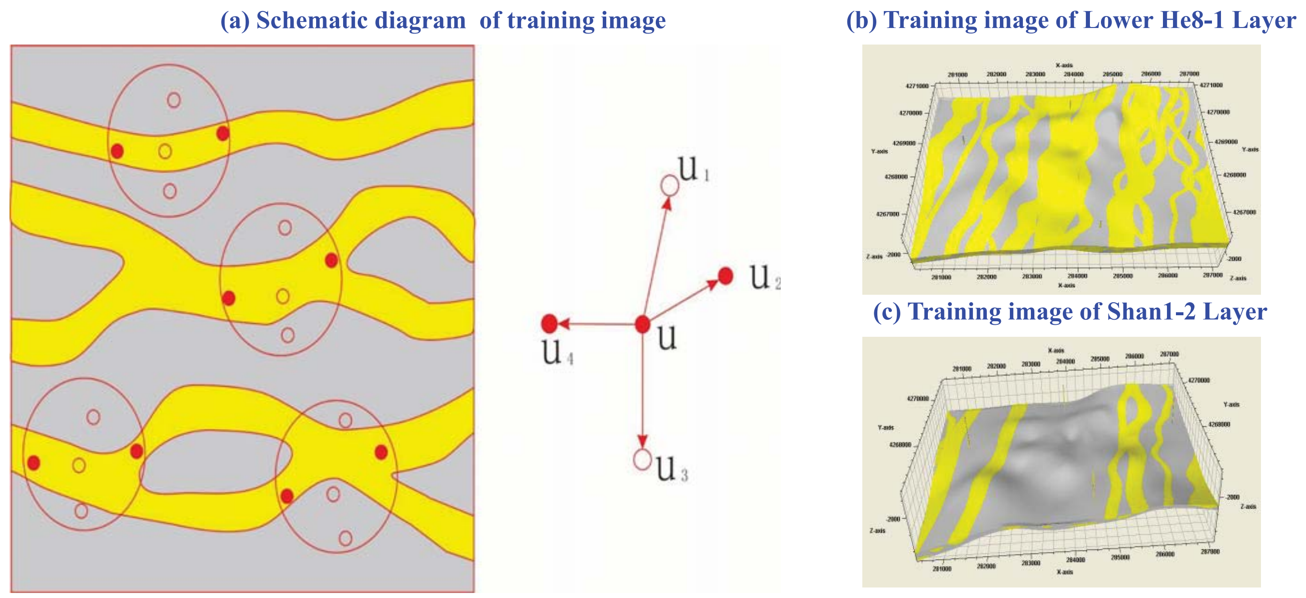

Figure 11. Schematic diagram and real cases of training image of multipoint geo-statistics

In the model by multipoint geo-statistics theory (Fig. 12). :

•At well points, it consisted with the sandstone thickness isopach map.

•At inter-well areas, with the integration of seismic data, sand probability volume and modeling algorithm, it predicts the distribution of sandbodies reasonably.

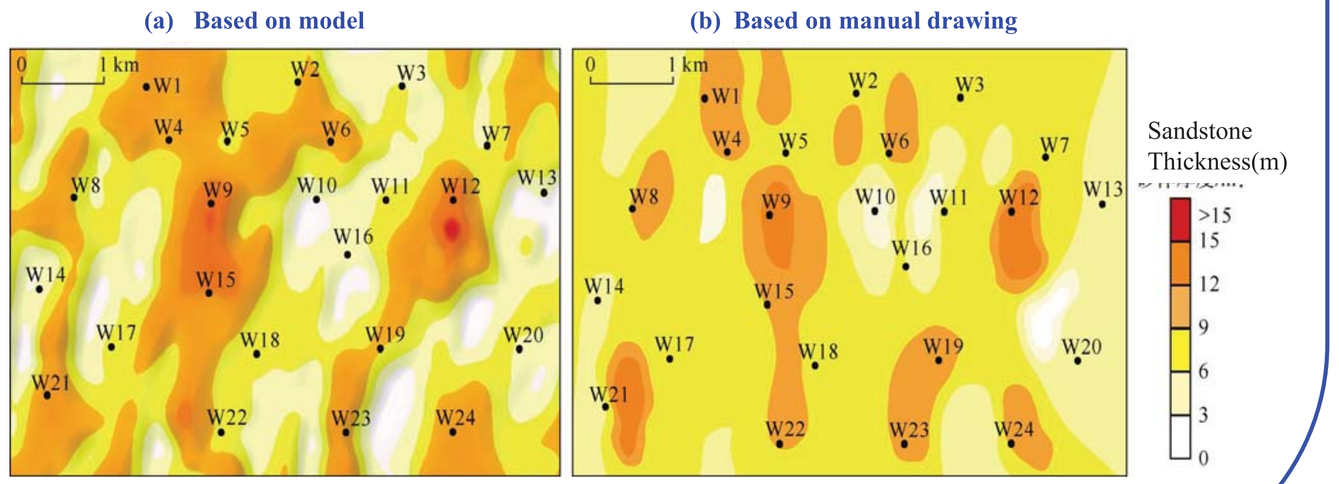

Figure 12. Sandstone thickness isopach maps comparison

SEDIMENTARY FACIES MODEL

Gentle tectonic setting and strong hydrodynamics make channels deposition migrate& superimpose frequently, forming a large scale of braided river sedimentary system.

•It covers several kilometers on the plane and include 2 - 3 layers vertically;

•It is classified into 3 zones: superimposed zone, transitional zone and intersystem zone.

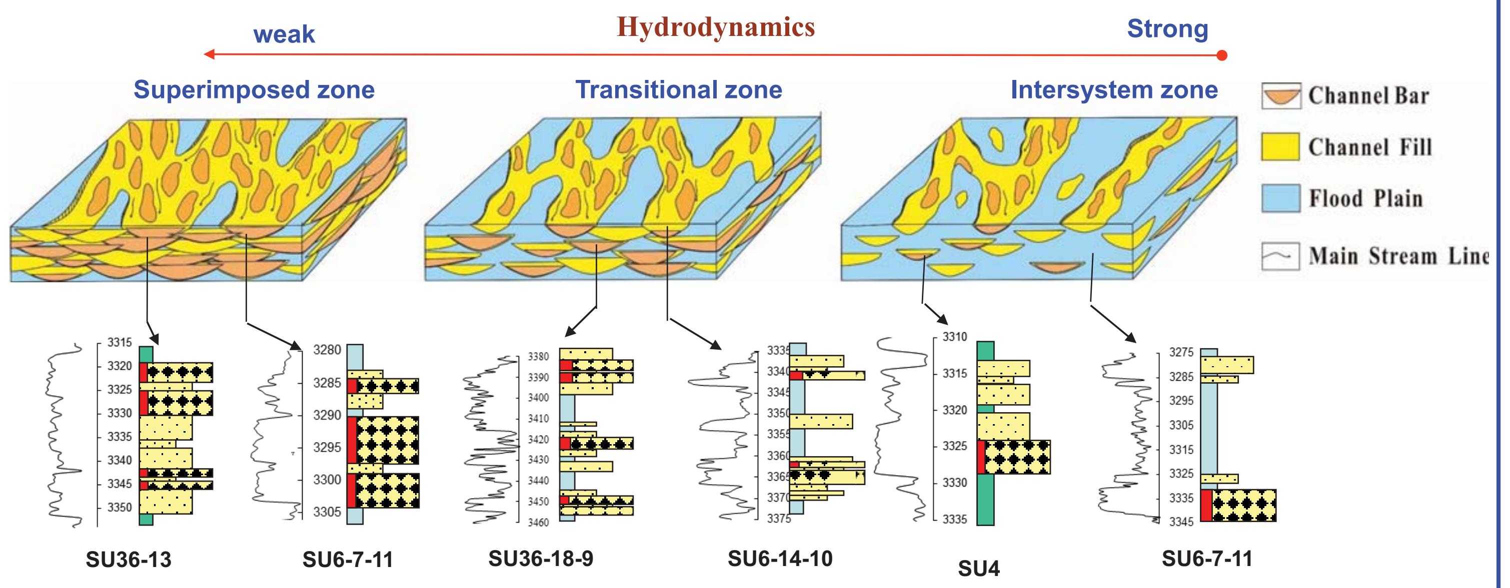

Figure 13. Reservoir sedimentary pattern of braided river sedimentary system zones

Braided river sedimentary system has strong control influence on the sedimentary microfacies' development types, frequency and scale (Fig. 14). Channel bars in superimposed zone have large development frequency and scale.

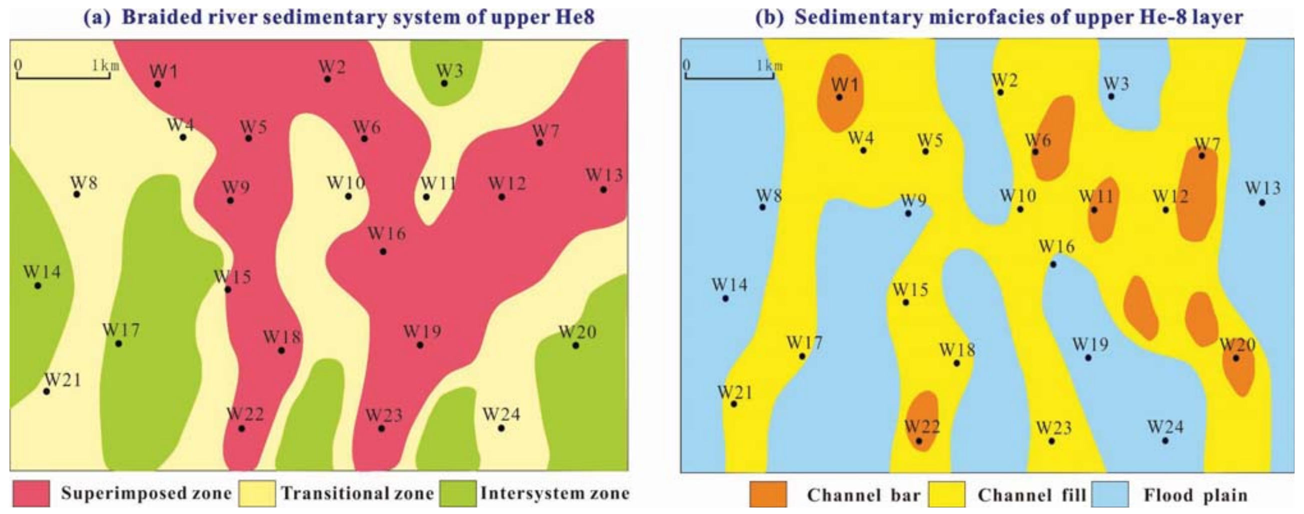

Figure 14 Braided river sedimentary system and sedimentary microfacies plan

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- Under the control of both rock facies and braided river sedimentary system, channel bars' distribution is more concentrated at certain local zones (Fig. 15a), consistent with sedimentary characteristics (Fig. 14b);
- While only restricted by the rock facies(Fig. 15b), channel bars are distributed with fixed probability and almost equal scale, which play down the inherent inhomogeneity of sedimentary facies, thus the simulation effect is poor.

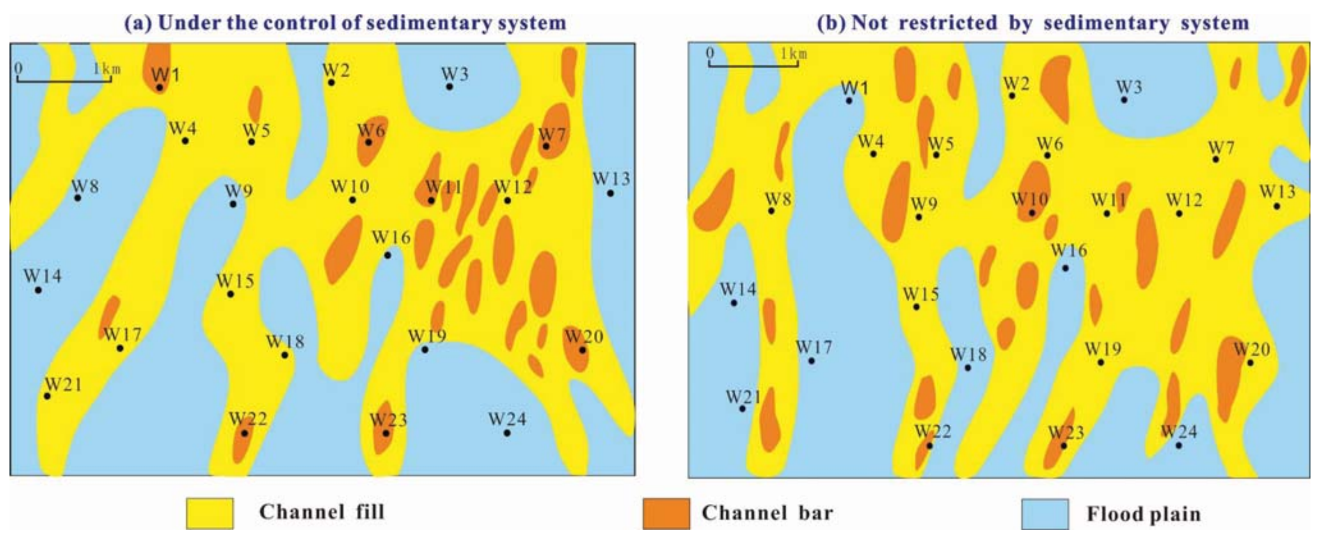

Figure 15. Sedimentary microfacies models contrast by two modeling methods in Sulige gasfield

EFFECTIVE SANDBODY MODEL

Build effective sand body model combining two methods. Modify models until the two methods have the highest coincidence rate.

- Continuous modeling method. Based on reservoir property models(Fig. 16), define the grids up to standard ($\varphi \geq 5\%$, $K \geq 0.1$md and $Sg \geq 45\%$) as effective.

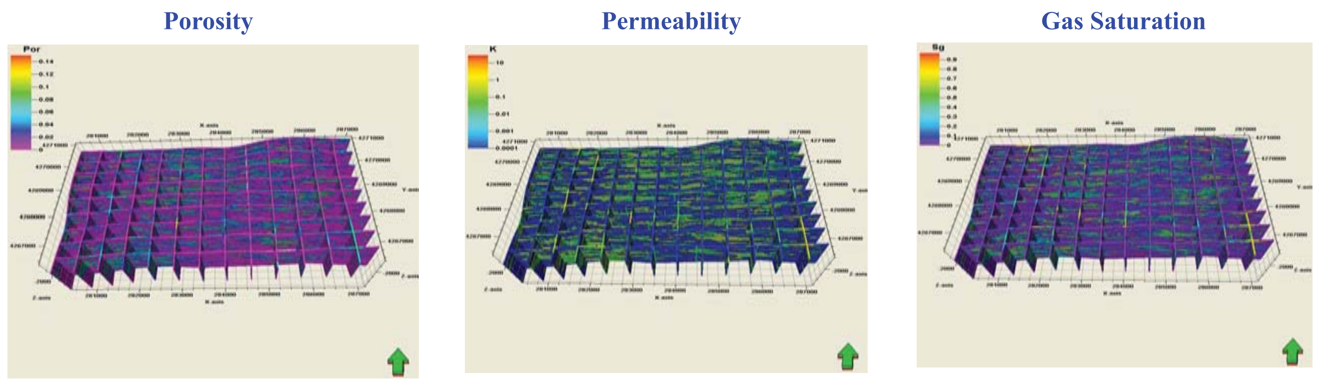

Figure 16. Reservoir property panels

- Discrete modeling method. The effective sandbodies (gas layers and gas-bearing layers) , simulation facies; the dry layers, background facies(Fig. 17).

Integrating rock facies model and effective sandbodies model to demonstrate the dual spatial structure of "net pays encased in tight sands " with high precision (Fig.18).

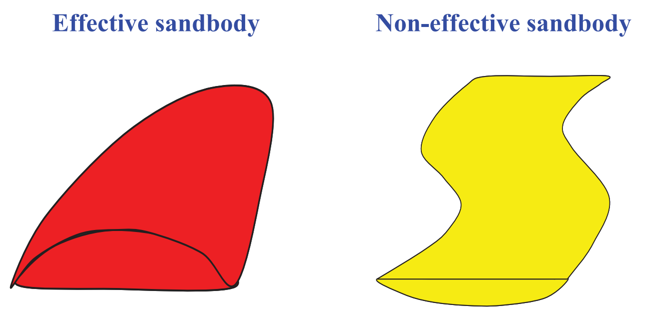

Figure 17. Effective and non-effective sandbodies shape

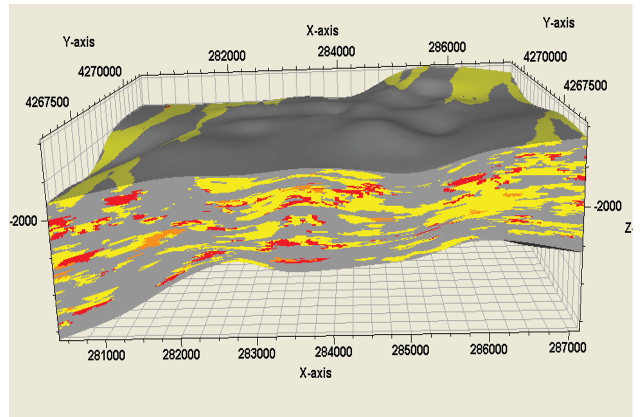

Figure 18. Effective sandbody model

MODEL TEST

Several model tests indicate the new geological model can improve the model precision to a great extent (Fig. 19~21) .

- Modeling pattern coarsening study shows in well pattern of 1 200m× 1 800m, the new model is basically reliable with the sand identification accuracy over 70%, having 26% more than that of traditional model.
- Numerical simulation shows 83.3% wells has less than 5% error in history match of production and pressure.

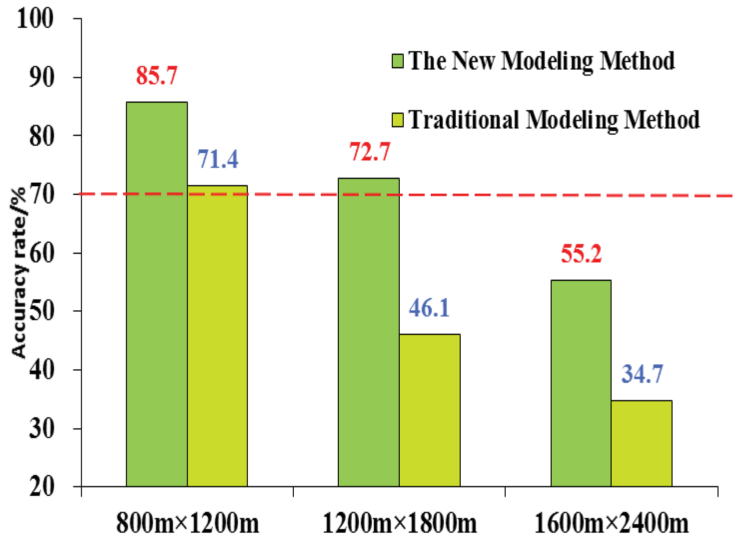

Figure 19. Modeling pattern coarsening result comparison

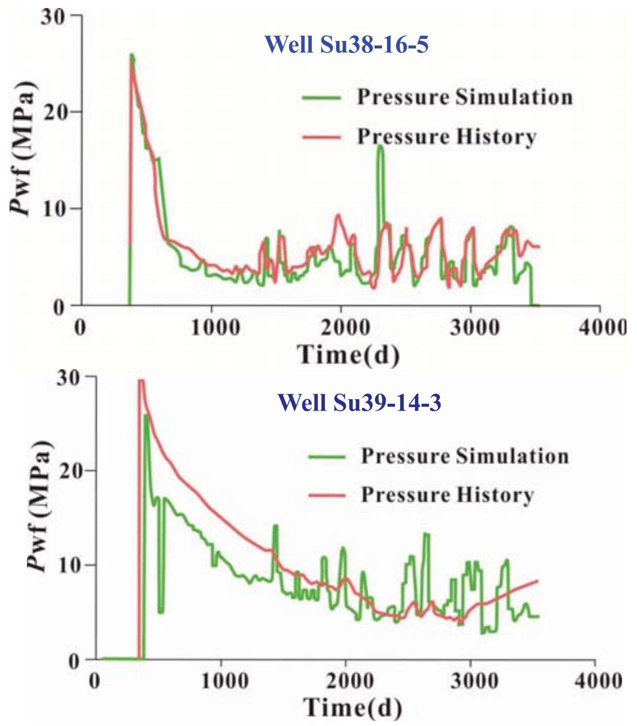

Figure 20. Historical simulation result of two wells

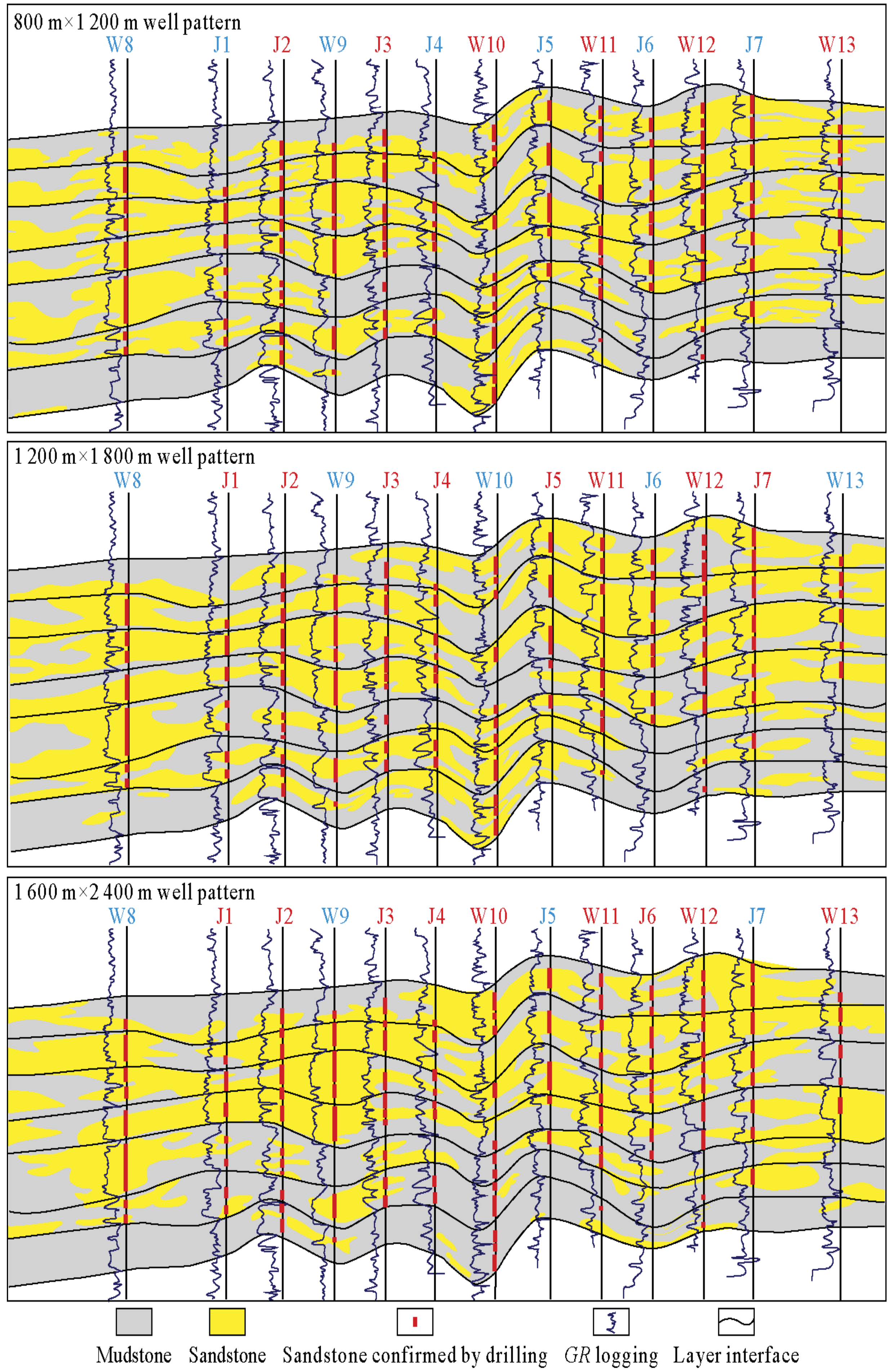

Fig. 21 Verification by modeling well pattern coarsening

(Red wells are removed and not used in the modeling, while blue wells are used in simulation)