Predicting Interwell Heterogeneity in Fan-Deltaic Reservoirs: Outcrop Analogues and Applications of Lidar Technology in the Kuqa Foreland Area, Northwestern China*

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Abstract

The fan-deltaic reservoirs are widely developed in the Cretaceous Bashenjiqike Formation in the Kuqa foreland area, Northwestern China, which also has the advantageous places of oil and gas accumulation. However, the reservoirs have shown strong heterogeneity and complex relationships between oil and water in the oilfield development process. In areas with few wells, large interwell spacing and low seismic resolution, outcrop analogues can provide detailed information on sand body architecture, geometry and connectivity that is not directly available in the subsurface. In addition, the aim of this study is to define the best approach to rebuild realistic reservoir heterogeneity models. Utilizing Lidar technology for full coverage scanning in a typical outcrop to acquire three-dimensional data, matching with the measured geological information and sampling analysis data, a digital outcrop model has been built and the sand body architecture has been effectively revealed.

The results indicate that the sand body configuration of the fan-delta front is represented multiple underwater distributary channels stacked vertically, accompanied by a few mouth bars and distal bars. There is a good negative correlation between the sand thickness and width-thickness ratio. Three different sand body architecture types are presented: (1) incomplete stacked stitching, (2) side stitching, and (3) isolated bodies, during which there is the stable and lateral distribution of mudstone, while the sand body connectivities are very different owing to the architecture differences. Despite the sand distribution features of large areas and good continuity with content of more than 80%, some physical property interlayers are easily formed in the channel bottom

and side interface due to the higher clay content. The sand bodies are locally connected with each other but not smoothly, with some not even connected. The application of Lidar technology has improved the reservoir model accuracy greater than ever and provided a strong basis for further study of reservoir quality distribution and its controlling effects of remaining oil distribution. This will help old oilfields with high water cut to further enhance oil recovery.

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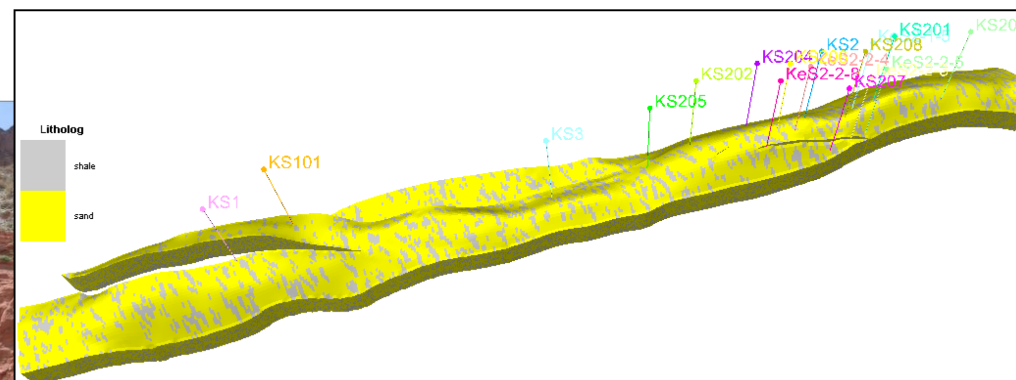
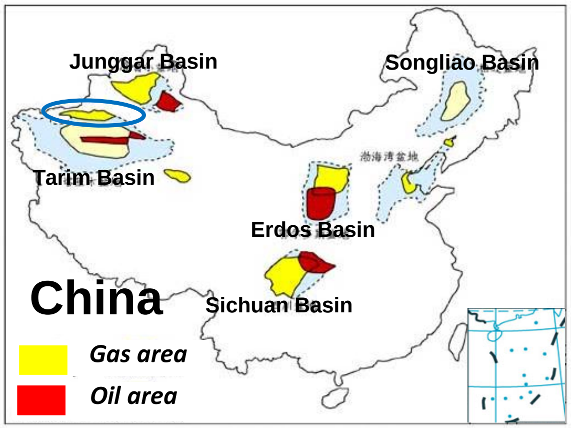
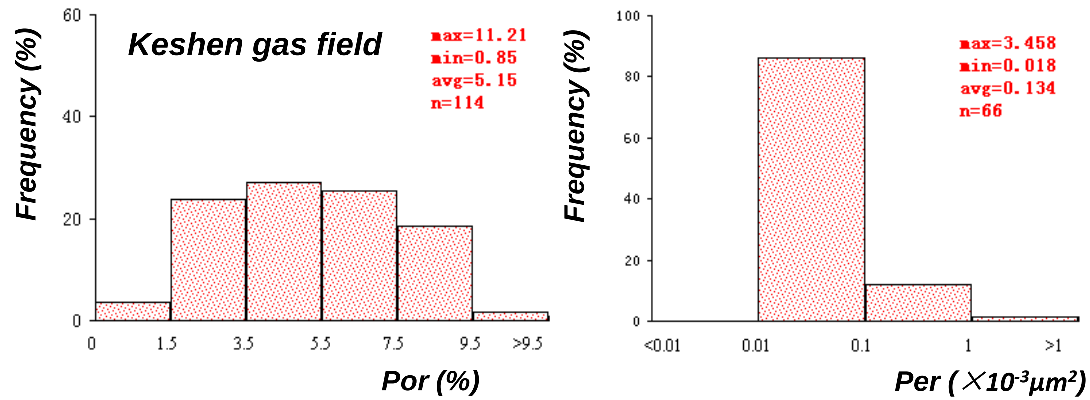


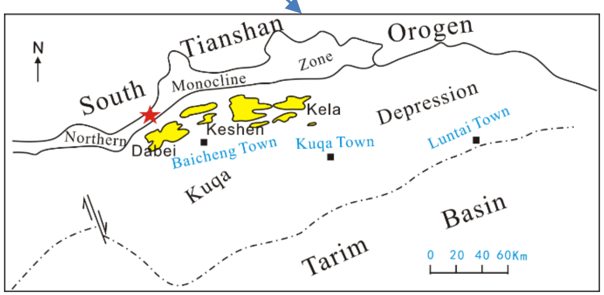
Introduction

The fan-deltaic reservoirs in Cretaceous Bashenjiqike Formation are widely developed in the Kuqa Depression, NW China. They have shown strong heterogeneity and complex relationship between oil and water in the development process.

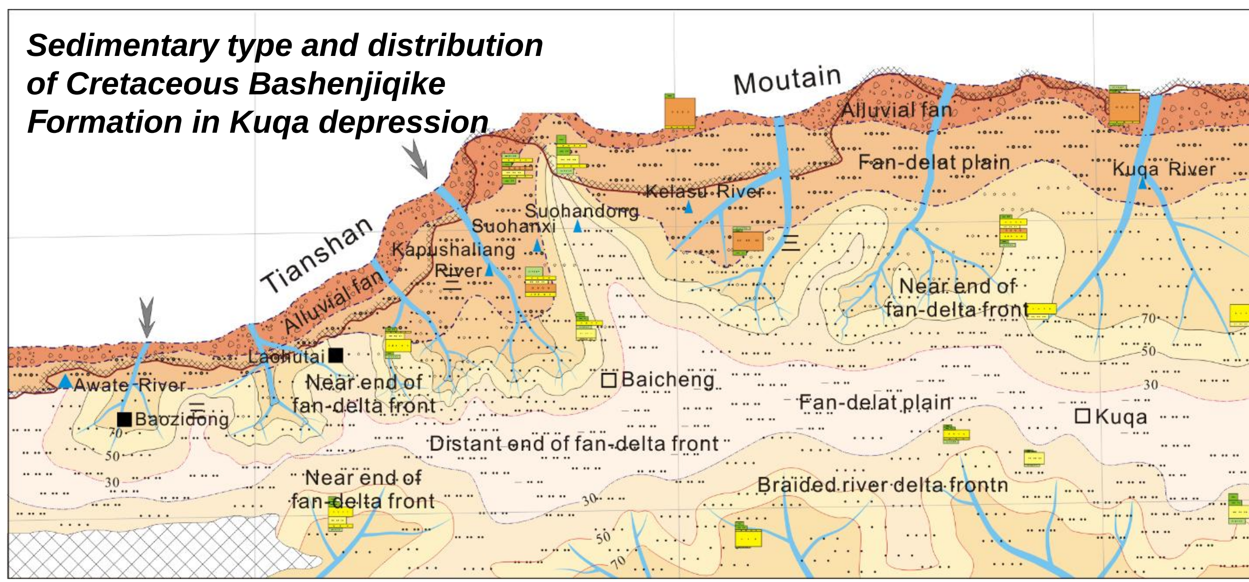


Oil and gas area of low abundance in China





Gas fields have been found in Kuqa depression



Introduction

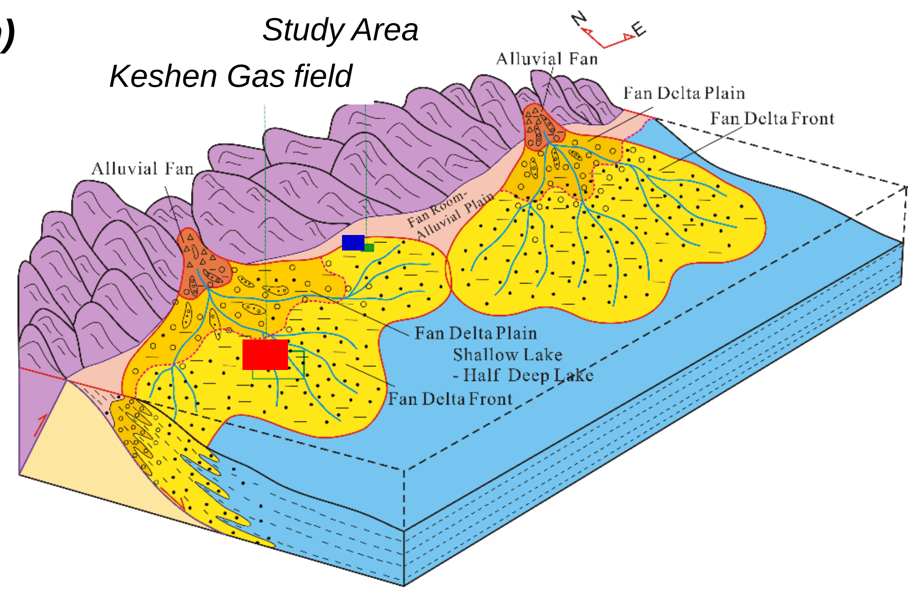
Study area, Suohan Outcrop, northern Kuqa depression

(Study area: Length 70m and Width 20m)

Data Used in Study

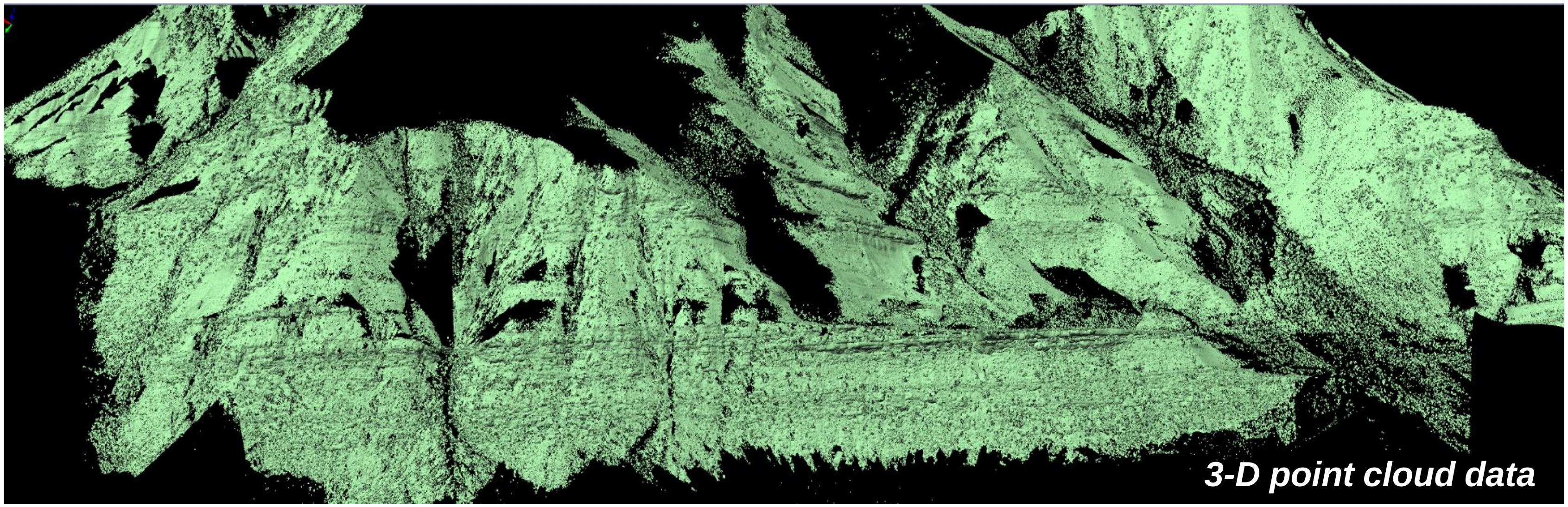
7 Lines of Lithology observation

63 core samples have been drilled



The purpose strata is 3rd section of Cretaceous Bashenjiqike Formation with the sedimentary facies of fan delta front which is present in Keshen Gas Field.

Introduction

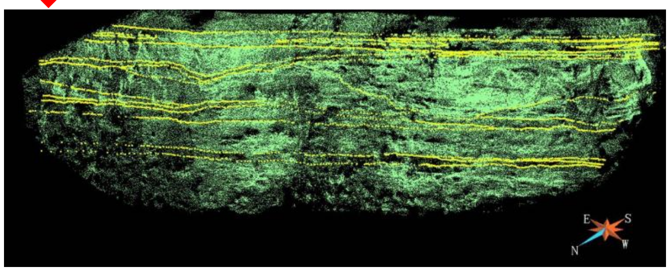


- ***LIDAR: Light Detection and Ranging which can collect a large amount of 3-D data across vast outcrop sections that can be given geological significance and achieve quantitative measurement***

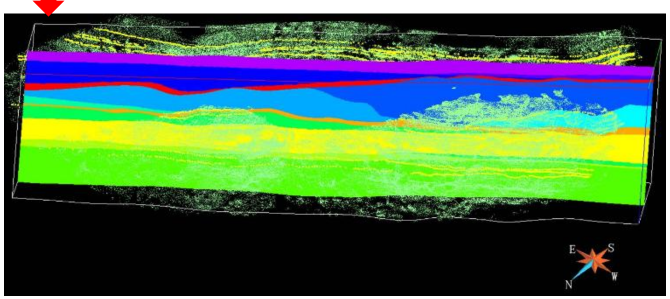
- ***The LIDAR unit used for this survey is Opetech ILRIS 3-D, with scanning accuracy of 3mm and measure distance of 12~20m, the cross section area of about 1400m^2 and 5 scanning stops.***

Workflow diagram of Lidar technology from left to right

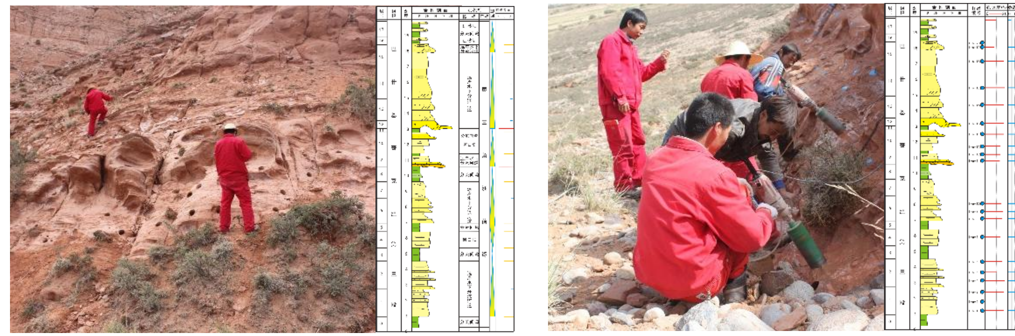
Step 1: data acquisition



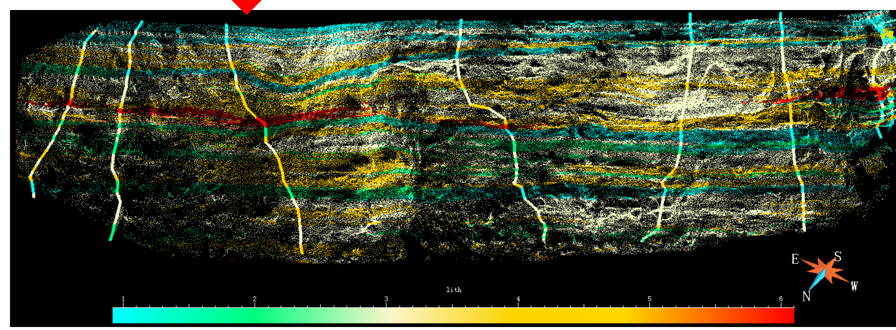
Step 2: point clouds and layer trace



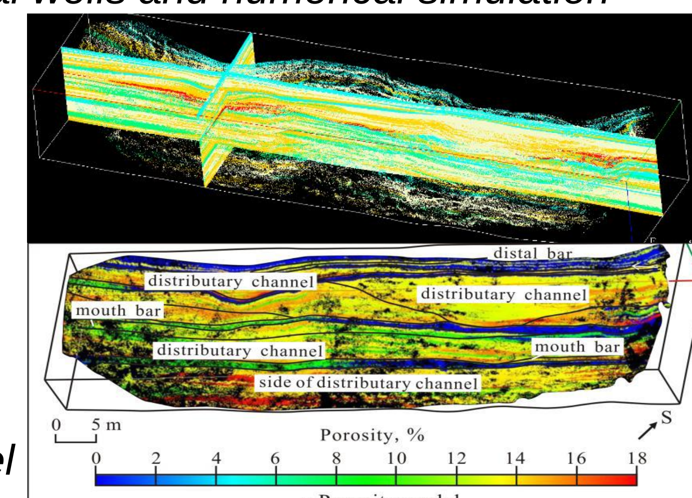
Step 3: actual shape of architecture



Step 4: measured sections

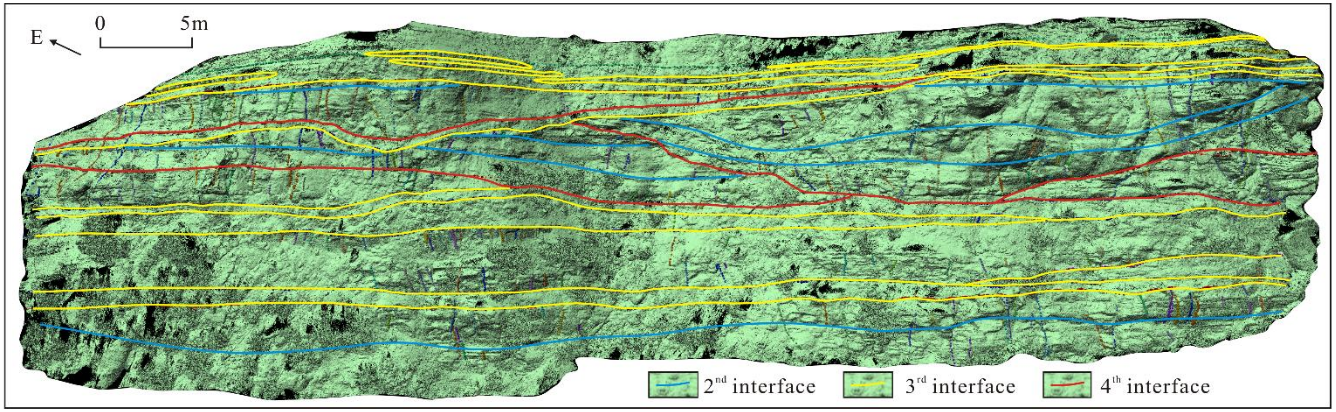


Step 5: virtual wells and numerical simulation

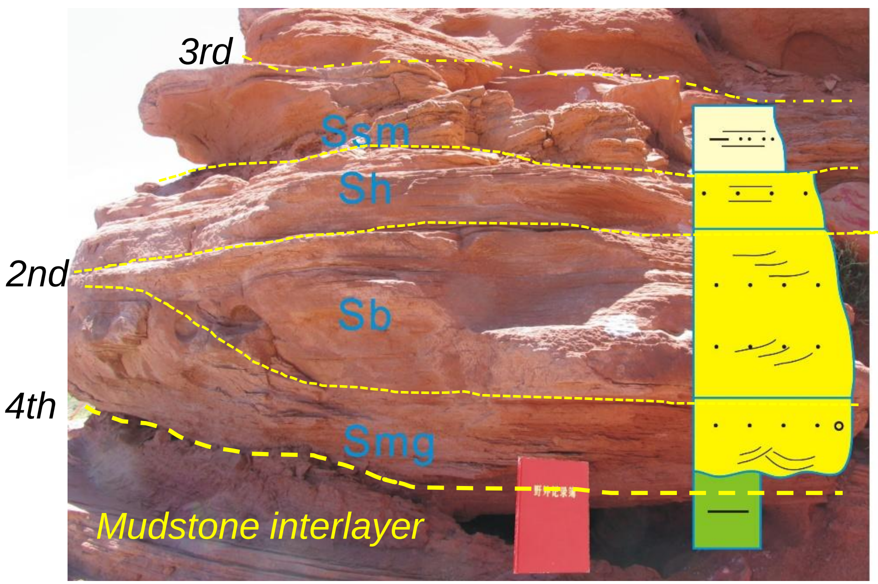


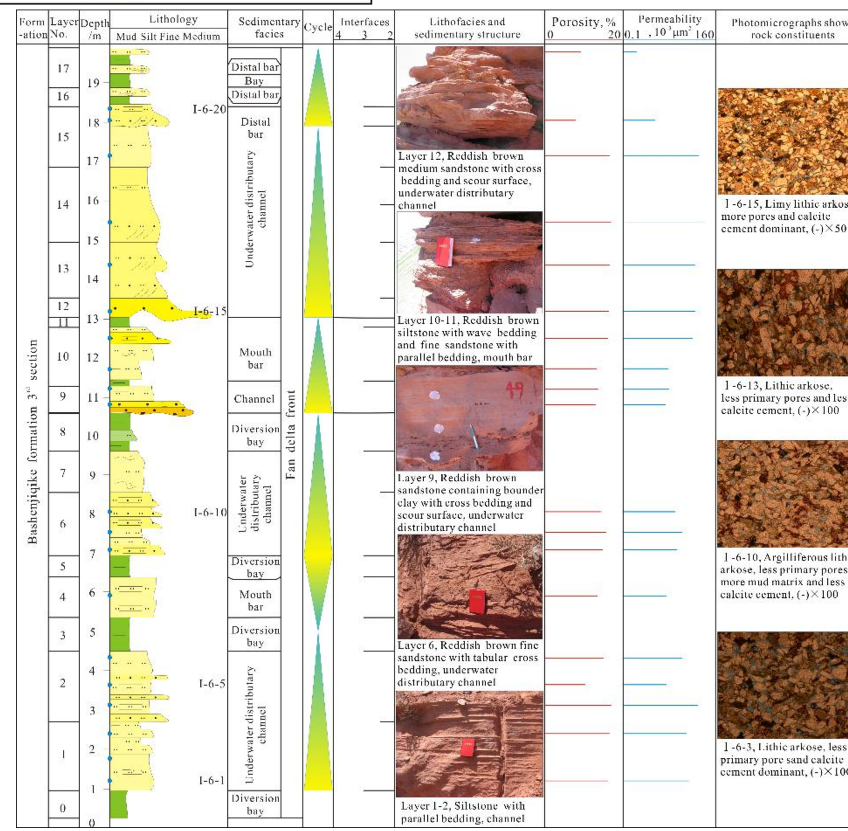
Step 6: digital outcrop model

Layer interface dividing and reservoir structure analysis



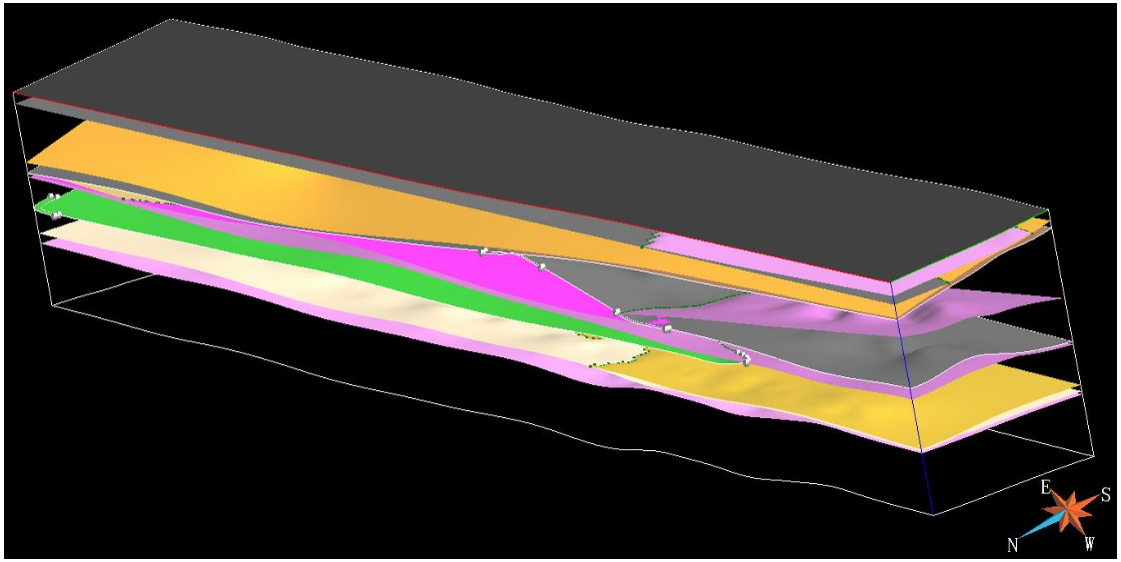
Layer interface tracing in the data volume



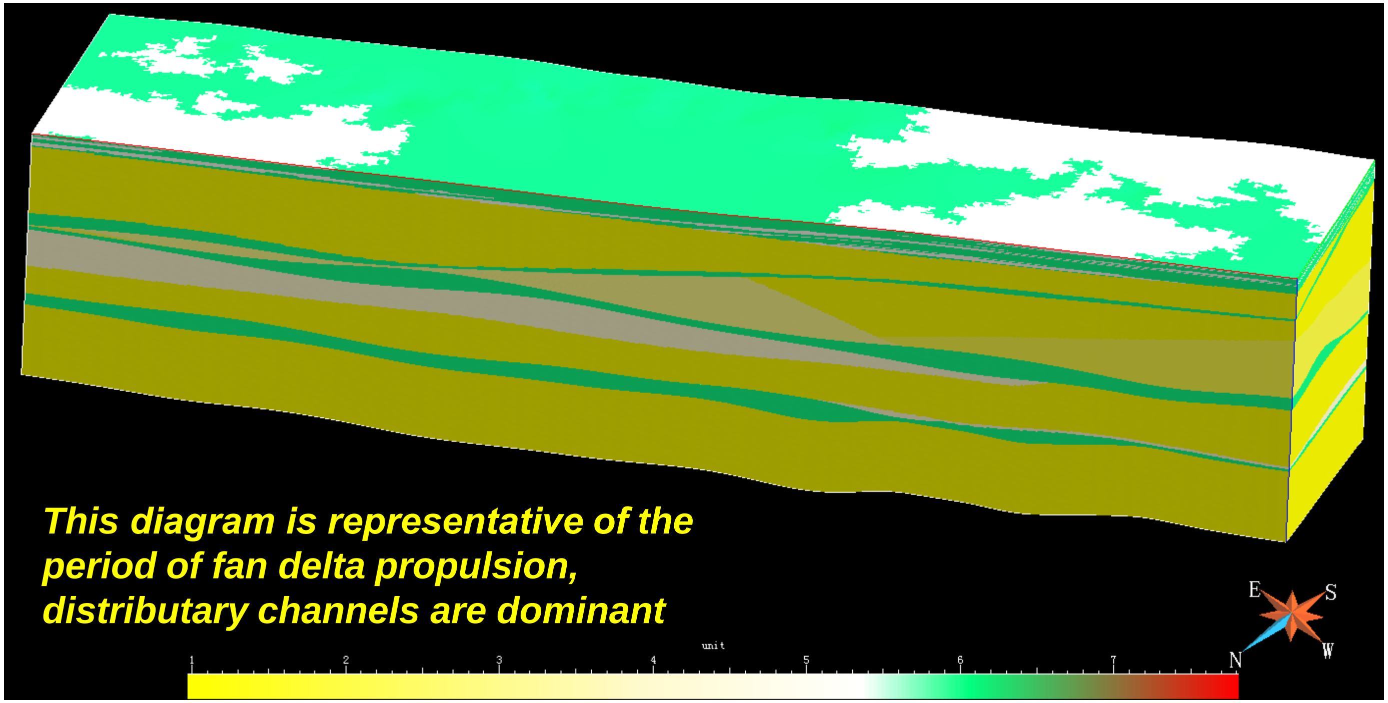


Stratigraphic column of section I-6

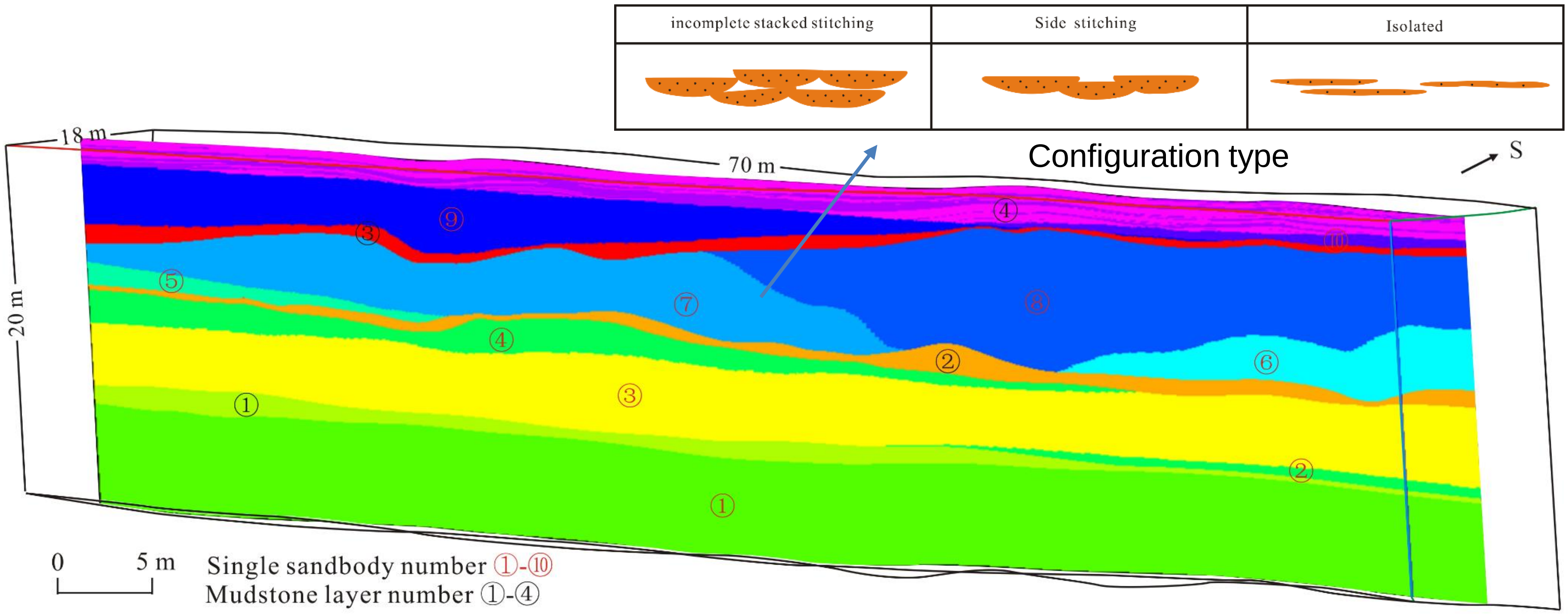
Sand body modeling and sedimentary facies evolution



A three-dimensional model based on digital outcrop interpretation. Strata framework of trend (136°) and dip (35°) in GoCAD software



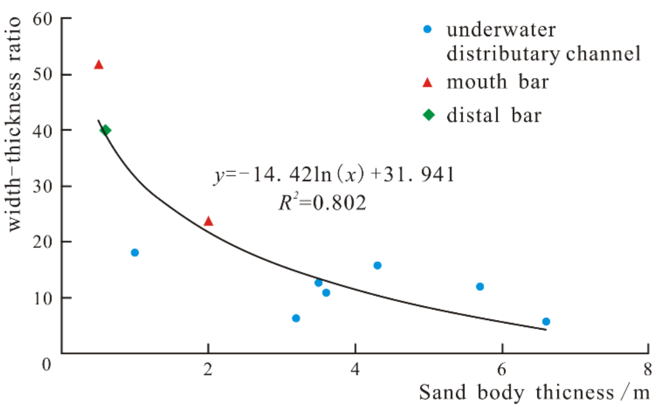
Architecture of single sand body and mudstone



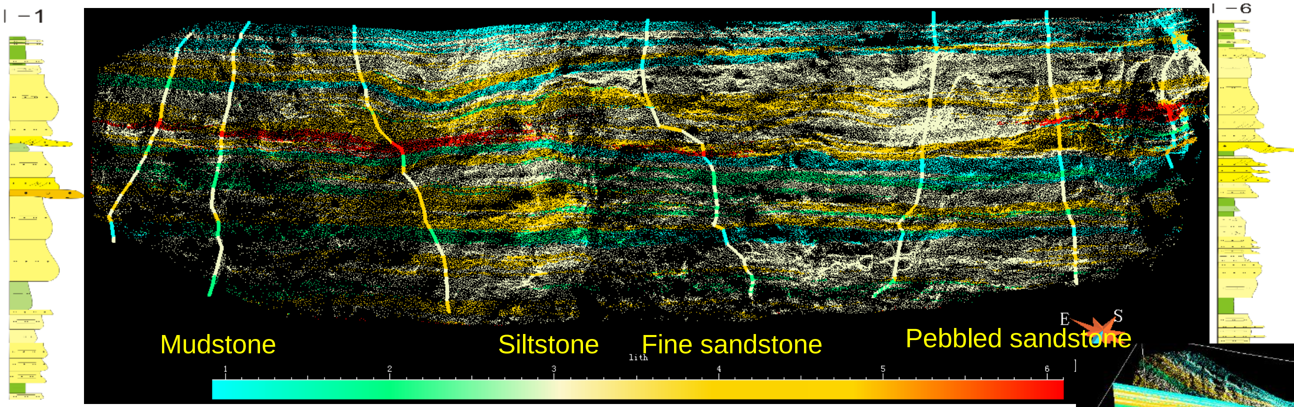
Scale list of single sand bodies

Number	Width (m)	Central thickness (m)	width/thickness ratio	Sand body origin
1	68	5.7	11.9	Edge of distributary channel
2	26	0.5	52	Mouth bar
3	68	4.3	15.8	Edge of distributary channel
4	48	2	24	Mouth bar
5	18	1	18	Distributary channel
6	39	3.6	10.8	Distributary channel
7	20	3.2	6.3	Center of distributary channel
8	37	6.6	5.6	Center of distributary channel
9	44	3.5	12.6	Center of distributary channel
10	24	0.6	40	Distal bar

Correlation diagram of single sand body thickness and width-thickness ratio

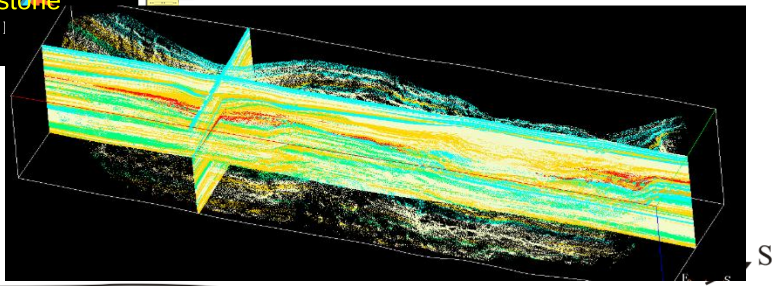


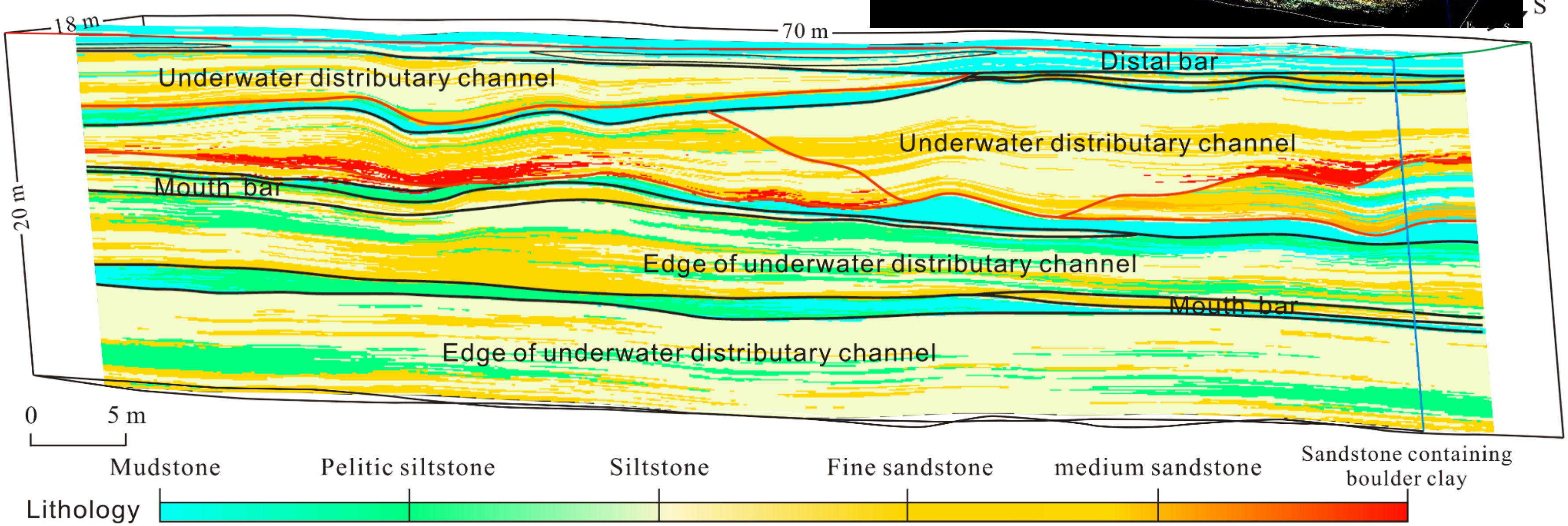
Lithofacies inversion model in the cross section



Virtual well data input and controlling

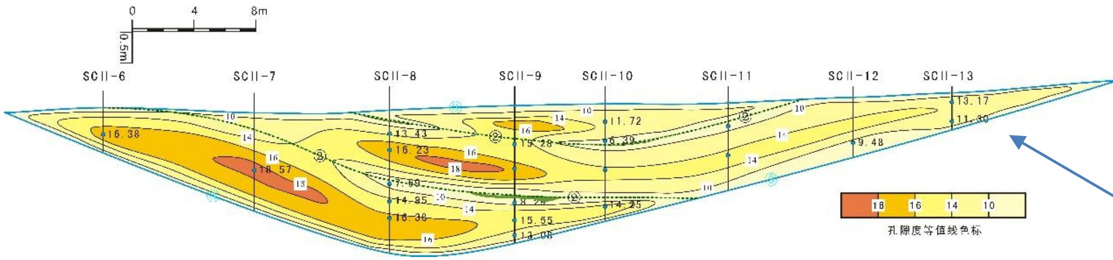
Vertical and cross section of lithofacies version model



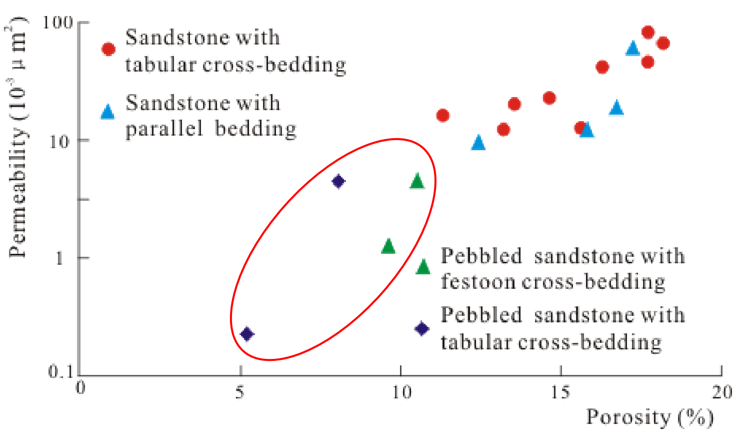


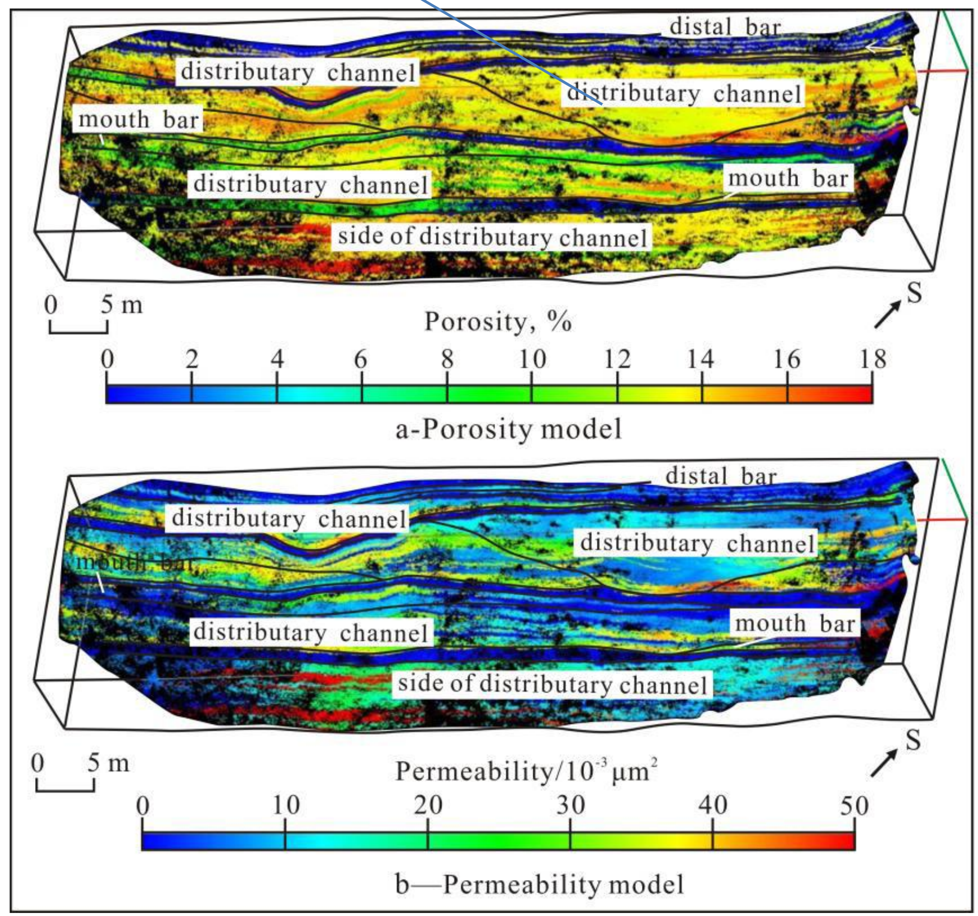
The sand distribution features: large area, with good continuity and more than 80% sand

Inversion models of porosity and permeability



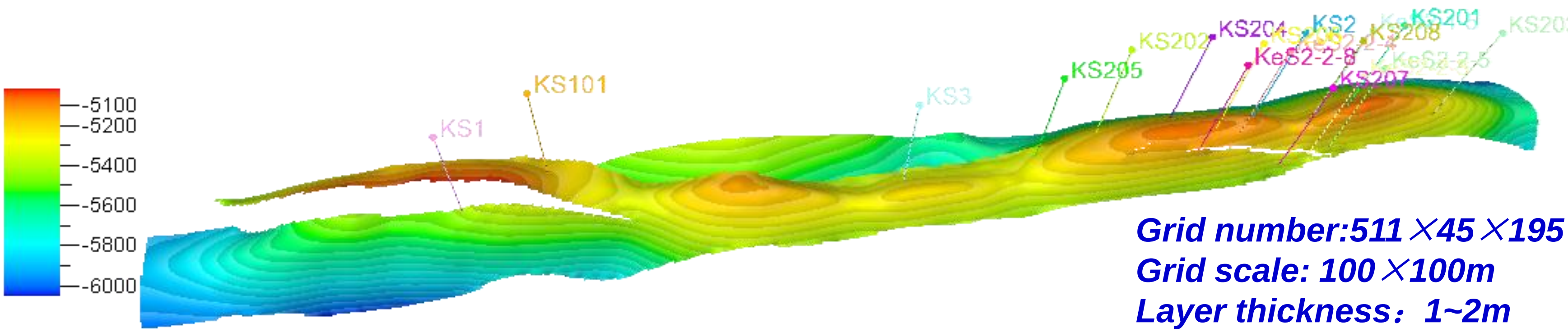
Porosity model of single channel





The sand bodies are locally connected, but not smoothly; some not even connected.

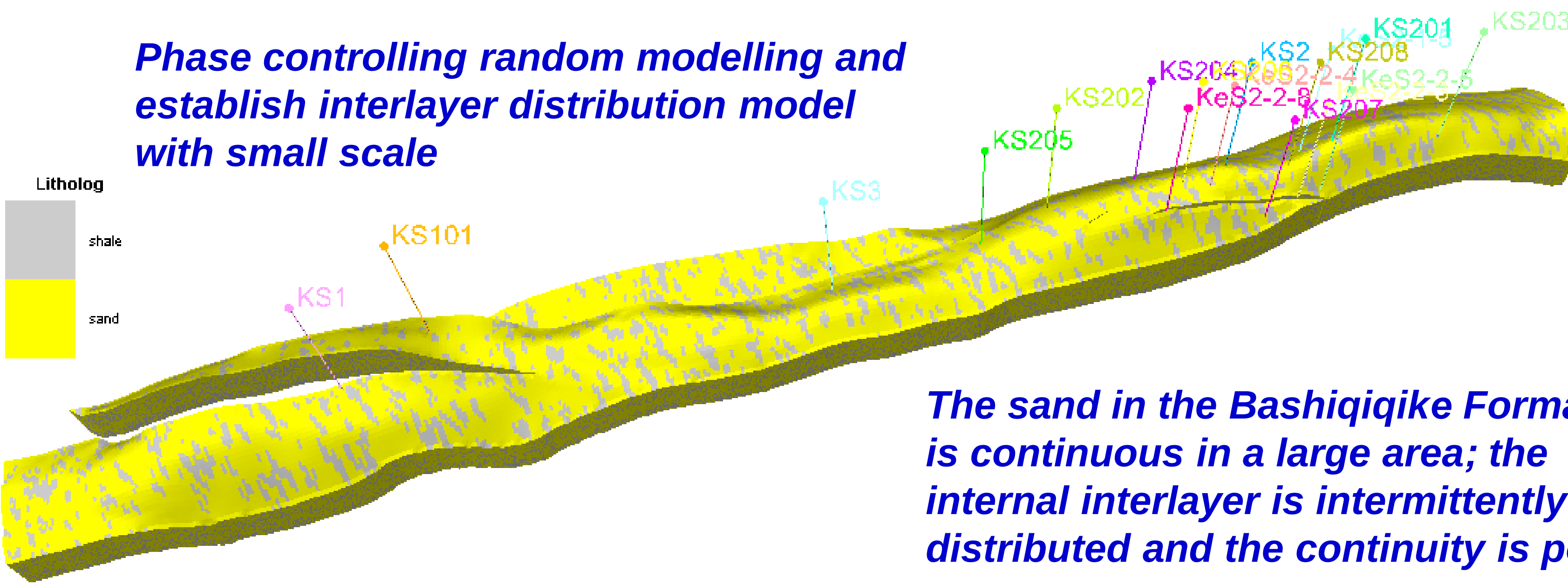
Subsurface geological modeling



Grid number:511×45×195
Grid scale: 100×100m
Layer thickness：1~2m

Structural model of upper surface of Bashenjiqike Formation

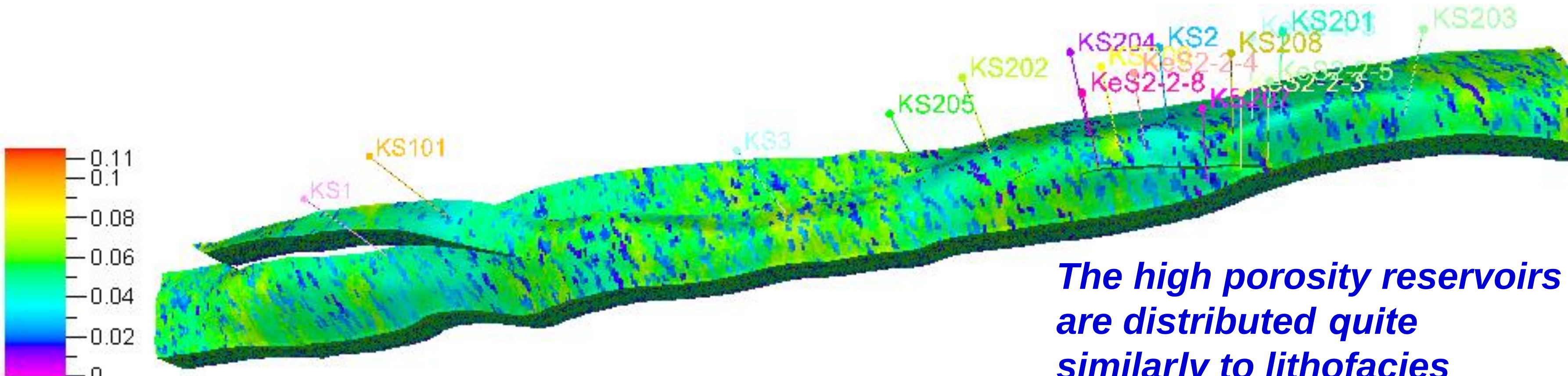
Phase controlling random modelling and establish interlayer distribution model with small scale



The sand in the Bashiqiqike Formation is continuous in a large area; the internal interlayer is intermittently distributed and the continuity is poor.

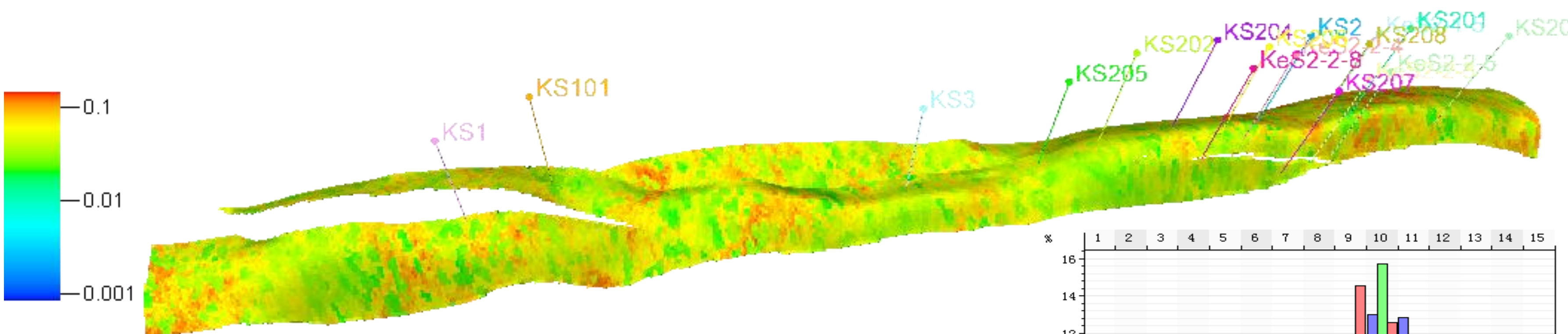
Lithofacies model of Bashenjiqike Formation

Subsurface geological modeling



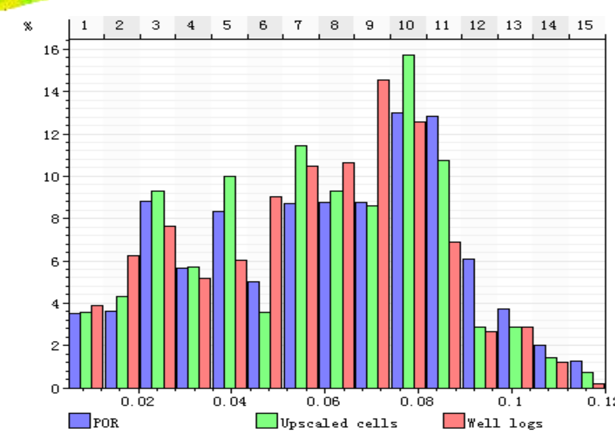
The high porosity reservoirs are distributed quite similarly to lithofacies

Porosity model of Bashenjiqike Formation



Permeability model of Bashenjiqike Formation

The high permeability zones are irregularly distributed, with many low permeability areas between those zones



Geological model verification

Conclusions

- ***The sand body configuration of fan-deltaic reservoirs perform as multiple distributary channels stacked vertically, accompanied by a few mouth and distal bars with three architecture types.***
- ***Despite the sand distribution features being as large area with good continuity, interlayers with different properties formed in the channel bottom and side interface us high clay content sediments.***
- ***The application of Lidar technology has improved reservoir model accuracy greatly and provide a strong basis for subsurface geological modelling and simulation.***

Acknowledgement

- ***This study was funded by the China National Major Projects and the Tarim Oilfield Company, PetroChina.***

- ***We greatly acknowledge Mr. Wang Chunyang and Mr. Yang Dexing from the East Geophysical Exploration Company, CNPC for the assistance of data acquirement and reservoir model foundation. We also thank Mr. Lei Ganglin from Exploration and Development Institute of Tarim Oilfield Company.***


Thank You!