Quantitative Modeling of Depositional Processes and Sedimentary Facies of Shallow Water Deltas*

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Search and Discovery Article #51205 (2015)**
Posted December 14, 2015

*Adapted from oral presentation given at AAPG/SEG International Conference & Exhibition, Melbourne, Australia, September 13-16, 2015
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Abstract

Shallow water delta depositional systems have recently been identified as a major lithological and/or tight reservoir play. Due to its extremely heterogeneous nature, conventional seismic data does not have the resolution to adequately characterize the thin-bedded (from cm to m scales) reservoir sandbodies in such shallow water deltaic systems. We used the forward stratigraphic modeling program, Sedsim, to model fine-scale sedimentary heterogeneities of modern deltas in in the Poyang Lake, southern China and a Triassic deltaic sandstone sequence in the Ordos Basin, western China. A series of shallow-water deltas are developed in the Poyang Lake, providing an excellent modern analogue for understanding key depositional processes that control deltaic development and evolution. We simulated the evolution of the shallow-water deltas over the past 1200 years. The simulation indicates that the delta plain is dominated by distributary channel sandbodies of cm-dm scales and thins towards the lake center, whereas the delta front thickens lake-center-wards, and the frequency of lake level oscillations appears to be a significant controlling factor in determining of the deltaic architecture within the deltaic systems. The Triassic Yanchang Formation in the Ordos Basin is the most important large-scale lithological and tight reservoir sequence in China. We simulated the Chang-6 to Chang-8 members (231.0 Ma and 217.5 Ma) over an area of 295 km x 495 km with a spatial resolution of 5 km and a temporal resolution of 50 ka and two nest models with 1 km spatial resolution. The simulation matches the known depositional thickness and facies derived from logs and cores and sedimentary heterogeneities down to sub-meter scale. The palaeogeography plays an important role in governing the deltaic migration, while the high frequency lake level oscillation and sediment supply control the fine scale facies variations. The delta plain is dominated by distributary channel sand-bodies, while the delta front is characterized by sheet-like sandstone. The sand-rich delta-plain and delta-front have been identified as the best reservoir properties with a porosity range of 7-13% and a corresponding permeability range of 0.3 mD to 1 mD.

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Quantitative Modelling of Depositional Processes and Sedimentary Facies of Shallow Water Deltas

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Presentation outline

- Quantitative forward stratigraphic modelling
- Shallow Water Deltaic Models
- *Sedsim* computer program
- Examples
  - ➢ Morden Shallow Water Deltas of Poyang Lake
  - ➢ The Triassic Yanchang Formation of Ordos Basin
- Conclusions

Forward stratigraphic modelling

- **Why do forward stratigraphic modelling?**

➢ ***The quality of most tight reservoirs depends primarily on the original environmental variations within depositional systems (Bloch and McGowen, 1994)***

- **What can the forward stratigraphic models do?**

➢ ***Reconstruct the original depositional environment based on field data***

➢ ***Predict potential reservoirs away from well data and below seismic resolution***

> ***"All models are wrong,***
> ***but some are useful"***
> ***George E.P. Box (1979)***

Various forward stratigraphic models

3D Forward stratigraphic models can be divided into several main subcategories as follows:

- **Hydraulic process-response models (e.g. Sedsim, Simsafadim- clastic)**
- **Diffusion models (e.g. Dyonisos, Dibafill)**

Shallow water deltaic models

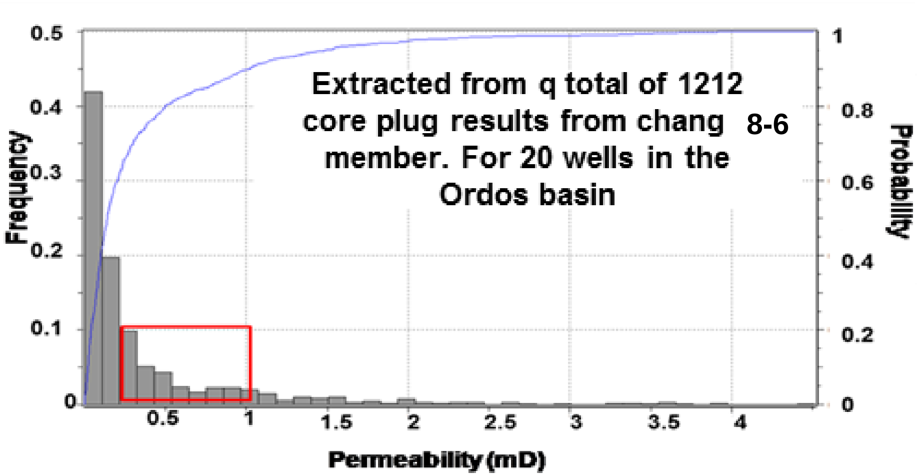
Key issues:

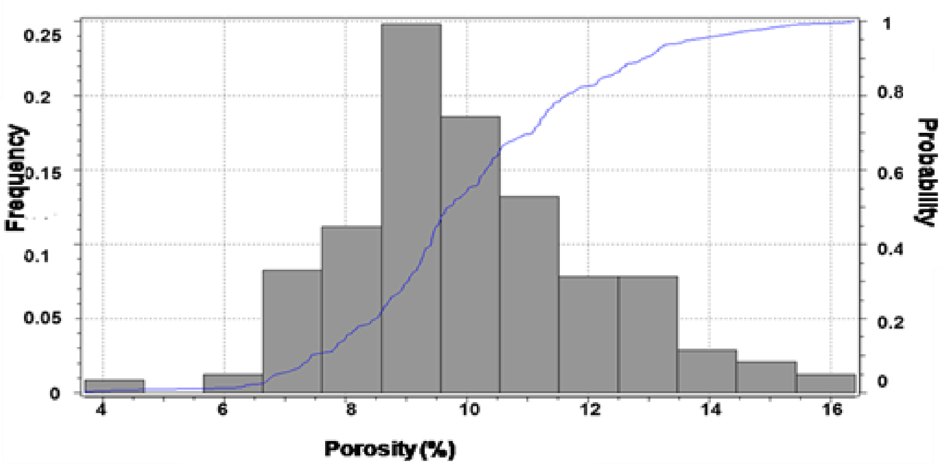
- Thin sandy layers of sub-metre scale cannot be distinguished on seismic data
- Sedimentary micro-facies cannot be effectively recognised and interpreted due to rapid changes and the complex distribution of sandbodies
- Direct physical correlation of effective sandbodies is quite difficult due to scattered subsurface well data and isolated outcrops

Shallow water deltaic models

Aims:

- ➢Provide a reference model by simulating the development and evolution of modern shallow-water deltas in the Poyang Lake
- ➢Predict the effective tight reservoir plays in the Triassic Fm, Ordos Basin

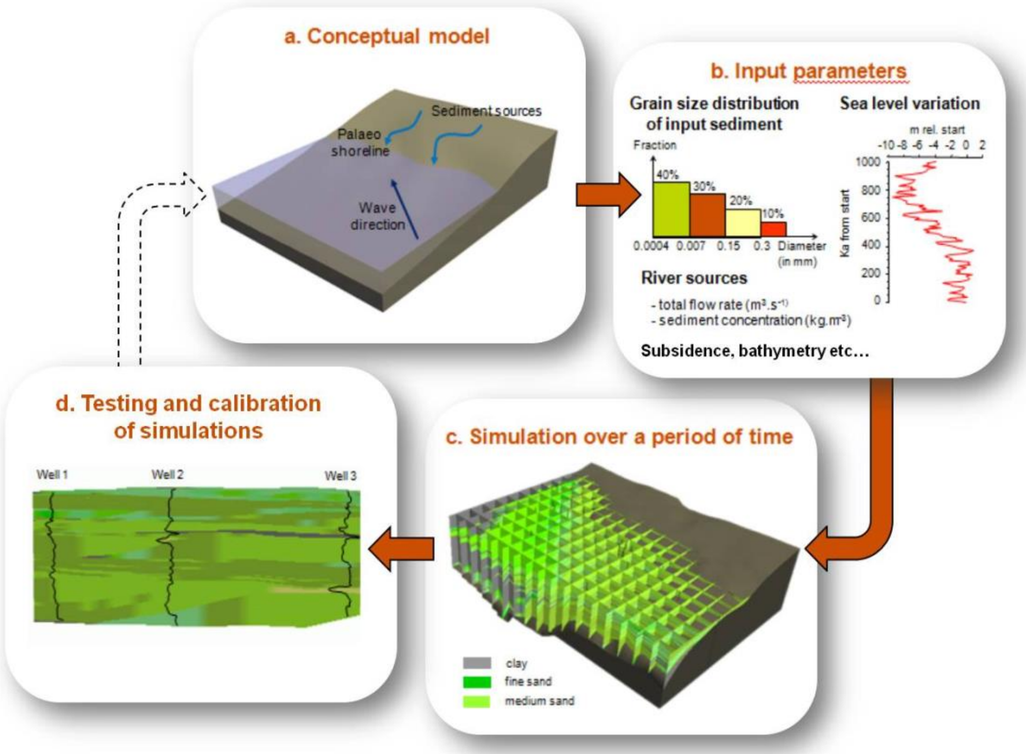




➢The effective target reservoirs of the Triassic Chang-8 and Chang-6 members are defined as sand bodies with the Φ of 7%-13% and K of 0.3mD to 1mD(Yao et al., 2013)

Sedsim computer program

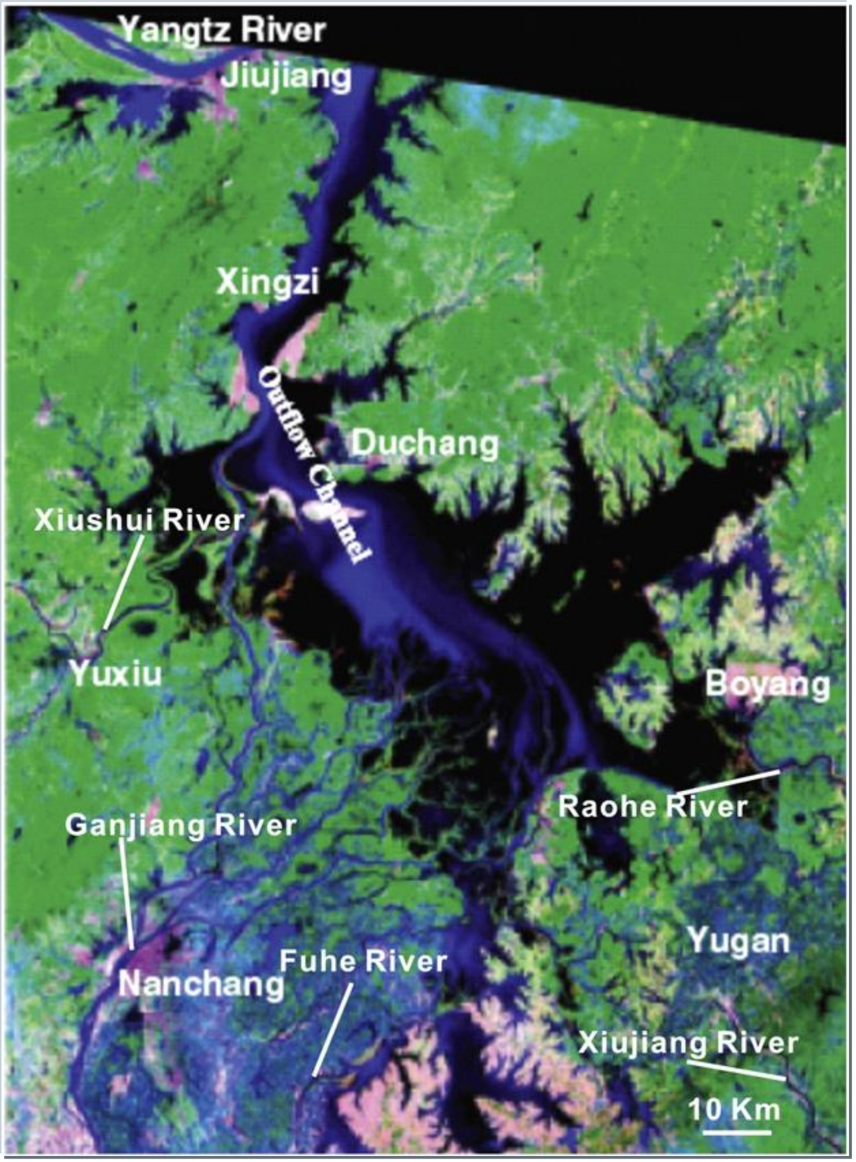
➢By invoking the Naviere-Stokes equations and the continuity equation (Tetzlaff and Harbaugh, 1989) , Sedsim is capable of directly simulating the depositional processes and their products during a basin evolution with limited information (Griffiths et al., 2001).



Stratigraphic Forward Modelling workflow

The simulation workflow is repeated while modifying the conceptual model and input parameters until an appropriate convergence with available data is achieved.

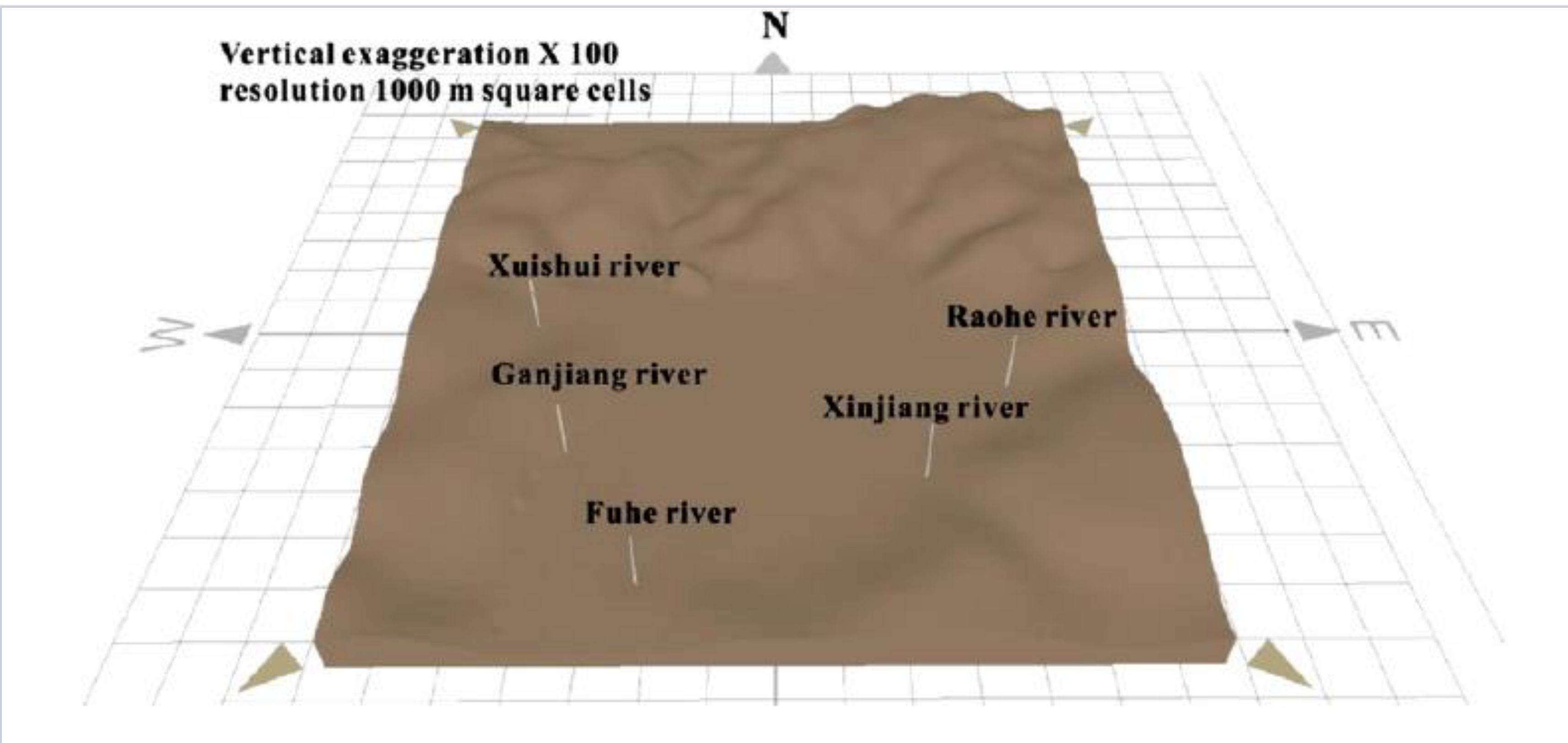
Simulating modern shallow-water deltas



- The Poyang Lake is situated in the northern part of the Jiangxi Province, China, and is in a structural depression south of the Yangtze River
- The basin has a flat morphology with a gentle slope (~0.1°)
- The average water depth of the lake basin is about 8.4 m (Zou et al., 2010)
- Five major rivers flowing in the relatively flat regions surrounding the Poyang Lake form a series of delta systems in the basin

Simulating modern shallow-water deltas

- No major tectonic movement over the deltaic development period in the past 1200 years apart from a very slow subsidence
- The study area is approximately 182 km long and 164 km wide, which is represented by 182×164 grids with a cell spatial resolution of 1 km

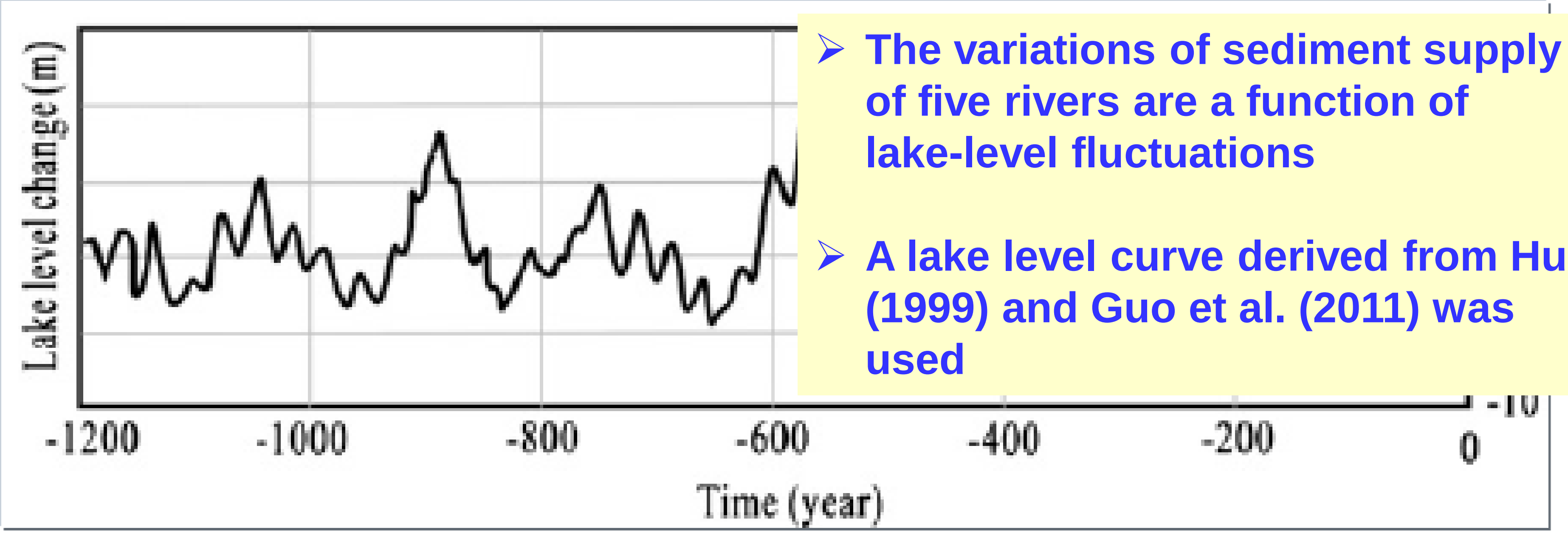


Simulation – Input parameters

Input parameters used in the SEDSIM simulation.

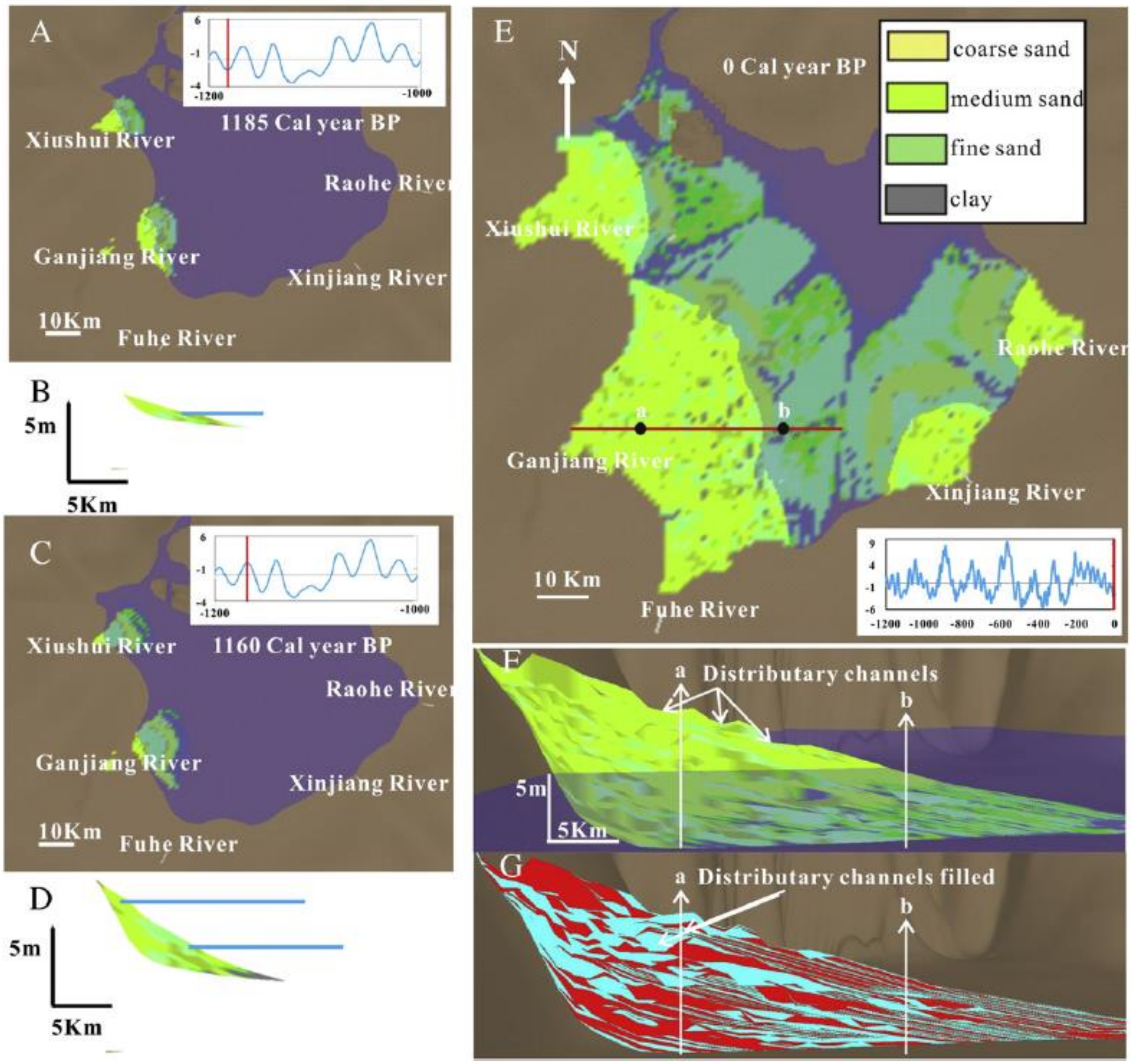
Major river sources	Deposition duration time (year)	Velocity (vx, vy) (m s^{-1})	Discharge rate (m^3/s)	Con.[a] (kg/m^3)	Sediment[b] Composition in % (c, m, f, vf)
Ganjiang	1200	(0.5, 0.05)	5140	0.21	(0, 40, 40, 20)
Xiushui	1200	(0.03, 0.1)	961	0.19	(0, 40, 45, 15)
Fuhe	800	(0.01, 0.14)	1047	0.12	(0, 40, 45, 15)
Xinjiang	800	(−0.2, 0.1)	1361	0.14	(0, 40, 45, 15)
Raohe	800	(−0.03, 0)	964	0.1	(0, 40, 45, 15)

[a] Concentration.
[b] c: coarse, m: medium, f: fine, vf: very fine.



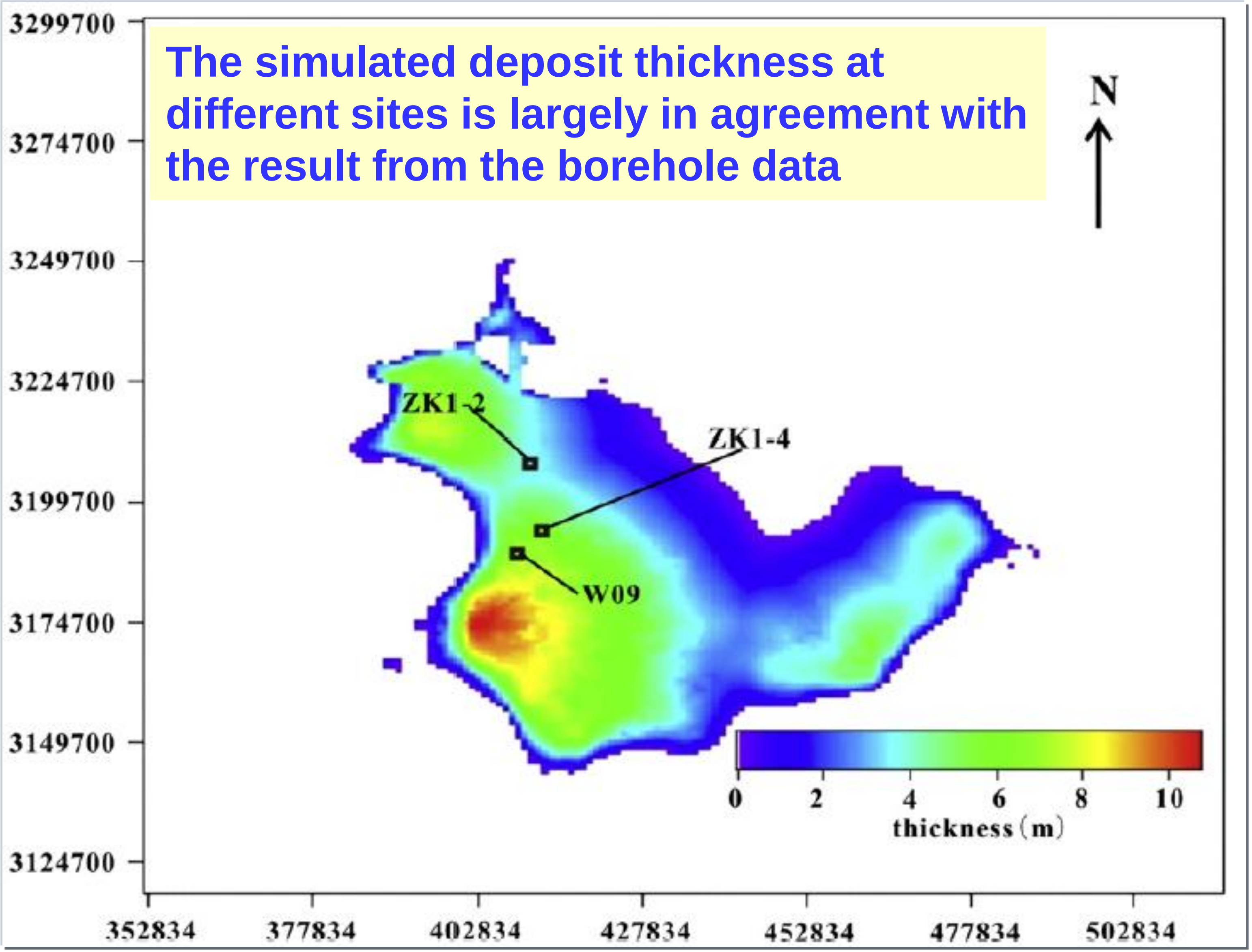
- The variations of sediment supply of five rivers are a function of lake-level fluctuations
- A lake level curve derived from Hu (1999) and Guo et al. (2011) was used

Simulation – Depositional history



- In the proximal area of the deltas the zones of vertical strata are mainly characterized by distributary channel sandbodies because the channels bifurcate and become shallower,
- In the distal area it is characterised by thin layers of fine-grained sediments on the extremely low slope(~0.03°) as the delta migrating into deeper water

Simulation validation – Thickness



Simulating tight reservoirs in Ordos Basin

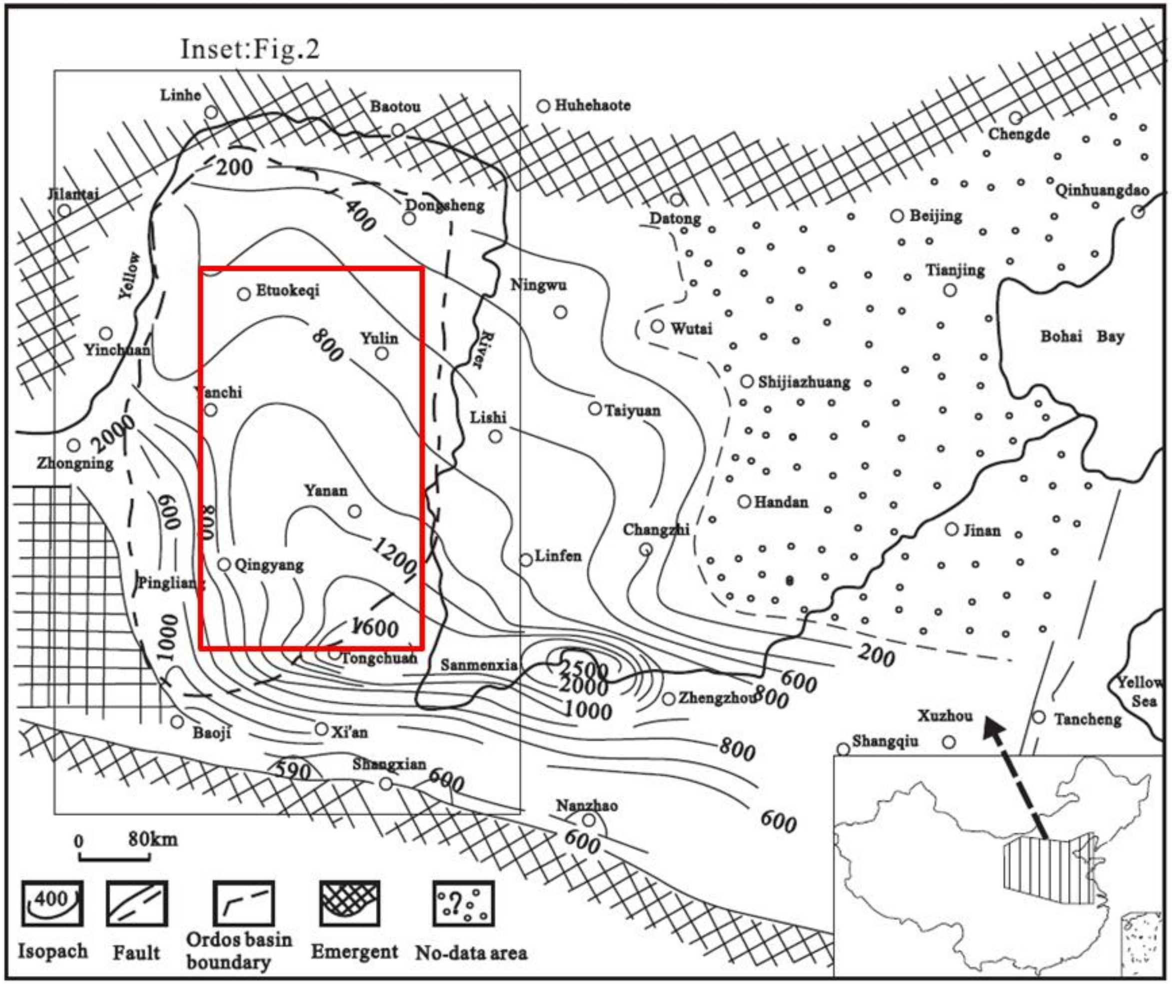


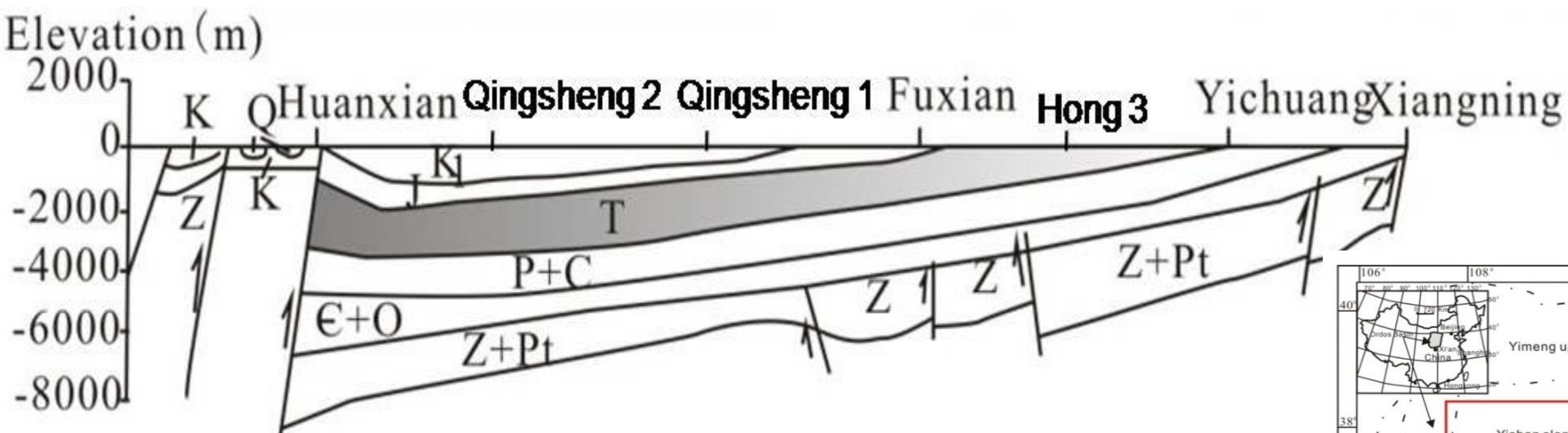
Fig. 1. Isopach map (metres) of the Late Triassic Basin of north China (modified from Zhu & Xu, 1990).

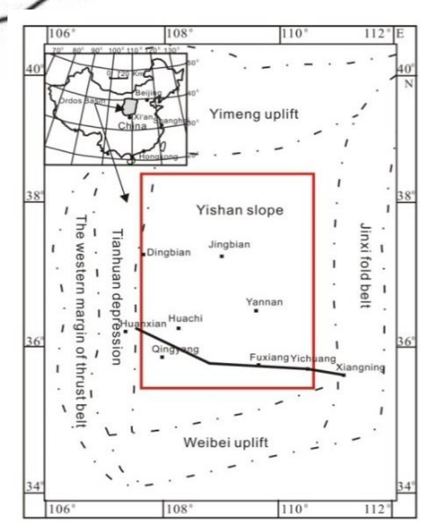
Taken from Zou et al. (2010)

- Ordos Basin is locate in central China, was a large intracratonic lacustribe basin with an opening to the SE during the Late Triassic
- The basin was bounded by the Yin mountains to the N, the Alashan to the NW, the Longxi Uplift to the SW and the Qinling mountains to the S

Simulation- Geological setting

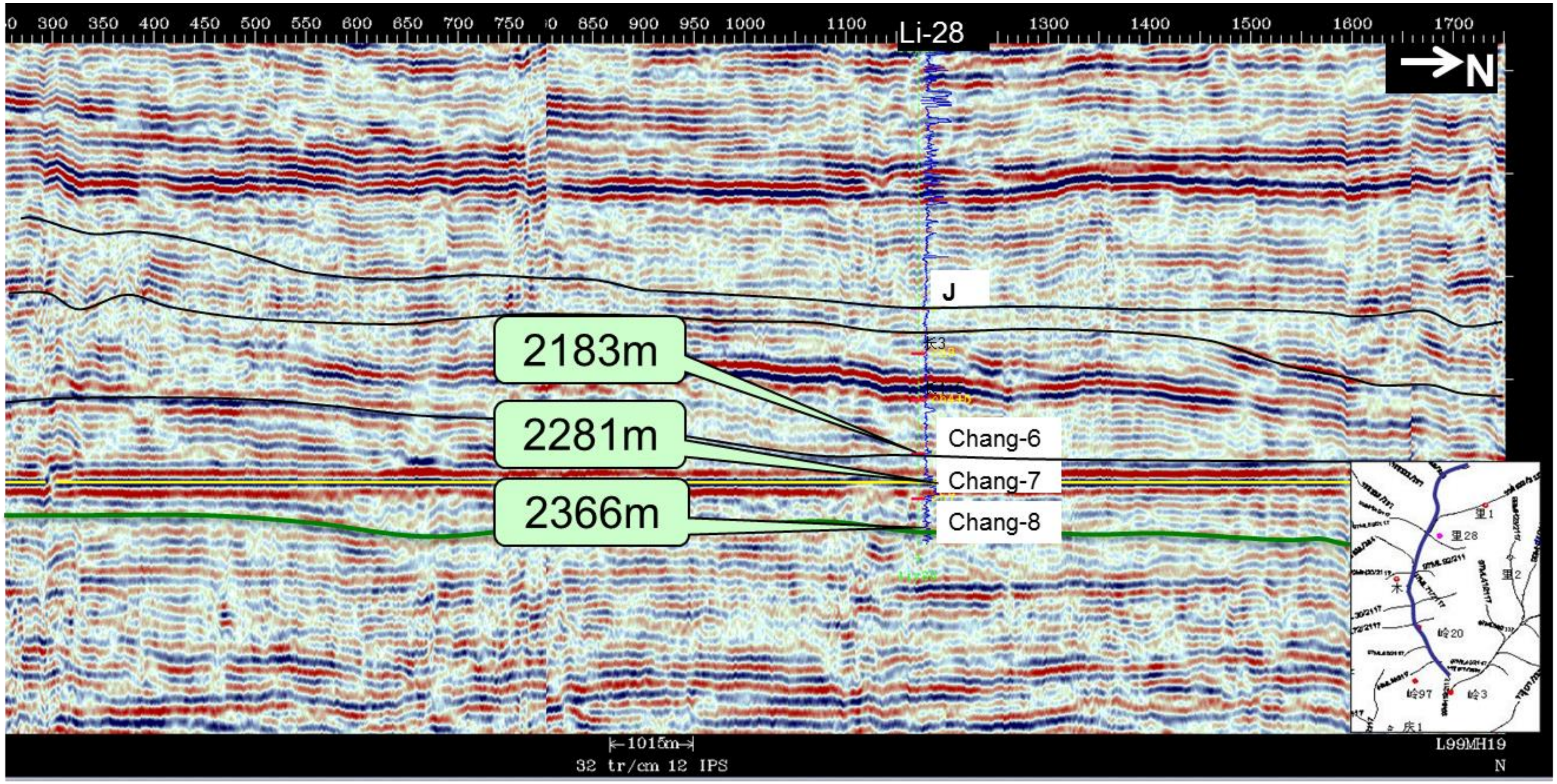
➢**During the Triassic, the interiors of the Ordos Basin continent was not affected by the regional plate tectonics, was dominated by deposition with slow rates of 25-35.7 m/Ma (Li et al., 2007; Zhao et al., 2012).**



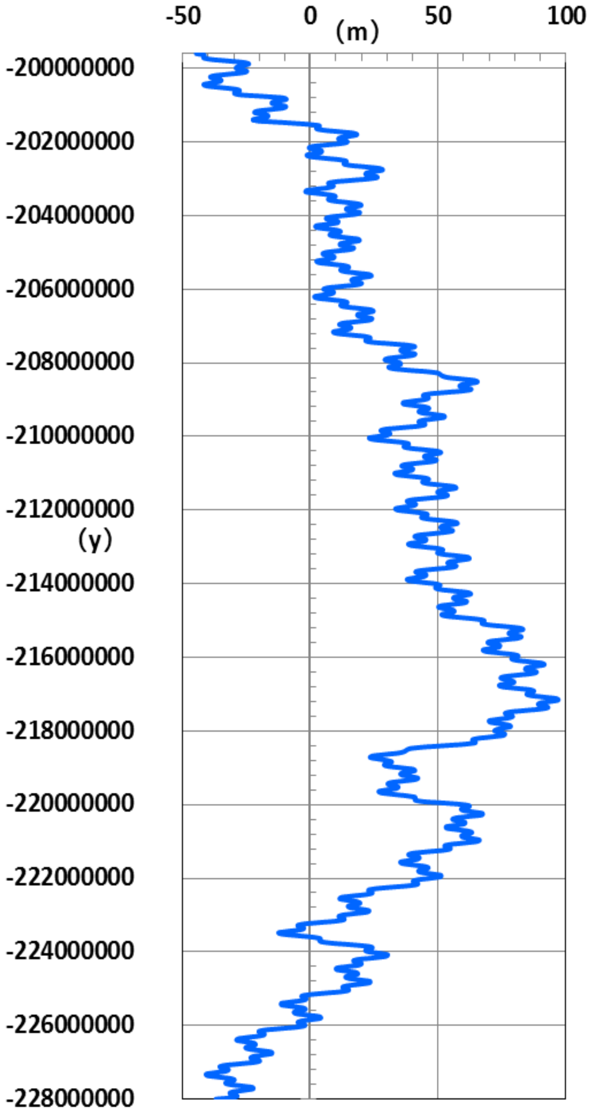


Simulation- Geological setting - seismic

- The initial basin morphological gradient is quite gentle, about 0.1° or 2 m/km during the Late Triassic (Liu et al., 2011).



Simulation parameter- lake level change

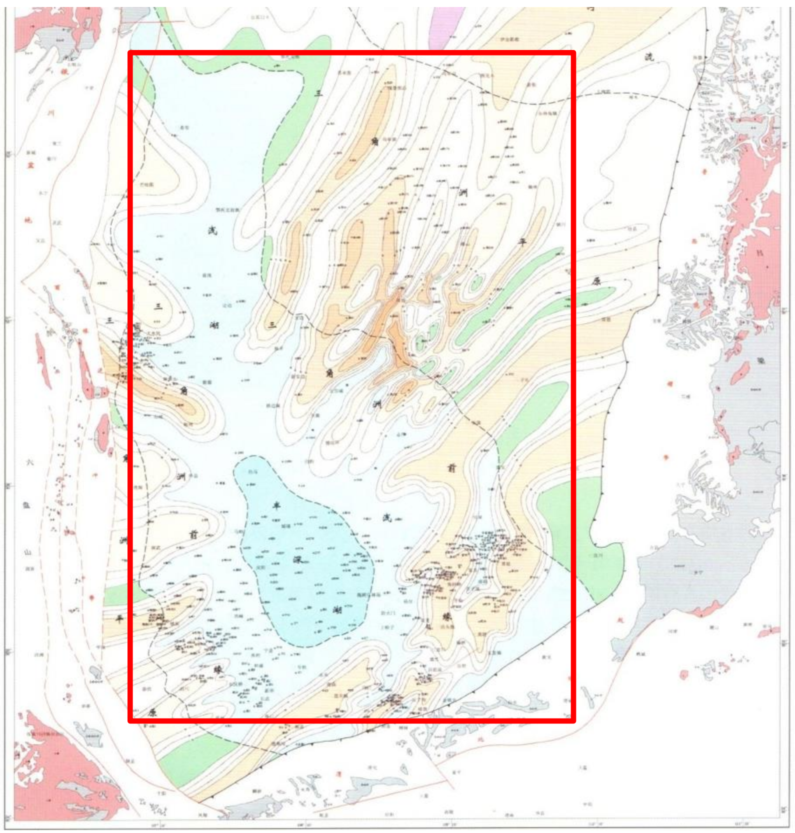


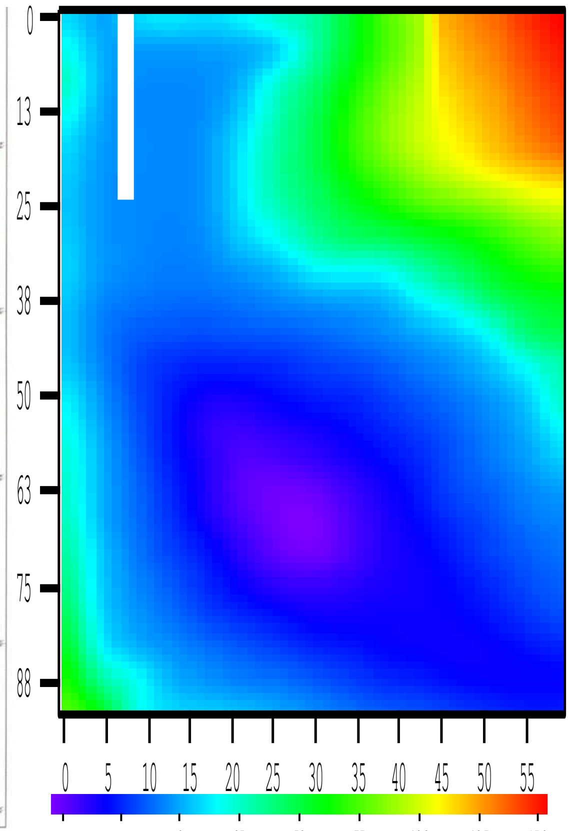
Modified after Zou et al. (2010)

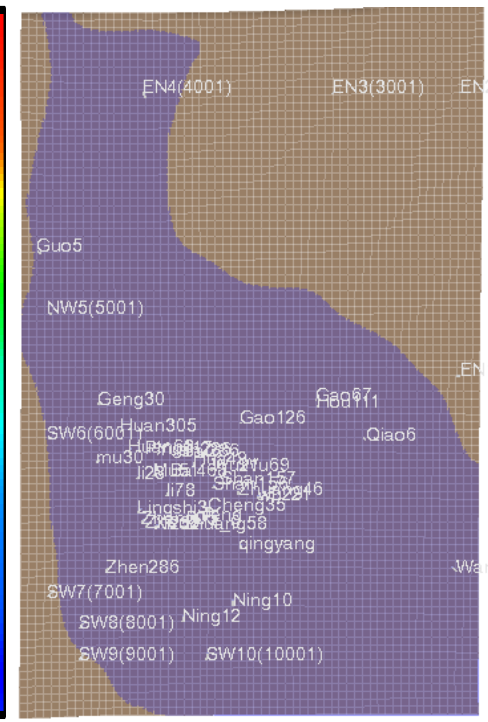
- **Lake level from Zou et al. (2010) was modulated with high-resolution Milankovich frequencies and resampled at 40 ka time step**
- **Simulation duration: 231 Ma to 228.2 Ma (Yang et al., 2013)**

Simulation parameter - topography

The inferred palaeo-bathymetry of the Chang-9 member was used to reconstruct a gently sloping from the north to the south, with the depression center of the basin in the southeast



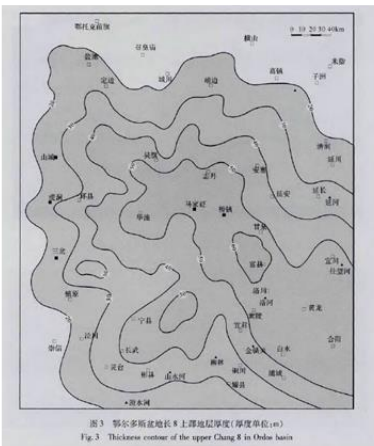




The interpreted facies of the Chang 9 member (Yang, et al., 2013)

Simulation parameter - Subsidence

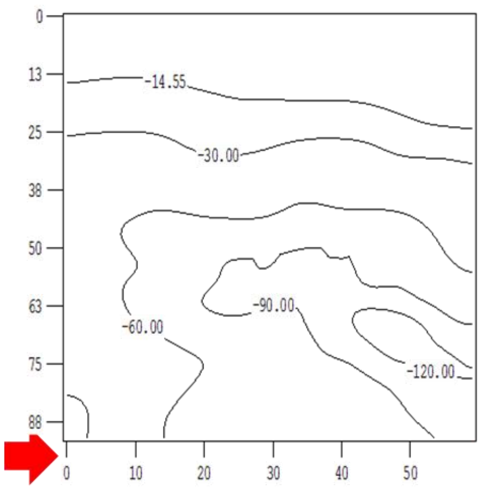
The initial subsidence rates of *ca* 25-35.7 m/Ma was used as the interiors of the continent was unaffected by the regional plate tectonics during the Triassic (Li et al., 2007; Zhao et al., 2012).

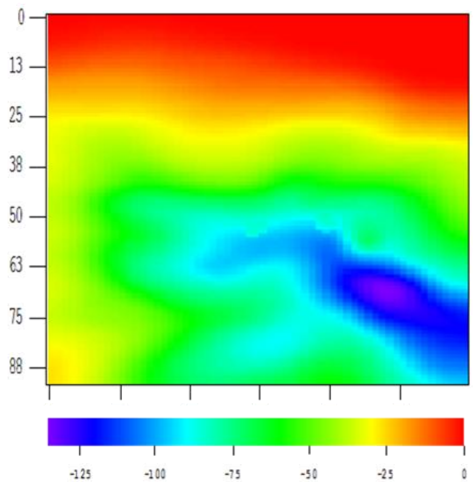


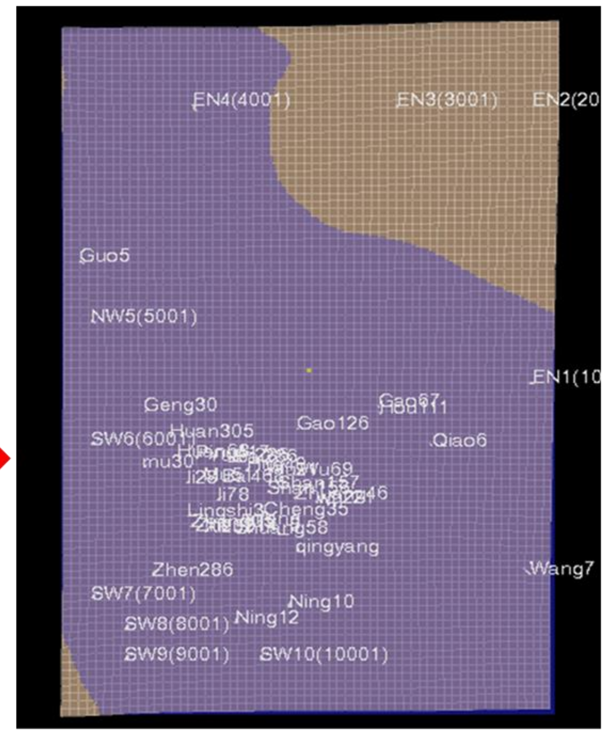
（Liu et al，2011）

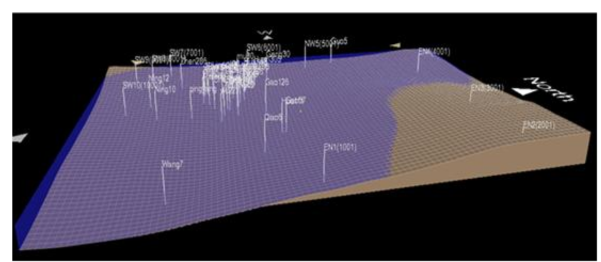
井名	长8厚度（m）	井名	长8厚度（m）
里10	101	木51	92
环305	86	镇505	106
里28	85	木55	90
里46	84	午69	81
山157	88	午93	85
里78	83	午21	92
元286	85	城35	76
西232	81	庄46	81
里91	87	华49	35
木30	82	耿30	82
里99	86	郭5	86
岭试3	90	宁12	82.6
里148	81	宁10	85.2
里162	42	桥6	79.5
白472	86	旺7	73.6
里93	88	高67	86
里199	85	侯111	82

测井共79口



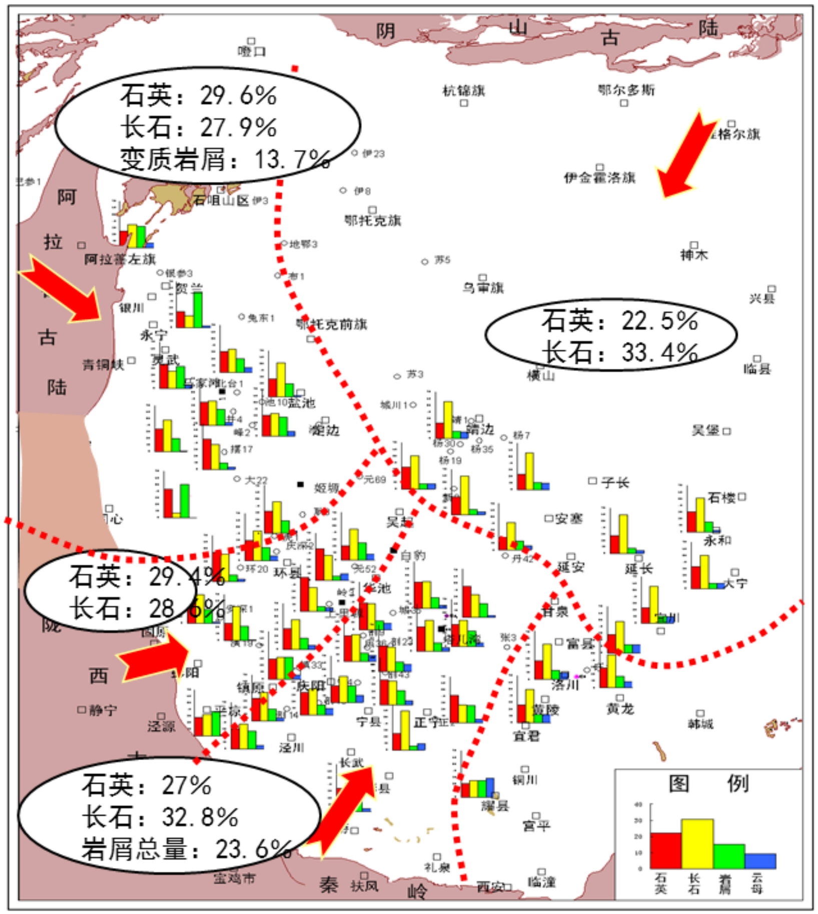




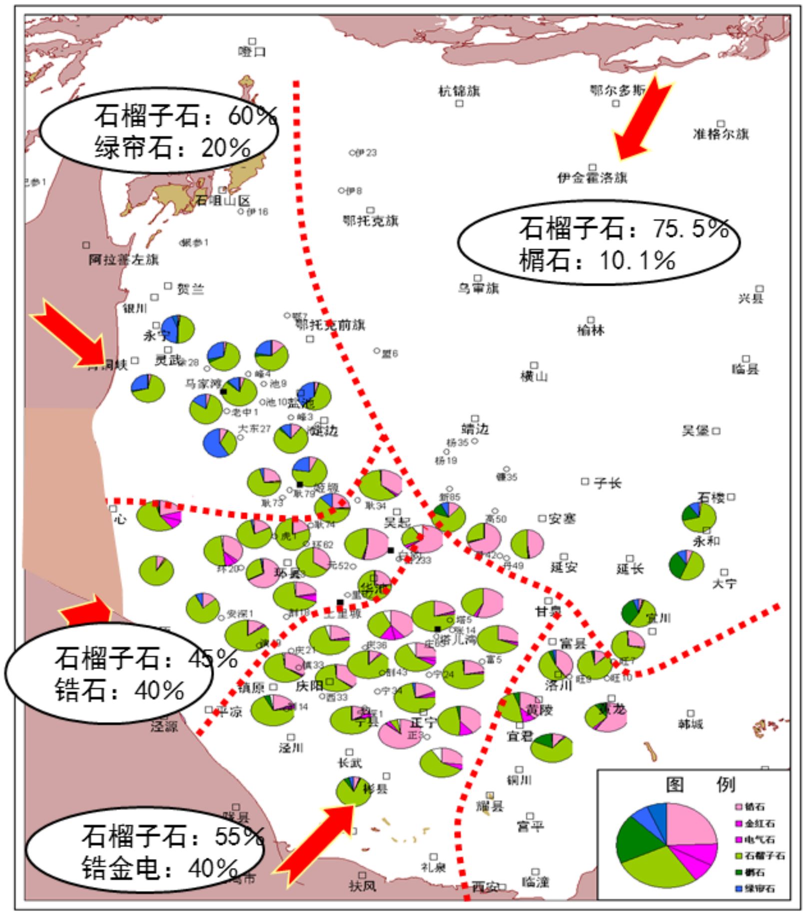


Simulation parameter – Sediment supply

Sediments settled in the basin were sourced from northeast, northwest, west and southwest.



The distribution of clastic component in chang-8 , Ordos basin

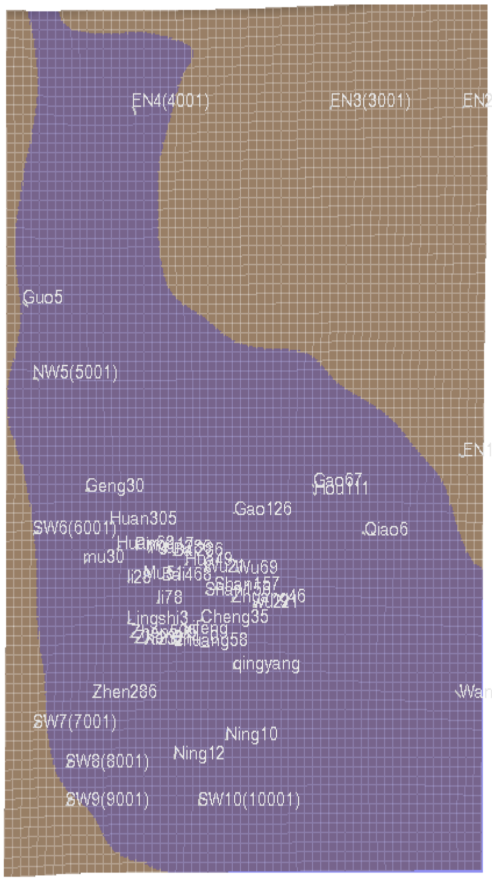


The distribution of heavy mineral in chang-8 , Ordos basin

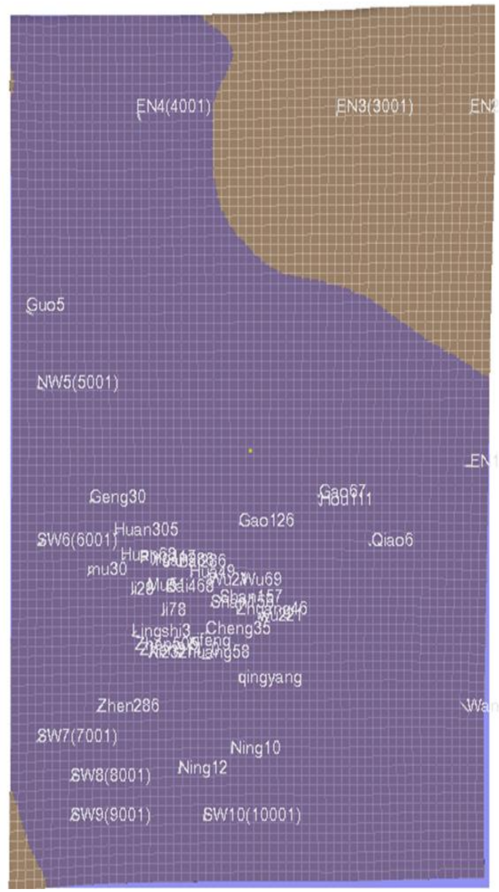
Taken from unpublished Changqing Oilfield data base, 2013

Simulation parameter – Input parameters

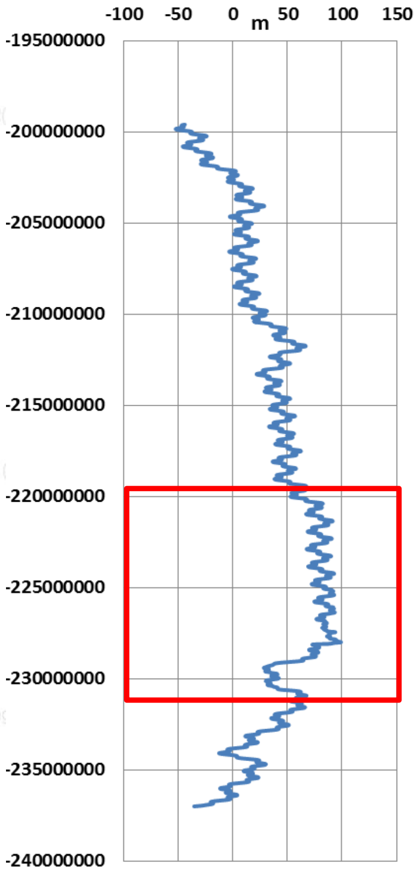
Topography



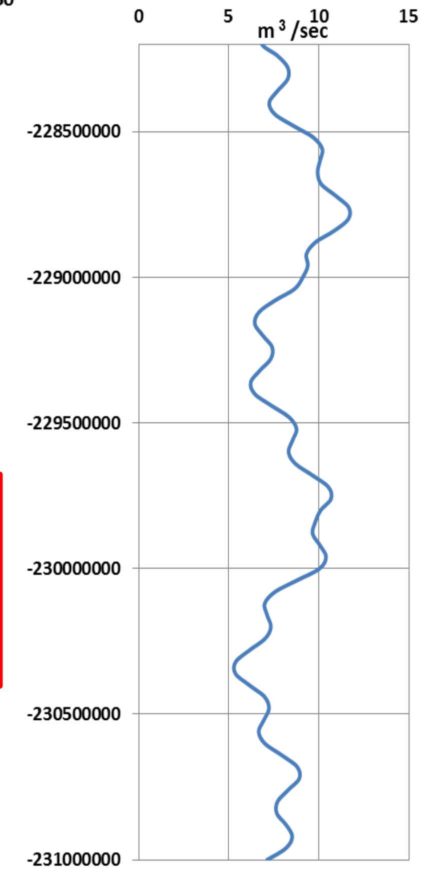
Subsidence



Lake level



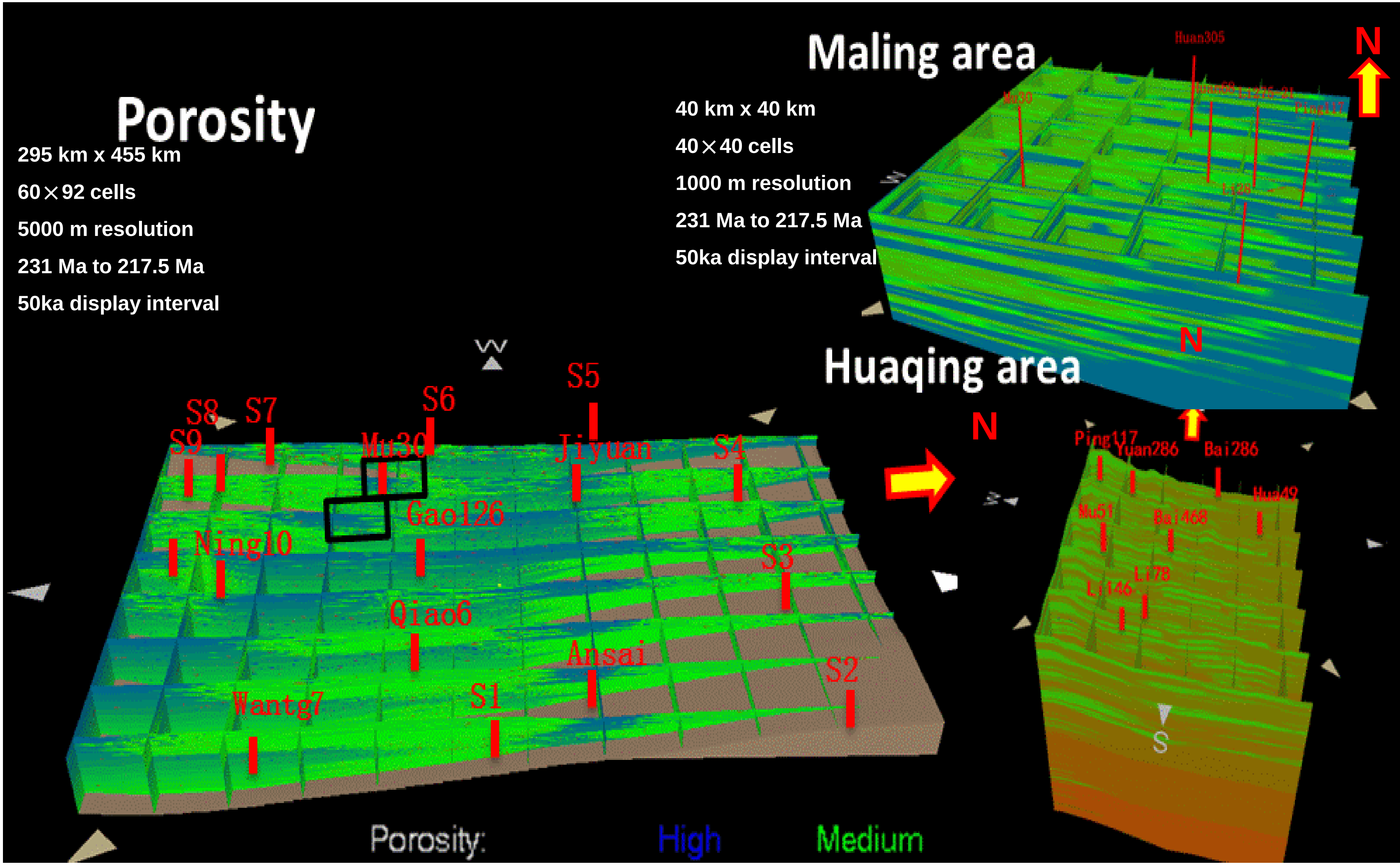
Sediment supply



295 km x 455 km, 60×92 cells, 5000 m resolution,

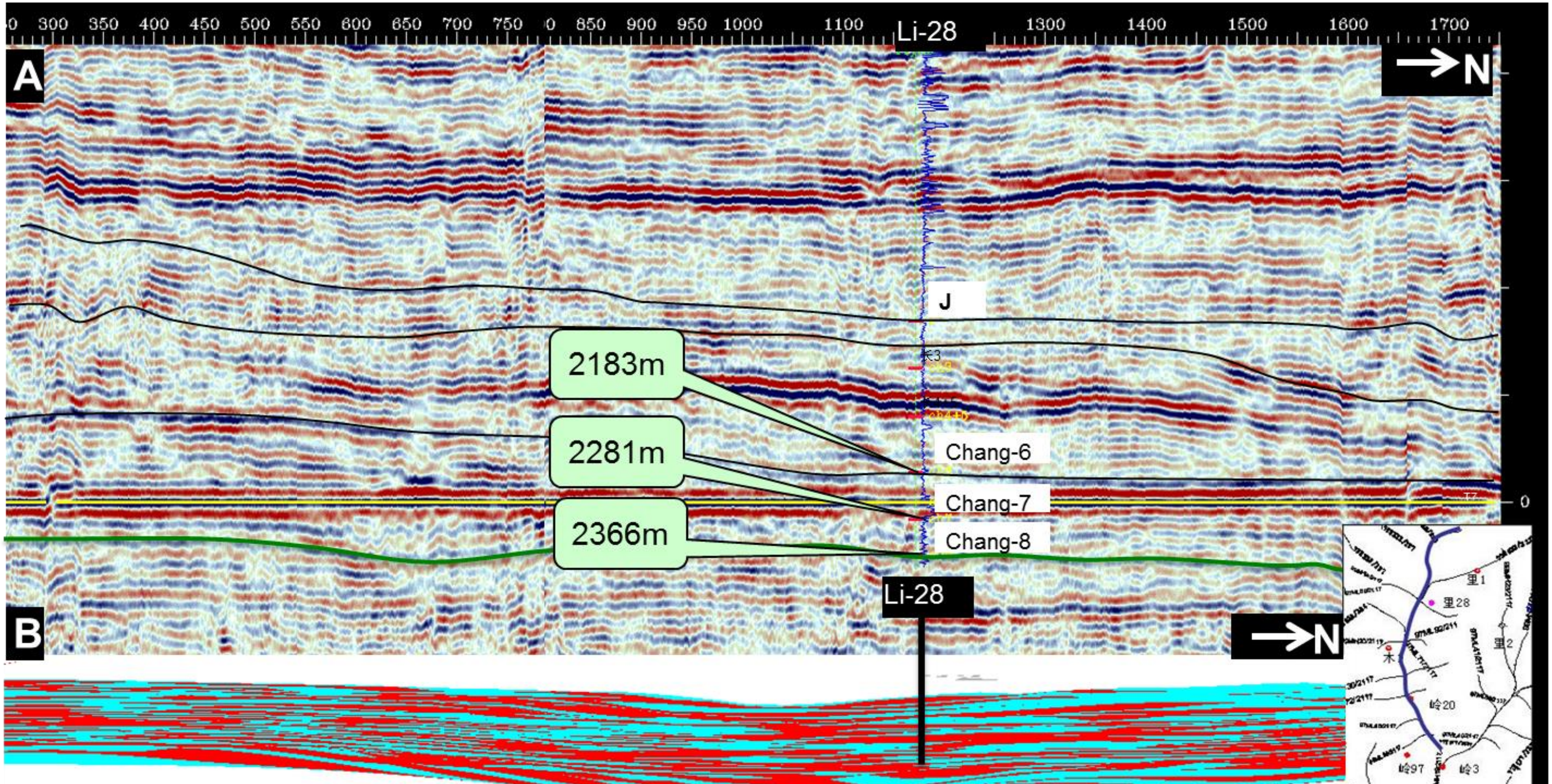
231 Ma to 217.5 Ma, 50ka display interval

Simulation results – Depositional history



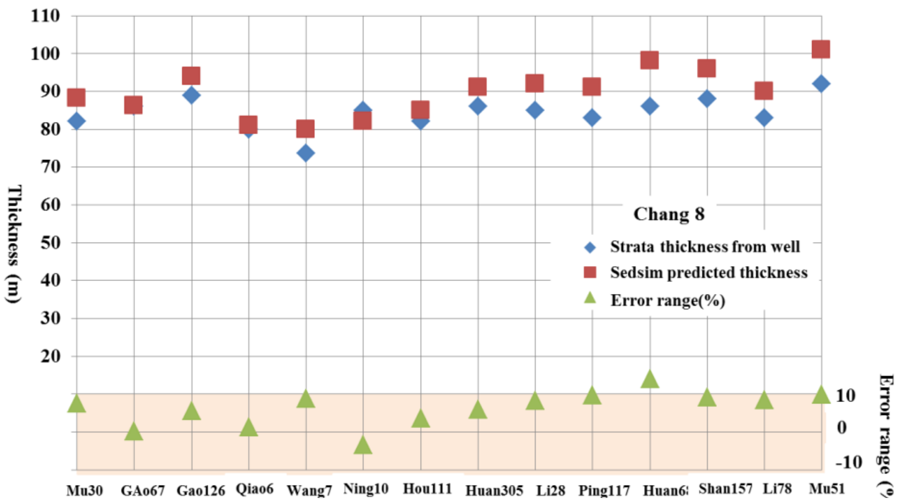
Simulation validation – Seismic data

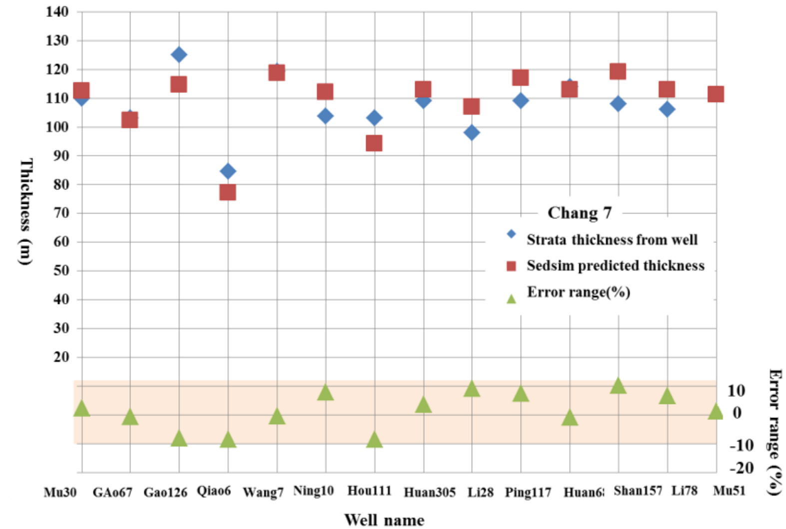
- ➢Strata thickness is gradually thicker from the south to the north, in agreement with the result from the seismic data
- ➢ Resolution of the Sedsim model is 10 times better than the seismic

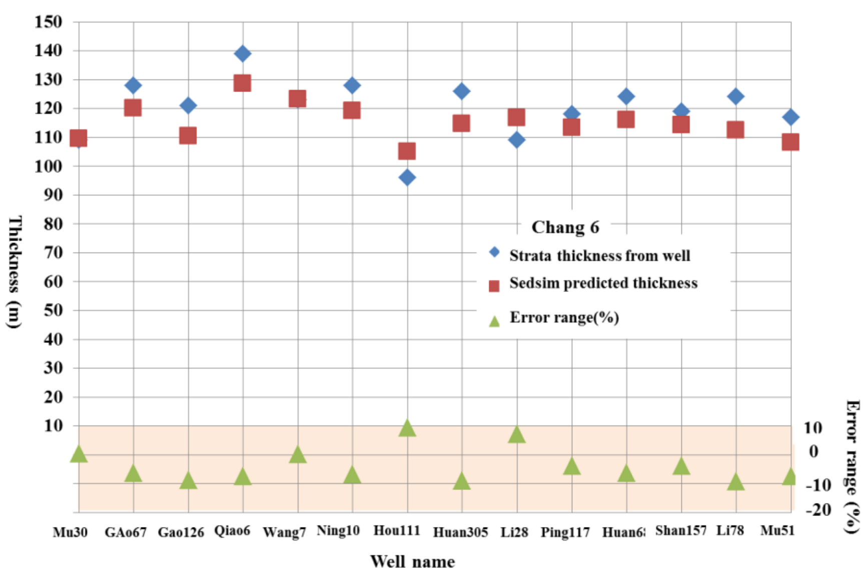


Vertical exaggeration of (B) is 2 times vertical thickness of (A)

Simulation validation – Thickness



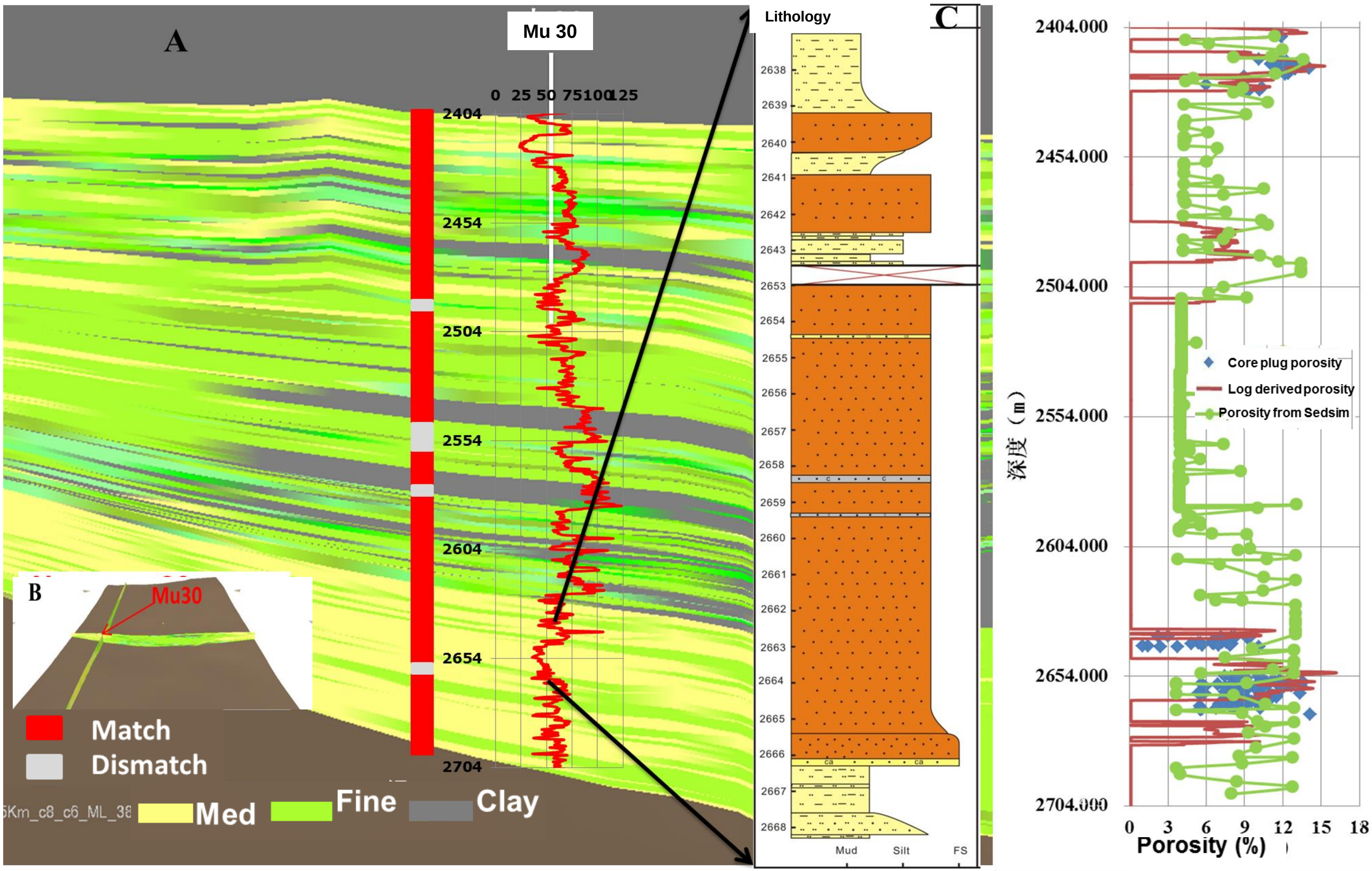




The thicknesses of 14 wells obtained from Sedsim simulation are in good agreement with the observed results from the wells picked, with a 90% match achieved

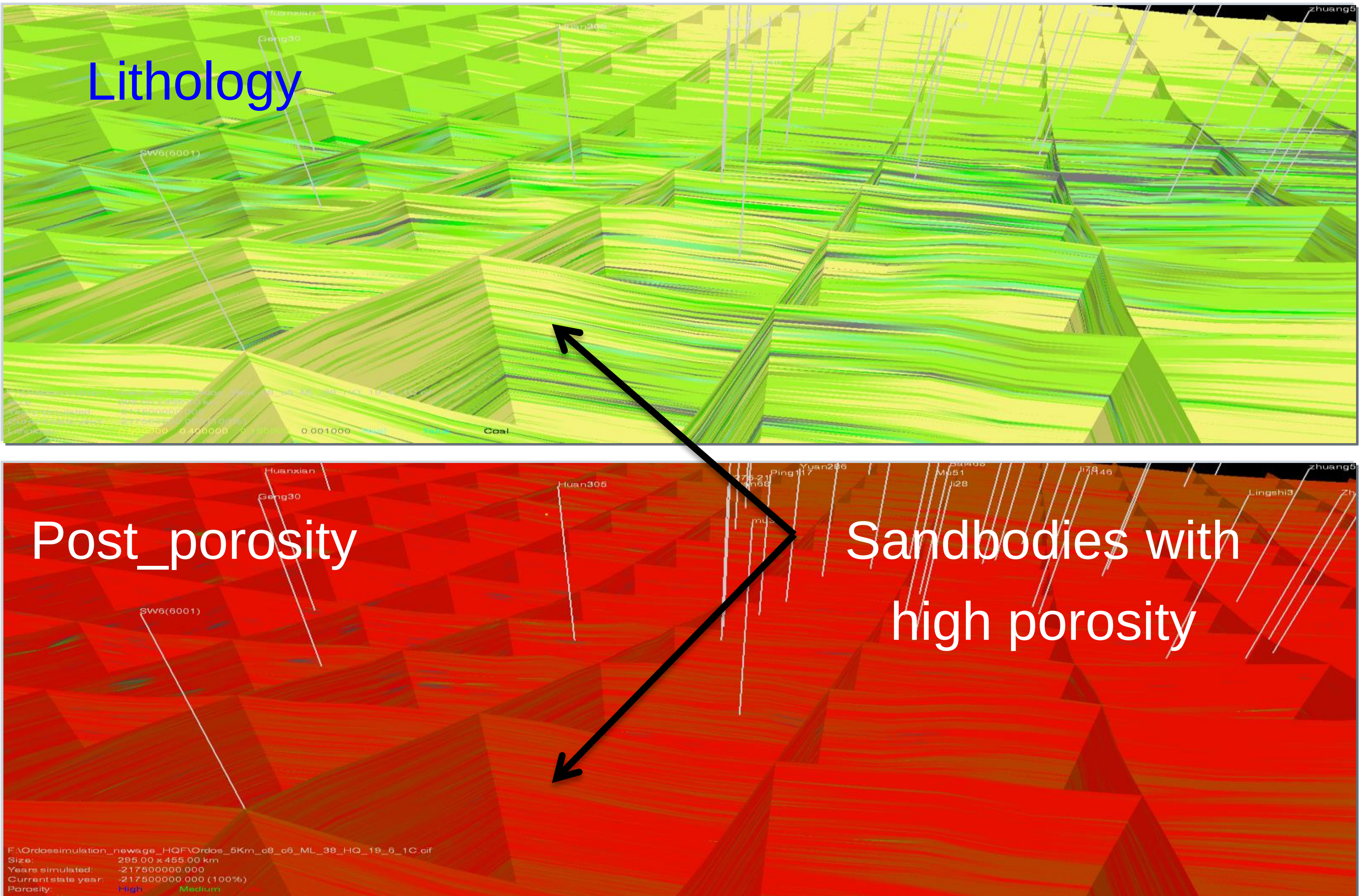
Simulation validation – Well data

The pseudo-Vsh trend from the Sedsim model is quite comparable with that of Well Mu-30 picked



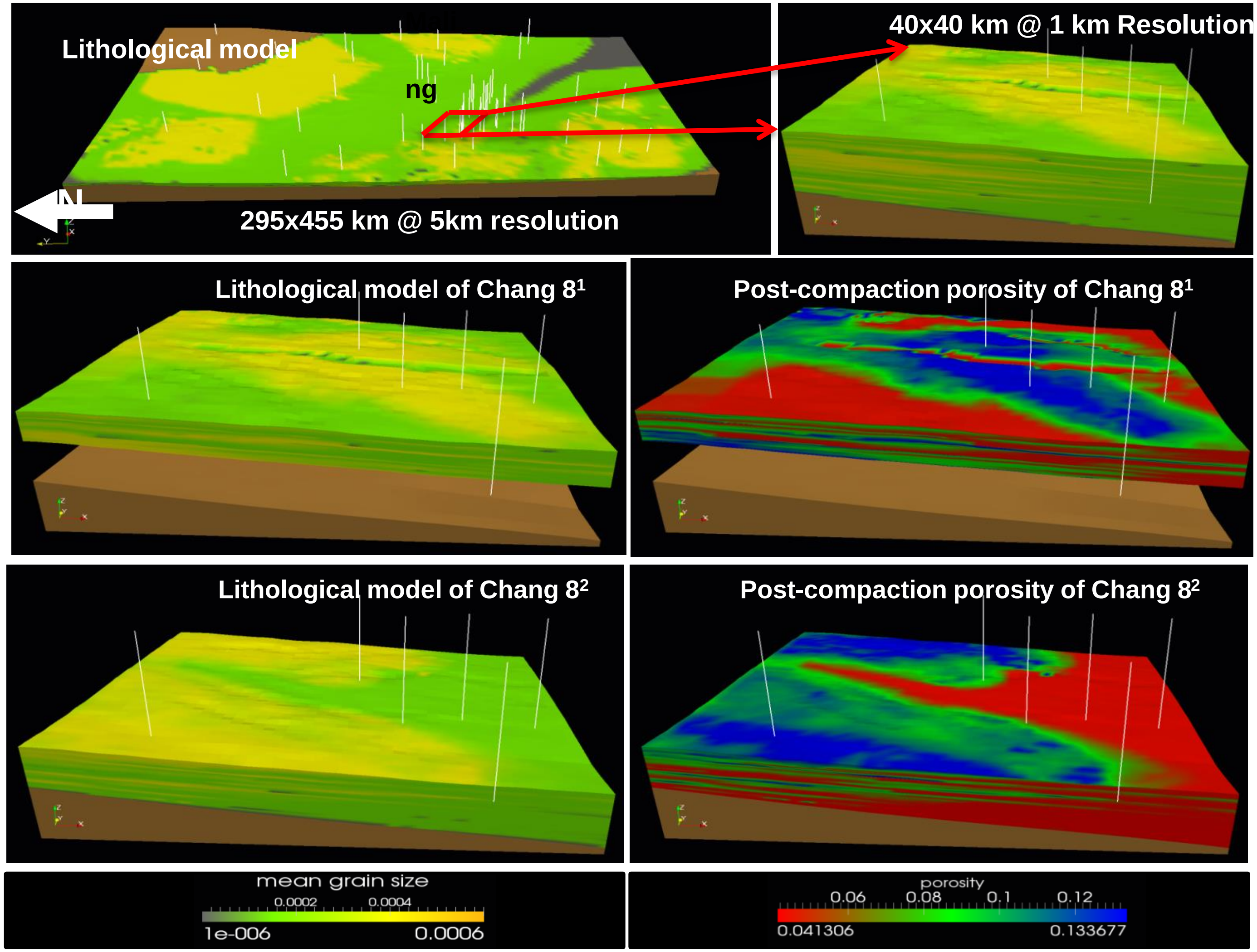
Simulation results– Heterogeneity

Lithology and porosity of the tight sand reservoirs are characterised by strong heterogeneous in 3-dimentions



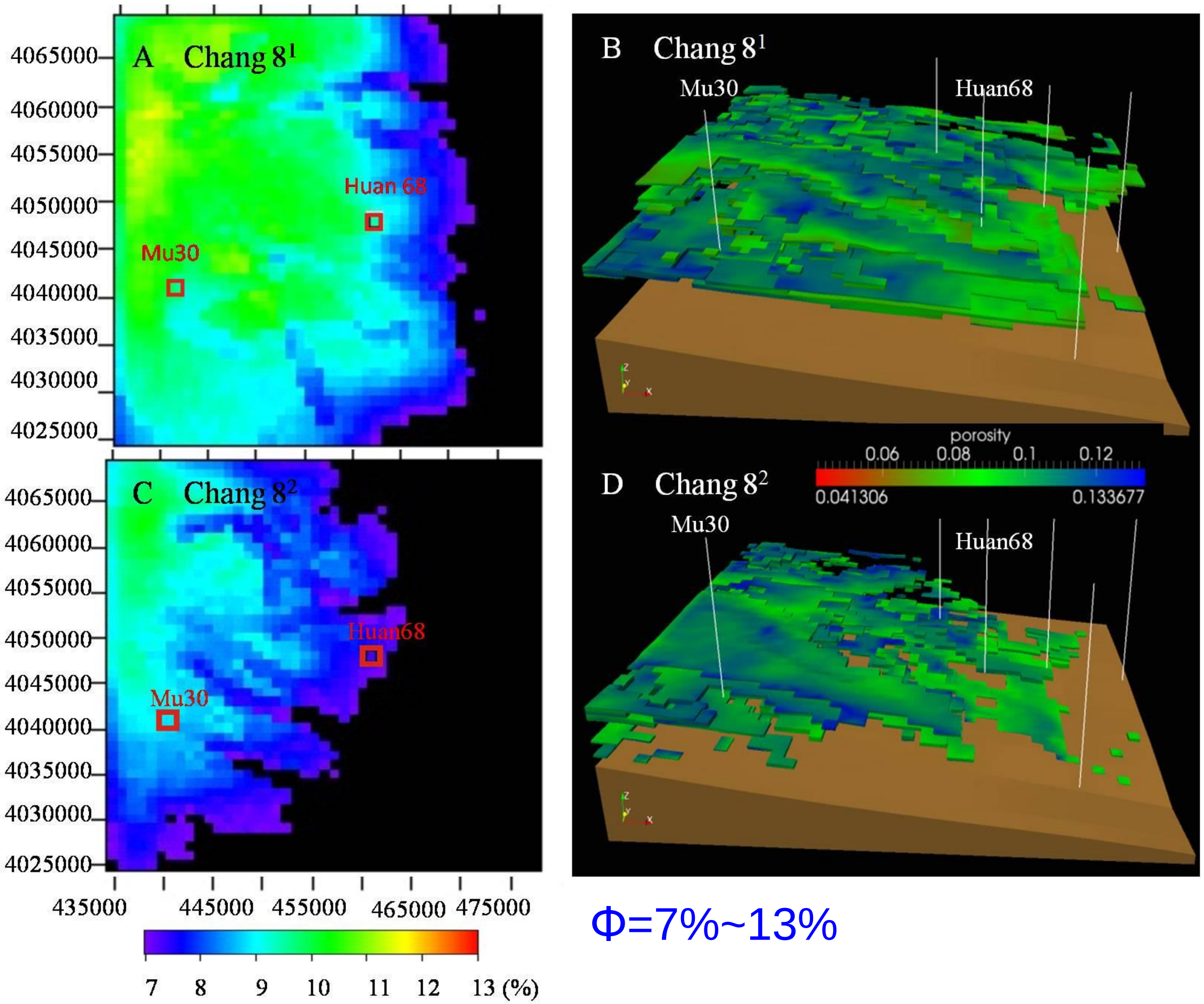
Simulation results– Potential reservoirs

The 3D heterogeneity of the reservoirs indicates that Chang-8[1] is coarser and more porous compared with that of Chang-8[2]



Simulation results– Potential reservoirs

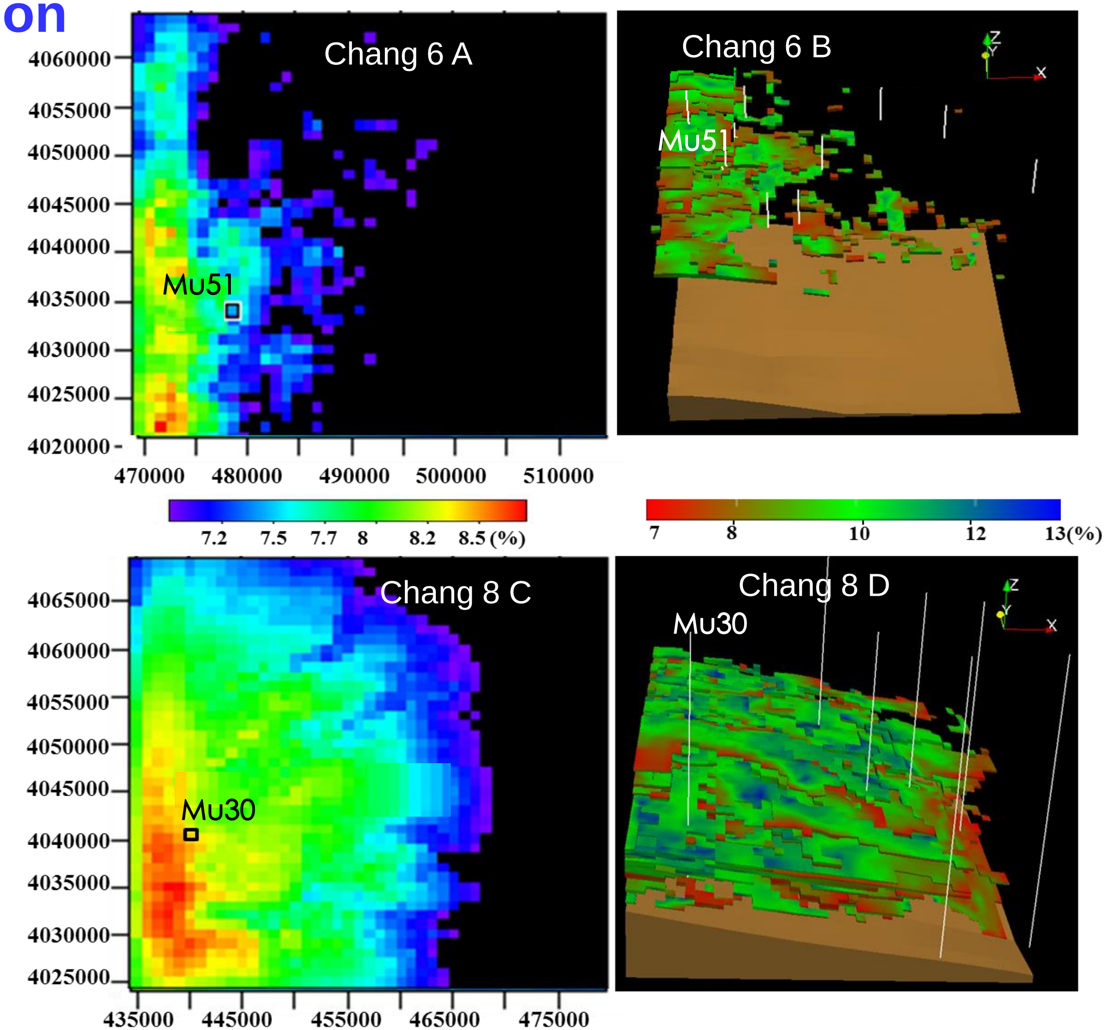
Areas with the favourable Φ for development in Chang-8 correspond mainly to delta-front deposits & a few sand-rich areas on the delta-plain



Φ=7%~13%

Simulation results– Potential reservoirs

The reservoirs of the Chang-8 member have greater potential than that of Chang-6 in terms of total sandbody volumes and Φ distribution



Φ=7%~13%

Conclusions

1. The bathymetry or morphology seems to be a key player in the deltaic migration, while high frequency lake level oscillations and sediment supply control the fine-scale facies variations

2. The delta plain is dominated by distributary channel sand-bodies, while the delta front is characterized by sheet-like sandstone units

3. The sandbodies on the delta plain and delta front with a porosity range of 7%-13% are the “sweet spot” target zones for future exploration

4. Sedsim is a useful tool for exploration and production in the investigation of shallow-water delta system to predict sedimentary geometries and distributions, test hypothesis, and better understand the sediment processes and development

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