Comprehensive Prediction of Favorable Gas Reservoir in the Large-Scale Tight Sandstone of Upper Triassic Xujiahe Formation in Hechuan Area of Sichuan Basin, China*

Anna Xu[1], Zecheng Wang[1], Congsheng Bian[1], Zhaohui Xu[1], and Xiufen Zhai[1]

Search and Discovery Article #50805 (2013)**
Posted June 30, 2013

*Adapted from oral presentation given at AAPG 2013 Annual Convention and Exhibition, Pittsburgh, Pennsylvania, May 19-22, 2013

[1]Research Institute of Petroleum Exploration & Development, PetroChina, Beijing 100083, China (xan@petrochina.com.cn)

Abstract

Hechuan area is located in the gentle slope of Central Sichuan Uplift in Sichuan Basin. It belongs to a gas-bearing structure of gentle anticline; the major gas layer is Triassic Xujiahe Member 2 sandstone, which is consisted of multistage stacked braided river and delta sand bodies. The characteristic is the wide spread of sand body and the good lateral connection. But the porosity and permeability is low, mostly between 2~7% and 0.001~1mD. The gas reservoirs with porosity more than 4% only developed in very limited local areas, with severe heterogeneity and poor lateral connectivity. Geologic, seismic, and well logging data are used in this paper to predict the distribution of large-scale tight gas reservoirs by three steps and three methods. Firstly, the core, casting slices, well log data and production performance test results are studied to determine the controlling factors and limit values of gas reservoirs. The results show that the micro-facies and diagenesis are the dominant factors controlling the distribution of favorable gas reservoirs. Fractures can improve local petrophysical properties. Higher porosity and permeability can be found in coarse sandstone of channels, with dissolved vugs and fissures, which means favorable gas reservoir zones in large area of tight sandstone. The lower limit values of permeability, pore-throat size, and porosity for gas-bearing reservoirs in Xujiahe Member 2 sandstones are respectively 0.05mD, 0.2μm, and 4.5%. Secondly, considering micro-facies, diagenetic facies, and fractures as three key factors in controlling development of reservoirs, three methodologies are used in comprehensive prediction of gas reservoirs, which are the facies controlled stochastic simulation method, the logging lithological facies interpretation method, and the fractures indication technique by the stress-strain relation of rocks. The thickness of gas-bearing sandstones and the distribution of higher porosity and permeability are predicted, while the thickness of dissolved sandstone and general distribution of fractures are predicted. Thirdly, applying the above results, the images obtained through these three methods are stacked to synthetically predict and evaluate the distribution of favorable reservoirs. The results show that the gas-bearing reservoirs in Member 2 Xujiahe Formation are located in the structural axis or tectonic hinges, and areas where main channel or sand bars micro-facies, and fractures are well developed. In summary, the prediction of large scale tight gas sandstone reservoirs should be conducted following major controlling factors, and comprehensive research should be carried out using optimized prediction technique methods, which are applicable in the geological setting of the studied area.

Comprehensive Prediction of Favorable Gas Reservoir in the Large-scale Tight Sandstone of Upper Triassic Xujiahe Formation in Hechuan Area of Sichuan Basin, China

Anna XU *, Zecheng WANG ,Congsheng BIAN, Zhaohui XU，Xiufen ZhAI

Research Institute of Petroleum Exploration & Development, PetroChina

The National Oil and Gas Special Project No. 2011ZX05004

* xan@petrochina.com.cn

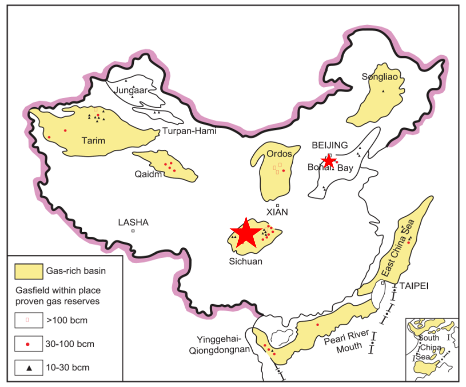
May 2013

Presentation Outline

1. **Background**
2. Methods and Results
3. Conclusion and Discussion

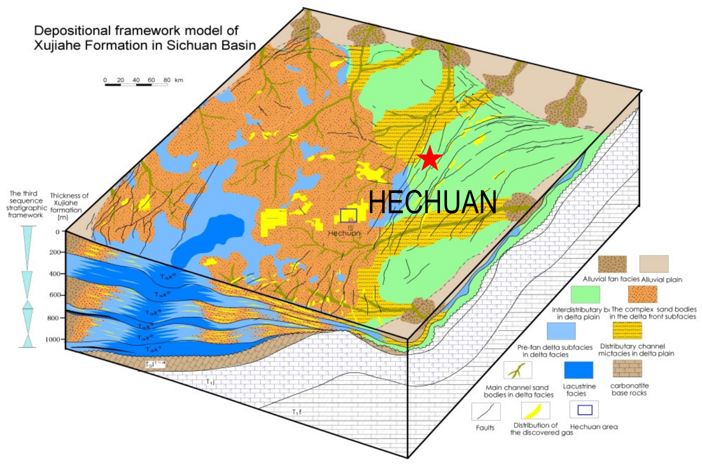
1. Background

Gas fields in China

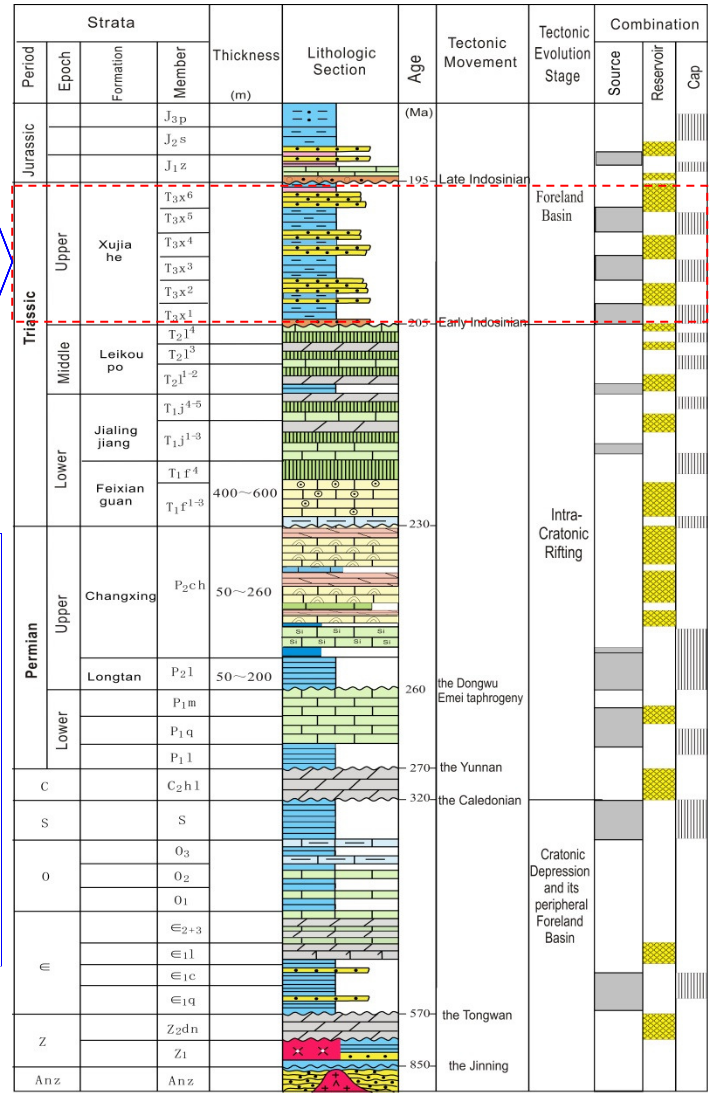


Sichuan Basin is in the southern of China

Location of Hechuan area



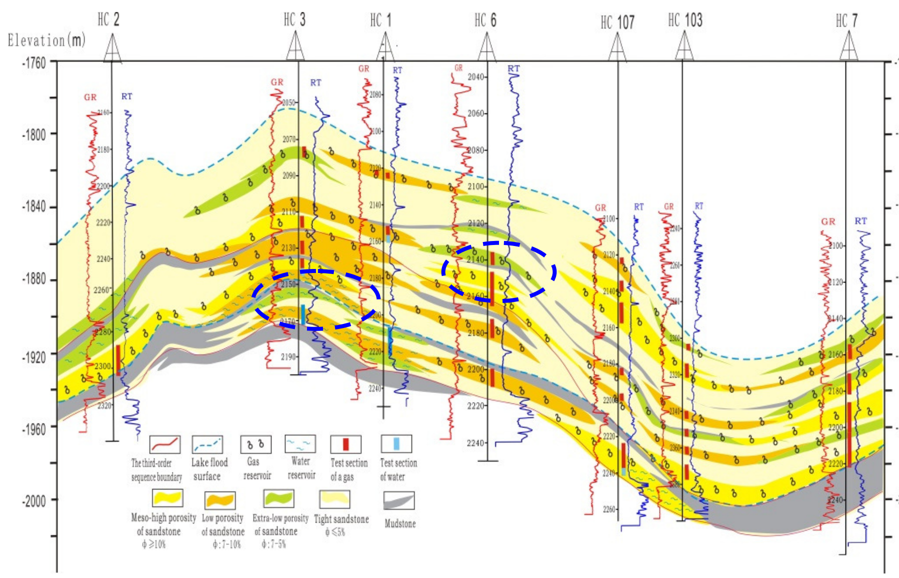
- T_3X is pay zones(6 members)
- multi-staged sandstones of braided river delta facies
- favorable source-reservoir-cap rocks assemblages



Stratigraphic column of Sichuan Basin

1. Background

Typical profile of gas reservoirs of Xu 2 Member with different porosity of sandstone

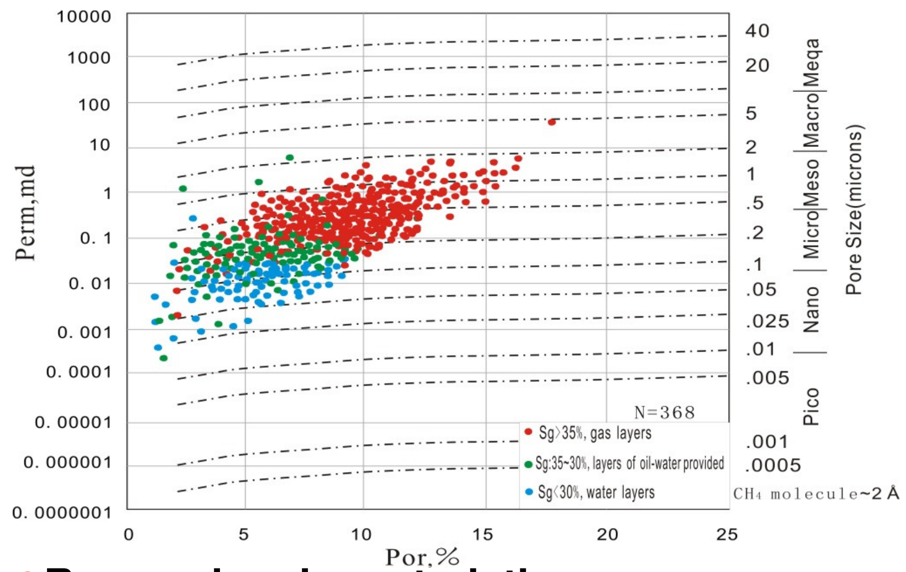


- **Tectonic features** → anticline structures，complete trap with few mini-fractures
- **Production characteristics** → 85% of wells belongs to the wells with low / ultralow's production and are mostly gas-water wells
- **Distribution of gas/water** → complex, Controlled by distribution of relative high-quality reservoirs
- **Heterogeneity of reservoirs：** Strong

  Kv: 0.61~0.91(interlayer)

  0.63~0.86(internal layer)

The distribution of porosity and permeability in Xu 2 Member reserviors, Hechuan area



- **Reservoirs characteristics**

  1.The large-scale tight sandstone with some relative high-quality reservoirs

  2.Good correlation between permeability and porosity

  3.K=0.05mD is a critical value—Perm can be used to divided the gas/water layer ; Por⩾5% is taken as the reference due to the same range between gas and water layers

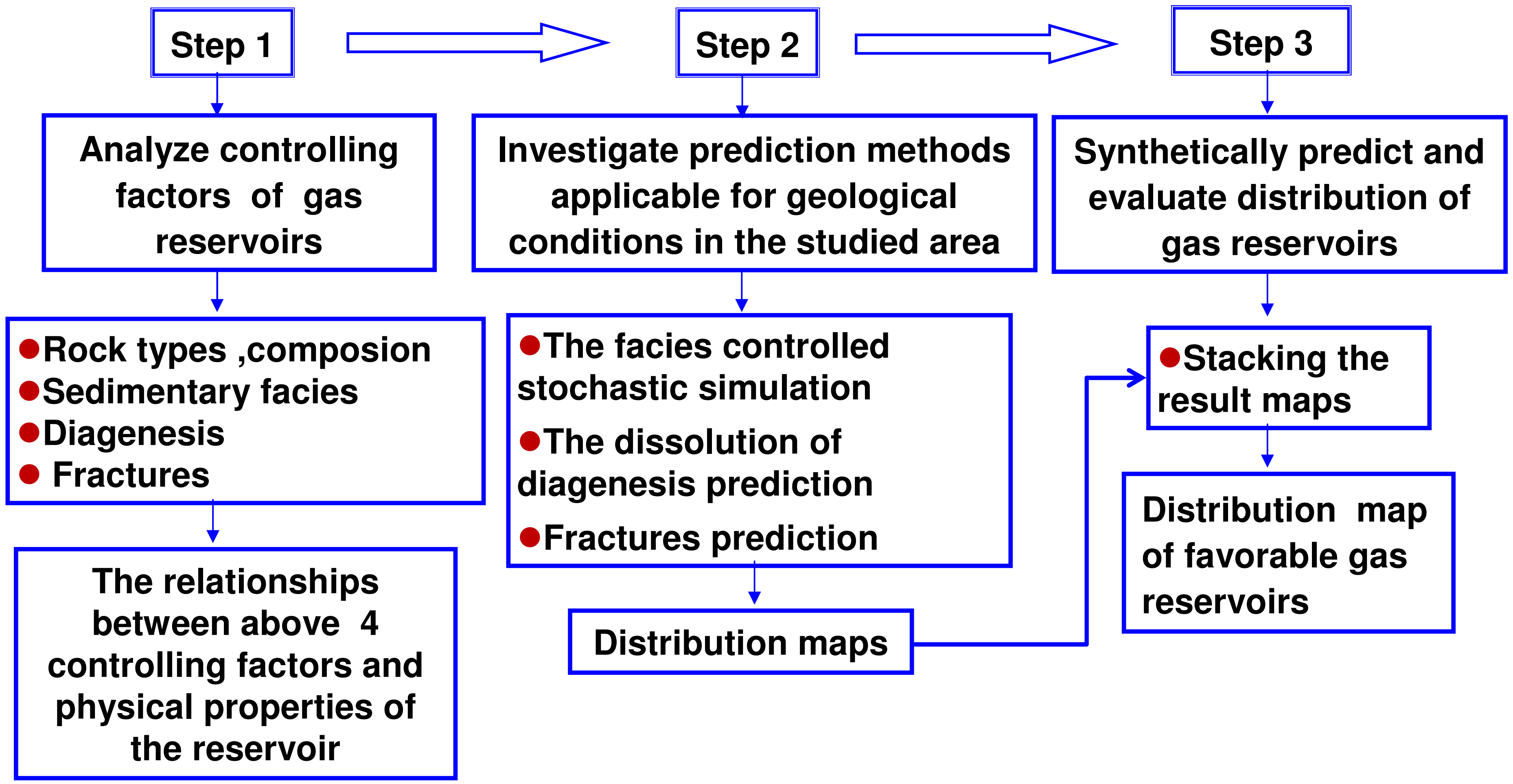
Distribution and prediction of gas-bearing reservoirs is the key problem

Presentation Outline

1. Background
2. **Methods and Results**
3. Conclusion and Discussion

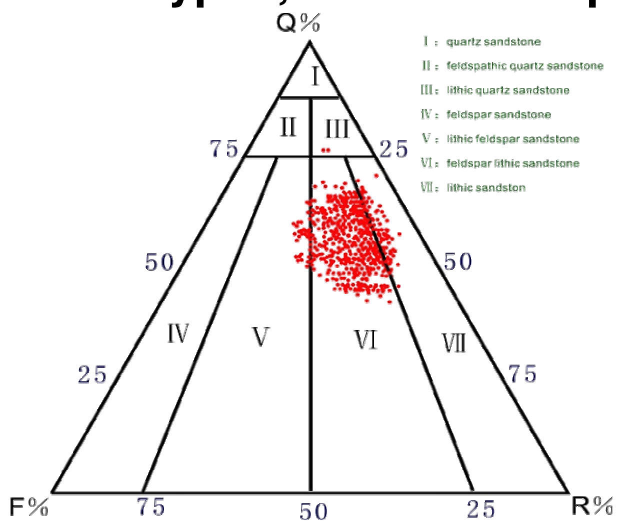
2. Methods and Results

On basis of the key problem of Hechuan, in our study, the following three procedures are designed and three methods are adopted.



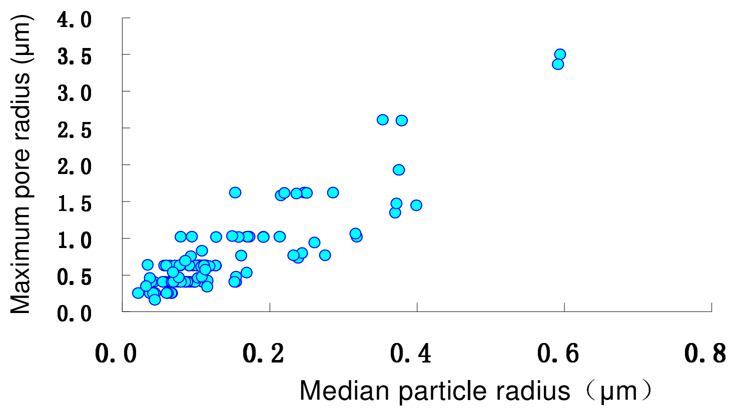
Step1   Analyze controlling factors of gas reservoirs

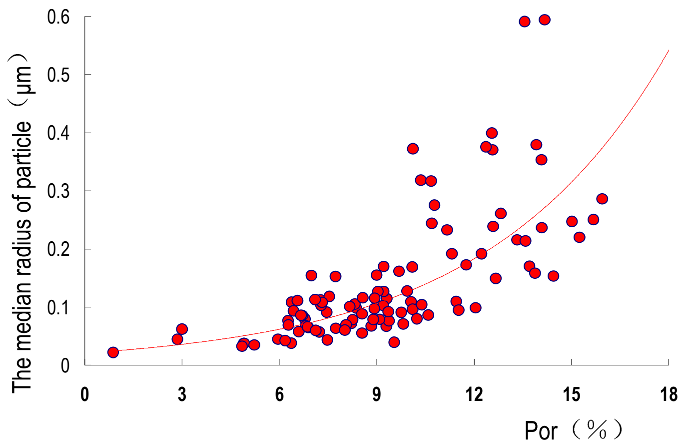
●Rock types, mineral composition and the physical properties of reservoir



Triangle map for the classification of Xujiahe 2 sandstones

Correlation between median radius of particle and maximum pore radius/porosity of Xu2 member



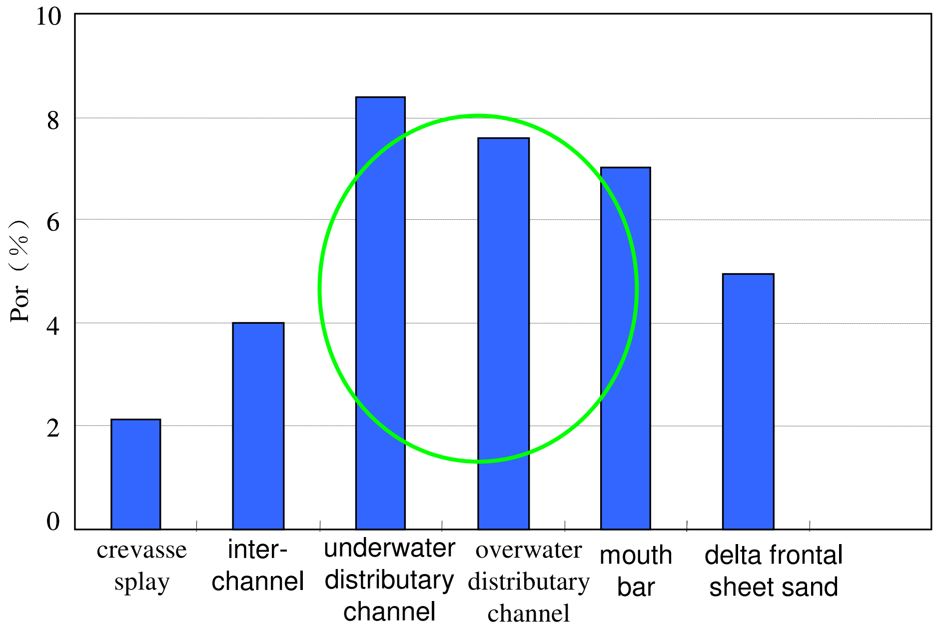


- ● Lower texture maturity and composition maturity, high Igneous rock cuttings content
- ●Some high quality reservoirs exist in the large-scale tight sandstone
- ● Rock types and mineral composition have a great influence on the physical properties of reservoir

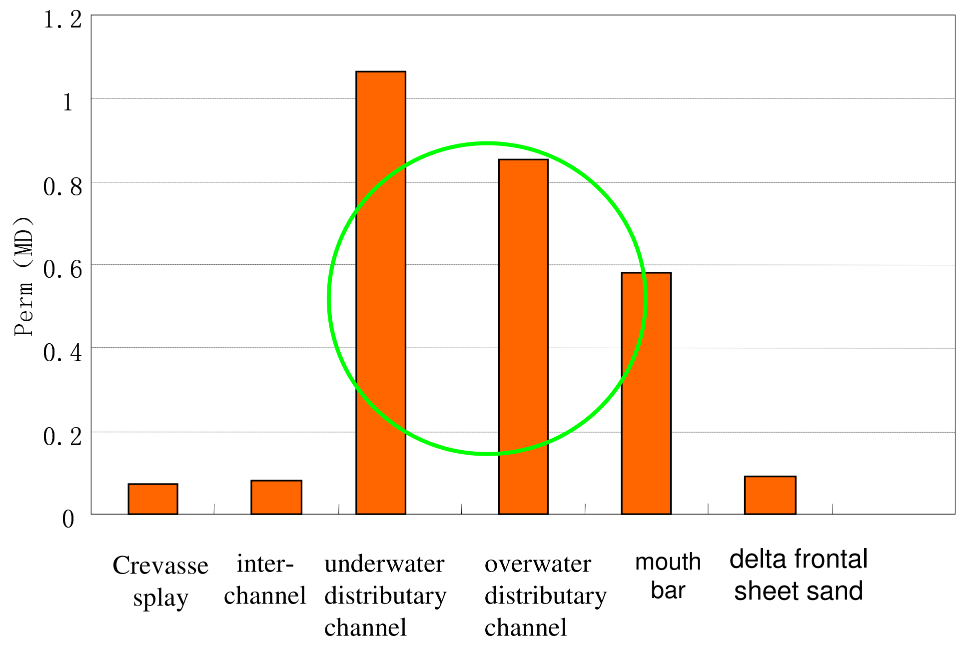
Step1 Analyze controlling factors of gas reservoirs

- **The sedimentary facies and the physical properties of reservoir**

Histograms of correlation between microfacies and reservoir physical properties of Xu 2 Member in Hechuan area



The correlation between microfacies and Por in Xu 2 Member



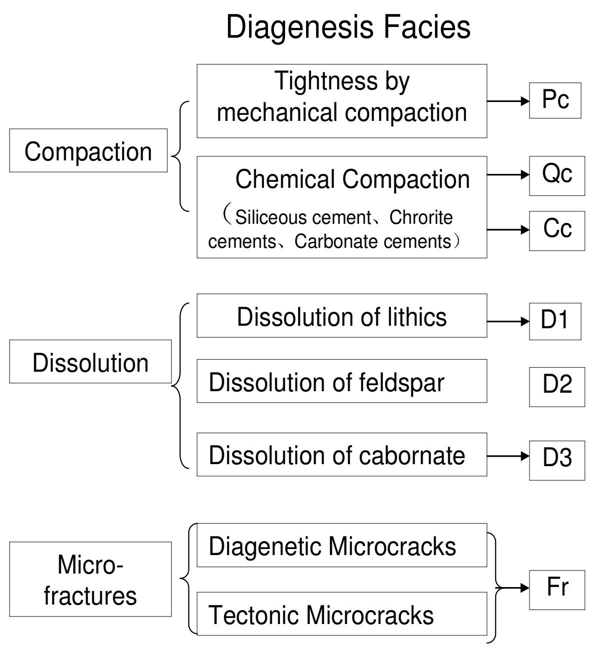
The correlation between microfacies and Por in Xu 2 Member

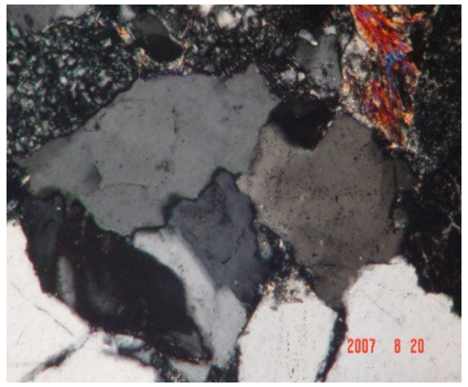
Different sandstones from different microfacies have the different properties of reservoir

Channel or mouth bar sandstones with medium-coarse grains are favorable reservoirs

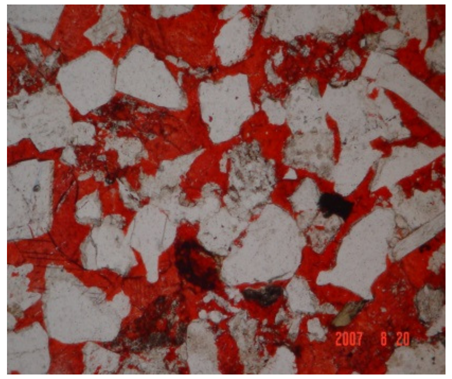
Step1 Analyze controlling factors of gas reservoirs

●The diagenesis and the physical properties of reservoir

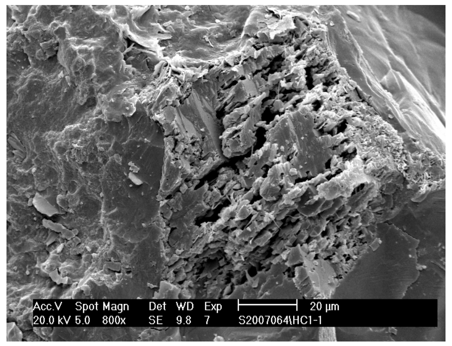




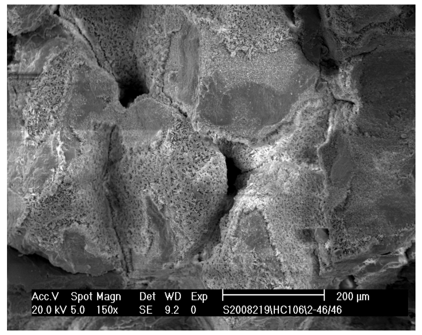
Hc7 well，2190.17m，PLM of the casting thin sections,10×10 ,mineral grains with inlaid contact**, strong compaction**



Hc3 well，2154.84m，plane polarized light of the casting thin sections,5×10 , **calcite crystal cementation**



Hc1 well, 2158.528m，SEM of **feldspar dissolution pores**, ×800



Hc106 well, 2193.4m, SEM of **residual interparticle pores of feldspar dissolution** ,×150

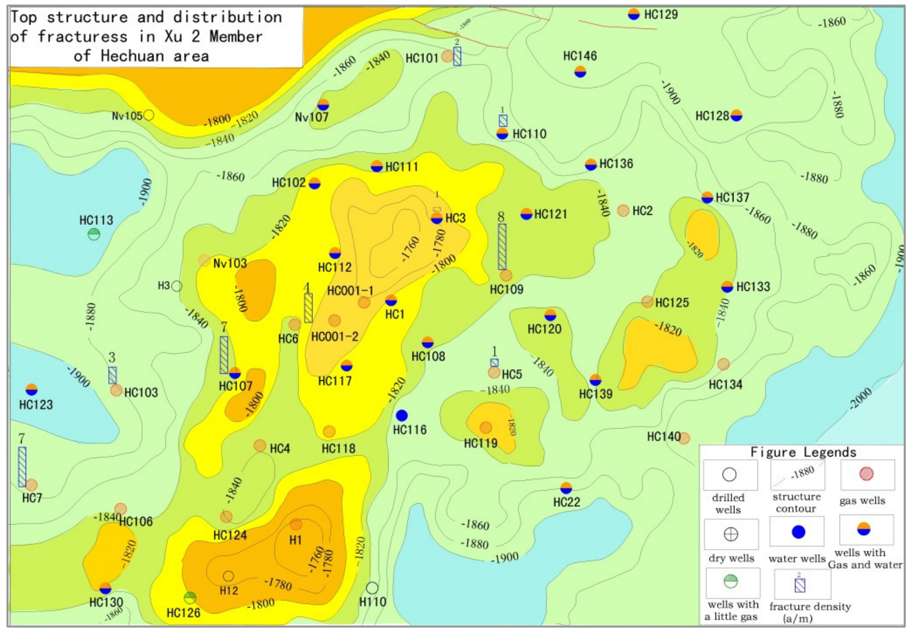
●Mineral composition, grain size, sedimentary microfacies and cement content determine the direction of diagenetic transformation

●Dissolution of alkali feldspar and chlorite rim belongs to the constructive diagenesis that make reservoir's porosity increases

The favorable reservoirs are the medium to coarse grained sandstones with more alkali-feldspar and chlorite rim，and less matrix, less plastic or carbonate detritus

Step1 Analyze controlling factors of gas reservoirs

● The fractures- and the physical properties of reservoir



Top structure and distribution of fracturess in Xu of Hechuan area

1. Fractures can improve greatly the physical properties of reservoir
2. Only a handful of small-scale,semi-filled vertical fractures developed in HC area
3. Fractures mostly distributed in the axis of anticline

Photos of fractures in cores of Xu 2 Member in Hechuan area

Semi-filled vertical fractures, 2278.94~2279.29m, Xu 2 Member, Hc 5 Well

Semi-filled vertical fractures, 2179.03~2179.26m, Xu 2 Member, Hc 7 Well

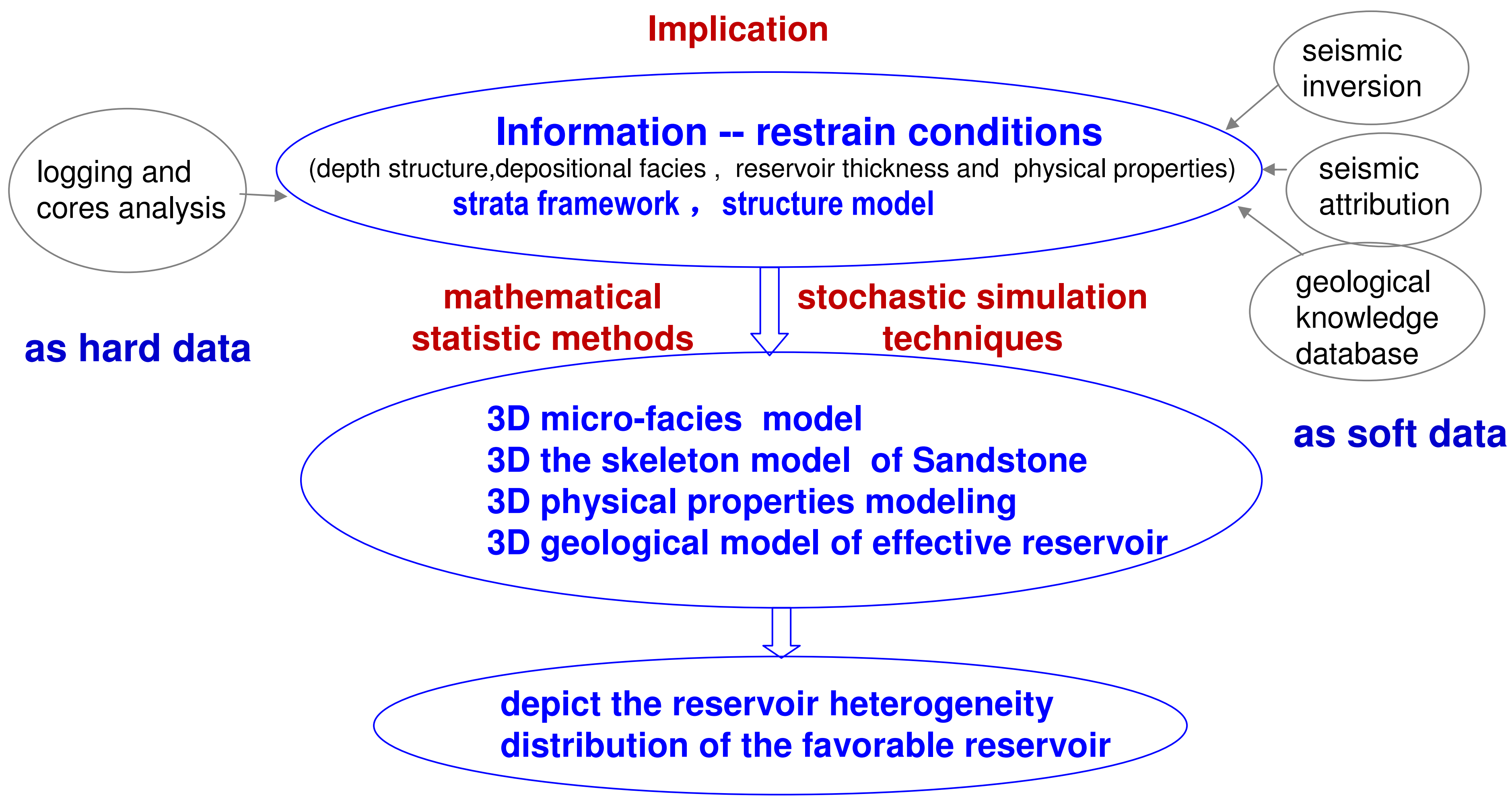
The Perm of reservir with fractures is greater 10 times than that of formation without fractures

Step 2 Study prediction methods

On basis of above control factors of the favorable reservoir ⇨ Three prediction methods

Control factors		Prediction methods
● **Sedimentary microfacies** Channel or mouth bar sandstones with midium-coarse grains	⇨	● **Reservoir prediction** By isochronal facies-restrained stochastic simulation
● **Diagenesis facies and rock type or composition** Dissolution of the coarse grained sandstone with large amounts of alkaline feldspar and chlorite	⇨	● **Diagenetic facies interpretation** By models of deposition-diagenesis facies of logging curves
● **Fractures** The axis and two limbs of anticline	⇨	● **Prediction of fracture-type reservoir** Based on the correlation between stress-strain of rocks and permeability

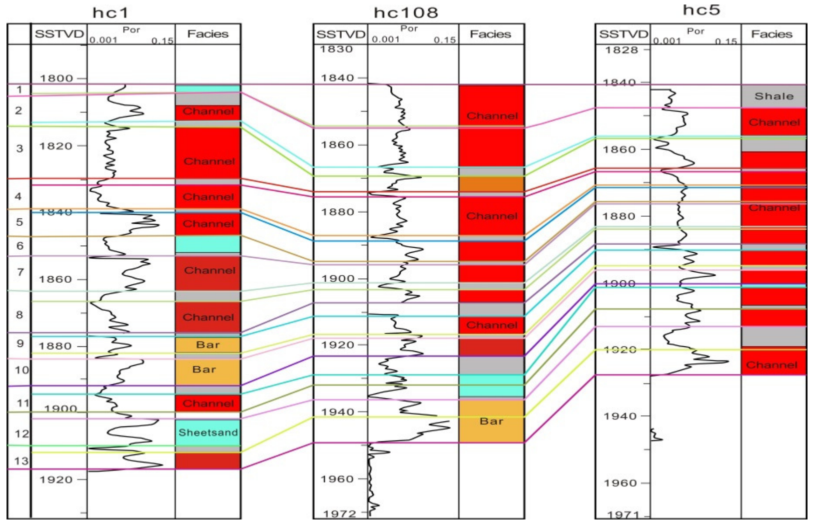
● 1. Reservoir prediction of isochronal facies-restrained stochastic simulation



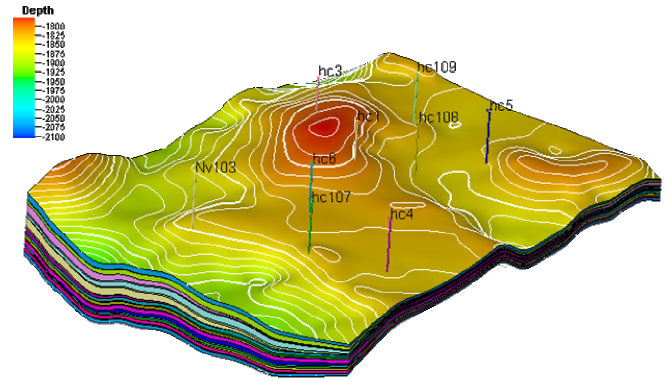
Applicable conditions: Gentle structures with few fractures, physical properties of sandstones are controlled by micro depositional facies

● 1. Reservoir prediction of isochronal facies-restrained stochastic simulation

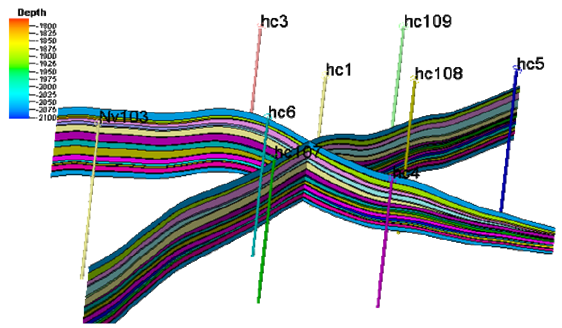
Procedures and results-----consist of 8 steps



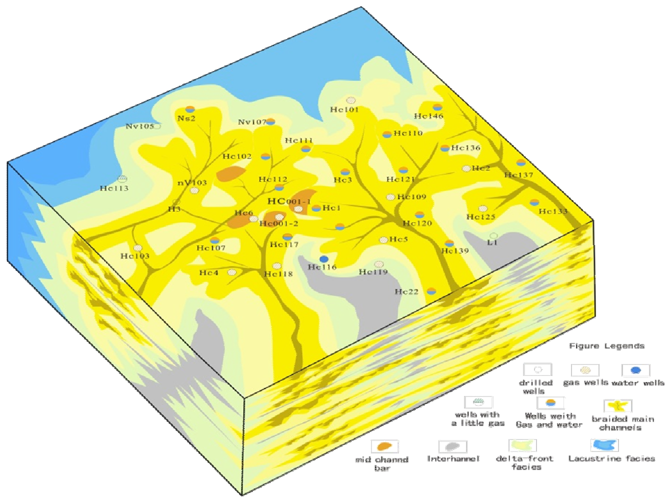
(1)The total sequence stratigraphicframework is divided into four sand groups with 13 minilayers



(3) 3D model of structures



(2) Stratigraphic framework

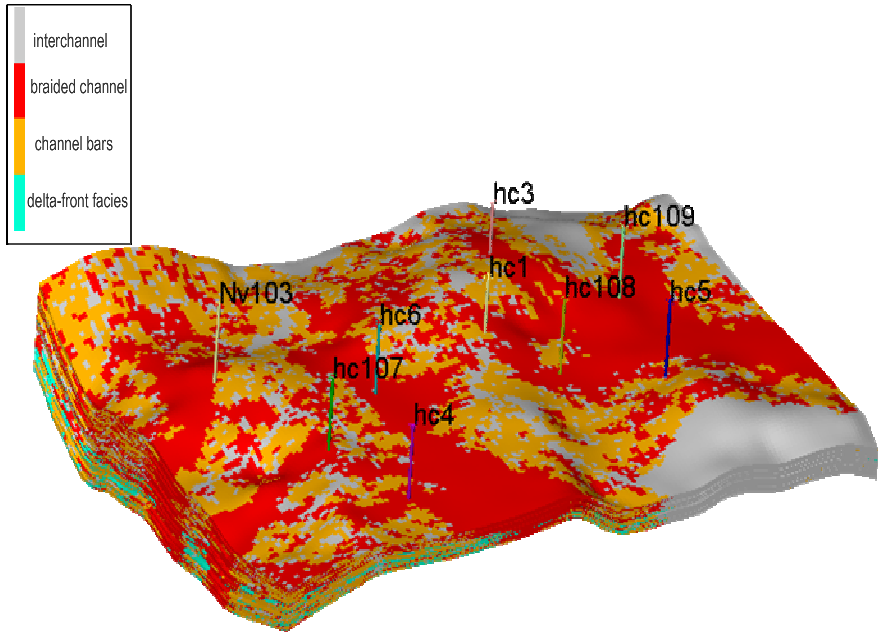


(4) Sedimentary facies model

The key is the variation function about the braided river delta sedimentary microfacies

● 1. Reservoir prediction of isochronal facies-restrained stochastic simulation

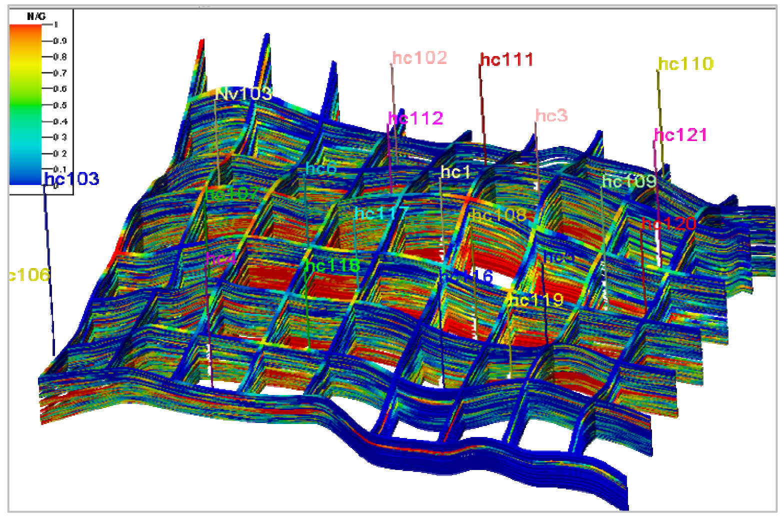
●(5)3D model of depositional facies



Three-dimensional geological model of sedimentary facies

Sequential indicator simulation

●(6)3D the skeleton model of Sandstone



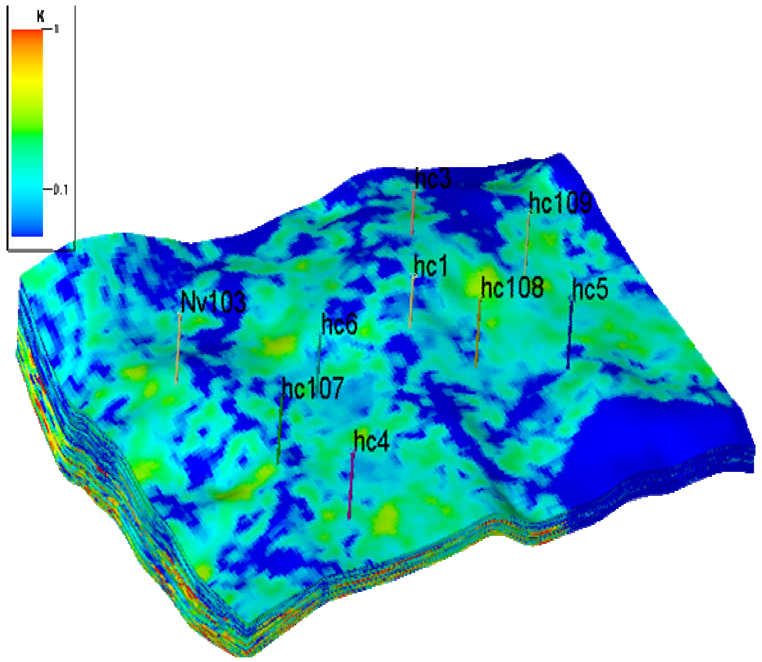
3D the skeleton model of sandstone

●The sandstones of underwater distributary channel microfacies widely distributed

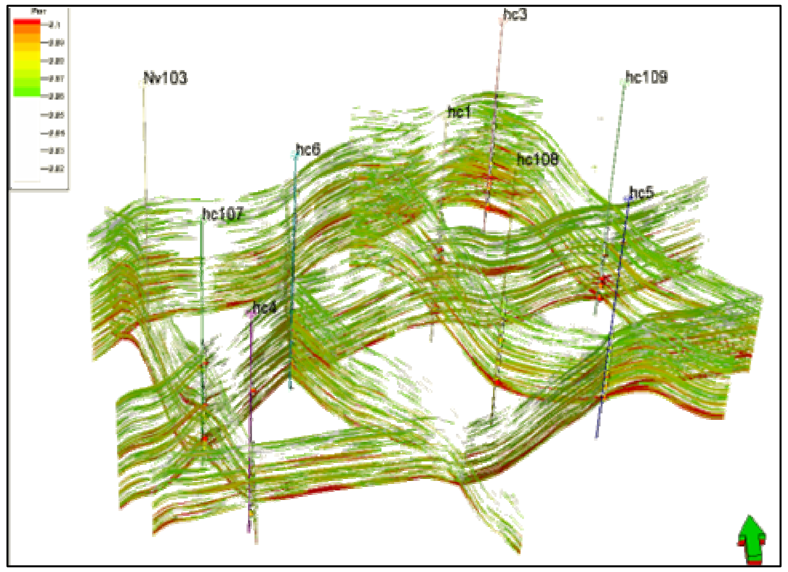
●Channel microfacies develop in the upper, channel bar microfacies in the lower part

● 1. Reservoir prediction of isochronal facies-restrained stochastic simulation

●(7)3D physical properties modeling ● （8）3D geological model of effective reservoir



3D model of permeability distribution

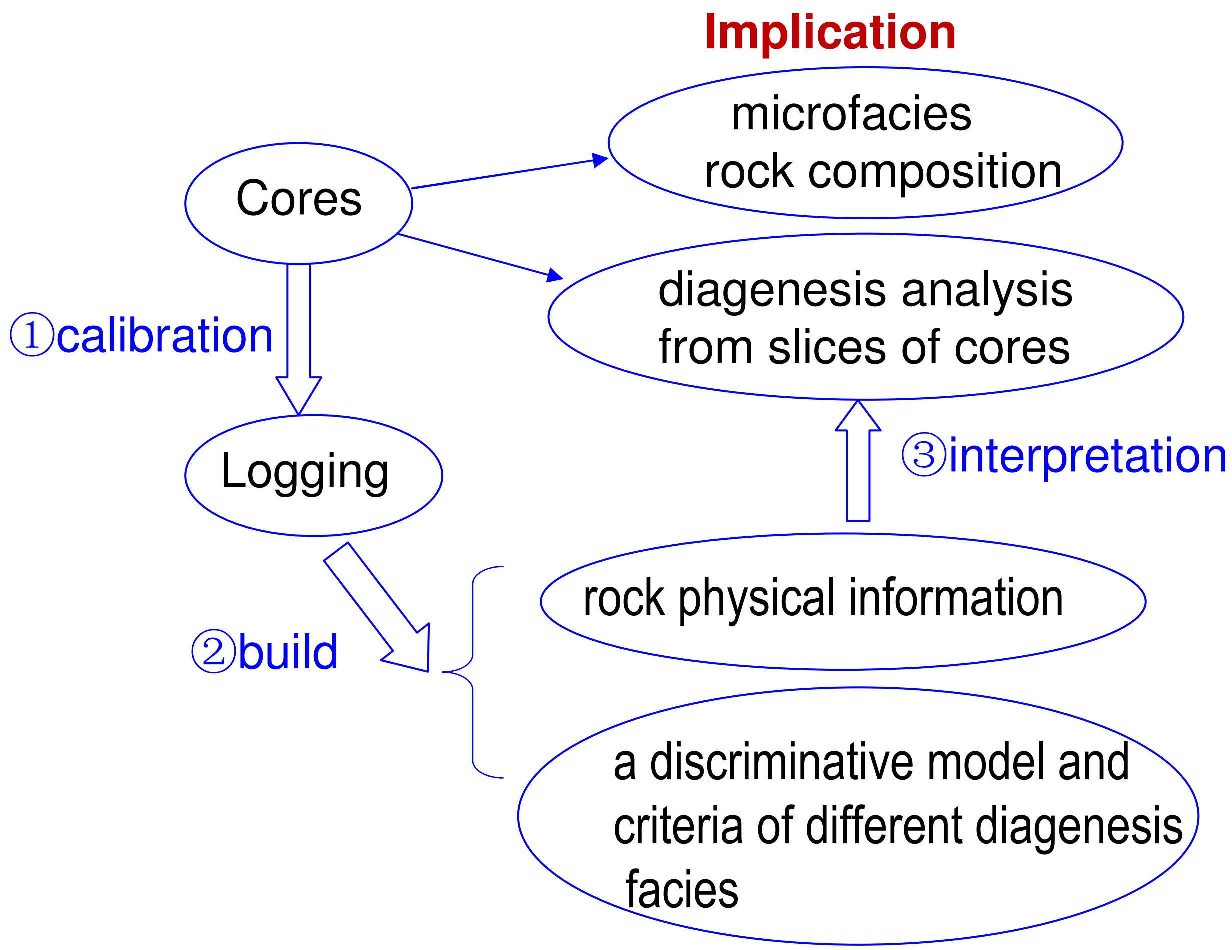


3D geological mode of effective reservoir in the Xu 2 member

●The favorable reservoir with medium / high porosity and permeability mostly distribute along the channel and mouth bar microfacies

●K=0.05mD ,Por≥5% are taken as the threshold value of the effective reservoir to eliminate some sandstones without high storage capacity;

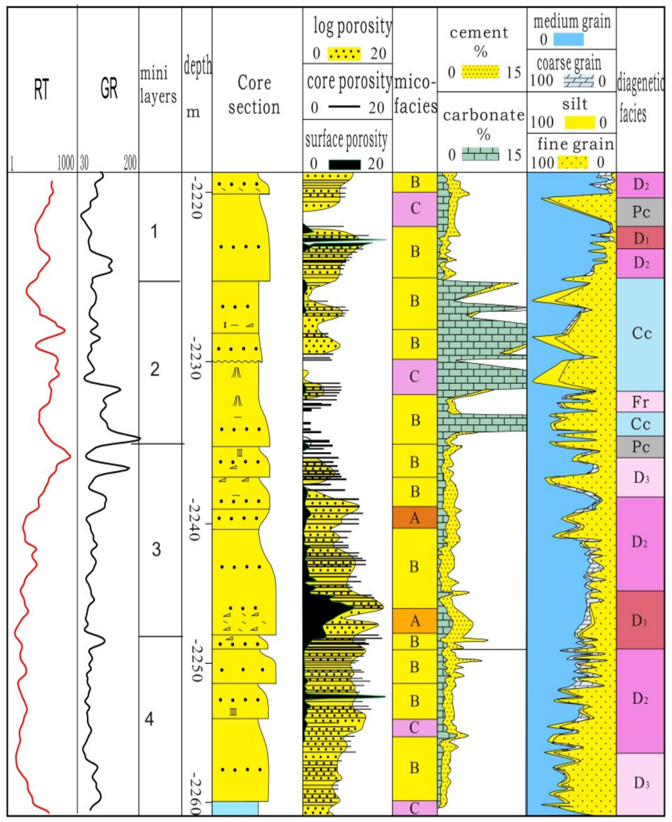
● 2. Diagenetic（Dissolution） facies interpretation



Applicable conditions: Distribution of favorable reservoirs are controlled by diagenesis, poor development of fractures

●2. Diagenetic（Dissolution） facies interpretation

Procedures and results-----consist of 4 steps



Comment:A for channel microfacies,B for Bar microfacies,C for the overflow sand flat microfacies; Pc for tightness by mechanical compaction,Cc for Carbonate cements,Fr for micro-fractures, D1、D2 and D3 for Dissolution frome intense to minor respectively

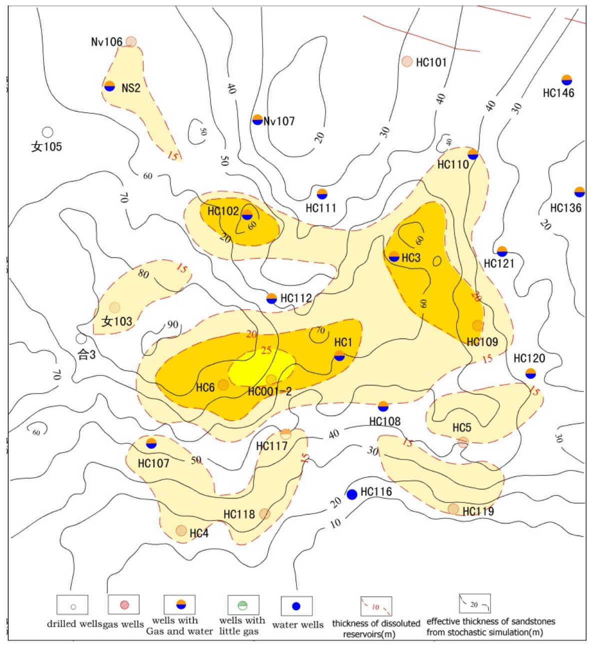
Porocity、sedimentary and diagenetic facies analysis diagram from typical wells cores in Hechuan area

(1)Microfacies,rock composition ,diagenesis analysis

(2)The diagenesis information of logging is calibrated by diagenesis information from cores analysis

(3) Establish criteria for logging curves of different diagenetic facies

(4)Predict the thickness of reservoirs from dissolution



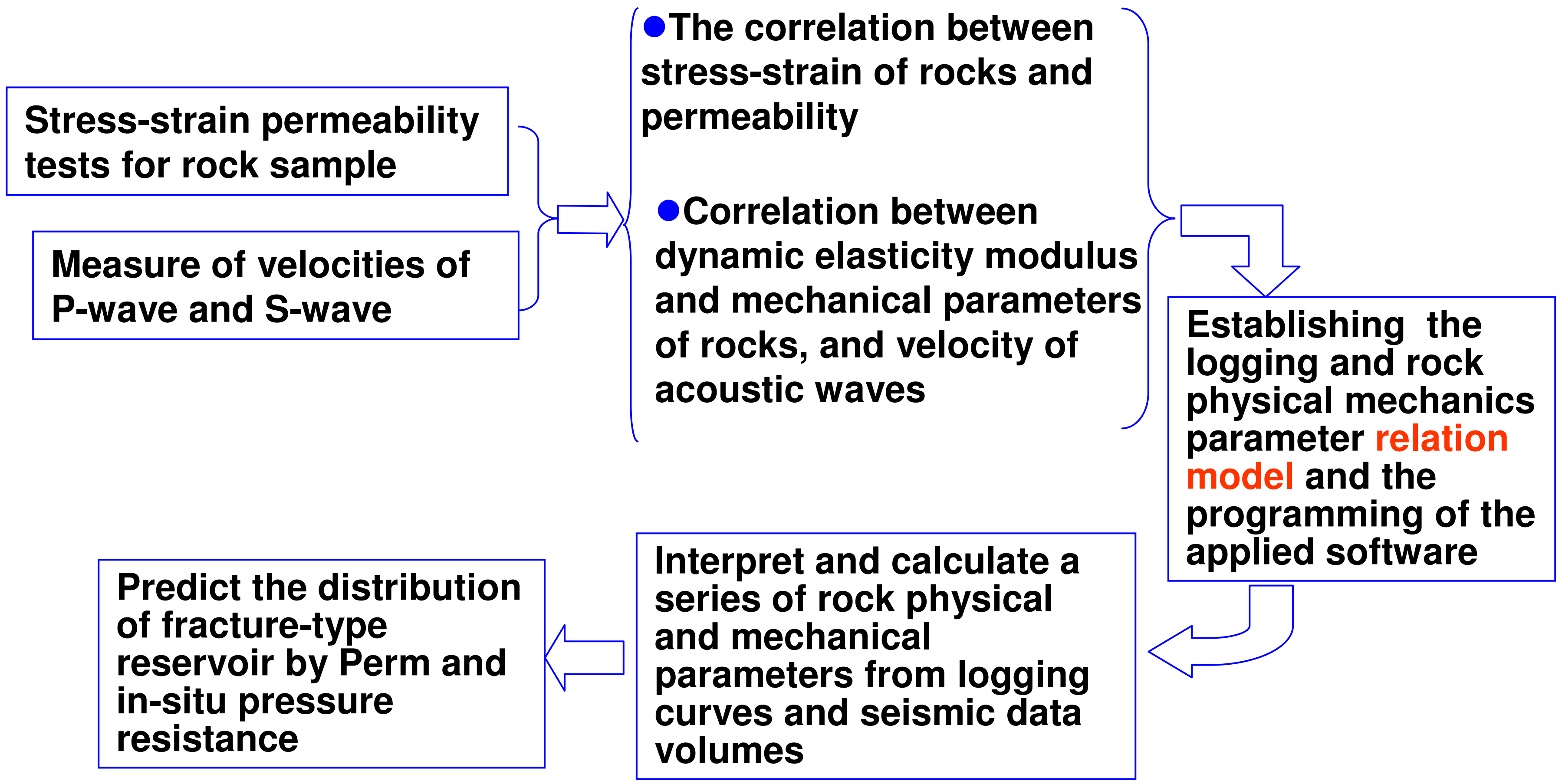
The thickness overlay of by superimposing the reservoir from dissolution on the effective sandstonesin Xu 2 member

Some relative high-quality reservoirs develop in the large-scale tight sandstones

Applicable conditions: Distribution of favorable reservoirs are controlled by diagenesis, Poor development of fractures

●3. Fractures prediction by the correlation between stress-strain of rocks and permeability

Implication

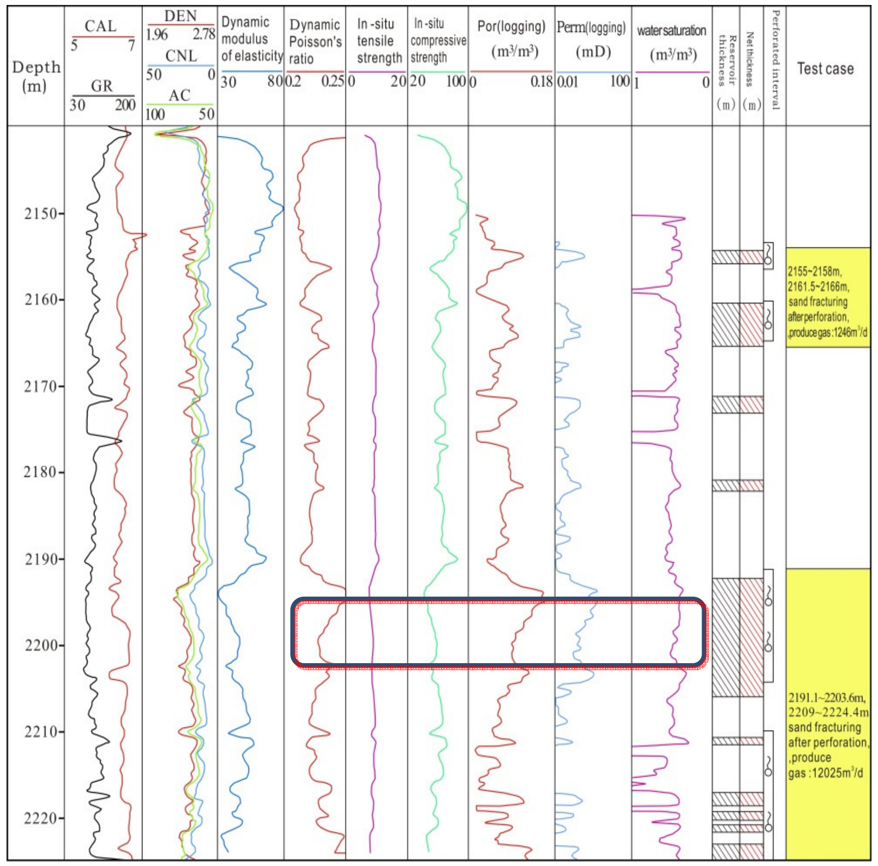


Applicable conditions: The development of fractures and its trend is closely related to the regional tectonic

●3. Fractures prediction by the correlation between stress-strain of rocks and permeability

Procedures and results

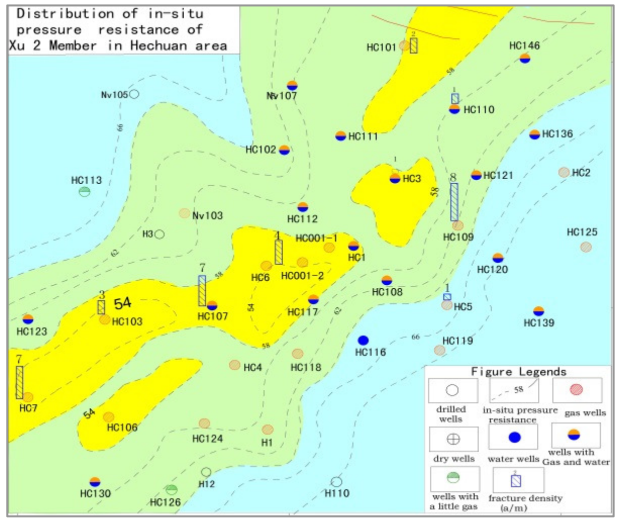
Interprection of Hc7 well about logging and rock physical mechanical parameters



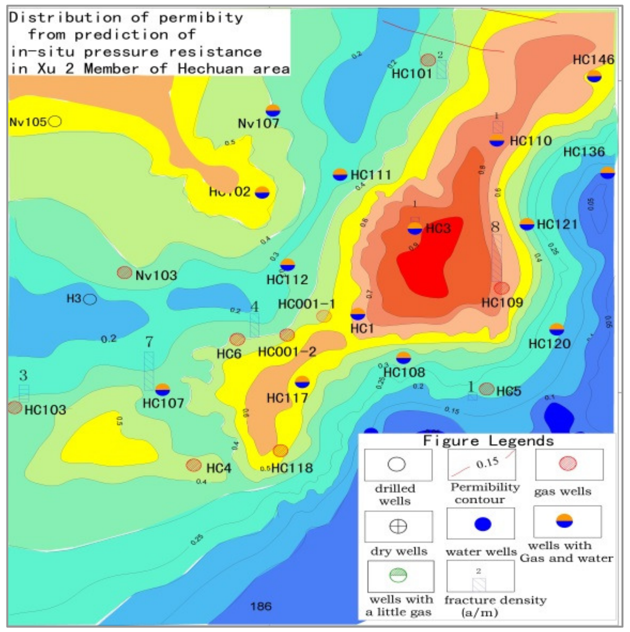
●Deformation of rocks in Hechuan is in periods of flexible deformation and expanding microcracks

●Correlation between stress-strain and permeability exists in rocks, and is better when Perm. is more than 0.1mD

Distribution of in-situ pressure resistance of Xu 2 Member in Hechuan



●In-situ pressure resistance is smaller at tectonic hinge areas ,which is the same with the statistic data of fractures from single well

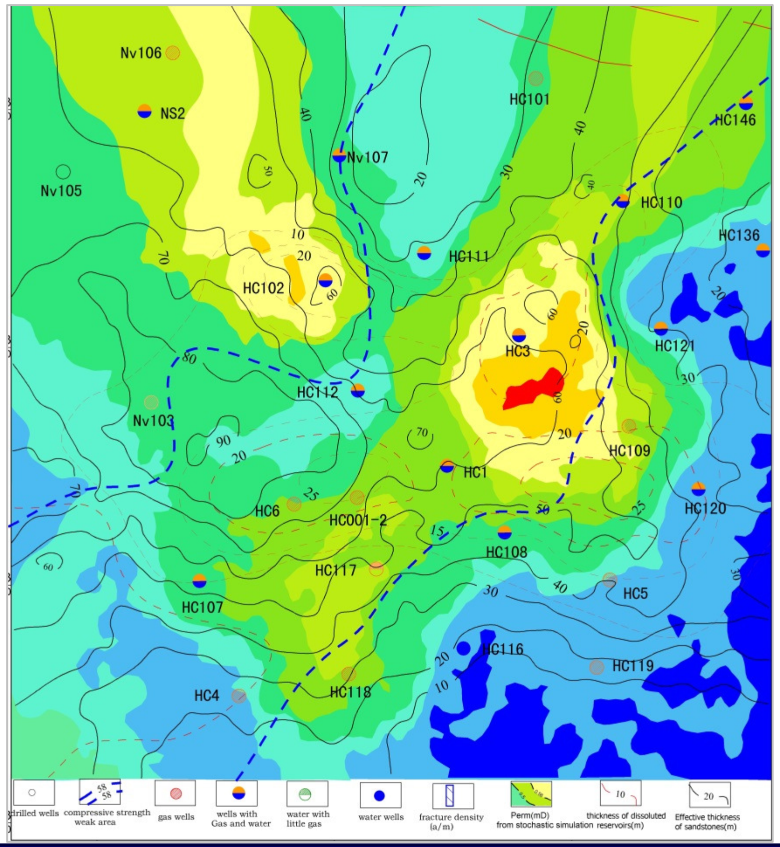


●The macro-trend of permeabillity from in-situ pressure resistance is the same with from the facies-restrained stochastic simulation although its values is bigger than that of logging

Step3 Comprehensive prediction & evaluation of gas reservoirs

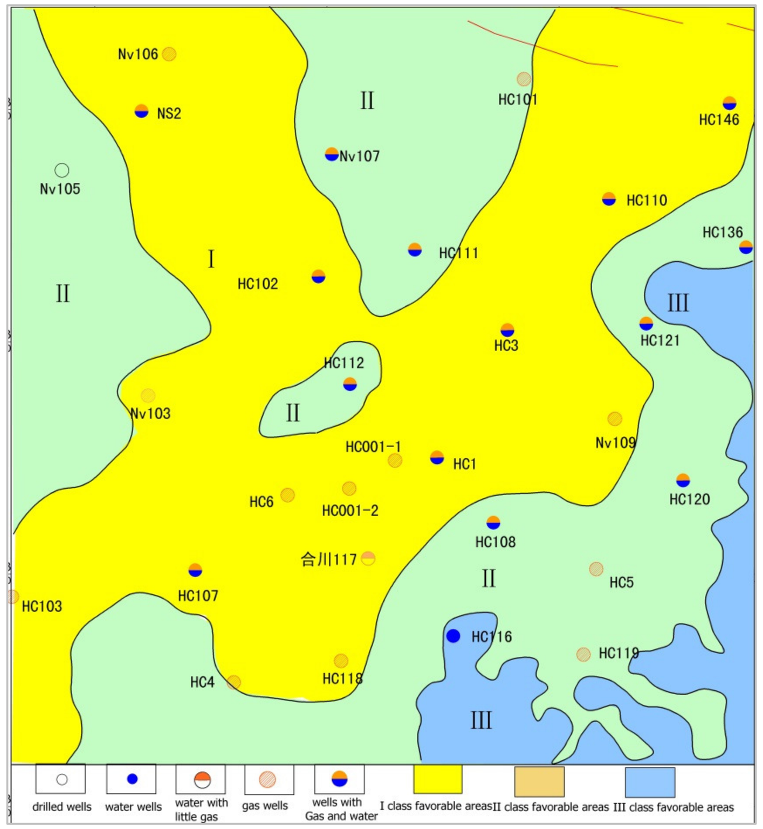
● **Analysis of multi-stacked maps**

Stacked comprehensive evaluation map of Xu 2 Member in Hechuan area



● **Reservoir classification and evaluation**

Comprehensive evaluation map of gas reservoirs in Xu 2 Member, in Hechuan



● **Stacked map consists of distribution of Perm and thickness of reservoir from facies-restrained stochastic simulation ,thickness of dissolution and in-situ pressure resistance**

● **Three types of the favorable reservoirs is divided**

● **Distribution of the favorable reservoirs is controlled by Channel or mouth bar and thickness of dissolution , fractures can improve the physical properties of reservoir to some extent**

Presentation Outline

1. Background
2. Methods and Results
3. **Conclusion and Discussion**

3. Conclusions and Discussion

Conclusions

- Our adopted methods is restricted and there are many places to deepen and improve due to limited data.
- Critical factors needed to be considered when choosing the prediction methods of gas reservoirs in the tight sandstones:
  - ✓ The geological setting of the studied area
  - ✓ The obtained data
  - ✓ Matching technologies applicable to the targeted area and picking out to do comprehensive prediction
- The following precedures should be paid more attention in study of tight sand gas reservoir
  - ✓ Subdivision and correlation of sand layers within sequence stratigraphic frameworks
  - ✓ Analysis of depositional microfacies and diagenesis
  - ✓ Prediction of reservoirs using combined wells and seismic data
  - ✓ Prediction of fractures

3. Conclusion and discussion

Discussion

- How to establish the 3D model of reserviors from the dissolution in a quantitative way?
- How to reduce the error of permeability between the predicted values from in-situ pressure resistance and from the logging when studying the fracture?

Energize, Harmonize, Realize.

Caring for energy, caring for you.