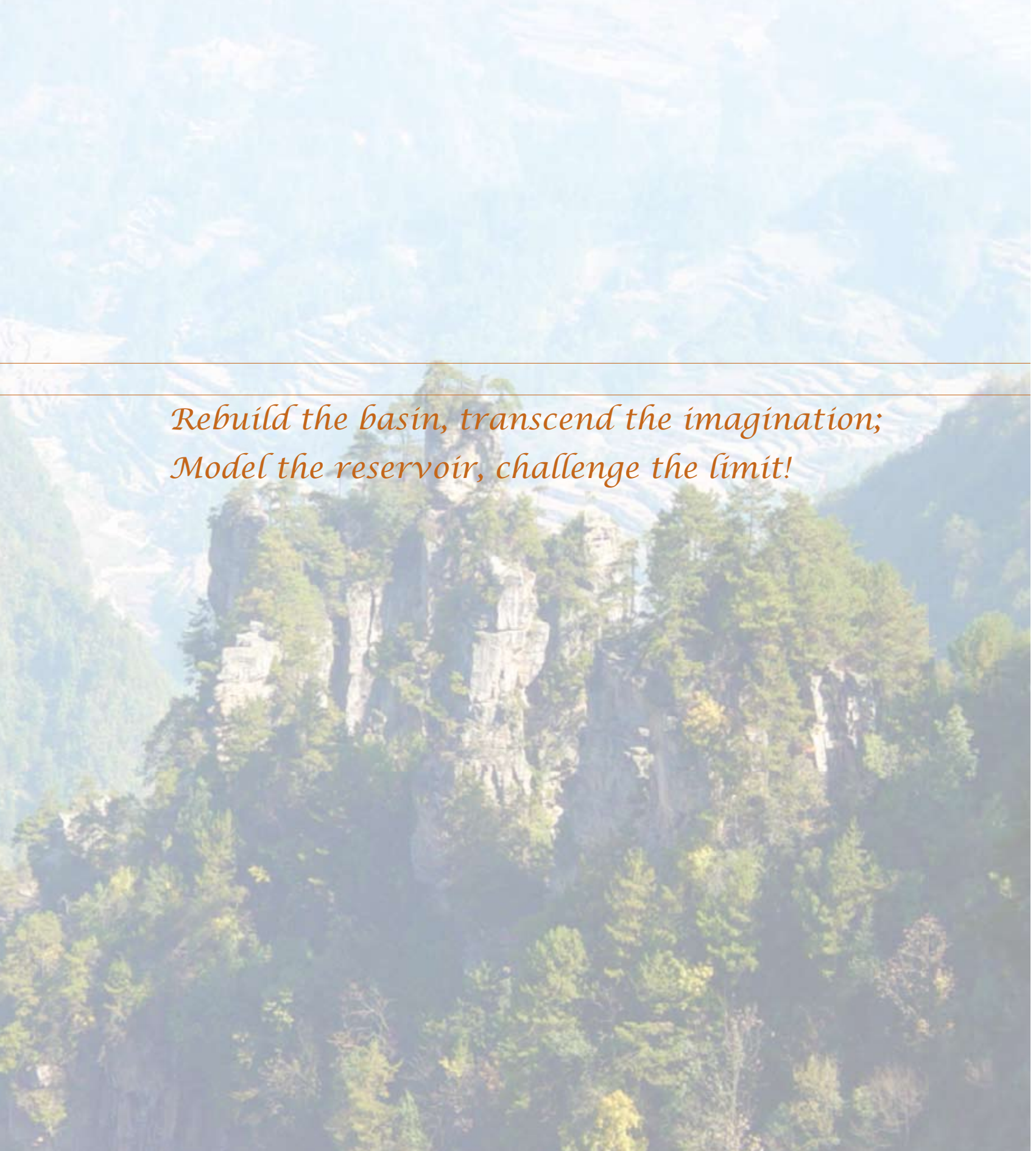
# Basin Integrated Modeling System

Science & Technology Management Department

2011

CHINA NATIONAL PETROLEUM CORPORATION



*Rebuild the basin, transcend the imagination;*
*Model the reservoir, challenge the limit!*

# Contents

China National Petroleum Corporation (CNPC) is a state-authorized investment agency and a state holding company. As an integrated oil company of cross-regions, cross-industries and cross-countries, it adopts modern enterprise system to realize the integration of upstream and downstream operations, internal and external trade and production and marketing. CNPC has 17 upstream companies, 33 downstream companies and 36 large-scale marketing companies. It is China's largest producer and supplier of oil and gas, and also one of the largest refined oil products and petrochemicals. In 2010 CNPC produced 105 million tons of crude oil and 72.5 billion cubic meters of natural gas, while crude processing volume reached 135 million tons. The total revenue of RMB1,720 billion with a profit of RMB172.7 billion had been achieved the same year. Its profit is among the highest of the domestic enterprises in China.

CNPC was ranked 10th in Fortune Global 500 in 2010 and 5th among global top 50 oil companies.

CNPC strictly follows by the combined strategies of increasing resource capacity, expanding market shares and consolidating the international role, and persists in regarding technical innovation as a key framework to advance technological progress. To develop its core businesses, focuses will be placed on the solutions of key bottleneck technologies and key proprietary technologies. Thanks to continuously improving of the technical innovation system, optimizing the configuration of technological resources and strengthening the construction of strong talent teams, CNPC's technological creativity has been considerably upgraded. Consequently, a large number of technologies have been developed independently, with its own intellectual property.

The Basin Integrated Modeling System (BASIMS) is one of representatives for major innovations of CNPC.

# 1 INTRODUCTION

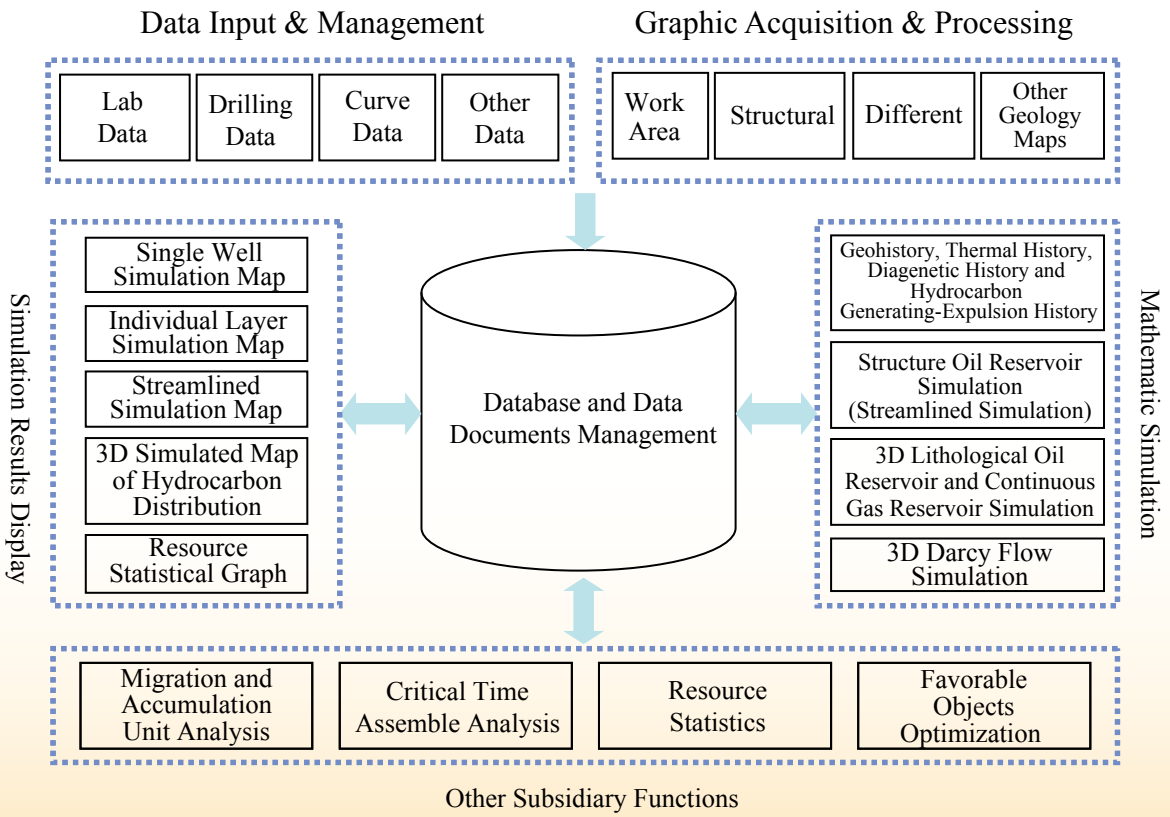
A set of basin modeling software, Basin Integrated Modeling System (BASIMS), was developed successfully by CNPC based on the research over 20 years. The BASIMS developed in step with the advanced level of similar international software since the beginning. So far, 223 sets of BASIMS were sold, which included 192 sets in CNPC, 13 sets in Sinopec, 3 sets in CNOOC, 11 sets in the former Department of Geology and Mineral, 3 sets in universities and one in Taiwan. BASIMS was widely used in petroleum resource evaluation, exploration and comprehensive geological research in China (such as the second national petroleum resource evaluation in 1992-1994, the third national petroleum resource evaluation in 2000-2003) and some overseas areas (such as Sudan) .

Different editions of BASIMS and the research achievements have won the state and provincial-level science and technology progress awards for many times, and BASIMS was promoted as the homemade unique software and the new technology by CNPC. The BASIMS research team has published more than 80 papers, 5 books and participated in the international academic exchange for many times, and the software enjoy higher reputation at home and abroad.

The latest edition of BASIMS 2009 is the integrated system of data processing & management, reservoir interactive modeling & viewing and comprehensive analysis. It is the most important research platform for reservoir comprehensive evaluation and petroleum resource evaluation. The core technologies include: (1) the traditional simulation of geohistory, thermal history, diagenetic history and hydrocarbon generating-expulsion history; (2) the streamlined simulation to structural reservoir; (3) the conventional 3D simulation to the lithological reservoir development; (4) the non-conventional 3D continuous gas reservoir simulation; (5) the classical 3D Darcy flow simulation, etc.

The major functions of BASIMS 2009 are geohistory simulation, geological resource evaluation, hydrocarbon location forecast, favorable play optimization as well as supplying the important parameters and geological basis for drilling disposition.

Modules of Data Input and Management, Graphic Acquisition and Processing, Mathematic Simulator, Results Display and other subsidiary functions were included in BASIMS 2009. The module of Mathematic Simulator includes the geohistory simulation, thermal history, diagenetic history and hydrocarbon generating-expulsion history, streamlined modeling and continuous gas reservoir modeling method, etc.




System Function Diagram

# 2 Function of Modules

## 1. Design and Construction Techniques

Buried history simulation: Multistage simulation method is used to recover the primeval formation characteristic, such as thickness and primeval porosity at the beginning deposition, to rebuild the porosity variation and denudation during the course of buried history.

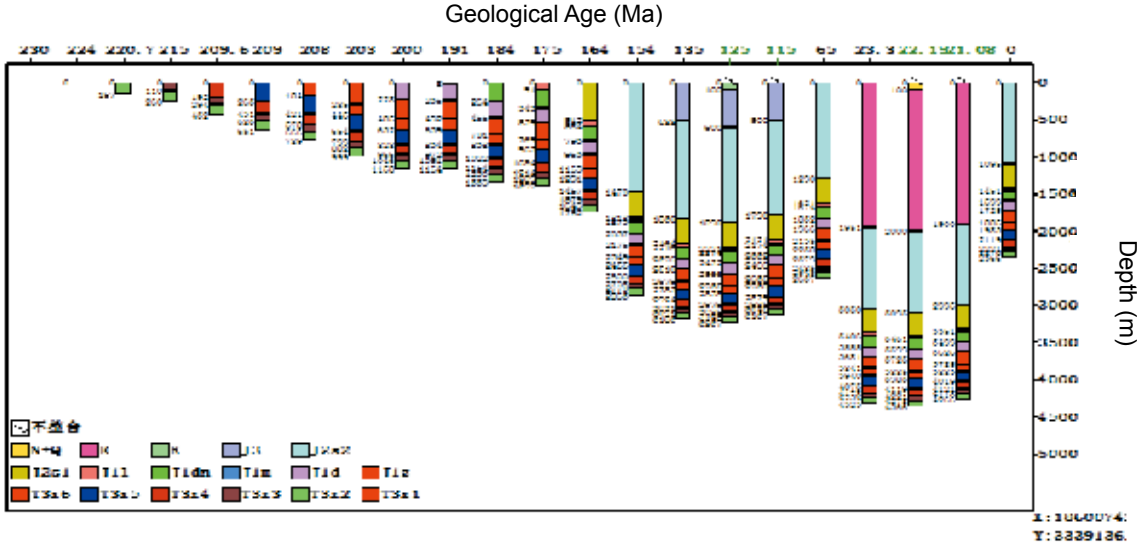
- Subsidence history simulation: Airy's isostatic model is used to simulate the history of tectonic subsidence, load subsidence and total subsidence accurately.
- Structural evolution simulation: Balanced section recovering method is used to recover the tectonic characteristic and evolution of main profiles.

## 2. Geothermal History Module

- The simulation of geothermal history and organic material evolution: The method of multi-index inter-calibration is used to simulate the geothermal evolution and Ro history of depositional basin.
- Denuded thickness calculation: The method of interactive modeling is used to calculate denuded thickness in important denudation stage based on accurate evolution value of geothermal gradient and paleoheat flow in the sedimentary basin.

## 3. Diagenetic History Module

- Single factor simulation: To simulate diagenetic evolution index such as quartz overgrowth, transformation from montmorillonite to goeschwitzite and kerogen acidific quantity, etc.
- Diagenetic stage evaluation: To evaluate




Stripping Column (Well Hechuan 123)

diagenetic history and stage of different formations based on the comprehensive evaluation standard which is given by specialists, and this evaluation will provide important parameter for the research of reservoir and sandstone induced porosity variation.

## 4. Hydrocarbon Generation Module

• Hydrocarbon generation history simulation: The methods of oil/gas generation ratio, degradation ratio or chemical kinetics are used to simulate the hydrocarbon evolution and source rock generation history. Some important evaluation indexes are included in the simulation, such as hydrocarbon generation quantity and hydrocarbon generation summit, etc.

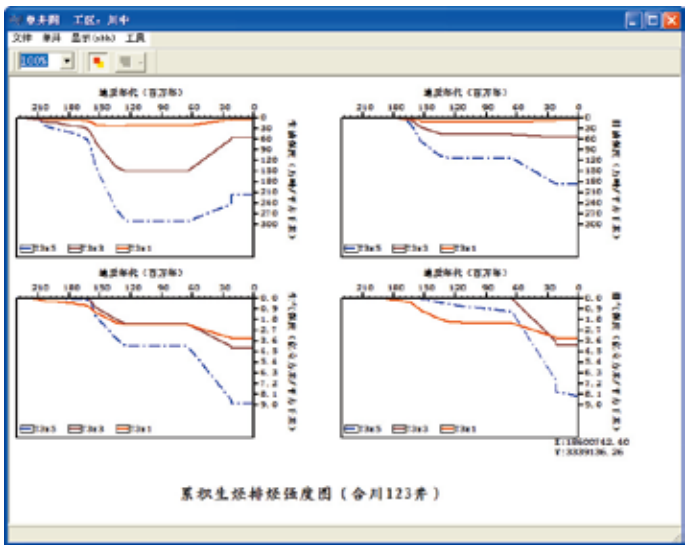
## 5. Hydrocarbon Expulsion History Module

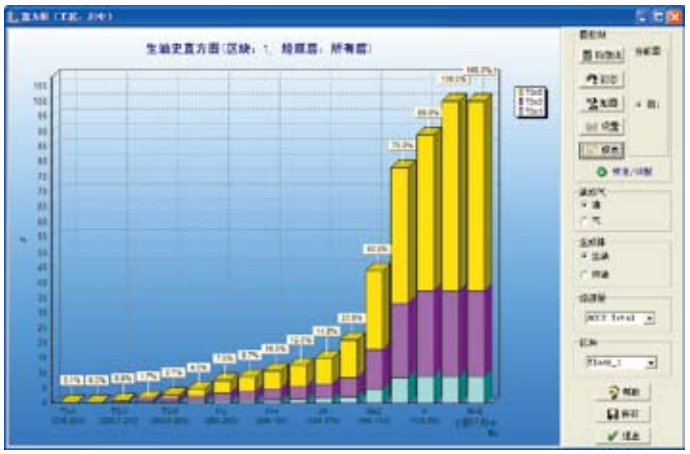
• Hydrocarbon expulsion history simulation: The methods of compaction oil expulsion and material balance gas expulsion are used to simulate the source rock hydrocarbon expulsion history. This simulation will provide some important parameters such as sedimentary basin's total hydrocarbon expulsion quantity, expulsion efficiency, expulsion summit and expulsion center distribution, etc.

## 6. Migration and Accumulation History Module

• Streamlined simulation: The method of buoyancy-driven flow is used to simulate oil/gas migration in structural reservoir, trap charging and accumulation location.

• Lithologic trap charging simulation: To track and determine the lithologic traps with efficient passageway to source rocks based on reservoir physical properties; to simulate the trap charging passageway and charging quantity.

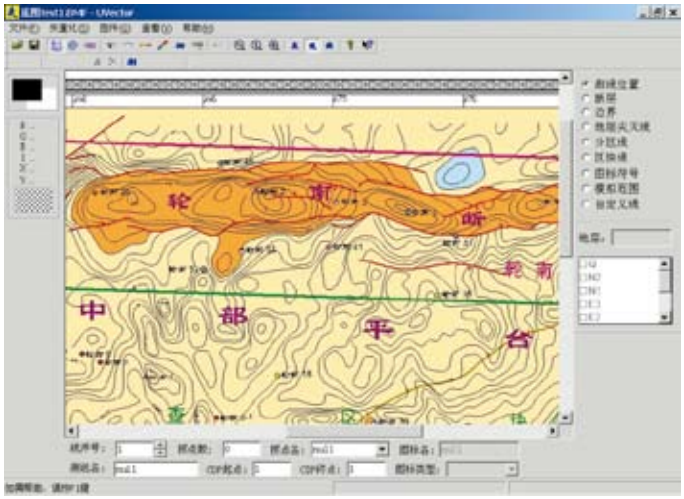




• Continuous gas reservoir simulation: To simulate the distribution and resource of continuous gas reservoir with over-pressured driven model based on piston charging characteristic and source rock gas pressure addition calculation.

• Typical 3D and 3-Phase simulation: the sum and balance of different forces (buoyancy, capillary force and viscous force) were considered in the simulation, and it describes the oil/gas/water migration course from source rocks to traps and quantitatively simulates the accumulated amount available.

# 3 Unique Technologies



Working area base map vectorization

## 1. Two Schemes of Formation Framework Building

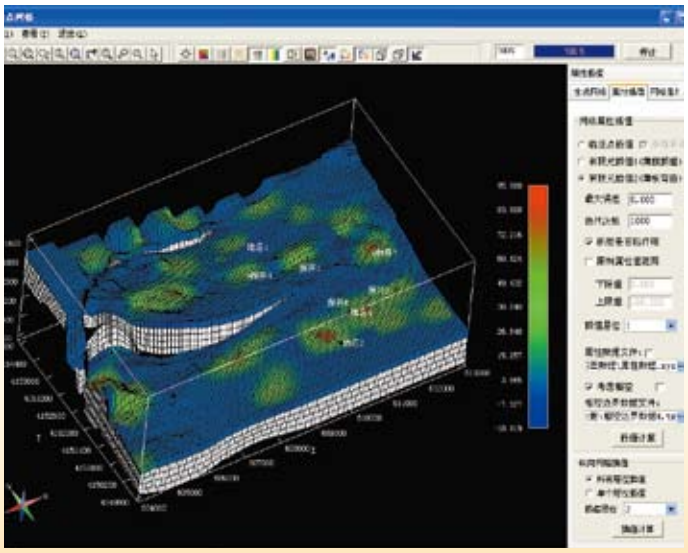
### 1.1 The scheme used in the area of high-degree exploration

To build formation framework on drilling individual layer data, that is, to build the regional formation framework quickly based on the construction of drilling individual layer database. The framework will provide the solid geological model for mathematic calculation.

### 1.2 The scheme used in the area of low-degree exploration

To build formation framework based on structural maps. More clearly, by building the standard data structure based

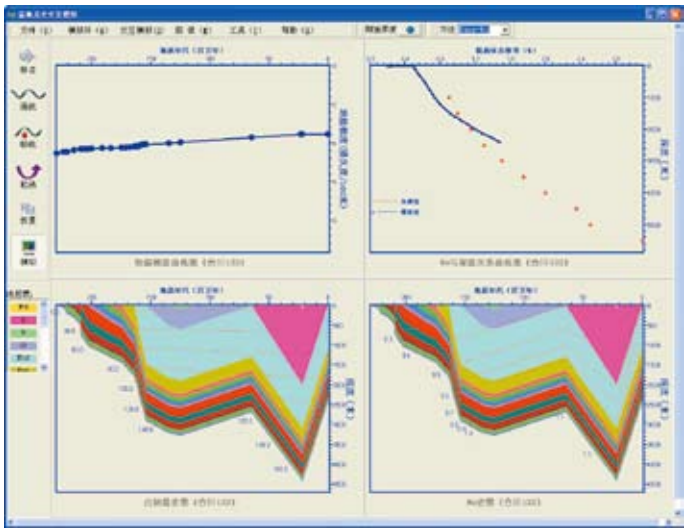

Isoline input with different formats



Build formation framework

on graphic data collection and digitization, simulating the artificial well network and interpolating relevant parameters, to build the regional formation framework with incomplete data. Besides, this can provide the reasonable geological model for mathematic calculation.

## 2. Technology of Interactive Simulation and Batch Simulation



• Technology of interactive simulation

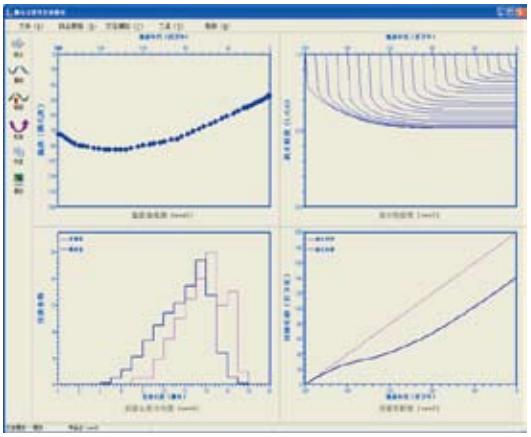
To meet the requirement of parameter quick adjustment, typical well fine simulation and special object simulation.

• Technology of interactive simulation and batch simulation

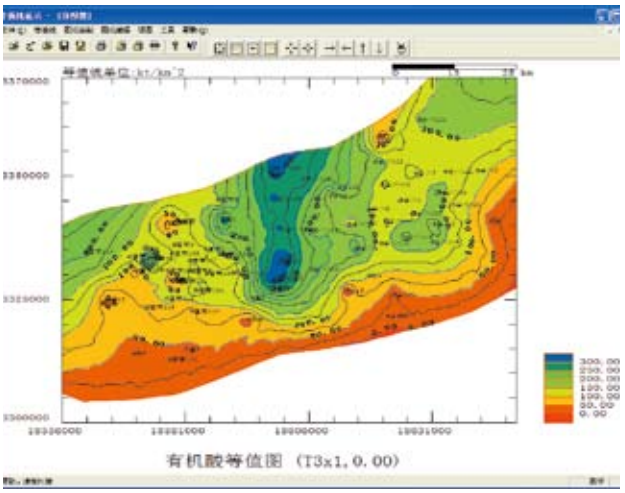
To meet the requirement of large-scale calculation in exploration and production

## 3. Simulation Technology of Geothermal History and Diagenetic History

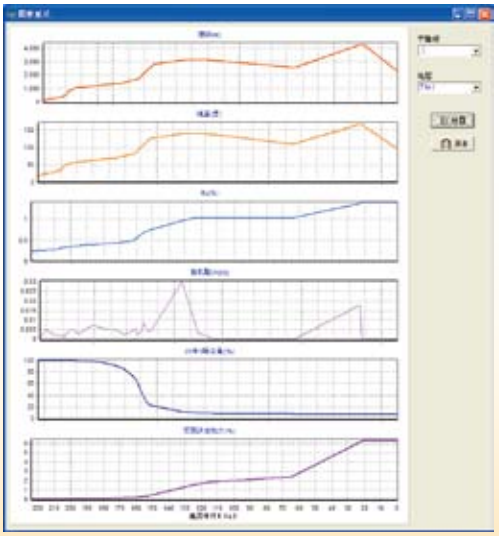
This technology can provide different thermal evolution models, diagenetic evolution parameter simulation models and comprehensive evaluation methods of diagenetic evolution stages.



Thermal Evolution Simulation on Apatite Fission Track




Kerogen Acidific History Simulation

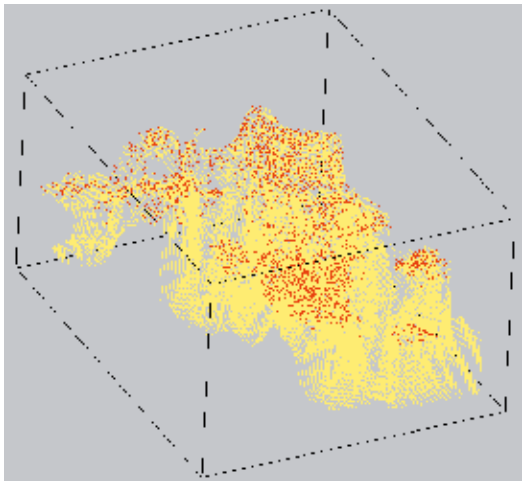


Single factor simulation results of geothermal history and diagenetic history

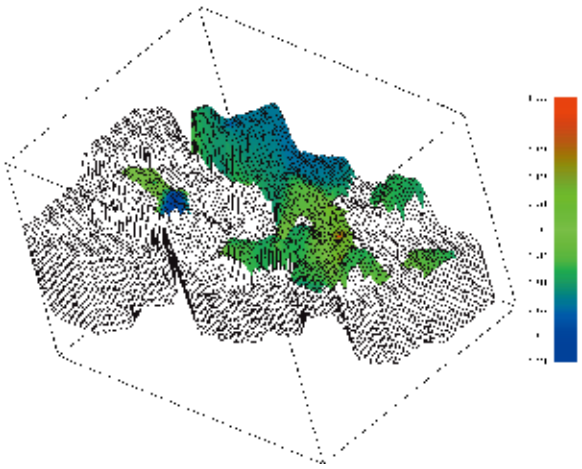
Diagenetic stage evaluation parameter standard and evaluation results of different formations

## 4. Simulation Technology of Oil/Gas Charging in 3D Lithologic Traps

This technology can automatically track reservoirs with passageway back to source rocks based on reservoir characteristics, delineate efficient lithologic traps and simulate the charging passageway and charging quantity of traps to guide the exploration of lithologic traps.



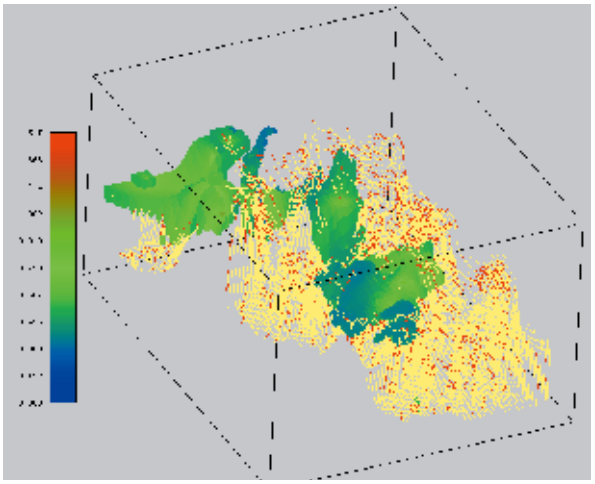
Simulation result of gas charging passageway



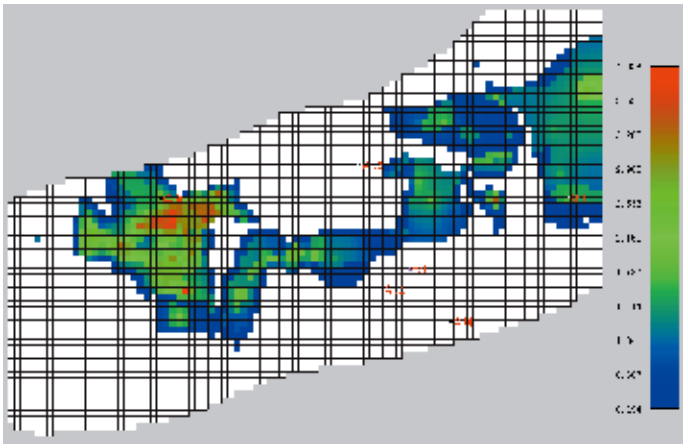
Simulation result of gas charging history

## 5. Simulation Technology of Continuous Tight Sandstone Gas Reservoir

The continuous gas reservoir has no close relationship with water head and gas buoyancy in water and it has no obvious contact surface of bottom water and edge water. We can see the inversion phenomenon between gas and water in continuous gas reservoir which was not organized



Simulation result of gas charging passageway and gas accumulation



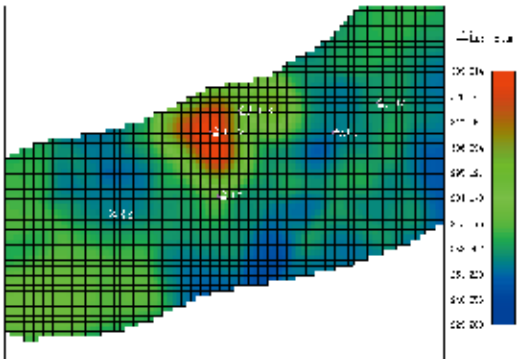
Simulation result of gas resource abundance

by many scattered gas reservoirs with independent boundary. Therefore, the traditional forecast method for discrete gas reservoir scale and number is not useful for continuous gas reservoir.

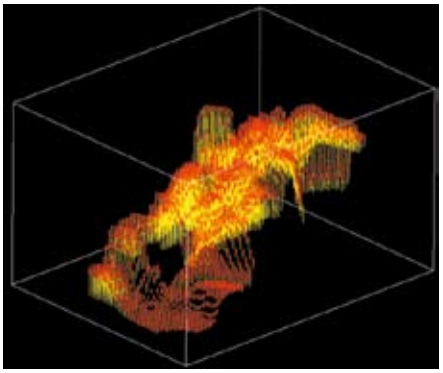
Over-pressured driven model is used successfully in BASIMS 2009 to simulate the distribution and resource of continuous gas reservoir based on reservoir characteristics and the reckoning of the amount of pressurization from gas generation of source rocks.

## 6. Streamlined Simulation Technology of Tectonic Reservoir

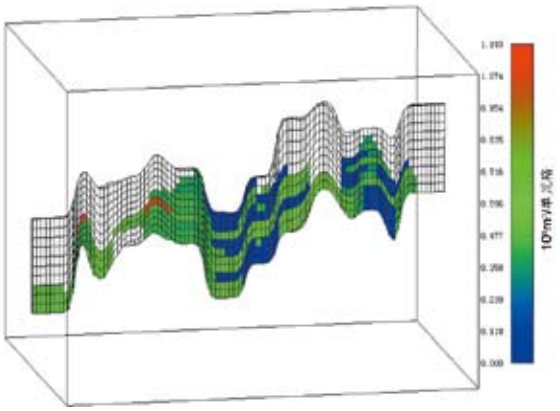
There are many difficulties in simulation with the method of strictly fluid mechanics, even poor geological results produced, for it is difficult to select accurate geological parameters and the control factors of oil/gas secondary migration are complicated. Hence, those complicated factors should be simplified. Streamlined Simulation



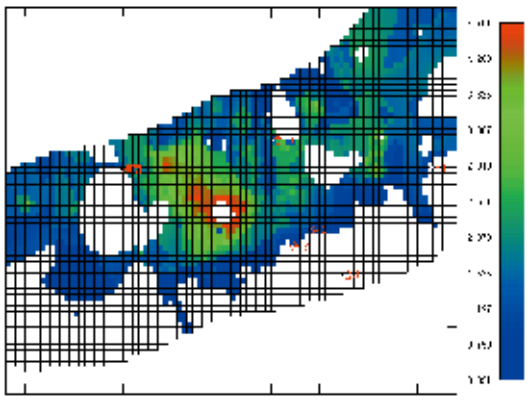
Simulation result of gas charging pressure



Simulation result of gas charging passageway

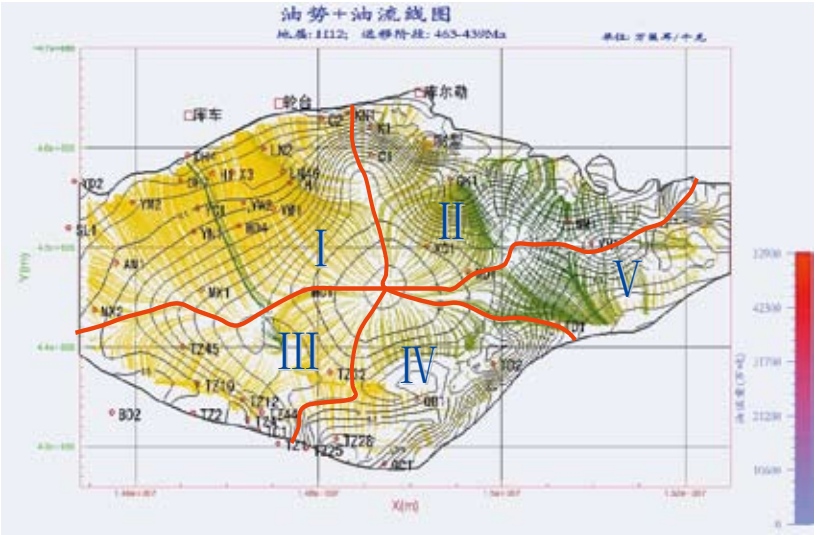


Simulation result of gas accumulation quantity (slice map)

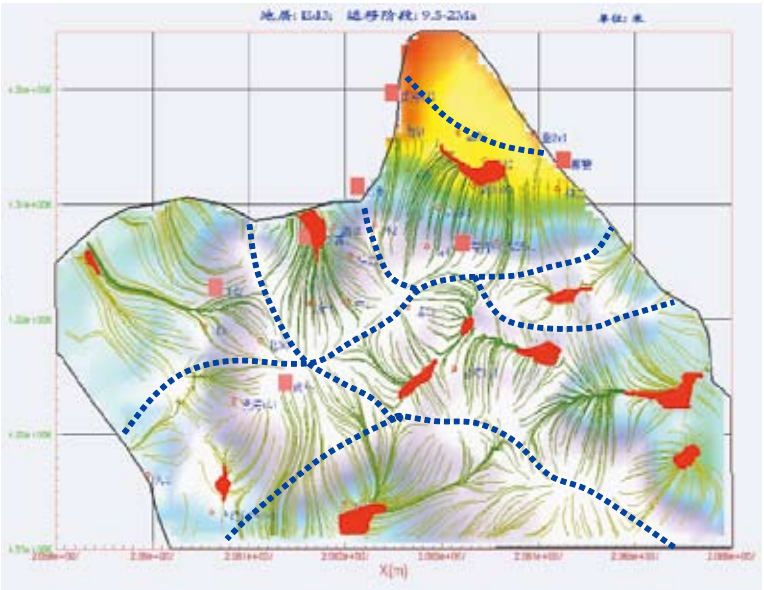


Continuous tight sandstone gas resource abundance

Technology is a simple rapid and illustrative technology in the research of fluid heading and regularity. In recent years, it has become one of the unique technologies in basin modeling software.




Migration and accumulation units division of petroliferous system

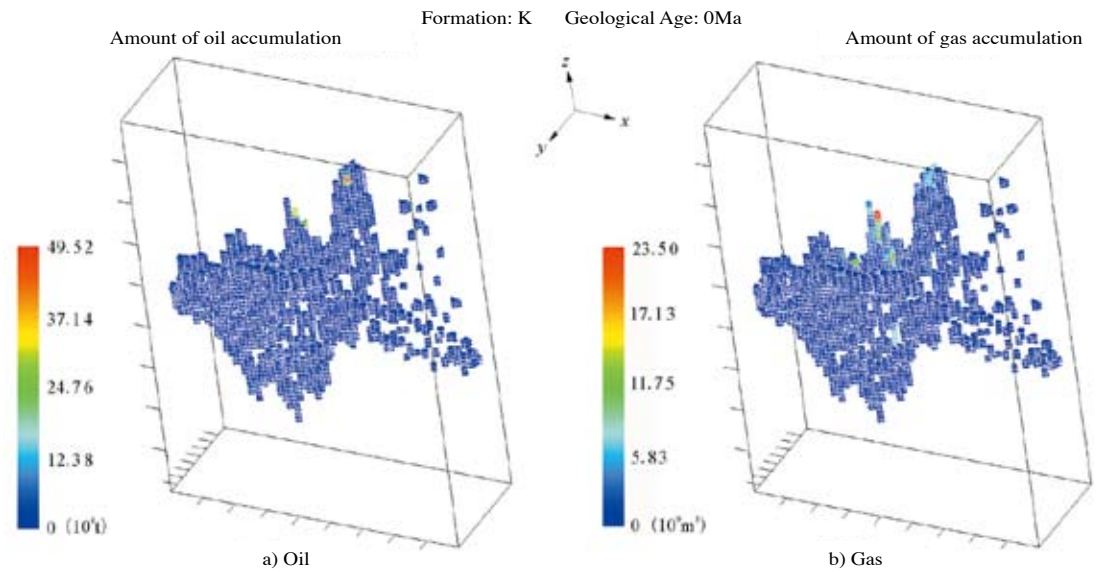


Simulation result of gas migration and accumulation

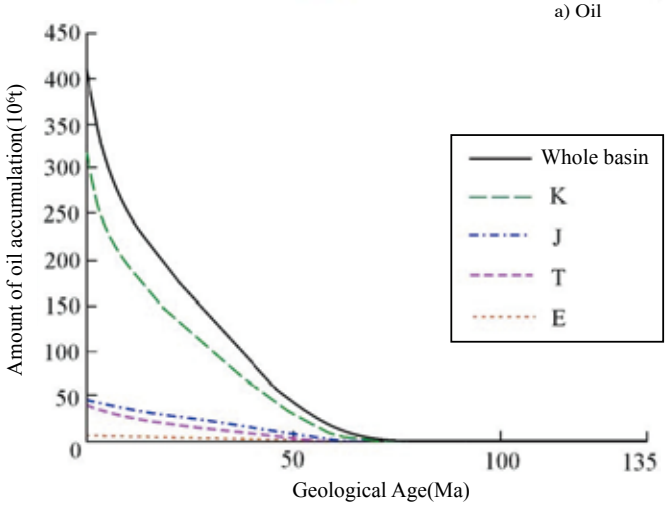
The simulation results of geohistory, geothermal history, diagenetic history, hydrocarbon generation and expulsion history and the advantages of 3D visualization technique are used successfully in BASIMS 2009 to simulate the oil/gas migration in tectonic bedding. It will provide important parameters for prospect evaluation and hydrocarbon potential forecast.

## 7. 3D and 3-Phase Darcy Flow Simulation Technology

Multiphase Darcy Flow Simulation Technology is the most complicated and earliest method in several hydrocarbon migration and accumulation technologies. The sum and balance of different forces (buoyancy, capillary force and viscous force) are considered in the simulation, and it describes the oil/gas/water migration course from source rocks to traps. This technology is regarded as "pure physical method" and "main technology".




a) Oil b) Gas




a) Oil accumulation quantity of Cretaceous in Kuche Depression (present), 318 million tons.

b) Gas accumulation quantity of Cretaceous in Kuche Depression (present), 1689.9 billion $m^3$.

c) Oil accumulation quantity of different formations.

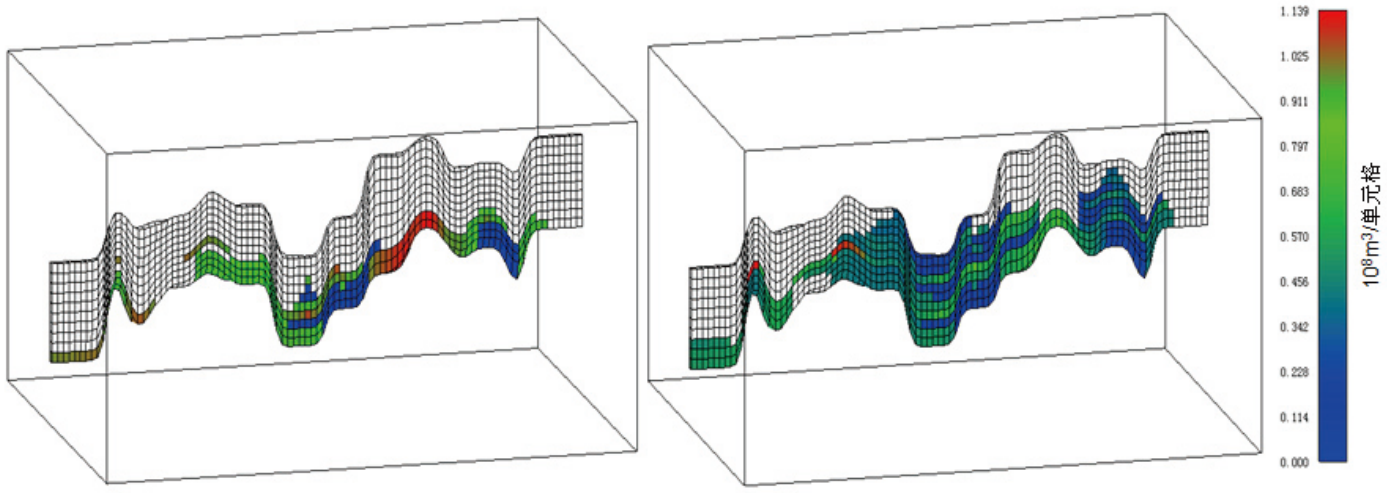
# 4 Typical Cases

## 1. Tight Sandstone Gas Reservoir in Xujiahe Formation of Sichuan Basin

Hechuan-Tongnan region of Sichuan Basin is the simulation area with effective area 3,855km$^2$. It is 92km from east to west and 70km from south to north. The target is second member of Xujiahe Formation in upper Triassic ($T_3x_2$) with depth 2060~2420m, the absolute altitude is about -1760 ～ -2120m and the thickness is 76~140m. The first member of Xujiahe Formation ($T_3x_1$) is source rock with thickness less than 50m. The third member of Xujiahe Formation ($T_3x_3$) is seal layer with thickness 40~110m. There are 34 industrial gas wells among the total 64 wells in the area by the end of 2008. Hechuan-1 gas field and Tongnan-2 gas field were discovered with reserves of 234 billion m$^3$. Hechuan gas reservoir is the typical tight sandstone gas reservoir with average porosity less than 10%, the main permeability is less than $0.1\times10^{-3}$μm$^2$and the average pore throat diameter is less than 1μm.

Research results show that the main distribution positions of discovered gas reservoir are relatively high parts which were controlled mainly by buoyancy. The key points of following exploration are gas reservoir distribution and the prospect of tight sandstone with low porosity and low permeability in low structural parts.

Basin modeling results show that the second member of Xujiahe Formation has experienced four stages: rapid deep burial, uplift, deep burial again and uplift again. The second member of Xujiahe Formation has completed the period of compaction and diagenetic stage before Jurassic,

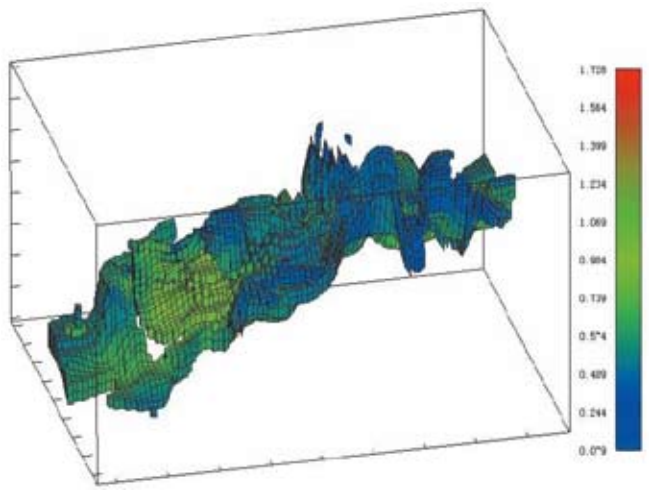



Simulation result slice map of gas accumulation quantity in different key stages (the left is 65Ma, the right is 0Ma)

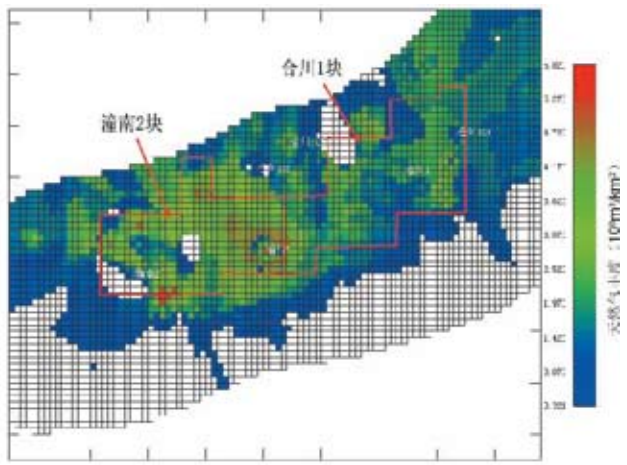
the beginning age of gas generation in first member of Xujiahe Formation is late Jurassic, the summit age is Cretaceous, and the end age is early Cenozoic. The main oil/gas accumulation age is middle and late Cretaceous, and the main gas accumulation occurred after sandstone compaction.

BASIMS 2009 is used to quantitatively simulate the resource distribution of tight sandstone, based on the geological model of "first compact and then accumulation" and the non-buoyancy driven characteristic of tight sandstone gas reservoir. The simulation results show that:

- The coincidence rate of reserve forecast in the discovered Block Hechuan-1 and Block Tongnan-2 is up to 88% which means that the forecast model is reasonable.
- Half of the gas resource in the area is still to be discovered. The main distribution area is in northeastern Hechuan, northern and southeastern Tongnan. This result points out that the later exploration direction is continuous tight sandstone gas reservoirs.



Simulation result of continuous tight sandstone gas reservoir

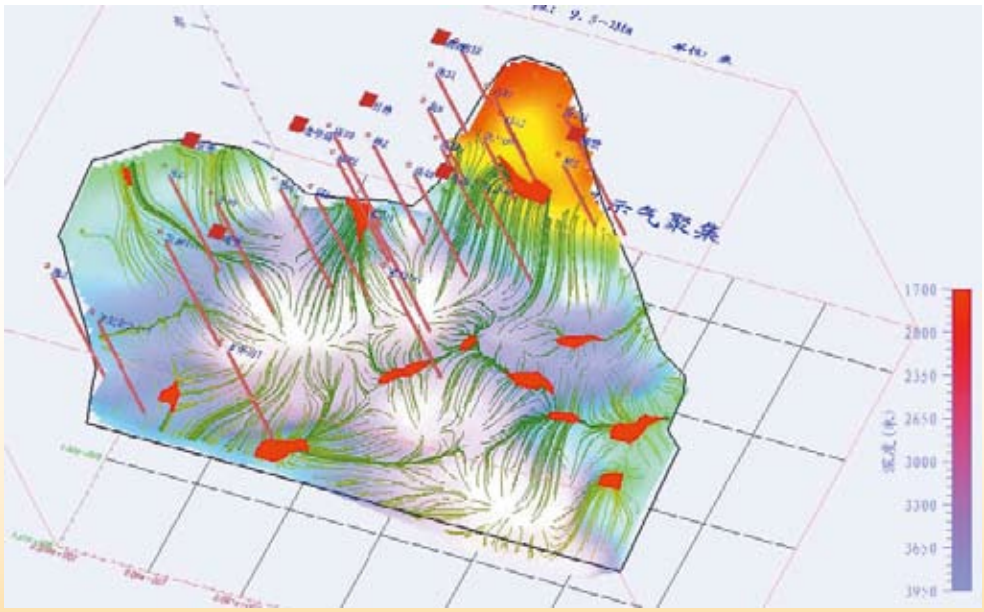



Cumulative resource abundance of continuous gas and conventional gas

## 2. Oil reservoir of Dongying Formation in Nanpu Depression, Bohao Bay Basin

Nanpu Depression lies in the northern Bohai Bay Basin which is a small-size prolific depression with area 2,462km2. The geographical position is between Qinhuangdao and Tangshan of Hebei Province. Several inland oil fields such as Gaoshangbao, Liuzhan, Laoyemiao and Beibao were discovered by the end of 2004. The statistical data shows that 224 exploration wells drilled into or through the layer Ed1, which includes 34 production wells and 190 dry wells.

The key point of following exploration is how to simulate and forecast the beach resource distribution based on the data of inland oil field. Based on the results of hydrocarbon generation intensity simulation and streamlined simulation of oil/gas migration and accumulation in 2005, the Nanpu Depression was divided into nine evaluation units: Beipu structural belt, Laoyemiao structural belt, Gaoshangpu-Liuzan structural belt, Hatuo buried-hill drape structural belt, Laopu buried-hill drape structural belt, southwest fault step structural belt, Nanpu fault anticline structural belt, Matouyin uplift and Xinanzhuang-Baigezhuang uplift. The beach area has the largest exploration potentiality based on the resource and distribution calculation in different evaluation units, and the remained resource accounts for 55.23% of the total resource. The simulation results guide the oil/gas exploration in beach area.



# 5 R&D Equipment

Research Institute of Petroleum Exploration & Development (RIPED) of CNPC has excellent research and lab environment. It has 64 labs (including one national and 7 CNPC's key labs) and more than 400 sets of advanced and large-scale research and experiment equipment with advanced computer hardware, the relevant software and strong network system such as IBM SPII(48CPU)large-scale parallel computer and virtual reality system, etc.

The oil/gas resource evaluation system, especially the BASIMS, can provide the customers at home and abroad:

Resource evaluation of conventional and non-conventional oil/gas with different exploration degrees;

Resource evaluation methods and parameter system for different prospecting targets;

Resource evaluation basic data support and database building;

Package of evaluation software service from basin, petroliferous system, region to trap.

# 6 Expert Team

**Shi Guangren** (Professor-level senior engineer) As a qualified specialist of computer application in petroleum and basin modeling, he has long been responsible for and directly participated in different quantitative geological research projects. He is the head and core researcher of BASIMS's earlier versions. He was awarded "Sun Yueqi Energy Award" and "National Science and Technology Advancement Award" and enjoys the government's special allowance. He has published 42 research papers and 6 monographs.

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**Li Jianzhong**(Doctor, senior engineer) He has long been engaged in petroliferous basin tectonic analysis, comprehensive geological evaluation and research of exploration, and undertaken many research projects. He put forth the resource analogy method in lithologic oil/gas reservoir belt based on the systematic research of the resource potentiality in the petroliferous basin and exploration areas in homeland, and the method was used in the last national resource evaluation. He has published 12 research papers and 3 monographs.

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**Guo Qiulin**(Doctor, professor-level senior engineer ) He has long been engaged in the research of oil/gas resource evaluation such as basin modeling, region and trap evaluation, resource distribution forecast, etc., and now assumes the senior manager of the present BASIMS. He was awarded the "National Science and Technology Advancement Award" and has published 50 research papers and 4 monographs.

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**Zhang Qingchun** (Doctor, professor-level senior engineer) Oil/gas resource evaluation specialist. He has long been engaged in basin analysis and oil/gas resource (incl. non-conventional oil/gas) evaluation research and postgraduate teaching. He is responsible for many projects about the promotion and application of BASIMS as well as postgraduate teaching work. He has published more than 50 research papers and 8 monographs.

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**Mi Shiyun** (Doctor, senior engineer) As an expert long engaged in basin modeling software research and promotion, he assumes the main leader of previous basin modeling system (BASIMS workstation version). He has published more than 10 research papers and 4 monographs.

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**Xie Hongbing** (Doctor, senior engineer) As an expert long engaged in basin modeling software research and oil/gas resource evaluation, he takes charge of software development and application in BASIMS.

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**Chen Ningsheng** (Senior engineer) As a specialist of software development and test, he is primarily engaged in grid modeling and computer research. He is one of the main researchers for 3D module in BASIMS.

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**Ma Jinshan** (Senior engineer) He is mainly engaged in basin modeling software transplant, development and test.

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