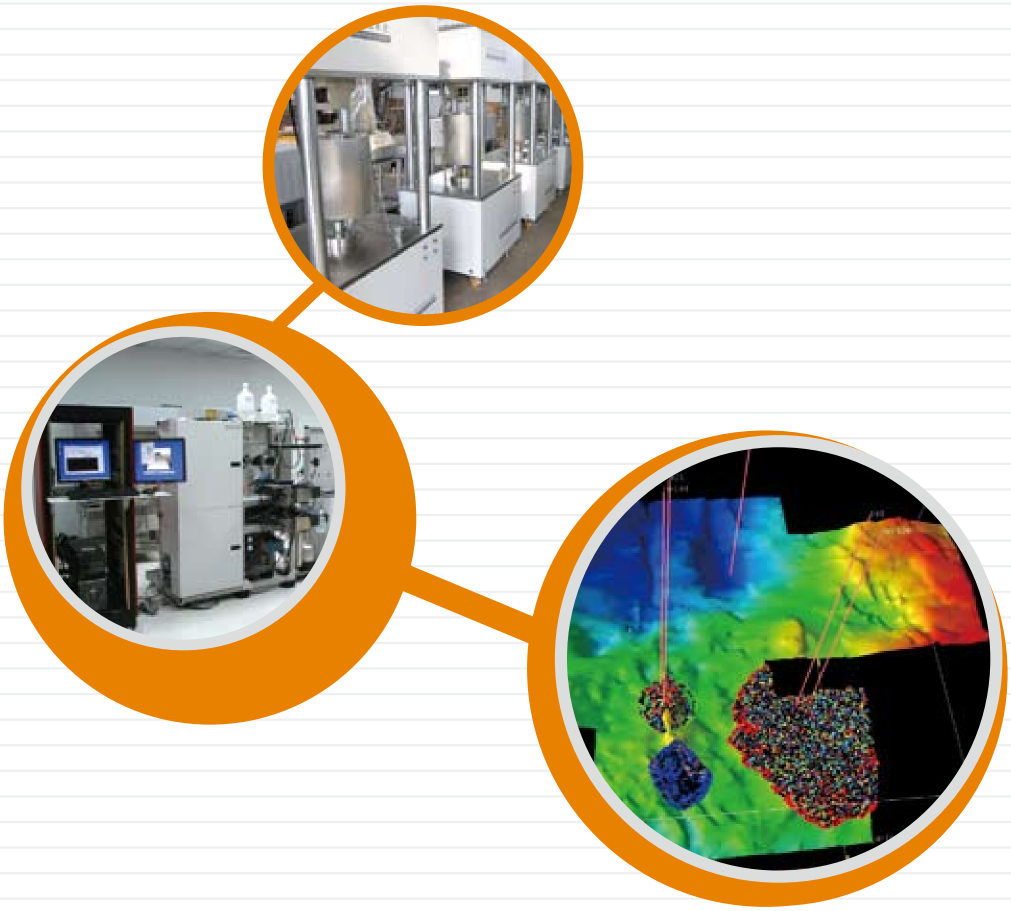
Exploration Evaluation Technology for Lithostratigraphic Reservoir

Science & Technology Management Department

2011



CHINA NATIONAL PETROLEUM CORPORATION

CNPC stands as the Navigator of the Exploration Evaluation Technology for Lithostratigraphic Reservoir!

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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.

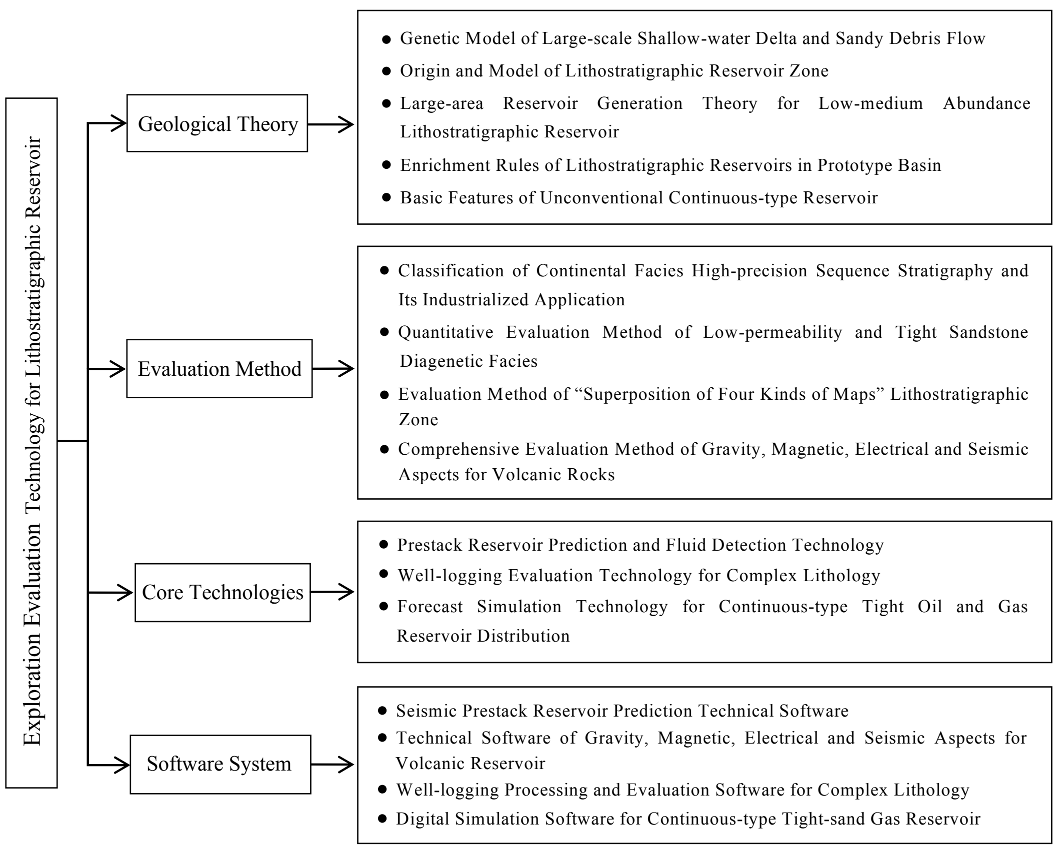
CNPC strictly follows by the combined strategies of increasing resource capacity, expanding market shares and consolidating the international role, and persists in regarding technical innovation as a key framework to advance technological progress. To develop its core businesses, focuses will be placed 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 Exploration Evaluation Technology for Lithostratigraphic Reservoir is one of representatives for major innovations of CNPC.

1 Introduction

CNPC has organized actively to tackle the key problems with respect to geologic theories of lithostratigraphic reservoir and exploration technologies, and made great theoretical breakthroughs and technical innovations. Thus, CNPC had the honour to win the first prize of "National Science and Technology Progress Award" in China in 2007. Meanwhile, CNPC has published 2 relevant monographs and 30 more research papers, applied for 9 national patents for invention and obtained 3 sets of software copyrights.

The Exploration Evaluation Technology for Lithostratigraphic Reservoir, mainly composed of Geological Theory, Evaluation Method, Core Technologies and Software System, is a significant guarantee for fast evaluation, exploration of scale and growth of reserves in lithostratigraphic reservoirs.



1. Geological Theory of Lithologic Reservoir

In recent years, CNPC has carried out pertinent scientific and technological projects about lithostratigraphic reservoirs, made important breakthroughs, opened up new prospecting domains and directed the prospecting deployment of lithostratigraphic reservoirs and discovery of new reservoirs.

1.1 Genetic Model of Large-scale Shallow-water Delta and Sandy Debris Flow

The Genetic Model of Large-scale Shallow-water Delta and Sandy Debris Flow has been established, which extend the exploration domain in the centre of lake basin and represents a great exploration breakthrough. Meanwhile, large-scale reserves are attained in the explorations of lake basin center in Ordos, Songliao Basin.

(1) The genetic model of shallow-water delta in large down-warped lake basin is established (Figure. 1), which reveals the dynamic mechanics of the widely distributed underwater distributary channel sand bodies in the centre of lake basin.

1.2 Formation Mechanism and Distribution Rules of Low-permeability and Tight Sandstone, Carbonatite and Volcanic Reservoirs

(1) The formation mechanism of large-area low-permeability and tight sandstone is revealed, and the distribution rules of favorable reservoirs are made clear.

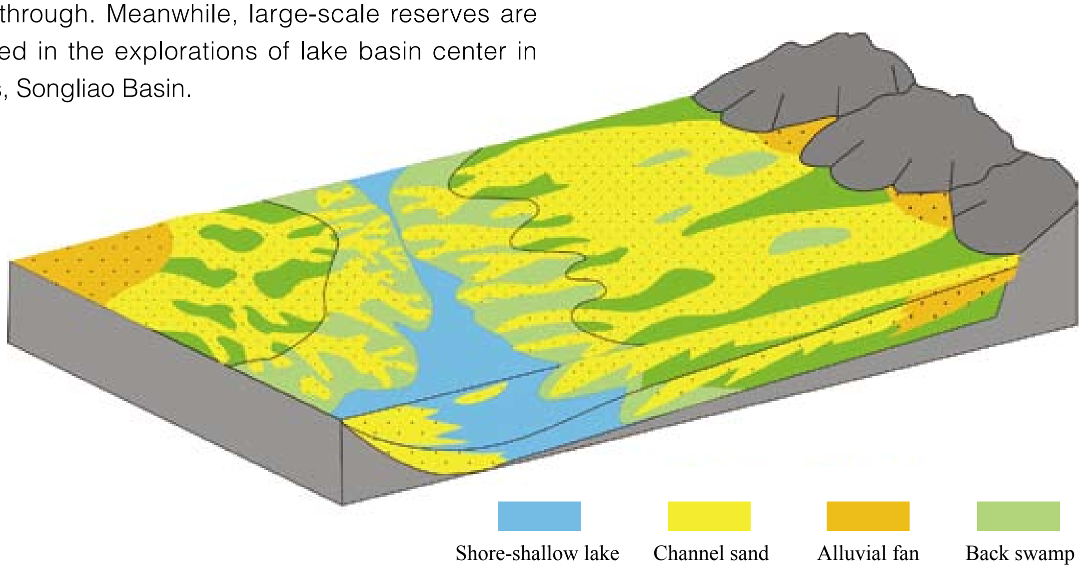


Figure 1 Depositional model of shallow-water delta in Chang 8 of Yanchang Formation in Ordos Basin

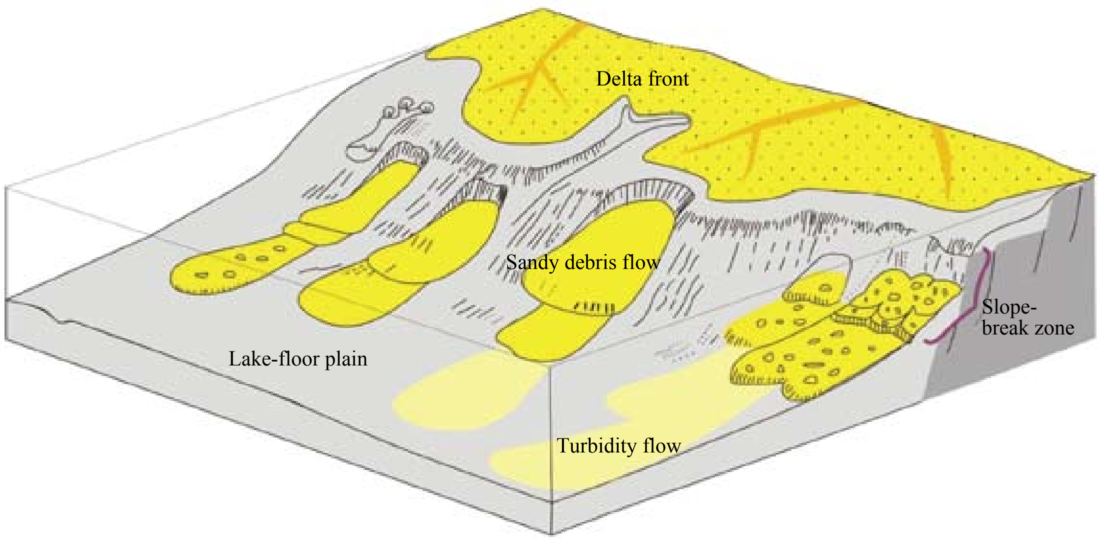


Figure 2 Depositional model of Mesozoic sandy debris flow in Ordos Basin

(2) CNPC lays the foundation for determining the distributions of hydrocarbon source rocks and favorable reservoirs of reef flat, evaluation of oil and gas resources' potentiality and selection of favorable zones, via the fine depiction of the marine carbonate platform margin, refinement of the platform's internal structure as well as researches in lithofacies paleoreconstruction, multi-phase superimposed reformation mechanism of carbonatite reservoirs, origin classification of karst reservoirs, heterogeneous carbonatite reservoir description and evaluation technologies, etc.

(3) The formation mechanisms of weathering-crust and primary-type volcanic reservoirs are revealed, and the distribution rules of the effective volcanic reservoirs are confirmed.

1.3 "Structure-sequence" Play Theory

(1) The concept of lithostratigraphic reservoir zone of structure-sequence play is proposed.

(2) The classification principle for lithostratigraphic reservoir zone based on structure-sequence play is proposed.

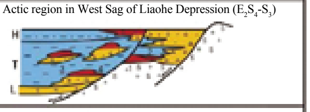
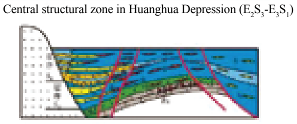
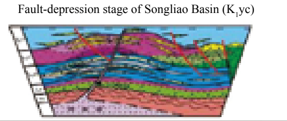
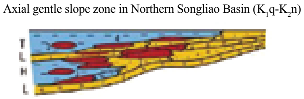
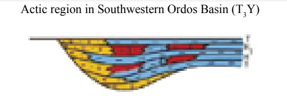
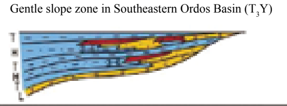
The classification principle for lithostratigraphic reservoir zones: 1. to highlight the tectonic setting of zone formed; 2. to highlight the features of sequence stratigraphic texture, types of reservoirs and traps for the main exploration layer system; 3. to highlight the master control factors and distribution rules for oil and gas migration, accumulation and reservoir generation.

(3) 14 kinds of structure-sequence play models for four types of onshore basins are established.

14 kinds of structure-sequence plays are established (Figure 3) via the systematic dissection of main oil and gas-enriched zones in four types of China's onshore prototype basins (i.e. continental facies fault depression, depression, foreland and marine facies craton).

1.4 New Classification Scheme for Lithostratigraphic Trap

Ten control factors for the formation of "six lines" and "four planes" lithostratigraphic traps are revealed (Figure 4).

Basin type	Tectonic setting		Structure-sequence play	Typical examples
Fault depression type	Steep slope		Play of steep slope fault terrace—lake transgression and high-position fan delta, subwater fan	Actic region in West Sag of Liaohe Depression (E_2S_4-S_3) 
	Gentle slope		Play of multi-fracture system's gentle slope—lake transgression and high-position braid river delta, subwater fan	Gentle slope zone in West Sag of Liaohe Depression (E_2S_4-S_3) 
	Central structural belt		Play of multi-central structural zones—lake transgression and high-position fan delta, subwater fan	Central structural zone in Huanghua Depression (E_2S_3-E_3S_1) 
	Deep fracture zone		lay of deep fracture zone—explosive eruption and overflow facies	Fault-depression stage of Songliao Basin (K_1yc) 
Depression type	Long axis		Play of long-axis gentle slope—lake transgression and high-position/low-position river delta, subwater fan	Axial gentle slope zone in Northern Songliao Basin (K_1q-K_2n) 
	Minor axis	Steep slope	Play of minor-axis steep slope—lake transgression and high-position/low-position braid river delta, subwater fan	Actic region in Southwestern Ordos Basin (T_3Y) 
		Gentle slope	Play of minor-axis gentle slope—lake transgression and high-position/low-position river delta	Gentle slope zone in Southeastern Ordos Basin (T_3Y) 

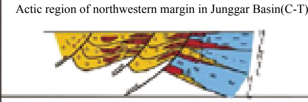
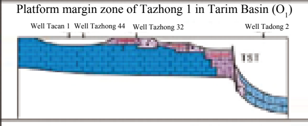
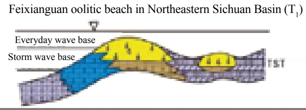
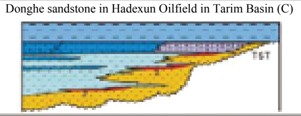
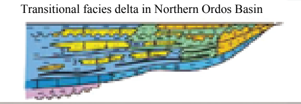
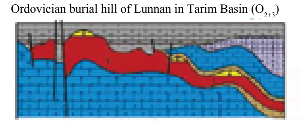
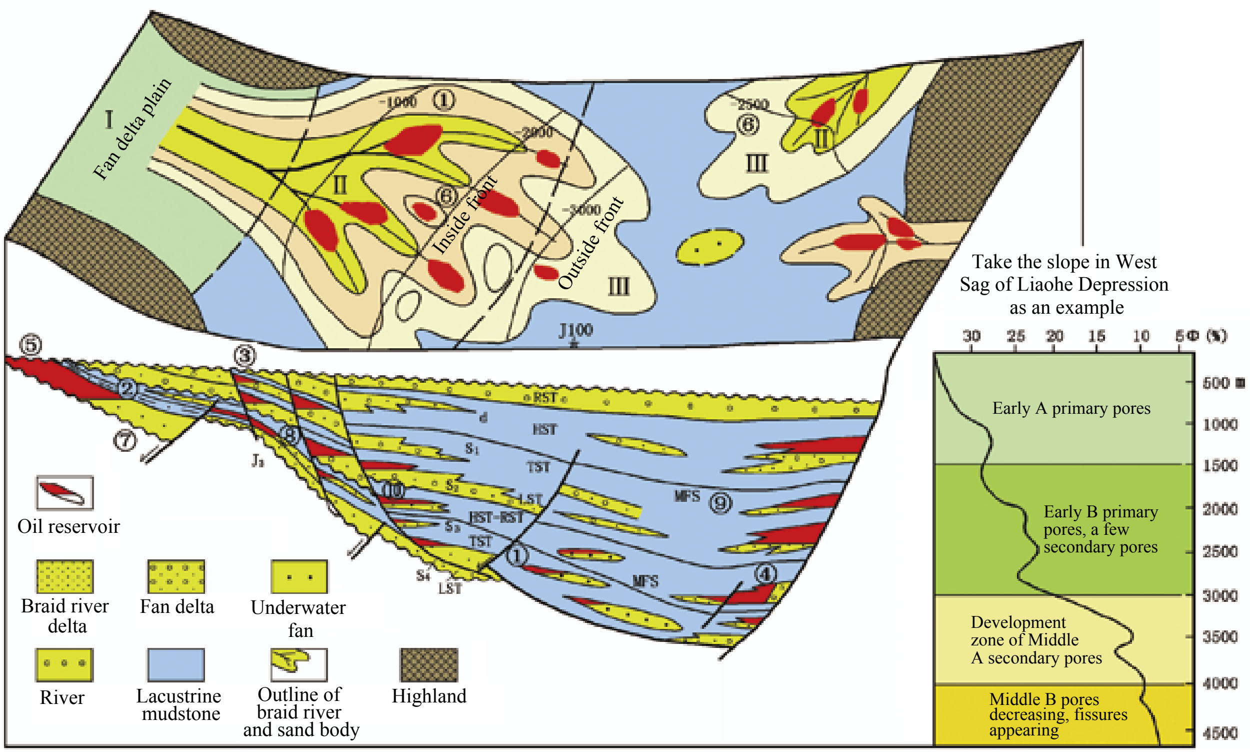
Basin type	Tectonic setting	Structure-sequence play	Typical examples
Foreland type	Steep slope	Play of foreland steep slope—lake transgression and high-position/low-position alluvial fan, fan delta	Actic region of northwestern margin in Junggar Basin(C-T) 
	Gentle slope	Play of foreland gentle slope—lake transgression and high-position/low-position river delta, shoal bar	Gentle slope zone in Eastern Sichuan Basin (T_3x) 
Craton type	Platform margin	Play of platform margin and transgressive reef flat	Platform margin zone of Tazhong 1 in Tarim Basin (O_1) 
	Platform interior	Play of platform interior and transgressive shoal bank	Feixianguan oolitic beach in Northeastern Sichuan Basin (T_1) 
		Play of platform interior and shoreland transgressive shoal bank	Donghe sandstone in Hadexun Oilfield in Tarim Basin (C) 
		Play of platform interior and transitional facies high-position delta	Transitional facies delta in Northern Ordos Basin 
	Palaeohighr	Play of palaeohigh and karst	Ordovician burial hill of Lunnan in Tarim Basin (O_{2+3}) 

Figure 3 14 kinds of structure-sequence play model sections in 4 types of China's onshore basins



① lithologic wedge out, ② Stratigraphic overlapping line, ③ Stratigraphic denudation line, ④ Change line of physical property, ⑤ Fluid mutant line,⑥ Structural contour, ⑦ Fault plane, ⑧ Plane of unconformity, ⑨ Flood surface, ⑩ Top and bottom planes

Figure 4 Sketch map of formation elements for lithostratigraphic traps

"Six lines" refers to lithologic wedge out, stratigraphic overlapping line, stratigraphic denudation line, change line of physical properties, fluid mutant line and structural contour.

"Four planes" refers to fault plane, plane of unconformity, flood surface, top and bottom planes.

1.5 Large-area Reservoir Generation Theory for Low-medium Abundance Lithostratigraphic Reservoir

(1) The formation mechanism of large-area lithostratigraphic reservoirs in the delta frontal zone is proposed. In the continental depression basin, the factors (e.g. large-area interlacing superposition and joining together of large-scale delta sand bodies and lacustrine facies of oil source rocks, lithologic traps developed by underwater distributary channels, low oil, gas & water columns and middle or low pressure system) are in favour of forming large-area lithostratigraphic reservoirs.

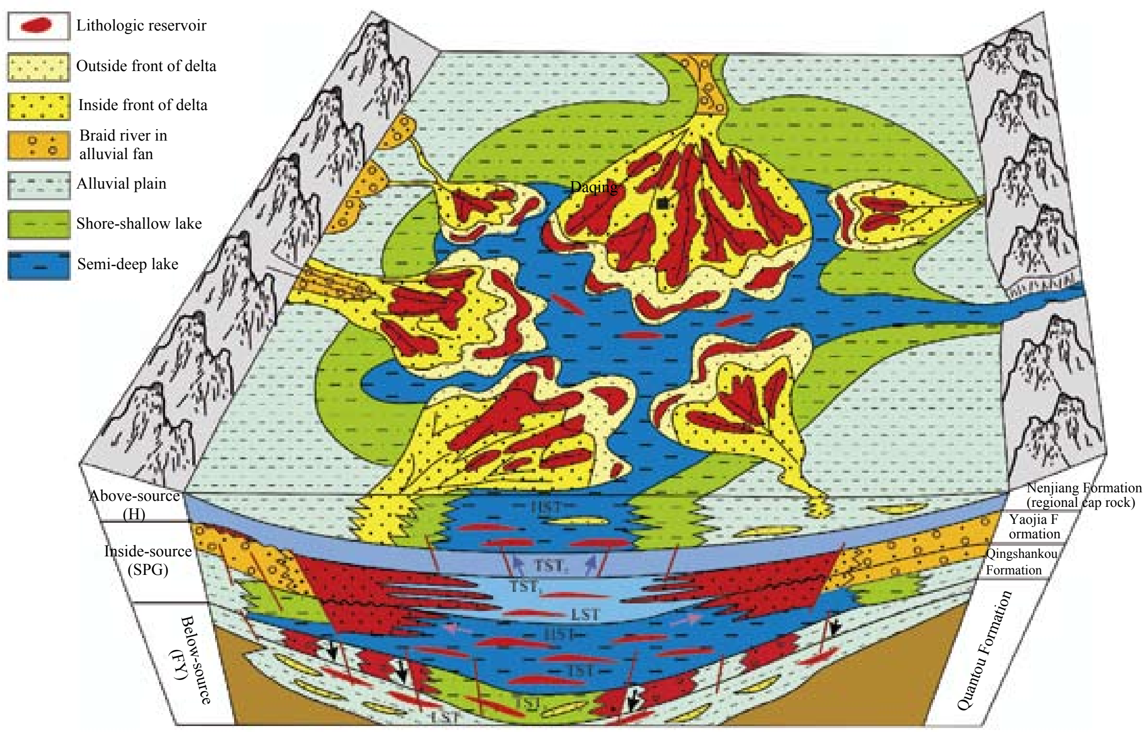
(2) The formation mechanism and distribution rules of reservoirs in the delta plain-frontal transition zone are pointed out. It is easy to form large-area gas reservoirs under the conditions of optimum diagenetic traps (e.g. constructive diagenesis, high-energy channels, channel bar) contacting with the

widely distributed source rock coal measure strata.

(3) The distribution theory of three plays for low-medium abundance lithostratigraphic reservoirs is revealed. It is proposed that with the initial and largest lake flood surface as the border, the plays are classified into three types: in-source, below-source and above-source (Figure 5). Moreover, the control factors for the distribution of the three plays of reservoirs and the reservoir generation mechanism of below-source superpressure backward charging type, are revealed. And the frontier in the exploration of the underlying strata of main hydrocarbon source rocks is pioneered.

1.6 Enrichment Rules of Lithostratigraphic Reservoirs in Four Types of Prototype Basins (continental fault depression, depression, foreland and marine craton)

(1) The oil and gas distribution rule in fault depression basin is “sag-wide oil-bearing” in the oil



H-Heidimiao reservoir; SPG—Sartu, Putaohua, Gaotaizi reservoirs; FY—Fuyu and Yangdachengzi reservoirs

Figure 5 Sketch map of play classification and oil and gas distribution in depression basin

and gas-enriched depression.

(2) The distribution rule in continental depression basin is "large-area reservoir generation in the frontal zone".

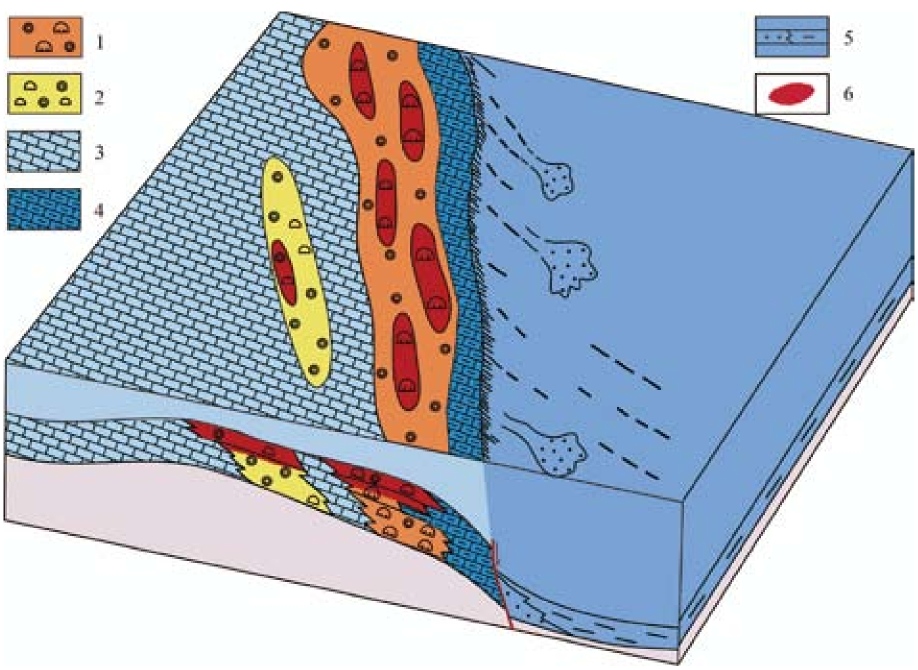
(3) The distribution rule in the thrust belt of foreland basin is "reservoir generation being controlled by fan body and volcanic weathering crust".

(4) The distribution rule in the marine craton basin is "oil and gas being controlled by reef flat body in the platform marginal zone" (Figure 6).

1.7 New Cognition of Continuous-type Reservoir

(1) The concept and features of continuous-type reservoir and pertinent exploration technology are defined.

In terms of whether there exists definite trap limit as well as the distribution status of oil and gas accumulation, reservoirs can be classified into conventional trap type and unconventional trap type (Figure 7) while the latter can be divided into



1—platform marginal reef flat facies; 2—platform interior mound bank facies; 3—platform interior carbonate facies; 4—slope facies; 5—basin facies; 6—lithologic deposit

Figure 6 Play of marine cratonic platform margin–transgressive system tract reef flat

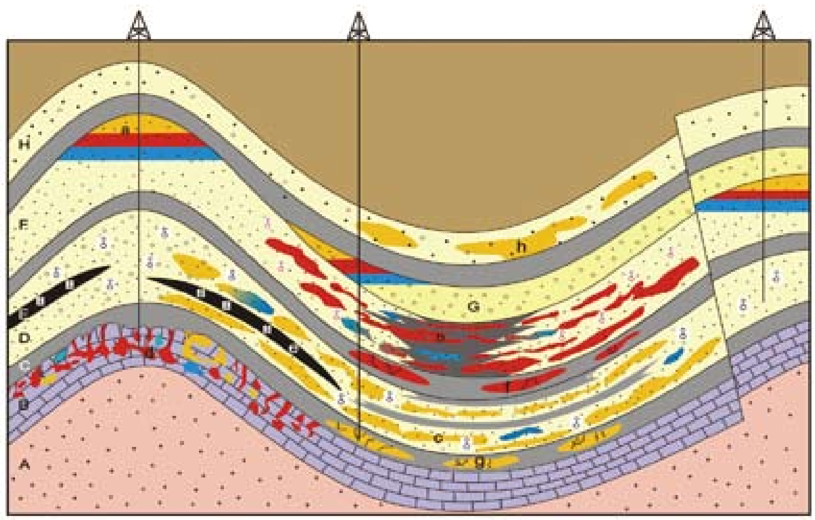
continuous type, transition type and discontinuous type. The conventional trap reservoir refers to that having distinct trap limit in the reservoir bed with medium-high permeability.

(2) The evaluation criteria for tight-sandstone gas are developed.

(3) The reservoir generation mechanism of tight sandstone is revealed.

(4) The exploration potential for tight sandstone is defined, tight sandstone exploration is promoted and great breakthrough is made.

(5) The key research of shale gas is propelled and the exploration territory of shale gas is opened up.



A bedrock; B carbonatite; C shale; D fine sandstone; E coal bed; F gritstone; G conglomerate; H rock cap; a structural reservoir; b continuous–type sandstone oil reservoir; c continuous–type sandstone gas reservoir; d continuous–type reservoir of carbonate crack and cavity; e coalbed gas; f shale oil; g shale gas; h biogas.

Figure 7 Distribution pattern of continuous-type reservoirs in oil and gas bearing basins

2. Evaluation Method for Lithologic Reservoir

2.1 Continental High-precision Sequence Stratigraphic Classification

The research process and technical specification for the industrialized application of sequence stratigraphy in six steps are proposed for the first time as below:

1. Sedimentary setting analysis;
2. Sequence division and comparison;
3. Tracing closure for sequence interface;
4. Sequence restrained reservoir inversion;
5. Comprehensive analysis of sedimentary facies;
6. Target evaluation and rule research for reservoir generation.

The “six-step method” increases the quantification degree of research findings of sequence stratigraphy and the precision of prediction for lithostratigraphic traps. Meanwhile, on the basis of the tracing closure inside sequence interface, new technologies covering reservoir inversion, horizontal section, seismic waveform classification, 3D visualization interpretation, etc. are applied in the sequence analysis to chart a series of sandstone thickness maps, sandstone percentage composition isoline map. Hence, the quantification level of sequence analysis is improved.

2.2 Quantitative Evaluation Method of Diagenetic Facies

The purpose of diagenetic facies evaluation is to confirm the special distributions of different types of diagenetic facies, quantitatively predict the distribution area of favorable diagenetic facies, and then confirm the distribution of favorable reservoirs. Four steps for the quantitative evaluation of diagenetic facies in tight sandstone reservoirs with low porosity and permeability are proposed: 1 to determine the diagenetic sequence; 2 to determine the genetic type of diagenetic facies; 3 to determine the distribution of diagenetic facies; 4 to make a comprehensive evaluation, i.e. on the basis of diagenetic features, sedimentary features and physical properties reflected in well-logging data and seismic data, to synthetically draw up the planar distribution map of lithofacies and finally forecast the distributions of favorable reservoir zones (Figure 8).

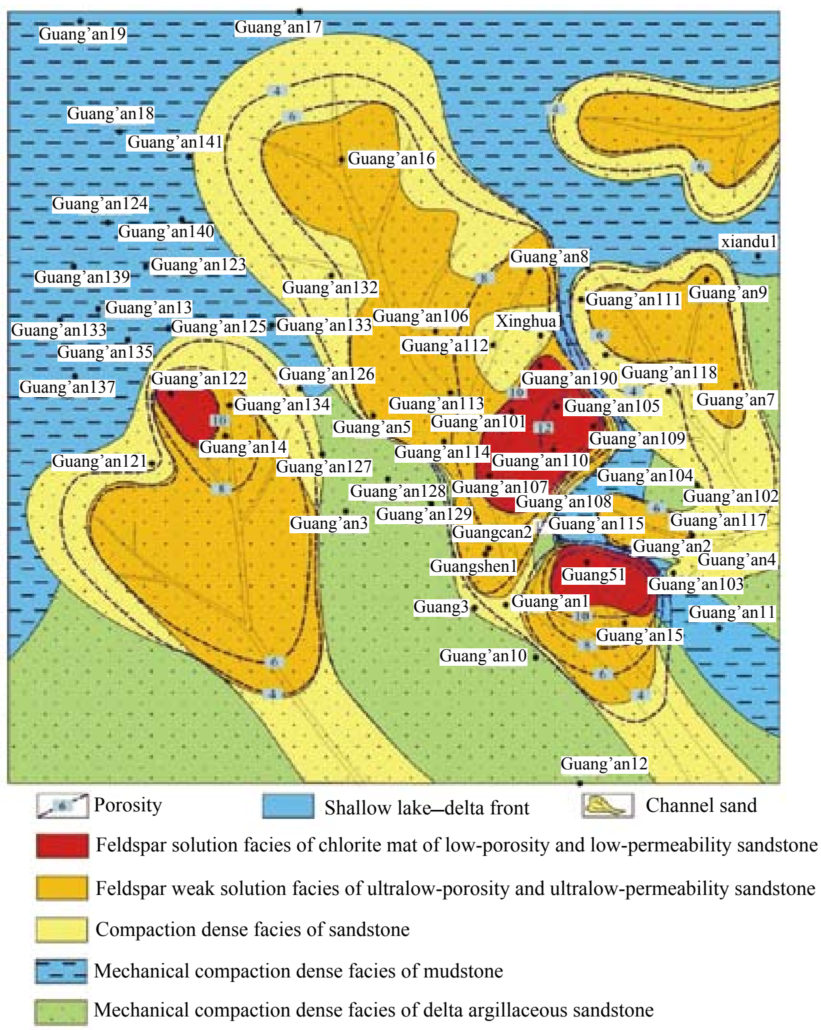


Figure 8 Superposition map of sedimentary facies, diagenetic facies and porosity isolines

2.3 Evaluation Method of "Four-map Superposition" for Lithostratigraphic Zone

By use of the evaluation clue of "structure-sequence reservoir generation zone", the industrial mapping technique of "four-map superposition" (i.e. sedimentary microfacies distribution map of third-order sequence units for primary target, effective oil and gas distribution map, structural map of reservoir top surface and exploration maturity map in different exploration targets) is developed.

2.4 Comprehensive Evaluation Method of Gravity, Magnetic Force, Electrical and Seismic Aspects for Volcanic Rocks

Volcanics presents specific geophysical properties, especially having such features as strong magnetism, electric property and larger density that make the non-seismic prospecting technology play a vital role in volcanic comprehensive prediction. The comprehensive exploration of gravity, magnetic, electrical and seismic aspects for volcanics can be generalized as four steps, namely, regional prediction, target prediction, reservoir prediction, oil and gas bearing property prediction (Figure 9), among which the appropriate and relatively mature technology and process flow have been formed in the first three steps. The technology has played an important role in the prediction of volcanic distribution and reservoir evaluation in the deep reservoirs in Songliao Basin and Northern Xinjiang.

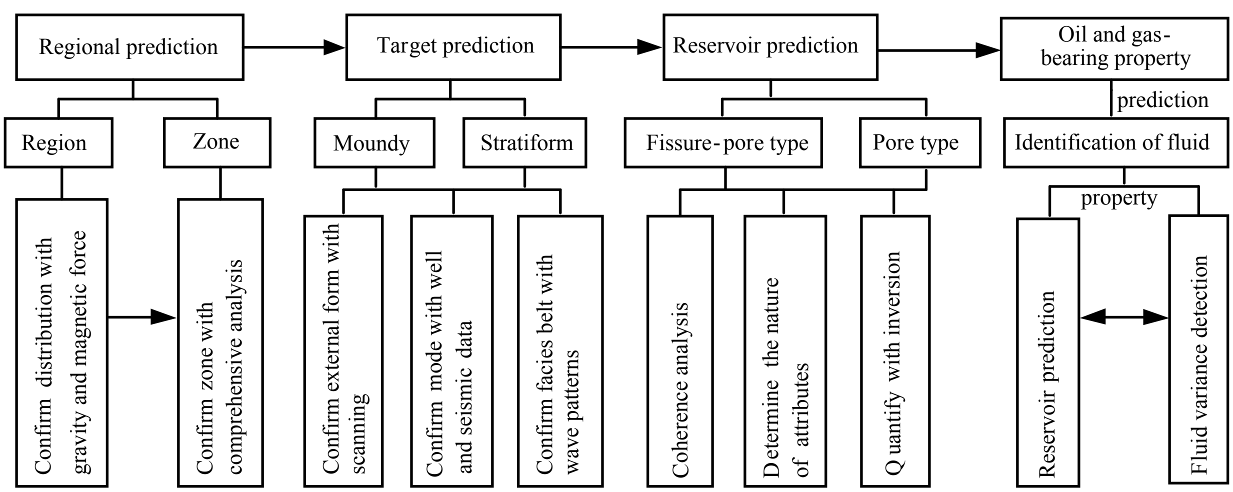


Figure 9 Forecasting technology for gravity, magnetic, electrical and seismic aspects for volcanic reservoir

3 Exploration Technologies for Lithologic Reservoir

3.1 Prestack Reservoir Prediction and Fluid Detection Technology

The Prestack Seismic Reservoir Prediction and Fluid Detection Technology covers petrophysical analysis, prestack seismic fidelity processing, prestack seismic attribute analysis, prestack seismic inversion and prestack seismic fluid identification, etc.

3.2 Evaluation Technology for Complex Reservoir Logging

Three technical series are developed, involving Well-logging Identification and Evaluation for Low Resistivity Oil/Gas Layer, Well-logging Evaluation for Low-permeability Clastic Reservoir with pore texture as core, and Well-logging Evaluation for Fissure and Cavity Reservoir with ECS-electric imaging as core.

4 Software Technologies for Lithologic Reservoir Exploration

It includes the Prestack Prediction Technology for Complex Reservoir RIT, Well-logging Processing and Evaluation Software for Complex Pore Texture and Lithology as well as Integrated Prediction Software for Gravity, Magnetic, Electrical and Seismic Aspects for Volcanic Reservoir.

4.1 Prestack Prediction Technology for Complex Reservoir RIT (Reservoir Identification Technology)

Key technologies (e.g. Prestack reservoir prediction includes petrophysical analysis, prestack seismic fidelity processing, prestack seismic attribute analysis, prestack seismic inversion) and corresponding modules are developed.

(1) Petrophysical Analysis Module

It mainly includes the core test analysis, rock physics modeling, sensitivity factor analysis of lithology and fluid, AVO forward modeling, etc. Via the analysis of core test data, the relations between the elastic parameters of different kinds of lithologies and physical parameters of reservoirs are established under reservoir conditions. On the basis of Gassmann's equation, the skeleton pattern of rock physics and parameters (e.g. well-logging porosity, shale content and saturation, well-logging velocities of longitudinal and transversal waves, density data) are predicted and evaluated, the response characteristics of rock velocity under the conditions of different fluids are studied, and the indication factors sensitive to lithology or fluid are extracted and used in the seismic reservoir prediction. According to rock physics and propagation theory of seismic wave, the virtual well-logging curves for different lithologies, fluids, porosities and reservoir thicknesses are calculated, the AVO forward modeling is conducted, the synthetic seismograms are charted and the response characteristics of reflecting seismic amplitude for different reservoir parameters are researched.

(2) Correction Module for Prestack Seismic Amplitude Preservation

It mainly includes the necessary residual amplitude correction and frequency compensation of gather data after the conventional prestack fidelity processing in order to meet the requirements of prestack inversion. Generally, the amplitude frequency correction method is aimed at the NMO stretch to compensate the amplitude distortion and frequency attenuation for frequency vs. incident angle (offset) generated by the NMO stretch influence. The correction method of seismic wavelet consistency inside gather is applied to compensate the wavelet distortion caused by the interbed multiples and strata absorption, etc.

(3) Prestack Seismic Attribute Analysis Module

It mainly includes two classes of attributes: amplitude and frequency. The attribute analysis of amplitude includes the fitting methods of two parameters and three parameters with different kinds of AVO approximation formulas, to inverse the attributes like P wave, G wave, pseudo S wave and density as well as their combination attribute profiles. The attribute analysis of frequency includes the analysis of frequency vs. incident angle change and the extraction method of prestack attenuation. And frequency vs. offset/incident angle change is

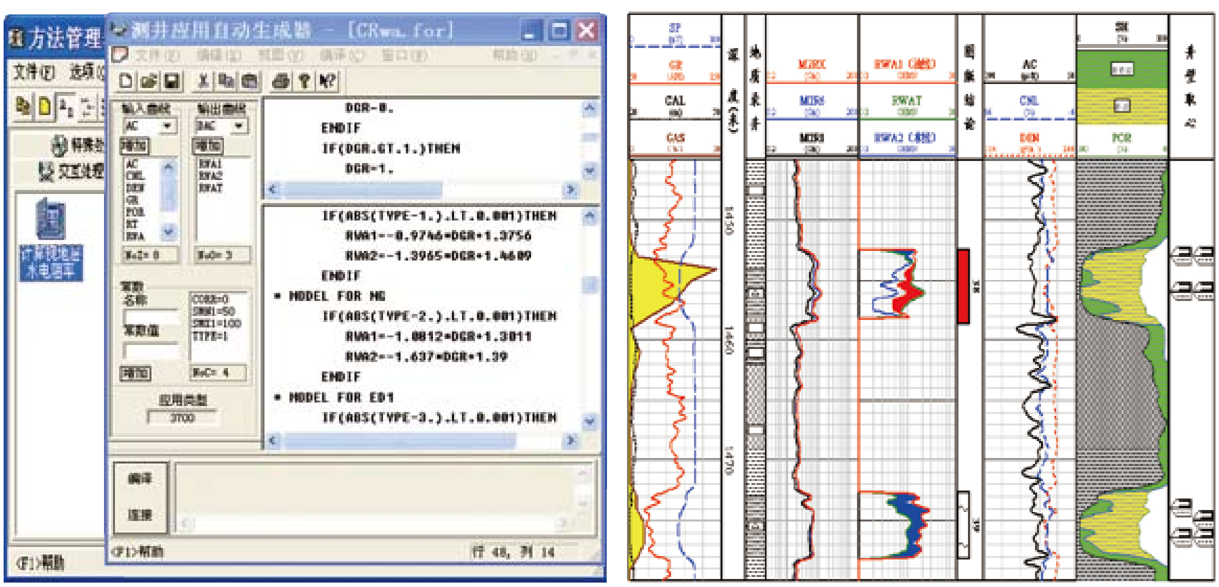


Figure 10 Software for Quickly Identifying Low Resistivity Oil Layer and processing example

extracted from the prestack gather. The information about prestack attenuation is extracted, and by using the formula of frequency vs. incident angle change, the frequency attribute profile and frequency gradient attribute profile of zero angle are fitted and solved with inversion.

(4) Prestack Seismic Inversion Module

It mainly includes the prestack elastic impedance inversion, joint inversion of prestack longitudinal and transverse waves and parameter inversion of prestack wave equation, etc. Since the abundant seismic and well-logging data are used in prestack seismic inversion, its reliability is higher than the poststack acoustic impedance inversion and can be used in the semiquantitative or even quantitative description of oil and gas bearing property. The prestack elastic impedance inversion utilizes well-logging data (e.g. different offset gather data and transverse wave, longitudinal wave, density) to gain various elastic parameters related to lithology and oil/gas bearing property with the joint inversion method, and then synthetically identify the physical properties of reservoirs and oil/gas bearing property. According to the AVO approximate formula, the prestack joint inversion of longitudinal wave and transverse wave is the technology that inverts out the impedances of longitudinal wave and transverse wave, density data volumes from prestack gather synchronically. Based on the wave equation, the elastic parameter inversion of prestack wave equation directly inverts out the Lame elastic parameter and density parameter from the prestack shot gather data.

4.2 Well-logging Processing and Evaluation Software for Complex Pore Texture and Complex Lithology

(1) Module for Quickly Identifying Low resistivity Oil/Gas Layer

As per the origin of low resistivity oil/gas layer and well-logging evaluation scheme, the relevant software is developed (Figure 10). The Calculation Module of Apparent Formation Water Resistivity based on lithology (△ GR) is written on the platform “Forward”, and the intersection with actual rwa is conducted, so the low-resistivity oil layer caused by the fine lithology and strong conduction of appending clay can be identified quickly.

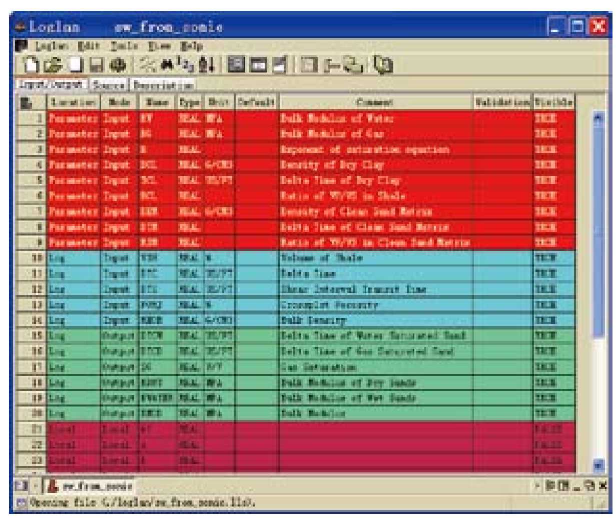


Figure 11 Evaluation Module for Gas-bearing Property with Array Sonic Well-logging researched and developed on Geolog

4.3 Comprehensive Optimization of Volcanics Prospect (COVP)

Comprehensive Optimization of Volcanics Prospect mainly includes three modules: Volcanic Distribution Prediction, Volcanic Lithology Prediction and Optimization Evaluation of Volcanic Prospect Targets.

(1) Prediction Module of Volcanic Distribution

By use of the regional aerial magnetic and gravity data and by means of the processes of higher derivative enhancing, regularization algorithm in downward continuation and seismic constraint forward layer-stripping, the volcanic gravity and magnetic abnormalities are extracted, and the volcanic macroscopic distribution on plane is predicted initially.

(2) Prediction Module of Volcanic Lithology

By use of the drilling and well-logging data and measuring data of the core's physical properties, the statistical characteristics of volcanic density, sonic differential time, susceptibility and resistivity of different lithologies are analyzed, the multi-parameter cross plot is established and the effective identification flow for volcanic lithologic intersection is confirmed. The volcanic lithologic distribution is predicted comprehensively (Figure 12) via the planar features of the volcanic abnormalities extracted from the high-precision gravity and magnetic data as well as the vertical features in seismic and electrical profiles.

(3) Target Optimization and Evaluation Technology in Volcanic Prospect Zones—Analysis Module of Four-map Superposition

It is used to comprehensively analyze the data covering tectonic setting, regional volcanic distribution and source rock, to evaluate the advantages of volcanic reservoir generation based on the research results of volcanic lithologies and drilling, and to optimize and predict oil and gas prospect zonal targets.

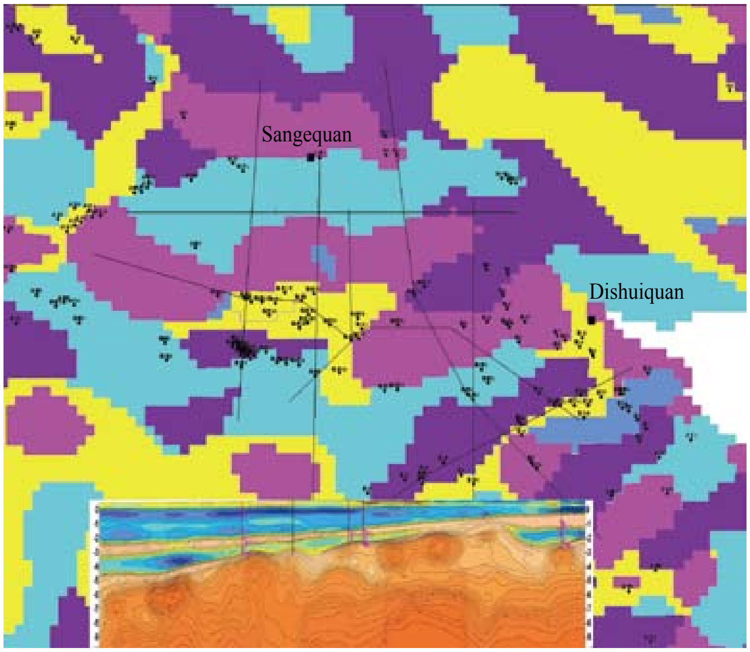


Figure 12 Software interface of comprehensive optimization of volcanic prospect

3 Typical Cases

1 Classification Comparison and Map Plotting for Continental High-precision Sequence Stratigraphy of Xujiahe Formation in Sichuan Basin

Xujiahe Formation of Upper Triassic in Sichuan Basin can be divided into 6 lithologic members from bottom to top—Mem. Xu 1 to Mem. Xu 6, in which Mem. Xu 1, Xu 3, Xu 5 are primarily mudstones while Mem. Xu 2, Xu 4, Xu 6 are sandstones. Xujiahe Formation in Sichuan Basin presents the geological features of the extensive reservoir generation and continuous distribution of natural gas.

1.1 Classification Scheme of Sequence Stratigraphy and Sequence Feature

On the basis of the outcrop sections, drilling core, well-logging section and relevant geochemical data (i.e. laboratory and field data), the outcrops of Xujiahe Formation of Upper Triassic in Sichuan Basin are studied, and with the consideration of the typically assistant sections and seismic reflection profiles, Xujiahe Formation is divided into 3 Grade II (S1 and S2), 5 Grade III (SQ1- SQ5), 19 Grade IV and several Grade V sequences. With Grade II cyclical sequence as the contrasting skeleton and with Grade III sequence interface as the borderline of isochronic comparison, the high-resolution sequence stratigraphic comparison and the establishment of sequence stratigraphic isochronic framework are made for Xujiahe Formation.

1.2 Lithofacies Map Plotting in the Framework of Continental High Resolution Sequence Stratigraphy

On the basis of high-resolution sequence analyses of Xujiahe Formation of Upper Triassic in more than ten surface sections and more than 226 wells in Sichuan Basin and in light of the features like geological properties and genetic type of the sequence interface, regional distribution, yielding scale and time span, Xujiahe Formation is divided into 2 super-long periods (S1 and S2) respectively representing “basin-forming era of lower Xu basin” and “basin-forming era of upper Xu basin”, and 5 long periods with lake transgression lake regression sedimentary cycles I (SQ1-SQ5). The sequence-lithofacies paleographic map for each period of Xujiahe Formation in Upper Triassic in Sichuan foreland basin is charted (Figure 13) by selecting the facies tract of the base-level rise and decline of long-period cyclical sequences (or regional lake transgression, lake regression) as the isochronic stratigraphic unit for map plotting, and adopting the “single factor analysis and multifactor comprehensive mapping method” with the consideration of the source area analysis.

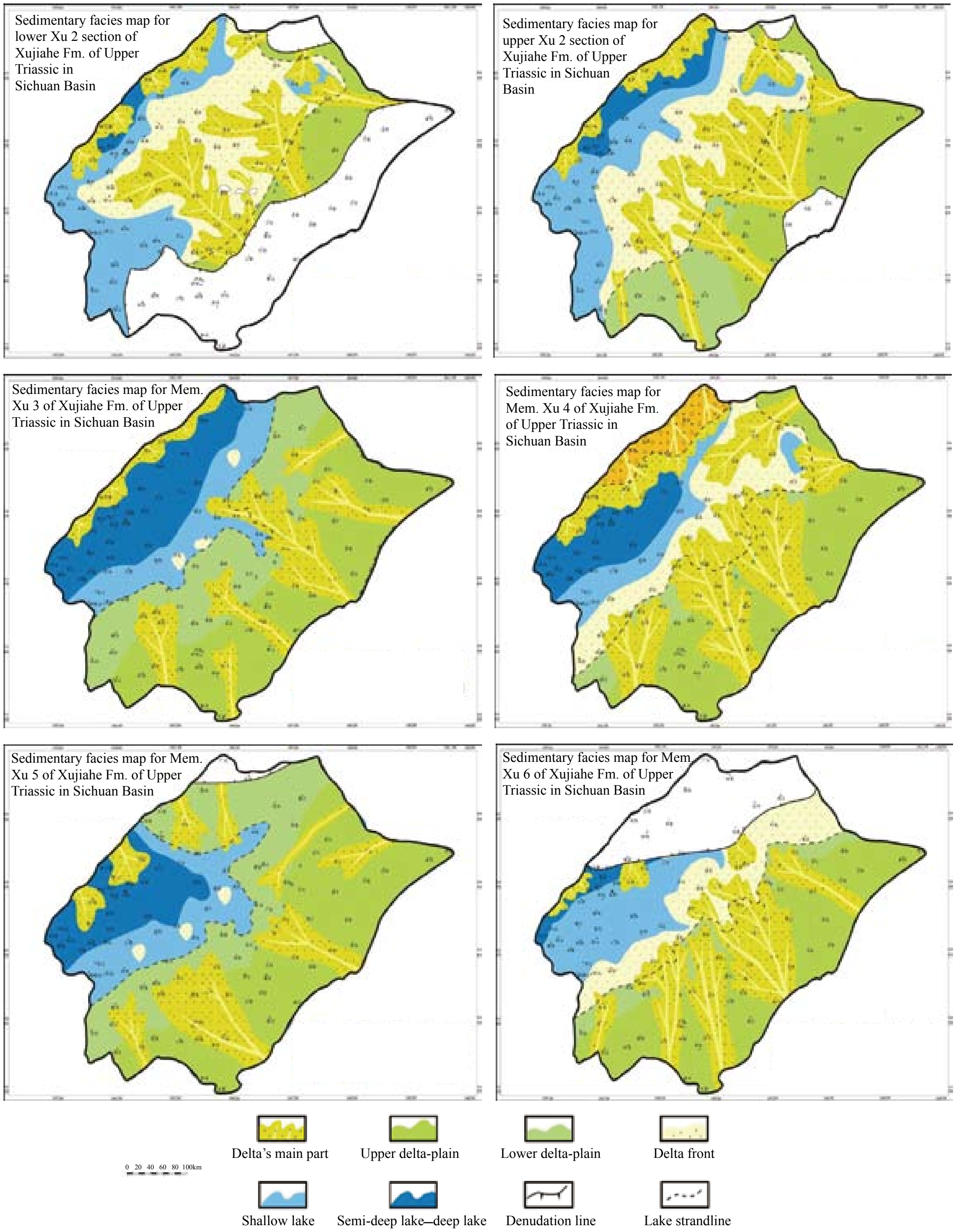


Figure 13 Sedimentary facies maps for Mem. 1 - 6 of Xujiahe Formation of Upper Triassic in Sichuan Basin

2. Zonal Evaluation Flow for Mem. Xu 4 of Quantou Formation in Southern Songliao Basin by "Four-map Superposition"

Fuyu reservoir in Mem. Xu 4 of Quantou Formation in Southern Songliao Basin is the principal oil-bearing series, whose proved reserves is above 60% of the total proved reserves and residual perspective resource reaches 0.6 billion tons.

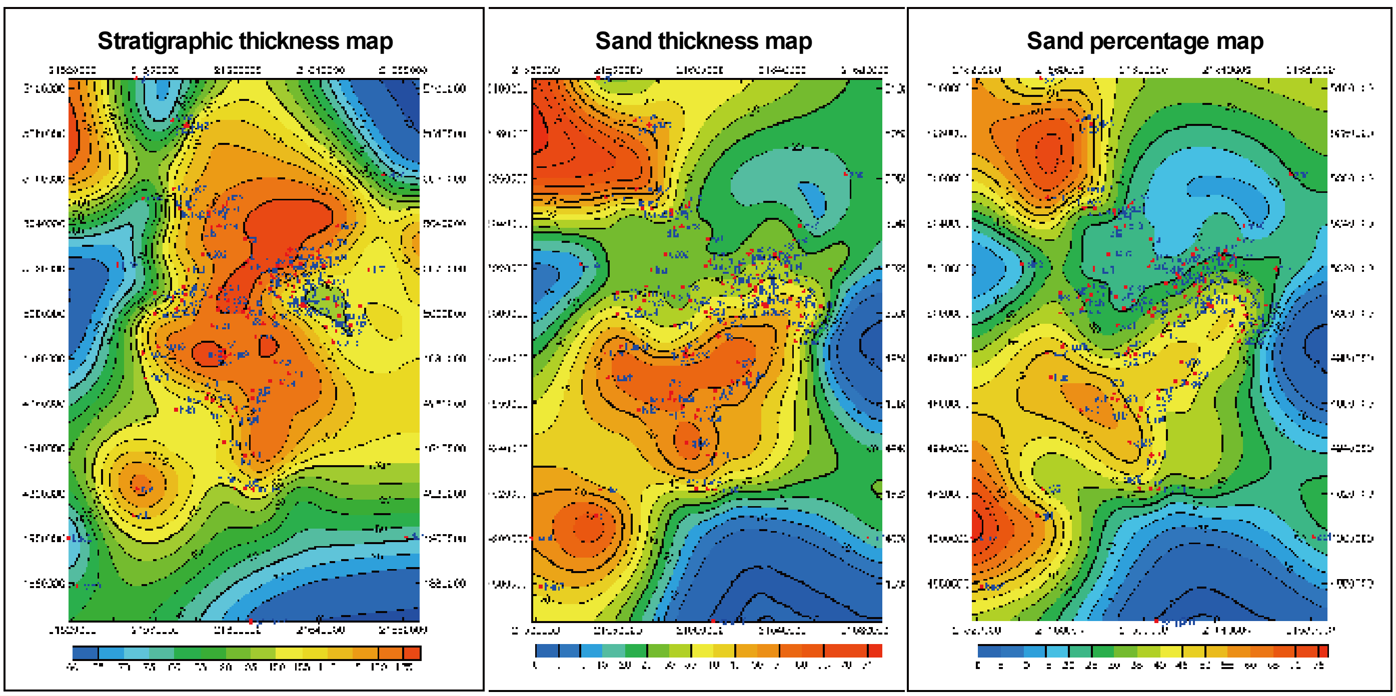


Figure 14 Strata and sand body distribution maps for Mem. Xu 4 of Quantou Fm. in central depression area, Southern Songliao Basin

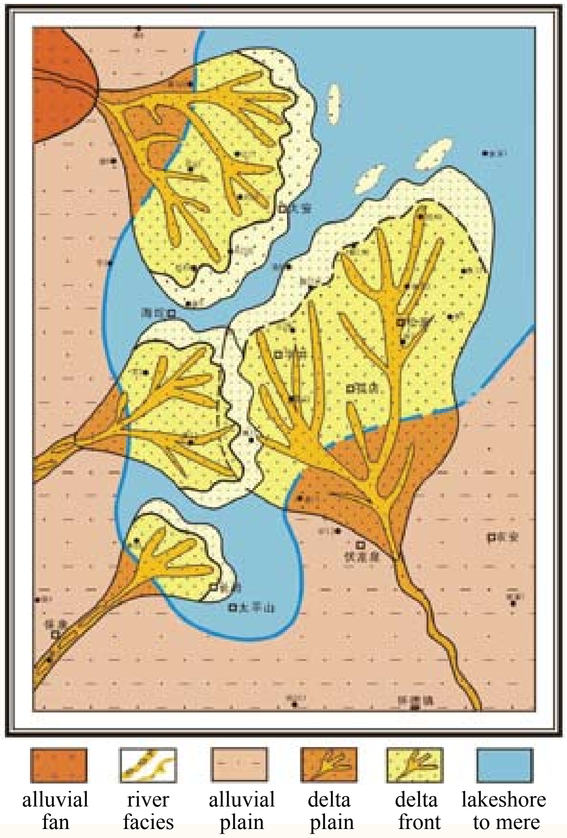


Figure 15　Sedimentary facies map for Mem. Quan 4 in central depression area, Southern Songliao Basin

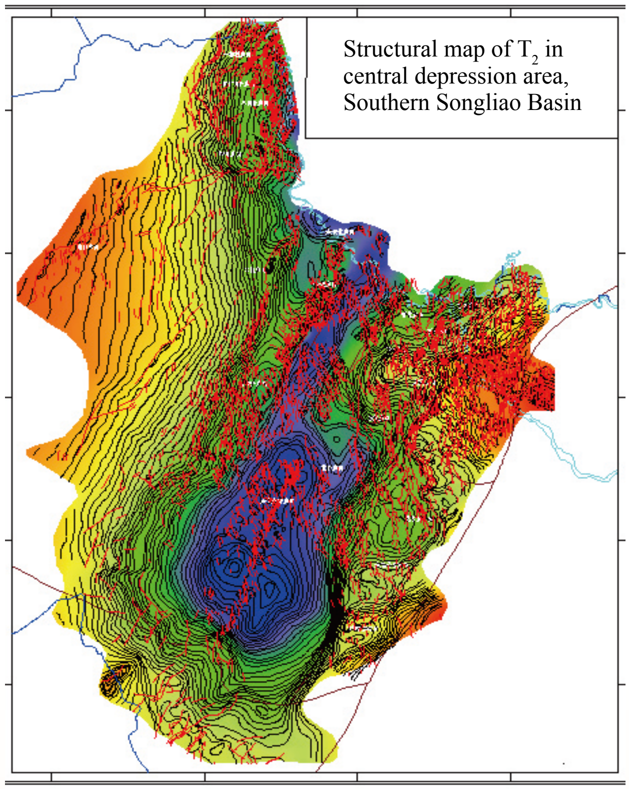


Figure 16　Structural map of T_2 in central depression area, Southern Songliao Basin

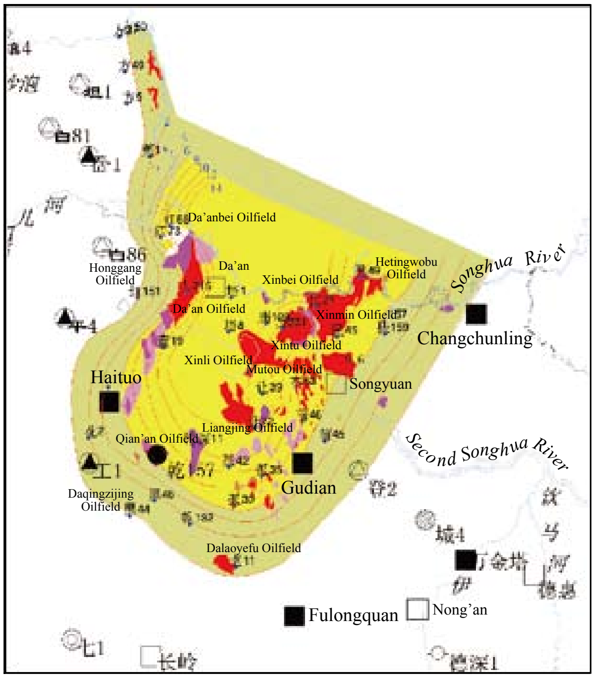


Figure 17 Relation between oilfield and overpressure distribution of Qingshankou Fm. in central depression area, Southern Songliao Basin

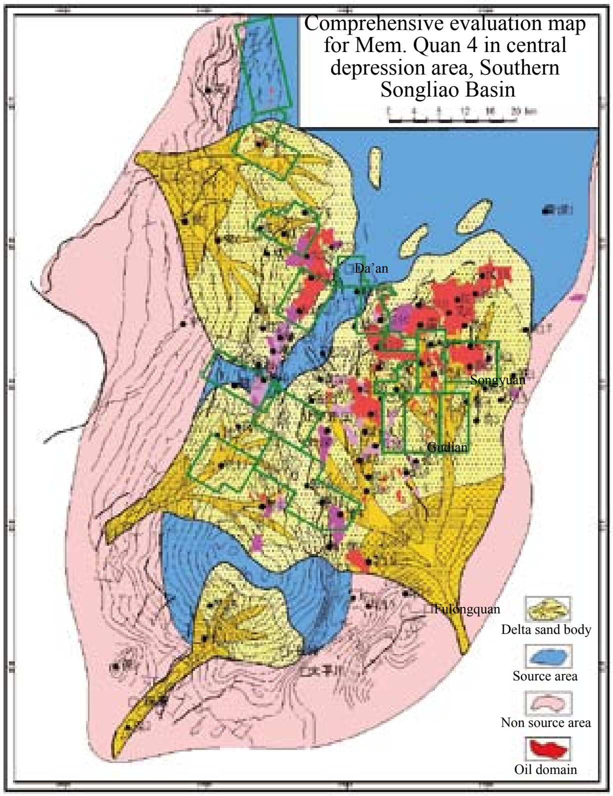


Figure 18 Comprehensive evaluation map for 'four-map superposition" zone of Mem.Quan 4 in centre depression area, Southern Songliao basin

3. Volcanic Reservoir Evaluation of Xushen Deep-seated Gas Field in Songliao Basin

At present, volcanic rocks represent the most important exploration area in the deep zone of Songliao Basin. The historical breakthrough for volcanic exploration was realized in Xujiaweizi Fault Depression during the “Tenth Five Year Plan”, namely, the discovery of Xushen Gas Field, which represents the deepest giant gas field in volcanic rocks in the world. Volcanics presents the features such as high electrical property and strong magnetism, so aimed at the volcanic reservoir prediction, the Comprehensive Evaluation Technology of Gravity, Magnetic, Electrical and Seismic Aspects for Volcanic Reservoir was developed and has brought about remarkable results in the oil and gas production.

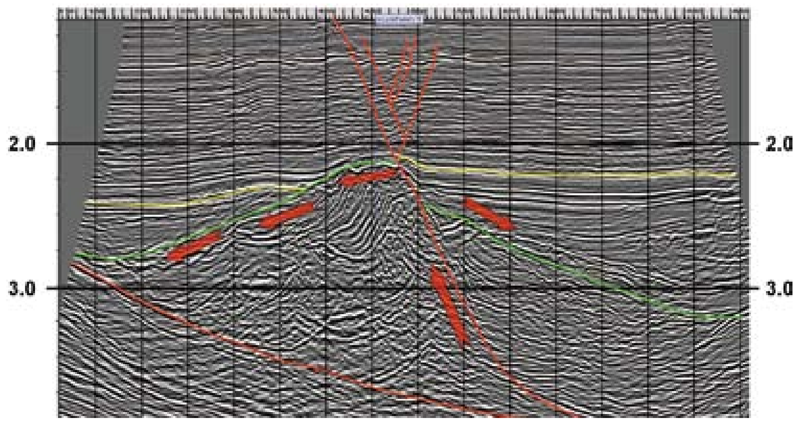


Figure 19 Cross-section display of a crater in Well Xushen 1

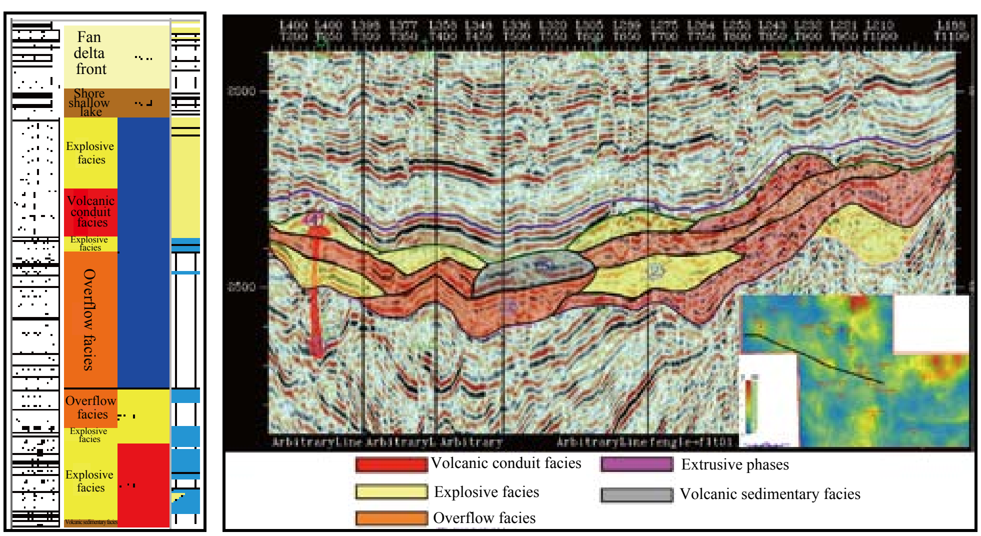
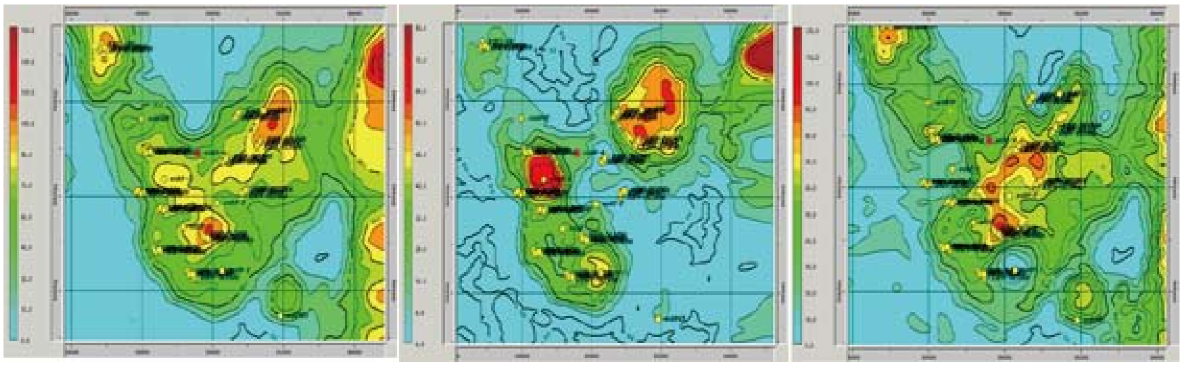


Figure 20 Classification of volcanic lithofacies with well-logging and seismic data



Total thickness   Thickness of Cass Ⅱ Reservoir   Thickness of Class Ⅲ Reservoir

Figure 21 Distribution maps of effective thickness of reservoirs in Well Field Xushen 9, Songliao Basin

Based on all the above parameters, the high-efficiency volcanic reservoir is predicted. Finally, the comprehensive evaluation of volcanic reservoirs is carried out from macroscopic to microscopic, from qualitative to quantitative analysis, from non-seismic to seismic methods, from poststack to prestack and from exploration to development.

4. Well-logging Processing and Evaluation of Complex Pore Texture and Lithology in Qikou Sag

As per the exploration needs, the evaluation idea for complex reservoirs is combined with the features of reservoirs in the area, and the petrophysical research is conducted systematically and thoroughly. The research results are then applied timely in production to solve the evaluation puzzle of clastic reservoirs in the area.

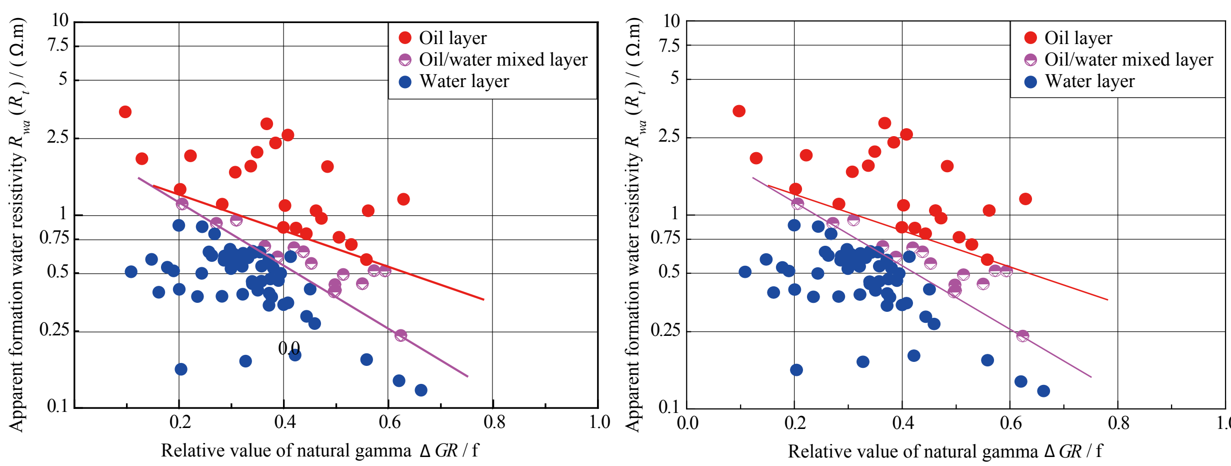


Figure 22 Multiple parameter plates for identifying low-resistivity oil layers in shallow-middle reservoirs of Minghua, Guantao in Qikou Sag

4 R&D Equipment

1. Key Laboratory for Oil and Gas Reservoir

The key laboratory, which has passed the national metrology authentication for many times since 1994, provides test services for many scientific research institutions and petroleum companies both at home and abroad, and has won high prestige. 9 industry standards of petroleum and natural gas were developed and revised.

The main industry standards drafted by the Key Laboratory for Oil and Gas Reservoir:

No.	Standard name	Standard code
1	Identification of rock sample by cathodoluminescence	SY/T 5916—94
2	Determination of homogeneous temperature and salinity of inclusions in sedimentary rock	SY/T 6010—94
3	X—ray diffraction analysis method of relative content of clay mineral in sedimentary rock	SY/T 5163—1995
4	X—ray diffraction quantitative analysis method of common non—clay mineral and total content of clay mineral in sedimentary rock	SY/T 6210—1996
5	Quantitative analysis method of energy spectrum in rock minerals	SY/T 6189—1996
6	Analytical method of rock sample by scanning electron microscope	SY/T 5162—1997
7	The method of separation and examination of heavy minerals for sedimentary rock	SY/T 6336—1997
8	Thin section examination of rock	SY/T 5368—2000
9	The division of diagenetic stages in clastic rocks	SY/T 5477—2003

The Key Laboratory for Oil and Gas Reservoir has 32 suits of experiment & analysis equipment, including laser on-line isotope mass spectrometer, energy spectrum—wave spectrum SEM, electronic probe, X-ray diffractometer, ground penetrating radar, Gamma ray spectrometer, element capturing meter, high-definition cathodoluminescence microscope, various polarizing microscopes and stereomicroscopes, electric geological cold-hot stage and semi-automatic rock thin section preparation devices, etc. Additionally, the large-scale diagenism physical simulation unit is developed by the personnel in laboratory.

The laboratory can undertake a series of laboratory analysis tests (e.g. reservoir petrology, type of reservoir space and microstructure, microzone component, microzone isotope, fluid inclusion, rock mechanics, compaction-denudation modeling) and field tests (e.g. the configuration of outcropping sand body, seismic imaging of internal texture of sand body, and element measurement of outcrop and core).

Large-scale Diagenism Physical Simulation System

2. Geophysical Key Laboratory

It owns 25 sets of software of three types, including seismic data processing, seismic comprehensive interpretation and reservoir prediction, software development tool with the depreciation coefficient of 87%. Also, it is armed with 4 sets of microcomputer cluster with total 1120CPU and ten sets of workstation/microcomputer workstation that are used in the research and application of the complex target imaging and complex reservoir prediction technology, with the depreciation coefficient of 46%.

Microcomputer Cluster System

3. Well-logging Key Laboratory

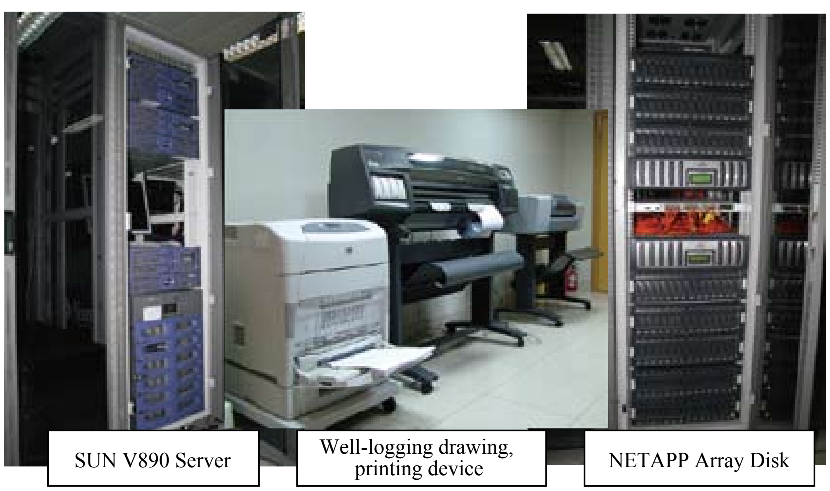
The Well-logging Key Laboratory encompasses five branches: Rock Physics Laboratory, Fundamental Methodology Research Department, Processing and Interpretation Research Department, Well-logging Geology Research Department and Information and Software Research Department.

The personnel in Well-logging Key Laboratory designed and made two sets of typical non-standard experimental systems (i.e. Conjunction System of HTHP Rock Electrical Property and Capillary Pressure, and Nuclear Magnetic Resonance Measuring System in HTHP Displacement State), both of which are of the internationally advanced

Conjunction System of HTHP Rock Electrical Property and Capillary Pressure (RCS-763Z)

level.

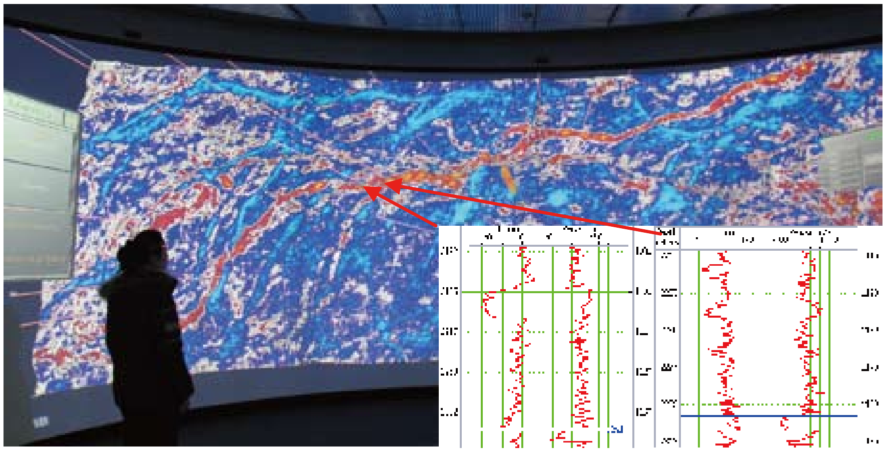
1 The Conjunction System of HTHP Rock Electrical Property and Capillary Pressure can be used to measure parameters, e.g. the electric property and capillary pressure (under high temperature and high pressure) of full-diameter core samples of complex reservoirs with low porosity and low permeability; 2 The Nuclear Magnetic Resonance Measuring System in HTHP Displacement State can measure nuclear magnetic resonance parameters, e.g. relaxation times and diffusion coefficients in both longitudinal and transverse directions for the same sample with different saturations under the condition of not dismounting the sample, and can effectively promote the research and evaluation of the pore textures of heterogeneous complex reservoirs as well as fluid identification with nuclear magnetic resonance.



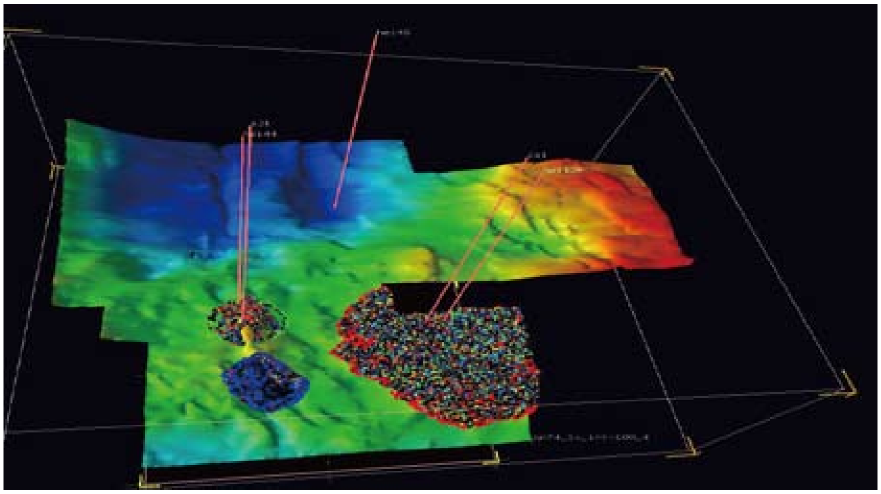
Workstations and large-scale servers, etc. in Well-logging Key Laboratory

4. Application Platform "Virtual Reality"

The integrated application of Virtual Reality for the exploration and development is generated by the petroleum exploration and development technology as well as the computer-related high-tech development. This provides a uniform platform of comprehensive research and decision-making for geologists, explorers, reservoir engineers and technical personnel for drilling engineering. Moreover, this enables the professionals of different disciplines to roam in the underground data space, quickly scan the spatial distribution features of strata and reservoirs, discover the oil and gas data and delineate the range of oil and gas accumulation via the accurate positioning and real-time operation. In addition, the professionals can utilize the decision-making package of multi-data real-time response in the virtual system to realize the integrated design of geologic and drilling parameters of structures and lithologic deposits, thus providing solutions for the optimization of horizontal wells and highly efficient development of complex oil reservoirs.



Incised channel sand bodies are identified with Virtual Reality.



Application research of volcanic gas reservoir is described with Virtual Reality.

5 Expert Team

Jia Chengzao(Geologist in petroleum geology and tectonics, Doctor, Academician of Chinese Academy of Sciences, Ph.D. supervisor)

He has long been engaged in the research related to structural geology, rules of oil and gas distribution in oil and gas bearing basin and exploration deployment. He has generalized and developed the geological theory on the formation of coal-derived oil and gas of foreland thrust belt, established the geological theory and exploration technology for China's lithostratigraphic reservoirs. He has obtained 2 first-prizes and 3 second-prizes of "National Science and Technology Progress Award" as well as 15 ministerial-level awards. He has published over 10 monographs including Oil and Gas Exploration in Foreland Thrust Belt and Geological Theory and Exploration Technology for Lithostratigraphic Reservoir as well as over 50 research papers.

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Zhao Wenzhi(Petroleum geologist, Doctor, professor-level senior engineer, Ph.D. supervisor, Chief Scientist of National 973 Project)

He has long been engaged in the comprehensive research of petroleum geology and the deployment of oil and gas resource estimation and exploration. He has obtained the innovation results in the aspects of extensive reservoir generation mechanism, the formation conditions of low-medium abundance lithologic reservoirs, the potential evaluation of cracked gas in post-maturity stage for organic materials, the evaluation method of complex oil and gas bearing systems, etc. He has obtained one first-prize and 3 second-prizes of "National Science and Technology Progress Award" as well as 4 ministerial-level awards. He has published 6 monographs including Introduction to Synthetic Study on Petroleum Geology and China's Marine Petroleum Geology and Superposition Oil and Gas Bearing Basins, as well as more than 60 research papers.

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Zou Caineng(Petroleum geologist, Doctor, professor-level senior engineer, Ph.D. supervisor, expert who enjoys the special government allowance)

He has long been engaged in the comprehensive research of petroleum geology and oil and exploration deployment, etc. He has obtained the innovation results in aspects of the prediction technology of oil and gas reservoirs, zonal evaluation methods and distribution rules of lithostratigraphic reservoirs. He has generalized and developed the geological theory for China's unconventional continuous-type reservoirs. He has obtained one first-prize of "National Science and Technology Progress Award" and more than 10 provincial and ministerial-level awards, and published 4 monographs including Formation and Distribution of Large Oil and Gas Provinces and Lithostratigraphic Reservoir, as well as more than 70 research papers.

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Yuan Xuanjun(Sedimentologist and petroleum geologist, Doctor, professor-level senior engineer, Master's supervisor)

He has long been engaged in the research related to the depositional features of oil and gas bearing basins and the comprehensive research of petroleum geology, etc. He has made some innovations in aspects of the genetic models and distribution of sand bodies in continental lake basins, enrichment rules, zonal evaluation and optimization of lithostratigraphic reservoirs, etc. He has obtained one first-prize of "National Science and Technology Progress Award" and 2 ministerial-level awards. He has published more than 10 research papers and co-authored 6 monographs.

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Zhu Rukai(Expert in sedimentary reservoir, Doctor, professor-level senior engineer, Master's supervisor)

He has long been engaged in the research on map plotting of lithofacies paleogeography, formation mechanisms and distribution rules of reservoirs, etc. He has made some innovations in the distribution of sedimentary system for marine layer systems, master control factors for volcanic reservoir development, quantitative evaluation of low-permeability tight diagenetic facies, etc. He has obtained 5 ministerial-level awards, published more than 80 research papers and co-authored 5 monographs.

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Tao Shizhen(Geologist of oil and gas reservoir generation, Doctor, senior engineer)

He has long been engaged in the research on oil and gas reservoir generation and comprehensive research of petroleum geology, etc. He has proposed the principle of experimental discrimination of inclusions in sedimentary rocks and the determination method of stage order for oil and gas generation. He has made some innovations related to the formation of lithostratigraphic trap, mechanism of reservoir generation, distribution of large oil and gas provinces, etc. He has obtained 2 first-prizes of ministerial level, published 75 research papers and co-authored 8 monographs.

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Hou Lianhua(Expert in trap and zone evaluation, senior engineer,Doctor of Engineering)

He has long been engaged in the comprehensive research of petroleum geology and research related to oil and exploration deployment, etc. He has made some innovations related to the enrichment rules of lithostratigraphic reservoirs, zone evaluation methods, reservoir prediction, target optimization and evaluation of volcanics, etc. He has obtained 2 first-prizes and 3 second-prizes of ministerial level, published more than 30 research papers and co-authored 4 monographs.

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Guo Qiulin(Expert in basin modeling, Doctor, professor-level senior engineer)

He has long been engaged in the methodological research of basin modeling and software design, etc. He has made some innovations related to basin numerical modeling methods, lithostratigraphic zone and trap evaluation, petroleum resources evaluation, etc. He has obtained one prize of "National Science and Technology Progress Award" as well as 8 provincial and ministerial-level awards, and published 4 monographs and over 60 research papers.

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Yao Fengchang(Geologist of seismic reservoir prediction, Doctor, professor-level senior engineer, Ph.D. supervisor)

He has long been engaged in the seismic special processing, new technique & method research, software development and comprehensive interpretation, etc. He has obtained one second-prize of "National Science and Technology Progress Award" and 6 ministerial-level science and technology progress awards, published more than 40 research papers and co-authored 2 monographs.

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Zhou Cancan(Expert in well-logging interpretation, Doctor, professor-level senior engineer, Ph.D. supervisor)

He has long been engaged in the methodological and technology research on well-logging evaluation of complex reservoirs. He has obtained the innovation results in the establishment of well-logging technology system of low resistivity oil/gas layers, electric method and application technology of nuclear magnetic resonance well logging, evaluation technologies of complex clasolite reservoirs, etc. He has won one second-prize of “National Science and Technology Progress Award”, published more than 40 research papers and co-authored 2 monographs.

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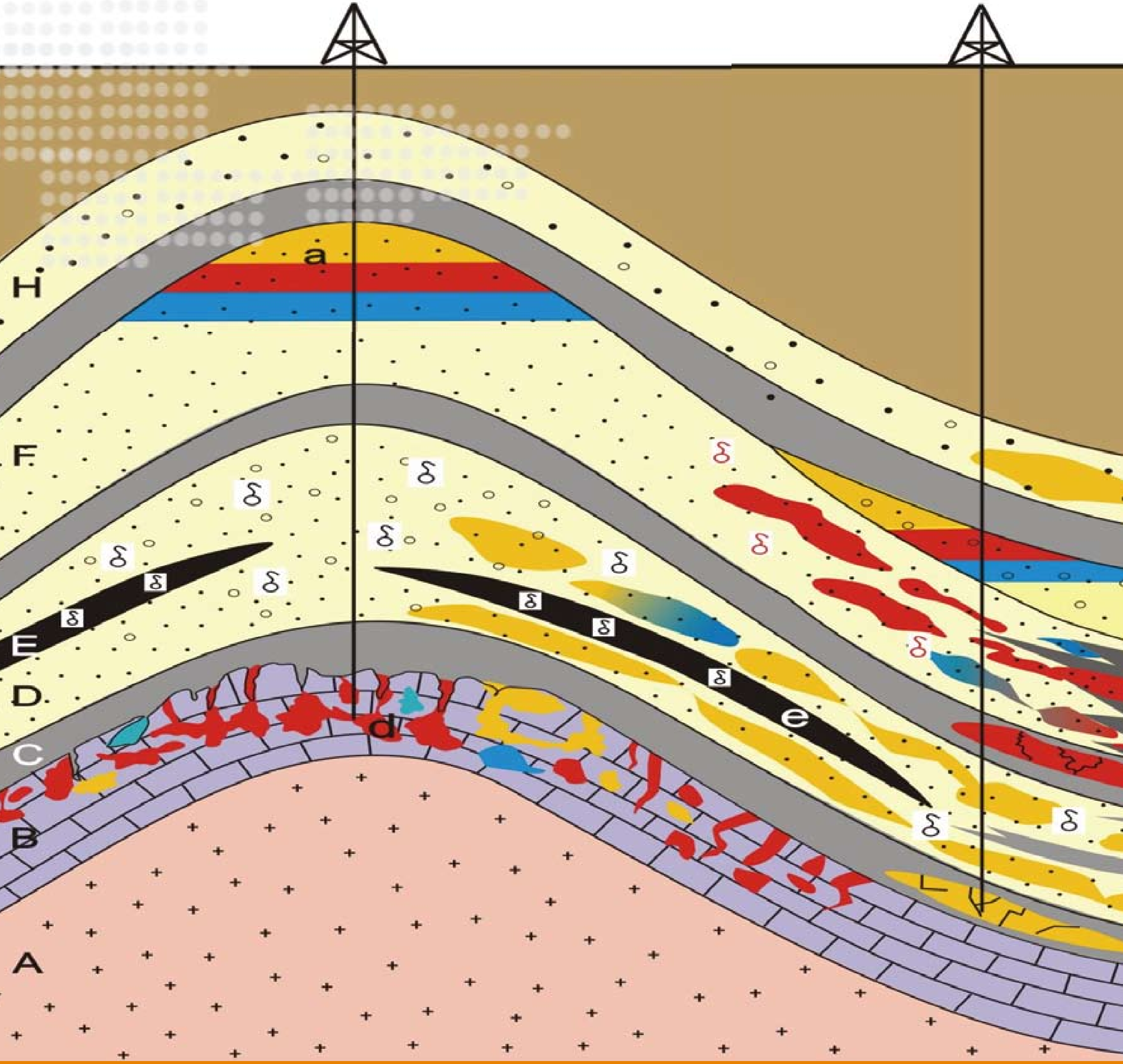

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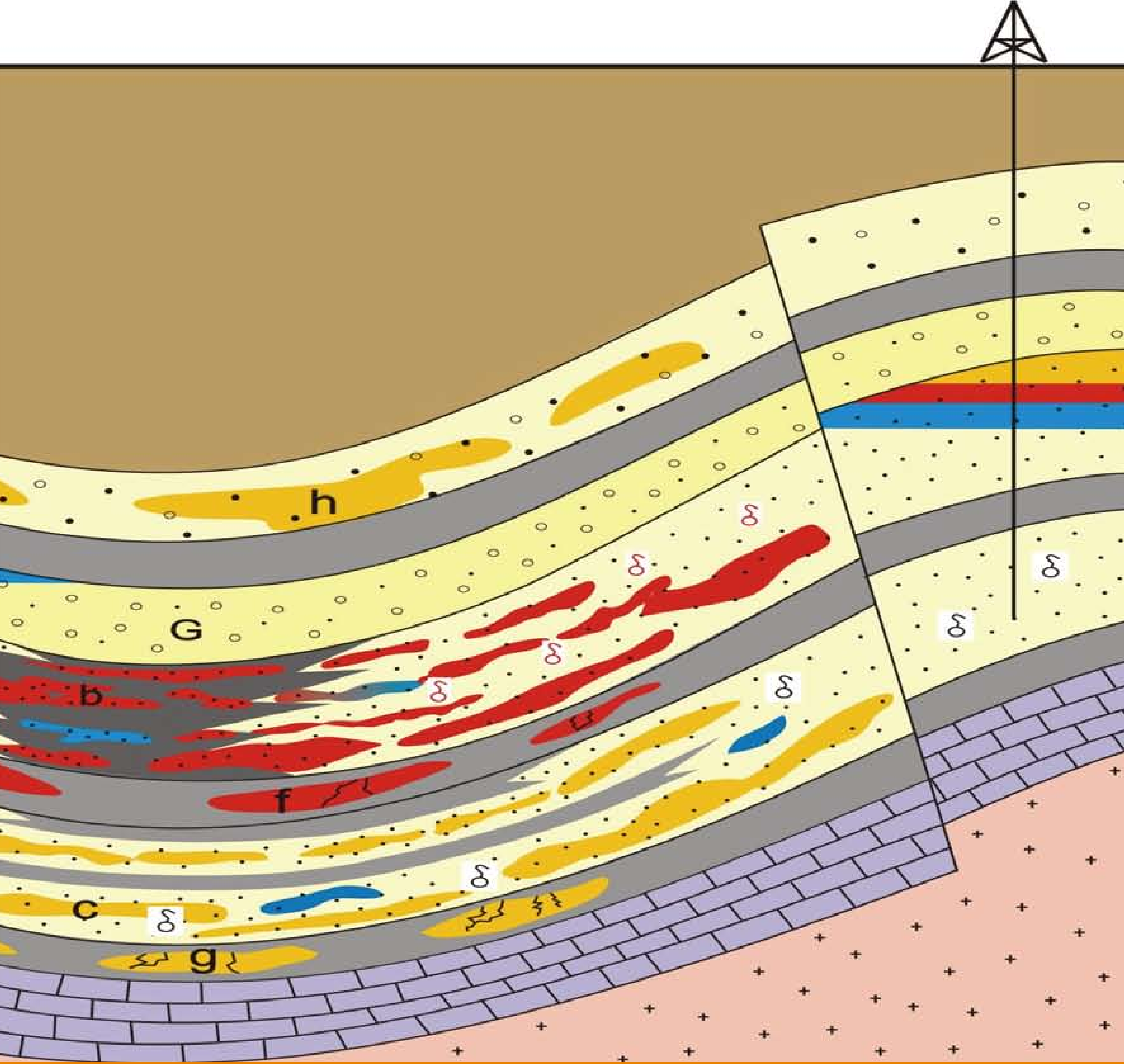
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