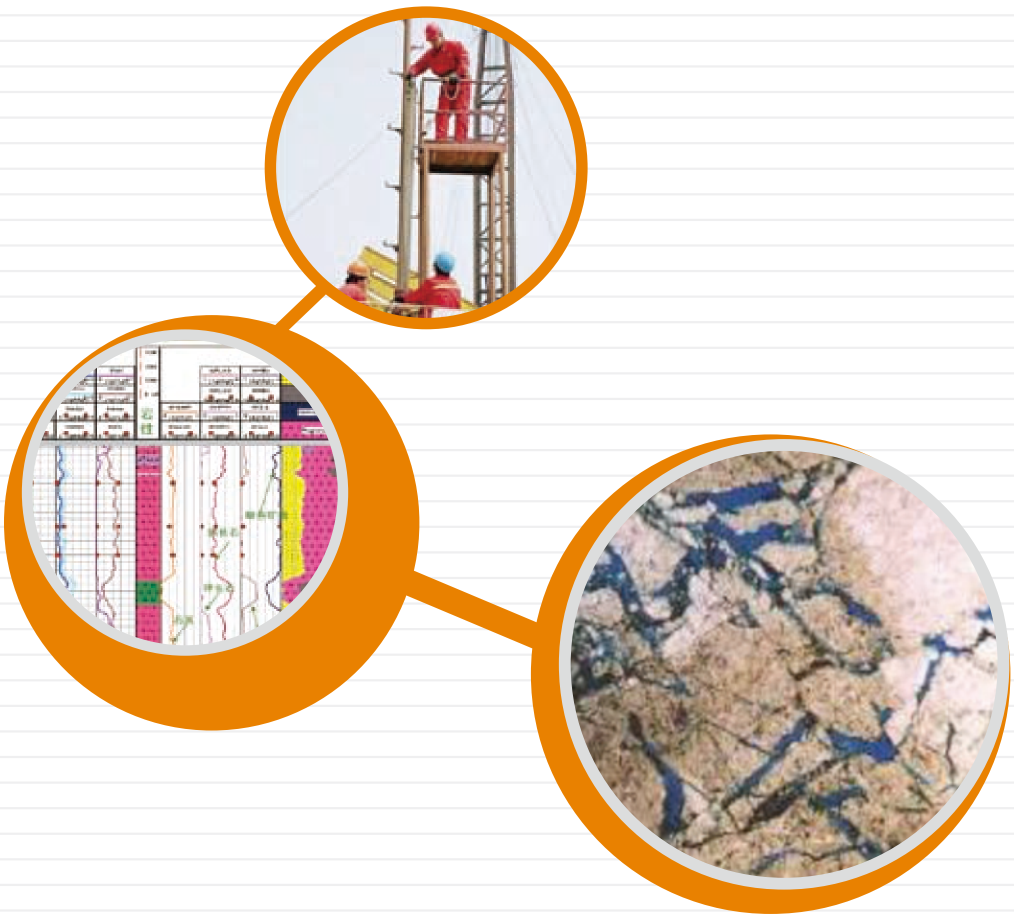
Logging Evaluation Technologies of Complex Lithologic Reservoir

Science & Technology Management Department

2013



CHINA NATIONAL PETROLEUM CORPORATION

Complex Lithologies Indentification, Easy with GW-CLE Technologies!

Contents

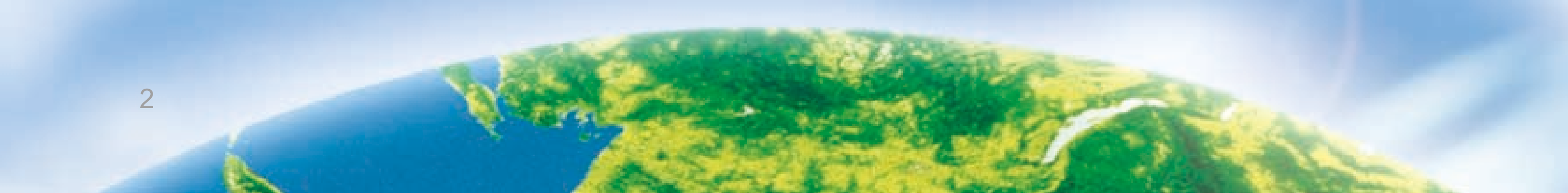
China National Petroleum Corporation (CNPC)is a state-authorized investment agency and a state holding company. On July 1998, with the implementation of the Institutional reform of the State Council, CNPC was reorgnized to become an integrated oil company of cross-regions, cross-industries and cross-countries, it adopts modern enterprise system to realize the integrations of upstream and downstream operations, internal and external trade, production and marketing. CNPC's business covers six main sectors: oil and gas operations, petroleum engineering service, petroleum engineering construction, petroleum equipment manufacturing, financial services and new energy development. In 2012 CNPC produced 110 million tons of crude oil and 79.82 billion cubic meters of natural gas, while crude processing volume reached 191 million tons. The total revenue of RMB 2,690 billion with a profit of RMB139.1 billion had been achieved the same year.

CNPC was ranked 4th among the world's largest 50 oil companies and 6th in Fortune Global 500 in 2012.

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.

Logging Evaluation Technologies for Complex Lithologic Reservoir is one of representatives for major innovations of CNPC.

CLEAN ENERGY SUPPLY FOR BETTER ENVIRONMENT



1 INTRODUCTION

With the deepening of petroleum exploration and development, complex lithologic reservoirs have become the focus of the world's attention.

Complex lithologic reservoirs include metamorphic rock reservoirs, carbonate reservoirs and igneous reservoirs. The oil and gas reserve in carbonate reservoirs is nearly upto 50% of the global oil and gas reserves, and the oil and gas production from carbonate reservoirs accounts for 60%. Igneous rocks can also act as very good reservoirs. Commercial oil flows have been obtained from igneous rocks in USA, Venezuela, Brazil, Japan, Argentina, Libya, Cuba, India and some other countries. Various primary and secondary fractures of metamorphic rocks can act as oil and gas storage spaces, thus forming good reservoirs.

Due to complex lithology composition and structure and the complexity of various exploration conditions, it is difficult to identify the lithology of complex lithologic reservoirs, to find them and calculate their geologic parameters, so that the evaluation of complex lithologic reservoirs has become the difficulty in oil and gas exploration at present.

Logging Evaluation technologies of Complex lithologit Reservoir can be used to comprehensively evaluate complex lithologic reservoirs, to accurately evaluate downhole strata and media properties, timely and to accurately find and evaluate oil and gas reservoirs, to solve the geology and engineering problems in the exploration and development process of complex lithologic reservoirs and to quicken oil and gas exploration and development progress in terms of lithologic identification, reservoir identification and reservoir evaluation and have been widely applied in metamorphic rock, carbonate rock and igneous oil and gas blocks in Bohai Bay Basin, Tarim Basin, Sichuan Basin and Ordos Basin of China as well as the Middle East, Central Asia, South America, etc.

- Logging Evaluation Technologies of Complex Lithology Reservoir
  - Lithologic Identification Technology
    - Comprehensive Lithologic Identification Technology of Metamorphic Rocks
    - Comprehensive Lithologic Identification Technology of Carbonate Rocks
    - Automatic Lithologic Identification Technology
  - Reservoir Identification Technology
    - Reservoir Identification of Technology Based on Imaging Logging Mode Library
    - Identification Technology of Reservoirs with Complex Pore Structure
    - Visualization Technology of Geologic Bodies Attitude on Well Trajectory Cross Section
    - Fracture Effectiveness Evaluation Technology
    - Comprehensive Identification Technology of Reservoirs
  - Reservoir Evaluation Technology
    - Evaluation Technology of Mineral Content and Effective Porosity Based on the Optimization Theory
    - Matrix Porosity Evaluation Technology Based on Variable Matrix Interval Transit Time
    - Fracture Parameter Evaluation Technology Based on Acoustoelectric Imaging Simulation Well
    - 3D Digital Core Building Technology
    - Reservoir Fluid Evaluation Technology
    - Evaluation Technology of Waterflooded Layers

2 UNIQUE TECHNOLOGIES

2.1 Lithologic Identification Technology

Lithologic identification is the foundation of reservoir identification and quantitative evaluation of reservoirs. Without correct lithologic identification, qualitative identification and quantitative evaluation of reservoirs would be blind and even wrong and would affect perforation, production test and the whole completion process. Therefore, lithologic identification plays an extremely important role in the reservoir evaluation process.

Metamorphic rocks, carbonate rocks and igneous rocks have complex mineral composition and multivariant pore space structures, so it is extremely difficult to analyze and identify their lithology using logging information.

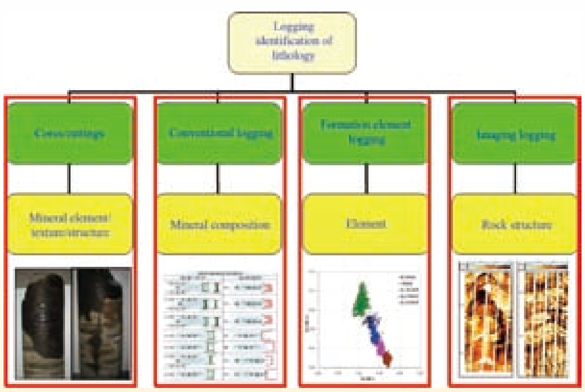
CNPC has formed a set of feasible lithologic identification technology series and has successfully solved the difficult problem about complex lithology identification.

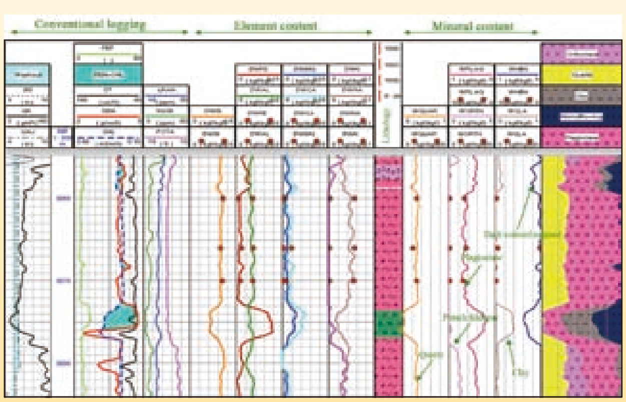
Lithologic identification technology series include three major unique technologies such as comprehensive lithologic identification technology of metamorphic rocks, comprehensive lithologic identification technology of carbonate rocks and automatic lithologic identification technology and can be used to realize comprehensive identification of metamorphic rocks, carbonate rocks and igneous rocks.

Comprehensive Lithologic Identification Technology of Metamorphic Rocks

The comprehensive lithologic identification technology of metamorphic rocks is based on experimental analyses and petrophysics.

The lithology of metamorphic rocks can be analyzed qualitatively, evaluated quantitatively and identified automatically and the purpose of accurately identifying metamorphic rocks can be achieved comprehensively using conventional logging data, formation element logging data and imaging logging data in combination with the technologies such as neural network, fuzzy mathematics, cross plot, etc.

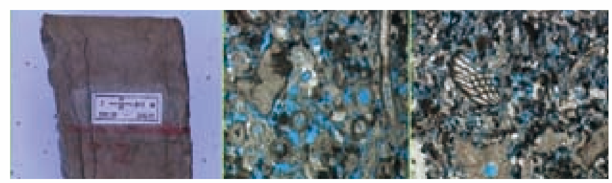




Comprehensive lithologic identification result

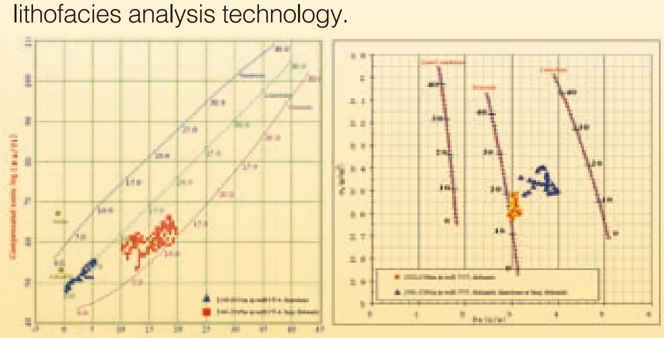
Comprehensive Lithologic Identification Technology of Carbonate Rocks

The mineral components of the matrix of complex lithologic carbonate reservoir rocks are mainly calcites and dolomites and generally contain some clay minerals, organic matters, gypsums, salt rocks, pyrites, silica, etc. Their content is not high, but they affect reservoirs to a large extent and make a large contribution to logging information. Therefore, it is very necessary to effectively carbonate reservoirs using logging data or combining logging data with other data.



core and slices

The comprehensive lithologic identification technology of carbonate rocks can be used to effectively identify and divide the mineral components of carbon reservoirs, their sedimentary diagenesis environment, main rock types and lithofacies development belts with specific lithologic combinations and to predict oil and gas enrichment areas using microscopic core analysis technology and macroscopic lithofacies analysis technology.



Lithology identification with cross plot

2.2 Reservoir Identification Technology

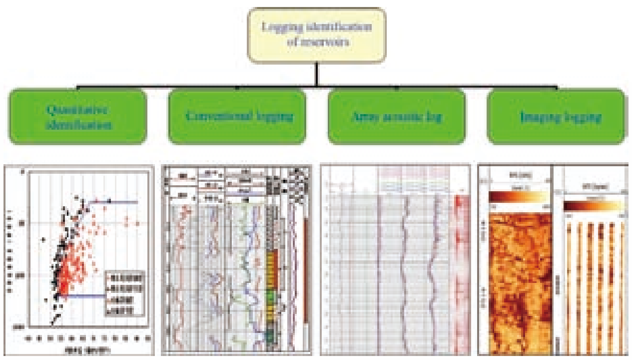
Reservoirs were identified mainly depending upon logging data before imaging logging appeared. However, complex lithologic reservoirs have complicated geologic conditions and especially fractured reservoirs and cave reservoirs have serious heterogeneity longitudinally and transversely, thereby making it difficult to identify reservoirs singly depending upon conventional data.

Based on conventional logging date analysis,new logging technologies including imaging logging, dipole s-wave logging, NMR logging, etc. are applied to finely and accurately indentify the complex lithologic reservoir, and to establish and improve the effective evaluation metheds of the indentification of true and false fractures, and care and fractural cave.

The reservoir identification technology series include the unique technologies such as reservoir identification technology based on imaging logging mode library, fracture effectiveness evaluation technology, identification technology of reservoirs with complex pore structure with NMR logging, visualization technology of geologic bodies attitude on well trajectory cross section and comprehensive identification technology of reservoirs.

Comprehensive Identification Technology of Reservoirs

Based on the dominant lithologic sequence theory, quantitatively identify reservoirs using the cross plot technology; qualitatively identify reservoirs using conventional logging data; qualitatively describe the fracture development degree and attitude of reservoirs using imaging logging data; evaluate the effectiveness of reservoir



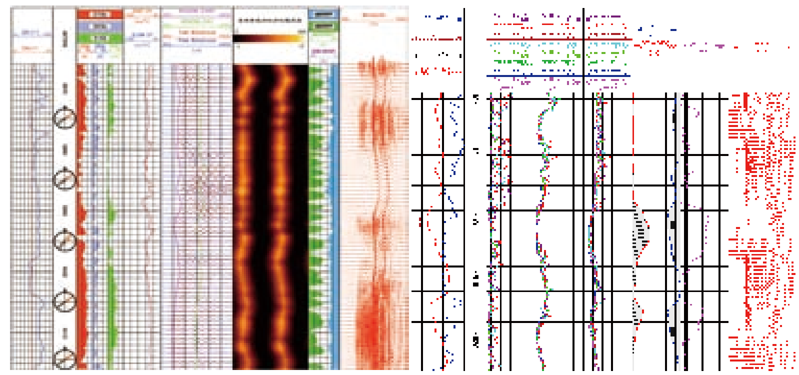
fractures using multi-pole array acoustic logging data, thus obtaining the reservoir division criterion and achieving the purpose of comprehensively identifying reservoirs.

Fracture Effectiveness Evaluation Technology

The fracture effectiveness evaluation technology includes the fracture effectiveness evaluation technology based on cross-dipole acoustic waves and the fracture effectiveness evaluation technology based on Stoneley waves.

The fracture effectiveness evaluation technology based on cross-dipole acoustic waves is used to determine the maximum principal stress direction of formations according to the anisotropic azimuth of cross-dipole S-waves and thus to judge fracture effectiveness by analyzing the angle relationship between the strike direction of fracture systems and the earth stress direction.

The fracture effectiveness evaluation technology based on Stoneley waves is used to judge fracture filling state



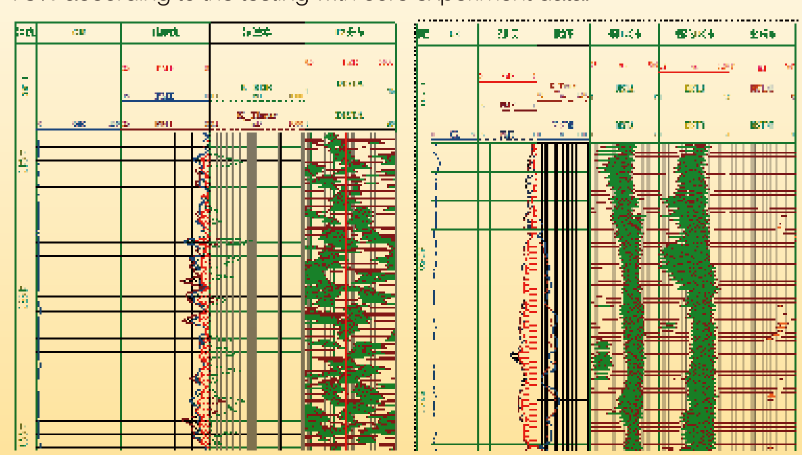
Fracture Effectiveness Evaluation Technology Based on Cross-dipole Acoustic Waves

and thus fracture effectiveness according to the amplitude attenuation and time delay of array acoustic waves.

Identification Technology of Reservoirs with Complex Pore Structure

The identification technology of reservoirs with complex pore structure is used to visually reveal the pore structure of complex lithologic reservoirs and to identify the corresponding reservoir types according to the distribution of NMR logging standard T_2 spectra.

The technology can be compared with core analysis but is more inexpensive than drilling coring and can realize continuous measurement. The coincidence rate can reach 75% according to the testing with core experiment data.



2.3 Reservoir Evaluation Technology

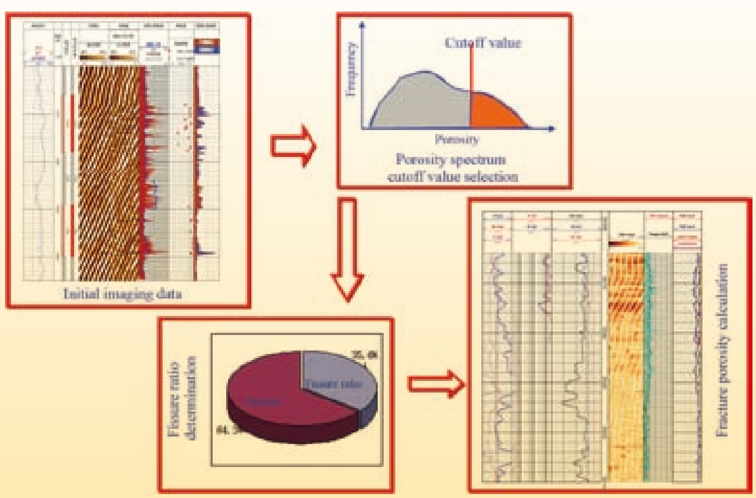
Reservoir evaluation is intended to comprehensively evaluate oil and gas reservoirs, to calculate the parameters of complex lithologic reservoirs and to ascertain fluid properties from the viewpoint of logging based on logging data in combination with geologic data, seismic data, core analysis data, dynamic and static data in the development process, etc.

Fracture Parameter Evaluation Technology Based on Acoustoelectric Imaging Simulation Well

- Derive the fracture width calculation formula based on acoustoelectric imaging simulation well; calculate the fracture width from the formula.

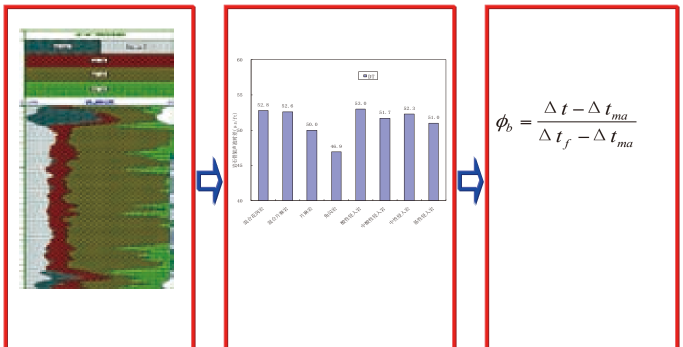
Rock fractures

- Evaluate matrix pores and secondary pores using the imaging logging porosity spectrum analysis method.



- The secondary porosity of fractures can be accurately calculated and the fracture development degree can be judged.

Matrix Porosity Evaluation Technology Based on Variable Matrix Interval Transit Time



Mineral content calculation   Variable matrix value of rocks   Matrix porosity calculation mode

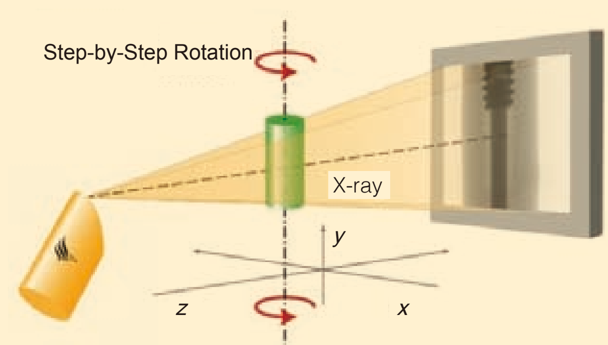
The matrix porosity evaluation technology based on variable matrix interval transit time can be used to accurately calculate the content of various minerals comprising rocks with multi-mineral interpretation and processing software. Based on this, the variable matrix interval transit time value of rocks can be accurately calculated, and thus the rock matrix porosity can be accurately calculated with the matrix porosity interpretation model.

The matrix porosity calculated with this technology according to the variable matrix interval transit time value of rocks is more accurate than that according to the matrix interval transit time value of a single mineral.

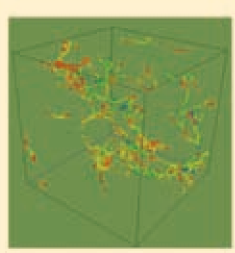
3D Digital Core Building Technology

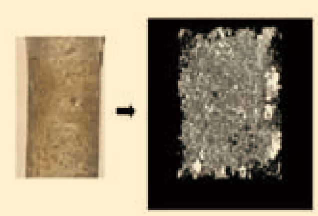
The 3D digital building technology is used to carry out 360° scanning of cores using X-ray bundles. X-ray bundles interact with rock components of different densities to cause the corresponding absorption and attenuation, thereby obtaining the 3D grayscale image of cores with the electronic computer fault scanning technology.

3D digital building of physical cores is realized through binaryzation of 3D grayscale images and the analysis of the representative elementary volume (REV) of cores and pore structure. At present, the CT (Computed Tomography) precision with X-rays can reach 1μm.



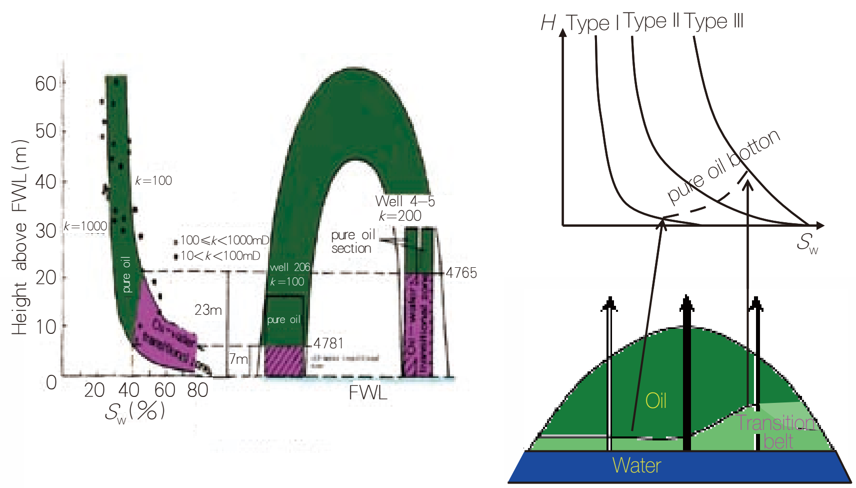
Experimental Principle of the 3D Digital Core Building Technology


Topological structure of pores


3D Digital Core Building of Dolomites

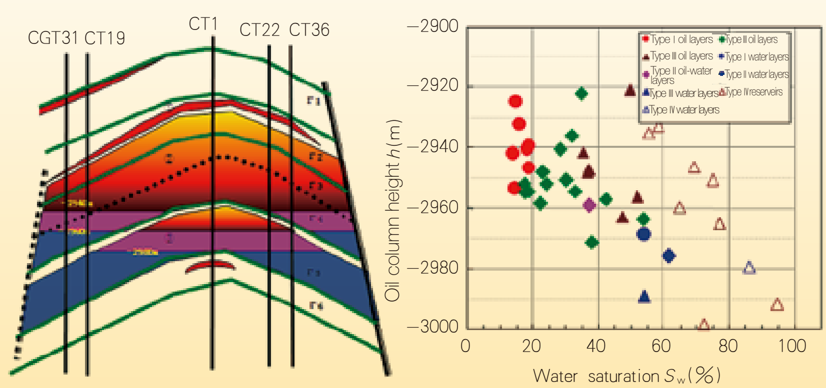
Reservoir Fluid Evaluation Technology

Comprehensively evaluate complex reservoir fluid properties and identify oil, gas and water contacts combining multiple disciplines, based on logging data.



Fine Interpretation of Structures in Oil-water Transition Belts

The reservoir fluid evaluation technology includes evaluation technology of reservoir fluid properties with the cementation index method, evaluation technology of reservoir fluid properties with the apparent fluid parameter method, analysis technology of gas-oil-water contacts and oil-water transition belts under the reservoir background and fluid identification technology combining well logging and mud logging.

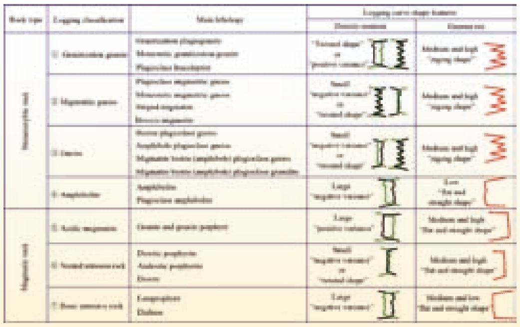


Analysis of gas-oil-water contacts and oil-water transition belts

3 TYPICAL CASES

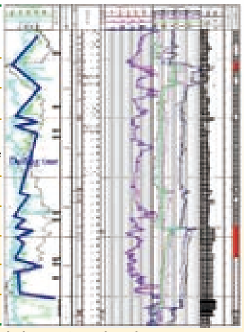
3.1 Logging evaluation of Archaeozoic metamorphic rock buried hill reservoirs in Liaohe oilfield

Archaeozoic buried hill belts in Liaohe oilfield are typical metamorphic rock development belts, and there are difficult problems including confused division of lithology, unclear identification of reservoirs, unknown buried hills, unpredictable reserves, etc. With the logging evaluation technology for metamorphic rocks, CNPC has determined the “dominant lithology” of reservoirs and the oil production bottom boundary of reservoirs and established the identification and evaluation criteria for lithology, fractures and reservoirs in Archaeozoic buried hills in Liaohe depression. The interpretation coincidence ratio of the lithology has reached over 90% from failure to systemically identify the lithology initially, the one-time identification accuracy ratio of reservoirs has been increased to over 95% from 85%, the one-time interpretation coincidence ratio of oil layers has been increased to over 85% from 74%, and the oil production bottom boundary depth has been expanded to -4700m. The newly increased proven reserves and integral proven reserves of Xinglongtai buried hills are 3173×10^4t and 1.27×10^8t respectively and the newly increased predicted reserves of Damintun south buried hills are over 6000×10^4t, thus providing technical support to the exploration and development of metamorphic rock buried hill reservoirs in Liaohe oilfield.

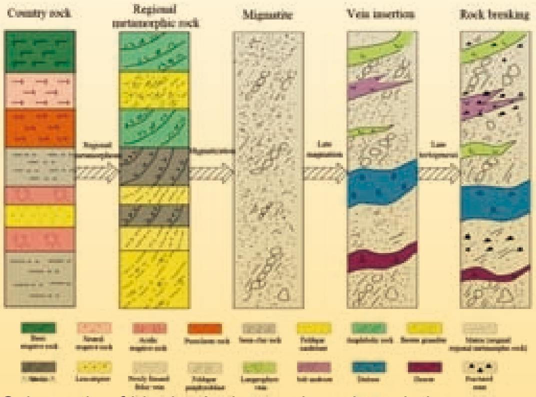


Conventional lithology logging characteristic mode library

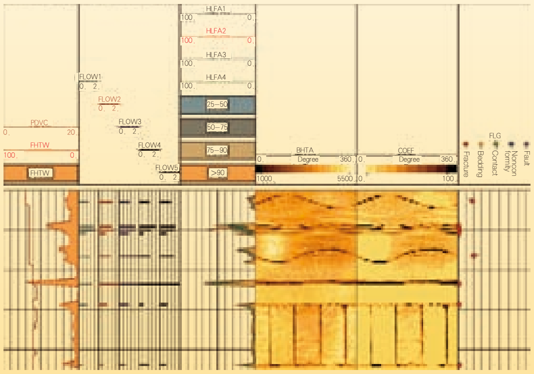
Lithology standard	Logging interpretation of granitization granite, migmatitic gneiss, gneiss and acidic and neutral intrusive rocks		
Qualitative division standard for reservoirs	Conventional logging	“Low resistivity features at high resistivity”, increase in three porosities	
	Acoustic/electric imaging logging	Visual identification of buried hill fracture development sections	
	Array acoustic log	Identify fracture development sections and judge fracture effectiveness through acoustic amplitude attenuation, frequency shift and time lag.	
	Mud logging	High level show from gas logging or cuttings logging	
	Drilling	Drilling time decreased obviously	
Quantitative division standard for reservoirs	Logging item	Upper limit	Lower limit
	Deep resistivity	2000 Ω·m	100 Ω·m
	Interval transit time		55μs/ft



Archaeozoic reservoir division standard

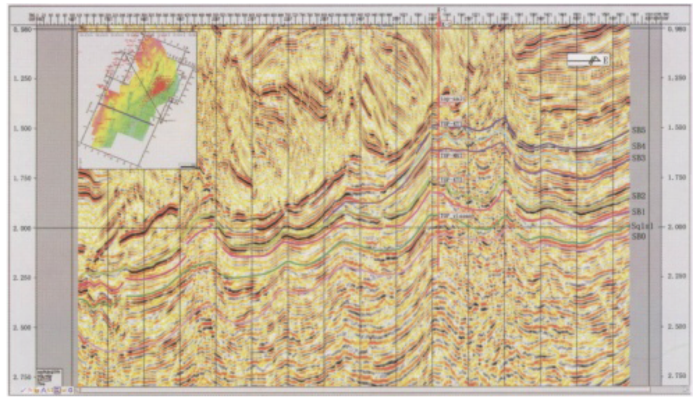


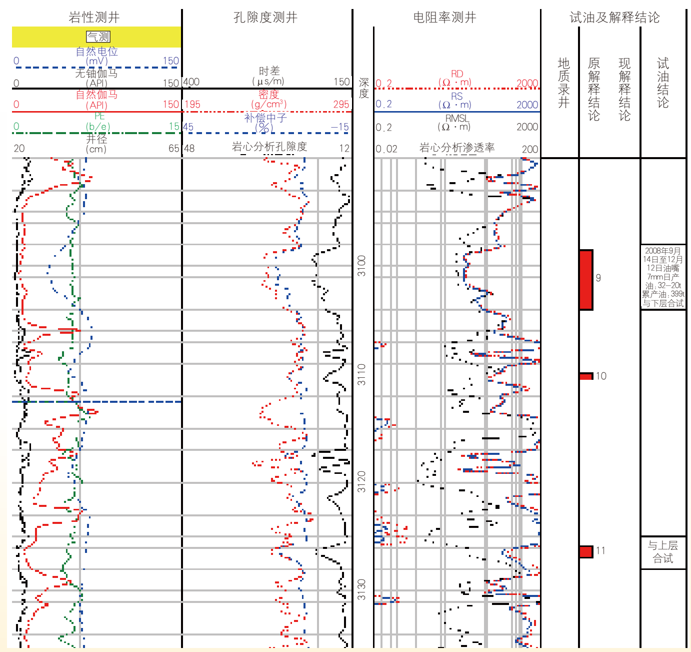
Schematic of Liaohe Archaeozoic rock evolution process



Fracture evaluation

3.2 Logging evaluation of carbonate reservoirs in North Truva Oilfield in Kazakhstan


Seismic data

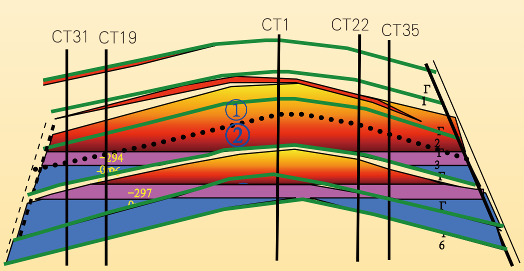


Logging data

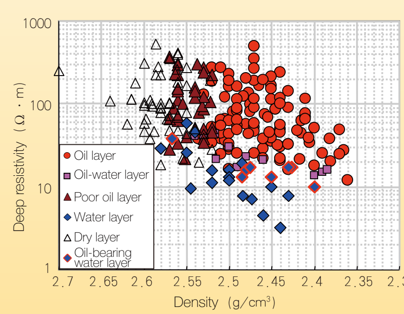
North Truva Oilfield in Pre-caspian Basin is the first integral large oilfield of 100 million ton reserves that was discovered by CNPC in Kazakhstan. The main target formation in the oilfield is Carboniferous carbonate reservoirs. Due to being affected by overlying extra-thick rock salts, seismic prediction of reservoirs is difficult and the recognition of reservoirs is always fuzzy. With the deepening of exploration and development, the difficult problems about lithology, reservoir property, oil (gas) bearing property, reservoir type, etc. have gradually become apparent and it is extremely urgent to carry out logging evaluation of carbonate reservoirs and reservoir regularity research.

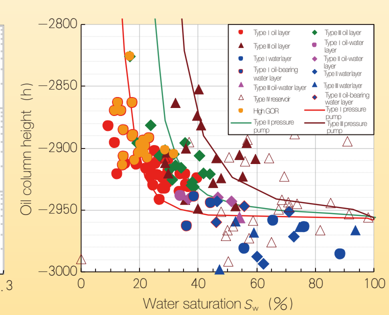
Fine studies of logging data indicate that the reservoir types are complex and changeable and oil water contacts are not single in the oilfield. There are at least four fault blocks on plane, each of which has an independent oil and water system. Due to being affected by the variation of reservoir's physical properties, there are over 30m oil-water transition belts locally longitudinally.

The established oil, gas and water identification charts and interpretation standards have been widely applied in North Truva Oilfield, and the coincidence ratio of oil, gas water interoperation has been greatly increased from 75% to 97%, thus providing important technical support to shifting of exploration to development of the oilfield.



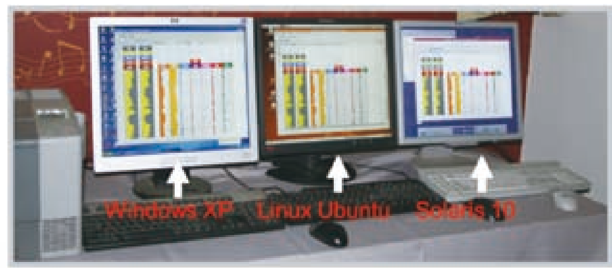
Reservoir analysis





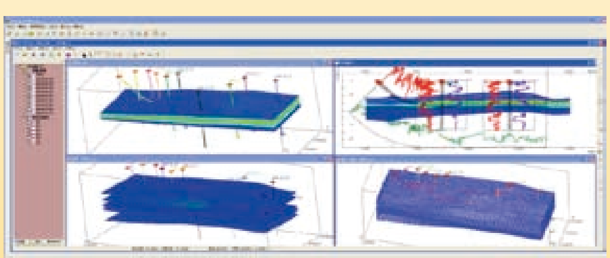
4 R&D EQUIPMENT

CNPC has advanced and perfect R&D equipment, including: independently developed integrated logging data interpretation and processing software CIFLog-GeoMatrix, electric simulation experiment well, acoustoelectric imaging simulation test unit and radioactive calibration well group.



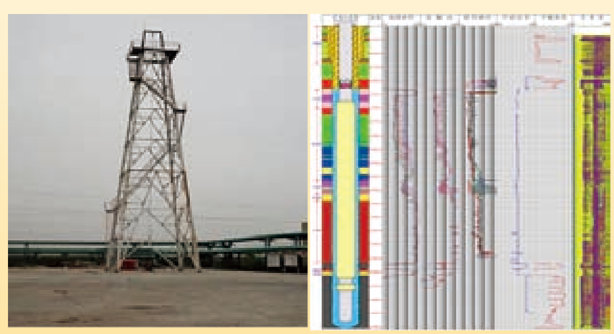
CIFLog-GeoMatrix integrated logging data interpretation and processing software

CIFLog-GeoMatrix integrated logging data interpretation and processing software uses Java's self-balancing technology to realize cross-platform and multi-operating system processing without need to convert logging data. Multilingual packs and resource file configuration technology are used to realize quick conversion of various languages package, resource files and symbol systems. One-key rapid switching technology in different systems is adopted. The multilingual support to the development system can realize quick transplantation of original logging interpretation methods, thus meeting the diversified demands of the international market. By using the processing modules with complete functions, and introduced logging equipment and homemade logging equipment share a set of software and hardware system for interpretation and processing, thus meeting the diversified demands of multiple logging series that coexist in the market.



Electric simulation experiment well

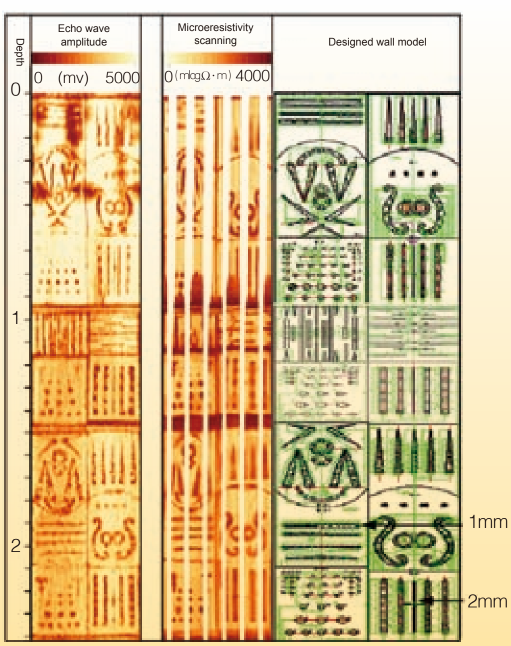
The depth of the electric simulation well is 553m and it is made of metallic and nonmetallic materials using special process. Multiple simulation formations with different resistivities, time differences and cementation degrees have been formed. Alternately thin and thick horizons are combined, which are mainly used to detect and calibrate electric and acoustic logging tools.



Electric simulation experiment well

Acoustoelectric imaging simulation test unit

The acoustoelectric imaging simulation test unit is a set of four-group full-space vertical formation simulation test unit. Natural limestones, natural granites and natural sandstones are used to make the acoustoelectric imaging simulation well with three sorts of hole diameter such as Φ152mm, Φ215mm and Φ241mm and combining Φ152mm with Φ215mm. Various pores, holes and fractures are made on the borehole wall to simulate various geologic phenomena of formations. This is used to calibrate relevant logging tools and establish a digital simulation system; then according to relevant logging tools, the corresponding processing evaluation standard is established for various known rock responses.



Acoustoelectric imaging simulation test unit

Radioactive calibration well group

There are totally 8 radioactive tool calibration wells, which can be used to calibrate the tools involving neutron, density, gamma ray, spectra, etc. There are 7 calibration wells with the diameter of 1m and the depth of 16m and 1 GRP cased well with the diameter of 300mm and the depth of 20m.


Radioactive calibration well group

5 QUALIFICATIONS & STANDARDS

5.1 Qualifications

CNPC has national grade A qualification in EPC, engineering exploration design, etc. and grade I construction qualification by the Ministry of Construction and the Ministry of Communications and has obtained national grade AAA credit rating certificates and passed GB/T19001 quality management system certification.

CNPC has a high-level expert team long engaged in the R&D of logging evaluation technologies for complex lithologic reservoirs. The project “Research on Logging Evaluation Methods for Liaohe Land Archaeozoic Metamorphic Rock Buried Hill Reservoirs” was awarded with grade II science and technology advance prize of CNPC in 2012.

5.2 Patents

Totally 6 relevant patents obtained.

Patent Name	Patent No.
Measurement method of Stoneley waves slowness in well bore	201210493582.2
Formation anisotropy evaluation method	201210493762.0
A quantitative fracture evaluation method based on ultrasonic imaging logging	201210125518.9
A method for determining the content of multiple mineral components in formations	201210125507.0
A method for determining formation attitude in well bore	200510076818.2
A full-borehole wall restoration method with electric imaging logging charts	200510075171.1

5.3 Standards

CNPC strictly carries out relevant national or industrial standards.

Technical requirements for geologic feature description of reservoirs	SY/T 5355—2000
Single open hole logging data processing flow	SY/T 5360—2004
Application Software Engineering Specification of Petroleum Industry	SY/T 5232—2012
Laboratory measurement specification of rocks acoustic characteristics	SY/T 6351—2012
Reservoir description methods	SY/T 5579.1—2008
Technical specification of logging data processing and interpretation of exploration wells	SY/T 6451—2010
Specification of electric and acoustic imaging logging data processing and interpretation	SY/T 6488—2000
Technical specification of Processing and Interpretation of Complex Lithological Formation Logging data	SY/T 6546—2011
Specification of Nuclear Magnetic Resonance Logging Data Processing and Interpretation	SY/T 6617—2005
Quality specification of petroleum logging initial data	SY/T 5132—2012
Technical specification of wireline formation tester logging data interpretation	SY/T 5691—2006
Measurement and calculation methods of rock resistivity parameters in laboratory	SY/T 5385—2007
5700 imaging logging data interpretation and processing process	Q/SY-GWDC-CJ0965—2010
Specification of logging data interpretation of a single exploration well	Q/SY-GWDC-CJ1272—2010
Specification of logging data interpretation of adjustment wells	Q/SY-GWDC-CJ1273—2010

6 EXPERT TEAM

Lu Dawei professor level senior engineer, petroleum geophysical logging expert. He now serves as the executive member of Chinese Petroleum Society, the director of the Petroleum Logging Specialized Committee of Chinese Petroleum Society, the chairman of Beijing Branch of SPWLA, the director of the Petroleum Logging Specialized Standard Committee and the chief editor of the journal Well Logging Technology. He has organized the preparation of medium to long term technical development plans in China's petroleum logging industry many times.

Tel.: 13901062602

Li Ning professor level senior engineer, senior technical expert, Ph. D. candidate supervisor. He serves as the leader of the special national oil and gas project "Integrated Logging Evaluation Technology, Matching Equipment and Processing and Interpretation Software for Complex Reservoirs". He took charge of studying and development two generations of China's large logging processing and interpretation software. He was awarded with 2 grade II national science and technology advance prizes and 7 provincial and ministerial prizes. 56 papers 5 monographs published.

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Wang Hao Technical export. He took charge of and participated in completing over 20 scientific research projects and was awarded with 2 grade II technical innovation prizes of CNPC. 15 papers published.

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Wu Dong technical expert. He was awarded with 1 grade science and technology advance prize of the National Energy Administration, 7 provincial and ministerial prizes and 18 bureau level prizes. Over 20 papers published.
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You Zheng Technical expert. He took charge of and participated in completing over 10 scientific research projects, awarded with 6 bureau level prizes and applied for 1 patent of invention. Over 10 papers published.
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