

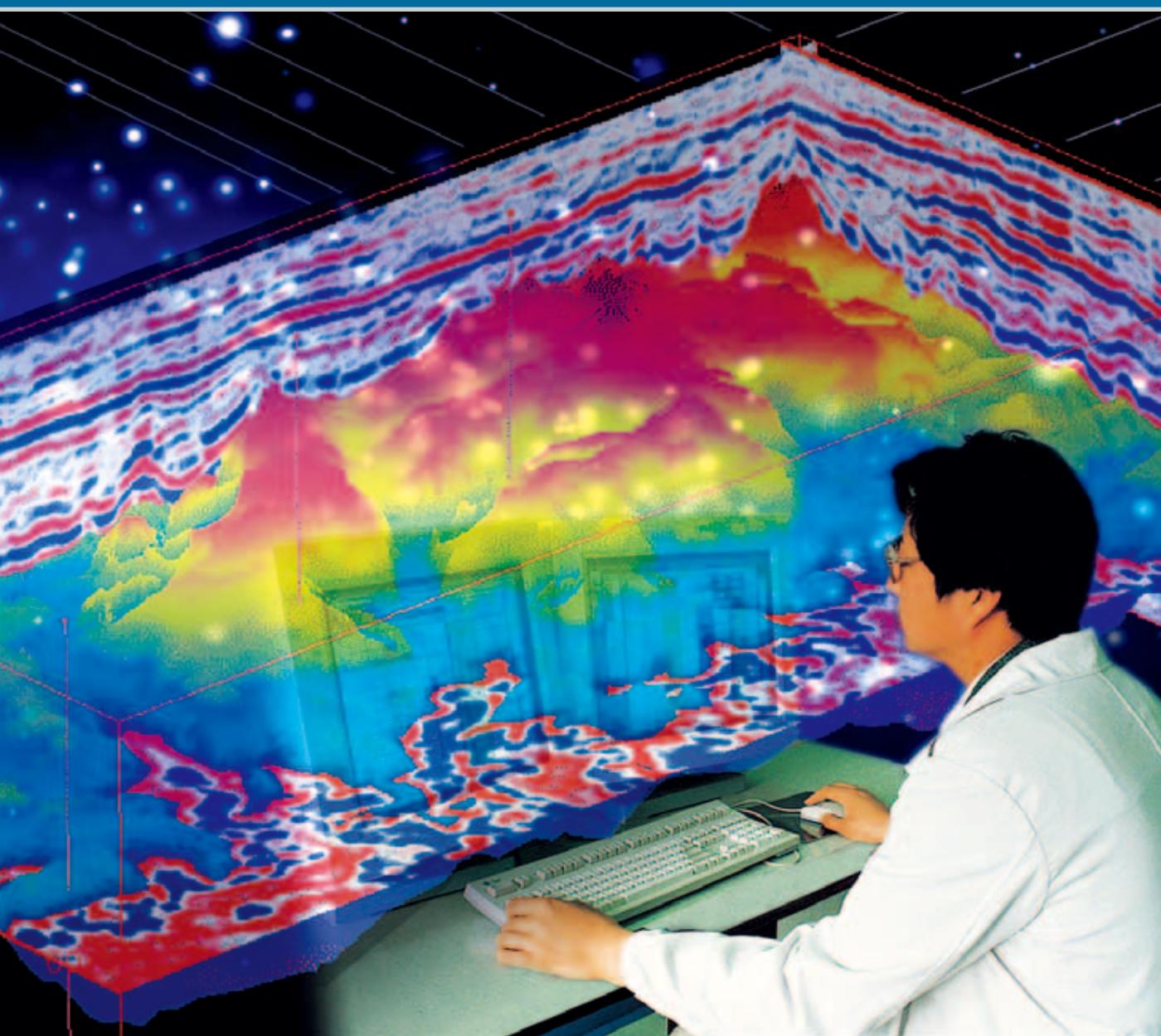
Technology Shapes the Future



**China National Petroleum Corporation**

**A**s an international energy company embracing technology and innovation, CNPC has long been committed to research and develop sophisticated and practical technologies and solutions in oil and gas exploration and development operations.

Facing up to the end of 'easy oil', we have to turn to much tougher targets to meet ever increasing energy demand. We focus our R&D efforts on finding and tapping subtle and complex reservoirs, enhancing recovery of mature oilfields, unlocking unconventional hydrocarbons, improving operational safety, and mitigating impact to the environment.



# Exploration of lithostratigraphic reservoirs

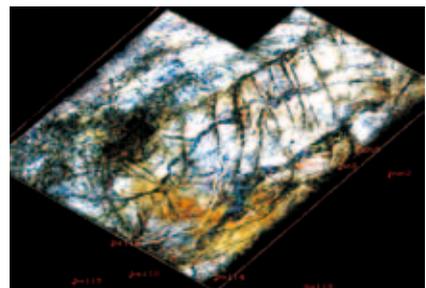
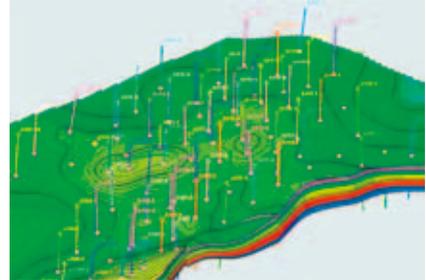
Since lithostratigraphic reservoirs became an important onshore exploration target in the early 1990s, CNPC has begun to study the geological theory and exploration technology for this type of oil and gas accumulations. After years of efforts, significant breakthroughs are achieved:

- i) Genesis theory of lithostratigraphic reservoir zones and traps in “four types of basin and three types of reservoir body”
- ii) Genesis theory of large-area lithostratigraphic reservoirs of low-to-average abundance
- iii) Enrichment law of lithostratigraphic reservoirs in four types of prototype basin
- iv) New zone evaluation method by “four-chart overlapping” based on hydrocarbon units
- v) Two core technologies for commercial application of continental sequence stratigraphy and seismic prediction of reservoirs

These geological theories and exploration technologies have been commercialized to enable large-scale exploration of lithostratigraphic reservoirs, leading to significant oil and gas discoveries. A number of billion-ton grade fields have been identified in the deep zone of Songliao Basin, Xifeng of Ordos Basin, central part of Sichuan Basin, central part of Tarim Basin and northwest edge of Junggar Basin. In recent years, more than 60% of CNPC’s proven reserves are contributed by lithostratigraphic reservoirs. ■

## Four types of basin entrapping lithostratigraphic reservoirs

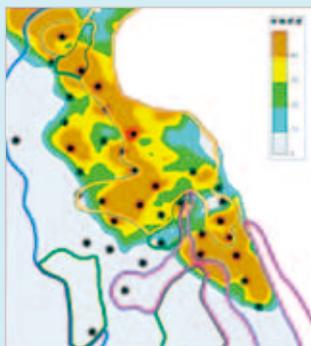
- ◆ continental depression basin
- ◆ continental rift basin
- ◆ continental foreland basin
- ◆ marine craton basin



## Lithostratigraphic reservoir

Oil and gas reservoirs have been classified into three categories i.e. structural, stratigraphic and lithological, based on the mechanism of trap formation. Structural reservoirs are reservoirs caught in a trap formed by a deformation in the form of fold or fault in the rock layer that contains the hydrocarbons. Stratigraphic traps are formed by the blocking of unconformity due to an interruption in deposition. The reservoirs thus sealed are called stratigraphic reservoirs. Lithological traps are formed by lateral lithologic changes. The reservoirs thus sealed are called lithological reservoirs. Stratigraphic and lithological reservoirs are also known as lithostratigraphic reservoirs. Lithostratigraphic reservoirs are characteristic of variation in physical properties, heterogeneity, concealment, complicated forming conditions as well as migration and accumulation complexities.

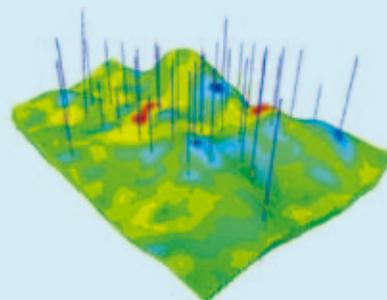
# Exploration and development of volcanic gas reservoirs



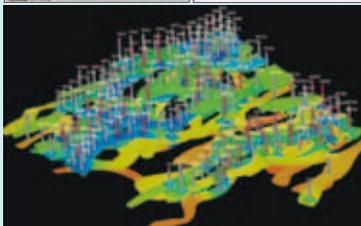
In recent years, volcanic gas reservoirs have become a new front of CNPC's exploration and development efforts. Volcanic gas reservoirs are difficult to tap due to their complex lithology, complicated pore space, and high heterogeneity.

Based on the geological characteristics of volcanic rocks, we have marshaled resources from multiple disciplines and developed unique technologies in lithology and lithofacies identification, identification and prediction of effective reservoirs and fractures, evaluation of gas reserves and productivity, and optimization of well location and well pattern for the exploration of volcanic gas reservoirs. Meanwhile, major technologies for development have been created, including staged fracturing and reservoir protection.

These innovative technologies have facilitated the discovery of some volcanic gas reservoirs, including Daqing's Xushen gas field and Jilin's Changling-1 gas field in Songliao Basin, and Kelameili gas field in Junggar Basin. From these fields, 400 billion cubic meters of cumulative gas reserves have been proven and more than 2 billion cubic meters of natural gas can be produced every year. ■



# Development of low-permeability oil and gas reservoirs



Low-permeability reservoirs have become a major target of CNPC's exploration and development operations in recent years. Low-permeability reservoirs contribute 80% of the newly proven reserves and several low-permeability fields each with over 100 million tons of oil in place or 100 billion m<sup>3</sup> of gas in place have been discovered in the Ordos and Songliao basins.

CNPC has made consistent efforts and obtained remarkable results in the technical research to solve the difficulties in developing reservoirs whose permeability is 1 mD, 0.5 mD or even 0.3 mD. A series of innovative techniques and integrated solutions have been developed in precise reservoir description, well pattern optimization, reservoir modification and ground process optimization etc. These techniques and solutions have facilitated efficient and cost-effective development of a number of fields including Ansai oilfield, Xifeng oilfield and Sulige gas field whose permeability is low or extremely low. ■

# Redevelopment of mature oilfields

Mature oilfields still have a substantial part of the Original Oil in Place (OOIP) with a great potential of recovery. CNPC has shaped its philosophy and technology of redevelopment in years of oilfield development practice, and launched the redevelopment campaign in some mature oilfields. Redevelopment refers to the new round of recovery improvement process based on new concepts, methods and techniques when an oilfield comes to the threshold of depletion by conventional development ways. Through renovation of the entire development system in terms of geology, reservoir, well drilling, surface engineering, oil recovery and gathering, the ultimate recovery of mature fields may be remarkably enhanced.

## Redevelopment targets:

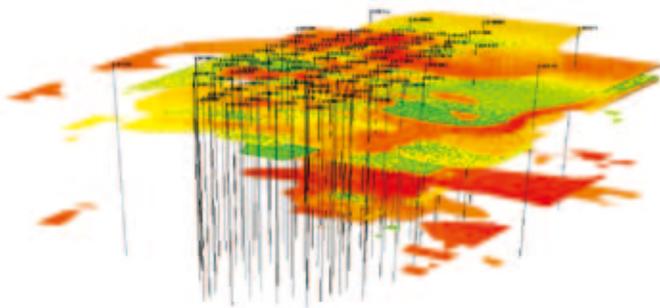
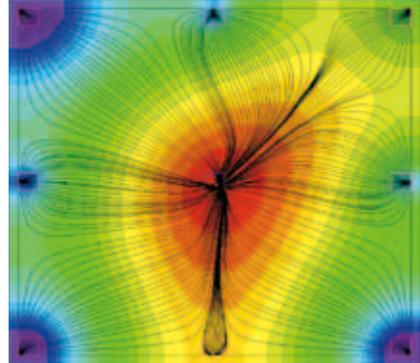
Mature oilfields with total water cut of more than 85%, and over 70% of the recoverable reserve been extracted after 20-plus years of production.

## Technical roadmap:

Reconstructing the recognition system of the subsurface world, rebuilding the underground structure of well patterns, and reorganizing ground process flows.

## Objective:

Substantially increase production rate, and enhance ultimate recovery efficiency up to over 50%. ■



## Xinhai Block 27 in Liaohe

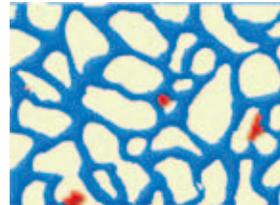
Xinhai Block-27 is located at the southern tip of the central bulge in the Liaohe fault basin. In 1991, vertical well pattern by cold flow production method was adopted during primary development, with 59 vertical development wells being drilled. At the production peak stage in 1994, 360 tons of oil was produced every day. Serious watering out caused by bottom water coning, edge water incursion and ex-casing channeling had reduced daily output to 32 tons in 2004, with the total water cut up to 93.6% and ultimate recovery efficiency of 15.3%.

In the same year, redevelopment was launched at the block. 33 thermal recovery horizontal wells were drilled, producing 15.3t/d for each, 11 times as many as individual vertical wells in the same period. Oil production has increased from 32t/d to 351t/d, production rate from 0.26% to 2.84%, and recovery efficiency from 15.3% to 31.0%, while the total water cut has dropped from 93.6% to 83.3%. The dying oilfield was rejuvenated after 16 years of exploitation.

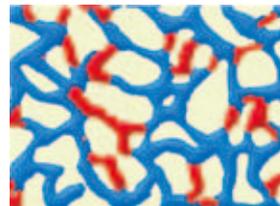
# Chemical flood for EOR

CNPC is a world leader in polymer flooding, ASP flooding and alkaline surfactant foam flooding solutions and applications. The polymer flooding approach has been commercially used in Daqing Oilfield since 2002, with the oil production driven by polymer flooding exceeding 10 million tons per year and recovery rate 10% higher than water flooding. The research on ASP flooding has achieved major advancements in mechanism investigation, surfactant formulation and formula assessment.

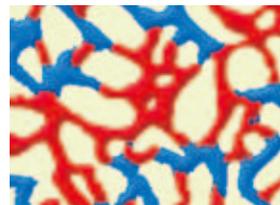
The proprietary alkylbenzene sulfonate surfactants have been developed and commercialized. The ASP flooding approach has shown satisfactory results in terms of oil recovery and water-cut reduction in experiments and applications as well, with a recovery rate 10% higher than polymer flooding and 20% higher than water flooding. Commercial applications have been carried out in Daqing oilfield and Xinjiang oilfield. Alkaline surfactant foam flooding is an advanced form of ASP flooding. Laboratory experiments and field tests show that Alkaline surfactant foam flooding is able to achieve a recovery rate 30% higher than water flooding and therefore poised for a great prospect of commercialization. ■



Residual oil after ASP flooding

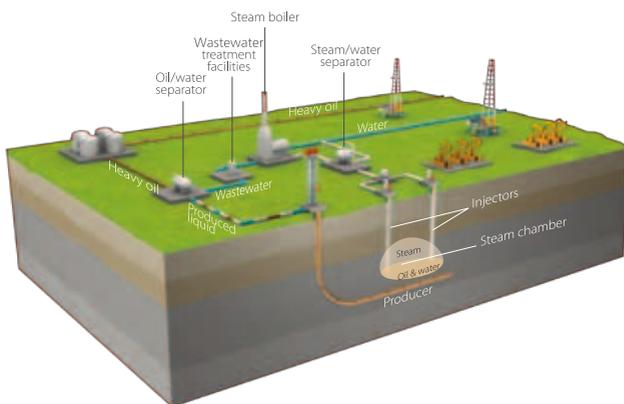


Residual oil after polymer flooding



Residual oil after water flooding

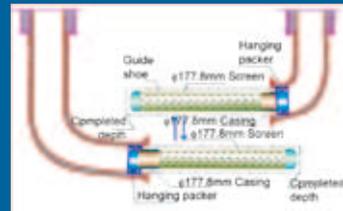
# Thermal production of mid-to-deep heavy oil



As a result of years of study and practice, CNPC has developed large-scale 3D thermal production simulation installations, and technology packages of steam flood and SAGD for mid-to-deep heavy and ultra heavy oil production. The recovery efficiency has been enhanced to 55-60% from 20-25% by huff and puff. At present, steam flood and SAGD have been applied to 199 well groups in Liaohe oilfield, achieving an annual heavy oil production capacity of one million tons. ■

- ◆ Steam flood has been applied to 150 well groups at Block Qi-40 to cover a reserve volume of 106 million tons, making it the world's first mid-to-deep heavy oil field that is commercially developed by steam flood.
- ◆ Industrial pilot of SAGD was conducted in 49 well groups at Block Du-84, covering heavy oil in place of 130 million tons which is suitable to be extracted by steam assisted gravity drainage.

By now, a completed SAGD technical solution for mid-to-deep heavy oil production has been worked out in Liaohe oilfield. Innovative methods, such as vertical well plus horizontal well for combined displacement and drainage based on preheat initiation, pairing horizontal wells with different temperature for injection-production circulating preheat, and metering and monitoring of SAGD balance injection-production have been applied to boost the recovery efficiency up to 55%-60%. ■



## CO<sub>2</sub> injection for EOR & underground storage

The mechanism of oil displacement by carbon dioxide injection is identified, and the flowing behaviors and storage conditions of the injected CO<sub>2</sub> are studied. As a result, an optimum injection plan is worked out to maximize CO<sub>2</sub> storage as well as oil displacement.

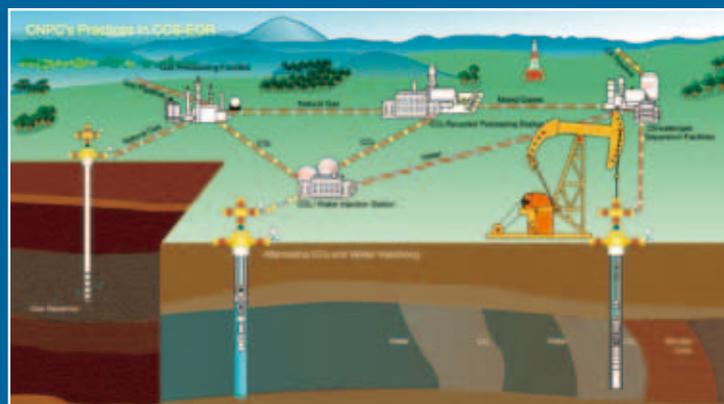
Control of CO<sub>2</sub> flooding profile: Non-flowing polymer gel will be formed chemically to plug the underground cracks and pores in order to multiply the swept volume of CO<sub>2</sub> and facilitate oil displacement.

Surface engineering of CO<sub>2</sub> flooding: Focusing on effective CO<sub>2</sub> capture and safe injection, an integrated system will be introduced for separation, purification, transfer and injection of CO<sub>2</sub>, fluid collection and

gathering, and cyclic injection. Thus, CO<sub>2</sub> can be effectively stored underground.

Block Hei-59 at Jilin Oilfield became the first pilot project to use CO<sub>2</sub> flooding for CO<sub>2</sub> emission reduction. Kicked off in April 2008, the project consists of 6 injection wells and 25 oil-producing wells which have

shown highly-efficient miscible displacement. In comparison with water flooding, the per-well production increases by 30% and the recovery efficiency goes up by 10%, resulting in a yearly crude production of 30,000 tons and a cumulative crude production of 180,000 tons by 2015. ■

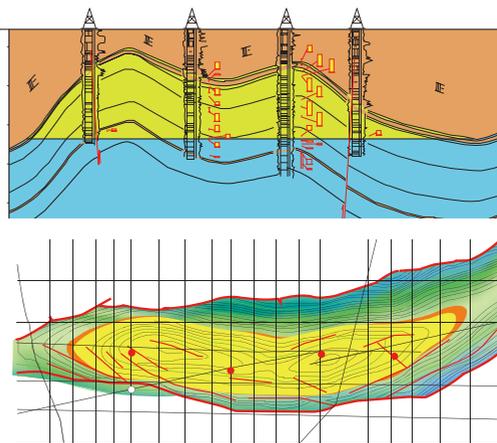


# Development of abnormally high pressure gas field

Kela-2 gas field, located in the Tarim Basin and becoming operational in 2004, is of high-steep structure with its 284 billion cubic meters of gas in place buried at a depth of 3,500-4,100 meters. The field produces 11.7 billion cubic meters of natural gas per annum, with the reservoir pressure of 74.35 MPa and the pressure coefficient of 2.02.

A sophisticated development technology package for gas fields with abnormally high pressure and high productivity was utilized during the development of Kela-2 gas field.

- ◆ Fine geological modeling of abnormally high pressure gas fields with high-steep structure  
3D geological model in conformity with 90% of the actual geological characteristics
- ◆ Development program for high productivity with fewer wells  
17 production wells with a production capacity of 10.7 billion cubic meters
- ◆ High-quality fast drilling with high-steep structure and narrow pressure window  
Sixfold rate of penetration
- ◆ Safe completion technologies for gas wells with abnormally high pressure and ultrahigh productivity  
Single-well production of 5 million cubic meters per day
- ◆ Surface high pressure gas gathering and processing technologies with high automation and low-energy consumption  
16MPa high pressure one-stage station gas gathering and processing flow ■



# Gas lift oil recovery



In oil and gas field development, gas lift is a cost-effective artificial lift technology that utilizes the energy in gas wells for oil recovery with minimal energy consumption and initial investment.

CNPC launched its gas lift research in the 1990s, and has developed 29 unique technologies in eight categories, as well as 97 specifications, 48 types, and five categories of gas-lift tools. We offer one-stop services for the planning of gas lift engineering projects, gas lift design and optimization, the manufacturing, debugging, and detecting of gas lift tools, gas lift troubleshooting and completions, and production management.

By applying gas lift to production initiation at new wells and as a stimulation measure, we have exclusively developed the gas-lift-based fracture flowback technique and drainage gas recovery technology, as well as the auxiliary wireline operation technology for gas lifting.

**Gas-lift-based fracture flowback** is a unique technology in which high-pressure gas-lift tools are installed to the fracturing string. Without pulling out the string after the fracturing operation, the rapid flowback of fracturing fluid is realized by gas lift. This technology has delivered a 100% success rate during engineering. In equivalent conditions, it can shorten the flowing back period from the conventional 15-20 days to 1-2 days, with a fluid cleanup rate of up to 100%.

**Drainage gas recovery by gas lift** is a technology that uses the unloading principle of gas lift production to discharge the water deposited at the bottom of a gas well, thereby reduce bottom-hole flowing pressure in order to resume the normal production of gas wells and increase individual well output. In China's Sichuan and Chongqing regions, gas-lift drainage is an important production measure and significantly improves the recovery of those fields with water-bearing gas reservoirs.

**Wireline operation** is a technology in which a wireline truck is used to run down the wireline-operation tools through the oil tubing for

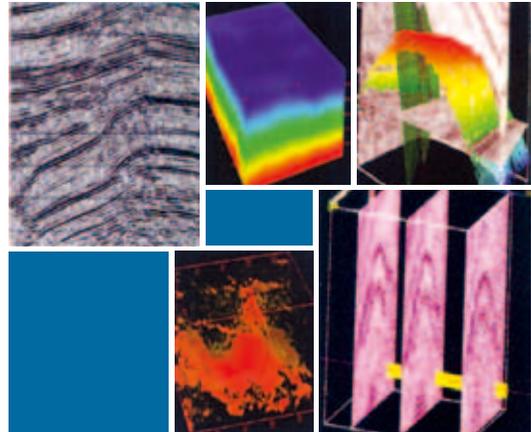
downhole operations, including downhole testing, running and pulling of downhole gas lift valves and plunger-lift tools, turning on or off of the downhole control sliding sleeve, downhole fishing, handling and prevention of downhole accidents, and other special operations. It allows output allocation, troubleshooting and production data testing. Its many advantages include straightforward operation, short operation cycles, and no damage to reservoirs. CNPC has now developed 29 tools for the needs of wireline operation in 60.3mm (2 3/8") and 73mm (2 7/8") tubings. ■

The Zhanazhol oilfield in Kazakhstan has been developed for almost 30 years. By applying gas lift technology, CNPC shortened the flowing back cycle and the production cycle, and increased the average daily production per individual well by 18.8 metric tons. Currently gas lifting has been applied to more than 250 oil wells in Zhanazhol oilfield, and daily output of gas lift wells takes more than 67% of the total in the whole field.

# GeoEast® — an integrated processing and interpretation system

GeoEast provides a unified data platform, a unified display platform and a unified development platform. It supports data sharing, visualized interaction and a collaborative mode for processing and interpretation. With the flexible, modular and scalable architecture, GeoEast can be customized to a workstation or a PC-Cluster version to meet the needs of on-site processing and large processing centers.

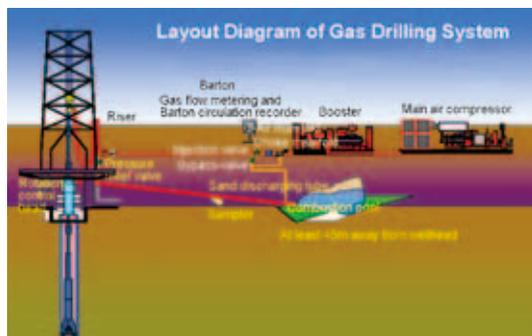
GeoEast 2.0 boasts its improvement in stability, efficiency, and applications which synchronize with the advanced geophysical software packages in the world. Its applications are not only for land 2D and 3D seismic data processing, conventional structural interpretation, and 3D volume interpretation, but also for dealing with complex low S/N land data, resolution improvement, and 3D VSP data processing and interpretation. In addition, the system provides the basic processing and interpretation flows for the processing of multi-component and ocean streamer seismic data. The functions of pre-stack reservoir inversion and attribute extraction are now under development. ■



## Underbalanced drilling / gas drilling

The supporting devices and downhole tools such as spin-type blowout preventer, snubber, air compressor, pneumatic hammer and pneumatic screw are successfully developed.

Underbalanced drilling using different types of medium, including light mud, dry air, aerated mud, foam and mist, is introduced together with a complete supporting process involving downhole casing valve, gel-type valve and snubbing equipment. Gas drilling using air, natural gas or nitrogen is also utilized to discover and preserve oil and gas reservoirs and facilitate the drilling process.



During 2005-2010, 1,005 underbalanced wells were drilled, representing 20% of the prospecting wells. Underbalanced drilling has played a critical role in discovering a number of oil and gas reservoirs such as Qiongx in Sichuan Basin, Santanghu in Turpan Basin, Qikou in Dagang oilfield and volcanic reservoirs in Xinjiang. Among them, there are 226 wells using gas drilling, with the average drilling speed 4-15 times higher than that of conventional drilling approaches. ■

# Lateral and fishbone well drilling

Drilling lateral and fishbone wells can effectively increase the contact area between horizontal intervals and reservoirs, and thereby boost the production per individual well.

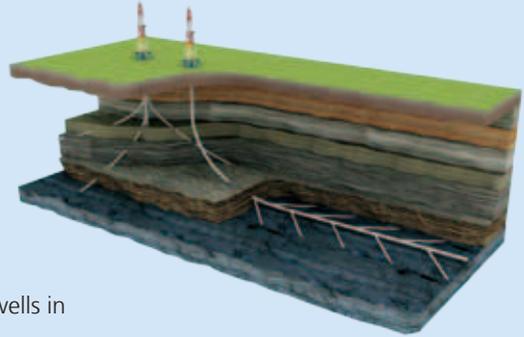
CNPC has made significant progress in lateral and fishbone well drilling.

Five sets of process engineering have been developed for the drilling of directional lateral wells, lateral horizontal wells, fishbone wells, multi-layer lateral wells, and underbalanced lateral wells.

Remarkable results have been achieved in developing heavy oil reservoirs, low-permeability buried hill reservoirs, thin reservoirs, and coal bed methane reservoirs.

More than 80 lateral wells have been completed in the Liaohe, Jilin, Sichuan, and Daqing oil and gas fields, resulting in an output of 2-10 times that of neighboring wells in the same blocks.

Well Jing 52-H1Z, a 20-lateral fishbone well in Liaohe oilfield, has a 1,002m-long main horizontal interval, 3,331.19m footage of lateral bores, and the length of horizontal intervals totaled 4,333.19m. ■



# Coiled tubing technology and equipment

Breakthroughs are achieved in core technologies such as injector head of the coiled tubing. A series of fittings for 3/8"-2-3/8" coiled tubing is developed independently. The critical issues in tubing material and manufacturing are solved. The first production line for coiled tubing in Asia is constructed, making China the second country in the world having the proprietary knowledge of coiled tubing manufacturing.

A dozen of coiled tubing operations and supporting tools are devised, including fracturing acidizing, sand washing, unclogging and plugging etc. These techniques are used in more than 200 wells in Sichuan, Dagang, and Liaohe oilfields with satisfactory results. ■

