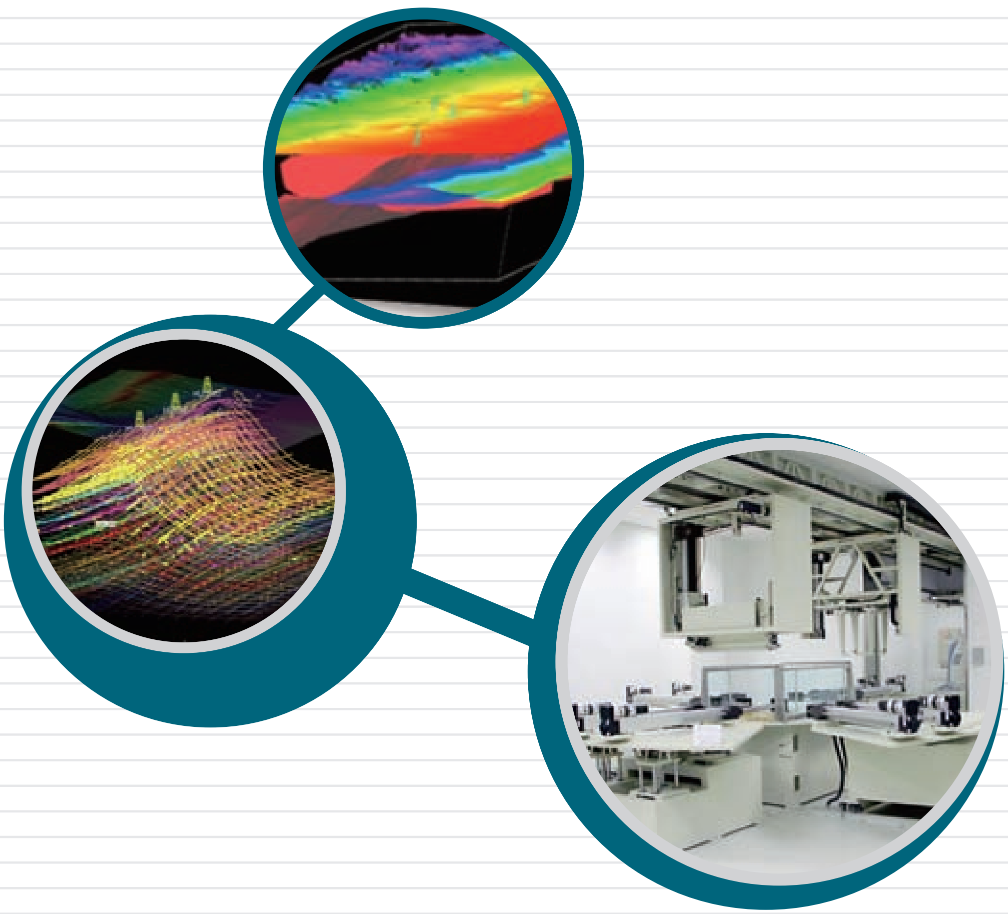
Modeling and Imaging Technologies for Foreland Thrust Belt Structure

Science & Technology Management Department

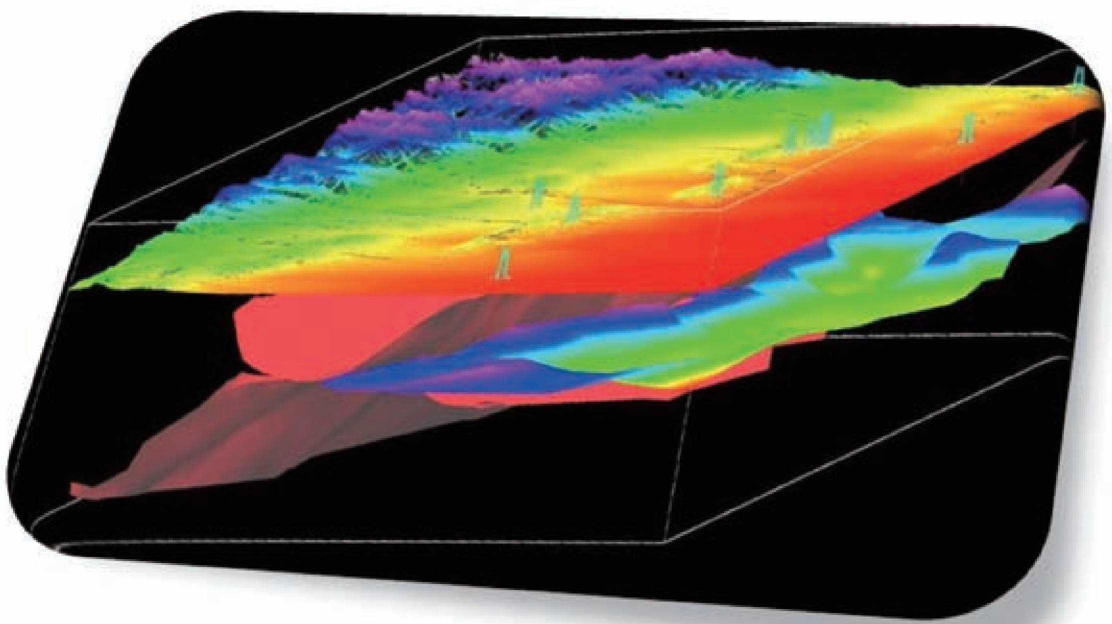
2013



CHINA NATIONAL PETROLEUM CORPORATION

Intuitively Reveal Thrust Structure Efficiently

Explore Foreland Hydrocarbon Resources!



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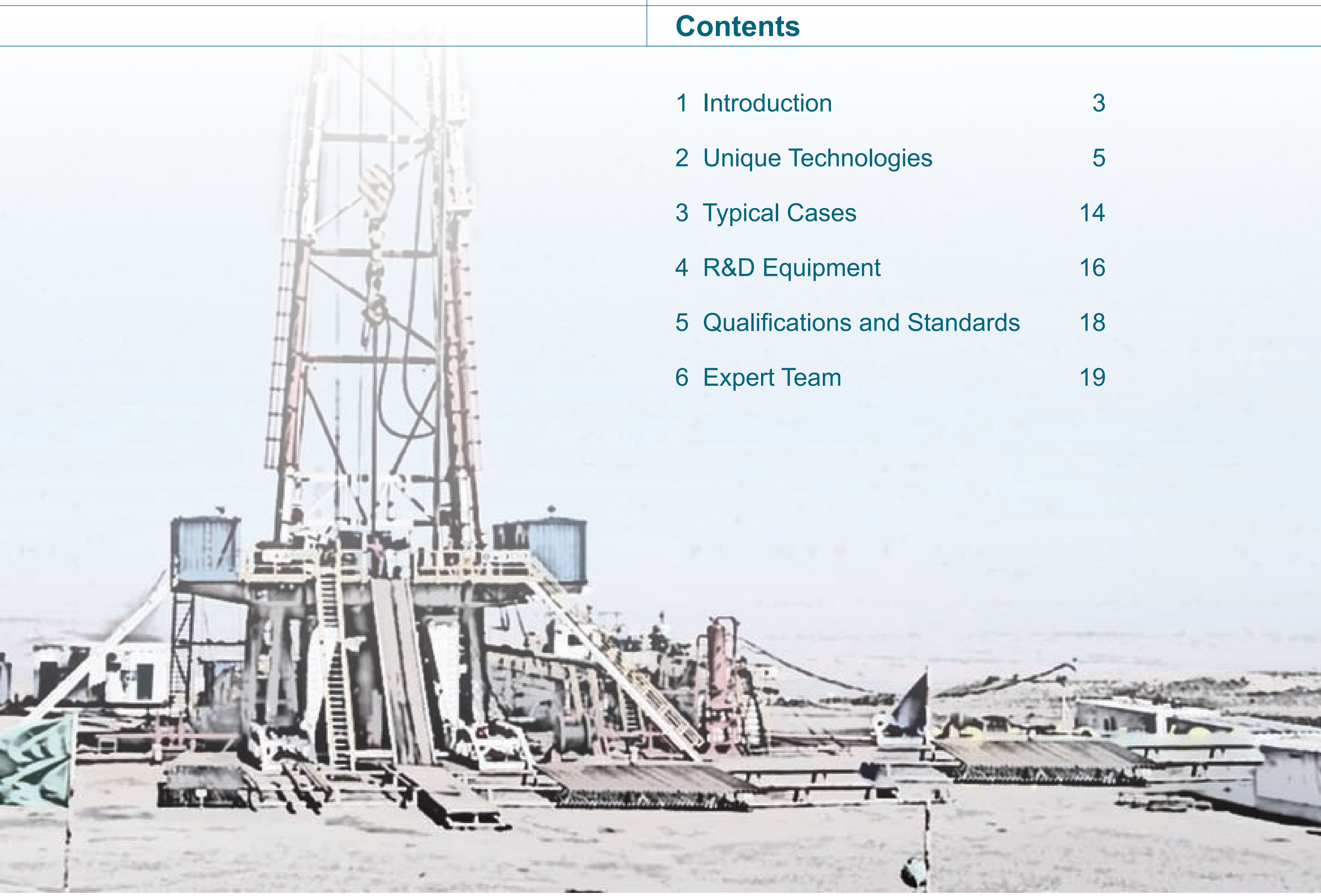


China National Petroleum Corporation (CNPC) is a state-authorized investment agency and a state holding company. On July 1998, with the implementation of the Institutional reform of the State Council, CNPC was reorgnized to become an integrated oil company of cross-regions, cross-industries and cross-countries, 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.

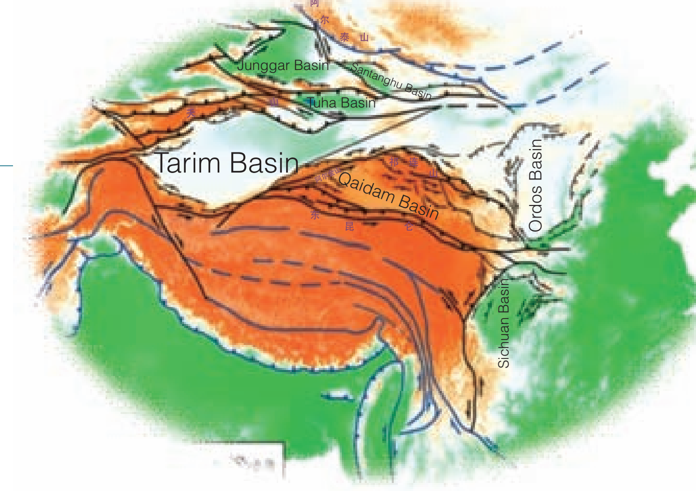
CNPC was ranked 4th among the world's largest 50 oil companies and 6th in Fortune Global 500 in 2012.

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.

Modeling and Imaging Technologies for Foreland Thrust Belt Structure is one of representatives for major innovations of CNPC.

CLEAN ENERGY SUPPLY FOR BETTER ENVIRONMENT

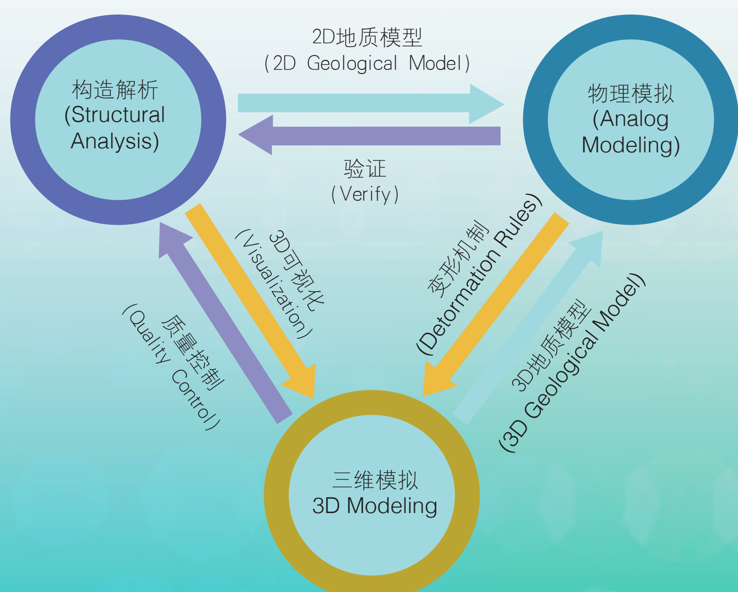
1 INTRODUCTION

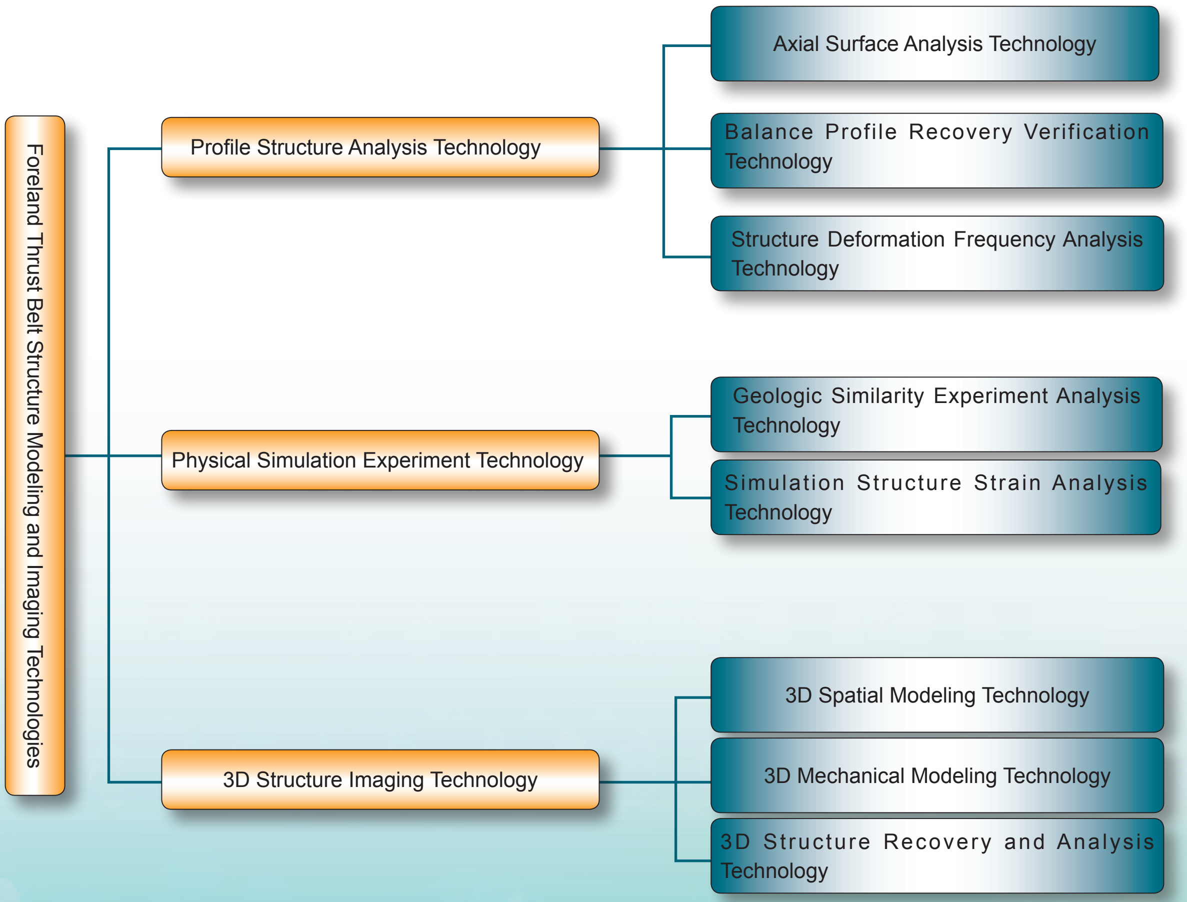


The foreland thrust belt is a transition area located between a strongly deformed and deteriorated orogenic belt and an undeformed foreland, where is featured with thrust faults and fold structures developed.

The foreland thrust belt structure modeling and imaging technologies based on plate tectonics theories and fault-related fold theories have formed profile geological modeling technology, physical simulation experimental technology as well as 3D modeling technology of structure imaging and strain recovery, which have provided technical support for modeling the foreland thrust belt structure, and enriched structure research methods.

Foreland thrust belt structure modeling and imaging technologies may quantitatively and intuitively describe 1D, 2D and 3D structural features and corresponding structure recovery and kinematic process, and apply such data as surface and geologic structures, seismic reflection profiles and drilling separating zones to build the rational geological interpretation model of the complex structure seismic profiles, and verify the rationality of 2D and 3D structure geological interpretation via physical simulation experiment, and reproduce the structure deformation process and space structure. The technologies have been broadly applied in markets both at home and abroad and obtained a breakthrough progress in foreland basin research and hydrocarbon exploration in the central and eastern regions of China.




Foreland Thrust Belt Structure Modeling and Imaging Technologies
Profile Structure Analysis Technology
Axial Surface Analysis Technology
Balance Profile Recovery Verification Technology
Structure Deformation Frequency Analysis Technology
Physical Simulation Experiment Technology
Geologic Similarity Experiment Analysis Technology
Simulation Structure Strain Analysis Technology
3D Structure Imaging Technology
3D Spatial Modeling Technology
3D Mechanical Modeling Technology
3D Structure Recovery and Analysis Technology

2 UNIQUE TECHNOLOGIES

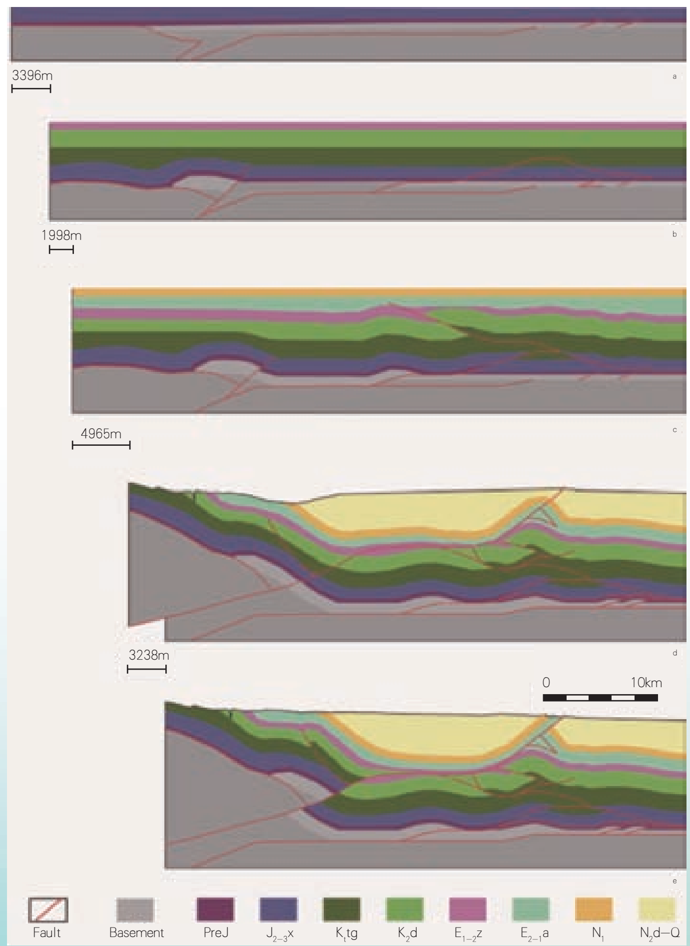
2.1 Profile Structure Analysis Technology

Fault displacement, geometric shapes and growth pattern of the folds etc. are determined based on point—line data constrained line—surface structure, and rational geologic structure model can be effectively built through 2D profile geologic Structure Analysis technology. The geometric shape of the formation can be restricted via the surface geologic structure; moreover, the fault development position and attitude can also be determined. The geometric mechanism and kinematic process of structural deformation are further analyzed by combining the fault attitude and the formation fold shapes thereof.

Applicable to fragile geologic structures under positive squeezing background.

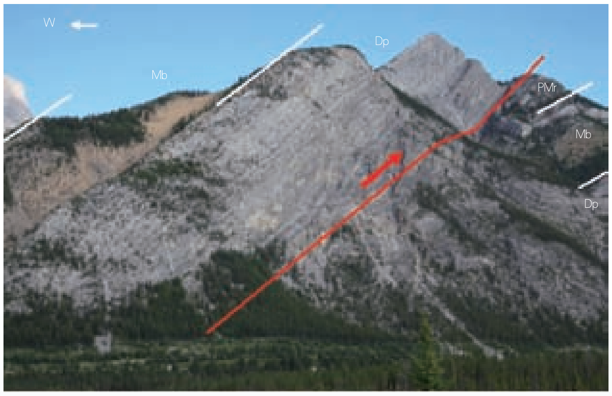
Strong structure deformation of the foreland basin, and in particular to the foreland thrust belt adjacent to the orogenic belt usually causes complex geologic structure and topography. Thus, it is difficult to collect and process geophysical data, which causes poor seismic quality and is hard to carry out geologic structure interpretation and plane mapping.

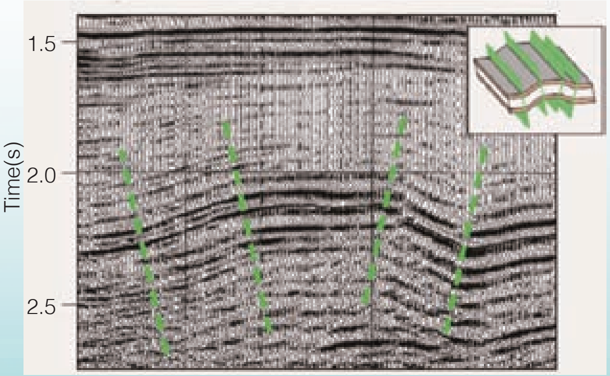
Therefore, the geologic structure interpretation model of seismic data must be built to guide seismic profile interpretation and mapping.

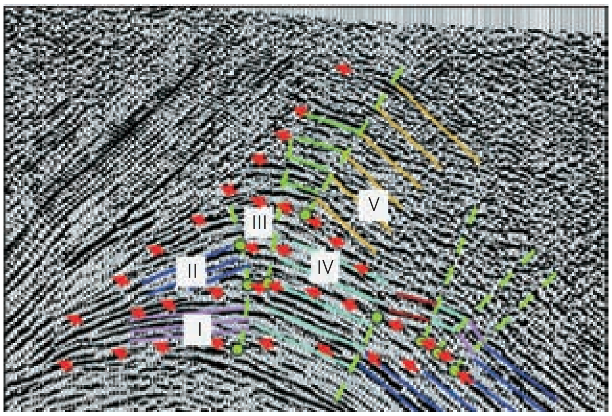


• Axial Surface Analysis Technology

a. Structure element projection and calibration;
b. Fold and axial surface analysis;
c. Fault determination.





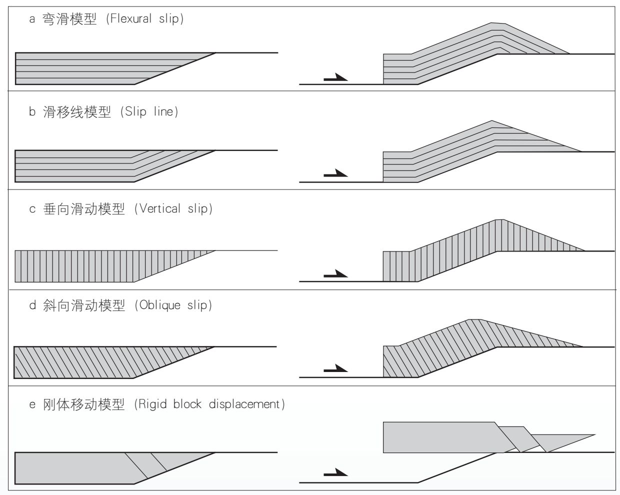


In the fragile geologic structure formed under positive squeezing background and the seismic profile in the depth domain of consistently vertical and horizontal zooming, the geometric shapes of the faults and formation folds can be effectively recognized and described, and the kinematic process such as fault displacement, deformation mechanism and growth pattern etc. can be determined by analyzing and determining unknown structure elements via the known structure elements. 2D Structure Analysis technologies such as structure element projection and calibration, isoclinic inclination region division, axial surface analysis, fault recognition, structure interpretation scheme determination, structure trend analysis etc. are included.

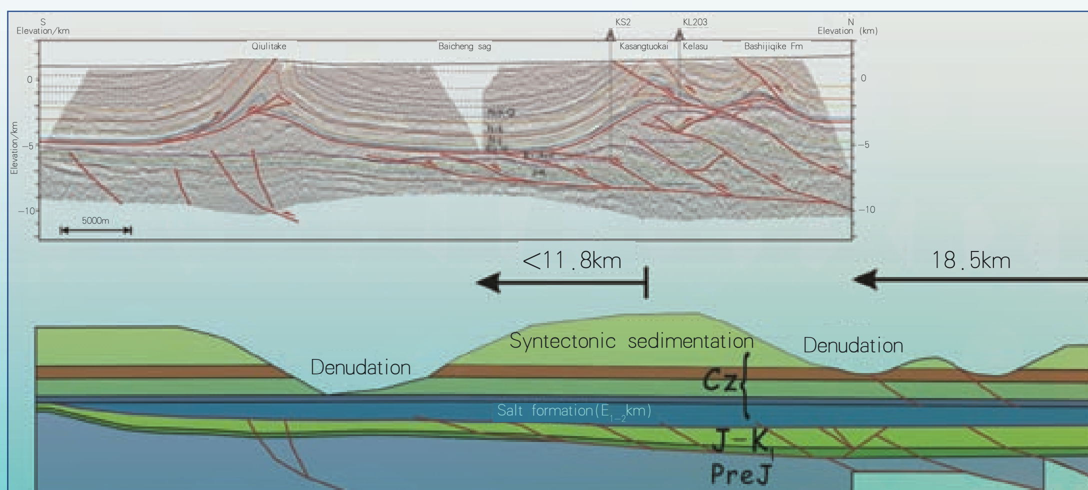
• Balance Profile Recovery Verification Technology

Balance calculation methods are mainly forward method (from an undeformed state to state after deformation) and recovery method (from the deformed state to the original state without going through structure function) by following up the principle that rock stratum length or area keeps unchanged before and after deformation. The rationality and accuracy of structure interpretation are effectively analyzed and evaluated; and the structure deformation process (time, sequence and amount of deformation) are cleared.

It is applicable to the fragile geologic structures under positive squeezing and extension background.



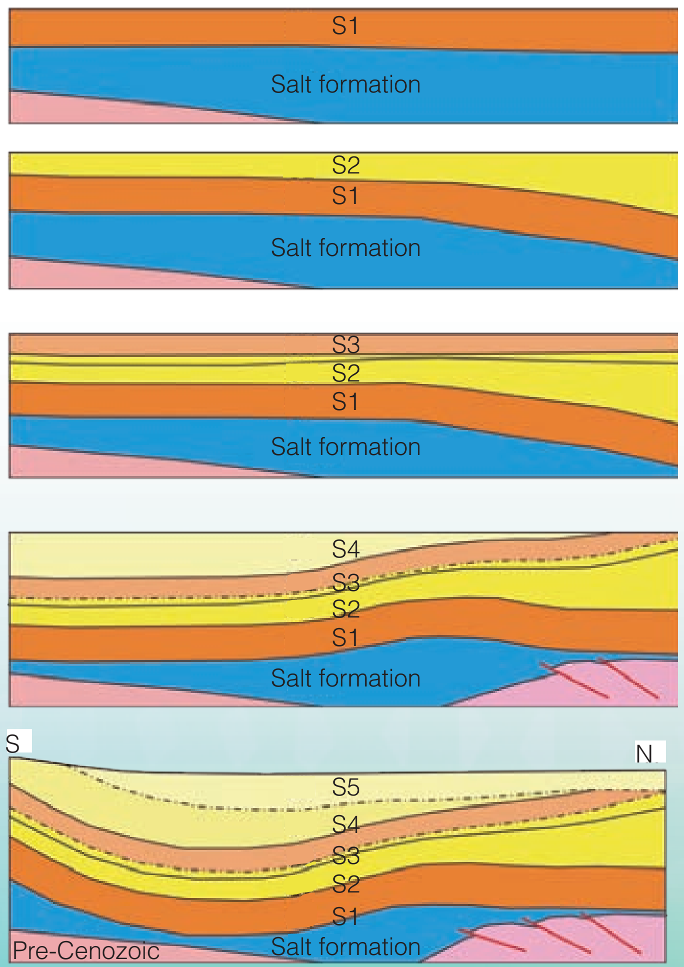
Kinematic model



• Structure Deformation Frequency Analysis Technology

Determine the structure deformation time of stage and the structure properties, clear the structure deformation and the sedimentary process controlled thereof, and analyze the forming process of the regional structure evolution and structure geologic bodies. Include the analysis contents such as dip unconformity, growth formation and structure process, etc.

- Dip unconformity analysis
  ① Obvious lacuna;
  ② Formation reflection wave groups cutting off;
  ③ Axial surface termination or cutting off;
  ④ Structure deformation of unconfoemity surface.
- Depositional packing analysis
  ① Stratigraphic thickness plane change;
  ② Formation fold deformation.
- Growth formation
  ① Growth axils surface or growth triangle;
  ② Wedge shaped growth formation.

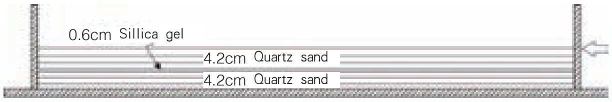


5 basic structure processes of salt activities in Kuqa depression

2.2 Physical Simulation Experiment Technology

The physical simulation experiment technology for structure deformation which is also called as similarity physical simulation analysis is a common and efficient experiment research method for scientific research. By following up the experiment similarity basic principles, model research can provide the researcher with reference phenomena, process and analysis data by zooming in or zooming out the prototype equidistantly.

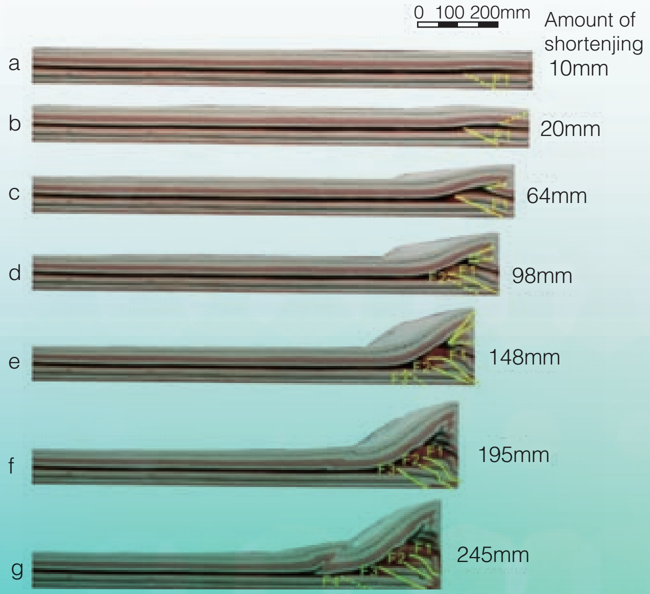
Physical experiment equipment



Physical experiment model design

• Geologic Similarity Experiment Analysis Technology

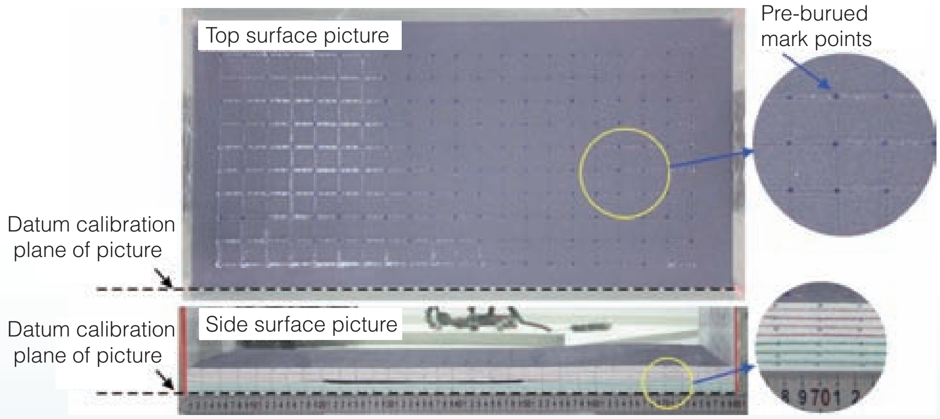
Build the similarity scalars for the physical simulation experiment parameters based on the mechanical structure features of rocks and materials in accordance with the material constitutive equation.



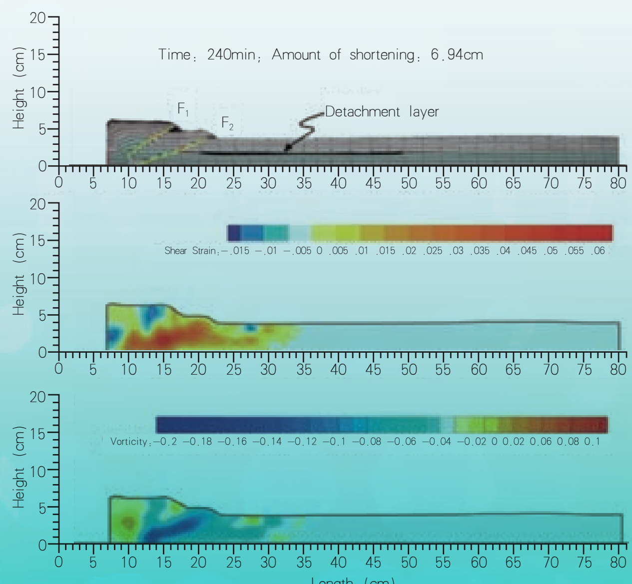
Experiment process

• Simulation Structure Strain Analysis Technology

Obtain the displacement field of the structure deformation based on the image analysis on particle displacement, implement analysis on dynamic mechanism, calculate such mechanical parameters such as shear strain, volumetric strain, vorticity etc., and analyze the simulation structure deformation mechanism.



Experiment model of pre-buried mark points



The shear strain diagram and vorticity diagram of particle structure strain analysis show the strain accumulation and deformation activities of faults and analyze the generation process and development position of the faults.

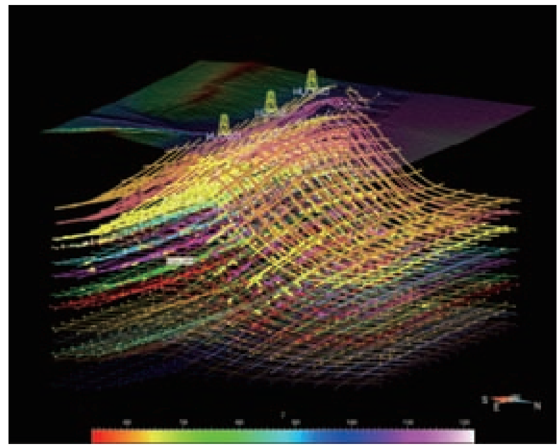
2.3 3D Structure Imaging Technology

Truly reveal the formation structure models of the geologic body in 3D space, and recover the structure deformation in 3D space.

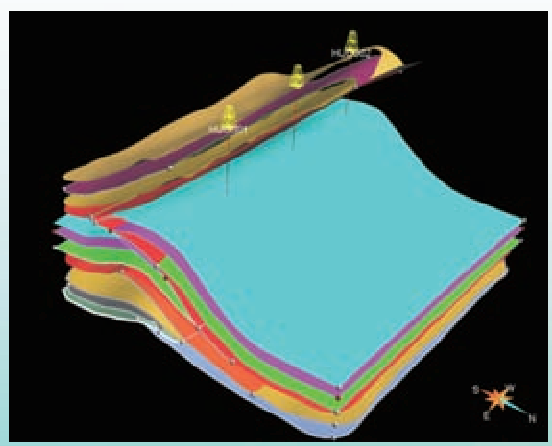
• 3D Spatial Modeling Technology

Obtain underground geologic data based on surface geologic survey information, build the 3D surface model of the geologic body via modeling software, determine the distribution state and contact relationship of the position and the fault in 3D space, and erect framework model, gridding model and 3D physical model.

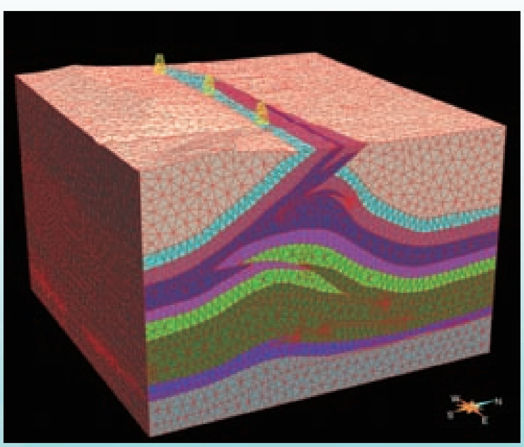
It is applicable to fault and fault surface interpretation data body with space coordinates.



Result data



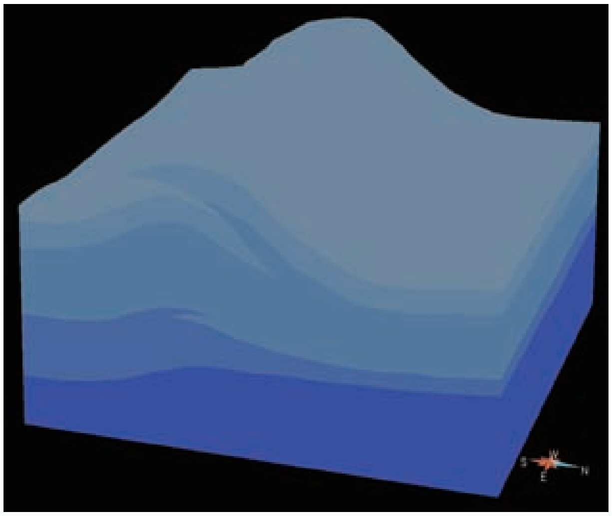
Surface model



Physical model

• 3D Mechanical Modeling Technology

Set corresponding mechanical parameters for 3D volume models of different formations based on building 3D physical model and several key elasticity modulus (including: young's modulus, shear modulus, modulus of compression, Poisson ratio and lame constant etc.) in mechanics of materials, thus building 3D physical model.



3D physical surface model

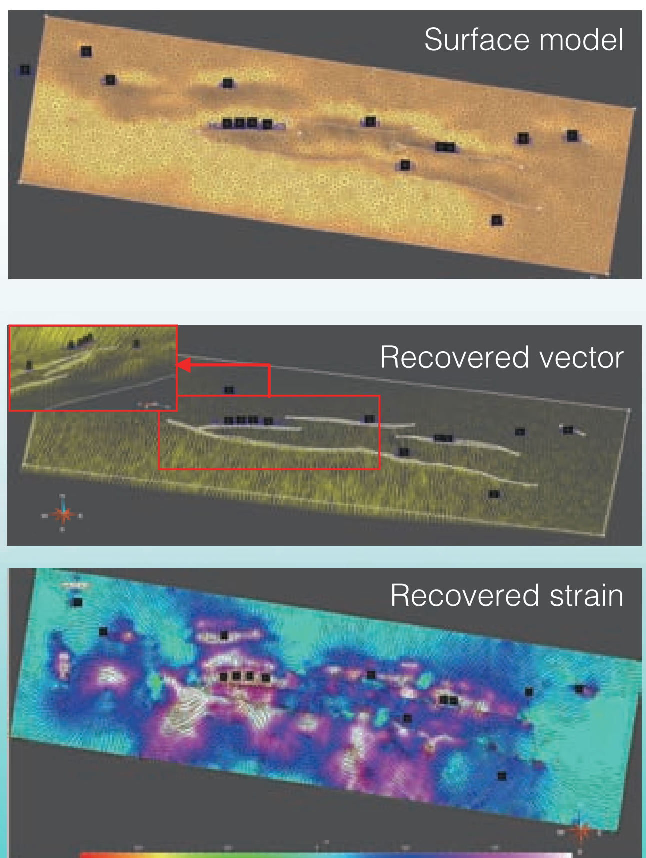
Elastic parameters of partial rocks

Lithology	P-wave velocity (m/s)	Tensile strength (MPa)	Young's modulus (GPa)	Poisson's ratio	Unconfined compressive strength (MPa)	Intemal friction factor
Granite	3000~5000	7~25	50~70	0.1~0.26	100~250	~1.4
Marble	3500~6000	7	50~70	0.06~0.22	3500~6000	~0.7
Sandstone	1400~4000	4~25	10~20	0.21~0.38	20~170	~0.5
Mudstone	2900~4500		15~25	0.25~0.4	56	
Shale	1400~3000	2~10	5~70	0.2~0.4	5~100	

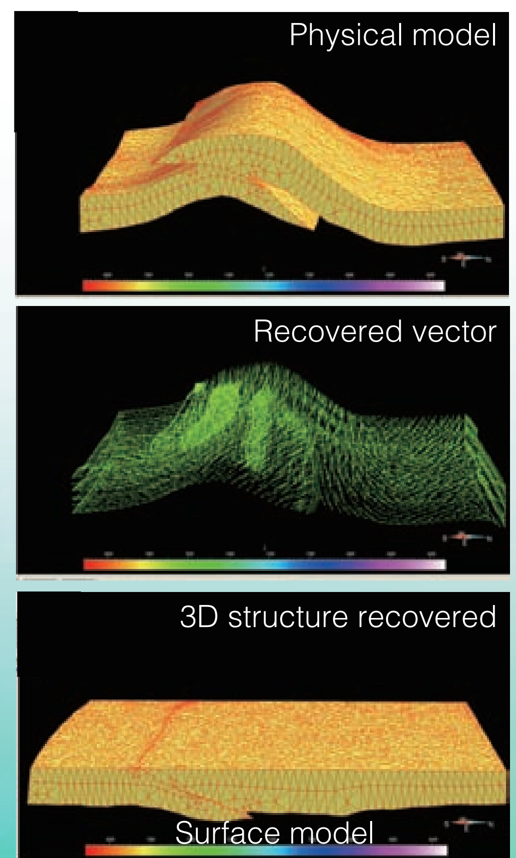
• 3D Structure Recovery and Analysis Technology

Fault and fold removing effects in 3D space are applicable to the fault and surface interpretation data bodies with space coordinates. The 3D physical recover method is adopted to recover the physical model along a horizontal datum plane via determining the limiting conditions such as nail line and nail surface based on the mechanical structure of the deformed formation and the minimum strain principle during the recover process, and adopts dynamically loose and finite element means to calculate strain, and analyze the fault development position and strength.

◆ Surface Structure Strain Recovery



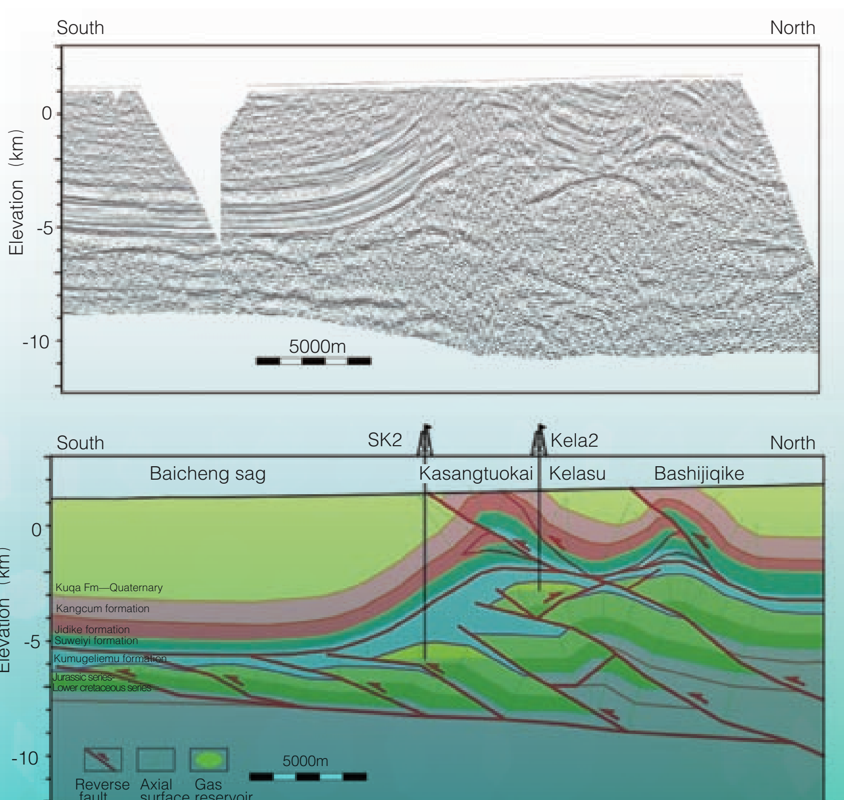
◆ Volume Structure Strain Recovery



3 TYPICAL CASES

Many oil and gas fields of over hundred million tons reserves such as Kela-2 large gas field, Keshen oil and gas area, Dina oil and gas area, Dabei oil and gas area etc. have been discovered in the Kuqa foreland thrust belt between the south Tianshan orogenic belt and Tarim craton.

Topographic map of Kuqa Basin and adjacent region

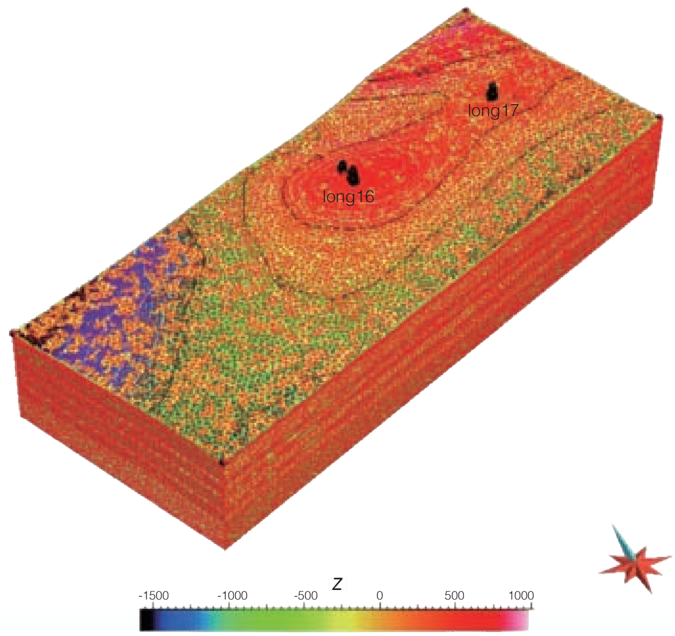


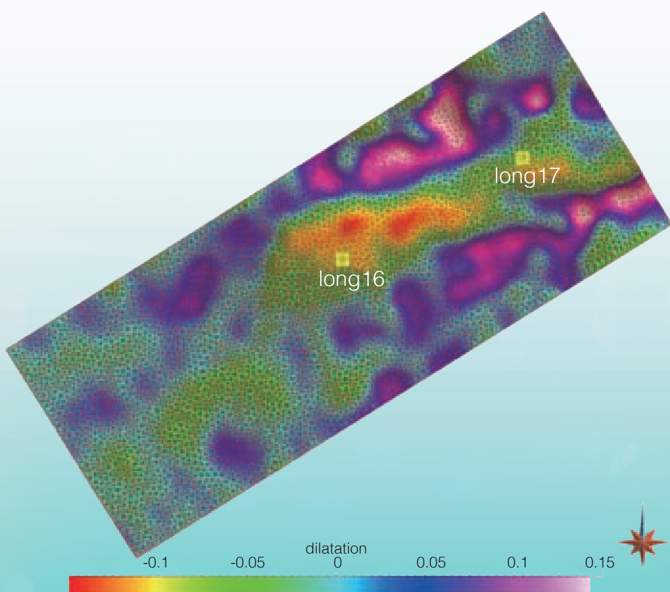
Seismic profile (upper) and geologic profile (lower)

Regional seismic profile structure analysis shows the profile structure of the Kuqa foreland thrust belt and the sub-salt complex imbricate thrust zone system. A series of thrust nappe thrust faults and tectonic slices from the north to the south are developed below Paleogene salt strata and above the bottom slip faults of upper Triassic strata, middle and upper Jurassic Coal Series to form passive roof dual structure. in which Kela-2 gas reservoir in Kelasu anticline is the largest integrated natural gas field of China at present, and is also the major air source for the West-East NG Transmission of Tarim oilfield.

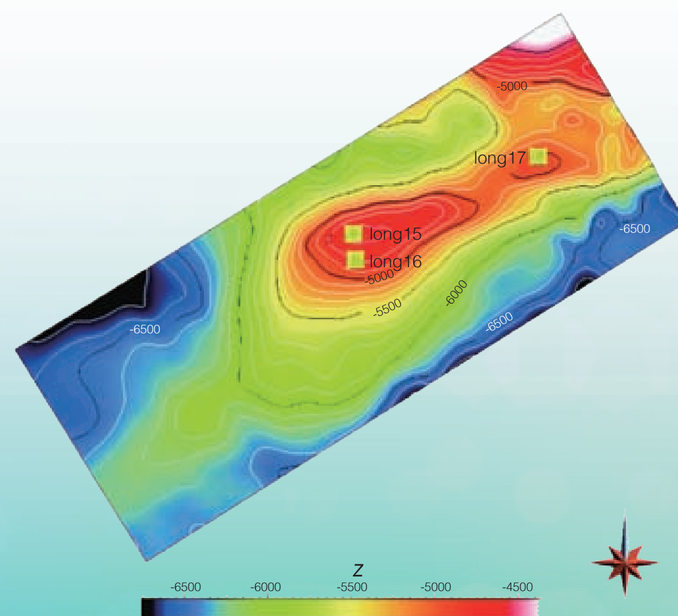
Structural superimposition of different directions generally exist in the northwest region of Sichuan basin. It is discovered by Jiulongshan anticline 3D structure modeling and recovery that the Jiulongshan structure has the reconstruction effect on the squeezing effect of different directions before and after late structure deformation. Mesozoic structure is deformed to form Jiulongshan NEE main anticline, and Cenozoic NE superposition of structures changes early NE structure and causes high point migration.

3D structure recovery shows that the lines of Long 16-Long 17 are all strong squeezing regions and an early structure height point region and fracture development region exist in the middle, which are beneficial risk objectives of oil and gas drilling.





T_1f bottom surface structure shape and structure recovery major strain distribution after structure activities since eliminating the cretaceous period



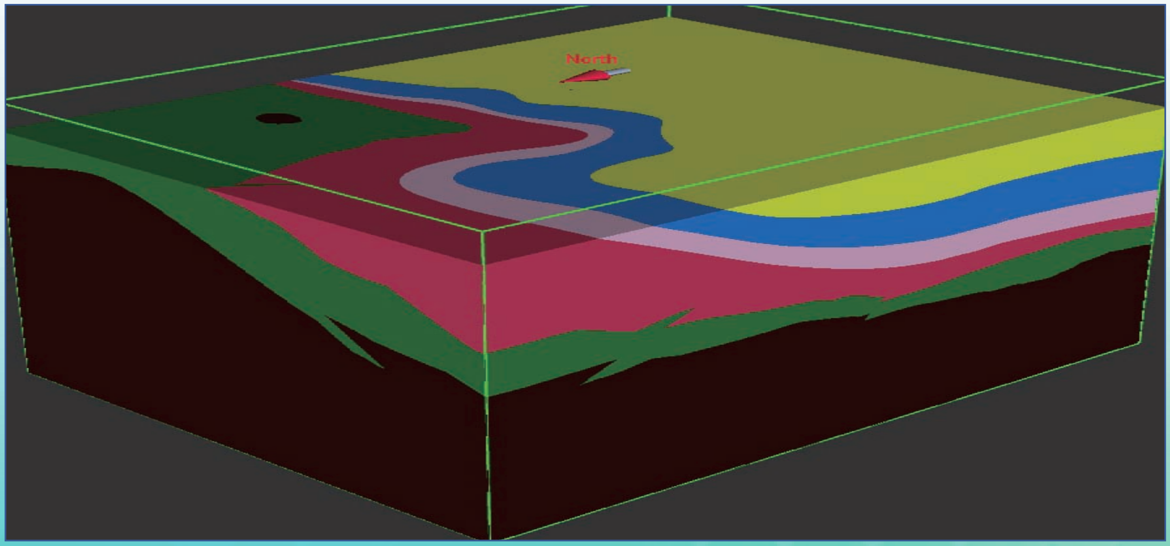
T_1f bottom surface structure shape at present

4 R&D EQUIPMENT

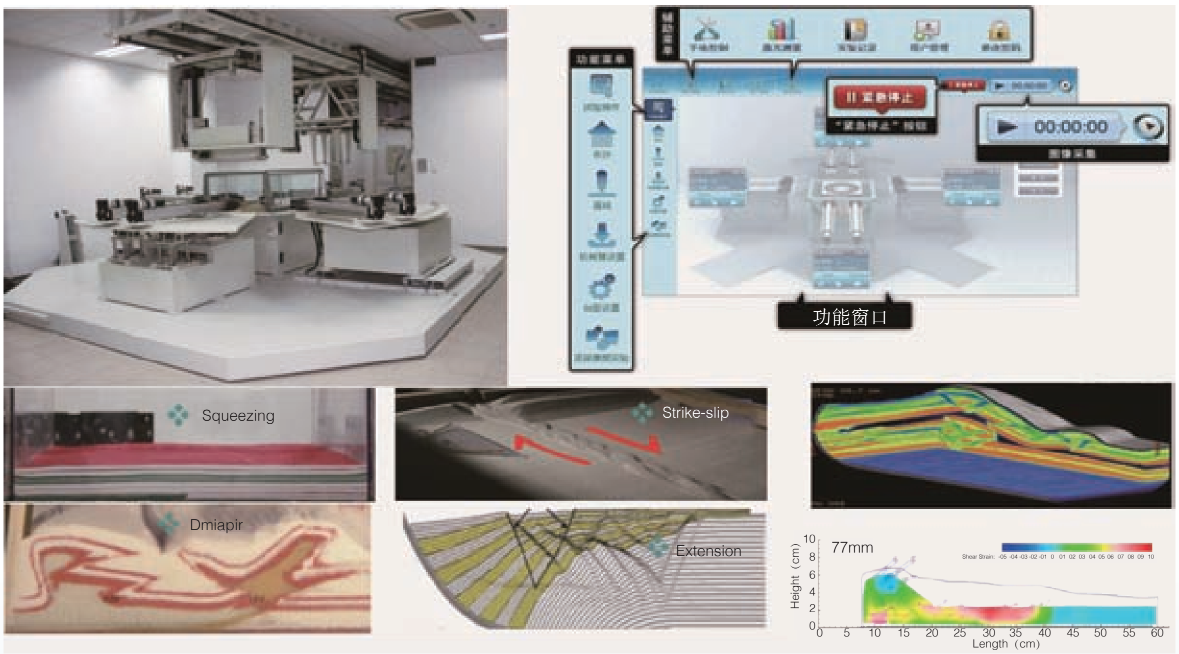
The software and hardware in the lab generally reach the domestic leading level and partial of the equipment enters international reach international advanced level, which enriches the means and methods for researching structural geology, and solves the corresponding scientific problems during oil and gas exploration and drilling.

Workstation and industrial software

Mature industrial software such as integrated software for Epos exploration and development, GOCAD integrated geologic modeling and structure strain recover software and Traptester fault plugging, fracture predication and fault modeling analysis software etc. that can comprehensively develop such work as 2D/3D seismic data analysis, balanced geologic profile verification, 2D/3D structural geologic modeling and fault plugging property. etc., has been introduced.



Geologic body 3D visualization



Independently researched and developed basin structure physical simulation experiment equipment which adopts the characteristic technologies such as multi-direction power, 3D measurement and digitalized simulation may implement high precision simulation on heterogeneous, non-uniformly deformed, and multi-power composite structure deformations under fractal boundary conditions.

Implement such researches as multi-direction squeezing, extension, strike-slip deformation and growth structure simulation, diapir and salt structure deformation simulation, bottom friction boundary structure deformation simulation, CT detection and 3D modeling analysis, laser positioning and surface profile measurement, etc. Finely describe the geometric characteristics and kinematic relationship of the structure deformation, analyze the boundary conditions and kinematic factors of the structure deformation, inspect the fields such as complete structure interpretation models and build basin structure geometric characteristics, etc.

① Multi-function: simulate the structure deformations of multi-direction power, multi-boundaries and different formations;

② Automation: implement automatic process control and guarantee the repeatability of the experiment.

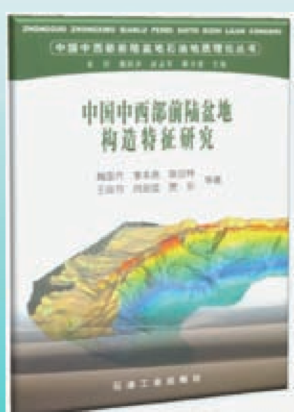
③ Stereo display: display the 3D structure deformation features and distribution rules;

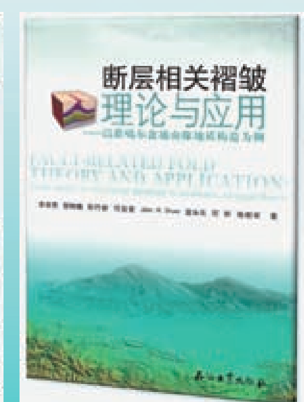
④ Quantitative analysis: quantitatively analyze the structure stress and strain, and disclose the deformation mechanism.

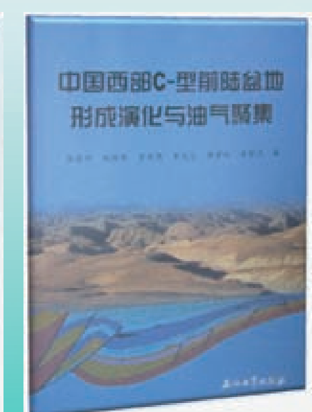
5 QUALIFICATIONS AND STANDARDS

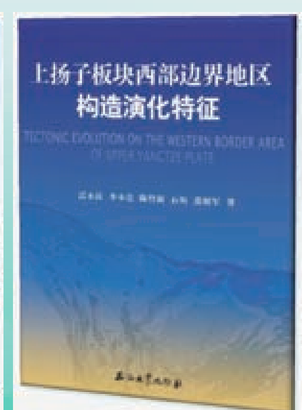
Won many national and provincial/ ministerial prizes. Among these prizes, 1 grade II national science and technology advance prize and 2 utility model patents are included.

Plenty of research achievements have been obtained and 4 monographs and more than 10 academic papers were published.









6 EXPERT TEAM

Jia Chengzao Academician of the Chinese Academy of Science, petroleum geologist and structural geologist. He is engaged in geologic research and oil exploration of Tarim basin for a long period of time. He has summarized and developed the geology theory for forming coal-formed hydrocarbon super-high pressure large gas fields in the foreland thrust belts and the petroleum geology theory of superimposed and composite basins, and made outstanding contribution to the discovery of Kela-2 large gas field and West-East NG Transmission Project. His representative works include China Tarim Basin Structural Feature and Oil/Gas, Foreland Thrust Belt Hydrocarbon Exploration, Basin Group Structural Geology and Natural Gas in Northern Margin of Tethys Tectonic Belt and China Petroleum Geology Theoretical Problem and Onshore Hydrocarbon Exploration Strategy in Early 21st Century. He was awarded with grade I national science and technology advance prize in 2001.

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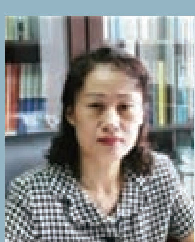

Song Yan doctor, professor level senior engineer, senior technical expert of CNPC, subject matter expert of State 863 Plan in resources and environment field, chief scientist of state 973 CBM Project, and member of the national committee of CPPCC. She is engaged mainly in hydrocarbon accumulation and natural gas geology researches. She was awarded with 1 award of grade I national science and technology advance prize, 2 awards of grade II national science and technology advance prizes, 1 provincial/ ministerial technical innovation super prize, 4 awards of grade I provincial/ ministerial science and technology advance prizes, 4 awards of grade II provincial/ ministerial science and technology advance prizes, and 1 award of "9th five-year plan" scientific and technological research project excellent achievement prize of the Ministry of Science and Technology of China. Over 170 papers and 17 monographs written/edited published.

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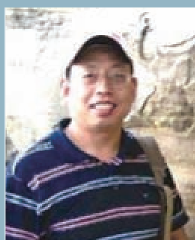

Zhao Mengjun doctor, professor level senior engineer, member of the Eighth Petroleum Geology Specialized Committee of Chinese Petroleum Society, and leader of Hydrocarbon experiment technology group. He is engaged in natural gas geology and hydrocarbon accumulation geologic research for a long period of time, has taken charge of and participated in completing more than 50 scientific research projects, and has obtained outstanding achievements in such major exploration fields as natural gas, foreland basin, CBM etc. as well as the geologic theory researches of petroliferous basins such as Tarim Basin, Qaidam Basin, etc. He was awarded with 1 award of grade II national science and technology advance prize, and 7 awards of grade I and grade II provincial/ ministerial prizes. Over 130 papers and 10 works published/co-published.

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Liu Shaobo doctor, senior engineer. member of Petroleum Science and Technology Equipment Specialized Committee of Chinese Petroleum Society, and member of International IPTC Conferencing Technology Committee. He is engaged mainly in hydrocarbon accumulation simulation, hydrocarbon enrichment law and unconventional hydrocarbon researches. He was awarded with 1 award of grade II national science and technology advance prize, 5 awards of grade I provincial/ ministerial prizes, 2 awards of grade II provincial/ ministerial prizes and 1 award of grade III provincial/ ministerial prize.70 research papers and 3 works published.

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Guan Shuwei doctor, senior engineer. He is dedicated in the structural research of the foreland thus belts in the central and eastern regions of China, specially skilled in complex structure analysis and modeling fields and obtained outstanding achievements. He was awarded with 2 awards of grade I and 2 awards of grade II prizes at ministry and bureau level. Over 30 papers and 1 work published.

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Lei Yongliang doctor, senior engineer. He is engaged mainly in basin structural geology researches, and has obtained outstanding achievements in structural-chronology and physical simulation experiment research fields. Over 20 papers and 2 works published/co-published.
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Yang Geng doctor, senior engineer. He is engaged mainly in basin structural geology researches and has obtained outstanding achievements in such fields including regional geologic analysis, basin, complex structure analysis and modeling theories, etc. Over 20 papers and 2 works published/co-published.
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Chen Zhuxin doctor, senior engineer. He is engaged mainly in basin structural geology researches such as the research work of regional structure analysis, structural geology analysis, modeling, etc. Over 20 papers and 2 works published/co-published.
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