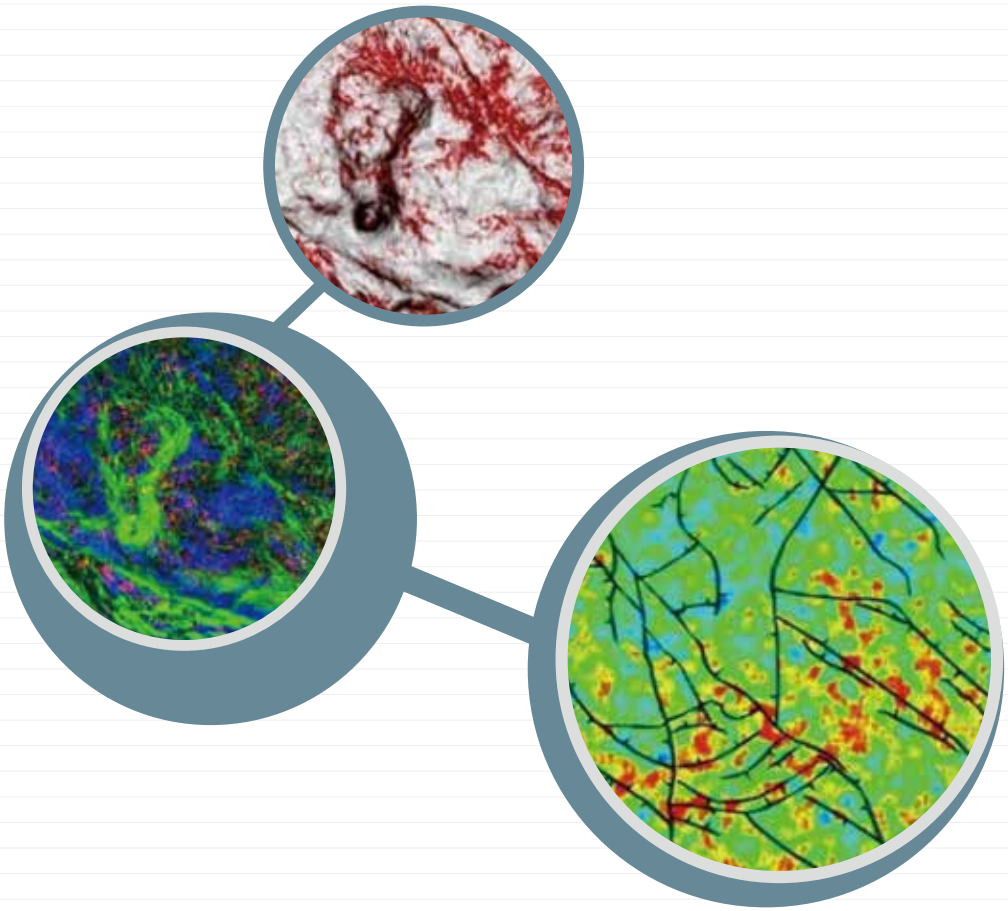
GeoFrac Integrated Seismic Fracture Prediction System

Science & Technology Management Department, CNPC

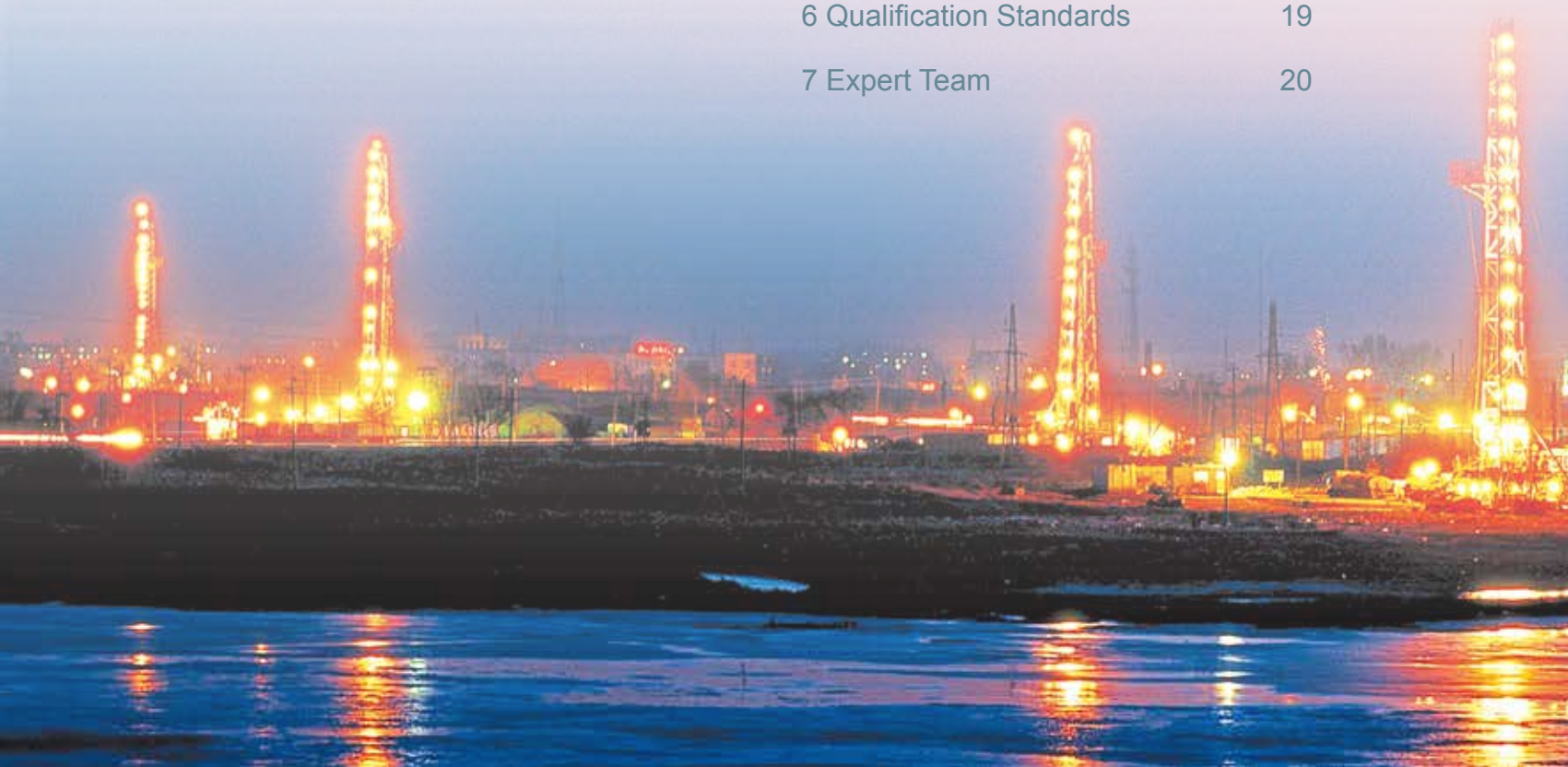
2015



CHINA NATIONAL PETROLEUM CORPORATION

To Improve Seismic Data Quality, Starting with Field Seismic Acquisition Quality Monitoring System!

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 2014 CNPC produced 113.67 million tons of crude oil and 95.46 billion cubic meters of natural gas, while crude processing volume reached 150.2 million tons. The total revenue of RMB 2,730 billion with a profit of RMB173.4 billion had been achieved the same year.

CNPC was ranked 3th among the world's largest 50 oil companies and 4th in Fortune Global 500 in 2014.

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 GeoFrac integrated seismic fracture prediction system is one of representatives for major innovations of CNPC.

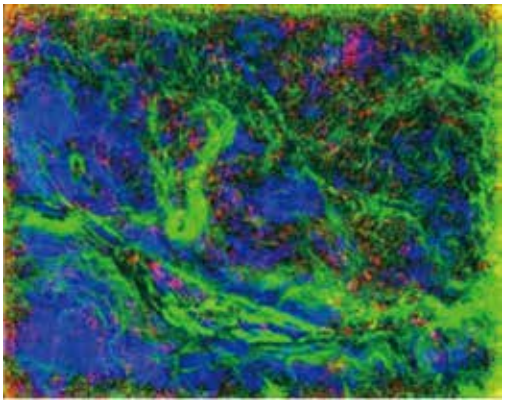
OFFERING ENERGY SOURCES, CREATING HARMONY

1 INTRODUCTION

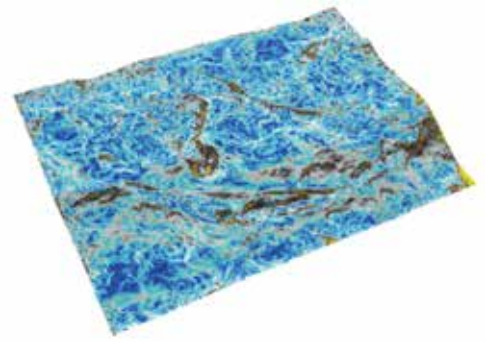
Based on the anisotropic theory, “GeoFrac integrated seismic fracture prediction system” has been developed with the current advanced SOA design, iterative software development model, software reconfiguration technology, etc. and has integrated the technical characteristics including well-seismic joint interactive fracture analysis, anisotropic prestack fracture prediction, prestack/poststack integrated fracture prediction, 3D visual multi-scale fracture carving, etc. The system includes 8 subsystems involving data management, prestack attribute analysis, integrated fracture prediction, 3D visualization, etc. and is intended to solve reservoir fracture prediction problem. The system provides effective technical means for oil and gas exploration and development and production increasing.

Characteristic Technologies

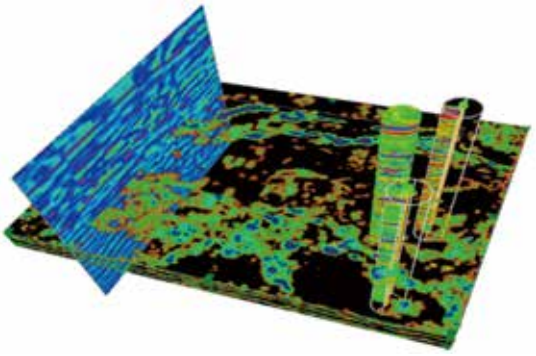
- Well-seismic joint interactive fracture analysis
- Anisotropic prestack fracture prediction
- Prestack/poststack integrated fracture analysis
- Multi-attribute integration technology
- 3D visual multi-scale fracture carving
- High efficiency management of prestack big data
- Multi-module real time communication
- Convenient algorithm integration



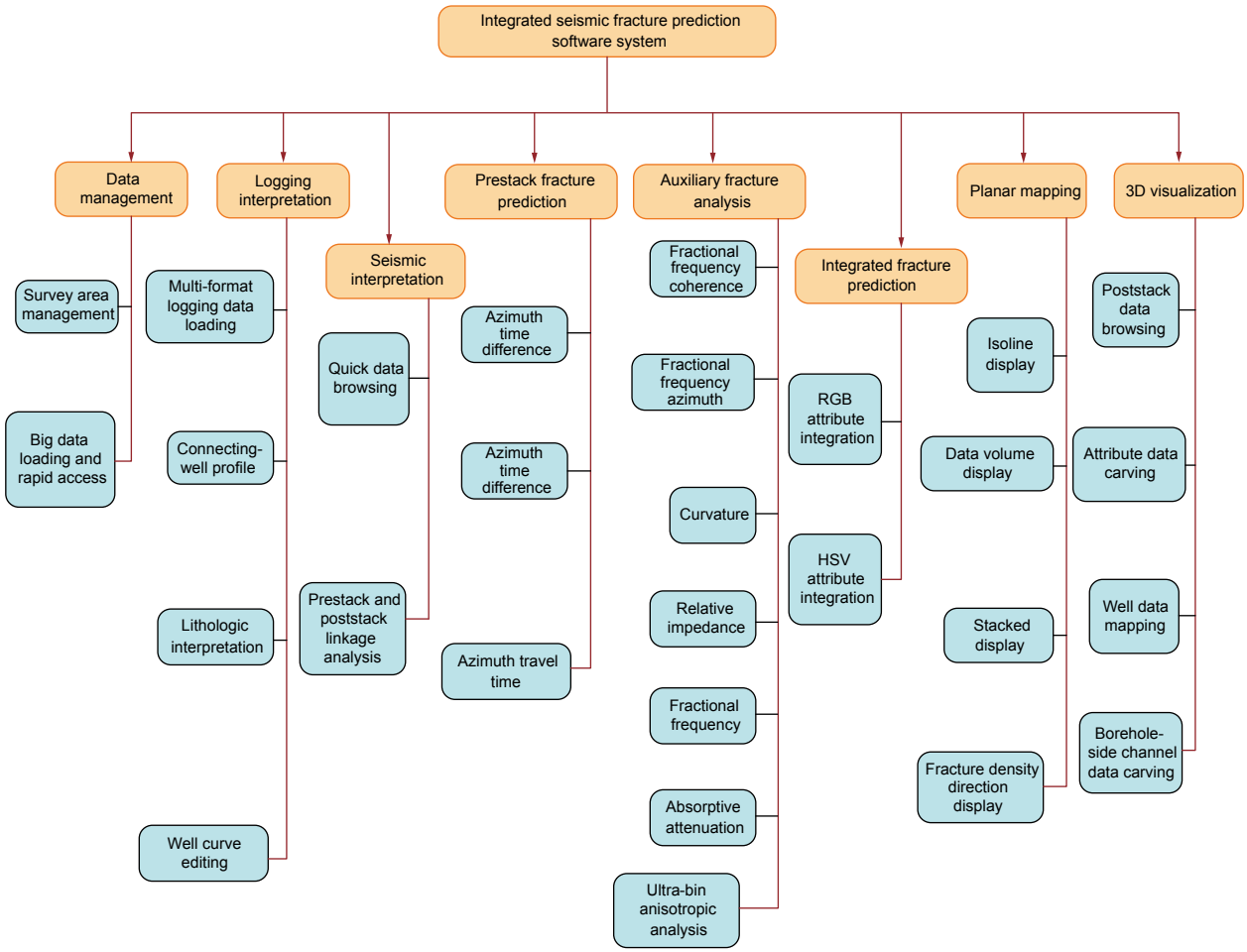
Curvature, coherence, fracture density, multi-scale integrated fracture prediction



Fracture distribution prediction with multi-attribute integration technology



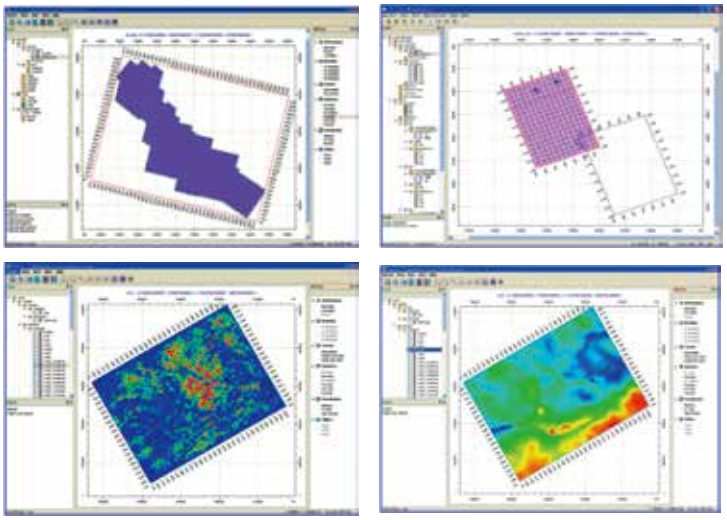
Reservoir distribution prediction with 3D perspective and well bore superposition



"GeoFrac integrated seismic fracture prediction system" realizes integrated analysis of geologic information, logging information and seismic information as well as prediction of prestack and poststack seismic data fracture direction and density. The system fully reflects the technical feature "poststack constrained by prestack, seismic constrained by logging, geophysical constrained by geology" and is characterized by high data management efficiency, stable performance, mutual combination of prestack with post stack, high prediction precision, etc. The system realizes the characteristic functions including prestack data single-point azimuth feature analysis, 3D seismic data prestack azimuth attribute extraction, interactive linkage analysis of prestack and poststack data, integrated multi-scale fracture prediction and other functions also provides an integrated solution to complex fracture reservoir prediction.

2 FUNCTION MODULES

2.1 Data management

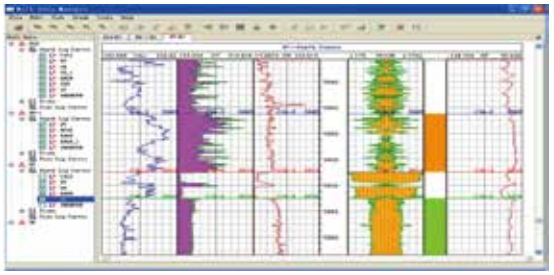


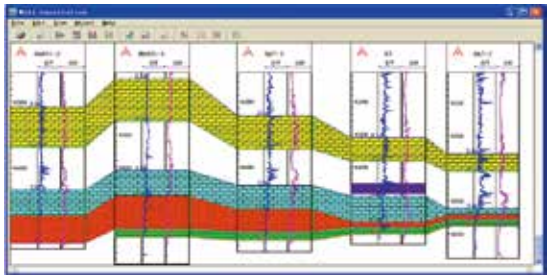
Management of multiple survey areas: manage survey areas using the rasterization technology. Data types includes prestack and poststack seismic data, horizon, fault, velocity, logging data and geologic data.

Data drive interaction: the data drive mode is used in interactive operation. Various data all can be displayed and edited via survey area data tree and the corresponding operation can be performed.

2.2 Logging Interpretation

Various display modes and interpretation of logging data. Connecting-well profiles are worked out according to multi-well curves and separate layer data.



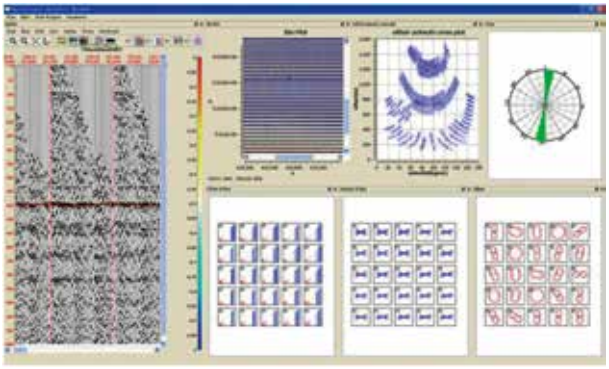


2.3 Seismic data interpretation

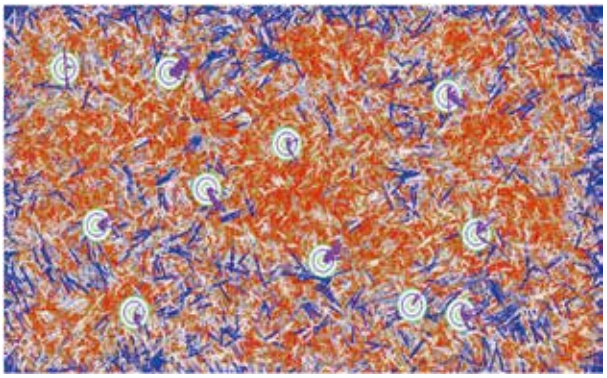
Poststack seismic data interpretation: various display modes of seismic data, including poststack seismic data, prestack gather display and interpretation horizon projection.

Prestack and poststack seismic data joint interaction analysis: including prestack/poststack joint interpretation, real time gather extraction, and real time partial gather stack. Call out prestack gathers in real time on the favorable area determined by poststack profile, make a joint linkage analysis, and improve prediction accuracy. This is the effective quality monitoring means for prestack fracture prediction.

Poststack fracture prediction



Prestack fracture prediction



Integrated fracture prediction

2.4 Poststack fracture prediction

Fracture prediction with geometric attributes: carry out poststack fracture prediction using geometric attributes such as dip angle, azimuth, curvature, coherence cube, etc.

Fault interpretation with multi-attribute integration: carry out multi-attribute fault interpretation using multiple means such as convergence, threshold constraint, integration, etc. and depict the fault distribution in the target area.

2.5 Prestack fracture prediction

AVD attribute extraction and analysis: extract the attribute information on prestack data variation with azimuth (AVD) and analyze AVD features, then relevant fracture information.

Anisotropic parameter inversion: carry out inversion of fracture parameters using prestack data based on anisotropic principle.

2.6 Integrated fracture prediction

Regional fracture statistics: interactively select a planar target area and make a statistical analysis of fracture features of the area.

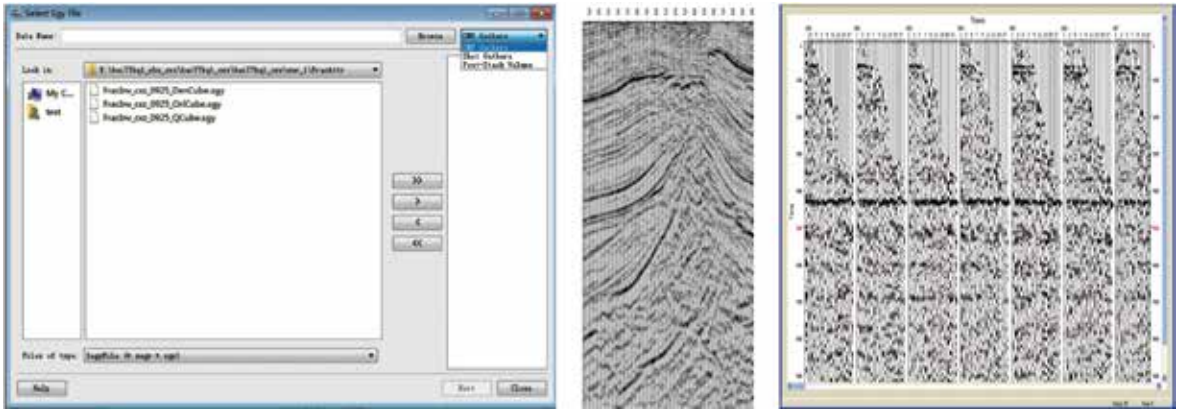
3D fracture carving: carve fracture shape in space using 3D visual technology and means such as threshold value, etc.

Integrated fracture prediction: analyze and predict the favorable part of fractured reservoirs using the multi-attribute integration technology and prestack/poststack fracture prediction results.

3 CHARACTERISTIC TECHNOLOGIES

3.1 Massive data high-efficiency management technology

Quickly retrieve various data, manage various data of multiple grades, and realize high-efficiency management of big data volumes and multiple data using multi-index and multi-search engine modes based on whole-survey area gridding technology and memory file mapping technology.



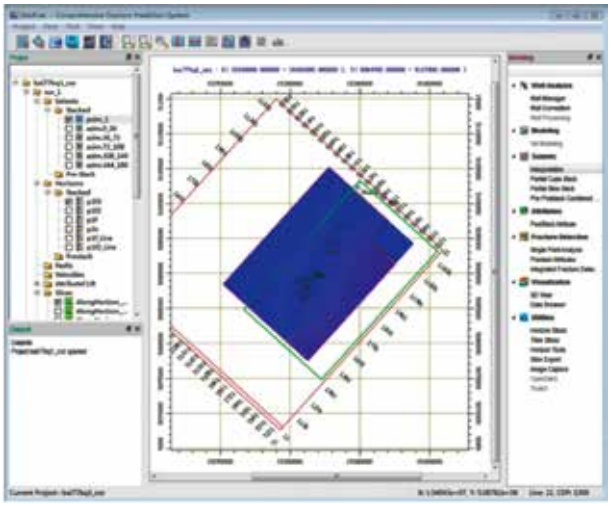
Uniform loading of prestack/poststack data

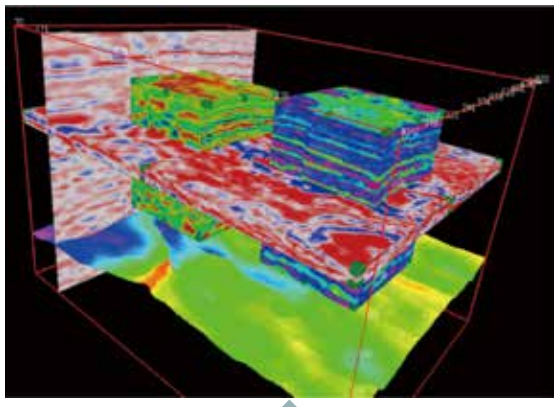
Batch loading of massive data is realized, thus greatly increasing data loading velocity, optimizing system operation efficiency and shortening prestack fracture prediction period.

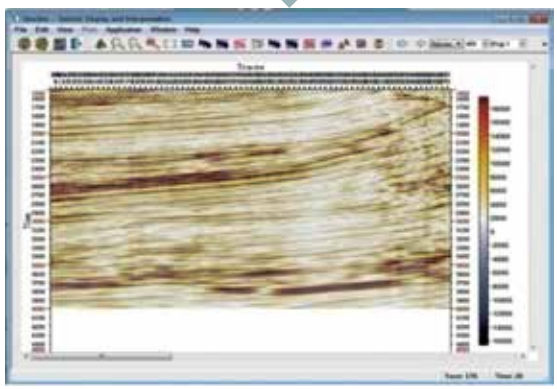
Batch loading of big data

3.2 Cross-platform underlying communication technology

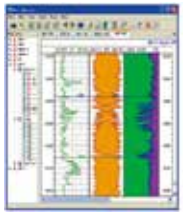
Multiple communication technologies ensure interaction between components and real time data transmission.

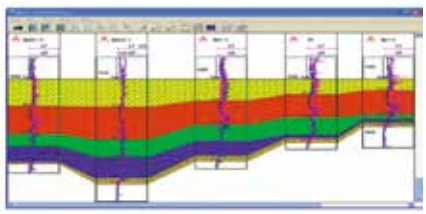






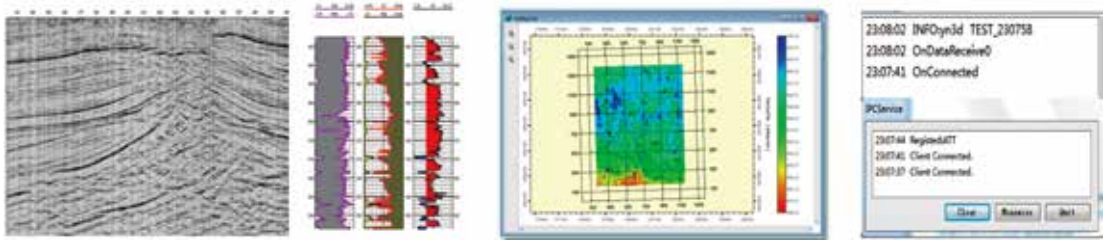
Thread communication technology: It can meet the needs of data transmission, message response, etc. among objects and threads, and act on the inside of each subsystem.





Network communication technology: It can meet the needs of communication among components and subsystems, act on all subsystems, and ensure interaction and data sharing among all subsystems.

Carry out real time interaction inside subsystems depending upon thread communication means.

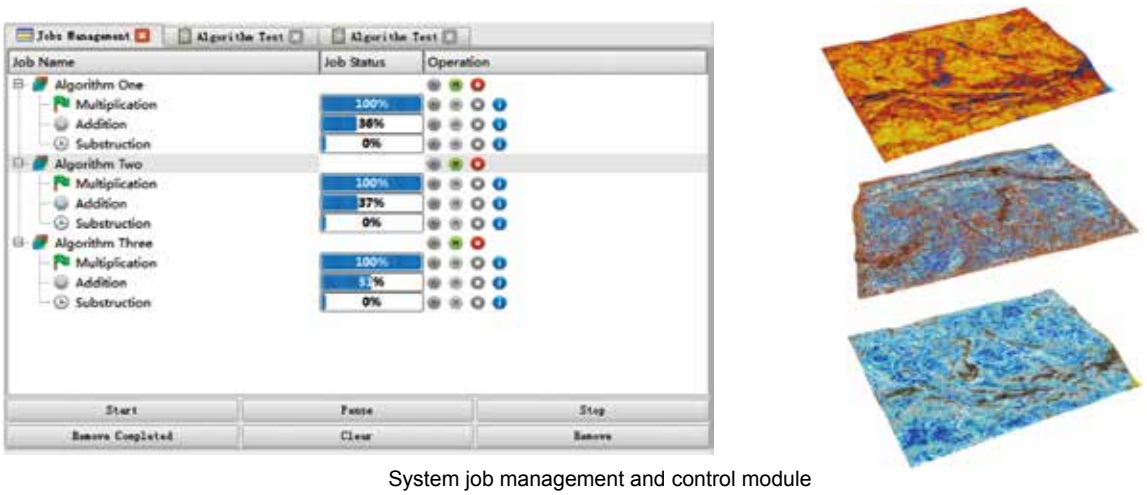


Data transmission among all subsystems using the network communication technology

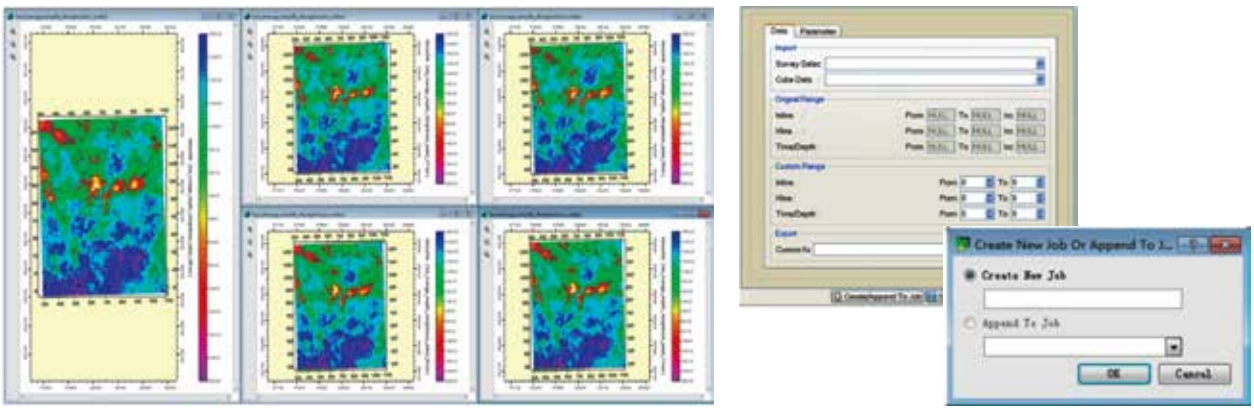
3.3 Multi-core parallel technology

Multi-thread operation management: parallel management of system operation, including monitoring of thread operation situation and control of thread operation process. Calculate various poststack attributes using the multithread management technology; carry out high-efficiency management of anisotropic inversion based on prestack gather data; utilize computer performance to the greatest extent possible, distribute appropriate resources to each job, and cause system operation to be highly effective and smooth.

MapReduce based on parallel calculation: parallel operation used in large scale data sets to improve prestack big data operation efficiency.



System job management and control module



Prestack separate-azimuth attribute analysis

3.4 Single-point interactive prestack fracture analysis technology

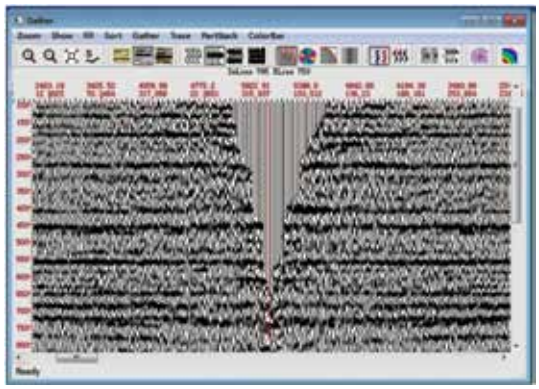
Provide a prestack fracture prediction parameter optimization scheme, involving shot and geophone analysis, analysis of folds, azimuth range analysis, azimuth offset intersection analysis, prestack gather horizon correction, and borehole-side anisotropic analysis. Carry out whole-area prestack anisotropic inversion by selecting the best bin, inversion method and prestack attribute according to the borehole-side single-point interactive analysis result.

Interpret and correct prestack gather horizons in manual, semi-automatic and full automatic modes to ensure prestack fracture prediction accuracy.

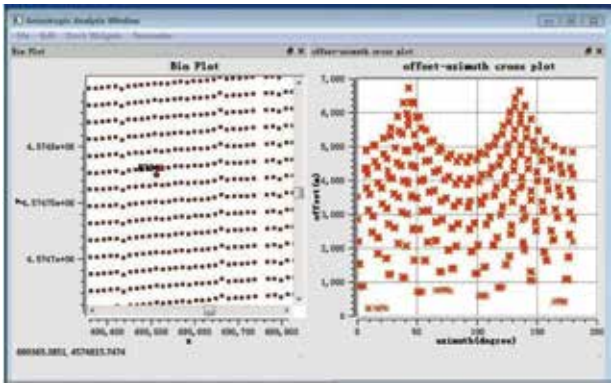
Select appropriate offset according to azimuth offset intersection single-point analysis to ensure azimuth uniformity and improve inversion result stability.

Ultra-bin anisotropic analysis: provide multiple inversion methods and ultra-bin selection modes to ensure that the inversion result tallies with logging data.

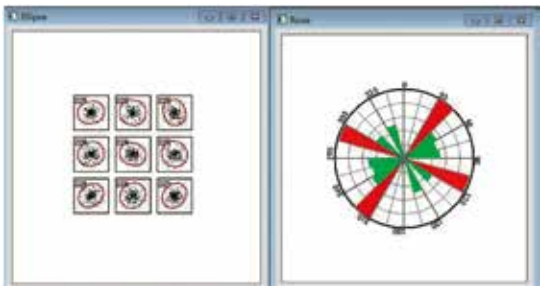
Analyze the folds of any ultra-bin and the distribution law of azimuth and effectively evaluate the analyzed prestack data.



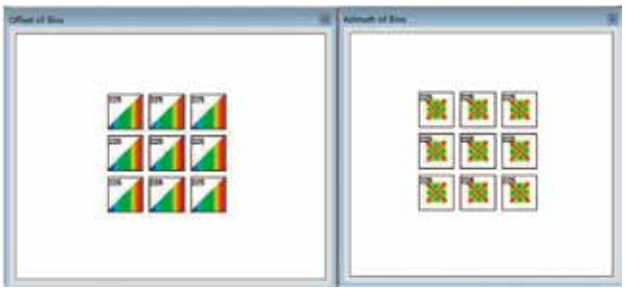
Prestack gather horizon interpretation and correction



Azimuth offset intersection single-point analysis



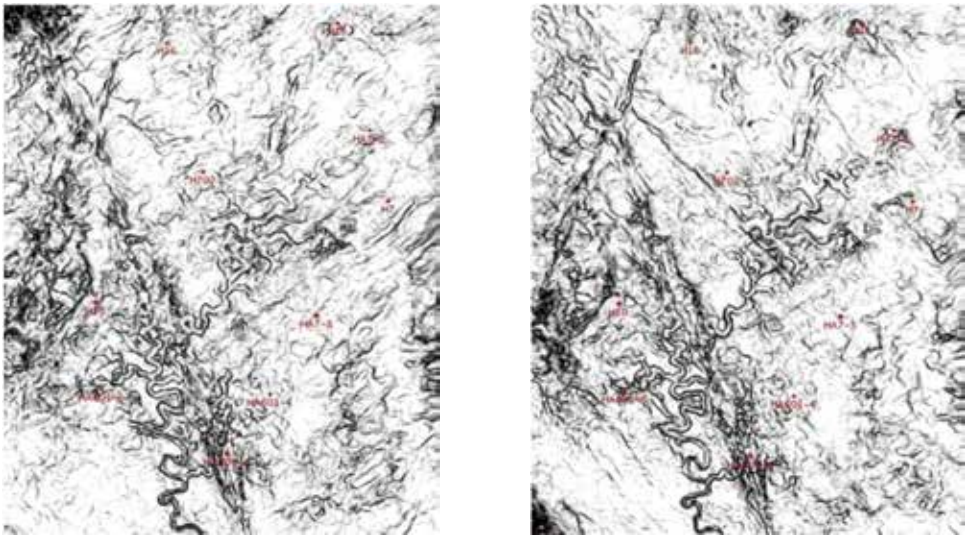
Ultra-bin anisotropic analysis



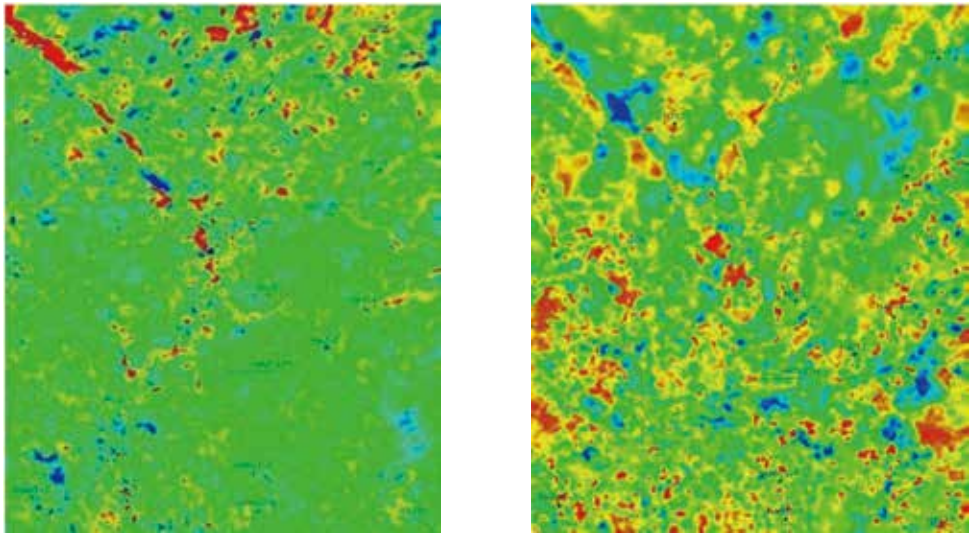
Ultra-bin folds and azimuth analysis

3.5 Prestack azimuth anisotropic analysis technology

Analyze and calculate planar (along-horizon, along-time) multi-azimuth prestack attributes; optimize sensitive attributes for fracture prediction through difference analysis of prestack attributes of fault development belts.

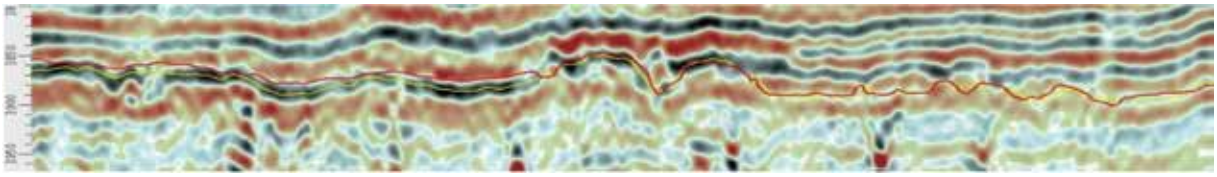


Analysis of the features of variation of seismic attributes with azimuth

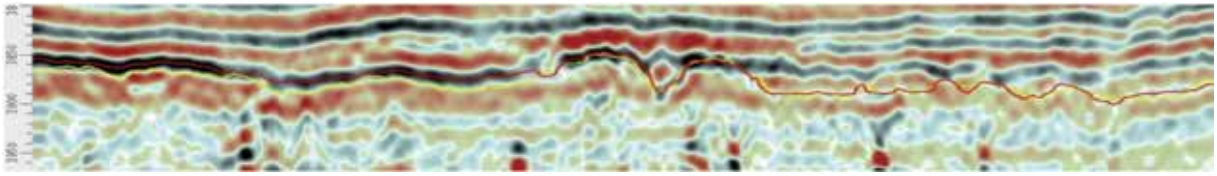


Analysis of the features of variation of different attributes at the same azimuth

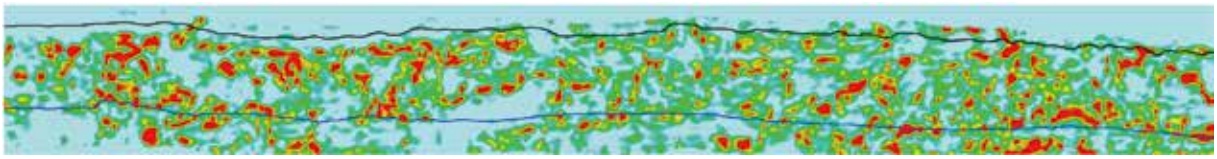
3.6 3D fracture monitoring and analysis technology



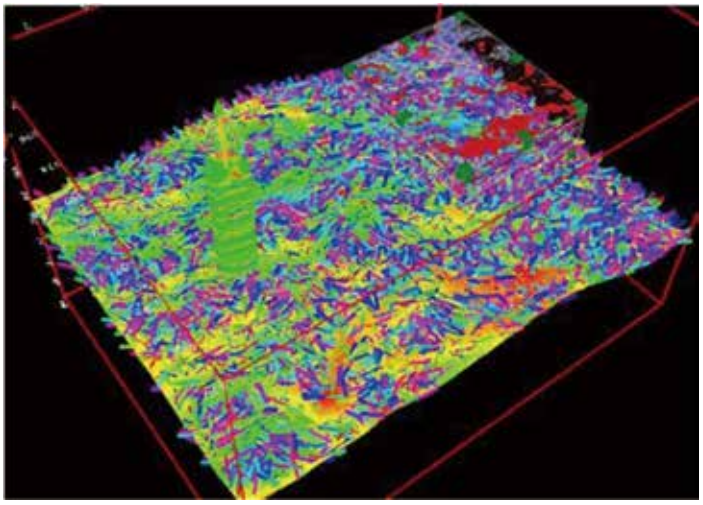
Analysis of seismic data at 45° azimuth



Analysis of seismic data at 135° azimuth



Fracture analysis result in 3D data volume azimuth anisotropism

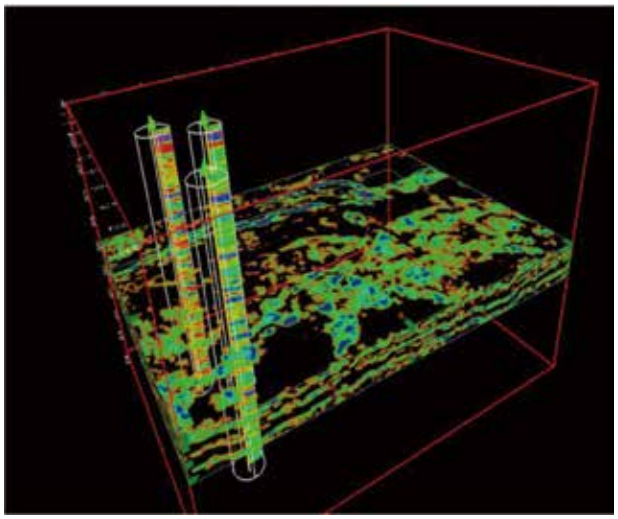


3D fracture density and direction detection result

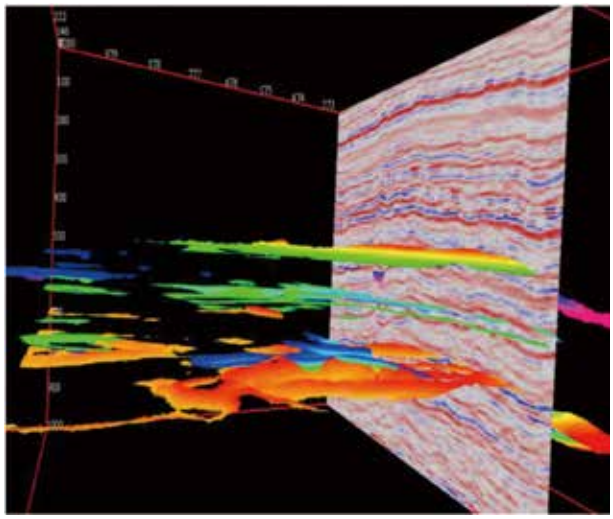
3D fracture detection: preprocessing of 3D prestack data volumes, including gather time difference correction, phase correction, wavelet impact elimination, etc. Carry out anisotropic inversion using the preprocessed prestack gathers and separate-azimuth data volumes to obtain 3D fracture parameter volumes.

3.7 Integrated 3D fracture visualization technology

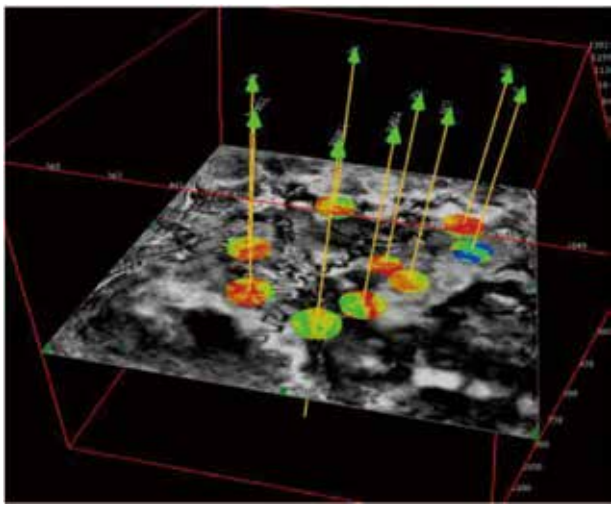
GeoFrac system provides 3D visualization technology with many functions. The technology can be used to visually display seismic data, logging data, horizon data, attribute data, etc., constrain threshold values, perform along-horizon and along-volume perspective, quickly show fracture distribution features, carve target anomaly bodies, and provide visual geologic features.



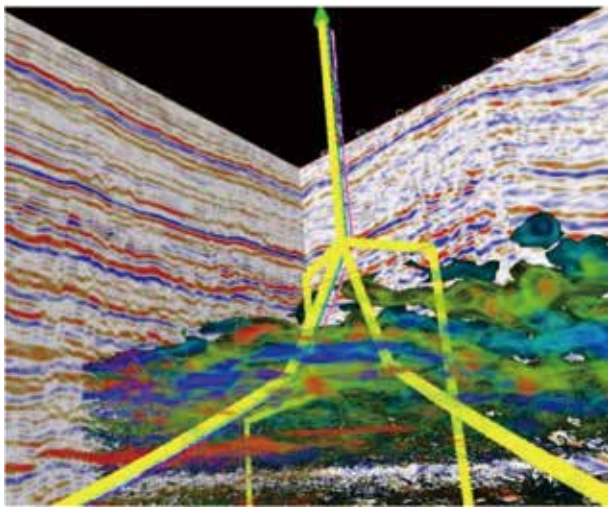
Inter-layer fracture density visualization



Multi-layer fracture density visualization



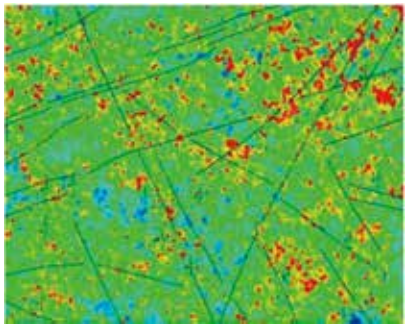
Fracture density visualization along well position



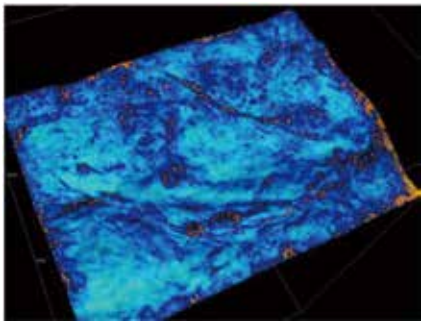
Target body fracture density visualization at well position

3.8 Integrated fracture analysis technology

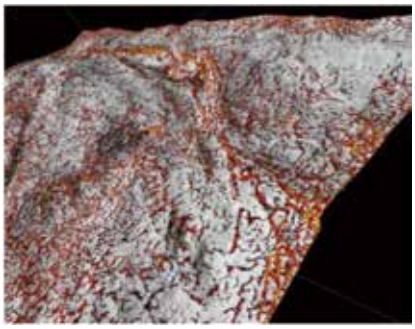
Carry out multi-information integration based on the iconography principle “color code integration, color gamut rotation and value domain complementation”. Enhance the sense of layering, cause display contents to be more plentiful and reveal more geologic information on the premise of keeping various prediction results unchanged.



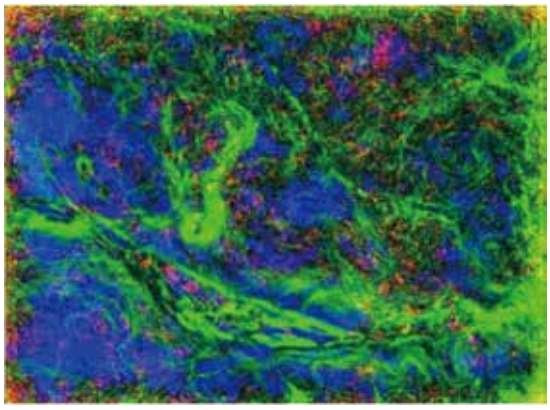
Prestack fracture prediction result



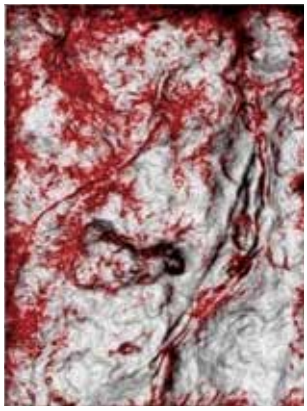
Poststack coherence attribute result



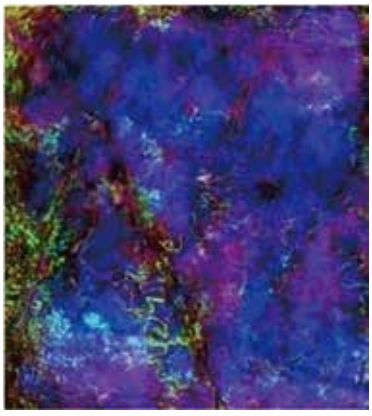
Poststack curvature attribute result



Integrated fracture reservoir prediction result



Coherence + fracture density Integrated fracture reservoir prediction result



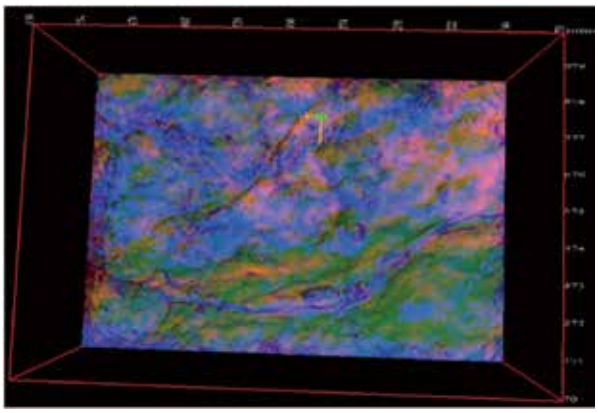
Coherence + spectral imaging + fracture density Integrated fracture reservoir prediction result

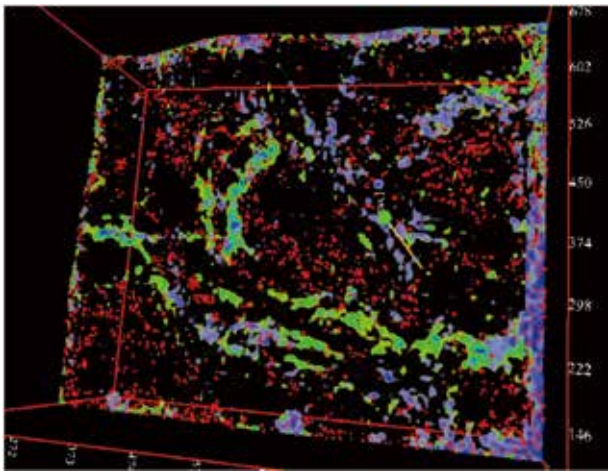
4 TYPICAL CASES

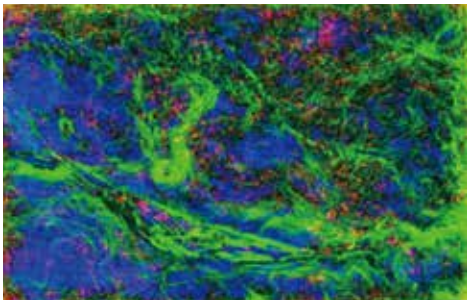
4.1 Prediction of fractured reservoirs in Moxi region in Sichuan basin

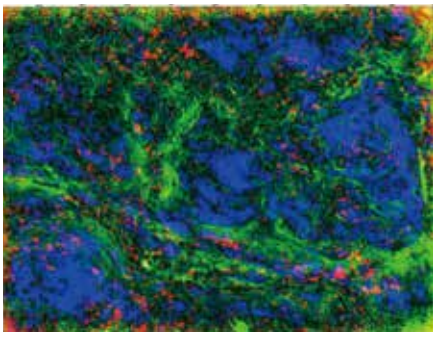
Moxi 3D survey area is a NE-SW long-strip block. The research work has been done mainly aiming at Lower Palaeozoic of Moxi structure. There are four sets of target formations: Ordovician Nanjinguan Fm., Cambrian Xixiangchiqun Fm. and Longwangmiao Fm. and Sinian Dengying Fm.

According to the prediction result, the green part is fault development area, and the red part is the area with high fracture density. The prediction result indicates that a set of large fault is developed in the south of the survey area and fractures are developed mainly in the north of the survey area and near the fault.





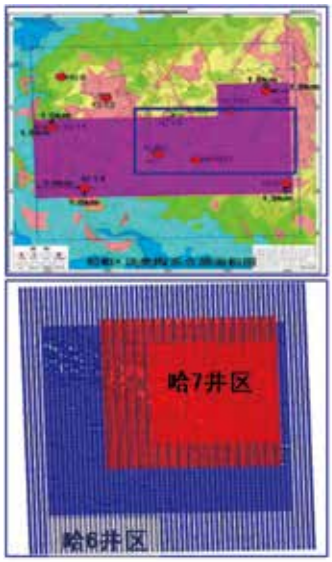


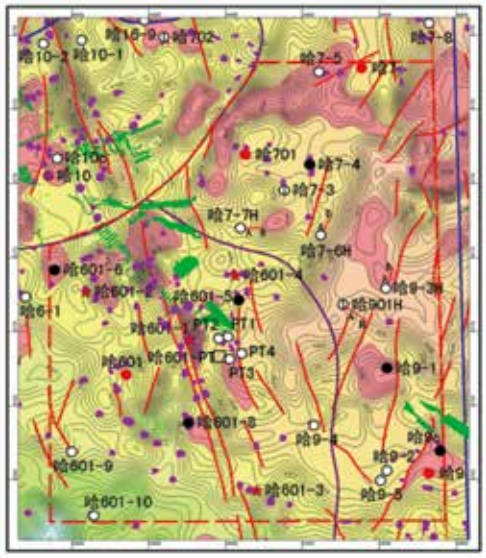


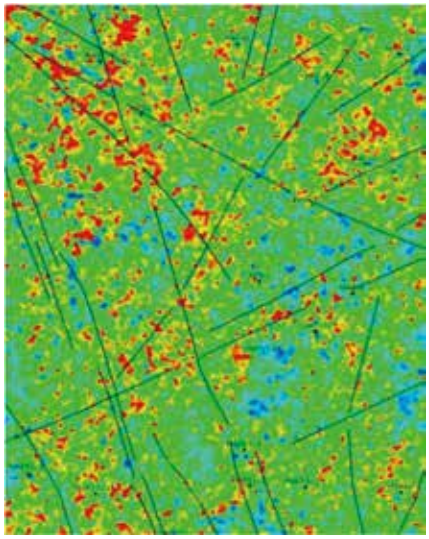
4.2 Prediction of carbonate fracture-cavity reservoirs in Halahatang region in Tarim basin

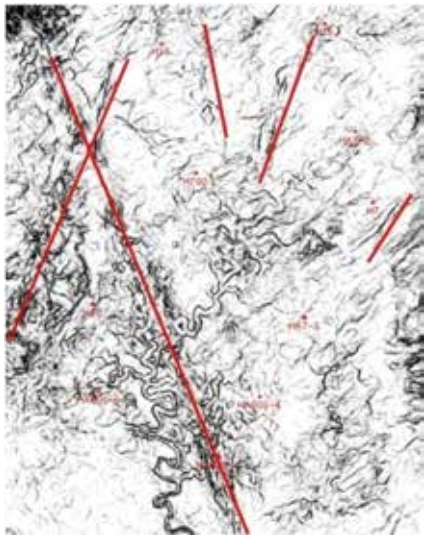
Halahatang region, located in Halahatang sag in Tabei uplift, is the southwest extension of Lunnan Ordovician bulge, and the target formation is Medium-Lower Ordovician Yijianfang to Yingshan Fm.

The target formation in Halahatang research region is located in the transition area of carbonate ancient buried hill with slope belt, where palaeogeomorphology is high and karsts and faults are developed. According to the prediction result, NW-SE and NE-SW strike-slip faults are developed in the research region, and fractures are developed around the faults.









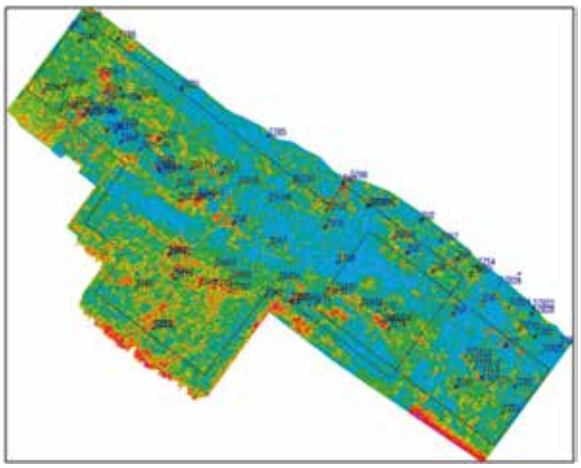
4.3 Prediction of fractured reservoirs in ZG8 to ZG43 well area in Tarim basin

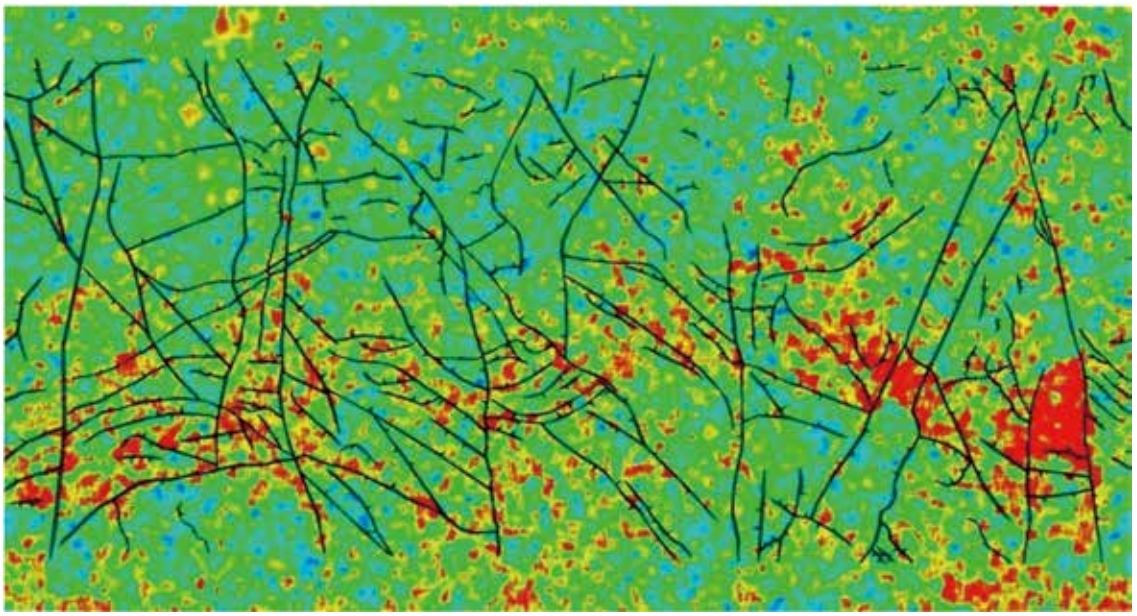
ZG8-ZG43 well area, located in the central east of Tazhong north slope, belongs to TZ10 structure belt, aiming at Lower Ordovician Yingshan Fm.

Carry out fault prediction with poststack attribute and fracture parameter inversion using prestack azimuth attribute. The prediction result shows:

Near-EW thrust fault and NE-SW strike-slip fault are mainly developed in the survey area.

Two slopes such as south and north ones are formed on the two sides of the structure belt. The south is uplifted, the north is inclined, the east is high, and the west is low. The development degree of fractures is the highest in the high part of the central uplift area and its two limbs, thus indicating the direction of high-efficiency well deployment.





Plan view of target formation fracture density

5 SCIENTIFIC RESEARCH EQUIPMENT

The scientific research equipment includes: two sets of SUN E20K systems, 128 CPUs, 512MB memory, which are mainly used in seismic interpretation and application software development; in addition, seismic interpretation systems such as Landmark, Geofram and so on are set up. HP PC-Cluster system with 256 nodes and 2048 cores is mainly used in seismic data processing, and the installed software includes Omega Epos GeoEast seismic processing system etc. IBM PC-cluster system with 192 nodes and 3072 cores is used mainly in seismic data processing, and the installed software includes Omega GeoEast integrated seismic processing and interpretation system etc. Two sets of GPU systems such as S1070 and S2090 with 36 nodes and 60000 CUDA cores are used mainly in prestack time migration, reverse time migration and GPU parallel application software development. HDS AMS1000, EMC CX4-960, Isilon 6k Isilon36K, Isilon X200 storage systems and IBM TS3584 automatic tape library system are set up.

The number of CPUs reaches 600, the total storage capacity exceeds 2PB, and over 100 pieces (sets) of graphic workstations including IBM, Sun, HP and so on are set up.

6 QUALIFICATION STANDARDS

Northwest Branch Institute of RIPED is the important geophysical method research and geosciences software R&D base of CNPC. Northwest Branch Institute of RIPED has been committed to geophysical exploration method research and software R&D over the years. Northwest Branch Institute of RIPED has formed multiple patent products in seismic data acquisition quality monitoring, model constrained seismic data processing, logging constrained high precision wave impedance inversion, prestack AVA synchronous inversion, attribute extraction and multi-attribute optimization and integration, complex medium forward modeling, integrated seismic fracture prediction, oil and gas detection based on multi-phase medium, etc. Northwest Branch Institute of RIPED has CNPC key reservoir description laboratory and PetroChina key geophysical laboratory and take the lead in the capacity of fine processing and interpretation of seismic data in China.

Software products with independent intellectual property rights

- Geo Face Integrated Seismic Fracture Prediction Software System
- Geo SeisQc Seismic data acquisition quality analysis and evaluation system
- CRIS V3.0 Integrated seismic inversion and oil and gas detection system
- CCFY Integrated reservoir inversion software
- HARI Integrated reservoir inversion software
- SEMPAR Integrated reservoir inversion software
- DHAF Oil and gas detection software
- MODPRO Image processing software package
- Paraming Prestack depth migration software
- MDIS and MTIS Static correction software

Integrated seismic fracture prediction system patents

- Fracture prediction method and device (201010205983.4)
- P-wave fracture prediction and delamination technology (201010567725.0)
- A non-zero offset seismic signal energy calibration device and system (201020273840.2)
- A method and device for obtaining seismic thin reservoir velocity in well control (201010594743.8)
- Application method of transverse variable-speed small-scale reflection coefficient formula (201110314489.6)
- Multi-layer fracture prediction method and device (201010172047.8)
- A method and equipment for testing natural gas reservoir based on seismic signal (20111014370.3)

7 EXPERT TEAM

Wang Xiwen

Senior technical expert, professor level senior engineer, doctor. He is mainly engaged in technical research on seismic wave propagation theory and application, wavelet analysis, fine reservoir prediction, effective identification of lithologic traps, etc. He has obtained 4 grade I provincial and ministerial science and technology advance prizes, 1 grade II provincial and ministerial science and technology advance prize, 7 grade I bureau level science and technology advance prizes and 4 grade II bureau level science and technology advance prizes. 1 monograph and 58 academic papers written by him have been published.

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Zhou Chunlei Technical expert, senior engineer. He is mainly engaged in R&D of geophysical forward modeling and inversion theory, seismic data processing software, oil and gas detection, reservoir prediction, software integration technology, etc. He has obtained 1 grade I science and technology advance prize of Gansu Province, 2 grade II ministerial prizes, 5 grade I bureau level prizes and 6 grade II bureau level prizes. Multiple papers written by him have been published.

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Zhang Qiaofeng Technical expert, senior engineer. She is mainly engaged in seismic data processing, seismic reservoir inversion, full 3D visual interpretation, geosciences software testing, etc. She has participated in seismic inversion work in key blocks of oilfields including Daqing, Changqing, Qinghai, Tarim, Junggar, Sichuan, Nanhai, Venezuela, etc. She has obtained 1 grade II ministerial prize. Multiple papers written by him have been published. Technical expert, senior engineer. She is engaged mainly in seismic data processing, seismic reservoir inversion, full 3D visual interpretation, geosciences software testing, etc. She has participated in seismic inversion work in key blocks of oilfields including Daqing, Changqing, Qinghai, Tarim, Junggar, Sichuan, Nanhai, Venezuela, etc. She has obtained 1 grade II ministerial prize. Multiple papers written by her have been published.

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