Progress of GeoEast Interpretation Technology

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Summary

GeoEast sees significant usability enrichments and performance enhancements in the last ten to twenty years. To meet the demand for complex reservoir prospecting, it has been successfully developed into a cross-discipline platform that incorporates structure interpretation, attribute analysis, seismic inversion, 5D interpretation, joint well-seismic geological analysis, seismic guided drilling and geological modeling into a comprehensive geological-geophysical interpretation system, enabling structural interpretation, reservoir prediction, hydrocarbon detection and geological analysis in various depositional environments. It has been broadly employed in multi-client projects under CNPC around the world.

Introduction

With the constant exploration and development in the petroleum industry, the focus of seismic exploration has evolved from the simple structural traps to complex lithologic traps, and from shallow to the deep exploration. This industry is currently challenging exploring prospects with more complex structures, at deeper depths, and in smaller-scale. To successfully give insight into complex structural settings, we have developed high-efficient structure interpretation technology. To effectively improve the accuracy of reservoir characterisation, fluid and sedimentary facies in the litho-stratigraphic trap such as the complex reservoir, volcanic rock, and carbonate, we have developed complete technology such as seismic attributes, seismic inversion, and 5D interpretation. To meet the demand of exploration-development integration and enhancement in the geological analysis, we have developed the joint well-seismic interpretation, sequence-stratigraphy interpretation, 3D geological modeling, and geo-steering horizontal well planning.

Over the past ten to twenty years continuous efforts in research and development, GeoEast has been developed into an integrated geophysical-geological interpretation system, including structural interpretation, attribute analysis, seismic inversion, joint well-seismic geological analysis, geo-steering and geological modeling. This fully integrated software suite has been widely used in domestic and foreign projects of CNPC (Figure 1).

1. Efficient structure interpretation technology

Structure interpretation, the most time-consuming part in seismic interpretation project, plays a fundamental role in seismic interpretation. The seismic interpretation projects diversified from individual regional study to basin-scale analysis with the focus of exploration on increasingly more complex geological scenarios. To do the proprietary analysis in complex fault system with massive data, GeoEast confronts with a primary problem; that is, to sustainably enhancing the interpretation efficiency.

A highly automatic structure interpretation solution has thus been introduced to GeoEast based on the extensive demand analysis, which yields improvements in effective and efficient structure interpretation (Figure 2).

The characterized structure interpretation technologies are addressed as follows:

1) Seismic attribute-based subtle fault identification

Structure-oriented filtering is initially performed to improve the seismic to noise ratio, highlighting the discontinuities of seismic events. Multi-attributes are then employed to precisely identify, and finely describe subtle faults including curvature, coherence, variance, edge detection, dip, ant, fault index, and attribute fusion. A series of technology to identify subtle fault has been formed (Figure 3).
2) Adaptive time window coherence

Previous technologies adopt a fixed time window to calculate coherence at each depth. However, via these methods, it is difficult to provide the optimized results for all seismic data set due to the variation of dominant frequency at each depth. To resolve this problem, a method called adaptive time window coherence technology has been developed. The coherence is calculated based on the sliding window to ensure the optimized results at each depth, which highly improve the accuracy of fault identification (Figure 4).

3) Fault auto-tracking

Fault auto-tracking technology can be utilized in seismic data with a high signal-to-noise ratio (SNR) through the following steps. Coherence is firstly extracted with structure oriented filtered seismic data, based on which ant volume is obtained to improve the continuity of the fault. Fault auto-tracking technology is then employed to track the fault line, through which spatial fault planes are formed (Figure 5).

4) Fault auto-interpolation based on seismic attributes constraints

In most cases, the SNR of seismic data cannot meet the quality requirement of fault auto-tracking. GeoEast addresses this problem by interpolating the faults with seismic attribute constraints. Fault interpretation is firstly carried out on the primary framing seismic sections, followed by auto-interpolation of these faults which form fault planes. The locations of faults are adjusted subsequently according to the seismic attributes such as coherence and ant, ensuring the location accuracy and thus further improving the accuracy of fault interpretation.

5) Coupled horizon and fault interpretation

To improve the efficiency of horizon interpretation, GeoEast has been enriched with various interpretation methods, enabling the auto-interpretation on the 2D seismic section or in 3D volume. In the case of a project with a large number of faults, inaccurate fault locations, or inconsistent horizons and faults, users have to manually delete the redundant parts of the faults or extend the horizons to the faults, which is quite time-consuming. Our coupled horizon-fault interpretation technology has solved this problem. The horizons can be automatically cut or extended when users modify the interpreted fault (Figure 7).
6) Fault polygon automatic interpretation and statistics

There exist over ten thousand faults in some prospects which covered an area of over ten thousand square kilometres. It is torturous to edit the fault polygons and count the fault elements manually. To increase the efficiency, GeoEast provides a series of fault polygon auto-statistics solutions via the following steps. First, fault polygons are auto-tracked according to the intersection of fault and horizon; second, based on the distribution, the fault elements are auto-calculated, such as length, strike, throw, inclination, and dip, leading to hundredfold improvement in efficiency and the noteworthy reduction in manual labour (Figure 8).

2. Accurate reservoir characterisation

Reservoir prediction moves to smaller-scale and thinner, more subtle targets. The low SNR and shadow effect in the shallow layers further increase the difficulty in reservoir prediction. Via researching and developing technology in seismic data conditioning can successfully increase the SNR and highlight the geological character. Combined with multi-seismic attribute extraction, analysis and inversion can improve the accuracy of reservoir prediction.

GeoEast provides over 100 types of volume attributes, more than 60 surface attributes, and nine classifications (Figure 9), which have been employed in reservoir characterisation study in various geological bodies such as river sand, and carbonate fractures.

1) Gaussian filtering

In terms of noisy data, attributes could not only reflect subtle geological character but also emphasise on noise, so that the signal would also be inundated. However, Gaussian filtering, a linear filtering method, has effectively solved this problem and can be applied to remove Gaussian noise, which has been widely used in noise reduction during the image processing. The Gaussian filter is performed on the seismic data prior to curvature extraction. The acquisition footprint has been removed and the SNR has been improved, resulting in the more precise image of subtle faults (Figure 10).

2) Seismic attribute-based geobodies visualization technology

The prospecting focus has gradually moved from structure trap to litho-stratigraphic trap exploration. Apart from clastics reservoirs, volcanic and carbonate reservoirs are exerting an increasingly more important part in the petroleum industry. GeoEast has developed featured attributes analysis adapted to different geological scenarios to identify and visualise geological targets (Figure 11).

Clastics reservoirs, such as sand bodies (e.g., channels), can be effectively identified through attributes extraction and other analysis technologies such as spectral decomposition, coherence energy gradient, high-light volume, attributes classification. Volcanic reservoirs identification could be performed through texture, differential amplitude and other attributes that can highlight the reflection characteristics and support the reservoir characterisation, visualisation and evaluation. Vuggy carbonate reservoirs study could be conducted through volume curvatures, pre-stack attributes, volume classification, and geobody auto-tracking in 3D visualisation leading to the clarification of the locations of vugs and fractures and their spatial relationships in karst reservoirs.
Figure 11: Geobodies visualization utilising the seismic attributes, (a) palaeogemorphology and palaeochannel characterisation, (b) carbonate fracture-cave bodies delineation, (c) channel visualization via highlight volume, (d) volcanic rock carved by texture.

3) Sedimentary facies and reservoir parameters prediction

There have existed various categories of seismic attributes with the fast-developing technology. It is difficult for users to select the effective ones for specific reservoir characterisation studies. However, GeoEast can provide the full solution. The proper attributes could be selected via attributes comparison (in the vertical profile, map view, and cross-plotting); meanwhile, auto optimal selection and compression could also be realised through critical technologies such as PCA and KPCA. Once the optimal attributes are selected, supervised neural network (such as BP and SPR) and wiggle (spectrum) classification are carried out to accomplish seismic facies analysis and reservoir quantitative interpretation (Figure 12).

Figure 12: Reservoir parameters prediction

4) Hydrocarbon detection

The seismic spectra of the hydrocarbon-bearing reservoir would be distinguished from the surroundings; that is, the energy at low frequency will increase while decrease at the high-frequency side. According to this phenomenon, hydrocarbon detection technology has been incorporated into GeoEast based on time-frequency analysis, two-phase medium theory and pattern recognition, which have been widely applied in reservoir prediction of carbonate, clastics and volcanic rocks (Figure 13).

Figure 13: A case study of hydrocarbon detection

5) 5-D interpretation

Along with the progress of seismic processing to broadband frequency, wide azimuth and high density, seismic interpretation moves from previous 3D data to 5D seismic data (adding incident angle and azimuth to the original 3D seismic parameters). 5D data contains abundant information. It is essential to investigate how to utilise this information into geological interpretation effectively.

Once the 5D gathers are optimised, partial angle/offset stacking is performed according to the geological condition, which is followed by elliptical fitting to determine the fracture orientations. This technology provides users with access for conducting pre-stack fracture analysis, identifying oil and gas with hydrocarbon detection technology based on optimal azimuthally stacking data. These full 5D interpretation capabilities enable users to have an in-depth understanding of 5D seismic information and obtain sufficiently abundant information (Figure 14).

Figure 14: 5D seismic data analysis

6) Seismic inversion

In view of seismic inversion, GeoEast offers 4 post-stack seismic inversion methods (broad-band constrained, simulating annealing, neural network, and sparse spike inversion), 2 pre-stack seismic inversion approaches (elastic impedance, and Bayesian Inversion) and associated functions (well logging pre-processing, well tie, wavelet extraction, cross-plotting, histogram, initial model building, sand body carving) (Figure 15).

Figure 15: Seismic inversion methods
3. Joint well-seismic geological analysis

In oil and gas exploration and development, to increase the successful drilling chance, it is essential to make full use of seismic and well data. GeoEast enables customers to integrate these data easily, supplying enormous flexibilities to meet clients’ increasingly urgent demand in the integration of exploration and development.

1) Joint well-seismic interpretation

Petrophysical interpretation and multi-well correlation are conducted at the beginning. Structure interpretation is then performed based on the seismic arbitrary line passing through the correlated wells. Once these are done, a 2D geological profile can be automatically generated. Figure 16 illustrates the sub-layer well correlation and reservoir interpretation with seismic attributes and inversion constraints. Figure 17 demonstrates the play section, the ultimate product, integrated with well logging, seismic and reservoir characterisation study, which allows for the in-depth integration of well log and seismic information.

2) Sequence-stratigraphy interpretation

Based on the sequence stratigraphy theory, users define the sequence framework according to the depositional cycle of a single well and multi-well correlation. The 3D seismic stratigraphic analysis technology is applied to auto track all the sub-layers covered the seismic data. Wheeler transform is then performed to quickly identify the flooding surfaces, assisting in understanding the depositional cycle characteristics of each system tract and source-reservoir-seal combinations (Figure 18, 19).

3) Seismic guided drilling technology

Increasingly more oil and gas fields have moved to the phase of development and production, during which horizontal wells are widely utilised in shale gas and coalbed methane production to maximise recovery. We focus on planning the horizontal well trajectory to precisely meet the target guided by seismic and geological data with sufficient employment of the available geophysical data. Hence, a drilling tool has been combined into GeoEast including seismic-based well trajectory planning, accurate velocity field building, high-efficient time-depth conversion, and iterative velocity correction, giving the response to the accuracy improvement on the target entrance (Figure 20).
4) 3-D geological modeling

Geological modelling bridges the gap between exploration and development. GeoEast provides the working environment for this integration which allows for simultaneous interpretation and modelling. It offers a user-friendly approach in modelling complex structures such as normal and reverse faults, unconformities, salt diapers and property modelling by structural constraints (Figure 21).

Conclusions

According to users’ demand, many structure interpretation technologies have been enriched and enhanced in GeoEast such as geometric attributes and horizon-fault auto-tracking, enabling high-efficient and accurate interpretation for frontier exploration, field development, and risk reduction. Additional improvements have been incorporated in reservoir prediction, including the integration of seismic data conditioning, and corresponding attributes extraction methods related to different geological scenarios to improve the identification accuracy of the targeted geological body. In line with these improvements, technologies in the geological analysis have also been actively developing. A featured comprehensive software suite and solutions to extend have been formed on the basis of joint well-seismic interpretation, making it extend exploration to development.

At present, GeoEast interpretation technologies have been widely used in both onshore and offshore projects of CNPC. They have provided invaluable insights into structure interpretation, reservoir characterisation, and an in-depth understanding of the geology. In the future, GeoEast would be increasingly more promising and be applied in increasingly more geological scenarios, delivering comprehensive interpretation technologies, user-friendly software operations, and insight solutions to our clients.